Cooperative Institute for Marine and Atmospheric Studies

Fifth Annual Report

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OF MARINE AND ATMOSPHERIC SCIENCE

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I. EXECUTIVE SUMMARY

The Cooperative Institute for Marine and Atmospheric Studies (CIMAS) is a research institute hosted at the University of Miami (UM) in the Rosenstiel School of Marine and Atmospheric Science (RSMAS) and including at present eight additional Florida and Caribbean University Partners (FAU, FIU, FSU, NSU, UF, UPR USF, UVI). CIMAS is jointly sponsored by the University of Miami and the National Oceanic and Atmospheric Administration (NOAA). CIMAS works particularly closely with three NOAA facilities located in Miami: the Atlantic Oceanographic and Meteorological Laboratory (AOML), the Southeast Fisheries Science Center (SEFSC) and the National Hurricane Center (NHC). Reflecting the diversity of research conducted throughout NOAA, CIMAS research encompasses seven inter-related Research Themes which are linked to NOAA's Strategic Science Goals. These mandatory Research Themes were specified and defined by NOAA in the request for proposals (RFP) to which CIMAS responded during the re-competition process.

Theme 1: Climate Research and Impact
Theme 2: Tropical Weather
Theme 3: Sustained Ocean and Coastal Observations
Theme 4: Ocean Modeling
Theme 5: Ecosystem Modeling and Forecasting
Theme 6: Ecosystem Management
Theme 7: Protection and Restoration of Resources

Total external funding (Tasks 1, II, III and IV) during this reporting period was $21.0M. Task I which includes not only Administration but also Research Infrastructure (ship-time, computing resource access etc.) and Education and Outreach was ca. $1.5M. The University of Miami contributed an additional $.24 M towards Administration. Task II, which supports CIMAS employees conducting closely collaborative research off- campus was ca. $ 8.2M.

Individual research project funding (Tasks III and IV) totaled ca. $11.29M. The largest portions were the research projects within Themes 3 and 1 (Sustained Ocean and Coastal Observations & Climate Research Impacts) which together account for 49%. The smallest portions were in Themes 5, 7 and 4 (Ecosystem Modeling & Forecasting, Protection and Restoration of Resources, and Ocean Modeling) which together account for only 19 %. These percentages are somewhat misleading in that Theme assignments herein reflect only the *primary* not *secondary* or *tertiary* Theme designations. In many cases which Theme is *primary* is somewhat arbitrary given the interdisciplinary character of the research. Moreover the above expenditures (Tasks II, III or IV) refer only to the new CA initiated October 2010. They do not include continuing expenditures during these same time period under prior agreements or awards.

During this reporting period a total of 159 individuals at UM were directly provided salary support through CIMAS. Of these, 135 received over 50% of their support through CIMAS. Of the 135 research employees who received over 50% NOAA support, 74 worked at AOML, 38 at the SEFSC, 2 at RSMAS, 2 at NHC, 15 at the University of Puerto Rico and 4 in other locations.. Twenty one of these employees were Research Scientists including 2 part time former NOAA employees. The employees in the Research Associate and Research Scientist ranks have a diverse demographic profile. The population is 43% female. Foreign born individuals make up 50% of the total. The largest foreign sub-groups are Hispanics (21%) and Asian and Pacific Islanders (17%). The population of CIMAS remains relatively young in comparison with NOAA overall (or the local NOAA facilities – AOML, SEFSC and NHC) with an average age of 40. The distribution is bimodal in that a number of NOAA FTE retirees are re-employed through CIMAS as required to complete projects or mentor successors.

During this last year there were 104 peer-reviewed publications and another 41 non-peer reviewed technical reports or other publications resulting from research projects conducted directly under our present Cooperative Agreement award number. Results of a few individual projects are highlighted below. They were selected from various themes to be representative of the diversity of activities carried out within CIMAS and are sorted with respect to the high level NOAA scientific goal they primarily support. An effort was made to avoid projects highlighted in previous Annual Reports. A more detailed description of all the CIMAS projects can be found either in the body of the Report within the set of individual project summaries sorted alphabetically by principal investigator provided for each of the seven individual CIMAS Research Themes (Section VI) or in either Appendix I (Projects Linked to CIMAS) or Appendix II (Other Projects which includes some with non-NOAA funding). The publications and presentations resulting from the CIMAS projects in the latter tables are in general enumerated within the body of their respective individual reports and not be included in the tabulation above. They are more numerous by at least a factor of two than the publications tabulated directly under the Cooperative Agreement award number.

SOME RESEARCH HIGHLIGHTS

Goal 1: Healthy Oceans: Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems

2014 National Coral Reef Monitoring Plan: Florida Benthic Sampling
A research team from the Oceanographic Center of Nova Southeastern University (NSU-OC) conducted surveys of coral reef benthic communities in southeastern Florida, from Broward County to the Dry Tortugas.. Data analyses are ongoing and results will be presented in partnership with NOAA's Coral Reef Conservation Program in the form of an annual monitoring report, as well as a periodic "Report Card" (still in development) that describes the condition of coral reefs under US jurisdiction.

Elucidating Net Ecosystem Prediction and Calcification at the Atlantic Ocean Acidification Testbed
The main purpose of this project was to develop and implement a new diagnostic tool to monitor and assess coral reef health. The research team tested a combined flow and biogeochemical sensing system and measured how productive and how well coral reef were calcifying.

Evaluation of Management Strategies for Fisheries Ecosystems
No-take marine reserves can be a useful tool for fisheries management, but they also make it more difficult to assess the sustainability of fisheries in the surrounding area. In order to effectively manage the fisheries around marine reserves, it is necessary to understand how the marine reserve influences the population dynamics. The project team combined an individual based movement model with fisheries stock assessment techniques to assess the status of Caribbean spiny lobster at Glover's Reef atoll, Belize, and found that, in part because of the reserve, the fishery was sustainable.

Nonlinear Time Series Models for Forecasting Stock Abundances in the Gulf of Mexico
Nonlinear modeling can improve stock assessment techniques. Improving stock assessments, and in particular forecasting subpopulation abundances, is necessary for sustainable harvesting of marine resources. With nonlinear modeling, the forecasting is not constrained by the mechanistic assumptions that are required by traditional assessment methods. Nonlinear modeling relaxes these assumptions, but nonetheless captures dynamical trends in stock abundance.

Development of a Towed Camera System for Assessing Demersal Fish Stocks: C-BASS (Camera-Based Survey System)
Reef fish are notoriously difficult to assess because their habitats are not conducive to the use of traditional sampling gears such as trawls. This new technology has the potential to be transformational in providing such estimates in such habitats. Preliminary analyses show that the C-BASS did not significantly change the behavior of most species encountered. Ultimately such systems will significantly improve the precision, timeliness and credibility of NMFS fishery stock assessments.

Application and Automation of Underwater Image Mosaics for Sampling, Characterizing, and Classifying Corals as Protected Stocks and Habitat
The lack of marine remote sensing technologies that can directly sense benthic species or living from dead marine substrates is a critical knowledge gap impacting the management of both fish and coral stocks. Emerging underwater imagery tools can resolve individual coral colonies and other benthic organisms for identification by an analyst. Underwater images are easy to acquire, have high resolution for species delineation, and can cover increasingly large spatial scales (either with image mosaics or large quantities of images across many marine habitats). By combining large-area image acquisition technologies with current state-of-the-art automated classification techniques are improving the efficiency of benthic habitat characterization and assessment of protected coral stocks.

Living on the (Shelf) Edge: Using Advanced Glider Technology to Assess Fishery Resources along the South Atlantic Continental Shelf Break
Data sets of conductivity, temperature, chlorophyll fluorescence, CDOM, backscatter fluorescence, and dissolved oxygen were collected throughout the upper 200m of the water column. Passive acoustic recordings were also collected. The project team demonstrated, for the first time (to our knowledge), the use of an ocean glider to perform an extended (month-long) survey in a western boundary current, including the ability (at times limited) to enter and exit the current to control glider location.

Goal 2: Weather Ready Nation: Society is prepared for and responds to weather-related events

NIDIS Apalachicola-Chattahoochee-Flint River Basin Drought Early Warning System
Seasonal hydrological and nutrient loading forecasts for watersheds for the Southeastern United States
The research team was able to show useful seasonal deterministic and probabilistic skill of streamflow and nutrient loading over several watersheds in the Southeastern United States (SEUS) for the winter and spring (December-May) seasons over a 20-year period (1982-2001). by forcing the three conceptual rainfall-runoff hydrological models with resampled historical rainfall observations derived by matching observed analogues of forecasted quartile rainfall anomalies from a seasonal climate forecast model. Skill in prediction of seasonal nutrient loading is nearly identical to the skill in predicting the seasonal streamflow.

Assessing the Impact of Global Hawk Dropsonde Observations on the Prediction of Tropical Storm Gabrielle (2013) by Utilizing the Hurricane Ensemble Data Assimilation System (HEDAS)
Experiments conducted using NOAA/AOML/HRD's HEDAS data assimilation system for Tropical Disturbance Gabrielle (2013) suggest that high-resolution manned and unmanned aircraft observations in and around the center of the system introduce a cascade of positive impacts as a function of the number and type of observation platforms are utilized. The addition of the Global Hawk UAS observations improved the intensity forecast with a tropical storm that reached peak intensity within 2-3 days much like the observed scenario.

Developments in the High-Impact Weather Prediction Project
Significant advancements were towards creating a global, nested-grid framework in NMMB, demonstrating 'proof-of-concept' of a 3 km resolution global tropical cyclone model with multiple moveable nests located anywhere in the world, towards developing a robust shell-script based system capable of performing automated forecasts of the NMMB model and updating plots to the AOML/HRD website for 'real-time' public dissemination and the idealized storm capability in NMMB was completed, allowing for analysis and evaluation of code modifications in a well-controlled environment.

Sustained and Targeted Ocean Observations for Improving Atlantic Tropical Cyclone Intensity and Hurricane Seasonal Forecasts
During the first glider missions upper-ocean observations under hurricane wind conditions were collected during the passage of Tropical Storm Bertha (2014), and of Hurricane Gonzalo (2014). Observations were transmitted in real-time and assimilated in numerical models used in the forecast; they are now being re-analyzed to improve our understanding of the upper-ocean response to TC wind conditions..

Marine Optical Buoy (MOBY) Operations and Technology Refresh
The measurement of ocean color from satellites, because of the intervening atmosphere and low reflectance of light from the ocean versus the atmosphere, requires extremely high accuracy from the sensor. For the ocean color data record to be compared, merged, and maintained over a significant time period with multiple international satellite sensors requires a common calibration

point, maintained at the highest accuracy possible. The MOBY calibration site provides that single reference point used to tie these measurements together. This allows the ocean color record to be maintained over generations of satellite instruments which is essential to studies of climate change and climate impacts.

Goal 3: Climate Adaptation and Mitigation: An informed society anticipating and responding to climate and its impacts

Southwest Atlantic Meridional Overturning Circulation ("SAM") Project

Monthly climatologies of temperature and salinity from observations and numerical models were used to estimate the Meridional Overturning Circulation (MOC) in the South Atlantic at 34°S. Observational estimates suggest that the geostrophic transport plays an equal role to the Ekman transport in the MOC seasonal variations, whereas in the models, the Ekman transport controls the MOC seasonality. The seasonality of the geostrophic transport from observations is largely controlled by the seasonal density variations at the western boundary, but in the models, the eastern boundary dominates. The observed density seasonality at the western boundary is linked to the intensity of the Malvinas Current, which is poorly reproduced in the models. The weak seasonal cycle in the model geostrophic transport can primarily be attributed to excessively strong baroclinicity below the surface mixed layer, whereas the observations show a strong vertical coherence in the velocity down to 1200 m.

High-Frequency Variability of Near-Surface Oceanic Velocity From Surface Drifters

Understanding the cascade of energy in the ocean from large-scale forcing by winds and tides to small-scale high-frequency currents and associated mixing processes remains one of the outstanding issues in physical oceanography. A new quality-controlled global database of surface drifter positions and velocities at an unprecedented level of temporal (*hourly*) and spatial resolution is being made publically available through this project.

The South Atlantic Overturning Circulation and Extreme Weather

Multi-decadal variability of the South Atlantic Ocean plays a key role in modulating atmospheric circulation via interhemispheric redistributions of momentum, heat, and fresh water, forcing a thermally direct anomalous Hadley circulation in the atmosphere. This has implications on weather extremes. For example, weaker SAMHT leads to increase warm temperature extreme and an increase in the number of heat wave days over the Western United States.

PIRATA Northeast Extension (PNE)

CIMAS scientists participating in the PIRATA Northeast Extension (PNE) project quantified the seasonal cycle and interannual variability the northward transport of near-surface freshwater, from its origins under the ITCZ to the southern edge of the subtropical salinity maximum at 20N. and described for the first time the mean vertical and cross-equatorial structure of the upper-ocean meridional currents in the Atlantic cold tongue region, using in situ observations including drifters, Argo, shipboard/lowered ADCP, and moored ADCP.

Developing the Operational Calibration/Validation Components for VIIRS SST Retrievals
Using a large data base of coincident measurements from VIIRS and in situ temperatures from buoys, we have continue to refine the atmospheric correction algorithm to provide more accurate SSTs measurements across the entire VIIRS swath. The application of our results will provide significantly more accurate SST measurements from VIIRS for many applications, and lay the foundations for the next series of NOAA weather satellites that will also carry VIIRS.

South Atlantic Meridional Overturning Circulation: Pathways and Modes of Variability
The pathways of North Atlantic Deep Water (NADW) in the South Atlantic are revealed through analysis of new observations including hydrographic sections, Argo data and chlorofluorocarbon measurements, and a global ocean-only numerical model. The joint analysis provided for the first time evidence of the two main passages of the recently ventilated NADW in the South Atlantic. It was concluded that the NADW follows two different pathways south of 5°S. The main pathway (~71%) is southward in the DWBC flowing along the coast of South America. A smaller portion (~22%) flows eastward towards the interior of the basin.

Goal 4: Resilient Coastal Communities and Economies - Coastal and Great Lakes communities that are environmentally and economically sustainable

Florida Area Coastal Environment (FACE) Program
The FACE program seeks to understand the natural and anthropogenic contributors to coastal water quality and resulting ecosystem health, to elucidate the factors that can be controlled by society (i.e., wastewater plant managers and water management districts). The research team members are addressing the question of the impact of land-based sources of pollution on coral reefs of the southeast Florida reef tract, via the acquisition of high-quality chemical and physical oceanographic data. These data are fundamental to the question of the role of ocean outfalls in the maintenance of coastal ecosystem health.

II. CIMAS MISSION AND ORGANIZATION

CIMAS, the University Partners, and NOAA

The Cooperative Institute for Marine and Atmospheric Studies (CIMAS) is hosted at the University of Miami (UM) in the Rosenstiel School of Marine and Atmospheric Science (RSMAS) and includes at present eight additional Florida and Caribbean University Partners (Florida Atlantic University (FAU), Florida International University (FIU), Florida State University (FSU), NOVA Southeastern University (NSU), University of Florida (UF), University of Puerto Rico (UPR) University of South Florida (USF) and University of the Virgin Islands (UVI). CIMAS works particularly closely with the three NOAA facilities located in Miami: the Atlantic Oceanographic and Meteorological Laboratory (AOML), the Southeast Fisheries Science Center (SEFSC) and the National Hurricane Center (NHC) - see www.ci-mas.org for additional details and geographic distribution.

Goals

Although CIMAS had served its purpose well for more than three decades, it needed to substantially change in order to keep pace with changes in scientific and societal priorities as well as changes in both NOAA and the regional university landscape. The re-competition process represented an opportunity to establish a renewed institution that would take full advantage of the scientific and educational capabilities of the academic community within our region, better connect NOAA with the needs of its stakeholders and enable NOAA to better address the enormous challenges of the twenty first century.

Vision:

- *To serve as a center of excellence in Earth System, Ecosystem and Human Dimensions Science and improve information about and understanding of the changes transforming our environment and society.*
- *To disseminate this information and the understanding resulting from it through targeted education and outreach activities.*
- *To facilitate the process of applying our scientific knowledge to effectively sustaining, protecting and restoring our natural environment as well as the economy and human society that ultimately depend upon it.*

Mission:

- *To conduct research in the terrestrial, ocean, and atmospheric environments consistent with the priorities expressed in NOAA's present and future Goals and Mission.*
- *To characterize physical, chemical and biological interactions and processes within, between, and amongst these environments.*
- *To better understand the role of humans in affecting these environments and the impacts of change in these environments upon human societies and economies.*
- *To create and implement formal education and training programs creating the intellectual capital required by the present and future NOAA.*

To achieve this Vision and carry out this ambitious Mission, CIMAS re-invented and restructured itself:

- By enhancing interconnections with the regional NOAA community beyond Virginia Key (including inter alia NWS/NHC, NOS/NMFS/FKNMS, Florida Sea Grant, SECART, GOMART);
- By broadening the participation of the regional academic community beyond UM by incorporating; complementary capabilities from other Florida and U.S. Caribbean research universities (specifically FAU, FIU, FSU, UF, USF, NSU, UPR and UVI);
- By offering NOAA access to state-of-the-art research infrastructure both at UM and its partner universities (including high performance computing facilities, ships, ocean engineering technology, hurricane simulation facilities etc);
- By putting in place new graduate and undergraduate educational programs to train the NOAA workforce of the future.
- By establishing collaborative relationships with other regional Cooperative Institutes (specifically NGI, CIOERT and CICS);
- By specifically addressing NOAA priorities most relevant to our thematic focus including the Future NOAA Workforce, the NOAA Hurricane Forecasting Improvement Program, Extreme Weather Events, Climate Services and Ecosystem Approaches to Management as reflected in NOAA's Annual Guidance Memorandums, Research Plans and various Strategic Plans as well as responding to major events such as Hurricane Sandy and the Deepwater Horizon oil spill.
- Most recently (during this last project period) we also established an Ocean Modeling and OSSE Center (OMOC) in collaboration with AOML.

How CIMAS Carries Out Its Mission

CIMAS addresses issues of national interest within the context of NOAA's missions of environmental prediction and stewardship. CIMAS accomplishes this:

- *By fostering, facilitating and implementing joint projects between regional university scientists and those employed by NOAA;*
- *By providing a mechanism for engaging undergraduate students, graduate students and post-doctoral fellows in this research;*
- *By arranging for visiting specialists to enhance the general effort in relevant research areas through short term consultations and seminars or by arranging for their involvement in ongoing projects for longer time periods;*
- *By providing training for personnel in various areas of research in marine and atmospheric science.*

CIMAS enhances NOAA-university cooperation and thus promotes both the quality and attractiveness of the local NOAA facilities as a scientific working environment. It also serves to increase the breadth of university activity in research areas that are complementary to NOAA's mission.

The Link between CIMAS Research and NOAA Goals
CIMAS research and its scientific objectives have been guided by the general objectives of NOAA's scientific mission goals when CIMAS was established:

Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

Goal 2: Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

Goal 3: Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

Goal 4: Resilient Coastal Communities and Economies - *Coastal and Great Lakes communities that are environmentally and economically sustainable*

These NOAA's scientific mission goals are consistent with the broader scientific mission of CIMAS and each research project in CIMAS (even those funded by non-NOAA funds) must contribute to at least one of these NOAA goals.

The Administration and Governance of CIMAS

The organization of CIMAS is designed to reflect the joint interests of the universities and NOAA in carrying out the CIMAS Mission. The Director of CIMAS is a senior faculty member of the host institution, the University of Miami. Aspects of the governance of CIMAS are dealt with in consultation with the CIMAS Council of Fellows and the CIMAS Executive Advisory Board. Fellows are scientists of established national or international standing who hold regular teaching or research faculty appointments in one of the nine participating universities or who are senior staff members at one of the three local NOAA facilities. The Fellows play an important role by providing guidance to the Director of CIMAS in matters regarding the implementation of research programs. One of the Fellows' most important tasks is fostering the development of new CIMAS research activities that benefit both NOAA and the universities by serving as a liaison between their university's faculty and CIMAS. The Council of Fellows is chaired by the CIMAS Director. The Executive Advisory Board consists of a senior administrator from each of the universities, the Directors of the three local NOAA facilities and the Director of the NOAA CI Office. The CIMAS Director participates as an *ex officio* member of the Board and is appointed by the Board.

CIMAS activities fall into four Task categories. The Administrative functions of CIMAS are carried out under Task I with funding provided by both the University and NOAA. This is the only funding annually "guaranteed" to CIMAS. Task I also includes both Research Infrastructure and Education & Outreach on as "as needed" basis. Under Task II CIMAS supports research scientists or research associates who work within off-campus research teams primarily at NOAA's Miami facilities (AOML, SEFSC and NHC). The expertise of these CIMAS employees complements that already present within NOAA. All Task II employees are University of Miami employees. CIMAS "Scientists" (as distinct from Post-Doctoral Investigators or Research Associates) can also serve as Principal Investigators and, with the approval of the Director, submit proposals to NOAA through Task III and to other agencies (or private entities) through Task IV as described below.

Research in CIMAS under this CA was also carried out under Tasks III and Task IV. These Tasks provided funding to both university faculty and CIMAS scientists to conduct project-based research consistent with CIMAS research themes. Task III encompasses research collaborations with NOAA scientists (typically but not necessarily located in Miami) and NOAA program offices (regardless of location). Support for individual Task III projects is based on proposals submitted to specific NOAA units or funding programs often but not necessarily in response to a competitive Announcement of Opportunity or Request for Proposals. Task IV encompasses projects that support or complement the NOAA mission and are consistent with the CIMAS Themes but are funded by other federal (non-NOAA), state or private funding sources. All funding provided by NOAA to CIMAS University Partners other than UM is through Task III as a subcontract from UM to those institutions.

III. PERSONNEL

Distribution of Personnel

CIMAS personnel participate in a wide range of NOAA-related activities. During the past twelve months a total of 169 persons were associated with CIMAS in various capacities. Of these, 135 received over 50% of their support from NOAA sources. Table 1 shows the distribution of these individuals by category and by their association with the local NOAA facilities. Of the 135 who received over 50% NOAA support, 74 are located at AOML, 38 at the SEFSC, 2 at RSMAS, 2 at NHC. 4 work at distant NOAA facilities and 15 at UPR.

Table 1: CIMAS Research Personnel 2013 – 2014

Category	Number	BS	MS	Ph.D
Research Associate/Scientist	71	35	32	4
Part Time Research Associate/Scientist	6	2	2	2
Postdoctoral Fellow	16			16
Research Support Staff	42	5	3	1
Total (> 50% NOAA support)	**135**	**42**	**37**	**23**
Full Time Administrative Staff	5			2
Task I Undergraduate Students	12			
Task I Graduate Students	7			
Visiting Scientist	10			
NOAA Association	74-AOML 38-SEFSC 2-RSMAS 21- (2) NHC, (15) UPR, (4) Other			
Obtained NOAA employment within the last year	0			

CIMAS Research Associates/Scientists are hired into a well-delineated series of categories that allow for professional advancement in the research ranks. There is a sequence of five positions targeted for advanced technical or scientific staff conducting University research. Advancement is not automatic with time-in-grade. Additional education, continuing professional achievement, and/or increased responsibility are the basis for advancement to higher-level positions. The progression order is: Research Associate, Senior Research Associate, Assistant Scientist, Associate Scientist, and Scientist. The "Scientist" ranks (Assistant Scientist, Associate Scientist and Scientist) are designed to closely parallel in pay, prestige and description the Research Faculty track at the University (i.e., Assistant Research Professor, Associate Research Professor and Research Professor). Over the last twelve months, there were in addition a total of 15 Postdoctoral Fellows. Postdoctoral Fellows have become an increasingly important part of the CIMAS employee pool during the current Cooperative Agreement. A new category of CIMAS employment is research support employee (e.g. computer program or engineer). At present there are two such employees but we expect this category to grow in the coming years.

Research Support Staff are temporary employees, hired for the duration of specific projects. These include persons with a variety of backgrounds including both retired PhDs and local high school students often as a part of CIMAS associated K-12 Outreach programs.

It should be noted that although CIMAS has had the status of a "Division" within UM's Rosenstiel School it has no faculty. School faculty participate in CIMAS activities in many ways, but hold their primary appointment in one of the School academic divisions (including both the CIMAS Director and CIMAS Associate Director). University faculty are not counted in the listing of CIMAS employees not even those who serve as CIMAS Fellows or serve as the Principal Investigators in conducting Task III research projects. All the graduate students who work on CIMAS Task I programs and are included above also have their primary affiliation with a RSMAS Academic Division which has the ultimate responsibility for overseeing their students' academic performance and the granting of degrees. The undergraduates listed are majors in the University of Miami Marine and Atmospheric Science undergraduate program which is administered and staffed by RSMAS faculty.

See *Section X* for a list of the students and post-docs associated with CIMAS during this last project period.

Over the past twelve months, CIMAS has continued its systematic efforts to improve the working environment of its many off-campus employees. Specific efforts included:

1. Updating its' Awards Policy modeled upon the awards available to NOAA employees (http://cimas.rsmas.miami.edu/pdfs/CIMAS_Award_Program_Policy.pdf) and awarding 13 awards under this policy;
2. Expanding the breadth and increasing the upper limit of the Pay Bands applicable to CIMAS employees (http://cimas.rsmas.miami.edu/pdfs/pay-bands.pdf) and not only hiring new employees within these limits but raising the salary of legacy employees so that all now fall within the appropriate pay bands;
3. Assisting personnel with respect to the markedly increasing difficulty of negotiating the escalating requirements of the Department of Homeland Security (many CIMAS Task II employees are not U.S. citizens) and U.S. Department of Labor; and,
4. Preparing and providing briefing documents and workshops for relevant NOAA personnel (advisors and administrators) regarding UM Human Resources policies, practices and regulations.
5. Providing support for part-time liaison positions at each of the two primary off-campus work sites (AOML and SEFSC).

CIMAS Fellows

At present there are 31 CIMAS Fellows. 6 CIMAS Fellows are from RSMAS, 8 from the local NOAA facilities and 17 from the Partner Universities. A list of the present CIMAS Fellows is given in the *Fellows* section of this report along with their affiliation. The CIMAS Director serves *ex officio* as the Chair of the Fellows. Given the geographic dispersion of the membership, meetings are conducted as GOTOMEETING teleconferences.

CIMAS Executive Advisory Board

The Board includes the Directors of the local NOAA facilities (R. Atlas, OAR/AOML; B. Ponwith, NMFS/SEFSC and R. Knabb, NWS/NHC), the Director of the NOAA CI Office (Cynthia Decker, Acting) and senior administrators from each of the Partner Universities including the Dean of the host institution, UM/RSMAS (R. Avissar), who chairs the Advisory board (A list of members is given in the *Executive Advisory Board* section of this report along with their affiliation). Given the geographic dispersion of the membership, these meetings as well are conducted as GOTOMEETING teleconferences.

CIMAS Administration

CIMAS administrative staff consists of a Director: Dr. Peter B. Ortner, an Associate Director: Dr. David Die, and three full-time administrative personnel. Part-time or work-study students are employed on an as needed basis.

Transition to Federal Positions

More than thirty five former RSMAS undergraduate/graduate students and/or research employees funded through CIMAS currently hold Federal positions in the three local NOAA facilities. This total represents only a small fraction of the hundreds contributed to the national NOAA workforce over the lifetime of CIMAS. In this last reporting period no CIMAS employees transitioned to Federal position although __ graduate students or post docs supported through CIMAS did transition.

Demographics of CIMAS Employees

The CIMAS population is 57% male. Foreign-born individuals make up 50% of the personnel; of these Hispanics make up 21% of the ranks; Asian and Pacific Islanders, 17%. Only 1% are African-Americans despite our efforts to expand this group's participation. The population of CIMAS is relatively young with an average age of 40. The largest age decade is that between 30 and 40, for a total of 62. Comparison with local laboratory populations and the overall NOAA federal workforce analyses, indicate this is a much younger and more diverse group than the overall NOAA population. It is somewhat bimodal in character in that NOAA FTE retirees are often rehired through CIMAS in order to complete projects and mentor successors.

CIMAS Student Employees

There are currently 7 UM/RSMAS graduate students supported through CIMAS Task I. Many others are supported on Task III projects and in other capacities (see *Section X* for the full list). In addition 12 undergraduates are currently supported. A number of high school students have been employed as temporary hires (under the category "Research Support Staff"). Most of these were enrolled in the Miami-Dade MAST Academy, a magnet school in the county (see Outreach) which is co-located on the Virginia Key Marine Campus adjacent to AOML and across the street from the Rosensteil School where CIMAS is located.

IV. FUNDING

General Funding:

This reporting period, funding from all sources totaled ca. $21.0M under the new Cooperative Agreement. A summary of funding under the four Tasks is shown in Table 1.

Table 1: Summary of Funding

Period	Task I	Task II	Task III	Task IV	TOTAL
Year 1	1,742,457	7,924,090	1,583,572	824,640	12,074,759
Year 2	3,269,557	7,880,380	6,236,972	2,012,573	19,399,482
Year 3	1,634,929	8,941,974	5,854,265	698,591	17,129,759
Year 4	2,731,785	8,062,381	10,745,986	430,260	21,970,412
Year 5	1,509,912	8,209,096	10,432,195	858,141	21,009,344
TOTALS	**10,888,640**	**41,017,921**	**34,852,990**	**4,824,205**	**91,583,756**

The sources of that funding are shown in Table 2. The major source of NOAA funding continues to be OAR which provided 55% of the total. A major source of NOAA funding this reporting period is the second year associated with the OAR portion of the Disaster Relief Appropriation Act of 2013. NMFS, NESDIS, NOS contributed at 21%, 12%, and 7% respectively. "Other" accounts for 5%, the source of funding include awards from NASA, NSF and private industry as well as sub-contractual awards from University of Washington and University of Wisconsin to CIMAS investigators.

Table 2: Funding by Source

1 July 2014 - 30 June 2015		
Source	**Funding $M**	**% Total**
NESDIS	2.40	12%
NMFS	4.50	21%
NOS	1.40	7%
NWS	0.20	1%
OAR	1.51	8%
OAR/AOML	7.10	34%
OAR/CPO	2.70	13%
Other	1.20	5%
GRAND TOTAL	**21.01**	**100%**

Funding by Task

CIMAS activities continue to be administratively grouped under four distinct Tasks that reflect complementary aspects of the CIMAS mission.

- **Task I** provides support for the Administrative structure of CIMAS (including website outreach, meeting costs, software subscription etc.), NOAA access to Research Infrastructure as well as support for students and limited-term visiting scientists. **UM directly contributes to the administration of CIMAS as a Division within the School moreover UM charges no Indirect Costs (IDC) whatsoever on Task I expenditures.**
- **Task II** provides support for off campus researchers and support personnel employed by CIMAS to conduct collaborative research primarily at NOAA facilities. Their expertise complements that already existing at NOAA or present at UM. Support for CIMAS postdoctoral research associates is also included under Task II. **UM charges only 26% IDC on Task II.**
- **Task III and Task IV** encompass project-specific research funding at CIMAS. These Tasks provide support for research by university faculty, scientists and students. Task III encompasses activities that are funded by NOAA and may be carried out in cooperation with NOAA personnel in the local NOAA laboratories and elsewhere in the United States. Task III proposals may be submitted by UM or Partner University faculty and scientists or by CIMAS research scientist employees. Task IV includes projects supported by other (non-NOAA) funding sources. The approval of the Director (as the designate of the RSMAS Dean), is required for CIMAS employees to submit Task III or IV proposals. Their subjects must be consistent with CIMAS research themes and contribute to NOAA strategic goals. **The UM indirect cost rate for Task III was 40% and for Task IV either the federally negotiated UM rate (currently 55%) or whatever rate is specified in the relevant RFP or FAO.** The reduced rate accorded NOAA for Task III is in recognition of the funding CIMAS receives under Task 1 for Administration costs toward which that IDC would have contributed. Task III awards to Partner Universities through CIMAS are allocated as subcontracts. Total UM IDC on these (regardless of the number of individual projects or total amount awarded by NOAA) is only $10K per Partner University (40% of the first $25K) over the lifetime of the Cooperative Agreement. Partner Universities are encouraged (but not required) to also offer NOAA an IDC rate below the federally negotiated rate. In most cases this has not been possible.

The total of Task I Funding this project period was $ 1.75M, of which $0.66M was for the Administration component (that sum included a 0.24M UM contribution) and the bulk of the remainder for Research Infrastructure. The distribution of NOAA Task 1 expenditures is shown in Figure 1. The category “Administration” 15% covers a portion of the salary of CIMAS staff including its Director and Associate Director. The category "Other" 7% includes: travel for students, visiting scientists and temporary staff in support of research activities, consulting agreements, other supplies (minor equipment, peripherals, etc.). Research ship-time accounts for 13% of the total. Temporary Staff accounts for 29% which covers persons hired on a temporary basis to support specific research projects. Other research infrastructure access (e.g. supercomputing access, capital equipment) accounts for 26% and student stipends another 6%.

Task I: General

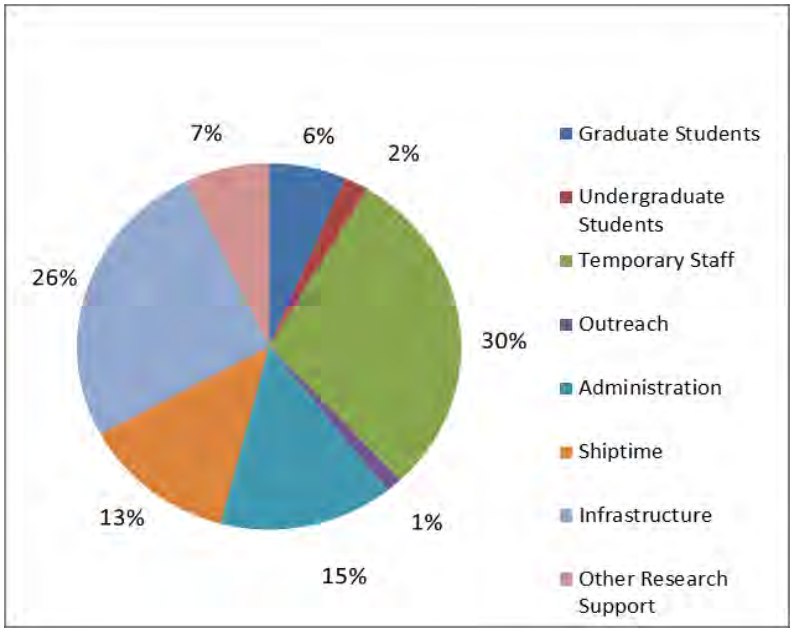

Figure 1: Distribution of Task1Funding

The funding provided for Task II employees totaled $8.2M over the past twelve months. The distribution of these funds by employee category is depicted in Figure 2.

Task II: Employees by Category

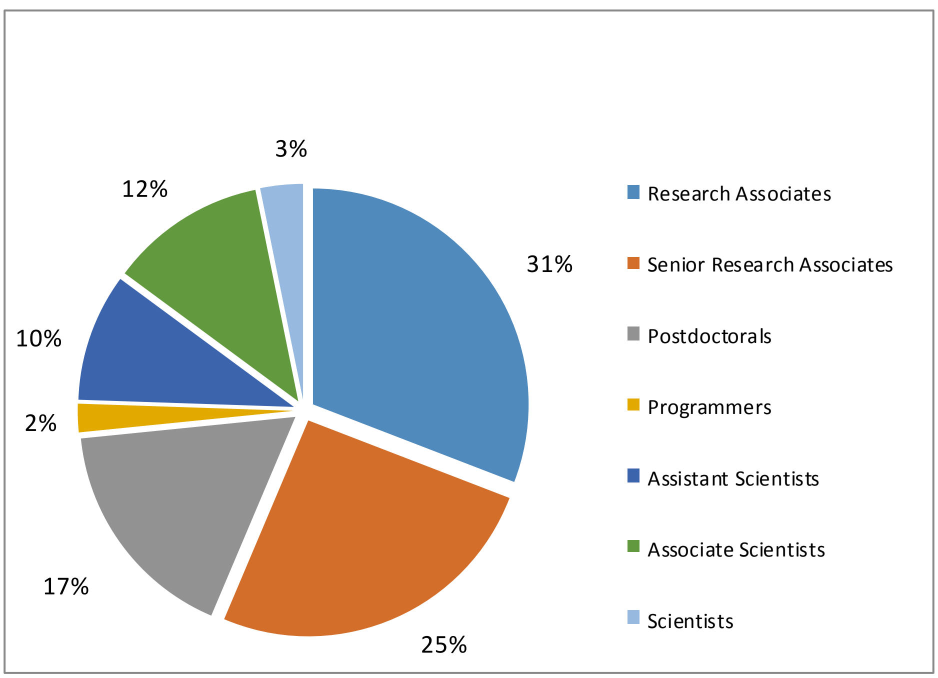

Figure 2: Distribution of Task 2: Funds by Employee Category

Funding By Theme

Project-specific research funding (Tasks III and IV) under the new CA totaled ca. $11.3M as shown above in Table 1. Figure 3 shows the percentage of Task III and Task IV funding expended upon each CIMAS Themes during the twelve months. Of total CIMAS research funds, Theme 3: Sustained Ocean and Coastal Observations continues to account for the largest portion of the funding 31%. The smallest portion of funding was in Theme 5: Ecosystem Modeling and Forecasting – 2%.

The distribution of project specific funding by Theme as shown in Figure 3 is based upon somewhat arbitrary assessments of the major focus of specific projects. In truth nearly all CIMAS projects are highly interdisciplinary and could reasonably be assigned to more than one Theme. To better reflect this complexity projects are given not only *primary* but also *secondary* (and sometimes *tertiary*) theme assignments. Moreover this figure only shows the distribution of funding under Tasks III and IV; it does not include the funding that supports Task II research personnel working on research projects that necessarily fall within these same Themes. While the salary of those personnel is paid through CIMAS all the other costs for those research projects are budgeted directly within NOAA and no specific project proposal was submitted through CIMAS to obtain the requisite funding.

Research Funding by Theme

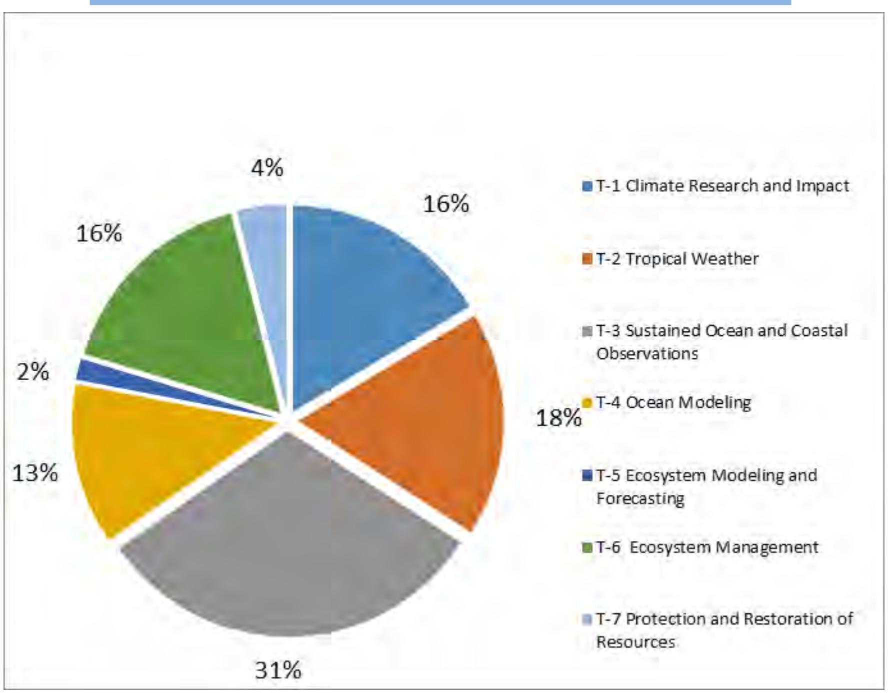

Figure 3: Percentage of Task 3 and Task 4 (Individual Research Project) funding per Theme

Table 3 below tabulates NOAA funding received by CIMAS under the present Cooperative Agreement (CA). This reporting period we received 1 more award under the Disaster Relief Appropriation Act of 2013 related to Hurricane Sandy resulting in total for DRA funding of 6.8M (see table 4).

Table 3: NOAA Projects with Individual Award Numbers

NOAA Award Number	Principal Investigator	Award Period	Report Due Date	Project Title	Total Funds
NA12NWS4680010	Aksoy, A	01/01/12 - 12/31/14	01/30/15	Investigation of HWRF Model Error Associated with Surface-LA	$213,436
NA14OAR4310193	Cook, G	08/01/14 - 07/31/16	05/30/15	Developing decision support tools for understanding, communicating and adapting to the impacts of climate on the sustainability of coastal ecosystem services	$178,788
NA12OAR4310105	Criales, M	08/01/12 - 07/31/15	05/30/15	Integrated MODels for Evaluating Climate change, population growth, & water management (i.e. CERP) effects on south Florida coastal marine and estuarine ecosystems (iMODEC)	$264,858
NA14OAR4830172	Dunion, J	08/01/14 - 07/31/17	04/30/15	Using NOAA UAS Assets and OSSE/DA Capabilities to Improve Sampling Strategies and Numerical Prediction of Tropical Cyclone Track, Intensity and Structure	$1,249,008
NA12OAR4310073	Kamenkovich, I	08/01/12 - 07/31/16	05/30/15	Mesoscale Variability in the Gulf of Mexico and its importance in climate extremes over North America	$408,500
NA14OAR4830127	Kirtman, B	07/01/14 - 05/31/15	06/29/15	Severe Weather in the NMME	$69,990
NA12OAR4310089	Kirtman, B	08/01/12 - 07/31/15	05/30/15	A U.S national multi-model ensemble ISI prediction system	$259,626
NA130OAR4830224	Kourafalou, V	10/01/13 - 09/30/15	04/30/15	Extending the Gulf of Mexico to the North Atlantic in support of Development & Demostration of a Relocatable Ocean OSSE System	$1,301,395
NA12OAR4310083	Lee, S	08/01/12 - 07/31/16	05/30/15	Toward developing in a seasonal outlook for the Occurance of Major US tornado outbreaks	$225,000
NA14OAR4830103	Lee, S	02/01/14 - 01/31/16	04/30/15	CIMAS Contributions to OAR disaster Recovery Act Project	$1,983,254
NA13NMF4720057 *	Muhling, B	09/01/13 - 08/31/14	09/30/14	Accounting for the influence of feeding success on the growth and survival of bluefin tuna larvae in stock assessment efforts	$102,183
NA11NOS4780045	Ortner, P	09/01/11 - 08/31/16	06/30/15	2011 REPP-Understanding Coral Ecosystem Connectivity in the Gulf of Mexico-Pulley Ridge to the Florida Key	$3,351,343
NA13OAR4310131	Perez, R	09/01/13 - 08/31/16	06/30/15	South Atlantic Meridional Overturning Circulation: Pathways and Modes of Variability	$222,723
NA130OAR4830217	Shay, N	10/01/13 - 09/30/15	04/30/15	Evolving Data Fields for Use in OSSE Modeling	$105,935
NA11OAR4310077	Chen, S	09/01/11 - 08/31/15	06/30/15	Convective Structure and Environmental Conditions in the MJO Initiation over the Indian Ocean	$307,600
NA10OAR4310120	Soden, B	05/01/10 - 07/31/15	03/30/15	Development of a long-term Homogenized upper tropospheric water vapor data set from satellite microwave radiances	$457,924
NA12NWS4680004 **	Zhang, J	01/01/12 - 12/31/14	03/31/15	Advanced model diagnostics of tropical cyclone inner-core structure using aircraft observations	$202,592
NA14NWS4680028	Zhang, J	08/01/14 - 07/31/16	05/30/15	Addressing deficiencies in forecasting tropical cyclone rapid intensification in HWRF	$389,332
NA12NWS4680007 **	Zhang, X	01/01/12 - 12/31/14	01/30/15	Development of Multiple Moving Nests Within a Basin--Wide HWRF Modeling System	$155,009
NA13OAR4830232	Zhang, X	10/01/13 - 09/30/15	04/30/15	Services to Support the Hurricane Forecast Improvement Project	$1,027,950
NA14OAR4830119	Zhang, X	04/01/14 - 03/31/17	04/30/15	CIMAS Contributions to OAR disaster Recovery Act Projects	$1,016,570

* NMFS annoucements at a reduced 25% IDC, ** NWS and OAR annoucement not properly linked to CIMAS awarded at the regular UM overhead rate.

Funding distributed through CIMAS to the Partner Universities during the present reporting period was $1.3M or 18% of Task III. As discussed above, Partner Universities other than UM are eligible through CIMAS only for Task III funding.

Task III awards to CIMAS during this last reporting period under the new CI award policy whereby those projects get assigned a different accounting code (although they are "associated" with the overall Cooperative Agreement) are listed in Table 3.

Table 4: Sandy Awards to CIMAS

NOAA Award Number	Principal Investigator	Funding Source	Project Title
NA14OAR4830172	Dunion, J	ORA	Using NOAA UAS Assets and OSSE/DA Capabilities to Improve Sampling Strategies and Numerical Prediction of Tropical Cyclone Track, Intensity and Structure
NA14OAR4830127	Kirtman, B	ORA	Severe Weather in the NMME
NA130OAR4830224	Kourafalou, V	ORA	Extending the Gulf of Mexico to the North Atlantic in support of Development & Demostration of a Relocatable Ocean OSSE System
NA14OAR4830103	Lee, S	ORA	CIMAS Contributions to OAR disaster Recovery Act Project
NA130OAR4830217	Shay, N	ORA	Evolving Data Fields for Use in OSSE Modeling
NA13OAR4830232	Zhang, X	ORA	Services to Support the Hurricane Forecast Improvement Project
NA14OAR4830119	Zhang, X	ORA	CIMAS Contributions to OAR disaster Recovery Act Projects

Conclusion

In our funding summary we report only expenditures during the twelve months project period under the new Cooperative Agreement or associated with it under the new CI Policy. Awards that either just missed the deadline (or represented out-year funding under pre-existing awards – see examples in Table 3) were not included herein.

V. RESEARCH THEME OVERVIEW

Organization of CIMAS Themes

CIMAS conducts research, support research and education and provides outreach services with respect to the following scientific topics. These Research Themes were specified and explicitly defined by NOAA in the request for proposals (RFP) to which we responded in the recompetition process.

- Climate Research and Impact
- Tropical Weather
- Sustained Ocean and Coastal Observations
- Ocean Modeling
- Ecosystem Modeling and Forecasting
- Ecosystem Management
- Protection and Restoration of Resources

Research Themes

1. **Climate Research and Impacts -** *Research focused upon understanding oceanic and atmospheric processes associated with global and regional climate change on various temporal scales as well as the impacts of climate variability and change. Activity under this theme also includes both research to determine effective regional adaptation strategies, and the development of new climate information products and tools appropriate for evolving user needs, particularly in the Southeast United States and the Caribbean.*

Theme 1 activities contribute to NOAA Mission Goal 2: Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

2. **Tropical Weather** – *Research conducted under this theme encompass the collection and analysis of hurricanes and other tropical weather system observations. Research activities include identifying and validating observational needs, developing instrumentation, obtaining observations, studying the optimum configurations for observation networks, modeling and data assimilation, expediting and facilitating the transition of research to operations, and developing analysis and forecast applications for operations.*

Theme 2 activities contribute to NOAA Mission Goal 3: Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

3. **Sustained Ocean and Coastal Observations -** *Research focused on the collection and analysis of observations of the ocean and coastal environment important for understanding and monitoring on a range of timescales, particularly in the Gulf of Mexico, Caribbean and Atlantic. This includes the development and improvement of ocean and coastal observation platforms and instruments that measure biological, physical, and chemical parameters; studying the optimum configurations for observation networks; modeling, data assimilation, and diagnostic analysis of local, regional, and global marine data sets; and information product development.*

Theme 3 activities contribute to NOAA Mission Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*
Theme 3 activities contribute to NOAA Mission Goal 2: Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*
Theme 3 activities contribute to NOAA Mission Goal 3: Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

4. Ocean Modeling – *Research focused upon improved model representation of ocean processes particularly those processes governing sea surface temperature, upper ocean heat content, and salinity variability including air-sea exchanges, heat-flux, lateral ocean advection, and entrainment at the base of the ocean mixed layer that play a significant role in controlling short-term variability in ocean and coastal circulations as well as long-term variations. It also includes modeling of the ocean from the surface to the ocean floor to improve understanding and, eventually, forecasting of climate variability and climate change.*

Theme 4 activities contribute to NOAA Mission Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*
Theme 4 activities contribute to NOAA Mission Goal 2: Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*
Theme 4 activities contribute to NOAA Mission Goal 3: Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

5. Ecosystem Modeling and Forecasting – *Research focused upon improved forecasting of the structure and function of marine ecosystems including the provision of ecosystem services, particularly in the Southeast U.S. coastal ocean, the Caribbean Sea, and Gulf of Mexico Large Marine Ecosystems. These regions are the primary geographic focus of this and the following two research theme areas. Modeling and forecasting topics include: human health (e.g., beach closings, fish contaminants, and harmful algal blooms), fish recruitment and productivity, and protected species sustainability and recovery, all of which are deemed relevant to NOAA's responsibilities with respect to the assessment and management of living marine resources and their habitats.*

Theme 5 activities contribute to NOAA Mission Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

6. Ecosystem Management – *Research focused upon promoting sustainable coastal development, facilitating community resiliency, and enabling NOAA's ecosystem approach to management in the Southeast U.S. coastal ocean, the Caribbean Sea, and Gulf of Mexico marine ecosystems by enhancing scientific understanding of the interconnections between the marine ecosystem and the adjacent watershed including their human health and resource stewardship implications. This research theme (as well as the one following) specifically includes human dimensions science in addition to the natural sciences.*

Theme 6 activities contribute to NOAA Mission Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

7. Protection and Restoration of Resources – *Research focused upon the prototype development of technology, tools, and effective approaches to restoration, as well as bio-geographical characterizations, intended to enable improvements in defining and protecting components of marine protected areas and restoring habitats and populations. A wide range of problems are addressed from removing contaminants to providing new materials and techniques to protect underwater cultural resources.*

Theme 7 activities contribute to NOAA Mission Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

In Section VI following, Task II and III research activities under the Cooperative Agreement award number are briefly described and the participating university and NOAA personnel enumerated. Considerably more detailed information on specific research activities can be obtained by contacting the participants. As discussed above, the activities are sorted by *primary* theme but in some cases this is an essentially arbitrary decision and the same project could as well have been assigned to another thematic category. For that reason we asked those preparing reports to choose not only the primary theme but also if they so desired *secondary* and *tertiary* themes. For NOAA funded Task III projects linked to CIMAS that have their own project numbers see Appendix I. For Task IV projects see Appendix II. To avoid unnecessarily burdening the responsible principal investigators of such Task III and all Task IV projects we did not require submission of a CIMAS specific report such as those included in Section VI. Each Appendix begins with a Table of the funded projects sorted alphabetically by the last name of the Principal Investigator. We then provide in the same alphabetical order the most recent report submission required by the projects respective funding program. These two Appendices (and the numerous projects therein) were not included in the last Annual Report required of Cooperative Institutes by the NOAA Cooperative Institute Program Office (CIPO). In the case of CIMAS, not including them would give a misleadingly narrow view of the contributions being made by CIMAS to the NOAA scientific enterprise. Including them herein was approved by the new Acting Director of the CIPO. It is important to understand that as result of this publications or reports generated by the projects contained in the appendices were not necessarily included in the publication summary provided herein which represents therefore a conservative under-estimate of total publications resulting from CIMAS activities.

VI. RESEARCH REPORTS

THEME 1: Climate Research and Impact

Western Boundary Time Series Project

Project Personnel: G. Berberian, R. Domingues, R. Garcia, S. Garzoli, J. Hooper, G. Rawson, R. Roddy, K. Seaton and Q. Yao (UM/CIMAS)

NOAA Collaborators: M. Baringer, Y-H. Daneshzadeh, C. Meinen, P. Pena, U. Rivero, R. Smith and A. Stefanick (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Theme:

***Objectives*:** To monitor the meridional overturning circulation through sustained time series observations of the North Atlantic western boundary currents.

***Strategy*:** To use a wide range of observations – submarine telephone cable measurements, hydrographic, satellite, freely dropped and moored instruments - to study the Florida Current, Deep Western Boundary Current and Antilles Current systems.

Research Theme:

***Theme 1*:** Climate Research and Impact (*Primary*)

***Theme 3*:** Sustained Ocean and Coastal Observations (*Secondary*)

***Theme 4*:** Ocean Modeling (*Tertiary*)

Link to NOAA Strategic Science Goals:

***Goal 3*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

NOAA Funding Unit: OAR/AOML and OAR/CPO **NOAA Technical Contact:** David Legler

Research Summary:
Variations in the transport of the Meridional Overturning Cell (MOC) in the Atlantic Ocean have been shown in numerical climate models to have significant impacts on the climate over a wide range of locations around the globe. In the Atlantic, near 27˚N, the warm upper-limb of the MOC is principally carried by the Florida Current between the eastern Florida coast and the Bahamas, although the Antilles Current east of the Bahamas also carries some of the warm northward flow. The southward deep flow of the MOC is contained primarily within the Deep Western Boundary Current east of Abaco Island in the Bahamas, although some fraction is also thought to transit near the Mid Atlantic Ridge. Long-term observations of the Florida Current, Antilles Current and Deep Western Boundary Current are required in order to quantify the natural time scales of variability for these currents.

This project maintains NOAA's well-established and climatically significant Florida Current volume transport time series. More than 30 years of daily mean voltage-derived transports have been obtained for the Florida Current using out-of-use and in-use telephone cables spanning the Straits of Florida. The cable voltages are converted to physically meaningful volume transport estimates, i.e. intensity of the flow, using electromagnetic induction theory and data from calibration sections on research vessels. Quarterly calibration cruises for cable transport and water mass changes within the Florida Current were conducted on the University of Miami's R/V Walton Smith, small sport fishing boats charter from Sailfish Marina in West Palm Beach, and on the NOAA/AOML Research Vessel Hildebrand. During the past year, the monitoring and data distribution systems for the Florida Current cable program have continued, providing Florida Current volume transports in near real time via the web page (See Figure 1) http://www.aoml.noaa.gov/phod/floridacurrent.

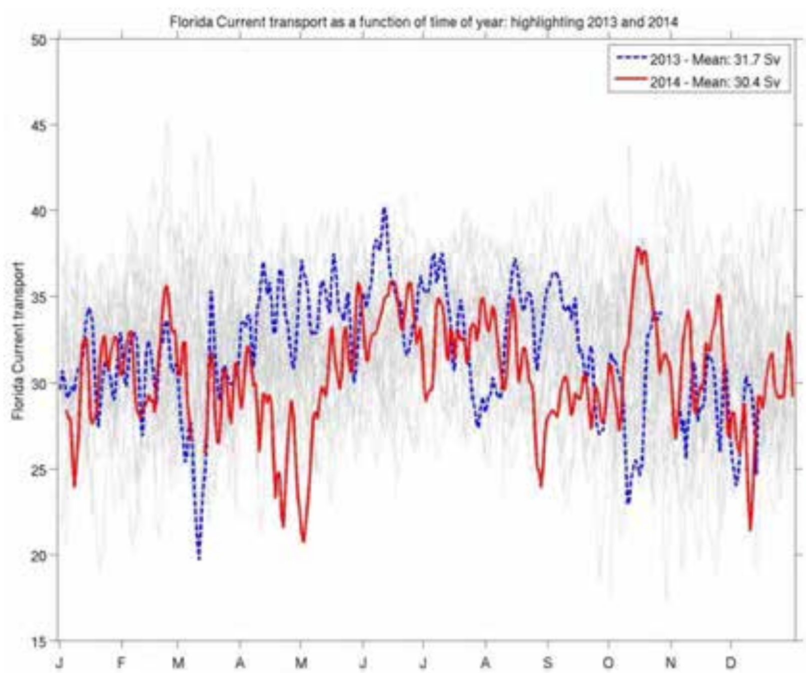

Figure 1: Volume transport of the Florida Current at 27ºN. The two most recent years are highlighted in color.

This project also maintains moored instruments and repeated hydrographic sampling east of Abaco Island that has established a high-temporal-resolution record of water mass properties in the Deep Western Boundary Current. Events such as the intense convection period in the Labrador Sea and the renewal of classical Labrador Sea Water in the 1980s are clearly reflected in the cooling and freshening of the Deep

Western Boundary Current waters off Abaco, and the arrival of a strong pulse of Labrador Sea Water approximately 10 years later. Through a collaboration with the National Science Foundation-funded Meridional Overturning Circulation Heat-flux Array experiment and the United Kingdom National Environmental Research Council funded RAPID-Meridional Overturning Circulation program, this program executes hydrographic cruises each year to monitor water mass changes along 26.5ºN east of Abaco Island in the Bahamas. These cruises usually involve collaborations with other scientists from RSMAS/University of Miami and the National Oceanographic Centre, Southampton (NOCS), United Kingdom.

Research Performance Measure: The scientific and support personnel continue to achieve the main project objectives – to maintain the continuity of the long-term data sets and to continually improve the calibration of the data obtained. Several data reports with hydrographic data collected during cruises in the WBTS region were also completed.

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Assessing Inertial Effects on Surface and Subsurface Drifting Buoy Motion

Project Personnel: F.J. Beron-Vera and M.J. Olascoaga (UM/RSMAS)
NOAA Collaborators: R. Lumpkin (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To investigate inertial (i.e., finite-size, buoyancy) effects on the motion of drifting buoys.
***Strategy*:** To accomplish this goal, drifting buoys from the Global Drifter Program were analyzed in light of recent theoretical results based on the Maxey-Riley formalism which indicated that anticyclonic coherent Lagrangian eddies should attract (repel) negatively (positively) buoyant finite-size particles, while cyclonic coherent Lagrangian eddies should attract (repel) positively (negatively) buoyant finite-size particles.

CIMAS Research Theme:

***Theme 1*:** Climate Research and Impact *(Primary)*
***Theme 3*:** Sustained Ocean and Coastal Observations *(Secondary)*

Link to NOAA Strategic Goals:

***Goal 3*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

NOAA Funding Unit: OAR/CPO **NOAA Technical Contact:** Molly Baringer

Research Summary:

We have analyzed the global drifter database with a focus on looping trajectories (loopers). Cyclonic loopers dominate over anticyclonic loopers for drogued drifters. The dominant polarity is reverted for drifters that have lost their drogue. The duration of cyclonic loopers exceeds that of anticyclonic loopers irrespective of whether or not the drifters are drogued. Contraction dominates over expansion in the case of cyclonic loopers, while expansion dominates over contraction in the case of anticyclonic loopers. This holds irrespective of whether or not the drifters are drogued. Overall half of the population of drifters exhibit dissipative behavior which is consistent with the behavior of inertial particles near coherent material eddies. We speculate that windage effects contribute to the deviation of the other half of the population from the Maxey-Riley theory, which needs to be appropriately modified.

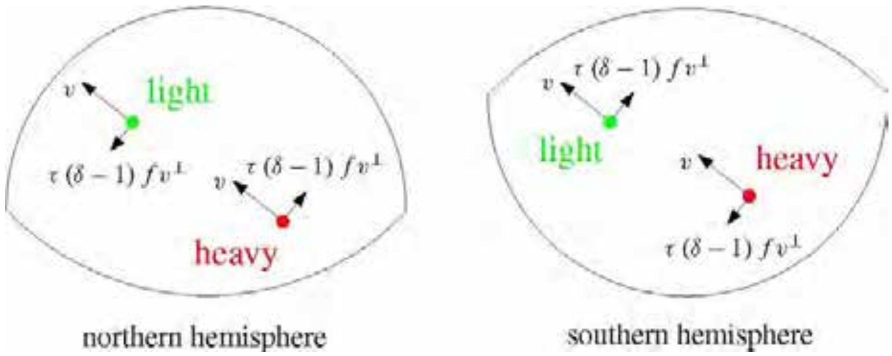


Figure 1: Velocity contributions to inertial particle's velocity: light (heavy) particle motion deflects to the right (left) of fluid particle motion in the northern hemisphere and vice versa in the southern hemisphere.

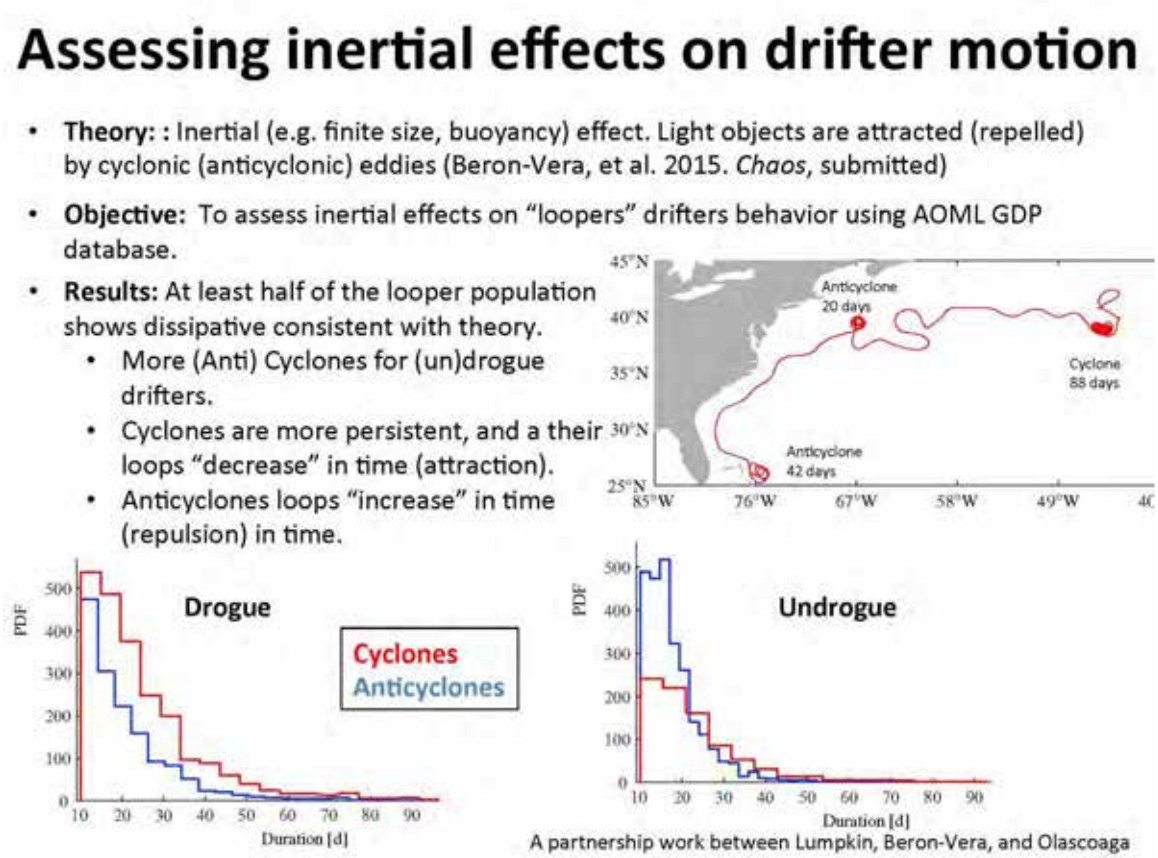


Figure 2: Summary of the results obtained.

Research Performance Measure: The objectives of the project have been reached with respect to data analysis and comparison with the Maxey-Riley theory. One peer-reviewed paper has been submitted for publication in *Chaos* (Beron-Vera et al., 2015).

Ocean Indicators in the Tropical and South Atlantic Ocean

Project Personnel: S. Dong, M. Goes, R. Domingues and R. Perez (UM/CIMAS); F.J. Beron-Vera (UM/RSMAS)

NOAA Collaborators: G. Goni, F. Bringas, J. Harris, Y.-H. Chong (NOAA/AOML); R. Msadek (NOAA/GFDL)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To monitor and assess the state of the ocean and its changes through a suite of indicators that are crucial for understanding the variability in the ocean and climate, such as boundary currents and meridional overturning circulation.

Strategy: To accomplish this goal, some of the longest ocean data sets in existence are jointly analyzed and integrated into ocean indices and indicators to: (i) improve the scientific understanding of the ocean and climate system; (ii) provide assessments of current states of the climate and ocean system for scientific analysis, numerical modeling comparisons; and (ii) identify potential impacts to inform service, planning, and management decisions.

CIMAS Research Theme:

Theme 1: Climate Research and Impact *(Primary)*

Theme 3: Sustained Ocean and Coastal Observations *(Secondary)*

Link to NOAA Strategic Goals:

Goal 3: Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

NOAA Funding Unit: OAR/CPO **NOAA Technical Contact:** Molly Baringer

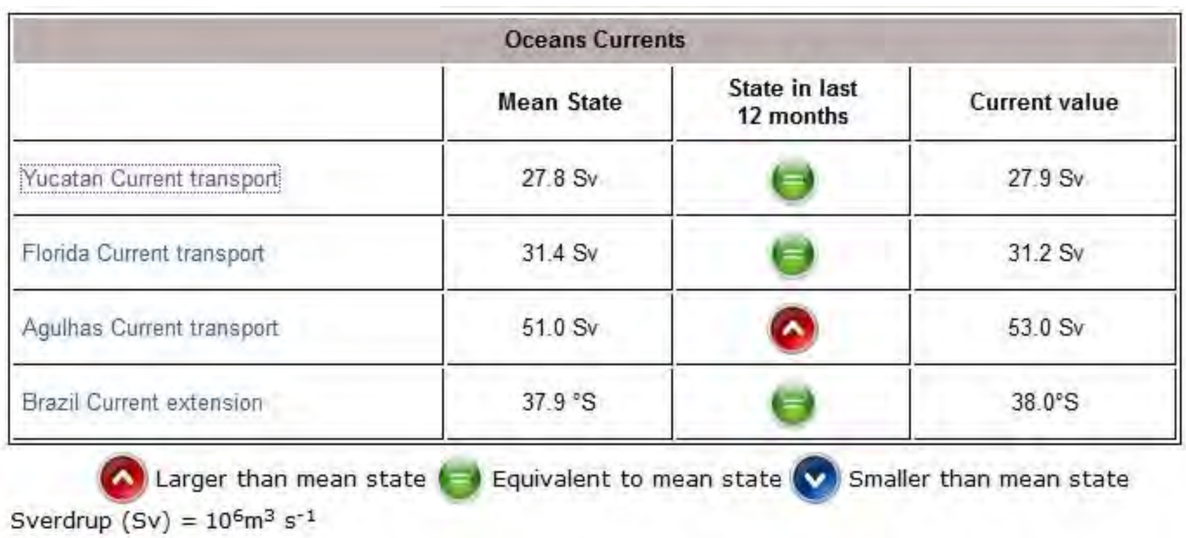
Research Summary:

This project brings together observational and numerical modeling scientists with the goal of implementing key ocean indices and indicators based on the ocean observing system, and assessing numerical model outputs using these parameters derived from observations. The main accomplishments during this year were related to the implementation of automated programs to compute near-real time series of parameters linked to key surface currents and undercurrents, and to meridional heat transport (MHT) by those currents in the South Atlantic Ocean. A dedicated web page was created to provide easy access to these parameters, and also to communicate general trends:
http://www.aoml.noaa.gov/phod /indexes/.

During July 1st, 2014, to June 30, 2015, near-real time estimates of the South Atlantic Meridional Overturning Circulation (MOC) were computed and analyzed and a manuscript is currently being prepared. This study, originally funded by NASA and lead by S. Dong and G. Goni, incorporates satellite altimetric measurements to complement and expand the estimates of MOC made with in situ observations in the South Atlantic. To accomplish this, synthetic temperature and salinity profiles were derived from altimeter sea height anomalies (SHA) along zonal sections between 20ºS and 34.5ºS, where SHA and isotherm depths are highly correlated. Estimates of MOC and MHT from those synthetic T/S profiles compare well with previous estimates derived from XBT measurements. Consistent with studies based on XBTs and Argo data, both the geostrophic and Ekman contributions to the MOC exhibit strong annual cycles, and play an equal role in the MOC seasonal variations. The strongest variations on seasonal and interannual time scales in our study region are found at 34.5ºS. The dominance of the geostrophic and Ekman components on the interannual variations in the MOC varies with time and latitudes.

In two additional studies (Goes et al., *Geophys. Res. Lett.,* 42, 1848-1855, 2015, and Goes et al., *J. Geophys. Res. Oceans*, 120, 161–181), an analysis of the uncertainties of the measurement uncertainties, as well as in the methodological and operational approximations used to estimate the MOC and MHT at 34.5S have been performed using a high resolution analysis model, and several recommendations such as time and spatial sampling, and reference velocity for geostrophic calculations, were made in order to maximize the information for the MOC and MHT long-term estimation.

The monitoring of several key ocean current parameters continued this year, with results posted on the web site. Preliminary results from the first year of this proposal include estimates of the variability during the last 12 months of the Yucatan, Florida, and Agulhas transports, and of the Brazil Current southernmost extension (Figure 1). The observation of Florida Current transport (Figure 2) is crucial for monitoring Atlantic MOC, a leading factor for global and regional climate change and variability. The observation of transports of Florida Current, Yucatan Current, Brazil Current, and Agulhas Current is important for evaluating the meridional coherence of MOC variability at different latitudes. The Brazil current has been shown in previous studies to have coherent variations with the AMOC, and provides a good proxy for AMOC. Time-series of the separation latitude for the Brazil-Malvinas confluence (Figure 3) also provide an estimate of the size and intensity of the subtropical gyre in the South Atlantic.



Oceans Currents			
	Mean State	State in last 12 months	Current value
Yucatan Current transport	27.8 Sv	=	27.9 Sv
Florida Current transport	31.4 Sv	=	31.2 Sv
Agulhas Current transport	51.0 Sv	^	53.0 Sv
Brazil Current extension	37.9 °S	=	38.0°S

Figure 1: Ocean currents state during January 2014 to January 2015. The current state is evaluated at the 95% confidence level.

Time series of key off-equatorial currents (North Equatorial Countercurrent, North Equatorial Undercurrent, and South Equatorial Undercurrent) properties, such as maximum velocity, transport, and location, were also calculated using the AX08 XBT data and salinity from historical T-S relationships. Properties of the North Equatorial Countercurrent were calculated using the methodology of Goes et al. (2013), which uses regression of sea surface height on the dynamic height and density of the water column. The methodology for computing synthetic profiles based on altimetry has now been updated, and a manuscript is currently being prepared. An updated T-S lookup table has been created to infer salinity at the XBT temperature profiles. This is an update of Hansen and Thacker (2007) methodology, using updated temperature profiles up to 2014 from historical CTD, XCTD, and Argo data. The new TS relationships use a multiple linear regression of salinity on pressure and temperature at selected temperature intervals, and accounts for seasonality as well as non-stationary. The updated geostrophic calculations of the equatorial currents are under way. To produce estimates of the Equatorial Undercurrent (EUC) we have been testing different methods using the equatorial beta plane approximation. Figure 4 shows a snapshot of salinity and equatorial velocities estimated by the synthetic method.

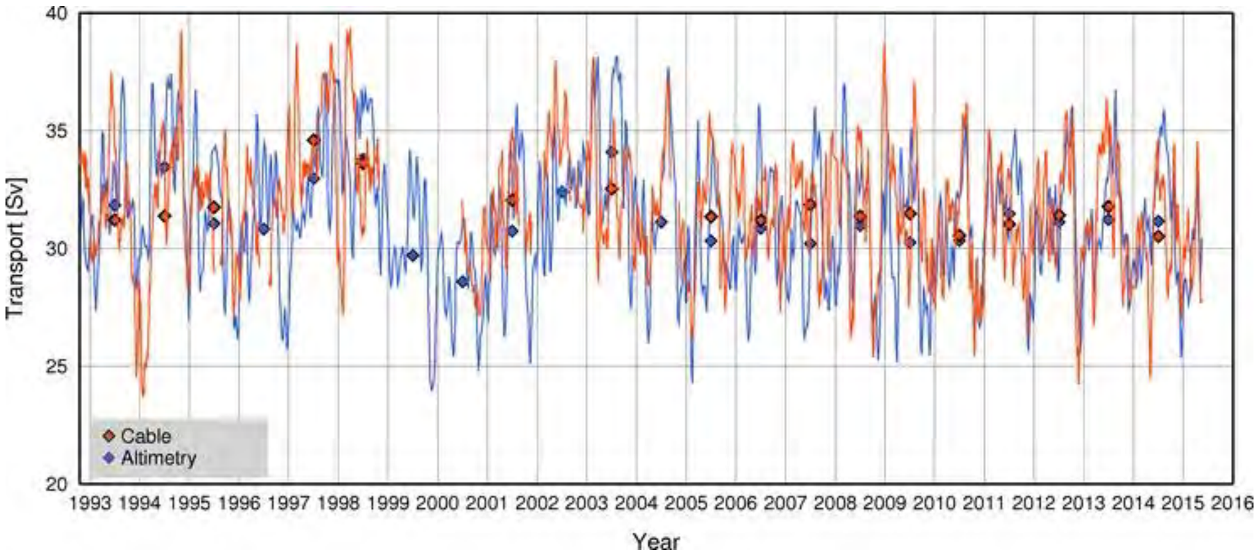


Figure 2: Florida Current transport time-series in Sverdrups (1Sv = 10^6 m^3 s^-1) derived satellite-altimetry (blue line) and from voltage measurements using telephone cables at the Florida Straits (red line). The diamonds show annual mean values.

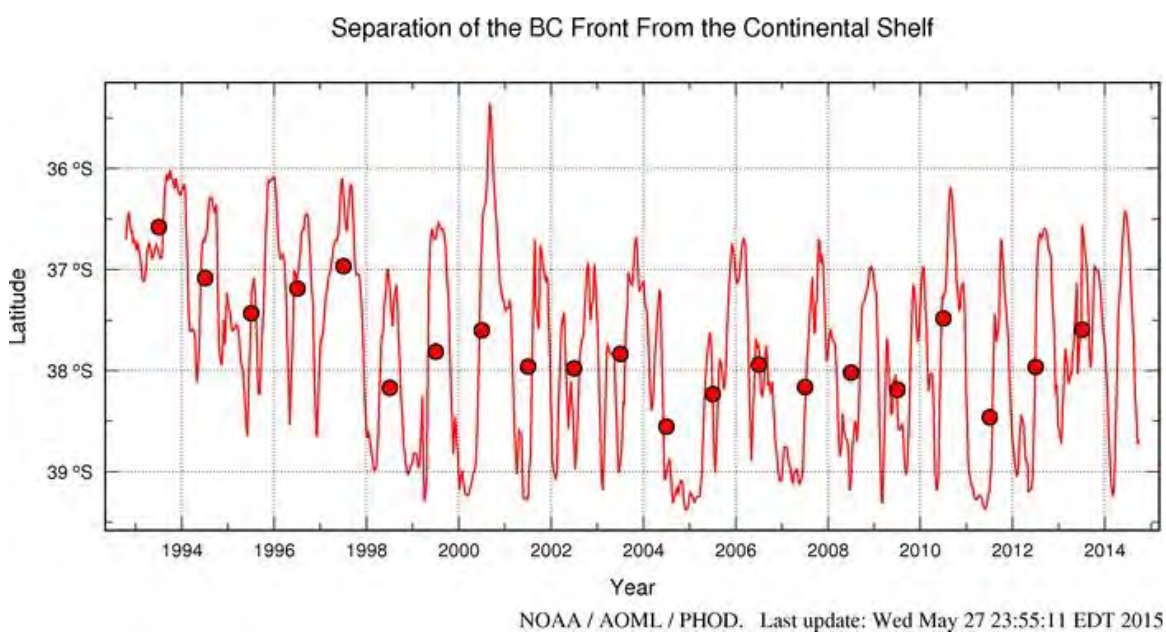


Figure 3: Latitude of separation of the Brazil Current front from the continental shelf derived from satellite-altimetry.

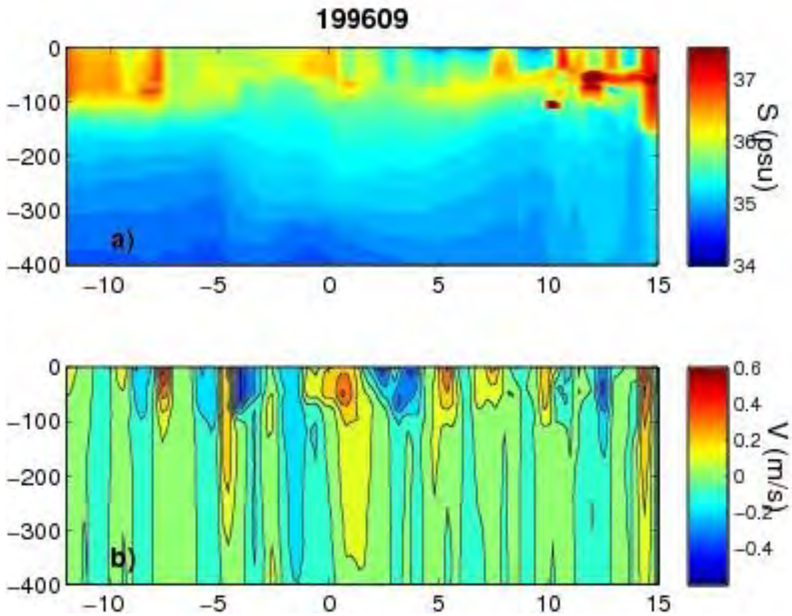


Figure 4: (a) Salinity and (b) velocity for March 1995 estimated along the reference AX08 XBT transect using the synthetic method and new TS lookup table.

Complementing a newly funded NASA funded project to study the variability of the South Atlantic subtropical gyre, R. Perez (in collaboration with S. Dong and R. Msadek) are examining the variability of the currents that delineate the western and southwestern boundary of the gyre, specifically the Brazil Current, and the latitude of the boundary between the Brazil and Malvinas Currents. Satellite and in situ data, in conjunction with ocean-only and coupled climate models, are being used to characterize the time-mean and variability of these oceanic features. On interannual and decadal time-scales, the subtropical gyre can either intensify/expand (spin-up) or weaken/contract (spin-down). One of the goals of this study is to characterize how the Brazil and Malvinas Currents vary in concert with the South Atlantic subtropical gyre, and whether this has an impact upon the Atlantic Meridional Overturning Circulation. One crucial ocean indicator that is being used for this analysis is the Brazil Current frontal separation from the continental shelf (http://www.aoml.noaa.gov/phod/altimetry/cvar/mal/index.php).

In the Southwest Atlantic, using recently developed techniques from nonlinear dynamical systems, a methodology has been implemented (Wang et al. 2015) to extract from the satellite altimetry record a signal of coherent water transported across the South Atlantic. This technique enables detection of mesoscale eddies with material boundaries that preserve coherence for many months. As a result, these coherent material eddies can trap water of unique characteristics and effectively carry them within across the South Atlantic. The detection was conducted near the Walvis Ridges in the so-called Agulhas corridor. Some of these eddies can be traced back into the Indian Ocean and thus can be unambiguously identified with Agulhas rings. Many of them reach the bifurcation of the subtropical gyre off the coast of Brazil, to partly form the Brazil Current. While some of these contents are transported northward along the coast, a much larger fraction of them are transport southward, back into the subtropical gyre.

Specifically, 1 to 4 coherent material eddies were detected with diameters ranging from 40 to 280 km yearly. A total of 23 eddy cores of about 50 km in diameter and with at least 30% of their contents traceable into the Indian Ocean were found to travel across the subtropical gyre with minor filamentation. Only 1 eddy core was found to pour its contents on the North Brazil Current. While ability of eddies to carry Agulhas leakage northwestward across the South Atlantic was supported the analysis, results indicated a more restricted transport than suggested by earlier ring transport assessments. A coherent water transport time series over the period 1993-2013 is shown in Figure. 5. Gray-shaded bar portions correspond to Indian Ocean water transport. The maximum annual transport produced by 1-year coherent material eddies is about 0.3 Sv. These estimates are two orders of magnitude smaller than earlier estimates obtained as total volume of eddies detected during a given year, divided by 1 year. The reason for this large discrepancy actually resides in that these earlier estimates implicitly assume that eddies whose diameters at detection time are 250 km or so can preserve material coherence over periods as long as 1 year, which cannot be guaranteed by Eulerian analysis of altimetry or the inspection of in-situ observations. Truly material eddies as large as 250 km in diameter revealed from altimetry in the region of interest can be guaranteed to preserve coherence for at most 3 months. Beyond 3 months or so, eddies of this size shed filaments that typically reach the generation region or further east. The maximum annual transport of Indian Ocean water trapped inside 1-year coherent material eddies does not exceed 0.2 Sv. This is also smaller, by two orders of magnitude, than annual Agulhas leakage estimates obtained from numerical simulations. While these Agulhas leakage estimates still lack observational support, the noted large mismatch suggests that eddies may not be as efficient in transporting leaked Indian Ocean water across the South Atlantic as the early eddy transport estimates appear to indicate. This work expands the scope of the Leakage of Indian Ocean waters into the South Atlantic Ocean" and Interbasin exchanges of water masses south of Africa" indices by identifying the portions of the leakage and transport, respectively, that are carried coherently. A recent manuscript reporting these results by Wang et al., (2015) was published in Geophysical Research Letters.

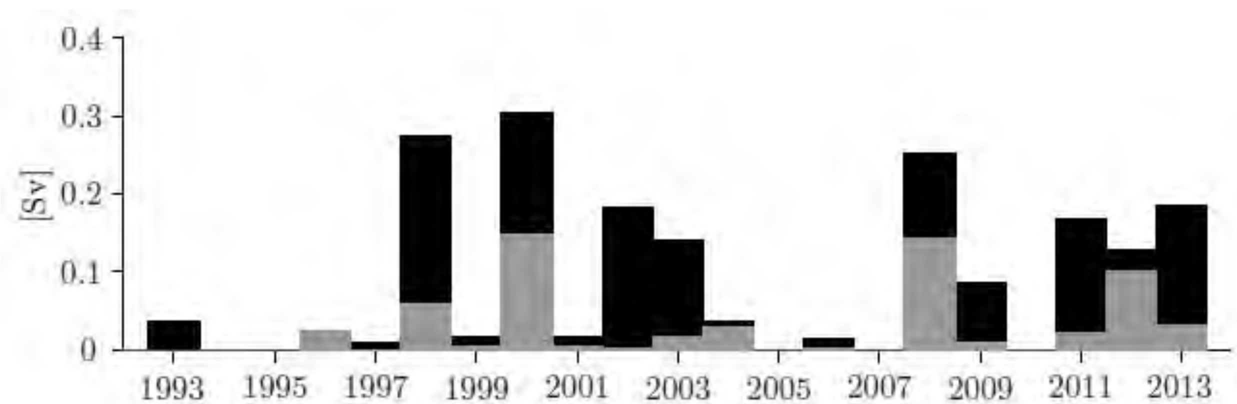


Figure 5: Annual average time series of transport across the South Atlantic produced by coherent material eddies. Gray-shaded bar portions correspond to transport of Indian Ocean water trapped inside the eddies.

Research Performance Measure: All objectives were met with respect to the analysis and implementation of ocean indices to monitor key ocean parameters in the Atlantic Ocean. Six peer-reviewed papers were published in Journal of Geophysical Research Oceans, Geophysical Research Letters, and the Marine Technology Society journal.

Southwest Atlantic Meridional Overturning Circulation ("SAM") Project

Project Personnel: S. Dong, R. Garcia, S. L. Garzoli and R. C. Perez (UM/CIMAS)
NOAA Collaborators: C.S. Meinen, P. Pena, U. Rivero and R. Smith (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Theme:

***Objectives*:** To sustain a time series measurement system for the South Atlantic western boundary components of the Meridional Overturning Circulation at 34.5°S.

***Strategy*:** To use moored instruments and hydrographic observations collected in partnership with international collaborators to study the Brazil Current and the Deep Western Boundary Current systems.

CIMAS Research Theme:

Theme 1: Climate Research and Impacts (*Primary*)
Theme 3: Sustained Ocean and Coastal Observations (*Secondary*)
Theme 4: Ocean Modeling (*Tertiary*)

Link to NOAA Strategic Science Goals:

***Goal 3*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

NOAA Funding Unit: OAR/AOML and OAR/CPO **NOAA Technical Contact:** Molly Baringer

Research Summary:

Studies using numerical climate models have suggested that variations in the transport of the Meridional Overturning Circulation (MOC) are correlated with significant changes in surface air temperatures and precipitation both regionally and globally. Observations and modeling studies have also indicated that water mass transformations occurring in the South Atlantic alter the waters circulating in the global MOC resulting in changes to the global circulation system. NOAA has maintained a crucial long-term array measuring the western boundary components of the MOC in the South Atlantic near 34.5°S since 2009 via the 'Southwest Atlantic MOC', or 'SAM', project. The SAM project represents a collaborative effort with partners in Argentina, Brazil, France, and South Africa to monitor the MOC-related flows in the South Atlantic and to improve our understanding of the key processes that cause this variability. The NOAA component of this international effort is focused on the western boundary currents, specifically the Brazil Current in the upper layer and the Deep Western Boundary Current (DWBC) at depth. Study of the DWBC is of particular interest because it is believed to carry a significant percentage of the lower limb of the MOC, and prior to the SAM project, observations were insufficient to constrain its mean and variability in this region. Long-term observations of these key flows will be required to understand the mechanisms leading to changes in the MOC system in the South Atlantic, and the impact of those MOC changes on the global climate. The goal of the NOAA SAM program and the international collaborating programs is to measure the MOC in the South Atlantic with a trans-basin array from South America to South Africa along 34.5°S. With nine moorings on the western side of the basin (as of December 2013) and fourteen moorings on the eastern side of the basin (as of September 2014), this trans-basin array ("SAMBA") has achieved a new milestone of collecting multi-year daily trans-basin MOC measurements. Efforts now are focused on mid-deployment data retrievals, instrument recovery and redeployment, and obtaining funds for future augmentations to the array.

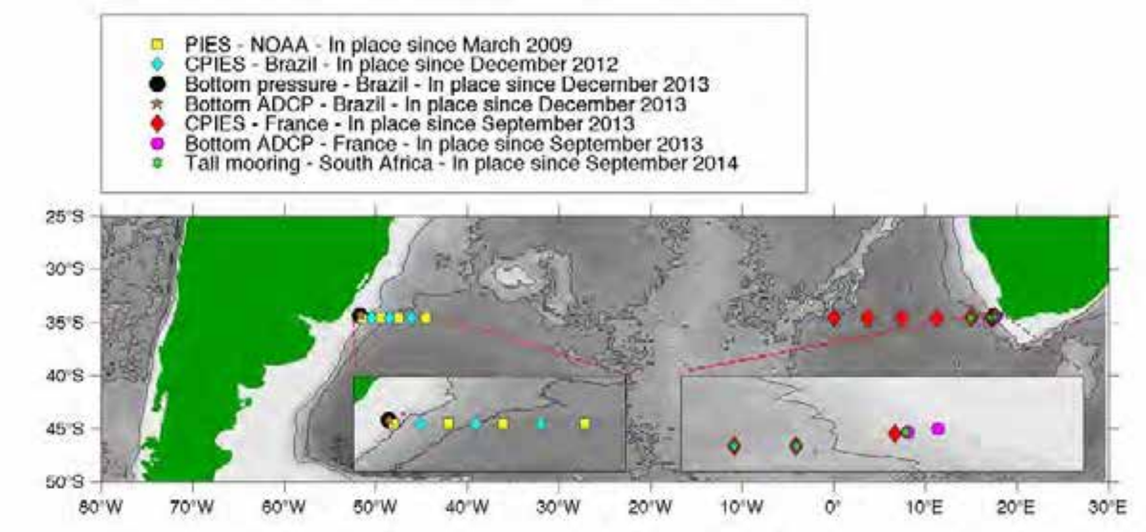


Figure 1: Map indicating the location of the four NOAA PIES making up the SAM array and the Brazilian CPIES deployed in December 2012 and coastal moorings deployed in December 2013. Also shown are the French and South African moorings which were added to the experiment in September 2013 and September 2014, respectively. With these latest deployments, SAMBA has achieved a new milestone of collecting multi-year daily trans-basin MOC measurements.

Research Performance Measure: During this performance period, data downloaded from the last cruise in the SAM region (October 2014) were processed and quality controlled. During this cruise, data from two of the Brazilian CPIES instruments were also successfully downloaded and analyzed for first time. Observations and numerical models were used to estimate the Atlantic Meridional Overturning Circulation (AMOC) at 34°S (Dong et al. 2014, Garzoli et al. submitted) and compared with measurements collected from SAM instruments (Garzoli et al. submitted). SAM PIs led and/or co-led an article describing different types of observational systems used by NOAA, CIMAS, and their partners to study the complex nature of the AMOC (Perez et al., 2015). The SAM and SAMBA arrays along 34.5°S were featured in this article, along with the RAPID/MOCHA/WBTS array at 26.5°N. Results from several studies were presented at the U.S. AMOC Annual Meeting in Seattle (WA) in September 2014, at the Fall AGU Meeting in San Francisco (CA) in December 2014, at the SAMOC V workshop in Buenos Aires (Argentina) also in December 2014, at the NOAA Climate Observation Division (COD) meeting in Baltimore (MD) in June 2015, and at the IUGG General Assembly in Prague (Czech Republic) in June-July 2015.

High-Frequency Variability of Near-Surface Oceanic Velocity From Surface Drifters

Project Personnel: S. Elipot (UM/RSMAS); R. Perez (UM/CIMAS)
NOAA Collaborators: R. Lumpkin (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To characterize and quantify the high-frequency variability of the near-surface oceanic velocity field on a global scale; to improve our understanding on the distribution and characteristics of inertial motions, tides (diurnal and semidiurnal) and submesoscale motions.

Strategy: To build a new quality-controlled global database of surface drifter positions and velocities at an unprecedented level of temporal (*hourly*) and spatial resolution.

CIMAS Research Theme:

***Theme 1*:** Climate Research and Impact (*Primary*)
***Theme 3*:** Sustained Ocean and Coastal Observations (*Secondary*)

Link to NOAA Strategic Goals:

***Goal 3*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

NOAA Funding Unit: OAR/AOML **NOAA Technical Contact:** Molly Baringer

Research Summary:

Understanding the cascade of energy in the ocean from large-scale forcing by winds and tides to small-scale high-frequency mixing remains one of the outstanding issues in physical oceanography. Many uncertainties remain regarding not only the rates, but also the mechanisms, by which the ocean's energy reservoir is supplied, distributed, and dissipated. This lack of knowledge affects our capability to understand and predict large-scale and regional oceanic circulations and global climate. To date, observations have been insufficient to shed light on the spatial structure of high-frequency kinetic energy sources and sinks. Although recent studies have made it clear that the distribution of these sources and sinks is not homogenous and varies with time.
In order to produce a global description of upper-ocean velocity variability in the inertial, diurnal and semi-diurnal frequency bands, we are analyzing trajectories and velocities of surface drifters from the Global Drifter Program (GDP). NOAA's GDP maintains a 5° x 5° global array of ~1250 satellite-tracked surface drifters providing observations of near-surface oceanic currents. The standard drifter product is made available with 6-hourly resolution, which provides valuable information on a wide range of time and space scales. However, in 2005 the number of satellites available for the Argos satellite tracking system increased from two to five (and sometimes six) satellites, reducing the time interval between consecutive drifter position fixes to 1-2 hours on average. As a result, the GDP dataset contains physically meaningful, high-frequency information about near-surface currents including sub-mesoscale, inertial and tidal signals, at all latitudes.

This year, research efforts have centered on developing a global *hourly* drifter product from Argos satellite-tracked surface drifters. We have evaluated a number of methods (from simple linear interpolation to higher order polynomials, and using a priori errors) to interpolate the uneven drifter position fixes to uniformly sampled *hourly* positions and velocities. These methods were tested on a subset of surface drifters that have been equipped with both Argos system and Global Positioning System (GPS) during the first phase of the SPURS experiment (example in Figure 1). Having dual hourly Argos and GPS fixes allows for a rigorous examination of the errors associated with each interpolation schemes (Figure 2). The most promising method (A minimum variance unbiased estimator, so-called Gauss-Markov estimator) is one that includes a set number (here 5) of the Argos positions with the lowest errors (given by the Argos class, see Figure 1). In this case, the modal value of the error distribution on hourly position is about 220 m, just twice the spatial resolution of the drifter dataset (110 m).

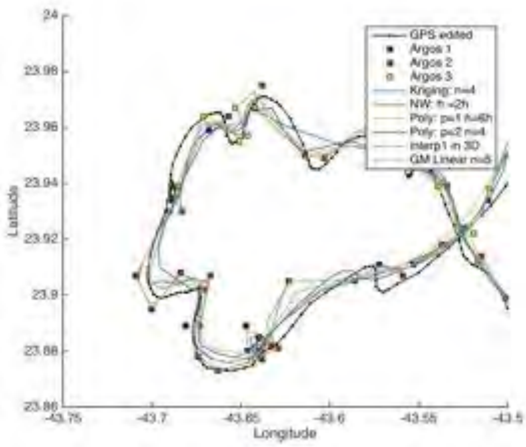


Figure 2: Probability distribution function (PDF) of position errors (in km) for the surface drifters of the SPURS experiment. Left panel is the PDF on a logarithmic-linear scale, right panel on a double logarithmic scale. The legend indicate the interpolation methods: Kriging, Nadaraya-Watson kernel estimator (NW), Order 1 polynomial with 6-h bandwidth (Poly), order 2 polynomial with variable bandwidth (Poly variable), linear interpolation in three dimension (Interp1 in 3D), Gauss-Markov 5-best estimator (GM).

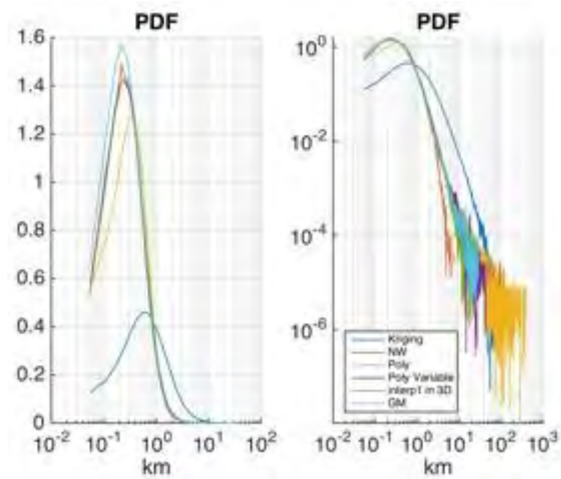


Figure 1: Example of a drifter observed positions and estimated trajectories. One of the objectives of the research is to devise an interpolation method (colored trajectories) based on Argos positions (colored squares) that gets as close as possible to the GPS positions (black trajectory).

Research Performance Measure: We have so far worked on a subset of the GDP dataset from the first phase of the SPURS experiment (82 individual trajectories totaling 424,000 hourly positions), to determine the optimal method to apply to the entire and global dataset. Excellent progress is being made, and all research objectives are being met. We anticipate releasing and analyzing the first version of the *hourly* global drifter in summer 2015.

Elucidating Net Ecosystem Prediction and Calcification at the Atlantic Ocean Acidification Testbed

Project Personnel: I. Enochs (UM/CIMAS)
NOAA Collaborators: D. Manzello (NOAA/AOML)
Other Collaborators: W. McGillis (Columbia University)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** Develop and validate the Benthic Ecosystem metabolism ocean Acidification Measurement System (BEAMS) to quantify a fundamental parameter of ecosystem functioning. This quantity provides a metric of the energy and mass transferred to a reefal system and determines the health within that ecosystem. This methodology determines Net Ecosystem Calcification (NEC) and net Ecosystem Production (NEP). As a part of ocean acidification, the affect it has on calcifying organisms is a paramount issue. The approach relies on boundary layer techniques of measuring gradients of scalar quantities. We will use autonomous oxygen and pH sensors to measure these gradients over seasons at AOAT Cheeca Rocks. Benthic metabolism is of key interest for coral reefs, estuarine systems, and productive coastal shelves. Our final products will be easily deployed measurements to monitor benthic ecosystem metabolism.

***Strategy*:** We use and adapt the CROSS (Coral Reef Oxygen Sensing System) and added a solid-state pH sensor and co-pumping system for BEAMS. BEAMS relies on the gradient method of measuring fluxes of chemical constituents from the benthos. In short, using basic physics it can be shown that the difference in concentration (gradient) of the chemical (or physical) constituent of interest is directly proportional to the flux from the surface. We measure pH (hydrogen ion) and O_2 (oxygen) by developing a robust instrument module with dual inlets at different heights to determine the gradient. The method is used with boundary layer flow analysis, the biogeochemical chemical process parameters NEC and NEP through determination of Alkalinity and dissolved inorganic carbon (DIC) during the deployments. Acoustic Doppler Velocimeter (ADV), and Modular Acoustic Velocity Sensor (MAVS) provides the flow fields. NEP can be directly determined from the calculated fluxes from the O_2 gradient. NEC that is a direct indicator of growth and dissolution of calcifying organisms is determined from the combination of O_2 and pH. The critical assumptions that go into the NEC calculation are derived in this work. We use the strong correlation between pH and carbonate ion concentration gradients to derive rates of calcium carbonate formation and dissolution. A primary objective is to study coral reef health at the AOAT. The natural diurnal cycle of pH in coral reefs causes pH minima mimicking ocean acidification environments expected decades from now. Moreover, it gives current rates of NEC and NEP.

CIMAS Research Theme:

***Theme 1*:** Climate Research and Impact
***Theme 6*:** Ecosystem Management
***Theme 7*:** Protection and Restoration of Resources

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*
***Goal 3*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

NOAA Funding Unit: OAR/AOML **NOAA Technical Contact:** Molly Baringer

Research Summary:

Links to the NOAA Strategic Plan

Maintaining coastal Ecosystem Health is one of the key research and monitoring activities under the **Healthy Oceans** theme. This project also addresses **the Climate adaption and mitigation** theme, as the changes in benthic NEP and NEC are directly related to the impacts of climate change on the coastal ocean and atmospheric CO_2 rise. The instrumentation provides an improved basis for confidence in understanding key oceanic, biogeochemical, and socioeconomic components of the climate system and impacts. Coastal ocean acidification is a considerable threat to maintaining healthy coasts but we are not thoroughly prepared to quantify the effects particularly its impact of coral reefs and benthic shellfish. This non-invasive, and portable tool has the potential to monitor and understand changes from which effective adaptation mitigation strategies can be developed. Adding this monitoring capacity is critical for marine resource managers to prepare for and respond to the impacts of a changing climate, ocean acidification.

The goal was to implement the **boundary-layer gradient method** to map out coral reef ecosystem metabolism. The near bottom flux of a chemical constituent into or out of the sediment or biota on the seafloor is determined from the product of the vertical eddy diffusivity related to drag coefficient estimated from measurements of horizontal velocity at two closely spaced depth just above the seafloor and the concentration gradient of the constituent of interest measured over the same depth interval. We have been able to show that application of this method using oxygen sensors produces net photosynthesis and respiration rates that agree well with those determined by Eulerian and dome methods. Figure 1 shows a March 2014 time series of nep and nec. Figure 2 is the diurnal ensemble average of nep and nec. The strong utility of the method is that it can be applied to constituents for which no chemical sensor exists but which can be measured from water samples. The BEAMS package is a light-weight unistructure made of thin aluminum struts that stands 1 m high that carries an acoustic Doppler Velocimeter (ADV), a pH-O_2 measuring seafox, a MAVS time of flight 3-D velocimeter, and a light sensor. The instrument measures the oxygen and pH flux every 30. The footprint of the measurement is an oval that is approximately 30-50 m^2. The boundary-layer gradient flux method has the potential to open up a large spectrum of chemical constituents for which we will now be able to measure their seafloor fluxes under completely natural, unperturbed conditions.

Table 1: ***2012-2015*** **CROSSBEAMS deployments.**

site	Cheeca Rocks								Flower Garden	
year	2012		2013		2014		2015		2015	
rate	NEP	NEC	NEP	NEC	NEP	NEC	NEP	NEC	NEP	NEC
January	●		●				●	●		
March					●	●	●	●		
April										
May	●		●	●						
June									●	●
July			●	●						
August										
Sept	●				●	●				
October					●	●				
Nov										
Dec			●	●						

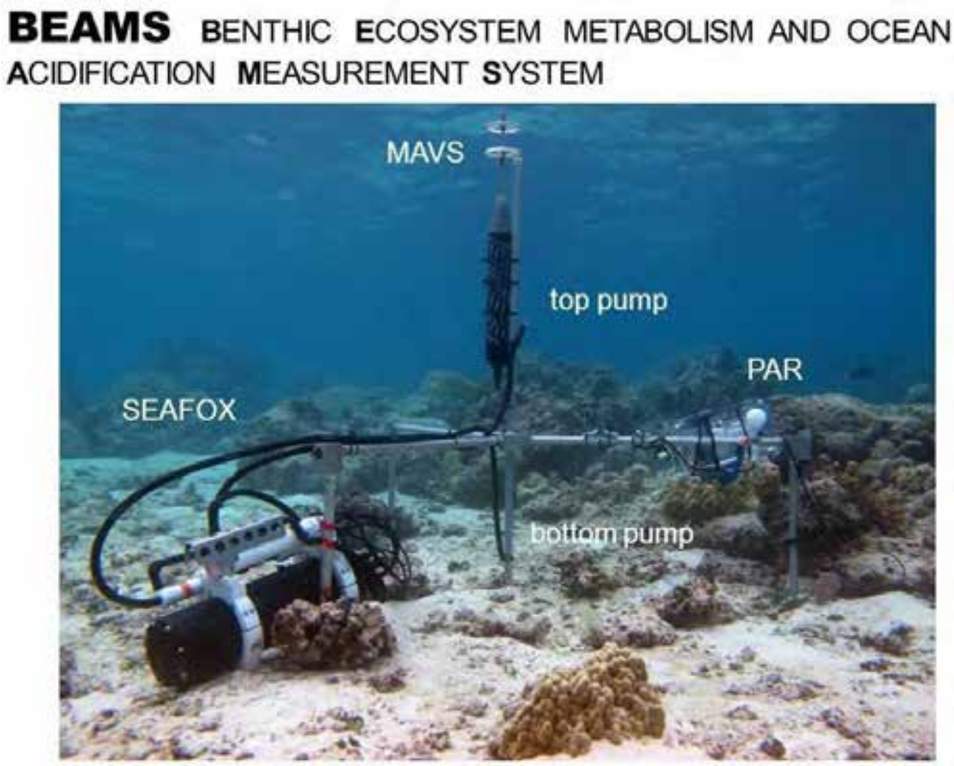


Figure 1: BEAMS deployed showing (1) pump sample locations, (2) seafox used for temperature, O_2 and H^+ gradient measurements, (3) MAVS velocity measurements, and (4) PAR measurements. Gradients of O_2 and H^+ are used to calculate DIC and TA gradients.

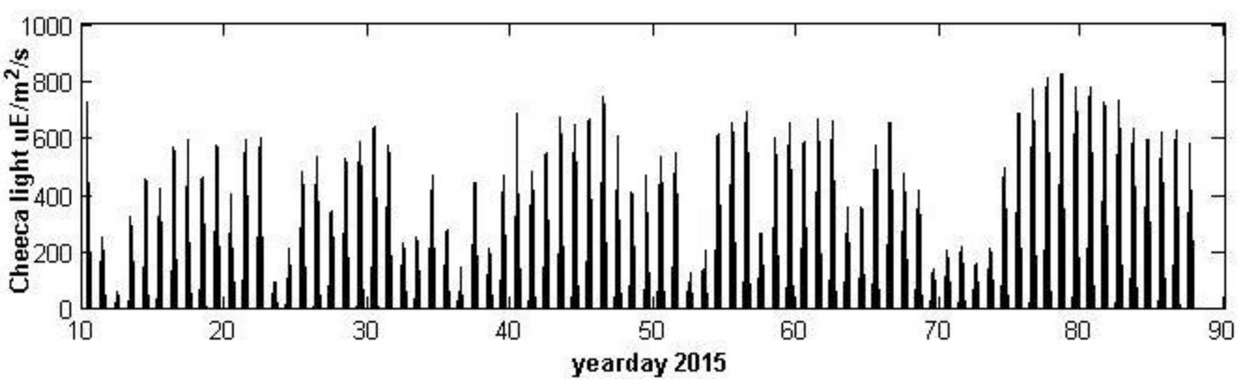


Figure 2: Timeseries (*January-April 2015*) of underwater PAR at the Cheeca Rocks. Light-NEP:NEC rating curves are used to generate integrated metabolism. PAR intensity at substrates are a function of both atmospheric and ocean conditions. Storm events can reduce daytime atmospheric incidence and have prolonged effects on underwater turbidity.

Research Performance Measure: The research objectives where met and we performed four three-day deployments on the Cheeca Rocks coral reefs since the last project period. Sampling occurred in September 2014, October 2014, January 2015, and March 2015. For each field deployment, NEP and NEC in addition to light and meteorological conditions where measured.

The North American Multi-Model Ensemble (NMME) Intraseasonal-to-Interannual Prediction Experiment

Project Personnel: B. Kirtman (UM/RSMAS)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To improve intra-seasonal to interannual prediction through a mutli-model ensemble prediction strategy.

Strategy: The research is carried out as part of the CIMAS program, and address the CIMAS climate impacts and research theme in that the objectives include improving understanding of seasonal-to-interannual prediction using multi-model ensembles. In addition, the results of the proposed research serve NOAA's goal of understanding climate variability and change to enhance society's ability to plan and respond using quantitative information from a US National multi-model seasonal-to-interannual predictive system.

The recent US National Academies "Assessment of Intraseasonal to Interannual Climate Prediction and Predictability" (NRC 2010, http://www.nap.edu/catalog.php?record_id=12878) was unequivocal in recommending the need for the development of a US NMME operational predictive capability. Indeed, the national effort is required to meet the specific tailored regional prediction and decision support needs of the emerging National Climate Service. The challenge is to meet this national need without diluting existing model development activities at the major centers and ensure that the forecast products continue to improve and be of societal value.

There is little doubt that US participation in EUROSIP is beneficial to both the US and European forecasting communities. However, as a US National Climate Service emerges and as the possible National Center for Predictions and Projections (NCPP) develops, the need for a NMME system becomes paramount for supporting continued research on MME based prediction that can transition to operations. For example, a NMME system facilitates modifications (e.g., extending the forecast to longer time-scales) to the forecast strategy, allows for better coordination of the forecast runs compared to EUROSIP (e.g., hindcast period, forecast scheduling etc.) and allows free exchange of data beyond what is supported by EUROSIP. Also, by testing various national models on weather and seasonal time-scales, the NMME system will accelerate the feedback and interaction between US ISI prediction research, US model development and the decision science that the forecast products support. For instance, the prediction systems can potentially be used to evaluate and design long-term climate observing systems, because US scientists will have open access to the prediction systems (i.e. data, data assimilation and forecast models). Our national interests require that we (1) run these ISI prediction systems operationally in the US, (2) retain the flexibility to modify the prediction systems and how they are used based on emerging national needs, and (3) ensure that there is a robust communication and collaboration network open among operational ISI forecasting, research and model development.

CIMAS Research Theme:

***Theme 1*:** Climate Research and Impact

Link to NOAA Strategic Goals:

***Goal 3*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

NOAA Funding Unit: Climate Program Office
NOAA Technical Contact: Dr. Annarita Mariotti

Research Summary

The research leverages an existing National Multi-Model Ensemble (NMME) team that has already formed and began producing routine real-time seasonal to interannual (ISI) predictions in August 2011, providing them to the NOAA Climate Prediction Center (CPC) on an experimental basis for evaluation and consolidation as a multi-model ensemble ISI prediction system. The experimental prediction system developed by this NMME team is as an "NMME of opportunity" in that the ISI prediction systems are readily available and each team member has independently developed the initialization and prediction protocol. We will refer to the NMME of opportunity as phase 1 NMME (or NMME-1).

The research activity is to develop a more "purposeful NMME" in which the requirements for operational ISI prediction are used to define the parameters of a rigorous reforecast experiment and evaluation regime. This will be phase 2 NMME (or NMME-2). The NMME team will design and test an operational NMME protocol that will guide the future research, development and implementation of the NMME beyond what can be achieved based on the phase 1 NMME project.

The proposed activity:

- Builds on existing state-of-the-art US climate prediction models and data assimilation systems that are already in use in NMME-1 and ensure interoperability so as to easily incorporate future model developments.
- Takes into account operational forecast requirements (forecast frequency, lead time, duration, number of ensemble members, etc.) and regional/user specific needs. A focus of this aspect of the work will be the hydrology of various regions in the US and elsewhere in order to address drought and extreme event prediction.
- Utilizes the NMME system experimentally in a near-operational mode to demonstrate the feasibility and advantages of running such a system as part of NOAA's operations.
- Enables rapid sharing of quality-controlled reforecast data among the NMME team members, and develop procedures for timely and open access to the data, including documentation of models and forecast procedures, by the broader climate research and applications community.

The activity also includes several NMME research themes:

i. The evaluation and optimization of the NMME system in hindcast mode (e.g., assessing the optimal number of ensemble members from each model, how to best combine the multi-model forecasts, sources of complementary prediction skill, etc.), methodologies to recalibrate individual dynamical models prior to combination, and provision of probabilistic quantitative (rather than categorical) information. There will also be a thorough evaluation of the forecasts across multiple time scales (e.g., variability beyond week two).
ii. Designing and evaluating a sub-seasonal (weeks 3 and 4) multi-model predictive protocol.
iii. The application of the NMME forecasts for regional downscaling and hydrological prediction.

a) NMME Data Production

- NMME team continues to meet monthly via telecom to address all science and data production issues
- NMME team now has a "data working group" to coordinate with NCAR on phase-II data serving
- All forecast providers (RSMAS/COLA/NCAR, GFDL, CMC, NASA) continue to submit real-time predictions on time all the time.
- IRI continues to upload and serve all real-time and retrospective data
- CPC continues to ingest data, produce graphical images of forecasts and skill assessments including probabilistic measures. CPC also developing evaluation of skill of real-time forecast.

- New monthly mean data (Tmin, Tmax, Z500, Soil Moisture, Runoff) are now routinely being provided to CPC and IRI from all forecast providers.
- Phase-II high frequency and additional fields data archive at NCAR is fully populated for CCSM4, GFDL-FLOR, CanCM3, CanCM4, GOES5, and CFSv2 is in progress.
- CCSM4 retrospective forecasts are completed and have been upload at NCAR phase-II data server
- CCSM4 sub-seasonal increased start frequency forecast have been completed.
- CFSv2 phase-II data conversion from GRIB2 to NetCDF4 is in progress

b. Land and Atmosphere Initialization in CCSM4
Several prediction experiments have been made with CCSM4 to investigate the role of land surface initialization in improve the forecast skill over North America. In particular, the experimental design follows the NMME forecast protocol implemented with CCSM4, but with the specific intent of separating remote responses from SSTA vs. land and atmosphere initialization in the forecast skill. Four experiments are described here:

(i) CAM4 (the atmospheric component of CCSM4) forecasts initialized in 1 May 1982-2010 are made with observed atmospheric and land initial conditions but with climatological SST.
(ii) CAM4 (the atmospheric component of CCSM4) forecasts initialized in 1 May 1982-2010 are made with observed atmospheric and land initial conditions but with observed SST.
(iii) CAM4 (the atmospheric component of CCSM4) forecasts initialized in 1 May 1982-2010 are made with climatological initial condition for the atmosphere and land and climatological SST.
(iv) CAM4 (the atmospheric component of CCSM4) forecasts initialized in 1 May 1982-2010 are made with climatological initial condition for the atmosphere and land and observed SST.

All of these forecast experiments are ten member ensembles. Comparisons isolate the relative roles of land and atmosphere initialization versus the remote response from SST. For example, comparing (i) vs. (iii) shows the skill from land and atmosphere initialization without the SSTA influence and comparing (ii) vs. (iv) shows the skill due to land and atmosphere initialization with SSTA influence. These comparisons are summarized in Figure 1 and Figure 2 and are being prepared for publication in Infanti and Kirtman (2015).

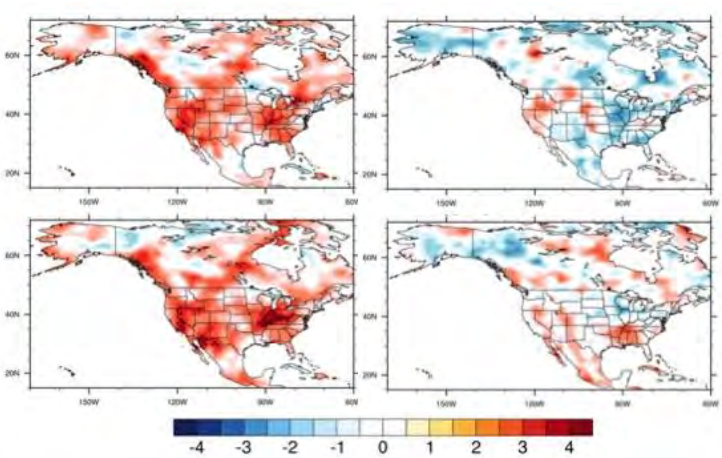


Figure 1: Z-statistic calculated from the correlation between "predicted" and observed precipitation. Results from experiment (i) in the upper left, experiment (ii) in the lower left, experiment (iii) upper right and experiment (iv) in the lower right.

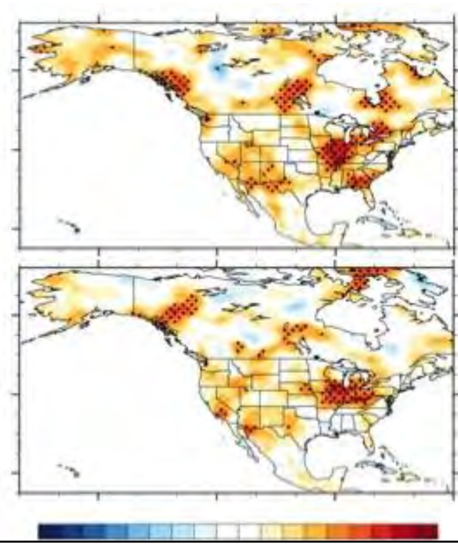


Figure 2: Difference in the Z-statistic. Top panel shows experiment (i) minus experiment (iii) and the bottom panel shows experiment (ii) minus experiment (iv). Stippling corresponds to 95% statistical significance.

c. Comprehensive CCSM4 vs. CCSM3 hindcast quality comparison
To assess hindcast skill in CCSM3 and CCSM4 we use both deterministic and probabilistic methods, as this gives a more complete representation of the skill. We focus on hindcasts of sea surface temperature, precipitation, and 2-meter temperature. We form anomalies by removing the 1982-2010 climatology from each ensemble member for each forecast initialization period separately.

The initialization strategy developed for CCSM4 was specifically designed with the NMME forecast protocols in mind. This can be seen by the fact that the ocean, land and atmospheric initial conditions are taken from CFSR for both the retrospective forecast and the real-time forecasts. This is done so that CCSM4 can meet the on-time NMME protocol requirements and use state-of-the-art initial conditions. The approach has the added advantage that we can examine how using the same initial conditions with a very difference forecast tool (CFSv2 vs. CCSM4) affects the prediction. In contrast, the CCSM3 forecasts use climatological states for the land and atmosphere and an ocean-only data assimilation system for the ocean states.

To highlight the contribution from CCSM4 we show a brief comparison with CCSM3. Figure 3, for example, shows the T2m one season lead Ranked Probability Skill Score (RPSS) for forecasts initialized on 1 January and 1 June. Clearly, CCSM4 is out performing CCSM3. These results are being prepared for publication in Kirtman et al. (2015).

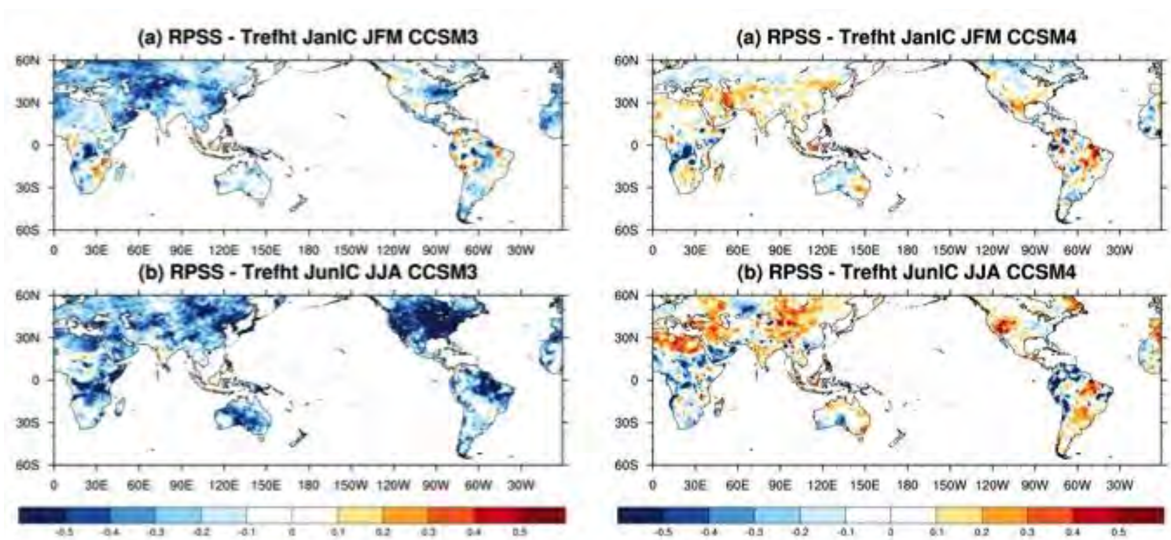


Figure 3: T2m one season lead Ranked Probability Skill Score (RPSS) for forecasts initialized on 1 January and 1 June. The results from CCSM3 are on the left and the results from CCSM4 are on the right.

Research Performance Measure: The performance metric for this project is continuing to run CCSM3.0 predictions in real-time and CCSM4 prediction in real-time.

Predicting the Potential Impact of Climate Change on the Intra-Americas Sea Using Downscaled Climate Models

Project Personnel: Y. Liu, S.-K. Lee, B.A. Muhling, D.B. Enfield and R. Domingues (UM/CIMAS)
NOAA Collaborators: J.T. Lamkin, W. Ingram and M. Schirripa (NOAA/SEFSC); G.J. Goni (NOAA/AOML)
Other Collaborators: M.A. Roffer (Roffer's Inc); F.E. Muller-Karger (USF)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To quantify potential impacts of climate change on bluefin tuna spawning habitat in the Gulf of Mexico.

Strategy: To downscale global climate models to the scale of the Gulf of Mexico, and predict changes in spawning habitat using habitat preference models.

CIMAS Research Theme:

Theme 1: Climate Research and Impact (*Primary*)
Theme 5: Ecosystem Modeling and Forecasting (*Secondary*)

Link to NOAA Strategic Science Goals:

Goal 3: Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts* (I)

Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems* (*Secondary*)

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

Although the Atlantic bluefin tuna (BFT) is widely distributed, its spawning in the western Atlantic has been recorded predominantly in the Gulf of Mexico (GoM) from April to June with the optimal spawning temperature of 24 - 27°C. Adult BFTs are adversely affected by warm water (>28°C) and thus avoid warm features in the GoM such as the Loop Current (LC) (Muhling et al. 2013).

In this project, we examine the potential impact of anthropogenic greenhouse warming on the Intra-Americas Sea (IAS, Caribbean Sea and Gulf of Mexico) by downscaling the Coupled Model Intercomparison Project phase-5 (CMIP5) model simulations under historical and two future emission scenarios using an eddy-resolving resolution regional ocean model (Liu et al. 2015). The simulated volume transport by the western boundary current system in the IAS, including the Caribbean Current, Yucatan Current and LC, is reduced by 20-25% during the 21st century, consistent with a similar rate of reduction in the Atlantic Meridional Overturning Circulation (AMOC). The effect of the LC in the present climate is to warm the Gulf of Mexico (GoM). Therefore, the reduced LC and the associated weakening of the warm transient LC eddies have a cooling impact in the GoM (Fig. 1), particularly during boreal spring in the northern deep basin, in agreement with an earlier dynamic downscaling study. In contrast to the reduced warming in the northern deep GoM, the downscaled model predicts an intense warming in the shallow (≤ 200 m) northeastern shelf of the GoM especially during boreal summer (Fig. 1) since there is no effective mechanism to dissipate the increased surface heating. This warming trend may increase the chance for hurricane intensification during landfall in the northern and eastern Gulf, and may also expose the animals and other organisms living in the GoM to increasing frequency of thermal stress. This work also explores the effects of 20th century warming and climate variability in the IAS using the regional ocean model forced with observed surface flux fields. The main modes of sea surface temperature variability in the IAS are linked to the Atlantic Multi-decadal Oscillation and a meridional dipole pattern between the GoM and Caribbean Sea. It is also shown that variability of the IAS western boundary current system in the 20th century is largely driven by wind stress curl in the Sverdrup interior and the AMOC.

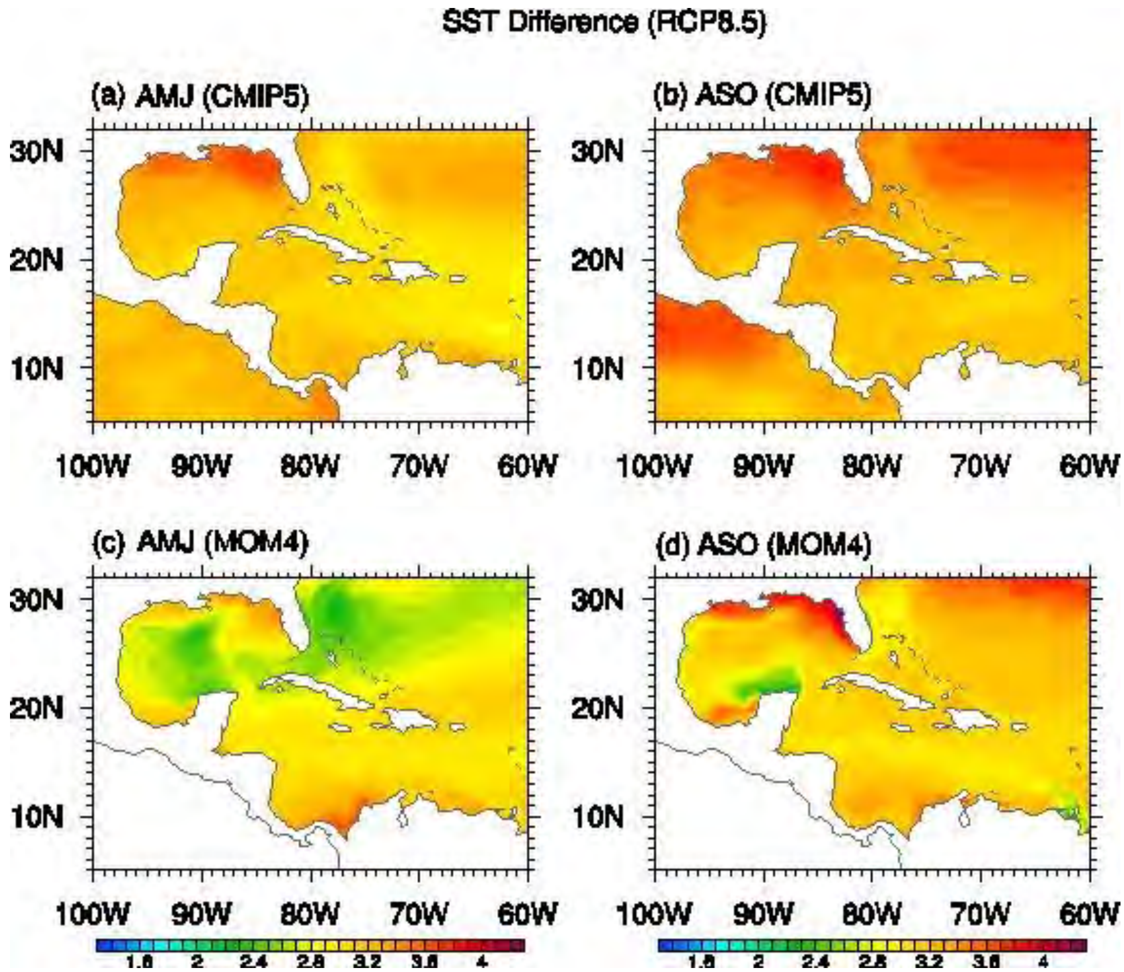


Figure 1: SST difference in the IAS between the late 21st century (2090 ~ 2098) and late 20th century (1990 ~ 1998) for (a) the boreal spring months of AMJ and (b) the boreal summer months of ASO obtained from the weighted ensemble of 18 CMIP5 models simulations under the historical and RCP8.5 scenario, (c) and (d) are same as (a) and (b), except that the SST differences are obtained from the high-resolution MOM4 experiment (EXP_HIS and EXP_8.5). The unit for the temperature is °C.

The increasing water temperatures due to climate change will likely have significant impacts on distributions and life histories of Atlantic tunas. In this project, we combined predictive habitat models with a downscaled climate model to examine potential impacts on adults and larvae of Atlantic BFT and skipjack tuna (Katsuwonus pelamis) in the IAS (Muhling et al., 2015). An additional downscaled model covering the 20th century was used to compare habitat fluctuations from natural variability to predicted future changes under two climate change scenarios: Representative Concentration Pathway (RCP) 4.5 (medium-low) and RCP 8.5 (high). Results forecast marked habitat losses for both adult and larval bluefin tuna on their northern Gulf of Mexico spawning grounds during this century because of intense warming (Fig. 2). In contrast, the projected habitat suitability for skipjack tuna increased as temperatures warmed

(Fig.2). Impacts of climate change on pelagic habitats of several other Atlantic tuna and billfish species are also being evaluated as part of this project.

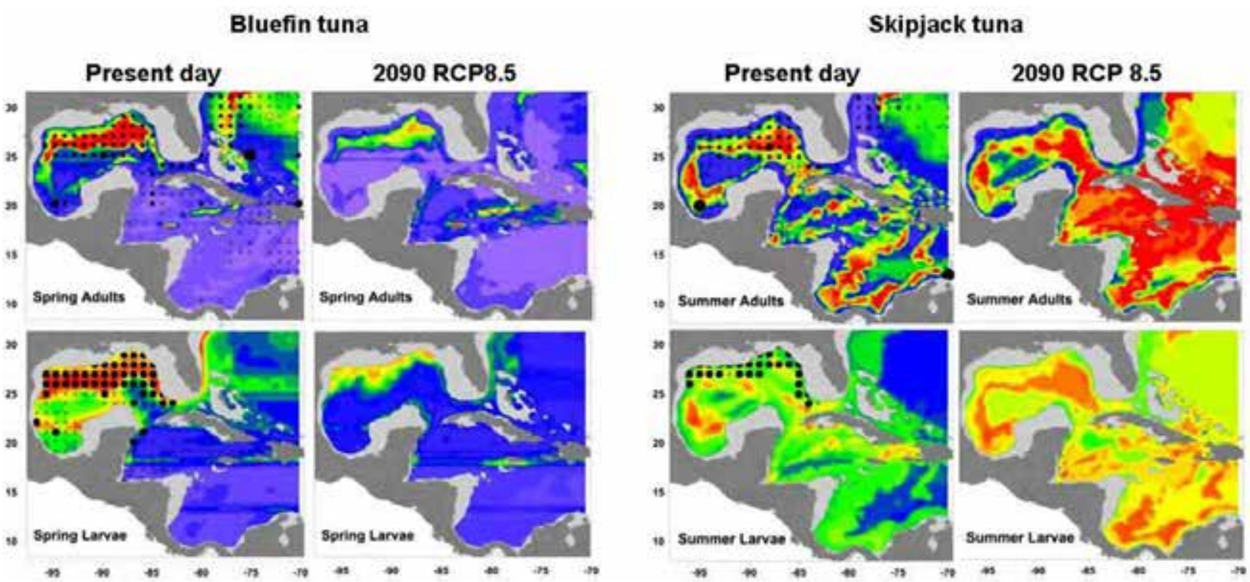


Figure 2: (a) Kriged predicted probabilities of occurrence for adult (1990 – 2009) and larval (2000 – 2013) BFT during spring (contours). (b) Kriged predicted probabilities of occurrence for adult (1990 – 2009) and larval (2000 – 2013) skipjack during summer (contours). Results are shown for the 2000s, and for 2090 under RCP 8.5. Observed data from the ICCAT Task II database (adults) and SEAMAP plankton surveys (larvae) are also shown for the same time period. Locations where adults were recorded, but effort was low, are shown as open circles.

Another manuscript entitled "Variability of preferred environmental conditions for Atlantic bluefin tuna (*Thunnus thynnus*) larvae in the Gulf of Mexico during 1993-2011" by R. Domingues, G.J. Goni, F. Bringas, B.A. Muhling, D. Lindo-Atichati, and J. Walter is currently under review at Fisheries Oceanography. In this study, information reported by previous studies about the preferred environmental conditions for the occurrence of BFT larvae in the GoM were integrated into a dimensionless index, the BFT_Index (Fig. 3). This index was used to evaluate the spatial and temporal variability of areas with favorable environmental conditions for larvae within the GoM during 1993-2011. The main findings of this study were that: (1) the proposed index successfully captured the spatial and temporal variability in the in situ occurrence of bluefin tuna larvae; (2) areas with favorable environmental conditions for larvae in the GoM exhibited year-to-year spatial and temporal variability linked with mesoscale ocean features and sea surface temperature; (3) comparison of the BFT_Index-derived variability with recruitment of age-0 fish estimated from recent stock assessment indicated that changes in environmental conditions may be linked with a relevant component (~58%) of the recruitment variability. The comparison with the recruitment dataset further revealed the existence of key regions linked with recruitment in the central/northern GoM, and that the LC may function as a trap for larvae, possibly leading to low survival rates. Above (below) average conditions for occurrence of larvae in the GoM during spring were observed in 2000, 2001, 2002, 2006-2008, and 2011 (1994, 1996, 1998, 1999, 2003, and 2010). Results reported by this study have potential applications to assessment of BFT.

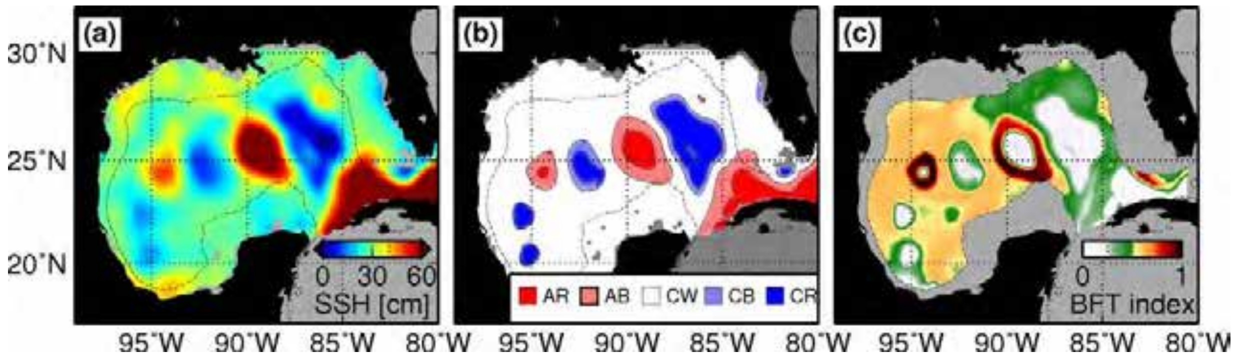


Figure 3: Maps for May 20, 1998 of: (a) Sea Surface Height; (b) type of mesoscale features; and (c) BFT_Index. Overlaid in the maps is the 200 m isobath (dashed line). In (b), AR refers to anticyclonic region, AB to anticyclonic boundary, CW to common waters, CB to cyclonic boundaries and CR to cyclonic regions.

Research Performance Measure: We have met our primary objectives: to quantify the impacts of natural and anthropogenic climate variability on bluefin tuna spawning habitat in the Gulf of Mexico. Three papers have been published and one manuscript has been submitted.

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The South Atlantic Overturning Circulation and Extreme Weather

Project Personnel: H. Lopez (UM/CIMAS)
NOAA Collaborators: G. Goni (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:
***Objectives*:** To investigate the relationship between the South Atlantic Overturning Circulation (SAMOC)/South Atlantic Meridional Heat Transport (SAMHT) in modulating extreme weather events of the form of heat waves, droughts, and precipitation extremes globally.
***Strategy*:** Combine data analysis and coupled general circulation model outputs.

CIMAS Research Theme:
Theme 1: Climate Research and Impact

Link to NOAA Strategic Goals:
Goal 3: Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

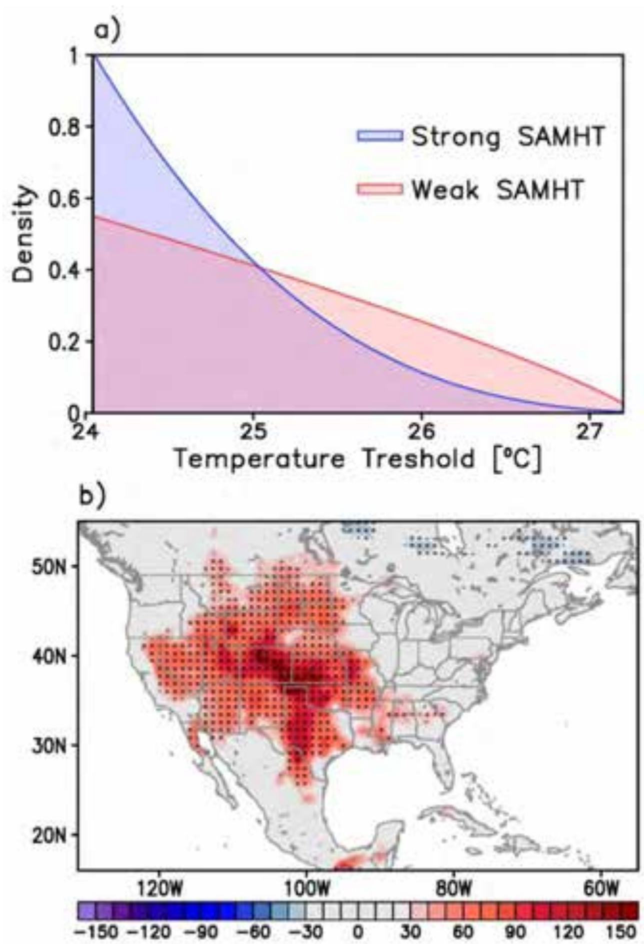
NOAA Funding Unit: OAR/AOML **NOAA Technical Contact:** Molly Baringer

Research Summary:
The objective of this work is to investigate the relationship between South Atlantic Meridional Heat Transport (SAMHT) and heat waves over the northern hemisphere. The number of heat waves and their severity has been increasing in recent decades. This extreme weather event is responsible for the loss of

thousands of human life, wild fires, significant loss in agriculture, and animal life (e.g., Russia 2010, Texas 2011 events).

The South Atlantic meridional heat transport is being assessed; however, its role on modulating climate and extreme weather events has not been reported. In this study, we demonstrate a physical mechanism on how South Atlantic MHT influences the variability of heat waves on decadal timescales. The analysis is based on several century-long integration of a state-of-the-art coupled general circulation model, namely CESM1 from the National Center for Atmospheric Research (NCAR). The mechanism presented in this study is that decadal variation in SAMOC and associated SMHT modulates inter-hemisphere atmospheric heat and moisture flux by modification of the Hadley circulation. This in turn, influence the monsoon circulation, forcing stationary wave patterns that give rise to atmospheric blocking events and heat waves over Northern Hemisphere summer. This mechanism is supported by the fact that mid-latitude atmospheric circulation during the summer is mainly driven by tropical convection associated with monsoonal circulation.

Analysis of boreal summer (i.e., June-July-August-September) mean daily temperature over the Western United States is presented in Figure 1a. We model the excess over a high threshold by looking at summer daily mean temperatures warmer than a fixed threshold and computing the generalized Pareto probability density function. Weaker SAMHT leads to increase warm temperature extreme (Figure 1a). Also, Figure 1b shows an increase in the number of heat wave days over the Western United States when the SAMHT is weak.



Research Performance Measure: The research objectives were met based on the primary objective: to quantify the role of the South Atlantic Ocean in modulating extreme weather events. The potential impact of the SAMHT on climate and extreme weather events demonstrates the importance of understanding and monitoring the MOC variability in the South Atlantic.

Figure 1: a) Generalized Pareto probability density function for June-July-August-September mean daily temperature over the Western United States for summers with weak (red) SAMHT and strong (blue) SAMHT. b) composite difference of heat wave days during weak minus strong South Atlantic heat transport divided by total heat wave days. We multiplied that by 100 to give units of percentage increased. Black stipples indicate 95% confidence based on a non-parametric Kendall-τ significance test.

NIDIS Apalachicola-Chattahoochee-Flint River Basin Drought Early Warning System

Project Personnel: V. Misra and D. Zierden (FSU)
Other Collaborators: Auburn University; University of Florida

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: 1) Participation in ACF drought assessment webinars. This activity involves a survey of a wide variety of climate and drought products and summarizing the information in the form of Powerpoint slides as well as present the information during the webinars. These webinars not only assess the current conditions or state of drought in the ACF basin, but also use the most advanced climate forecast information in looking ahead and anticipating drought (or abundance of water). 2) Coordination with Florida and Alabama drought monitoring groups in weekly input to the *U.S. Drought Monitor.* Use the information from the routine webinars to coordinate input to the weekly *U.S. Drought Monitor* through existing groups in Florida and Alabama and engage experts (Bill Murphey and Nysha Dunkely with Georgia DEP) in Georgia. 3) Incorporation of SECC produced drought monitoring products into webinars and *U.S. Drought Monitor* assessments. Make better use of SECC drought products such as the ARID drought index, GriDSSAT satellite and crop model water stress, and the Lawn and Garden Moisture Index. 4) Monitoring and analysis of surface weather observations in support of drought assessments. This activity includes retrospective examination of historical climate observations and downscaled reanalysis to better characterize the nature and frequency of drought in the basin. 5) Increase awareness and reach of NIDIS webinars and products through social media, email listserves, and press releases. 6) Participation in NIDIS and *U.S. Drought Monitor* workshops and forum.

Strategy: NIDIS initiated the Apalachicola-Chattahoochee-Flint River Basin early warning pilot in December of 2009 as the basin had experienced a string of recent droughts. The Florida Climate Center has been involved in the early warning system since its inception by attending workshops and scoping meeting, engaging stakeholders, and provide climate information in support of NIDIS activities. One of the activities in which the Florida Climate Center has been a key contributor is the bi-weekly (in times of drought) or monthly drought assessment webinars. These webinars draw on experts from climate science, the Army Corps of Engineers, USGS, NWS, and the Apalachicola National Estuarine Research Reserve to assess the current state of drought in the basin and its impacts and provide outlooks for the next one to three months. The Florida Climate Center serves as the climate science lead in these webinars and utilizes a variety of NOAA and Southeast Climate Consortium drought products in these assessments. The Florida Climate Center proposes to continue leading these webinars, enhance the information and products presented, and work to expand the reach of the NIDIS regional project through stakeholder engagement.

CIMAS Research Theme:

***Theme 1*:** Climate Research and Impact

Link to NOAA Strategic Goals:

***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

NOAA Funding Unit: OAR/CPO **NOAA Technical Contact:** Caitlin Simpson

Research Summary:

The National Climate Assessment discusses the changes in heavy rainfall events and predicts there will be a 27% increase in the portions of the Southeast United States. The Florida Climate Center is investigating seasonal heavy rainfall events based on threshold analysis for the period of record at 100 National Weather Service Cooperative Stations in the Southeast U.S to see what changes have been observed and what trends in the data exist.

Another study examines how extreme precipitation influences temperatures, and how temperature extremes influence precipitation in the Southeastern U.S., seasonally, using observational data. For the precipitation influencing temperature approach, three precipitation regimes are created (wet, dry, and neutral) to observe possible shifts in the distributions of seasonal average daily maximum and minimum temperatures based on precipitation extremes. Similarly, for the temperature influencing precipitation, three temperature regimes are created (warm, cool, and neutral), to observe how the frequency of rainfall events of 1.00” or more shifts in each temperature regime. For the precipitation influencing temperature approach, most notably, it is found that in summer, spring, and fall, in a wet precipitation regime, the maximum temperatures are typically warmer (cooler) than the average maximum temperatures in a neutral regime; the opposite pattern is observed for winter. It is also found that these temperature distributions do not shift in a uniform way across the Southeast, though several regional continuities exist. For the temperature influencing precipitation approach, it is found that spring, summer, and winter show the largest differences in the frequency of rainfall events of 1.00” or more between the cool and warm temperature regimes. This study also examines five case study stations in the Southeast to observe regional nuances in temperature and precipitation patterns.

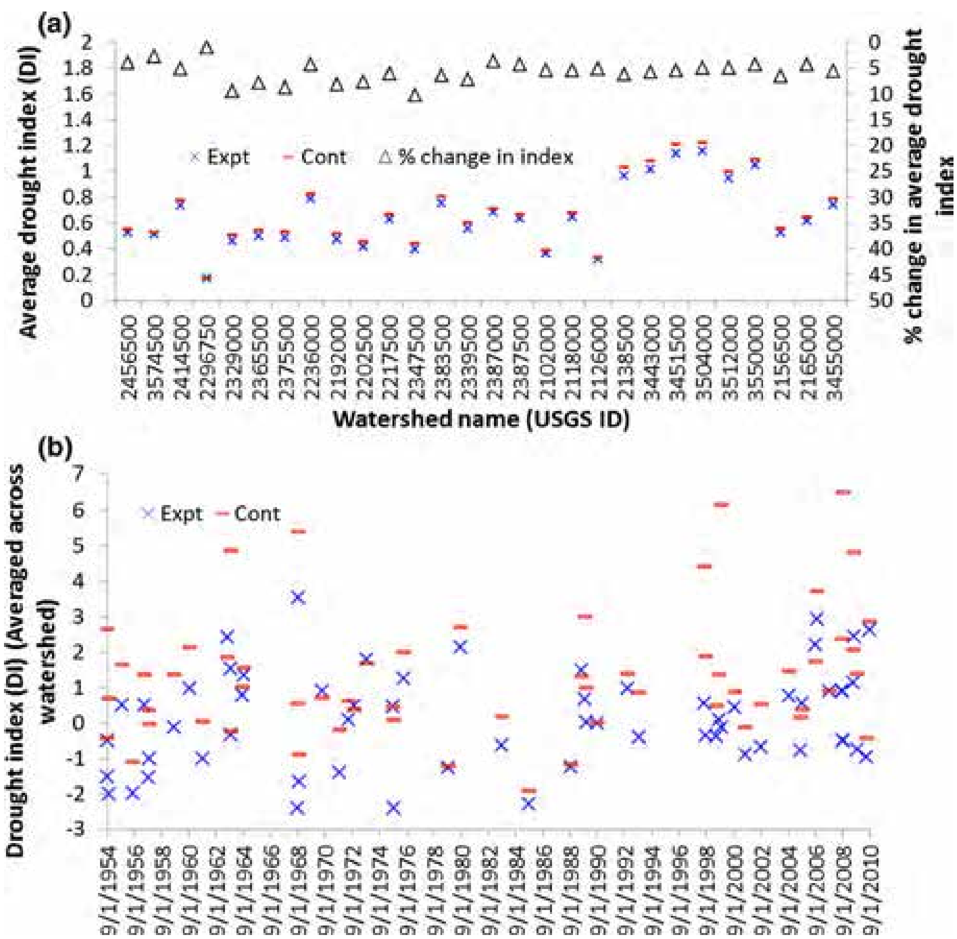


Figure 1: a) Time averaged Cont and Expt drought index over the period 1948–2006 and percent change in drought index between them. b) Cont and Expt drought index for each year averaged over all 28 SeUS watersheds.

Research Performance Measure: Florida State University presented in 12 monthly ACF drought assessment webinars in 2014, where Florida State Climatologist was the climate lead. Information on state of drought and the recent and current climate was presented as well as briefings on the change state of the Pacific Ocean, expected impacts, and other seasonal forecast information. Tonya Haigh at the National Drought Mitigation Center led an assessment of these webinars by interviewing many of the participants, audience, and stakeholder on their usefulness. We are now implementing many of the suggestions from this assessment in future webinars to improve information delivery and content. The Florida Climate Center led a statewide drought discussion group and coordinated weekly input and suggestions for the *U.S. Drought Monitor*. The group also coordinated with neighboring states to ensure consistency across state lines and the ACF basin.

RESEARCH REPORTS

THEME 2: Tropical Weather

Assessing the Impact of Global Hawk Dropsonde Observations on the Prediction of Tropical Storm Gabrielle (2013) by Utilizing the Hurricane Ensemble Data Assimilation System (HEDAS)

Project Personnel: A. Aksoy and K.J. Sellwood (UM/CIMAS)
NOAA Collaborators: S.D. Aberson and R. Atlas (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:
***Objectives*:** Evaluate the impact of observations from the unmanned Global Hawk aircraft on the numerical prediction of tropical cyclones as part of NOAA's Sensing Hazards with Operational Unmanned Technology (SHOUT) Project.
***Strategy*:** Conduct Observing System Experiments (OSE) using data from Global Hawk field missions and utilizing NOAA/AOML/HRD's own data assimilation system HEDAS.

CIMAS Research Theme:
***Theme 2*:** Tropical Weather

Link to NOAA Strategic Goals:
***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

NOAA Funding Unit: NOAA/UAS
NOAA Technical Contact: Robbie Hood (UAS Program Director)

Research Summary:
The primary scientific objective of NOAA's Sensing Hazards with Operational Unmanned Technology (SHOUT) Project is to determine the potential utility of observations from high-altitude, long-endurance

unmanned aircraft systems (UAS) such as the Global Hawk aircraft to improve forecasts of high-impact weather events or mitigate any degradation in the forecasts in the event of a future gap in satellite coverage. Hurricanes and tropical cyclones are among the most potentially destructive high-impact weather events and pose a major forecasting challenge to NOAA. Observations collected during the first collaborative phase of SHOUT and previous NASA-led campaigns with the Global Hawk enable an initial assessment of the value of these observations for improving forecasts of tropical storm track and intensity in regional numerical models.

The Global Hawk aircraft was originally developed as part of NASA's The Hurricane and Severe Storm Sentinel (HS3) project, which was a five-year mission specifically targeted to investigate the processes that underlie hurricane formation and intensity change in the Atlantic Ocean basin. The NASA Global Hawk UASs are ideal platforms to investigate hurricanes, capable of flight altitudes greater than 55,000 ft and flight durations of up to 30 hr. During the HS3 missions, two Global Hawks were utilized, one with an instrument suite geared toward measurement of the environment (AV-6) and the other with instruments suited to inner-core structure and processes (AV-1). The environmental payload includes the scanning High-resolution Interferometer Sounder (S-HIS), the AVAPS dropsonde system, the TWiLiTE Doppler wind lidar, and the Cloud Physics Lidar (CPL) while the over-storm payload includes the HIWRAP conically scanning Doppler radar, the HIRAD multi-frequency interferometric radiometer, and the HAMSR microwave sounder. Field measurements took place for one month each during the hurricane seasons of 2012-2014.

One of the noteworthy Global Hawk missions during HS3 was into Tropical Storm Gabrielle (2013), which existed between 4-13 September 2013 and affected Puerto Rico and the Dominican Republic as a tropical depression and passed near Bermuda as a tropical storm. One of such cases was on 7 September 2013 at 18 UTC when Gabrielle was still a weak tropical disturbance with an intensity of 25 kt and minimum sea level pressure of 1009 mb, with not much of an organized structure except a low-level wind circulation and disorganized convection displaced east due to strong westerly shear. This structure is depicted in the infrared satellite image from the GOES-East satellite as of 7 September 2013 at 18 UTC (Fig. 1).

Figure 1: NOAA GOES East infrared satellite image for 7 September 2013 18 UTC. The center of Tropical Disturbance Gabrielle is indicated by the red mark.

What was noteworthy about Gabrielle was that it was sampled by a number of aircraft both manned and unmanned. At 7 September 2013 18 UTC, two NOAA P-3 aircraft (N42 and N43), the NOAA G-IV aircraft (N49), one Air Force Reserve C-130 aircraft (USAF 301), as well as the Global Hawk AV-6 aircraft (NASA876) were operational which makes this case one of the rare cases when all of these aircraft were sampling a tropical cyclone simultaneously, so that the impact of the data from these various aircraft can be conveniently evaluated against each other. The distribution of all available observations from various observing platforms around the center of Gabrielle is shown in Fig. 2. About 25% of the observations were obtained from the HS3 Global Hawk mission, which is believed to be a sufficient contribution, quantity-wise, to expect a measurable impact from their assimilation relative to all of the other observations that are routinely available during NOAA Hurricane Field Program flight missions.

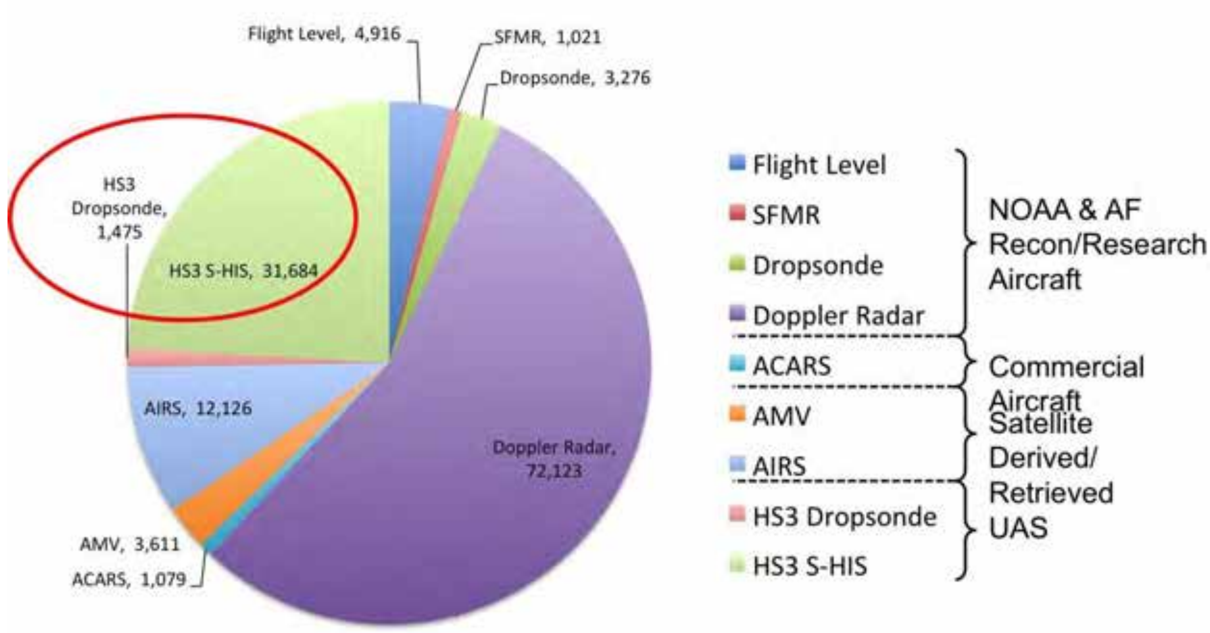


Figure 2: The distribution of all available observation platforms and the number of observations from each as assimilated in HEDAS for Tropical Disturbance Gabrielle at 7 September 2013 18 UTC.

To evaluate the impact of the Global Hawk observations, NOAA/AOML/HRD's Hurricane Ensemble Data Assimilation System (HEDAS) is utilized, which is an ensemble Kalman filter (EnKF) data assimilation system to assimilate high-resolution, vortex-scale observations that are routinely collected and transmitted in real time during NOAA's annual Hurricane Field Program and regular reconnaissance flights (Aksoy et al. 2012, Aksoy 2013, Aksoy et al. 2013, Vukicevic et al. 2013, Aberson et al. 2015). Various observation types that are assimilated include Doppler radar radial wind speed, dropwindsonde wind velocity, pressure, temperature, and humidity, flight-level wind velocity, pressure, temperature, and humidity, and stepped-frequency microwave radiometer (SFMR) surface wind speed. HEDAS has been developed within the framework of NOAA's Hurricane Weather Research and Forecast (HWRF) model. Data assimilation is performed on a domain with 3-km horizontal resolution, while HWRF runs in a nested 9/3-km configuration during cycling. At this scale, the numerical model is capable of resolving the details of the hurricane vortex. By incorporating high-resolution airborne observations into the model through data assimilation, a realistic vortex structure is obtained for the initialization of a subsequent 5-day model forecast.

Starting with the 2013 hurricane season, HEDAS has begun to also assimilate some satellite products in addition to the now-standard aircraft observations. These satellite products included Atmospheric Motion Vectors (AMVs), as well as thermodynamic profiles from the Atmospheric Infrared Sounder (AIRS) and

Global Positioning System (GPS) Radio Occultation platforms. The preliminary results from this experiment were summarized in a poster at the American Meteorological Society's 31st Conference on Hurricanes and Tropical Meteorology that was held in San Diego on 31 March-4 April 2014.
HEDAS experiments with the above-mentioned observations indicate that vortex-scale observations introduce a cascade of positive impacts as a function of the number and type of observation platforms are utilized (Figs. 3 and 4). The control (no data assimilation) as well as the operational HWRF forecasts never re-organize Gabrielle beyond a tropical disturbance, as a result of which the system continues to drift westward with no intensification (red and purple lines in Figs. 3 and 4). This also demonstrates that only incorporating observations in the environment of a tropical disturbance (as is the case with the control experiment that is initialized from a global model (GFS) analysis that has incorporated many observations in the storm environment), may not be sufficient to obtain a good forecast of its future evolution.

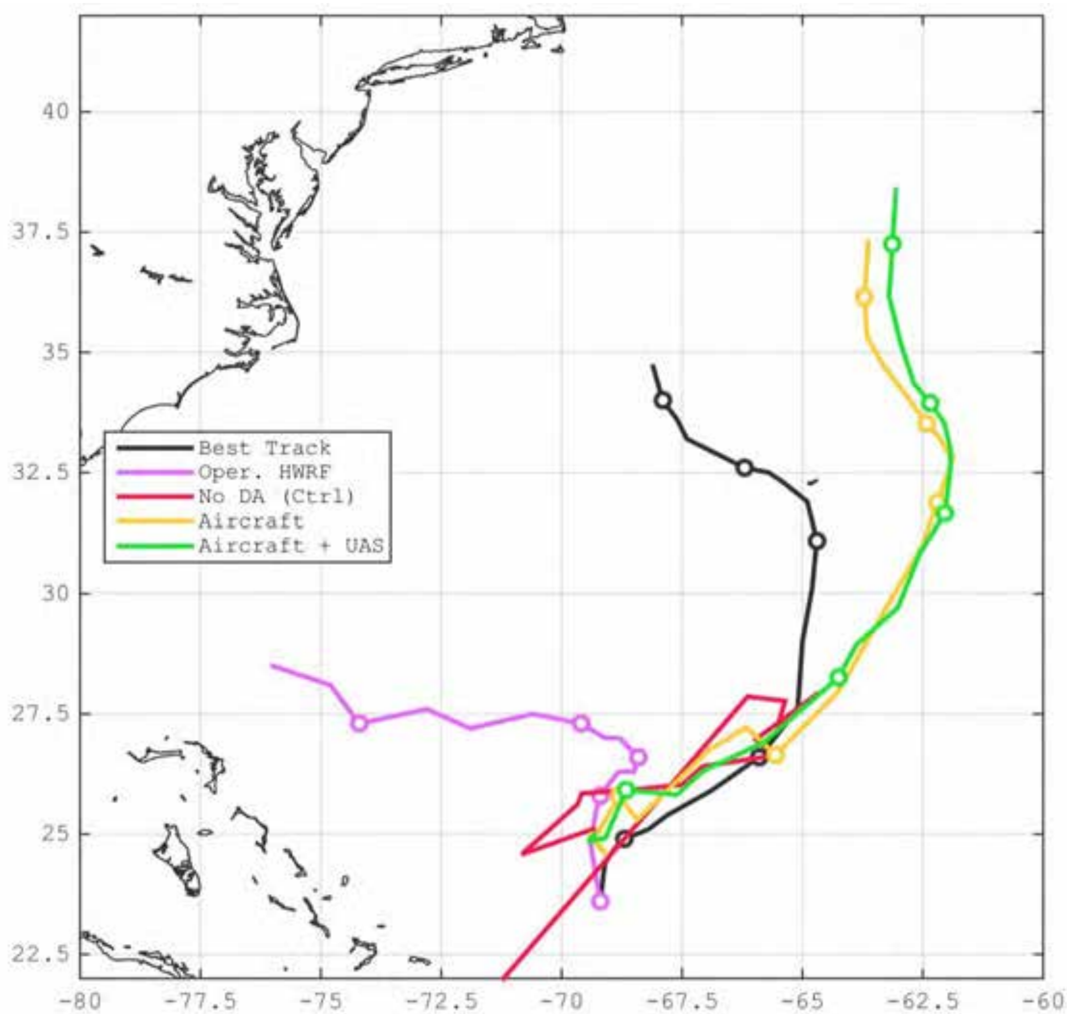


Figure 3: Track forecasts initialized at 7 September 2013 18 UTC for control (no data assimilation, red), as well as initialization from HEDAS analysis with standard observations (yellow) and all (standard plus UAS) observations (green). The corresponding operational HWRF forecast is shown in purple and the NHC Best Track estimates are shown in black.

Next, when standard aircraft observations are assimilated, a much better track forecast is achieved that is very accurate for the first two days and then continues to maintain a good representation of the overall trend (including the westward turn between days 3 and 4, yellow line in Fig. 3). At the same time, the intensity forecast (yellow line in Fig. 4) indicates that Gabrielle is maintained as a tropical depression but does not intensify into a tropical storm. Finally, adding the Global Hawk UAS observations into the observation pool improves further the intensity forecast, where now a tropical storm, albeit weaker than the Best Track analysis, is predicted after about 2 days, with peak intensity occurring at 72 h that is only lagged by 6 h compared to the Best Track analysis (green line in Fig. 4). This gradual improvement in track and intensity forecasts as more vortex-scale observations are assimilated confirms the importance of observing the structure of a tropical cyclone and suggests that the Global Hawk UAS adds a distinct value to the standard aircraft observations that are routinely collected.

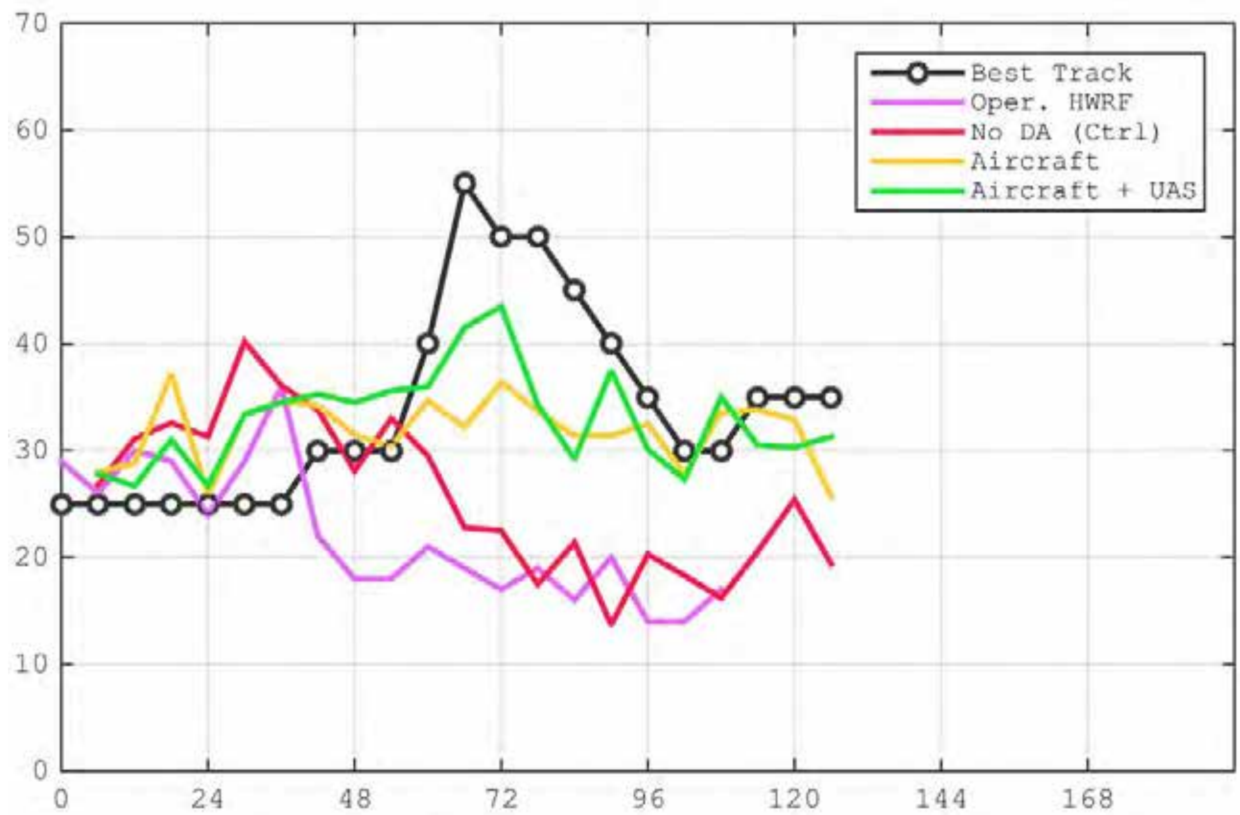


Figure 4: As in Fig. 3 but for intensity (maximum 10-m wind speed, knots).

Research Performance Measure: All major objectives are being met on schedule.

Impact of Hyperspectral Sounder on Prediction of Tropical Cyclones

Project Personnel: B. Annane, L. Bucci, J. Delgado, R. Hoffman and K. Ryan (UM/CIMAS)
NOAA Collaborators: R. Atlas and S. Murillo (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To systematically evaluate the impact of retrievals from a hyperspectral sounder on the accuracy of tropical cyclone (TC) track and intensity predications.

Strategy: To conduct rigorous regional Observing System Simulation Experiments (OSSEs).

CIMAS Research Theme:

Theme 2: Tropical Weather

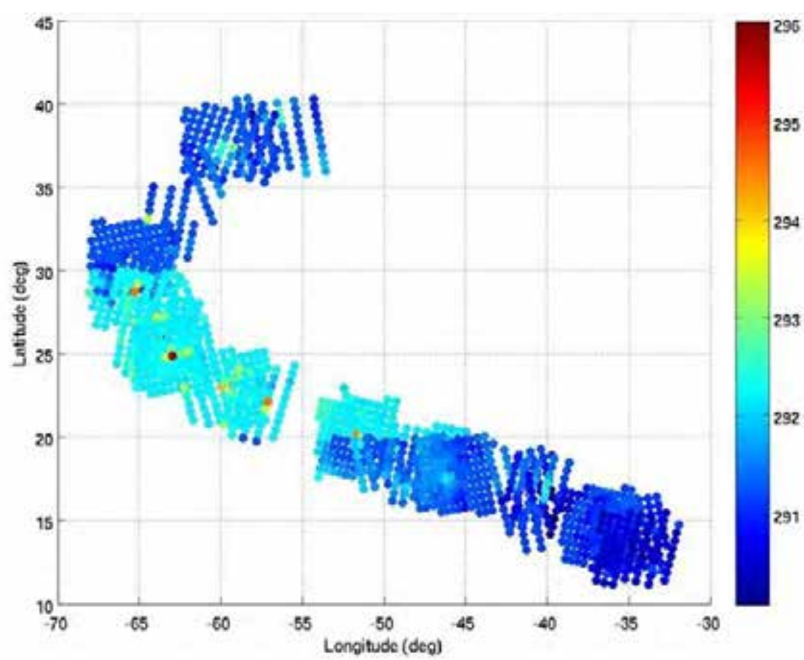
Link to NOAA Strategic Goals:

Goal 2: Weather-Ready Nation - *Society is prepared for and responds to weather-related event*

NOAA Funding Unit: OAR/AOML **NOAA Technical Contact:** Molly Baringer

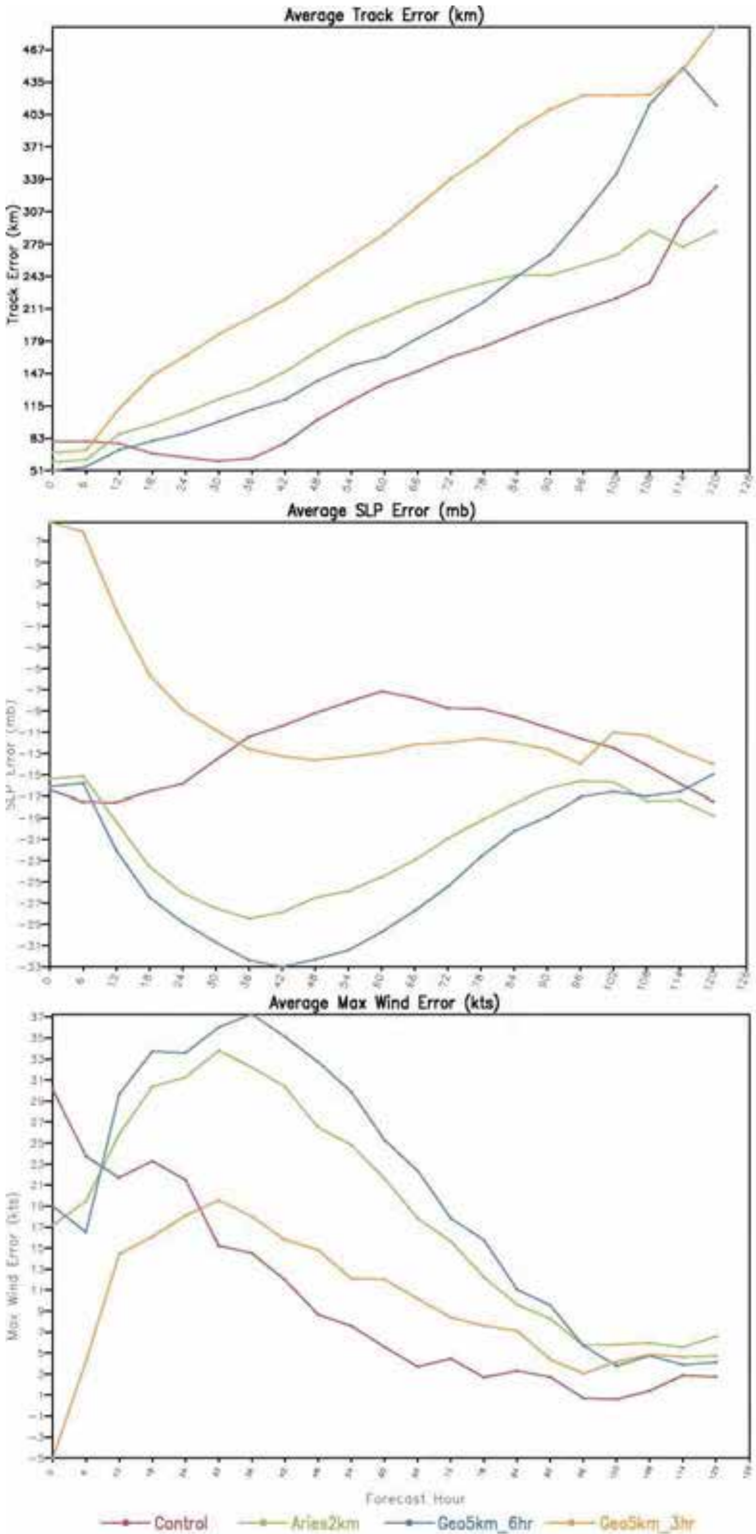
Research Summary:

The lifetime of observing systems is finite and it is important to plan for replacement instruments that meet the needs of current and next generation numerical weather prediction (NWP) system. The Atmospheric Infrared Sounder (AIRS) is one such instrument nearing the end of its design life. This instrument provides accurate daily coverage of temperature and water vapor soundings and has among the highest impact of any single instrument to the operational forecast (Cardinali, 2009). Observing system simulation experiments (OSSEs) have been developed to evaluate the potential impact that new observing systems could have on analyses and forecasts (Atlas, 1997). This study uses OSSEs to evaluate a potential next generation AIRS-like instrument.



Several experiments were conducted to compare various temporal and spatial coverages and data assimilation strategies. Results show that short term forecasts (6-24 hours) of TC track and intensity improve when high resolution tempera-ture retrievals are added over the hurricane. The intensity forecast improves when cycling is increased from six to three hours, but the track and vortex structure is degraded. Future work includes extending spatial coverage from storm scale to basin scale and investigating the impact of moisture retrievals on TC predictions.

Figure 1: 850 hPa temperature (K) retrievals simulated from 1km storm-following nest WRF-ARW Nature Run over 13 day period.



Technical advances were made for this project as well, particularly to the software developed in-house to run the OSSEs. For one, it now uses the 2014 operational HWRF model, pre-processor, and postprocessor, and the latest community version of GSI. The system was ported to work on the S4 supercomputer at the University of Wisconsin and it is now working on one of NOAA's latest supercomputers, *Theia*. Additionally, experiments are now logged in a database containing various metadata that describe details such as the model configuration used, observations assimilated, etc.

We also developed a package for creating plots that evaluate the tropical cyclone "vitals" statistics of experiments. These allow us to efficiently perform high level evaluation of different experiments.

Research Performance Measure: The research program is on schedule.

Figure 2: (a) Average error over 16 cycles. Position (track) error in km (b) Average error over 16 cycles. Minimum central pressure error in hPa. (c) Average error over 16 cycles. Maximum 10m wind speed error in kts.

Hurricane Risk to U.S. Offshore Renewable Energy Facilities

Project Personnel: S. Cocke and D.-W. Shin (FSU); M. Powell (FSU, formerly NOAA/AOML)
NOAA Collaborators: S. Murillo (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To assess risk of wind threat to offshore wind turbines due to hurricanes
***Strategy*:** Analyze vertical profile of hurricane wind near the hub height of turbines using GPS drop sondes and other sources of observational data. Use catastrophe modeling to determine return periods of high hurricane winds.

CIMAS Research Theme:

***Theme 2*:** Tropical Weather *(Primary)*
Theme 1 Climate Research and Impact (*Secondary*)

Link to NOAA Strategic Goals:

***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events (Primary)*
***Goal 4*:** Resilient Coastal Communities and Economies - *Coastal and Great Lakes communities that are environmentally and economically sustainable* (*Secondary*)

NOAA Funding Unit: OAR/AOML **NOAA Technical Contact:** Molly Baringer

Research Summary:

The project has two key components. The first is to study the vertical profile of hurricane winds near the hub height of wind turbines. The second is to determine the return period of high hurricane winds at the hub height. This research will be beneficial in determining the design conditions and risk for offshore wind turbines along the U.S. coast. Dr. Powell is analyzing GSP sonde data located in regions near potential wind farm sites. Drs. Cocke and Shin are developing a risk model using standard catastrophe modeling approaches to create maps of the return periods of high hurricane winds.
We are less than a year into the 3-year project, and thus work is very much in progress. For 2015, the field program plan will continue to provide an experiment module to provide GPS sonde profiles for any storm passing over a DOE offshore wind energy demonstration site. For example, Figure 1 shows a distribution of sondes launched during several flights into 2014 Hurricane Arthur. We plan to expand the effort to gather GPS sonde launches from additional storms in mean boundary layer winds above 20 m s^{-1}. These sonde data are available from AOML's ftp site but will need to be organized according to the level and type of post processing conducted on the measurements. For example the processing conducted by default uses a 10 s smoothing of the 2 Hz measurements and the post processed data use a 5 s smoothing. Furthermore, two post processing methods have been used, *Editsonde* (developed at NOAA-AOML-HRD) and ASPEN (developed at NCAR). Both databases of processed sondes will be combined to create a unified set of GPS sonde profiles for water depths in a range similar to that for the project location. We will then combine wind profiles gathered in similar mean boundary layer wind conditions to document the mean wind profile, shear stress, and marine roughness conditions at the site as a function of wind speed.

We will also be developing the wind return period mapping capability for the location of the demonstration project, as well as other defined wind energy lease block locations. Our PNAS publication (Powell and Cocke, 2012) discussed the importance of using hurricane wind field information (rather than fitting extreme value distributions) when estimating risk to offshore wind farms. Our effort will build on a technique similar to that used in the Florida Public Hurricane Loss Model (FPHLM, Powell et al., 2005). The method will model the lifecycle of a stochastic set of storms which have characteristics consistent with the HURDAT2 historical hurricane database, but which have intensities consistent with physically realistic values based upon potential intensity. Once the stochastic set of tracks is developed we will apply a wind field model to create the wind time history and capture the peak wind from each event at the turbine hub height (~100 m) and the upper (~170 m) and lower (30 m) extents of the rotor zone. From these values we can rank order the peak winds at each level throughout the stochastic set to develop wind maps for the ranked wind speed associated with an exceedance probability of 0.01 (one in 100 year event), 0.004 (one in 250 year event), and 0.002 (one in 500 year) at each of the three levels.

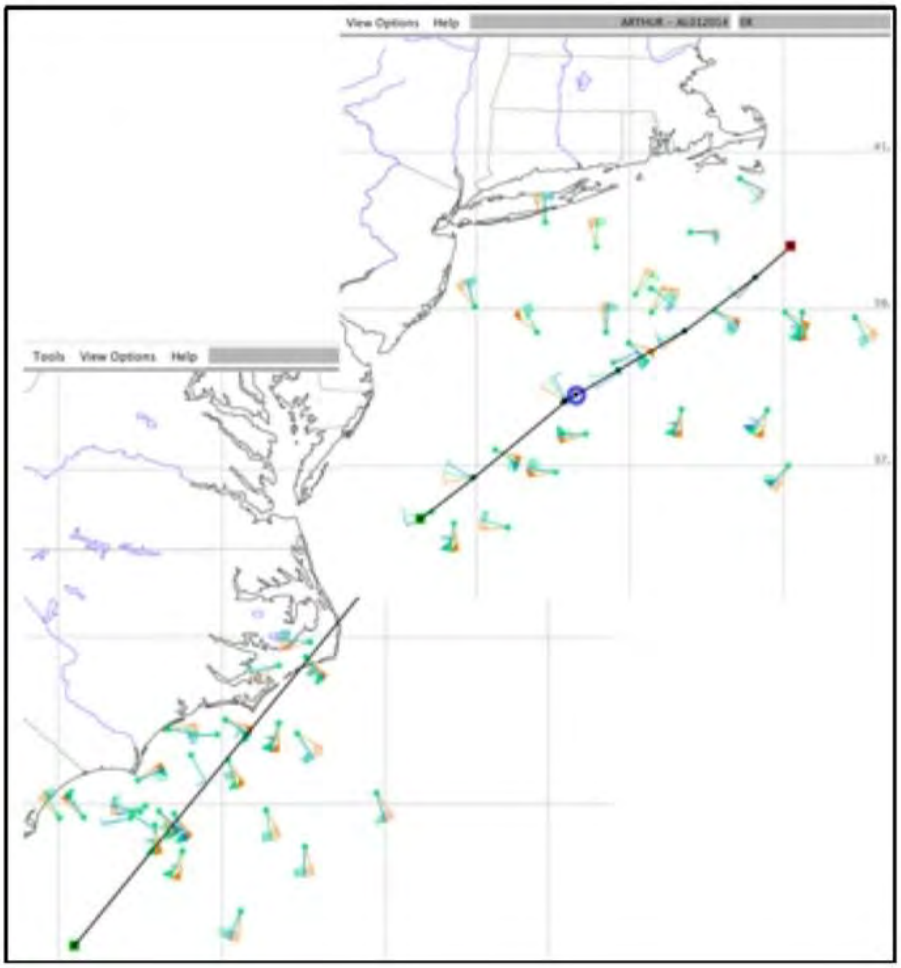


Figure 1: GPS sonde wind profile locations for the set of NOAA G4, NOAA P3, and Air Force C130 reconnaissance aircraft missions into Hurricane Arthur from July 3-4, 2014.

Research Performance Measure: The project encountered some delays due to the federal government furlough and putting the institutional agreements into place. We are less than one year into a 3-year project, but we anticipate completing the project within a 3-year time period as originally proposed.

Improving the Scalability of a Hurricane Forecast System in Mixed-Parallel Environments

Project Personnel: J. Delgado and X. Zhang (UM/CIMAS)
NOAA Collaborators: T. Quirino and S. Gopalakrishnan (NOAA/AOML

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To reduce the execution time of HWRF for multi-storm forecasts.

***Strategy*:** To modify the HWRF hurricane modeling framework so that high resolution storm-following nests pertaining to different storms can be integrated by different sets of CPUs.

CIMAS Research Theme:

***Theme 2*:** Tropical Weather

Link to NOAA Strategic Goals:

***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

NOAA Funding Unit: OAR/AOML **NOAA Technical Contact:** Molly Baringer

Research Summary:

One factor limiting tropical storm forecast accuracy is the resolution at which the earth is modelled. Resolution, in turn, is limited by computational power. A solution that has been used as a compromise in the Hurricane Weather Research and Forecasting (HWRF) software framework is to have high resolution regions of interest (i.e. the area in which a tropical storm occurs) known as *nests* within a larger, coarser resolution domain. This allows us to forecast at relatively high resolution with a reasonable amount of processing power. The latest research version of HWRF being developed at HRD, known as the *basin scale HWRF,* improved the state of the art by allowing multiple storm-following nests to be used in a single weather simulation. These nests are sequentially *integrated* by the same set of processors. This enhancement has shown improvements in forecast accuracy, but requires more processing power. Meanwhile, there is a limit on the number of processors that can be used to integrate a *nest* of a given size. To address this issue, HRD researchers devised a way to modify the HWRF framework so that the *nests* can be integrated concurrently by different sets of processors in order to make it possible to run these kinds of simulations within operational time constraints. The methodology used is depicted in Figure 1.

We modified the WRF framework such that it integrates the nests in parallel. As a result, we are now closer to our goal of making the execution time of the operational HWRF system independent of the number of storms – as long as enough CPUs are available. In fact, the computational portion of the code, which is what we have focused on, is now constant. The time spent in communication increases as more storms are added to the integration.

Figure 2 shows how the execution time for a 5-day forecast increases as the number of storms increases when using 300 processors to integrate each storm using the serial integration approach and our parallel integration approach. As can be seen, the parallel version significantly reduces execution time. The increase in overall execution time is solely due to the additional communication.

Research Performance Measure: Our objective was to make the computation portion of the execution time of the basin scale HWRF independent of the number of storms integrated as long as sufficient processors are used. This was achieved.

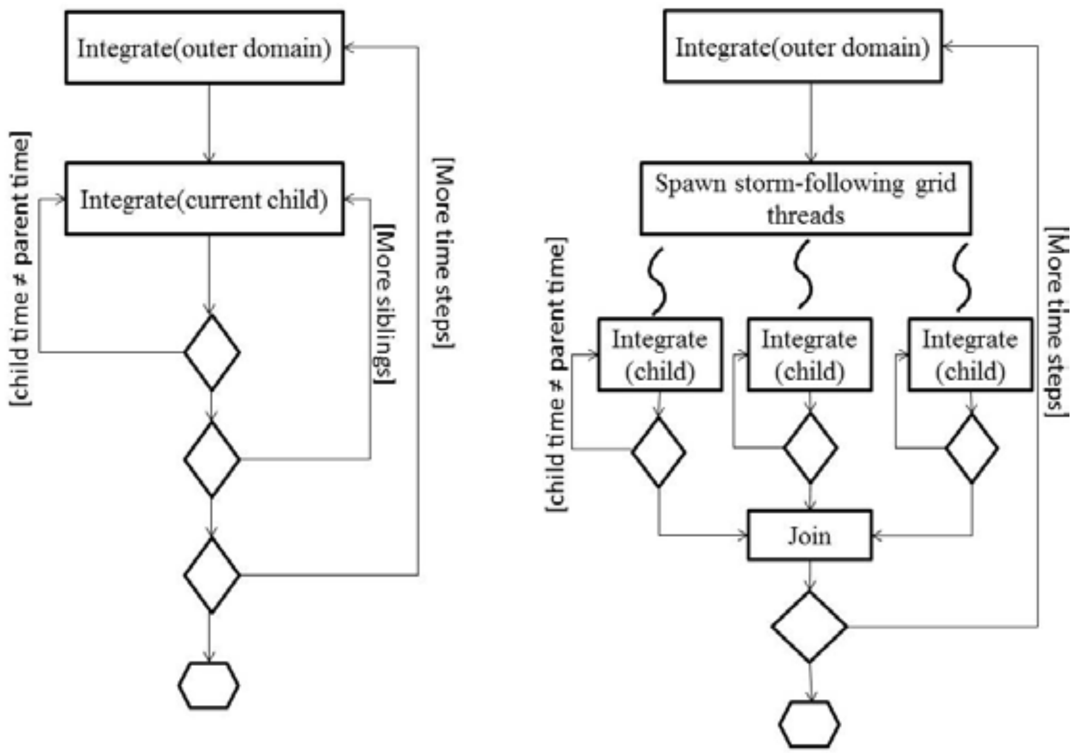


Figure 1: Original (left side) vs. modified (right side) HWRF integration workflow. On the left side, the original framework integrates *nests* sequentially. On the right side, the modified framework integrates storm-following *nests* in parallel.

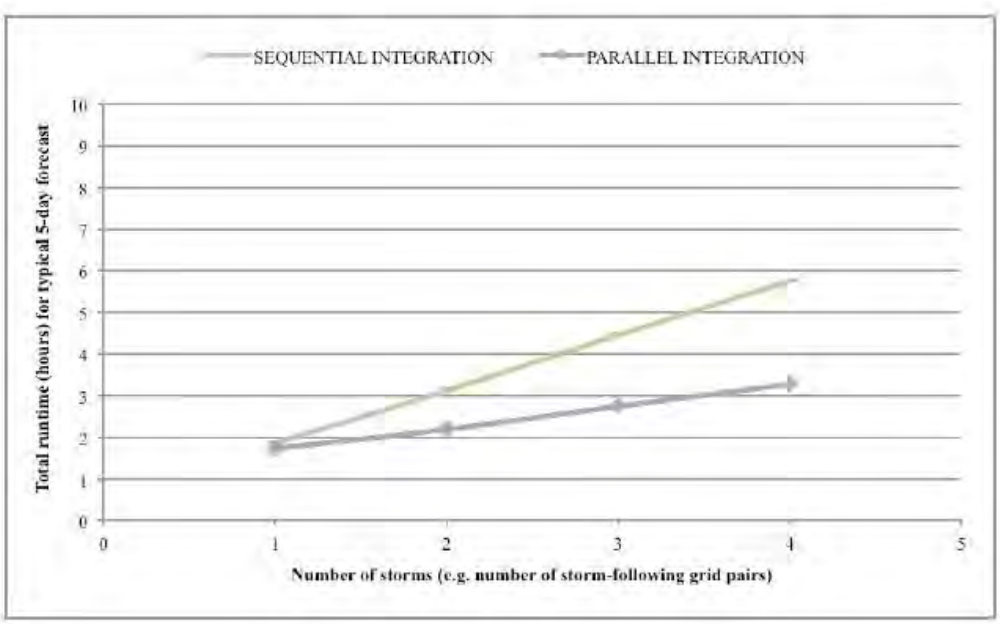


Figure 2: Execution time of a typical 5-day forecast using sequential (green) and parallel (purple) nest integration as a function of the number of storms.

Re-Analysis of the Atlantic Basin Tropical Cyclone Database in the Modern Era

Project Personnel: S. Delgado and B. Moses (UM/CIMAS)
NOAA Collaborators: C.W. Landsea (NOAA/NHC); F.D. Marks (NOAA/AOML); J.L. Beven II (NOAA/NHC)
Other Collaborators: M. Kieper (FIU)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To reanalyze the HURDAT Atlantic hurricane climatology in order to improve understanding and statistical descriptions of historical hurricanes.

Strategy: To revise and update HURDAT based upon the gamut of historical sources, additional observations, better meteorological insight, and synoptic reanalyses now available.

CIMAS Research Theme:

Theme 2: Tropical Weather *(Primary)*
Theme 1: Climate Research and Impact *(Secondary)*

Link to NOAA Strategic Goals:

Goal 2: Weather-Ready Nation (*Primary*)
Goal 1: Climate Adaptation and Impact (*Secondary*)

NOAA Funding Unit: OAR/AOML/HRD **NOAA Technical Contact:** Molly Baringer

Research Summary:

The Hurricane Database (HURDAT) is the historical archive that describes all tropical cyclones from 1851 to the present in the North Atlantic Basin, which includes the Caribbean Sea and Gulf of Mexico. NOAA's National Hurricane Center (NHC) maintains HURDAT and updates it annually. HURDAT represents six-hourly positions, intensities and central pressures for all Atlantic tropical and subtropical cyclones. From 2004 onward, HURDAT also includes radii of 34, 50, and 64 kt (1 kt = 0.515 m s^{-1}) winds. Since HURDAT is essential to the work of research scientists, operational forecasters, insurance companies, emergency managers, and others, it has taken on the status of a legal document.

Accuracy of the HURDAT database is essential, but it originally contained both systematic biases and random errors. NHC's Atlantic Hurricane Reanalysis Project (AHRP) is a continuing effort to correct these errors based upon all available data and to provide the most accurate database possible. We are reassessing track, intensity, genesis, and dissipation for each existing tropical cyclone in HURDAT. Additionally, we have detected and analyzed previously unrecognized tropical cyclones. The resulting changes will be recommended to the National Hurricane Center Best Track Change Committee (NHCBTCC) for inclusion in the next release of HURDAT. Changes to HURDAT become official only with NHCBTCC's approval.

Reanalysis of all Atlantic tropical cyclones in 1965 and hurricane Camille of 1969 are complete. We expect to have 1964 and 1966 done by the end of June. A summary of significant results since July of 2014 follows:

The year 1965 was an average year with nine tropical cyclones developing in the Atlantic Ocean. Four reached hurricane intensity and only Hurricane Betsy became a major hurricane. Most of the hurricanes stayed over the central Atlantic and away from land. Hurricane Betsy made landfall in the Florida Keys and southeastern Louisiana during the peak of the hurricane season. The intensity at landfall has been adjusted from 110 kt originally in HURDAT to 100 kt in the Florida Keys and from 135 kt to 110 kt in Louisiana, indicating that Betsy was a category 3 at landfall, not a category 4 as previously shown. Moreover, the peak intensity of Betsy was reduced from 135 kt originally in HURDAT to 120 kt. Three new tropical storms were added to 1965 and none made landfall. One of the new tropical storms originated from an extratropical cyclone that formed late in November northeast of the Leeward Islands and acquired tropical characteristics a day before the hurricane season officially ended.

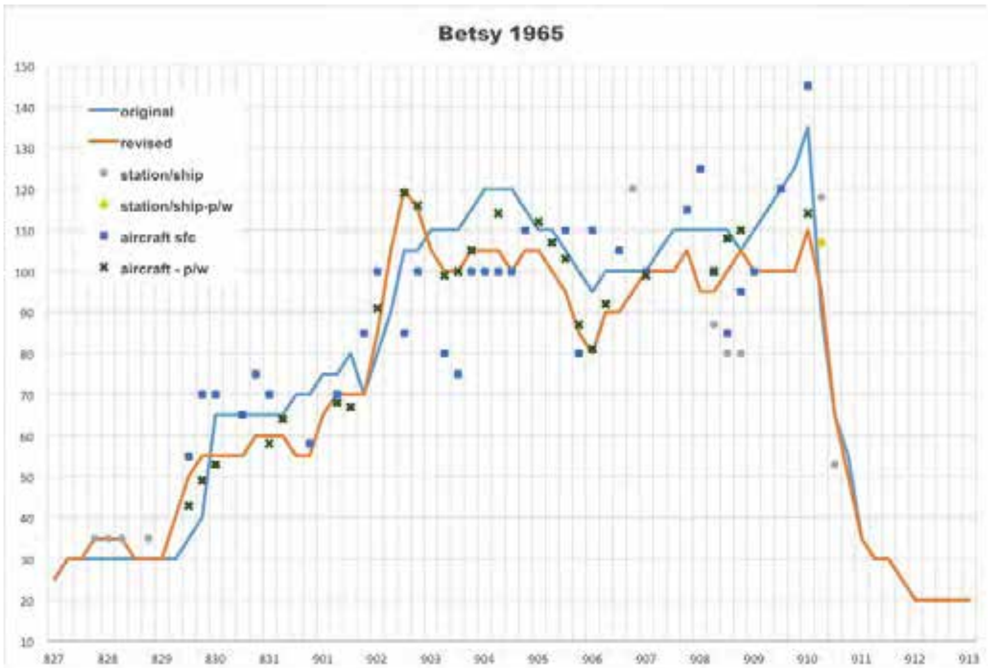


Figure 1: Original (blue) and revised (orange) intensities (wind speed in knots) of Hurricane Betsy of 1965, illustrating changing assessments of hurricane intensity due to reanalysis based on the data available.

1966 was an active hurricane season with several long-lived tropical cyclones. The season also had an early start, with at least (pending complete reanalysis) five tropical cyclones before August. Hurricane Alma formed in early June and made landfall in the Florida panhandle. The hurricane also struck the westernmost part of the Florida Keys where originally in HURDAT had reached a peak intensity of 110 kt, but this has been reduced to 100 kt. Becky, Dorothy and Lois were small hurricanes in the north Atlantic that had extratropical origins. Faith was a classic Cape Verde hurricane, forming close to the western coast of Africa and recurving east of the United States. Faith also caused damages in Norway and other parts of northern Europe as a potent extratropical cyclone. Inez was also a long-lasting hurricane that formed east of the Lesser Antilles and struck southern Florida before a final landfall in Mexico. Finally, Judith was a weak tropical cyclone east of the Lesser Antilles that was upgraded to a tropical storm and an intensity estimate made based on satellite images, before the reconnaissance aircraft investigated the storm. This may have been the first time that satellite images were used to upgrade and estimate the intensity of a tropical cyclone. Previously, satellite images had been used to complement the information received from ships and reconnaissance aircrafts.

A reanalysis of 1969's Hurricane Camille has been completed as part of the Atlantic Hurricane Database Reanalysis Project. The reanalysis of Hurricane Camille has been expedited to allow for a homogeneous comparison of all four of the U.S. landfalling Saffir-Simpson Hurricane Wind Scale Category 5 hurricanes since 1900. A review of the available ship, station, radar, aircraft and satellite observation is presented, along with the reanalysis methodology. Highlights of the Best Track Change Committee approved changes to Camille's genesis, track, intensity, and dissipation are discussed. As part of the preparation for the reanalysis, research on Hurricane Camille uncovered new data useful to the reanalysis. Focus was placed on understanding the internal structure in a modern context, especially whether eyewall replacement cycles occurred, including comparisons with a similar hurricane used as a proxy. A more detailed understanding was gained of the tropical wave and genesis phases. In addition, a 901 mb dropsonde that was later rejected was re-analyzed to find out why, and to see if an accurate central pressure could be determined. New landfall surface pressures along the Mississippi coast were discovered and a significant revision is made to the U.S. landfall central pressure and intensity (maximum sustained surface winds). (Additionally, a radar "loop" was constructed from archived WSR-57 film, including landfall, marking the very first time that this historic hurricane can be viewed in a time-lapse movie format.)

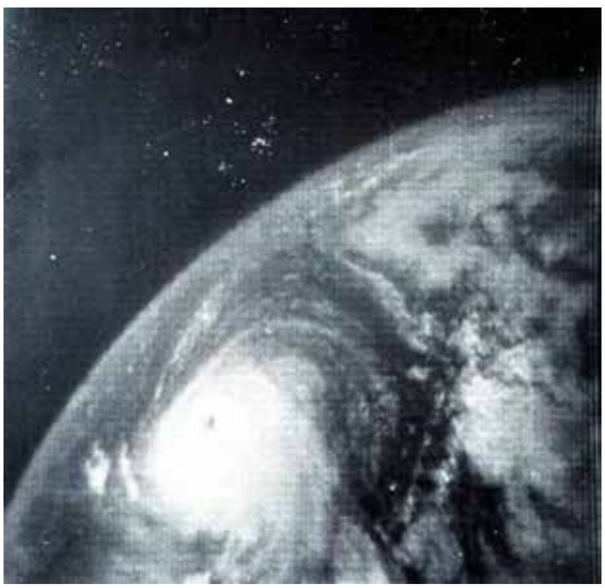


Figure 2: TIROS VIII (Television Infrared Observing Satellite) image of Hurricane Betsy on 4 September 1965, while the system was located north of the Bahamas.

Figure 3: NIMBUS 2 image of Hurricane Inez on 9 October 1966, showing a well-organized tropical cyclone over the Gulf of Mexico.

Mr. Brenden Moses is a full-time undergraduate student at Miami-Dade College and he is assisting in the hurricane database reanalysis project. Mr. Moses' responsibilities include developing hurricane databases, providing website design for the project, and conducting meteorological analyses of the storms' positions, intensities, and structure. He is also taking the lead on the 1964 hurricane season revisions.

Research Performance Measure: The reanalysis of 1964 and 1966 should be complete in June. By the end of 2015, we are expecting to have completed the reanalysis of the hurricane seasons of 1967-1969. The amount of data available is incrementally growing as we get closer to the present, thus it is taking longer to reanalyze each individual tropical cyclone.

Using NOAA UAS Assets and OSSE/DA Capabilities to Improve Sampling Strategies and Numerical Prediction of Tropical Cyclone Track Intensity, and Structure

Project Personnel: J.P. Dunion, A. Aksoy, L. Bucci, B. Klotz, K. Sellwood and J. Zhang (UM/CIMAS)
NOAA Collaborators: R. Atlas and M. Black (NOAA/AOML)
Other Collaborators: L. Bosart and R. Torn (University at Albany-SUNY)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To provide real-time objective guidance for planning NOAA SHOUT Global Hawk UAS flight tracks and GPS dropwindsonde sampling strategies in and around tropical cyclones to improve model forecasts of storm track and intensity;

***Strategy*:** Collaborate with NOAA Environmental Modeling Center (EMC) to generate once-daily 80-member HWRF model ensembles for tropical cyclones of interest during the 2015 NOAA SHOUT field program and use these forecasts to calculate optimal target locations for periods when the Global Hawk will be flying; develop the necessary software to translate from HWRF output to figures that can be used by the mission scientists; form a team to quality control Global Hawk GPS dropwindsonde data in real-time and transmit that information to the Global Telecommunications System where it will be available for model assimilation (including in HWRF).

CIMAS Research Theme:

***Theme 2*:** Tropical Weather

Link to NOAA Strategic Goals:

***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

NOAA Funding Unit: UAS Program **NOAA Technical Contact:** Dr. Robbie Hood

Research Summary:

The 2015 NOAA SHOUT field program will be conducted from 25 Aug to 27 Sept and will utilize the Global Hawk Unmanned Aircraft System (UAS) to observe North Atlantic and possibly eastern North Pacific tropical cyclones (TCs). The Global Hawk will be equipped with multiple instrument platforms that include aircraft-deployed GPS dropwindsondes that measure temperature, pressure, wind, and humidity at a vertical resolution of 2.5-5 m.

One of the main goals of this project during the 2015 SHOUT field campaign will be to provide real-time support for designing optimal GPS dropwindsonde sampling strategies for the Global Hawk using a real-time ensemble data assimilation and forecasting system. Specifically, this effort will develop objective guidance for planning when and where GPS dropwindsondes should be deployed by the Global Hawk in order to optimize model track and intensity forecasts. The project team has made arrangements to generate ensemble model forecasts that can be used in the targeting calculations needed to support this objective and to analyze some of the results from the 2014 season. We received a commitment from NOAA HWRF team lead Vijay Tallapragada and team member Zhan Zhang to generate once-daily 80-member HWRF ensemble forecasts for a TC of interest during SHOUT. These forecasts will then be used to calculate optimal GPS dropwindsonde target locations for various forecast lead times during potential periods when the Global Hawk would be flying. We are currently developing the necessary software to translate from HWRF output to real-time analyses that can be used by SHOUT mission scientists to plan Global Hawk flight patterns and GPS dropwindsonde sampling strategies. We are also working with NOAA EMC to run a test forecast from 2014 Hurricane Edouard and will use this case to test the targeting software that is being developed. Figure 1 shows an example of the output generated by the targeting software, where colored circles indicate regions where there is relatively high variability amongst the model ensembles regarding either track (Fig. 1, left) or intensity (Fig. 1, right) forecasts. The warmer colors denote regions where the assimilation of GPS dropwindsondes can reduce that variability in the model forecasts. This figure shows that the Hurricane Bertha 48-hr track forecast valid for 06 August 1200 UTC would have been optimized by sampling the region off the southeast U.S. coast north of the Bahamas, several hundred kilometers north of the storm center on 04 August. For the Hurricane Edouard case in Figure 1, the 48-hr intensity forecast valid for 15 Sept 1200 UTC would have been optimized by mainly sampling the region around the northern semicircle of the storm out to a radius of ~300 km from the storm on 13 Sept. These prototype analyses are currently being refined and will be produced in real-time during the summer of 2015 and will be used as guidance for Global Hawk mission planning.

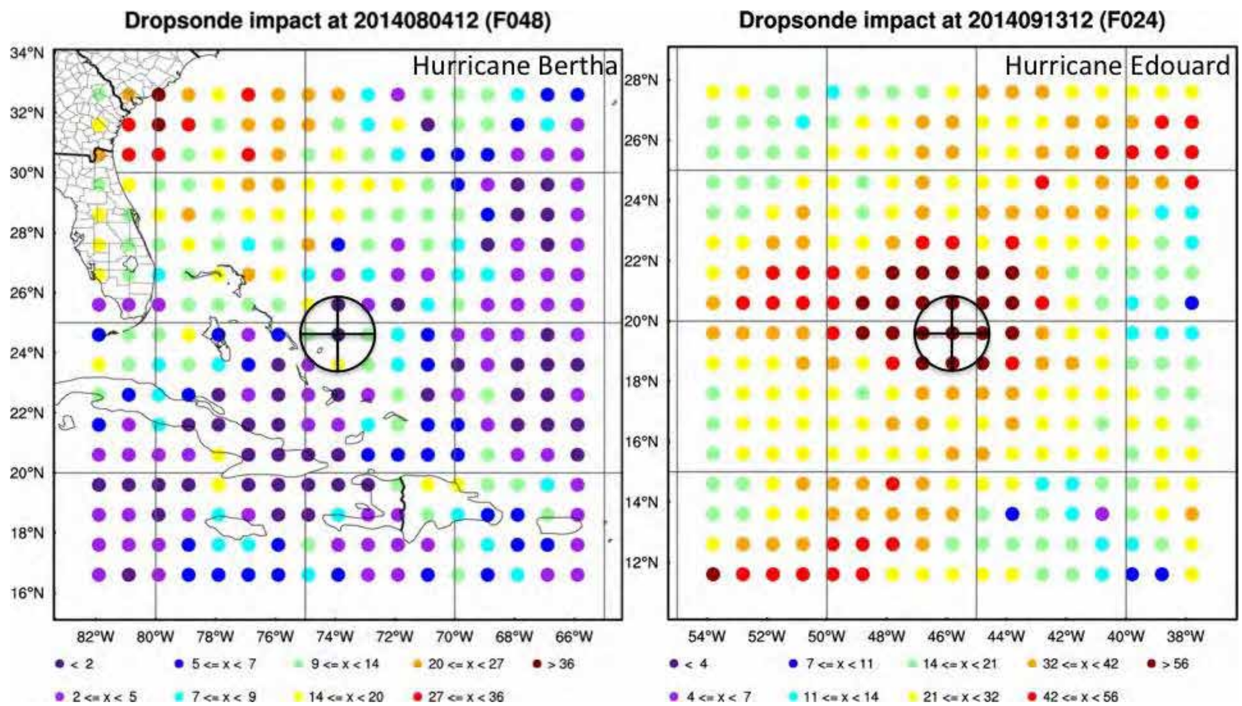


Figure 1: Sample output from the model-generated targeting software showing regions where GPS dropwindsonde observations could reduce variability in WRF model ensemble forecasts (warmer colors denote areas where observations cold most positively impact the model forecasts). Plots show the relative sensitivities for reducing the ensemble variability of the (left) 48-hr track forecast for 2014 Hurricane Bertha for GPS dropwindsondes deployed on 04 Aug 2014 and (right) 48-hr intensity forecast for 2014 Hurricane Edouard for GPS dropwindsondes deployed on 13 Sept 2014.

Research Performance Measure: This project is in the year-1 phase of a proposed 3-year effort. Accomplishments that focus on the goal of providing real-time objective guidance for planning NOAA SHOUT Global Hawk UAS flight tracks and GPS dropwindsonde sampling strategies in and around TCs that improve model forecasts of storm track and intensity include:1) Developed a prototype real-time demonstration system that could be used in future years to identify optimal Global Hawk sampling strategies. This included using 60 member WRF ensemble forecasts to test recent historical TC cases; 2) Collaborated with NOAA EMC to receive a commitment from HWRF Team lead Vijay Tallapragada and team member Zhan Zhang to generate once-daily 80-member HWRF ensemble forecasts for TCs of interest during SHOUT. These forecasts will then be used to calculate optimal sampling strategies for periods when the Global Hawk will be flying; 3) Developing necessary software to translate from HWRF model output to figures that can be used by the mission scientists. In addition, NOAA EMC will run a test forecast from 2014 Hurricane Edouard in the next 1-2 months that will provide data to test the targeting software that is being developed by the project team; 4) Co-PI Dunion presented a NOAA SHOUT field campaign overview at the 95th American Meteorological Society Annual Meeting in Phoenix, AZ (January 2015); 5) Co-PI Dunion presented a 2015 NOAA SHOUT overview with emphasis on Global Hawk data for forecasting applications at the NOAA National Hurricane Center in Miami, FL (May 2015).

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Improved SFMR Surface Wind Measurements in Intense Rain Conditions

Project Personnel: B. Klotz (UM/CIMAS)
NOAA Collaborator: E. Uhlhorn (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To formulate new wind and rain models in the SFMR algorithm that removes the high surface wind speed bias in heavy rain and to evaluate performance of these changes.
***Strategy*:** To evaluate and produce statistics on the new algorithm performance compared to the current operational algorithm and assess its ability to reduce the bias in heavy rain.

CIMAS Research Theme:

***Theme 2*:** Tropical Weather

Link to NOAA Strategic Goals:

***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

NOAA Funding Unit: NOAA/OAR/USWRP/JHT **NOAA Technical Contact:** Jiann-Gwo Jiing

Research Summary:

The airborne stepped frequency microwave radiometer (SFMR) estimates surface wind speed and rainrate in most conditions, but is particularly useful in hurricanes. However, due to several factors, retrieval accuracy of the operational algorithm is degraded in conditions where weak-to-moderate winds are coupled with heavy precipitation, especially tropical depressions and weak tropical storms. Typically, winds are overestimated in such conditions when using the current operational algorithm.

Discussion of the bias correction and updated algorithm were provided in the 2014 CIMAS report. To summarize these results, it was determined that the updated algorithm does not fully remove the high wind speed bias in weak wind speeds and heavy rain, but the wind speed and rain rates better compare to other trusted data sources. After producing this revision, it is necessary to evaluate the performance of the algorithm. Because there is still somewhat of a high bias at the weak wind speeds and heavy rain, a simple correction was also applied to the updated algorithm using the bias sensitivity. This term reflects the amount of bias remaining per mm hr^{-1} of rain rate for each surface wind speed bin. These bins are separated into storm category designations (i.e., Tropical Depression, Tropical Storm, Hurricanes, and

Major Hurricanes). Figure 1 displays this bias sensitivity and the resulting linear fit to these data. As expected, the weaker wind speed regimes have a much higher sensitivity than the intense hurricanes.
Using the linear fit as shown in Figure 1, an additional correction can be applied to the revised algorithm wind speeds. In the event that the corrected wind speeds are higher than the original wind speeds, the original wind speed is used to prevent over-inflation. Figure 2 displays the probability density functions of the difference between the operational and corrected wind speeds for various rain rate bins. It is clear that as rain rate increases, there is a larger difference between the operational and corrected wind speeds. In general, weak rain events (< 10 mm h^{-1}) require corrections approximately five knots (2.5 m s^{-1}, 5.75 mph) while heavy rain events (> 40 mm h^{-1}) require a correction of approximately 15 knots (7.5 m s^{-1}, 17.25 mph). The statistics reveal the general impact of the updated algorithm on a large dataset. However, it is important to also analyze the impact for individual storms. Figure 3 provides an example from Hurricane Cristobal in 2014. At the peak wind speed (~2318 UTC) there is also a coincident peak in rain rate of 70 mm h^{-1}. The operational wind speed (blue line) is about 7-8 knots higher than the corrected wind speeds (green line). A GPS dropsonde surface adjusted wind speed near the time of the peak wind speed indicates that the wind speed was approximately 60 knots. The corrected SFMR wind speed is much closer to this value than the operational wind speed, which indicates that the correction increases the reliability of the SFMR wind speed for this case. With the improvements to the algorithm, it is clear that improved wind speeds in the presence of rain will be provided once the update becomes operational.

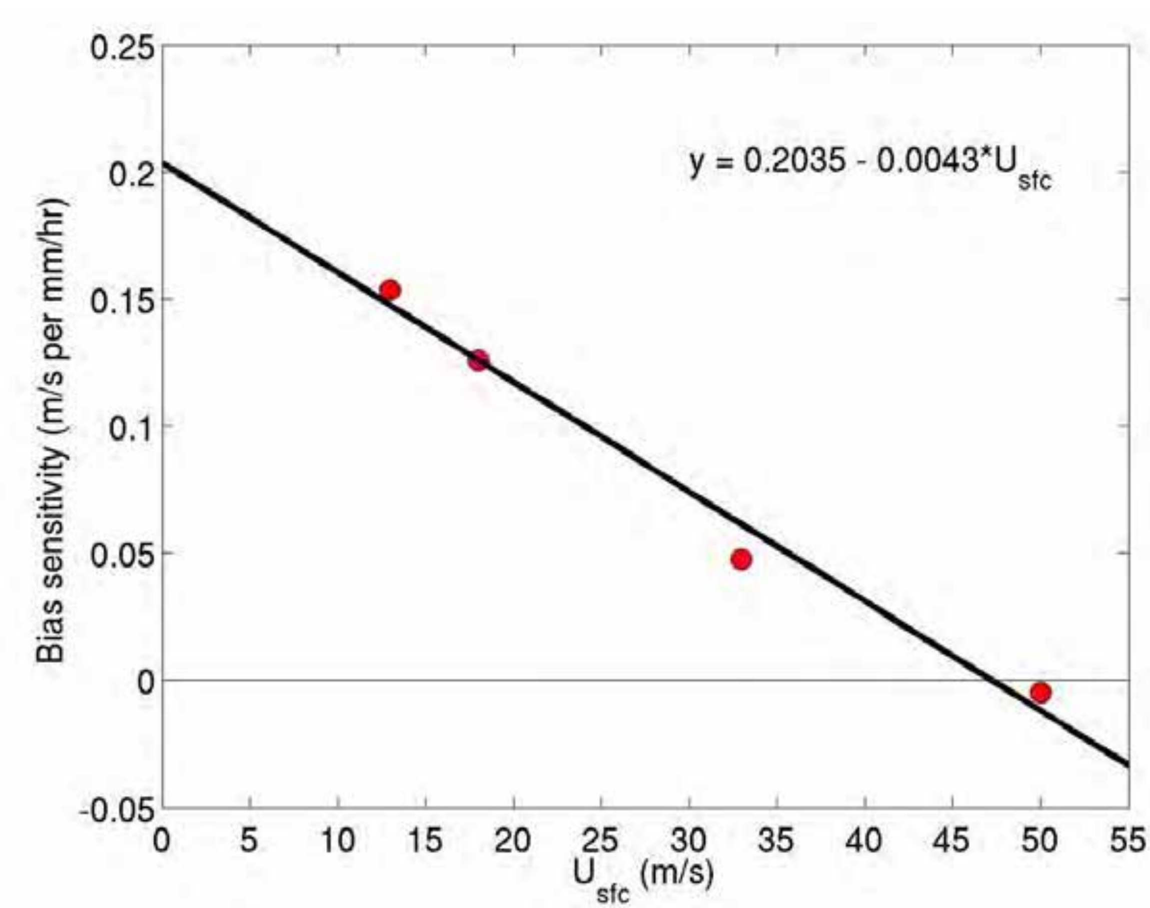


Figure 1: Bias sensitivity of the operational wind speed per mm h^{-1} of rain rate. The red dots indicate the bin-averaged sensitivity for various storm categories. The black line is the linear least-squares fit to the data.

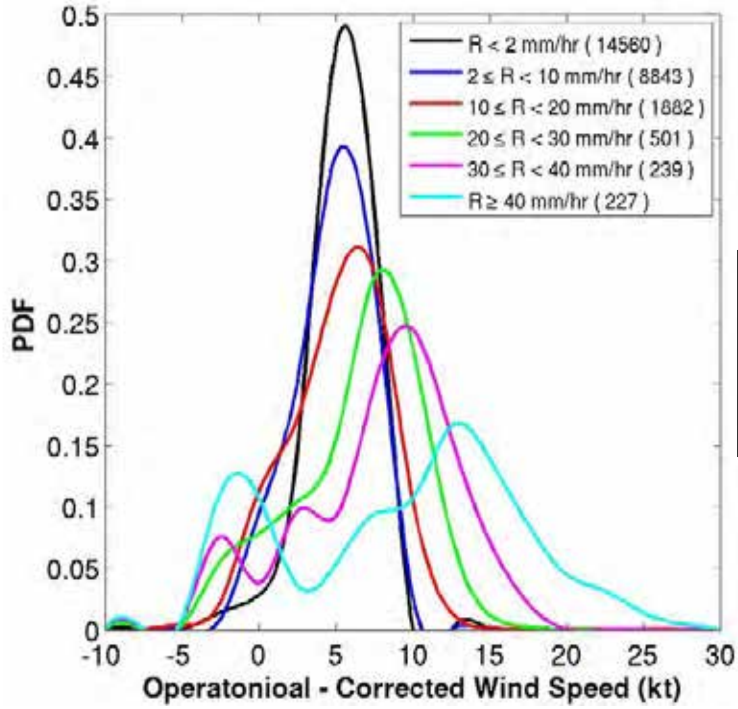


Figure 2: Probability density functions of the difference between operational and corrected wind speeds are provided for various rain rate bins. The value in parentheses indicates the total number of observations in that particular bin.

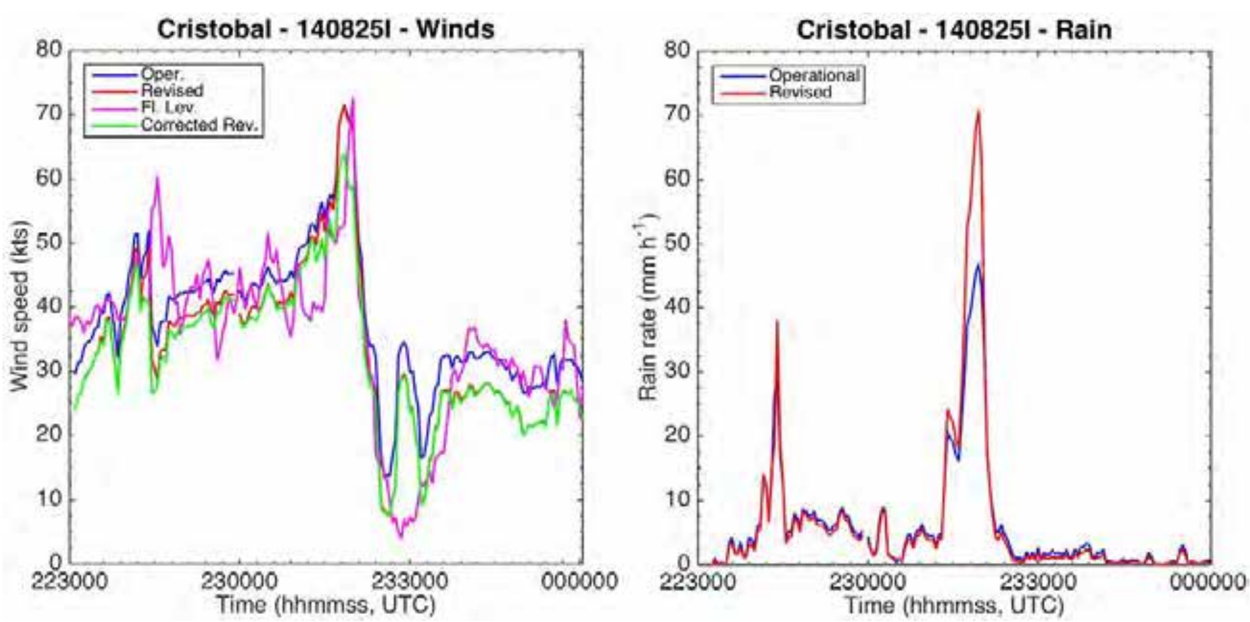


Figure 3: An example of the comparison between the operational and corrected wind speeds is provided from Hurricane Cristobal (2014). In the left panel, the blue (green) line represents the operational (corrected) wind speeds. Additionally, the flight-level (pink) and uncorrected revised SFMR (red) wind speeds are shown. In the right panel, the blue (red) line represents the operational (revised) algorithm rain rates.

Research Performance Measure: All research goals have been met. The algorithm has been approved by the JHT committee for operational use and is in the process of being implemented on all airborne SFMR.

Near-automation of real-time airborne radar analysis onboard NOAA aircraft

Project Personnel: Sonia Otero (UM/CIMAS)
NOAA Collaborators: J. Gamache and S. Murillo (NOAA/AOML/HRD)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To improve our understanding of the wind distribution in tropical cyclones.
Strategy: To apply advanced computing methodologies to integrate cyclone data and to make the data more readily available to scientists and the National Weather Service in real-time.

CIMAS Research Theme:

***Theme 2*:** Tropical Weather

Link to NOAA Strategic Goals:

***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

NOAA Funding Unit: OAR/AOML/HRD **NOAA Technical Contact:** Molly Baringer

Research Summary:

Airborne Doppler radar has been on the NOAA WP-3D aircraft since 1981. Since then, the Doppler radar system has been updated and more fully integrated with the radar system aboard the WP-3D, and on the NOAA G-IV aircraft since 2011. These radars have been powerful research tools for decades, and since 2005 data and analyses have been sent from the aircraft in real time. Doppler superobs were first assimilated in a real-time research model in 2008 during Tropical Storm Fay. HWRF (Hurricane Weather Research and Forecasting Model) assimilation of Doppler radial velocities first occurred in a real-time parallel run during Hurricane Tomas of 2010, and since 2013, they have been assimilated in the operational runs of HWRF.

Providing analyses and Doppler radial velocities in real time requires an automated analysis and quality control system. To use the Doppler velocities, a great deal of quality control is needed, including removal of side-lobe noise, removal of sea-surface reflection, and de-aliasing. Several passes through the Doppler data are required to be able to quality control the radial velocities correctly.

The initial submission of a radar task does require human interaction, however. A java application allows data entry of the required information or of parameter customization: storm center and motion, beginning and end time of input data, the radial directions of flight tracks from the storm center, the resolution of the analysis, and the stringency of the quality control (based upon the gradients of wind velocity, more stringent in hurricanes and even more stringent in major hurricanes). Nonetheless, the application strives to minimize human error by taking advantage of the real-time 1Hz feed archived at the AOC website for each mission. Operators are forced to link a radar job to one of those flight missions, not only for routing job to the target aircraft, but also to acquire the mission and storm description as filled by the flight director.

Preferably, radar jobs are submitted from the ground; but, in the event of a prolonged network disconnect with the aircraft, operators onboard have the ability to also generate radar jobs.

Once a radar job file is uploaded at the AOC website, the rest of the steps are fully automated to completion. AOC has developed scripts where, once the radar workstation is started on the aircraft, a person on the ground can submit a job file, the transmission software aboard the aircraft detects a new job file, the quality-control/analysis process takes place, and once it is finished the various products are transmitted off the aircraft to the appropriate agencies.

The quality-controlled Doppler radial velocities are sent to NCEP (National Centers for Environmental Prediction) Central Operations (NCO) for assimilation into HWRF. They are also used to produce superobs for HRD and its research partners.

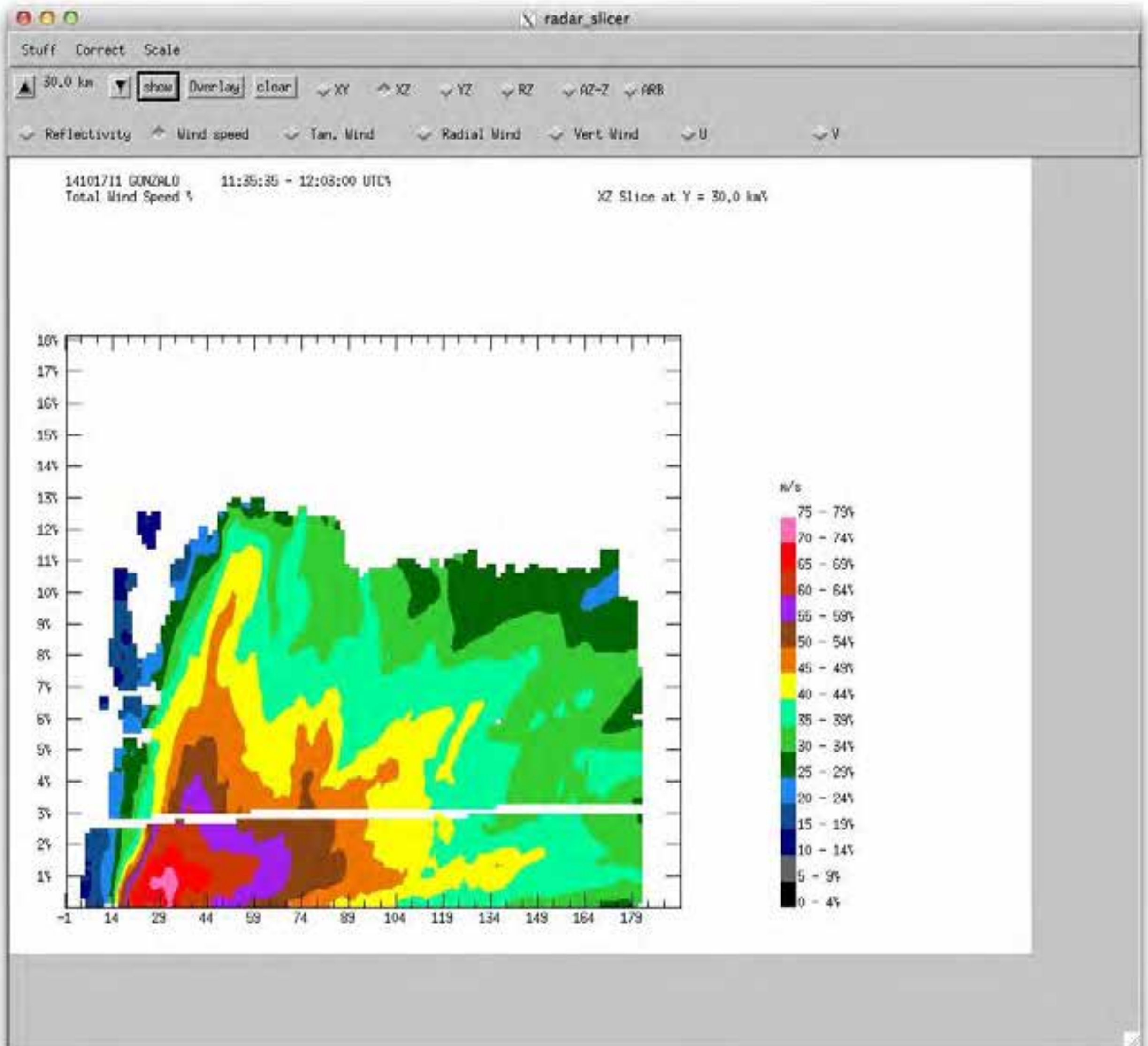


Figure 1: Vertical cross-section of total wind speed across one flight leg obtained from the aircraft Doppler radar during Hurricane Gonzalo, October, 16 2014. X-coordinate is distance from storm center and y-coordinate is height above sea surface.

Research Performance Measure: All objectives have been met on schedule.

Studies in Support of NOAA's NESDIS Operational Ocean Heat Content Product Suite

Project Personnel: L.K. (Nick) Shay (UM/RSMAS)
Other Collaborators: E. Maturi and D. Donohue (NOAA/NESDIS)

Long Term Research Objectives and Strategy to Achieve Them:

***Objective*:** To provide a high resolution Oceanic Heat Content (OHC) product (0.25^o) from altimeter derived fields for the North Atlantic, and the Pacific Ocean Basins to NOAA NESDIS for 24/7 operations. A key aspect of this product is that the isotherm depths (20 and 26^{o}C), ocean mixed layer depth, and OHC will be carefully evaluated from *in-situ* data from floats, drifters, expendable bathythermographs (XBT) transects, long-term Pirata and TOGA TAO moorings and airborne XBTs (AXBTs, AXCTDs) including data acquired from the Deep Water Horizon monitoring over about 90 days following the incident and measurements from the ONR ITOP experiment in the western Pacific Ocean basin.

***Strategy*:** To build realistic climatology for a two and a half layer model and evaluate a daily global OHC product based on satellite altimetry-derived sea surface height anomalies (SSHA) from available missions (Jason, SARAL, and Cryosat-2) with observations from various in situ platforms. This product (North Atlantic and North Pacific) has been transitioned to NOAA NESDIS for 24/7 operations. The building of the South Pacific Ocean Climatology (SPOC) product suite has been completed and transitioned to NOAA NESDIS in the *pre-operational mode.* Cryosat-2 data is being entrained into the analysis and will be completed in the next couple of months.

CIMAS Research Theme:

***Theme 2*:** Tropical Weather

Link to NOAA Strategic Goals:

***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

Research Summary:

A daily Systematically Merged South Pacific Regional Temperature and Salinity climatology (SPAC) has been developed following the Systematically Merged Atlantic Regional Temperature and Salinity (SMARTS) (Meyers (et al., 2014) and a Systematically merged Pacific Ocean Regional Temperature and Salinity (SPORTS) climatology constructed from GDEM 3.0 and WOA for the two and a half layer model using a 15-day running mean to insure continuity between the months for mean isotherm depths and reduced gravities. Thermal profiles were acquired from multiple platforms including floats, XBT transects (see Figure 1), moorings and AXBTs for a seventeen-year period totaling 244,000 points. In addition, airborne measurements from the Deep Water Horizon response in 2010 were also entrained into the Atlantic and Pacific Ocean basins analysis to improve the satellite-derived algorithm. Altimeter-derived SSHA (including those from SARAL) have been blended and objectively from various platforms using the Mariano and Brown (DSR, 1992) approach to estimate space based values of isotherm (and mixed layer) depths and OHC values. Based on these measurements, we have found high correlations and low RMS differences between observed and space-based estimates of the product fields based on these climatologies for the Atlantic and the entire Pacific Ocean. An example of the new SPOC ocean product suite is shown in Figure 2 prior to Cyclone Pam in 2015.

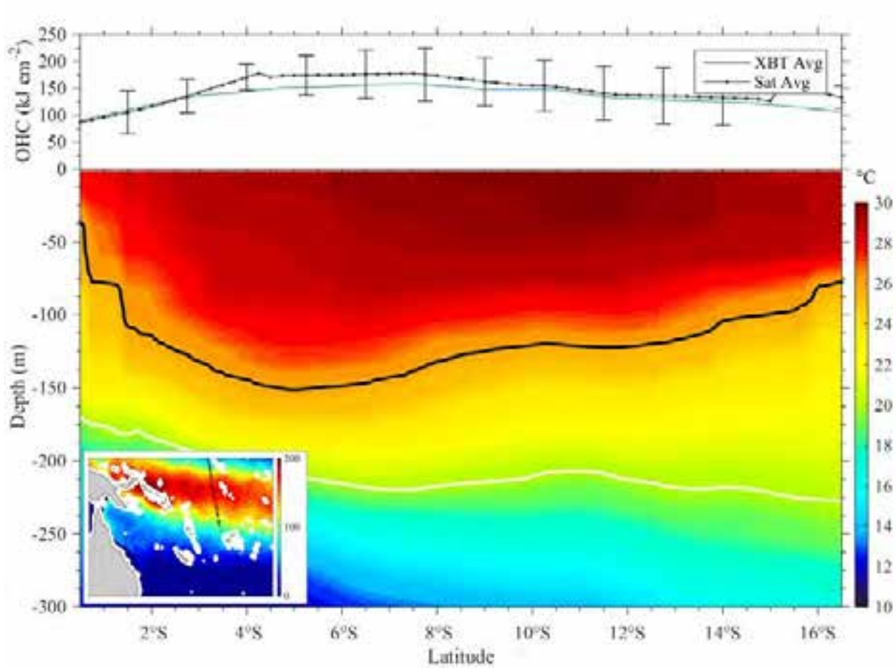


Figure 1: Average satellite derived OHC (black line) from 1998-2002 during the month of April and average OHC (red line) (top panel) from five-annual XBT transects along the black line in bottom inset in the SPOC domain. Average temperature structure along annual XBT transect (inset) during the month of April for 1998-2002 (bottom panel). The 20°C and 26°C isotherm depths are depicted by white and black lines, respectively. (Inset) Average satellite derived OHC (kJ cm^{-2}) from 1998-2002 during the month of April.

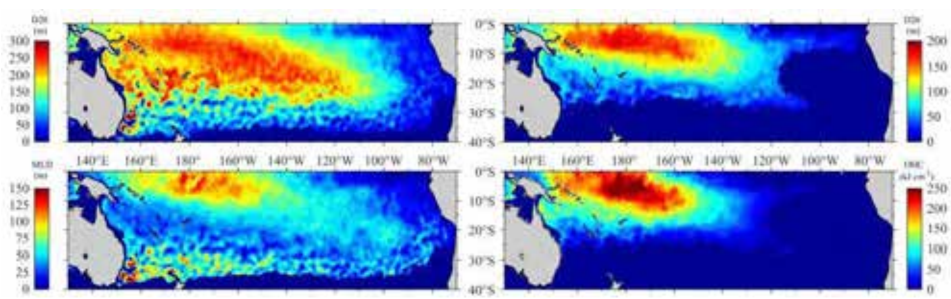


Figure 2: Four panel graphic of 20°C isotherm depth, 26°C isotherm depth, mixed layer depth (all in meters), and OHC (kJ cm^{-2}) on 1 March 2015 a few days prior to the passage of cyclone Pam from the SPOC product suite.

Research Accomplishments: These new products originally developed by Mainelli (2000), Shay and Brewster (2010) and Meyers et al. (2014) have been successfully transitioned to NOAA NESDIS and to NHC for Statistical Hurricane Intensity Prediction Scheme (SHIPS) and used at the Joint Typhoon Warning Center. In general, the addition of OHC values reduced intensity forecast error about 5 to 6% above the SST influence on hurricane intensity over the North Atlantic Ocean Basin for example. However, it has been shown that deep warm mixed layers (high OHC) become even more important in the western parts of the basins. OHC reduced intensity forecast error by an additional 22% during hurricane Ivan's passage in 2004 as well as ST Haiyan in the western Pacific Ocean basin. With this enhanced (and evaluated) product (including the ingest of SARAL SSHA), OHC uncertainties have been reduced, and the product fields are available year round through NOAA NESDIS with an archive dating back to 1998 at RSMAS for improved analyses and forecasts for both weather and climate studies.

Addressing Deficiencies in in Forecasting Tropical Cyclone Rapid Intensification in HWRF

Project Personnel: J. Zhang and H. Chen (UM/CIMAS); D.S. Nolan (UM/RSMAS)
NOAA Collaborators: R.F. Rogers (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** The overall object this project is to evaluate and improve the model performance of the HWRF model in forecasting rapid intensification (RI) of tropical cyclones.

***Strategy*:** To achieve this objective, we will focus on: (1) to identify key physical processes associated with RI using HWRF forecasts and the hurricane nature runs; (2) to quantitatively evaluate deficiencies and biases in inner-core structure and environmental conditions associated with RI forecasts by the HRWF model.

CIMAS Research Theme:

***Theme 2*:** Tropical Weather

Link to NOAA Strategic Goals:

***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

NOAA Funding Unit: NWS/NWSPO **NOAA Technical Contact:** Daniel Melendez

Research Summary:

Improving the intensity and track forecast of TCs undergoing RI is important because under-prediction of RI could lead to a heavy toll of human lives and cause tremendous financial loss, especially if RI takes place shortly before a TC makes landfall on a heavily populated coastal city. However, forecasting RI has long remained a challenge because of the lack of understanding of the processes underlying RI and the deficiency in hurricane models to reproduce these processes. The objective of this project is to address deficiencies in forecasting RI by the HWRF model. This project emphasizes the use of the HWRF ensemble forecast product from EMC, and airborne flight-level, dropsonde and Doppler radar data to pinpoint the deficiencies and improve the performance of the operational HWRF model.

Cases are selected from the retrospective simulations using the HWRF model in three groups: 1) HWRF captured RI (*Hit*), 2) HWRF missed RI (*Miss*), and 3) HWRF predicted RI that did not occur (*False Alarm*). Cases in group 1 (*Hit*) with substantial aircraft observations are analyzed to identify important processes underlying RI (Fig. 1). The nature run simulated using the WRF-ARW model are also analyzed to document key physical processes associated with RI (Fig. 2). Cases in groups 2 (*Miss*) and 3 (*False Alarm*) are analyzed in comparison with the findings learned through analyzing cases in group 1 in order to identify deficiencies in the simulated multi-scale structures. Model errors believed to contribute to these deficiencies will be identified and reduced, with the goal of producing improved multi-scale structures and better forecasts of RI. Composite analysis of the HWRF forecasts with different physics setups is also conducted to investigate the impact of model physics on RI forecasts (Fig. 3). The newly developed HWRF ensemble product will be utilized to further understand the processes associated with RI and address the model deficiencies in year 2.

Research Performance Measure: The program is on schedule. Three peer-reviewed articles have been published in *Monthly Weather Review* and *Journal of the Atmospheric Sciences*.

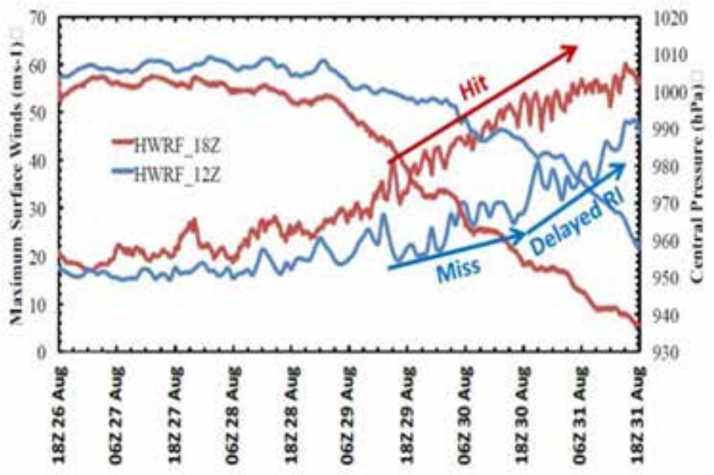


Figure 1: Time series of minimum central pressure and maximum 10-m winds for the Hit (i.e., 18 UTC 26 August initial time; red) and Miss (i.e., 12 UTC 26 August initial time; blue) HWRF forecasts.

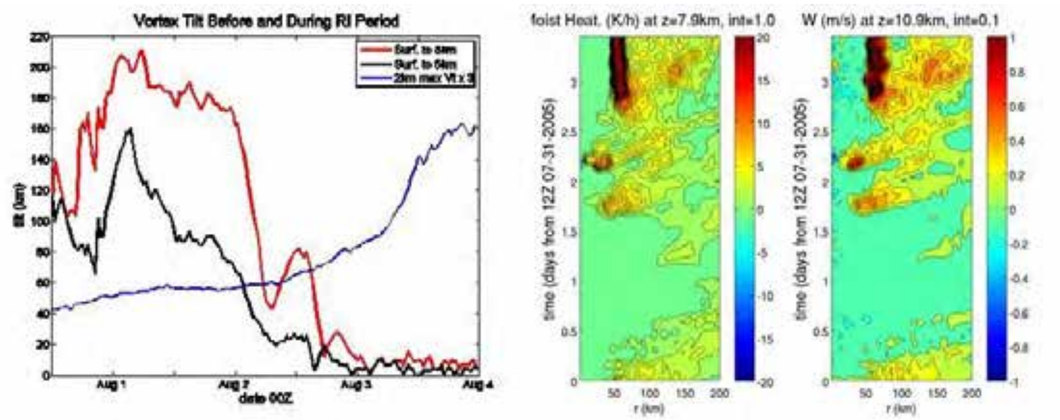


Figure 2: Structure changes in nature run (NRH1) before RI: a) surface to 8km (red) and 5km (black) tilt, along with the maximum azimuthal-mean tangential wind at z = 2km, which shows the large increase in intensity after 06Z August 3; b) Hovmoller diagrams of azimuthal-mean most heating and vertical velocity at z = 7.9 and 10.9 km, respectively. The azimuthal mean shows the contributions of two large convective bursts (which are in fact highly localized) before the eyewall forms.

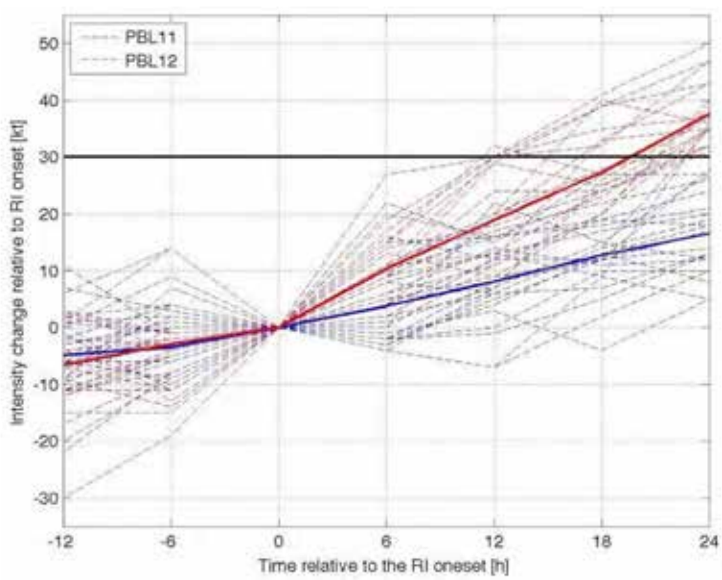


Figure 3: Plot of intensity change in kt for PBL11 (blue) and PBL12 (red) HWRF forecasts as a function of time relative to the onset of RI events that are seen in PBL12 not in PBL11. Note that the boundary layer vertical diffusion in HWRF was upgraded based on aircraft observations for PBL12.

Services to Support the Hurricane Forecast Improvement Project

Project Personnel: X. Zhang, A. Aksoy, J. Zhang, G. Alaka, H. Chen, R. Gall, B. Klotz, K. Sellwood, R. St. Fleur and J. Delgado (UM/CIMAS)

NOAA Collaborators: S.G. Gopalakrishnan, T. Quirino, F. Marks, S. Goldenberg (AOML/HRD); AOML/HRD IFEX team

Other Collaborators: V. Tallapragada, Q. Liu, Z. Zhang, S. Trahan and D. Sheinin (NCEP/EMC); B. Thomas (U. Rhode Island)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: Our overall objective is for CIMAS and its collaborating groups to further advance the capabilities, accuracies and reliability of numerical hurricane forecasting in FY14-15 under HFIP.

Strategy: To achieve this objective, we will focus on (1) experimenting with alternative physics packages; (2) exploring the assimilation of satellite data through regional OSSE system; (3) implementing new capabilities in the operational HWRF model; (4) collaborating with NWS and other federal scientists, and research scientists from other organizations on furthering HFIP's plans and objectives; (5) managing the technical aspects and R2O and O2R transitions of the HFIP program.

CIMAS Research Theme:

Theme 2: Tropical Weather

Link to NOAA Strategic Goals:

Goal 2: Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

NOAA Funding Unit: NWS **NOAA Technical Contact:** Molly Baringer

Research Summary:

HWRF Model Development. The PI (Xuejin Zhang) and collaborators developed an experimental Basin-scale HWRF system in AOML/HRD and UM/CIMAS. The Basin-scale HWRF system can:

- support multiple movable nests to enhance the horizontal resolution for each target storm;
- initialize each vortex with GSI data assimilation and vortex initialization capability for intermediate and inner domains of each storm; and
- ingest NCEP's real-time global SST (RTG_SST_HR) analysis to better represent the tight gradients in the Gulf Stream region of the Atlantic Ocean and the temporal evolution of daily SST.

During the past year, we further developed Basin-scale HWRF that could support GSI data assimilation and are in the process of upgrading to the 2015 version of the Basin-scale HWRF system, which will be first time the Basin-scale HWRF has full functionalities of the 2015 operational HWRF implementation (Table 1). In particular, the 2015 Basin-scale HWRF will be conformed to the two-way ocean coupling and physics options of the 2015 operational HWRF. The Basin-Scale HWRF system:

- has full capability of the operational HWRF system;
- has advanced capability to forecast multiple storms within multiple basins or single basin (e.g., Atlantic and/or East Pacific basins); and
- features fully coupled multiple ocean basins.

The PI (Xuejin Zhang) worked closely with EMC scientist, Dr. Dmitry Sheinin, and URI scientist, Dr. Biju Thomas, to upgrade the ocean coupler and ocean initialization for 2015 Basin-Scale HWRF system. The modeling group worked with DTC and EMC to integrate the HRD-CIMAS Basin-Scale

HWRF system into the 2015 operational HWRF system, which is based on Python scripts. Thus, the groundwork for a transition of the Basin-Scale HWRF system into 2016 operations has been established.

Table 1: Comparison of model configurations among 2013 and 2015 basin-scale HWRF systems and 2015 operational HWRF.

	2015 Operational HWRF	2013 Basin-scale HWRF	2015 Basin-scale HWRF
Domain	18 KM: 77.58° x 77.58° 6 KM: 12.66° x 12.18° 2 KM: 7.90° x 7.06°	27 KM: 178.20° x77.58° 9 KM: 10.56° x 10.2° 3 KM: 6.12° x 5.42°	27 KM: 178.20° x 77.58° 9 KM: 12.66° x 12.18°§ 3 KM: 7.90° x 7.06°
Model top	2 hPa	2 hPa	2 hPa
Vertical levels	61	61	61
Vortex initialization	Vortex Initialization at 2 km	Vortex Initialization at 3 km	Vortex Initialization at 3 km
Data assimilation	Hybrid DA + HWRF ensemble DA for TDR	No GSI DA	Hybrid DA¶
Cycling	Storm component cycling within 30°x30° analysis domain	Storm component cycling within 30°x30° analysis domain	Storm component cycling within 30°x30° analysis domain
Ocean coupling	18-6 KM: Yes 2 KM: Downscaled	No coupling	27-9 KM: Yes 3 KM: Downscaled
Physics Scheme			
Microphysics	Modified Ferrier-Aligo (High Resolution)	Modified Ferrier (High Resolution)	Modified Ferrier-Aligo (High Resolution)
Radiation	RRTMG(SW,LW)	GFDL	RRTMG (SW,LW)
Surface	GFDL	GFDL	GFDL
PBL	2015 GFS	2013 GFS	2015 GFS
Convection	SAS, No CP (2 KM), Shallow Convection	SAS, No CP (3 KM), Shallow Convection	SAS, No CP (3 KM), Shallow Convection
Land surface	NOAH LSM	GFDL Slab	NOAH LSM

§ : The domain size may be changed in order to obtain better scalability
¶: May explore the independent basin-domain DA if satellite project get funded, not priority before HFIP demo season

Model Physics Evaluation. The co-PI (Jun Zhang) evaluated model physics using HWRF retrospective simulations and observational data. We focused on evaluating the structural differences between two sets of HWRF simulations with: 1) PBL scheme as in the 2012 version of the operational HWRF model (referred to as PBL12 hereafter), and 2) PBL scheme as in the 2011 version of the operational HWRF model (PBL11 hereafter). We aim to further investigate the effect of the observation-based upgrades of the PBL physics in HWRF in 2012 and after on the simulated hurricane intensity and structure. We used structural metrics to evaluate the model. These metrics include:

- boundary layer height scales,
- eyewall slope (Fig. 1),
- warm core structure (Figs. 2,3), and
- vertical velocity distribution (Fig. 4).

During the past year, we evaluated the impact of boundary layer physics in terms of vertical eddy diffusivity on the shape of wind profile in the surface layer. The observed wind profiles have relatively larger wind shear and are quantitatively closer to those in the PBL12 composite. Both model simulations and observations indicate a logarithmic wind profile above the lowest model level. It appears that the wind speed increases with height more quickly in the PBL12 composite than in the PBL11 composite, indicating the near-surface vertical wind shear is stronger in the PBL12 (Fig. 5). We further evaluated the impact of horizontal diffusion on hurricane intensity and structure in HWRF simulations using idealized simulations.

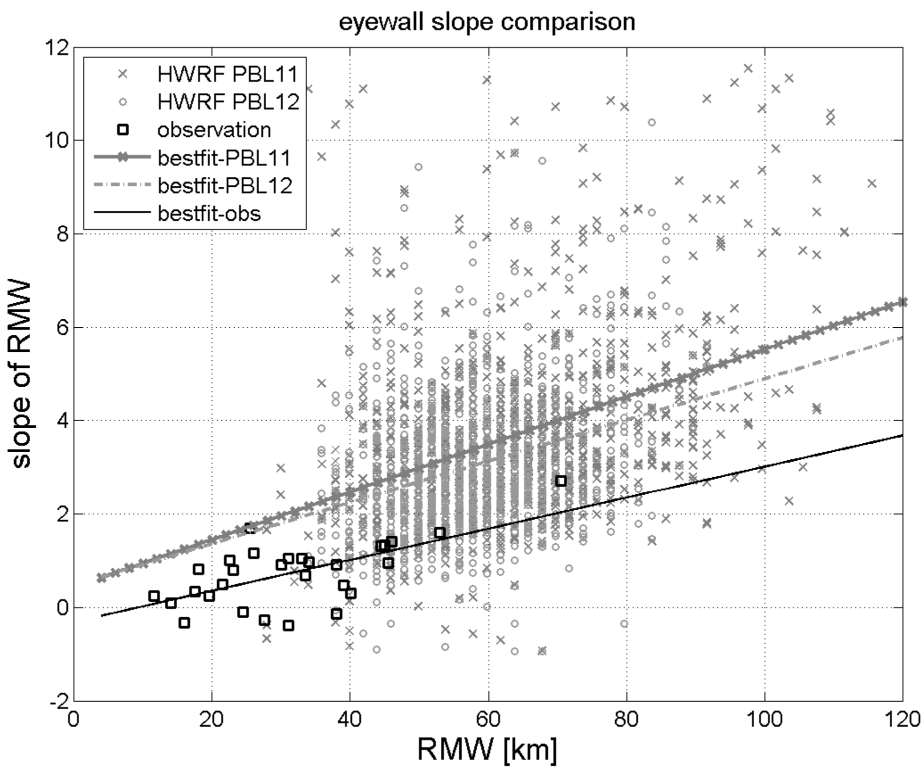


Figure 1: Plot of the slope of the RMW as a function of RMW at 2 km for HWRF forecasts with PBL11 and PBL12. The observed relationship from Doppler radar data given by Stern et al. (2014) is also shown.

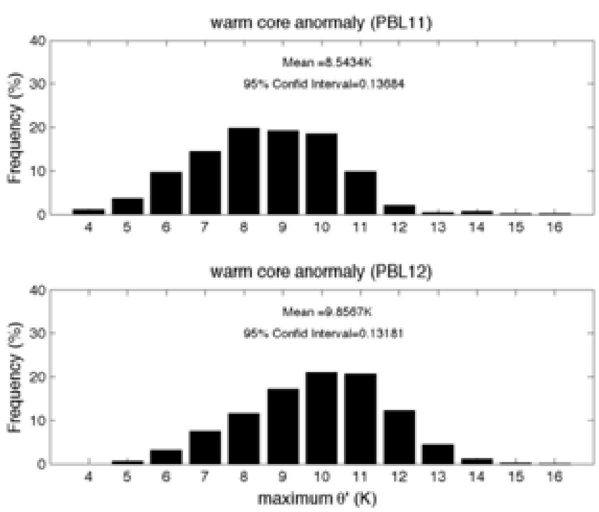


Figure 2: Frequency distribution of the peak warm core anomaly for HWRF forecast with (a) PBL11 and (b) PBL12.

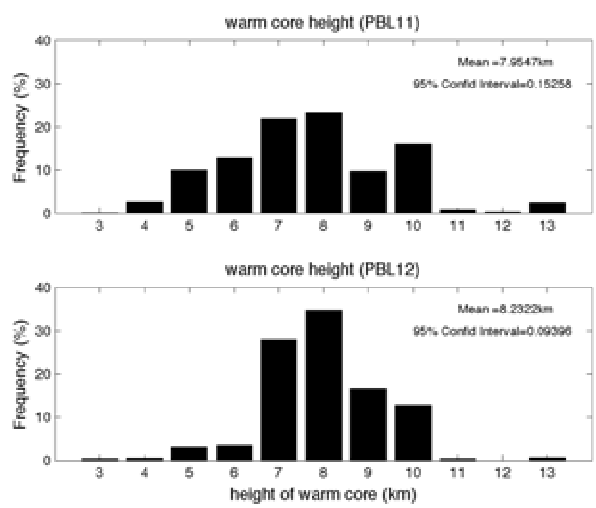


Figure 3: Frequency distribution of the warm core height for HWRF forecast with (a) PBL11 and (b) PBL12.

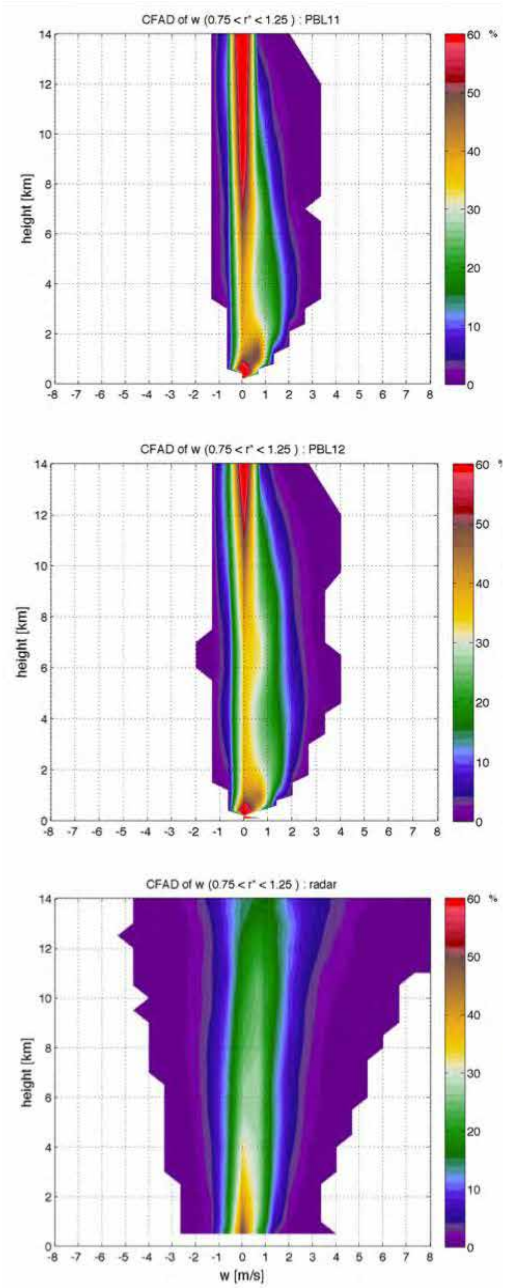


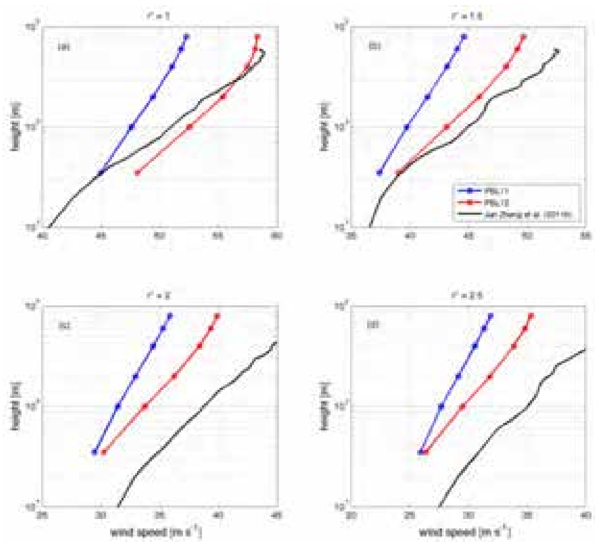
Figure 4: Contoured Frequency by Altitude Diagrams (CFADs) of vertical wind velocity (w) for PBL11 (upper panel), PBL12 (middle panel), and Doppler radar (lower panel) for the eyewall region (0.75<r*<1.25), where r* is the radius normalized by the radius of the maximum wind speed.

We also participated in the microphysics evaluation led by the Dr. Frank Marks. We were responsible for providing observational data from high-altitude G-IV dropsondes to compare with idealized HWRF simulations with different microphysics schemes. We found that the peak intensity is more sensitive to L_h for smaller values of L_h (Fig. 6). When L_h increases to the model horizontal resolution (3 km) and larger, the peak intensity becomes less sensitive to L_h. This behavior indicates that the effect of L_h on simulated peak intensity is larger when L_h is smaller than the model's horizontal resolution of the inner nest grid scales.

Other sensitivity experiments have also been run using HWRF to test the impact of model horizontal resolution on simulated hurricane intensity and structure. The results of the sensitivity experiments will be documented in a peer-reviewed paper.

Hurricane Observation Program. One important goal is to provide useful observations for HFIP through the AOML IFEX program. CIMAS scientists (including J. Zhang, A. Aksoy, K. Sellwood, H. Chen, and B. Klotz), HRD scientists, the AOC flight crew, and our other partners/collaborators completed several data-rich missions in 2014. We deployed 33 P-3 missions and 15 G-4 missions in seven tropical cyclones in both the North Atlantic and East Pacific basins. We successfully transferred TDR data to operational center for HWRF to assimilate them in real-time. We successfully tested our new observing technology, Unmanned Arial System (UAS, Coyote), in major hurricane wind force. During the UAS test mission, we also coordinated multiple missions, including NOAA's two P-3s, G-4, and NASA's Global Hawk, flew simultaneously into Hurricane Edouard and obtained rare data for scientists to study the major hurricane physical processes and to calibrate the future observing technology. The data we gathered can also be used to test, refine and improve **numerical models. All 2014 missions were supported by the** Disaster Relief Appropriations Act of 2013 and NOAA's HFIP.

Surface wind speed and rain rate observations from the SFMR were reported in real-time to the National Hurricane Center for forecasters to diagnose tropical cyclone strength. These wind speeds were also used in AOML's data assimilation system for improving the HWRF forecasts. During the 2014 hurricane season, winds were updated with a newly-devised algorithm and were compared to the current operational wind speeds. In weak wind speeds and heavy rain conditions, the updated algorithm still produces a high bias, but this bias is reduced by several meters per second. The new algorithm will become operational for the 2015 season and will be available for future assimilation into the HWRF model.



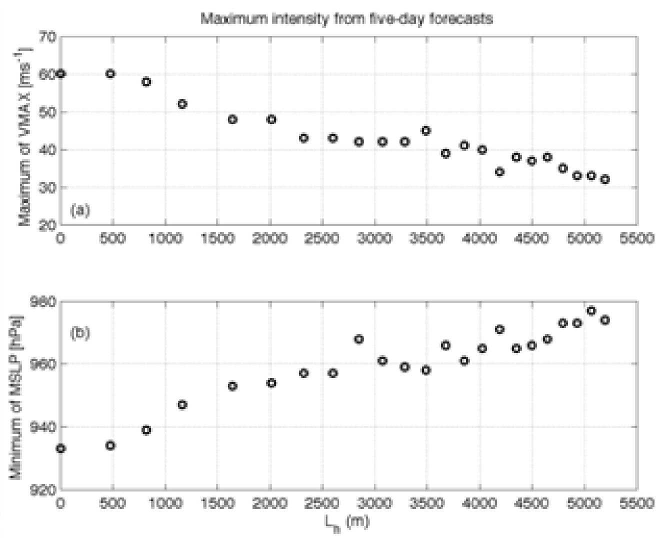


Figure 5: Plots of vertical wind profiles in the layer between the lowest model level and 600 m from the PBL11 and PBL12 composites at found radial locations r*=1 (a), r*=1.5 (b), r*=2 (c) and r*=2.5 (d). The mean wind profile from the dropsonde composite of Zhang et al. (2011) is also shown.

Figure 6: Simulated maximum intensity in terms of maximum wind speed (a) and minimum sea level pressure (b) during each five-day simulation as a function of horizontal mixing length (L_h). Here VMAX is defined as the maximum 10-m wind speed at each forecast hour, and MSLP is the minim sea level pressure.

Data Assimilation and Observing Strategy. The co-PI (A. Aksoy) and the data assimilation team successfully prepared the HWRF Ensemble Data Assimilation System (HEDAS) for the 2014 Atlantic hurricane season. From a developmental perspective, the following new features were integrated into HEDAS for 2014:

- New capability to differentiate localization parameters by observation type;
- New capability to overwrite namelist-driven localization radii by individual observations through observation files;
- More accurate horizontal wind speed forward operator that accounts for the rotated grid of the HWRF model;
- New observation types to assimilate: Rawindsondes, Aircraft Communications Addressing and Reporting System (ACARS) on commercial aircraft, and the NASA Global Hawk High Altitude Monolithic Microwave integrated Circuit (MMIC) Sounding Radiometer (HMSR) thermodynamic profiles.

After 2014 hurricane season, the data assimilation team modified HEDAS scripts to work with the latest HWRF version with restart capability. This version of HWRF was obtained from NCEP/EMC, but had some changes that required modification of the HEDAS scripts. We now have a complete end-to-end HEDAS system and we have begun to run retrospective experiments to evaluate the impact of various observing systems (Table 2).

Observation processing for the HEDAS data assimilation system has been updated for 2015 and is ready to be implemented for the 2015 hurricane season. Figure 7 shows the canonical correlation vector (CCV) observations for TRMM/TMI, which chooses different features that are mutually uncorrelated and comes with a measure of uncertainty. In addition, HEDAS satellite simulation code was upgraded to get 37 GHz brightness temperatures and produces synthetic satellite graphics using the polarization correction technique (Fig. 8).

Table 2: HEDAS experiment descriptions

Experiment	Description
HEDAS Control (HECT)	No vortex-scale data assimilation. HEDAS ensemble is spun up from the GFS ensemble for the duration of a typical HEDAS experiment (8 hours), but no DA is carried out.
HEDAS All Obs (HEAD)	All available vortex-scale observations are assimilated in HEDAS. Observations assimilated are: (1) P-3 TDR, flight level, dropsonde, SFMR; (2) G-IV TDR and dropsonde; (3) Air Force flight level, dropsonde, SFMR; (4) Global Hawk dropsonde; (5) ACARS commercial aircraft obs; (5) AMVs; (6) AIRS clear-air thermodynamic retrievals; (7) GPS-RO thermodynamic retrievals.
HEDAS No Doppler (HEND)	All available vortex-scale observations except for all P-3 and G-IV TDR observations are assimilated.
HEDAS No G-IV Doppler (HENG)	All available vortex-scale observations except for only G-IV TDR observations are assimilated.
HEDAS No AMV (HENA)	All available vortex-scale observations except for AMV observations are assimilated.
HEDAS Radiance (HERA)	All available vortex-scale observations as described in HEAD plus satellite all-sky radiance observations are assimilated.

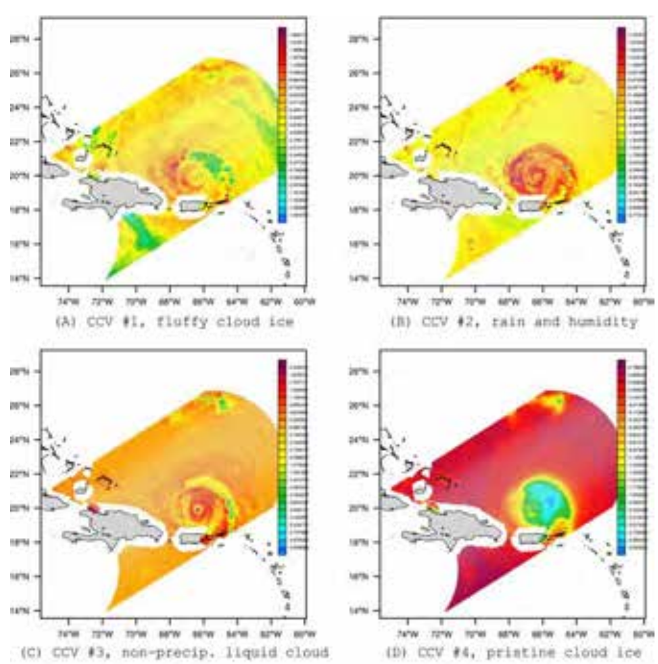


Figure 7: The canonical correlation vector (CCV) observations for TRMM/TMI.

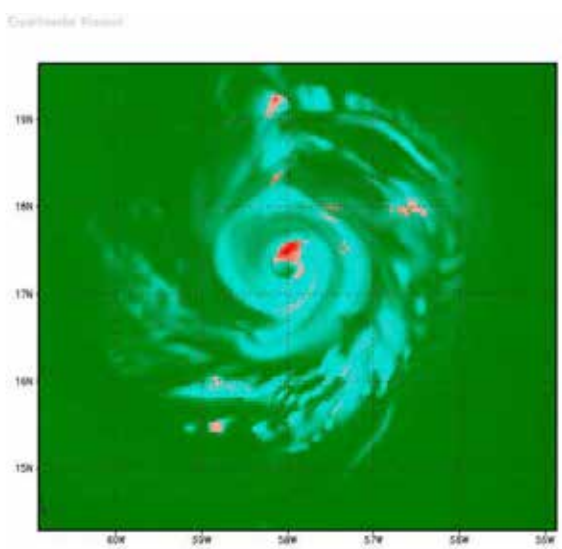


Figure 8: Simulated 37GHZ brightness temperature using the Polarization Correction Technique. A cyan colored ring about the center has been shown to be correlation with hurricane intensification. The pink/red colors indicate deep convection/ice concentration.

We investigated the relationship between vortex imbalances and spin-down in the HWRF model initialized from observations. We found that the imbalance might be due to the relative lack of thermodynamic observations, especially at upper levels. In the case of Tropical Storm Gabrielle, only a limited number of vertical temperature and moisture observations were used to initialize HWRF (Fig. 9).

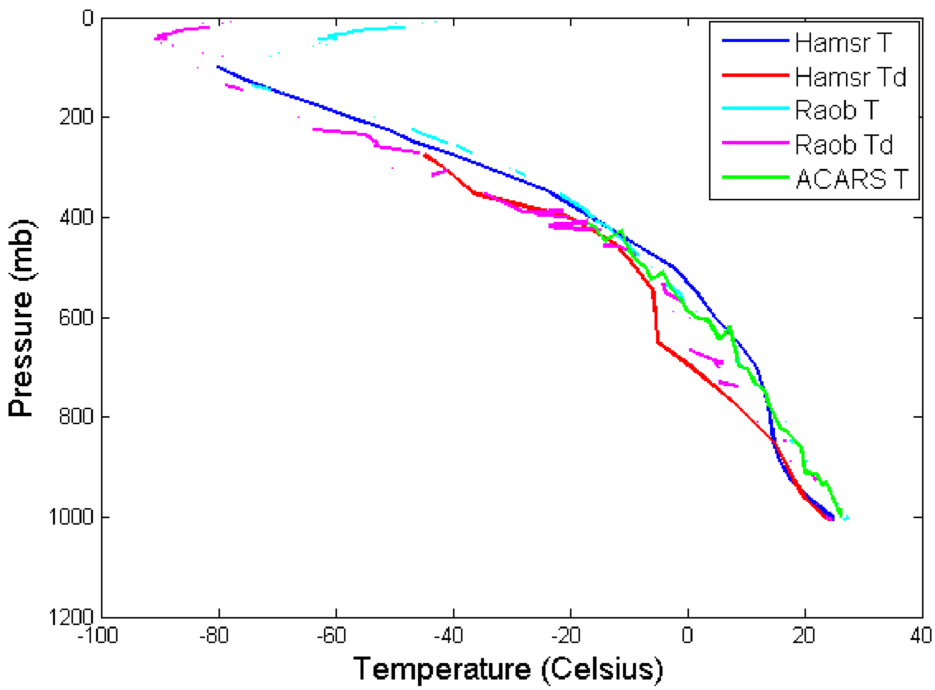


Figure 9: ACARS, rawindsonde and HAMSR temperature and dewpoint from soundings taken at 0Z on Sept. 4, 2013 near Barbados, the approximate initial location of TC Gabrielle.

The DA group also worked on finding a solution to the non-functioning restart capability in the latest version of the HWRF model. This was a critical issue that prevented us from running HEDAS in real time during the 2014 hurricane season.

Verification. Zhang oversaw the verification effort. We submitted 2011-2013 retrospective forecasts to HFIP for stream 1.5 competition based on 2013 basin-scale HWRF modeling system. Overall, 2013 Basin-scale HWRF system forecasts show an improvement over operational HWRF forecasts. Here is the main conclusion from HFIP stream 1.5 evaluation team report :

(1) "The comparisons between the basin-scale HWRF track forecasts and those for the individual top-flight models for track produced SS improvements of 11-15% in the AL basin and 13-27% in the EP basin upon HWFI guidance for nearly all lead times."

(2) "For intensity, the comparisons between HWHI and HWFI resulted in a strong signal of improvement over HWFI from 72-120 h with associated percent improvements of 12-20% in the AL basin and at 84 h and 108-120 h with percent improvements of 16-26% in the EP basin."

HRD scientist S. Goldenberg, CIMAS Post-doc G. Alaka, and CIMAS Research Associate R. St. Fleur led the verification effort of 2014 forecasts by the basin-scale HWRF system. We transferred all Tier 1 data to TCMT for independent verification. G. Alaka successfully implemented DTC's community verification package, MET-TC, for verification of the Basin-scale HWRF system. He is further developing the software to generate new products to quantify and identify model deficiencies.

According to TCMT verification for the 2014 hurricane season, the track and intensity skills of 2013 Basin-scale HWRF system are close to or better than those of the 2014 operational HWRF, except the track forecast after 72h in the Atlantic basin (H3WI in Fig. 10). In general, both the operational HWRF and the Basin-scale HWRF systems are in the top tier among all track and intensity forecasts (Figs.10-11). We will further analyze and diagnose the deficiencies and advantages in the basin-scale HWRF in order to further improve the operational HWRF modeling system and provide the development direction of the operational HWRF modeling system.

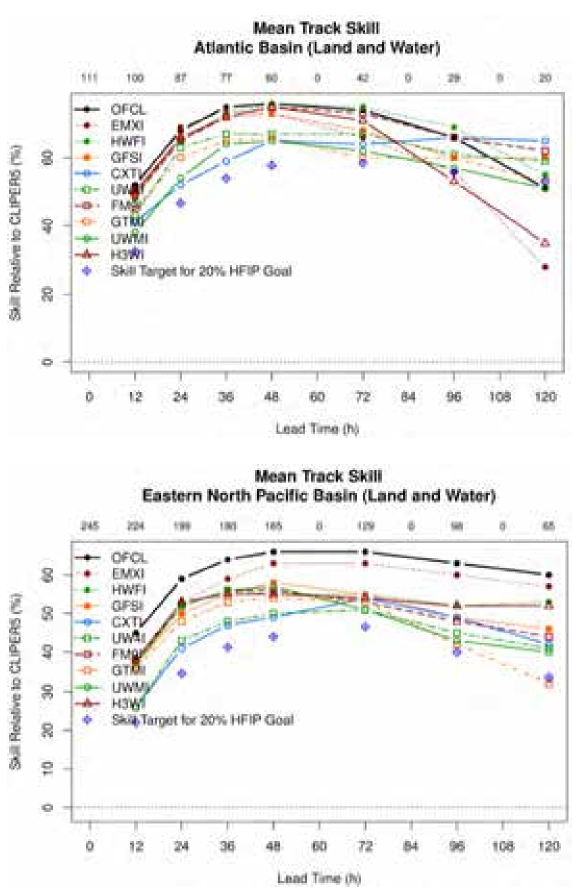


Figure 10: The 2013 Basin-Scale HWRF track forecast verification for the 2014 hurricane season. The 2013 Basin-Scale HWRF ID is denoted as H3WI; the 2014 operational HWRF ID donated as HWFI; NHC official forecast ID denoted as OFCL. University of Wisconsin ID denoted as UWMI, which is a stream 2 model in HFIP demo system. The HFIP skill targets are shown. Other models IDs are consistent with operational IDs.

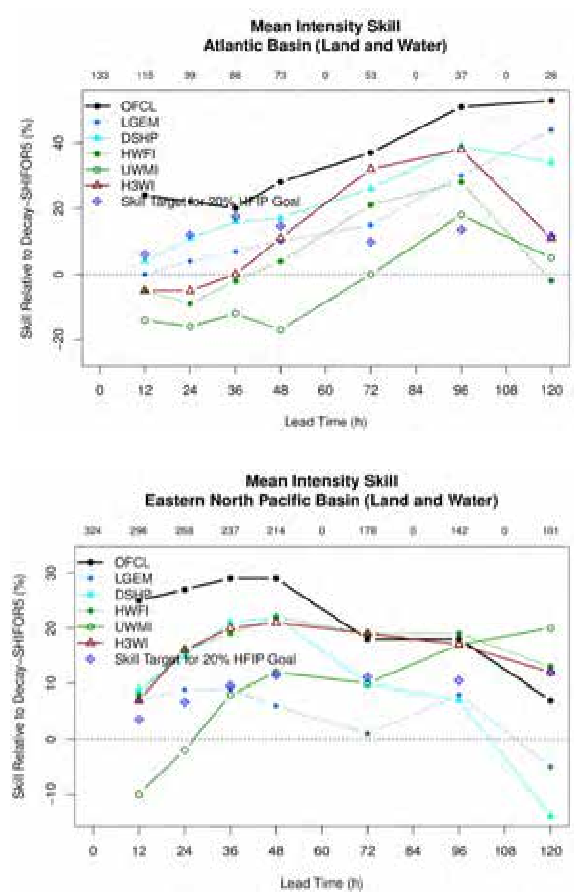


Figure 11: As in Fig. 10, except for intensity forecast verification.

Research Performance Measure: All objectives are being met on schedule.

Developments in the High-Impact Weather Prediction Project

Project Personnel: X. Zhang and S. Diaz (UM/CIMAS)
NOAA Collaborators: S.G. Gopalakrishnan, T. Quirino (AOML/HRD); T. Black, M. Pyle, Q. Liu, W. Liu and V. Tallapragada (NCEP/EMC)
Other Collaborators: J. Prusa (Teraflux Inc.); Itri Corp.

Long Term Research Objectives and Strategy to Achieve Them:
***Objectives*:** To create a multi-scale hurricane prediction system working at cloud-resolved resolution providing improved predictions of tropical cyclones; and to improve our understanding of the processes that influence from these devastating storms through better representation of the physical processes within the HWRF/NMMB under NEMS frameworks.
***Strategy*:** To design a modeling system to operate at about 3 km resolution, capable of capturing tropical cyclone inner core processes as well as interactions with the large-scale environment, critical for improving track, intensity, rainfall and size predictions.

CIMAS Research Theme:
***Theme 2*:** Tropical Weather

Link to NOAA Strategic Goals:
Goal 2: Weather-Ready Nation - Society is prepared for and responds to weather-related events

NOAA Funding Unit: OAR **NOAA Technical Contact:** Molly Baringer

Research Summary:
Global Multiple Moving Nests: The modeling group made significant advancements towards creating a global, nested-grid framework in NMMB. The group developed an algorithm that parallelizes the process by which high-resolution global terrain data is generated. The algorithm splits the data into patches that are processed independently and later combines them into a single global data set. As a result, model initialization time decreased from 60 minutes to 5 minutes. The group also identified a source of numerical instability that occurs as nests move to polar latitudes. Although a robust solution has not been developed, a preliminary solution was implemented in collaboration with EMC. Finally, the group modified the NMMB framework and nest-motion subroutines to support interaction between the global domain and the moving nests. This work allows for successful simulation of a global NMMB model with multiple moveable nests. Figure 1 shows the effects of increasing resolution on a global simulations. Figure 2 demonstrates ‘proof-of-concept’ of a 3 km resolution global tropical cyclone model with multiple moveable nests located anywhere in the world.

Hurricane Specific Modeling: In collaboration with EMC, we transitioned two of the three hurricane-specific components from HWRF model (nesting and physics) to the NMMB/NEMS framework. The third component, hurricane initialization, is on schedule to be incorporated by the end of the calendar year. This achievement enables the proven success of the HWRF system to be expanded to large regional, or global domains. This multiple storm tracking and prediction capability improves forecasting capability around the globe. The GFDL tracker was also implemented for NMMB.

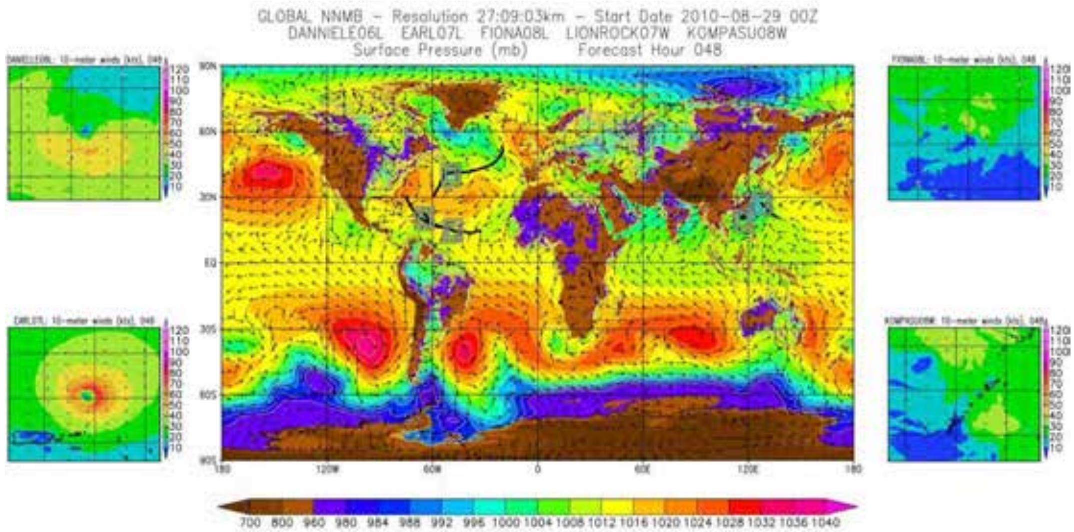


Figure 1: 48th hour forecast from a five-day simulation initialized on 08/30/2010 at 00Z of the Global NMMB in NEMS framework configured at uniform 27 km resolution. Embedded in this Global model are 5 sets of two way interactive, telescopic moving nests at 9 and 3 km resolutions (shown in white boxes) for capturing inner core structure of TCs Danielle, Earl, and Fiona in the Atlantic, and Lionrock and Kompasu in the West Pacific. The black line shows the 5-day forecast tracks from the moving nests. The insets show predictions of 10-m wind at 3 km resolution for 4 of the TCs in the global domain.

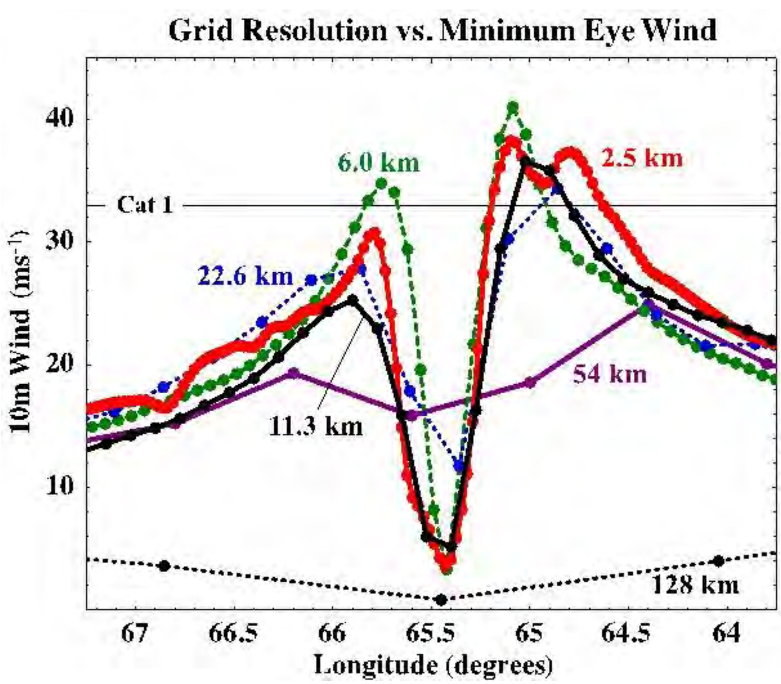


Figure 2: Effect of mean grid resolution on global simulations of Hurricane Earl at 06 UTC Aug 31 2010. The lowest (global) resolution shown is 128 km vs the highest (innermost nest) is 2.5 km. Results from four simulations are shown: triple (2-way) nest mean resolutions of 128-43-14.2 km, 54-18.0-6.0 km, and 22.6-7.5-2.5 km; and one double (2-way) nest with mean resolutions of 34-11.3 km. GFS initializations at 18 UTC Aug 26.

NMMB End-to-End Automation System: The group also developed a robust shell-script based system capable of performing automated forecasts of the NMMB model. This development significantly reduces 'man-in-the-loop' time for model set up and reduces chances of error. Processes are included to transfer automatically-generated diagnostic plots to the AOML/HRD website for 'real-time' public dissemination. The system is similar to that previously developed to support HRD's basin-scale HWRF model developments. The system is capable of performing fully automated retrospective and real-time runs of the NMMB model. Support for high-resolution, single-domain forecasts was also added. In addition, the group created a cycling directory structure in order to support the HWRF initialization process that is to ported to the NMMB model. The end-to-end NMMB system works seamlessly on the NOAA supercomputing clusters Jet, Zeus, and Theia.

SVN Repository for Hurricane Related Software: The group worked closely with EMC to create the 'Hurricane NMMB' repository. The repository will manage and archive all HIWPP-related collaborative developments to the NMMB model and related components. All of our model developments were submitted to this repository. Use of the repository by all parties ensures all changes are documented, and that all parties work with the most recently update versions of the software.

Idealized Tropical Cyclone Capability in NMMB: The group recently achieved the milestone of a 126 hour forecast of an idealized storm in a 75x75 degree domain with moving nests. This capability allows for analysis and evaluation of code modifications in a well-controlled environment. The idealized tropical cyclone capability is on schedule to be included to the Hurricane NMMB SVN repository. Figures 3, 4, & 5 display the surface wind field, surface pressure drop, and horizontal wind field of an idealized tropical cyclone, respectively.

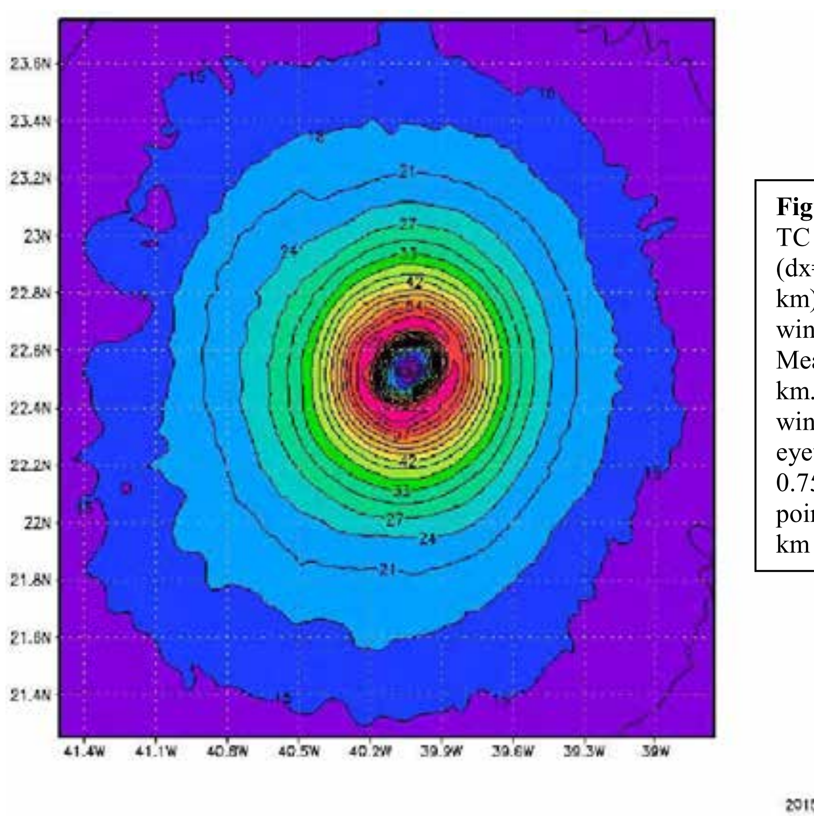


Figure 3: Surface wind field for idealized TC at 126hrs simulation, domain D03 (dx=dy=0.02780 ; mean resolution of 3.0 km). Contours every 3 ms^{-1}. Maximum wind = 64.3 ms^{-1} ≈ 125 kt (144 mph). Mean radius of maximum wind = 18.6 km. Minimum eye wind = 4.4 ms^{-1}. NS wind gradient along southern inner eyewall = 5.4 $ms^{-1}km^{-1}$. Storm location 0.75 degrees S and 0.75 degrees E of point of initialization (net motion of 110 km towards SE).

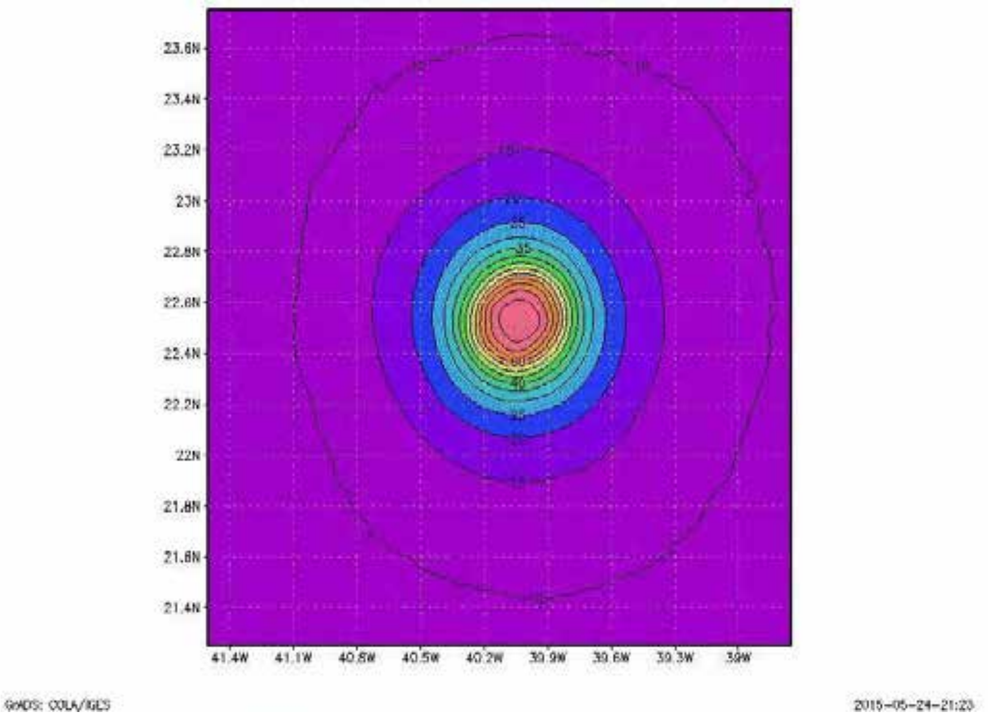


Figure 4: Surface pressure drop, Δp = p∞ - pmin for idealized TC; same time and domain as for Figure 3; where p∞ = 1010.3 hPa. Contours every 5 hPa. The maximum Δp = 79.5 hPa (pmin = 930.8 hPa absolute). Radius of 10 hPa contour ~ 120 km. At model level one (z ~ 25 m) this radius is ~ 275 km – see Figure 5.

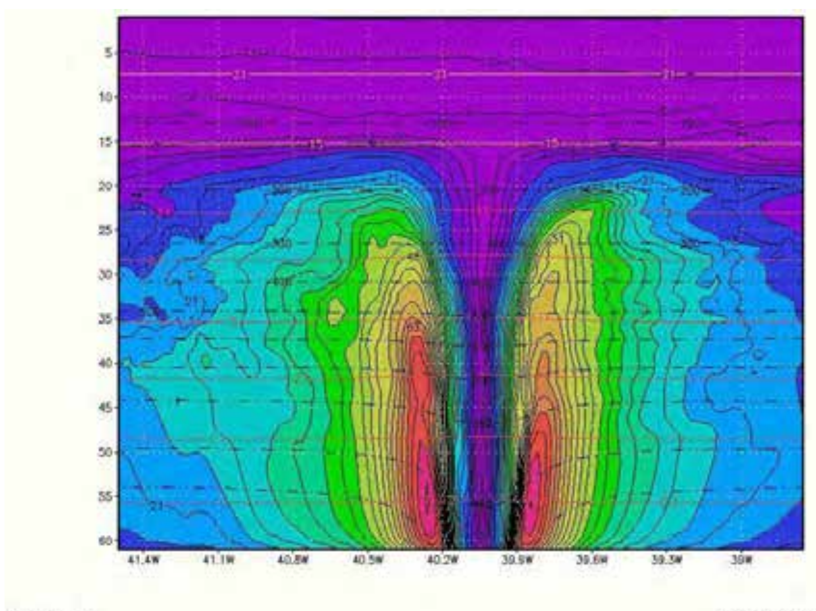


Figure 5: Vertical XZ slice of horizontal wind field for idealized TC at y = 22.39 degrees; same time and domain as for Figure 3. Contours every 3 ms^{-1}. Vertical axes gives model level, with level 1 being the model top. Also shown are isolines of constant pressure (hPa) by dot-dash black lines, and geopotential height (km) by solid colored isolines. The pressure increment is 100 hPa except for a 50 hPa increment between the lowest two isobaric surfaces with the lowest being at 950 hPa. A maximum horizontal wind of ~ 75 m^{-1} (146 kt) occurs in both the western and eastern portions of the eyewall at ~ 300 m elevation.

Development of Parallel version of Diapost: We have developed a diagnostic tool called DIAPOST. This tool was developed primarily to support hurricane research with HWRF model output, which lies on a staggered Arakawa rotated E-grid. The HRD modeling group has modified Diapost to also support the staggered rotated B-grid used in the NMMB model. In addition, the group parallelized the tool using MPI and PNETCDF to support large, computationally expensive grids, such as those used in global configurations.

Scalability Assessment of Basin-Scale NMMB: The group investigated the scalability of large, high-resolution domains of 18/6/2 km resolution for nested cases and 3 km resolution for single-domains without nests. The group found that although single domains scale very well with increasing resolution and number of processors, child and grandchild nests do not, due in part to their small grid sizes. The group identified an optimal configuration in the current NMMB system. A 3 km resolution, single-domain NMMB forecast ran for domains of sizes 54x54 and 54x73 degrees. Excessively long queue times have thus far prevented forecasts of larger domain, which require a greater number of processors.

TABLE 1: MILESTONES AND COMPLETION DATES

Milestones

Milestones Description	Work period	Status
• Initial training on NMMB/NEMS completed • Development branch within EMC subversion set up • **HWRF components for transition to NMMB/NEMS identified/prioritized** • Sanity check of NMMB completed	CY14Q3	Done
• **NMMB configured as research model for hurricanes** • Transition to jet continuing; Zeus resource allocated	CY14Q4	Done Testing ongoing
• NMMB for hurricane forecasts mimics operational HWRF configuration • Scalability test completed • **Idealized capability for simulations developed** • HWRF physics schemes and vortex initialization testing began	CY15Q1	Development done Testing ongoing Everything on track
• **Idealized capability released to developers and collaborators** • Testing and evaluation of appropriate physics suite from HWRF begun • Implementation and testing of HWRF nest motion algorithm in NMMB begun • HWRF nest upgrades transitioned to NMMB • Physics and dynamics tuning begun • **Vortex initialization testing** • Effectiveness of 2-way nesting testing	CY15Q2	Development ongoing Testing ongoing Everything on track

Research Performance Measure: All objectives are the track. See details in Table 1.

Development of Multiple Moving Nests Within a Basin-Wide HWRF Modeling System

Project Personnel: X. Zhang and R. St. Fleur (UM/CIMAS)
NOAA Collaborators: S.G. Gopalakrishnan, T.S. Quirino and F.D. Marks, (NOAA/AOML /HRD); V. Tallapragada, Q. Liu, Z. Zhang and S. Trahan (NOAA/NCEP/EMC)
Other Collaborators: D.-L. Zhang (U. Maryland)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To guide and accelerate improvements in hurricane track and intensity forecasts with emphasis on rapid intensity (RI) change and the reduction of false alarms.

***Strategy*:** To improve hurricane forecasts through the development of numerical modeling and data assimilation techniques valid for scales of motion down to about 1-km resolution.

CIMAS Research Theme:

***Theme 2*:** Tropical Weather

Link to NOAA Strategic Goals:

***Goal 2*:** *Weather-Ready Nation* - Society is prepared for and responds to weather-related events

NOAA Funding Unit: NWS and AOML/HRD
NOAA Technical Contact: D. Melendez and Molly Baringer

Research Summary

Research to Operation transition: Zhang, collaborating with HRD scientist Thiago Quirino, EMC scientists Qingfu Liu, Samuel Trahan, and Zhan Zhang, and CIMAS staff Russell St. Fleur, completed the development of the basin-scale HWRF system. *The system source code was committed to DTC repository and the nesting code was transited in the operational HWRF system in 2012. The entire basin-scale HWRF system including automation scripts was transferred to DTC in 2014 for possible research-to-operation transition and public release*.

Real-time and retrospective experimental forecasts: The basin-scale HWRF system conducted HFIP stream 2.0 real-time forecasts for 2013 and 2014 hurricane seasons and retrospective forecasts for 2011-14 season in the Atlantic and East Pacific basins basin with 2013 version basin-scale HWRF system. The total cycles were 706, 1026, 745, and 648 for 2011, 2012, 2013 and 2014 seasons respectively. Real-time forecast and diagnostic products were archived at HRD real-time experimental forecast products website: https://hwrf.aoml.noaa.gov/realtime. Retrospective products are archived on HRD data portal and jet mass storage. They are available by request.

Verifications

The basin-scale HWRF modeling system: The basin-scale HWRF system utilized GFS analyses and forecasts as its input. Initializing multiple vortexes was based on operational HWRF's vortex initialization procedure (Tallapragada et al. 2014, http://www.dtcenter.org/HurrWRF/users/docs/scientific_documents/HWRFv3.6a_ScientificDoc.pdf). The first guess fields, initial conditions and lateral boundary conditions were generated from the same GFS system including its hybrid ensemble DA system during 2011-2014 seasons. The analyses and real-time forecasts or re-forecasts were used. The data were then transferred to ESRL's supercomputer JET by EMC's HWRF group. The model configuration and its counterpart configurations of the 2013 and 2014 version operational HWRF were summarized in Table 1.

Table 1: Summary of HWRF system configuration and physics schemes

	2103 operational HWRF	2013 basin-scale HWRF	2014 operational HWRF
Domain	27 km: 77.58˚ × 77.58˚ 9 km: 10.56˚ × 10.2˚ 3 km: 6.12˚ × 5.42˚	27 km: 178.20˚ ×77.58˚ 9 km: 10.56˚ × 10.2˚ 3 km: 6.12˚ × 5.42˚	27 km: 77.58˚ × 77.58˚ 9 km: 10.56˚ × 10.2˚ 3 km: 6.12˚ × 5.42˚
Model top	50 hPa	2 hPa	2 hPa
Vertical levels	42	61	61
Vortex initialization	Modified Vortex Initialization at 3 km, with 30˚×30˚ analysis domain and GSI DA	Modified Vortex Initialization at 3 km, with 30˚×30˚ analysis domain and No GSI DA	Modified Vortex Initialization at 3 km, with 30˚×30˚ analysis domain and hybrid DA
Cycling	Only 3 km domain and No GSI DA	Only 3 km domain and No GSI DA	Cycling and GSI DA
Ocean coupling	27-9 KM: Yes 3 KM: No, Downscaled	No coupling	27-9 KM: Yes 3 KM: No, Downscaled
Physics scheme			
Microphysics	Modified Ferrier (High Resolution)	Modified Ferrier (High Resolution)	Modified Ferrier (High Resolution)
Radiation	GFDL	GFDL	GFDL
Surface	GFDL	GFDL	GFDL
PBL	2013 GFS	2013 GFS	2013 modified GFS
Convection	SAS (High Resolution), No CP (3 km), Shallow Convection	SAS (High Resolution), No CP (3 km), Shallow Convection	SAS (High Resolution), No CP (3 km), Shallow Convection
Land surface	GFDL Slab	GFDL Slab	GFDL

Methodology and results: We obtained ATCF files of 2011-2014 seasons from the operational HWRF and the 2014 pre-implementation retrospective and real-time forecasts. The HWRF forecast system replaced the 2012 operational HWRF on 2 July 2013 on operational supercomputer in NCEP's operational center. Therefore, we only use 2013 ATCF file forecast tracks after 2 July 2013 in this verification. The verification results are shown in Figure 1. In general, basin-scale HWRF forecast statistically better tracks (5-10% improvement) comparing to operational HWRF in both the Atlantic and E. Pacific basins during four seasons. Intensity forecasts show constant 5% or more improvement in the Atlantic basin while slightly inferior forecasts (< 5%) in the E. Pacific basin in the first 72 hours then better in the 96-120 hours. The verification results further suggest that the oceanic effect on intensity should be taken into account if the storm moves slowly in the forecast.

Further verifications were done after 2014 season. The results indicate 2014 operational HWRF further improved track forecasts another ~5% (Figure 1) especially in day 4 and 5. This indicates the basin-scale HWRF can be further improved after other components in the system are improved such as land surface physics, ocean coupling, and initialization including large-scale environment and inner core. All of these components are not implemented in the basin-scale HWRF system yet. The research is beyond the scope of this research project.

Model improvement direction: The intensity errors were noticeably reduced in both basins compared to 2014 operational HWRF. The difference of the two systems is the ocean coupling in term of physical processes. The basin-scale HWRF system does not have ocean coupling while operational HWRF system couples with 3-D Princeton Ocean Model. The basin-scale HWRF system is fed by GFS Sea Surface Temperature (SST), which is provided by Reynolds 1.0°×1.0° weekly SST analysis (Reynolds & Smith, *J. Climate*, 7, 929-948, 1994). The weekly averaged SST smoothed the significant upwelling cooling effect over the storm passage corridor. The absence of oceanic effect in basin-scale HWRF system significantly degrade the intensity forecasts of the slow moving TC such as Leslie although it generated similar or better track forecasts (Figure 2). We will further quantify how significant the ocean effects are in the forecast model by mining this three-year dataset.

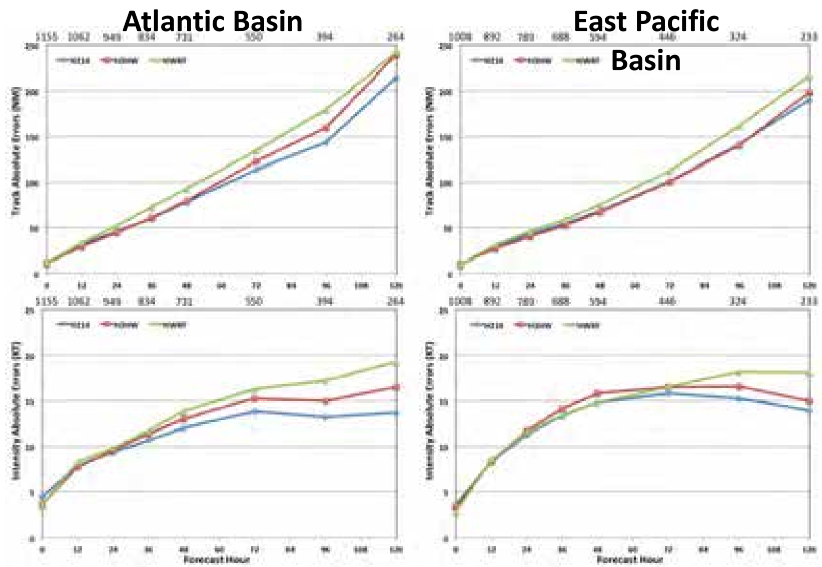


Figure 1: Verification of the 2013 basin-scale HWRF Forecasts (H3HW, red), real-time operational HWRF (HWRF, green), and 2014 operational HWRF (H214, blue) (2011-2014).

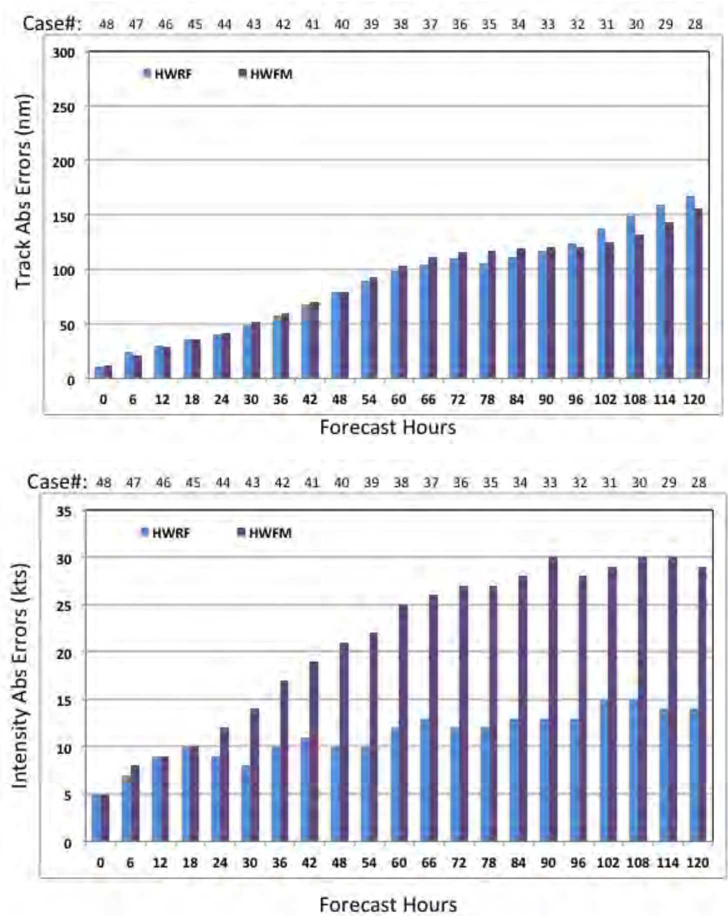
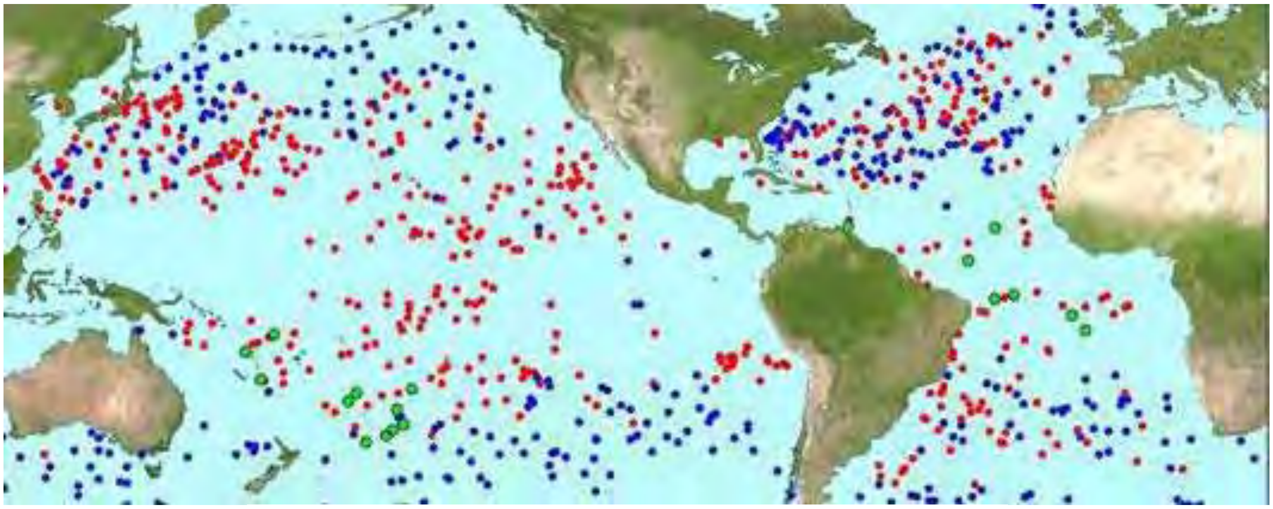


Figure 2: Track and intensity forecast verification of Hurricane Leslie. (a) Track; (b) Intensity.

Broad impacts: Zhang in collaboration with HRD scientists: S. G. Gopalakrishnan, H. Chen, P. Reasor, F. Marks, and S. Goldenberg are mining the massive datasets focusing on several research directions: Hurricane Sandy track and intensity evolution and its mechanism, shear-related hurricane structure, forecast track and intensity verification, and storm-storm interaction and forecast application (Xu et al., *Adv. in Meteorology* 2013, 2013, http://dx.doi.org/10.1155/2013/487010). Naval Postgraduate School professor M. Montgomery and his team applied the basin-scale forecasts on genesis prediction in 2013-14 season and support HRD IFEX map discussion.

Research Performance Measure: All milestones will be achieved and the project timeline is on track.



RESEARCH REPORTS

THEME 3: Sustained Ocean and Coastal Observations

US Argo Project: Global Ocean Observations for Understanding and Predicting Climate Variability

Project Personnel: C. Atluri, Z. Barton, S. Dong, E. Forteza, S.L. Garzoli, M. Goes, V. Halliwell, S. Majumder, J. Nair and R. Sabina (UM/CIMAS)
NOAA Collaborators: C. Schmid, U. Rivero, P. Pena and M. Baringer (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:
Objectives: To improve our understanding of interannual to multidecadal ocean variability and its role in climate.
Strategy: To monitor ocean parameters over large areas of the ocean through the maintenance of an array of 1500 profiling floats as a part of a global array of 3000 floats.

CIMAS Research Theme:
Theme 3: Sustained Ocean and Coastal Observations

Link to NOAA Strategic Goals:
Goal 1: Climate Adaptation and Mitigation (*Primary*)
Goal 2: Weather-Ready Nation (*Secondary*)

NOAA Funding Unit: OAR/AOML **NOAA Technical Contact:** Molly Baringer

Research Summary:
The Argo array is part of the Global Climate Observing System/Global Ocean Observing System (GCOS/GOOS). Argo floats provide measurements of temperature and salinity to depths of 1000-2000 meters, and currents at the drift depth of the floats. Researchers in many scientific disciplines, including meteorology, climatology and oceanography, use data collected from the floats. The Argo array achieved

its goal of a total of 3000 floats in November 2007 and is maintaining the number of floats.

The US Argo Data Assembly Center (US DAC) at AOML is responsible for deploying floats, and for acquiring and processing the data. The US DAC has developed and maintained an automatic system for decoding, quality control, and distribution of data obtained from the US Argo floats in real-time. The system runs in a 24/7 mode. The data are open to the public, and are used by scientists working on climate models and oceanographic data analysis.

Some of the accomplishments in this year are:

1) 419 floats were deployed by the USA institutions.
2) 43 of these floats were deployed jointly by AOML and CIMAS.
3) 2,086 US floats actively reported data during this period.
4) 89,600 profiles, approximately, have been distributed on Global Data Centers.
5) 63,217 profiles were sent to GTS by the US DAC where 94% of them were distributed during the first 24 hours since the profiles were obtained.
6) The US Argo Data Assembly Center (US DAC) at AOML has increased the operational capacity and now collects and process data 3 times a day to improve the time between the collection of the profile and the real availability of the data to the weather service and the research community. Since this improvement the numbers of files reaching the GTS in less than 24 hours increased from 74% last year to 94% this period.
7) The US DAC maintains a website: http://www.aoml.noaa.gov/phod/argo/index.php that provides documentation and information about the operations at the US Argo DAC, which is updated daily (e.g. Figure 1).
8) Three new iridium decoders have been implemented by the dynamically programmed code, which process 22 other float types.
9) A new software development for decoding very high resolution near surface profiles reported by Iridium floats as sts files has been written, tested and moved to production. These data will be very useful for sea surface temperature and salinity measurements from satellites.
10) Decoding of the ARGO floats with near surface temperature measurements have been changed such that the measurements are in parallel to the primary profile. Rigorous testing and reprocessing of the affected floats is also done.
11) Salinity Adjustment Determination: The program that uses the most recent profile of a given float that went through a change to support the new real time Quality Control Software has been moved to operations
12) Scripts related to FTP are also improved to include new file types that need to be downloaded.
13) Software to improve the position of the deep solo physical files has been written, tested and is ready to be moved into production. .
14) A system for accelerated data processing is being developed for the purpose of making data from floats deployed near tropical cyclones available faster, with the purpose to make these data much more useful for hurricane forecasting.
15) Over the past year, development of the combined real-time quality control and file production software was tested and deployed operationally. This version produces the V3.0 NetCDF files for the Argo profile data. Development continues, such as the addition of additional tests for Near-Surface profiles. Also the changes necessary to produce V3.1 NetCDF files for profiles have been started.
16) US Argo Atlantic deployments were coordinated and done by AOML. During the past year several deployments of Atlantic Argo floats were made by CIMAS and NOAA personnel on scientific cruises and from ships of opportunity. Vessels are constantly sought out to assist with the deployment of Argo floats. Planning and logistics for these cruises are done in coordination with WHOI to ensure the number of floats available for the cruise, and ensuring that the ship and the scientific parties have space and are able to deploy the floats. An opportunity arose this year to deploy floats in an area that has historically been limited for deployments due to the limitations of the floats. Owing to this new

version of the floats, areas of the Caribbean ocean have been targeted, and recently, CIMAS personnel were able to deploy floats in the Caribbean onboard the research vessel Nancy Foster.

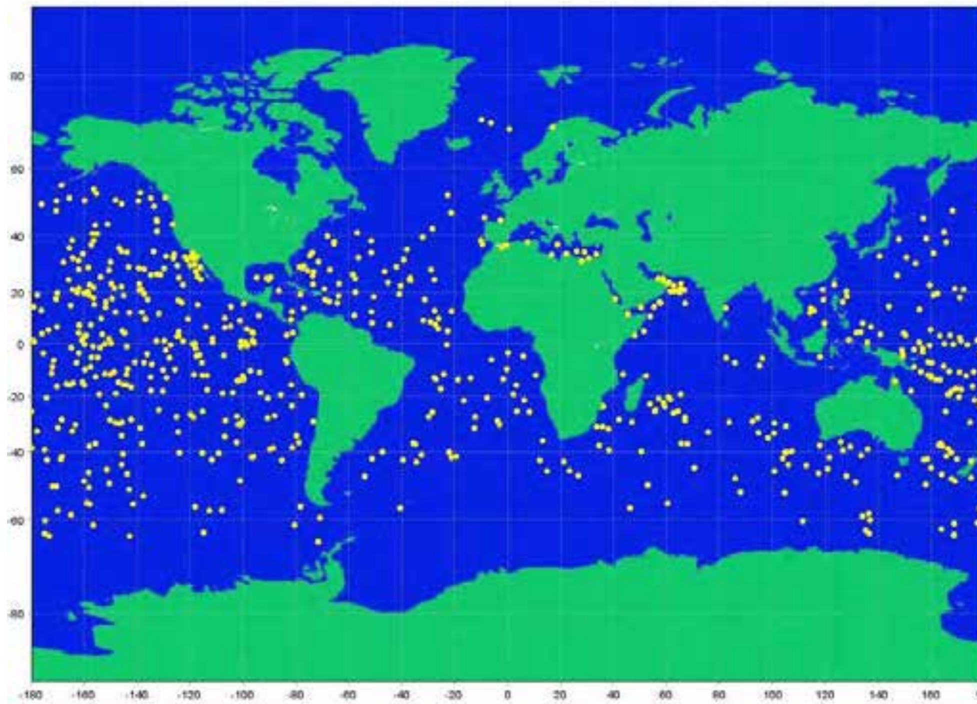
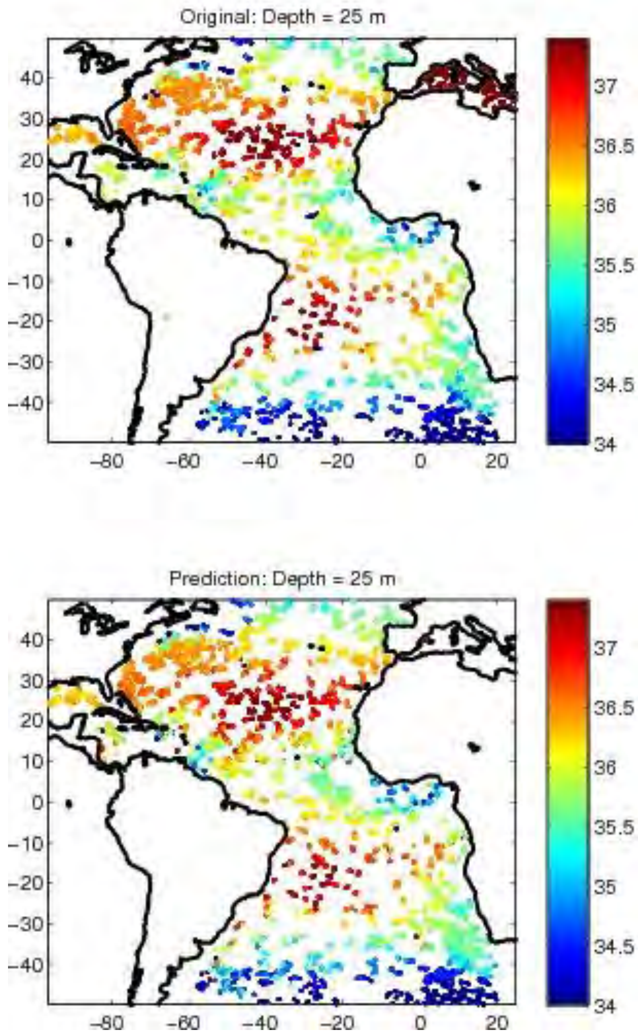


Figure 1: Location of US Argo floats in May 2015,

Results from scientific studies that used Argo data:
Volume and heat transports in the South Atlantic are estimated using data from Argo floats and a three dimensional velocity field (Schmid 2014, *Deep Sea Res.*, doi: 10.1016/j.dsr.2014. 04.0152014) derived from Argo data and AVISO sea surface heights collected in the years 2000-2014. Since these velocity fields extend only up to 2000m the deepest layers are padded with climatology. The use of climatology for the deepest layers and unavailability of Argo data near the boundaries give rise to uncertainties in the transport estimates. These uncertainties are quantified by comparing results from Argo fields with output from the global high-resolution HYCOM model with data assimilation.

The decadal sub-surface salinity changes are investigated across the Subtropical South Atlantic Ocean using ocean reanalysis products as well as climate model experiments (Figure 2). Results show that there is a recent significant salinity increase at the core of the salinity minimum at intermediate levels. The main underlying mechanism for this sub-surface salinity increase is the lateral advective (gyre) changes due to the Southern Annular mode variability, which conditions an increased contribution from the Indian Ocean high salinity waters into the Atlantic. An initial analysis is performed to validate the ability of SODA and ECCO2 reanalysis to represent the recent (2000s) climatology of the Antarctic Intermediate Water (AAIW) mean. The reanalysis outputs are compared to the Argo climatology of Roemmich and Gilson (2009). The two products produce different climatologies of salinity minimum in the 2000s. ECCO2 shows less bias towards observations, since it assimilates both surface and profiles data, which confirms the value of assimilating Argo's temperature and salinity data in models to improve the representation of water masses.



A new TS lookup table for salinity inference
A new lookup table has been constructed to allow inference of salinity on temperature profiles via a TS relationship. This methodology is an update of Hansen and Thacker (2007) methodology, using updated temperature profiles up to 2014 from historical CTD, XCTD, and Argo data. The new TS relationships use a multiple linear regression of salinity on pressure and temperature at selected temperature intervals, and accounts for seasonality as well as non-stationarity. Initial validation has been performed using the latest Argo data from 2015 (Figure 2). The method is able to capture the main features of salinity across the whole Atlantic, including in the mixed layer.

Research Performance Measure: This program has attained all objectives and has met all time schedules. It continues to operate as planned.

Figure 2: Comparison between salinity at 25 m deep from the original Argo data and the prediction using the updated TS lookup table.

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The GO-SHIP Repeat Hydrography Program

Project Personnel: L. Barbero, G. Berberian, J. Hooper, K. Sullivan (UM/CIMAS); C. Langdon (UM/RSMAS)
NOAA Collaborators: R. Wanninkhof, J.-Z. Zhang and M. Baringer (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

Objective: To determine decadal changes in physics and biogeochemistry in the ocean interior and to constrain ocean CO_2 inventories to 2 Pg C/decade.
Strategy: To reoccupy transects on a decadal timescale to observe changes in the ocean and to quantify the uptake of anthropogenic CO_2 by the ocean.

CIMAS Research Theme:

***Theme 3*:** Sustained Ocean and Coastal Observations

Link to NOAA Strategic Goals:
Goal 3**:** Climate adaptation and mitigation

NOAA Funding Unit: CPO/COD **NOAA Technical Contact:** Kathy Tedesco

Research Summary:
The Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP) is a global re-occupation of select hydrographic sections to quantify changes in storage and transport of heat, fresh water, carbon dioxide (CO_2), oxygen, nutrients, chlorofluorocarbon tracers and related parameters. The effort started in 2003. In 2015 the Pacific meridional P16N transect from 20˚S to 56˚N was completed in full.

Data from these cruises are compared to data from previous surveys (e.g., World Ocean Circulation Experiment (WOCE)/Joint Global Ocean Flux Survey (JGOFS) during the 1990s and the CLIVAR/CO_2 campaign from 2003-2012) to measure changes in the physics and biogeochemistry of the oceans, and to determine where/how much excess atmospheric CO_2 is entering the oceans on decadal timescales. The program is designed to assess changes in the ocean's biogeochemical cycle in response to natural and/or man-induced activity. Global warming-induced changes in the ocean’s transport of heat and freshwater, which could affect the circulation by decreasing the thermohaline overturning, can be followed through long-term interior measurements. The program also provides data for continuing model development that will lead to improved forecasting skill for oceans and global climate.

During FY-2015 we completed a meridional section in the Pacific from 20˚S to 56˚N called P16N with full physical and chemical characterization of over 200 water column profiles. CIMAS project personnel and NOAA collaborators were responsible for CTD, ADCP, O_2, nutrients, and inorganic carbon measurements.

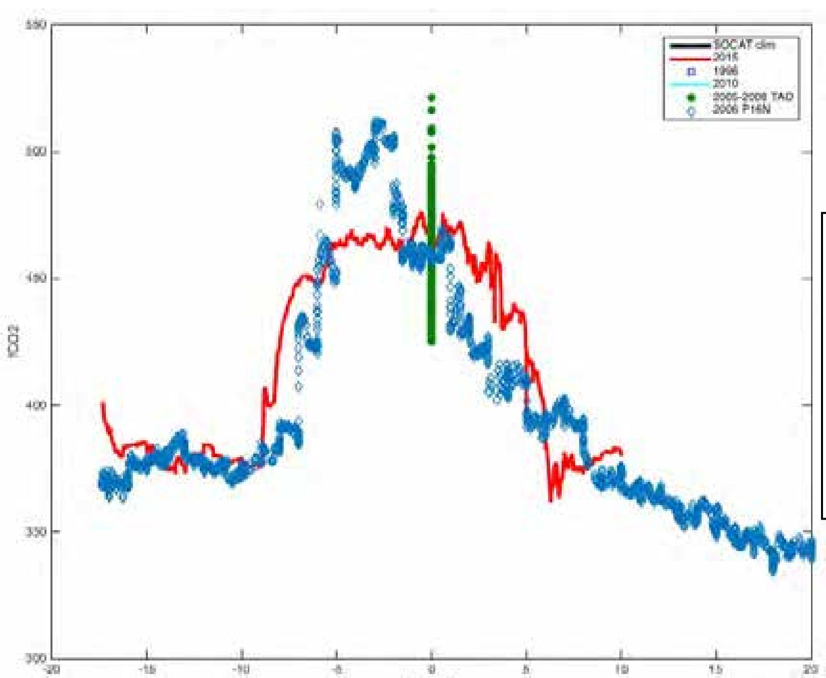

Figure 1 caption: Surface water CO_2 levels during P16N (red line) compared to previous occupations and mooring data at 0˚N, 155 ˚W (green line). The lower peak values and higher SST (not shown) near the equator indicate the onset of an El Nino during April/May 2015 (plot courtesy of S. Siedlecki).

Research Performance Measure: The Repeat Hydrography Sections are progressing according to the timeline provided by the GO-SHIP (http://www.go-ship.org/). The performance measure for FY-15 of completing the re-occupation of the P16N cruise was met.

PIRATA Northeast Extension (PNE)

Project Personnel: Z. Barton, S. Dolk, R. C. Perez, G. Rawson and K. Seaton (UM/CIMAS)
NOAA Collaborators: R. Lumpkin, C. Schmid and G.R. Foltz (NOAA/AOML); P. Freitag, M. McPhaden and M. Strick (NOAA/PMEL)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** PIRATA stands for "Prediction and Research moored Array in the Tropical Atlantic". PIRATA is a multinational observation network, established to improve our knowledge and understanding of coupled ocean-atmosphere variability in the tropical Atlantic. It is a joint project of Brazil, France, and the United States of America. PIRATA is motivated by fundamental scientific issues and by societal needs for improved prediction of climate variability and its impact on the countries surrounding the tropical Atlantic Ocean.

***Strategy*:** 1) To improve the description of the intraseasonal-to-interannual variability in the atmospheric and oceanic boundary layers of the tropical Atlantic Ocean; 2) to improve our understanding of the relative contributions of air-sea fluxes and ocean dynamics to the variability of sea surface temperature and subsurface heat content; 3) to provide a set of data useful for developing and improving the predictive models of the ocean-atmosphere coupled system; 4) to document interactions between tropical Atlantic climate and remotely forced variability, such as El Niño Southern Oscillation and the North Atlantic Oscillation; 5) to design, deploy, and maintain an array of moored oceanic buoys that collect oceanic and atmospheric data and transmit it, via satellite in near-real time, to monitor and study the upper ocean and atmosphere of the tropical Atlantic Ocean.

CIMAS Research Theme:

***Theme 3*:** Sustained Ocean and Coastal Observations (*Primary*)
***Theme 1*:** Climate Research and Impact (*Secondary*)
***Theme 2*:** Tropical Weather (*Tertiary*)

Link to NOAA Strategic Goals:

***Goal 3*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*
***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

NOAA Funding Unit: OAR/CPO **NOAA Technical Contact:** Sid Thurston

Research Summary:

NOAA/AOML's contribution to PIRATA is to organize and conduct annual cruises to service moorings of the PIRATA Northeast Extension (PNE), and collect a suite of oceanographic and meteorological observations in the region. PNE is a joint AOML/PMEL project that expands the PIRATA array of ATLAS (Autonomous Temperature Line Acquisition System) moorings into the northern and northeastern sectors of the tropical Atlantic Ocean. This region has strong climate variations from intraseasonal to decadal timescales, with impacts upon rainfall rates and storm strikes for the surrounding regions of Africa and the Americas. Important processes in this region include formation of Cape-Verde-type hurricanes, seasonal migration of the Intertropical Convergence Zone (ITCZ) and the Guinea Dome, interannual variations of the ITCZ migration associated with rainfall anomalies in Africa and the Americas, off-equatorial eddy heat advection by tropical instability waves (TIWs), and ventilation of the oxygen minimum zone.

The PNE moorings are serviced by annual cruises, during which opportunistic oceanographic and meteorological observations are collected. Post-cruise processing and distribution on the PNE web site (http://www.aoml.noaa.gov/phod/pne/index.php) adds value by making the data available to the scientific community. Research using PNE cruise data is conducted by CIMAS scientists as well as the climate research community and is aimed at advancing our understanding and improving numerical simulation of climate signals in the tropical Atlantic.

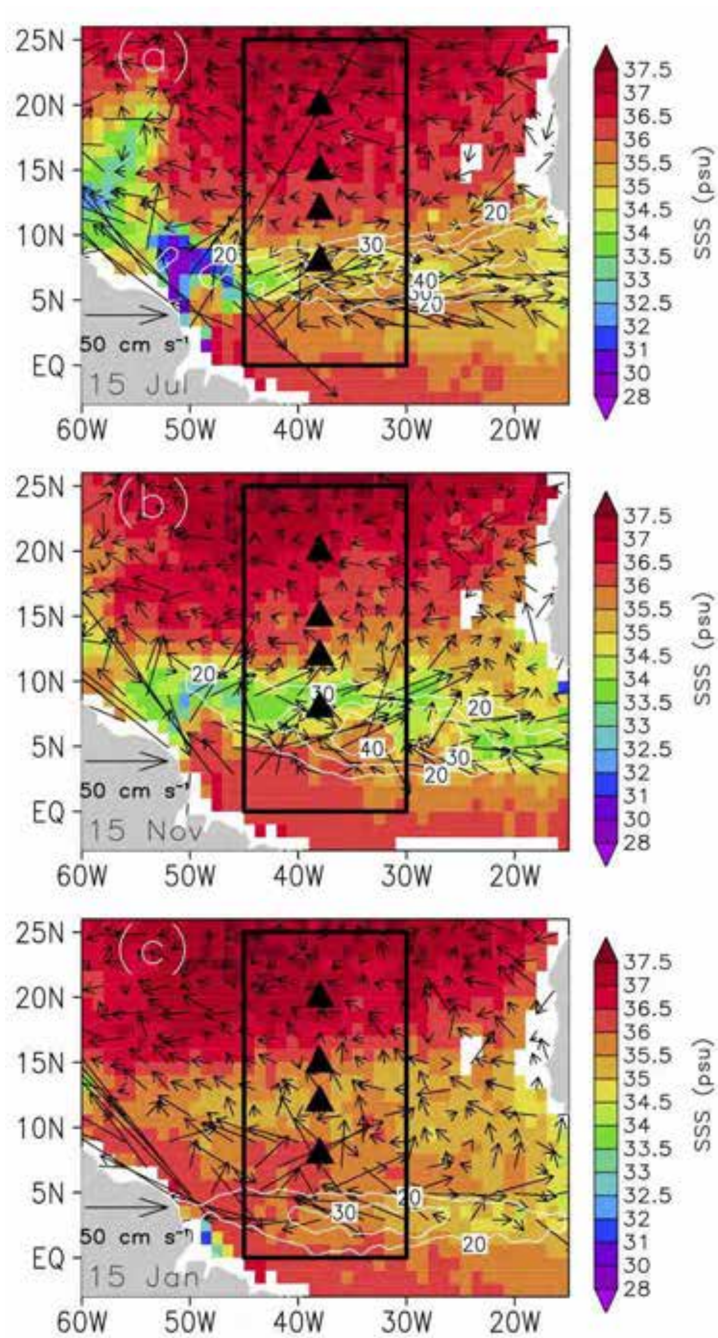

Figure 1: Weekly sea surface salinity (SSS) from Aquarius (shaded), rainfall from TRMM (white contours), and surface currents from a drifter-altimetry synthesis (arrows) centered on (a) July 15, (b) November 15, and (c) January 15 in 2012. Black triangles indicate the positions of the PIRATA moorings used in this study.

CIMAS and AOML personnel participated in the PIRATA Northeast Extension (PNE) cruise aboard the UNOLS R/V Endeavor from December 29, 2014 to February 12, 2015. Rick Lumpkin (AOML) served as chief scientist, with scientific support provided by Zachary Barton, Shaun Dolk, Kyle Seaton, and Erik Valdes, all CIMAS personnel. ATLAS moorings were recovered and redeployed and conductivity-temperature-depth (CTD) casts were conducted to a depth of 1500 m; surface drifting buoys were also deployed. In addition, as part of AOML funded project called TACOS (the Tropical Atlantic Current Observations Study), 11 current meters were deployed at the 4N, 23W PNE mooring site. These instruments were installed and deployed by PMEL technicians on a next generation TFLEX mooring on January 23, 2015. These current meters will provide invaluable data about how the ocean currents in the region vary with depth, and over time.

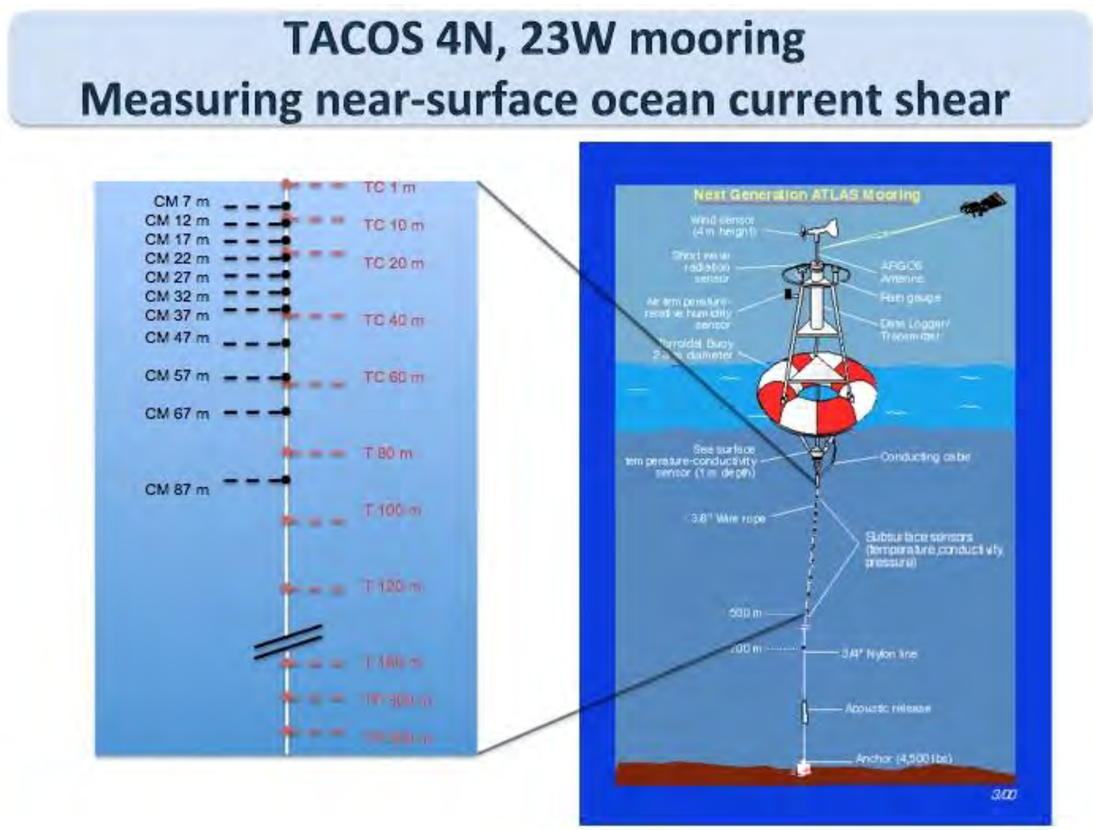

Figure 2: Schematic of the TACOS current meter instruments deployed on the 4N, 23W PNE mooring on January 23, 2015.

Research Performance Measure: All major objectives are being met. Two PNE-related papers have been published in Climate Dynamics and the Journal of Physical Oceanography.

Global Drifter Program

Project Personnel: S. Dolk, R. Perez and E. Valdes (UM/CIMAS)
NOAA Collaborators: R. Lumpkin and M. Pazos (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To maintain a global 5x5 degree array of 1250 satellite-tracked surface drifting buoys to meet the need for an accurate and globally dense set of in-situ observations of mixed layer currents, sea surface temperature (SST), atmospheric pressure, winds and salinity; to provide, archive, and disseminate a uniform quality-controlled data set of SST and surface velocity.

***Strategy*:** To produce an annual plan for the global distribution and deployment of 1000-1050 drifters through interaction with international partners; to coordinate drifter objectives with NOAA field personnel, contractors, shipping companies and various ship personnel; to verify deployment status and update the Drifter Database and to monitor on a daily basis systems status.

CIMAS Research Theme:

***Theme 3*:** Sustained Ocean and Coastal Observations
***Theme 1*:** Climate Research and Impacts *(Secondary)*

Link to NOAA Strategic Goals:

***Goal 3*:** Climate adaptation and Mitigation: *An informed society anticipating and responding to climate and its impacts*

NOAA Funding Unit: OAR/AOML **NOAA Technical Contact:** Molly Baringer

Research Summary:

The Global Drifter Program (GDP) is a principal component of the Global Surface Drifting Buoy Array, a branch of NOAA's Global Ocean Observing System (GOOS) and a scientific project of the Data Buoy Cooperation Panel (DBCP). There are two major activities in this program.

- *Drifter Operations Center (DOC)* whose task is to maintain a global 5x5 degree array of 1250 satellite-tracked surface drifting buoys to meet the need for an accurate and globally dense set of in-situ observations of mixed layer currents, sea surface temperature (SST), atmospheric pressure, winds and salinity.
- *Drifter Data Assembly Center (DAC)* whose tasks are: to arrange data dissemination to the Global Telecommunications System (GTS); to provide uniform quality-controlled data from the historical data sets of SST and surface velocity, web access, archival and distribution. These data support short-term (seasonal to interannual) climate predictions as well as climate research and monitoring.

The design of the Global Drifter Program drifter has continued to evolve - as demonstrated by the recent large-scale deployment of salinity-measuring drifters - while its qualitative characteristics and water-following properties have remained relatively stable since the earliest deployments. Incremental improvements in design and manufacturing continue to increase drifter lifetime. We continue to develop new methodologies for drifter data analysis, aided by increasing information from the ever-growing drifter array and from other sources of complimentary observations. Dense deployments in eddy-rich, frontal regions will help us improve our understanding of eddy fluxes and their role in modifying air-sea heat fluxes and water mass formation.

The major challenge facing the DOC is to arrange deployments in regions of surface divergence and areas infrequently visited by research or voluntary observation vessels. This logistical challenge is being addressed by increased international cooperation, and the development of tools to predict global drifter array coverage based on its present distribution and historical advection/dispersion. As the array grows, it provides invaluable observations of ocean dynamics, meteorological conditions and climate variations, and offers a platform to test experimental sensors measuring rain rates, biochemical concentrations, and air-sea fluxes throughout the world's oceans.

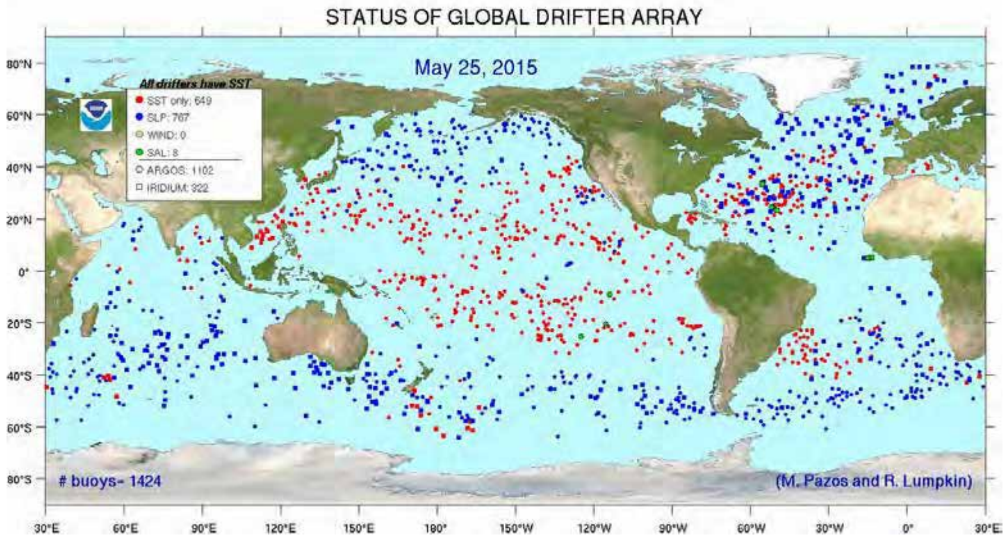

Figure 1: Status of the Global Drifter Array (updated weekly)

The DAC is responsible for processing data from all drifters in the project: on the maintenance and support of a population of ~1250 active drifters (see Fig. 1). The DAC works closely with researchers to provide high-quality drifter data in a rapid and accessible manner. The DAC has four primary objectives: Global Telecommunications System (GTS) data distribution, data quality control, web access, and instrument performance evaluation. The DAC inserts and deletes drifters onto the GTS distribution. The accuracy of data is monitored and data are removed from the GTS once sensors fail or a drifter runs aground. The DAC also notes drifters that have lost their drogue so that this information can be relayed in the GTS message.

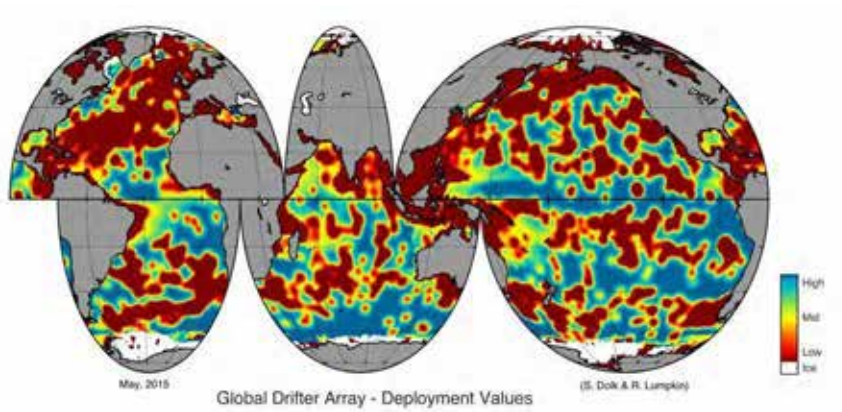

Figure 2: Deployment Value Map(s) (updated monthly)

Research Performance Measure: Regional deployments were conducted to provide spatial coverage and maximize drifter lifetimes. The goal of making timely quality-controlled data available to the research and operational communities was met.

Ship of Opportunity Program

Project Personnel: S. Garzoli, C. Gonzalez, S. Dong, Z. Barton, R. Domingues, M. Goes, G. Rawson, Q. Yao, R. Roddy, K. Seaton and R. Sabina (UM/CIMAS)
NOAA Collaborators: G. Goni, M. Baringer, F. Bringas, J. Harris, U. Rivero, P. Pena, A. Stefanick, J. Farrington and Y-H. Daneshzadeh (NOAA/AOML)
Other Collaborators: J. Trinanes (University of Santiago de Compostela, USC); P. Chinn (Consultant)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To characterize the upper ocean thermal structure and to investigate the large-scale, low-frequency modes of climate variability using observations of ocean and atmospheric properties obtained, transmitted and quality controlled within the Ship of Opportunity Program (SOOP) using volunteer merchant ships.

***Strategy*:** Make routine observations along major shipping routes throughout the global ocean including design, development and maintenance of a system for the merchant fleet to acquire ocean and meteorological information and transmit that information in real-time to users worldwide called SEAS (Shipboard Environmental Acquisition System). Make upper ocean temperature observations using expendable bathythermographs (XBTs) deployed closely spaced across large ocean regions along repeated transects (the high density XBT network) to measure the mesoscale ocean temperature structure and to combine these observations with those from other platforms, such as satellite altimeters, floats, drifters and moorings, to enhance the global ocean observing system and provide estimates of the meridional heat transport and upper ocean heat content.

CIMAS Research Theme

***Theme 3*:** Sustained Ocean and Coastal Observations *(Primary)*
***Theme 1*:** Climate Research and Impact *(Secondary)*

Link to NOAA Strategic Goals:

***Goal 1*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*
***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

NOAA Funding Unit: OAR/CPO **NOAA Technical Contact:** Molly Baringer

Research Summary:

The global atmospheric and oceanic data from Ships Of Opportunity Program (SOOP) serve as a key component for understanding long-term changes in climate. This project is designed to measure the upper ocean thermal structure along major shipping lines globally with high resolution in key regions of the Atlantic and Pacific Oceans (Figure 1) with the objective of a) monitoring meridional heat transport, b) assessing variability of boundary currents, and c) contributing with approximately 15% of the global upper ocean heat content data. NOAA/AOML is involved in one or more components of the 8000 XBTs that are deployed annually in Frequently Repeated and High Density modes. In addition, approximately 14000 XBT observations, from NOAA and non-NOAA operations, are quality controlled in real-time at AOML every year. This project is a component of the NOAA's Program Plan for building a sustained Ocean Observing System for Climate and directly addresses one of its milestone*: Occupy transects of the Ship Of Opportunity Program (SOOP) for high accuracy upper ocean observations.*

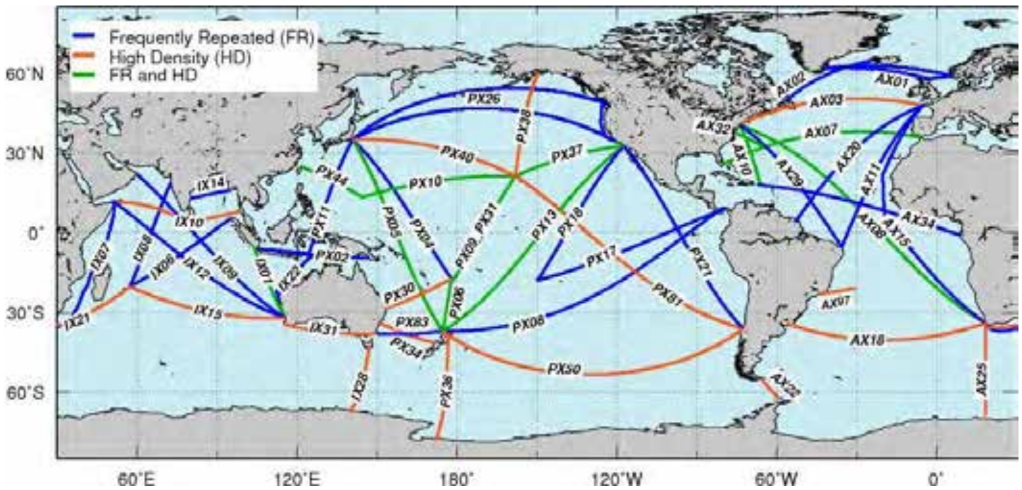

Figure 1: OceanObs09 XBT transects recommended by the scientific community to be occupied in frequently repeated mode (FR, in blue), high density mode (HD, in orange) or both (in green).

The SOOP currently maintains, exclusively or as part of international and/or multi-institutional collaborations, the following transects in High Density mode: AX01, AX02, AX07, AX08, AX10, AX18, AX20, AX22, AX25, AX32, AX97, MX01, MX02, and MX04. This program also collaborates with the Scripps Institution of Oceanography in the XBT data quality control and transmission in real-time from six transects in the Pacific Ocean: PX06, PX09, PX10, PX31, PX37 and PX44 to monitor properties in the upper layers.

High Density XBT transects provide real time high resolution temperature profiles spaced approximately 20-50 km apart. These transects are critical to investigate the upper ocean circulation since they are the only means to measure subsurface temperature fields on spatial and temporal scales designed to map the mean and fluctuating components of the ocean thermal structure. Data obtained from these transects are used to investigate the inter-basin mass exchange between the Indian and Atlantic Ocean (AX25), the meridional heat transport at 30°S (AX18) and 30°N (AX07), the variability of the Gulf Stream (AX10) and the zonal current system in the tropical Atlantic (AX08). Moreover, in the South Atlantic, transect AX18 provides information on major boundary currents, such as the Brazil, Malvinas, Benguela and Agulhas, and their associated eddies. Additionally, transect AX02 crosses the North Atlantic subpolar gyre near 60°N, in an area of large decadal change both for the gyre circulation and in temperature and salinity, which has increased since 1992 according to data from other observing systems in the region. These are all important components of the Meridional Overturning Circulation in the Atlantic Ocean.

The SOOP includes extensive operations that collect, organize, and distribute the data, which are gathered from as many as eighteen cruises conducted by AOML each year, including in excess of 200 days at sea and approximately 8000 XBTs deployed. Figure 2 shows the location of XBT deployments by the international community during calendar year 2014 **(total of 17,666 XBT deployments**). AOML operate XBT deployments in transects AX10, AX07, AX08, AX18, and support deployments and transmissions in several additional transects carried out in partnership with national and international collaborators. Data obtained from these transects are provided to the scientific community to investigate the variability and upper ocean thermal structure of boundary current, subtropical gyres, equatorial current system to study and understand the role that the ocean plays in climate fluctuations, and to improve the ability to predict important climatic signals, such as the North Atlantic Oscillation. For more details about the XBT network, please see *www.aoml.noaa.gov/phod/hdenxbt/*. In addition, observations from other in situ and remote observing platforms are used to complement the observations provided by the XBT transects. The

SOOP also supports other observational networks, such as the global drifter array, and Argo profiling floats by performing deployment of instruments at no cost along the XBT transects.

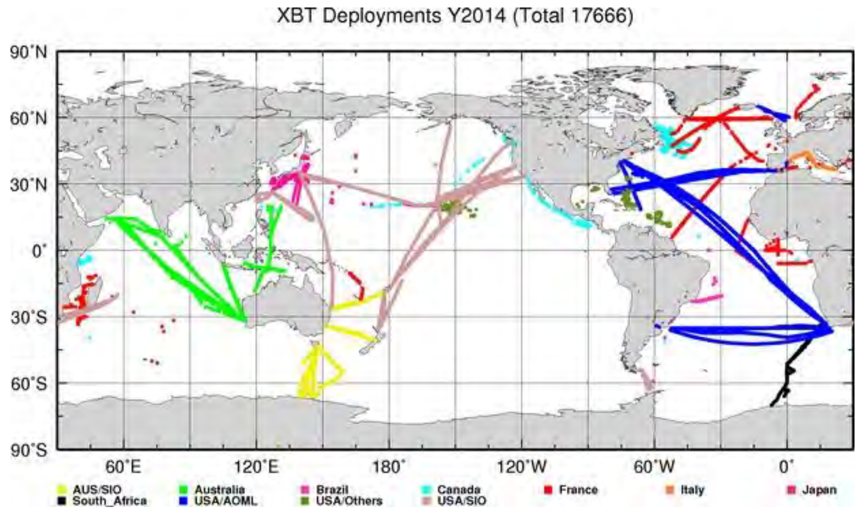

Figure 2: Locations of XBT deployments by AOML and the international community during calendar year 2014.

One of the most important contributions of the XBT network is the monitoring and study of the Meridional Overturning Circulation (MOC) and the Meridional Heat Transport (MHT). The MOC is the main mechanism for global redistribution of heat in the ocean. The Atlantic Ocean is the major ocean basin involved in large-scale northward transports of heat typically associated with the MOC, where warm upper layer water flows northwards, and is compensated for by southward flowing North Atlantic Deep Water. This large-scale circulation is responsible for the northward heat flux through the entire Atlantic Ocean. The MHT is continuously monitored in the South and North Atlantic using data from two XBT transects: AX18 in the South Atlantic (Figure 3), and AX07 in the North Atlantic (Figure 4).

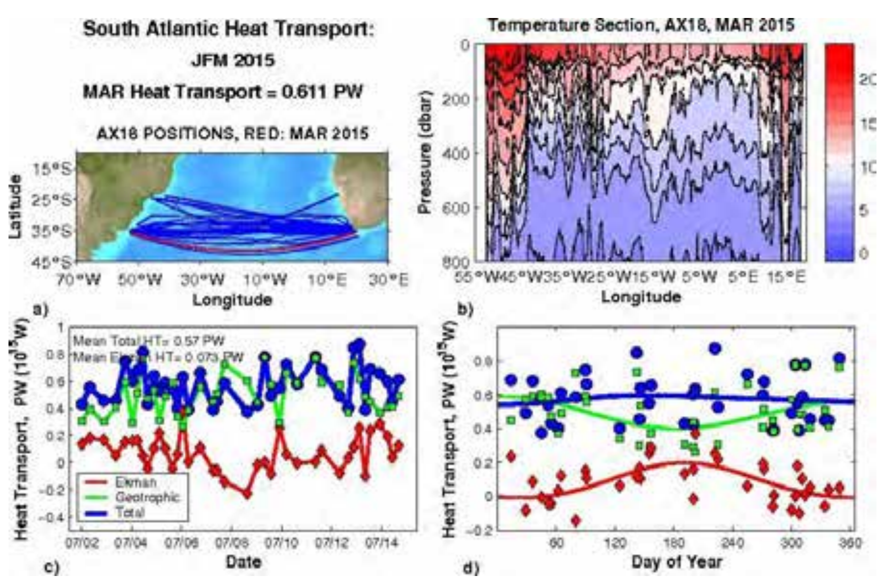

Figure 3: South Atlantic MHT calculated using data from the AX18 high density XBT transect, which runs from the Rio de la Plata region to South Africa.

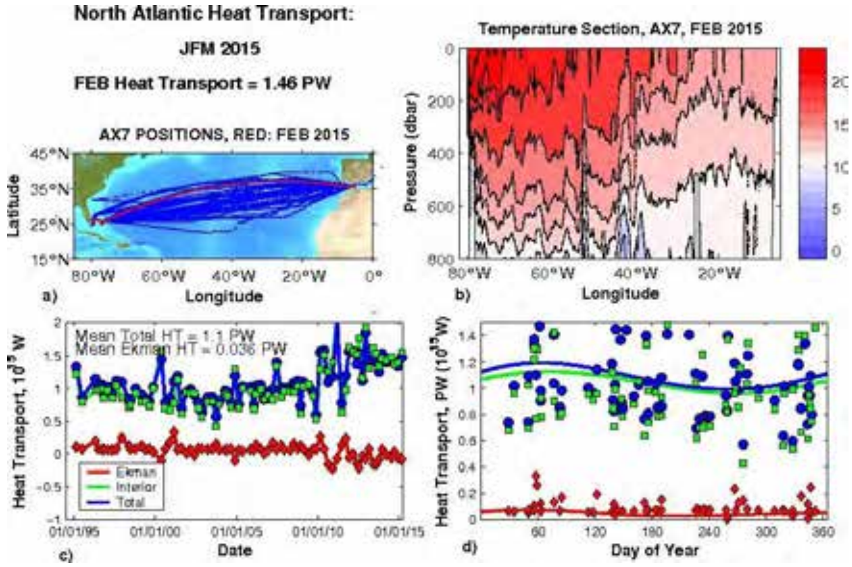

Figure 4: North Atlantic MHT calculated using data from the AX07 high density XBT transect, which runs from Florida, USA, to Gibraltar.

In addition to the XBT network, AOML continued the TSG operation as a component of SOOP.
TSGs are instruments that continuously measure the values of sea surface temperature and salinity along the ship path. TSG observations are used in conjunction with pCO_2 observations and provide critical information to determine frontal regions and mixed layer depths for ocean acidification assessments. During fiscal year 2014, AOML received, processed and distributed TSG data from 7 ships of the SOOP (Semester at Sea's MV Explorer, MV Oleander, MV Barcelona Express, MV Reykjafoss, MV Bernardo Houssay of the Argentinean Coast Guard, and Royal Caribbean's Explorer of the Seas and Allure of the Seas in collaboration with University of Miami/RSMAS) and from 11 ships of the NOAA fleet (RV Okeanos Explorer, RV Pisces, RV Oregon II, RV Ronald H Brown, RV Bell M Shimada, RV Oscar Elton Sette, RV Rainier, RV Gordon Gunter, RV Oscar Dyson, RV Nancy Foster, RV Hi'ialakai). More than 30 million TSG records were processed at AOML during FY2014 (Figure 5).

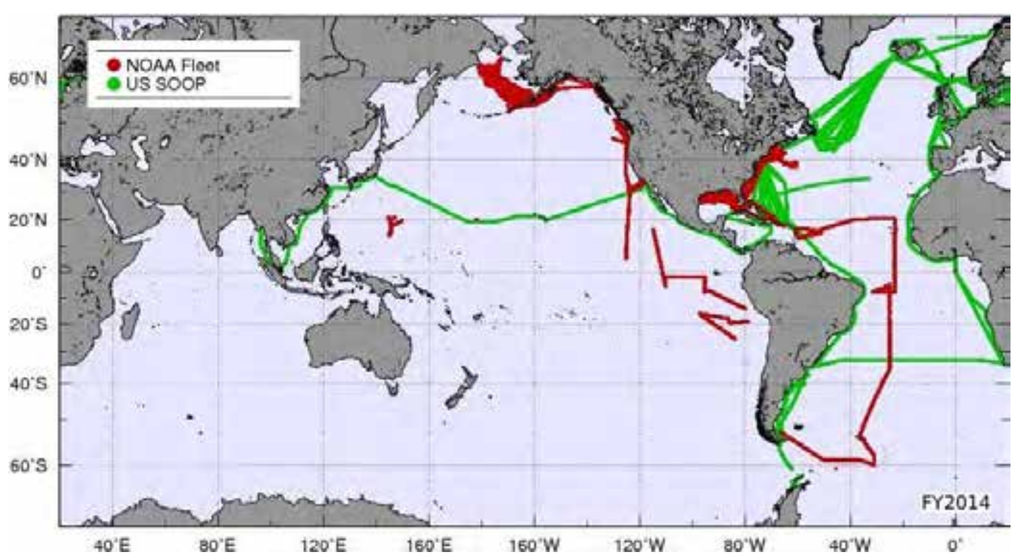

Figure 5: Locations of TSG records received, processed, and distributed by AOML during fiscal year 2014.

In addition to observational efforts, the AMVERSEAS software, which is supported by SOOP, is also used to: (i) provide regular reports to the US Coast Guard's Automated Mutual-Assistance Vessel Rescue System (AMVER), which aids in finding ships in the vicinity of vessels in distress; and (ii) transmit meteorological observations from vessels through the Shipboard Environmental data Acquisition System (SEAS), which contributes to the largest source of marine meteorological observations used by the NOAA National Weather Service for marine forecast.

During the reporting period, the components of the project linked with the operations and data distribution were marked by:

(i) The development of an Iridium-based system for real-time transmission of XBT data. The system has been successfully integrated into the AMVERSEAS software, and will replace the previous component based on Inmarsat Thrane & Thrane transmissions. Once fully implemented, the transition to the new system will translate in approximately $100,000.00 in annual savings with transmissions costs.

(ii) Updates in the BUFR (Binary Universal Form for the Representation of meteorological data) encoding procedures to minimize the submission of descriptors set to their default values, while taking advantage of the new the metadata-rich SEAS binary format. This effort builds on the XBT operational requirements, which aim to provide and update the different metadata fields being included in the BUFR template.

(iii) The start of the migration of systems performing the automatic quality control of XBT data to an operational LINUX environment. Programs were modified and recompiled in the new environment, and a new feature has been added to enable the LINUX-based system to work on a full XBT profile. Future improvements will include updating the climatologies and other reference datasets, the addition of new quality control procedures, and integrating it in the operational data distribution.

The research component of the project provided advances in the following fields:

(a) Dong et al. (2015): surface salinity variations and processes affecting surface salinity in the high-salinity region of the subtropical North Atlantic (the SPURS-1 area) were investigated by combining data from in situ observations and satellite remote-sensing measurements. The seasonal evolution of the mixed-layer salinity, which is characterized by high values from April to August and low values from September to March, is largely controlled by the freshwater flux term, with vertical entrainment playing a secondary role. On interannual timescales, ocean advection plays a larger role in salinity changes during 2008–2012, whereas the surface freshwater flux term dominates surface salinity evolution during 2004–2007 and in 2013. Sustained XBT measurements in the North Atlantic (Figure) also showed strong interannual variations in subsurface temperatures (Figure 6). The SPURS-1 region exhibits colder temperature anomalies are observed in the north of the SPURS-1 region (AX07), and warmer anomalies in the southwestern region (AX08). Altimeter, Argo and XBT transect data demonstrates that the Gulf Stream was relative weak and had a more southerly position during 2012-2013, suggesting a significant anticorrelation of the salinity changes between the two transect regions on interannual time scales, with changes in the subtropical gyre region (25°N−40°N, 80°W−50°W) leading the SPURS-1 region by five months.

(b) Goes et al., (2015a): the sensitivity of calculations of the Meridional Overturning Circulation (MOC) and Meridional Heat Transport (MHT) to uncertainties in XBT measurements was quantified using an eddy-resolving model simulation. Results showed that XBT measurement biases after 2010 can translate into small MOC and MHT errors: on the order of 0.38 Sv ($1 Sv = 10^6 m^3 s^{-1}$) or 3% for the MOC, and of 0.025 PW ($1 PW = 10^{15} W$) or 8% for the M HT (Figure 7). Historical XBT-derived trends in the MOC and MHT estimates across 34°S were strong and statistically significant after the late 1990s, 0.3 Sv decade^{-1} and 0.02 PW decade^{-1}. These trends were mostly due to the XBT linear depth bias. Long-term trends calculated from Simple Ocean Data Assimilation reanalysis, estimated as 0.1 Sv/decade and 0.006 PW/decade, were 3 times smaller than the XBT-derived historical trends.

These results highlight the need for an adequate correction of historical XBT data for detecting trends in the MOC and MHT estimates in the South Atlantic.

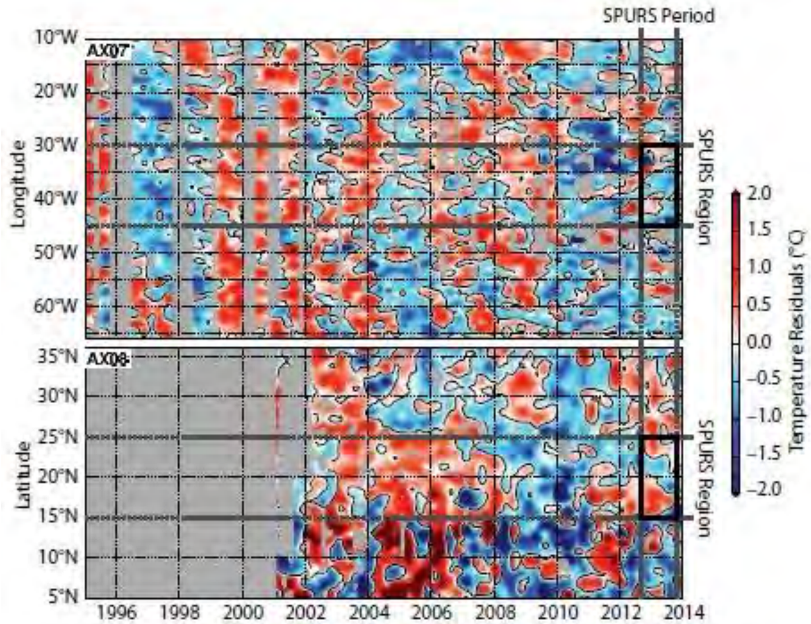

Figure 6: Hovmoller diagram of subsurface temperature anomalies at 100 m depth from XBT transects AX07 (top panel) and AX08 (bottom panel). Black boxes indicate the SPURS-1 period/region.

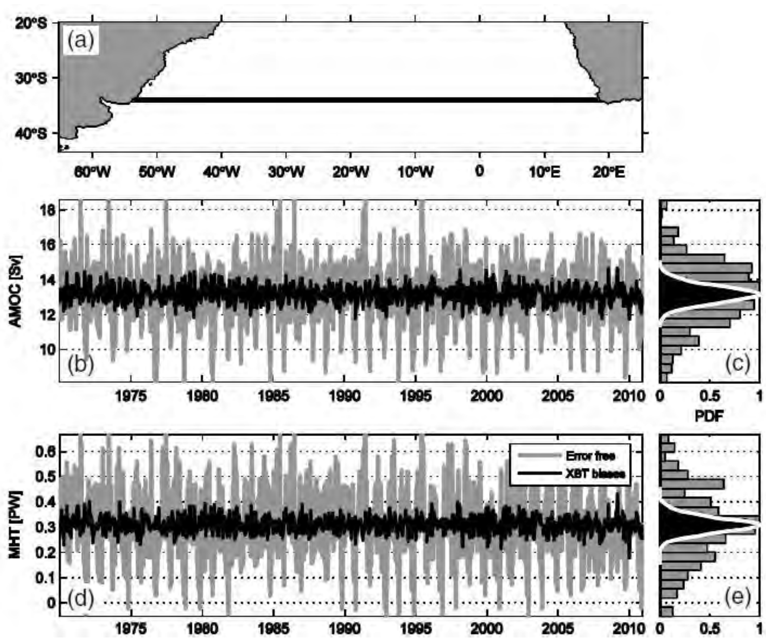

Figure 7: (a) Map containing the mean location of the AX18 XBT transect in the model. (b, d) Time series of the model MOC (Sv) and MHT (PW) (gray line) and respective MOC and MHT anomalies generated by random XBT errors (Z0, Z1, and T0) approximated by a uniform distribution bounded by the manufacturer's tolerance errors. For scaling purposes, the mean values of the MOC and MHTare added to the anomaly time series. (c, e) Normalized histograms of the respective variability associated with the MOC and MHT time series (gray bars) and of the simulated errors (black area).

(c) Perez et al. (2015): This study described the different types of observational systems used by scientists of the National Oceanographic and Atmospheric Administration and their partners at national and international institutions to study the complex nature of the AMOC. Among the observing systems, the XBT project provides observations that are used to monitor the AMOC from transects at 30ºN (AX7) and 34ºS (AX18), and also meridional heat transport across those latitudes.

(d) Goes et al., (2015b): a high-resolution ocean assimilation product was used to simulate an XBT-based observational system across the South Atlantic with the objective of evaluating the sensitivity of the meridional heat transport, meridional overturning circulation, and geostrophic velocities to key observational and methodological assumptions. Key assumptions taken into account were horizontal and temporal sampling of the transect, salinity, and deep temperature inference, as well as the level of reference for geostrophic velocities. With the current sampling strategy, the largest errors in the meridional overturning and heat transport estimations are the reference (barotropic) velocity and the western boundary resolution (Figure 8). We show how altimetry can be used along with hydrography to resolve the barotropic component of the flow. We use the results obtained by the state estimation under observational assumptions to make recommendations for potential improvements in the AX18 transect implementation.

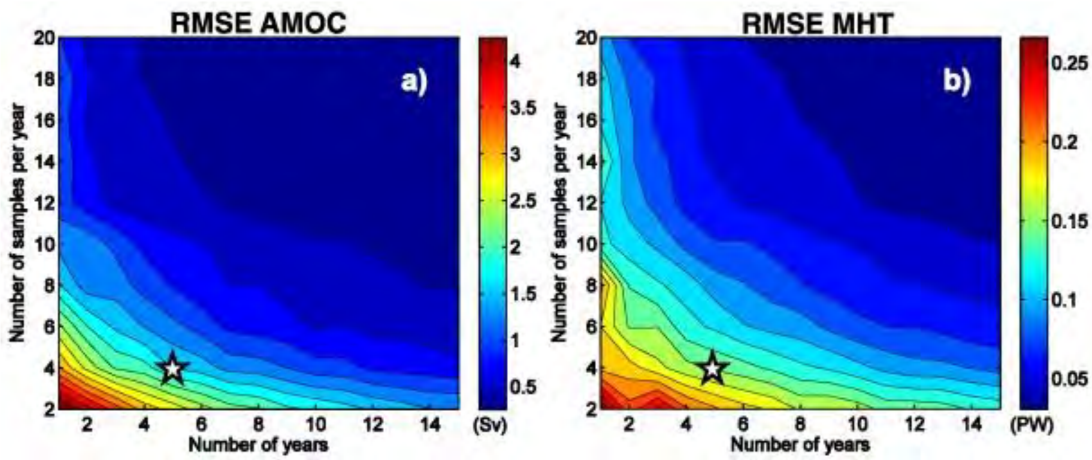

Figure 8: RMS error of the reconstructed (a) AMOC and (b) MHT associated with different time samplings, i.e., the number of samples per year (y axis) and the number of year (x axis). The RMS error is calculated from the difference between the seasonal cycles, calculated as the sum of the first and second harmonics, of the resampled time series and the time series using the original model sampling. The number of samples per year is randomly selected, and this process is realized 400 times to average the random realizations. The stars in Figures 4a and 4b correspond to the current location of the AX18 sampling in the time sampling parameter space.

(e) Dong et al. (2014): This study investigates the causes for differences in the AMOC seasonal variations estimated from observations and numerical models. Observational estimates suggest that the geostrophic transport plays an equal role to the Ekman transport in the AMOC seasonal variations at this latitude, whereas in the models, the Ekman transport controls the AMOC seasonality. The seasonality of the geostrophic transport from observations is largely controlled by the seasonal density variations at the western boundary, but in the models, the eastern boundary dominates. The observed density seasonality at the western boundary is linked to the intensity of the Malvinas Current, which is poorly reproduced in the models. The results indicate that the weak seasonal cycle in the model geostrophic transport can primarily be attributed to excessively strong baroclinicity below the surface mixed layer, whereas the observations show a strong vertical coherence in the velocity down to 1200 m.

Research Performance Measure: All operational research goals were met during this year with respect to real-time data transmissions and to the percentage recovery of good data based upon rigorous internal quality control. All scientific goals were met with respect to timely assimilation of the data generated into operational NOAA modeling efforts.

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Florida Area Coastal Environment (FACE) program

Project Personnel: M. Gidley (UM/CIMAS)

NOAA Collaborators: J. Stamates, J. Bishop, T. Carsey, C. Featherstone and C. Sinigalliano (NOAA/AOML); R. Kotkowski and M. Doig (NOAA Corps)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To quantify impact of nutrient sources, including six treated-wastewater outfalls and SE Florida inlets, on the water quality and coastal ecosystems of SE Florida.

***Strategy*:** To perform extensive coastal water quality and current measurements, and inlet water quality and flow measurements in specific areas of interest.

CIMAS Research Theme:

***Theme 3*:** Sustained Ocean and Coastal Observations (*Primary*)
***Theme 6*:** Ecosystem Management (*Secondary*)
***Theme 7*:** Protection and Restoration of Resources (*Tertiary*)

Link to NOAA Strategic Goals:

***Goal 4*:** Resilient Coastal Communities and Economies - *Understand the impacts of land-based sources of pollution.*

***Goal 1*:** Healthy Oceans - *Increase our knowledge and understanding of the mechanisms and impacts of environmental changes on marine species and ecosystems.*

NOAA Funding Unit: OAR and NOAA-CRCP
NOAA Technical Contact: Molly Baringer

Research Summary:

The FACE project is primarily concerned with anthropogenic discharges in the Florida's coastal ocean. FACE field operations include a wide range of physical, biological, and chemical oceanographic measurements such as ocean currents, nutrients, acoustic and chemical sensing of plumes, and microbiological measurements. This year, we initiated a project with the Florida Department of Environmental Protection to develop numeric nutrient criteria for the coastal ocean. The project includes twelve bimonthly water quality cruises in the coastal ocean off of Broward and Miami-Dade Counties, as well as acoustic Doppler current profiler instrumentation operating in the area. The water quality cruises are conducted in conjunction with parallel coral reef survey cruises conducted by Dr. Paul Jones and Dr. Ian Enochs also at AOML. Some preliminary results are shown in Figure 1, where a summary of near-seafloor TN measurements off of Miami-Dade and Broward Counties is shown; the figure clearly shows the significant impact of the plume from the Port of Miami. Figure 2 is a heatmap showing microbial abundance from a coastal inlet, treated-wastewater outfall, and reef sites off of SE Florida. This project will continue through 2015.

Research Performance Measure: A program to provide water quality and coral reef habitat data in support of the development of numeric nutrient criteria for the coastal waters of southeast Florida is underway. Relevant reports will be written for FDEP and will become a NOAA Technical Report available from NOAA/AOML and (www.aoml.noaa.gov/general/lib/NOAA%20Publications.html) at the FACE website (www.aoml.noaa.gov/themes/CoastalRegional/projects/FACE/faceweb.htm).

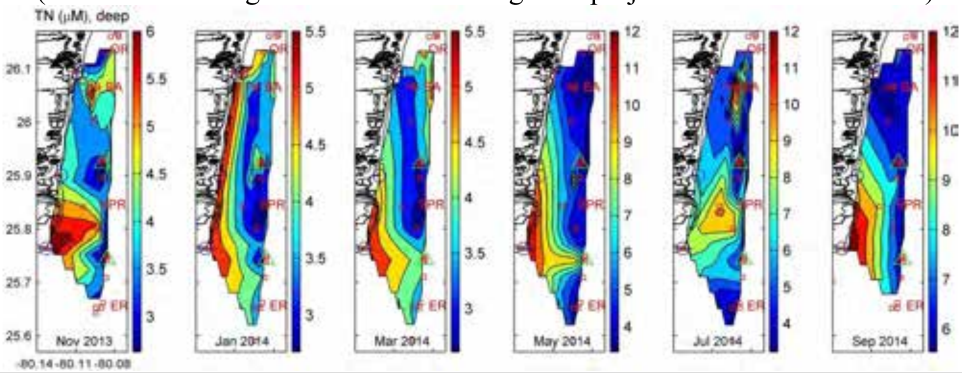


Figure 1: Contour plots of total nitrogen (TN) from near-bottom water samples obtained during six cruises from November 2013 through September 2014. Note evidence of plume from the Port of Miami inlet. Sample sites are denoted by red squares, treated-wastewater outfalls (Miami-North and Miami-Central) by green triangles, coastal inlets (Pt. Everglades, Baker's Haulovoer, and Port of Miami) denoted by red circles. Reef regions denoted as OR (Oakland Ridge); BA (Barracuda), PA (Pillars), and ER (Emerald Reef).

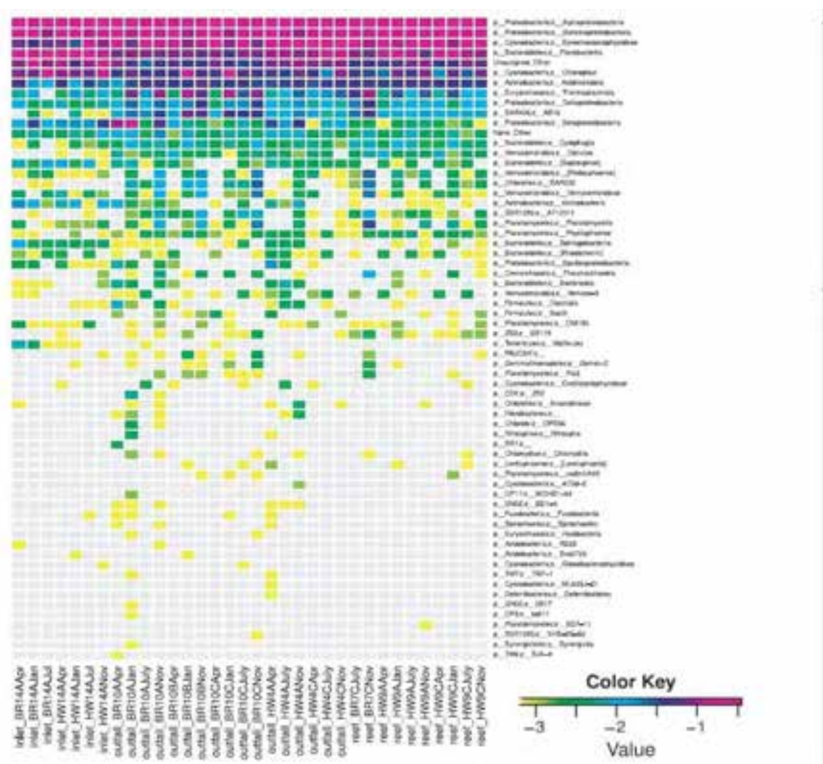


Figure 2: Hierarchical clustering of bacterioplankton 16S profiles at the class level, from Broward county inlets, treated-wastewater outfalls and reefs. Heatmap values reflect log-normalized proportions and were generated using the skiff tool in CloVR (Angiuoli et al. 2011). Relative microbial abundance is shown by the spectrum of colors on a logarithmic scale. For example, a more reddish color indicates higher abundance, while yellow indicates less common taxa. From Campbell *et al.* 2015.

NOAA Coral Reef Conservation Program Quantifying the Contribution of Upwelling to LBSP on SE Florida Reefs by Sub-Watershed (NSU Contribution)

Project Personnel: L. Gramar (UM/CIMAS)
Other Collaborators: A.V. Soloviev (NSU)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To quantify the longterm relative contribution of oceanic upwelling by sub region within southeast Florida, to a mass balance budget that Florida Dept. of Environmental Protection (FDEP) will use to address nutrients, carbon, and other pollutants of concern. The need for such information has been directly identified in both the Florida Local Action Strategy (LAS) and FDEP CRCP strategic management plan (20112016).

Strategy: To provide historical data from the ADCP mooring on the Dania Beach shelf, validate analysis of four to ten years of in situ records for ocean currents and temperature from the coral reef lines on SE Florida shelf (Dania Beach), and assist in analysis for mechanisms, frequency, and inshore mixing produce by upwelling events.

CIMAS Research Theme:

Theme 3: Sustained Ocean and Coastal Observations (*Primary*)
Theme 6: Ecosystem Management (*Secondary*)

Link to NOAA Strategic Goals:

Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: AOML **NOAA Technical Contact:** Molly Baringer

Research Summary:

We provided a data report and data, which represents an approximately fourteen year data set collected from multiple ADCP moorings. First, the report discusses data from bottom mounted ADCP at an 11-m isobath on the Dania Beach shelf which has an approximately 14-year record. Next, we discuss a four year data set collected from a subsurface ADCP mooring located at a 244-m isobath. Finally, we discuss an Acoustic Wave and Current Profiler (AWAC) system used to collect data off the Dania Beach shelf at the 11-m isobath for approximately two months. We pre-processed the data from all three moorings by trimming the beginning and end of each raw data file to exclude data during times that the instrument was disturbed by the boat and/or divers. These files were then converted to Matlab format for further analysis.

Several storm events resulted in temperature drops of greater than 2°C near shore, and alteration to heat fluxes. Negative values for cross shelf velocity were also regularly observed during hurricane events. For all hurricanes and tropical storms that passed south Florida during our 11-m ADCP record (1999 – 2013), we observed echo amplitude, east and north velocity components and temperature. We also calculated cross shelf heat fluxes associated with the upwelling events initiated by hurricanes. An example during Hurricane Wilma is shown in Figure 1.

In addition using these data we validated a prior analysis (Gramer) analysis of in situ ocean currents and available temperature data.

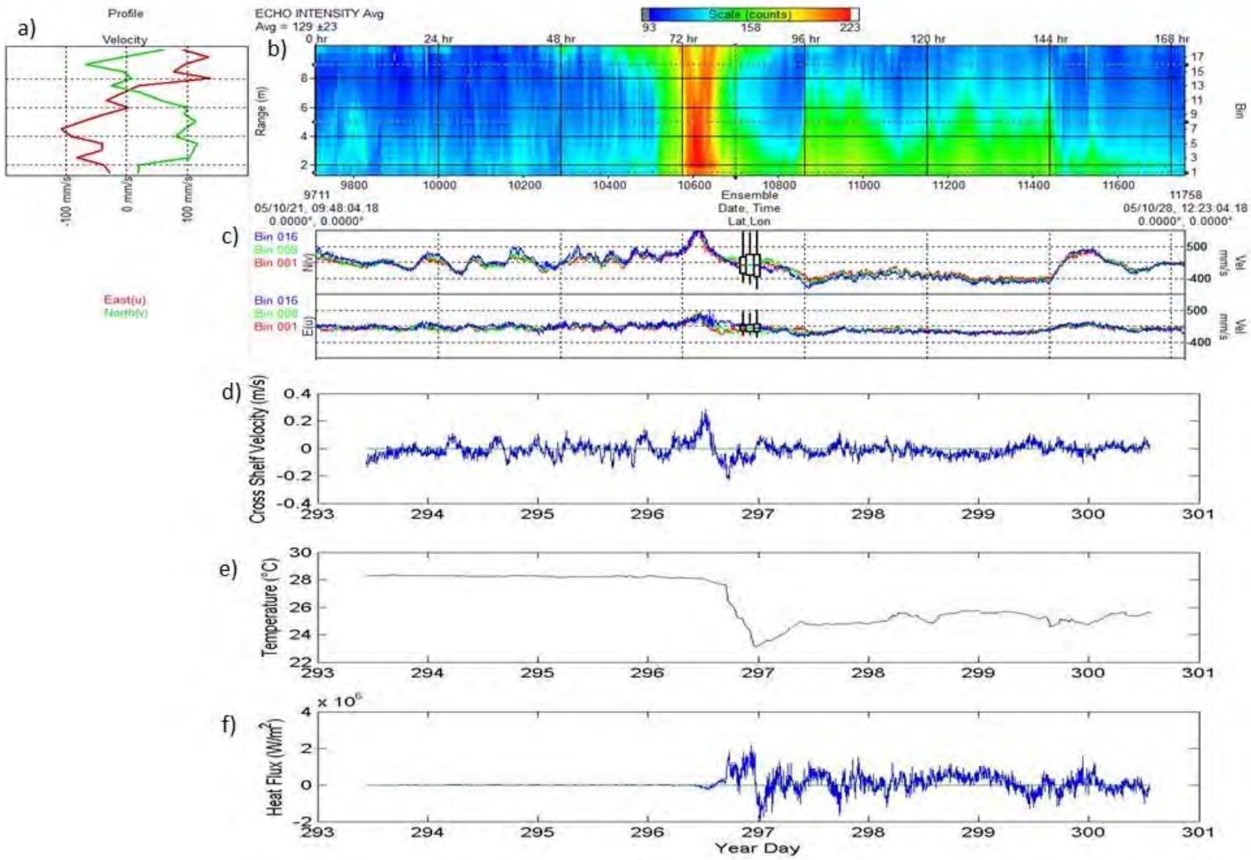


Figure 1: An upwelling event during Hurricane Wilma 2005. a) East and north current velocity before and after the storm; b) Echo intensity measured from the 11-m mooring; c) Time series of the north and east components of velocity; d) Cross shelf velocity (transformed into principle coordinates), u_{cf} ; e) Temperature at the location of the ADCP, T ; f) "instantaneous" cross-shelf advection term, $h_{cf} = c_p \rho (T - T_0) u_{cf}$, where c_p is the specific heat of water, ρ is the water density, and T_0 is the near-bottom temperature at the location of the ADCP before storm (Year Day 293.4467) .

Research Performance Measure: Outcomes of this research met the initially outlined tasks. We provided historical data from the ADCP moorings on the Dania Beach shelf and published an open access data report and validated prior analyses.

Calibration/Validation Support for NPP VIIRS Data Product Continuity

Project Personnel: C. Hu (USF)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To assess VIIRS data product continuity from its predecessors, diagnose reasons for discrepancy. To improve VIIRS data product continuity through algorithm development.

***Strategy*:** To use field and laboratory measured data to evaluate VIIRS data products for coastal oceans, and to use algorithm tuning to improve data product continuity.

CIMAS Research Theme:

***Theme 3*:** Sustained Ocean and Coastal Observations (*Primary*)
***Theme 5*:** Ecosystem Modeling and Forecasting (*Secondary*)

Link to NOAA Strategic Goals:

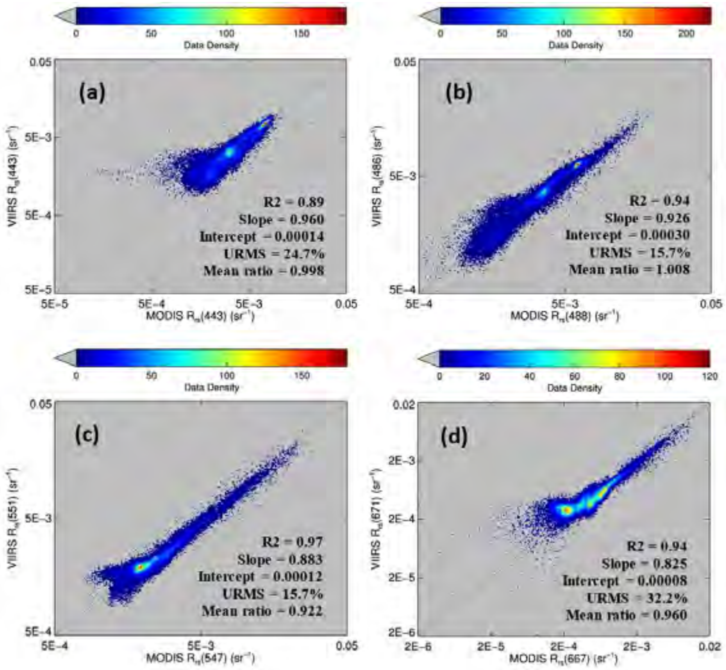
***Goal 3*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NESDIS
NOAA Technical Contact: Menghua Wang

Research Summary:

To date, the following activities have been conducted to achieve the project objectives:

- *In situ* Rrs data were collected between April 2012 and October 2013 in Tampa Bay and off the coast of central west Florida using an above-water spectrometer and community accepted protocols. A total of 80 quality controlled Rrs spectra were collected. These data were used to evaluate VIIRS performance in Florida's coastal waters. The data were also passed to NOAA/NESDIS to support their cal/val activities
- Participated in the cruise survey onboard the NOAA ship Nancy Foster to collect bio-optical data in the South Atlantic Bight in November 2014. Most data have been processed, quality controlled, and submitted to NOAA/NESDIS to support VIIRS cal/val. Some optical profiling data are still being diagnosed to assure calibration accuracy.
- Attended most bi-weekly telecons to report results to the whole team, and learn from other team members. Provided comments and suggestions to NOAA/NESDIS algorithm refinement
- Compared performance of MODIS and VIIRS in detecting a harmful algal bloom (HAB) in the NE Gulf of Mexico. The detection of VIIRS is not as good as MODIS due to lack of a fluorescence bank on VIIRS. Results were summarized and published by Hu et al. (2015a). Figure 1 shows the comparison between VIIRS- and MODIS-derived remote sensing reflectance (Rrs) data products at 4 spectral bands.
- Demonstrated the capability of VIIRS Day-and-Night Band (DNB) in detecting surface oil slicks at night under moon glint (Hu et al., 2015b).



Research Performance Measure: All major objectives are being met.

Figure 1: Comparison between MODIS/Aqua and VIIRS-derived Rrs data products. The data were collected from the northeast Gulf of Mexico on 30 June 2014. About 38,900 collocated data pairs from valid pixels on both MODISA and VIIRS were used to calculate the statistics. URMS is the unbiased RMS difference between the two measurements. Figure adapted from Hu et al. (2015a).

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Biogeochemical Measurements

Project Personnel: C. Langdon (UM/RSMAS)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To determine the changing oxygen content of the global ocean.

Strategy: Revisit hydrographic sections in the Atlantic and Pacific that were sampled ten years earlier and make discrete dissolved oxygen measurements for the surface to the bottom (24 depths) every 30 nautical miles.

CIMAS Research Themes:

Theme 3: Sustained Ocean and Coastal Observations

Link to NOAA Strategic Goals:

Goal 3: Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts* (*Primary*)

Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems* (*Secondary*)

NOAA Funding Unit: OAR/CPO/COD **NOAA Technical Contact:** Kathy Tedesco

Research Summary:

The last funding cycle supported participation on two cruises that were part of the Repeat Hydrography CO_2/Tracer Program (Global Ocean Ship-Based Hydrographic Investigations Program (GO-SHIP). These two cruises (A16N and A16S) spanned the Atlantic Ocean from Iceland to Antarctica. These sections were last occupied in 2003/2004. A total of 5,619 high precision oxygen measurements were made during these two cruises. The data collected can be used to see how conditions in the ocean have changed over the ten-year period between 2004 and 2014. Oxygen is a useful thing to measure because first and foremost it is essential to most forms of life in the ocean. Second, it turns out that oxygen is a sensitive indicator of changing conditions in the ocean. Changing wind patterns, warming, melting of polar ice, eutrophication all have impacts on the dissolved oxygen content of the ocean. Figure 1 shows how the oxygen content of the North Atlantic along the section shown in the map has changed over the last ten years. Shown in green are areas where oxygen content has shown little change and conditions are still healthy for marine life. Shown in blue are areas where the oxygen content has decreased significantly in the last ten years. The oxygen levels are not low enough to be stressful to marine life yet but the trend is cause for concern because similar changes have also been documented in the Pacific Ocean (Mecking et al. 2008, *Global Biogeochemical Cycles* 22, doi:10.1029/2007GB003101; Sabine et al. 2008, *J. Geophys. Res.: Oceans* 113(C7), C07021). These changes are happening very far from any likely source of direct human impact and can only be the result of very large-scale processes. The exact causes of the observed oxygen decreases in the Atlantic and Pacific are under investigation but the current thinking is that the conditions responsible for ventilating (supplying oxygen) to the deep ocean are weakening. The cause might be caused by warming and freshening of the ocean waters in the high latitude regions. Warmer and fresher water is less dense and hence less prone to sink and carry dissolved oxygen to the interior of the ocean basins. If the situation persists for many decades the end result could be massive dead zones where oxygen concentrations would be too low to support many forms of marine life.

The data from this cruise are available at the CCHDO website http://cchdo.ucsd.edu/.

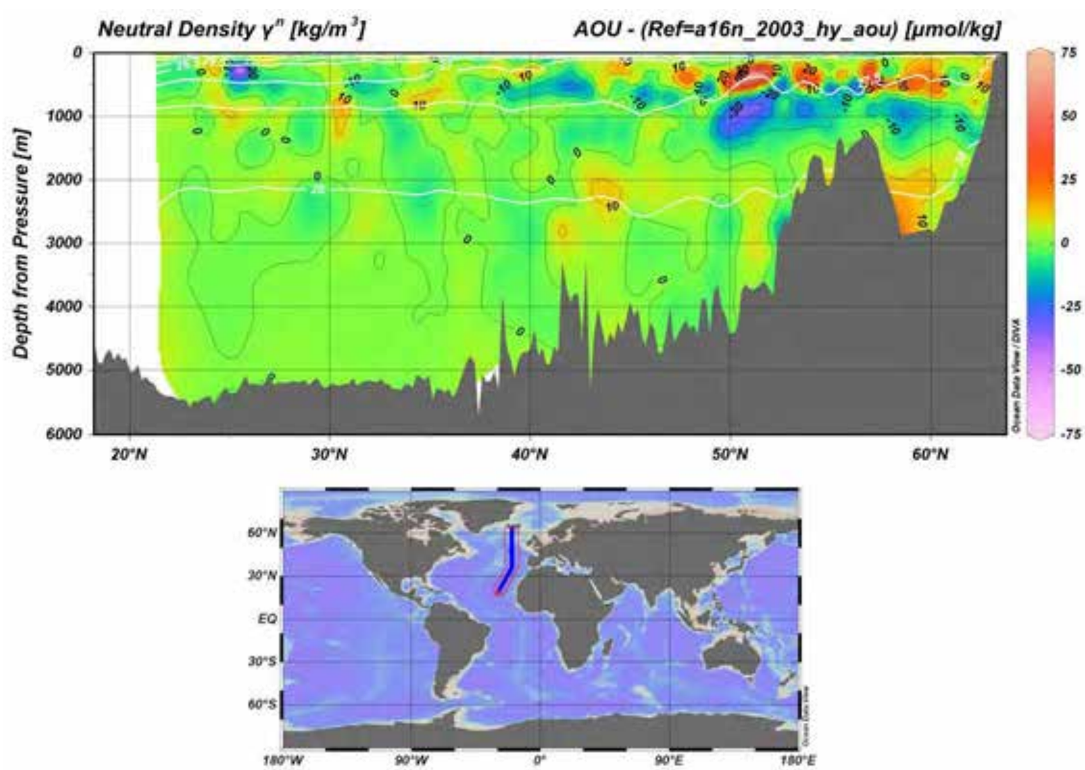

Figure 1: Section through the North Atlantic showing how the concentration of dissolved oxygen has changed between 2014 and 2004.

Research Performance Measure: This program is attaining all its goals on schedule.

Sustained and Targeted Ocean Observations for Improving Atlantic Tropical Cyclone Intensity and Hurricane Seasonal Forecasts

Project Personnel: S.-K. Lee, R. Domingues, G. Rawson, K. Seaton and J. Dong (UM/CIMAS)
NOAA Collaborators: G. Goni, F. Bringas and G. Halliwell (NOAA/AOML); W. McCall (NOAA/NDBC)
Other Collaborators: J. Morell and L. Pomales (U. Puerto Rico Mayaguez), H.-S. Kim (NCEP/EMC)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To obtain targeted and sustained ocean observations in the Caribbean Sea and Tropical North Atlantic Ocean to enhance our knowledge about the role that the ocean plays in the intensification of tropical cyclones (TC), and to assess the impact of these observations on the TC intensity forecast, and of seasonal forecasts.

Strategy: To implement an array of underwater gliders (hereafter referred as gliders) to carry out sustained and targeted upper-ocean profiling of temperature, and salinity in the Atlantic Warm Pool region. The proposed work aims to provide 4,500 to 5,500 profile observations per year using two gliders in the Caribbean Sea and north of Puerto Rico. Data transmissions are performed in real-time into the Global Telecommunication System (GTS) for assimilation in the forecast system.

CIMAS Research Theme:

***Theme 3*:** Sustained Ocean and Coastal Observations (*Primary*)
***Theme 2*:** Tropical Weather (*Secondary*)

Link to NOAA Strategic Goals

***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events*
***Goal 3*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

NOAA Funding Unit: OAR **NOAA Technical Contact:** Molly Baringer

Research Summary:

The main goal of this project is to carry out sustained and targeted upper-ocean observations in the Caribbean Sea and Tropical North Atlantic Ocean using a network of gliders to enhance our knowledge about the role that the ocean plays in the intensification of TCs, and to assess the impact of these observations on the TC intensity forecast, and of seasonal forecasts. To accomplish this, CIMAS purchased 2 Seaglider AUV Systems from Kongsberg Underwater Technology equipped with Seabird Sail sensors.

The first underwater glider planning meeting took place on March 25-26, 2014, in NOAA/AOML. Project personnel from AOML, NDBC, CIMAS, UPRM, and ANAMAR participated in the meeting to discuss various logistical, operational, and data management issues. The meeting included a sea trial near the cape Florida Channel. The objective of this at-sea test was to provide the international partners with instructions on how to deploy and recover the gliders.

On July, 2014, the first glider mission started with the successful deployment of both gliders off from Puerto Rico. Deployment activities were carried out aboard the R/V La Sultana (Figure 1) of the University of Puerto Rico at Mayaguez (UPRM), and one glider was deployed south of La Parguera, Puerto Rico on July/15/2014, and another approximately 14nmi north of San Juan, Puerto Rico on

July/19/2014. Both gliders provided real-time temperature and salinity profiles to 1000m 10 times a day, and the data was transmitted in real-time into the GTS, into NOAA' Integrated Ocean Observing System (IOOS), and distributed through AOML web pages. The gliders followed predetermined tracks (Figure 2), which were adjusted during TC wind conditions. During their first mission, unique ocean observations under TC wind conditions were obtained during Tropical Storm Bertha in August 2014, and during Hurricane Gonzalo in October 2014 (Figure 3). Preliminary analysis shows that the observed upper ocean changes during Hurricane Gonzalo were mainly caused by surface mixing and entrainment, near-inertial oscillations, and intensified upwelling. A manuscript reporting the upper-ocean response to Hurricane Gonzalo is currently in preparation. The first mission ended in November, 2014, with the successful recovery of both gliders after the collection of over 2800 temperature and salinity profiles, and surface and depth averaged ocean current velocities. The data was used by the Navy in their global HYCOM analysis, which was incorporated by NOAA/EMC to initialize HYCOM-HWRF, the next–generation hurricane forecast model developed by NOAA/EMC, in real-time.

Figure 1: (left) R/V La Sultana of the University of Puerto Rico at Mayaguez. (right) AOML's underwater glider SG609 floating at the surface.

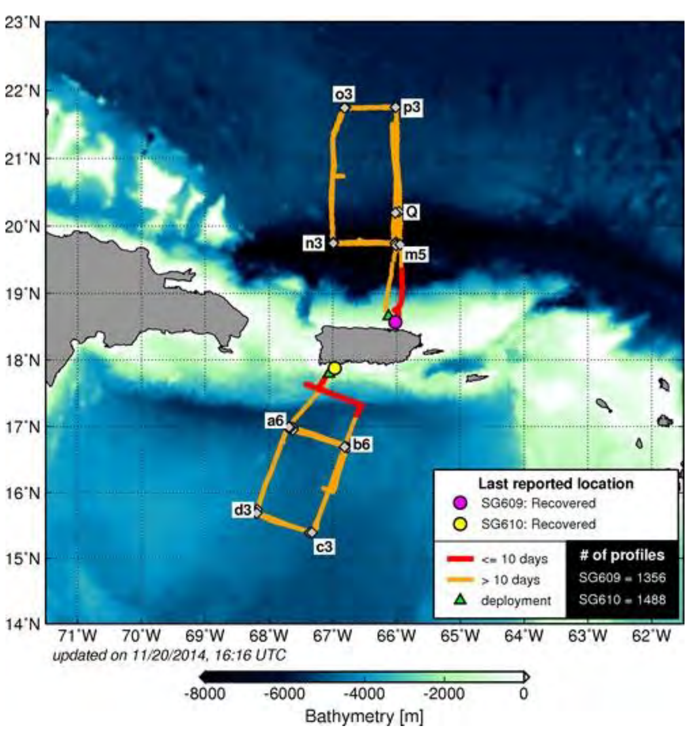

Figure 2: Location of the temperature and salinity observations collected by two gliders during their first mission carried out south and north of Puerto Rico from July-November, 2014. Over 2,800 profiles were collected during the first mission.

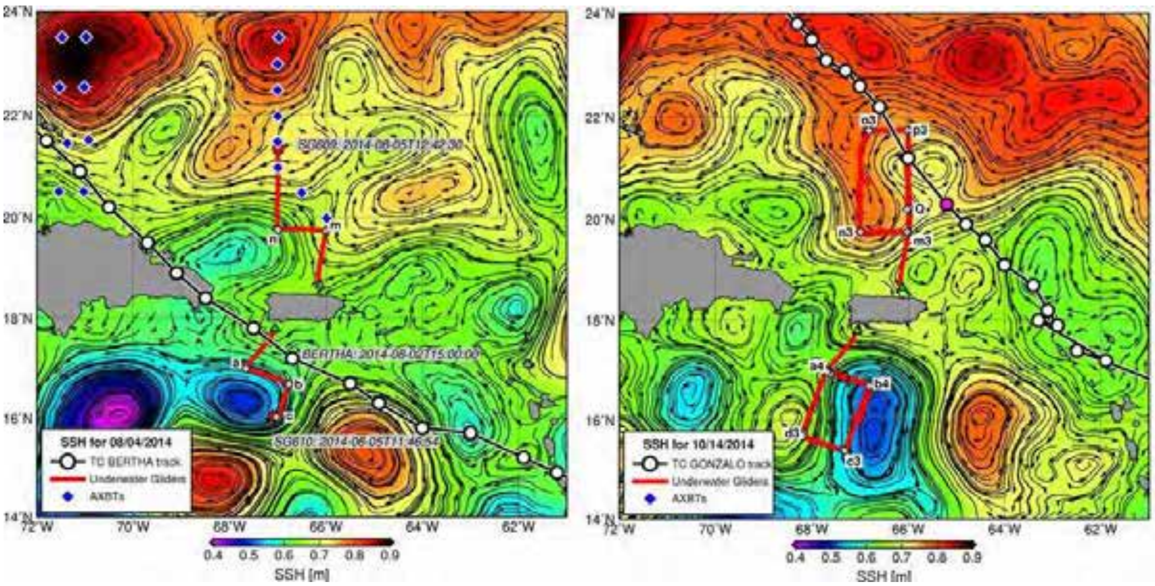

Figure 3: Tracks of (left) Tropical Storm Bertha in August, 2014, and of (right) Hurricane Gonzalo in October, 2014, overlaid on the altimetry-derived sea surface height (color shading) and geostrophic currents (arrows). Gliders tracks (thick red lines) and NOAA AXBT deployments (blue diamonds) are also shown.

On February 6, the second glider mission started with the deployment of two gliders in the Caribbean Sea, south of Puerto Rico, from the R/V La Sultana of UPRM (Figure 4). For this mission, a new sensor to measure dissolved oxygen concentration was installed on both gliders. The two gliders transected a region in the eastern Caribbean Sea providing over 2000 profile observations of temperature, salinity, oxygen and surface and depth-average current velocities until their recovery in April 27, 2015. Data from this mission was also distributed through AOML's webpages and transmitted in real-time into the GTS, into IOOS, and to modeling centers to better initialize the upper ocean conditions in this area for seasonal forecast of the Atlantic Warm Pool.

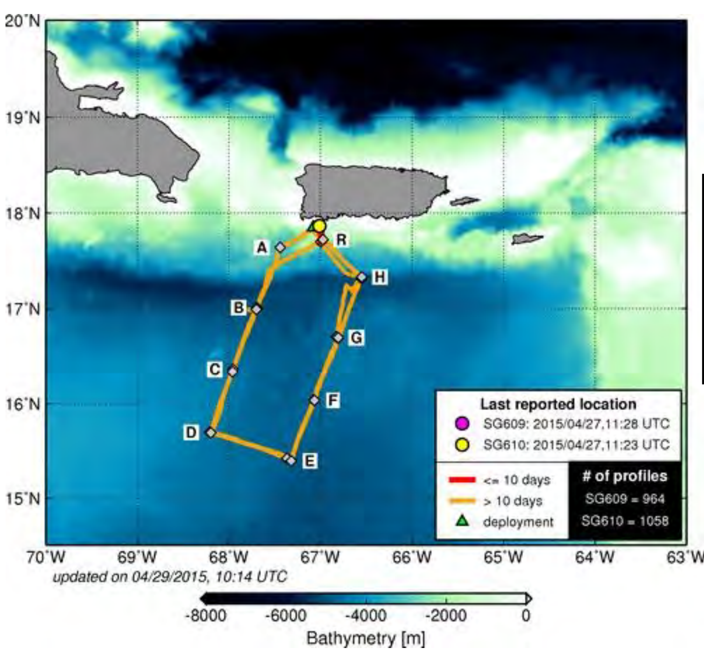

Figure 4: Location of the temperature, salinity, and dissolved oxygen observations collected by two gliders during their second mission carried out in the Caribbean Sea from February-April, 2015. Over 2,000 profiles were collected during the second mission.

Preliminary analysis of the impact of gliders data on forecast systems

The impact of the assimilation of ocean observations on reducing global Hybrid Coordinate Ocean Model (HYCOM) 48-h forecast errors in the eastern Caribbean Sea (75ºW - 55ºW and 5ºN - 25ºN) was assessed by partners at NRL. This assessment used an adjoint-based data impact procedure that characterizes the forecast impact of every observation assimilated, and it allows the observation impacts to be partitioned by data type, geographic region, and vertical level. The impact cost function is the difference between HYCOM 48- and 72-h forecast errors computed for temperature and salinity at all model levels and grid points. Figures 5 and 6 show the impacts of AOML/CIMAS's glider observations on reducing HYCOM 48-h temperature (ºC) and salinity (PSU) forecast error. Beneficial impacts are negative values, whereas nonbeneficial impacts are positive values. Results are pooled over the 01 Aug–15 Aug 2014 time period. The largest error reduction is due to the assimilation of temperature and salinity profiles from Argo and expendable bathythermograph (XBT). Assimilation AOML/CIMAS's glider data also effectively reduces global HYCOM 48-h forecast errors for both temperature and salinity. The beneficial impact by the gliders quite comparable to that by Argo floats (about 20 ~ 50%), suggesting that ***an observation system based on gliders is a viable option in the Caribbean Sea where Argo floats do not stay long or can hardly reach from the Atlantic Ocean***.

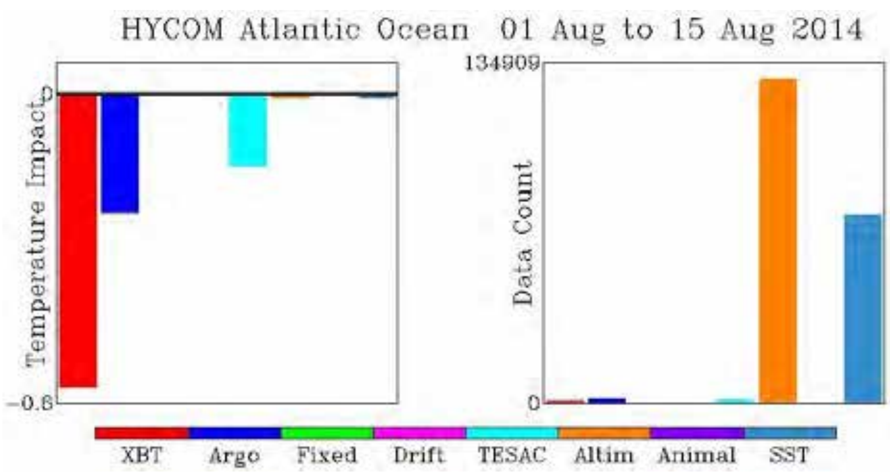

Figure 5: Impacts of the pilot glider profiles (TESAC) on reducing HYCOM 48-h (left) temperature (ºC) forecast error. Beneficial impacts are negative values, whereas nonbeneficial impacts are positive values. Results are pooled over the 01 Aug–15 Aug 2014 time period.

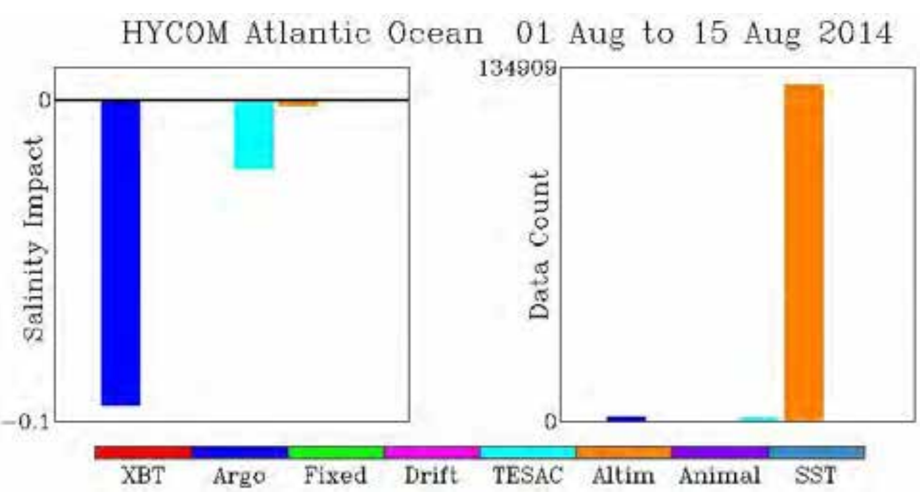

Figure 6: Same as Figure 3 except for salinity (PSU).

To evaluate the impact of glider's data on hurricane forecasts, different set of experiments are currently underway to optimize the data assimilation scheme used to incorporate observations from gliders on the forecast system. In one set of experiments, the idealized Hurricane Weather and Research Forecast (HWRF) of TCs with 1D HYCOM model coupling was developed with the latest HWRF version (v3.6) as part of the efforts toward building up a framework of HWRF idealized TC forecast with 1D and 3D HYCOM coupling. The simplified vortex and its environment in the idealized framework will allow researchers to isolate the factors affecting model performance on TC forecast and provide useful information to the operational forecast eventually. Two vortices with different sizes (radius of maximum wind or RMW of 50 km and 105 km) were generated to represent small and large storms and located at around 50º W and 20º N. The initial wind strength at RMW was 40 ms^{-1}. The earth curvature effect was allowed in this setup (Coriolis factor changed with latitude) so that even without any basic flow, the vortex would propagate slowly toward northwest due to the beta drift effect. To simulate storms with faster translation speeds, basic background flows of U = 2 and 6 ms^{-1} were added in the entire domain. The initial 1D ocean was initialized using a warm ocean profile with the initial SST of 29 ºC and Tropical Cyclone Heat Potential (TCHP) of 85 KJ cm^{-2}. In four days forecast of the idealized TCs, the storms moved to the northwest with an average translation speed of 1.4 ms^{-1}, 3.4 ms^{-1} and 7.7 ms^{-1} for basic flow U=0, 2 and 6 ms^{-1} respectively (Figure 7). For small storms, the tracks between coupled and non-coupled forecasts were similar with each other while the coupled forecast showed a more southward shift of the track compared with non-coupled forecast if the storm was large. The intensity difference between coupled and non-coupled forecast was also larger for large storms where the minimum sea level pressure of the non-coupled forecast was 10 hPa stronger at t=96 hours. The intensity of storms travelling faster was less affected by ocean coupling for both small and large storms.

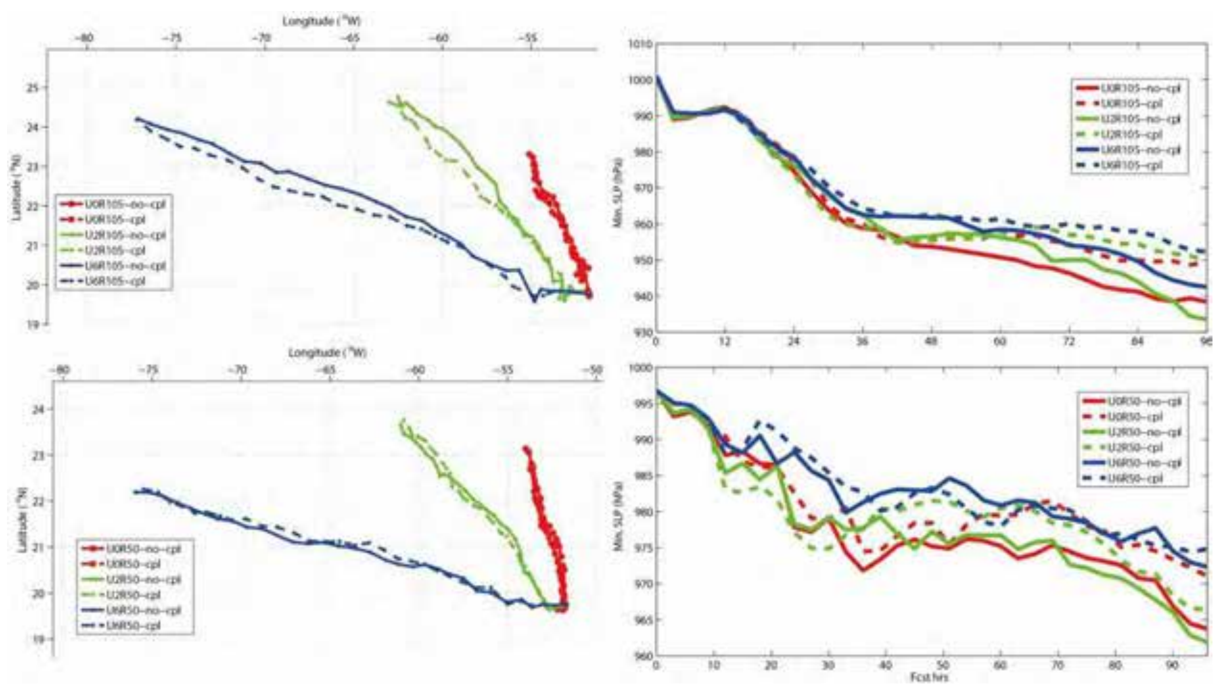

Figure 7: Left column: the predicted idealized TC tracks of twelve experiments for large storms (top left) and small storms (bottom left). Storm location plotted every 3 hours until 96 hours; Right column: the predicted minimum sea level pressure in hPa for large storms (top right) and small storms (bottom right). In the experiment names, "U" denotes the basic flow in ms^{-1} and "R" denotes the initial radius of maximum wind in km.

An additional set of experiments was conducted to investigate the sensitivity of Hurricane Edouard's (2014) forecast to Atlantic warm pool using an uncoupled high resolution (3 km) HWRF model. Five days forecasts were performed from 00 UTC Sep. 12 with the prescribed SSTs derived from Fleet Numerical Meteorology and Oceanography Center (FNMOC) high resolution ocean analysis for US Global Ocean Data Assimilation Experiment (GODAE) and Generalized Digital Environment Model (GDEM) climatology at September. The atmospheric initial condition and lateral boundary conditions were derived from Global Forecast System (GFS). Besides the year 2014, the FNMOC SST from previous years 2010 - 2013 at the same date and time were used to replace the 2014 FNMOC SST. In Figure 8, the prescribed SSTs from different experiments showed large variation in terms of Atlantic warm pool's location, size and strength. In 2014 and 2012, the Atlantic warm pool was strong and extended farther east to Sargasso Sea while much weaker warm pool retreated back to the west in 2013 and 2011. GDEM September climatology missed the warm pool completely in the region of interest. The track forecasts of Hurricane Edouard from all six experiments showed similar moving directions during most of the forecast hours (Figure 8). A larger impact from the location and size of Atlantic warm pool was observed on the intensity forecasts compared to the track (Figure 9). Three different groups were identified in the minimum sea level pressure prediction. Stronger storms were predicted with larger warm pools (year 2014 and 2012) which were closer to the best track. The SSTs with smaller warm pools lead to weaker storms. SST in the year 2010 had a relatively medium warm pool and an intensity forecast between the strong and weak storms.

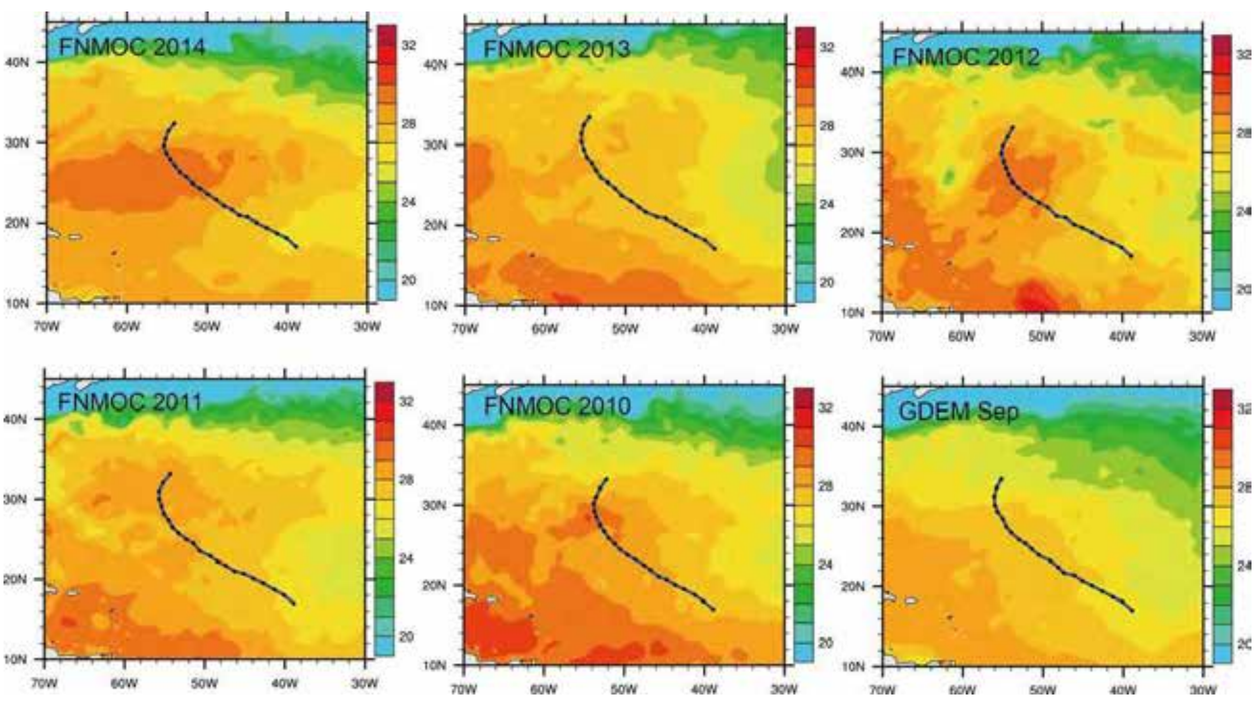

Figure 8: Prescribed SSTs for different experiments overlapped with 120 hours track forecast for each individual experiment (starting from 00 UTC Sep. 12 2014 plotted every 6 hours).

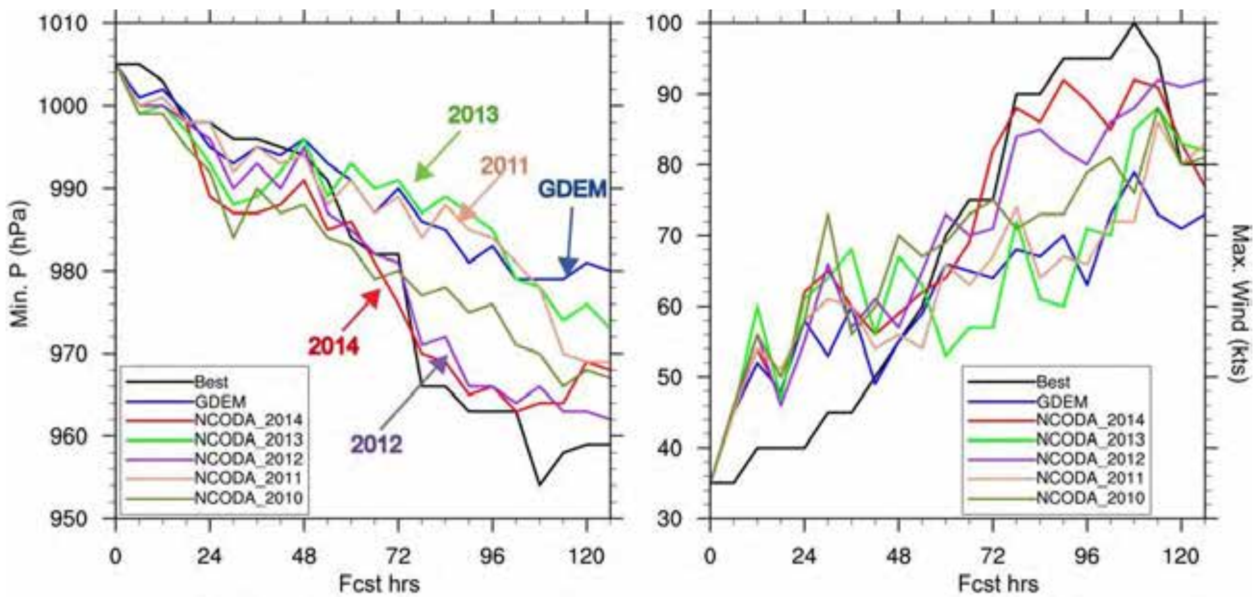

Figure 9: 120 hours minimum sea level pressure (left) and maximum surface wind forecasts (right) for Hurricane Edouard.

Research Performance Measure: All goals were met during this year with respect to real-time data transmissions and to the percentage recovery of good data. During July 1st, 2014 to June 30, 2015, over 4,800 temperature and salinity profiles were collected in the Caribbean Sea and Tropical North Atlantic.

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Developing the Operational Calibration/Validation Components for VIIRS SST Retrievals

Project Personnel: P.J. Minnett (UM/RSMAS)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To provide consistent, accurate SST fields derived from infra-red measurements from the VIIRS (Visible Infrared Imaging Radiometer Suite) on the Suomi-NPP satellite.

***Strategy*:** To acquire in situ measurements from drifting buoys, moorings and radiometers on ships, coincident with VIIRS satellite measurements, to support the development of accurate cloud identification algorithms and clear-sky atmospheric correction algorithms to derive SST's from VIIRS and to validate the VIIRS SST retrievals.

CIMAS Research Theme:

***Theme 3*:** Sustained Ocean and Coastal Observations

Link to NOAA Strategic Goals:

***Goal 3*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

NOAA Funding Unit: NESDIS **NOAA Technical Contact:** Alexander Ignatov

Research Summary:

The VIIRS was launched on the S-NPP satellite in the Fall of 2011 and the infrared bands were activated in February, 2012. The S-NPP is the prototype satellite of the future NOAA polar orbiting weather satellites, called JPSS (Joint Polar Satellite System), the first of which is scheduled for launch in 2017. The satellite series is planned to extend to 2038. Thus assessing the performance and improving the accuracy of VIIRS geophysical measurements is important and has long-term benefits. Our activities are focused on providing SST retrieval algorithms and associated coefficients based on matchups with in situ measurements from drifting and moored buoys, and ship-board infrared radiometers. In the past year we have continued to develop enhanced atmospheric correction algorithms to improve accuracies towards the edges of the swaths. VIIRS has a wider swath than the heritage sensors AVHRR and MODIS, meaning there is complete coverage of the globe twice per day, without gaps between the swaths of adjacent orbits. However, the SST retrieval problem is more severe towards the edges of the swaths because the atmospheric path length is three times that at nadir. Our new algorithms improve the accuracies of the VIIRS SSTs across the swath, with a marked improvement in accuracy at satellite zenith angles >45°, the cut-off angle for AVHRR SST retrievals, and >55°, the cut-off angle for MODIS SST (Figure 1). As the size of our match-up data base has grown since launch, we are now able to assess uncertainties at finer resolution of controlling parameters, and a recent result is the revelation of an asymmetry in the errors in the VIIRS SSTs as a function of satellite zenith angle. This is strongly indicative of a so-called "response versus scan angle" (rvs) problem that results from imperfect correction for the changing reflectivity as a function of incidence angle of a moving mirror in the optics of the instrument. In this case the "half-angle mirror" between the primary rotating telescope and the aft optics. This discovery is very recent and we are in the process of gathering pre-launch calibration measurements to help mitigate this source of error. Our efforts to provide more ship-board radiometric data continue, two M-AERI Mk2's installed on the *Allure of the Seas* and the *Celebrity Equinox.*

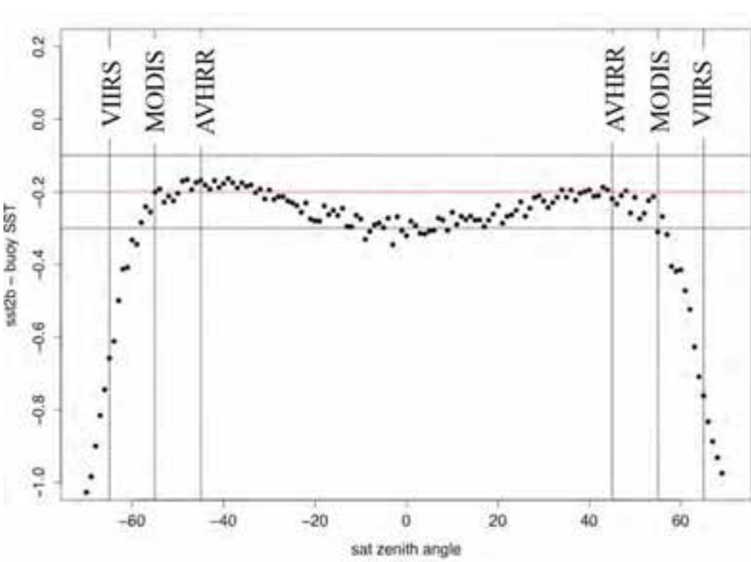


Figure 1: Errors in the VIIRS SSTs expressed as a function of satellite zenith angle. Our objective to bring the mean errors across the entire swath close to the red horizontal line, ideally within 0.1°C, as indicated by the black horizontal lines. The red line approximately marks the mean skin effect, which is the difference between the skin SST, the temperature of the ocean surface that emits the radiation detected by infrared satellite radiometers, and the subsurface temperature measured by the thermos-meters on drifting buoys. The vertical lines marked AVHRR and MODIS indicate the cut-off angles for SSTs derived from the measurements of these heritage radiometers.

Research Performance Measure: Our progress and accomplishments are in-line with the original objectives. The unanticipated discovery of a "response versus scan angle" effect of the "half-angle mirror" will likely set back progress next year as we will endeavor to develop a correction for this instrument artifact independently of improving the atmospheric correction algorithms.

Remote Sensing in Support of Climate Research

Project Personnel: R.C. Perez (UM/CIMAS)
NOAA Collaborators: G.J. Goni (NOAA/AOML)
Other Collaborators: J.A. Trinanes (University of Santiago de Compostela, USC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To develop a monitoring system for operational field missions and to implement new techniques for visualizing oceanographic & meteorological data over the Web.

***Strategy*:** Provide operational satellite monitoring capabilities in the Gulf of Mexico and Caribbean. Improve access to satellite Level0-4 products. Develop procedures and implement solutions for improving the rapid processing, visualization and distribution of remote sensing data and products. Provide solutions based on recognized standards for data and services. Promote integration of remote geospatial data sources by embracing and implementing service-oriented-architecture (SOA) solutions.

CIMAS Research Theme:

***Theme 3*:** Sustained Ocean and Coastal Observations (*Primary*)
***Theme 1*:** Climate Research and Impact (*Secondary*)

Link to NOAA Strategic Goals:

***Goal 3*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts (Primary)*

***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events (Secondary)*

NOAA Funding Unit: OAR/AOML and NESDIS **NOAA Technical Contact:** Molly Baringer

Research Summary:

A key outcome of this project is to develop and implement the technologies to provide raw and processed quality satellite products to scientists, decision-makers and the general public, ensuring reliable data availability and accessibility. The range of primary satellite products used by this project includes sea surface height, sea surface temperature, ocean color and surface winds. Work associated with this project involves management and operation of the High Resolution Picture Transmission (HRPT) satellite receiving station at NOAA/AOML. During this last year, we have continually received direct broadcast data from NOAA&EUMETSAT/POES satellites. Within this project, we provide NOAA/NESDIS Office of Satellite Data Processing and Distribution with rapid access to the raw telemetry and Level-1 products from a variety of sensors (HIRS, AMSU, MHS, DCS, SEM, ASCAT, etc). Additionally, all data collected from the Argos Data Collection System is sent to the Argos Data Processing and Distribution Centers in the U.S. and France.

During the past year, a 2.4-meter diameter satellite receiving antenna and associated processing and storage equipment was installed at AOML. This is the result of a joint agreement where NESDIS provided the funding for the grant award, AOML the infrastructure, and the University of Wisconsin-Madison/SSEC managed the project. The AOML site was chosen because its unique location with many advantages over other sites including immediate technical support; excellent line-of-sight that ensures optimal coverage of the Caribbean, Gulf of Mexico, and US East Coast regions; low radio-frequency interference; close interaction with federal and university researchers; synergy with local stakeholders; good bandwidth for rapid product dissemination; and, this site hosts the Caribbean and Gulf of Mexico

CoastWatch Regional node. The new system enables data acquisition from a new generation of polar satellites transmitting in X band. Real-time data are being delivered to NWS/NCEP for weather prediction. Additional SST and ocean color products are currently being developed, with the aim to integrate these products under the existing data distribution schema. The two stations greatly expand the range of satellites, and sensors received, and reduce the latency of information delivery.

Figure 1: New X-Band antenna on AOML's roof. It is protected from the environment by a radome, certified to 155 mph. The new system is capable to receive telemetry from the Suomi-NPP satellite and the future JPSS satellite missions.

The online data visualization package has been improved by adding the possibility to generate animations, export to KML, support spherical mercator projection, allow overlays, and include products from external servers. Current efforts are aimed to include in-situ data (from SOS servers) to combine them with satellite data. This work is ongoing and beta releases are being evaluated. This effort expands including the development of mobile applications for Android and IOS.

Several new data streams have been added to the suite of products, improving the quality and coverage of some of the existing ones. For example, for risk indexes associated with waterborne diseases, we are currently providing historical, operational and forecast fields, as well as daily and cumulative estimates. We have included as inputs to these indexes both satellite data and salinity fields from global and regional models.

Following NOAA/NESDIS/CoastWatch and NOAA/AOML requirements and goals towards promoting interoperability and information sharing, data distribution combines the traditional approach that provide direct access to data files through a URL, with other state-of-the-art technologies such as OPeNDAP, THREDDS, ERDDAP and OGC Web services (e.g. http://cwcgom.aoml.noaa.gov/thredds/catalog.html, http://cwcgom.aoml.noaa.gov/erddap/info/index.html). Through the implemented interfaces, users can download satellite products in a variety of commonly-used data and image formats such as MAT-files, NetCDF, and KML.

Figure 2: Weekly cumulative vibrio risk maximum displayed using the online viewer. Regions in Chesapeake Bay, Mississippi delta, and Brazil show significant risk. These fields are largely determined by sea surface temperature and sea surface salinity.

Within the Big Data (BD) approach taken in the last years, a new server was purchased to test BD techniques and methodologies. As part of this effort and after representing NOAA at the Copernicus BD Workshop that took place in Belgium, we attended the 2014 Conference on Big Data from Space (BiDS'14). BiDS'14 took place in Frascati, Italy, and the latest developments on BD processing and techniques were discussed at this meeting.

Europe's Copernicus programme relies on data from a constellation of satellites, the Sentinels, which will provide global monitoring capabilities. Last year, the first of these satellites, Sentinel-1A (S-1A), equipped with a C-band Synthetic Aperture Radar (SAR) was launched, and NOAA started testing and assessing European Space Agency data distribution framework and the quality of the products being provided. SAR data has many applications (such as oil detection, winds, waves, sea ice) and advantages, such as its all-weather capability. During the last year, a S-1A software package has been developed to-predict when the sensor will be over the region of interest (this feature allows users to know when data products will be available) and to automatically download S-1A data once the time and space intervals are provided. The software stores both the latest orbital information, as well as the historical records, which could lead to select delayed-time data in addition to the real-time products. Future improvements could also take into account the type of products we are interested in, as the swath size changes, as well as the sensor geometry.

In a joint effort between STAR/AOML&USF, we submitted a proposal to NOAA JPSS Proving Ground/Risk Reduction Call for Proposals. The main objective of this proposal is to develop and implement oil detection capabilities using visible imagery from the VIIRS sensor onboard Suomi-NPP.

Research Performance Measure: The research goals were met during this last year. New products have been developed and included for online distribution using open standards and protocols. New tools have been developed and improved for visualization and data access. These solutions have been integrated within a SOA framework.

The Ocean, Coastal, and Estuarine Network for Ocean Acidification Monitoring

Project Personnel: D. Pierrot, L. Barbero and K.Sullivan (UM/CIMAS)
NOAA Collaborators: R. Wanninkhof (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

Objective: Develop and implement a monitoring network for ocean acidification in the Gulf of Mexico, East Coast U.S., and open-ocean waters.

Strategy: To reoccupy coastal transects, and ships of opportunity to quantify the changes in - and causes of- ocean acidification.

CIMAS Research Theme:

Theme 3: Sustained Ocean and Coastal Observations

Link to NOAA Strategic Goals:

Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems* (*Secondary*)

NOAA Funding Unit: OAP/OAR **NOAA Technical Contact:** Libby Jewett

Research Summary:

This effort implements the North Atlantic Ocean, East and Gulf Coast Ocean Acidification (OA) observing system in response to the requirements of the Federal Ocean Acidification Research and Monitoring (FOARAM) Act. The observing system is used to determine patterns and trends in key indicators of ocean acidification. The observing network of the East and Gulf Coast is comprised of the following elements:

- Surface water measurements of ocean acidification using autonomous systems on 2 ships of opportunity (SOOP-OA).
- A dedicated research cruise, the East Coast Ocean Acidification (ECOA) cruise on the *NOAA ship Gordon Gunter* with surface and subsurface measurements to develop process level understanding of the controls on ocean acidification.
- The continued development of the observing system.

The development component includes analysis of pH, total alkalinity (TA) and dissolved inorganic carbon (DIC) samples taken on the SOOP-OA and other cruises. Data reduction, quality control and data management of the large data sets that are obtained are a critical component of the observing system. Data products and algorithms to extrapolate the OA indices in time and space are developed as part of the effort. Assistance with analyses and protocols is provided to other groups including those studying OA impacts on coral reef systems. The work involves partners at AOML, CIMAS, and NOAA/NMFS/NEFSC.

During the performance period we interpreted results from an oceanographic research cruise studying OA in the Gulf of Mexico, GOMECC 2, and compared the observations with the first occupation in 2007 (Wanninkhof et al., 2015). The comprehensive determination of inorganic carbon system parameters provides needed inputs to determine the aragonite saturation state. Comprehensive data reports, metadata and data were submitted to the NOAA NCEI (National Center for Environmental Information) (formerly NODC). A significant result was the finding that large changes in saturation state were encountered between 2007 and 2012 that are explained by large changes in the Loop Current, Gulf Stream, and Labrador Shelf Current along the Eastern Seaborne (Figure 1).

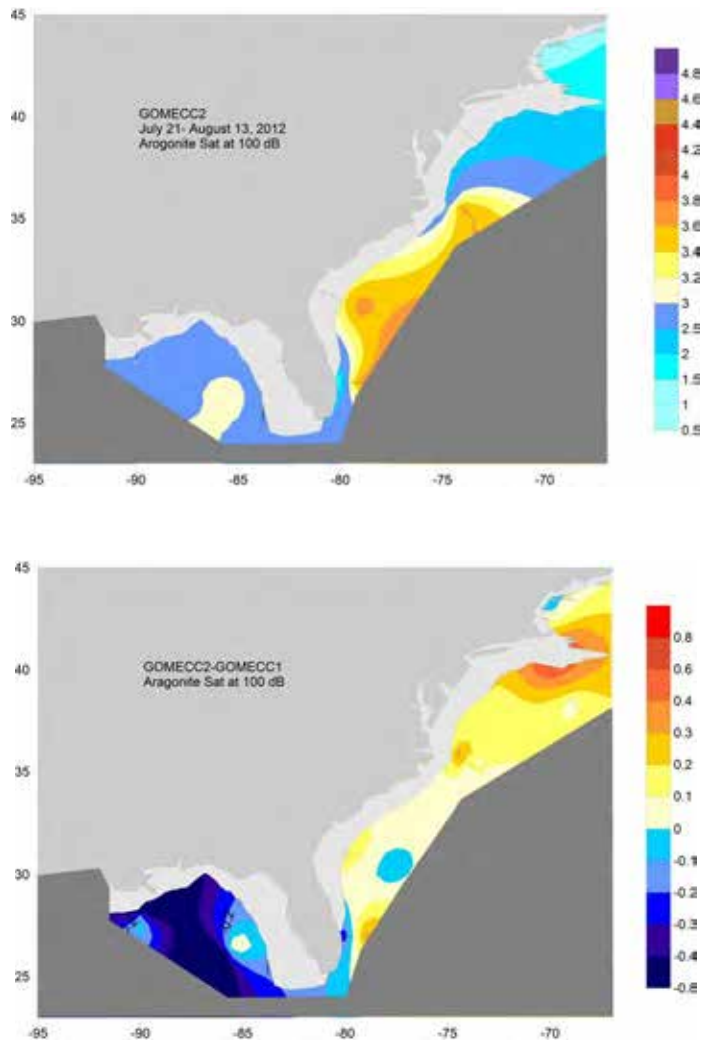


Figure 1: The aragonite saturation state, $(\Omega)_{Ar}$ at 100-m depth from the GOMECC-2 cruise (top) and the difference with GOMECC-1 (July 2007)(bottom). The research cruises are currently the only means to obtain subsurface data. The differences between 2007 and 2012 are attributed to changes in large-scale current structures in the Gulf of Mexico and in the Northeastern coastal seas. This is the first time the large changes in OA have been attributed to changes in currents and have provided key insights on the mechanisms governing OA trends in the realm (Wanninkhof et al., 2015).

As part of the OA effort we are establishing a monthly climatology of surface water ocean acidification parameters in the Gulf of Mexico in coordination with other participants of the North American Carbon Program and the Ocean Carbon and Biogeochemistry Program. This is possible by the large increase of observational data that has been obtained from the ship of opportunity programs run by our group.

Research Performance Measure: Provide quality-controlled data that is used to determine patterns and rates of OA in the realm. The data from the cruises has been submitted on time to the NCEI and were released to the public in 2014.

Surface Water Partial Pressure of CO_2 (pCO_2) Measurements from Ships

Project Personnel: D. Pierrot, K. Sullivan and L. Barbero (UM/CIMAS); F.J. Millero (UM/RSMAS)
NOAA Collaborators: G. Goni and R. Wanninkhof (NOAA/AOML)

Long Term Research Objectives & Strategy to Achieve Them:

Objectives: Constrain regional air-sea CO_2 fluxes to 0.2 Pg C/yr
Strategy: Sustained observations using automated pCO_2 systems on ships of opportunity

CIMAS Research Theme:

Theme 3: Sustained Ocean and Coastal Observations

Link to NOAA Strategic Goals:

Goal 3: Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

NOAA Funding Unit: COD/CPO **NOAA Technical Contact:** Kathy Tedesco

Research Summary:

The ship-based surface pCO_2 program is designed to provide sustained measurements of regional oceanic carbon sources and sinks on seasonal timescales by measuring surface water and marine boundary pCO_2 on ships of opportunity (SOOP). It is a collaboration of investigators at the NOAA laboratories AOML and PMEL, and the following academic institutions: Columbia University, the University of Miami, and the Bermuda Institute of Ocean Sciences. It is the largest program of its kind in the world. The program contributes to the goal of creating regional flux maps on seasonal timescales to quantify uptake of anthropogenic CO_2 by the ocean and short-term changes thereof. In the performance period the NOAA funded participants maintained instrumentation and reduced the data from six ships and posted the data. Flux maps, based on extrapolation routines using remotely sensed wind and sea surface temperature (SST) have been created to estimate global sea-air fluxes on seasonal time scales.

An appreciable focus continues to be global coordination of similar efforts. We have taken the lead in providing uniform autonomous instrumentation for installation on ships of opportunity. Through a successful technology transfer and continued guidance, General Oceanics, Inc. in Miami is producing units for the community at large. We are also leading an effort for uniform data quality control procedures and data reduction that now is used as a standard for the International Carbon Coordination project (IOCCP) of UNESCO/IOC. A major product, the Surface Ocean Carbon Atlas (SOCAT) version 3 containing over 19 million pCO_2 data points, will be released in September 2015 (Fig. 1). Efforts to produce SOCAT version 4 are underway.

As part of the project, improvements in auxiliary data such as sea surface temperature (SST) and sea surface salinity (SSS) from thermosalinographs (TSG) have been made. Currently the NOAA ships *Ronald H Brown* and *Gordon Gunter*, cruise ship *Equinox* and the container ship *Skogafoss* are transmitting TSG data in near-real time. All of the ships that are part of the project send complete daily files of pCO_2 to shore via internet or Iridium.

Research Performance Measure: Produce and update a global surface water CO_2 database.

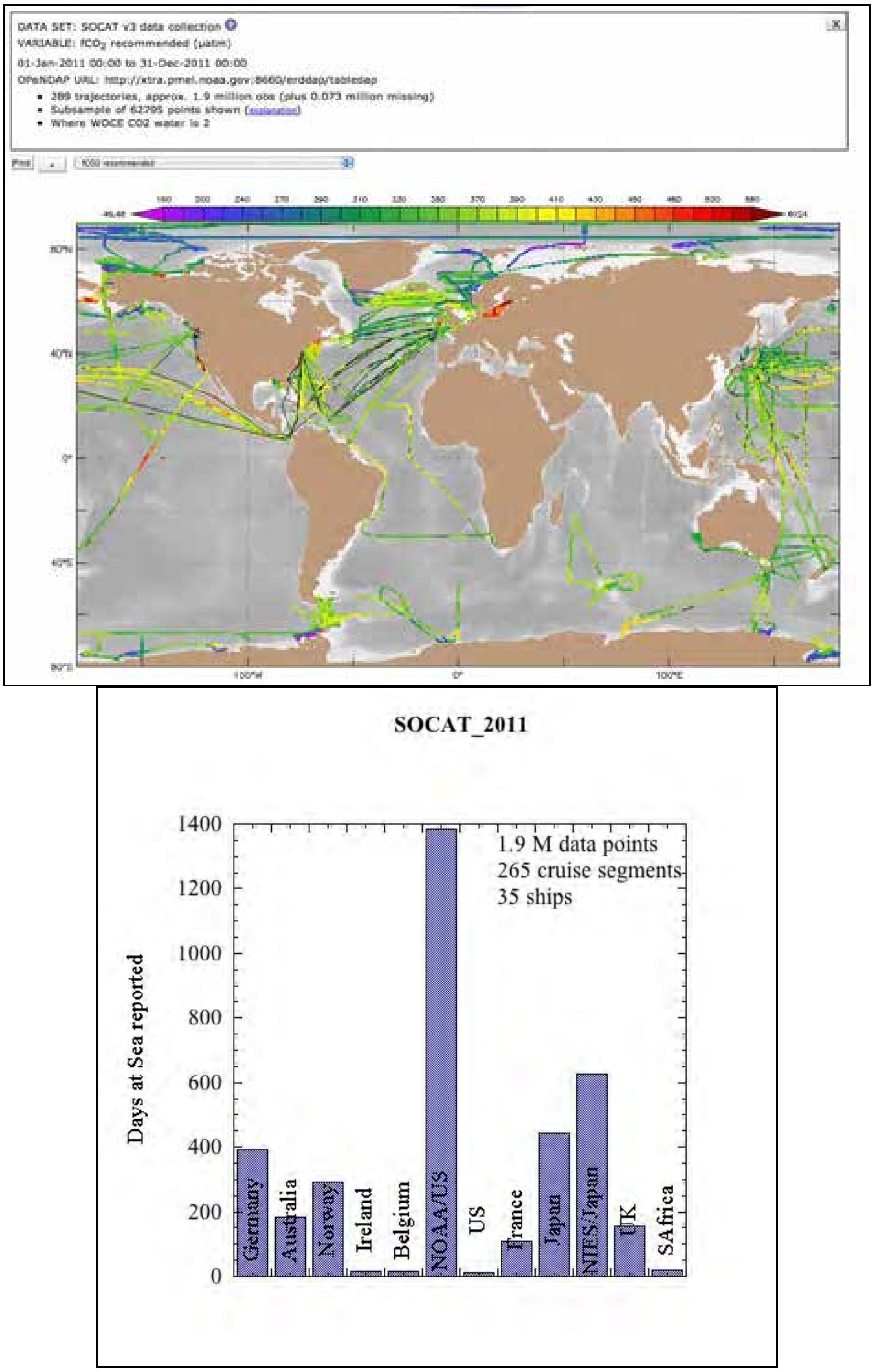


Figure 1: Cruise tracks where pCO_2 data were obtained for SOCAT for 2011 (top). Number of days of pCO_2 data for different contributors in the SOCAT database (www.SOCAT.info) (bottom). The NOAA funded consortium and associated partners are the largest contributors.

Coral Health and Monitoring Program (CHAMP)

Project Personnel: R. van Hooidonk, X. Serrano, I.C. Enochs, P.R. Jones, N. Amornthammaron, R. Carlton, G. Kolodziej, L.Valentino, M. Jankulak, K. Helmle, T. Burton, L. Olinger and K. Peables (UM/CIMAS); L.J. Gramer (UM/CIMAS and USF/FIO)

NOAA Collaborators: J. Hendee, D. Manzello and Michael Shoemaker (NOAA/AOML)

Other Collaborators: C. Hu and B. Barnes (USF); A. Soloviev and C. Dean (NSU); P. Fletcher (Sea Grant)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** 1) Facilitate in situ observations at coral reef areas, 2) integrate in situ, remote sensing, and other environmental data so as to better understand the physical and biogeochemical processes that affect the health and life cycles of organisms in the reef ecosystem, 3) compile forecasts for coral reef ecosystems to help to understand them, and to aid in decision support for Marine Protected Area management, 4) reconstruct coral growth and calcification records over the past centuries in order to identify baseline values, variability, and limiting environmental controls, 5) assess the effects of naturally-occurring CO_2 variation in the Florida Keys on the persistence of reef structures, biodiversity of their associated fauna, and growth/calcification of multiple species of coral, 6) develop climatologies and near real-time anomaly products for remote and in situ sensing of physical and biochemical conditions on monitored coral reefs, 7) assess the synergistic effects of thermal stress and nutrient enrichment in the early life stages of two Caribbean coral species, and 8) apply ongoing research in shallow-ocean fluid dynamics to improved understanding and conservation of coral reef ecosystems.

***Strategy*:** Construct and operate meteorological and oceanographic monitoring platforms near designated coral reefs; provide information to managers on small-scale geographic variations in thermal stress and cross-reef exchange with deeper ocean water, based on an improved understanding of the physical environment of reefs; provide data archiving and artificial intelligence tools to facilitate the acquisition and integration of high-quality data from these and other reef areas worldwide; utilize an integrated analysis of coral growth records, bioerosion monitoring units, settlement plates, as well as long-term records of carbonate chemistry, oceanographic, and meteorological conditions, to identify the past and present limiting controls on coral growth, reef structure, and community composition in order to improve ecosystem-based management of threatened coral reef resources; use state of the art climate models to forecast temperature and ocean acidification conditions on coral reefs on decennial to century scales; and conduct controlled-laboratory experiments to assess the effects of climate change and land-based sources of pollution.

CIMAS Research Theme:

***Theme 3*:** Sustained Ocean and Coastal Observations (*Primary*)
***Theme 1*:** Climate Research and Impact (*Secondary*)
***Theme 5*:** Ecosystem Modeling and Forecasting (*Tertiary*)

Link to NOAA Strategic Goals:

***Goal 3*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts* (*Primary*)

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems* (*Secondary*)

NOAA Funding Units: OAR/AOML, NOS/CRCP, OAR/OAP
NOAA Technical Contact: Molly Baringer

Research Summary:
The Coral Health and Monitoring Program (CHAMP) encompasses a wide array of coral-related research efforts accomplished by CIMAS personnel along with NOAA collaborators. This past year, CHAMP debuted a redesigned website that can be found at http://www.coral.noaa.gov. With this release the site takes on a cleaner, more modern look and becomes smartphone- and tablet-friendly, adapting its menus, image sizes and page organization seamlessly to accommodate the size of the visitor's browser window (Fig. 1). Among other upgrades the site features expanded personnel bios of CHAMP team members and highlights the activities of the newly christened Acidification, Climate, and Coral Reef Ecosystems TEam (ACCRETE).

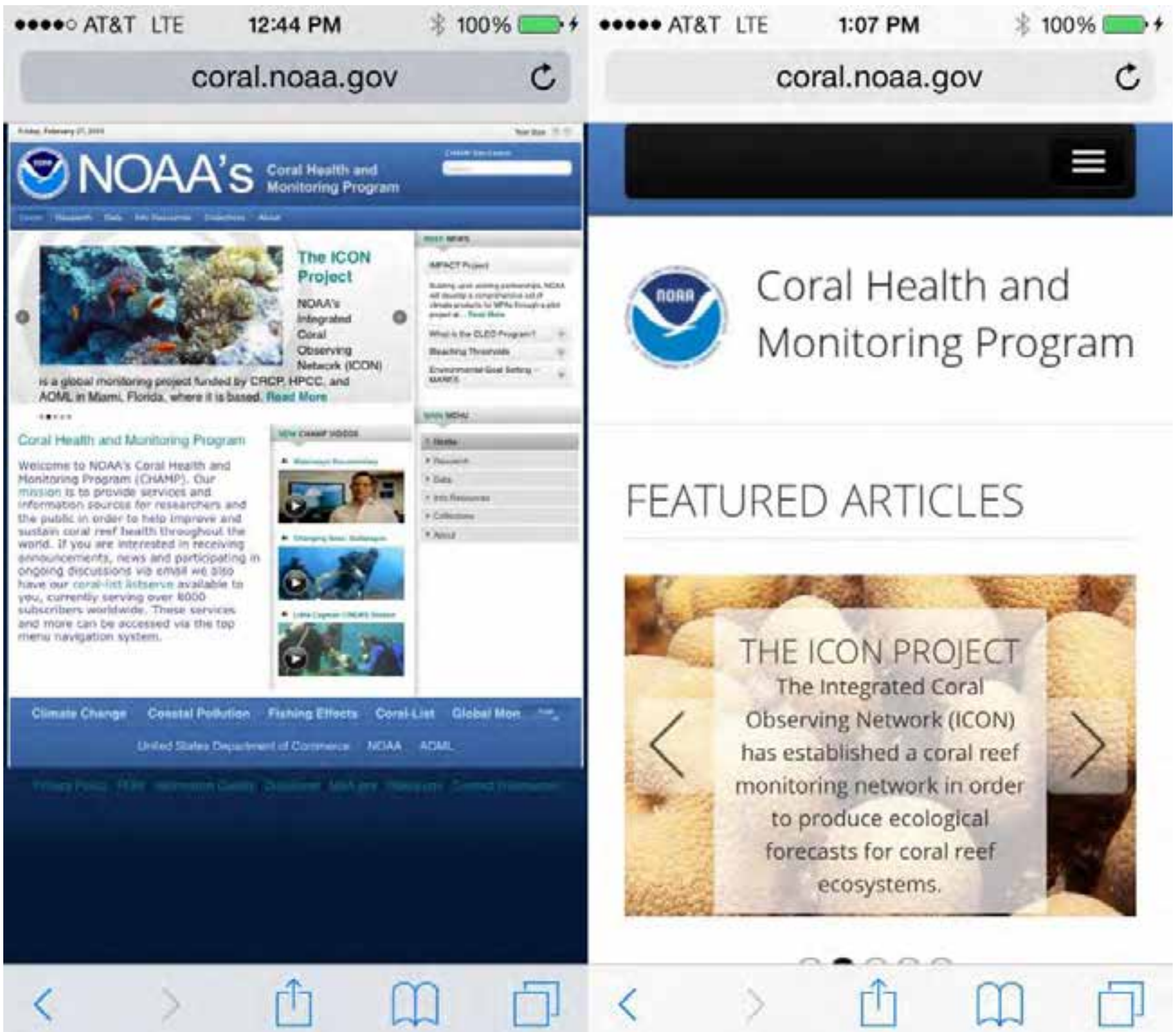


Figure 1: The CHAMP web site before (at left) and after, as loaded into the browser of an iPhone 5S.

CHAMP's Coral Reef Early Warning System (CREWS) continues to operate a network of buoys in the near vicinity of coral reefs throughout the Caribbean, working in partnership with the Caribbean Community Climate Change Centre (CCCCC or 5Cs). The one-year deployment anniversaries of two buoys in Tobago and one in Little Cayman were observed with annual maintenance operations, which brought those buoys to land for refurbishment and instrument replacement (Fig. 2). CIMAS personnel lent their programming expertise to update the logic of the Little Cayman buoy, and are now engaged in a full evaluation and programming rewrite of a buoy that will be deployed in Belize later this year. Other new buoys are planned in the near future for Barbados and the Dominican Republic.

Figure 2: The CREWS buoy was brought to shore early in 2015 to troubleshoot a power failure.

The ACCRETE lab is actively researching how climate change and ocean acidification will, and, already are, affecting the construction (coral growth, calcification) and breakdown (bioerosion, dissolution) of coral reef ecosystems, as well as the associated ramifications this has for ecosystem function (e.g., biodiversity). To this end, ACCRETE scientists utilize a unique interdisciplinary approach that incorporates aspects of biology, chemistry, and geology within an ecological framework. Through field, laboratory, and modeling studies, this laboratory is improving our understanding of the rate and magnitude of climate change and acidification on coral reefs, as well as the ecological impacts of these changes.

This year, ACCRETE/CIMAS personnel, Ian Enochs, Paul Jones, Renee Carlton, Graham Kolodziej, and Lauren Valentino continued implementation of the National Coral Reef Monitoring Plan (NCRMP), and climate/ocean acidification (OA) monitoring therein. NCRMP assets were deployed in St. Thomas, St. John, and throughout Puerto Rico, as well as in the SEFCRI region of Florida. These monitoring units included high-accuracy temperature loggers, as well as biodiversity, calcification, and bioerosion monitoring units. Bioerosion monitoring units constructed by CIMAS personnel were also deployed by collaborators at NOAA/CRED throughout American Samoa.

ACCRETE's NCRMP team continues to oversee data collection at sites throughout Florida, the Gulf of Mexico, the Caribbean and the Pacific. The most data-rich of these sites includes the MAPCO2 buoy located at Cheeca Rocks in the Florida Keys, the site of the Atlantic Ocean Acidification Testbed (AOAT). Ian Enochs, Mike Jankulak, Renee Carlton, Lauren Valentino, and Graham Kolodziej continued support and monitoring activities at the AOAT. Activities included carbonate budget surveys, high-resolution photo-mosaics, fish surveys, quantification of coral growth using coral cores, collection and processing of calibration/validation water samples, as well as electronics replacement and servicing of the MAPCO2 mooring.

CIMAS/ACCRETE PI Ian Enochs led a CRCP-funded expedition to the remote island of Maug in the Northern Marianas. Along with collaborators from Scripps, the Bigelow Lab, and local monitoring agencies CRM/DEQ, Ian collected data to characterize the unique ecology and carbonate chemistry of coral reefs surrounding subsurface volcanic CO_2 vents. Data were subsequently analyzed and are now in review.

ACCRETE personnel, along with collaborators from University of Miami, Mote Marine Laboratory, The Nature Conservancy, and NSU continued a project to evaluate the potential for natural OA refugia to enhance the growth of reef corals to be out-planted for restoration purposes. In-house instrumentation and water chemistry analysis was used to evaluate and monitor existing coral nursery and restoration operations. Elevated growth rates due to naturally high aragonite saturation states could increase the efficiency of restoration activities and allow for the advancement of these operations despite the ongoing deleterious effects of OA. This year, collaboration with NOAA PI Chris Kelble, and CIMAS scientist Lindsey Visser has led to periodic data collection throughout the Floriday Keys on board the RSMAS ship, the RV Walton Smith. This has provided valuable data and increased the spatial and temporal coverage of this project.

ACCRETE scientists conducted coral reef monitoring associated with the Numeric Nutrient Criteria (NNC) study, involving monitoring three replicate reef sites at each of four reefs (Fig. 3A). Reef biometric data was generated using the EPA Stony Coral Rapid Bioassessment Protocol and the Periphyton Rapid Bioassessment Protocol to assess nuisance algal growth. The two-year data collection period is approximately 75% complete. Benthic surveys provide information on coral abundance and health using SCUBA-based in-situ measurements (Figs. 3B and 3C), as well as seasonal fluctuations in total benthic organismal abundance by analysis of photo-quadrats (Fig. 3D). The water sampling of the study is providing accurate measurements of nutrient levels (total Nitrogen and Phosphorous), phytoplankton abundance (chlorophyll a) and other parameters (turbidity, temperature, salinity etc.), which will be used in conjunction with this data to assess nutrient criteria for reef development.
Concurrently, and in association with the NNC project, ACCRETE scientists are collecting water samples to measure the carbonate chemistry at these sites. Repeat monitoring sites were established this year and carbonate budget surveys were conducted to begin to elucidate how natural variation in carbonate chemistry influence reef growth and benthic composition.

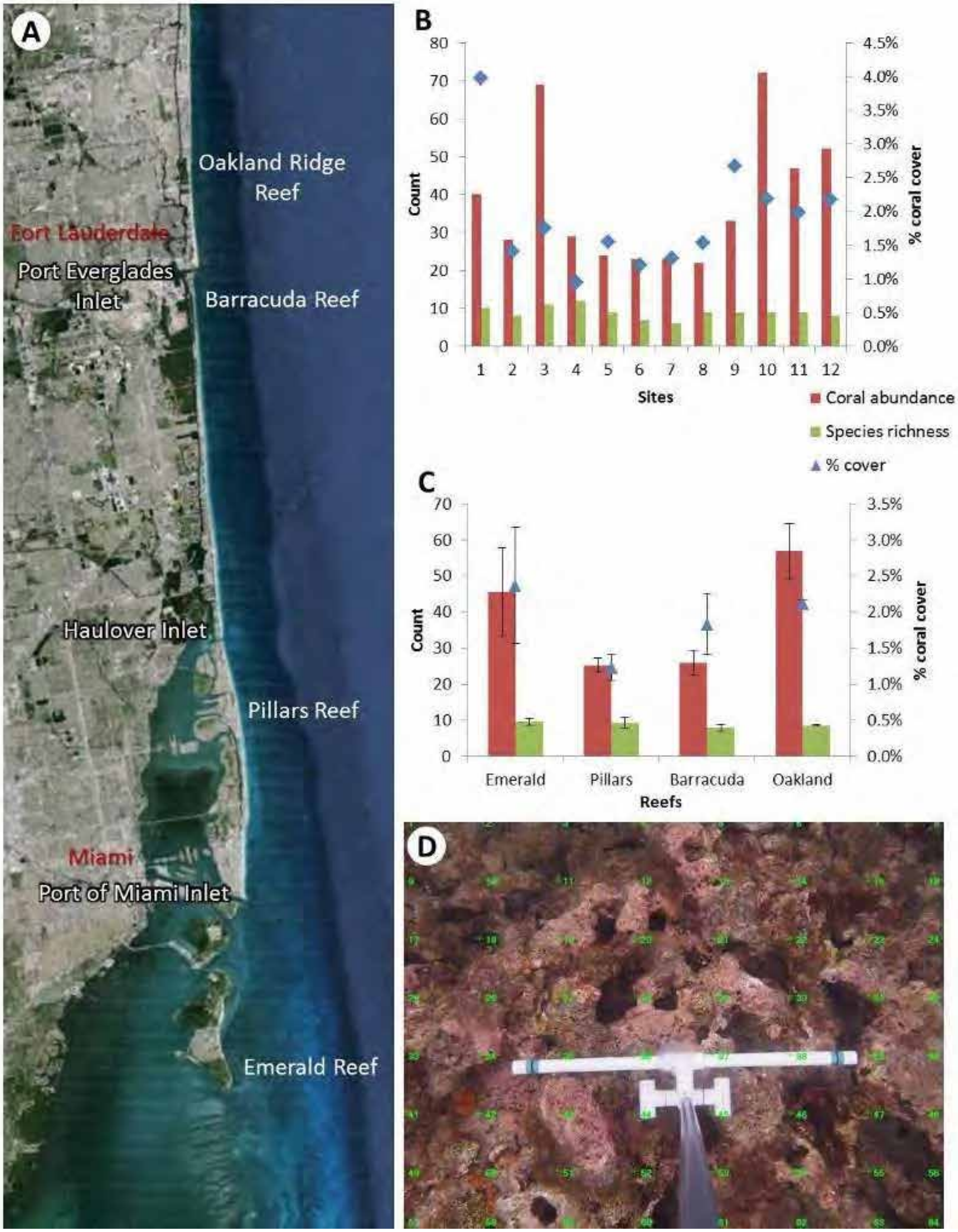


Figure 3: (A) Locations of the 4 reef sites visited for water quality sampling and benthic surveys; Coral abundance data for (B) each site surveyed and (C) summarized by reef; (D) Example of a photo quadrat used for benthic cover analysis.

In a collaborative effort with CIMAS scientist Sang-Ki Lee and Yanyun Liu, CIMAS scientist Ruben van Hooidonk utilized a state of the art, high resolution, regional ocean model and statistically downscaled fully coupled global models from the 5th Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR5) to project temperature stress on coral reefs in the coming century. These high-resolution projections provide detailed projections that can inform reef managers and policy makers. To supplement these efforts, near real time monitoring products of OA were developed using remote sensing. These products monitor pH, aragonite saturation state and total alkalinity in the wider Caribbean and the gulf of Mexico and are made available to the wider public on our website http://www.coral.noaa.gov/accrete/oaps.html (Fig. 4). In addition, projections of aragonite saturation state were used in a collaborative effort with the National Socio-Environmental Synthesis Center (SESYNC) to identify shellfisheries in the US vulnerable to the impacts of ocean acidification.

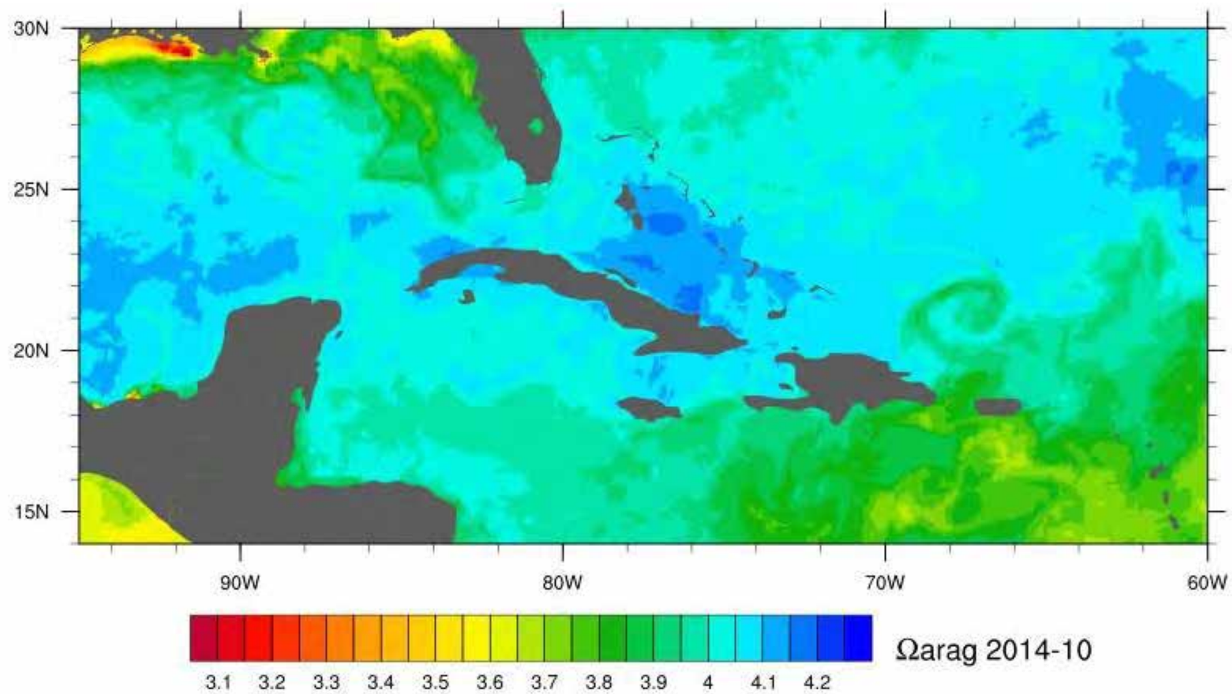


Figure 4: An image from the Ocean Acidification Product Suite showing aragonite saturation state computed from remotely sensed variables.

In a collaborative effort with RSMAS professor Dr. Andrew Baker and NOAA/NMFS scientist Dr. Margaret Miller, CIMAS scientist Xaymara Serrano conducted laboratory-controlled experiments with newly-settled coral recruits from the species *Porites astreoides* and *Orbicella faveolata* (Fig. 5), with the goal of investigating the synergistic effects of nutrient enrichment and elevated sea surface temperatures on the ecology, genetics and photophysiology of these species. Experiments were conducted at the new Marine Technology and Life Science Seawater (MTLSS) building. These recruits were exposed to three different nutrient levels (control conditions, 5uM $NaNO_3$ and 10uM $NaNO_3$) and two different temperature treatments (26°C or 31.5°C) in replicate aquaria. Throughout the duration of the experiments, an array of molecular and ecological techniques were applied to: (1) quantitatively monitor how coral recruits change the density of their symbionts in response to changes in nutrients and how these changes subsequently affect thermal tolerance, (2) assess how bleaching susceptibility may depend on the genetic identity of the coral or its algal symbionts and (3) monitor the photosynthetic efficiency of nutrient-enriched coral recruits (reduction in photosystem II quantum yield) prior, during and post-thermal stress.

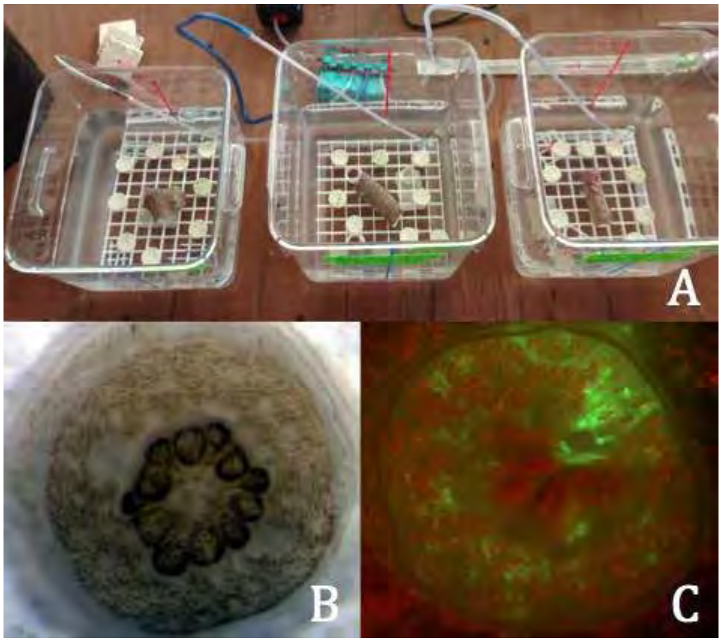


Figure 5: (A) Coral recruits (in settlement tiles) exposed to 2 different nutrient levels (5 and 10 μM NO_3) and control conditions. Coral recruit after exposure to 10 μM NO_3 for 3 weeks and observed in the microscope without (B) or with (C) fluorescence. Algal symbionts can be seen as brown (B) or red (C) spots in the pictures.

CIMAS researcher Dr. Lew Gramer has continued utilizing his doctoral and post-doctoral research to improve methods for dynamically downscaling basin- and climate-scale model, reanalysis, and remote-sensing products, to allow more accurate predictions of physical stress on corals and other benthic ecosystems. The aim of this research is to provide significant improvements in predicting resilience of shallow marine ecosystems to long-term environmental change, allowing environmental resource managers and reef restoration programs to plan and utilize scarce capital and human resources more effectively for environmental conservation and restoration. In 2014-2015, Gramer calibrated new indices for coral reef thermal stress at very fine (order 100 m) scale, for use in a reef resilience prioritization and planning tool being developed by the NOAA National Centers for Coastal Ocean Science (NCCOS) and other partners. This is planned as an ongoing project in multiple U. S. jurisdictions, but initial efforts have focused on the U. S. Virgin Islands (Fig 6). In addition, he has served since 2013 as principal investigator on two other related projects as part of NOAA CHAMP (below).

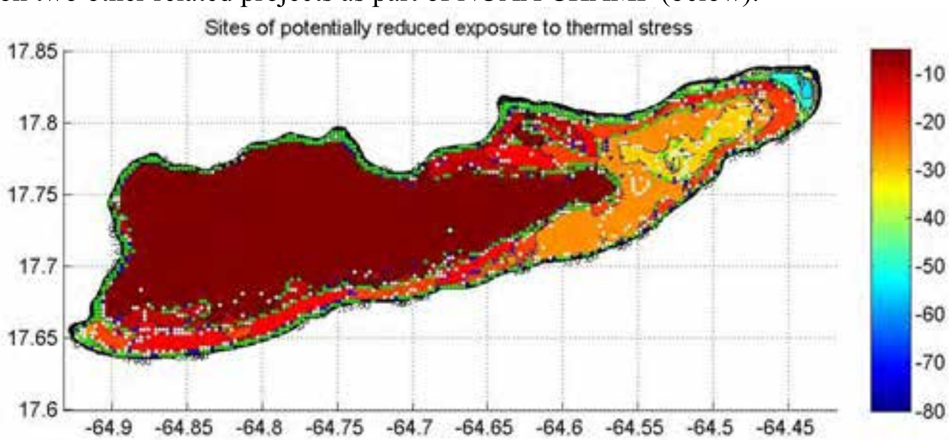


Figure 6: Bathymetric map of the shallow, narrow shelf of St. Croix, USVI, showing individual 270x270 m squares where benthic organisms are predicted to experience somewhat (white), moderately (blue), or significantly (green) lower impact from thermal stress, during future periods of higher regional-scale sea temperature but low to moderate wind and surface waves.

Sediment on reefs and adjacent coastal areas: information tools for managers in American Samoa, South Florida, CNMI (NOAA Coral Program Project 881)
Dr. Gramer has collaborated with Prof. Chuanmin Hu and Dr. Brian Barnes (University of South Florida) and instrumental scientist Dr. Amornthammarong of CIMAS/AOML on Year Two products from a NOAA CRCP-funded three-year project to monitor turbidity over shallow reef waters in southeast Florida, American Samoa, and the Commonwealth of the Northern Mariana Islands. In 2014-2015, customized ocean color data products were generated by USF partners, and analyzed by Gramer for each of these three regions. These data are generated at 250m spatial resolution, with forward processing occurring in near-real time. This processing methodology has been applied to the entire MODIS Aqua dataset (2002 – present) for these regions in order to generate long-term time series of derived products. From this dataset, time series at individual locations have been extracted, with the goal of identifying locations for sensor deployment with maximal quantity and quality of concurrent satellite data. Several data products have been examined to determine the factors contributing to speckling noise which limits accuracy of satellite retrievals. One conclusion is that insufficient masking of pixels affected by stray light may contribute to product uncertainty. These satellite ocean color products have been analyzed to understand the impact of the port of Miami dredging on turbidity plumes, and their impact on coral reefs. A manuscript is being drafted by USF partners, for submission to the journal Remote Sensing of Environment. 2015 also saw the assembly of a new sensor package by Dr. Amornthammarong and Michael Shoemaker at AOML to gather in situ measurements of turbidity; this sensor package has been deployed near Miami Channel in Florida, and will be deployed in the other two jurisdictions over time. These data allow calibration and validation of an algorithm to estimate nephelometric turbidity unit (NTU) time series from the ocean color data in key areas of each jurisdiction, across the full data period of MODIS Aqua (2002 – present).

Identifying LBSP management options: Quantifying the contribution of upwelling to LBSP on SE Florida reefs by sub-watershed (NOAA Coral Program Project 789)
Dr. Gramer also collaborated with Profs. Brian Walker and Alexander Soloviev (Nova Southeastern University), and Luke McEachron (Florida Fish and Wildlife Commission) to gather and analyze oceanographic data on upwelling in southeast Florida; the goal of this collaboration is to characterize the role of upwelling in the nutrient mass budget of the northern Florida reef tract. Approximately fourteen (14) years of acoustic Doppler current profiler (ADCP) ocean current profiles, and sea temperature data at multiple sites, have now been analyzed for the region, with continuous data covering all hurricanes and tropical storms that passed south Florida during the period (Fig 7). Analyses of summer periods between storms suggest that upwelling driven by mechanisms other than wind consistently delivers cool water masses onto the shallow shelf of southeast Florida during each summer; temperature observations at multiple sites from Miami-Dade to Martin Counties confirm that such rapid cooling events occur along the entire approximately 100 km of the northern reef tract each summer. Furthermore, during several tropical weather events, sea temperature drops of greater than 2°C were observed at 11 m depth near shore, with significant resulting alteration to heat fluxes. An example of this during passage of Hurricane Wilma in 2005 is shown in Figure 7.

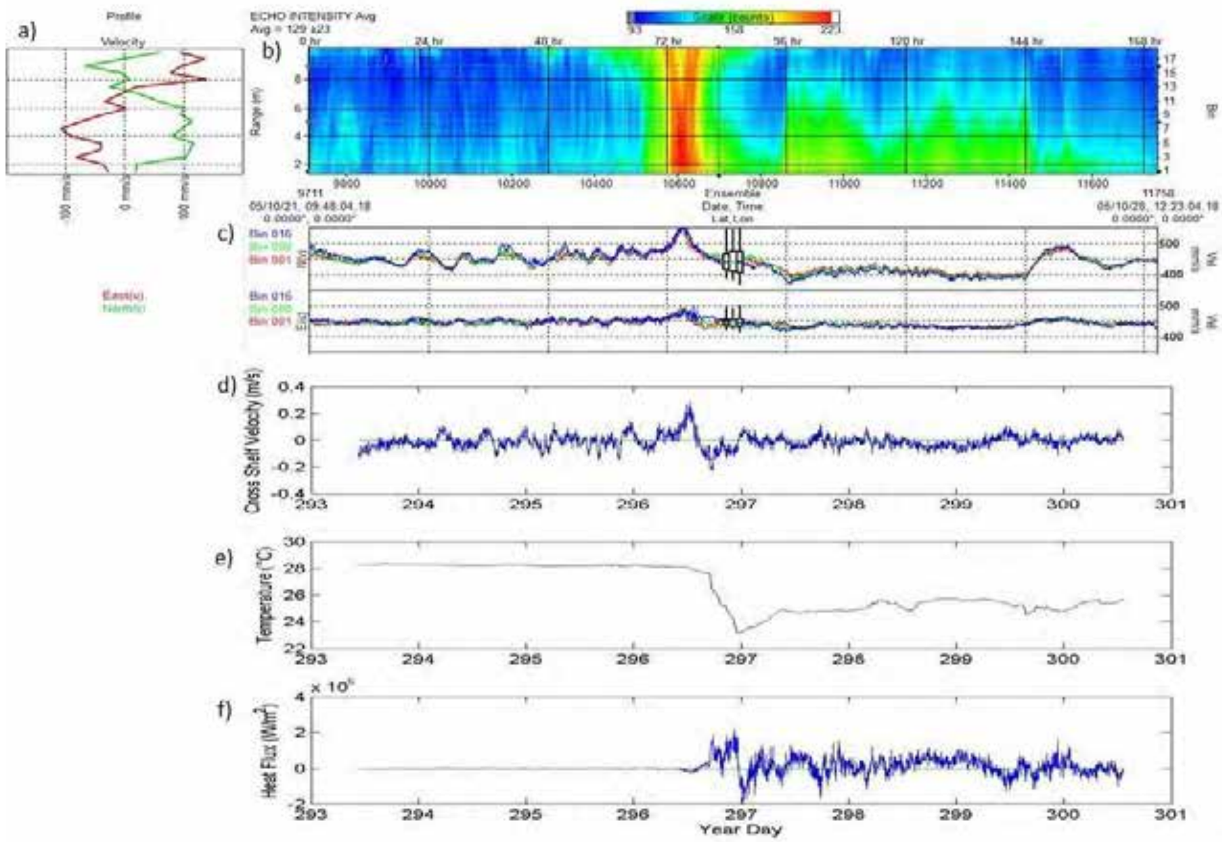


Figure 7: A major upwelling event during Hurricane Wilma in 2005: (A) mean east and north current profiles measured from an 11 m mooring, before and after the storm; (B) ADCP echo intensity; (C) time series of the north and east components of velocity; (D) cross-shelf velocity transformed into principle coordinates, u_{cf}; (E) temperature at the location of the 11 m ADCP; (F) "instantaneous" cross-shelf advection estimate, $h_{cf}=c_p\rho(T-T_0)u_{cf}$, where c_p is the specific heat capacity of water, ρ is sea water density, and T_0 is the near-bottom temperature at the location of the ADCP before the storm passage (estimated at Year-Day 293.45 of 2005).

Research Performance Measure: The CHAMP project addressed and met the defined objectives during 2014-2015 through a suite of research components that included ongoing data gathering as well as maintenance, data processing, and data delivery of existing CREWS stations throughout the Caribbean and Pacific. Additionally, biogeochemistry and oceanographic process studies and autonomous data-gathering were ongoing at the Cheeca Rocks AOAT and throughout the Florida Keys. These in situ measurements continue to drive field-based and laboratory research including studies of net ecosystem calcification, net community productivity, and benthic community composition. Coral growth records from colony cores and samples along with bioerosion monitoring units have been collected and analyzed using x-radiography, optical densitometry, and micro CT technologies in order to address baseline values, spatial gradients related to carbonate chemistry, as well as variability over time.

AOML's South Florida Program (SFP): Long-Term Measurement of Physical, Chemical, and Biological Water Column Properties in the South Florida Coastal Ecosystem

Project Personnel: L. Visser (UM/CIMAS)
NOAA Collaborators: E. Johns and C. Kelble (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To determine the circulation and water property patterns within South Florida coastal waters on event to inter-annual time scales, and to quantify the variability in these parameters so as to provide a historical basis for distinguishing future changes that may occur as a result of the Comprehensive Everglades Restoration Plan (CERP).

***Strategy*:** To conduct bimonthly and supplemental event-focused monitoring cruises and incorporate these results into system models supporting resource management decisions.

CIMAS Research Theme:

***Theme 3*:** Sustained Ocean and Coastal Observations

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: OAR and NMAO **NOAA Technical Contact:** Molly Baringer

Research Summary:

The Comprehensive Everglades Restoration Plan (CERP) is the largest and most expensive ecosystem restoration ever attempted. Its primary goal is to restore the quantity, quality, timing, and distribution of freshwater to as near historic levels as is feasible in the greater Everglades Ecosystem. Restoration activities will have a significant effect on the downstream coastal ecosystem that supports a large portion of south Florida's economy, including the Florida Keys National Marine Sanctuary (FKNMS) and Rookery Bay National Estuarine Reserve. The effect of restoration on the coastal ecosystem remains unclear, and some have hypothesized that the end result could be eutrophication of specific areas within the coastal ecosystem. This concern along with others in the terrestrial system has resulted in the adoption of iterative adaptive restoration, whereby each CERP project will be undertaken individually and management decisions will be altered if it is found they are likely to cause detrimental ecological effects.

Understanding the circulation and water property patterns of Florida Bay and surrounding waters is of vital importance to incorporate the health of the coastal ecosystem into the iterative adaptive restoration component of the Comprehensive Everglades Restoration Plan (CERP). The South Florida coastal ecosystem is economically and environmentally important and a large portion of the ecosystem is contained within the Florida Keys National Marine Sanctuary (FKNMS). The aim of this project is to quantify and comprehensively understand the variability of inter-related physical, chemical, and biological water column properties. This is achieved through a sustained research and monitoring program that incorporates analysis from regular cruises, and numerical modeling. The primary outcomes of this project have been rigorous quantification of the pre-CERP baseline condition, testable hypotheses, predictive models and alternative management options. Together these products provide a science-based methodology to assess CERP's effect on the coastal ecosystem and provide the feedback and predictive skill required by CERP's ambitious adaptive management plan.

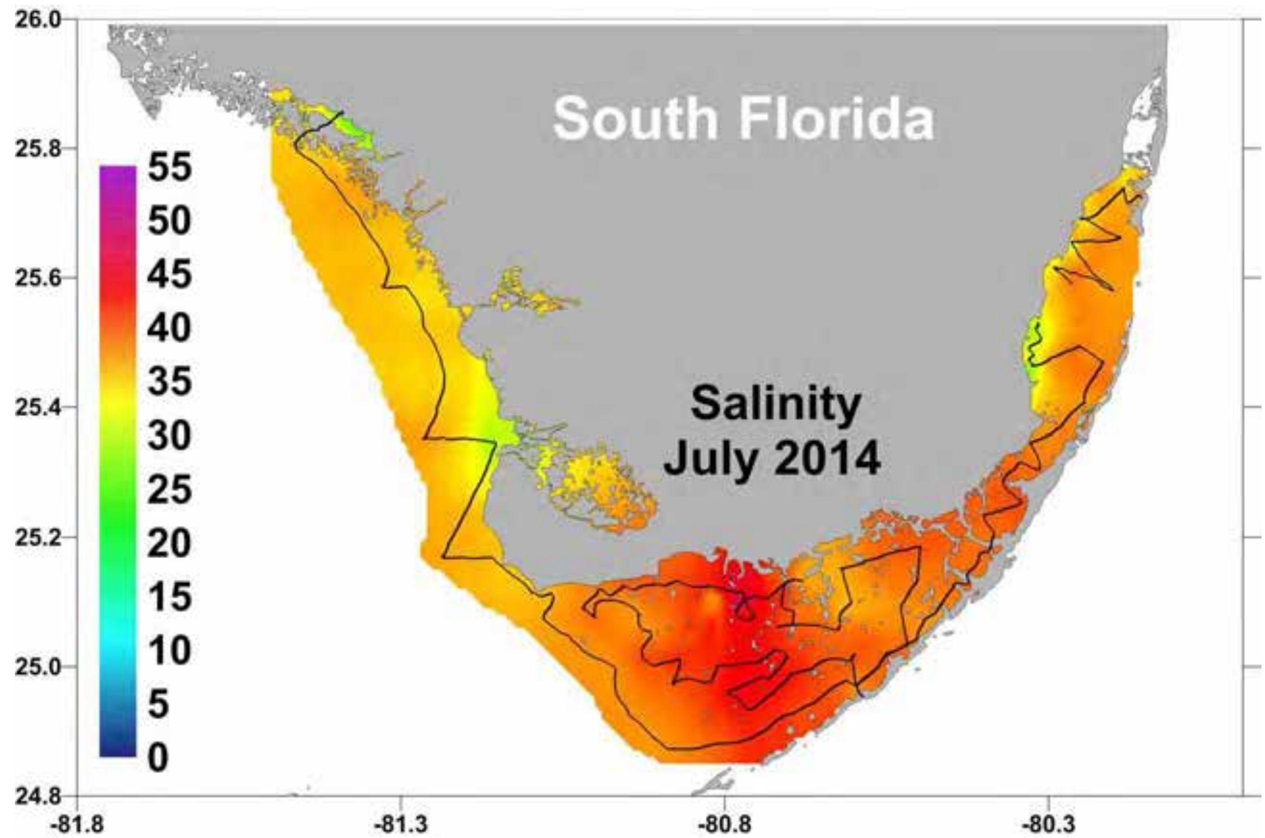


Figure 1: Salinity contour of South Florida coastal waters. These maps and others (e.g. for Florida Bay and the surrounding coastal waters, and numerous other measured parameters) are posted on the SFP web site at www.aoml.noaa.gov/sfp.

Research Performance Measure: All major research objectives are being met on schedule. The emphasis during this report period (1 July 2014 – 30 June 2015) has been on data collection, as regular sampling on the R/V Walton Smith resumed in December 2014. The primary measure of performance is the degree to which the data and analyses are incorporated into the scientific basis and adaptive management for CERP. The project data (and one of the project co-Principal Investigators) regularly provide critical contributions to the relevant components of the congressionally mandated System Status Reports.

Marine Optical Buoy (MOBY) Operations and Technology Refresh

Project Personnel: K.J. Voss (UM/Physics)
Other Collaborators: M. Yarbrough (SJSU/Moss Landing Marine Lab)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To provide the most accurate measurement of the water leaving radiance to be used as the primary calibration point for the international community of ocean color satellites, but primarily for the VIIRS instrument.

***Strategy*:** We are maintaining the operation of the Marine Optical Buoy (MOBY), moored off of the island of Lanai, Hawaii. In addition, to provide for future operation of this instrument, we are working on replacing many of the MOBY subsystems with modern optics and electronics.

CIMAS Research Theme:

***Theme 3*:** Sustained Ocean and Coastal Observations

Link to NOAA Strategic Goals:

***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

NOAA Funding Unit: NESDIS **NOAA Technical Contact:** Paul DiGiacomo

Research Summary:

The goal of this project is to provide data for the on-orbit calibration of the international constellation of ocean color satellites, but in particular for the NOAA VIIRS instrument on the Suomi NPP platform. We provide a time series of the most accurate measure of the water leaving radiance in a site with clear water and a clean maritime atmosphere (off of the island of Lanai in Hawaii). This time series began in 1997 and has been used as the primary calibration point by every national and international ocean color satellite instrument launched since 1997. This time series, with the highest quality data, allows multiple satellite missions to be tied together with a common calibration point, enabling an extended climate quality record of ocean color, spanning multiple satellite missions, to be produced.

The largest portion of this work is maintaining MOBY operations at the highest level of radiometric accuracy, which we do with our collaborators at the Moss Landing Marine Laboratory (SJSU) and NIST. This includes exchanging the MOBY instrument three times/year and replacing the main mooring for MOBY in alternate years. Each MOBY buoy system must be calibrated pre- and post-deployment, and diver calibrations/cleanings are performed monthly. All of these calibrations must be processed to maintain a real time data stream, along with a post-calibrated archive. The data is processed and then provided to users around the world through the NOAA CoastWatch site.

We have also been working on a “Refresh” of the optical and electronic systems in the MOBY system. For several years we have known that the current MOBY system was nearing it’s end of life and it was critical that a technology refresh occur. Thus we are working towards implementing a newer optical design into the MOBY system. This system, once built, will be fully characterized and calibrated with SI traceability (through NIST) and is designed to reduce the primary uncertainty components in the MOBY radiometric uncertainty budget (Brown *et al.,* 2007). Improvements include multi-channel simultaneous acquisition capability, internal radiometric response validation sources, and UV anti-biofouling sources to keep the external optical windows clean. Because strict attention has been paid to the MOBY uncertainty budget in the concept development of the new system, it will function with lower uncertainties than the current, extremely successful, MOBY system.

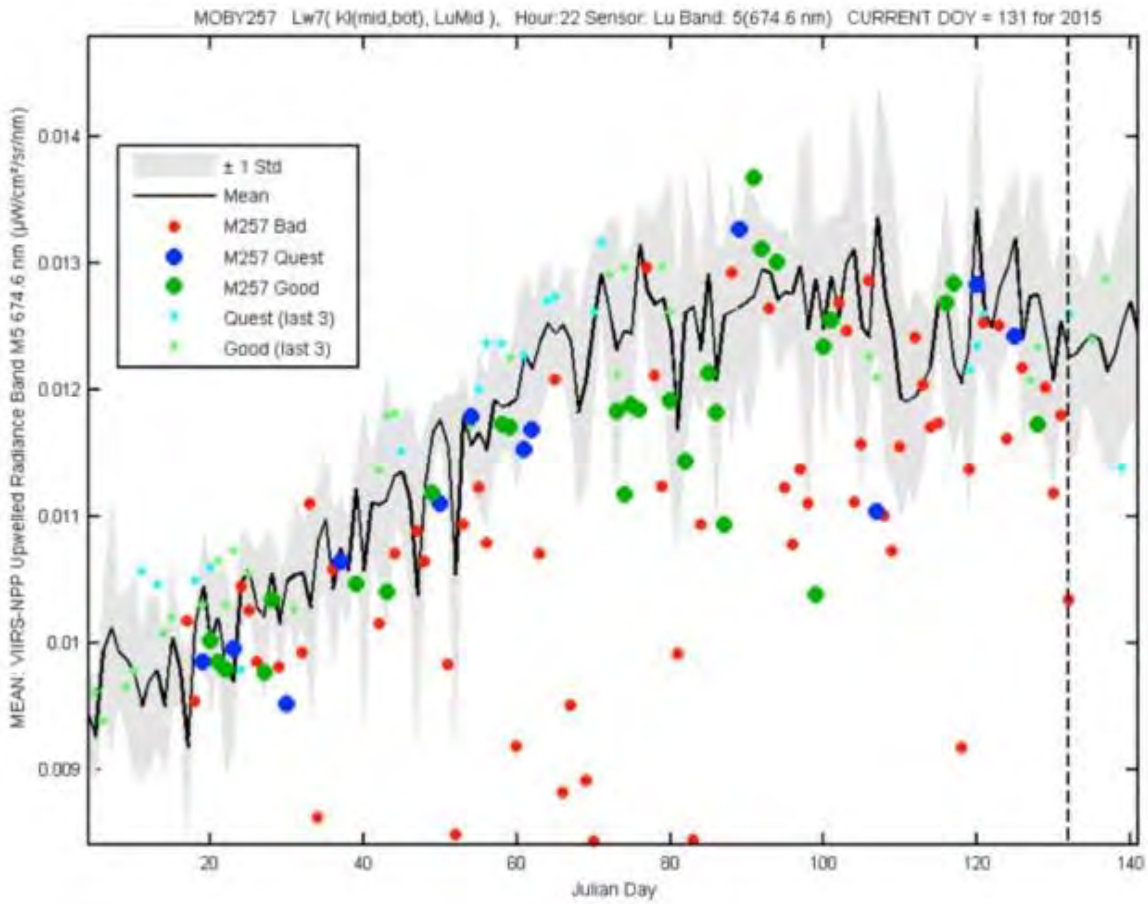
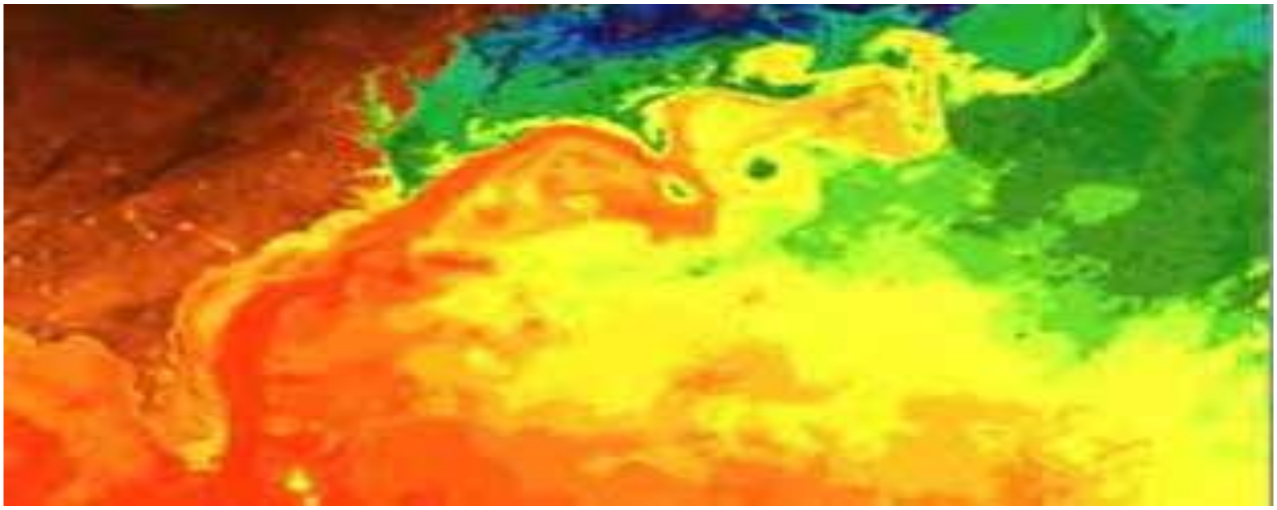


Figure 1: The most recent period in the MOBY time series. This deployment, M257, started in January 2015 and ended in mid May 2015, at which time deployment M258 began.

Research Performance Measure: We have been maintaining MOBY operations over this period, meeting our objectives of maintaining the accurate time-series for satellite vicarious calibration. Figure 1 shows results from the most recent completed deployment, which started in January 2015. The data from this deployment is shown as the discrete data points. The overall annual variation is due to the seasonal variation of surface solar irradiance. On this graph the entire time series daily mean for this time is shown as the black line (starting in 1997), with plus or minus one standard deviation indicated by the grey region. Bad data on this graph are predominately cloudy days, when the data would be invalid. Questionable data usually results from days for which the GOES imager may not show clouds, but the data is unstable over the measurement period, indicating the presence of small clouds. Good data is data that has passed all the quality control steps and is suitable for use in Satellite Vicarious calibration.

We are currently on schedule with our development of the MOBY-Refresh system.



RESEARCH REPORTS

THEME 4: Ocean Modeling

Development of an Earth System Component for Medium-Range Predictability in Coastal Seas: Initial Application on Gulf of Mexico Harmful Algal Blooms and Hypoxia Episodes

Project Personnel: V. Kourafalou and M. Le Hénaff (UM/RSMAS)
NOAA Collaborators: G. Halliwell, R. Atlas and C. Kelble (NOAA/AOML)
Other Collaborators: S. deRada (NRL/SSC)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To develop a comprehensive modeling tool that can be incorporated in an Earth System framework for medium-range (1-6 weeks) prediction of coastal circulation in environments subject to Harmful Algal Bloom (HAB) and hypoxia episodes.

Strategy: To expand the Observing Systems Simulation Experiments (OSSE) system (developed under the Joint UM/RSMAS/CIMAS and NOAA/AOML Ocean Modeling and OSSE Center) to biophysical capabilities, with initial application in the Gulf of Mexico.

CIMAS Research Theme:

Theme 4: Ocean Modeling

Link to NOAA Strategic Goals:

Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems* (*Primary*)

Goal 4: Resilient Coastal Communities and Economies - *Coastal and Great Lakes communities that are environmentally and economically sustainable* (*Secondary*)

NOAA Funding Unit: OAR/AOML **NOAA Technical Contact:** Molly Baringer

Research Summary:

The Gulf of Mexico (GoM), and particularly the Northern GoM shelf, is used as a test case study area for the development of a biophysical component within an Earth System modeling framework. This particular area is chosen for the frequent Harmful Algal Bloom (HAB) and hypoxia episodes associated with Mississippi River (MR) nutrient loads. Work has focused on model simulations and analyses in the coastal areas around the MR Delta, including coastal to offshore interactions that influence broader biophysical connectivity. These are controlled by fronts and eddies associated with the Loop Current, which further influence cross-shelf nutrient exchanges and the ventilation of shelf waters. The hydrodynamic modeling component is based on the HYbrid Coordinate Ocean Model (HYCOM), which has been previously applied on the Northern Gulf of Mexico in high resolution ($1/50^0$) and with an advanced parameterization of river plume dynamics that includes both salinity and momentum fluxes. This model has been recently expanded to include the entire GoM (ancillary NOAA project). For the purposes of this study, additional work on river plume dynamics has been performed, to achieve the most realistic representation of the transport and fate of MR waters, which are primarily responsible for the water quality of the shelf areas surrounding the Delta.

Figure 1 illustrates the impact of two important parameters for the modeling of the MR plume: a) momentum flux (in addition to salinity flux, which is commonly the only parameter used to describe the impact of river waters) and b) tides. Although river inputs are mainly characterized by their freshwater content (therefore, a salinity flux), they also introduce additional mass, which corroborates the development of buoyancy-driven flows. Tides are generally small in the GoM and often neglected in model simulations. However, they do provide an additional mixing mechanism for the riverine waters. Their effect is introduced in the simulation in two steps: first by including the sea level elevation associated with tides (estimated from the global tidal atlas FES2012) at the boundaries of the regional domain; then, by adding the tidal force to the movement equation driving the ocean in the model domain. Three simulations are presented in Fig. 1 for two different dates. The results are compared to observations (ocean color imagery, using ocean color as a proxy of MR waters, associated with turbidity and enhanced biological activity). When either momentum flux or tides (or both) are excluded, the MR plume is less extended than observed. The inclusion of tides affects the spreading of the MR plume on the shelf, but its effect is most critical at the shelf edge. The inclusion of momentum flux is an important factor in adding realism to the plume spreading. The inclusion of both tides and momentum flux allows the most realistic spreading of the MR plume, both on the shelf as well as toward the GoM interior (a known effect under Loop Current influence), in close agreement to the observations.

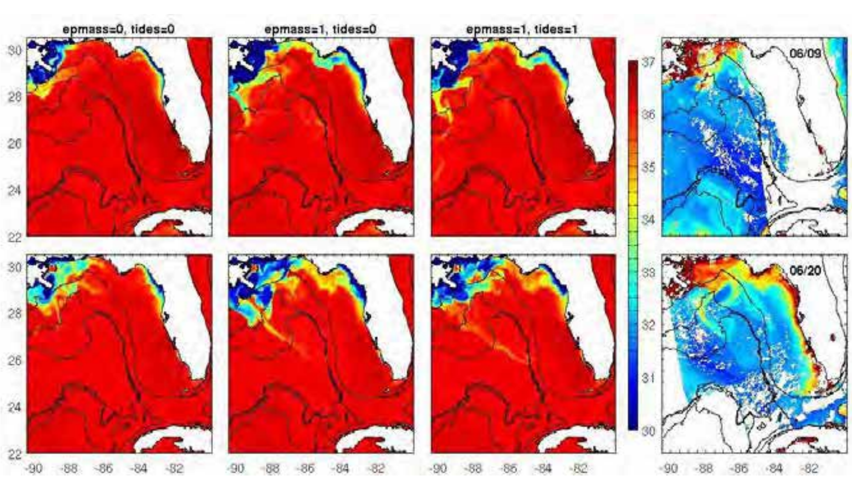


Figure 1: (Left 3 panels) Sea surface salinity from three 1/50° Gulf of Mexico simulations (zooms) with different attributes for the Mississippi River (MR) parameterization and the tides: no MR momentum flux, no tides; MR momentum flux, no tides; MR Momentum flux, tides. (Right panel) observed ocean color, for comparison. Two different dates are shown: June 9, 2014 (top), June 20, 2014 (bottom). The black lines indicate the 200, 2000, and 3000 m isobaths.

In parallel, the application of the Carbon, Silicate, Nitrogen Ecosystem (CoSiNE) model on the GoM is also under evaluation, examining the model skill to reproduce the spreading of nutrient-rich MR waters. Test case studies on several periods have been selected, representing different combinations of shelf and oceanic forcings that result in different manifestations of MR plume evolution. The combined HYCOM and CoSiNE simulations are an important step to expand the prototype ocean Observing System Simulation Experiment (OSSE) system developed by UM/RSMAS/CIMAS and NOAA/AOML through the joint Ocean Modeling and OSSE Center (OMOC). This OSSE biophysical system will be available for several applications in an Earth System modeling framework, toward improving the accuracy of both physical and biochemical analyses and forecasts in medium range (1 to 6 weeks).

Research Performance Measure: All major objectives have been met.

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Ocean OSSE Development for Quantitative Observing System Assessment

Project Personnel: V. Kourafalou, M. Le Hénaff, H.-S. Kang and M. Mehari (UM/RSMAS)
NOAA Collaborators: R. Atlas (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:
Objectives: To develop tools for quantitative ocean observing and forecasting.
Strategy: To integrate ocean model forecasting and Observing System Simulation Experiments under the Quantitative Observing System Assessment Program (QOSAP)

CIMAS Research Theme:
Theme 4: Ocean Modeling

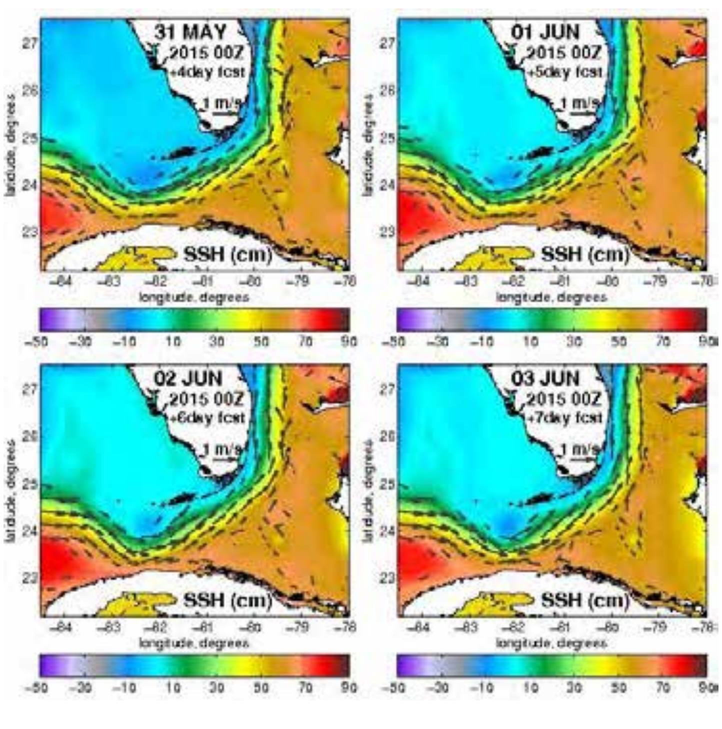
Link to NOAA Strategic Goals:
Goal 2: Weather-Ready Nation - *Society is prepared for and responds to weather-related events* (*Primary*)
Goal 4: Resilient Coastal Communities and Economies - *Coastal and Great Lakes communities that are environmentally and economically sustainable* (*Secondary*)

NOAA Funding Unit: OAR/AOML **NOAA Technical Contact:** Molly Baringer

Research Summary:
Comprehensive observational networks and appropriate modeling systems are needed to ensure the continuous monitoring of ocean variability and support forecasting activities that can deliver useful and reliable ocean services. This project aims at the development of methodologies and tools to quantitatively evaluate ocean observing systems and model forecasts. The overarching goal is to contribute to the Quantitative Observing System Assessment Program (QOSAP), by integrating ocean model forecasting and observing system design, optimization and evaluation. This integration is being achieved under the framework of Observing System Simulation Experiments (OSSEs), rigorously applied in the ocean for the first time through the joint UM/RSMAS/CIMAS and NOAA/AOML Ocean Modeling and OSSE Center (OMOC).

A forecasting model has been developed within the North Atlantic OMOC OSSE domain. This model has very high resolution ($1/100^0$, ~900m) and covers both coastal and deep sea areas, over the Florida Straits and around South Florida and the Florida Keys. This is a dynamically and topographically complex area, characterized by intense interactions between a strong oceanic current (the Florida Current branch of the Gulf Stream) and shallow coastal, island and reef systems in the Florida Keys, the Bahamas and Cuba. It is also an area of important fisheries, search and rescue, shipping and recreational activities. Reliable forecasts of the ocean state in this area have thus a vast number of users and stake holders. The forecasts were developed following a multi-year hindcast simulation of the "Florida Straits, South Florida and Florida Keys" (FKEYS) application of the Hybrid Coordinate Ocean Model (HYCOM). The near real time FKEYS-HYCOM simulations use the operational GFS (Global Forecast System) atmospheric forcing from the National Center for Environmental Prediction (NCEP), with the output on equally spaced $1/2^0$ horizontal grid at 3-h intervals to 240-h. The ocean initial and lateral boundary conditions come from the Navy's Gulf of Mexico (GoM) HYCOM model on $1/25^0$ grid; data are hosted at FSU/COAPS. Boundary conditions are updated daily from the G0M-HYCOM model, up to a 7-day period. Daily updated 7-day forecasts over the FKEYS domain are being performed and evaluated against multi-year statistics and ongoing observations. Maps for Sea Surface Height (SSH), Sea Surface Temperature (SST), temperature at 50m and surface currents are being publicly displayed.

An example of forecast fields is displayed in Figure 1. These are the last 4 days (day 4 through 7, May 31-June 3, 2015) of the forecast that started on May 27, 2015. The model fields are Sea Surface Height (SSH) with a few surface velocity vectors to indicate the circulation that accompanies the SSH changes (more detailed surface currents are displayed on accompanying web pages, see link under "Outreach"). The model predicted that the Florida Current would experience intense meandering, under the influence of a strong anticyclone over northwest Cuba (associated with the main Loop Current front) and substantial cyclonic eddy activity to the north of the Florida Current, impinging on the Florida Keys. Predicting the variability of such meandering patterns is one of the important circulation features that forecasts allow, which have implications on biophysical connectivity around South Florida and within the Gulf of Mexico and the Caribbean at large. The modeling framework allows the advancement of strategies for observing system design and quantitative evaluation of observing systems, by computing the improvement of model forecasts through data assimilation.



Research Performance Measure: All major objectives have been met.

Figure 1: Sea Surface Height and surface currents (only a few vectors are plotted for clarity) from the FKEYS-HYCOM forecast modeling system. Example is for the last 4 days of a 7-day forecast, starting from May 27, 2015.

South Atlantic Meridional Overturning Circulation: Pathways and Modes of Variability

Project Personnel: R.C. Perez, S.L. Garzoli, Q. Yao and R. Garcia (UM/CIMAS)
NOAA Collaborators: R. Msadek (UCAR, NOAA/GFDL)
Other Collaborators: R.P. Matano and V. Combes (OSU/CEOAS)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To improve our understanding of the pathways of the upper and lower limbs of the Meridional Overturning Circulation (MOC) in the South Atlantic.

Strategy: 1) To characterize the pathways of the upper and lower limb of the MOC in the South Atlantic and identify the dynamical mechanisms that control these pathways. 2) To identify the natural modes of variability in the South Atlantic and their impact on the MOC. 3) To determine the response of the South Atlantic pathways to predicted climate change scenarios and assess the impact of this response on the MOC.

CIMAS Research Theme:

Theme 4: Ocean Modeling (*Primary*)
Theme 1: Climate Research and Impact (*Secondary*)

Link to NOAA Strategic Goals:

Goal 3: Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

NOAA Funding Unit: OAR/CPO **NOAA Technical Contact:** James Todd and Sandy Lucas

Research Summary:

Previous observational and modeling efforts on the meridional overturning circulation (MOC) have been focused on the North Atlantic and the Southern Oceans, which are the preferential sites for deep-water formation. To understand the feedbacks between the North Atlantic and the Southern Oceans we need to improve our understanding of the pathways of the upper and lower limbs of the MOC in the South Atlantic Ocean, which are the most important links between them. The South Atlantic is not just a passive conduit for the transit of remotely formed water masses, but actively influences them through air–sea interactions, mixing, subduction, and advection.

As part of the project we are 1) characterizing the pathways of the upper and lower limb of the MOC in the South Atlantic and identify the dynamical mechanisms that control these pathways, 2) identifying the natural modes of variability in the South Atlantic and their impact on the MOC, and 3) determining the response of the South Atlantic pathways to predicted climate change scenarios and assess the impact of this response on the MOC. Our research is focused on the analysis of state-of-the-art eddy-permitting and eddy-resolving NOAA/GFDL climate model simulations (CM2.5 and CM2.6), non-eddying Coordinated Model Intercomparison Project and Intergovernmental Panel on Climate Change Fifth Assessment Report models including the NOAA/GFDL coarse resolution models (CM2.1, CM3), process-oriented numerical experiments using global and regional ocean models (OFES, ROMS), and global in-situ and satellite observations.

CIMAS personnel, S. Garzoli, R. Perez, S. Dong, Q. Yao, and coauthors, have continued to examine the fate of the Deep Western Boundary Current (DWBC) in the South Atlantic using in situ observations and output from a global ocean-only numerical model (Garzoli et al., 2015). V. Combes and R. Matano have generated regional ocean model simulations (Strub et al., 2015 and references therein), and used those simulations to study the pathways of key water masses in the South Atlantic. To accomplish this, synthetic tracers have been inserted at key locations in the model. These synthetic tracers are used to examine the pathway of surface and intermediate waters entering the South Atlantic Ocean via the Agulhas Eddy Corridor, and to study the multiple offshore intrusions of North Atlantic Deep Water (NADW) into the South Atlantic. The sensitivity of these pathways to model configuration (e.g., resolution, bottom topography) is also being examined. R. Perez, S. Garzoli, R. Msadek and coauthors published an article describing different types of observational systems used by NOAA, CIMAS, and their partners to study the complex nature of the AMOC (Perez et al., 2015). R. Perez, R. Msadek, S. Garzoli, and collaborators have used in situ and satellite observations and output from numerical models to study the seasonal to decadal variability of the water masses and volume and heat transport by the MOC in the South Atlantic (e.g., Dong et al., 2014, Perez et al., in prep). More recently, PIs have been begun examining the natural modes of variability in the South Atlantic and their impact on the MOC.

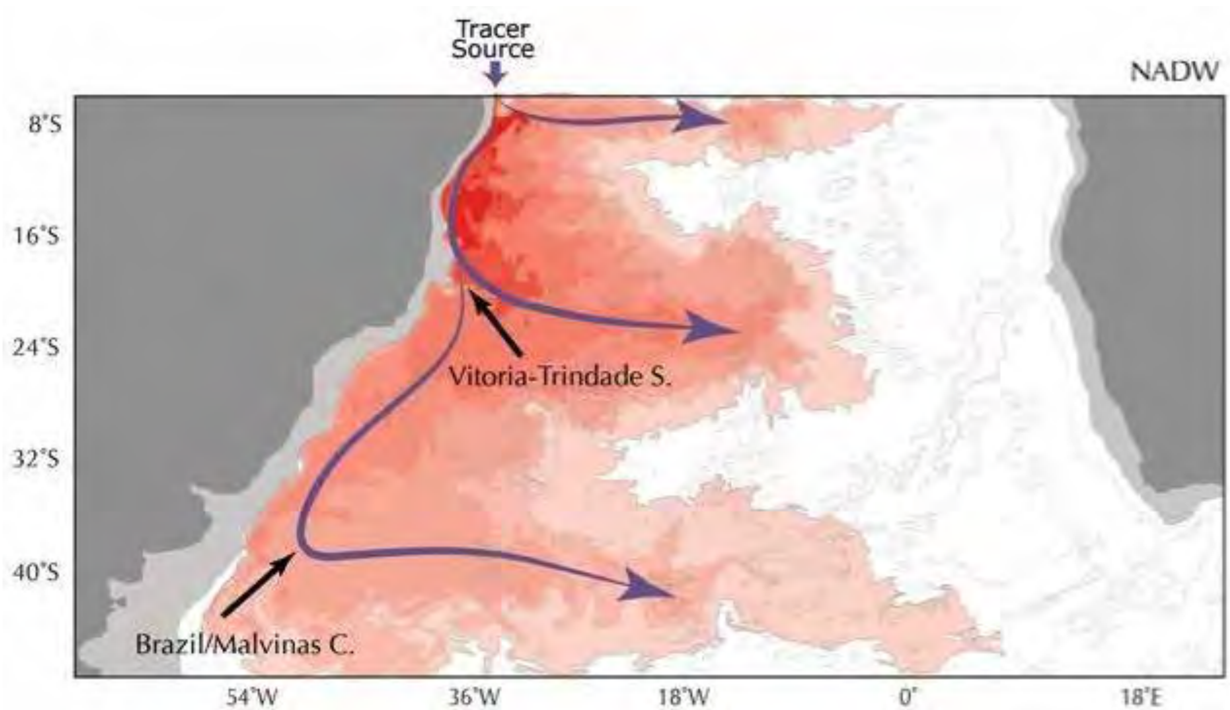


Figure 1: Average tracer distribution after 20-years of a ROMS simulation where tracers were released near 5°S in depth levels associated with North Atlantic Deep Water (NADW). Three offshore intrusions of NADW are depicted. The most remarkable is the one observed near 20°S, which is the approximate location of the Vitoria-Trindade Ridge, because there is no clearly defined offshore mean flow in this location.

Research Performance Measure: Major research objectives are being met, but there is still more progress to be made. Results from this project were presented at the U.S. AMOC Meeting in Seattle, WA in September 2014, the SAMOC workshop in Buenos Aires, Argentina in December 2014, and at the NOAA Climate Observation Division (COD) meeting in Baltimore (MD) in June 2015. Three peer-reviewed publications were published in Geophysical Research Letters, the Journal of Geophysical Research Oceans, and the Marine Technology Society Journal; and, one peer-reviewed manuscript was accepted in Deep Sea Research.

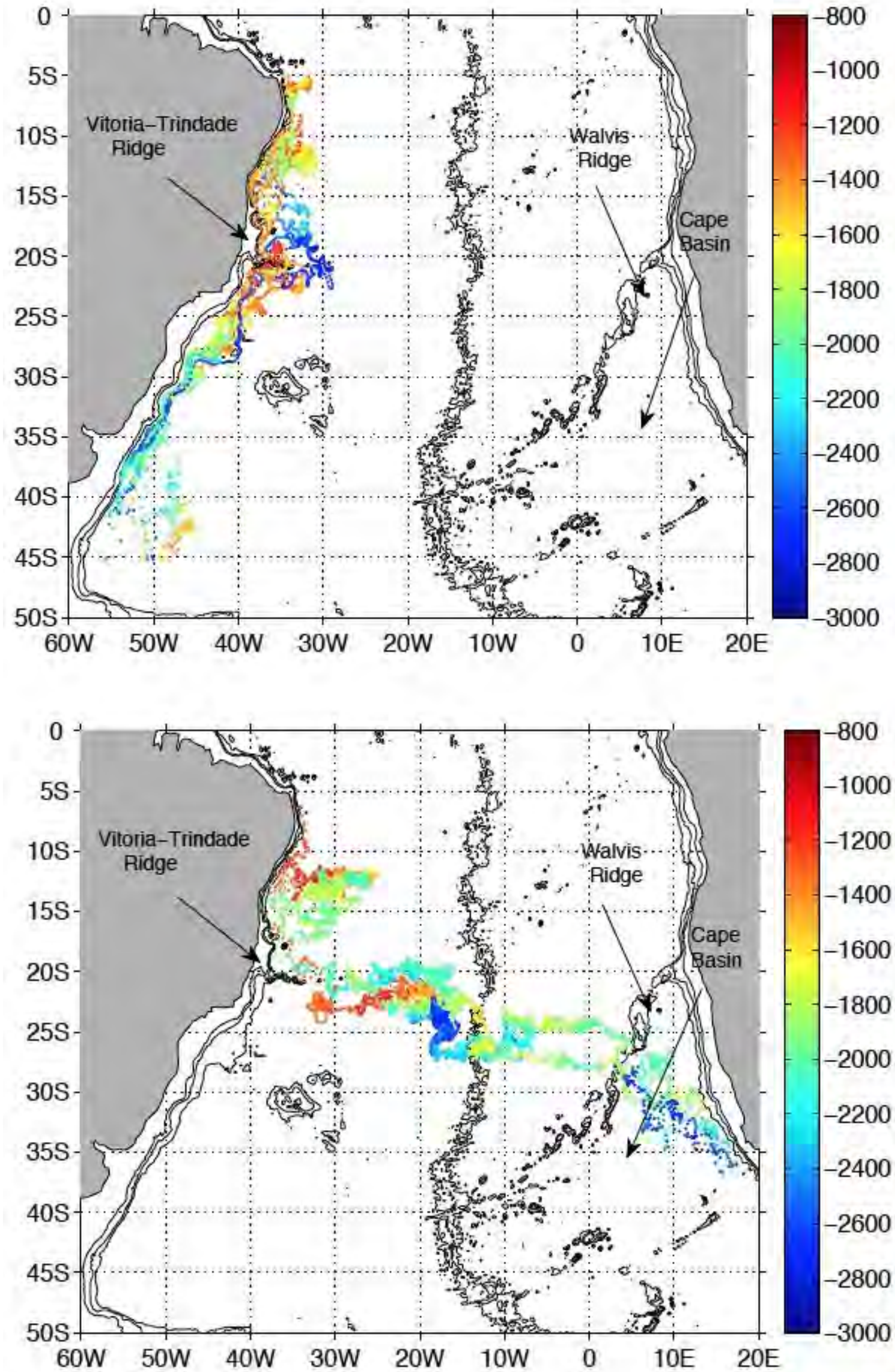


Figure 2: Some examples of the two main pathways for synthetic floats launched in the NADW layer at 5°S west of 30°W using the output from a global ocean-only numerical model. Approximately 70% of the synthetic floats follow the western boundary of South America (top panel), and 20% of the floats follow an interior pathway extending from the Vitoria-Trindade Ridge to the Cape Basin region.

Variability and Coherence of the Atlantic Meridional Overturning Circulation

Project Personnel: X. Xu and E.P. Chassignet (FSU/COAPS); S. Dong (UM/CIMAS)
NOAA Collaborators: M. Baringer and G. Goni (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To quantify to what extent is the AMOC variability coherent throughout the whole Atlantic and to determine whether the variability of the Agulhas leakage is directly connected to the AMOC variability at 35°S.

***Strategy*:** To perform a detailed model-data syntheses/comparison study using the observations at 26.5°N and 35°S and global high-resolution, eddy-resolving numerical simulations integrated with the HYbrid Coordinate Ocean Model (HYCOM).

CIMAS Research Theme:

***Theme 4*:** Ocean Modeling

Link to NOAA Strategic Goals:

***Goal 3*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts*

NOAA Funding Unit: OAR/ESPC **NOAA Technical Contact:** Molly Baringer

Research Summary:

Over the first year of this project, we established an overall evaluation of the current 1/12° eddy-resolving global HYCOM simulation in representing the circulation in the southern Atlantic Ocean, with focus on the inter-basin connections to the Pacific and Indian Oceans. The major difficulty is to represent the shedding and west-/northwestward propagation of the Agulhas Rings. The modeled Agulhas Rings propagate northwestward along a similar pathway, which form a tongue of high Eddy Kinetic Energy that extends deep into the South Atlantic and impacts the local circulation patterns east of the mid-Atlantic Ridge. However, the model results yield very realistic net transport and its vertical structure across the South Atlantic at 35°S and across 65°W in the Drake Strait, and thus are useful to interpret the large-scale circulation and water mass transformation in this region.

The model results suggest that the northward limb of the AMOC comes primarily (about 16 out of 19.6 Sv) from the westward Agulhas Leakage, or the warm route; the remaining small contribution comes from diapycnal water mass transformation from denser layer of North Atlantic Deep Water (NADW). Strong water transformation takes place in the southern Atlantic Ocean (Figure 1), by both surface buoyancy forcing and diapycnal mixing. Although the Antarctic Circumpolar Current (ACC) from the Pacific Ocean, or the cold route, does not directly contribute to northward limb of the AMOC, it plays an important role in modifying the water property of both the upper and the lower limbs of the AMOC. For an example, most (6 Sv) of the Antarctic Intermediate Water (AAIW) that flow across the 35°S exhibit water property closer to that in the ACC, whereas the rest (3.6 Sv) exhibit property close to that in the Agulhas Leakage (Figure 2).

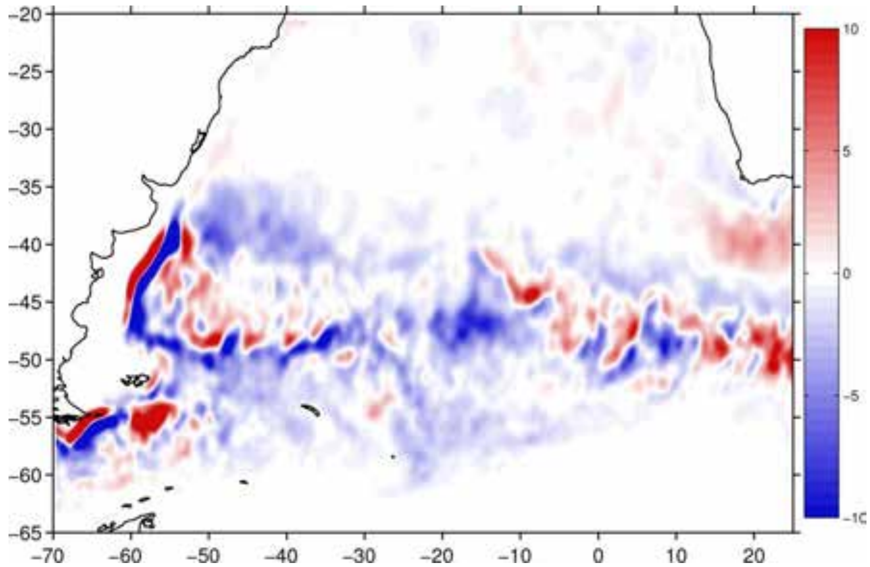


Figure 1: Modeled horizontal distribution of diapycnal water mass transformation across (σ_2) 36.12 kg m^{-3} (within the AAIW layer). The transformation in 10^{-6} m s^{-1} is defined as time-averaged convergence of the volume transport divided by the area. Negative values denote upward transformation from denser to lighter water masses.

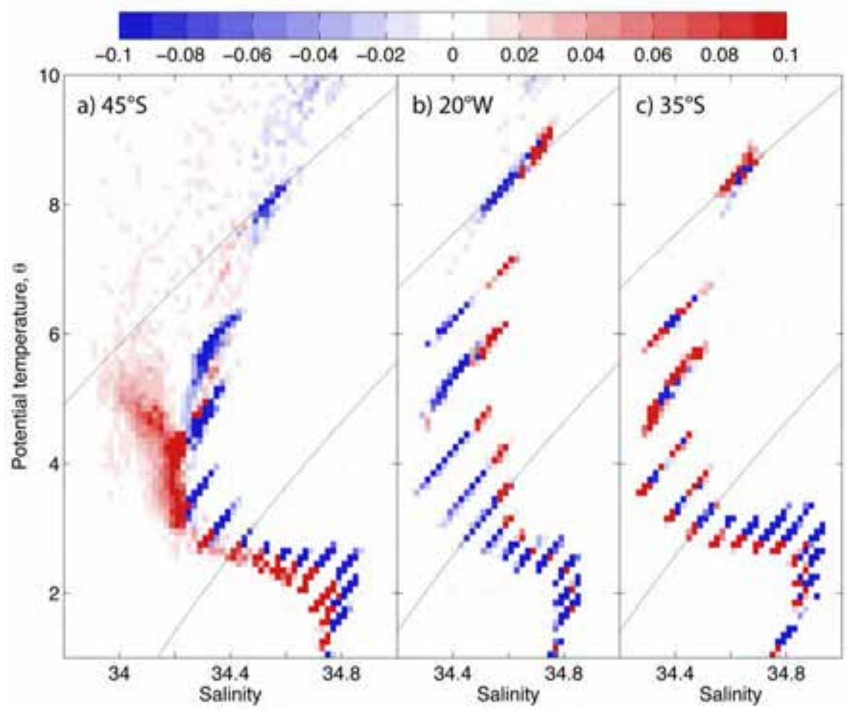
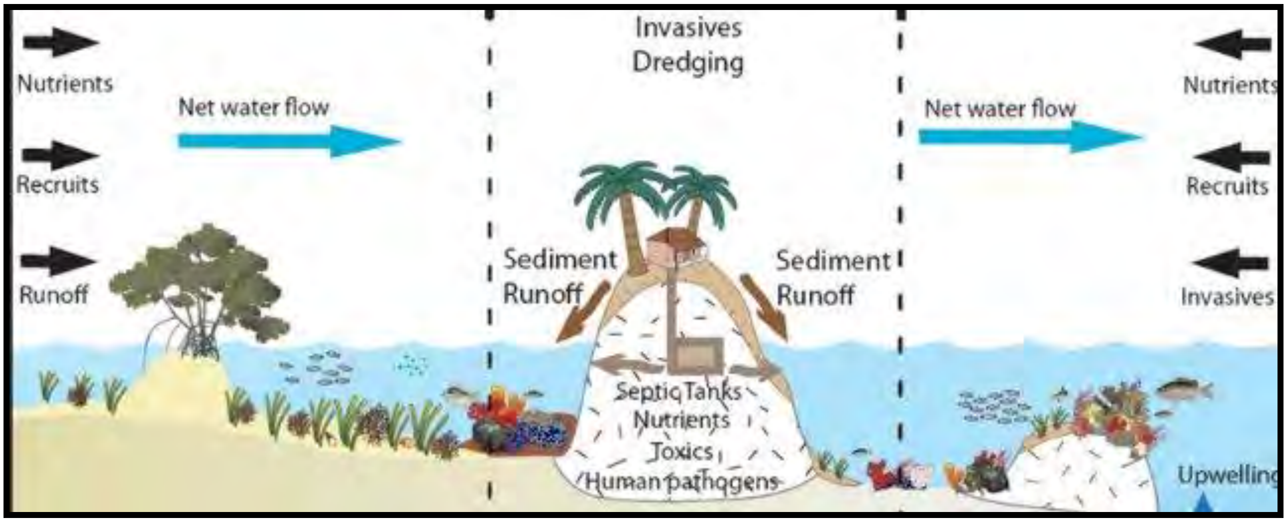


Figure 2: Modeled mean transport in Sv across three sections as a function of θ-S, evaluated in a Δθ-ΔS bin of 0.2°C-0.02. Positive values denoting northward or westward transport into the South Atlantic. The two isopycnals (σ_2 of 35.80 and 36.62 kg m^{-3}) represent the upper and lower most layer of AAIW in model.

Research Performance Measure: We have met our original near-term objective, which is to establish an overall evaluation of current 1/12 eddy-resolving global HYCOM simulation in representing the southern Atlantic Ocean circulation.



RESEARCH REPORTS

THEME 5: Ecosystem Modeling and Forecasting

Florida Reef Track Fish Management and Assessment

Project Personnel: J.S. Ault and S.G. Smith (UM/RSMAS)
NOAA Collaborator: J.A. Bohnsack (NOAA/NMFS)

Long Term Research Objectives and Strategy to Achieve Them:
***Objectives*:** To develop and implement quantitative methods for robust evaluation of status and trends of coral reef fish populations and communities in the Florida Keys coral reef ecosystem. To determine the efficacy of "no-take" marine reserves (NTMRs) in the Florida Keys National Marine Sanctuary (FKNMS; Sanctuary Preservation Areas SPAS; Tortugas Ecological Reserves TERs) and Dry Tortugas National Park (DTNP; Research Natural Area RNA) to sustain regional exploited reef fish populations. To transfer these robust approaches to other jurisdictions in the U.S. southeast Atlantic and Caribbean.
***Strategy*:** To conduct accurate and precise multispecies assessments, classify and map reef habitats, and monitor reef fish population abundance, and community composition in regional coral reef ecosystems. To use statistical sampling design and acoustic telemetry to determine population abundance, ontogenetic habitat associations, and ecosystem responses to exploitation and water management (i.e., MPA zoning; Comprehensive Everglades Restoration Program).

CIMAS Research Themes:
Theme 5: Ecosystem Modeling and Forecasting (*Primary*)
Theme 6: Ecosystem Management (*Secondary*)
Theme 7: Protection and Restoration of Resources (*Tertiary*)

Link to NOAA Strategic Plan Goals:
***Goal 1*:** Healthy Oceans – *Marine Fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:
Commercial and recreational fisheries target hundreds of fish and shellfish species across the seascape of southern Florida including inshore coastal bays, the flats of barrier islands, coral reefs and offshore pelagic waters. The ecological dynamics and economic sustainability of these valuable fishery resources are key conservation concerns. Overfishing, habitat degradation and prey reduction are the principal threats to sustainability of coral reef and coastal fisheries in Florida (Ault et al. 2014). This research provides quantitative assessments of NTMRs and other fishery management measures in meeting ecosystem goals. In 2014-2015 we continued evaluation of the performance of the SPAs and TERS in the FKNMS. This included design and conduct of spatially-synoptic sampling of reef fish and coral reef habitats in the Florida Keys, including an expanded survey domain to the SEFCRI region which extends the reef ecosystem north to Martin County. The reef fish visual census (RVC) is a collaborative multiagency reef fish monitoring efforts, conducted annually by a large and highly-skilled a team of research divers from the University of Miami, NOAA Fisheries, Florida Fish and Wildlife Conservation Commission, and the National Park Service (Brandt et al. 2009; Smith et al. 2011a). Community-level fishing impacts on sustainability status of southern Florida reef-fishes are shown in a "community control rule" format (Figure 1, Ault et al., 2014).

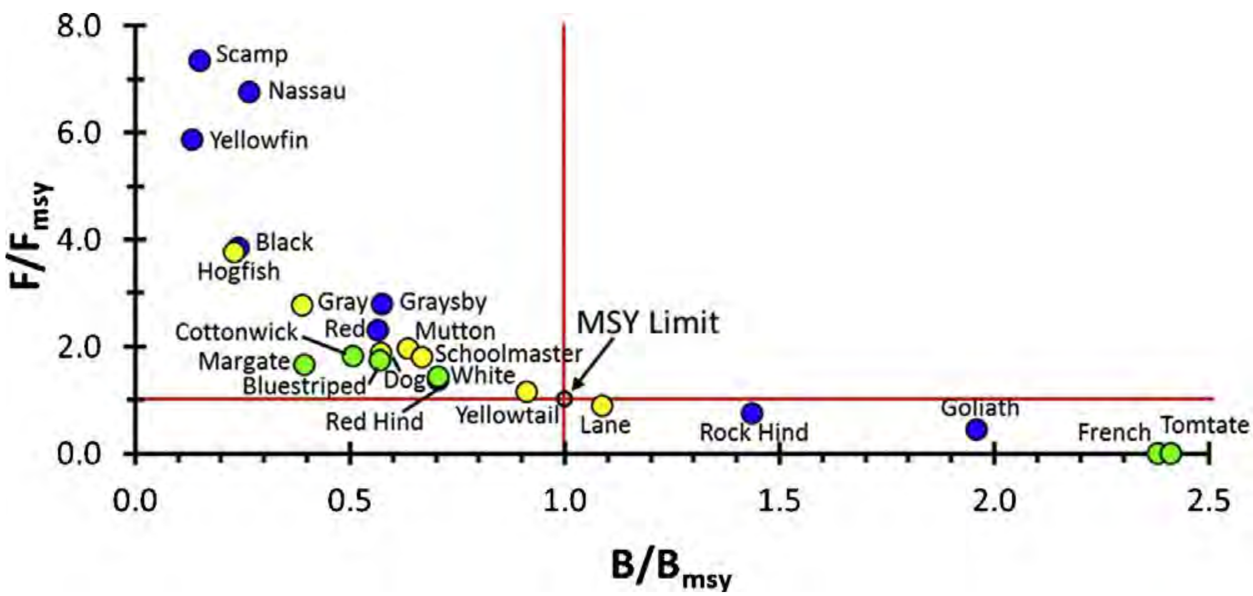


Figure 1: Limit control plots showing estimated levels of spawning stock biomass (x-axis) and fishing mortality rate (y-axis) with respect to MSY levels for exploited reef-fish communities in southern Florida (redrawn from Ault et al., 2014; blue circles, groupers; yellow circles, snappers and wrasses; green circles, grunts).

Average length in the exploited phase was the principal stock assessment indicator variable used to estimate fishing mortality rates for fishes in the reef fish community. The majority of species analyzed are experiencing unsustainably high rates of fishing mortality. The differential response to exploitation results from differing life history demographic characteristics, with slower-growing, longer-lived species such as groupers being more susceptible to fishing impacts compared to faster-growing, shorter-lived species such as grunts. By comparing a current year's findings to previous baseline survey information, scientists can determine what effects no-take marine reserves are having on the productivity of exploited fisheries in the Tortugas and through the entire coral reef ecosystem. For example, for mutton snapper spatial data we found that the extent of occupancy markedly increased after implementation of the protected areas (between 1999-2000 and 2010-2014). There were significantly more (and larger) fish in the two protected areas, but not in the fished areas where the number of large animals continues to decrease, which has been observed for a broad range of intensively exploited reef fish species. Results for the Dry Tortugas and Florida Keys indicate that NTMRs, in conjunction with traditional management measures, can rebuild sustainable fisheries and human livelihoods (Ault et al. 2013, 2014). This is a win-win for the integrity and sustainability of Florida's coral reef ecosystem and associated multibillion dollar economy!

Research Performance Measures: All research objectives were met**:** (1) conduct of statistically robust monitoring of fishes and habitats in the Florida Keys coral reef ecosystem; (2) quantitative multispecies assessments of reef fishery sustainability; (3) quantitative evaluation of NTMR efficacy.

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Evaluation of Management Strategies for Fisheries Ecosystems

Project Personnel: E.A. Babcock and D.J. Die (UM/RSMAS)
Other Collaborators: J. Hoenig and J.McDowell (Virginia Institute of Marine Science); C. Campbell Davies (CSIRO-Australia)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To develop tools for fishery management strategy evaluation within an ecosystem context and to improve fishery assessment methodology.

***Strategy*:** To develop ecosystem models based on both individual-based modeling (IBM) and the Atlantis whole-ecosystem modeling framework, to develop statistical methods for using tagging data and other improvements to stock assessment, and to use DNA sequencing with close-kin analysis to evaluate bluefin tuna population dynamics.

CIMAS Research Theme:

***Theme 5*:** Ecosystem Modeling and Forecasting (*Primary*)
***Theme 6*:** Ecosystem Management (*Secondary*)
***Theme 7*:** Protection and Restoration of Resources (*Tertiary*)

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems* (*Primary*)

Goal 4: Resilient Coastal Communities and Economies - *Coastal and Great Lakes communities that are environmentally and economically sustainable* (*Secondary*)

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

UM Ecosystem modeling: (PI: E. Babcock)

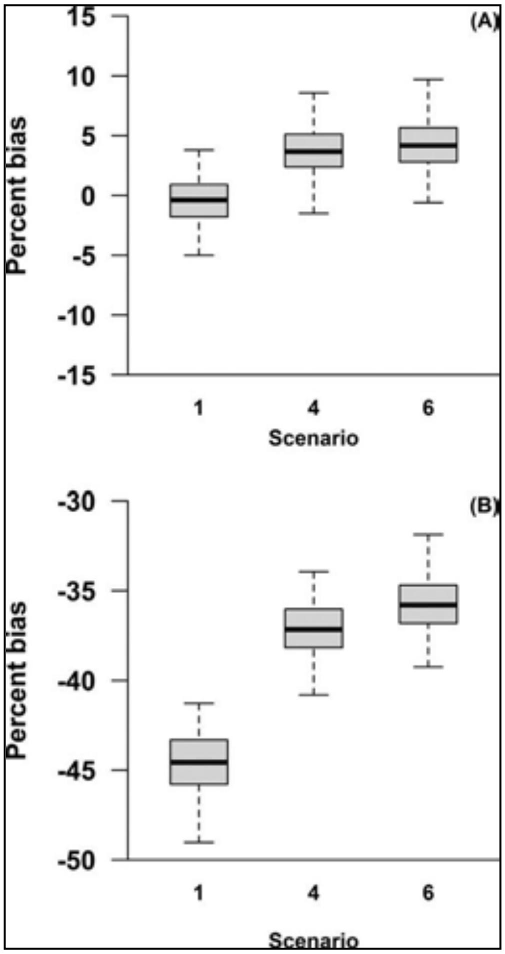
We collaborated with Cameron Ainsworth of U.S.F., and Michael Schirripa and others at NOAA/SEFSC to develop an ecosystem model for the Gulf of Mexico, using the Atlantis modeling framework. U.M. Ph.D. student Holly Perryman contributed to the Atlantis model and is now using the model to simulation-test alternative measures of the ecosystem impact of fishing, focusing on pelagic species. She has also modeled the spatial distribution of pelagic fish in the Gulf based on both surveys and fisheries data, an analysis which will be useful for predicting the impact of environmental changes on fish species. She is expected to defend her dissertation within a year. We also used individual based modeling (IBM) to evaluate the impact of Caribbean spiny lobster movement on the sustainability of a fishery in the mixed-use zone of a marine reserve (Babcock et al. 2015, Harford et al. 2015). We found that, given the fairly limited movement of lobsters, the no-take zone protected enough lobsters to make the fishery in the surrounding area sustainable, despite fairly high fishing mortality rates on the lobsters in the fished zone. We also developed two spatial simulation models for conducting management strategy evaluation. Management strategy evaluation enables various interacting components of a fishery system to be evaluated collectively, including resource monitoring, stock assessment and decision-making. These simulation models described the population dynamics of conch and Caribbean spiny lobster and enabled evaluation of a proposed adaptive management decision-making framework.

VIMS Stock assessment improvement (PI. J. Hoenig)

For the VIMS component of the program, with P.I. J. Hoenig, research aimed to improve fishery stock assessment. A new growth curve for Bluefin tuna was published (Ailloud et al. 2014). Work continues on this problem as new tag returns and hard part analysis are now available. The study of the properties of cohort slicing for estimating age composition has now been published (Ailloud et al. 2015). VIMS student Kristen Omori presented new study design for using electronic tags at the meeting of the American Fisheries Society in Quebec City and is writing up the results for publication. The gillnet survey of juvenile blacktip sharks in Charlotte Harbor, Florida, was continued for a second year, and work was begun to standardize the catch rates of the old net type and the modern nets used by Gulfspan (with R. Hueter, Mote Marine Lab). This work aims to establish an index of abundance for blacktip and bonnethead sharks. (Omori et al. 2015). A research project was initiated to evaluate exploitation rates in the Alabama red snapper fishery using change-in-ratio and index-removal methods (with J. Walter and M. Lauretta, NMFS-SEFC, and S. Powers and M. Drymon, Dauphin Island Sea Lab). Research on the effects of unreported catch and effort on surplus production model estimates is now being written up for publication and for inclusion in Kristen Omori's master's thesis. Work on the evaluation of the combined forward and inverse age-length keys was presented at the American Fisheries Society meeting in Quebec City by VIMS student Quang Huynh.

Bluefin tuna close-kin analysis (P.I.s J. McDowell, VIMS and C. Davies, CSIRO-Australia)

A preliminary sample set (n=24 Gulf of Mexico and n=24 Mediterannean Sea) was sent to Diversity Arrys Technology in Canberra, Australia for generation of single nucleotide polymorphism (SNP) data via Gentotyping by Sequening (GBS). This resulted in the identification of over 150,000 SNP loci across all samples. The data is currerntly being analyzed to evaluate whether stocks can be discriminated using this method. In addition, the NMFS lab in Miami is currently sorting Western Atlantic Bluefin tuna larval samples from larval tows conducted in the Gulf of Mexico and we are awaiting the arrival of those samples so we can determine if the larval survey provided effective samples for close-kin analysis.



Research Performance Measure: All of the objectives of this proposal were met or are in progress. The objectives were:
(1) Develop ecosystem models for the Gulf of Mexico and Florida using Atlantis, individual-based models and other modeling frameworks. The Atlantis work will be finished as Holly Perryman completes her dissertation. The IBM work is published.
(2) Develop experimental designs to use electronic tags for assessment, assess juvenile blacktip shark abundance, evaluate bluefin tuna growth, evaluate uncertainties in red snapper assessment, evaluate combine forward and inverse age-length keys. This work is either published or in progress.
(3) Hold workshops on fisheries quantitative methods. E. Babcock organized a 2-week class on multivariate statistical methods, which was attended by 9 UM graduate students and 6 NOAA employees.
(4) Pilot project on Bluefin tuna close-kin analysis. This work is ongoing at VIMS and CSIRO.

Figure 1: Bias in estimates of Caribbean spiny lobster population numbers in (A) the fished zone, and (B) the fished zone and the no-take zone together, when the population numbers are estimated from fisheries data without accounting for movement. Scenarios refer to alternative hypotheses about the amount of movement. These results indicate that movement information is needed to estimate the population size correctly.

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Use of the Ecosystem Model OSMOSE-WFS to Explore the Trophic Structure of the West Florida Shelf in the 2000s, and to Estimate Natural Mortality Rates and Simulate Fishing Scenarios for Gulf of Mexico Red Grouper (Epinephelus morio)

Project Personnel: A. Grüss (UM/CIMAS)
NOAA collaborator: M.J. Schirripa (NMFS/SEFSC)
Other collaborators: D.D. Chagaris (Fish and Wildlife Research Institute, St. Petersburg); C.H. Ainsworth (USF, St. Petersburg); Y.-J. Shin, P. Verley, L. Velez and R. Oliveros-Ramos (IRD, France)

Long Term Research Objectives and Strategy to Achieve Them:
Objectives: To develop an ecosystem model (OSMOSE-WFS) to provide parameter estimates and ecosystem considerations to fisheries stock assessments (SEDAR) each year, as well as recommendations to the Gulf of Mexico Fishery Management Council; to explore the trophic structure of the West Florida Shelf ecosystem in the 2000s; and to estimate age- and size-specific

annual natural mortality rates and simulate fishing scenarios for a socio-economically important fish population, Gulf of Mexico red grouper (*Epinephelus morio*), which was evaluated under the auspices of SEDAR in 2014-2015 (SEDAR 42).

Strategy: To set up collaborations with different American and French research institutes, so as to access the best available information and knowledge to construct, parameterize, calibrate and evaluate the OSMOSE-WFS model, as well as to update the model as new information and methodologies arise; and to simulate the dynamics of both individual species and large species groups to be able to both deliver information to single-species stock assessments and fisheries managers and offer a comprehensive snapshot of the trophic structure and functioning of the West Florida Shelf ecosystem in the 2000s.

CIMAS Research Theme:

Theme 5: Ecosystem Modeling and Forecasting (*Primary*)
Theme 6: Ecosystem Management (*Secondary*)

Link to NOAA Strategic Goals:

Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

We applied the individual-based, multi-species OSMOSE modeling approach to the West Florida Shelf ecosystem, with the intent to inform ecosystem-based fisheries management (EBFM) in this region (Figure 1). Our model, referred to as 'OSMOSE-WFS', explicitly considers both pelagic-demersal and benthic high trophic level (HTL) groups of fish and invertebrate species, and is forced by the biomass of low trophic level groups of species (plankton and benthos). OSMOSE-WFS is currently a steady-state model describing trophic interactions in the West Florida Shelf in the 2000s. The model was calibrated using a recently developed evolutionary algorithm that allowed simulated biomasses of HTL groups to match observed biomasses over the period 2005-2009.

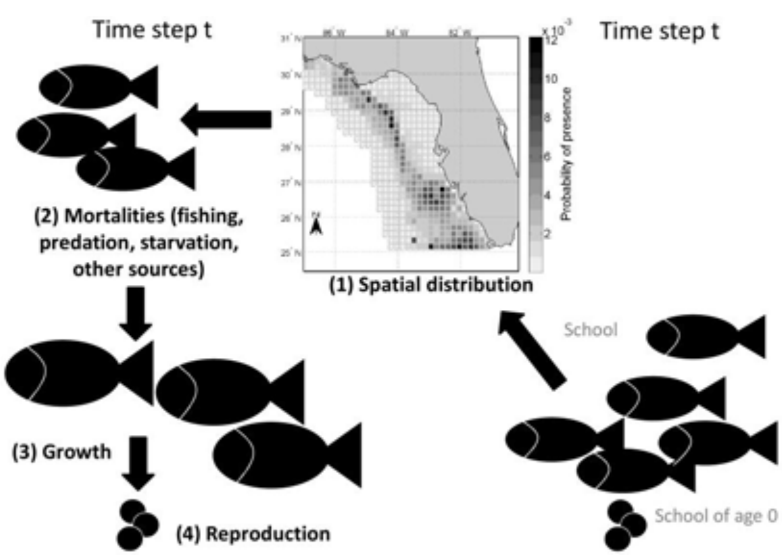


Figure 1: Succession of events within each time step (month) in the OSMOSE-WFS model. The distribution map used to symbolize the first event (spatial distribution) shows the spatial domain of OSMOSE-WFS, which is also the spatial domain considered implicitly in the non-spatial WFS Reef fish Ecopath model; this spatial domain extends from approximately 25.2° N to 31°N in latitude and from approximately 80.2°W to 87°W in longitude and comprises 465 square cells in a grid with closed boundaries.

The version of OSMOSE-WFS presented in this report is different from that presented in the previous CIMAS annual report. In June 2014, a new version of the OSMOSE modeling approach ('OSMOSE v3u1') was released. One of the differences between OSMOSE v3u1 and earlier versions of OSMOSE is the use of a recently developed mortality algorithm, called the 'stochastic mortality algorithm', which assumes that all types of mortalities are processes that are simultaneous, and that there is competition and stochasticity in the predation process. The OSMOSE-WFS model was updated to meet the specifics of OSMOSE and, therefore, had to be recalibrated so that biomasses of the HTL groups represented in the model keep matching observed biomasses over the period 2005-2009 (Figures 2 and 3). Once OSMOSE-WFS was recalibrated, the model was evaluated by comparing simulated diets to observed ones, and the simulated trophic levels to those in an Ecopath model of the West Florida Shelf (WFS Reef fish Ecopath). Finally, OSMOSE-WFS was used to explore the trophic structure of the West Florida Shelf in the 2000s and estimate age- and size-specific annual natural mortality rates and simulate fishing scenarios for a socio-economically important fish population, Gulf of Mexico red grouper (*Epinephelus morio*); Gulf of Mexico red grouper was evaluated under the auspices of SEDAR in 2014-2015 (SEDAR 42).

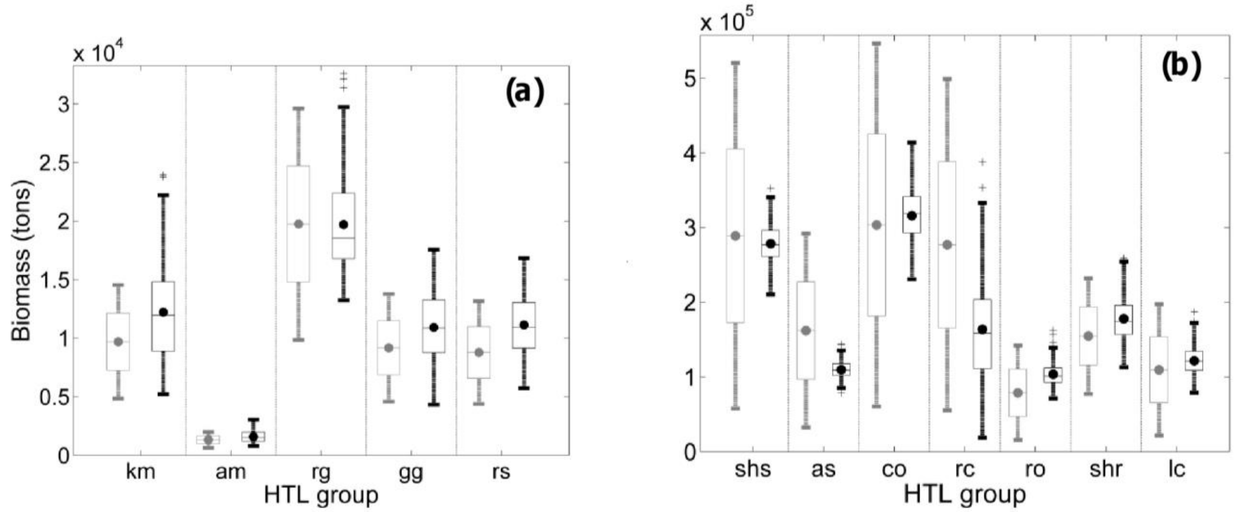


Figure 2: Biomasses observed over the period 2005-2009 (gray boxplots) and predicted by OSMOSE-WFS (black boxplots) for the 12 high trophic level (HTL) groups explicitly considered in OSMOSE-WFS. Mean observed biomasses (gray dots) are associated with valid intervals, i.e., minimum and maximum possible values, accounting for variability and uncertainty of mean biomass estimates over the period 2005-2009. Biomasses simulated with OSMOSE-WFS correspond to mean biomasses (black dots) +/- standard deviations for 10 replicates after 115 to 134 years of simulation. Note the change of scale of the y-axis between the left and right panels. (a) km: king mackerel – am: amberjacks – rg: red grouper – gg: gag grouper – rs: red snapper; (b) shs: sardine-herring-scad complex – as: anchovies and silversides – co: coastal omnivores – rc: reef carnivores – ro: reef omnivores – shr: shrimps – lc: large crabs.

OSMOSE-WFS outputs are in full agreement with observations as to the body size and ecological niche of prey of the different HTL groups, as well as to the trophic levels of these HTL groups. OSMOSE-WFS outputs are not in full agreement with observations as to the species composition of the diet of HTL groups. The age-specific natural mortality rates of red grouper predicted by OSMOSE-WFS were compared to the age-specific natural mortality rates reconstructed for SEDAR 42 (Figure 4), while the size-specific natural mortality rates of red grouper predicted by OSMOSE-WFS were compared to those in WFS Reef fish Ecopath (Figure 5). OSMOSE-WFS and WFS Reef fish Ecopath globally concur on the magnitude of the annual natural mortality of the different size classes of red grouper over the period 2005-2009, but not always on the main causes of natural mortality (Figure 5).

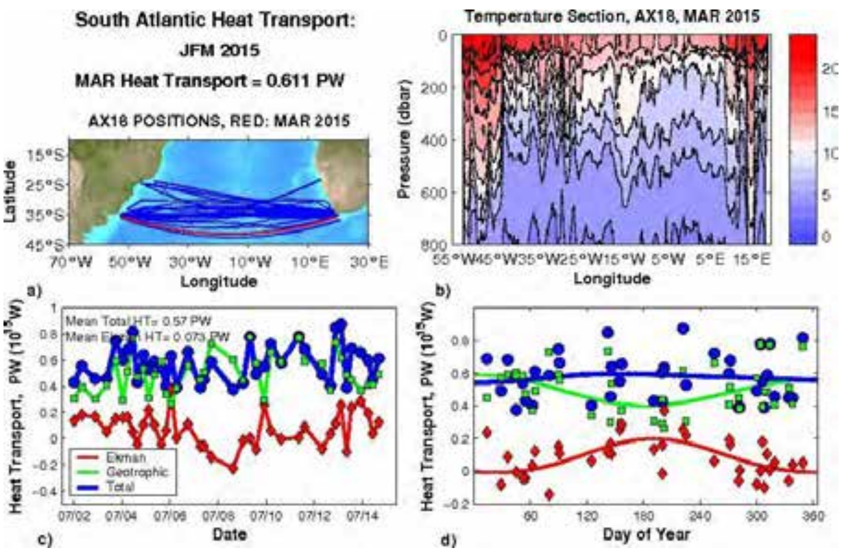


Figure 3: Mean trajectories of biomasses in OSMOSE-WFS after 0 to 134 years of simulation (a) for all HTL groups; and (b) for king mackerel, amberjacks, red grouper, gag grouper and red snapper. 10 simulation replicates were run to produce these plots.

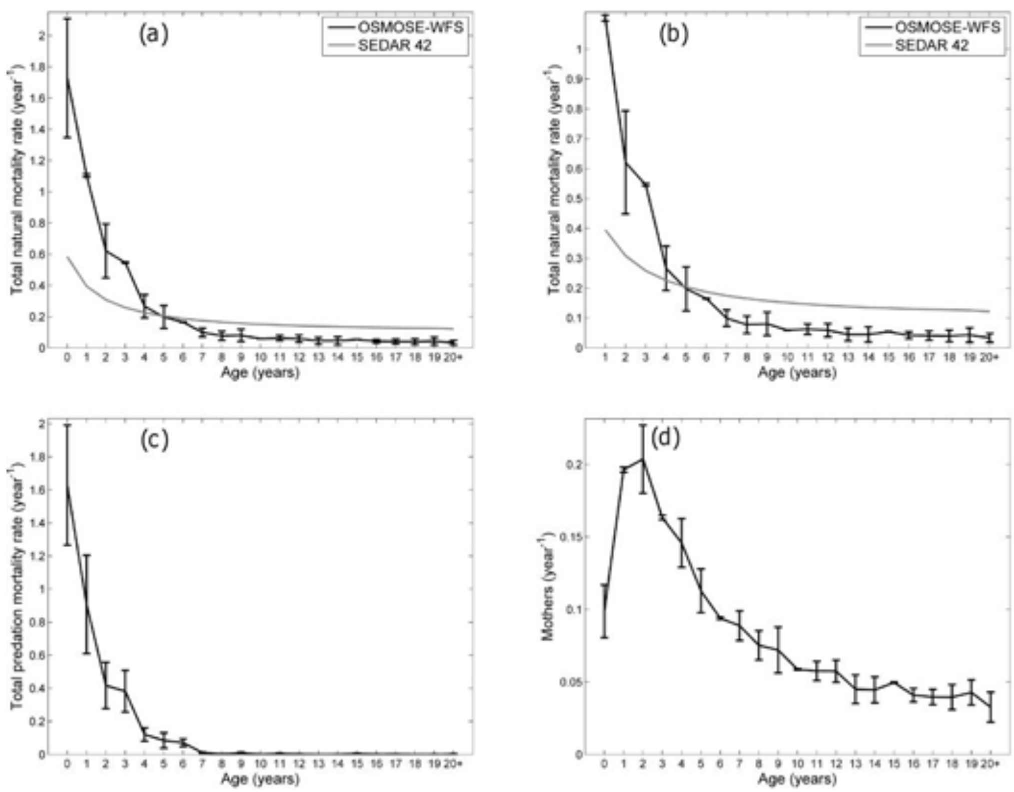


Figure 4: Annual natural mortality rates at age of red grouper predicted by OSMOSE-WFS. (a) Total natural mortality at age of red grouper predicted by OSMOSE-WFS compared to that produced for SEDAR 42. (b) Total natural mortality at age of red grouper from age 1 predicted by OSMOSE-WFS compared to that produced for SEDAR 42. (c) Total predation mortality at age of red grouper predicted by OSMOSE-WFS. (d) Natural mortality at age of red grouper due to causes other than predation (M_{others}) predicted by OSMOSE-WFS. For OSMOSE-WFS, 10 replicates and only the last 20 years of simulations (i.e., years 114 to 134) were considered. Note that age 0 in OSMOSE-WFS includes all red grouper individuals that are older than 1 month and younger than 1 year; 0-1 month old red groupers belong to the ‘ichthyoplankton’.

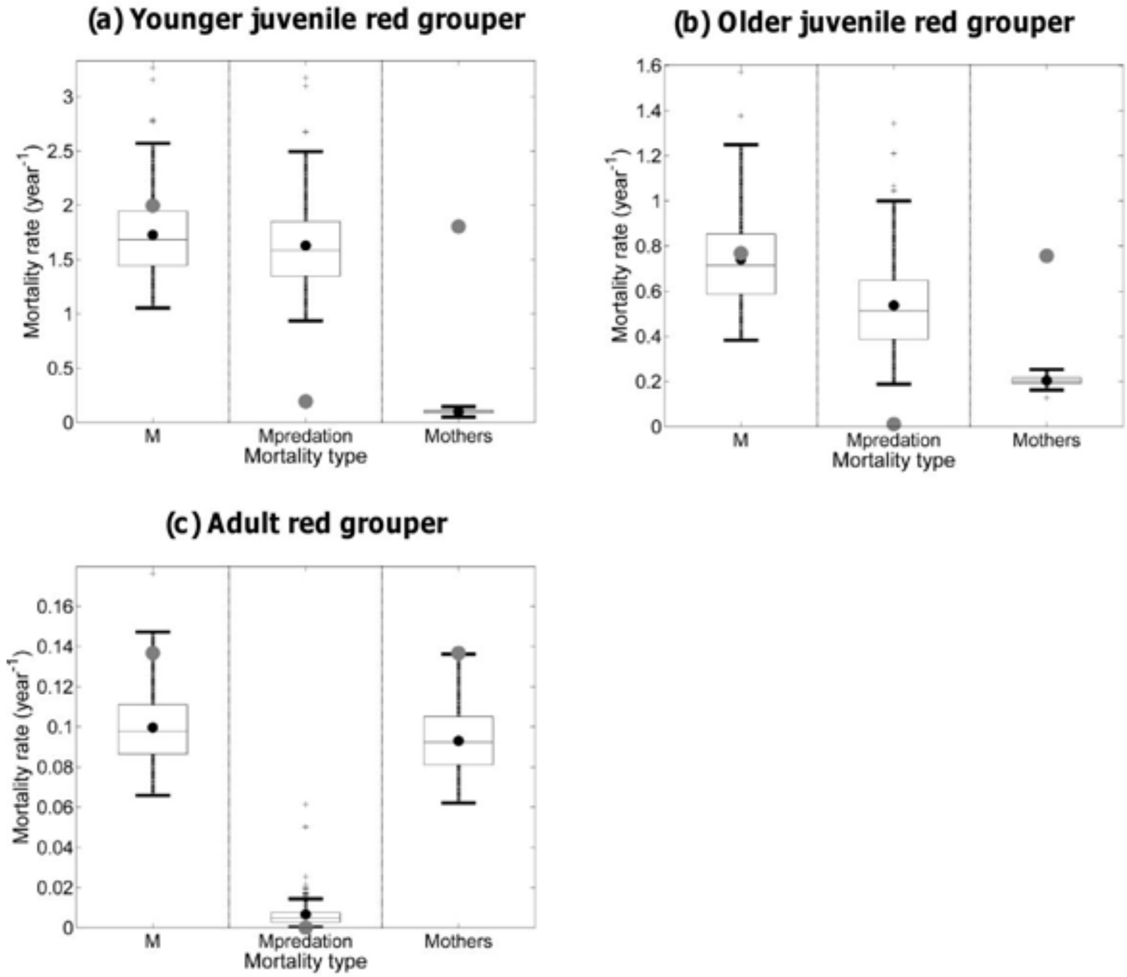
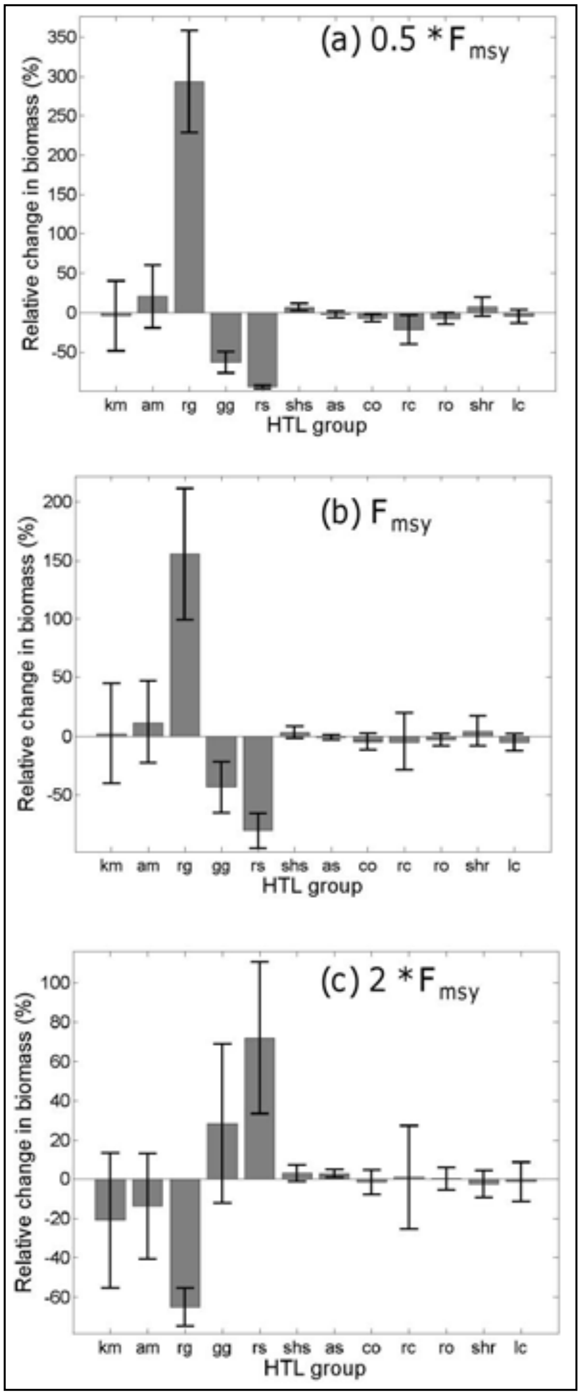


Figure 5: Annual natural mortality rates of (a) younger juvenile, (b) older juvenile and (c) adult red grouper predicted by OSMOSE-WFS (black boxplots) and WFS Reef fish Ecopath (large gray dots). Mean natural mortality rates predicted by OSMOSE-WFS are indicated by small black dots. For OSMOSE-WFS, 10 replicates and only the last 20 years of simulations (i.e., years 114 to 134) were considered. M: total natural mortality rate - $M_{predation}$: total predation mortality rate - M_{others}: natural mortality rate due to all other causes.

An equilibrium catch curve was constructed for Gulf of Mexico red grouper with OSMOSE-WFS and used to estimate the annual fishing mortality of the population resulting in maximum sustainable yield, i.e., its F_{msy}. Then, the long-term consequences of applying a fishing mortality to red grouper equal to half its F_{msy} or to its F_{msy} (i.e., the consequences of reducing the fishing mortality of red grouper), and of increasing the fishing mortality of red grouper to twice its F_{msy}, were investigated. Increasing the fishing mortality of red grouper would increase the biomass of major competitors, due to reduced competition for food (Figure 6). Conversely, decreasing the fishing mortality of red grouper would diminish the biomass of major competitors, due to increased predation pressure on the juveniles of the major competitors by red grouper (Figure 6). The fishing scenarios that we evaluated may have slightly different impacts in the real world, due to some discrepancies between the diets of red grouper and its major competitors predicted by OSMOSE-WFS and the observed ones. Modifications in OSMOSE-WFS were identified to reduce these discrepancies.



The model evaluations that we conducted by comparing the diets predicted by OSMOSE-WFS to observed ones, and the trophic levels predicted by OSMOSE-WFS to those in WFS Reef fish Ecopath, provides a strong basis for ongoing work exploring management and environmental scenarios so as to inform EBFM. From simple size-based predation rules, we were indeed able to capture the complexity of trophic interactions in the West Florida Shelf, and to identify the predators, prey and competitors of socio-economically important fish populations as well as pivotal prey species groups of the ecosystem. Moreover, the analysis of the fishing scenarios that we explored for Gulf of Mexico red grouper highlighted areas of improvement for OSMOSE-WFS, which will allow us to enhance the realism of the model and, therefore, confidence in the products that are delivered to SEDAR stock assessments and to the Gulf of Mexico Fishery Management Council.

Research Performance Measure: Our objectives were to: (1) have a steady-state OSMOSE-WFS model, fully operational and meeting the requirements of the last version of the OSMOSE modeling approach (OSMOSE v3u1), before the end of the year 2014; (2) use this model to inform fisheries stock assessments in 2014-2015; (3) submit working papers to inform the assessment of Gulf of Mexico red grouper (i.e., SEDAR 42); and (4) submit a manuscript on the present project entitled “Evaluating natural mortality rates and simulating fishing scenarios for Gulf of Mexico red grouper (*Epinephelus morio*) using the ecosystem model OSMOSE-WFS” to the peer-reviewed journal *Journal of Marine Systems* by the end of the fiscal year. All these objectives have been fully met.

Figure 6: Long-term changes in the biomass of the high trophic level groups represented in OSMOSE-WFS under different fishing scenarios relative to the status quo (in %). For (a), the annual fishing mortality rate F of red grouper is set to half its F_{msy} (i.e., the annual fishing mortality rate resulting in maximum sustainable yield) estimated with OSMOSE-WFS. For (b), the F of red grouper is set to its F_{msy}. For (c), the F of red grouper is set to twice its F_{msy}. km: king mackerel – am: amberjacks – rg: red grouper – gg: gag grouper – rs: red snapper - shs: sardine-herring-scad complex – as: anchovies and silversides – co: coastal omnivores – rc: reef carnivores – ro: reef omnivores – shr: shrimps – lc: large crabs.

Nonlinear Time Series Models for Forecasting Stock Abundances in the Gulf of Mexico

Project Personnel: W.J. Harford (UM/CIMAS)
NOAA Collaborators: M. Karnauskas, C. Porch, and X. Zhang (NOAA/SEFSC); B. Linton (NOAA/NEFSC)
Other Collaborators: H. Liu (Texas A&M)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To compare forecasts produced from nonlinear models to those produced from conventional assessment models; To examine possible associations between stocks, in terms of population dynamics trends to elucidate relationships between the study species and other components of the ecosystem.

Strategy: To achieve these objectives, nonparametric (and nonlinear) time series models were used to describing non-linear stock dynamics without requiring assumptions about mechanistic relationships that are associated with traditional stock assessment modeling.

CIMAS Research Theme:

Theme 5: Ecosystem Modeling and Forecasting

Link to NOAA Strategic Goals:

Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems (Primary)*

Goal 4: Resilient Coastal Communities and Economies - *Coastal and Great Lakes communities that are environmentally and economically sustainable (Secondary)*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

We explore the utility of nonlinear time series models in producing short-term forecasts of fish stock abundances in the Gulf of Mexico. These nonlinear models allow for considerable flexibility in representing ecological processes in the ocean, and therefore, serve as useful complements to traditional stock assessment methods. Nonlinear models are currently incorporated into assessments of stock inhabiting U.S. waters, and we extend their application to the Gulf of Mexico ecosystem.

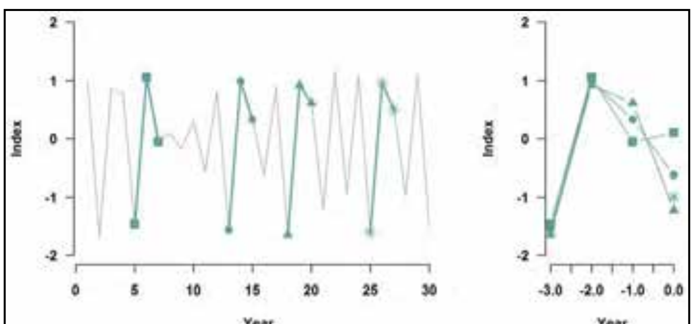


Figure 1: Nonlinear time series forecasting.

Research Performance Measure: This project was 9 months in durations, and active for 5 months of the 2015 FY. We have developed a toolbox of the statistical methods necessary to achieve our objectives. These methods were applied to king mackerel for an integrated ecosystem assessment to Bluefin tuna for an ICCAT Ecosystem sub-committee intersessional meeting. We also presented a two day CIMAS workshop on these statistical methods that included visit and participation of several national experts.

Living on the (Shelf) Edge: Using Advanced Glider Technology to Assess Fishery Resources along the South Atlantic Continental Shelf Break

Project Personnel: C. Lembke, A. Silverman, S. Butcher, M. Lindemuth and S. Murawski (USF)
NOAA Collaborators: T. Kellison (SEFSC, Beaufort)
Other Collaborators: C. Taylor (NOS, Beaufort); D. Mann and C. Wall (Loggerhead Instruments Inc.); R. He (North Carolina State University)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** (1) Conduct the deployment of a Slocum underwater glider along the southeastern coast from Cape Canaveral, FL to Cape Fear, NC. (2) Use the Southeast Atlantic Bight Gulf of Mexico (SABGOM) nowcast / forecast model to navigate the glider inshore and within the Gulf Stream. (3) Analyze sensor data collected by the glider, with particular focus on passive acoustic recordings of soniferous organisms with intent to: (a) Provide context for relative spatial distributions of multiple species, focusing on red grouper but including others as data permit, (b) location of acoustically detected single- or multi-species "hotspots", (c) potential locations of winter spawning aggregations for aggregating species.

***Strategy*:** USF's glider, equipped with a suite of biological, physical, chemical, and acoustic sensors was deployed on March 3 and recovered after traversing 900km on April 1, 2014. During the deployment, bi-weekly conference calls were conducted to discuss the glider's progress and forecasted conditions. During the deployment, some glider data was shared near real-time with the broader community through USF's COT Remote Observations Website (http://ooma.marine.usf.edu/CROW/), as well as updates to the Southeast Coastal Ocean Observing Regional Association (SECOORA). Upon retrieval, all data has been downloaded and processed.

CIMAS Research Theme:

***Theme 5*:** Ecosystem Modeling and Forecasting (*Primary*)
***Theme 6*:** Ecosystem Management (*Secondary*)
***Theme 3*:** Sustained Ocean and Coastal Observations
***Theme 4*:** Ocean Modeling

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

***Goal 4*:** Resilient Coastal Communities and Economies - *Coastal and Great Lakes communities that are environmentally and economically sustainable*

NOAA Funding Unit: NMFS/ASTWG (via SEFSC) **NOAA Technical Contact:** Todd Kellison

Research Summary:

USF's glider Bass was deployed 160 km ESE of Ponce de Leon Inlet just north of Cape Canaveral, at the 30m isobath on March 3, 2014, from the charter FV Sea Lover by Dr. Kellison, Dr. Taylor, and Mr. Butcher. By March 5 the glider left the shelf region and began entering the Gulf Stream, achieving a maximum estimated speed of 1.7 m/s, compared to an average speed of 0.23 m/s. The glider progressed up the coast until reaching the North Charleston MPA mid-day March 16. For the next two weeks the glider loitered in the region, spending over 90% of the time within the desired depth ranges. A return to the south toward the Edisto MPA was attempted, but prevailing northerly currents prevented timely progress. Throughout the deployment, regular conference calls between the pilots at USF, the modelers at NCSU, and the biologists at SEFSC were conducted to monitor progress and plan coming days to keep the glider in the zones of scientific interest despite the currents. The glider was recovered on April 1, 75km S of Cape Fear by C. Lembke and T. Kellison.

During this month long mission, the following data was collected: Passive Acoustic Recordings, Temperature, Conductivity, Fluorescence (Chl, CDOM, backscatter), Dissolved Oxygen, and Acoustic Tag Telemetry. USF conducted QA of the CTD, Fluorometer, and Dissolved Oxygen sensors. NCSU (R. He) analyzed all physical data and compared it to model results. The Vemco receiver data has been processed resulting in one tag detected off the coast of South Carolina, a scalloped hammerhead released from Cape Canaveral in June of 2013. Near real time data was transmitted not only to the research team involved in this project, but to the community at large through SECOORA and the deployment was used as a test case for attempting to transmit data to the IOOS National Glider DAC. While this last effort was not successful by the completion of the mission, valuable information was learned by both USF and the IOOS data managers which has led to enhancements to the uploading procedures and formats.

The primary focus of this mission was the utilization of the passive acoustics to a provide context for relative spatial distributions of multiple species, focusing on red grouper but including others as data permit. Loggerhead Instruments (C. Wall) manually processed all recorded acoustic files for known biological sounds. A variety of sounds were identified in the acoustic recordings, including those generated by red grouper (Figure 1 and 2), toadfish, two sounds previously documented in the Gulf of Mexico suspected to be produced by fish, whistles (Figure 3) and echolocation from marine mammals, and extensive vessel noise. Numerous sounds from previously undocumented sources were also recorded. Red grouper was the only serranid consistently identified from the sound data, with detections occurring inside and out of the U.S. South Atlantic Fishery Management Council marine protected areas.

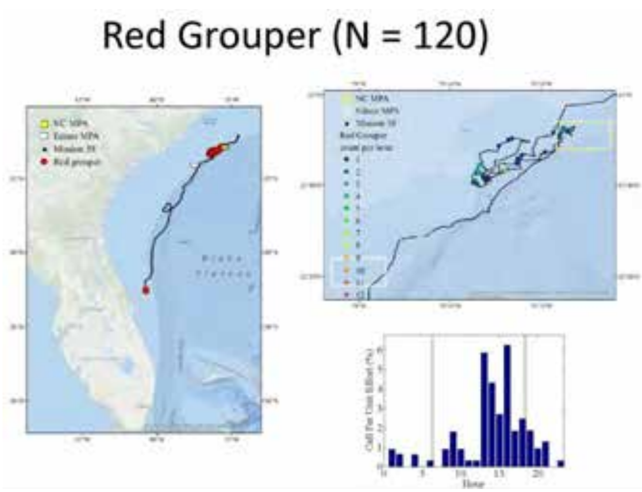


Figure 1: Location of acoustic files that contained red grouper sounds a) across the entire glider track (N = 120) and b) zoomed in to the northern portion of the track binned as percentage of 30 s files per hour. c) Percentage of 30 s files containing red grouper sounds normalized by the total number of files recorded by hour. Grey bars indicate local sunrise and sunset.

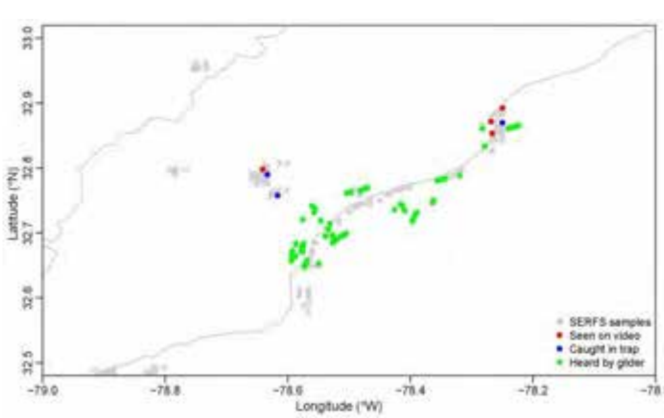


Figure 2: Location of red grouper observed in SEUS waters off South Carolina during the Southeast Reef Fish Survey (SERFS) sampling (gray), on video (red), caught in a trap (blue), and recorded by the glider (green). The video and trap data are from SERFS.

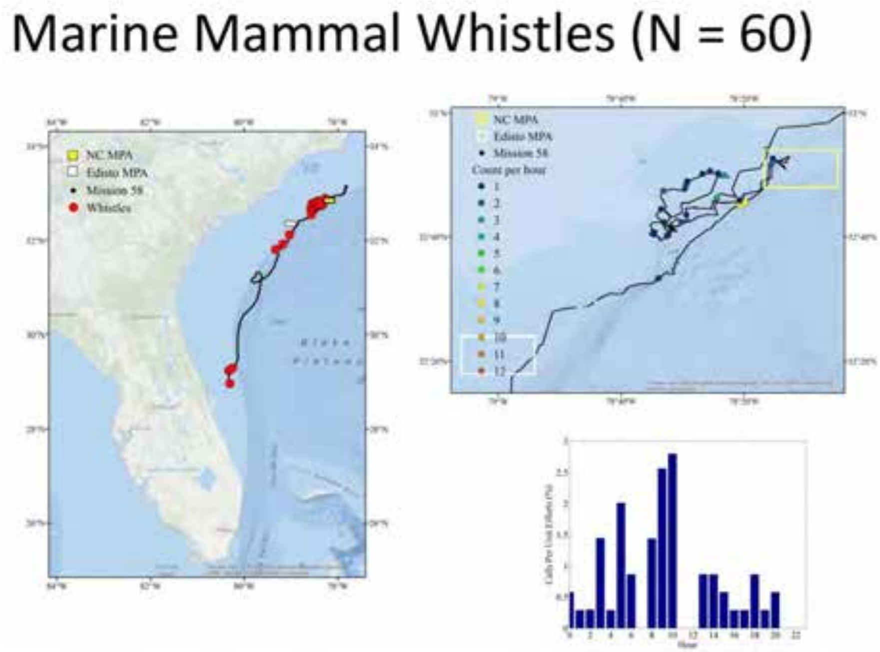


Figure 3: Similar to Figure 1 focusing on marine mammal whistles.

Table 1: Number of files observed to have specific sounds (N) with the mean, standard deviation ("S.D."), and range of depths these sounds were recorded, and the percentage of detections recorded during daytime hours ("Daytime (%)"). The source of the two harmonic frequencies is unknown.

Sound	N	Depth Mean ± S.D.	Range	Daytime (%)
Fish				
Red grouper	120	39.4 ± 3.1	34.6 - 66.1	70.8
Toadfish	4	40.9 ± 0.5	40.6 - 41.6	100
300 Hz FM Harmonic	70	44.1 ± 15.4	34.6 - 92.5	0.8
365 Hz Harmonic	373	39.0 ± 3.6	34.5 - 62.2	0.3
Marine Mammal				
Whistles	60	40.6 ± 12.8	34.6 - 117.0	56.7
Echolocation	28	46.0 ± 38.7	34.5 - 243.4	32.1
Other				
Boat	2151	44.7 ± 28.4	14.9 - 266.9	45.1

Research Performance Measures: Objectives 1 and 2 (as described above) were accomplished. Proper planning and preparation utilizing past, current, and forecasted data allowed the glider to navigate the coastal shelf waters and the Gulf Stream within the desired regions.

Objective 3 was met by demonstrating the potential utility of a glider-based passive acoustics approach to generate results relevant to fish, marine mammal and boat distributions – in essence, relevant to fisheries management, protected species management, and marine spatial planning. All recorded observations are tallied below.

Applying Bio-physical Monitoring and Capacity Assessments to Mesoamerican Reef Marine Protected Areas

Project Personnel: E. Malca and B. Muhling (UM/CIMAS)
NOAA Collaborators: J. Lamkin and T. Gerard (NOAA/SEFSC)
Other Collaborators: E. Sosa-Cordero, L. Carrillo-Bibriezca and L. Vasquez-Yeomans, (ECOSUR); M.J. González (MARfund)

Long Term Research Objectives & Strategy to Achieve Them:

Objectives: To establish research priorities in the Mesoamerican region in order to provide baseline data (oceanographic and larval fish distributions) to support connectivity and fisheries management decisions in the region.

Strategy: Our strategies are: to carry out larval and oceanographic collections to assess larval transport & recruitment pathways in the Mesoamerican reef system. In addition, to enhance international capacity for the topic of connectivity as it relates to research and management with local and regional practitioners in the Mesoamerican Reef.

CIMAS Research Theme:

***Theme 5*:** Ecosystem Modeling and Forecasting

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

Connectivity research has become an ambitious focus through the study of physical and meteorological processes in the ocean that strongly impact biological and ecological populations and communities living in marine and coastal habitats. We utilized existing regional capacity-building collaborations (El Colegio de la Frontera Sur, Healthy Reefs Initiative and the Mesoamerican Reef Fund) in order to carry out capacity building workshops focusing on connectivity in the Mesoamerican Reef System.

A sixth activity titled Connectivity Exercises (ECOME) in multiple marine protected areas (MPAs) was carried out during the new moon: August 22-28, 2014 in Mesoamerica to collect larval and juvenile reef fishes during the new moon. A total of 11 MPAs representing the 4 countries in Mesoamerica participated.

Research Performance Measure: Despite funding limitations, the program has been proceeding as a result of multiple contributions and outreach activities sponsored by all partners involved in this project. Members of the "Connectivity Network" carried out a training workshop in Sandy Bay West End and other sites within Roatan Marine Park in Honduras to augment already developed reef fish monitoring capacity to now include light traps focused in reef fish monitoring. In addition, members of the network participated in a technical meeting titled "La pesqueria de meros y especies afines en la peninsula de Yucatán on 12/4-12/5 in Merida, Mexico (travel sponsored by the meeting).

Results from the Connectivity Exercises (ECOME) were presented at multiple meetings: (a) XVII Congreso Sociedad MAR para la Biología y Conservación, Copan, Honduras, 10/13-17 and (b) Gulf and Caribbean Fisheries Institute Annual Meeting in Barbados, 11/3-11/7/2015 (sponsored travel funded by

CAMPAM network and SPAW). A final report is currently being prepared to recap results and capture lessons learned from the project in both English and Spanish. Lastly, a seventh ECOME is planned for the late summer with at least four marine protected areas participating so far.

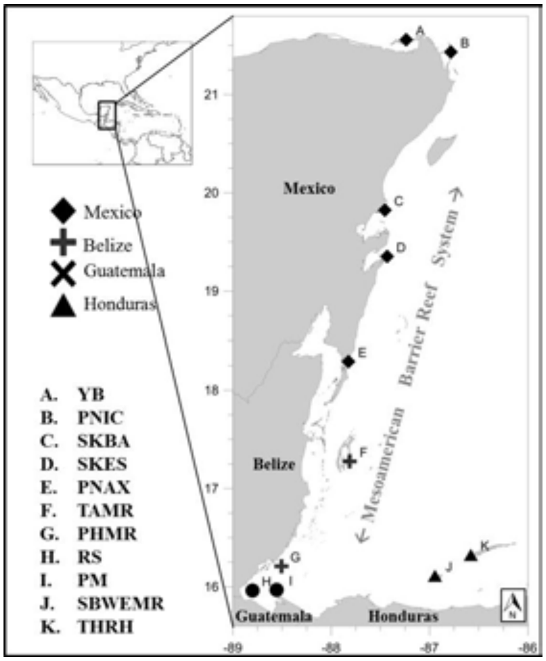


Figure 1: Eleven marine protected areas in the Mesoamerican Barrier Reef System that participated in ECOME 1, 2 and/or 3 in 2010-2014. From North to South and East to West: (A) Area de Proteccion de Flora y Fauna Yum Balam, YB; (B) Parque Nacional Isla Contoy, PNIC; Reserva de la Biosfera Sian Ka'an: (C) Bahía Ascensión, SKBA, (D) Bahía Espiritu Santo, SKES; (E) Parque Nacional Arrecifes de Xcalak, PNAX; (F) Turneffe Atoll Marine Reserve (TAMR); (G) Port Honduras Marine Reserve (PHMR); (H) Área de Uso Múltiple Rio Sarstún, RS; (I) Refugio Vida Silvestre Punta Manabique, PM; (J) Sandy Bay West End Marine Reserve, SBWEMR, and (K) Zona de Protección Especial Marina Turtle Harbour - Rock Harbour, THRH.

Figure 2: Water column collector deployed (left) and collection effort (right) in Zona de Protección Especial Marina Turtle Harbour - Rock Harbour, Honduras during ECOME 1 in 2013.

Caribbean Sea and Gulf of Mexico Bluefin Tuna Research

Project Personnel: B. Muhling, E. Malca, S. Privoznik and A. Shiroza (UM/CIMAS)
NOAA Collaborators: J. Lamkin and T. Gerard (NMFS/SEFSC); Aras Zygas (NOAA)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To define and investigate bluefin tuna and other highly migratory species' spawning grounds in the western central Atlantic, including the Gulf of Mexico, Caribbean Sea and adjacent regions.

***Strategy*:** To complete detailed fisheries oceanography surveys of the Caribbean and western Atlantic in early spring, including plankton sampling for fish larvae.

CIMAS Research Theme:

***Theme 5*:** Ecosystem Modeling and Forecasting

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans – *Marine fisheries, habitats, and biodiversity sustained within healthy and reproductive ecosystems*

NOAA Funding Unit: SEFSC **NOAA Technical Contact**: Theo Brainerd

Research Summary:

The western stock of Atlantic bluefin tuna (*Thunnus thynnus*) is only known to spawn in the Gulf of Mexico and adjacent areas, during spring (April to June). Previous and ongoing collaborations with scientists from UM/CIMAS, NOAA and other domestic and international institutions have confirmed that spawning activity exists throughout the Gulf of Mexico, as well as in the Mexican Caribbean and north of the Bahamas. In 2015, we extended the larval sampling efforts to new areas in the Western Caribbean, in an effort to determine the extent of spawning in this region. In addition, we used adaptive sampling methods to further develop and test the existing larval bluefin tuna habitat model.

The 2015 research cruise completed intensive sampling throughout the Caribbean, collecting and preserving larvae for studies of growth, isotopic trophodynamics, condition and feeding patterns. The spatiotemporal extent of sampling was designed to complement the NOAA-led annual spring survey, which was completed on the NOAA ship Oregon II. Scientists from UM/CIMAS, NOAA-SEFSC, NOAA-AOML, IEO (Instituto Español Oceanográfico, Spain), El Colegio de la Frontera Sur - ECOSUR (México), University of the Virgin Islands, University of the West Indies, University of Puerto Rico, University of South Florida, and USVI Department of Planning and Natural Resources participated during the research cruise (Figure 1). The NOAA research vessel Nancy Foster was used for the 47 days of sampling completing 274 stations (Figure 2).

Similarly to cruises completed in previous years (2009-2014), physical data from CTD casts, and biological data from plankton net tows were collected *in situ*. Plankton samples were sorted at sea, and preliminary abundances of larval tunas and lobsters were recorded. A subset of larvae was then frozen separately in liquid nitrogen, and will be used for tissue stable isotope analyses. We will continue our collaborations with the Instituto Español Oceanográfico in Spain to compare results between the Gulf of Mexico, the Western Caribbean and the Mediterranean Sea.

Preliminary results from the research cruise indicate that blackfin tuna (*Thunnus atlanticus*) larvae were highly abundant in the sampled area. While no bluefin tuna were observed during the cruise, the remaining plankton samples will be examined thoroughly to make a final determination. These results suggest that spawning of bluefin tuna is more restricted in time and space than for other Atlantic tunas, including congeners. A large number of lobster early life stages (phyllosoma) were also collected throughout the cruise. These have been preserved, and will be used for future ecological studies (Figure 3).

Figure 1: Larval fish research cruise participants for April – June, 2015.

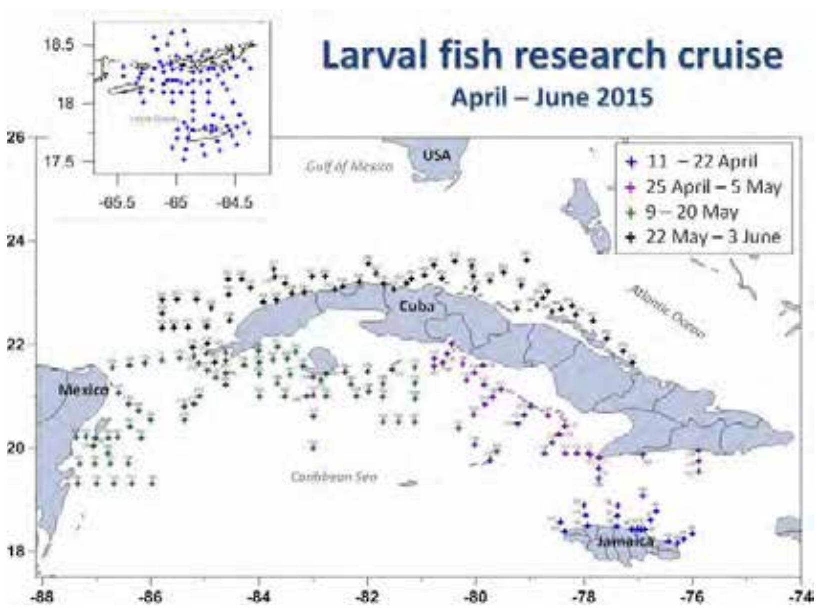


Figure 2: Stations sampled during larval fish research cruise aboard NOAA SHIP NANCY FOSTER for April – June 2015.

In addition, research efforts also included biological and physical oceanography sampling around the U.S. Virgin Islands for the purpose of evaluating distribution and transport of coral reef fishes. While research questions were somewhat different from Bluefin Tuna research, this unique opportunity allowed us to collect data that will potentially elucidate abundances of reef fishes and in turn spawning habitat for parrotfishes which may be applied to management actions recently implemented in the region. The long-term sustainability of fisheries in the Virgin Islands and surrounding regions will depend on a comprehensive understanding of regional spawning aggregations, larval transport, and overall larval recruitment in the study area.

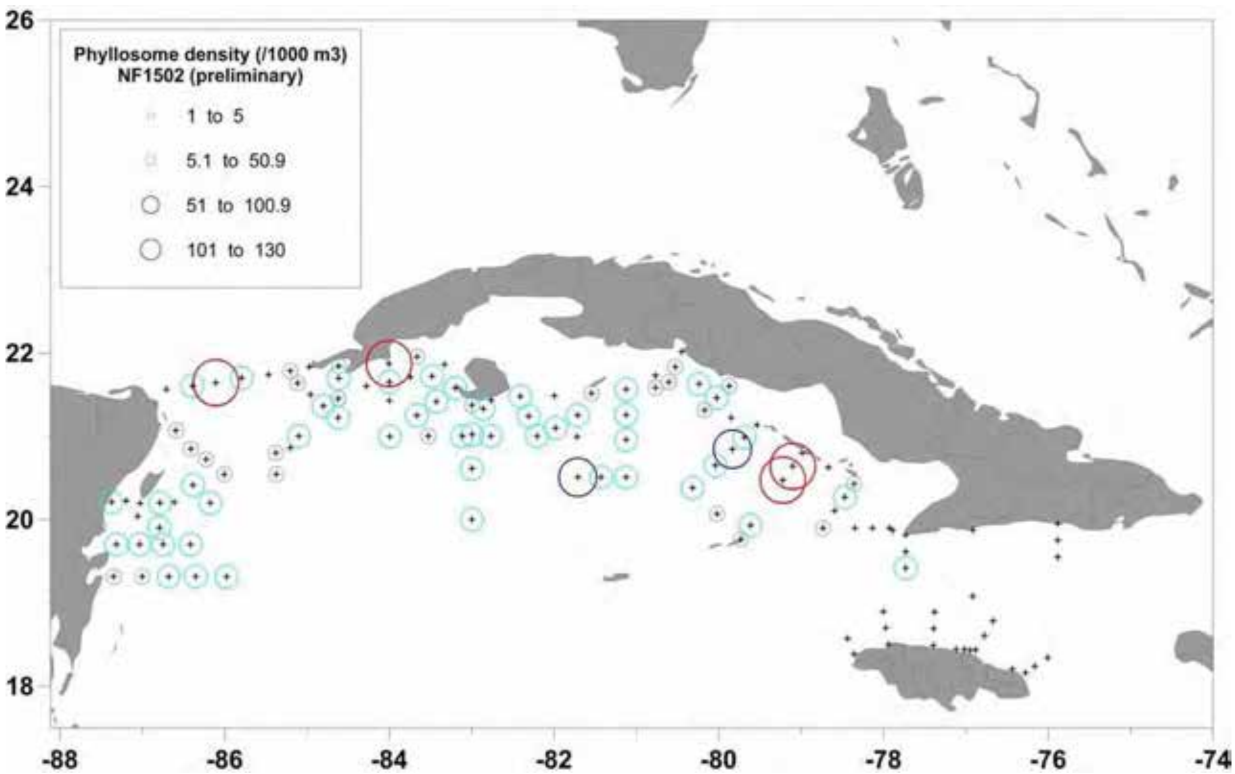


Figure 3: Preliminary abundances of larval lobsters from the 2015 cruise during legs 2 and 3 in the Western Caribbean.

Research Performance Measure: The research program is on schedule. This year's (NF1502-03) cruise was successfully completed on June 3, 2015; sample processing has started and sorting will begin shortly. Last year's cruise (WS1405) has been completely sorted and larval bluefin tuna identification has been completed. For the trophodynamics sub-project, frozen samples of ichthyoplankton, mesozooplankton, microzooplankton and phytozooplankton were shipped to the IEO laboratory in Malaga, Spain for processing. Otolith removal has been completed on the larval bluefin tuna from this shipment and is awaiting ageing. For the ageing sub-project, 138 larval bluefin tuna have been aged from the 2012 survey. Additional otoliths from 2013 and 2014 will also be aged to develop an age and growth curve encompassing multiple years (2012-2014). Lastly, ageing of larval Skipjack tuna (*Katsuwonis pelamis*) has commenced for a multi-species comparison.

Prioritizing Spawning Habitats in Terms of their Relative Contribution to Recruitment Success

Project Personnel: C.B. Paris and A. Vaz (UM/RSMAS)
NOAA Collaborators: M. Karnauskas and J. Walter (SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

Objective: To improve the estimation of spawning sites for gag grouper along the northeastern Gulf of Mexico shelf edge using the Connectivity Modeling System for simulating larval dispersal. Ultimately estimated spawning sites will be used to: i) guide future survey efforts for spawning activity, ii) standardize CPUE indices, since catch rates may be greatly increased at spawning times and locations, iii) guide spatial management measures in the region to help rebuild the stock.

Strategy: To implement new features in the Connectivity Modeling System (CMS) considering more refined larval traits and behavior, which in turn will improve the predictions of spawning sites.

CIMAS Research Theme:

***Theme 5*:** Ecosystem Modeling and Forecasting

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

The Connectivity Modeling System (CMS, Paris et al. 2013) is a community multi-scale biophysical modeling system, based on a stochastic Lagrangian framework. The model computes the probability of population connectivity based on larval transport from spawning to settlement locations. The dispersal of eggs and larvae is simulated as an active process since larval traits are assimilated into CMS (Paris and Cowen 2004, Paris et al. 2005, Paris et al. 2007).

Here, modeling efforts with CMS are focused on refining the CMS capabilities to represent crucial processes taking place during early larval stages. By enhancing CMS ability to represent important larval traits, we are also improving the estimations of recruitment contribution relative to oceanographic factors which are used for stock assessment and conservation measures.

To date, we implemented three new modules on CMS:

i) pelagic larval duration regulated by water temperature,
ii) spatially-explicit mortality scheme defined by temperature,
iii) distinct ontogenetic vertical migration schemes based on the depth at the larvae's location.

We have also expanded the biased random walk module simulating larval navigation towards settlement habitat based on acoustic signal (Staaterman et al. 2012), to include larval navigation directed by spatial-temporal varying cues and by sun compass.

Temperature can both directly and indirectly influence both larval growth and mortality rates. This influence is primarily related to individual metabolism, but community processes, such as ecosystem productivity, also play an important role. Given the overwhelming evidence of temperature affecting growth and mortality rates of planktonic organisms (Houde 1989, O'Connor et al. 2007), it is essential to include this influence on the simulation of larval grown and dispersal. The new module developed on the Connectivity Modeling System (CMS) can use water temperature to mediate the pelagic larval duration, given by the relationship given by Houde (1989): $D = 952.5T\text{-}l^{0752}$, where D is the larval stage duration in days and T is the water temperature in degrees Celsius.

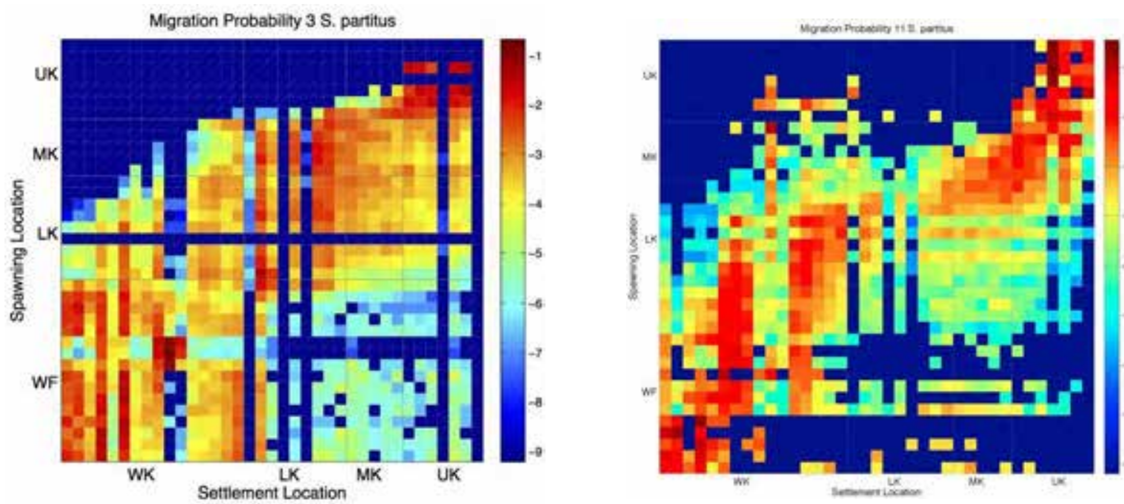


Figure 1: Migration connectivity matrix in the Florida Keys for the bicolor damselfish *Stegastes partitu*s; pelagic larval duration (PLD) is fixed to 30 days A) and variable based on temperature B); larval mortality of 0.2/day is included in both cases.

The mortality rate follows Houde (1989), and was based on observations of early life stages organisms: $Z = 0.0256 + 0.0123\ T$, where z is the daily mortality rate and T is the water temperature in degrees Celsius.

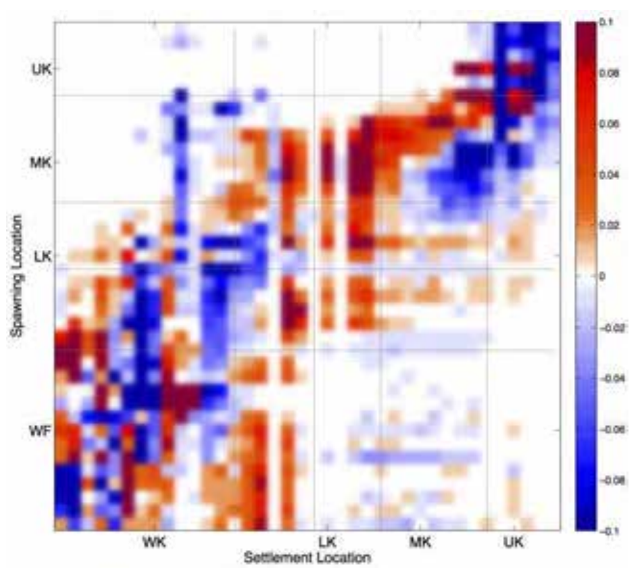


Figure 2: Differential migration connectivity matrix in the Florida Keys for the bicolor damselfish *Stegastes partitu*s, between fixed and variable PLD.

Field work conducted in the Gulf of Mexico has revealed that the gag grouper larval vertical distributions is significantly different when larval patches are located over the continental shelf or over deep water regions. Thus, we implemented an option on the Connectivity Modeling System where different migration schemes will be used accordingly to the location of the larvae in either deeper oceanic areas or shallower continental shelf regions.

Initial tests with these modules were conducted by dispersing larvae in the Florida Keys region for 3 months. The next step in the project is to conduct further testing of the module, including dispersal in the key region of the northern GoM. Furthermore, we expand the newly created modules, allowing more flexibility and user customization.

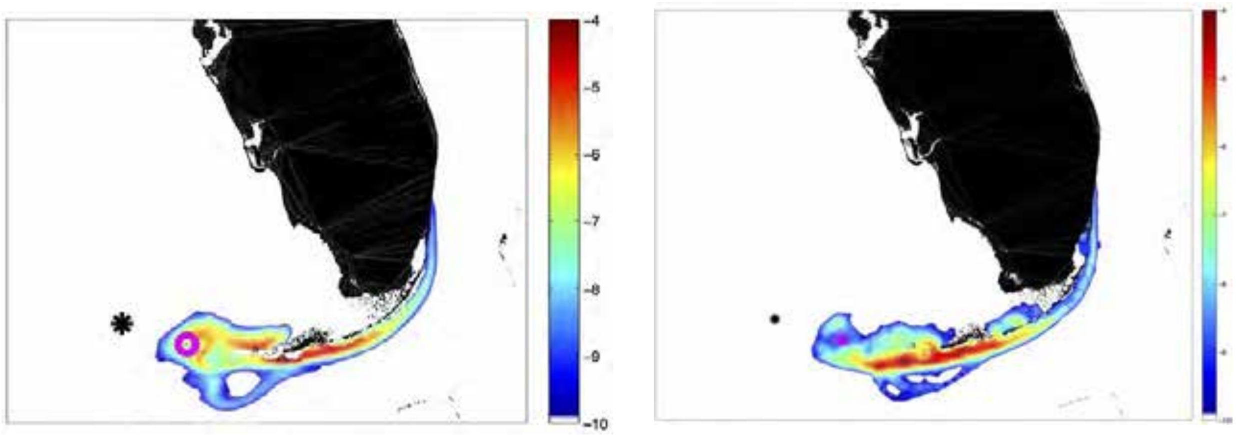


Figure 3: A Probability density distribution (PDF) of larval trajectories with fixed pelagic larval duration (PLD) A) and variable PLD B).

Research Performance Measure:
Objective 1 – Following our initial commitments, we have implemented the proposed improvements on the CMS representation of larval traits and behavior, namely: i) pelagic larval duration regulated by water temperature, ii) spatially-explicit mortality scheme defined by temperature, iii) distinct ontogenetic vertical migration schemes based on the depth at the larvae's location. We have also expanded the biased random walk module, which simulates larval navigation, to include larval navigation directed by spatial-temporal varying cues as well as sun compass.

Objective 2 – We have tested the new modules, and we will release the three Modules' Source Codes on the online open-source CMS software via GitHub only after full debugging and publications. However, the modules codes are available upon request (contact: cparis@rsmas.miami.edu)

Objective 3 – We applied the improved model to select research questions regarding commercially fished species in the Gulf of Mexico as shown in the following publications and papers in review:

Evaluating Methods for Setting Catch Limits for Gag Grouper (Mycteroperca microlepis): A Comparison Between Data-Rich and Data-Limited Stock Assessment Methods

Project Personnel: S.R. Sagarese (UM/CIMAS)
NOAA collaborators: J.F. Walter III and M.D. Bryan (NOAA/NMFS/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To test whether a similar assessment result could have been achieved with less data or with computationally less-intensive methods on aggregated data for Gulf of Mexico (GOM) gag grouper. Specifically, we (1) apply a suite of data-limited methods using the 'DLMtool' package in R developed by T. Carruthers (Univ. of British Columbia); (2) compare derived overfishing limits (OFL) to the OFL obtained with the data-rich Stock Synthesis assessment model; (2) assess the sensitivity of OFL recommendations to data inputs for each data-limited method; and (3) evaluate the relative performance of data-limited methods using management strategy evaluation.

***Strategy*:** To benefit from the experience of assessment analysts, a recently developed R package, and from data collected by NOAA/NMFS to determine whether data-limited models or simple management procedures could replicate trends obtained using the time-consuming application of the data-rich Stock Synthesis assessment model. This information will help inform the stock assessment process for other shallow-water grouper species which are data-limited.

CIMAS Research Theme:

***Theme 5*:** Ecosystem Modeling and Forecasting (*Primary*)
***Theme 6*:** Ecosystem Management (*Secondary*)

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

Recent mandates to combat overfishing and enhance management efficacy, such as the requirement of scientifically-derived annual catch limits for all managed marine resources, are a challenge for the stock assessment process in areas such as the southeast US where species biodiversity exceeds that of other marine ecosystems. Groupers are some of the most economically important reef fishes in the southeast US, yet the majority of grouper species are considered data-limited. Given that data limitations for other shallow-water grouper species such as scamp (*Mycteroperca phenax*) may not support the same detailed analyses as conducted for gag (*M. microlepis*) and red groupers (*Epinephelus morio*), there is substantial interest in applying data-limited methods to derive annual catch limits for other grouper species to inform management.

We address an issue raised at the Gulf and Caribbean Fisheries Institute Data-Limited Assessment Workshop by testing whether we could have achieved a similar assessment result with less data or with computationally less-intensive methods on aggregated data for Gulf of Mexico (GOM) gag grouper. By applying data-limited methods to a data-rich stock with similar fishery characteristics, we gain insight into some of the key assumptions and sensitivity to input parameters. Furthermore, by evaluating the performance of the data-limited methods against an integrated Stock Synthesis assessment model that deals with complexities such as hermaphroditism, time-varying processes of selectivity and incomplete retention, and episodic mortality, we identify key issues that might confound data-limited methods for application to other shallow-water grouper stocks.

Most data-limited methods provided lower estimates of the overfishing limit (OFL) compared with Stock Synthesis (Fig. 1), suggesting that in the absence of a more flexible "data-rich" modeling framework, quota recommendations would result in more conservative or precautionary advice for gag grouper. Methods that incorporated an ancillary estimate of the relative stock status, such as Depletion-Corrected Average Catch with Mean Length Estimation (DCAC_ML) and Surplus Production Stock Reduction Analysis (SPSRA), often outperformed other data-limited methods in reproducing the OFL derived with Stock Synthesis. Sensitivity analyses revealed that quota recommendations were heavily influenced by data inputs where required that included natural mortality, steepness of the stock recruitment relationship, catch, current abundance, and depletion estimates. For groupers, understanding the degree of doming in selectivity appears to be a critical component in data-limited assessment, and will likely be important in translating results into management advice.

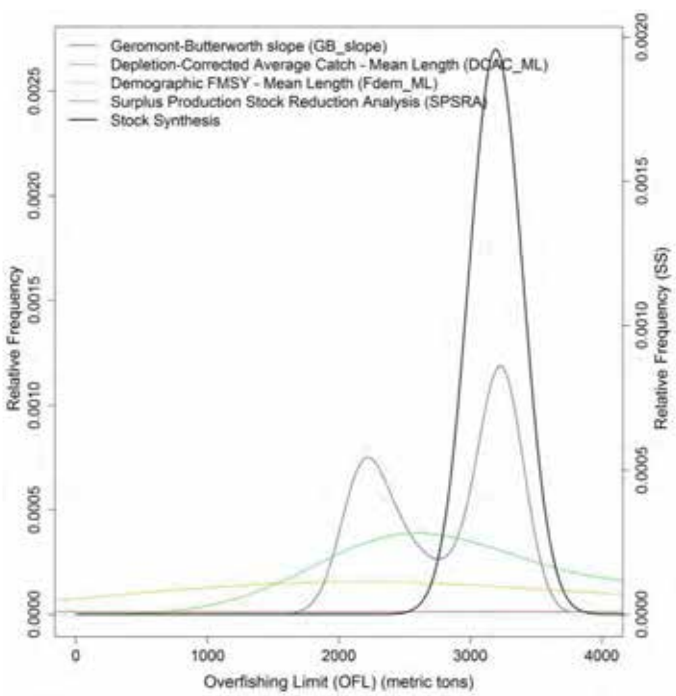


Figure 1: Comparison of the overfishing limits estimated by the data-rich Stock Synthesis model and data-limited methods using the recreational headboat index of abundance.

The management strategy evaluation performance for SPSRA and Depletion-based Stock Reduction Analysis with a 40-10 harvest control rule indicated a low probability of overfishing. These methods could provide viable management recommendations at the cost of lower potential yields. Data-limited methods that used mean length to estimate current fishing mortality such as DCAC_ML produced OFL results closest to Stock Synthesis, indicating that the added information provided by mean lengths may be quite informative.

Research Performance Measure: Our objectives for the present study were to: (1) complete data analyses by May 2015; (2) present results at the 30th Lowell Wakefield Fisheries Symposium held from May 12 – 15 in Anchorage, Alaska; and (3) submit a manuscript to the peer-reviewed proceedings by May 15. All major objectives have been met.

Mapping Ontogenetic Spatial Distributions of Gag Grouper (Mycteroperca microlepis) and Red Grouper (Epinephelus morio) in the Northern Gulf of Mexico Using Generalized Linear Models

Project Personnel: S.R. Sagarese, A. Grüss (UM/CIMAS)
NOAA collaborators: J.F. Walter III and M. Karnauskas (NOAA/NMFS/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To aggregate fishery-dependent and -independent data sources to develop stage-specific spatial maps for gag and red groupers in the northern Gulf of Mexico (GOM). Specifically, we (1) map critical ontogenetic habitats for juvenile and adult gag and red groupers in the northern GOM; (2) examine the spatiotemporal overlap between stage-specific grouper distributions and the distribution of red tides on the West Florida Shelf (WFS); and (3) estimate the larval dispersal and settlement patterns and annual recruitment anomalies due to oceanographic factors of red grouper on the WFS.

***Strategy*:** To benefit from long-term survey data collected by NOAA/NMFS and the experience of habitat modelers to develop reliable spatial maps of fish populations which are an integral component of an ecosystem approach to fisheries management.

CIMAS Research Theme:

***Theme 5*:** Ecosystem Modeling and Forecasting (*Primary*)
***Theme 6*:** Ecosystem Management (*Secondary*)

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

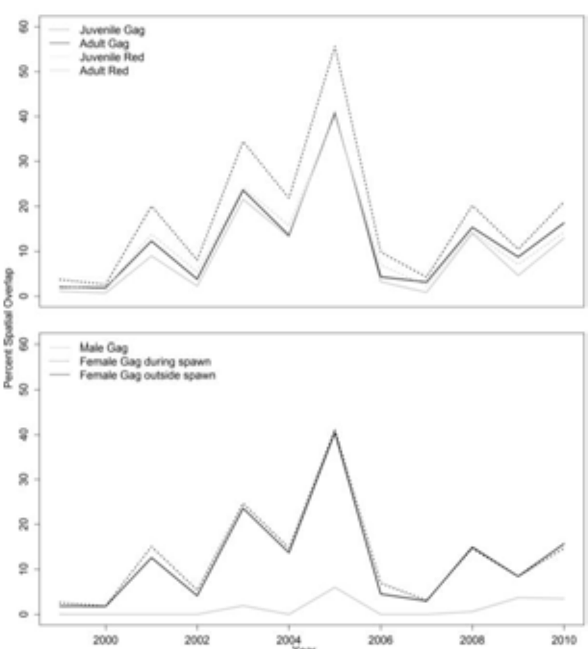
Research Summary:

Spatial mapping of fish populations is an integral component of an ecosystem approach to fisheries management because ecosystem models often require distribution maps to elucidate spatial dynamics for inter-species interactions. We developed generalized linear models (GLMs) to map the occurrence of two socio-economically important species of the northern GOM, red grouper (*Epinephelus morio*) and gag grouper (*Mycteroperca microlepis*). We combined multiple fishery-dependent and -independent data sources to develop stage-specific spatial maps for gag and red groupers in the northern GOM. Due to the paucity of sex data in all datasets, length data were used to apportion gag and red groupers into juvenile (ages 1 − 3) and adult (ages 3+) stages based on estimated body lengths at 50% maturity. Adult gag grouper were further divided into adult males, adult females during the spawning season (January – April), and adult females outside the spawning season (May – December) to elucidate potential spawning habitat.

Binomial GLMs were employed to predict occurrence of ontogenetic grouper distribution as a function of year, month, time of day, latitude, longitude, depth, sediment type, and the confounding factor of gear. Candidate GLMs for each grouper stage were evaluated and the best model given the data and method used was selected on the basis of Akaike information criteria (AIC), estimated AIC model weights, and performance diagnostics. For each grouper life-history stage, an optimum probability threshold was defined by the receiver operating characteristic (ROC) curve where the sum of the true positive rate and the sum of the true negative rate are at their maximum. Small-scale residual variation in occurrence due to fine-scale habitat characteristics not captured within each dataset was examined by quantifying the residual probability of occurrence for each grouper stage. Residual probability of occurrence was then kriged to map known areas of presence. Kriged residual occurrence was added to predicted occurrence to produce an index of occurrence for each grouper stage. Final indices of occurrence were obtained through the use of optimum probability thresholds which allowed converting the probabilities of occurrence that are below the thresholds to zeros, so that one can distinguish between those areas where grouper life-history stages have a low probability of presence and those areas where they are clearly absent. The annual spatial overlap of grouper distribution with red tide distribution as a percentage was then investigated.

Critical ontogenetic habitats were identified and generally aligned with the current understanding of these species' distributions in the northern GOM region. Presence of both juvenile and adult gag groupers was more probable in the Florida Middle Grounds, with adult presence also likely at deeper depths (40m – 100m) on the southern WFS. The distribution map produced for adult male gag grouper displayed relatively high probabilities of presence throughout the edge of the WFS in regions both inside and outside known spawning sites, suggesting that gag grouper may spawn below 27°N along the edge of the WFS. For red grouper, juveniles and adults were widespread throughout the WFS, with high probabilities of occurrence at depths shallower than 40 m in the Florida Middle Grounds and between Sarasota, Florida, and Naples, Florida.

Peak overlap with red tide in 2005 for both juveniles and adults of gag and red groupers maintains the notion that both species were negatively impacted by the severe red tide event which persisted in 2005 (Fig. 1). Trends in overlap estimated for other grouper stages were generally similar, with the exception of adult male gag grouper, which rarely overlapped with the red tide events. Our results provide qualitative evidence (overlap in time and space) of a substantial impact of red tide events on grouper population dynamics in the northern GOM.



Since red groupers spawn at their home site, the final index of occurrence produced for red grouper adults was employed to determine red grouper spawning sites, and then simulate the larval dispersal, settlement and recruitment patterns of red grouper on the WFS using the Connectivity Modeling System (CMS). Simulations with the CMS allowed us to estimate an index of annual recruitment deviations expected from oceanographic factors for GOM red grouper for the years 2003-2013. The index of annual recruitment deviations that we produced informed the assessment of GOM red grouper conducted under the auspices of SEDAR (SouthEast Data, Assessment and Review) 42. It was presented at the SEDAR42 data workshop, and later modified to address suggestions presented at the workshop.

Figure 1: Exposure of gag and red groupers to red tide events based on percent spatial overlap of grouper distributions with red tide distribution derived from model-based predictions. Spatial overlap was calculated as the number of grid cells with both red tide and grouper predicted to occur divided by the number of grid cells where grouper were predicted to occur and where red tide prediction was feasible.

Research Performance Measure: Our objectives for the present study were to: (1) have spatial distribution maps completed by November 2014 for use during the SEDAR 42 Data Workshop; (2) submit a manuscript on grouper distributions and overlap with red tide to a peer-reviewed journal by June 2015; and (3) produce an index of recruitment anomalies for consideration within the GOM red grouper assessment by June 2015. All major objectives are being met.

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Ecosystem Considerations Within Single-Species Stock Assessments

Project Personnel: S.R. Sagarese (UM/CIMAS)
NOAA collaborator: J.F. Walter III (NOAA/NMFS/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To serve as a liaison between stock assessment analysts and the Integrated Ecosystem Assessment (IEA) program and to develop IEA products and incorporate ecosystem considerations (e.g., red tide mortality) produced by the Gulf of Mexico IEA into the red grouper (*Epinephelus morio*) stock assessment model.

***Strategy*:** To benefit from additional manpower tasked with testing different methods and multiple environmental indices for incorporation into the Stock Synthesis integrated assessment framework, thereby ensuring consideration and integration of environmental indices into single-species stock assessments conducted at the SEFSC.

CIMAS Research Theme:

***Theme 5*:** Ecosystem Modeling and Forecasting (*Primary*)
***Theme 6*:** Ecosystem Management (*Secondary*)

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

Significant progress has been made within the Gulf of Mexico in terms of identifying and incorporating ecosystem products into single-species stock assessments. For GOM red grouper (*Epinephelus morio*), Integrated Ecosystem Assessment products were tested within the Stock Synthesis integrated assessment framework, including indices of red tide and recruitment anomalies. Specific objectives of the present study were to: (1) develop an index of red tide mortality for red grouper using Ecopath with Ecosim in a similar manner as developed for gag grouper (*Mycteroperca microlepis*) during SEDAR 33; and (2) assess whether the inclusion of environmental indices increased the plausibility of the 2015 stock assessment model for GOM red grouper.

Contemporary fisheries management mandates the consideration of environmental effects and other ecosystem processes when modeling stock dynamics. Within the Gulf of Mexico, red tide events caused by the dinoflagellate *Karenia brevis* are a key ecosystem stressor. For grouper species, a significant impact has been hypothesized because much of their habitat coincides with areas susceptible to harmful algal bloom and mortality has been documented for large groupers including red grouper. Biological justification, identification, and incorporation of environmental influences on stock dynamics can reduce uncertainty associated with estimated model parameters and derived reference points, greatly enhancing model reliability.

Paralleling the SEDAR 33 effort, we developed an estimate of natural mortality on red grouper caused by *K. brevis* blooms on the West Florida Shelf. To enable investigation of red tide mortality solely on adult red grouper, a "Red grouper fleet" was added to the original WFS Red tide EwE model developed by Alisha Gray (University of South Florida). This fleet was created so that red grouper fisheries mortality could be manipulated separately. The overall scale of the red tide mortality trend relative to predation mortality and fishing mortality for red grouper was minor. Resulting estimates of red tide mortality were slightly lower compared to the estimated red tide mortality for gag grouper.

Using the 2015 base stock assessment model for GOM red grouper configured by SEFSC analyst M. Bryan, natural mortality (M) was linked to red tide indices. Three scenarios based on candidate red tide indices and methods for inclusion were devised and compared. Environmental consideration of red tide generally improved model fit in comparison to base models with no red tide (Figure 1).

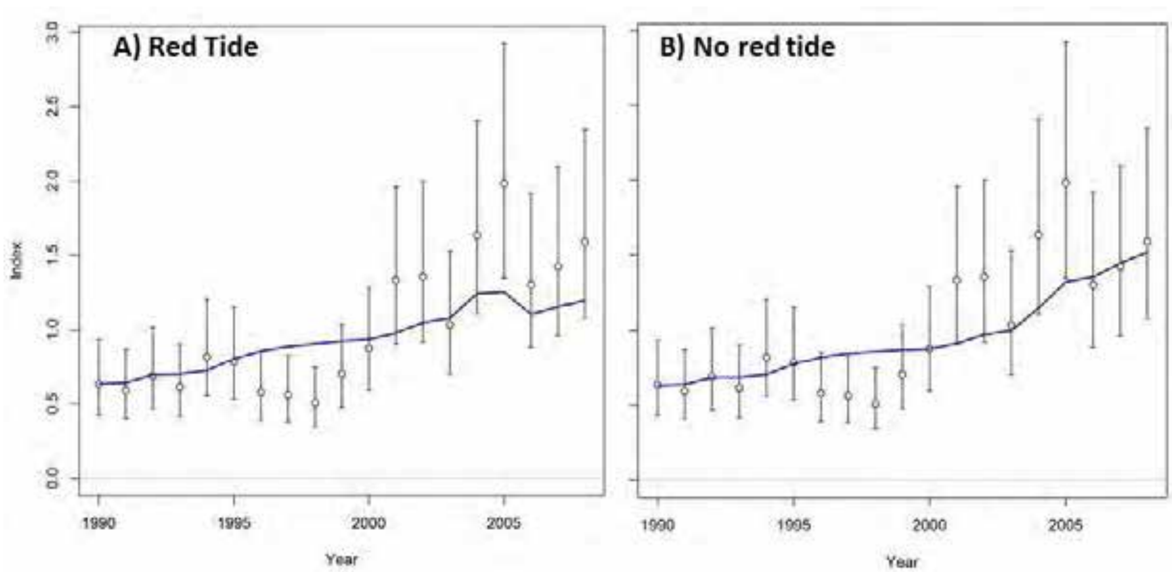

Figure 1: Model fits to indices of abundance for the commercial hand line both with (A) and without red tide (B). Blue line reflects expected index, dots reflect observed values, and vertical lines reflect lower and upper bounds for each annual index observation. A significant improvement in model fit with red tide is evidenced by the fitted line (blue) more closely matching the observed index (dots).

An age-specific vector of natural mortality estimated by OSMOSE-WFS, a two-dimensional individual-based and multispecies model that describes trophic interactions in the West Florida Shelf ecosystem in the 2000s, was also tested within SS. This vector represents the summation of mortality due to (1) predation, (2) starvation, and (3) diverse sources including red tide events, diseases and mortality due to marine organisms not explicitly considered (e.g., marine mammals). Overall, implementation of this vector did not improve model fit.

An index of recruitment anomalies (2003-2013), estimated from the Connectivity Modeling System, a biophysical model which simulated the transport and survival of spawned eggs and larvae, was also tested as an environmental effect on recruitment deviations. Recruitment anomalies informed recent years of the assessment where cohort strength is poorly estimated.

Research Performance Measure: Our objectives for the present study were to: (1) develop an index of red tide mortality from EwE by March 2015; and (2) test all environmental indices within the Stock Synthesis model during the Assessment Workshop process. All major objectives have been met.

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Quantifying the Trophic Importance of Gulf Menhaden Brevoortia patronus Within the Northern Gulf of Mexico Ecosystem

Project Personnel: S.R. Sagarese (UM/CIMAS)
NOAA collaborators: J.F. Walter III, M.V. Lauretta and J.E. Serafy (NOAA/NMFS/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To elucidate the trophic role of Gulf menhaden within the northern Gulf of Mexico (GOM) ecosystem to inform ecosystem modeling efforts. Specific objectives of this study were to: (1) review species-specific predators of Gulf Menhaden obtained from an extensive literature search; and (2) estimate the proportion of Gulf Menhaden in each predator's diet using a meta-analysis and statistical methods for estimating diet composition.

***Strategy*:** To perform a meta-analysis and conduct advanced statistical procedures to produce a realistic representation of trophic interactions concerning Gulf Menhaden in the GOM to inform ecosystem modeling and alleviate previous concerns regarding the highly uncertain trophic role of Gulf menhaden in past ecosystem models.

CIMAS Research Theme:

***Theme 5*:** Ecosystem Modeling and Forecasting (*Primary*)
***Theme 6*:** Ecosystem Management (*Secondary*)

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

The Gulf Menhaden, *Brevoortia patronus,* is frequently cited as playing a predominant role in the trophic structure and function of the northern Gulf of Mexico (GOM) marine ecosystem. However, one of the key areas of uncertainty of GOM ecosystem models to date has been the role of Gulf Menhaden, particularly which species consume them and how much is consumed. A comprehensive literature search was undertaken to locate as many diet studies for GOM predatory species as possible. A wide variety of references were incorporated, including biological field reports, specialized studies, academic theses, peer-reviewed studies, the GOM Species Interactions database (GoMexSI) and FishBase (www.fishbase.org).Preference was given to data reported in any metric relating to biomass since this input is a requirement for ecosystem models.

Diet composition was estimated using three methods: (1) a simple, unweighted arithmetic mean; (2) a weighted mean which accounted for differences in study region, method reported (e.g., biomass), and sample size; and (3) a probabilistic bootstrap approach (Fig. 1) which combines observations in a manner that reduces bias associated with any study-specific sampling effects. We also assessed whether the relative contribution of *Brevoortia* spp. to the diets of predators differed between regions and groups of predators. The prevalence of unidentified prey groups (e.g., unidentified fish, crustaceans, animal remains, etc.) found throughout this meta-analysis required an assumption that the relative biomass of all prey groups corresponding to these unidentified classifications could be used to allocate unidentified prey items to identified groups.

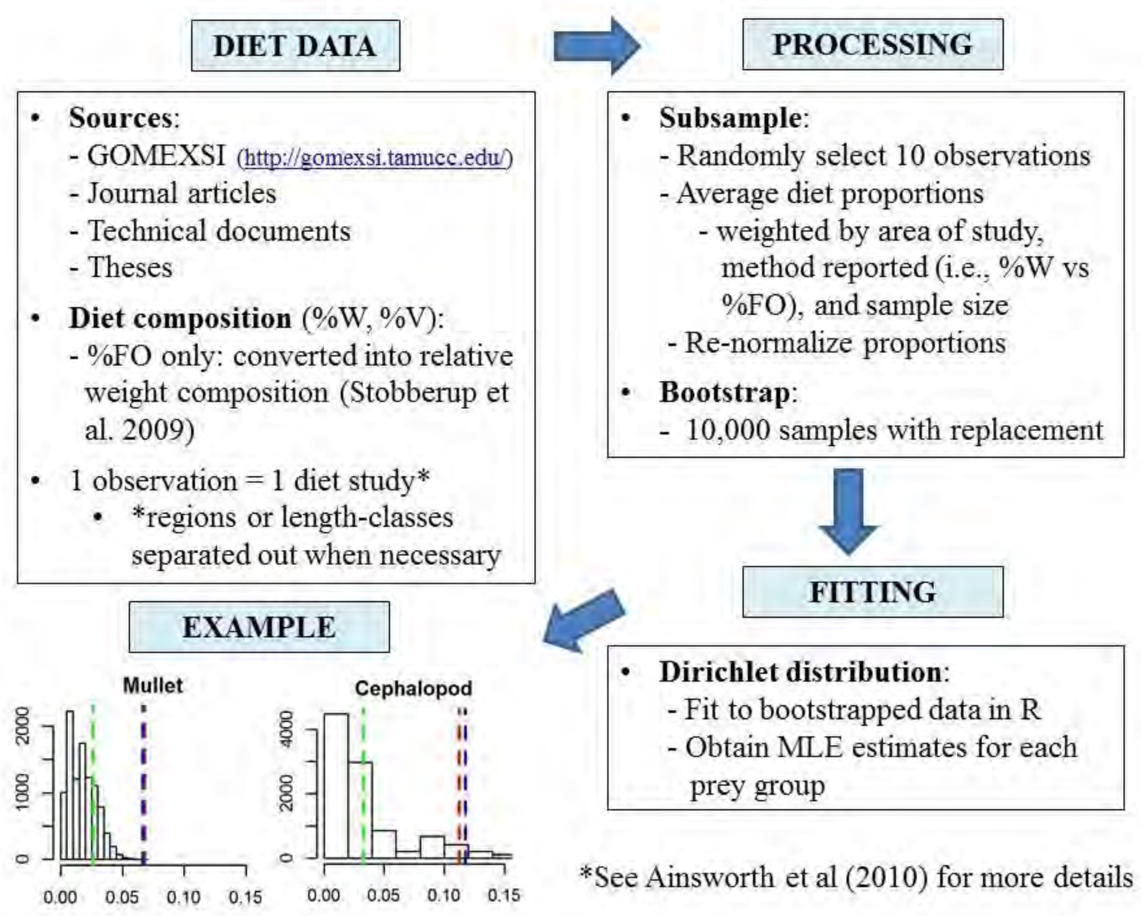

Figure 1: Procedure followed for meta-analysis to quantify trophic interactions within the Gulf of Mexico and identify the importance of Gulf menhaden to predator diets. Methods of estimation include simple mean (blue), weighted mean (red), and maximum likelihood based on a probabilistic approach (green). Procedure adapted from Ainsworth et al. (2010) and Masi et al. (2014).

A total of 568 references were used to quantify trophic interactions in the GOM and provided 1,906 diet observations for various life-history stages and regions (both within and outside of the GOM). Of the references examined, 136 referenced some form of predation on menhaden, although the most commonly reported prey item was 'unidentified clupeid.' A total of 296 diet observations of menhaden predation were identified, with roughly half occurring in the GOM. A total of 79 species were reported to consume menhaden (*Brevoortia* spp. or unidentified clupeid), with Gulf menhaden identified in the gut contents of dolphins, seabirds, sharks, mackerels, jacks, pelagic piscivores, seatrouts, and coastal piscivores. The contribution of menhaden to predator diets peaked for blacktip shark (8%) but generally ranged between 2% and 3% for most predators. After accounting for unidentified prey items, the overall contribution of menhaden to total diet ranged from 0.3% for skates and rays to 11.8% for juvenile king mackerel.

Research Performance Measure: Our objectives for the present study were to: (1) have all diet analyses completed by December 2014; and (2) submit a manuscript on the trophic role of Gulf menhaden by March 2015. The manuscript is presently under review and therefore all major objectives are being met.

Courtesy of Daniel Benetti

RESEARCH REPORTS

THEME 6: Ecosystem Management

Reef Visual Census (RVC): Reef fish Monitoring in the Florida Keys and Dry Tortugas

Project Personnel: J. Blondeau (UM/CIMAS)
NOAA Collaborators: J. Bohnsack (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To provide continued reef fish and habitat monitoring in Florida's coral reef tract to assess population and habitat trends, fish-habitat associations, and ecosystem responses to natural events (e.g. hurricanes), management measures and anthropogenic impacts. To examine the effectiveness of marine reserves and other management strategies in the Florida Keys National Marine Sanctuary (FKNMS —Sanctuary Preservation Areas SPAs, Tortugas Ecological Reserves TERs and Dry Tortugas National Park – Research Natural Area RNA).

Strategy: Employ a multi-agency (UM/CIMAS, NOAA/SEFSC, Florida Fish and Wildlife Commission FWC, and the National Park Service NPS), spatially-explicit, fishery-independent monitoring program of coral reef fish composition, occurrence, abundance, size structure and habitat along the Florida reef tract.

CIMAS Research Theme:

Theme 6: Ecosystem Management (*Primary*)
Theme 7: Protection and Restoration of Resources (*Secondary*)

Link to NOAA Strategic Goals:

Goal 3: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems (Primary)*

Goal 4: Resilient Coastal Communities and Economies - *Coastal and Great Lakes communities that are environmentally and economically sustainable (Secondary)*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

The Florida Keys Reef Visual Census (RVC) project is a continuous, long-term monitoring effort aimed at large-scale tracking of reef fish and coral habitat metrics along the Florida reef tract, from Martin County to Key West, including the Dry Tortugas. This fisheries independent monitoring effort employs a spatially explicit, stratified random design enabling us to efficiently examine the effectiveness of management actions, as well as the impacts of fishing and other natural stressors, such as hurricanes, on the ecosystem. Specifically, this research allows us to quantitatively assess reef fish population changes, habitat associations, and ecosystem responses to fishing, management actions (including MPA zoning), and other human activities. This was the first year of monitoring under the National Coral Reef Monitoring Program (NCRMP), with the purpose of standardizing all monitoring efforts in US held coral reefs. In the Florida Keys and Dry Tortugas, no changes to fish protocol were made, but a line-point intercept (for benthic cover) and a coral demographic sample were added at a subset of sites. This longitudinal monitoring approach is a vital component enabling us to detect annual and decadal reef fish population changes across the Florida coral ecosystem.

To accomplish a large-scale monitoring protocol, however, a multi-agency cooperation is needed. Additionally, the sampling domain extended north through Martin County and additional agencies were added. University of Miami's CIMAS, NOAA's Southeast Fisheries Science Center, National Park Service and the Florida Fish and Wildlife Commission worked closely together to complete sampling sites, stretching from Miami to the Dry Tortugas. This year, 320 sites were completed between Miami/Dade and Martin Counties by additional agencies including, Broward County, CRCP, West Palm DEP, FWC Tequesta, Miami/Dade County and NSUOC. The ability to monitor the entire Florida reef tract, from Martin County to Dry Tortugas, enables us to characterize reef fish populations and their habitat associations across a large spatial scale. And the stratified random sampling design allows us to accomplish our objectives efficiently and in the most cost effective way.

The benefit of a healthy coral reef ecosystem goes beyond the intrinsic natural value and has the ability to provide monetarily to the local economies in terms of tourism and recreational and commercial fisheries. However, to track the changes in fish populations and habitat health as a result of anthropogenic impacts, as well as natural events, we need a continuous monitoring effort so that informed management decisions are made.

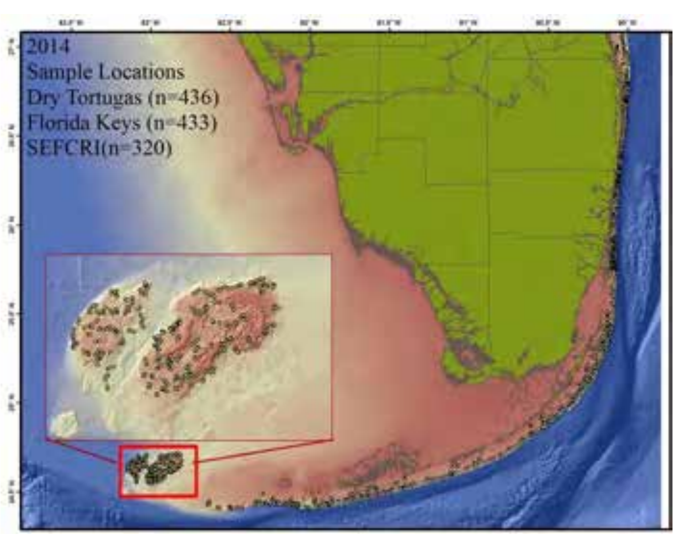

Figure 1: Sampling site locations for 2014 in the Florida domain.

Research Performance Measure: Divers conducted photo-documentation, RVC fish surveys, and habitat assessments at 433 sites in the Florida Keys, 436 sites in the Dry Tortugas and 320 sites in the SEFCRI region. NOAA SEFSC divers collaborated with the University of Miami and RSMAS, FKNMS, Florida Fish and Wildlife Department/FWRI, State of Florida, Nova Southeastern University, and the National Park Service (South Florida and Caribbean Network). In total, 4718 dives were needed to complete the 2014 mission to monitor reef fish community composition, habitat composition, and abundance and size structure for more than 300 reef fish species on Florida's coral reef tract. Data are used to assess population and habitat trends (e.g., whether species are overfished), ecosystem responses to fisheries management actions, including determining the effectiveness of no-take MPAs and benthic community and coral demographics. All field related and QAQC milestones were met and objectives completed.

To further facilitate and promote the RVC dataset, a custom R packages was developed and tested to calculate common metrics (i.e. fish density, occurrence, biomass and size structure). This package, designed in the open-source, statistical package R, retrieves analysis ready data from a NOAA server and computes common metrics for any species correctly based on the 2-stage approach.

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Examining the Status and Distribution of Reef Fish Spawning Aggregations in the Southeast Florida Coral Reef Initiative (SEFCRI) Region

Project Personnel: K.M. Boswell and D. Burkepile (FIU)
NOAA Collaborators: J.C. Taylor (NOAA/NOS); T. Kellison (NMFS/SEFSC); K. Gregg (NMFS/SER)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: Locate and assess Fish Spawning Aggregations (FSAs) in the South East Florida Coral Reef Initiative (SEFCRI) region to inform and guide the development of a regional resource management plans by the State of Florida Fish & Wildlife Conservation Commission (FWC), South Atlantic and Gulf Fisheries Management Councils, and NOAA Fisheries.

Strategy: To address our objective we have engaged with local fishers and divers to collect historical and anecdotal reports of recreationally and commercially important FSAs in the targeted region. Using those reports, a comprehensive hydroacoustic-diver field survey was developed to study the reported spawning locations. Field observations and compiled reports will then be assembled into a comprehensive geospatial database and Geographic Information System (GIS) for visualization that can be used by state and federal management agencies for policy development and amendment.

CIMAS Research Theme:

***Theme 6*:** Ecosystem Management (*Primary*)
***Theme 7*:** Protection and Restoration of Resources (*Secondary*)

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: CRCP **NOAA Technical Contact:** J. Christopher Taylor

Research Summary:

Reef fish spawning aggregations (FSAs) are a vital part of the life cycle of many reef fishes, yet the act of aggregating makes this an attractive and lucrative target for exploitation. Additionally, knowledge of FSA locations in South Florida is predominately limited to commercial and experienced recreational anglers, leaving these resources vulnerable to overexploitation. Thus our research integrates the considerable knowledge of local fisherman and community members with fisheries research techniques to investigate the spatial, temporal, and ecological aspects of FSAs in the South Florida region.

During the 2014/2015 research year we accumulated a significant number of anecdotal reports, evaluated the existing literature, and began building relationships with local recreational fishing establishments and commercial fisherman in the area. Our evaluation of the literature revealed that very little is known about the spatial aspects of aggregations in South Florida, but research from the greater Caribbean has identified peak reproductive periods for a range of species, providing important insight into the seasonality of FSA formation (Figure 1). Furthermore, stakeholders have assisted in the identification of approximately 12 potential aggregation sites in the SEFCRI region (Figure 2), and have anecdotally corroborated the information obtained from the literature related to seasonality. These data have been compiled and presented to the SEFCRI Technical Advisory Council (TAC)for the development of a regional management plan, but are also being used to develop a comprehensive field monitoring program that will incorporate both hydroacoustic surveys (fisheries sonar) and diver surveys.

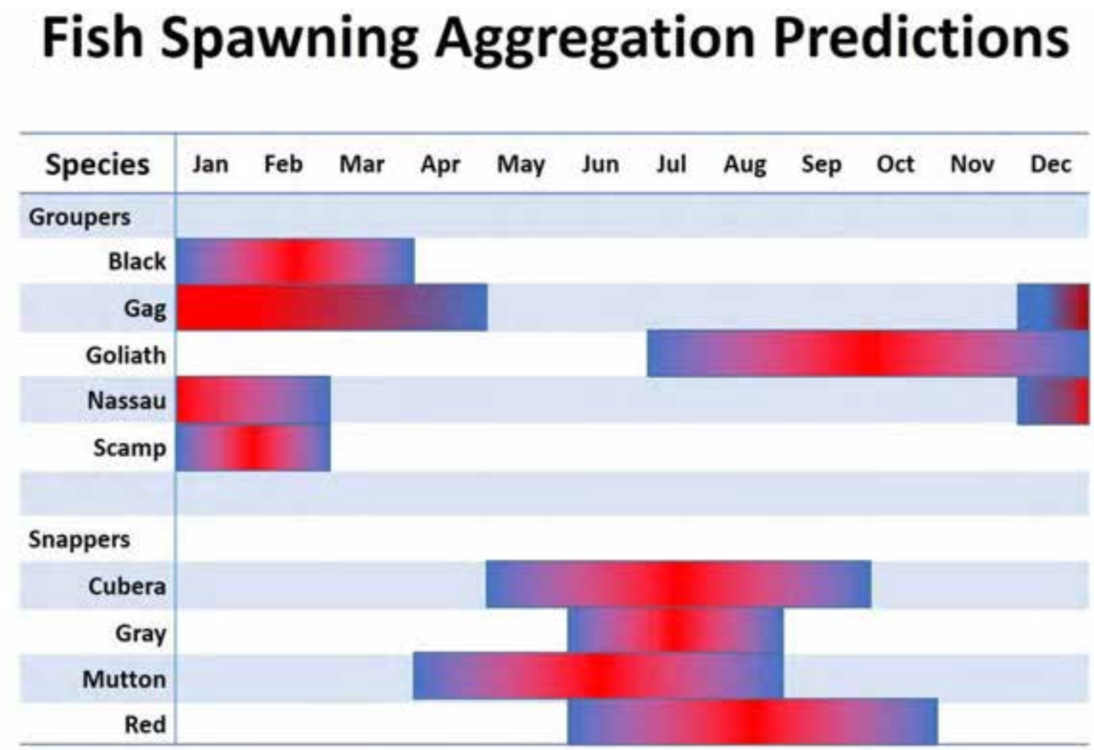


Figure 1: Seasonality of FSA formation for select species throughout the Caribbean as described in the literature, and by experienced resource users. Red areas represent peaks in spawning activity, indicating the highest degree of overlap between sources.

Preliminary field expeditions have been productive in highlighting the strengths of hydroacoustic surveys paired with diver surveys (Figure 3), and further investigation at the reported aggregation sites will be the focus for FY2015 and 2016.

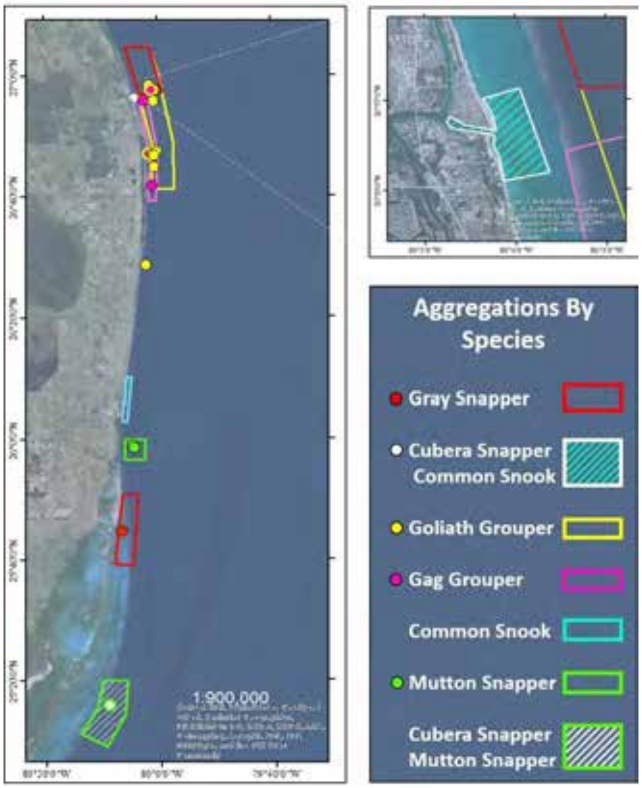


Figure 2: Reported aggregation sites are presented in this figure to assist the SEFCRI-TAC in the development of a regional resource management plan.

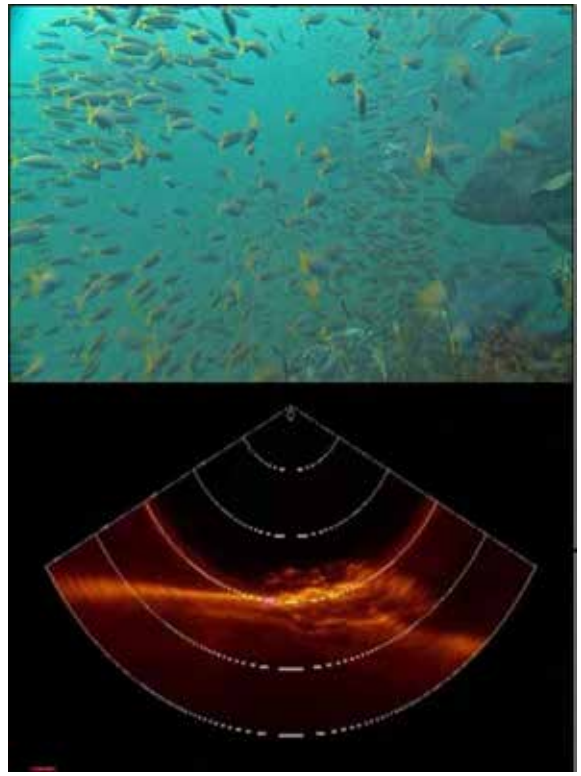


Figure 3: Divers were deployed on an area of interest identified by a multibeam sonar survey, confirming the presence of both the target species (Goliath grouper) and a high abundance of associated fishes. This figure exemplifies the strength of hydroacoustic surveys when paired with “ground-truthed” diver surveys.

Research Performance Measure: The objectives were to (1) locate and assess FSAs in the SEFCRI region; and (2) provide policy-makers with information to assist in the development of a regional resource management plan. To address the first objective, we have compiled an extensive geospatial database consisting of 12 reef fish aggregations from 7 species that have been identified by resource users, reported in the scientific literature or documented and confirmed in the field. Addressing objective 2, we delivered the compiled database and geospatial layers to the SEFCRI-TAC for the development of their anticipated regional management plan, which will begin this summer. Additionally, NOAA collaborator Dr. Christopher Taylor presented the progress of our research to the CRCP leads in Washington, DC; and graduate student Benjamin Binder presented the progress directly to the SEFCRI-TAC, and at the 37th Association of the Marine Laboratories of the Caribbean conference in Curacao.

Targeted Products for Improving Ecosystem-Based Fishery Management in the Gulf of Mexico

Project Personnel: D. Die (UM/RSMAS)
Other Collaborators: J. Simons and H. Liu (Texas A&M)
NOAA Collaborators: M. Karnauskas, X. Zhang, C. Porch and M. Schirripa (NMFS/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: (1) Extract, compile, edit, and serve diet data for fishes in the Gulf of Mexico that are priority species for ecosystem-based fisheries models in the Gulf. (2) Edit and test all extracted data that is loaded into the GoMexSI database. (3) Continue to refine and enhance the GoMexSI database and webpage interface.

Strategy: (1) Consult the list of species that are managed by the GMFMC and the GSMFC, and Gulf fisheries ecosystem modelers to compile a list of species that may be in need of new or additional diet data. After assessing the list against our database of diet data, select the species that we have data for but have not yet extracted and entered it into the database. Hire students to perform the data extraction and editing. (2) After data is entered by the students into a spreadsheet, the PI and the student will convene to edit the entered data on a printed spreadsheet versus the original file. After the editing is completed, the spreadsheet will be converted to a csv file, and uploaded into GoMexSI on Github. The data will then be tested against standard lists such as taxonomies to assure that all the data are correct. Error lists will be generated and those data points in error will be corrected. (3) Based on our own experience and comments received from GoMexSI users, we will continue to strive to enhance and improve the GoMexSI database and webpage. A GoMexSI workshop to train local personnel and to review needed elements for the database and webpage was held to address this objective.

CIMAS Research Theme:

Theme 6: Ecosystem Management (*Primary*)
Theme 5: Ecosystem Modeling and Forecasting (*Secondary*)
Theme 7: Protection and Restoration of Resources (*Tertiary*)

Link to NOAA Strategic Goals:

Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

Goal 4: Resilient Coastal Communities and Economies - *Coastal and Great Lakes communities that are environmentally and economically sustainable*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

The Gulf of Mexico Species Interaction (GoMexSI) project is an ongoing effort to discover, collect, assess, extract, and catalog published and unpublished records of species interactions (e.g. predator/prey, host/parasite, etc.) in the Gulf of Mexico. One of the primary data sources are the predator/prey interactions of fishes. These data are very valuable, as they are utilized by the most used fishery models (EwE, Atlantis, OSMOSE) that are being used to develop ecosystem based fishery management strategies in the Gulf of Mexico. We have consulted the list of fish species managed by the GMFMC and the GSMFC and prioritized our data extraction operations around this list.

We currently have 785 references to the diets of fish in the Gulf of Mexico on hand. To date we have processed (extracted, edited, and loaded) all or part of 190 (24%) of these references, which represent 115 unique data sources. Including all prey items, we have identified, and have in the database, 2,007 unique interactors. There are currently 68,579 lines of species interaction data in the GoMexSI database. These data come from all over the Gulf and its estuaries (Figure 1). In addition to the fish we have begun searching for and collecting references to the diets of other taxa (e.g. marine mammals, sea and shore birds, sea turtles, etc.). See Table 1 for a list and status of each of the additional taxa.

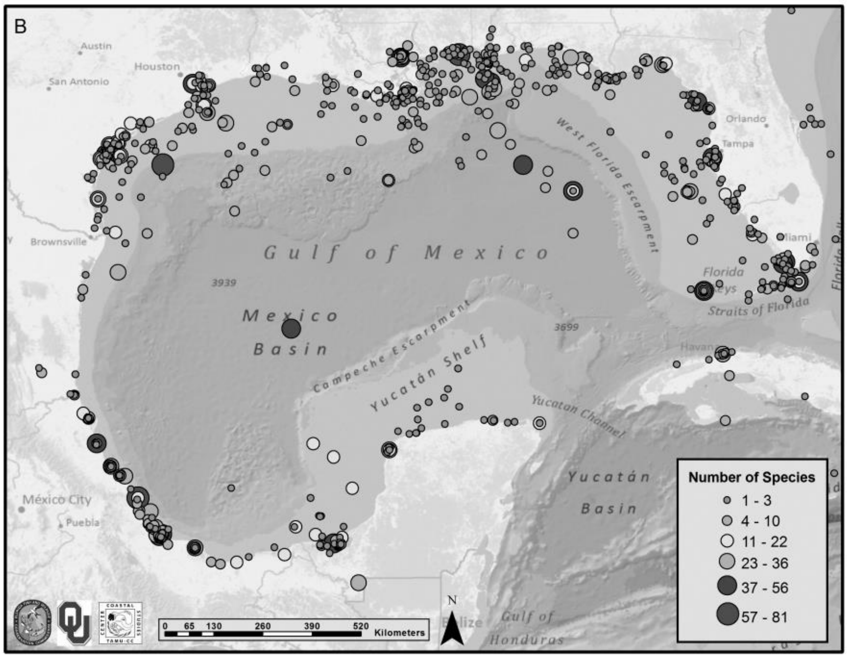


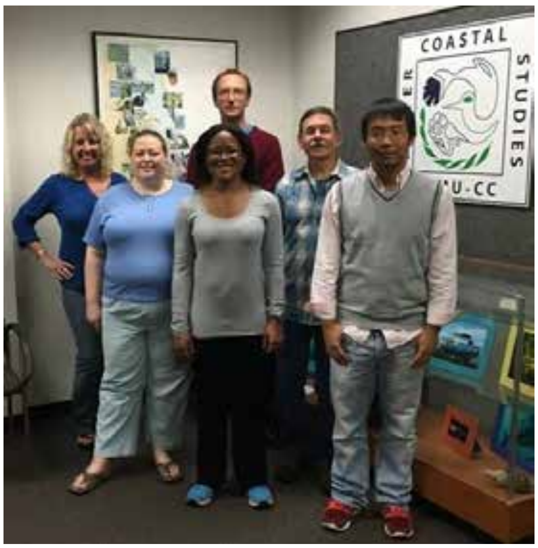
Figure 1: Map showing the location of the centroid of 747 fish diet references from the Gulf of Mexico, with the size and gray scale of the point giving an indication of the number of fishes examined for diet.

Table 1: List of additional taxa that will be included in the GoMexSI database model. Table includes the number of references for trophic data that have been identified, the number of references on hand or needing to be located, and the number of unique species represented in those references observed to date.

Taxon	Tot # of Refs Identified	Tot # of Refs on Hand	# of Refs still to locate	Tot # of Species
Annelida	9	9	0	140
Arthropoda	98	90	8	378
Aves	54	51	3	30
Cnideria	9	9	0	8
Ctenophera	2	2	0	1
Echinodermata	6	6	0	4
Mammalia	31	27	4	13
Mollusca	16	14	2	46
Reptilia	34	33	1	5
Totals	259	241	18	625

The GoMexSI data are served through two outlets: the GoMexSI webpage (gomexsi.tamucc.edu) and the Github GoMexSI (https://github.com/GoMexSI/) site. There are three query pages on the website where the data can be examined, or the data can be downloaded to a csv file. From Github the data can be accessed using the Cypher query language, or rglobi (an R package).

We hosted a GoMexSI/GloBI workshop at the Center for Coastal Studies (TAMUCC) in December of 2014. The database designer and software engineer, Jorrit Poelen came in from Oakland, CA to lead the 2.5 day workshop, which was designed to train five local personnel (Figure 2) on the use of Neo4j (the database software), Cypher (Neo4j's query language), and rglobi (an R package to access GloBI/GoMexSI data. A one hour call-in was hosted for interested parties who could not attend in person, to give them a chance to ask questions about GoMexSI/GloBI/Neo4j/Cypher/rglobi. The workshop included discussions to explore areas in which we could improve the database and webpage, and a whiteboard session, where the examine the relationships of the data generating process, the interaction data extraction, spatial data extraction, data normalization and access, and a data use case example (Figure 3).



Research Performance Measure: We have continued to push forward on many fronts in the GoMexSI project. Much effort has been expended to capture the data for the managed fish species in the Gulf, we continue to edit all lines of entered data and then test them against published taxonomies and vocabularies, and we have and are continuing to improve access to the database, and functionality and usefulness of the GoMexSI webpage. All objectives have been met and/or are continuing to be addressed.

Figure 2: Photo of the onsite participants for the GoMexSI/GloBI workshop held at the Center for Coastal Studies (TAMUCC) in December 2014. Left to right: Tracy Weatherall, Theresa Mitchell, Kalen Rice, Jorrit Poelen (back), Jim Simons, Xiaopeng Cai.

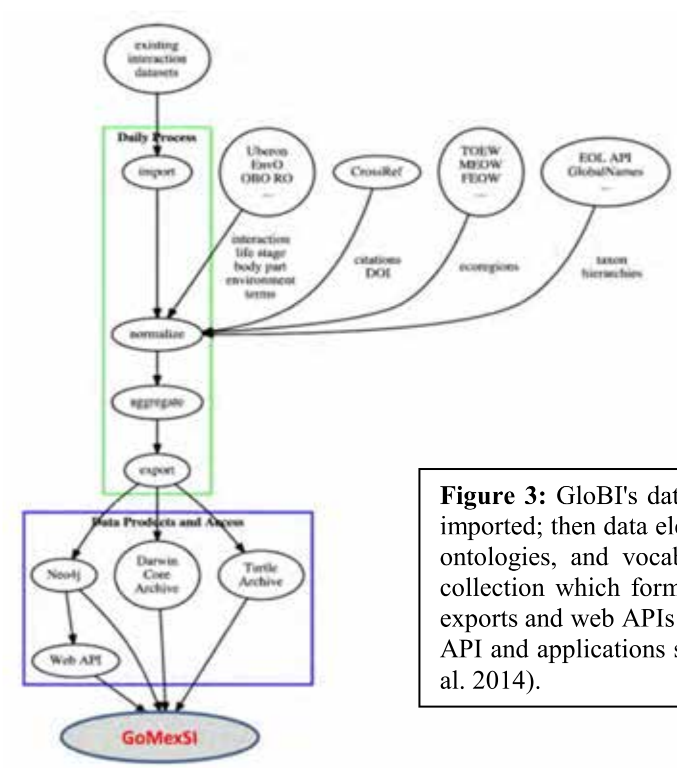


Figure 3: GloBI's data aggregation process: First, existing datasets are imported; then data elements are normalized, using existing taxonomies, ontologies, and vocabularies. These data are then added to the data collection which forms the basis for data-access methods, such as file exports and web APIs provided by GloBI's web API and Neo4j's Cypher API and applications such as GoMexSI. (Figure adapted from Poelen et al. 2014).

The importance of Parrotfish on the Maintenance and Recovery of Coral-Dominated Reefs

Project Personnel: D. Burkepile (FIU); T. Adam (formerly FIU)
NOAA Collaborators: B. Ruttenberg (formerly NOAA/SEFSC); M. Miller (NOAA SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To summarize scientific information on the effects of parrotfish on algal and coral communities, identify clear knowledge gaps about the impact of grazers on coral reef communities, and begin addressing some of the critical unanswered scientific questions identified by the synthetic analysis. This project funded a post-doctoral researcher, Dr. Thomas Adam from June 2012 through July 2014, to spearhead these objectives.

Strategy: (1) Conduct a thorough review and synthesis of the existing literature and existing datasets that have examined the relationship between parrotfish, parrotfish grazing, and measures of coral demography, status, recruitment, and recovery and (2) Begin addressing knowledge gaps identified in the review with targeted field studies. One of the major knowledge gaps identified in the review was a lack of information on species-specific grazing impacts. Field studies were therefore developed to document grazing preferences, grazing rates, and habitat selection in a suite of parrotfish species to better predict their impacts on coral reef ecosystems. A second large gap identified was the impact of large piscivorous fishes on the behavior and grazing patterns of parrotfishes. We conducted a series of field studies using behavioral observations, stable isotopes, and decoy predators (grouper and barracuda) to examine how foraging and territorial behavior of parrotfishes changes with fluctuation predation risk.

CIMAS Research Theme:

***Theme 6*:** Ecosystem Management

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NOAA/CRCP **NOAA Technical Contact:** Theo Brainerd

Research Summary:

Herbivorous fish can benefit reef-building corals by controlling algae that compete with corals for space. On many reefs, parrotfishes appear to be particularly important for controlling algae and creating favorable habitat for coral recruitment. However, evidence that herbivores in general and parrotfish in particular can promote coral recovery on Caribbean reefs has been inconsistent, and it is now clear that the impact of herbivores on the maintenance and recovery of coral-dominated reefs will be highly context-dependent. During the research year (2014/2015) we published a thorough synthesis of the existing literature examining the relationships between parrotfish and different measures of the status of coral populations and communities. This synthesis indicates that impacts of herbivores on coral populations will be modulated by physical characteristics of reefs such as depth and wave exposure, local anthropogenic impacts such as nutrification and sedimentation, recent ecological history, and predicted impacts of global climate change. While the synthesis revealed many knowledge gaps, it also suggested several concrete actions managers can take to help improve the health of coral reef ecosystems. To communicate these findings we wrote a summary report targeting coral reef managers that was featured on NOAA CORIS website. During the research year (2014/2015) we also finished processing and analyzing data from a field study quantifying the basic feeding ecology (including feeding preferences, grazing rates, and foraging ranges) of nine of the most common parrotfish species in the Florida Keys National Marine Sanctuary and submitted the results of this study for publication.

Our field observations revealed two distinct and complementary functional groups of Caribbean parrotfishes, those that can prevent the establishment of macroalgae by intensively grazing on algal turfs while scraping or excavating the calcium carbonate reef framework, and those that primarily feed on fleshy brown macroalgae that can overgrow corals (Fig. 1). This research also revealed that species with similar diets were dissimilar in other attributes, including habitat selection and the substrates they target while foraging. In particular, some species were more likely to exert their impacts in places that are favorable for corals (e.g., high-relief reefs with low levels of macroalgae and sediments), while others predominantly exerted their impacts in places that are poor or marginal habitats for corals (e.g., unconsolidated coral rubble and low-relief hardbottom) (Fig 2). Together these observations greatly increase knowledge of the functional roles of different species of Caribbean parrotfishes. We are also conducting ongoing observational and experimental work to elucidate the mechanisms driving differences in foraging behavior, and to quantify the amount of algae removed by different size classes and species of parrotfishes.

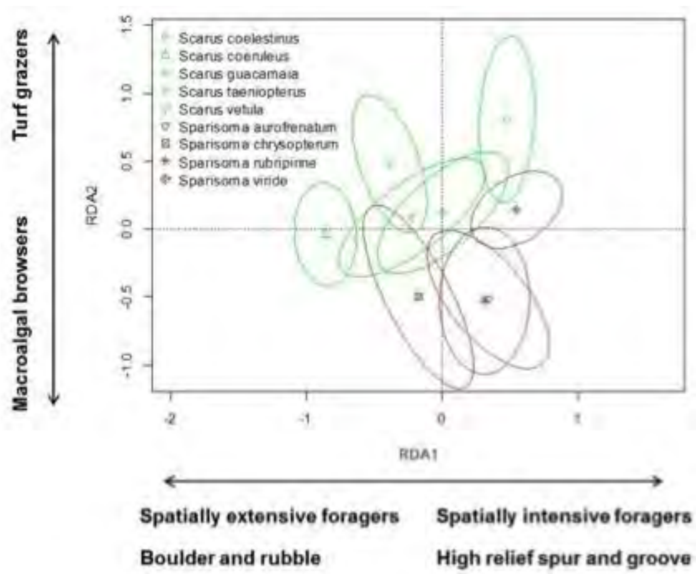


Figure 1: Species-averaged dendogram with proportion of different food items eaten by nine species of Caribbean parrotfishes showing that parrotfish cluster into two groups based on their diets. *Sp. chrysopterum*, *Sp. rubripinne*, and *Sp. aurofrenatum* feed largely on macroalgae (mainly *Dictyota* spp.), while fishes in the genus *Scarus* and *Sp. viride* feed primarily on microscopic turfs, endolithic algae, and CCA.

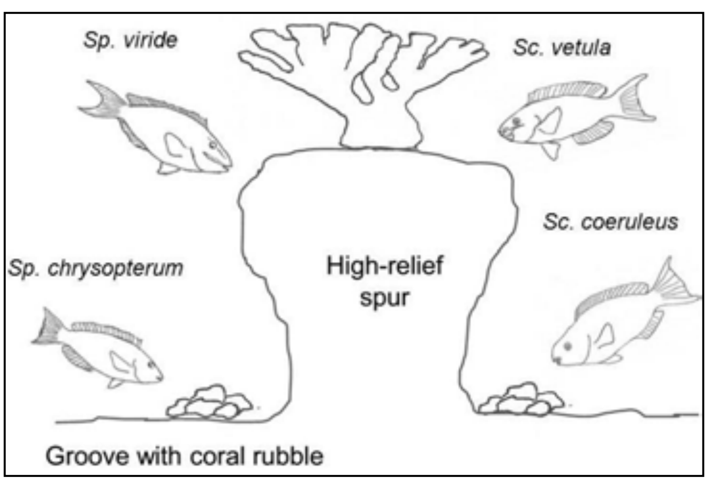


Figure 2: Stylized depiction of four species of Caribbean parrotfishes showing how different species forage on different parts of the reef and target different substrates.

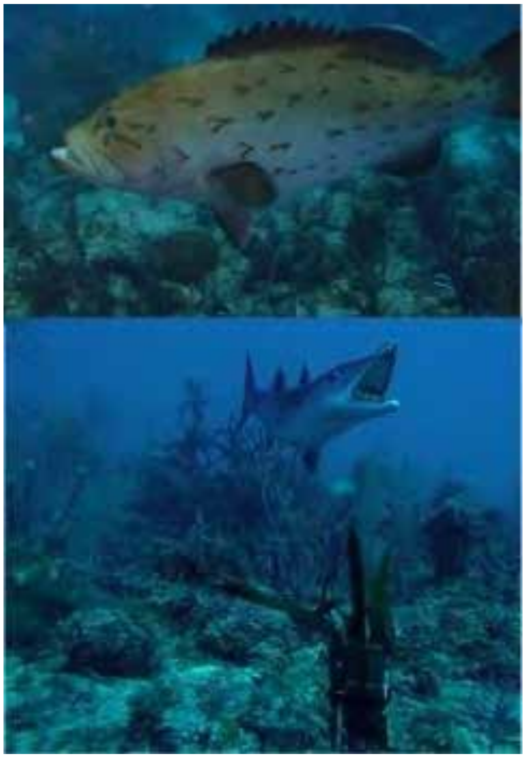


Figure 3: Predator decoys of (a) black grouper (*Mycteroperca bonaci)* and (b) great barracuda (*Sphyraena barracuda*) anchored to the seafloor with a standardized assay of *Thalassia testudinum* in the foreground.

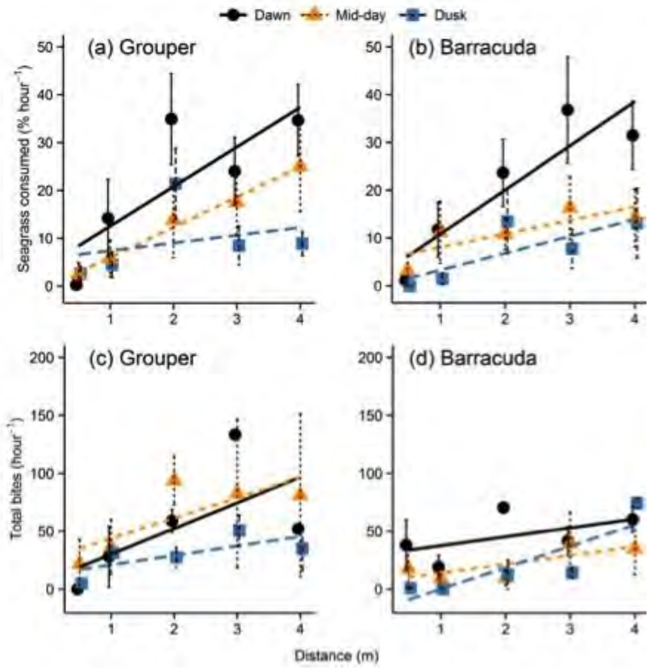


Figure 4: (a-b) The segrass consumed (% hour^{-1}) and (c-d) total bites (hour^{-1}) for grouper and barracuda treatments (mean ± SE) with increasing distance from decoys. Solid lines represent fitted linear regressions for three time periods: dawn (circles with solid lines), mid-day (triangles with short dashed lines) and dusk (squares with long dashed lines).

Research Performance Measure: The synthesis has been completed and was published as the Feature Article in the February issue of Marine Ecology Progress Series. Following the publication of the synthesis, we published a summary report with specific recommendations for managers. We also submitted a manuscript summarizing the most critical aspects of our field research which has been accepted for publication pending minor revision. Information from both the synthesis and field work have been presented at multiple scientific meetings.

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Gulf of Mexico Integrated Ecosystem Assessment

Project Personnel: G.S. Cook, A. Gruss and K.A. Kearney (UM/CIMAS)
NOAA Collaborators: C.R. Kelble (NOAA/AOML); M. Karnauskas and M. Schirripa (NOAA/SEFSC); P. Fletcher (NOAA/Florida Sea Grant)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives*:* To develop scientific products and analytical tools required for integrated ecosystem assessments within the Gulf of Mexico large marine ecosystem.

Strategy*:* To accomplish these objectives we are developing ecosystem indicators, conducting integrated ecosystem-level risk assessments, developing network-based methods for exploring trade-offs in complex multi-sector systems, and informing resource management decision-making to minimize risk to ecosystem services provisioning while bettering the resilience and sustainability of coastal communities.

CIMAS Research Theme:

***Theme 6**:* Ecosystem Management (*Primary*)
Theme 5: Ecosystem Modeling and Forecasting (*Secondary*)
Theme 7: Protection and Restoration of Resources (*Secondary*)

Link to NOAA Strategic Goals:

Goal 1**:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems (Primary)*
Goal 4**:** Resilient Coastal Communities and Economies - *Coastal and Great Lakes communities that are environmentally and economically sustainable (Secondary)*

NOAA Funding Unit: OAR/AOML **NOAA Technical Contact:** Molly Baringer

Research Summary:

The marine environment provides a broad spectrum of benefits to people including the provisioning of seafood, recreational and commercial opportunities, oil and gas production, attenuation of pollutants, and protection from storms. These diverse benefits to society, or ecosystem services, are one of the primary reasons that some of the fastest growing population centers in the nation, and the world, are located in coastal zones. However, this beneficial relationship has the unintended consequence of placing increased pressure on the natural components of the coastal ecosystem, ironically threatening the long-term economic sustainability, health, and resilience of these coastal communities. To protect human communities in coastal regions will require an understanding of the dynamics governing these complex human-natural systems, so that we can develop multi-sector ecosystem-based management approaches that protect and sustain marine ecosystems and ecosystem services.

The Gulf of Mexico (GoM) is vital to the economic health of the United States. Almost ten million jobs exist in the coastal counties of the GoM, contributing $6 billion annually to the US Treasury. From a biological standpoint this region also plays a critical role. Over 15,000 species inhabit the GoM, and its watersheds contain half of the nation's coastal wetlands. Furthermore this region produces more than 1 billion pounds of commercial seafood annually, and is responsible for 44% of the US marine recreational fishing catch. However the footprint of the GoM extends well beyond the coastal waters of Texas, Louisiana, Mississippi, Alabama, and Florida. The Gulf of Mexico is intrinsically linked to the health of 31 of the 50 US states, and it can impact and be impacted by its multitude of upstream waterways. Clearly, protecting the resilience of this marine ecosystem and sustaining the production of its ecosystem services is vital to the long-term security of our nation and its economy.

Since the GoM is a large and complex marine ecosystem we have taken a scaled approach to exploring how this system is structured and how it functions. At smaller geographic scales we are working with stakeholders to identify and develop ecosystem indicators for coastal south Florida. Leveraging existing partnerships within south Florida we have developed several county-level projects to develop the ecosystem-based management tools necessary to study the various sectors comprising the broader Gulf of Mexico. For example, building upon results from the Marine and Estuarine Goal Setting for South Florida (MARES) project we developed matrix-based approaches for understanding and ranking the various pressures impacting the south Florida coastal ecosystem (Cook et al., 2014), and have developed a suite of indicators for beach ecosystems located along the southeast coast of Florida (Marshall et al., 2014).

At the broader Gulf of Mexico scale we recently analyzed over 100 indicators representing physical, biological, and economic aspects of the GoM and using a Drivers-Pressures-State-Impact-Response (DPSIR) framework, identified an ecosystem-wide reorganization in the mid 1990s (Figure 1, Karnauskas et al., 2015). Additional analyses showed the shifts in Drivers and Pressures, States, Impacts and Responses, and specifically a shift in composition of fishery landings in the GoM in the late 1970s aligned with the advent of the Magnuson-Stevens Fishery Conservation and Management Act, and shifts in the mid 1960s and 1990s aligned temporally with changes in the Atlantic Multidecadal Oscillation (AMO; Figure 2). Based on this comprehensive analysis we provided recommendations on how resource managers can adjust to various climate regimes in the broader Gulf of Mexico.

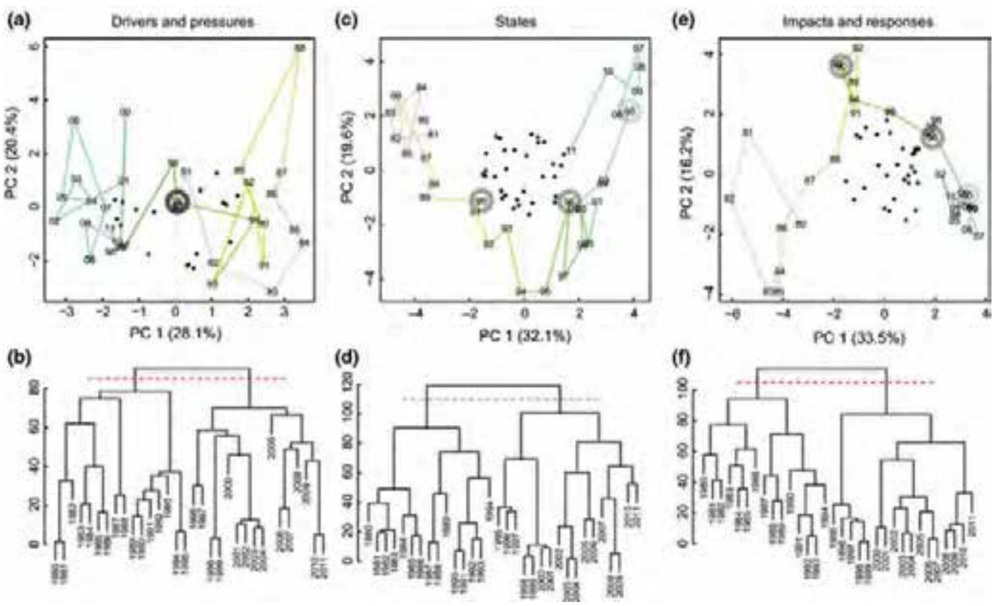

Figure 1: Multivariate analyses of three groups of ecosystem indicators: drivers and pressures (a, b), states (c, d), and impacts and responses (e, f). Top row (a, c, e): Yearly scores of first two principal components are plotted, based on principal components analysis (PCA) of ecosystem indicator values from 1980 to 2011. Segments are color-coded on a continuous scale to aid reader in the interpretation of change through time. Circles represent breaks in the first principal component (i.e. the first year of a new regime) as identified by the STARS algorithm; significance is denoted by darkness of circle color (darker lines = higher significance; all breaks $P < 0.01$). Small dots denote indicator loading on the first two axes. Bottom row (b, d, f): Chronological clustering analysis of ecosystem indicators from 1980 to 2011. Horizontal dotted lines denote the threshold for significance of breaks.

Through these projects we developed complementary frameworks for exploring and characterizing the various pressures threatening ecosystem service sustainability in coastal south Florida and the broader Gulf of Mexico. The results from these studies highlight the challenges we face at different spatial scales; at the local scale there are logistical challenges inherent to managing and mitigation planning for far-field pressures (e.g. climate change, sea level rise, etc.), while at the vast Gulf of Mexico scale understanding and disentangling the effects of climate drivers from those effects caused by a complex tapestry of interacting anthropogenic pressures can prove daunting without spatially and temporally comprehensive datasets.

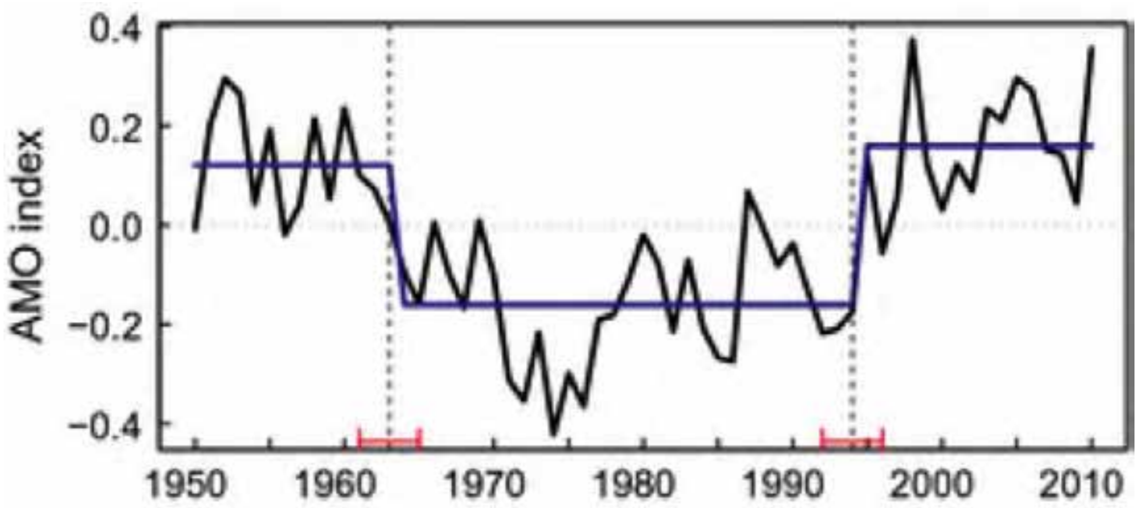

Figure 2: Time series of the Atlantic Multidecadal Oscillation (AMO), with significant historical shifts and their confidence intervals identified using a sequential F-test algorithm.

Research Performance Measure: All major research objectives are being met and are on schedule. By leveraging the intellectual products created through various projects we have created a framework for identifying and characterizing indicators for assessing the health of the Gulf of Mexico ecosystem across spatial and temporal scales. Currently we are building upon these studies and applying these products in concert with ecosystem and network models along the west Florida Shelf to better understand how the broader Gulf of Mexico large marine ecosystem is structured and how it functions.

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Juvenile Sportfish Monitoring in Florida Bay, Everglades National Park

Project Personnel: T. Creed, and L. Visser (UM/CIMAS)
NOAA Collaborators: J. Browder, B. Huss and C. Kelble, (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To determine the baseline distribution and current variability of juvenile spotted seatrout within Florida Bay including quantification of the potential mechanisms that may limit this distribution; to provide the basis for distinguishing future changes that may occur as a result of the Comprehensive Everglades Restoration Plan (CERP).

Strategy: To carry out regular sampling of juvenile spotted seatrout throughout Florida Bay and incorporate these results along with ancillary water quality and habitat data into statistical analyses and models to determine the underlying cause for the current distribution and produce predictive, testable hypotheses regarding the effect of CERP projects on juvenile spotted seatrout distribution.

CIMAS Research Theme:

***Theme 6*:** Ecosystem Management (*Primary*)
***Theme 3*:** Sustained Ocean and Coastal Observations
***Theme 5*:** Ecosystem Modeling and Forecasting
***Theme 7*:** Protection and Restoration of Resources

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC and OAR/AOML
NOAA Technical Contact: Theo Brainerd and Molly Baringer

Research Summary:

This project is a component of the Restoration Coordination and Verification (RECOVER) Monitoring and Assessment Plan of the Comprehensive Everglades Restoration Program (CERP). The Comprehensive Everglades Restoration Program is the largest and most expensive ecosystem restoration ever attempted. The primary goal is to restore the quantity, quality, timing, and distribution of freshwater to as near historic levels as feasible in the greater Everglades Ecosystem. Restoration activities will have a significant effect on the downstream coastal ecosystem that supports a significant portion of south Florida's economy, including the recreational fishery within Florida Bay.

The spotted seatrout, *Cynoscion nebulosus*, is an important recreational sportfish in Florida Bay and spends its entire life history within the Bay. Salinity and freshwater influx affect spotted seatrout distribution both directly through physiology and indirectly by affecting habitat (i.e. seagrass), prey and predator distributions and species compositions. Therefore, juvenile spotted seatrout are a good indicator to assess the effect of CERP on Florida Bay's recreational fishery.

Juvenile spotted seatrout populations have remained low throughout central Florida Bay, but have been slightly higher in the west sub-region from 2008 through 2014. There has been a statistically significant shift to lower juvenile spotted seatrout populations in the central bay since 2008. The cause of this shift is not certain, but 2008 had the highest salinities observed during the MAP sampling, which may have resulted in a shift in seatrout populations. The highest densities and frequencies of occurrence overall occurred in 2006 in Whipray and in West. A notable increase in spotted seatrout densities in north-central Florida Bay occurred in the fall of 2005, following a substantial decrease in salinity as a result of hurricanes.

Three sub-regions showed juvenile spotted seatrout population inversely correlated with salinity, but the West did not (Fig. 1). The west sub-region lacked any correlation with salinity suggesting that salinity may not be the major influence on juvenile spotted seatrout here and other factors may play a role in seatrout abundance. This could be in part, because the salinities in the west are more stable.

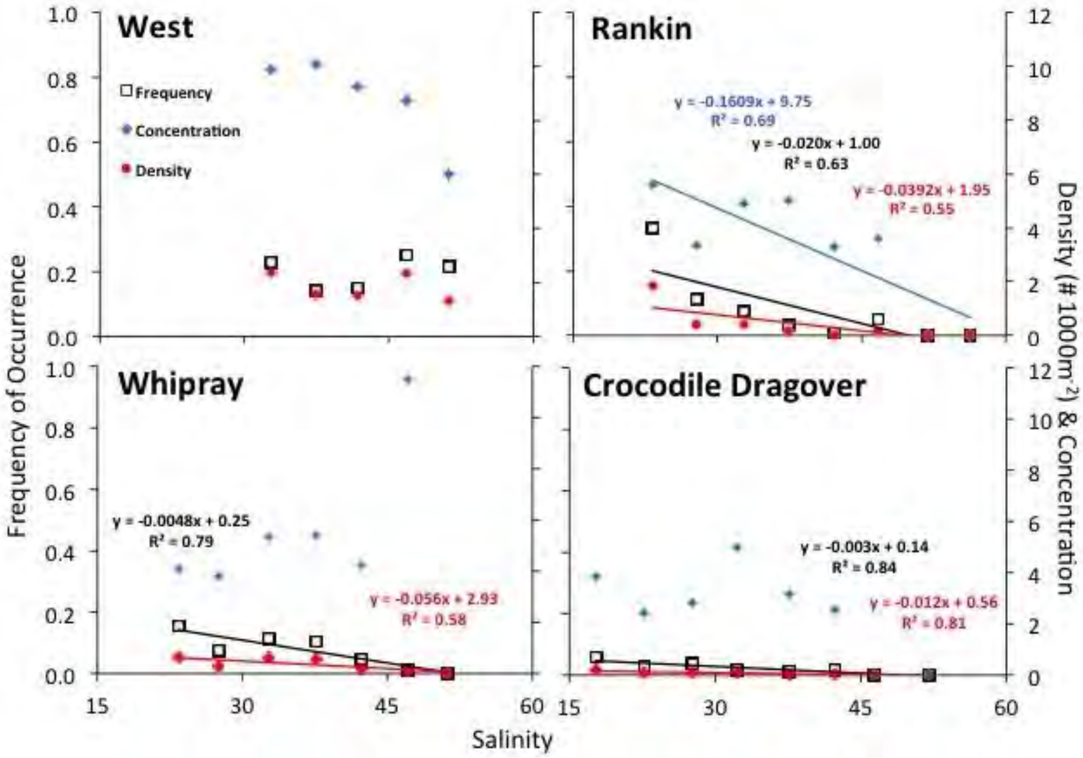

Figure 1: Scatter plots depict the relationship between the juvenile spotted seatrout population and salinity within each sub-region. The black boxes are frequency of occurrence, the blue diamonds are concentration and the red circles are density. Only significant linear regressions are depicted.

There was a significant positive linear relationship of spotted seatrout density, frequency of occurrence, and concentration, between seagrass percent cover throughout Florida Bay. This suggests that as percent cover increases juvenile spotted seatrout are caught more frequently and at higher densities. The spatial distribution of seagrass in Florida Bay varies by region, with a strong east west gradient. The west sub-region has the highest seagrass percent cover with a decreasing trend towards Crocodile Dragover. Juvenile spotted seatrout frequency of occurrence follows a similar spatial pattern to seagrass percent cover.

A logistic regression was employed on the data collected from 2004 to 2010 to quantify the impact of salinity, temperature on juvenile spotted seatrout frequency of occurrence. Juvenile spotted seatrout are unlikely to be observed at temperatures below 20°C, reflecting the seasonal spawning cycle. In hypersaline waters, juvenile spotted seatrout are only found in areas with moderate temperatures. Overall, this probability plot shows that juvenile spotted seatrout prefer low salinity and moderate temperatures.
Perhaps most importantly, our analyses this year with our new water-quality-model-based HSI confirmed that simulated NSM conditions provided a sound restoration target for juvenile spotted seatrout abundance in each of our Florida Bay sampling sub-regions. Furthermore, the HSI model sufficiently discriminated between the alternatives of the Central Everglades Project design and future without CEPP, with regards to differences in juvenile spotted seatrout abundances.

Research Performance Measure: We have quantified a significant relationship with juvenile spotted seatrout to salinity that has allowed for the development of a testable hypotheses regarding the effect of CERP on juvenile spotted seatrout distributions. This project data (and the Project Principal Investigator)

provided critical contributions to the relevant components of the congressionally mandated 2013 System Status Report, indicating that this project is contributing to science-based management within CERP.
We have begun the development of a revised performance measure for juvenile sportfish in the southern coastal systems. The preliminary steps of this process have focused on the development of Habitat Suitability Index (HSI) models that will be used to predict the habitat suitable for juvenile *C. nebulosus* and other sportfish from submerged aquatic vegetation and water quality parameters. The performance measure will then examine the area of suitable habitat under current conditions compared to the area of suitable habitat predicted from the natural system model and climate change scenarios. The change in area of suitable habitat will be used to derive a quantitative performance measure with a target that CERP can aim to achieve in light of likely climate change scenarios.

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Net Revenues of the Federal Fin-Fish Commercial Fisheries in the Gulf of Mexico

Project Personnel: E. Overstreet (UM/CIMAS)
NOAA Collaborators: C. Liese and L. Perruso (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To develop and report net revenues of commercial fishing operations in the Gulf of Mexico reef fish (snappers and groupers) and coastal migratory pelagics (mackerels). A central gap in the Southeast's commercial fishery economic assessments are estimates of net revenues for federally-managed fin-fish fisheries; including Gulf of Mexico Reef Fish - Non-IFQ, Red Snapper IFQ, Grouper-Tilefish IFQ, and Coastal Migratory Pelagics. These fisheries include two catch share fisheries; and one non-catch share fishery (vermillion snapper) that are part of the national performance indicator project.

***Strategy*:** To ensure both statistical representativeness and meaningfulness/usefulness of the economic results, the already collected economic data needs to be analyzed/post-stratified to take into account: 1) the applicable sampling designs (the design changed over time); 2) the actual realized fishing activity each year (the designs incorporated historical fishing activity), and 3) it needs to be an iterative process. To clarify the latter, after adjusted confidence intervals for summary statistics for a given post-stratification are calculated, it is likely that we will need to circle back and adjust the stratification, i.e., further reduce the number of strata to increase sample size in each. Dimensions available for stratification include time and space; vessel/owner/permit characteristics; and annual and trip-level fishing activity, including gear, effort and catch by species. Statistical precision will tentatively require high levels of aggregation, while economic meaningfulness and usefulness for fishery management will tentatively argue for low levels of aggregation.

CIMAS Research Theme:

***Theme 6*:** Ecosystem Management

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems* (*Primary*)

***Goal 4*:** Resilient Coastal Communities and Economies - *Coastal and Great Lakes communities that are environmentally and economically sustainable* (*Secondary*)

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:
This project only started March 2, 2015. Project personnel are becoming familiar with manipulating and querying the SEFSC's coastal logbook database (Oracle); and has generated informal reports on various aspects of the data (in SAS and R). Code is being migrated from SAS to R. Segmenting of the fisheries (for economic analysis) has started; taking account of the complex statistical designs that generated the data.

Research Performance Measure: Progress is being made toward economic analysis of economically and statistically meaningful sub-populations of the SE federal fin-fisheries (including trip- and annual/vessel-level).

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Pelagic Fisheries Logbook Program

Project Personnel: A. Shideler (UM/CIMAS)
NOAA Collaborators: D. Gloeckner and M. Maiello (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:
***Objectives*:** To assist with all phases of collection and processing of pelagic longline vessel logbook data for entry in the Pelagic Longline Logbook system (PLL) and pelagic individual fish weight data for entry in the Domestic Longline System (DLS), including efforts to improve compliance and quality control utilizing the new Unified Data Processing system (UDP); and to provide data summaries and reports when requested by researchers, law enforcement, and vessel owners.
***Strategy*:** To identify potential sources of data error with colleagues and create programs that identify errors and inconsistencies; to communicate with commercial fishermen with regards to information required for logbook completion and permit renewal; to conduct regular audits to identify logbook compliance issues and to expand these audits to encompass a broader region.

CIMAS Research Theme:
***Theme 6*:** Ecosystem Management

Link to NOAA Strategic Goals:
***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary: The Domestic Pelagic Longline Data program has collected commercial pelagic longline fishing data from 1986 to present for fishing activities targeting various species in the Gulf of Mexico, Caribbean, and Atlantic Ocean. The fishery-dependent data collected via logbooks by this program focus on Atlantic highly migratory species (HMS) including swordfish and tunas (Figure 1, Figure 2). Data collected by the program are used in annual reports to the International Commission for the Conservation of Atlantic Tunas (ICCAT) on overall landings, catch rates, and catch at size (Figure 3). This program requires collaboration with individuals within the Sustainable Fisheries Division at NOAA Southeast Fisheries Science Center (SEFSC).

Figure 1: *Xiphias gladius*, the swordfish (www.safmc.net)

Figure 2: *Thunnus thynnus*, the Atlantic bluefin tuna (www.safmc.net)

Of particular interest to the program is the improvement of data flow and quality control to ensure that future assessments and analyses of the data facilitate accurate fishery management decisions. A compliance audit which reconciles logbook data with dealer reported data identifies delinquent or missing logbook reports. The results of the audit have also been used by other scientists within NOAA to identify missing dealer reports. Additionally, the recent development and implementation of the Unified Data Processing (UDP) system has expanded validation of data and created a mechanism to provide feedback to permit holders about required logbook information. Pelagic individual fish weight data, currently held in the Domestic Longline System (DLS), will soon be processed within UDP to better integrate catch and effort data.

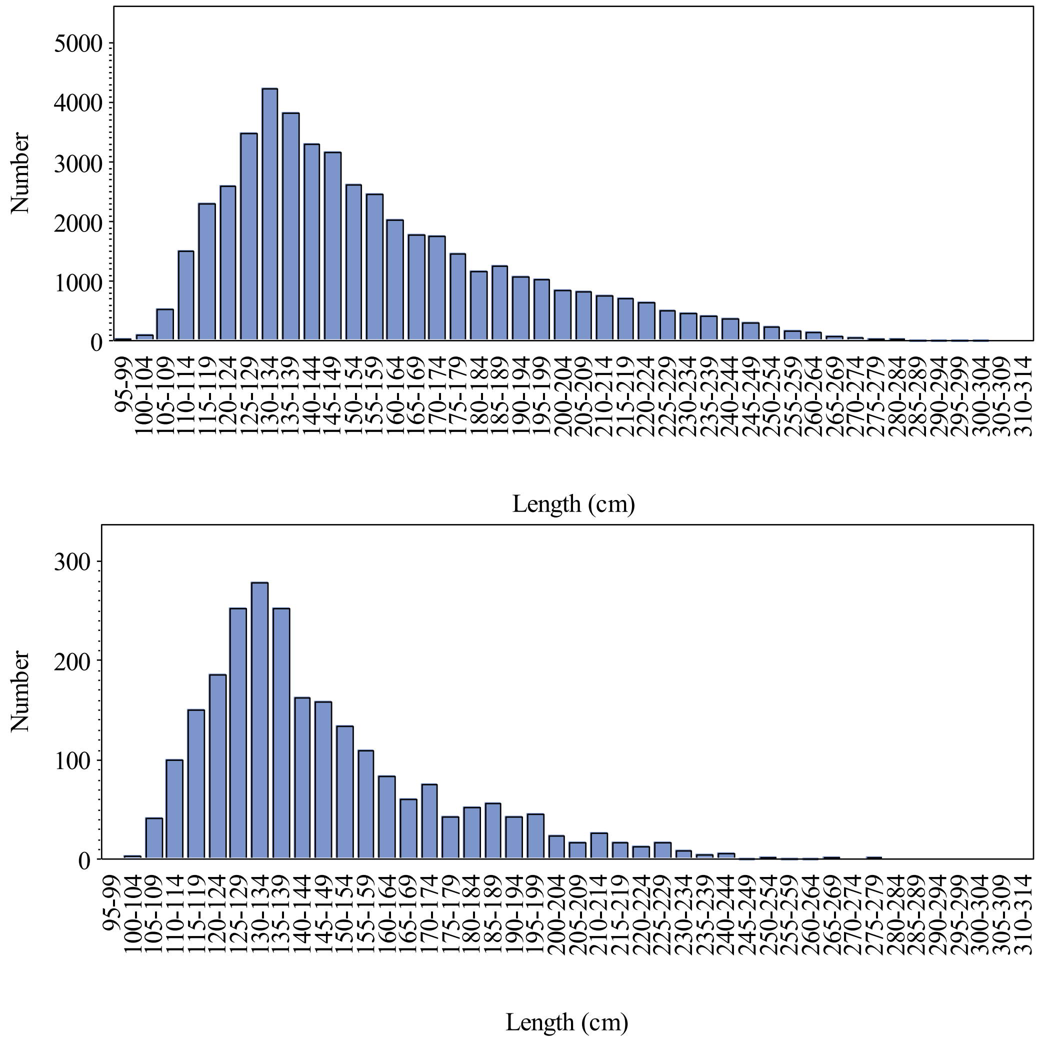

Figure 3: Length frequency (lower jaw fork length, in cm) of swordfish caught in commercial (A) longline and (B) hand gear fisheries obtained from catch as size (CAS) data reported to the Pelagic Longline program for 2013.

Research Performance Measure: One hundred twenty-six validations designed to improve logbook data quality have been integrated into UDP. Thirty-six vessels have been contacted about missing or invalid information submitted on logbooks.

Synthesis of Information on Octocoral Biology, Ecology, and Fisheries in the South Atlantic in Support of Effective Management

Project Personnel: S.L. Miller, P. Espitia, M. Chiappone and L.M. Rutten (NSU)
NOAA Collaborators: J. Schull and A. David (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** Octocorals, also known as gorgonians and soft corals, were previously managed by the U.S. South Atlantic (SAFMC) and Gulf of Mexico (GMFMC) Fishery Management Councils through the Coral Fishery Management Plan (FMP). Because octocorals are mostly collected from Florida waters, the Florida Fish and Wildlife Conservation Commission (FWC) is currently tasked with monitoring octocoral landings in Federal and state waters off Florida. Collection of 70,000 colonies per year total in the Economic Exclusive Zone is permitted under the SAFMC Coral FMP and Rule 68B-42.006 of the Florida Administrative Code, but has never been exceeded (Table I-4, FWCC 2014). Concerns by the SAFMC arose because catch data, as opposed to population data, were used to set Acceptable Biological Catch limits (ABCs) and Overfishing Limits (OFLs) under the new Federal fishery management standards. A goal of this project was to assess the sustainability of the octocoral fishery relative to FWC Trip Ticket data and existing knowledge of octocoral populations and ecology.

***Strategy*:** Results from interviews with marine life collectors, data from long-term population surveys, and literature reviews were all used to achieve the overall research objective of this project.

CIMAS Research Themes:

***Theme 6*:** Ecosystem Management
***Theme 7*:** Protection and Restoration of Resources

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

***Goal 4*:** Resilient Coastal Communities and Economies - *Coastal and Great Lakes communities that are environmentally and economically sustainable*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

Based on interviews with collectors, a synthesis of FWC Trip Ticket results, and results from population monitoring, the long-term stability of the octocoral fishery is not likely to significantly change (Figure 1). Distribution and abundance information obtained from an exhaustive search of the literature, along with age, growth and habitat data, suggests that current information is comprehensive and definitive, such that stock assessment or population dynamic modeling are not required to assess the status of collected octocoral species. For multiple sample periods, over a decadal period, the Florida Keys-wide abundance estimates presented for 15 species clearly document that octocoral populations are large (tens of millions to hundreds of millions, per species) and stable or increasing (Figure 2). The numbers of colonies collected in the Florida Keys in 2009 under the "other" and "purple" octocoral species groups represented 0.003% and 0.001% percent, respectively of their estimated population sizes. The major conclusion of this work is that the take of octocorals below the 70,000 Total Allowable Catch (referred to as quota by FWC) per year threshold (that has never been reached) does not adversely affect the fishery. This conclusion is based on the large population estimates determined for octocorals relative to the relatively small (insignificant) number of octocorals collected. Information collected by FWC through the Trip

Ticket program is more than adequate to understand and manage the octocoral fishery. Minor reporting clarifications and better taxonomic resolution in reporting would help improve the accuracy of collecting data, but improved accuracy is not necessary to assess the current state of the fishery – the octocoral fishery appears to be sustainable at current collecting levels and could likely sustain even higher levels of harvest, if demand were to increase.

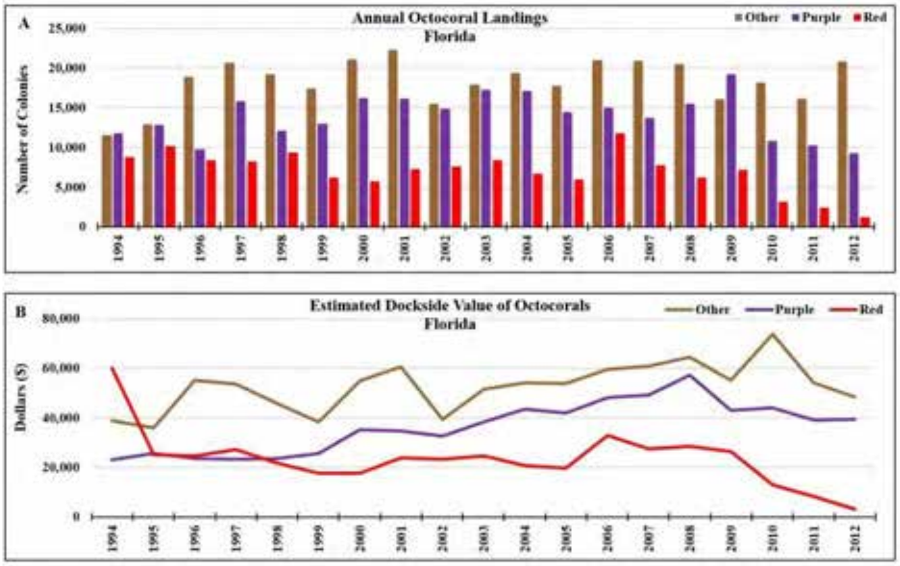

Figure 1: (A) Annual octocoral landings and (B) dockside value of octocoral species groups (other, purple, and red) in State and Federal waters off Florida, 1994-2012 (unpublished commercial octocoral collection data from FWC).

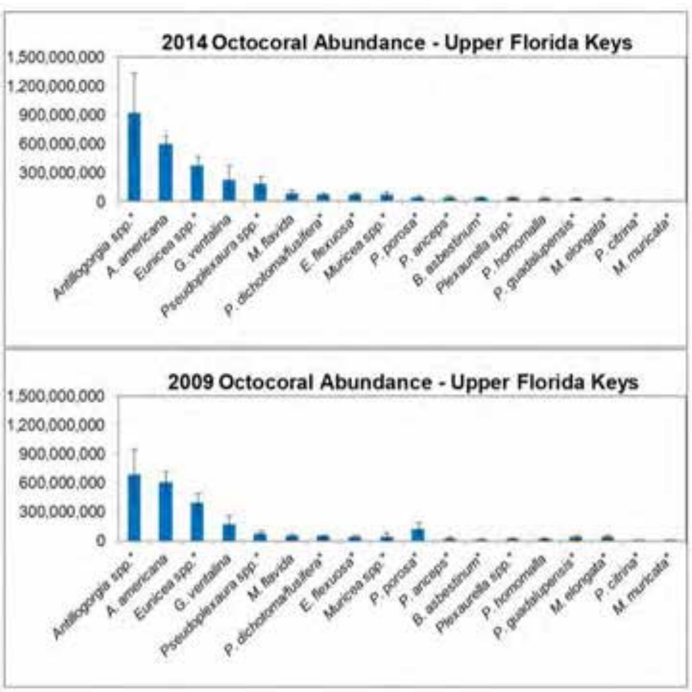

Figure 2: Octocoral abundance in the upper Florida Keys (Carysfort, northern Key Largo to Alligator Light, Upper Matecumbe Key), based upon surveys during 1999-2002, 2005, 2009, and 2014. Species are ranked along the x-axis from high-to-low based upon 2014 data. Error bars represent 95% confidence intervals. Octocoral species or genera targeted in the octocoral fishery are indicated with an asterisk (*).

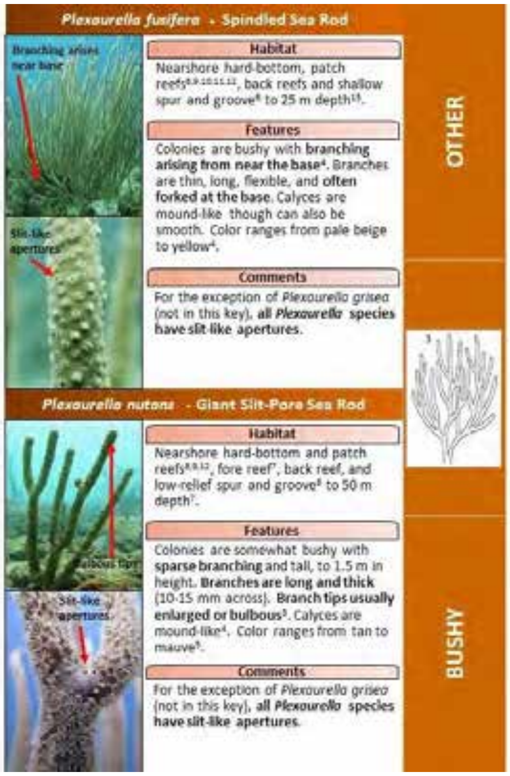

Figure 3: Octocoral Identification Guide, example page for the spindled sea rod (*Plexaurella fusifera*) and the giant slit-pore sea rod (*P. nutans*).

Research Performance Measure: Outputs from this work include: 1) Final Report Completed: Description of the U.S. South Atlantic Octocoral Fishery 2014 Final Report to the South Atlantic Fishery Management Council, December 2014. Included in the report is a description of the octocoral fishery, an extensive review of the biology and ecology of octocorals, an analysis of current data collection programs for management, information needs and recommendations, and an extensive bibliography. 2) An octocoral identification guide was completed (see Figure 3 for two species). 3) A NOAA Technical Memorandum is in the final stages of preparation, based on the projects Final Report. 4) A peer-reviewed publication is in preparation.

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Development of a Towed Camera System for Assessing Demersal Fish Stocks: C-BASS (Camera-Based Survey System): Phase II - Survey Implementation

Project Personnel: S. Murawski, C. Lembke, A. Silverman, S. Butcher, S. Grasty, J. Brizzolara, E. Hughes and K. Davis (USF/CMS)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** (1) Complete hardware engineering of towed imaging system. (2) Complete sea trials of camera system operations (3) Conduct a partial survey of reef fish abundance and distribution along the West Florida shelf. Areas surveyed will include the Madison-Swanson, the Florida Middle Grounds and the Steamboat Lumps closed areas. (4) Define requirements for software systems for rapid image classification.

***Strategy*:** To engage a multidisciplinary team of biologists and engineers in the collaborative development of an altogether new technology to determine the abundance, habitat associations and species interrelationships among reef fish populations inhabiting untrawlable habitats.

CIMAS Research Theme:

Theme 6: Ecosystem Management (*Primary*)
Theme 7: Protection and Restoration of Resources (*Secondary*)

Link to NOAA Strategic Goals:
Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/ST **NOAA Technical Contact:** Theo Brainerd

Research Summary:
During the project period we undertook structured analyzes of video imagery and environmental data from the C-BASS cruises conducted in 2013 and 2014. In order to produce of fish biomass (in absolute terms) several critical factors need to be assessed. (1) To convert raw fish counts (e.g., Figure 1) into density measurements (numbers m^{-2}), an estimate of the width of the area being imaged is necessary. As width of the path viewed is a function of height above the bottom, several experiments were undertaken to estimate this function (Figure 2). (2) In addition to the path width, an estimate of the path length is necessary to estimate the area viewed per one minute video segment. This was accomplished using GPS coordinates associated with the beginning and end of each one minute segment, (3) Efficient survey design involves stratifying the density estimates by the various habitat types (e.g., reef, sand, slope, cobble, etc.) to do so we used existing backscatter and imagery collected on our cruises to estimate the amount and spatial distribution of various habitat types (Figure 3) in the two areas being analyzed. Transect data were subsequently post-stratified into these various habitat types), and (5) The behavior of various species in relation to the presence of the towed camera can be used to adjust the density estimates for under- or over-estimates due to repulsion or attraction to the camera system (Figure 4). All of these factors were used to estimate total fish abundance and biomass in the surveyed regions, which was accomplished in Grasty, 2015.

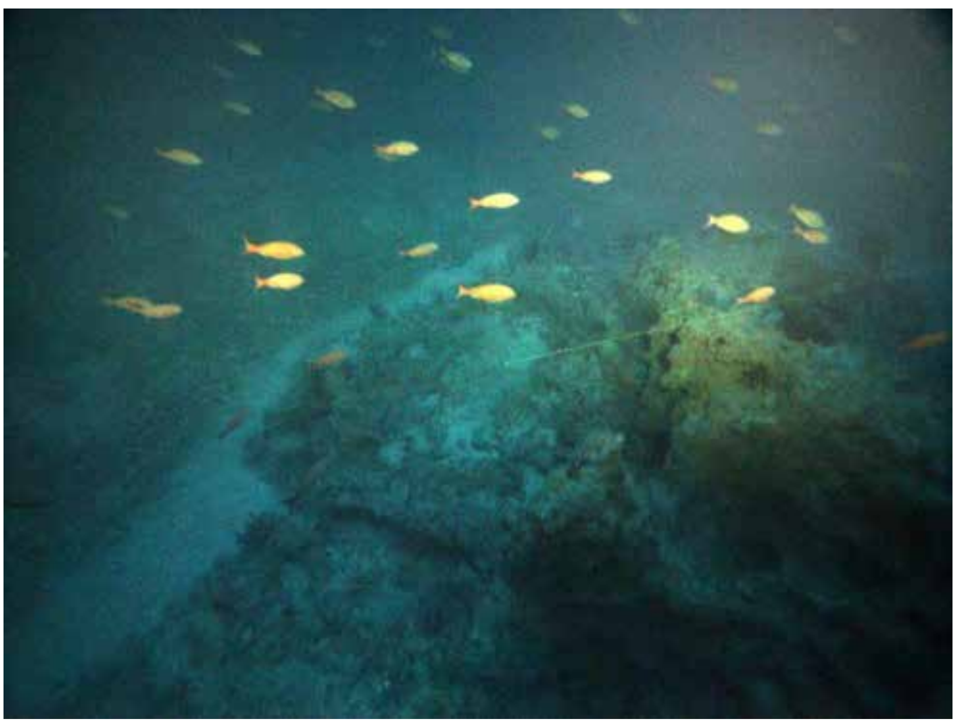

Figure 1: Image of vermillion snapper on the West Florida Shelf as seen by the C-BASS Camera System, May, 2014.

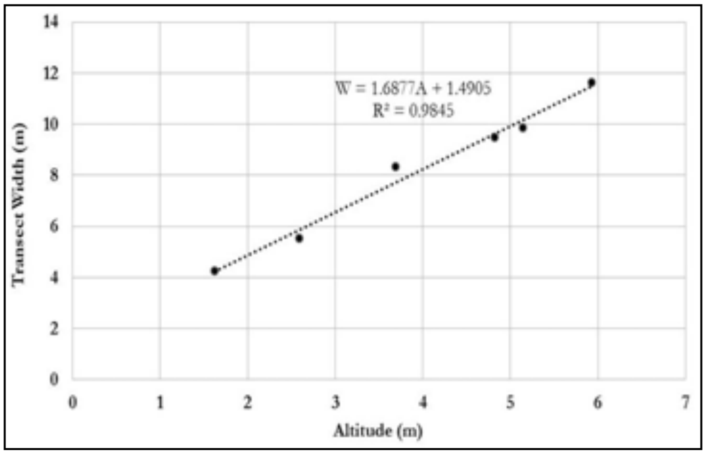

Figure 2: Relationship between the altitude of the C-BASS towed instrument and the width of the tow path observed (in meters).

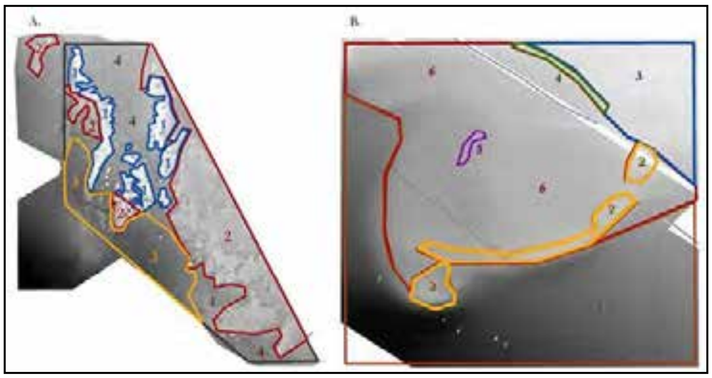

Figure 3: Stratification of the Florida Middle Grounds (A) and the Madison-Swanson area (B) off the West Florida Shelf into strata of similar bottom habitat types (numbers).

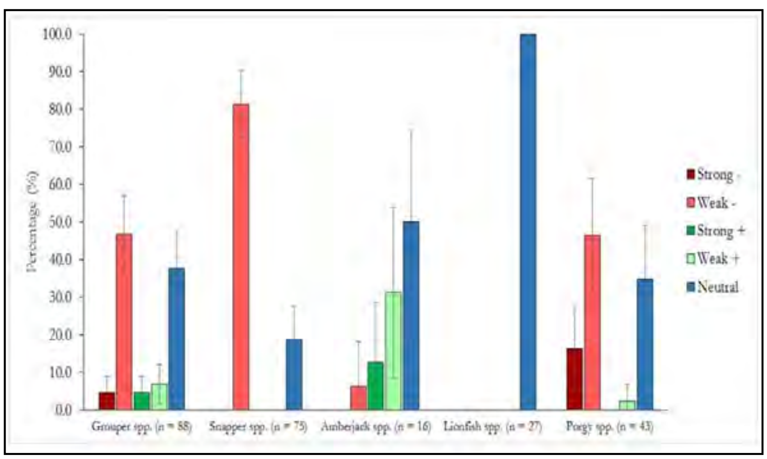

Figure 4: Proportional behaviors observed for five fish groups observed reacting to the C-BASS towed camera system on the West Florida Shelf.

Research Performance Measures: Objectives 1-4 (as described above) have been completed. Cruises were completed in June 2013, November, 2013, and May 2014. In all three MPAs, density estimates for fishes were developed, which were number counts divided by the area sampled by the video cameras (see above). The density estimates were converted to total population estimates by multiplying the average density by stratum type (numbers m^{-2}) by the physical area of each stratum (Figure 3). The C-BASS vehicle performance was significantly upgraded, and now is poised to transition from a research tool to an operational fish survey tool. Ongoing research with the imagery obtained from the three cruises conducted in the progress period includes: (1) density and species composition for observed fishes in the three MPAs, (2) classification of density estimates by habitat type as observed in the videos, (3) use of the EK-60 backscatter data to correlate with observed habitat types to develop an algorithm for classifying habitats using only acoustic data, (4) correlation of video species identity and density with EK-60 acoustic imagery, (5) development of algorithms for understanding the spatial geography of fishes and habitats (species associations) using video imagery, and (6) assessment of the species composition and density of benthic invertebrates (corals, gorgonians, sponges) associated with sampled habitats (new graduate student project) to assess reef health. For objective 4 we have developed performance criteria for computer-enhanced video interpretation, assuming different levels of capability to recognize and classify fish encountered on the video imagery.

C-BASS Towed Camera Experiment Florida Middle Grounds

Project Personnel: S. Murawski, C. Lembke, A. Silverman, S. Butcher and Sarah Grasty (USF/CMS)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** (1) Test the behavior of various reef fish species in the presence of mobile cameras. (2) Estimate the density (numbers of fishes by species per unit area) observed by various types of imaging systems.

***Strategy*:** To engage a multidisciplinary team of biologists and engineers in understanding the behavior of fishes in relation to various imaging systems.

CIMAS Research Theme:

***Theme 6*:** Ecosystem Management (*Primary*)
***Theme 7*:** Protection and Restoration of Resources (*Secondary*)

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/ST **NOAA Technical Contact:** John Quinlan

Research Summary:

The purpose of this grant is to support a large-scale experiment being facilitated by NOAA to test various gears to estimate reef fish population sizes in the Florida Middle Grounds Habitat Area of Particular Concern (HAPC), off the west coast of Florida. The National marine Fisheries Service (NMFS)/NOAA, through its Advanced Science and Technology Working Group (ASTWG) has supported the development of optical methods to estimate fish density in areas considered "untrawlable". These areas, which exist throughout the coastal areas of the country, are becoming a more difficult problem for fish stock assessments because of the proliferation of various fishery closed areas, and because coral reefs and other high relief habitats are underrepresented using typical fishery sampling methods.

The NOAA untrawlable habitat camera experiment was intended to test C-BASS and several AUVs and ROVs, in order to understand the potential biases of each relative to several fixed camera locations in the Florida Middle Grounds. Each of the mobile gears was be "flown" over the fixed bottom cameras to test two hypotheses: that the behavior of various species are not modified by the presence of mobile cameras, and that the density (numbers of fishes by species per unit area) are similar among the various gears.

A field experiment testing the various fixed and mobile gears was be undertaken during 3-22 August, 2014. The experiment used the UNOLS R/V *Pelican,* and deployed three fixed camera pods (Figures 1 and 2) taking high resolution black and white pictures (Figure 3) as the various vehicles (Figure 2) were towed along the transect where the bottom camera pods were located. The experiment was highly successful. The C-IMAGE vehicle made over a dozen passes that were captured on the fixed camera PODS. Additionally, the cameras aboard the C-BASS also observed the fixed camera pods and the fish densities in the surrounding area. From these observations, we estimated the abundance of various species and species groups observed in the fixed cameras before, during and after the towed cameras passed the field of view of the various cameras. These data (Figure 4) Indicate that, for the most part, the abundance of species remained unchanged in the presence of the towed cameras, further supporting the hypothesis that for most species, the behavior of fishes is unchanged in the presence of towed camera systems. Work continues to estimate the before, during and after fish densities from all camera passes and to estimate fish densities from C-BASS cameras. As well, acoustic and photographic imagery are being analyzed to understand fish school behavior and impacts in relation to the presence of towed camera gears.

Figure 1: Schematic of fixed camera systems on the seabed and the C-BASS towed camera system transiting among them.

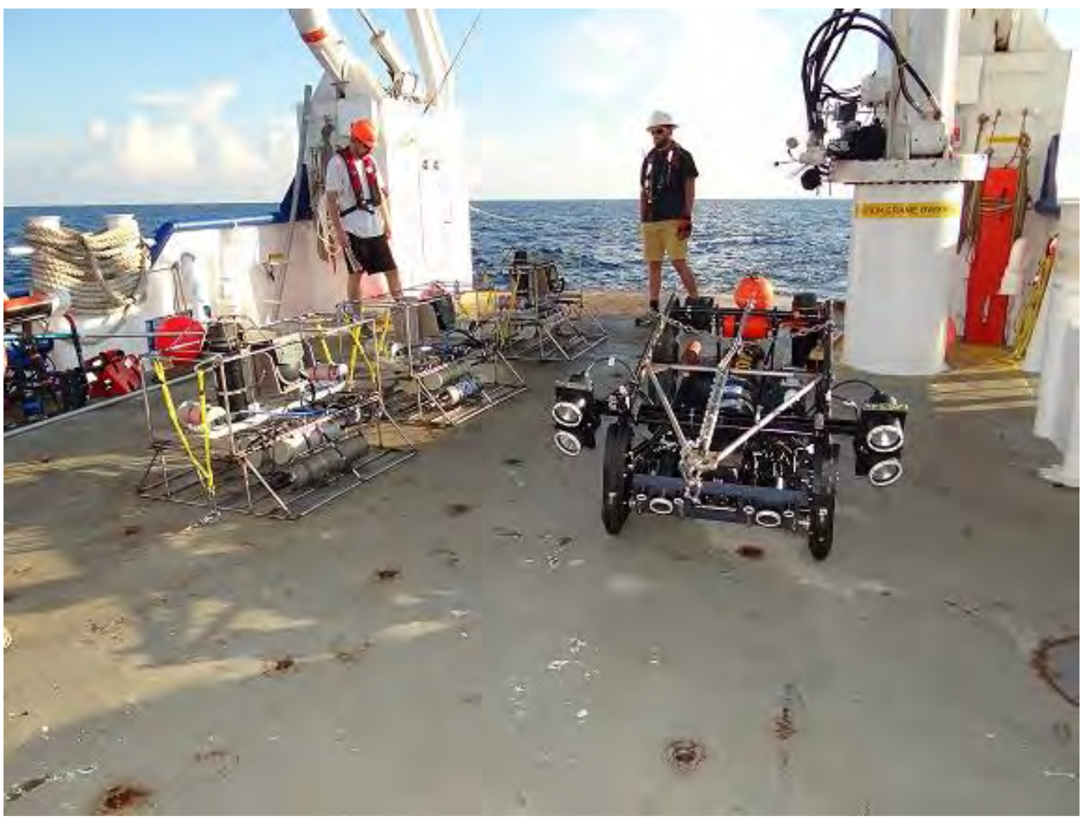

Figure 2: Fixed camera pods (left) and the C-BASS towed camera vehicle (right) being deployed in the Florida Middle Grounds.

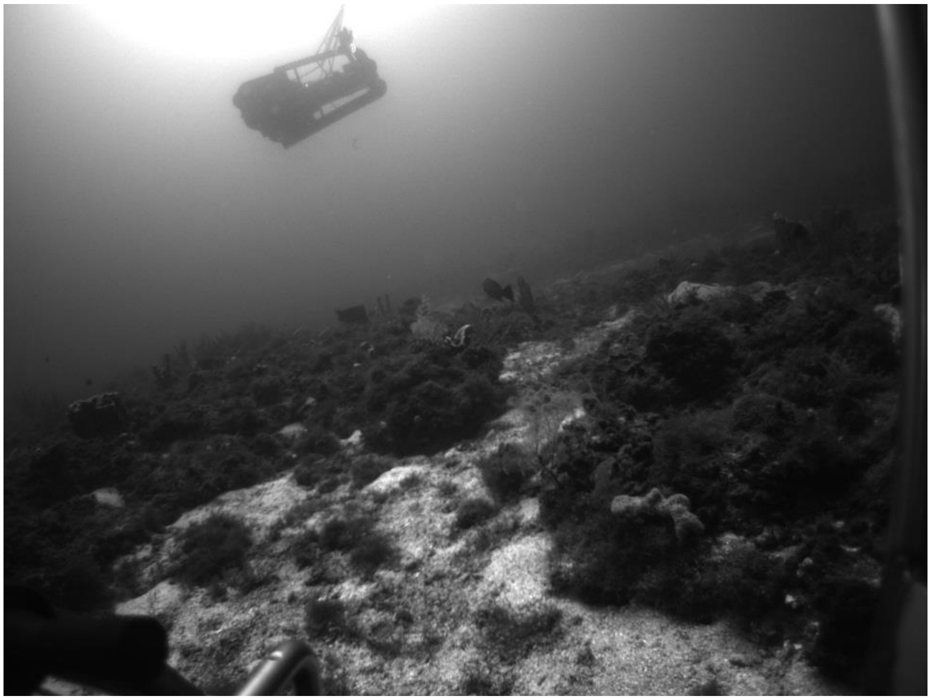

Figure 3: Image of the C-BASS towed camera system taken from the fixed camera pod. A scamp is visible in the foreground.

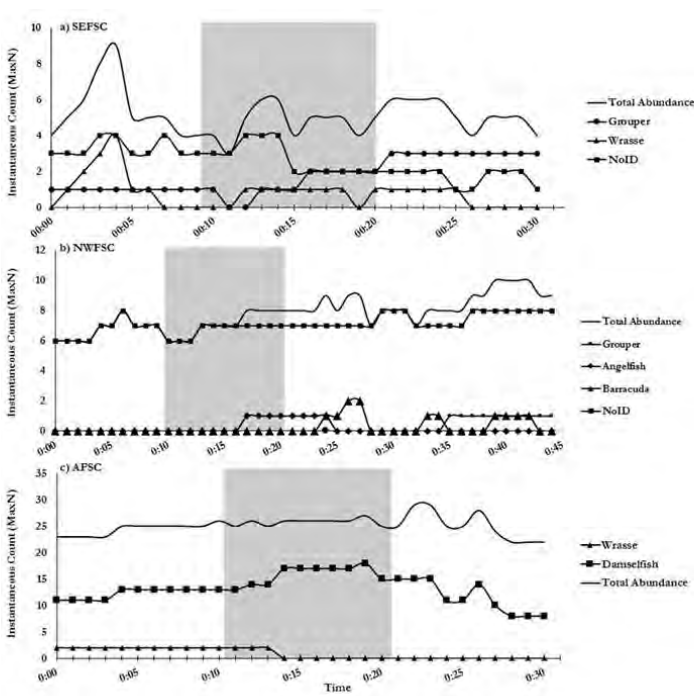

Figure 4: Fish density information passing three fixed camera pods (a, b,c). Data are counts of fishes before, during (shaded portion of the graph) and after the passage of the C-BASS fixed camera system.

Research Performance Measures: Objectives 1 was completed, the research cruise compared ROV, AUV and towed camera system data to estimates obtained from the bottom camera arrays. Significant data were obtained during the cruise. Objective 2 is being completed now. Analysis of the imagery to determine densities is ongoing.

How Precise and/or Accurate do Forecasts of FATE Ecosystem Indicators Need to be to be Useful to Stock Assessments?

Project Personnel: E. Peebles (USF/CMS); M. Murphy (USF/CMS and Florida Fish and Wildlife Commission)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** Our goal is to quantify the level of environmental forecast precision needed to significantly improvement stock assessment projections. This should allow stock assessment scientists to determine if the available climate forecasts instill a meaningful amount of information into stock assessments.

***Strategy*:** We are incorporating an important ecosystem indicator into a typical, single-species population dynamics model and evaluate how stock assessment projections for these populations are affected at various levels of indicator variability. Specifically, we will investigate how various levels of uncertainty in forecasting the winter North Atlantic Oscillation/Gulf Stream North Wall (NAO/GSNW) indexes affect our ability to model and project future swordfish (*Xiphias gladius*) recruitment and stock dynamics.

CIMAS Research Theme:

***Theme 6*:** Ecosystem Management

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

The original plans were to run stock assessment model projections under various levels of linkage between future recruitment levels and forecast environmental drivers. A significant part of this problem is determining how well the environmental drivers can be forecast and at what level of certainty out to a useful (for managers) number of years (2-3 years). Apparent improvements have been made in forecasting large atmospheric features like the North Atlantic Oscillation with lead times approaching 4 months (Scaife *at al.* 2014, *Geophys. Res. Lett*., 41, 2514–2519). The potential exists for even longer-term forecasting via advances in understanding teleconnections between the North Atlantic and the tropical Pacific via the stratosphere (Bell *et al.* 2009, *J. Clim*., 22, 4083–4096) or through cyclic solar irradiance variations (Ineson *et al.* 2011, *Nature Geoscience*, 4, 753-757).

At this point in this project, extensive effort has been concentrated on understanding the evolving capabilities of modern stock assessments, like Stock Synthesis 3 (SS3, Methot 2013, User manual for stock synthesis, model version 3.24s. NOAA Fisheries Seattle, WA). Over the past year or two a large number of modifications to this standard, state-of-the-art assessment have required attention. The original meshing between the simulator, FSIM (Goodyear 2005, FSIM, version 4.0 User's guide. philgoodyear@cox.net), and the stock assessment model, is well established though not absolute. Under deterministic, fixed parameters at the correct FSIM-based values, the stock assessment model can return the correct population dynamics specified by the simulator (Fig 1). However, when the assessment model is used to solve for future recruitment under different levels of information (environmental drivers at different levels of certainty) and uncertainty entered into the simulation, the stock assessment model fails to clearly return the true state of nature prior to these projections (Fig. 2). In order to understand and eliminate the error associated with this mis-specification of the stock assessment model to the simulator, time has been spent understanding the SS3 program by using it in real-world assessments for species like hogfish, mutton snapper, and red drum. A special workshop is scheduled to be taught by Drs. Rick Methot and Ian Taylor to investigate these advances is being held at FWRI for southeast region assessment analysts in December 2015.

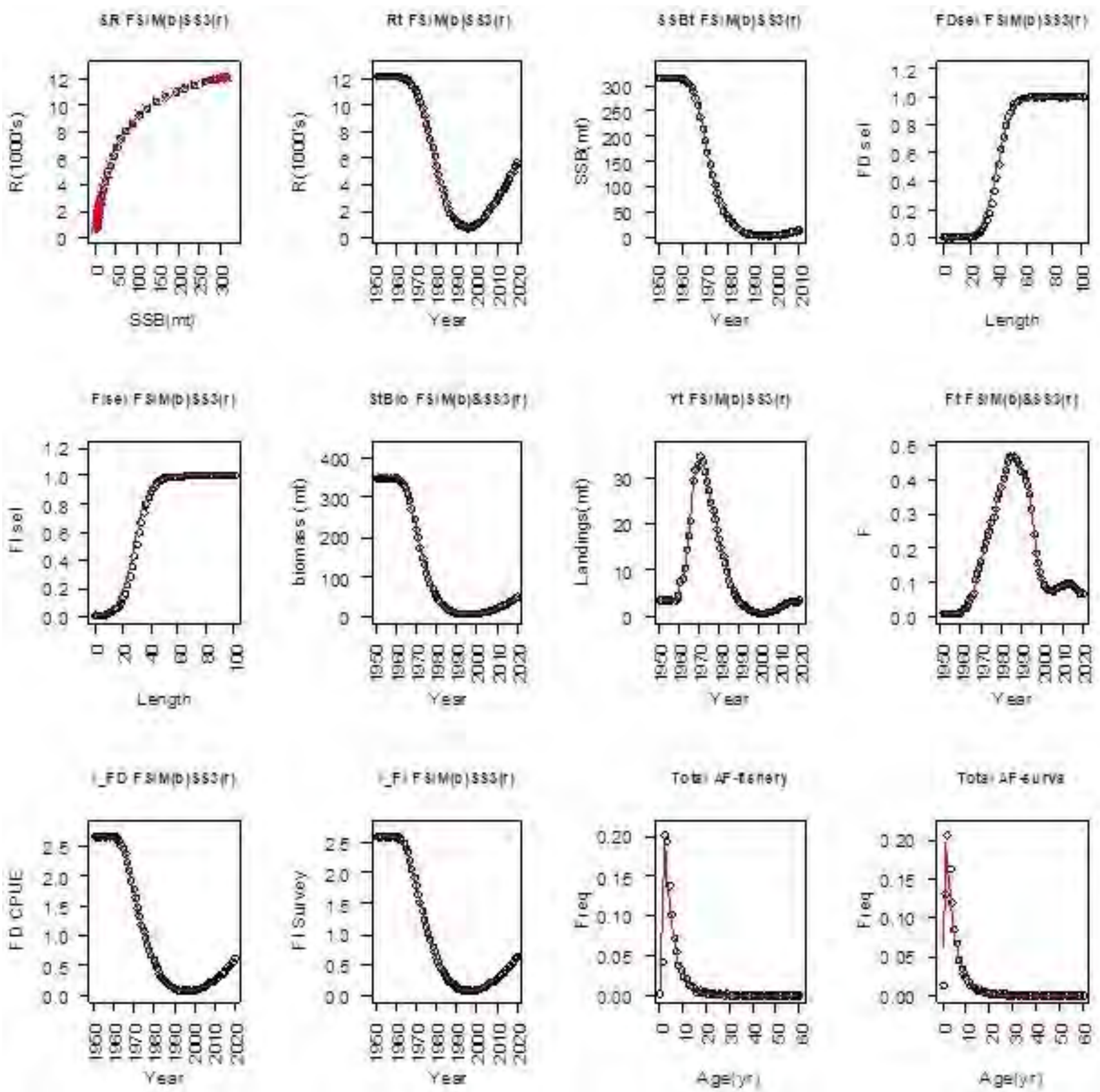

Figure 1: Comparison of FSIM-simulated population dynamics and abundances, fisheries, and surveys (black) to those returned by the stock assessment model Stock Synthesis 3 when starting parameter values were true values. These include (starting top left): Spawner-recruit data, recruit time series, spawning stock biomass time series, length selectivity by fishery, length selectivity by survey, total biomass time series, yield, instantaneous fishing mortality, fishery catch per unit effort, survey catch per unit effort, age frequency in the fishery, and age frequency in the survey.

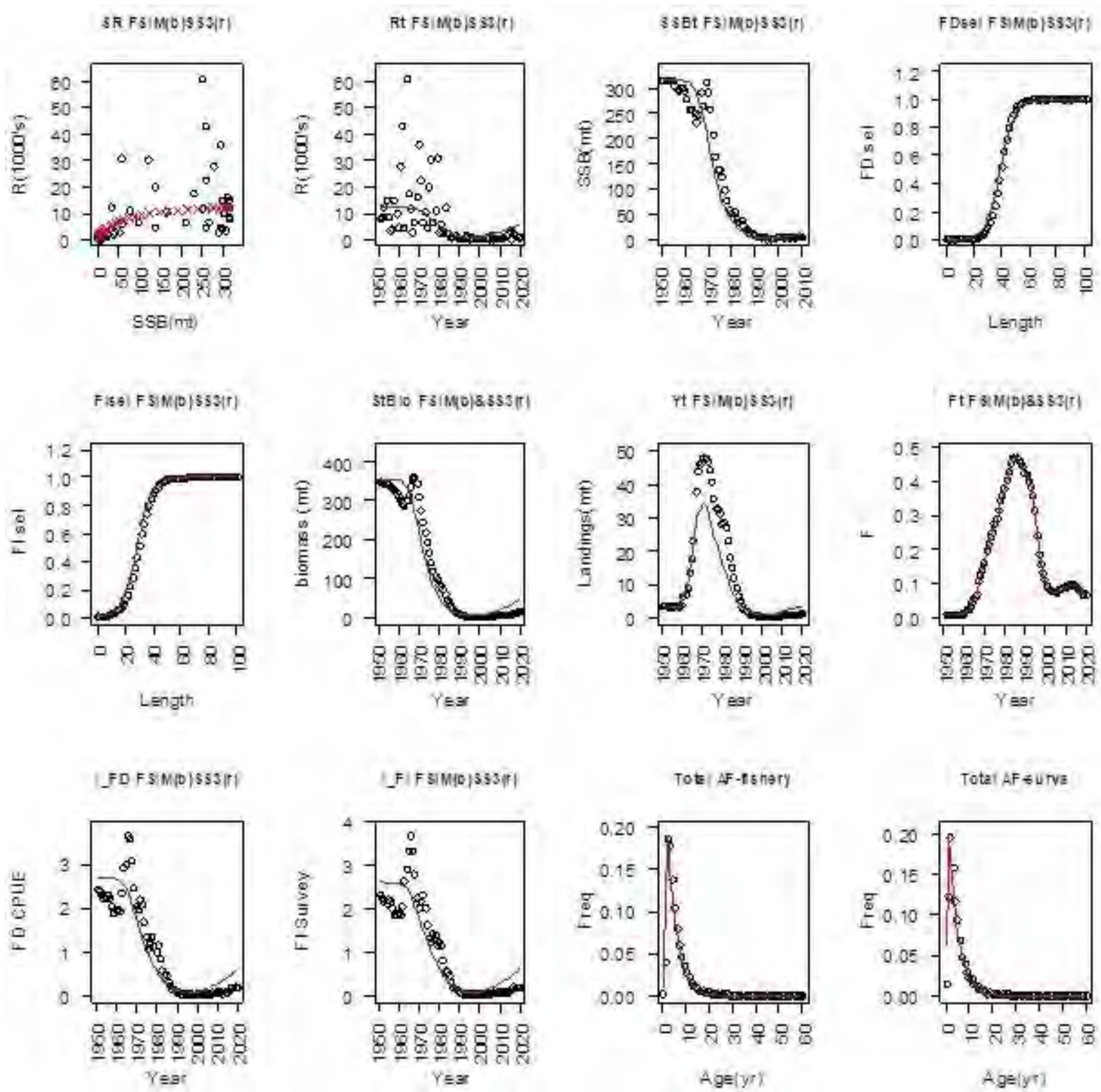

Figure 2: Comparison of FSIM-simulated population dynamics and abundances, fisheries, and surveys (black) to those returned by the stock assessment model Stock Synthesis 3 when the model attempts to estimate the parameters. These graphs include (starting top left): Spawner-recruit data, recruit time series, spawning stock biomass time series, length selectivity by fishery, length selectivity by survey, total biomass time series, yield, instantaneous fishing mortality, fishery catch per unit effort, survey catch per unit effort, age frequency in the fishery, and age frequency in the survey.

The strategy used to investigate the forecast accuracy accrued by including a recruit-correlated environmental feature in the forecast period remains the same: 1) run a complete scenario with the simulated data, 2) then run a complete-year scenario including only catch (excluding all survey indices, length/age comps, environmental signal) for the final 10-year ‘forecast’ period, and 3) run a complete-year scenario including only catch and the recruit-correlated environmental signal (excluding the other survey indices, length/age comps) for the final 10 years. The rate of change in the environmental signal (amplitude increase with constant periodicity) and the uncertainty of the environmental index were systematically changed to simulate different levels of environmental variability and forecasting abilities. Very preliminary findings for a simplified, recovering (increasing in abundance and age structure) fish population indicated a general improvement in the accuracy of the mean projected stock biomass as the uncertainty of the environment-based recruitment index decreased from a CV of 0.9 to 0.1 of only about 5-13%. The response of stock biomass to recruitment fluctuations is, of course, dependent on the relative proportion of the stock made up of new or recent recruits. The preliminary analysis was for a recovering long-lived (60 years) fish, so the potential biomass changes were dampened somewhat by the amount of biomass in older age groups.

Another feature of Stock Synthesis, the forecast module, is currently being investigated for similar capabilities to be used in testing the effects of including environment-linked recruitment deviations on stock projections. To gain experience with the performance of this module, I am used it to help evaluate the potential recovery of hogfish, *Lachnolaimus maximus*, in South Florida as part of a Southeast Data, Assessment, and Review (SEDAR 37) being conducted at the Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute (FWRI). At this point it appears that this forecast module will not be useful in evaluating the recruit-environment linkage, though it may have some undocumented features that will come to light at the December workshop.

As the refinements to the simulation programming continues, it is clear that to test the benefits of including environmental forecasts in stock projections it will be important to mimic 'real-world' assessment choices. These often include fixing hard-to-estimate parameters, e.g., natural mortality and initial fishing mortality, and a large degree of uncertainty in all data collected in earlier years.

This work continues to be discussed among colleagues involved in conducting several stock assessments at FWRI, including those for mutton snapper *Lutjanus analis*, hogfish, striped mullet *Mugil cephalus*, black drum *Pogoinas cromis*, red drum *Sciaenops ocellatus*, and spotted seatrout *Cynoscion nebulosus*. The population simulator, the Stock Synthesis assessment model, and simplified Stock Synthesis - only catch (Cope 2012, *Fisheries Res.*, 142, 3-14) are being used within the FWRI stock assessment group but because this current project is still incomplete there has been no direct application of any results yet. Additionally, analytical tools for retrieving and manipulating satellite-based remotely sensed oceanographic features that may be linked to recruit survival were developed while taking a course on "Remote Sensing in Oceanography" taught by Frank Muller-Karger, College of Marine Science, University of South Florida.

Research Performance Measure: This project has not been completed but will be within the research conducted by Michael Murphy as part of the graduate program at USF College of Marine Science.

Support for the Marine Resource Assessment Program at the University of South Florida, College of Marine Science

Project Personnel: E. Peebles, C. Ainsworth (USF/CMS)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To develop and implement a new, interdisciplinary concentration in Marine Resource Assessment (MRA) at USF-CMS as part of its Ph.D. and M.S. programs in marine science. The new concentration will provide training in quantitative population dynamics and in the emerging field of ecosystem-based management. Its mission will be to train a new generation of quantitative ecologists that can effectively address issues concerning the sustainability of the world's living natural resources.

***Strategy*:** Students with concentrations in MRA will be expected to engage in thesis or dissertation topics that deal directly with interactions between living resources and anthropogenic factors, including subjects such as bio-physical interactions, changing predator-prey relationships, fishing, and identification of essential linkages that determine habitat quality. It is expected that students who select the MRA concentration will interact strongly with one or more of the state and federal resource-management agencies that are located near USF-CMS in Florida, including the National Marine Fisheries Service (NMFS) the Fish and Wildlife Research Institute of the Florida Fish and Wildlife Conservation Commission, and the Florida Integrated Science Center of the US Geological Survey.

CIMAS Research Theme:

***Theme 6*:** Ecosystem Management

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

The schedule of course offerings remains once every two years for each of the courses listed below under the "MRA Core Courses" heading. The MRA program has succeeded in involving NOAA instructors in the design and execution of key coursework, specifically the *Fish Population Dynamics* course, which was team-taught by highly experienced NOAA personnel upon execution of the present agreement in August 2010 and has been taught since then by Dr. Cameron Ainsworth, a former NOAA fisheries biologist and modeler (contracted by NMFS NWFSC, Seattle). Dr. Ainsworth recently offered an *Ecosystem Modeling* course that was remotely attended by 18 fisheries professionals from ten different NMFS labs on the east and west coasts of the US. Dr. Christopher Stallings, who is another faculty member recruited to USF under the NOAA-sponsored MRA program, continues as the lead instructor for *Fish Biology*.

Dr. Ernst Peebles of USF continues to serve as Principal Investigator and Chair of the ad-hoc MRA committee at USF-CMS, a position that leads the coordination of future MRA program development under the guidance of appropriate USF Marine Science faculty. Dr. William Hogarth served as the original Principal Investigator for this award. As a result of Dr. Hogarth's transition from Dean of USF-

CMS to Director of the Florida Institute of Oceanography, Dr. Peebles assumed the role of Principal Investigator on the present award during 2011.

There are currently 29 fulltime USF-CMS students participating in the MRA program, with 13 being Master's students and 16 being doctoral students. The present award provides fellowships for 5 of the 29 students; all 5 are doctoral students. The remaining 24 MRA students work as Graduate Assistants on research grants and compete for internal and external graduate fellowships (see *2014-15 Awards & Honors* in Section IX below).

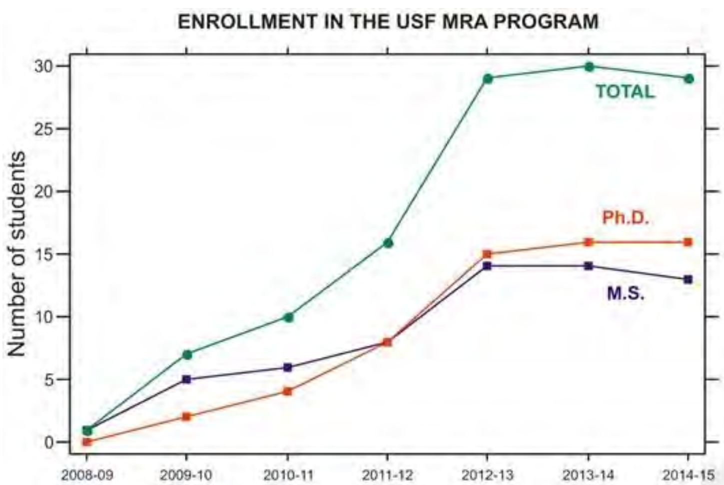

Figure 1: Enrollment in the USF-CMS Marine Resource Assessment (MRA) program by type of student and academic year.

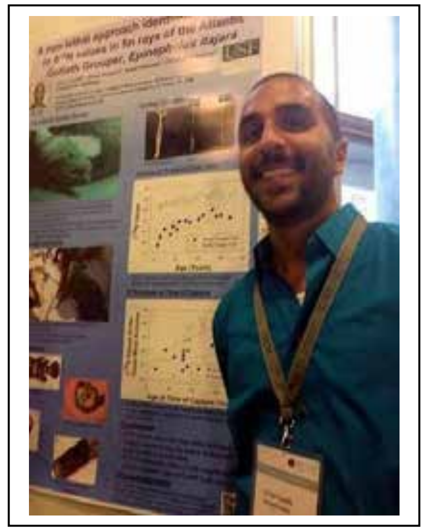

Figure 2: USF MRA student and NOAA Fellowship recipient Orian Tzadik in Coruña, Spain, where he won Best Poster in the Early Career Scientist category at the ICES 2014 Annual Science Conference.

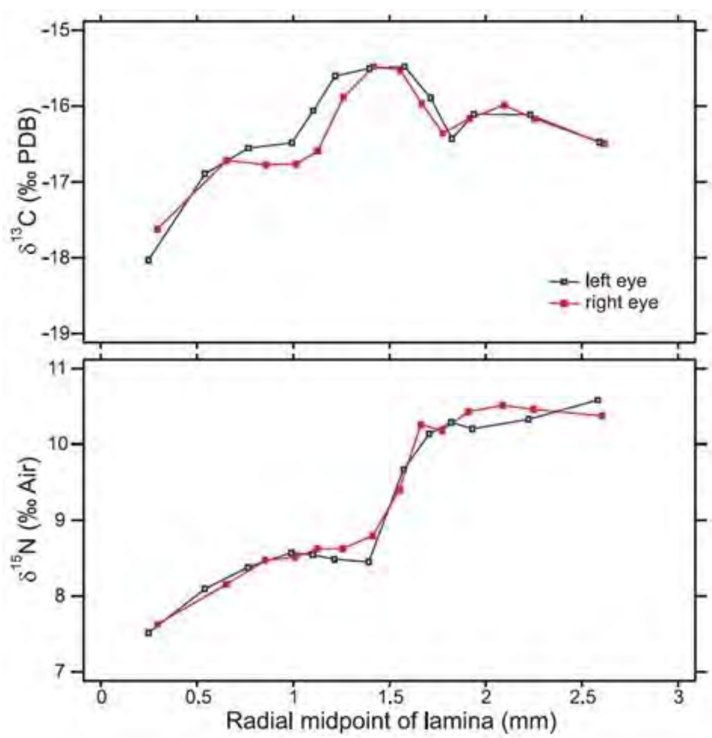

Figure 3: A figure related to the discovery that fish eye lenses contain lifetime isotopic records that can be used to recreate the geographic and trophic histories of individual fish. This work is part of USF MRA student and NOAA Fellowship recipient Amy Wallace's dissertation, and was published in *PLoS One* during 2014 (Wallace et al. 2014).

Figure 4: USF MRA student and NOAA Fellowship recipient Amy Wallace (right) and Nirley Hirachi (left), a visiting doctoral student from Federal University of Rio Grande do Norte, Brazil, place an otolith sample into a glass vial aboard the *R/V Weatherbird II* in the northern Gulf of Mexico (Steve Murawski photo).

Research Performance Measure: The MRA-related coursework supported by the present agreement has been successful at attracting career-minded students in the area of MRA. Participation in the MRA Area of Concentration is a popular request among prospective students; hundreds of qualified prospective students have applied to the program, but the number that is accepted has become limited by available resources (Fig. 1). MRA students currently represent >30% of the student body at USF-CMS, which is comparable to the proportion concentrating in Biological Oceanography and is larger than the proportions concentrating in Chemical, Geological, and Physical Oceanography.

Enrollment by professional fisheries scientists in MRA courses has exceeded expectations. Agency students have been associated with the following labs:
(1) Florida FWC: Fish and Wildlife Research Institute, St. Petersburg, FL.
(2) NOAA Fisheries: Labs at Beaufort, NC; Sandy Hook, NJ; Miami, FL; Stamford, CT; Pascagoula, MS; Galveston, TX; Panama City, FL; Woods Hole, MS; La Jolla, CA; St. Petersburg, FL.
As intended, most MRA graduates are employed in the living-resource management field after graduation (69%) or pursue a doctoral degree (31%; see *MRA Graduates* in SectionVII. Education and Outreach).

Coral Reef Conservation Program (CRCP) Local Action Strategy (LAS) Project 3B "Southeast Florida Coral Reef Fishery-Independent Baseline Assessment"

Project Personnel: R. Spieler and K. Kilfoyle, B. Walker (NSU/OC)
NOAA Collaborators: J. Blondeau and J. Bohnsack (NOAA/SEFSC)
Other Collaborators: S. Smith, N. Zurcher and D. Bryan (UM/RSMAS); K. Gregg (ECS-Federal, Inc. In Support of NOAA-Fisheries Service); M. Balling, C. Boykin, J. Jimenez, J. Monty, M. Sathe, K. Trotta and J. Walczak (FDEP-CRCP); E. Ault and J. Beal, (FWC Tequesta Laboratory); S. Thanner (Miami-Dade County, DERM); K. Banks and P. Quinn (Broward County, DERD)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To: 1) determine changes in southeast Florida reef fish populations over time and in response to future management strategies, and 2) provide a seamless integration with the existing Reef Visual Census (RVC) program data, which will allow for the entire Florida Reef Tract to be evaluated in a holistic manner.

***Strategy*:** To assess the condition of fish resources of the northern Florida Reef Tract (northern Miami-Dade, Broward, Palm Beach, and Martin counties), an assessment/monitoring plan was designed and implemented through a joint cooperative effort by scientists at the University of Miami Rosenstiel School of Marine and Atmospheric Science, NOAA-Southeast Fisheries Science Center and Nova Southeastern University Oceanographic Center (NSUOC).

CIMAS Research Theme:

***Theme 6*:** Ecosystem Management
***Theme 3*:** Sustained Ocean and Coastal Observation
***Theme 5*:** Ecosystem Modeling and Forecasting
***Theme 7*:** Protection and Restoration of Resources

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems

NOAA Funding Unit: CRCP **NOAA Technical Contact:** Theo Brainerd

Research Summary:

This is the 3rd year of a multiyear project to assess the condition of fish resources of the northern Florida Reef Tract (northern Miami-Dade, Broward, Palm Beach, and Martin counties). Scientists from multiple academic institutions (UM, NSU) and governmental agencies (NOAA, FDEP, FWC, DERM, DERD) are employing a statistically robust survey design to assess fish populations and their associated habitats with a non-destructive visual census method using SCUBA.

The data from this project year have not been fully analyzed. To date, multivariate analysis/multi-dimensional scaling (MDS) plots showed patterns in the reef fish communities associated with benthic habitats. Water depth was a primary determinant of fish distribution with differences in assemblages between shallow and deep sites. Also, most of the surveys in the southern regions (Broward-Miami, Deerfield, and South Palm Beach) clustered tightly together indicating high similarity between communities in the deep habitats within these regions. Conversely, fish communities in North Palm Beach and Martin were much more variable and mostly separated in disparate areas of the plot. This suggests that the Martin and North Palm Beach fish communities are distinctly different from the southern regions.

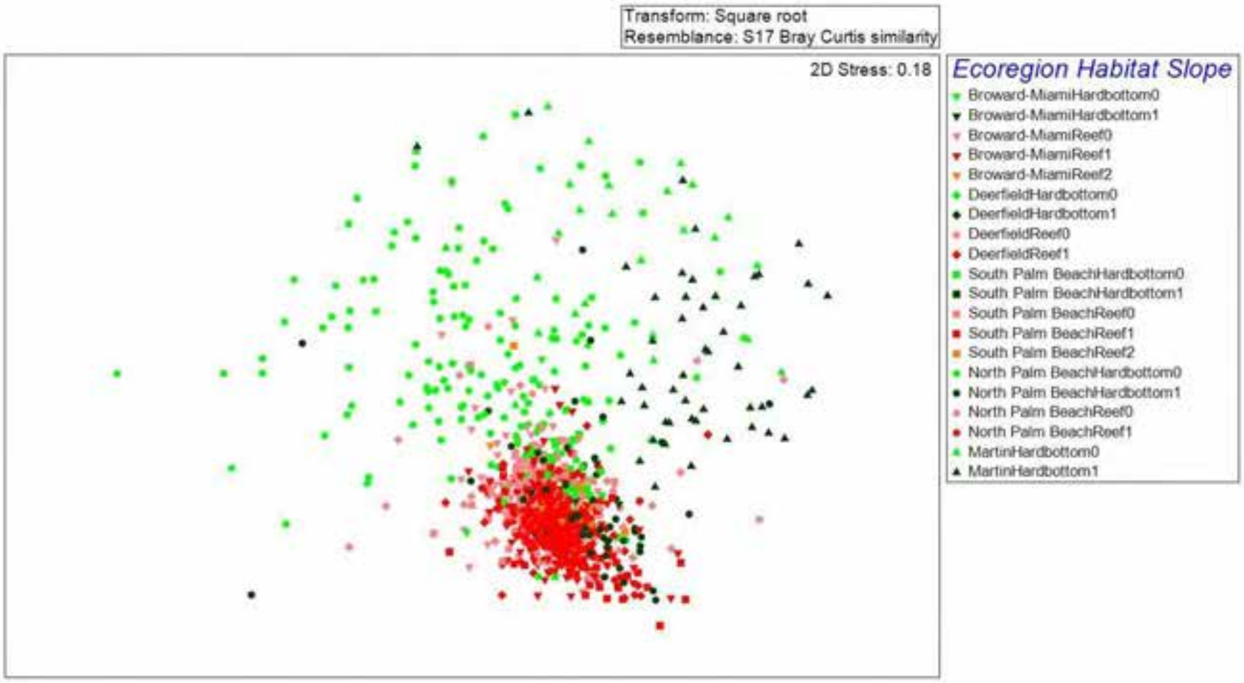

Figure 1: MDS plot of DEEP habitats (2012 – 2014) categorized by Coral Reef Ecosystem Region, General Habitat, and Slope.

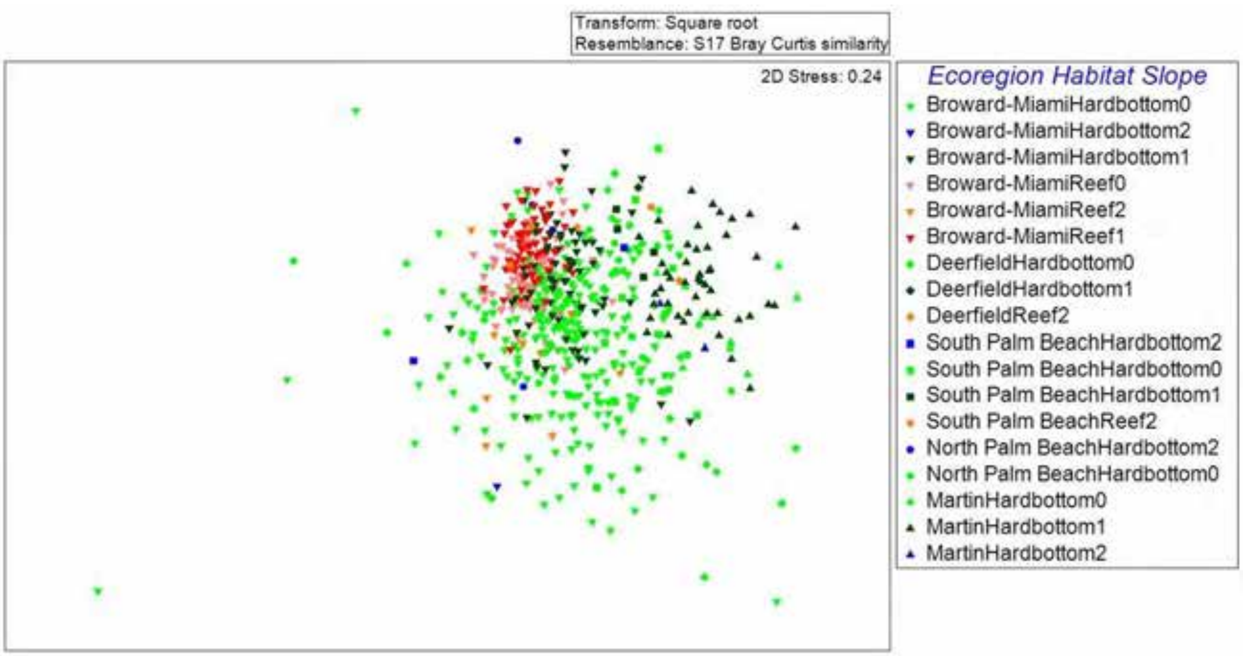

Figure 2: MDS plot of SHALLOW habitats (2012 – 2014) categorized by Coral Reef Ecosystem Region, General Habitat, and Slope.

The dataset, in its entirety, provides the opportunity for further mining to examine individual species and reef fish assemblage correlations with a host of abiotic and biotic variables. Thus, from both management and ecological-sciences perspectives, it is a valuable resource. It is already clear there are significant differences in the geographic distribution of reef fishes at local and regional scales. There are interacting strata and latitudinal differences in total reef fish abundance, species distribution, sizes, and assemblage structure. The combination of data from all three years will provide a complete regional baseline fishery-independent assessment.

Research Performance Measure: All major objectives are being met.

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Evaluation of ESA listed Acropora spp. Status and Actions for Management and Recovery

Project Personnel: D.E. Williams, A.J. Bright and R. E. Pausch (UM/CIMAS)
NOAA Collaborator: M.W. Miller (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: 1) To document and identify demographic variables (recruitment, mortality etc.) in the Florida Keys *Acropora* spp. population. 2) To document the threats (disease, predation, bleaching etc.) impacting the remaining elkhorn (*Acropora palmata)* populations in the upper Florida Keys and determine the relative importance of each 'threat'. 3) To continue annual assessment of *Acropora palmata* in Curaçao for comparison to local populations. 4) To assess the effectiveness of predator removal as a management tool.

Strategy: 1) To assess on a quarterly basis the status of individually-tagged colonies of coral at several sites in the upper Florida Keys. 2) Periodic assessments of other Caribbean *Acropora* spp. populations. 3) In 2014, a warm-stress-induced mass bleaching event was intensively characterized in the focal population.

CIMAS Research Theme:

***Theme 6*:** Ecosystem Management (*Primary*)
***Theme 7*:** Protection and Restoration of Resources (*Secondary*)

Link to NOAA Strategic Goals:

***Goal* 1:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

The overall objectives of this project are to document the dynamics of the remaining Elkhorn populations in the upper Florida Keys and to compare its performance to other Caribbean locations. This is an on-going monitoring project entering its eleventh year of thrice yearly surveys in the upper Florida Keys and ninth year of annual surveys in Curaçao. Study units are 150 m^2 plots in which all attached *Acropora palmata* colonies are mapped and surveyed each year. In Florida, individually tagged *A. palmata* colonies are surveyed more frequently to document their condition. Based on these observations, we can estimate basic population parameters including recruitment, growth and mortality, along with the causes of recent tissue mortality and the sources of recruitment (asexual or sexual).

During summer 2014, we observed bleaching among many coral species in the upper Florida Keys. As water temperatures continued to rise, increasing numbers of coral species were observed with bleached tissue. In mid to late August, we observed bleaching affecting acroporid corals (Fig. 1) at various sites. Based on these informal observations, we undertook additional surveys of our 7 existing *A. palmata* monitoring sites. While the Florida Keys reefs have experienced moderate bleaching events in the past decade, this is the first bleaching event to affect local *A. palmata* since the 1998 El Niño-associated bleaching event (Miller et al. 2002).

This additional survey effort has allowed us to provide a detailed timeline in relation to the accumulation of thermal stress to aid in pinpointing bleaching thresholds for *A. palmata*. Overall, we estimate that approximately one third of live tissue area of the focal *A. palmata* population was lost during this bleaching event (i.e. between our planned seasonal surveys in June 2014 and Feb 2014). Interestingly, substantial variability in the bleaching response (Figs 1 and 2) was observed both among and within sites and genotypes. Elucidating this variability is the focus of an NSF-RAPID grant (Williams Co-PI with Iliana Baums, Penn State Univ) received in Nov 2014.

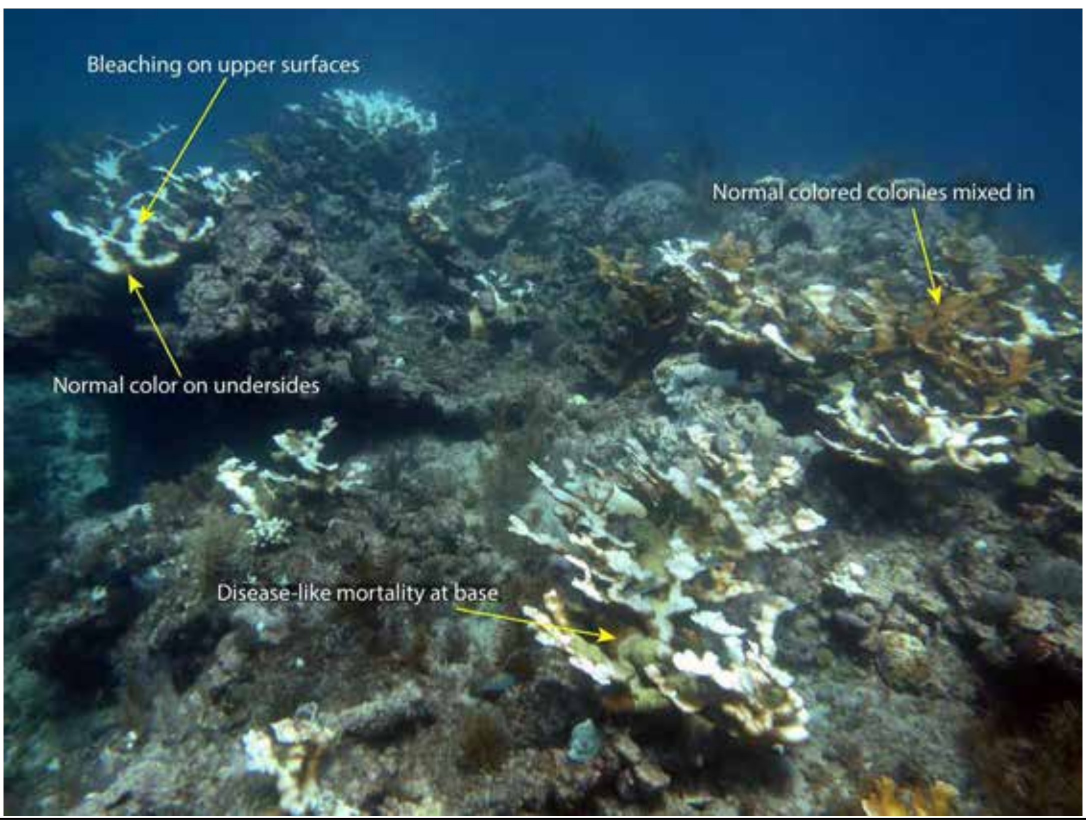

Figure 1: Wide range of colony conditions observed on a small spatial scale (French Reef 9/18/2014) during the 2014 mass bleaching event. Some colonies retained their normal color throughout the event. Others bleached on part of the colony (typically the top surfaces) while other parts were normal color or only pale (typically the shaded portions). Tissue mortality similar to disease was also observed progressing across areas of normal colored tissue.

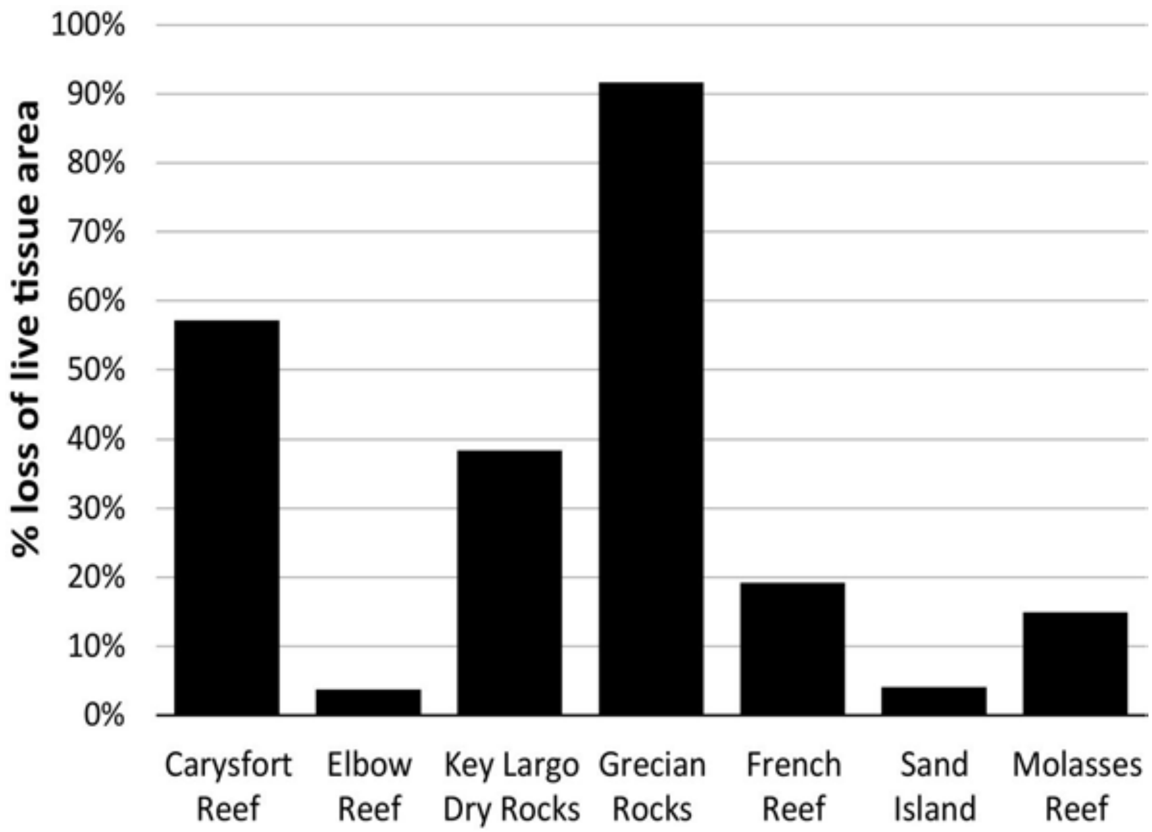

Figure 2: Estimated loss of live A. palmata tissue between June 2014 and Feb 2015 among individual permanent plots. Bleaching prevalence, intensity and tissue loss were severe at Grecian Rocks (GR) and Carysfort (CF) reefs but minimal at Elbow (EL) and Sand Island (SI) reefs.

Research Performance Measure: All planned surveys of the Florida Keys sites and the Curaçao sites were conducted as scheduled with three additional (unplanned) surveys conducted in the Florida Keys during fall 2014 to fully document a mass bleaching event affecting the population. A peer-reviewed publication on previous predator removal experiment has been published.

RESEARCH REPORTS

THEME 7: Protection and Restoration of Resources

Unified Data Processing [UDP] and Fisheries Trip Matching-Southeast Fisheries One Stop Shop [FTM-SE-FOSS]

Project Personnel: S. Aguilar (UM/CIMAS)
NOAA Collaborators: J. Hall [UDP], D. Gloeckner, S. Turner, C. Bumpus and O. Rodriguez [FTM-SE-FOSS] (NOAA/SEFSC)
Other Collaborators: ArTech Group [UDP]

Long Term Research Objectives and Strategy to Achieve Them:
Objectives: 1) [UDP] The objective is to create a Compliance Page that is going to indicate if a vessel is on compliance. 2) [FTM-SE-FOSS] The FTM system is a trip matching tool that compares different data sets and report the matching trips.
Strategy: 1) Identify required data, understand the rules of when a vessel is on compliance and develop the queries and report pages in SQL and Apex. 2) Get the current source code of the system. Understand how it was developed. Understand the different processes in the system (load data, refresh data and matching). Develop queries and reports in SQL and Apex.

CIMAS Research Theme:
***Theme 7*:** Protection and Restoration of Resources

Link to NOAA Strategic Goals:
***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:
The CIMAS PI participated in two different projects:
1.The development of Compliance module for the UDP system. The module was finished and delivered.

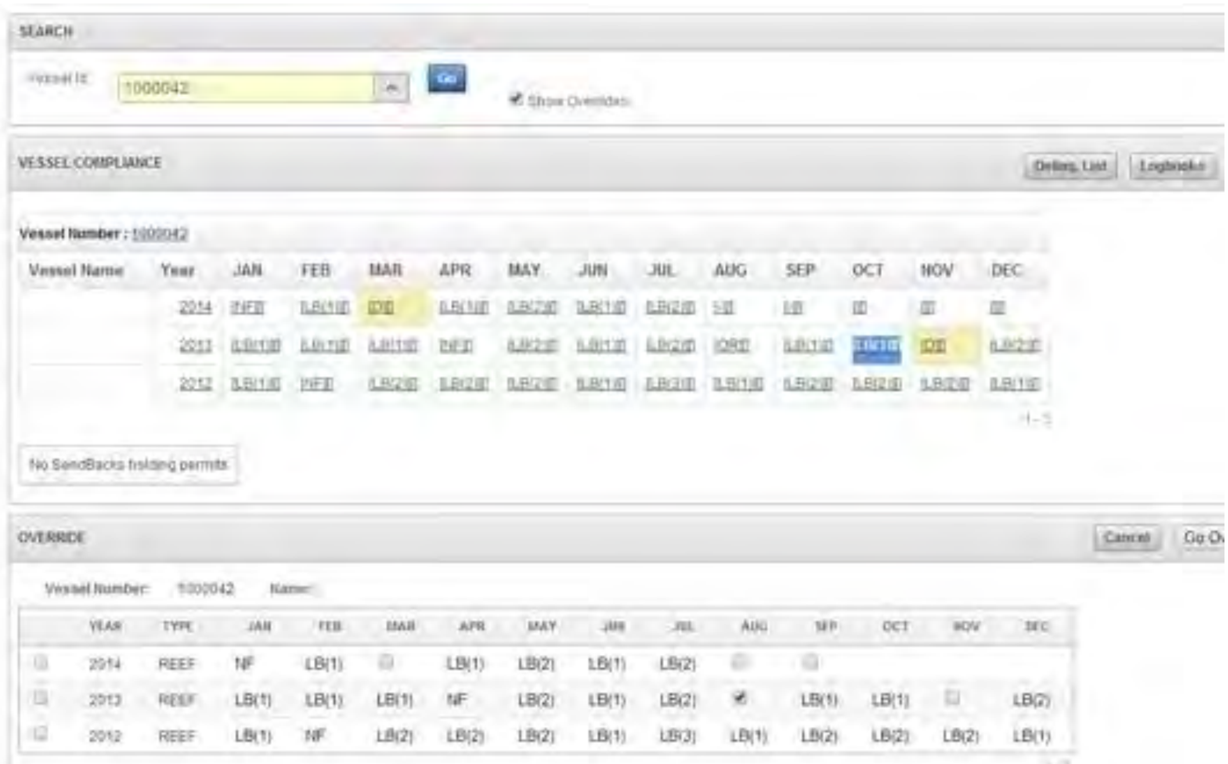

Figure 1: UDP Compliance Page

2.FTM-SE-FOSS project: The system was developed in Oracle-APEX. The task was to understand how FTM (Fisheries Trip Matching) module was developed, incorporate new set of data and update existing data sets, check the matching process and make it operative to the users. Improvements were made on the loading data module and matching process module and a new UDP data set was incorporated. New reports were also created. The system is now being testing by the NMFS users.

Research Performance Measure: Development of Computer System UDP: Compliance module was developed and delivered. FTM-SE-FOSS: Currently working on this system. Phase in development cycle: Testing.

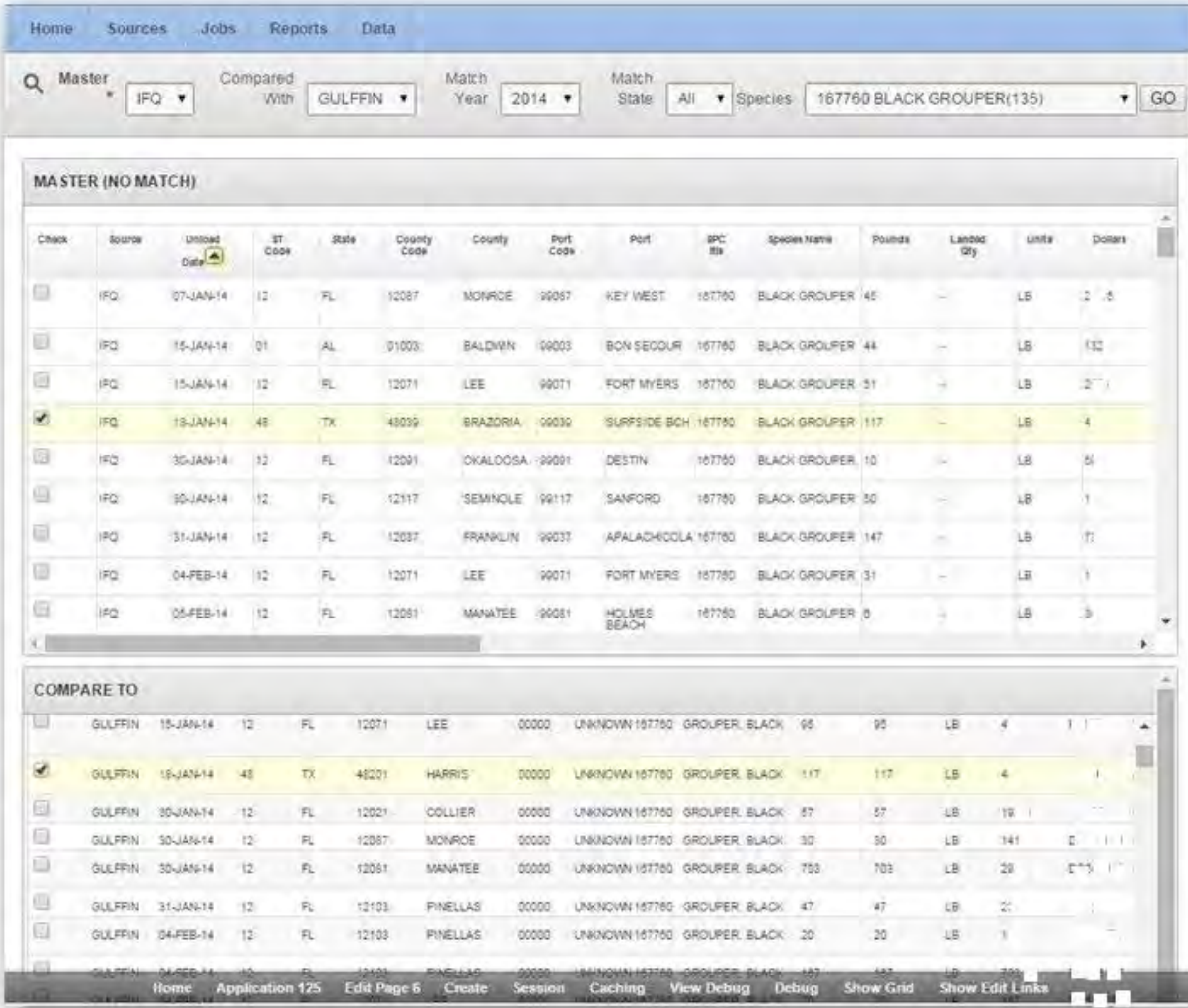

Figure 2: FTM Report of No-Matching Trips.

Using SEDAR-Assessed Stocks to Validate the Accuracy of Data-Poor Methods

Project Personnel: R. Ahrens (USF)
NOAA Collaborators: J. Berkson (NOAA/SEFSC and Sea Grant)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To ascertain which data-poor stock assessment methods provide management recommendations similar to that recommended for SEDAR-assessed species

***Strategy*:** To compare the catch recommendations from a suite of data-poor stock assessment methods for SEDAR-assessed species against the SEDAR assessed OFL.

CIMAS Research Theme:

Theme 7: Protection and Restoration of Resources

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NOAA/AOML **NOAA Technical Contact:** Molly Baringer

Research Summary:

Many fish stocks in the Southeast do not have sufficient data to allow for traditional stock assessments. These 'data-poor' stocks lack or have unreliable information concerning catch time-series, stock size, or life history parameters. Such data are the primary information sources for traditional stock assessments. Without this information it is difficult to conduct stock assessments and determine overfishing catch limits (OFLs) and other reference points (e.g., MSY) legally required for every fished stock by the Magnuson-Stevens Act. While data-poor stocks are present around the United States, 75% of stocks and stock complexes assessed for OFLs in the Southeast are stocks that have only catch history data. Alternative data-poor methods to calculate OFLs in such cases exist, but their effectiveness is still subject to question. Two of the more common data-poor methods, DCAC and DB-SRA, have been applied to data-rich stocks on the West Coast and found to be relatively accurate at estimating Maximum Sustainable Yield in comparison to the more traditional stock synthesis assessment method. Accuracy ranged from 70% to 85% for DCAC and 80% to 155% for DB-SRA for the west coast studies, but no similar work has been done on stocks in the Southeast. This study compares OFLs and biological reference point outputs from the Southeast Data, Assessment, and Review (SEDAR) stock assessments to those of data-poor methods (Figure 1). The accuracy of the data-poor estimates when compared to the SEDAR estimates for fisheries in the Southeast will be used to determine which, if any, simplified assessment methods are appropriate for use on a per-species basis and reveal which methods are best suited to set OFLs for data-poor fish stocks in the Southeast.

In this study, there was no standout method overall, within life histories, or within regions (Figure 2). No methods in either MSY or OFL scenarios accurately approximated MSY or OFL values for a majority of stocks. DCAC-based methods did not always perform better than DB-SRA-based methods and the relative accuracy of methods for individual stocks was not always consistent between MSY- and OFL-based scenarios. Basic depletion-based methods performed moderately well relative to other methods. DB-SRA and DB-SRA 40 performed the least poorly of any methods in accuracy at predicting SEDAR OFL values, and DB-SRA 40 and DCAC40 for SEDAR MSY values, though accuracy within 10% was not common for any of the methods in OFL- or MSY-scenarios. DCAC and DCAC40 consistently have the most precise estimates in both MSY- and OFL-based scenarios, and all DCAC methods, excluding mean-length methods, did underestimate 46%-86% of the time on a stock-by-stock basis. Given these factors, DCAC methods may be suitable for situations in which precautionary management is necessary. Given the DB-SRA methods' performance and the fact that many data-poor stocks in the Southeast do not have the full historical time series of catch that DB-SRA methods require, it is not congruous with data-poor stocks in this region. Mean-length based methods tended to produce the poorest estimates. This is in part due to the small sample size of stocks with mean-length information, but consistent extreme overestimation is likely to be due to the way these methods handle catch-at-length. In the Southeast, catch at length data is one of the more accessible resources after catch series for stocks, though true data-poor stocks are likely to have neither of these resources. If available, catch at length data should be used with caution, especially in data poor situations, as these indices are often times biased from the true state of the stock and inaccuracies in the data may seriously skew results. Surplus production methods were very variable in their performance. SP-MSY, the simplest method tested, performed relatively consistently with moderate accuracy, moderate precision, and underestimation for 65% of its stocks in MSY scenarios and 77% of its stocks in OFL. SP-SRA did much more poorly, with extreme variations in accuracy and precision in both MSY and OFL comparisons.

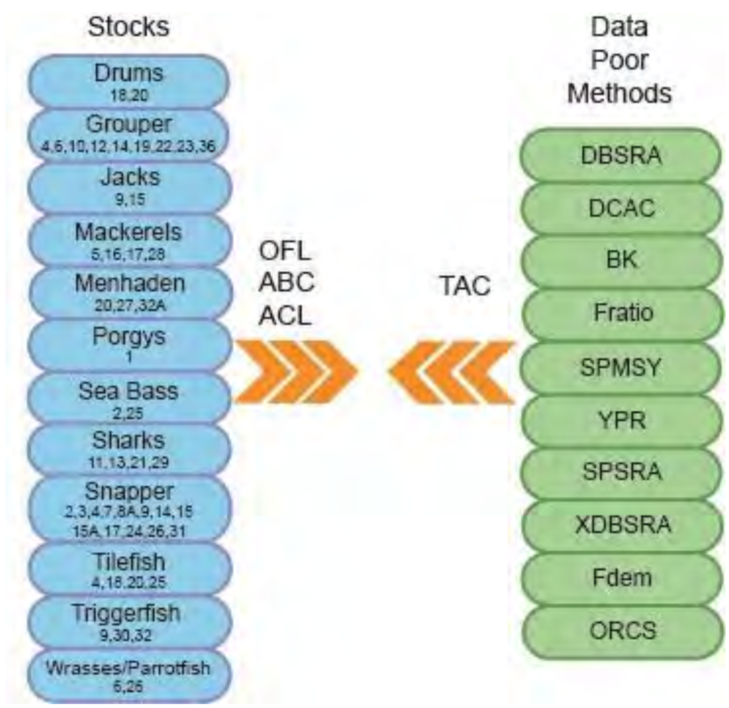

Figure 1: Schematic depicting species grouping and the associated SEDAR number from which annual catch limits (ACL), allowable biological catch (ABC), and overfishing limit (OFL) will be compared to total allowable catch (TAC) from data poor methods.

Based on this analysis, there is no standout method when considering assessments of data-poor stocks in the Southeast. In terms of accuracy, depletion-based methods do perform the least poorly overall. In terms of demonstrated overall appropriateness, DCAC, DCAC40, or DCAC4010 tend to produce precautionary OFLs and therefore may be useful methods to consider against standard scalar methods. SP-MSY may be the most appropriate method for Southeastern data poor stocks due to its extremely low and obtainable data needs, though DCAC might be preferable if sufficient data needed to inform the model is available. Further investigation into the performance of SP-MSY in the Southeast and other regions is definitely warranted. Unfortunately, none of these methods perform both precisely and accurately enough to recommend them for stocks in which exploitation is desired to be maximized; they would be appropriate only for precautionary estimates of catch targets. This can be considered a positive attribute for most data-poor stocks, however, as precautionary management is responsible in situations where stock biomass and resiliency is unknown. Regardless of what method may be considered, managers must have clear productivity and exploitability goals in mind for the stock in question in order to choose the model that best suits those goals without sacrificing the best available approximation of stock status.

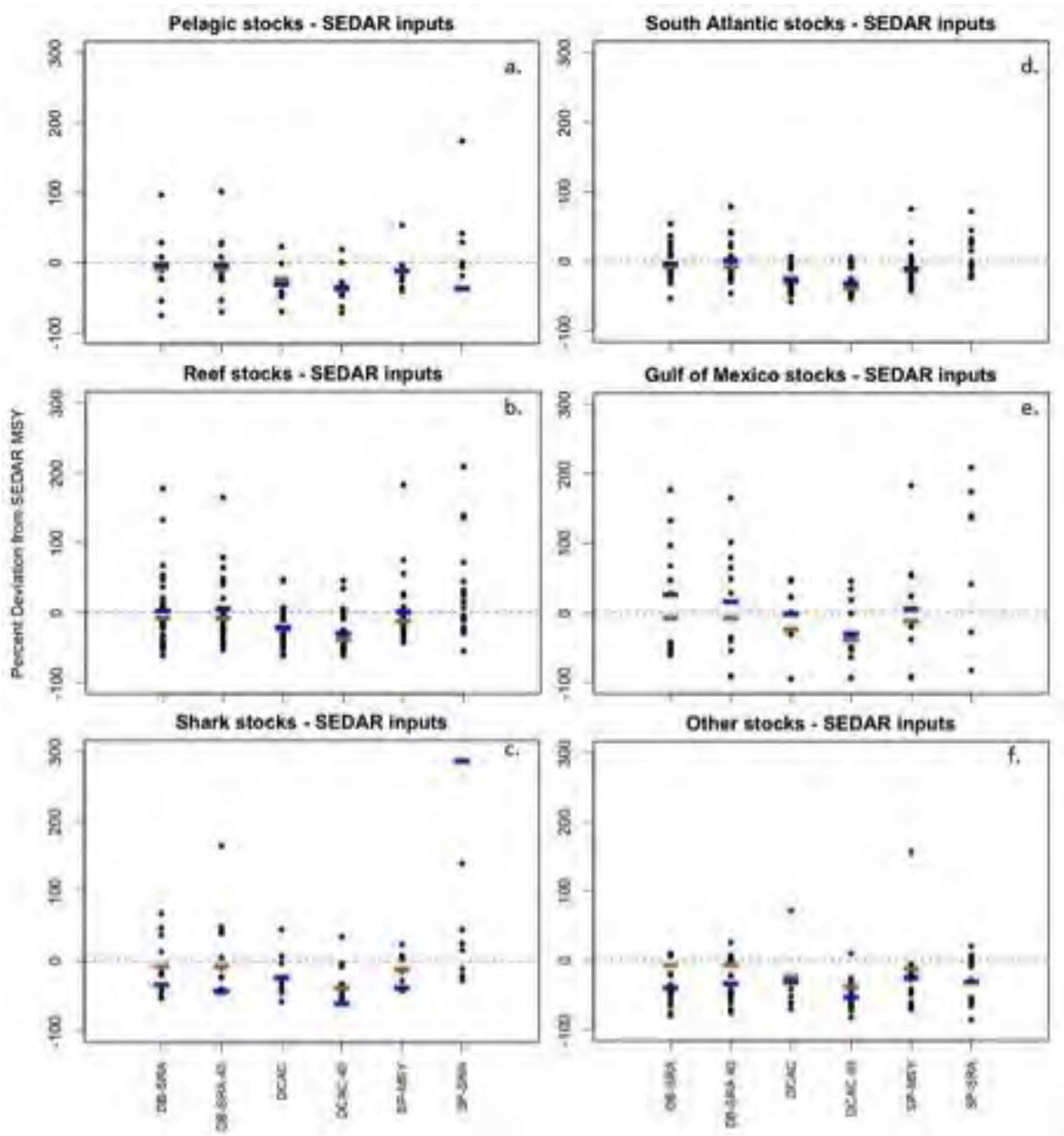

Figure 2: Performance of each data-poor method for stocks of different life history groups (a, b, c) and stocks of different regions (d, e, f). Black circles are the median MSY estimate for each stock for each method. Blue lines represent the mean value of all medians for that method within each group, while red lines represent the mean value of all medians for that method, undifferentiated by group. Mean values of SP-SRA were too large to be shown on these plots due to the effects of outliers.

Research Performance Measure: The final performance measures for this product will be a completed Master's thesis and a peer-reviewed publication. To date a rough draft of the Master's thesis has been completed and it is anticipated that a thesis defense will occur in July 2015. A rough draft of the scientific publication is anticipated to be completed by early fall of 2015.

Marine Mammal Research and Stranding Response

Project Personnel: L. Aichinger Dias (UM/CIMAS)
NOAA Collaborator: L. Garrison (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** 1) To assist during **Natural Resource Damage Assessment (NRDA)** studies associated with the **Deepwater Horizon (DWH)** Oil Spill in the Gulf of Mexico. 2) To support the investigation of the **Northern Gulf of Mexico Marine Mammal Unusual Mortality Event (UME)**. 3) To assist the **Southeast Fisheries Science Center (SEFSC**)'s Protected Resources and Biodiversity Division in research and management of protected cetacean species under the Marine Mammal Protection Act (MMPA). 4) To support the **Marine Mammal Health and Stranding Response Program (MMHSRP)** and ensure data quality in compliance with the Data Quality Act.

Strategy: 1) To collect, analyze and manage data for the NRDA injury and restoration assessments associated with the DWH Oil Spill in the Gulf of Mexico. 2) To perform data management, auditing and handling of evidentiary images in response to the investigation of the Marine Mammal UME in the northern Gulf of Mexico. 3) To assist in project planning and field work during cetacean surveys onboard NOAA research vessels. 4) To perform management of data and samples collected during the NOAA research surveys. 5) To respond and coordinate response actions during cetacean strandings dead or alive in the US Southeast Region. 6) To validate historical stranding data working with the SEFSC staff and stranding network members to implement effective data auditing and correction.

CIMAS Research Theme:

***Theme 7*:** Protection and Restoration of Resources

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

The activities developed and supported at the SEFSC's Marine Mammal Program relate to three main areas of investigation: 1- Gulf of Mexico research under the NRDA and related to the marine mammal UME, 2- population assessments for management of protected species and 3- stranding response under the MMHSRP.

The investigation of the DWH Oil Spill in the Gulf of Mexico (hereafter referred to as Gulf) continues to be highly active. In the past year, data were organized and technical reports written for use in the NRDA Injury and Restoration Assessments. Also from the Gulf, photographs and radiographs of stranded cetaceans were organized in support of the investigation of the Northern Gulf of Mexico Marine Mammal UME. These images have been used in technical reports as well as peer-viewed publications related to the oil spill.

In the summer of 2014, Diaz participated in the **Sperm Whale Autonomous Tracking (SWAT)** cruise as a photographer and data manager. The primary objective of the SWAT project was to assess the abundance, habitat and spatial distribution of sperm whales (*Physeter macrocephalus*) in the southeastern Gulf by means of visual and acoustic monitoring, biopsying sampling and deployment of satellite tags.

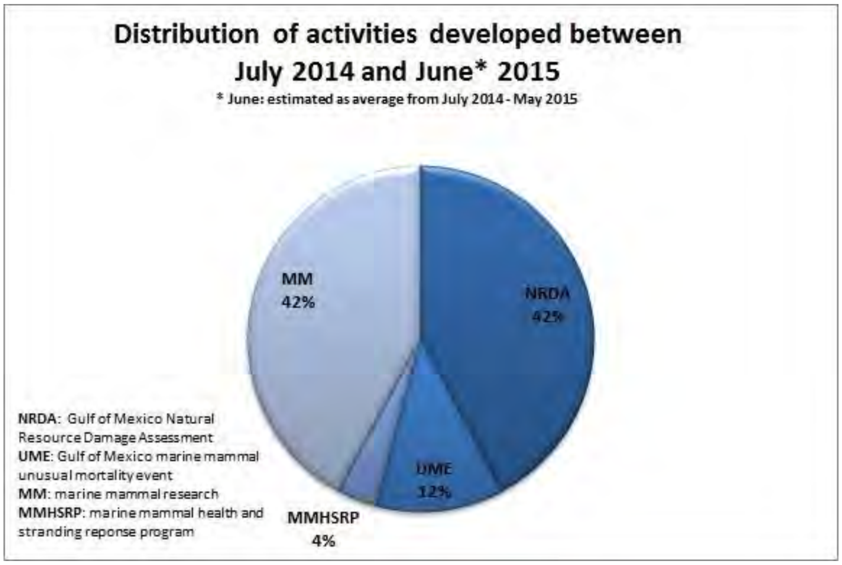

Figure 1: Distribution of activities developed between July 2014 and June 2015.

Another research activity to which this project contributed was long-term monitoring of bottlenose dolphins (*Tursiops truncatus*) in Biscayne Bay. By means of photo-identification, the SEFSC has been monitoring this wild dolphin population since the 90's and has a catalog of more than 200 resident animals. During field efforts, Diaz worked as a photographer and off-season, I assisted in project planning and writing of technical reports.

During the year when a stranding event occurred, Diaz assisted in the response with respect to carcass transportation/disposal and performing necropsies.

Research Performance Measure: all objectives were completed on time.

- Managed data and wrote reports for the Offshore Marine Mammal Injury Assessment under the NRDA Injury and Restoration Assessment Reports.
- Managed evidentiary images (photographs and radiographs) of stranded cetaceans from the Northern Gulf of Mexico Marine Mammal UME and associated legal deliverables, totaling nearly 110 GB of data.
- Assisted in data management and auditing in support of the investigation of the Northern Gulf of Mexico Marine Mammal UME.
- Worked as a marine mammal observer and photographer and managed data and samples collected during the SWAT cruise in the Gulf of Mexico.
- Assisted in project planning and development for the Biscayne Bay Photo-ID project also working as a photographer during two field seasons.
- Assisted in stranding response and coordinated necropsy efforts during bottlenose dolphin (*Tursiops truncatus*) strandings in the Miami area.
- Training accomplished: 24-hour Hazardous Waste Operations and Emergency Response (HAZWOPER); Department of Transportation/ International Air Transport Association Hazardous Material Shipping (DOT/IATA); First aid, cardiopulmonary resuscitation (CPR) and automated external defibrillator (AED).
- Participated in the NOAA Open House event, describing to members of the public the scientific activities developed by the marine mammal branch staff at the SEFSC.

Developing a Decision-Support Tool for the Management of Clam Farms on the FL Gulf Coast

Project Personnel: S. Baker, L. Sturmer and P. Suprenand (University of Florida)
NOAA Collaborators: J. Berkson (NMFS/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To develop a practical tool for understanding and predicting the risk of crop loss for use by Florida clam culturists in decision-making and farm management. Information from the Cedar Key area on the Gulf Coast of Florida will be used to develop a tool for this region, and provide a proof of concept for a more general model.

***Strategy*:** To: 1) Identify and format available environment, clam mortality, health, physiology and productivity data, 2) Synthesize data and develop a predictive model of crop loss risk, and 3) Provide a preliminary decision tool to growers.

CIMAS Research Theme:

***Theme 7*:** Protection and Restoration of Resources

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NOAA Fisheries, Office of Aquaculture
NOAA Technical Contact: Michael Rust

Research Summary:

Hard clam culture research and monitoring activities have amassed a large quantity of data related to the environment, clam mortality, health, physiology, and productivity in Florida. Other than casual use by growers and researchers, and use in documenting qualifying perils, the environmental data sets have not been systematically examined and remain underutilized. In conjunction with the clam breeding research, field data sets on clam growth and mortality in different years and at different lease sites exist, as do laboratory data on upper thermal limits and survival time in multi-stressor challenges. Despite a great amount of work and data, no immediate and practical tool has been developed to help farmers reduce crop loss. To maintain and grow the economic impact of the hard clam aquaculture industry of Florida, to meet the increasing national and global demand for aquaculture products, and to respond to global climate change, the industry needs a practical tool for understanding and predicting the risk of crop loss for use in decision-making and farm management.

We are evaluating water quality data (temperature, salinity, and dissolved oxygen concentrations) from two aquaculture leases in Cedar Key, Florida spanning from 2002 and 2013, and collected *in situ* using data sondes. Water quality data is being used to identify periods of time that corresponded to events that negatively influenced the physiological well-being of the northern quahog, *Mercenaria mercenaria*. Poor water quality events were characterized as periods when one or more water quality variables remained outside of *M. mercenaria's* optimal physiological range. These physiological ranges were based on published studies, as well as a set of mesocosm treatments simulating various combinations of suboptimal water quality conditions over a 22-day periods. We are developing an Environmental Impact Index (EII), based on physiological ranges, which considers the relationships between water quality variables and the duration of a suboptimal water quality event. The water quality data is being analyzed to characterize relationships between water quality variables and a suite of regional environmental variables, ranging from wind direction to nearby river gauge heights. These relationships are being used to develop mathematical models for predicting clam lease temperatures, salinities, dissolved oxygen concentrations, and the EII for a period of three days from a selected start date of a suboptimal water quality event. Ultimately, water quality predictions are intended to enhance current online, real-time water quality information made available to clam farmers for making decisions related to aquaculture planning and success.

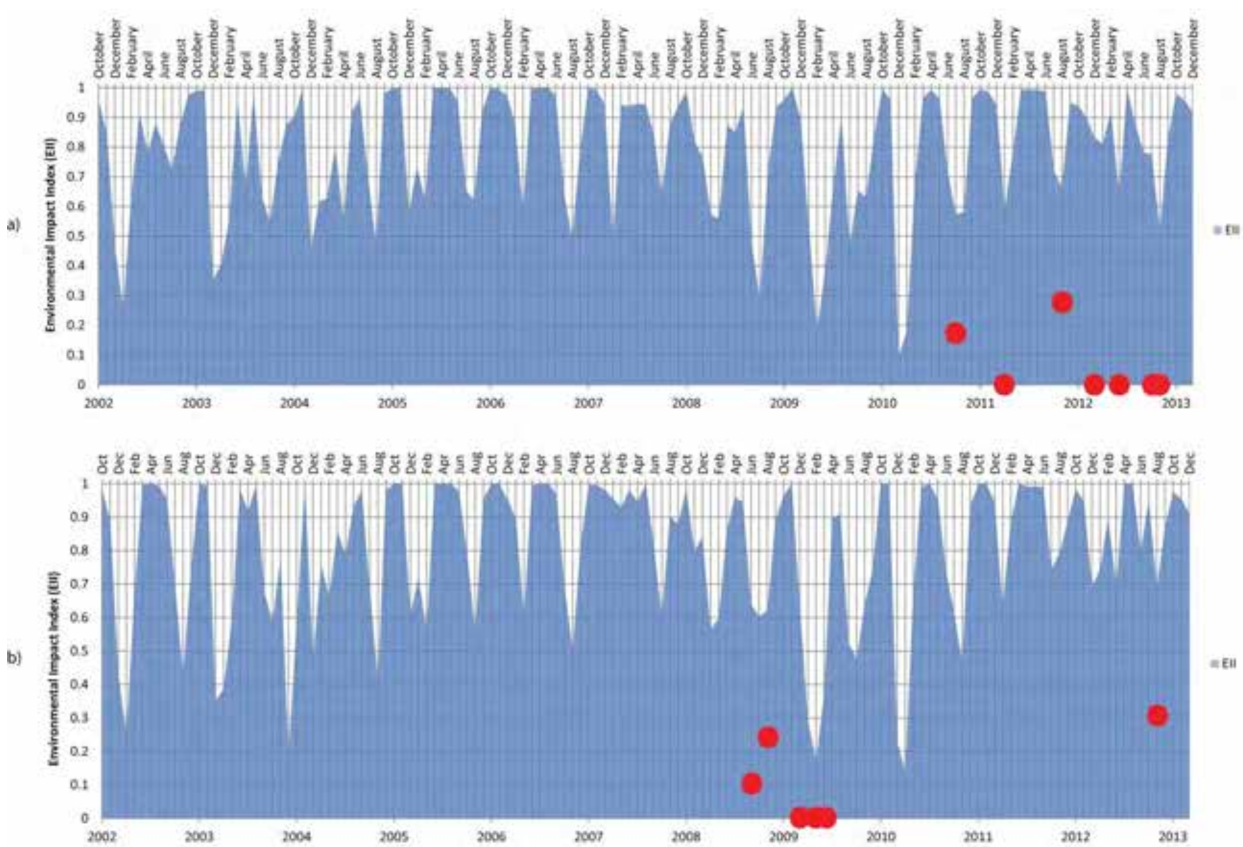

Figure 1: Calculated temporal Environmental Impact Index (EII) values from 2002 to 2013 for a) Gulf Jackson, and b) Dog Island. Red points are the months and lowest values in current study's recent events when EII fell below 0.30.

Research Performance Measure: Progress toward the research objective is consistent with the funding level and hiring timeline. Our performance measures are 1) To identify and format available data, 2) To synthesize data and develop a predictive model of crop loss risk, and 3) To provide a preliminary decision tool to growers. Water quality, environmental, and clam productivity data spanning more than a decade has been obtained and formatted for use. Available data has been synthesized and the key variables in mortality events have been identified. A predictive model of clam mortality risk has been developed using the key variables identified and incorporating the uncertainty in the system. A pilot risk management tool is being developed for use by clam growers. Given key variables the model may be used to predict that environmental conditions will fall outside the physiological limits at a particular lease area, for example.

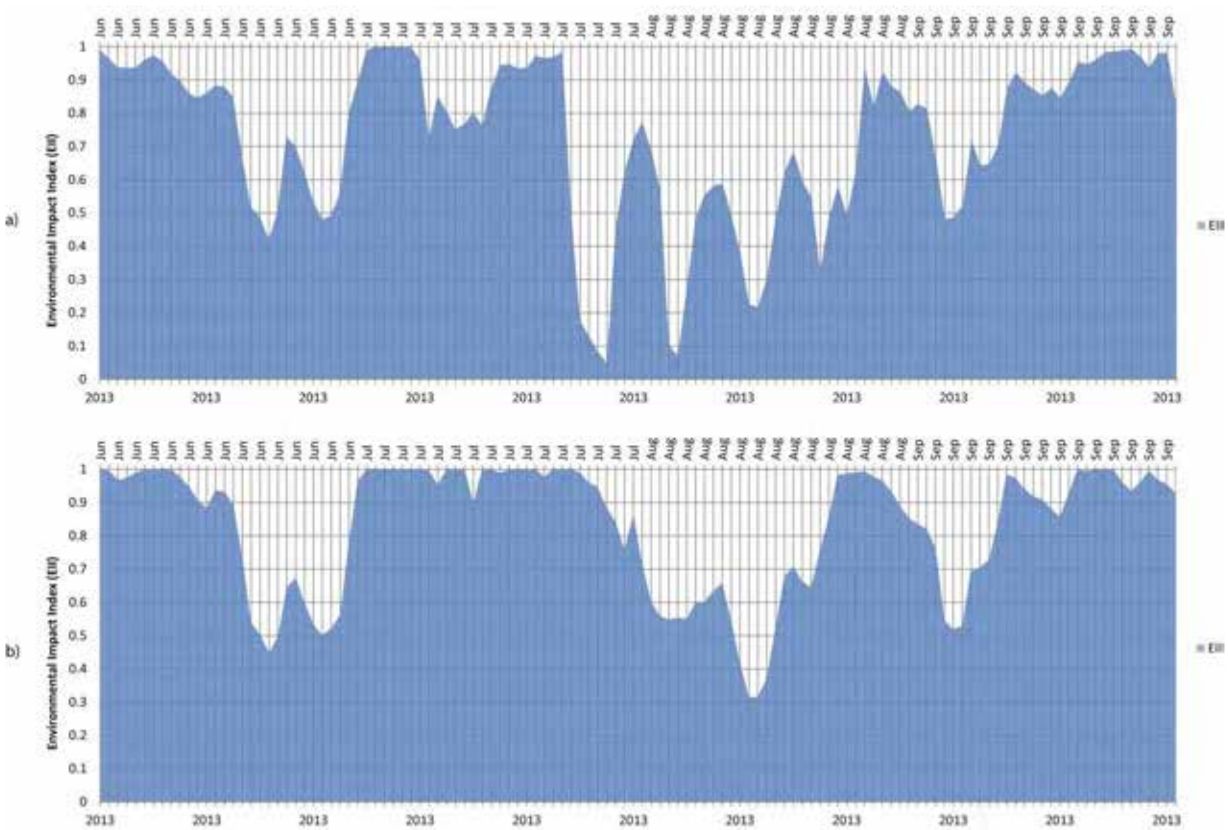

Figure 2: Calculated temporal Environmental Impact Index (EII) values in the summer (June through September) 2013 for a) Gulf Jackson, and b) Dog Island.

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Coastal Fisheries Logbook Program

Project Personnel: J. Diaz (UM/CIMAS)
NOAA Collaborators: D. Gloeckner, M. Judge, N. Baertlein and J. Hall (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Theme:

***Objectives*:** To determine the fishing effort of federally-permitted commercial fishers in the South Atlantic and Gulf of Mexico.

***Strategy*:** To collect fishery dependent catch data by providing trip report logbooks to all federal South Atlantic Snapper/Grouper, Gulf of Mexico Reef Fish, Shark, King Mackerel, Spanish Mackerel, and Dolphin/Wahoo permit holders in the U.S. Atlantic and Gulf of Mexico.

CIMAS Research Theme:

***Theme 7*:** Protection and Restoration of Resources

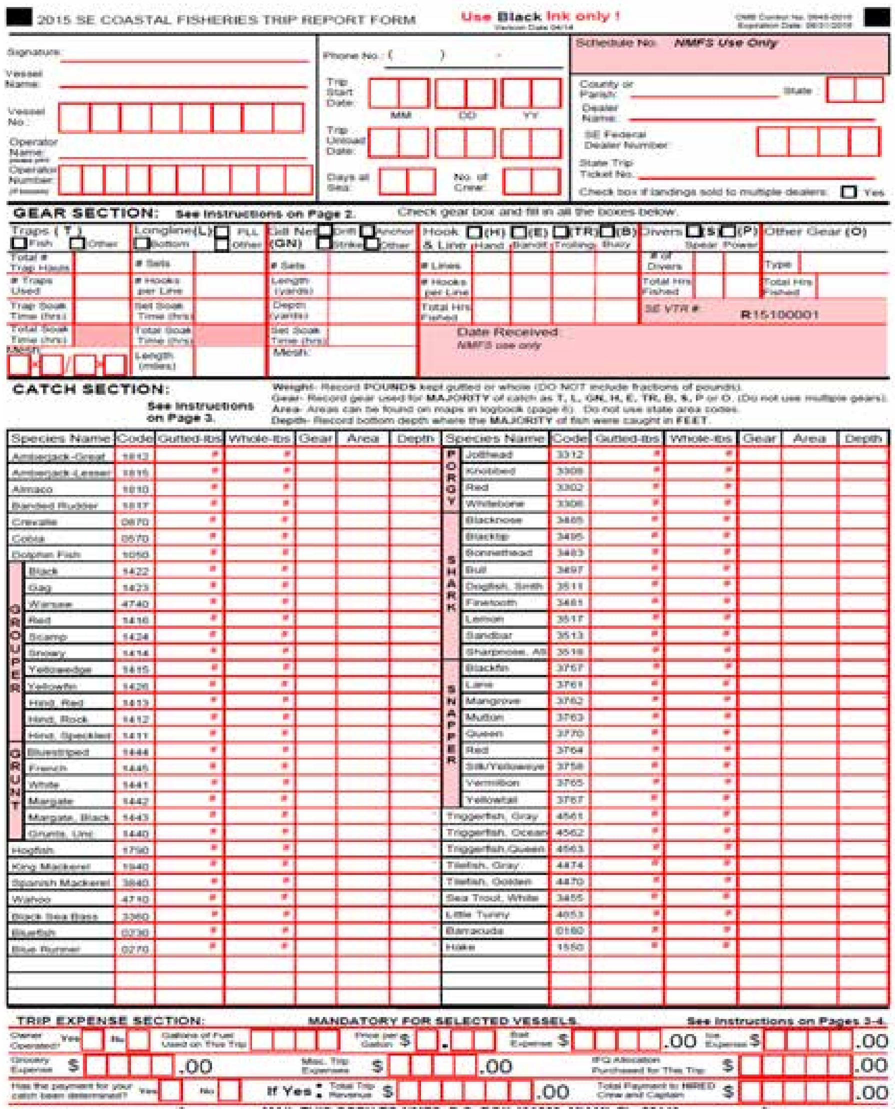
Link to NOAA Strategic Goals:

***Goal 1*:** Protect, Restore, and Manage the Use of Coastal and Ocean Resources through an Ecosystem Approach to Management

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

The Coastal Fisheries Logbook Program is an ongoing fishery-dependent data collection program that collects statistics for the commercial fisheries found in the South Atlantic (SA) and Gulf of Mexico (GOM). Over the past 23 years, fishers in the SA and GOM who possess federal commercial fishing permits (SA Snapper-Grouper, GOM Reeffish, King Mackerel, Spanish Mackerel, Shark, & Atlantic Dolphin/Wahoo) have been required to submit a trip report form which primarily collects landings and fishing effort data. Data collected is used for fisher permit compliance. Data is also used in conjunction with other fishery-dependent, and independent, data sets for stock assessments and fisheries management decisions. A recent stock assessment of Gulf of Mexico red grouper utilized indices of abundance created from logbook data.



2015 SE COASTAL FISHERIES TRIP REPORT FORM — Use Black Ink only !

GEAR SECTION: See Instructions on Page 2.

Date Received: NMFS use only

CATCH SECTION: See Instructions on Page 3.

Weight- Record POUNDS kept gutted or whole (DO NOT include fractions of pounds).
Gear- Record gear used for MAJORITY of catch as T, L, GN, H, E, TR, B, S, P or O. (Do not use multiple gears).
Area- Areas can be found on maps in logbook (page 6). Do not use state area codes.
Depth- Record bottom depth where the MAJORITY of fish were caught in FEET.

Species Name	Code	Gutted-lbs	Whole-lbs	Gear	Area	Depth
Amberjack-Great	1813					
Amberjack-Lesser	1815					
Almaco	1810					
Banded Rudder	1817					
Crevalle	0870					
Cobia	0570					
Dolphin Fish	1050					
Grouper: Black	1422					
Grouper: Gag	1423					
Grouper: Warsaw	4740					
Grouper: Red	1416					
Grouper: Scamp	1424					
Grouper: Snowy	1414					
Grouper: Yellowedge	1415					
Grouper: Yellowfin	1426					
Grouper: Hind, Red	1413					
Grouper: Hind, Rock	1412					
Grouper: Hind, Speckled	1411					
Grunt: Bluestriped	1444					
Grunt: French	1445					
Grunt: White	1441					
Grunt: Margate	1442					
Grunt: Margate, Black	1443					
Grunt: Grunts, Unc	1440					
Hogfish	1790					
King Mackerel	1940					
Spanish Mackerel	3840					
Wahoo	4710					
Black Sea Bass	3360					
Bluefish	0230					
Blue Runner	0270					

Species Name	Code	Gutted-lbs	Whole-lbs	Gear	Area	Depth
Porgy: Jolthead	3312					
Porgy: Knobbed	3309					
Porgy: Red	3302					
Porgy: Whitebone	3306					
Shark: Blacknose	3485					
Shark: Blacktip	3495					
Shark: Bonnethead	3483					
Shark: Bull	3497					
Shark: Dogfish, Smth	3511					
Shark: Finetooth	3481					
Shark: Lemon	3517					
Shark: Sandbar	3513					
Shark: Sharpnose, Atl	3518					
Snapper: Blackfin	3757					
Snapper: Lane	3761					
Snapper: Mangrove	3762					
Snapper: Mutton	3763					
Snapper: Queen	3770					
Snapper: Red	3764					
Snapper: Silk/Yelloweye	3758					
Snapper: Vermilion	3765					
Snapper: Yellowtail	3767					
Triggerfish, Gray	4561					
Triggerfish, Ocean	4562					
Triggerfish, Queen	4563					
Tilefish, Gray	4474					
Tilefish, Golden	4470					
Sea Trout, White	3455					
Little Tunny	4653					
Barracuda	0180					
Hake	1550					

TRIP EXPENSE SECTION: MANDATORY FOR SELECTED VESSELS. See Instructions on Pages 3-4.

MAIL THIS COPY TO NMFS, P.O. BOX 491500, MIAMI, FL 33149

Figure 1: An example of the trip report logbook that is sent out to federally permitted fishers in the South Atlantic and Gulf of Mexico. Once trips are completed by the fisher, they are returned to the Southeast Fisheries Science Center via USPS, postage-paid envelopes.

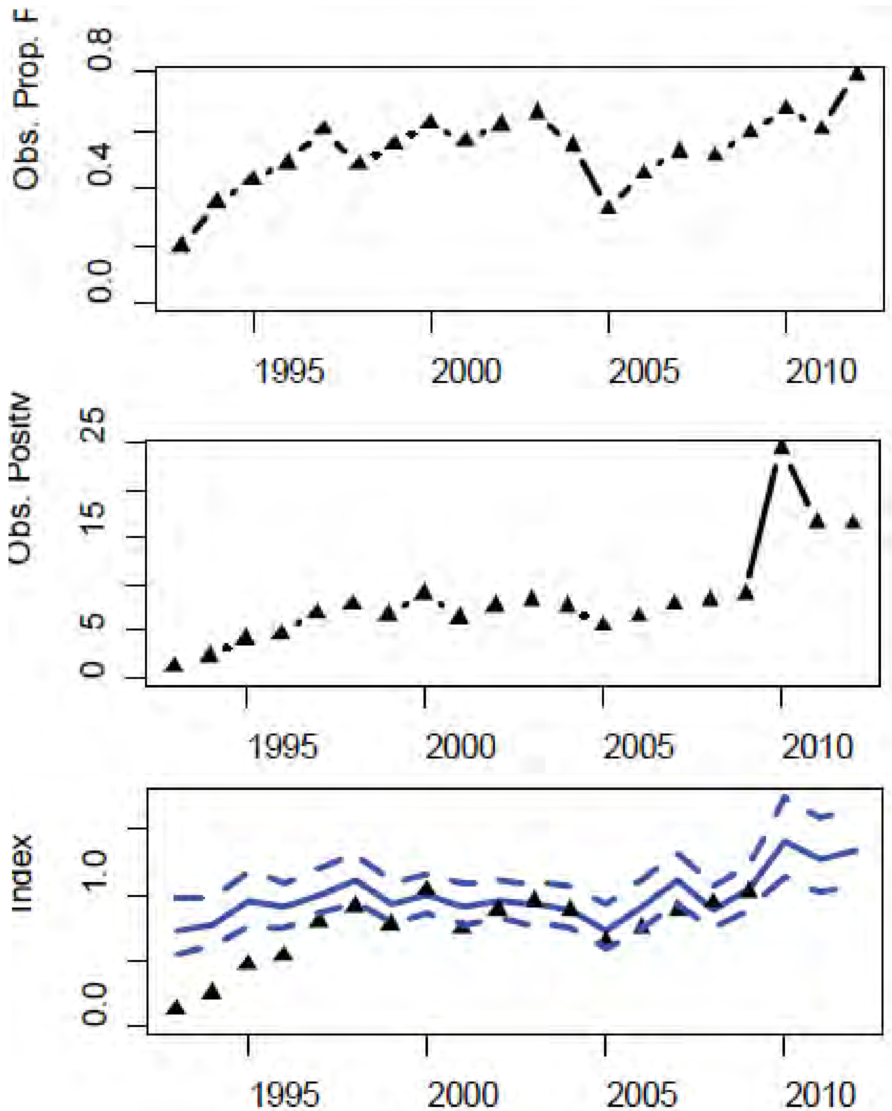


Figure 2: The recent SEDAR 38 utilized a commercial logbook continuity index of relative abundance of King mackerel in the U.S. Gulf of Mexico. Figure 2 shows the proportion of sample that observed King mackerel (top), observed mean catch-per-unit-effort on positive trips (middle), and the predicted mean index (bottom).

Research Performance Measure: Our objective, the monitoring of compliance by fisherman by the timely submission of data, has been successfully accomplished.

Mandatory Ship Reporting System

Project Personnel: R. Domingues and P. Chinn (UM/CIMAS)
NOAA Collaborators: G. Goni, F. Bringas, J. Harris and J. McKeever (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** Contribute to the conservation of the northern right whale population by educating and improving the awareness of mariners on the plight of the right whale.

***Strategy*:** The Mandatory Ship Reporting system requires all commercial vessels heavier than 300 gross tons to report to the Coast Guard upon entering two designated report areas (Figure 1). Reports are received through e-mail (RightWhale.MSR@noaa.gov) or Telex (236737831), processed and stored in a database. Complying vessels are provided with a return message containing information about how to reduce the risk of ship strikes with whales, which includes the location of latest whale sightings.

CIMAS Research Theme:

***Theme 7*:** Protection and Restoration of Resources (*Primary*)
***Theme 6*:** Ecosystem Management (*Secondary*)

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/OPR/MMSTCD and USCG
NOAA Technical Contact: Molly Baringer

Research Summary:

The North Atlantic right whale has shown no significant signs of recovery over the past 60 years despite being a protected species. Ship strikes account for nearly one third of all known right whale mortality. In an effort to reduce the number of whales killed or injured by ship strikes, the United States proposed the creation of the Mandatory Ship Reporting System (MSR) to educate merchant mariners on the plight of the right whale, and to provide information about reducing the risk of ship strikes. The MSR was formally adopted in December, 1998, through the Resolution A.858(20), and commenced its operation on 1 July 1999. It requires all commercial vessels heavier than 300 gross tons to report to the U.S Coast Guard (USCG) upon entering two designated report areas (Figure 1).

In 2013, the National Marine Fisheries Service (NMFS) and the USCG decided to transition the system to an in-house government facility because of certain I/T security requirements. The new version of the MSR, fully developed and hosted by AOML/PhOD, became operational on April 1st, 2014. Since it became operational, the system hosted at AOML has received and processed more than 4600 reports from 1050 different vessels. All vessels reporting to the MSR were provided with a response message containing information on how to avoid collisions with whales, speed limit requirements, and the location of latest whale sightings.

The information collected by the MSR database yields data on ship traffic volume, routes, and ports of call and assists in tailoring any necessary future ship strike mitigation measures. It also enables the generation of reports about the ship compliance with the U.S. MSR.

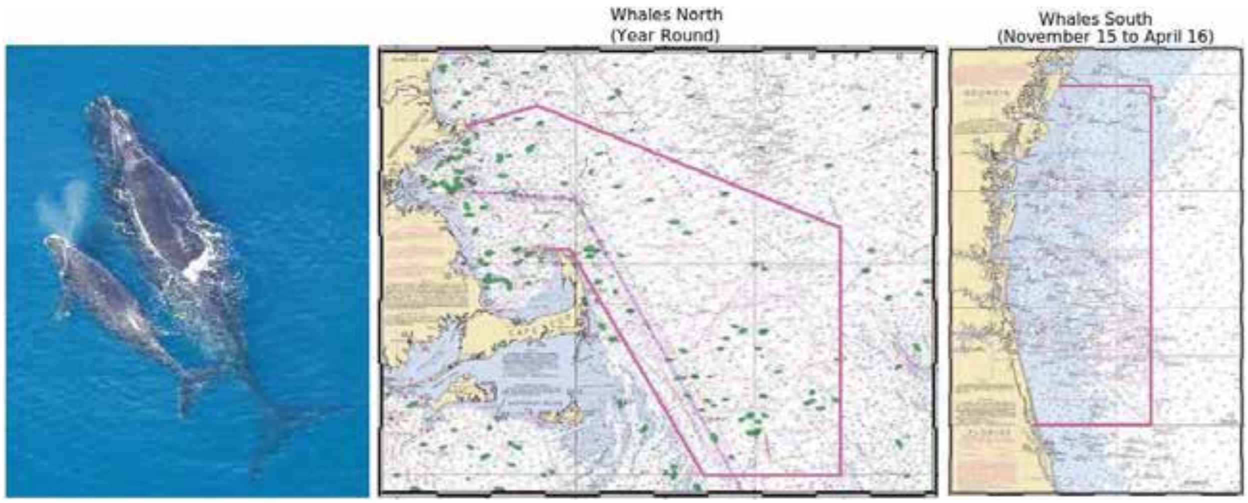


Figure 1: (left) North Atlantic right whale with calf. The (center) Whales North and (right) Whales South reporting areas along the east coast of United States within the Mandatory Ship Reporting system. The reporting requirements for each area are emphasized above the maps.

Research Performance Measure: All planned goals were met during this year. During the period between July 1, 2014 and June 30, 2015, the MSR hosted at AOML has received and processed more than 3900 reports from 920 different vessels.

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Investigation of the Movement of Adult Billfish in Potential Spawning Areas

Project Personnel: J.P. Hoolihan (UM/CIMAS); J. Luo (UM/RSMAS)
NOAA Collaborators: E.D. Prince (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To characterize the horizontal and vertical movement of istiophorid billfish and other tropical pelagic fishes in potential spawning areas in the context of large marine ecosystems.

Strategy: To utilize electronic tags, plankton nets, and biological samples to describe habitat utilization and spawning state of subject teleosts. Describe depth of pelagic longline gear using electronic monitors and integrate pertinent oceanographic data from the World Ocean Atlas web site.

CIMAS Research Theme

Theme 7: Protection and Restoration of Resources
***Theme 3*:** Sustained Ocean and Coastal Observations

Link to NOAA Strategic Goal

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:
We used recreational fishing vessels to (1) catch pelagic fishes known to interact with pelagic longline fishing gear, (2) attach pop-up satellite archival tags (PSATs) to them and (3) release them to study their horizontal and vertical movements for periods up to 180 days. In July 2014, 14 PSATs were deployed in the eastern Pacific off the coast of Costa Rica. Overall, more than 300 PSATs have been deployed by the NOAA-SEFSC Migratory Fisheries Biology Branch and about 78% of them reported summarized data via the Argos satellite system. In addition, we have physically recovered >20 PSATs that had previously transmitted summarized data. PSAT non-volatile memory retains large volumes of high resolution data that is available for download. This augmented the PSAT data base with detailed information that is not available through Argos transmissions. During 2014, analyses of PSAT data from white marlin, and yellowfin tuna were reported in peer-reviewed journals. Specifically, we addressed time spent at depth and temperature relative to the uniform temperature mixed layer. The Delta T metric represents an important input variable for habitat standardization models, which are used to predict vertical distributions and abundance needed for stock assessments.

Research Performance Measure: 1) High recovery rate for data collected by pop-up satellite tags indicates that fish tagging protocols and deployment durations are appropriate. 2) Successful acquisition of high resolution data on pelagic longline gear "behavior" and the effects of gear modifications on animal interactions with pelagic longline fishing gear. 3) Many joint authored (NOAA/RSMAS) peer review papers have resulted over the last few years. Those from 2014-2015 are listed below. Other can be accessed at: http://www.sefsc.noaa.gov/fisheriesbiology.jsp

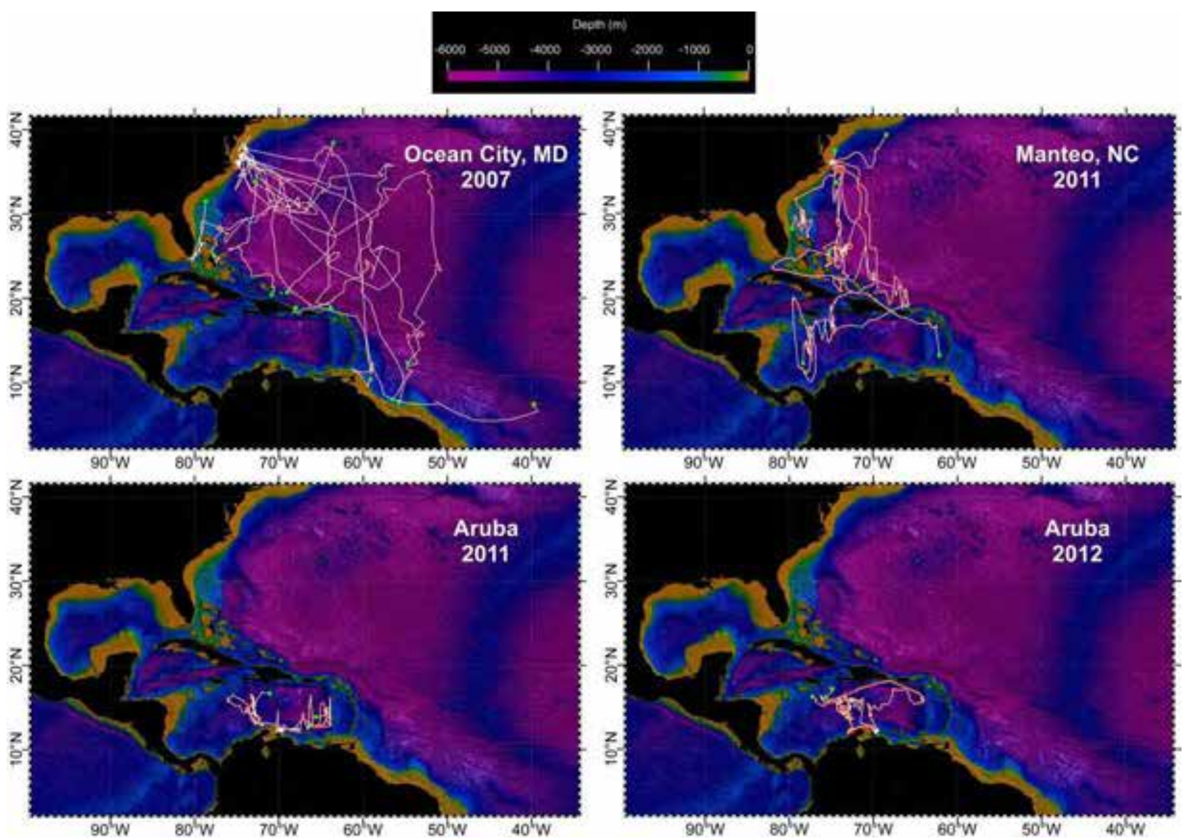

Figure 1: Estimated most probable horizontal tracks for 28 PSAT monitored white marlin plotted by year (2007-2012) and deployment location. Circles denote deployment locations (white), pop-up locations (green), and intermittent locations estimated from light level data (red, *ICES J. Mar. Sci*., doi: 10.1093/icesjms/fsv082).

Spatial Analysis of Pop-up Satellite Archival Tag Data for Tuna and Istiophorid Billfishes incorporating Oceanographic Environmental Data and considering the Implications of Climate Change

Project Personnel: J. Luo, J. Ault and L. Shay (UM/RSMAS); J. Hoolihan (UM/CIMAS)
NOAA Collaboraters: E. Prince (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To analyze pop-up satellite tag data to improve our understanding of the spatial/environmental habitat of tuna and billfishes, and to consider how environmental factors affect interactions with pelagic longline fishing gear.

***Strategy*:** To provide analytical support to the SEFSC Highly Migratory Species (HMS) Branch relative to analyses of data derived from electronic popup satellite archival tag data, and analysis of oceanographic features associated with the movement data derived from these electronic tags.

CIMAS Research Theme:

***Theme 7*:** Protection and Restoration of Resources (*Primary*)
***Theme 3*:** Sustained Ocean and Coastal Observations (*Secondary*)

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*
***Goal 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

For centuries, the mechanisms surrounding spatially complex animal migrations have intrigued scientists and the public. We present a new methodology using ocean heat content (OHC), a habitat metric that is normally a fundamental part of hurricane intensity forecasting, to estimate movements and migration of satellite-tagged fishes. Previous satellite-tagging research of fishes using archival depth, temperature and light data for geolocations have been too coarse to resolve detailed ocean habitat utilization. We combined tag data with OHC estimated from ocean circulation and transport models in an optimization framework that substantially improved geolocation accuracy by 80 percent over SST-based tracks. The OHC-based tracks provided the first quantitative evidence that many of the tagged highly migratory fishes displayed significant affinities for ocean fronts and eddies. The OHC method provides new quantitative tools for studying dynamic use of ocean habitats, migration processes and responses to environmental changes by fishes, and further, improves ocean animal tracking and extends satellite-based animal tracking data for potential physical, ecological, and fisheries applications.

Research Performance Measure: This project accomplished more than the original objectives

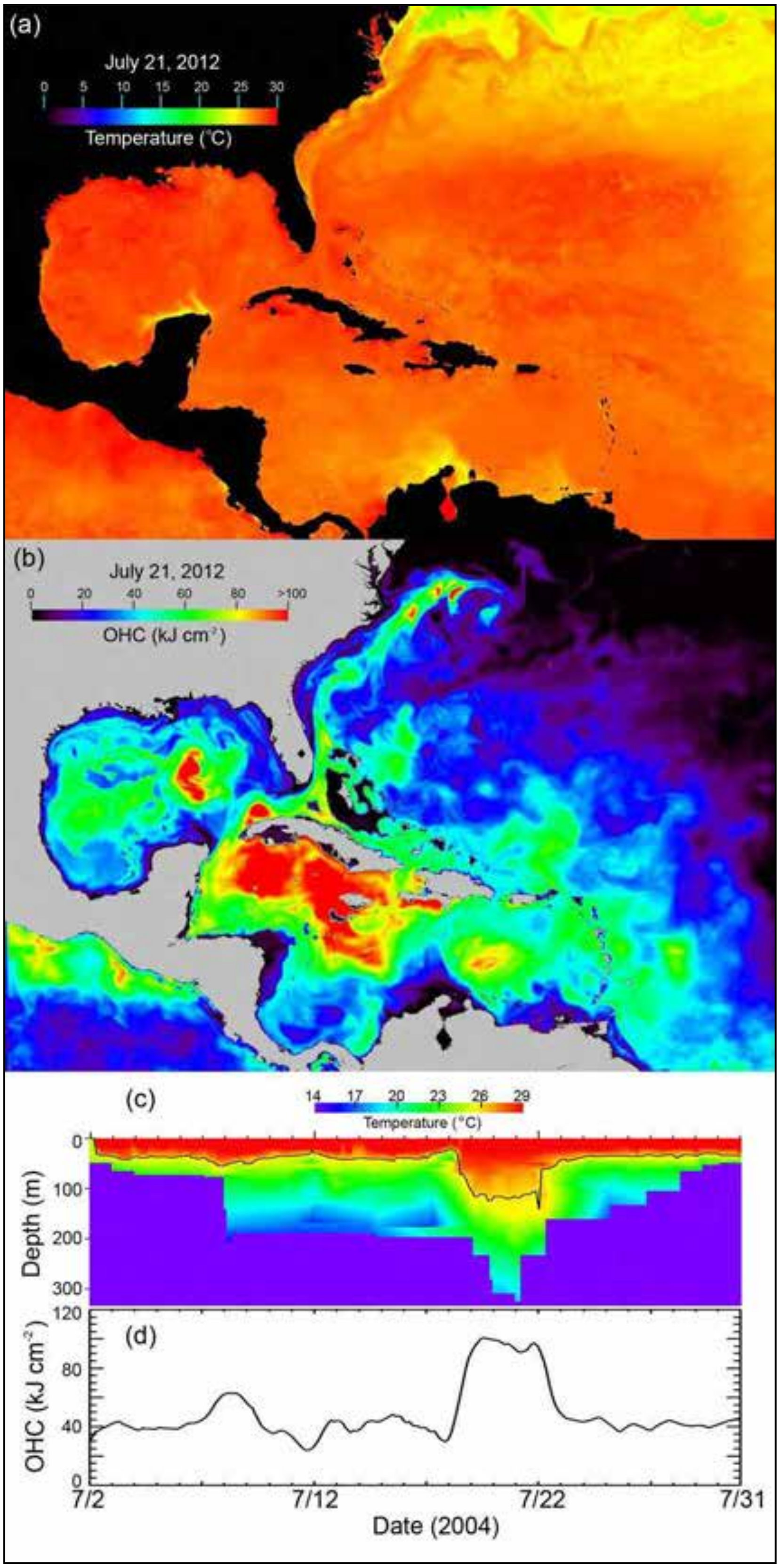

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Figure 1: Ocean fronts and eddies revealed by ocean heat content (OHC). (a) Sea surface temperature (SST) and (b) OHC, on July 21, 2012. (c) Profile of depth and temperature (PDT) from a PSAT tagged blue marlin in Gulf of Mexico during July 2012. The black line shows the depth of the 26 ^{o}C isotherm. (d) OHC estimated from the above PDT profile.

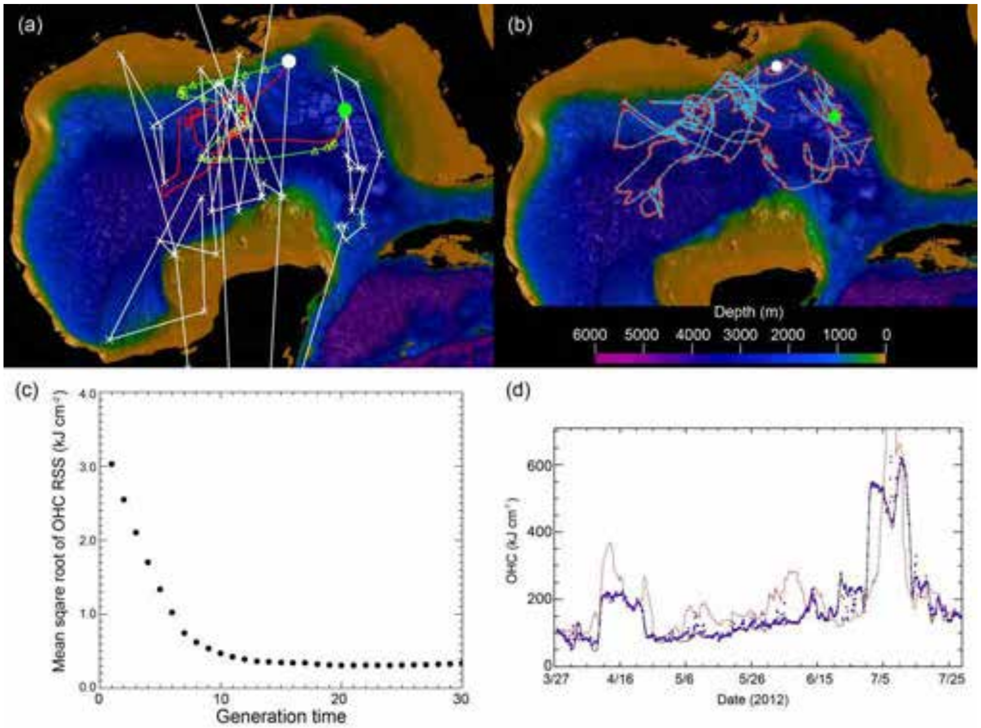

Figure 2: Movement tracks of a yellowfin tuna by different geolocation methods**.** (a) Geolocation estimates from light data (white x and line); light-based Kalman filtered track (yellow triangles and green line); KF-SST track (red line). The white dot indicates the tag deployment location and the green dot indicates the tag pop-off location. (b) GA-OHC filtered track of the same fish. (c), The root-mean-square (*RMS*) error of OHC between the observed OHC_T and predicted OHC_M as a function of generation time. (d), Comparison of OHC values between KF-SST and GA-OHC filtered tracks (black line is the OHC_T estimates from PSAT depth and temperature data; red line is OHC_M values at the location determined by the KF-SST filtered track; and, purple dots are the OHC_M values at the location determined by the GA-OHC filtered track.

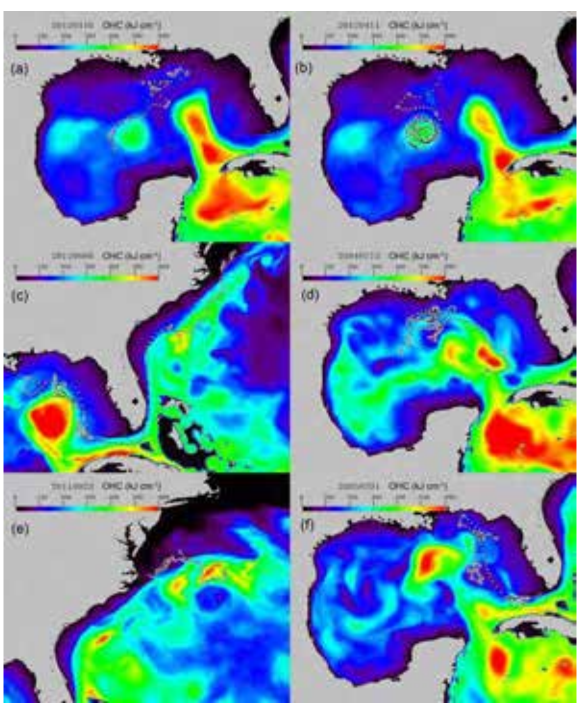

Figure 3: Front and eddy utilization by pelagic tunas and billfishes. (a) A yellowfin tuna along the edge of an eddy in the center of GoM on April 14, 2012. (b) Another yellowfin tuna along the edge of an eddy in the center of GoM on March 23, 2012. (c) A bluefin tuna along the eastern edge of the Loop Current (LC) and later along the western edge of the Gulf Stream from April 26 to June 6, 2012. (d) A blue marlin along the eastern edge of the LC on July 12, 2004. (e) A white marlin along the edge of the Gulf Stream on September 23, 2011. (f) A sailfish at the edge of Florida Current and the eastern edge of the LC from May 10 to July 1, 2005.

2014 National Coral Reef Monitoring Plan: Florida Benthic Sampling

Project Personnel: S.L. Miller, M. Chiappone, and L.M. Rutten (NSU)
NOAA Collaborators: J. Schull and J. Bohnsack (NOAA/SEFSC)
Other Collaborators: J. Ault and S. Smith (UM/RSMAS)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: The National Coral Reef Monitoring Program (NCRMP*)* aims to answer the following questions across four monitoring themes (benthic community condition, fish community structure, climate, and human dimensions): 1) What is the status of coral reef ecosystem biota? 2) Is community structure changing over time? 3) What are the trends in temperature and acidification in waters surrounding coral reefs? 4) What is the status of human knowledge, attitudes, and perceptions regarding coral reefs? 5) How are human uses of, interactions with, and dependence on coral reefs changing over time?

Strategy: When fully implemented over the course of several monitoring cycles, NCRMP will provide information needed to tailor investments and strategies to ensure that NOAA's Coral Reef Conservation Program's (CRCP) goals and objectives are achieved, and that U.S. coral reef ecosystems – and the communities that depend on them – benefit from our collective conservation activities. NCRMP has developed benthic protocols and a sampling design to meet NCRMP monitoring goals that include Line Point Intercept Surveys for benthic cover, Coral Demographic Surveys, Benthic Fauna (for queen conch, spiny lobster, and the sea urchin *Diadema antillarum*) Surveys, Topographic Complexity Measurements, and Site Photographs.

CIMAS Research Themes

Theme 7: Protection and Restoration of Resources
Theme 6: Ecosystem Management
Theme 1: Climate Research and Impact

Link to NOAA Strategic Goals:

Goal 1: *Healthy Oceans* - Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

Benthic habitat surveys in 2014 (with some sites sampled in 2015) were conducted throughout southeast Florida that targeted and completed 150 sites, including 100 in the Florida Keys and 50 off of Broward County, using small boats and SCUBA diving on day trips. At each site, one 15-m Line Point Intercept (LPI) transect was surveyed for cover (100 points per transect) and a 10-m x 1-m Coral Demographic transect was surveyed for all corals greater than 4 cm in maximum diameter and identified to species, measured for colony dimensions (max. diameter, perpendicular diameter, and height), as well as conditions including percent live vs. dead tissue and evidence of tissue bleaching and disease. The work contributes to the NCRMP 2014 benthic monitoring efforts in Florida and comprises part of a long-term coral reef monitoring program throughout the Florida Keys that typically samples three times as many sites every few years. Additional work in 2015 (underway) to augment sampling, focuses on about a week of sampling in the upper Florida Keys, ten days in the lower Florida Keys, and two weeks in Biscayne National Park.

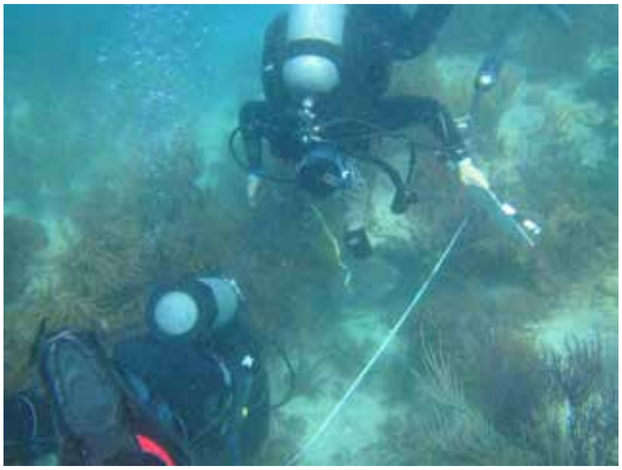

Figure 1: Divers working along a coral demographic transect.

Figure 2: Patch reef in the Florida Keys with high diversity and cover.

Research Performance Measures: 1) Completion of NCRMP benthic surveys in Florida. 2) Finalize transfer of 2014 benthic data into NCRMP data platform. 3) Assist SEFSC with finalization of Florida 2014 NCRMP protocols. 4) Assist with final Florida report writing. 5) Evaluate tradeoffs and impacts of Florida NCRMP sample design.

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Coral Restoration and Recovery

Project Personnel: R.E. Pausch, D.E. Williams, A.J. Bright, C. Cameron and L. Richter (UM/CIMAS)
NOAA Collaborators: M.W. Miller (NOAA/SEFSC)
Other Collaborators: Coral Restoration Foundation and Mote Marine Lab

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To enhance scientific basis for implementing restoration and recovery of coral populations in south Florida and the Caribbean, especially those listed under the Endangered Species Act.

Strategy: To undertake observational and experimental studies to evaluate factors affecting and potentially enhancing coral success, especially of early life stages and cultured/restocked colonies.

CIMAS Research Theme:

Theme 7: Protection and Restoration of Resources

Link to NOAA Strategic Goals:

Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

This ongoing project incorporates several components focused on supporting restoration and recovery of reef corals, especially those under protection as threatened species. The first component involves studies related to spawning, larval and post-settlement ecology of broadcast-spawning coral species (particularly

Acropora spp. and *Orbicella faveolata*). During the current project year, coral spawning in the Florida Keys was prolific and we completed fertilization assays to test the compatibility of three, haphazardly-selected parental genotypes on fertilization success for both *A. palmata* and *O. faveolata*. For both species, parental identity had significant and large effects on fertilization success, much larger effects than were detectable for aspects of water quality. These results point to parental incompatibility in extant Florida Keys populations being a significant depensatory factor impairing larval production in both these imperiled species.

A new project component was implemented specifically evaluating aspects of outplant design for fragments of elkhorn coral (*A. palmata*) which is just recently becoming available for large-scale restoration due to nursery culture effort by our NGO partners (Coral Restoration Foundation). The initial experiment conducted in 2014 showed no advantage in terms of growth or survival of larger (i.e., projected area ~100 cm^2; 67% survival from May -Nov) nursery-cultured fragments compared to smaller fragments (~ 50 cm^2; 73% survival from May-Nov). Relatively high rates of mortality in this experiment are attributable to a mass bleaching event affecting *A. palmata* in the Florida Keys in fall 2014, though the bleaching response of these outplanted fragments was variable (Fig 1) despite all the outplants being fragments (clones) of a single genotype. A second experiment, initiated in May 2015, using only smaller fragments will compare the performance of different genetic individuals across distinct habitat types (fore-reef versus patch reef).

Previous project components 1) evaluating the status of robust *A. cervicornis* and co-occurring fish populations and 2) evaluating a simple intervention to mitigate effects of predation on restocked *A. cervicornis* colonies are completed with results in preparation for peer-reviewed journal submission or recently published (see below), respectively.

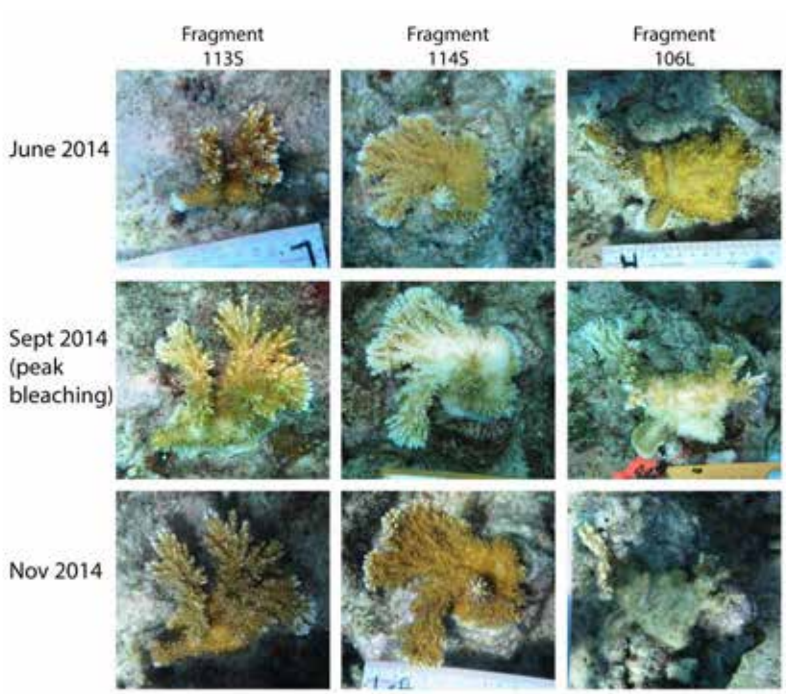

Figure 1: Illustration of progression of three elkhorn coral fragments outplanted to Molasses reef in our 2014 size comparison experiment. Many fragments (e.g. 114S and 106L) bleached appreciably during Sept 2014 (associated with warm temperature stress) while others (e.g. 113S) did not, despite all fragments being genetic clones. Many fragments that bleached severely subsequently died (e.g. 106L) while others recovered (e.g. 114S).

Research Performance Measure: Intensive field work is involved with each project component. The intended field schedule was largely accomplished, though the implementation of the second elkhorn outplant experiment was deferred from fall 2014 to spring 2015 in order to avoid the excessive heat and bleaching stress occurring in the fall of 2014.

Stock Structure of Common Bottlenose Dolphin in the Bays, Sounds and Estuaries in the Northern Gulf of Mexico

Project Personnel: N.M. Phillips (UM/CIMAS)
NOAA Collaborators: P.E. Rosel, L. Garrison, K. D. Mullin (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Theme:

***Objectives*:** To understand population structure and gene flow of common bottlenose dolphins in the bays, sounds and estuaries in the northern Gulf of Mexico in order to accurately assess and quantify the impacts of anthropogenic and environmental threats on these stocks.

***Strategy*:** To assess the population structure of common bottlenose dolphin via genetic analysis, using a combination of mitochondrial and microsatellite markers.

CIMAS Research Theme:

***Theme 7*:** Protection and Restoration of Resources

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

The common bottlenose dolphin is a well known marine mammal that is common in the bays, sounds and estuaries (BSEs) of the northern Gulf of Mexico (Figure 1). The utilization of BSE environments, which are typically heavily impacted by anthropogenic activities, means that these dolphins are exposed to a wide variety of threats, such as pollution, fisheries, industrial activities, boat traffic, disease and algal blooms. In addition, there have been repeated Unusual Mortality Events (UME's) involving common bottlenose dolphins in the northern Gulf of Mexico, some of which have unknown etiology. Determining the impacts of all of these stressors on BSE dolphin stocks is difficult because little is known about the seasonal movement, gene flow, abundance and levels of mortality for the majority of the 31 BSE stocks that have been delimited in the northern Gulf from the Florida Keys to the Texas-Mexico border. Most of these stocks have been designated based primarily on evidence for strong year-round site fidelity and inferences drawn from movement data in other areas of the northern Gulf of Mexico. Therefore, the aim of this research is to assess the population structure of bottlenose dolphins in selected bays, sounds and estuaries of the northern Gulf of Mexico using genetic methods to determine whether the current stock designations in these waters are biologically meaningful.

Figure 1: Common bottlenose dolphin, *Tursiops truncatus*

In the summer of 2014, a total of 71 skin samples were collected from common bottlenose dolphins for genetic analysis in Texas waters, 31 from the bays, including Corpus Christi Bay, Aransas/Copano Bays, San Antonio Bay and Matagorda Bay and 40 from the coastal waters adjacent to Corpus Christi Bay and

Matagorda Bay. Genomic DNA was extracted from all of these samples and we have genetically determined the sex of the sampled dolphins. Genetic data have been generated for these samples using two different molecular markers, mitochondrial DNA (mtDNA) control region and microsatellite loci. These samples collected in 2014 were combined with samples collected in 2012 and 2013 and data analysis focused on all samples collected from Texas (Figure 2) is currently underway. To date, we have found evidence for significant population structure for both datasets (mtDNA and microsatellites) at surprisingly small spatial scales, with Corpus Christi, Aransas and Copano Bays, San Antonio/Espiritu Santo bays, and Matagorda Bay each containing a genetically differentiated stock. Bayesian analysis of the microsatellite data identified a small number of immigrants suggesting there may be some movement of individuals into nearby stock areas, but the level of genetic differentiation indicates these individuals are either not breeding or such movements are not common. Significant genetic differentiation was also observed between each of these common bottlenose dolphin BSE stocks and the adjacent coastal stock.

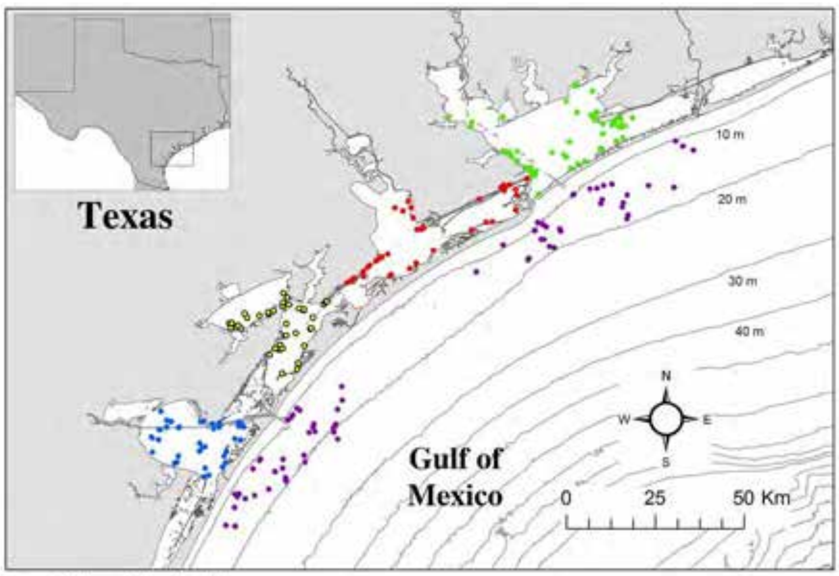

Figure 2: Sampling locations of common bottlenose dolphins in Corpus Christi Bay (blue), Aransas and Copano Bays (yellow), San Antonio and Espiritu Santo Bays (red), Matagorda Bay (green) and the adjacent coastal areas (purple) in Texas.

We have also published a NOAA Technical Memorandum that describes a threat assessment priority scoring scheme we developed to prioritize common bottlenose dolphin stocks in the BSE's in the northern Gulf of Mexico based on the number and severity of 19 threats the stocks face and an evaluation of the quality of data available for performing a stock assessment. Included in the Technical Memorandum are summaries and the overall priority scores for each the seven Texas BSE stocks. The main finding of the Texas summaries and scores is that Galveston Bay, Corpus Christi Bay and Laguna Madre are the areas with the highest level of threats while Sabine Lake has the lowest level of threats, although this may in part be due to data deficiencies. We are currently working on summaries for the Louisiana BSE stocks.

Research Performance Measure: Sample collection has been completed for this project. For all samples collected, DNA has been extracted, sex has been determined and all have been sequenced and genotyped and data analysis is underway. The Technical Memorandum for the developed threat assessment priority scoring scheme was published and the literature summaries for the Louisiana BSE stocks are being drafted.

Natural Resource Damage Assessment Plankton Processing

Project Personnel: S. Privoznik, A. Ender, P.E. Fortman, H. Krakoski, L. Rock, A. Jugovich, E. Keister, T. Morrell, A. Shiroza and J. Mostowy (UM/CIMAS)
NOAA Collaborators: J. Lamkin and T. Gerard (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To assist the NOAA Natural Resource Damage Assessment process relative to the Deep Water Horizon BP oil spill incident.
***Strategy*:** To analyze plankton samples through measurement of sample displacement volume, removal of fish eggs, fish larvae, and debris, and the identification of larval fish removed.

CIMAS Research Theme:

***Theme 7*:** Protection and Restoration of Resources

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

Plankton sampling in response to the Deep Water Horizon (DWH) oil spill in 2010 has generated larger volumes of samples than can be processed at marine laboratories in the Gulf region and/or at the Plankton Sorting and Identification Center in Poland where NOAA/NMFS/SEFSC sends plankton samples for analysis. The Early Life History laboratory at the NOAA/NMFS Southeast Fisheries Science Center, Miami Lab is responsible for the analysis and larval identification of DWH plankton samples which are critical to ongoing DWH oil spill impact assessments and to advance understanding of plankton dynamics in the highly productive Gulf of Mexico. The analyses and indentification itself is being performed by a number of CIMAS employees.

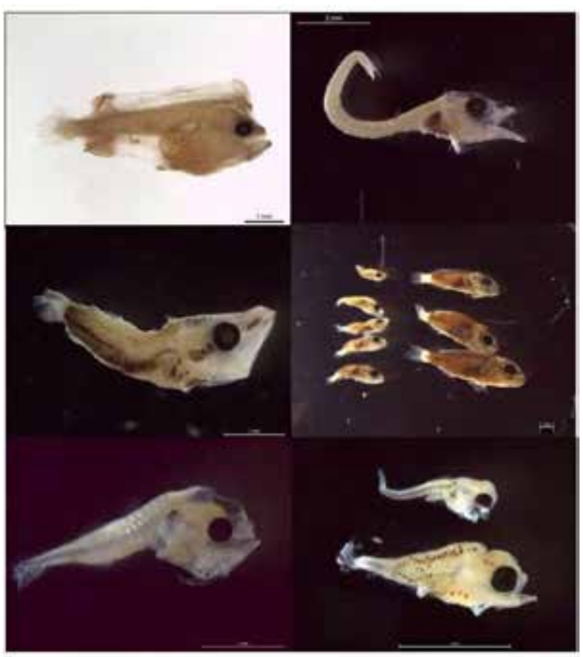

Figure 1: Larval fish samples identified from NRDA samples (Clockwise from top left): Achiridae, Chiasmodontidae, Kyphosidae, Stromateidae, Sciaenidae, Epigonidae.

Research Vessel	Tier	Sorting Completion
Bunny Bordelon	1B	100%
Bunny Bordelon	2B	100%
Bunny Bordelon	3D	100%
McArthur II	1A	100%
McArthur II	2A	100%
McArthur II	3A	100%
Meg Skansi	1C	100%
Meg Skansi	2C	100%
Nick Skansi	3A	100%
Nick Skansi	4C	100%
Sarah Bordelon	1C	100%
Sarah Bordelon	2C	100%

Research Vessel	Tier	Identification Completion
Bunny Bordelon	3D	100%
Nick Skansi	4C	6%

Figure 2: Table summary illustrating sample completion (sorting and identification) within all tiers received and completed by the Miami Lab as part of the DWH plankton processing project.

Research Performance Measure: The large volume of samples generated in response to the DHW was divided into prioritized Tiers among the multiple institutions to facilitate processing and data acquisition. The SEFSC Miami Lab has processed a total of 2,080 samples. To date, plankton samples from nine prioritized categories or "tiers" (Tiers 1A, B and C, Tiers 2A, B, and C, Tiers 3A and D, and Tier 4C) have been sorted. This includes samples from eight cruises carried out using the research vessels McArthur II, Bunny Bordelon, Sarah Bordelon, Meg Skansi, and Nick Skansi. The Miami Lab expanded its operation to include larval identification, and has identified 573 larval fish samples to the lowest possible taxonomic levels. 85% of sorted and identified samples at NOAA SEFSC Miami Lab have been entered into the online database shared by the NRDA labs.

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Quantitative Tools to Study Individual to Population-level Implications of Marine Animal Movement

Project Personnel: N.F. Putman (UM/CIMAS)
NOAA Collaborators: P.M. Richards (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To develop quantitative approaches for modeling movement of protected species, integration of population processes with oceanographic models, and development of tools that can be utilized for management of these resources.

***Strategy*:** To link behavioral data from telemetry studies to oceanographic processes through comparison with ocean circulation model output and simulate population level processes driven by demographic parameters, organism behavior, and environmental conditions.

CIMAS Research Theme:

***Theme 7*:** Protection and Restoration of Resources (*Primary*)
***Theme 5*:** Ecosystem Modeling and Forecasting (*Secondary*)

Link to NOAA Strategic Goals:

Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems* (*Primary*)

Goal 3: Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts* (*Secondary*)

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

The project began with CIMAS on March 2, 2015 as a continuation of work began with the National Research Council: *A "movement ecology" approach to predicting the oceanic distribution of sea turtles*. To date we have developed novel ways to mechanistically predict the movement, distribution, and abundance of juvenile sea turtles using lab and field-based information on swimming behavior, demographic parameters, and ocean circulation model output. These predictions are being further refined as we develop new ways to extract turtle behavior from tracking data through paired releases with surface-drifters and subsequently subtracting modeled ocean velocity from track velocity. We are currently working to apply this work to specific areas of interest and a variety of other taxa – ranging from cnidarians to salmonids

Research Performance Measure: Research performance is measured in terms of peer-reviewed publications produced. Papers highlighting the need as well as the proof of concept for including behavioral information (both laboratory and field-based) to better predict movement and distribution of sea turtles (3 papers) and salmon (1 paper) have been published or are in press. A manuscript showing how demographic information can be layered into these models to estimate abundance in juvenile turtles is currently in review.

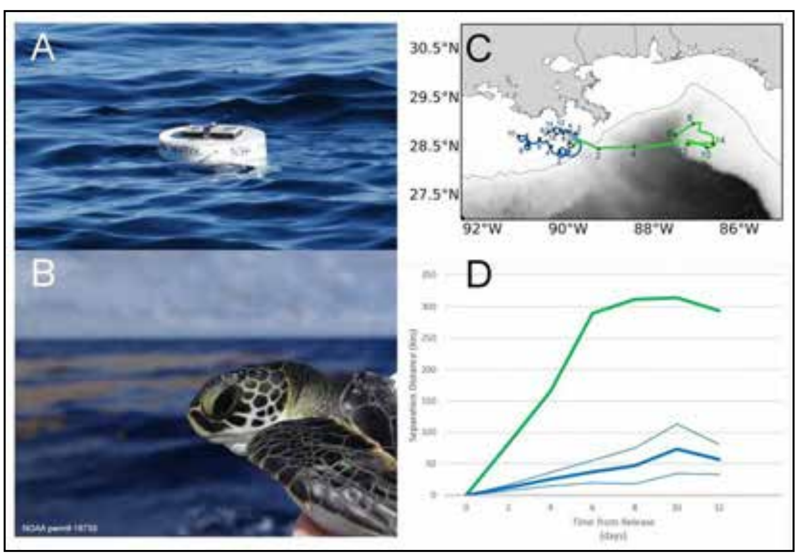

Figure 1: Contrary to the long-held hypothesis that small turtles simply drift with ocean currents, by releasing surface drifters alongside satellite-tracked sea turtles (A,B), we showed that turtles actively swim during their dispersive oceanic stage. (C) The track of a juvenile green turtle (green line) dramatically differs from tracks of two surface drifters (blue lines) simultaneously deployed with the turtle. Likewise, (D) separation distances between pairs of drifters released together (thick blue line mean, thin blue lines 95% CI) are much smaller than separation distances between drifters and juvenile turtles (green line). These and analyses of tracks relative to modeled ocean currents indicate that turtles do not simply drift with currents, rather swimming behavior plays an important role in the distribution of these animals. See Putman & Mansfield (2015 *Current Biology* 25, 1221-1227) for full details. We are using these and other tracking data to inform models of marine turtle movement to better predict spatiotemporal variation in distribution and abundance.

Application and Automation of Underwater Image Mosaics for Sampling, Characterizing, and Classifying Corals as Protected Stocks and Habitat

Project Personnel: R.P. Reid, A. Gleason and B. Gintert (UM/RSMAS)
NOAA Collaborators: M.W. Miller (NOAA/SEFSC); B. Vargas-Angel (NOAA/PISFC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To improve coral stock and habitat assessments through the use of landscape video mosaic and automated image classification technology. The specific goals of this project are to: 1) evaluate and improve a current state-of-the-art benthic classification algorithm in multiple habitats and for several ESA-listed coral species, 2) increase the area that can be rapidly mosaicked, and 3) increase sampling accuracy and efficiency of coral condition and Essential Fish Habitat (EFH) using biological metrics derived from underwater image mosaics.

***Strategy*:** To utilize image classification algorithms and underwater landscape mosaics to improve coral stock and habitat assessments. As an initial step, image classification algorithms are combined with underwater image mosaics to quantify demographics of coral populations. Second, existing data collection hardware and mosaic processing software are modified to decrease field time and increase the area that can be practically mosaicked. Finally, habitat metrics derived from underwater image mosaics are correlated with diver data on fish populations to improve overall habitat and stock assessment efficiency.

CIMAS Research Theme:

***Theme 7*:** Protection and Restoration of Resources

Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

As the foundation species in coral reef ecosystems, shallow scleractinian corals constitute both managed stocks in and of themselves and an important structural basis of Essential Fish Habitat (EFH) in coral reef regions. Since corals are both stocks and habitat, measurements of their abundance, condition, and habitat quality are needed for effective management. Current techniques to acquire such measurements are: a) labor intensive, b) not applicable in all areas or to all species, c) not necessarily comparable from place to place, and d) not always compatible with the objective to measure corals as EFH. The goal of this project is to test the ability of image-based technologies, specifically, underwater landscape mosaics and automated classification technology, to address these four limitations of coral surveys.

This project aims to improve the labor-intensive nature of coral reef assessment in two ways: first, by providing a means of collecting large amounts of coral reef data quickly in the field (creating landscape mosaics of reef areas), and second, by reducing the amount of time needed to extract meaningful scientific data from field images (applying state-of-the-art image classification techniques to imagery). Landscape image mosaics of coral reefs are created by stitching hundreds to thousands of downward-looking images into a single, image-map of an area-of-interest. These images contain information on the species composition, coral cover, and species diversity of a given area and shift the effort from time spent in the water on data collection, to time spent in the lab on data processing. By applying automated classification techniques to image mosaics, this project also aims to improve the laboratory analysis backlog by using minimal expert input to generate useful scientific data from large amounts of field imagery. To date, several image mosaics of threatened coral species *Acropora cervicornis* and *Acropora palmata* have been collected. Initial tests of classification algorithms show promise for using automated techniques to assess ESA-listed coral species directly from landscape mosaics (Fig. 1).

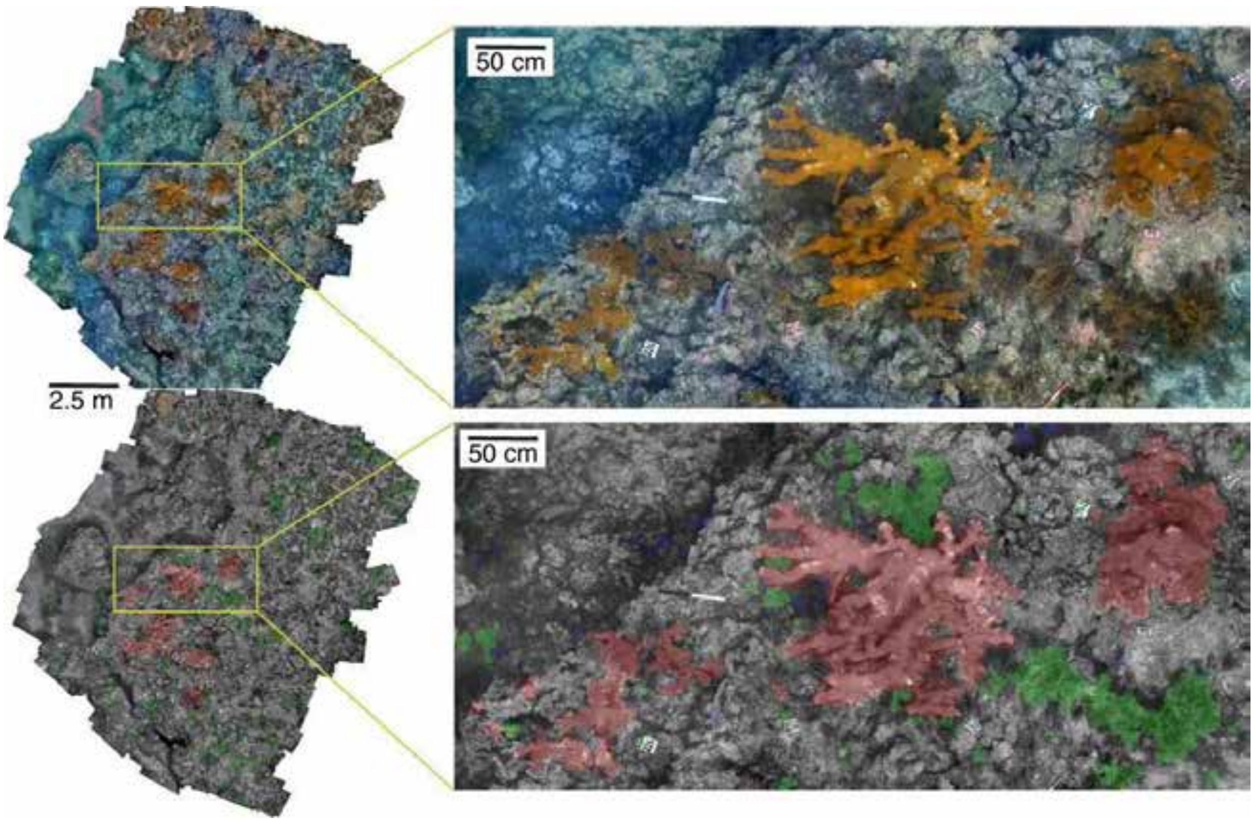

Figure 1: Example of classification results. Top left: an underwater image mosaic from a plot near Molasses Reef, FL, containing several colonies of *Acropora palmata*. Bottom left: same mosaic as the top panel but converted to greyscale. Pixels classified as *A. palmata* are tinted red, pixels classified as gorgonians tinted green. Panels on the right side show zoomed-in subsets of the mosaic (top) and classified mosaic (bottom).

A secondary objective of this project is to improve the speed of field data acquisition, particularly over large areas. The current approach for acquiring mosaic imagery involves one diver swimming over the plot of interest with one or two cameras. At small scales of 100 to 400 m^2, this approach works well, but the acquisition time increases exponentially as the survey area grows, making it difficult to acquire mosaics of ~500 m^2 using a diver and a single camera. To address this limitation, a linear camera array of 3 cameras equally spaced over a 2-m long pole was constructed. The linear camera array has suitable overlap between cameras for effective mosaicing of coral reefs while still being light and agile enough for a diver to operate. During testing, the array collected similar amounts of data to the single camera system in 1/3 of the field time (Fig. 2).

The final objective of this research is to establish the link between fish-habitat quality and metrics derived from landscape mosaics. Using fish census data collected at landscape mosaic sites, we will test whether measurements which are known to indicate fish-habitat quality, such as colony condition, colony density, or total linear extension (TLE), can be accurately extracted from landscape mosaics.

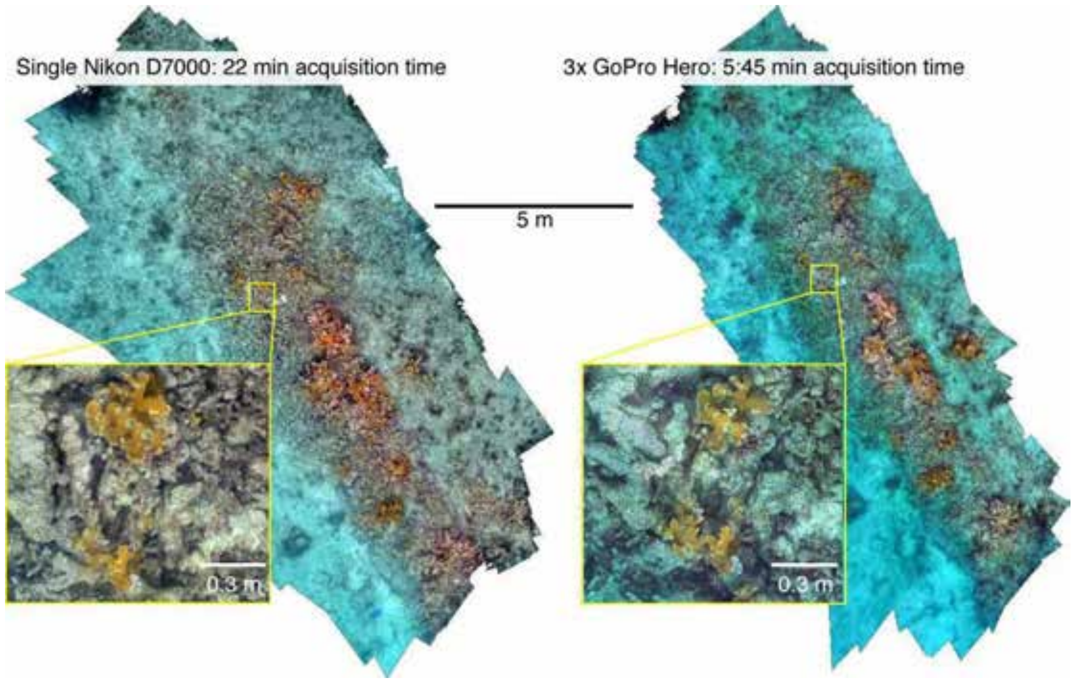

Figure 2: Comparison of two mosaics; one made with a single camera (left) and one made with an array of 3 cameras deployed on a pole. The same diver acquired data for both, and both datasets produced very similar results. The single-camera mosaic (left) covers a slightly larger area, but took almost 4 times as long to acquire.

Research Performance Measure: All major objectives are being met. Accomplishments to date include: 1) acquisition of existing imagery from PIFSC and acquisition of new imagery via GoPro camera arrays from wild and restored *A. cervicornis* 'thicket' sites in both Dry Tortugas National Park and the south coast of Puerto Rico, 2) collection of in situ data on *A. cervicornis* abundance and condition, and fish abundance at mosaic sites, 3) creation of landscape mosaics of *A. cervicornis* 'thicket' and *A. palmata* sites, 4) classification of ESA-listed species from other benthic categories from landscape mosaic images, and 5) using multiple camera arrays to reduce field acquisition time by 1/3.

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Linkages Between Coral Health and LBSP: Iidentifying Sub-Lethal Coral Response to Environmentally Realistic Nutrient Exposure

Project Personnel: D.A. Renegar (NSU)
NOAA Collaborators: J. Hendee (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: This project will determine key linkages between LBSP nutrient levels and coral health: specifically mean, low-, mid-low, mid-high- and high-nitrate conditions and the concomitant sub-lethal health effects measured by coral growth and calcification, PAM fluorometry, and histological/ultrastructural analyses of tissue and zooxanthellae condition. The objectives are to: 1) link specific nitrate levels with specific coral health metrics, 2) provide nitrate threshold levels that have been identified to yield measureable coral health improvements, and 3) allow assessment of the coral health response to management actions through field sampling and measurements based on the calibrated coral health metrics. The evidence demonstrated by this controlled tank experiment will provide managers with specific nitrate level/coral health outcomes to drive support for and establishment of the most attainable and cost-effective threshold levels. The overall aim is to reduce threats to coral reef communities by enabling and supporting management actions to implement the identified nitrate threshold levels determined through controlled tank experiments.

Strategy: The scope of the proposed work includes a six-month laboratory dose response experiment to determine the effects of environmentally-realistic levels of DIN on coral health and function. The dose response experiment will be embedded in incremental temperature changes to simulate potential seasonal temperature extremes. Plugs or branch tips of four species of Atlantic scleractinian corals, *Porites astreoides, Porites divaricata, Montastraea cavernosa, and Siderastrea siderea* will be exposed for six months to five concentrations of DIN. These concentrations have been determined from water quality data obtained by AOML-FACE, SECREMP, and other available water quality monitoring data. To link coral physiological performance to exposure over time, the maximum quantum yield of PSII photochemistry of each coral will be monitored weekly with a submersible pulse amplitude modulated fluorometer (PAM). To assess growth rate and calcification response, weekly buoyant weight measurements and quantitative imaging of each coral will be utilized. To quantify tissue condition, zooxanthellae density, and zooxanthellar ultrastructure, 25% of each coral will be fixed for histological and ultrastructural analysis at the end of the experimental period. These metrics will be used to identify cause and effect relationships and specific responses associated with quantified levels of nitrate. Coral collection, experimental set-up, and a portion of the laboratory experiment will be conducted during year 1. The conclusion of the experimental period and data analysis will continue in Year 2. Analysis of the data from multiple complimentary metrics of coral health utilized in this experiment will allow assessment of overall sub-lethal coral response to reduced, status-quo, and elevated nutrient concentrations. This examination of the varying effects of elevated nutrients over the range of potential temperature exposures will facilitate prediction of future coral health and coral reef condition, providing missing information for definitively linking terrestrial pollutants with coral degradation in the face of changing climate conditions.

CIMAS Research Theme:

Theme 7: Ecosystem Modeling and Forecasting (*Primary*)
Theme 6: Ecosystem Management (*Secondary*)

Link to NOAA Strategic Goals:

Goal 1: Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems* (*Primary*)

Goal 4: Resilient Coastal Communities and Economies - *Coastal and Great Lakes communities that are environmentally and economically sustainable* (*Secondary*)

NOAA Funding Unit: CRCP **NOAA Technical Contact:** Theo Brainerd

Research Summary:

Land-based sources of pollution are a pervasive threat in southeast Florida. This study addresses the effects of environmentally-relevant nutrient and temperature levels on four species of Atlantic scleractinian corals during a six-month tank experiment. Coral health will be assessed by growth rates, PAM fluorometry, and histological/ultra-structural analyses of tissue and zooxanthellae condition. These metrics will identify sub-lethal responses and the cause and effect relationships associated with quantified levels of nutrient and temperature exposure. The project will equip resource managers with experimentally determined linkages between coral health and specific nutrient thresholds for planning and implementing LBSP action strategies.

The impacts of land-based sources of pollution (LBSP) on coral reef ecosystems are of particular concern off of the heavily developed southeast coast of Florida. Elevated levels of nitrogen have been detected in canals, inlets, outfalls, and oceanic waters of south Florida. Elevated nitrogen in known to cause biologically deleterious effects; however, few studies have tested environmentally-realistic levels on Caribbean corals and none have linked nutrient concentration thresholds and the associated sub-lethal effects on coral health. Research demonstrating the relationship between nutrient exposure and sublethal coral susceptibility is essential for linking LBSP with current levels of coral reef degradation and establishing loading limits for best management practices that would improve water quality as well as protect, sustain, and potentially restore critical coral reef habitats.

The proposed project encompasses a six month controlled tank experiment to determine the effects of environmentally-realistic levels of dissolved inorganic nitrogen (DIN) on coral health and function. The use of multiple complimentary metrics for coral health assessment will allow identification of overall sub-lethal coral response to elevated nitrate concentrations within the seasonal temperature range. Direct linkage of multiple coral health metrics with specific nitrate threshold levels will fill critical scientific gaps in the knowledge necessary to assess current management strategies and carry out informed management actions targeted at reducing the levels and impacts of LBSP that will lead to further coral mortality and reef degradation.

We have compiled nitrate data from existing datasets to identify means and variability in reef waters, inlet waters, and nearby outfalls, and A teleconference to discuss the ideal nitrate concentration levels based on offshore water quality data was conducted (including Kurtis Gregg, NMFS; Jenny Baez, DEP CRCP; Rob Ferguson, NOAA; and Jack Stamates, NOAA) and the target nitrate levels were chosen. These target levels are 0.1 um (lower than the mean), 0.3 um (the mean), 1.0 um (low-high), 4.0 um (mid-high), and 8.0 (high). Setup of experimental tank replicates based on nitrate levels as discussed with mangers is complete, and experimental and chemical supplies have been acquired. Field sampling of corals has been conducted, and the corals are acclimating in the onshore nursery; pre-exposure baseline data collection is underway, and PSII quantum yield [Fv/Fm = (Fm − Fo)/Fm; mean ± SD] of the corals during the acclimation period is shown in Figure 1.

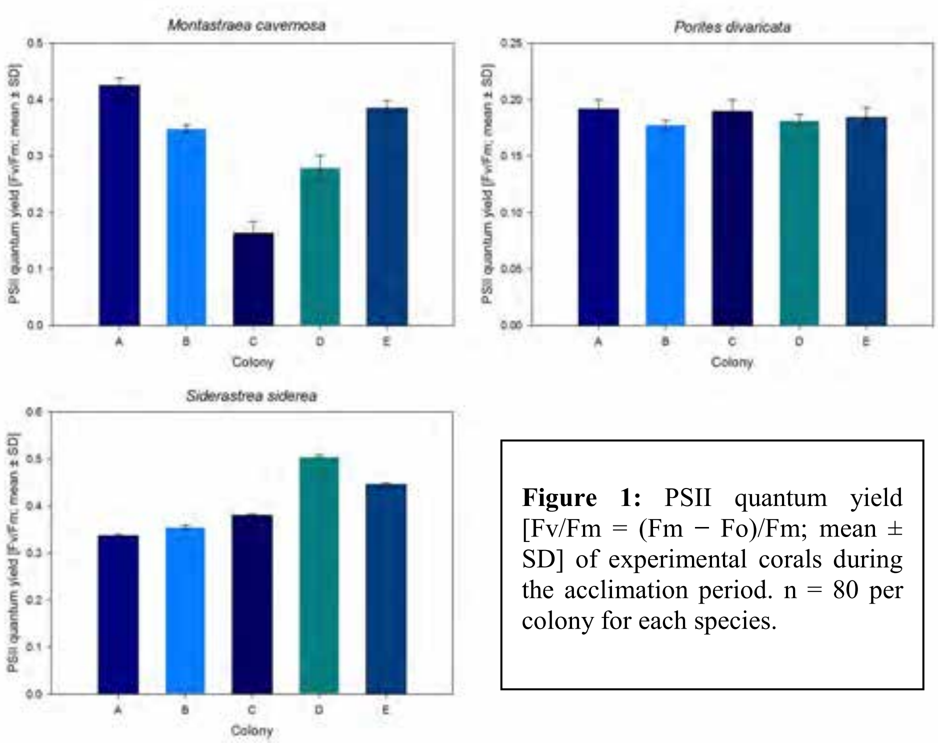

Figure 1: PSII quantum yield [Fv/Fm = (Fm − Fo)/Fm; mean ± SD] of experimental corals during the acclimation period. n = 80 per colony for each species.

Research Performance Measure: This is a 2-year project and currently it is still in Year 1. Due to processing delays, the project was not funded until 11/17/2014. Thus, the end date was extended until 9/30/15. Year 1 of this 2 year project is currently on track for completion by that date. We have compiled nitrate data, set up the experimental systems utilizing the chosen nitrate concentrations, and collected the needed experimental corals. The corals are acclimating in the onshore nursery, and pre-exposure baseline data collection is underway (Fig. 1).

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Marine Mammal Program Support

Project Personnel: J. Wicker (UM/CIMAS)
NOAA Collaborators: L. Garrison, A. Martinez and J. Contillo (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: 1) To assist the SEFSC's Protected Resources and Biodiversity Division through data collection and management within the Marine Mammal Program.

Strategy: 1) To perform field work and data management during marine mammal sampling efforts in the Gulf of Mexico and Atlantic Ocean. 2) To lead surveys within the Southeast Atlantic Marine Mammal Assessment Program and collect data on the abundance, habitat, and spatial distribution of cetaceans within U.S. waters. 3) To support Southeastern Gulf of Mexico Sperm Whale Study II by collecting biopsy samples, photographic data, acoustic data and visual data. 4) To assist on the Biscayne Bay's bottlenose dolphin population long term photo-identification study

CIMAS Research Theme:

***Theme 7*:** Protection and Restoration of Resources
***Theme 3*:** Regional Coastal Ecosystem Processes

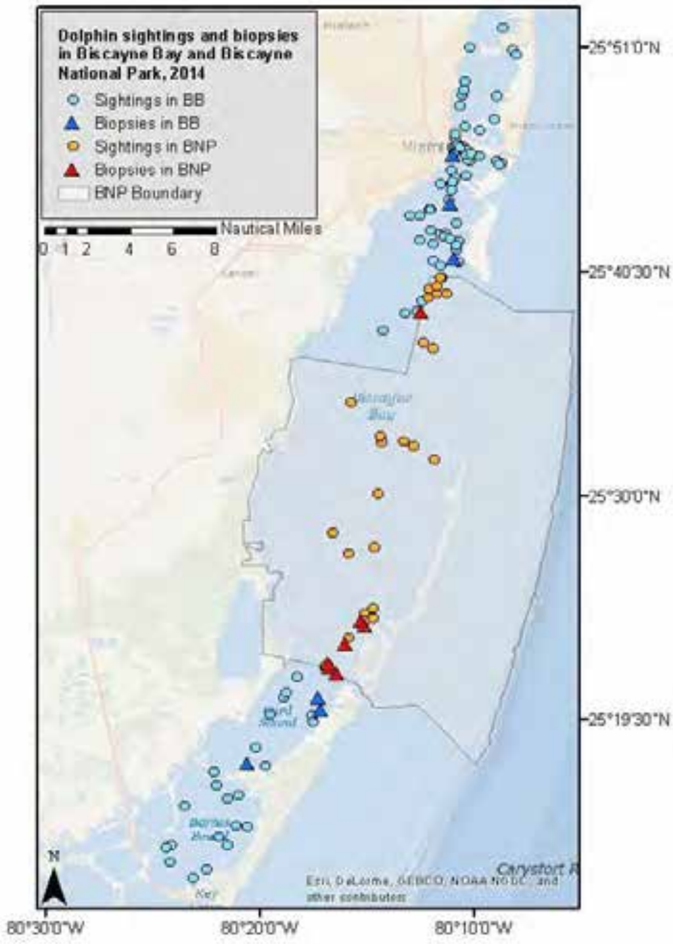
Link to NOAA Strategic Goals:

***Goal 1*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: NMFS/SEFSC **NOAA Technical Contact:** Theo Brainerd

Research Summary:

The National Marine Fisheries Service (NMFS) is responsible for monitoring the populations of marine mammals in the southeastern United States waters. Wicker supported research projects in the Gulf of Mexico and Atlantic Ocean resulting inover 173 marine mammal sightings, 18 biopsy samples, and 2,000 (km) of visual survey effort. The summer 2014 Southeastern Gulf of Mexico Sperm Whale Study II assessed the abundance, habitat and spatial distribution of Sperm Whales through visual and passive acoustic monitoring, satellite telemetry tags and biopsy sampling.



Research Performance Measure: All objectives were completed on time.

(1) Conducted Pre and Post cruise planning and supported the development of procedures and protocols for marine mammal research cruises with a focus on passive acoustic and photographic data collection and management.
(2) Served as a small boat coxswain onboard NOAA ship Gordon Gunter during the marine mammal large vessel survey during the summer of 2014.
(3) Assisted in the development of cruise plans and lead survey teams while in the field.
(4) Maintained and verified data quality, interacting with principal investigators to effectively execute scientific methodology during the cruises.
(5) Managed and updated the Biscayne Bay Photo ID Database and continued to import historical data into FinBase database
(6) Assist in NOAA small boat field work.

Figure 1: Dolphin Sightings in Biscayne Bay.

VII. EDUCATION AND OUTREACH

CIMAS research has, since its inception, worked hard in integrating its core science activities with the educational enterprise through the RSMAS graduate academic program. After the expansion of CIMAS to additional University partners, CIMAS has expended this link to other academic programs in other Partner Universities. The major example of this expansion in Formal Education is the USF Marine Resource Assessment program supported through CIMAS by an award from the National Marine Fisheries Service.

Formal Education Activities

The USF Marine Assessment Graduate Program

An update of the entire MRA program period is provided below to create a complete record of its curriculum and graduate-student activities. The following courses were developed for the MRA program as part of the present award's Statement of Work. "Florida FWC" refers to employees of the Florida Fish and Wildlife Conservation Commission. USF MRA students supported by NOAA-sponsored fellowships under the present award are identified by a double asterisk (**); these fellowships first became available during Fall 2011.

MRA Core Courses

Fish Biology, taught Spring 2009 (course was taught prior to present award as part of the MRA program) by Ernst Peebles, David Mann and Joseph Torres of USF-CMS (19 students, including 4 agency employees - 21% agency)

USF students: Heather Broadbent, Aaron Brown, Christine Cass, Lindsey Flynn, Danielle Greenhow, Sennai Habtes, Mark Hartman, Lara Henry, Sheri Huelster, Eloy Martinez, Monica Mion, Erica Ombres, Kara Radabaugh, Holly Rolls, Carrie Wall

Florida FWC students: Kelley Kowal, Christy Stephenson, Laura Wiggins

NOAA students: Catherine (Bruger) Hayslip (NMFS SERO, St. Petersburg)

This course was taught for the second time during Spring 2012 by Christopher Stallings, Ernst Peebles, and Joseph Torres of USF-CMS. (14 students, including 6 agency employees – 43% agency)

USF students: Dinorah Chacin, Michael Drexler **(formerly FWC), Alisha Gray, Joshua Kilborn**, Orian Tzadik (formerly FWC)**, Amy Wallace**, Sky Williams (part-time FWC), Maria Vega-Rodriguez

Florida FWC students: Christopher Bradshaw, Michael Murphy, Beverly Sauls, Dustin Addis (audited)

US Coast Guard students: Aron Kaloostian (Marine Science Technician, USCG)

NOAA students: Mary Janine Vara (NMFS SERO, St. Petersburg)

This course was taught for the third time during Spring 2014 by Christopher Stallings and Ernst Peebles of USF-CMS. (28 students, including 3 agency employees – 11% agency)

USF students: Erik Anderson, Emily Chancellor, Marcy Cockrell**, Joseph Curtis, Kristina Deak, Lindsey Dornberger, Jenny Fenton, Ileana Freytes-Ortiz, Sarah Grasty, Elizabeth Herdter, Jacquelin Hipes, Brock Houston, Stephanie Lawlor, Timothy Lee, Kaitlyn Lizza,

Michelle Masi, Leo Meirose, Garrett Miller, Morganne Morrison, Tiffany Nicholson, Michael Sipes, Susan Snyder, Lindsey Sorg, Kara Wall, Lena Wray
Florida FWC students: Oscar Ayala, Benjamin Kurth
NOAA students: Katie Davis (NMFS SERO, St. Petersburg)

Fish Population Dynamics, taught August 2010 by Dr. Jim Berkson (USF Courtesy Associate Professor) with Co-Instructors Dr. Katie Andrews (NMFS, SEFSC, Panama City Lab), Dr. Brian Linton (NMFS, SEFSC, Miami Lab), Dr. Shannon Cass-Calay (NMFS, SEFSC, Miami Lab), Dr. Steve Cadrin (University of Massachusetts at Dartmouth), and Dr. Rick Hart (NMFS, SEFSC, Galveston Lab)(13 students, including 8 agency employees – 62% agency)
USF students: Claudia Baron-Aguilar, Sennai Habtes, Sheri Huelster, Elon Malkin, Kara Radabaugh
Florida FWC students: Christopher Bradshaw, Angela Collins, Claire Crowley, Anne Dowling, Michael Drexler, Michael Murphy, Holly Rolls, Beverly Sauls
NOAA students: none

This course was taught for the second time during Fall 2012 by Cameron Ainsworth of USF-CMS (24 students, including 3 agency employees - 13% agency)
USF students: Dinorah Chacin, Emily Chancellor, Marcy Cockrell**, Lindsey Dornberger, Jenny Fenton, Jennifer Granneman, Sarah Grasty, Alisha Gray, Elizabeth Herdter, Jacquelin Hipes, Brock Houston, Joshua Kilborn**, Lucy Sprung, Timothy Lee, Kaitlyn Lizza, Matthew McCarthy, Michelle Masi, Susan Snyder, Paul Suprenand, Orian Tzadik**, Amy Wallace**, Sky Williams
Florida FWC students: Beverly Sauls, Lucy Sprung
NOAA students: Mary Janine Vara

This course was taught for the third time during Fall 2014 by Cameron Ainsworth of USF-CMS (8 students, including 5 agency employees - 63% agency)
USF students: Joseph Curtis, Brianna Michaud, Kara Wall
Florida FWC students: Oscar Ayala, Brittany Combs, Benjamin Kurth, Claire Crowley
NOAA students: Katie Davis (NMFS SERO, St. Petersburg)

Applied Multivariate Statistics, taught Spring 2010 by David Mann and David Jones of USF-CMS (13 students, including 4 agency employees - 31% agency)
USF students: Brian Barnes, Regina Easley, Lindsey Flynn, Adrienne George, Sennai Habtes, Mark Hartman, Sheri Heulster, Elon Malkin, Leslie Wade
Florida FWC students: David Chagaris, Claire Crowley, Holly Rolls
NOAA students: Catherine (Bruger) Hayslip (NMFS SERO, St. Petersburg)

This course was taught for the second time during Fall 2011 by David Jones and David Mann of USF-CMS (18 students, including 4 agency employees - 22% agency)
USF students: Dinorah Chacin, Michael Drexler (formerly FWC)**, Alisha Gray, Joshua Kilborn**, Natasha Mendez-Ferrer, Juan Millan, Kara Radabaugh, Benjamin Ross, Paul Suprenand, Orian Tzadik (formerly FWC)**, Maria Vega-Rodriguez, Amy Wallace**, Sky Williams, Bo Yang

This course was taught for the third time during Spring 2015 by David Jones of USF-CMS (8 students, including 1 agency employee - 13% agency)

USF students: Steven Douglas, Michelle Hoffman, Kimberly Lyons, Jason Richardson, Shaojie Sun, KaraWall, Mengqui Wang
Florida FWC students: none
NOAA students: Katie Davis (NMFS SERO, St. Petersburg)

Dynamics of Marine Ecosystems, taught Spring 2011 by Kendra Daly and Mark Luther of USF-CMS (9 students, including 4 agency employees - 44% agency)

USF students: Natasha Mendez-Ferrer, Benjamin Ross, Mark Squitieri, Tonu Toomepuu (audited), Sky Williams
Florida FWC students: Claire Crowley, Matthew Garrett, Richard Knudsen
NOAA students: Catherine (Bruger) Hayslip (NMFS SERO, St. Petersburg)

This course was taught for the second time during Spring 2013 by Kendra Daly and Mark Luther of USF-CMS (13 students, including 2 agency employees - 15% agency)

USF students: Mary Abercrombie (audited), Lucy Bartlett, Jenny Fenton, Ileana Freytes-Ortiz, Jennifer Granneman, Jacquelin Hipes, Brock Houston, Eddie Hughes, Joshua Kilborn**, Tim Lee, Mathew McCarthy
Florida FWC students: Michael Murphy, Brittany Combs
NOAA students: none

This course was taught for the third time during Spring 2015 by Kendra Daly and Mark Luther of USF-CMS (8 students, including 1 agency employee - 13% agency)

USF students: Oscar Ayala, Kate Dubickas, Megan Hepner, Selena Johnson, Michelle Michaud, Ann Sager, Elizabeth Simpson
Florida FWC students: none
NOAA students: Katie Davis

MRA Elective Courses

Fishery Ecology Reading Group, taught Fall 2011 by Chris Stallings, Cam Ainsworth, Ernst Peebles and Steve Murawski of USF-CMS (9 students, including 3 agency employees - 33% agency).

USF students: Dinorah Chacin, Michael Drexler (formerly FWC)**, Alisha Gray, Joshua Kilborn**, Orian Tzadik (formerly FWC)**, Amy Wallace**
Florida FWC students: Christopher Bradshaw, Beverly Sauls, Julie Vecchio
NOAA students: none

Ecosystem Modeling, taught Fall 2013 by Cam Ainsworth of USF-CMS (32 students, including 21 agency employees – 66% agency).

USF students: Emily Chancellor, Marcy Cockrell**, Lindsey Dornberger, Michael Drexler**, Kristen Emrich, Jennifer Granneman, Sarah Grasty, Elizabeth Herdter, Joshua Kilborn**, Timothy Lee
University of Miami student: Matt Nuttall
Florida FWC students: Wade Cooper, Claire Crowley, Michael Murphy

NOAA students (from 10 NMFS labs): Ariel Poholek, Derrick Alcott, Arnaud Gruss, Amy Uhrin, Jason Rumholz, Jennifer Samson, Joan Browder, Glenn Zapfe, Skyler Sagarese, Jennifer Leo, Kate Andrews (Seigfried), Mandy Karnauskas, Harmon Brown, Adam Schlenger, Emily Gardner, Matthew Campbell, Kevin Purcell, Kimberly Clements

Note: This course introduced NOAA, USF, UM and FWC students to a variety of approaches for quantitative modelling of marine ecosystems. Remote students participated in the course in real time via a two-way audio-visual connection using multi-party video conferencing. We offered an accredited certificate of completion signed by USF and the Ecopath with Ecosim consortium. 18 NOAA employees took the course, including participants from the following laboratories: Beaufort, NC; Sandy Hook, NJ; Miami, FL; Stamford, CT; Pascagoula, MS; Galveston, TX; Panama City, FL; Woods Hole, MS; La Jolla, CA; St. Petersburg, FL. Tuition was waived for all NOAA FTEs and contractors. This was done above and beyond our contractual requirement to provide training to NOAA employees. Such an arrangement is not necessary with state institutes like FWC since their employees are entitled to enroll in 6 credit hours per term under the State of Florida Educational Assistance Program. Course material was particularly relevant to NOAA employees participating in the Integrated Ecosystem Assessment (IEA) program, Marine Spatial Planning (MSP) program, or various FATE programs. However, any NOAA employee engaged in stock assessment could benefit as ecosystem interactions can be considered in the stock assessment process: for example, as part of Tier 3 next-generation stock assessments, as part of ecosystem consideration chapters, or in ecosystem terms of reference.

Special Topics in Biometry, taught Fall 2014 by David Jones of USF-CMS (11 students, including 2 agency employees - 18% agency)

USF students: Sean Beckwith, Dinorah Chacin, Marcy Cockrell, Joseph Curtis, Brock Houston, Abdiel Laureano-Rosario, Tasha Snow, Kara Wall, Mengqui Wang *Florida FWC students:* Benjamin Prueitt

NOAA students: Katie Davis (NMFS SERO, St. Petersburg)

MRA Graduates (All Years)

Claire Crowley (M.S., Spring 2012); employed by FWC FWRI
Catherine (Bruger) Hayslip (M.S., Fall 2013); employed by NMFS SERO
Beverly Sauls (M.S., Fall 2013); employed by FWC FWRI
Sky Williams (M.S., Fall 2013); North Pacific Groundfish Observer at Saltwater Inc.
Alisha Gray (M.S., Spring 2014); employed by FWC FWRI
Mary Janine Vara (M.S., Spring 2014); employed by NMFS SERO
Brittany Hall (M.S., Summer 2014); employed by FWC FWRI
Holly Rolls (Ph.D., Summer 2014); employed by FWC FWRI
Dinorah Chacin (M.S., Summer 2014); continuing in MRA program as Ph.D. student
Susan Snyder (M.S., Fall 2014); continuing in MRA program as Ph.D. student
Sennai Habtes (Ph.D., Fall 2014); employed by FWRI stock assessment group
Elizabeth Herdter (M.S., Fall 2014); continuing in MRA program as Ph.D. student
Sarah Grasty (M.S., Fall 2014); continuing in MRA program as Ph.D. student

RESEARCH HIGHLIGHTS – MRA FELLOWSHIP RECIPIENTS:

During the past year, five doctoral students were supported by fellowships under the present award. Below are highlights of each of the student's doctoral research projects.

Marcy Cockrell (advisor: Dr. Steve Murawski): Development of a decision-support framework for implementing marine protected areas on the West Florida Shelf.
Marcy has been working on a project jointly funded by NOAA and the National Science Foundation to understand choice behavior of where and when to fish and what species to target. This research has used accumulated satellite tracking data (>28 million position records) of reef-fish fishing vessels in the Gulf of Mexico. Data analyzed to date indicate significant spatial patterning and a significant habitual component to areas fished. Working with economists from the University of California, Davis, the research will include economic models of fisher's choice as well as the development of metrics of the degree of entropy in spatial fishing patterns. The attached figure provides spatial information for the number of site locations visited by one minute of latitude and longitude for the second half of 2009.

Michael Drexler (advisor: Dr. Cameron Ainsworth): An Atlantis model for the Gulf of Mexico (Atlantis-GoM):
Ecosystem-based management strategies for the Gulf of Mexico are being developed in support of NOAA's Integrated Ecosystem Assessment (IEA) Program. Integrating ecosystem considerations into fisheries management is a current scientific and policy priority for our NMFS partners. While the goals of the IEA process are broad and may be reached through a myriad of management strategies, Marine Protected Areas (MPAs) have the potential to impact multiple desired management outcomes.

For his research, Mike will continue to develop the Atlantis-GOM ecosystem model, incorporating all of the best information available through a network of federal and state collaborators. In addition, he has developed sub-models that estimate adult abundance across the entire GoM via habitat modeling and long-term population connectivity based on physical transport. These models will be incorporated into the larger Atlantis-GoM model and used to perform a spatially based management strategy evaluation, testing the expanded use of MPAs throughout the GoM and their connectivity across multiple species. The results from these simulations will improve our understanding of how spatially based fisheries management strategies affect ecosystems and provide strategic management advice regarding MPAs in the GoM.

Mike has completed one manuscript that examines altered larval dispersal patterns resulting from exposure to oil from the Deepwater Horizon event, and another that details results for an individual-based-model of larval transport in the Gulf of Mexico. He has recently taken a full-time job at the Ocean Conservancy, but continues to make good progress on his dissertation.

Joshua Kilborn (Co-advisors: Dr. David Naar and Dr. Ernst Peebles): Projecting longline CPUE using SEAMAP trawl catch composition and dynamic environmental factors.
Joshua is developing new multivariate techniques to identify statistically distinct communities of groundfishes on the West Florida Shelf (WFS), as represented by the Southeast Area Monitoring

and Assessment (SEAMAP) summer groundfish trawl surveys (2010-2013). Discrete community types are being examined for stability in space and time and are being associated with environmental parameters. A second, independently collected dataset, produced by National Marine Fisheries Service longline sampling in the summer months of 2010-2012, is being examined as well to identify spatiotemporal correlations between high catch-per-unit-effort (CPUE) for longline catch and the previously identified groundfish community/environment types. The goal of the project is to produce a predictive model that can forecast likely distributional changes in longline-associated species based on the SEAMAP trawl data and dynamic environmental variables. The model predictions can be used to increase the efficiency of future index surveys and to inform managers of the effects of changing biotic and abiotic conditions on the WFS.

Orian Tzadik (advisor: Dr. Christopher Stallings): Non-lethal alternatives to otoliths for application to juvenile groupers.
Ori is developing new, non-lethal approaches to retrospective analysis of individual fish life histories, including the history of such characteristics as movement and shifts in trophic position. This project is currently being applied to the Goliath Grouper other species of management concern in the Gulf of Mexico. More information on his project can be found at http://www.juvenile-grouper-project.com/index.php?subject=articles&page=7

Amy Wallace (advisor: Dr. Ernst Peebles): New methods for reconstructing site fidelity, movement, and trophic histories for predatory fishes in the Gulf of Mexico.
This project has developed new, stable-isotope-based method for reconstructing lifetime site fidelity and trophic position histories of individual fish using eye lenses as conservative isotope recorders (manuscript submitted). The first chapter of her dissertation was published in *PloS One* during 2014 – it is the first publication ever to address fish eye lenses and lifetime isotopic records. Additional efforts are underway to provide information that will improve the power and accuracy of the method.

RSMAS Graduate Education

For many decades, the Rosenstiel School of Marine and Atmospheric Science has offered graduate instruction leading to the Doctor of Philosophy (Ph.D.) and Master of Science (MS) degrees and the success of this program in serving the needs of NOAA has been highlighted in previous CIMAS annual reports. In 2014, RSMAS was restructured into a departmentalized school. New Ph.D. and MS degrees within the five new departments are offered in Atmospheric Sciences, Marine Biology and Ecology, Marine Ecosystems and Society, Marine Geosciences, and Ocean Sciences. Interdisciplinary, cross-departmental programs such as Meteorology and Physical Oceanography and Marine Biology and Fisheries will continue to remain a strength of the RSMAS program. Currently there are close to 200 students enrolled in the RSMAS PhD and MSc programs, 80% of whom are in the Ph.D. programs.

In addition to the involvement of CIMAS in the formal RSMAS graduate curriculum, CIMAS also funds and coordinates specialized training activities of interest to NOAA and CIMAS scientists and local students. Often a national or international expert is invited to cover a methodological topic of special relevance to NOAA science. In the last year CIMAS has supported a training workshop on Nonlinear Time Series Modelingwith a number of invited speakers from various Universities: George Sugihara and Hao Ye, Scripps Institution of Oceanography, Sarah Glaser, Korbel School of Int'l Studies, University of Denver, Hui Liu, Department of Marine Biology Texas A&M at Galveston and William Harford, Univerity of Miami; and a few NOAA scientists: Steve Munch, NOAA Southwest Fisheries Science Center and Mandy Karnauskas and John Walter, NMFS, Southeast Fisheries Science Center CIMAS students, post-docs and researchers participated in the workshop along NOAA scientists from the SEFSC laboratory. Outside participants from other Universities and NOAA labs joined the workshop through webinar. The two-day workshop was held March 19th and 20th, 2015 at the CIMAS. The workshop explored the use of nonlinear time series modeling and current applications in biological oceanography and fisheries science. The first day of the workshop consisted of seven presentations by experts from academia and government agencies. Presentations facilitated identification of current methodological challenges and current research needs, which subsequently formed themes for discussion on the second day of the workshop. Workshop participants also developed a work plan for a collaborative project to explore how nonparameteric (model free) time series methods could be used in fisheries management policies. The workshop attendance was 40-50 people with an additional ten people attending via webinar.

Many Ph.D. and M.S. graduates from RSMAS have joined the NOAA workforce, mainly at the NOAA AOML and SEFSC laboratories and at NOAA headquarters but also at other NOAA laboratories throughout the nation. This training pipeline for NOAA jobs was greatly facilitated by CIMAS activities such as 1) collaborative research teams of faculty, NOAA and CIMAS scientists and graduate students; 2) funding of graduate students with the support of NOAA fellowships and graduate research assistantships; and 3) participation of NOAA scientists in student mentoring training and teaching of graduate level courses 4) promoting Post-doc opportunities associated with NOAA labs and 5) funding students to participate in professional experiences along with NOAA scientists attending fish stock assessment meetings associated with the US fishery council process and ICCAT. Note that only those joining the NOAA associated workforce that are CIMAS employees (as scientists or post-docs) appear in our annual report. Another aspect of the connection with UM through CIMAS is that CIMAS employees working at the adjacent laboratories are eligible for tuition remission. Many have obtained M.S. degrees during their employment period and a smaller number have graduated from (and are currently enrolled in) the RSMAS Ph.D. programs. Tuition waivers are not provided UM employees for terminal degrees (Ph.D., J.D., M.D.) but a few CIMAS employees have even received a waiver exempting them from all tuition requirements for their Ph.D. work. In all these cases, their thesis or dissertation work overlaps and complements their primary CIMAS duties.

Since 2010, the University of Miami has run a Master of Professional Science (MPS) program intended for students who seek advanced training in marine and atmospheric science, while also cultivating a blend of team-building and communication skills, legal and regulatory knowledge, and business savvy, that should be highly valued by potential employers. In addition to two semesters of intensive course work, this program offers internships in relevant government NGOs and businesses. Most of the MPS tracks are relevant to NOAA. Examples include: computational meteorology and oceanography, exploration science, fisheries management and conservation, marine aquaculture, tropical marine ecosystem management, marine conservation, coastal zone management and weather forecasting. This program now has an enrollment of about 120 students and some of these students complete their internships in NOAA labs or collaborate with NOAA scientists, in some cases supported by CIMAS funds in other cases directly funded by NOAA. Selected students also engage in professional activities during their courses such as attending scientific meetings of the NOAA South East Data Assessment and Review.

RSMAS Undergraduate Education

The Rosenstiel School offers two undergraduate degree options, a Bachelor of Science in Marine and Atmospheric Science with majors in Marine Science or Meteorology and a Bachelor of Arts in Marine Affairs. In academic year 2014, more than 100 students enrolled in the program. The BSc students earn dual majors in Marine Science and, for example, Biology, Chemistry, Physics, Mathematics or Geology, and have among the highest GPA and SAT scores of all undergraduate programs at the University of Miami. The MSC curriculum is designed to take full advantage of the University's subtropical location, with year-round access to a variety of specialized marine environments including the deep ocean waters offshore, the coral reef tracts of the Florida Keys, and the estuarine sea grass beds and mangrove shoreline of South Florida. The transfer of the administration of this program to RSMAS in 2007 has created a more vibrant undergraduate experience for students and enhanced opportunities for undergraduate research. Many of these research experiences take advantage of the ongoing research collaboration between RSMAS and the AOML and SEFSC NOAA labs that are available through CIMAS.

RSMAS contributions to the MAST Academy and other local High Schools

Starting in 1984 the Rosenstiel School and CIMAS have participated in a high school apprenticeship program made possible through NOAA funding. Students participate in summer internships at AOML and SEFSC. This activity is carried out through a Miami-Dade County "magnet" school, the MAST Academy (Maritime and Science Technology High School) which is located on Virginia Key, only a few hundred meters from CIMAS and the NOAA laboratories. http://mast.dade.k12.fl.us/

The MAST Academy curriculum is organized around a marine theme. The school has been recognized by the U. S. Department of Education with a Blue Ribbon School of Excellence and by Business Week magazine as one of seven most innovative schools of choice in the nation. The total enrollment is 550 in grades 9-12. The school has a broad cultural-ethnic mix of students: 36% Caucasian; 32% African American; 29% Hispanic; 3% Asian. Approximately 94% of the students eventually enroll in college. MAST students excel according to traditional measures of student performance, exceeding national averages on the PSAT, SAT, and ACT. In past years, the school has received an "A" rating from the Florida Department of Education.

RSMAS participates in education-related activities at MAST by providing faculty and graduate students, including CIMAS-linked personnel, to deliver lectures and to teach courses. Every summer, 12-18 students are selected to participate in summer research programs supported through CIMAS. The students assist in programs at AOML and SEFSC as well as at RSMAS. In addition to the summer program, CIMAS hires MAST students during the course of the year. As a result of these activities MAST students have co-authored papers with RSMAS and NOAA scientists; students have attended national conferences and presented the findings of their research.

MAST is one of three schools involved with the RJ Dunlap Marine Conservation Program. The RJ Dunlap is a collaborative, multi-disciplinary research and education program that exposes students to marine science field research. They focus on the study and conservation of coastal Florida shark species, mangrove fish habitats, and the Florida watershed through in-service learning, education and research (see below). MAST students have also participated in other field programs, for example in a comprehensive habitat study of Biscayne Bay. In this way, the School and CIMAS scientists have developed a solid working and teaching relationship with the MAST Academy.

In addition to MAST students, we have students from other high schools participating in CIMAS - NOAA activities. Here we cite a few examples:

- Assisted in the NMFS-SEFSC fish tagging program. Prepared tagging kits for distribution to fishery constituents, coding incoming tagging data, data entry of both tag release and tag recapture, and interacting with constituents about tag requests and tag recovery reports.
- Assisted in sorting and identifying postlarval pink shrimp from the Florida Bay program and working with bird by-catch data.
- Assisted in downloading sea-surface temperature (SST) data from the NOAA Coast Watch web site and using it in analyses of fisheries and environmental data.
- Assisted in a study modeling connections between life stages and habitats of pink shrimp in South Florida.
- Assisted in using bioinformatics software in a study to identify, detect, and quantify microbial contaminants in coastal waters. Students worked on the development of a microbial contaminant database using FileMaker Pro Software.

Enhancing Minority Participation in NOAA Relevant Science

The National Oceanic and Atmospheric Administration (NOAA) established research and education centers to advance the community of under-represented minority scientists in the US and, especially, in the NOAA workforce. UM participates in this program under the leadership of Dr. David Die, CIMAS Associate Director, who is also the UM P.I. of the Living Marine Resources Cooperative Science Center (LMRCSC). This center is aligned with NMFS and therefore has as its objectives:

(1) prepare the future workforce in marine and fisheries sciences,
(2) strengthen collaborations across universities to enhance academic programs in marine and fisheries sciences,
(3) develop an exemplary capacity for scientific collaborations among partner institutions in the fields of marine and fisheries sciences.

As one of the three research-based University partners in the LMRCSC, UM involvement in the Center has been focused on increasing diversity among participants in the UM PhD programs in the following areas: Quantitative Fisheries Science, Fisheries socio-economics, Fisheries Habitat and Aquaculture. Although the program is not funded directly through CIMAS, Dr. Die's educational role within CIMAS supports the activities of the LMRCSC and CIMAS often funds part of the research and studies of the LMRCSC students who are housed in CIMAS when in residence in Miami. Moreover the participation of US Caribbean universities in CIMAS benefits the LMRCSC by enhancing the recruitment of a diverse student body. Through this program RSMAS has hosted undergraduate summer internship students from Universities outside the LMRCSC partnership as well.

Public Outreach and Informal Educational Activities Associated with Specific CIMAS Research Projects

CIMAS emphasizes that all projects should take advantages of opportunities for reaching users of its science outputs through outreach activities. These activities can use broad and innovative mechanisms such as the new web product *Publiscize* (www.publiscize.com), or may be project specific. *Publiscize* is a free service that helps scientists formulate their peer-reviewed articles into layperson summaries. The goal is to reduce science miscommunication and increase science awareness by helping scientists formulate their own research while spreading it throughout social media. Publicize has been developed by a RSMAS postdoc, Dr. Robert Seigel. An example of one such summary from a RSMAS PhD candidate can be seen at http://www.publiscize.com/scinopsis/caribbean-cooperation-conserve-lobsters. This summary is based on a single peer-reviewed journal article and also has a link back to the original journal article to help increase web traffic. Each article has a unique URL for the scientist to place on their CV, webpage, etc. A number of CIMAS projects are already contributing to Publiscize.

In addition CIMAS projects have their own specific outreach components, listed in the section below according to project names:

Western Boundary Time Series Project

- Television interview on the Gulf Stream - RTE public broadcasting channel, Ireland.

Southwest Atlantic Meridional Overturning Circulation ("SAM") Project

- C. Meinen gave a science seminar on SAM results to students at the University of Sao Paulo (Brazil) in October 2014.
- R. Perez participated in several K-12 outreach events at UM/RSMAS, NOAA/AOML, and local schools, participated in a panel discussion on Sea Level Rise attended by young professionals, and mentored 3 high school students for a week during the summer of 2014.

Developing Decision Support Tools for Understanding, Communicating, and Adapting to the Impacts of Climate on the Sustainability of Coastal Ecosystem Services

- Brad Klotz served on the 2015 Review Panel for NOAA Ernest F. Hollings and Educational Partnership Program Undergraduate Scholarship Programs.
- Co-PI Kelble's related project work received coverage in the Miami Herald, Local & State section, on Monday May 4th. The article, entitled *Dry Winter, slow Glades progress put Florida Bay at risk*, written by Jenny Staletovich of the Herald, and includes quotes from

Kelble concerning the impact of climate on precipitation and how elevated salinity in Taylor Slough (which flows into our central study region, Florida Bay) was due to an unseasonably dry winter, and how that can have downstream effects on the biotic components of our central sub-region.

Assessing Inertial Effects on Surface and Subsurface Drifting Buoy Motion

- Olascoaga participated at the UM/RSMAS Exploring Marine Science for Miami middle school female students. She imparted a lecture on oceanography covering various aspects including Lagrangian measurements on the surface ocean.
- Beron-Vera, Olascoaga and Goni are in the PhD committee of Yan Wang, of UM/RSMAS.

Hurricane Risk to U.S. Offshore Renewable Energy Facilities

- Department of Energy Webinar on Offshore Wind Energy: Characterizing Hurricane MET-Ocean conditions for design of offshore wind farms, January 15. Dr. Powell was one of three presenters.
- Dr. Powell conducted a review of the IEC international standard for relevance to Hurricane Design conditions. March 2015.

Re-analysis of the Atlantic Basin Tropical Cyclone Database in the Modern Era

- Delgado, S., 2014: Reanalysis of the 1954-1963 Atlantic hurricane seasons, HRD Monthly Science Meeting (Talk given 11 Sep. 2014).
- Delgado, S., 2014: Reanalysis of the 1954-1963 Atlantic hurricane seasons, National Climatic Data Center, Asheville, NC (Talk given 9 Oct. 2014).

High-Frequency Variability of Near-Surface Oceanic Velocity from Surface Drifters

- R. Lumpkin and R. Perez participated in making several videos about the drifter program and other NOAA/AOML and CIMAS research projects that appear on AOML's YouTube channel, https://www.youtube.com/user/phodaoml.
- R. Lumpkin and R. Perez participated in the NOAA/AOML Open House in May 2015.
- R. Perez participated in *Oceanography Supplement* on Women in Oceanography (non-peer reviewed).
- All project personnel participate in K-12 and general public outreach events.

Ocean Indicators in the Tropical and South Atlantic Ocean

- A web page dedicated to provide access to ocean indices and indicators produced by this project was implemented: http://www.aoml.noaa.gov/phod/indexes/.
- G. Goni mentored Ms. Michele Mestres, a summer high school student from MAST (Marine & Science Technology) High School of Miami, who completed a 9 week internship at AOML working on applications of underwater glider data. She completed her internship with a written report and oral presentation.
- Several outreach activities included providing tours of the AOML facilities including in August 2014 for RSMAS undergraduate students, in July 2014 a tour for congressional staffers.
- G. Goni and other divisional scientists worked in the creation of project videos now hosted on the PHOD web site (AOML XBT network, AOML Argo, AOML SAM, underwater glider projects, etc).

- J. Beron-Vera and G. Goni are in the Ph.D committee of Yan Wang, of the University of Miami.
- G. Goni, R. Perez and M. Goes participated in the NOAA Open House from May 14-16. They presented oceanographic concepts (MOC, ocean currents, etc.) and explained some of the instrumentation used at NOAA/AOML to students from local communities, members of the public and staff from a local senator's office.

The North American Multi-Model Ensemble (NMME) Intraseasonal-to-Interannual Prediction Experiment

- The results of the NMME project being served in graphical form only by CPC (http://www.cpc.ncep.noaa.gov/products/NMME/), and the digital data are being served at the IRI (http://iridl.ldeo.columbia.edu/SOURCES/.Models/.NMME/) and by NCAR ESG. The CPC site primarily serves the real-time needs of the project, and the IRI site, along with the analysis tools that are being developed at the IRI (http://iridl.ldeo.columbia.edu/home/.tippett/.NMME/.Verification/), primarily serves research needs in terms of assessing the prediction skill and predictability limits associated with phase-I and in terms of designing the phase-II experimental protocol. While the phase-I data is limited to monthly mean data, it is a research tool (or test-bed) that is proving extremely useful in supporting the basic prediction and predictability research needs of the project participants. This database also serves as "quick look" easy access data that is the external face of the NMME experiment to the research community.

Global Drifter Program

- In conjunction with the Adopt A Drifter Program, S. Dolk participated in numerous educational outreach programs, working with middle schools around the world to deploy and track drifting buoys. Through these efforts, students learn about the impacts of ocean currents and how this information is used to track marine debris, spilled oil, fish larva, etc.
- R. Perez participated in several K-12 outreach events at UM/RSMAS, NOAA/AOML, and local schools, participated in a panel discussion on Sea Level Rise attended by young professionals, and mentored 3 high school students for a week during the summer of 2014. A list of R. Perez outreach activities include:
  1) Density and convection current demonstrations for AOML Open House (May 2015).
  2) Participated in the Bring Your Child to Work Day (Apr 2015).
  3) Attended the AAAS Communicating Climate Science Workshop (Mar 2015).
  4) Career Day presentations at Sunset Elementary (Feb 2015).
  5) Career Day presentations at Frank C. Martin International K-8 Center (Dec 2014).
  6) Conducted a density demonstration and effect of temperature and salt on density for Disability Awareness event at NOAA/AOML (Nov 2014).
  7) Gave a presentation on "Sea Level Rise" during a panel discussion entitled "The Future of Fort Lauderdale: Protecting our Paradise against Rising Seas and Stronger Storms" for the Broward County young professional community (Jul 2014).
  8) Mentored three MAST high school students for a week on developing a demonstration on buoyancy (Jul 2014).

NIDIS Apalachicola-Chattahoochee-Flint River Basin Drought Early Warning System

- Outreach and education is one of the core roles of the Florida Climate Center (FCC). The FCC coordinates the Community Collaborative Rain, Hail and Snow (CoCoRaHS) Network for the state of Florida, which trains and educates volunteers to observe rainfall. These data are used for monitoring drought conditions, as well as excessive precipitation across the state. In addition to the CoCoRaHS activities, members of the climate office staff have taken part in numerous outreach events across portions of the state, including weather and climate classrooms at elementary and middle schools, university open houses, and summer camps.
- In conjunction with NIDIS and other projects, the Florida Climate Center directs independent research projects for a number of undergraduate students at FSU. These research projects all deal with changing temperature and precipitation patterns across the Southeast U.S., which ties in with the NIDIS pilot objectives.

Using NOAA UAS Assets and OSSE/DA Capabilities to Improve Sampling Strategies and Numerical Prediction of Tropical Cyclone Track, Intensity, and Structure

- J. Dunion, Guest Speaker, Marlborough Elementary School, Marlborough, CT (April 2015)
- J. Dunion, Guest Lecturer, Cooperative Institute for Research in the Atmosphere (February 2015)
- J. Dunion, Guest Speaker, Marlborough Public Library, Marlborough, CT (July 2014)
- J. Dunion, Guest Speaker, Marlborough Elementary School Career Day, Marlborough, CT (June 2014)

The GO-SHIP Repeat Hydrography Program

- D. Pierrot, J. Wanninkhof, and C. Langdon are actively involved in the international coordination and data quality control of efforts such as GO-SHIP repeat hydrography.
- J. Zhang is actively involved in the Joint IOC-ICES Study Group on Nutrient Standards (SGONS)

Florida Area Coastal Environment (FACE) program

- T. Carsey, *Just beyond the shore: Observations of southeast Florida's coastal ocean*, at the Citizen Scientist lecture series, Key Biscayne, Florida, on 12-November-2015.
- J. Stamates and T. Carsey*, Estimating Nutrient Loading to the Coastal Ocean Through Tidal Inlets,* presented at the Institute of Electrical and Electronics Engineers 11th Currents, Waves and Turbulence Measurement Workshop in St. Petersburg, Florida, on 2-March-2015.
- J. Stamates and T. Carsey, at *The Watershed Scale Planning to Reduce Land Based Sources of Pollution for the Protection of Coral Reef Ecosystems in Southeast Florida* meeting at SFWMD headquarters, Palm Beach County, on 17-April-2015.
- M. Gidley*, Utilization of 16S Metagenomic Analysis and Molecular Microbial Source Tracking to Characterize the Microbial Diversity and Potential Influence from Land-Based Sources of Pollution for Sentinel Coral Reefs in Southeast Florida*. Presented at the New Orleans meeting of the American Society of Microbiology (May 31-June 4).

Elucidating Net Ecosystem Prediction and Calcification at the Atlantic Ocean Acidification Testbed

- We continue to run a Citizen Science Program with the Earthwatch organization. Results and activities in this coral reef monitoring program are incorporated into the training we perform. This K-12 outreach; undergraduate student activities; public awareness; etc. Three day-long training sessions took place in October 4 (2014) and on April 23rd and May 14th (2015).

Sustained and Targeted Ocean Observations for Improving Atlantic Tropical Cyclone Intensity and Hurricane Seasonal Forecasts

- Website: http://www.aoml.noaa.gov/phod/goos/gliders/:
  Users can obtain more information about the project, and access real-time data and other information from the glider's mission, such as the last reported location of the gliders and the latest observations collected.
- Brown-bag lunch seminar on the Sea Glider deployment and observations, held on AOML's 1st floor conference room on September 5th, 2014
- Project video: http://www.aoml.noaa.gov/phod/videos/load.php?varid=gliders_2014
  A video targeting the general public providing general information about the project.
- Dr. Gustavo Goni participated in CariCOOS annual meeting, which was held in San Juan PR during March 12-13, 2014. Dr. Goni presented the seaglider project (Task-2) to the Integrated Ocean Observing System (IOOS) Caribbean Community, and coordinated local activities in PR with the UPRM participants.

PIRATA Northeast Extension (PNE)

- G. Rawson has created several videos about PNE and other NOAA/AOML and CIMAS research projects that appear on AOML's YouTube channel,
  https://www.youtube.com/user/phodaoml.
- R. Lumpkin, R. Perez, and S. Dolk participated in the NOAA/AOML Open House in May 2015.
- G. Foltz and R. Perez are mentoring a Hollings Undergraduate Scholar, Allyson Rugg, from May 26, 2015 to July 27, 2015.
- R. Perez participated in *Oceanography Supplement* on Women in Oceanography (non-peer reviewed). Many of the project personnel listed participate in K-12 and general public outreach events.

Marine Optical Buoy (MOBY) Operations and Technology Refresh

- K.J. Voss participated in the Immaculata La Salle High School Career day, March 6, 2015.

Ocean OSSE Development for Quantitative Observing System Assessment

- Daily updated maps (7-day forecasts) for Sea Surface Height (SSH), Sea Surface Temperature (SST), temperature at 50m and surface currents are made publicly available at: http://coastalmodeling.rsmas.miami.edu/Models/View/FORECAST_SOUTH_FLORIDA_AND_FLORIDA_STRAITS

Evaluation of Management Strategies for Fisheries Ecosystems

- E.A. Babcock teaches a UM undergraduate course on Fisheries and Conservation Biology of the Galapagos. She is also a co-P.I. on a study, funded by Earthwatch, which takes volunteers, including high school students, to Glover's Reef Marine Reserve, Belize, to help with our shark research program.
- D. Die coordinated the participation of CIMAS students and NOAA-SEFSC scientists in FISHACKATHON 2014 that was hosted by Venture Hive in Miami. Fishackathon is part of the US Department of State "Our Oceans conference" looking to develop technological products applied to ocean conservation and fisheries management.
  http://www.state.gov/s/partnerships/fishackathon/

Linkages between coral health and LBSP: identifying sub-lethal coral response to environmentally realistic nutrient exposure.

- Nicole Odzer, a high school junior, has participated in the experimental set-up and assisted with water quality measurements. The project has received a considerable amount of public exposure as the SEACOR experimental system is located adjacent to the NSU coral nursery, and is thus included in facility and laboratory tours.

Use of the ecosystem model OSMOSE-WFS to explore the trophic structure of the West Florida Shelf in the 2000s, and to estimate natural mortality rates and simulate fishing scenarios for Gulf of Mexico red grouper (Epinephelus morio)

- The present project was presented to fisheries scientists and decision-makers involved in the SEDAR process during the SEDAR 42 Data Workshop held in November 2014.
- The main findings of the present project and other projects conducted within NOAA's Integrated Ecosystem Assessment program were presented at the ICES Annual Conference on September 18, 2014.

Caribbean Sea and Gulf of Mexico Bluefin Tuna Research

- Undergraduate students from the University of Miami's RSMAS participated in the project in research cruises, sample and laboratory processing: Kathryn Doering, Katherine Dale, Justin Suca and Gavin Dehnert. The students provided valuable research support in the early life history unit laboratory in various projects and facilitated technical assistance while having the opportunity for hands-on learning.
  Websites with educational information regarding the project and research survey:
  http://nfchroniclesnoaa.blogspot.com/
  http://www.aoml.noaa.gov/keynotes/keynotes_0415_nancyfostercruise.html
- During port visits, multiple "open house" activities took place in St. Thomas, USVI, Montego Bay, Jamaica and Cozumel, Mexico with overall 100 people touring the research vessel and its facilities.

Applying Bio-physical Monitoring and Capacity Assessments to Mesoamerican Reef Marine Protected Areas

- Websites were created and updated quarterly to promote public awareness and provide a venue for communication and exchanges:
  http://www.marfund.org/en/new_projects/second_connectivity_regional_workshop.html
  http://ocean-ecosur.com/index.php/vinculacion/12-vinculacion/5-workshop-1

Living on the (shelf) edge: using advanced glider technology to assess fishery resources along the South Atlantic continental shelf break

- Multiple posts of deployment activity by NOAA's National Ocean Service, SouthEast Coastal Ocean Observing Regional Association, and the Ocean Tracking Network.
- Data sharing achieved via SECOORA, attempted via IOOS National Glider DAC.

The importance of parrotfish on the maintenance and recovery of coral- dominated reefs

- We have partnered with the Marine Lab (a program of the Marine Resources Development Foundation, a 501(c)3 organization in Key Largo) to help train students in basic techniques in marine behavioral ecology. Burkepile's lab has also work with MAST@FIU, a math and science magnet school on FIU's BBC campus, to engage the students in marine biology and coral reef ecology. With these students, we have given classroom lectures, worked on fish dissections, and done field samplings and exercises. We have also given presentations at Foothill Elementary School in Goleta CA.

Gulf of Mexico Integrated Ecosystem Assessment

- 2015 Review Panel for NOAA Ernest F. Hollings and Educational Partnership Program Undergraduate Scholarship Programs.

Development of a Towed Camera System for Assessing Demersal Fish Stocks: C-BASS (Camera-Based Survey System): Phase II - Survey Implementation

- Grasty, S.E. 2014. Use of a towed camera system for estimating reef fish population dynamics on the West Florida Shelf. Oral presentation, American Fisheries Society Annual Meeting, August, 2014, Quebec City, Ontario, Canada.

Support for the Marine Resource Assessment Program at the University of South Florida College of Marine Science

- http://www.marine.usf.edu/students/degree-requirements/marine-resource-assessment
- http://www.aqua.org/~/media/Files/fisheries-report/addressing-uncertainty-in-fisheries-science-and-management-report.pdf
- http://www.juvenile-grouper-project.com/index.php?subject=articles&page=7

Mandatory Ship Reporting System

- The Mandatory Ship Reporting system website: https://www.rightwhalesmsr.aoml.noaa.gov/
- News item about the Mandatory Ship Reporting system at AOML's Physical Oceanography Division website: http://www.aoml.noaa.gov/phod/news/load.php?pFullStory=20140416_20140515_MSR.html
- Article about the Mandatory Ship Reporting system at AOML's Newsletter, issue of March-April 2014: http://www.aoml.noaa.gov/keynotes/PDF-Files/Mar-Apr14.pdf
- Detailed information about the Mandatory Ship Reporting system at the NMFS website: http://www.nmfs.noaa.gov/pr/shipstrike/msr.htm

Coral Restoration and Recovery

- Public Lecture at Dry Tortugas National Park in July 2014 on the status of threatened *A. cervicornis* and our associated research.
- Webinar on larval research results given for NOAA Coral Reef Conservation Program (March 2015)

Application and automation of underwater image mosaics for sampling, characterizing, and classifying corals as protected stocks and habitat

- We conducted a citizen-science cruise in association with The International SeaKeepers Society in April, 2015. During the cruise, high school students learned about the uses of image mosaics in coral reef science and wereshown how to acquire useful scientific image mosaic data using a single GoPro camera.

VIII. CIMAS FELLOWS AND EXECUTIVE ADVISORY BOARD

The Fellows provide guidance to the Director on matters concerning the ongoing activities and future direction of CIMAS. Fellows-related matters are now addressed and implemented by means of email exchanges and all meetings conducted as teleconferences via GOTOMEETING.

COUNCIL OF FELLOWS

FELLOWS	AFFILIATION
Dr. Manhar Dhanak	**Florida Atlantic University**
Dr. Marguerite Koch	Florida Atlantic University
Dr. William T. Anderson	**Florida International University**
Dr. James Fourqurean	Florida International University
Dr. Eric Chassignet	**Florida State University**
Dr. Markus Huettel	Florida State University
Dr. Gustavo Goni	N OAA/AOML/Physical Oceanography
Dr. Frank Marks	NOAA/AOML/Hurricane Research Division
Dr. James Hendee	NOAA/AOML/Ocean Chemistry Division
Dr. Richard J. Pasch	**NOAA/National Hurricane Center**
Dr. James Bohnsack	**NOAA/Southeast Fisheries Science Center**
Dr. Lance Garrison	NOAA/Southeast Fisheries Science Center
Dr. John Quinlan	NOAA/Southeast Fisheries Science Center
Dr. Joseph Serafy	NOAA/Southeast Fisheries Science Center
Dr. Mahmood Shivji	**NOVA Southeastern University**
Dr. Alex Soloviev	NOVA Southeastern University
Dr. Karl E. Havens	**University of Florida**

Dr. Thomas S. Bianchi	University of Florida
Dr. Jerald S. Ault	**University of Miami/RSMAS**
Dr. Rana Fine	University of Miami/RSMAS
Dr. Brian Haus	University of Miami/RSMAS
Dr. Ben Kirtman	University of Miami/RSMAS
Dr. David Letson	University of Miami/RSMAS
Dr. Sharan Majumdar	University of Miami/RSMAS
Dr. Richard Appeldoorn	**University of Puerto Rico**
Dr. Kent Fanning	**University of South Florida**
Dr. Frank Muller-Karger	University of South Florida
Dr. Rick Nemeth	**University of Virgin Islands**
Dr. Tyler Smith	University of Virgin Islands

Chair:

Dr. Peter B. Ortner, Director	UM/CIMAS

***Ex Officio*:**

Dr. David Die, Associate Director	UM/CIMAS

EXECUTIVE ADVISORY BOARD

IX. AWARDS AND HONORS

2015 NOAA/Ernest F. Hollings Scholars

NOAA Office of Education
Ernest F. Hollings Undergraduate Scholarship Program

A total of 19 CIMAS affiliated students (including 15 from the University of Miami and 4 from our Partner Universities), were selected as 2014 and 2015 NOAA/Ernest F. Hollings Scholars.

Class 2014 – 107 scholars (12 CIMAS Related)

Betancourt, Pamela	Biology	Florida State University, FL
Connelly, Michael	Biology And Marine Science	University of Miami, FL
Cox, Danielle	Geology And Environmental Studies	University of Miami, FL
Hahlbeck, Nicholas	Marine Science/Biology	University of Miami, FL
Hummel, Abigail	Biology	University of Florida, FL
Levell, Samantha	Marine Biology	Florida State University, FL
Munguia, Steffanie	Biology	University of South Florida, FL
Paine, Julia	Marine Sciences	University of Miami, FL
Peake, Jonathan	Marine Science	University of Miami, FL
Roskar, Amelia	Marine Science/Biology	University of Miami, FL
Suca, Justin	Marine Science/Biology	University of Miami, FL
Taplin, Drew	Geography	University of Miami, FL

Class 2015 – 150 scholars (7 CIMAS Related)

Chomiak Leah	Oceanography	University of Miami, FL
Granzow Benjamin	Chemistry	University of Miami, FL
Kaczmarek Elska	Marine Science/Biology	University of Miami, FL
Luisi Charles	Marine Sciences	University of Miami, FL
Mazur Emily	Marine Science/Biology	University of Miami, FL
Meltzer Hallee	Environmental Science	University of Miami, FL
Reagan Kevin	Marine Science/Biology	University of Miami, FL

Ford Foundation Postdoctoral Fellowship awarded to CIMAS Postdoctoral Investigator, Xaymara Serrano

Ford Foundation fellowships are awarded in a national competition administered by the National Research Council (NRC), to individuals who, in the judgment of the review panels, have demonstrated superior academic achievement, are committed to a career in teaching and research, show promise of future achievement as scholars and teachers, and are well prepared to use diversity as a resource for enriching the education of all students.

Xaymara will use these funds to support her research on coral reef responses to climate change and land-based sources of pollution entitled: Synergistic effects of eutrophication and elevated sea surface temperatures in the early life stages of a common Caribbean reef coral.

She plans to conduct controlled laboratory experiments aimed at assessing the thermal sensitivity of new recruits from a major Caribbean reef coral species (*Porites astreoides*), after exposure to various ecologically relevant nutrient levels. To accomplish this, she intends to apply an array of molecular and ecological techniques to: (1) quantitatively monitor how coral juveniles change the density of their algal symbionts in response to changes in nutrients and how these changes subsequently affect thermal tolerance, (2) assess how bleaching susceptibility may depend on the genetic identity of the coral or its algal symbionts, and (3) monitor the photosynthetic efficiency of corals prior, during and post-thermal stress. To date, this is the first study aimed at exploring the combined effects of elevated temperature and nutrient enrichment on the ecology, genetics and photophysiology of a symbiotic coral during early stages of life. This information is critical for managers in the US and Caribbean regions because it is expected to provide empirical evidence that might support the implementation of environmental policies aimed at improving water quality and maximizing reef resilience.

Visiting Scientist at CIMAS and NASA Scientist Emeritus from NASA Goddard Space Flight Center, has been elected as a member of the National Research Council's Polar Research Board

Dr. Nancy Maynard, Visiting Scientist at CIMAS and NASA Scientist Emeritus from NASA Goddard Space Flight Center, was elected as a member of the National Research Countil's Polar Research Board in October 2014.

The new Board Chair is Julie Brigham-Grette, from University of Massachusetts-Amherst. Given her six years on the PRB, and numerous leadership roles within the Academies system and many other places, she brings a wealth of experience to this role.

Western Boundary Time Series Project

- Ricardo Domingues was selected as NOAA's Team Member of the Month, February 2015.

High-frequency variability of near-surface oceanic velocity from surface drifters

- R. Lumpkin (with M. Pazos) was selected as OAR's Employee of the Year in November 2014.

Global Drifter Program

- S. Dolk received a Honorable Mention Award in November of 2014 and received a cash bonus for his extraordinary efforts.

Using NOAA UAS Assets and OSSE/DA Capabilities to Improve Sampling Strategies and Numerical Prediction of Tropical Cyclone Track, Intensity, and Structure

- Jason Dunion - Co-Recipient: 2015 American Meteorological Society Special Award to the University of Wisconsin-CIMSS Tropical Cyclone Group for "*providing the weather community with valuable tropical cyclone-related satellite information and derived products for over two decades*."

Services to Support the Hurricane Forecast Improvement Project

- X. Zhang and J. Zhang won CIMAS Gold Medal Award, and their federal collaborators: V. Tallapragada, Q. Liu, S. Gopalakrishnan, T. Quirino, and F. Marks won Department of Commerce Gold Medal Award for design and implementation of the moving nest and initialization imrpovements to HWRF that enabled the third nest down to 3km resolution.

PIRATA Northeast Extension (PNE)

- R. Lumpkin (with M. Pazos) was selected as OAR's Employee of the Year in November 2014.
- S. Dolk was selected as OAR's NOAA Team Member of the Month in February 2015.
- G. Foltz will receive the IUGG Early Career Scientist Award in June 2015.

Marine Optical Buoy (MOBY) Operations and Technology Refresh

K. Voss – Recipient: Provost's Award for Scholarly Activity, March 27, 2015.

Gulf of Mexico Integrated Ecosystem Assessment

- C. Kelble, M. Karnauskas and M. Schirripa were awarded the 2015 NOAA Bronze Medal for Karnauskas *et al* (2015) peer-reviewed publication – highest honor award bestowed by the Under Secretary of Commerce for Oceans and Atmosphere.

Mandatory Ship Reporting System

- Ricardo Domingues was selected as NOAA's Team Member of the Month for the month of February 2015 for his work in developing the Mandatory Ship Reporting system.

Support for the Marine Resource Assessment Program at the University of South Florida College of Marine Science

- Dinorah Chacin – Achievement Rewards for College Scientists Scholarship (ARCS Foundation)
- Claire Crowley – William Hogarth Marine Mammal Fellowship (USF-CMS)
- Kristina Deak – James D. Watkins Student Award for Excellence in Research (GOMRI); GOMRI Scholar; Gulf Oceanographic Charitable Trust Endowed Fellowship (USF-CMS)
- Lindsey Dornberger – James D. Watkins Student Award for Excellence in Research (GOMRI); GOMRI Scholar; The Jack and Katharine Ann Lake Fellowship in Marine Science (USF-CMS)
- Benjamin Kurth – NSF Graduate Research Fellowship Program Honorable Mention; 2nd William and Elsie Knight Endowed Fellowship for Marine Science (USF-CMS)
- Michelle Masi – Carl Riggs Fellowship in Marine Science (USF-CMS)
- Brianna Michaud – Paul Getting Endowed Memorial Fellowship (USF-CMS)
- Susan Snyder – GOMRI Scholar; Garrels Memorial Fellowship in Marine Science (USF-CMS)
- Orian Tzadik – Best Poster in Early Career Scientist category, 2014 ICES Annual Science Conference, Coruña, Spain
- Amy Wallace – Tampa Bay Parrothead Fellowship in Marine Science (USF-CMS)

X. POSTDOCTORAL FELLOWS AND GRADUATE STUDENTS

CIMAS-Supported Postdoctoral Fellows and Graduate Students

Postdoctoral Fellows
Alaka, Ghassan
Chen, Hua
Dong, Jili
Gruss, Arnaud
Harford, William
Jones, Paul
Kearney, Kelly
Liu, Yanyun
Lopez, Hosmay
Majumder, Sudip
Ma, Jian
Phillips, Nicole
Putman, Nathan
Sagarese, Skyler
Serrano, Xaymara
Wang, Hui

Graduate Students
Task I
Council, E.
Drury, C.
Forrestal, F.
Hariharan, S.
Hoenig, D.
Sculley. M.
Simeon, Y.
Vaughan, N.

Task III
Employees
Domingues, Ricardo
Gramer, Lewis J.
Jankulak, Michael
Malca, Estrella
Privoznik, Sarah
Seaton, Kyle

Other Participants in CIMAS Projects

Postdoctoral Fellows
Stefanova, Lydia
Suprenand, Paul
Vaz, Ana Carolina
Woosley, Ryan

Other Participants in CIMAS Projects cont'd

Graduate Students
Ailloud, Lisa
Adam, Thomas
Binder, Benjamin M.
Brizzolara, Jennifer
Chacin, Dinorah
Davis, Katie
Dean, Cayla W.
Espitia, Paola
Fisch, Jay
Fisco, Dana
Fredrick, Joshua
Grasty, Sarah
Gray, Alisha
Grasso, Peter
Groenen, Danielle
Habtes, Sennai
Hall, Brittany
Helms, Charles
Herdter, Elizabeth
Hoskins, Mikayla
Hughes, Edward
Janine, Mary
Jermain, Robert
Kieper, Margie
Kilfoyle, Kirk
Knowles, Morgan
Kotkowski, Rachel
McCaskill, Claire
Nuttall, M.A.
Oliveros-Ramos, R.
Olsen, Emily
Omori, Kristin
Patranella, Allison
Perryman, H.A.
Pomales, Luis
Rolls, Holly
Rudzin, Johna
Selman, Christopher
Smith, Matthew
Snyder, Susan
Stocker, Joshua
Teter, Shara
Turner, Nicholas
Valla, Daniel
Zhao, J.

XI. RESEARCH STAFF

Aguilar, Sandra	Senior Research Associate III
Aichinger Dias, Laura	Research Associate II
Aksoy, Altug	Associate Scientist
Alaka, Ghassan	Postdoctoral Associate
Amornthammarong, Natchanon	Assistant Scientist
Annane, Bachir	Senior Research Associate III
Atluri, Charita	Senior Research Associate I
Barbero Munoz, Leticia	Assistant Scientist
Barton, Zachary	Research Associate I
Berberian, George	Research Associate II (PT)
Blondeau, Jeremiah	Senior Research Associate II
Bright, Allan	Senior Research Associate I
Bucci, Lisa	Senior Research Associate I
Cameron, Caitlin	Research Associate II
Carlton, Renee	Research Associate II
Cascioli, Robin	Research Associate I
Chen, Hua	Post-Doctoral Associate
Cook, Geoffrey	Assistant Scientist
Dahl, Brittany	Research Associate I
Delgado, Javier	Senior Research Associate II
Delgado, Sandy	Research Associate II
Diaz, Jose E.	Research Associate III
Diaz, Steven	Senior Research Associate I
Dolk, Shaun	Research Associate III
Domingues, Ricardo	Research Associate III
Dong, Jili	Postdoctoral Associate
Dong, Shenfu	Associate Scientist
Dunion, Jason	Senior Research Associate III
Ender, Alexandra	Research Associate I
Enochs, Ian	Assistant Scientist
Festa, John	Senior Research Associate III (PT)
Forteza, Elizabeth	Research Associate III

Gall, Robert	Scientist
Garcia, Rigoberto F.	Senior Research Associate II
Garzoli, Silvia	Scientist (PT)
Gidley, Maribeth	Assistant Scientist
Goes, Marlos	Assistant Scientist
Gonzalez, Caridad	Research Associate III
Gramer, Lewis J.	Senior Research Associate III
Gruss, Arnaud	Postdoctoral Associate
Halliwell, Vicki	Senior Research Associate III
Harford, William	Postdoctoral Associate
Helmle, Kevin	Assistant Scientist
Hoolihan, John	Associate Scientist
Hooper, James	Research Associate III
Jankulak, Michael L.	Systems Administrator
Jones, Paul	Postdoctoral Associate
Jugovich, Amelia	Research Associate I
Kearney, Kelly	Postdoctoral Associate
Klotz, Bradley	Senior Research Associate I
Kolodziej, Graham	Research Associate I
Le Henaff, Matthieu	Assistant Scientist
Lee, Sang-Ki	Scientist
Liu, Hailong	Senior Research Associate II
Liu, Yanyun	Postdoctoral Associate
Lopez, Hosmay	Postdoctoral Associate
Ma, Jian	Postdoctoral Associate
Majumder, Sudip	Postdoctoral Associate
Malca, Estrella	Senior Research Associate I
Muhling, Barbara	Associate Scientist
Nair Jayalekshmi	Research Associate III
Ortega-Ortiz, Joel	Associate Scientist
Otero, Sonia	Senior Research Associate II
Overstreet, Elizabeth	Senior Research Associate I
Pausch, Rachel	Research Associate I
Perez, Renellys	Associate Scientist

Phillips, Nicole	Postdoctoral Associate
Pierrot, Denis P.	Associate Scientist
Privoznik, Sarah	Research Associate II
Putman, Nathan	Postdoctoral Associate
Rawson, Grant T.	Research Associate III
Richter, Lee	Research Associate I
Roddy, Robert	Research Associate III (PT)
Ryan, Kelly	Sr. Research Associate II
Sabina, Reyna	Research Associate III (PT)
Sagarese, Skyler	Postdoctoral Associate
Seaton, Kyle	Research Associate II
Sellwood, Kathryn J.	Research Associate III
Serrano, Xaymara	Postdoctoral Associate
Shideler, Allison	Senior Research Associate I
Shiroza, Akihiro	Senior Research Associate I
St. Fleur, Russell	Programmer Intermediate
Sullivan, Kevin F.	Senior Research Associate III
Valdes, Erik	Research Associate III
Valentino, Lauren	Senior Research Associate I
van Hooidonk, Ruben	Assistant Scientist
Visser, Lindsey	Research Associate II
Volkov, Denis	Associate Scientist
Wang, Hui	Postdoctoral Associate
Wicker, Jesse A.	Research Associate III
Williams, Dana E.	Associate Scientist
Willis, Paul	Research Associate II (PT)
Yao, Qi	Senior Research Associate I
Zhang, Jun	Associate Scientist
Zhang, Xuejin	Associate Scientist

XII. VISITING SCIENTISTS

**Dr. Nancy Maynard - ** October 1, 2012 (to continue through December, 2015)
NASA Emeritus
NASA Goddard Space Flight Center
Greenbelt, MD

**Mr. Phil Gravinese - ** June 1, 2014 – September 30, 2014
Florida Institute of Technology
150 W. University Blvd.
Melbourne, FL 32901

**Dr. Jie Tang - ** July 1, 2014 – June 30, 2015
Shanghai Typhoon Institute, CMA
No.166 Puxi Road
Shanghai 200030, China

**Professor Roger Smith - ** September 28, 2014 – October 10, 2014
Meteorological Institute Ludwig Maximilians
University of Munich
Theresienstrasse 37 80333
Munich, Germany

6 October, 2014 – *"Why do model tropical cyclones intensify more rapidly at low altitudes?"*

**Dr. Janet Sprintall - ** October 14 – 17, 2014
Scripps Institution of Oceanography
Mail Code 0230
9500 Gilman Drive
La Jolla, CA 92093-0230

16 October, 2014 – *"Climate Variability Observed in the Drake Passage"*

**Dr. Kim Waddell - ** September 15, 2014
Gulf Resarch Program
The National Academies
500 Fifth Street
Washington, DC 20001

15 September, 2014 – *"Gulf Research Program Overview and Activity Update"*

**Dr. Elaine McDonagh - ** November 17 – 20, 2014
National Oceanography Centre
Natural Environment Research Council
University of Southampton Waterfront Campus
European Way, Southampton SO14 3ZH
United Kingdom

Dr. Paul DeBruyn - February 16 – 20, 2015
ICCAT
Corazón de María, 8
28002 Madrid, Spain

Dr. Laurie Kell - February 16 – 20, 2015
ICCAT
Corazón de María, 8
28002 Madrid, Spain

**Prof. U.C. Mohanty - ** 14 – 20 June, 2015
School of Earth Ocean and Climate Sciences
Indian institute of Technology Bhubaneswar
A2-708, Toshali Bhawan, Satya Nagar
Bhubaneswar-751007, Odisha, India

16 June, 2015 – *"Prediction of Tropical Cyclones /Over Bay of Bengal Using 2013 Version of HWRF System"*

XIII. PUBLICATIONS

Table 1: Publication Record 2014-2015 for Cooperative Agreement NA10OAR4320143

	Institute Lead Author	NOAA Lead Author	Other Lead Author
	2014-2015	**2014-2015**	**2014-2015**
Peer Reviewed	46	18	40
Non-Peer Reviewed	16	10	15

Refereed Journal Articles

Aberson, S.D., A. Aksoy, K.J. Sellwood, T. Vukicevic, and X. Zhang (2015), Assimilation of high-resolution tropical cyclone observations with an ensemble Kalman filter using HEDAS: Evaluation of 2008-2011 HWRF forecasts, *Mon. Wea. Rev.*, 143, 511-523.

Adam, T.C., D.E. Burkepile, B.I. Ruttenberg, and M.J. Paddack (2015), Herbivory and the resilience of Caribbean coral reefs: knowledge gaps and implications for management, *Mar. Ecol. Prog. Series,* 520, 1-20.

Ailloud, L.E., M.W. Smith, A.Y. Then, K.L. Omori, G.M. Ralph, and J.M. Hoenig (2015), Properties of age compositions and mortality estimates derived from cohort slicing of length data, *ICES J. Mar. Sci.*, 72, 44-53, doi:10.1093/icesjms/fsu088.

Ainsworth, C.H., and C.J. Walters (2015), Ten common mistakes made in Ecopath with Ecosim modelling, *Ecological Modelling,* 308, 14-17.

Amornthammarong, N., P.B. Ortner, J. Hendee, and R. Woosley (2014), A Simplified Coulometric Method for Multi-sample Measurements of Total Dissolved Inorganic Carbon Concentration in Marine Waters, *Analyst,* 139, 5263-5270.

Anthony, P.K.R.N., A. Marshall, A. Abdulla, R. Beeden, C. Bergh, R. Black, C.M. Eakin, E.T. Game, M. Gooch, N.A.J. Graham, A. Green, S.F. Heron, R.J. van Hooidonk, C. Knowland, S. Mangubhai, N. Marshall, J.A. Maynard, P. McGinnity, E. McLeod, P.J. Mumby, M. Nyström, D. Obura, J. Oliver, H.P. Possingham, R.L. Pressey, G.P. Rowlands, J. Tamelander, D. Wachenfeld, and S. Wear (2014), Operationalizing resilience for adaptive coral reef management under global environmental change, *Global Change Biol., 21, 48-61.*

Ault, J.S., S.G. Smith, J.A. Browder, W. Nuttle, E.C. Franklin, J. Luo, G.T. DiNardo, and J.A. Bohnsack (2014), Indicators for assessing the ecological and sustainability dynamics of southern Florida's coral reef and coastal fisheries, *Ecological Indicators*, 44, 164-172.

Babcock, E.A., W.J. Harford, R. Coleman, J. Gibson, J. Maaz, J. Foley, and M. Gongora (2015), Bayesian depletion model estimates of spiny lobster abundance at two marine protected areas in Belize with or without in-season recruitment, *ICES J. Mar. Sci.,* online access: 1-12, doi: 10.1093/icesjms/fsu226.

Brame, A.B., C.C. McIvor, E.B. Peebles, and D.J. Hollander (2014), Site fidelity and condition metrics suggest sequential habitat use by juvenile common snook, *Mar. Ecology Prog. Series,* 509, 255-269.

Burghart, S.E., L. Van Woudenberg, C.A. Daniels, S.D. Myers, E.B. Peebles, and M. Breitbart (2014), Disparity between planktonic fish egg and larval communities as indicated by DNA barcoding, *Mar. Ecology Prog. Series,* 503, 195-204.

Catano, L.B., B.K. Gunn, M. Kelley, and D.E. Burkepile (2015), Predation risk, resource quality, and reef structural complexity shape territoriality in a coral reef herbivore, *PLoS One* 10(2), e0118764, doi:10.1371/journal.pone.0118764.

Chen, H., and S.G. Gopalakrishnan (2015), A study on the asymmetric rapid intensification of Hurricane Earl (2010) using the HWRF system, *J. Atmos. Sci.*, 72, 531-550.

Cook, G.S., P.J. Fletcher, and C. R. Kelble (2014), Towards marine ecosystem based management in South Florida: quantifying interactions among ecosystem pressures, states, and services in a complex coastal system, *Ecological Indicators*, 44, 26-39.

Crowley, C.E, R.L. Gandy, K.L. Daly, and E.S. Van Vleet (2014), Problems associated with a lipofuscin extraction method used to age blue crabs (*Callinectes sapidus*) cultured in Florida, USA, *Aquatic Biology*, 21, 85-92.

Dong, S., M.O. Baringer, G.J. Goni, C.S. Meinen, and S.L. Garzoli (2014), Seasonal variations in the South Atlantic Meridional Overturning Circulation from observations and numerical models, *Geophys. Res. Lett.*, 41, 4611-4618, doi: 10.1002/2014GL060428.

Dong, S., G. Goni, and R. Lumpkin (2015), Mixed-lyer salinity baudget in the SPURS (Salinity Processes in the Upper ocean Regional Study) region on seasonal to interannual time scales, *Oceanography*, 28, 1, 78-85, doi:10.5670/oceanog.2015.05.

Drexler, M.D., M.L. Parker, S.P. Geiger, W.S. Arnold, and P. Hallock (2014), Population biology of the Eastern Oyster (*Crassostrea virginica*) inhabiting reef, mangrove, seawall, and restoration substrates, *Estuaries and Coasts*, 37, 962-972.

Dunion, J.P., C.D. Thorncroft, and C.S. Velden (2014), The tropical cyclone diurnal cycle of mature hurricanes, *Mon. Wea. Rev.*, 142, 3900-3919.

Ekstrom, J.A., L. Suatoni, S.R. Cooley, L.H. Pendleton, G.G. Waldbusser, J.E. Cinner, J. Ritter, C. Langdon, R. van Hooidonk, D. Gledhill, K. Wellman, and M.W. Beck (2015), Vulnerability and adaptation of US shellfisheries to ocean acidification, *Nature Climate Change,* 5, 207-214.

Enochs, I.C., D.P. Manzello, R. Carlton, D.M. Graham, R. Ruzicka, and M.A. Colella (2015), Ocean acidification enhances the bioerosion of a common coral reef sponge: implications for the persistence of the Florida Reef Tract, *Bulletin of Marine Science,* 91(2), 271-290, doi: 10.5343/bms.2014.1045.

Farmer, N.A., and J.S. Ault (2014), Modeling coral reef fish home range movements in Dry Tortugas, Florida, *The Scientific World Journal*, 2014, 14 pages, http://dx.doi.org/10.1155/ 2014/ 629791.

Foltz, G.R., C. Schmid, and R. Lumpkin (2015), Transport of surface freshwater from the equatorial to the subtropical North Atlantic Ocean, *J. Phys. Oceanogr.*, 45, 1086-1102, doi:10.1175/JPO-D-14-0189.1.

Goes, M., G. Goni, and S. Dong (2015), An optimal XBT-based monitoring system for the South Atlantic meridional overturning circulation at 34°S., *J. Geophys. Res.-Oceans*, 120, 1,161-181, doi:10.1002/2014JC010202.

Goes, M., M. Baringer, and G. Goni (2015), The impact of historical biases on the XBT-derived meridional overturning circulation estimates at 34°S., *Geophys. Res. Lett.*, 42, 1848–1855. doi: 10.1002/2014GL061802.

Grüss, A., M.J. Schirripa, D. Chagaris, M. Drexler, J. Simons, P. Verley, Y-J. Shin, M. Karnauskas, R. Oliveros-Ramos, and C.H. Ainsworth (2015), Evaluation of the trophic structure of the West Florida Shelf in the 2000s using the ecosystem model OSMOSE, *Journal of Marine Systems*, 144, 30-47, doi.org/10.1016/j.jmarsys.2014.11.004.

Grüss A, M. Drexler, C.H. Ainsworth (2014), Using delta generalized additive models to produce distribution maps for spatially explicit ecosystem models, *Fisheries Research*, 159, 11−24.

Hall-Scharf, B.J., and C.D. Stallings (2014), Experimental test of preference by a generalist piscivore on morphologically and behaviorally different prey, *J. Experimental Marine Biology and Ecology,* 460, 193-196.

Halliwell, G.R., V. Kourafalou, M. Le Hénaff, L.K. Shay, and R. Atlas (2014), OSSE impact analysis of airborne ocean surveys for improving upper-ocean dynamical and thermodynamical forecasts in the Gulf of Mexico, *Progress in Oceanogr.,* 130, 32-46*, DOI:10.1016/j.pocean.2014.09.004*.

Harford, W.J., C. Ton, and E.A. Babcock (2015), Simulated mark-recovery for spatial assessment of a spiny lobster (*Panulirus argus*) fishery, *Fisheries Research,* 165, 42-53, doi: 10.1016/j.fishres.2014.12.024.

Hoolihan, J.P., R.J.D. Wells, J. Luo, B. Falterman, E.D. Prince, and J.R. Rooker (2014), Vertical and horizontal movements of yellowfin tuna (*Thunnus albacares*) in the Gulf of Mexico, *Mar. Coast. Fish.*, 6, 211-222, doi: 10.1080/19425120.2014.9359004902U4.

Hoolihan, J.P., J. Luo, D. Snodgrass, E.S Orbesen, A.M. Barse, and E.D. Prince (2015), Vertical and horizontal habitat use by white marlin Kajikia albida (Poey, 1860) in the western North Atlantic Ocean, *ICES J. Mar. Sci*., doi: 10.1093/icesjms/fsv082.

Infanti, J.M., and B.P. Kirtman (2014), Southeast US Rainfall Prediction in the North American Multi-Model Ensemble, *J. Hydrometeor*, 15, 529-550.

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APPENDIX I

Task III Projects Linked to CIMAS

NOAA Award Number	Principal Investigator	Award Period	Report Due Date	Project Title
NA12NWS4680010	Aksoy, A	01/01/12 - 12/31/14	01/30/15	Investigation of HWRF Model Error Associated with Surface-LA
NA11OAR4310077	Chen, S	09/01/11 - 08/31/15	06/30/15	Convective Structure and Environmental Conditions in the MJO Initiation over the Indian Ocean
NA14OAR4310193	Cook, G	08/01/14 - 07/31/16	05/30/15	Developing decision support tools for understanding, communicating and adapting to the impacts of climate on the sustainability of coastal ecosystem services
NA12OAR4310105	Criales, M	08/01/12 - 07/31/15	05/30/15	Integrated MODels for Evaluating Climate change, population growth, & water management (i.e. CERP) effects on south Florida coastal marine and estuarine ecosystems (iMODEC)
NA14OAR4830172	Dunion, J	08/01/14 - 07/31/17	04/30/15	Using NOAA UAS Assets and OSSE/DA Capabilities to Improve Sampling Strategies and Numerical Prediction of Tropical Cyclone Track, Intensity and Structure
NA12OAR4310073	Kamenkovich, I	08/01/12 - 07/31/16	05/30/15	Mesoscale Variability in the Gulf of Mexico and its importance in climate extremes over North America
NA14OAR4830127	Kirtman, B	07/01/14 - 05/31/15	06/29/15	Severe Weather in the NMME
NA12OAR4310089	Kirtman, B	08/01/12 - 07/31/15	05/30/15	A U.S national multi-model ensemble ISI prediction system
NA130OAR4830224	Kourafalou, V	10/01/13 - 09/30/15	04/30/15	Extending the Gulf of Mexico to the North Atlantic in support of Development & Demonstration of a Relocatable Ocean OSSE System
NA12OAR4310083	Lee, S	08/01/12 - 07/31/16	05/30/15	Toward developing in a seasonal outlook for the Occurrence of Major US tornado outbreaks
NA14OAR4830103	Lee, S	02/01/14 - 01/31/16	04/30/15	CIMAS Contributions to OAR disaster Recovery Act Project
NA13NMF4720057 *	Muhling, B	09/01/13 - 08/31/14	09/30/14	Accounting for the influence of feeding success on the growth and survival of bluefin tuna larvae in stock assessment efforts
NA11NOS4780045	Ortner, P	09/01/11 - 08/31/16	06/30/15	2011 REPP-Understanding Coral Ecosystem Connectivity in the Gulf of Mexico-Pulley Ridge to the Florida Key
NA13OAR4310131	Perez, R	09/01/13 - 08/31/16	06/30/15	South Atlantic Meridional Overturning Circulation: Pathways and Modes of Variability
NA130OAR4830217	Shay, N	10/01/13 - 09/30/15	04/30/15	Evolving Data Fields for Use in OSSE Modeling
NA10OAR4310120	Soden, B	05/01/10 - 07/31/15	03/30/15	Development of a long-term Homogenized upper tropospheric water vapor data set from satellite microwave radiances
NA12NWS4680004 **	Zhang, J	01/01/12 - 12/31/14	03/31/15	Advanced model diagnostics of tropical cyclone inner-core structure using aircraft observations
NA14NWS4680028	Zhang, J	08/01/14 - 07/31/16	05/30/15	Addressing deficiencies in forecasting tropical cyclone rapid intensification in HWRF
NA12NWS4680007 **	Zhang, X	01/01/12 - 12/31/14	01/30/15	Development of Multiple Moving Nests Within a Basin--Wide HWRF Modeling System
NA13OAR4830232	Zhang, X	10/01/13 - 09/30/15	04/30/15	Services to Support the Hurricane Forecast Improvement Project
NA14OAR4830119	Zhang, X	04/01/14 - 03/31/17	04/30/15	CIMAS Contributions to OAR disaster Recovery Act Projects

* NMFS announcements at a reduced 25% IDC, ** NWS and OAR announcement not properly linked to CIMAS awarded at the regular UM overhead rate.

Project Progress Report

Award Number: NA12NWS4680010
Program Office: National Weather Service Program Office (NWSPO)
Period: 10/01/2014 – 12/31/2014

Project Title:
Investigation of HWRF Model Error Associated With Surface-Layer and Boundary-Layer Parameterizations To Improve Vortex-Scale, Ensemble-Based Data Assimilation Using HEDAS

Principle Investigator: Dr. Altuğ Aksoy
Co-Investigators: Dr. Jun Zhang, Mr. Bradley Klotz

Cooperative Institute for Marine and Atmospheric Studies
University of Miami, Rosenstiel School of Marine and Atmospheric Science

January 30, 2015

In this quarter, we mostly continued work on preparing journal manuscripts to be submitted in the early months of 2015. Our goal is to conclude this no-cost extension period with the submission/publication of these papers. The manuscripts that we are planning to submit will focus on the following subjects:

1. Impact of ocean coupling and SSTs in realistic idealized HWRF simulations
2. Parameter sensitivity in single-parameter experiments with realistic idealized HWRF simulations
3. Parameter sensitivity and ensemble response with simultaneous parameter perturbations in realistic idealized HWRF simulations
4. Storm-relative correlation structures in tropical cyclone vortices with realistic idealized HWRF simulations

Annual Project Progress Report

(Period: 06/01/2013 - 05/31/2014)

NA11OAR4310077

Convective Structure and Environmental Conditions in the MJO Initiation over the Indian Ocean

PI: **Shuyi S. Chen,** RSMAS/University of Miami, 4600 Rickenbacker Causeway
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Co-PI: **David Jorgensen,** National Severe Storm Lab/NOAA
Co-PI: **Augustin Vintzileos,** University of Maryland and CPC/NOAA
Co-I: **Jon Gottschalck**, Climate Prediction Center/NOAA

The goals of this PI team are to better understand the structure of convective cloud systems and their large-scale environment in the MJO initiation process and to improve MJO forecasts. The research project addresses two of the Dynamics of the Madden-Julian Oscillation (DYNAMO) science hypotheses: *i) interaction between environmental moisture and convection and ii) the dynamic evolution of the cloud population*, which is key to MJO initiation over the tropical Indian Ocean. It includes three components: 1) cloud cluster tracking analysis using hourly satellite IR data along with observations of environmental water vapor and SST as well as the global analysis of wind and temperature data, 2) aircraft observation of convective cloud systems during the DYNAMO field campaign, and 3) model evaluation and verification for improving operational MJO monitoring and forecasting.

1. Progress toward completion of the project

During the 3rd year of the project, the PI team has focused on data analysis and publications of the science results from DYNAMO. Four articles have been published in peer-reviewed journals (Kerns and Chen 2014a, 2014b, Judt and Chen 2014, Guy and Jorgensen 2014). New research results have emerged and summarized in several manuscripts (Chen et al. 2014a, 2014b, and Guy et al. 2014). In this progress report, we provide brief summaries for four main areas of research.

1) Dry air intrusions affect MJO Initiation over the Indian Ocean

Kerns and Chen (2014a) shows that dry air intrusion and advection from subtropics play an important role in MJO initiation over the tropical Indian Ocean. Dry air has two distinct roles in two stages during the MJO initiation:

- "Trigger" for equatorial convection – onset of MJO, which weaken ITCZ and shift convection toward the equator
- "Propeller" for eastward propagation of MJO, which suppresses convection to the west, which serves as a propeller pushing MJO convection eastward, and mid-low level dry air

reduces cloud (echo) tops, enhances convective cold cools and prolongs the boundary layer recovery, which contribute to the "shutdown" of widespread convection

During mid-late November, a strong MJO event, denoted MJO-2, initiated in the western IO and passed through the DYNAMO array. Dry air intrusions associated with synoptic variability in the equatorial region played a key role in the evolution of the MJO-2 in two ways (Kerns and Chen 2013a). First, a sharp dry air intrusion surging from the subtropics into the equatorial region suppresses convection in the ITCZ, which leads to an equatorward shift of convection. It is viewed as a triggering mechanism for the onset of equatorial convection in MJO-2. Prior to MJO-2, convection was concentrated in a double ITCZ pattern 5-10 deg. off the Equator, which was not favorable for the equatorial convection of the MJO. This sharp dry air surge disrupted the southern ITCZ and allowed convection to redevelop on the Equator. The second effect of dry air intrusions on MJO-2 is associated with Rossby-like waves embedded within the MJO. The westward-propagating Rossby-like waves draw drier air into their gyre circulations, bringing dry air into the equatorial region on the west side of the MJO. This dry air intrusion contributed to a 1-2 day break in the rainfall during the active phase of MJO-2, as well as the abrupt shutdown of MJO convection during transition to the suppressed phase in DYNAMO. The dry air intrusion suppresses convection in the westerlies of the MJO in the IO, which is in contrast to the MJO over the West Pacific.

The dry surge originated in the eastern IO and progressed to the western IO, penetrating to ~4^0S. The convection had been previously organized into an ITCZ band at 5-10^0S with little activity on the Equator. Convection could no longer develop in the southern ITCZ and shifted to the Equator. This initial burst of Equatorial convection apsnning ~20 deg. of longitude marked the beginning of the prominent eastward propagation of MJO-2.

At the back (west) side of the MJO, Rossby-like waves/synoptic gyres became pronounced enough to draw drier air into their circulations. This form of dry air intrusion is induced by circulation systems within the MJO envelope, and it is associated with more diffuse moisture gradients than the pre-MJO dry air *surge*. This drier air was drawn in from higher latitudes and across the zonal moisture gradient in the western equatorial IO. Unlike the west Pacific, the air in the western part of the basin is relatively dry. Finally, when the MJO westerlies weaken, the dry air intrusion would cease, and the build-up leading to the next MJO event can begin. The three roles of dry air intrusion during MJO-2 and associated large scale weather features are illustrated in Fig. 1.

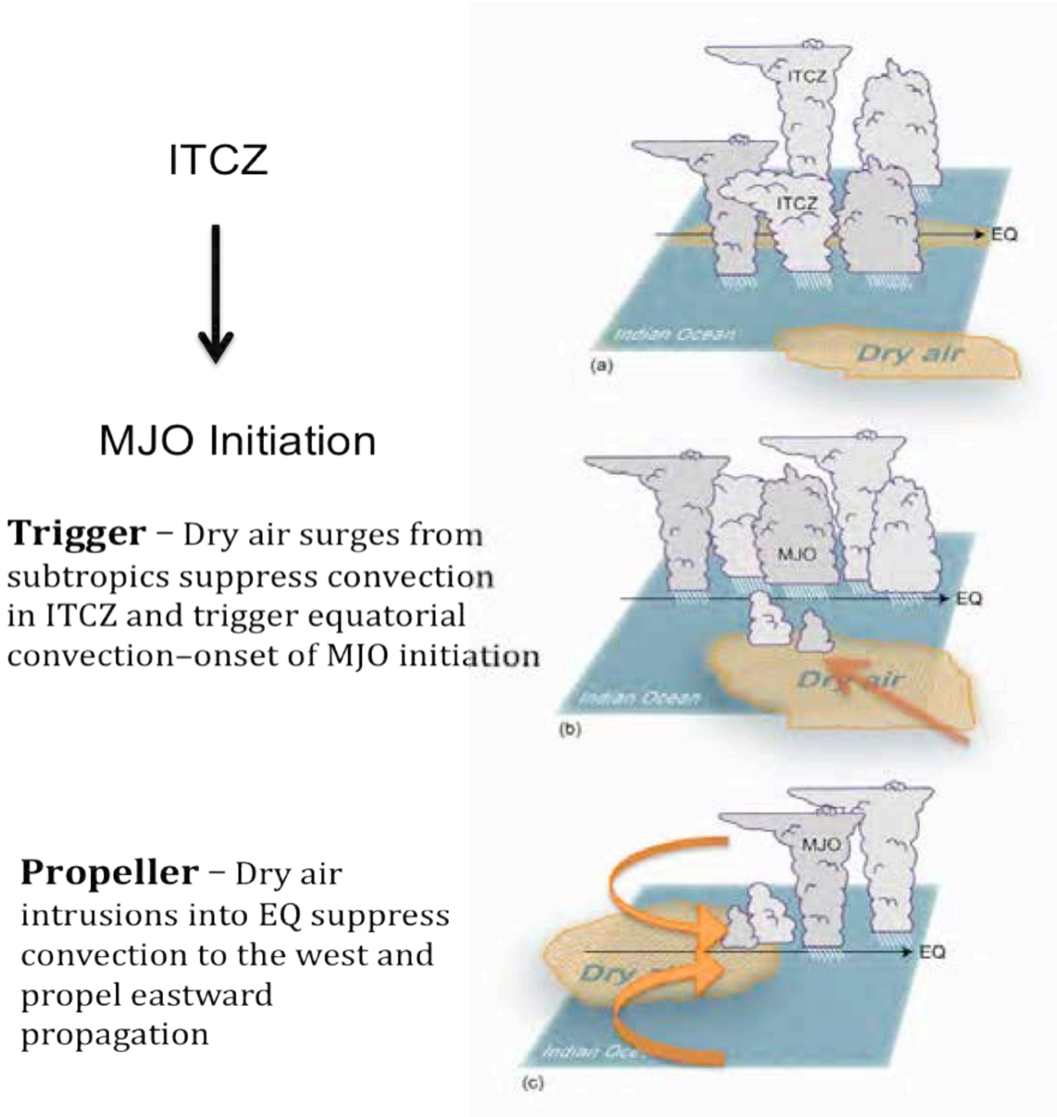

Figure 1. Schematic of the evolution of DYNAMO MJO-2 and roles of dry air in the MJO initiation based on the results from Kerns and Chen (2014a).

2) Convective and large-scale interaction

Multiscale interaction has been an important aspect in the MJO initiation. Judt and Chen (2014) has documented an convective explosive event observed on 28 November 2011 during DYNAMO. The key findings from Judt and Chen (2014) is summarized in Fig. 2:

- Equatorial low pressure system associated with MJO (Rossby Gyre) provided low-level forcing for convection.
- Outflow form prior convection to the east reduces vertical shear providing favorable upper-level condition for the explosive convective system on 28 Nov.

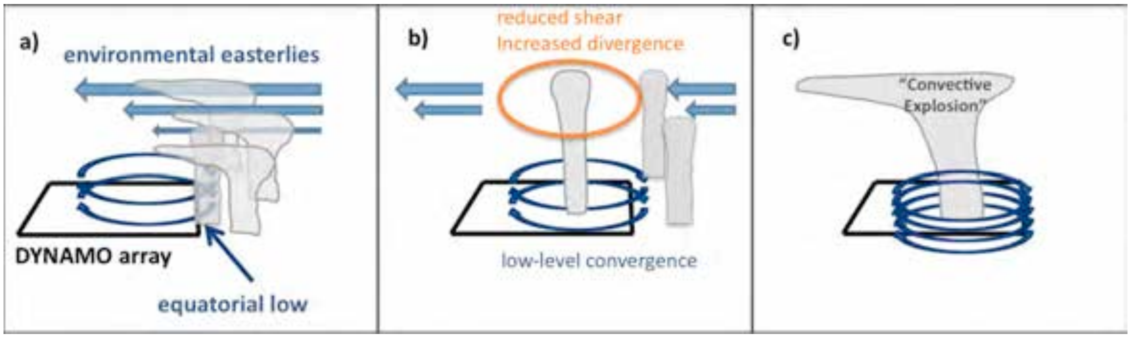

Figure 2. Schematic of the explosive convective event observed on 28 November 2011 during DYNAMO over the equatorial Indian Ocean: a) pre-development, b) early development, and c) mature stages. The black rectangle marks the DYNAMO array with the corner points at Diego Garcia, Gan, *R/V Revelle* and *R/V Mirai* as shown in Fig. 1 of Judt and Chen (2014). Circular arrows indicate the low-level flow associated with the equatorial low pressure system and straight arrows show the upper-level environmental easterly winds. (Adapted from Judt and Chen 2014.)

3) Evaluation/verification of global model forecasts during DYNAMO

The Global Forecast System (GFS) model is the operational global weather forecast model of the National Centers for Environmental Prediction (NCEP). GFS forecasts cycles are every 6 hours. Up to the 192 h forecast, 6-hourly fields at 1 deg. resolution were used. From 204-384 hour forecasts, 2.5 deg. data were used (see Table 1). The European Centre for Medium Range Forecasts (ECMWF) provided 6-hourly analysis fields and once-daily forecasts for the DYNAMO field experiment, as well as ensemble fields for a limited domain and at coarser resolution. For up to 10-day forecasts, the deterministic forecast interpolated to a 0.25 degree resolution grid was used (denoted ECMWF). For the 10-15 day forecast period, only ensemble forecasts were available. The ensemble forecasts were on a 1 degree grid. In this study, the control run of the ECMWF ensemble was used (referred to as ECMWFctl).

To better understand the multiscale interaction and contributions to the forecast errors by systems of different spatial scales, we computed RMSE fractions using the large-scale, synoptic scale, and mesoscale filtered U850. In general, the large-scale RMSE fraction was lower than the RMSE fraction of the unfiltered winds for all models (Figs. 3a, b). The synoptic scale and mesoscale RMSE fractions are higher than the RMSE fraction of the unfiltered field (Figs. 3c, d). Both models have little forecast skill at the mesoscale except when verified against their own analysis fields at 1-day lead time (Fig. 3d). The GFS RMSE fractions for the large- and synoptic scale filtered zonal winds are 0.1 – 0.2 higher than the ECMWF and ECMWF-ctl in the 5-15 day forecast lead time range (Figs. 3b, c). The ECMWF has a better forecast skill than GFS on both the large- and synoptic scales. For the large-scale filtered U850, the GFS RMSE fraction was close to 1 at the 15-day lead time, while the ECMWF-ctl RMSE fraction remains near 0.7 (Fig. 3b). Both the GFS and ECMWF essentially lost their predictive skill for synoptic scale systems at the 15-day lead time (Fig. 3c); nevertheless, the ECMWF model retained more skill than the GFS throughout the range of lead times considered.

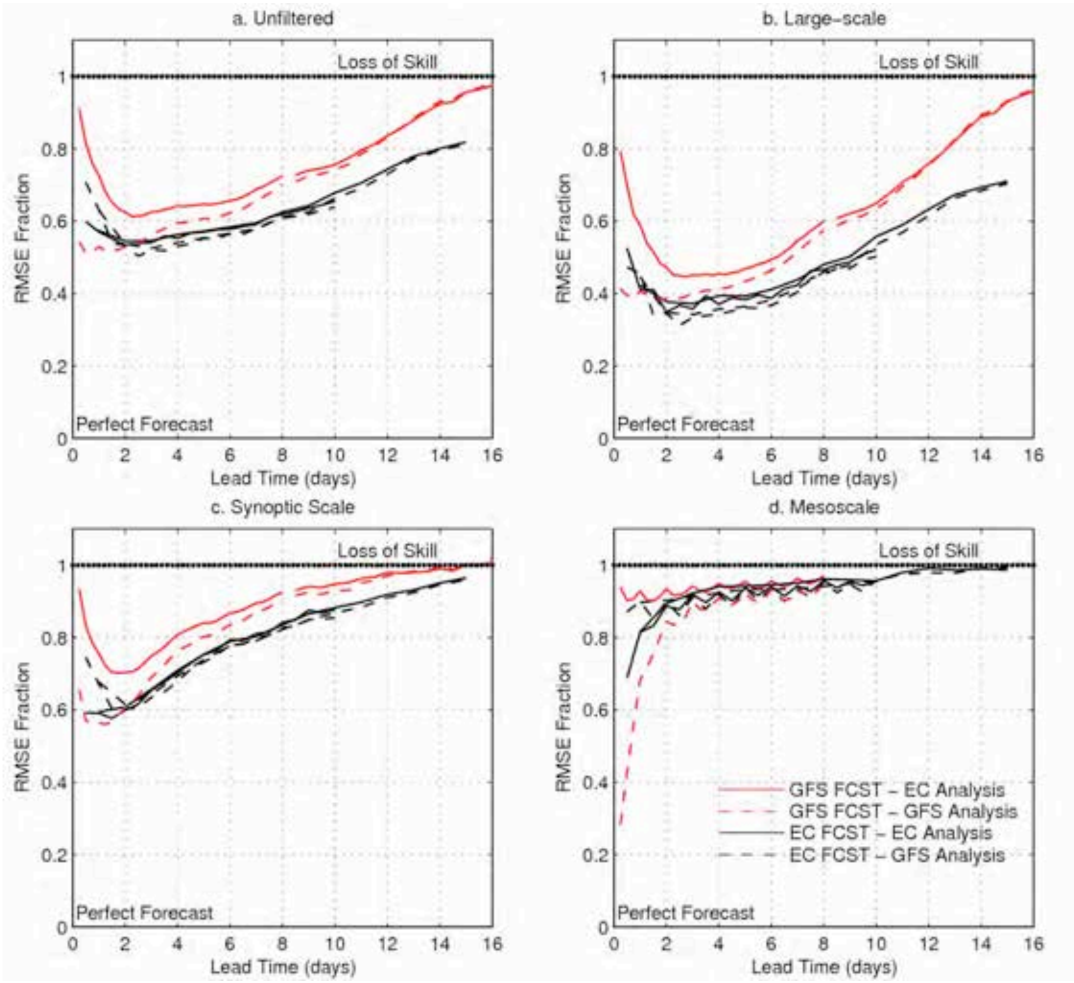

Figure 3. Root mean square error (RMSE) fraction (forecast error divided by persistence error) of zonal wind speed (U850) as a function of forecast lead time. (a) Unfiltered data, (b) large-scale filtered data, (c) synoptic scale filtered data, and (d) mesoscale filtered data. Black curves are for ECMWF and ECMWF-ctl. Red curves are for GFS. Solid curves are using ECMWF analysis to calculate errors while dashed curves use the GFS analysis. In (d), the GFS mesoscale filtered data for lead time longer than 8 days are not resolved because of low resolution. (Adapted from Kerns and Chen 2014b.)

4) Microphysical prosperities of MCSs observed in DYNAMO

The P-3 platform also allowed the strongest convection in the region to be identified and sampled. This provided a comparison of MCSs in similar stages of life cycle during the onset and peak (active) and inactive phases of the MJO and an off-equator ITCZ convective system within the DYNAMO region. Results indicated a morphology in agreement with the cycle of deepening and widespread convection during an MJO event. Analogous results of aircraft observations taken during the TOGA COARE experiment were compared to the findings of this study, showing distinct differences in the organization. Convective systems during DYNAMO were less linearly organized, having weaker associated cold pools, and no distinct strong rear-inflow jets present. Results of this work can be found in peer-reviewed literature (Guy and Jorgensen 2014).

The NOAA P-3 aircraft not only provided detailed vertical and horizontal structure of convective cloud systems, but also provided in-situ cloud and precipitation microphysical observations. The Particle Measuring System 2D precipitation (2D-P) probe collected data for particles between 100 µm – 6.2 mm (100 µm resolution), while the 2D cloud (2D-C) probe acquired data on particles from 12.5 µm – 1.55 mm (25 µm resolution). The data was thoroughly quality-controlled to retrieve a reliable database of individual droplet images. A gamma model was fit to the data and the method of moments technique was employed to allow the analysis of physical properties of droplets as a whole. Drop size distributions (DSDs) were produced for each RCE module. A comparison to other datasets (Fig. 4, only one representative day shown) indicated a distribution close to that observed in the Indian maritime region, but departing with results from the TOGA COARE experiment. This indicated that unique microphysical and/or dynamic processes occurred in the DYNAMO (Indian Ocean) region during the observed period.

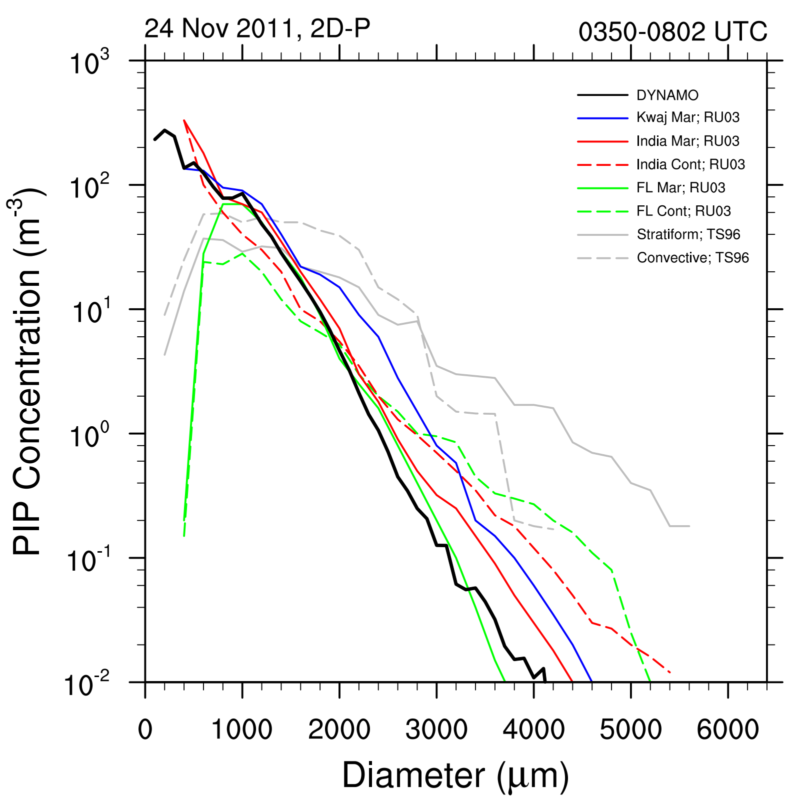

Figure 4. Drop size distribution observed by the 2D precipitation particle probe aboard the NOAA P-3 aircraft during the 24 November flight mission (black). Only data recorded below 3 km was used in this plot. Distributions from previous literature are shown for comparison.

The in-situ measurements also allowed the development of an empirical relationship to estimate precipitation rate from radar reflectivity, a common practice where limited rain gauge data exists. The third and sixth moments of each modeled DSD case (RCE) were found, rainfall rate (R) and equivalent radar reflectivity factor (Z), respectively. Linear regression was applied to establish a Z-R relationship (Fig. 5) for each case. The resulting variability of prefactors and exponents indicated the variability of the convective systems. The mean relationship was $Z = 366R^{1.43}$, which compared favorably to those calculated during the TOGA COARE and MISMO projects as well as other oceanic distributions.

The fact that measurements were acquired via aircraft allowed a vertical sampling of rain drop characteristics not normally available via the common ground-based equivalent disdrometer systems. Figure 6 shows the distribution of the 2D-P and 2D-C observations. Four distinct groupings of data were separated to allow the analysis of vertical changes of drop size distributions and microphysical parameter properties. Bins of 200 m were used to show the number of measurements at the vertical levels, seen as the bar histogram graph to the right of the scatterplot region. These numbers were largely controlled by flight level, but can be used to ensure that similar number distributions were used in comparison. The histogram above the scatterplot indicates that median drop diameters increased during the active phases of the MJO, while remaining smaller during inactive phases. In addition this plot also shows that the number of droplets increased, as expected with more spatially extensive convective systems. A manuscript relating the results of this work is in preparation and will be submitted to *Monthly Weather Review* soon.

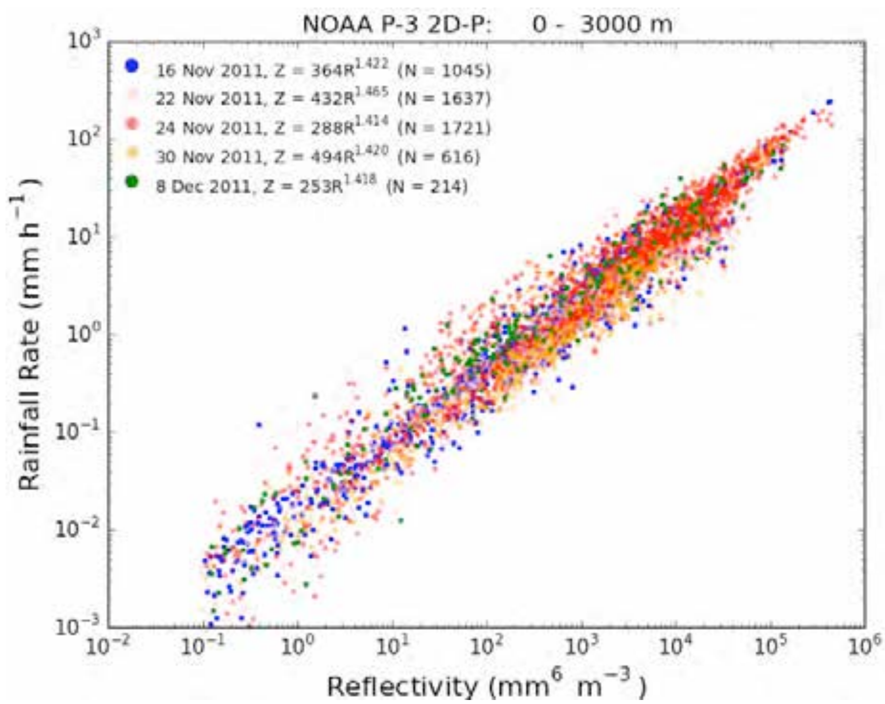

Figure 5. Log-log scatterplot of rainfall rate and reflectivity obtained from the method of moments technique applied to drop size distributions collected from the 2D precipitation particle probe aboard the NOAA P-3 aircraft. The Z-R relationship formulae are shown for each DYNAMO flight where usable data was recorded, with the number of samples in parentheses. Warm (cool) colors represent active (inactive) periods of the MJO.

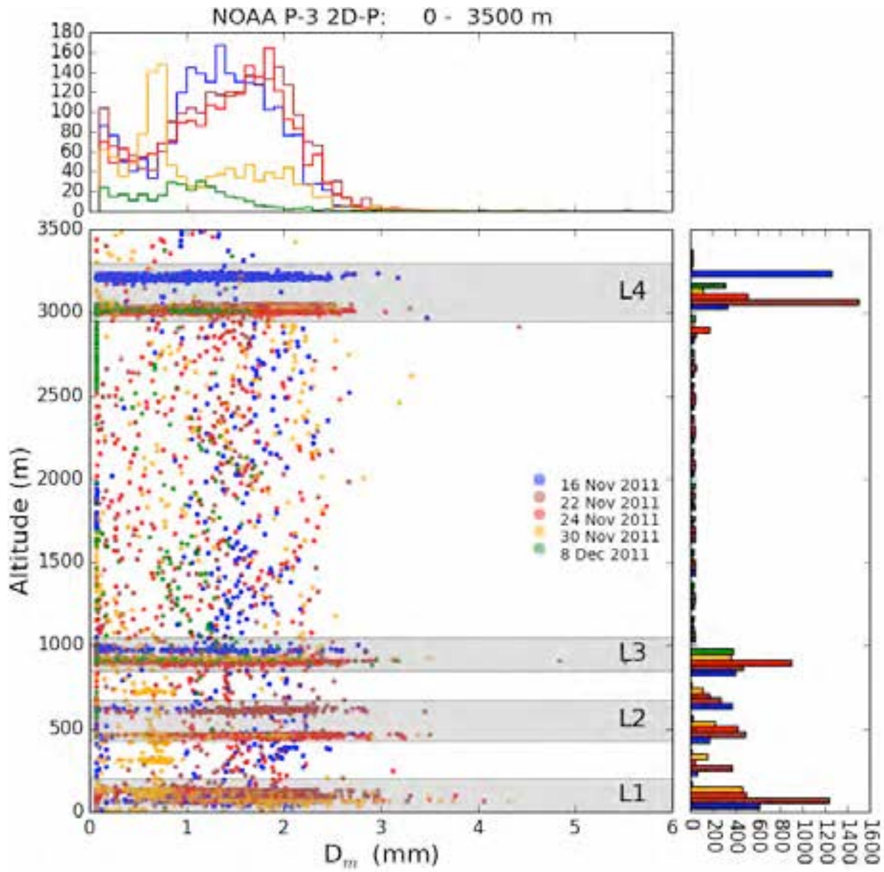

Figure 6. Vertical distribution of cloud and precipitation particle probe measurements of median volume drop diameter during DYNAMO. Warm (cool) colors represent active (inactive) periods of the MJO. The bar histogram to the right indicates the number of observations for each case in a 200 m vertical bin. The plot on top is a histogram of the median volume drop diameter by case.

2. Work in progress

During the remaining a few months of the project, the PI team will focus on finalizing DYNAMO data analysis and complete peer reviewed publications. We have several manuscripts that are near in completion. The RSMAS/UM and NSSL groups will work closely to complete the following:

- Determine the convectively generate cold pool strength and the surface/boundary layer recovery time using the GPS dropsonde, AXBT, and airborne radiometer and satellite SST data
- Provide a convective organization and large-scale context for other observations made during DYNAMO and a dataset for model evaluation/verification

- Characteristics of the convective systems (e.g., updraft/downdraft strengths, cold pool structure) will be documented and placed in the context of the larger scale MJO phase.
- Collaborate with the French Falcon aircraft team to document the microphysical properties of the convection investigated on Dec. 8 2011. That case is the only coordinated multi-aircraft investigation, within the S-POL radar range, obtained during DYNAMO.

The University Maryland and NOAA/CPC team will continue the diagnostic study of the GFS and CFS models, which will necessitate the adaption of the convective cluster tracker to the models, will investigate the divergence of observed and forecast cluster as a function of lead time. Observation and model fields are evaluated in both long-term statistics and event-by-event case studies. These diagnostic studies will not only help provide detailed model verification but also help develop an operational MJO monitoring and forecasting guidance using a combined cloud cluster observation and model forecast fields. These analyses will be examined and compared with the results from Weller and Hendon (2004) using Real-time Multivariate MJO series 1 (RMM1), and 2 (RMM2).

3. Publications

Kerns, B. W., and S. S. Chen, 2014a: Equatorial dry air intrusion and related synoptic variability in MJO initiation during DYNAMO, *Mon. Wea. Rev.*, **142**, 1326-1343.

Kerns, B. W., and S. S. Chen, 2014b: ECMWF and GFS model forecast verification during DYNAMO: Multi-scale variability in MJO initiation over the equatorial Indian Ocean, *J. Geophys. Res.,***119**, 3736–3755.

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NOAA OAR Climate Program Office - COCA-FY 2014
PROJECT ANNUAL PROGRESS REPORT

PROJECT TITLE: Developing decision support tools for understanding, communicating, and adapting to the impacts of climate on the sustainability of coastal ecosystem services

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SECTION I. PRELIMINARY RESULTS

A. Research Project Objective and **Stakeholders and Decision Makers** we are working with.

Objective
The primary objective of this research project is to develop decision support tools to explore the effect of urbanization on the resilience of coastal ecosystem services under future climate change scenarios. South Florida is poised for such an investigation, as past scientific syntheses in the region have resulted in: 1) the development of conceptual ecosystem models linking ecosystem structure and function to drivers, pressures, and ecosystem services; 2) indicators that assess the natural and human dimensions components of the ecosystem; and 3) quantitative models that examine changes in ecosystem state under different climate scenarios. Specifically, we are taking a two-pronged approach to develop multiple lines of evidence for informing ecosystem-based management decisions. Over the past year, and continuing through 2015, we are using expert opinion analysis to develop cause & effect networks linking climate and human-development pressures (e.g. sea level rise, marine construction), to local ecosystem states (i.e. habitat types such as seagrasses, mangroves, etc.), and their associated ecosystem services (e.g. recreational opportunities, pollution attenuation, hazard moderation) throughout south Florida (please see *Stakeholders and Decision Makers* below). A parallel examination is using habitat suitability models to estimate current and future changes in areal cover, abundance, and quality of those same habitat types throughout south Florida. Currently meta-regression valuation methods are being used to estimate the economic value of ecosystem services in the study region (for details please see *Ecosystem Services Valuation* below). Both network and habitat-suitability analyses are being applied in three distinct urbanization zones in south Florida: 1) the heavily urbanized

southeast coast (i.e. Biscayne Bay), 2) the moderately developed southwest coast (i.e. southern Charlotte Harbor, Sanibel-Captiva, Estero Bay, and 3) the relatively undeveloped coast spanning from Rookery Bay in the north west through Florida Bay and Everglades National Park to the south and east.

Stakeholders and Decision Makers
To date we have been working with numerous stakeholders and decision makers throughout the south Florida region. Within the larger South Florida region we have interacted with and identified our focal case study sites and associated stakeholders/decision makers. In the southwest this includes the Charlotte Harbor National Estuary Program (Lisa Beever, Director CHNEP), Estero Bay Aquatic Preserve (Cheryl Clark, Manager EBAP), City of Sanibel (James Evans, Director, Natural Resources), Sanibel-Captiva Conservation Foundation (Eric Milbrandt, Director, SCCF Marine Laboratory), Rookery Bay National Estuarine Research Reserve (Kevin Cuniff, Research Coordinator, RBNERR), Everglades National Park (numerous stakeholders and decision makers), Biscayne National Park (Brian Carlstrom, Superintendent BNP), Biscayne Bay Aquatic Preserves/Miami-Dade County (Pamela Sweeney, Chief of Permitting MDC (formerly Manager, BBAP)). Some of these individuals have already participated in information gathering exercises to identify and prioritize pending management questions (e.g. Clark, Evans, Milbrandt) as well as to create Pressure-State-Ecosystem services networks, and identify focal ecosystem services, while others have been contacted and similar information gathering exercises have been scheduled/will occur over the coming weeks and months (e.g. Cuniff/Rookery Bay NERR). These interactions with key stakeholders and decision makers have helped us better frame how our tools can inform their specific decision-making process. In year two of this study we will continue collaborating with these key stakeholders to refine our climate scenarios, network and habitat suitability models, and assess (using expert opinion analyses) how these may impact the resilience and value of ecosystem services along the aforementioned urbanization gradient of south Florida.

B. Approach

Our project consists of three distinct but highly complementary sub-components: 1) expert-based network analyses linking pressures, states (i.e. habitat types), and ecosystem services; 2) biophysical habitat suitability (HS) modeling; and 3) ecosystem services valuation (please see *Ecosystem Services Valuation* below). Much of year one has been spent in creating the baseline networks, HS models, and conducting ecosystem services valuations that will provide a framework for us to assess and simulate climate change-related impacts to ecological and ecosystem services. In the coming year of this project, these three sub-components will be integrated ultimately enabling us to explore how climate-related changes in the biophysical components of the environment result in alteration of habitat types, and the ensuing value of ecosystem services.

1. Study region

As mentioned above our study region spans from the southern portion of Charlotte Harbor down around south Florida and up toward Miami and Biscayne Bay. For the purposes of this study we have delineated this larger region into three sub-regions and four focal study sites spanning a gradient of human development. The southeast region is heavily urbanized, and based on our initial interactions with local, regional, and national resource managers, we will be focusing our analyses in year two on Biscayne Bay and adjacent Miami-Dade County. To the south and west of Miami-Dade County is our adjacent central, relatively pristine study area, represented by Everglades National Park and Florida Bay. To the north and west of Monroe County is a transition zone between our pristine central region and the suburban southwest coast of Florida. Our focal study site in this transition zone is the Rookery Bay National Estuarine Research Reserve, which lies in Collier County, and borders Monroe County to the southeast and Marco Island and Naples Florida to the northwest. Our final focal study site is the primarily suburban sub-region encompassing south Charlotte Harbor, Sanibel-Captiva, and Estero Bay (Lee and Charlotte Counties, which are adjacent to Collier County to the south).

2. Developing Integrated Conceptual Ecosystem Models

To facilitate the development of integrated conceptual ecosystem models (ICEMs) for our three urbanization sub-regions spanning south Florida, we (project PIs) identified a list of key natural resource managers within each sub-region. From this larger list we identified 3-4 “key” natural resource managers and decision makers representing local, state, and federal agencies. We held various formal and informal informational meetings with these individuals to identify which managers had a pending management decision and/or a need for the type of products we are developing through this COCA project.

During these informational meetings we were able to present our baseline ICEMS leveraged from our earlier MARES project. Very briefly, the goal of the MARES project was to “reach a science-based consensus about the defining characteristics and fundamental regulating processes of a South Florida coastal marine ecosystem that is both sustainable and capable of providing the diverse ecosystem services upon which our society depends.” Between 2009 and 2012 stakeholders identified the predominant pressures, states, and ecosystem services of the south Florida coastal marine environment. Using these data as our baseline we met with our short-list of key natural resource managers to conduct expert opinion polling exercises. In these informational meetings we introduced local experts to our COCA project, explained our methods and goals, and then had the local experts identify predominant Climate- and Urbanization-related Pressures within their management jurisdiction (e.g. Sea Level Rise on Sanibel-Captiva). They also identified the relevant ecosystem states (e.g. Estero Bay does not have Beach habitat), and the suite of ecosystem services derived from these ecosystem states (e.g. Mangroves in Florida Bay provide the Ecosystem Service Hazard Moderation). This information feeds directly into the habitat suitability models and the ecosystem service valuation work being completed by our Texas A&M University-Corpus Christi project partners (please see below). These data were then used to develop sub-region specific ICEMs and currently are being used to develop Pressure-State-Ecosystem Service semi-quantitative network models that will be used to simulate how various Climate Scenarios are predicted to impact the provisioning of ecosystem services in the second year of our study (Figure 1).

At this point we are scheduling follow-up workshops for summer and fall 2015 with local and regional experts (e.g. we will be meeting with local experts for our Charlotte Harbor/Sanibel-Captiva/Estero Bay focal study site on August 31st, 2015). At these follow-up workshops we will be presenting the baseline network models linking Pressures, States, and Ecosystem Services constructed from expert-opinion synthesized at our initial informational meetings. After presenting our initial baseline model results, experts will then participate in a scoring exercise to quantify individual linkages among Pressures, States, and Ecosystem

Services to conduct our ecosystem service risk assessment. These weighted networks will also be scored to assess the impact of our low- mid- and high-range climate scenarios on the strength of interactions within our weighted Pressure-State-Ecosystem Service networks.

3. Developing Hydrodynamic-Habitat Suitability Models

Our original postdoc on this project (Kearney) left the University of Miami to accept a project scientist position at the University of Washington shortly after COCA funds became available (please see *Section D. Discussion of any significant deviation from proposed workplan* below). However, we have hired a replacement scientist (Dr. Frank Marshall) who is taking over the hydrodynamic-habitat suitability empirical modeling component for our project. Before leaving Dr. Kearney developed coarse statistical habitat suitability models linking hydrodynamic properties of the water column with target habitat types and the provisioning of sportfish within our central study region (Figure 2). These statistical models link various physical parameters (e.g. temperature, salinity, precipitation) associated with the suite of climate-related Pressures identified in our management engagement activities (see above), with the distribution of key habitat types (e.g. spatial abundance of seagrass), and the generation of associated ecosystem services (e.g. recreational opportunities derived from sport-fishing in Florida Bay). The habitat suitability models enable us to quantify changes in seagrass cover, sportfish, and the prey base, which can be used to estimate changes in ecosystem services such as recreational opportunities, nutrient and pollution regulation attenuation under different climate and urbanization scenarios. We anticipate he will have completed the HSI modeling for our Everglades National Park and Rookery Bay focal study sites by the end of summer 2015, and will expand those methods and models into our suburban southwest (i.e. Charlotte Harbor/Sanibel-Captiva/Estero Bay) and urban southeast sub-region (i.e. Biscayne Bay) shortly thereafter.

We have identified the hydrodynamic models to be used in both the undisturbed central region and heavily urbanized southeast. In both cases, we will use the Flux Accounting and Tidal Hydrology at the Ocean Margin (FATHOM) model. This is mass balance model for predicting salinity in each box (Kelble et al. 2007). It has already been used in Florida Bay to examine climate change scenarios. Dr. Marshall (our replacement hire) has been refining and expanding FATHOM to enable scenario analyses that simulate potential management actions in addition to climate change. In the study area for the southwest coast we have not finalized the hydrodynamic model yet, but hope to do so in the coming month. We have access to a HYCOM model for this region, but want to first validate that it accurately predicts salinity in Charlotte Harbor.

4. Ecosystem Services Valuation

Members of the project team located at Texas A&M University-Corpus Christi have conducted a gap analysis and synthesized the primary studies and data necessary to conduct ecosystem services meta-regression analysis for Miami-Dade, Monroe, Collier, Lee, and Charlotte Counties (i.e. counties encompassing our focal study sites). From these analyses and based on the results from our focal study site manager interactions (please see above) the quantification of ecosystem services for several of the key habitat types found within our study region was initiated. The focus of this first year was on the development and testing of the meta-regression model as described below.

We used the Gulf of Mexico Ecosystem Services Valuation Database (www.GecoServ.org) to collect primary studies that valued ecosystem services provided by habitats present in the study sub-regions. For marshes, for example, we selected 32 studies providing 85 estimates for services such as habitat, nutrient regulation, gas regulation, disturbance regulation, waste regulation, water supply, food, raw materials, recreation, aesthetics, cultural and spiritual, medicinal resources, and science and education. However, only for recreation and disturbance regulation there were enough studies to allow us carrying out a meta-regression analysis.

A classical ordinary least squares regression model was used:

$$\ln (y_i) = a + b_s X_s + b_w X_w + b_E X_E + u_i$$

where ln (y_i) is the natural logarithm of the dependent variable (2012 U.S. $ per hectare per year); *i* is an index for all 85 observations; a is the constant term; b_s , b_w and b_E are the coefficients of the explanatory variables; X_s are study characteristics; X_w are the wetland characteristics (areal extent); X_E the socio-economic characteristics (population density); and *u* is the margin of error. These variables were selected based on previous meta-regression analysis and on results that showed which variables seemed to influence the value of ecosystem services the most (Table 1).

Table 1: Meta-regression model for marshes

Variable	**Coefficient**	***P* value**
(Constant)	3.180	.000
(Log) Area	-.152	.041
(Log) Person per square mile	.405	.036
Region Code	-.352	.000
Costal Type	-.449	.031
WTP	.796	.006
Replacement Cost	-.501	.063
Disturbance Regulation	.611	.026
Recreation	-.850	.001

OLS results: R^2= .427. *Adj.* R^2= .366. N= 85.

All explanatory variables were considered statistically significant at 1, 5, or 10% levels. Area and population density had the expected sign, negative and positive respectively, meaning that the largest the marsh the lowest the marginal per hectare value, and the largest the population surrounding the marsh, the highest the ecosystem service value. Region code was negative (1 = North America; 2 = Europe; 3= Asia; 4= Africa), showing that marshes in North America and Europe are valued more highly than those in Asia and Africa. Coastal type (1= Coastal marsh; 0= Inland marsh) had a negative value showing that inland marshes are valued more highly than coastal marshes. The two valuation methods found to be significant were willingness-to-pay (WTP) and disturbance regulation; WTP generated higher estimates than replacement cost.

The meta-regression analysis was tested on counties in our study areas (Table 2). According to our results, disturbance regulation has a higher value in all the counties considered for the testing of the model. The county with the highest value for both ecosystem services was Monroe, followed by Collier. The difference in values in this exercise is believed to be driven by a combination of the areal extent of marshes and population density.

Table 2: Value of ecosystem services provided by marsh calculated through a meta-regression analysis*

	Disturbance Regulation		**Recreation**		**Total**
Counties	US$ 2012 /ha/year	US$ 2012 /year	US$ 2012 /ha/year	US$ 2012 /year	US$ 2012 /year
Miami-Dade	$6,430	$15,176,199	$222	$524,989	$15,701,188
Monroe	$1,450	$28,352,749	$50	$980,805	$29,333,554
Collier	$2,258	$20,192,662	$78	$698,524	$20,891,186
Lee	$5,557	$9,493,366	$192	$328,404	$9,821,770
Total	$15,694	$73,214,976	$543	$2,532,722	

* Model variables: area represents the areal extent of marshes in each county; person per square mile is population density in each county; region code is set to 1 to represent North America; coastal type is also set to 1 to represent coastal marshes; WTP and replacement cost are given the weight of how frequent they were used in the dataset (16.7% and 14.6%, respectively).

C. Description of any matching funds/activities used in this project.
There are no matching funds for this project, however federal co-PIs (Kelble and Rudnick) have made in-kind donations of time and resources to facilitate completion of various project tasks.

D. Partners you are working with on this.
• NOAA, Atlantic Oceanographic and Meteorological Laboratory (AOML)
• US National Park Service/Biscayne National Park & Everglades National Park
• US Fish and Wildlife Service/J.N. Ding Darling NWR & Ten Thousand Islands NWR
• University of Miami
• University of Florida
• Texas A&M University – Corpus Christi
• Florida International University
• Florida Gulf Coast University
• Miami-Dade County
• Sanibel-Captiva Conservation Foundation
• City of Sanibel
• Florida Department of Environmental Protection/Estero Bay Aquatic Preserve
• Florida Department of Environmental Protection/Rookery Bay National Estuarine Research Reserve
• Charlotte Harbor National Estuary Program

SECTION II. ACCOMPLISHMENTS
A. Brief discussion of project timeline and tasks accomplished.

The following tasks have been accomplished during the reporting period 08/01/2014 - 04/30/2015:

- Identified "key" natural resource managers within our three sub-regions that have indicated a desire and need for our products and can use our products to inform climate-related decision-making
    - Urbanized Southeast Sub-Region (Miami-Dade County & Biscayne Bay): Pamela Sweeney, Chief of Permitting, Regulatory and Enforcement Division, Miami-Dade County; Brian Carlstrom, Superintendent, Biscayne National Park
    - Relative pristine Central Sub-Region (Monroe and Collier Counties, Everglades National Park and Florida Bay): Fred Herling, Chief Park Planner, Everglades National Park; Carol Mitchell, Deputy Director, South Florida Natural Resources Center, Everglades National Park; Bob Johnson, Director, South Florida Natural Resources Center, Everglades National Park; Kevin Cuniff, Scientific Research Coordinator, Rookery Bay National Estuarine Research Reserve, Florida Department of Environmental Protection
    - Suburban Southwest Sub-Region (Lee and Charlotte Counties, Charlotte Harbor, Sanibel-Captiva, and Estero Bay): Cheryl Clark, Manager Estero Bay Aquatic Preserve, Florida Dept. of Environmental Protection; James Evans, Director, Natural Resources, City of Sanibel; Eric Milbrandt, Director, Sanibel-Captiva Conservation Foundation; Lisa Beever, Director, Charlotte Harbor National Estuary Program.
- Through meetings/interactions with "key" personnel and local experts identified and defined suite of 14 potential climate and urbanization pressures within each sub-region

Ecosystem Pressures	Definition
Accelerated Sea-level Rise	the anticipated increase in the rate of sea-level rise
Boating Activities	damage that occurs due to boating activities, does not include fishing; includes non-extractive snorkeling and diving activities
Climate Change (Temperature)	deviations from typical/historical seasonal temperature patterns in air and/or water
Climate Change (Weather)	changes in weather patterns that are anticipated to occur as a result of climate change, storm frequency and intensity, etc.
Commercial Fishing	harvesting of living marine resources to sell for commercial purposes
Disease	a disorder of structure or function in a human, animal, or plant, especially one that produces specific signs or symptoms or that affects a specific location and is not simply a direct result of physical injury
Freshwater Quality	quality of freshwater flow from rivers, canals, stormwater drains, and wastewater to estuaries; includes land-based sources of pollution; eutrophication
Freshwater Quantity	quantity, timing, and distribution of freshwater flow from rivers, canals, stormwater drains, and wastewater to estuaries; includes land-based

	sources of pollution
Marine Contaminants and pollution	Marine-based contamination such as oil spills and nutrients from deep-ocean upwelling
Invasive Species	non-native species that threaten ecosystems, habitats or species
Marine Construction	construction that takes place within or adjacent to the marine ecosystem
Marine Debris/Ghost Traps	anthropogenic materials discarded or left/lost in the marine environment
Ocean Acidification	as CO_2 levels increase in the ocean the pH and aragonite saturation state are lowered
Recreational Fishing	any harvest of marine resources for recreation or personal consumption, not commercial sale

- Through meetings/interactions with "key" personnel and local experts Identified and defined suite of 11 potential ecosystem states within each sub-region

Ecosystem States	**Definition**
Beaches	sandy shorelines from the dune zone to the offshore edge of the surf zone
Coastal Wetlands	the saltwater zone on the mainland that is landward of the coastal margin, which includes marshes, flats, mangroves and the intermittent creeks in these areas.
Coral and Hardbottom	structures made from calcium carbonate secreted by corals and the limestone platform covered by a thin layer of sediments with a sparse mixture of stony and soft corals, macroalgae, and sponges
Fish and Shellfish (excluding oysters)	fish and shellfish (other than oysters) that are hunted by commercial and recreational fisheries or protected by management; and the prey species required to support them
Inshore Flats	flat bottom, sub- or intertidal habitats that lack epifaunal oyster or sea grass and are located inside the outer coastal margin
Mangrove Keys	mangrove islands located in both the populated Florida Keys and the unpopulated islands found within Florida Bay
Marine Birds	all bird species that are dependent upon the marine ecosystem for habitat or prey
Oyster Reefs	reef structure developed by oysters (e.g. *Crassostrea virginica*)
Protected Species	all marine species protected by the Endangered Species or similar Act that are not fish
Seagrass/SAV	submerged areas dominated by rooted, aquatic, vascular plants
Water Column	the physical, chemical and biological characteristics of the water column, including suspended benthic sediment, phytoplankton, and zooplankton

- Through meetings/interactions with "key" personnel and local experts identified and defined suite of 19 potential ecosystem services within each sub-region

Ecosystem Services	Definition
Biological Interactions	Species interactions
Climate Balance	Regulation of local to global climate processes
Gas Balance	Regulation of the chemical composition of the atmosphere and the oceans
Hydrological Balance	Movement, storage, and flow of water through the biosphere
Nutrient Balance	Maintenance of major nutrients within acceptable bounds
Pollutant Attenuation	Removal or breakdown of non-nutrient compounds and materials
Soil/Sediment Balance	Erosion control and sediment retention
Water Quality	Filtering of biotic and abiotic substances
Hazard Moderation	Dampening of environmental fluctuation and disturbance
Air Supply	Production of oxygen
Food	Provisioning of edible plants and animals for human consumption
Water Quantity	Retention and storage of freshwater
Medicinal Resources	Biological and chemical substances for use in drugs and pharmaceuticals
Ornamental Resources	Resources for fashion, handicraft, jewelry, decoration, worship, and souvenirs
Raw Materials	Materials for building and manufacturing. Fuel and energy. Soil and natural fertilizers
Aesthetic and Existence	Sensory enjoyment of the natural environment
Recreational Opportunities	Opportunities for rest, refreshment, and recreation
Science and Education	Use of natural areas for scientific and educational enhancement
Spiritual and Historic	Spiritual and historic sites and information

- For two of our four focal study sites (suburban SW: Charlotte Harbor/Sanibel-Captiva/Estero Bay and pristine central: Everglades National Park/Florida Bay) we have developed our baseline ICEMs and Pressure-State-Ecosystem Service network models (Figure 1).

- For the other two focal study sites, meetings have been scheduled with key managers (as identified above) to refine ICEMs and develop Pressure-State-Ecosystem Service Network models for the urban SE focal study site, Biscayne Bay and the SW pristine/suburban transition zone focal study site, Rookery Bay (both of these meetings will be completed by July 06, 2015).
- Scheduled future local expert group workshops to quantify interactions strengths in baseline Pressure-State-Ecosystem Service network models, and to score changes in interaction strengths under low-, mid- and high- climate change scenarios
- Built preliminary statistical habitat suitability models linking juvenile fish abundance to various bio-physical parameters (e.g. salinity, temperature, seagrass abundance) for central study region (Figure 2)
- In the central and eastern study sites we have identified the hydrodynamic model to be employed and accessed the code to alter these models to conduct scenario analyses
- Hired replacement scientist (Frank Marshall) to complete habitat suitability modeling for southwest and southeast sub-regions
- Developed project website (please see *Section III* below)
- Sorted through original ecosystem services valuation studies (available through GecoServ at gecoserv.org) for ecosystem states identified above. These primary valuation studies have been and will be utilized in the meta-regression analysis.
- Started gathering ecosystem state areal extents data from existing sources (available at http://ocean.floridamarine.org/mrgis/Description_Layers_Marine.htm#benthic). Areal extent is necessary information for the meta-regression analysis.
- Started gathering socio-economic information (population density) for the counties in the study area/sub-regions.
- Developed and tested a meta-regression model as described above.

B. Brief discussion on the application of your findings to inform decision making and any highlights of communicating or translating science to decision makers

As mentioned above we have had several opportunities to interact with key stakeholders and management decision makers throughout our study region. We have had face-to-face meetings with numerous managers to better understand their decision-making process, and to introduce them to our products and how they can be used to identify and rank relative risk to benthic habitat types within their study domains (e.g. mangrove, seagrasses, etc.), as well as to identify predominant pressures and habitats within their management jurisdictions. From these interactions we have gained a fundamental understanding of the ecosystems under consideration, and the concerns of various management agencies and personnel (e.g. in Sanibel, the primary pressure was sea level rise and the ecosystem state of primary concern was beaches, while in Estero Bay the primary pressures were terrestrial/freshwater runoff and boating activities associated with non-extractive users, while the predominant habitat types of concern were sea grasses and mangroves). These interactions will continue through year two of our project, and we have more formal workshops scheduled in our sub-regions to further refine our climate scenarios and weight the linkages in our Pressure-State-Ecosystem Service (P-S-ES) network models (e.g. co-PI Fletcher is organizing a mini-workshop at Florida Gulf Coast University for August 31th where ~20 local experts will weight P-S-ES interactions and score the predicted impact of future climate scenarios on these interactions).

Preliminary Pressure-State-Ecosystem Services findings for the relatively pristine Central Region (i.e. Everglades National Park and Florida Bay) were recently presented at the Greater Everglades Ecosystem Restoration conference in Coral Springs, FL, and we received feedback and had discussions about our project and preliminary findings, and scheduled follow-up meetings with several key managers and participants at this conference (e.g. Carlstrom/BNP, Cuniff/RB NERR, etc.).

Co-PI Kelble's related project work received coverage in the Miami Herald, Local & State section, on Monday May 4th. The article, entitled *Dry Winter, slow Glades progress put Florida Bay at risk*, written by Jenny Staletovich of the Herald, and includes quotes from Kelble concerning the impact of climate on precipitation and how elevated salinity in Taylor Slough (which flows into our central study region, Florida Bay) was due to an unseasonably dry winter, and how that can have downstream effects on the biotic components of our central sub-region.

C. Brief discussion of the planned methods to transfer the information and lessons learned from this project

In addition to our formal interactions with natural resource managers (as described above), several of our co-PIS work for federal natural resource management agencies in south Florida. Their involvement on and participation in various multi-agency teams (e.g. South Florida RECOVER team, NOAA Habitat Blueprint Implementation Team, Biscayne Bay Regional Restoration Coordination Team, etc.) ensures that these teams are apprised of our progress, and informed of our preliminary results at regular team meetings

D. Discussion of any significant deviations from proposed workplan

We have had not had any major deviations from our proposed workplan, and we anticipate the same outcomes as predicted originally. However, we have had three challenges/unforeseen circumstances that impacted out ability to stay on our original project timeline.

Challenge 1: Our initial Project start date was 08/01/2014. However funds were disbursed at the end of Fiscal Year 2014, and did not become available to spend against (at the University) until November 01, 2014. Therefore we started approximately four months later than expected.

Solution 1: We have revised our timeline, increased our frequency of stakeholder/management interactions, and streamlined our study design by identifying four focal study sites spanning our three urbanization zones, where managers have indicated a need for and a desire to use our COCA products.

Challenge 2: The second challenge was that our co-PI in charge of management engagement activities and decision-making was in a severe car accident. This co-PI had to undergo several months of therapy to recuperate (some of which overlapped with Challenge 1 above), however this delayed our timeline for stakeholder and decision maker interactions (e.g. to identify management priorities) until early 2015.

Solution 2: We have increased the frequency of manager engagement activities in 2015 to get us back in line with our revised timeline. It is anticipated we will be back on our original schedule for management engagement activities by December 31 2015.

Challenge 3: Our initial project postdoc (Kearney) moved to Seattle to accept an Assistant Scientist position at the University of Washington. Kearney was going to develop/run our habitat suitability models (as described in *Approach* above), however as we were delayed in receiving funds she did not make as much progress on the habitat suitability models prior to leaving RSMAS.

Solution 3: This problem has been resolved by hiring a new project scientist to complete the habitat suitability modeling. This new hire is focusing on developing Habitat Suitability models for our central study region currently, and based on preliminary progress, we anticipate this project component will be back on our revised timeline by Dec 31 2015.

E. List of completed publications, white papers, or reports

We anticipate having complete drafts of three peer-reviewed publications by the end of year two of this project.

SECTION III. WEBSITE ADDRESS FOR FURTHER INFORMATION

For further information please see our recently developed project website hosted on the NOAA Atlantic and Oceanographic Meteorological Laboratory server:
http://www.aoml.noaa.gov/ocd/ocdweb/coca.html

SECTION IV. ADDITIONAL RELEVANT INFORMATION

N/A

SECTION V. FIGURES

Please see below.

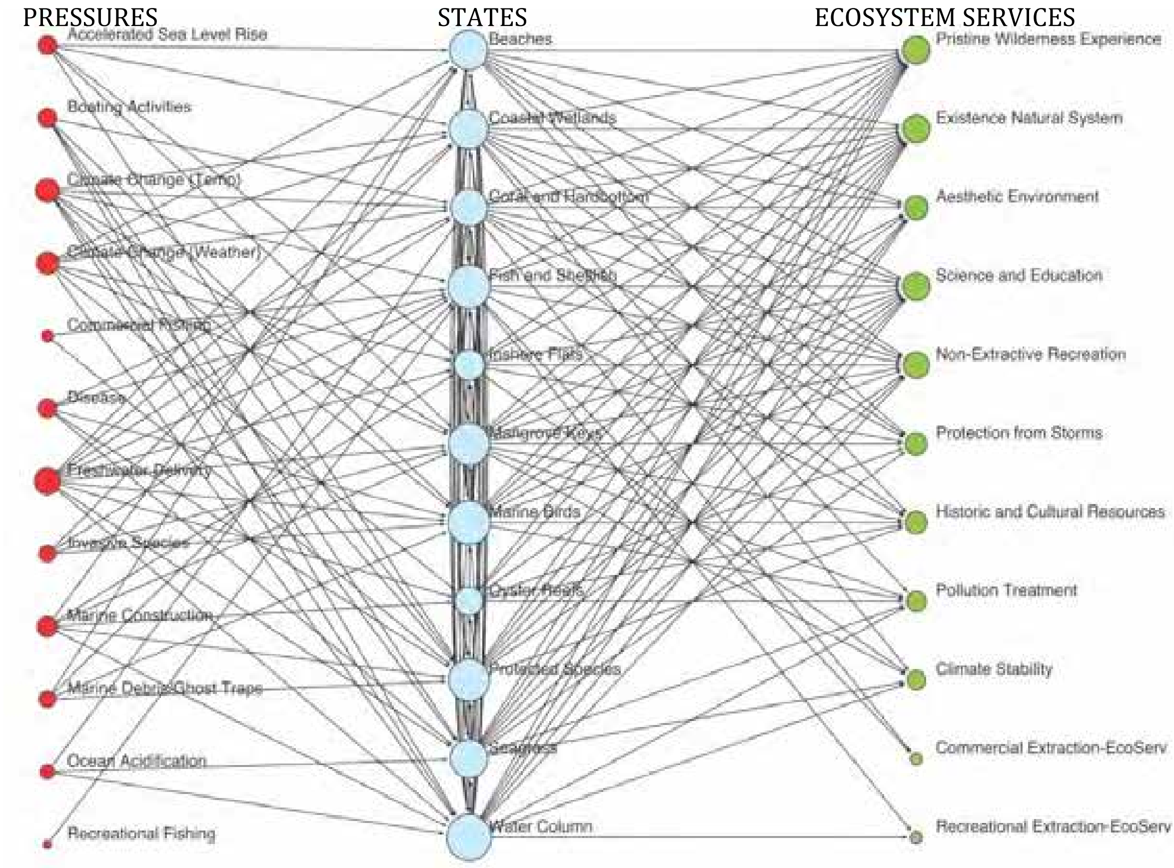

Figure 1. Ecosystem Pressure-State-Ecosystem Service network model for relatively pristine central study region (i.e. coastal Everglades National Park and Florida Bay). This model was constructed using regional expert opinion, and links various pressures, ecosystem states and habitat types, to a suite of ecosystem services. This network (and similar models developed for our other sub-regions) will form the baseline for our ecosystem services risk assessment to be competed during year two of this study.

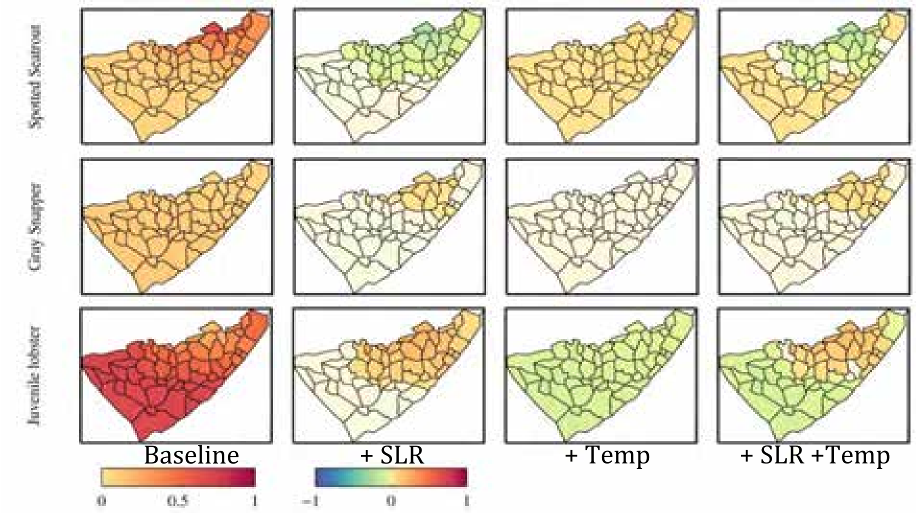

Figure 2. Habitat suitability models for spotted seatrout (*Cynoscion nebulosus*), gray snapper (*Lutjanus griseus*), and juvenile spiny lobster (*Panulirus argus*) in our relatively pristine central study sub-region. Figure panels depict (from left to right) habitat suitability for Flux Accounting and Tidal Hydrology at the Ocean Margin (FATHOM) model basins in Florida Bay for baseline (i.e. current) condition, and predicted changes in habitat suitability with increase in Sea Level Rise, increase in water Temperature, and combined effects of Sea Level Rise and water Temperature. Warmer colors indicate a relative increase in suitability; cooler colors indicate a relative decrease in suitability (adapted from Kearney et al 2015).

Quarterly Project Report to NOAA OAR

Award Number:	NA14OAR4830172
Project Title:	Using NOAA UAS Assets and OSSE/DA Capabilities to Improve Sampling Strategies and Numerical Prediction of Tropical Cyclone Track, Intensity, and Structure
Grantee:	Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami FL
Performance Period:	January 1, 2015 – March 31, 2015
Co-PIs:	Altug Aksoy and Jason Dunion

1. Goals and objectives

This investigation aims to utilize a combination of unmanned aircraft systems (UAS), satellite data, numerical modeling and data assimilation to address one of the main objectives identified by NOAA's Sensing Hazards with Operational Unmanned Technology (SHOUT) program. Specific emphasis of this effort include mission design and support for NOAA Global Hawk missions into tropical cyclones (TCs), optimizing Global Hawk aircraft real-time sampling strategies in both the TC inner core and the surrounding environment, using Global Hawk data to investigate various aspects of the TC inner core and surrounding environment (e.g. warm core, boundary layer, and cirrus canopy regions) in the context of TC intensity change, and numerical modeling analyses that will use a combination of high-resolution, multi-scale HWRF, a state-of-the-art, ensemble-based, high-resolution data assimilation system, and a comprehensive Observing System Simulation Experiment (OSSE) platform that combines all of these tools in an end-to- end system with a wide range of diagnostic tools designed to investigate TCs.

The following section highlights the Year-1 tasks that were carried out during the 01 January – 31 March 2015 performance period:

a. *The proposal team will collaborate with the NOAA-UAS science team to design aircraft flight patterns that will optimize adaptive sampling strategies for optimizing TC track and intensity forecasts and sampling of the TC inner core and near-environment. These aircraft experiments will be designed help facilitate the main objectives of this project and the NOAA-UAS mission;*
b. *Provide on-site (NASA Wallops) mission support during NOAA-UAS Global Hawk missions and provide a combination of on-site and off-site real-time GPS dropwindsonde processing support;*
c. *Provide real-time support for designing optimal GPS dropwindsonde sampling strategies for the Global Hawk using a real-time ensemble data assimilation and forecasting system;*
d. *Complete analysis of case studies with focus on Hurricanes Earl; acquire dropwindsonde data from the HS3 program and previous and current NOAA field campaigns; initiate composite analysis using data from multiple storms;*
e. *Open positions and carry out search for Postdoc and Computer Programmer;*
f. *Perform low and high resolution experiments with NR-R27 and NR-R9 for the TC mature phase to optimize UAS spatial sampling.*

2. Progress summary

a. *The proposal team will collaborate with the NOAA-UAS science team to design aircraft flight patterns that will optimize adaptive sampling strategies for optimizing TC track and intensity forecasts and sampling of the TC inner core and near-environment. These aircraft experiments will be designed help facilitate the main objectives of this project and the NOAA-UAS mission;*

Co-PI Dunion has been an integral part of several efforts that are underway to help prepare for the 2015 SHOUT field program. These include designing and editing the 2015 NOAA SHOUT Mission Operations Plan, designing SHOUT Global Hawk flight tracks, organizing the mission science team that will support Global Hawk missions in real-time, organizing the forecast team that will support SHOUT mission planning and operations, organizing the GPS dropsonde real-time processing team, implementing Global Hawk track drawing capabilities and integration into the NASA MTS aircraft monitoring system, and organizing the SHOUT dry run (10-19 August 2015) that will help prepare the SHOUT science team for the mission science period (25 Aug - 27 Sep 2015). Co-PI Dunion and Co-I Torn have also been working with NOAA/NCEP/EMC to establish the capability to access HWRF model ensemble data in real-time during the 2015 Atlantic hurricane season. This data will help support the SHOUT objective to use adaptive sampling techniques to target Global Hawk GPS dropsonde observations in model-sensitive regions with the goal of improving forecasts of tropical cyclone track and intensity.

b. *Provide on-site (NASA Wallops) mission support during NOAA-UAS Global Hawk missions and provide a combination of on-site and off-site real-time GPS dropwindsonde processing support;*

Co-PI Dunion and several members of the proposal team are planning to provide on-site mission science support at NASA Wallops during the science operations phase of the field campaign (25 Aug - 27 Sep 2015). These same team members will also provide real-time Global Hawk GPS dropsonde processing support both remotely (from Miami) and on-site at NASA Wallops. This data will be transmitted in real-time to the Global Telecommunication System (GTS) and thereby be made available to forecast and modeling centers around the globe. For this purpose, co-I Sellwood has worked on preparing materials for the in-house dropsonde processing training that will provide the technical skills to the team members who will provide on-site mission science support.

c. *Provide real-time support for designing optimal GPS dropwindsonde sampling strategies for the Global Hawk using a real-time ensemble data assimilation and forecasting system;*

During this period, arrangements were made to generate ensemble forecasts that can be used in the targeting calculations needed for SHOUT and to analyze some of the results from the 2014 season. Co-I Torn was able to receive a commitment from HWRF Team lead Vijay Tallapragada and team member Zhan Zhang to generate once-daily 80-member HWRF ensemble for the storm of interest during SHOUT. These forecasts will then be used to calculate optimal target locations for various valid times to potential periods when the Global Hawk would be flying. Co-I Torn is currently developing the necessary software to translate from HWRF output to figures that can be used by the mission scientists. In addition, Mr. Zhang will run a test forecast from Hurricane Edouard (2014) during the next quarter, which Co-I Torn will use to test the targeting software.

In addition, Co-I Torn began an analysis of the results from Hurricane Edouard from the Advanced Hurricane WRF (AHW) initialized 1200 UTC 12 September 2014. The figure below shows the sensitivity of Edouard's forecast valid at 1200 UTC 15 September 2014 to the 700 hPa moist static energy field at 1200 UTC 13 September 2014. In essence, this is the type of output that would be available the day before a mission and shows how to reduce the uncertainty in a forecast valid two days later. This figure suggests that the largest sensitivity is in the northwest quadrant of the storm roughly 100-200 km from the storm center, such that decreasing the moist static energy at this time is associated with a more intense storm 48 h later, and 500 km to the southwest of the storm center, such that increasing the moist static energy at this time is associated with a more intense TC. These two areas are actually related to the amount of convection on the northeastern or downshear side of the storm, such that increasing this convection is associated with a more intense storm, which in turn leads to lower MSE on the left-of-shear side. As a consequence, the intensity forecast would benefit from sampling these two particular locations of the storm.

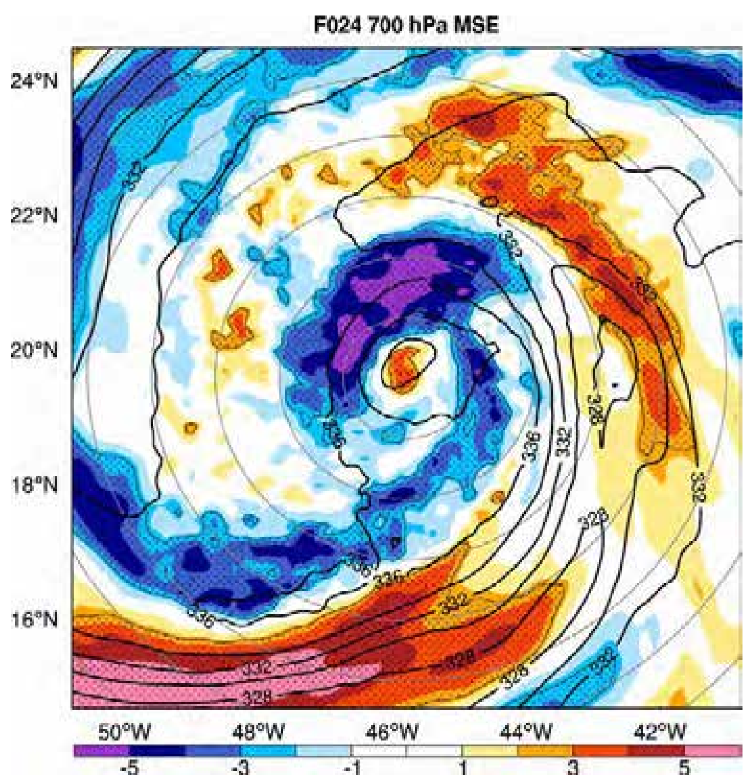

Figure 1. Sensitivity of the 1200 UTC 15 September axisymmetric tangential wind to the 1200 UTC 13 September 700 hPa moist static energy (shading, units: m/s). The black contours are the ensemble-mean 700 hPa moist static energy. The gray lines denote 100 km range rings.

d. Complete analysis of case studies with focus on Hurricanes Earl; acquire dropwindsonde data from the HS3 program and previous and current NOAA field campaigns; initiate composite analysis using data from multiple storms;

Co-I Jun Zhang led the analysis of the GPS dropsonde data collected in Hurricane Earl (2010) during the collaborative NASA, Genesis and Rapid Intensification Processes (GRIP) and the NOAA Intensity and Forecasting Experiment (IFEX). The dropsondes were released from four different types of research aircraft (WP-3D, DC-8, C-130 and G-IV). Excellent data coverage was found in the Earl case even when the data are grouped into a 12 h window. We focused on investigating the atmospheric boundary layer structure and dynamics. In our previous report, we presented the results from the composite analysis for the axisymmetric tangential wind speed, radial wind speed, agradient wind (the departure of the total tangential wind from the gradient wind), and convergence for the intensifying period of Earl between 18Z on August 29 and 6 Z on August 30. We found that the boundary layer during the intensification of Earl is supergradient inside the RMW, with the peak supergradient wind located at the height of maximum tangential wind speed.

In recent months, we used the dropsonde composite to evaluate the performance of the operational HWRF model in simulating the boundary layer structure of Hurricane Earl (2010). Figure 2 compares the simulated gradient and agradient wind components, the latter defined as the departure of gradient wind from tangential wind, with the corresponding fields derived from the observations during the same 12 h period between 18Z on August 29 and 6 Z on August 30. The gradient wind is calculated by solving the quadratic equation expressing gradient wind balance in terms of the radial pressure gradient. It can be seen that the model captures the regions of observed supergradient winds in the eyewall region and subgradient winds outside the eyewall. The agreement between the model and observational composites is quantitatively good. The difference is mainly in the magnitude of agradient wind (the modeled value is smaller than observed). This discrepancy may be due to the fact that the data coverage of the observations is not as large as in the model so more smoothing is in the modeled fields.

In year one, we will continue analyzing the droposnde data along with Doppler radar and flight level data collected in Hurricane Earl as we proposed for this project. We started analyzing dropsonde data from other tropical cyclones (e.g., Hurricane Edouard 2014) from NASA's HS3 field campaign, and NOAA's IFEX and UAS programs. Results will be shown in subsequent reports.

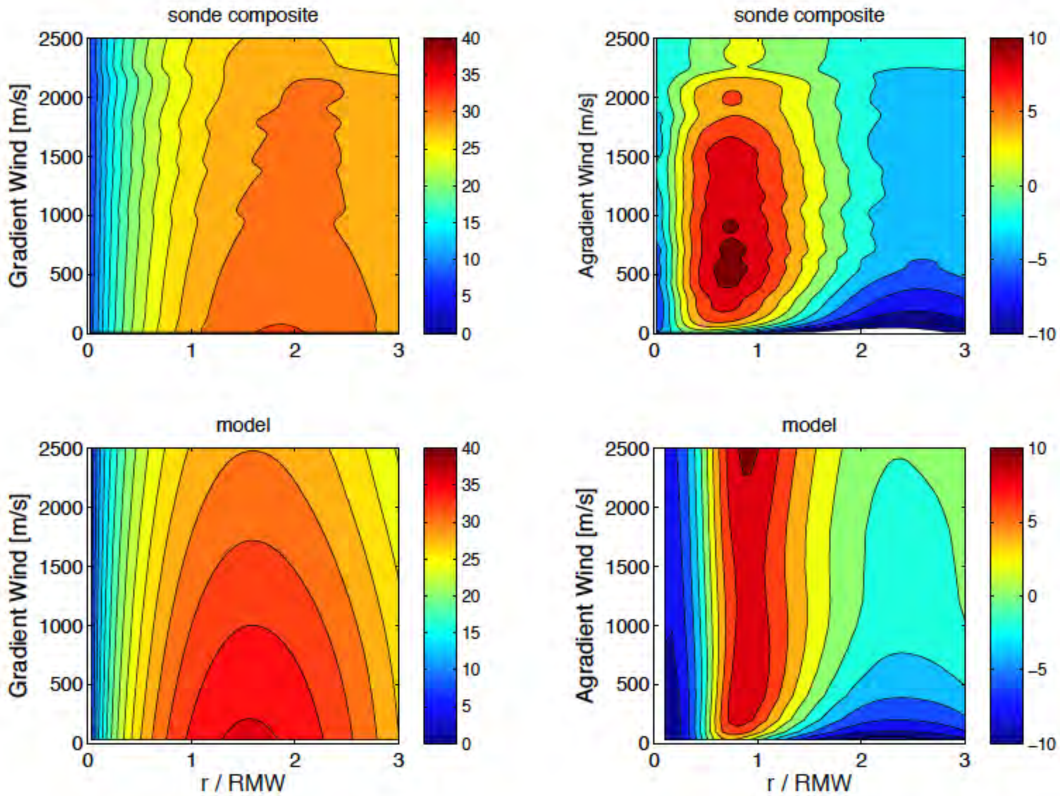

Figure 2: Radius-height plots of azimuthally averaged gradient wind (left) and agradient wind (right). The radius is normalized by the radius of maximum wind speed at 2 km. The upper panels are from the HWRF forecasts while the lower panels are from dropsonde composites. Theforecast and observational data are within the same period from 18 UTCZ 29 August to 6 UTC 30 August.

e. Open positions and carry out search for Postdoc and Computer Programmer

An interview committee was formed from NOAA/AOML Hurricane Research Division (HRD) employees. This committee has conducted formal interviews with a total of six candidates for the two positions opened. For the postdoctoral position, a selection has been made to make an offer to Dr. Hui Wang, who recently received her Ph.D. degree from the Florida State University Meteorology Department. We are currently in the process of obtaining the NOAA clearance for Dr. Wang and expect her to join our team by the end of May 2015. As for the computer programmer position, we are still in the process of making an offer to our top-ranked candidate and expect to hear about their decision during the first week of May 2015.

f. Perform low and high resolution experiments with NR-R27 and NR-R9 for the TC mature phase to optimize UAS spatial sampling

Software that simulates aircraft observations from the regional WRF-ARW nature run (NR-R27 and NR-R9) has been adapted by co-I Buci and is being tested. The software reads in output files from the nature run and interpolates the data to the location of the observations. Observation types successfully tested are the mass and wind variables measured by flight level instruments. Simulated dropsondes are currently being tested. Plans also include testing simulated SFMR and tail Doppler radar velocities. The final product will be able to simulate a variety of instruments from any flight pattern that the user chooses.

Once this simulation capability has been developed, we will begin constructing hypothetical UAS flight patterns and assimilating dropsonde observations as the first phase of measuring the impact of UAS observations on TC forecasts. This capability will be both tested in our in-house HEDAS vortex-scale data assimilation system and our in-house GSI-based regional OSSE system. In this report period, work has been also carried out by co-I Sellwood to adapt the dropsonde data processing capability already built into HEDAS to append the UAS dropsonde data to BUFR files that can be assimilated by GSI.

Mesoscale variability in the Gulf of Mexico and its importance in climate extremes over North America

*I. Kamenkovich (***lead PI***), G. Halliwell, B. Kirtman,* **and** *V. Kourafalou*

Progress Report Year 2015

NA12OAR4310073

Results and Accomplishments

1. Analysis of an ocean-only high-resolution Gulf of Mexico simulation (V. Kourafalou, M. Le Hénaff, G. Halliwell)

In order to accurately represent and study the regional mesoscale dynamics, the high-resolution simulation of the Gulf of Mexico (GoM) has been extended, covering October 1st, 2009 to December 31st, 2013. This simulation uses the HYbrid Coordinate Ocean Model (HYCOM), with 1/50° resolution (~1.8 km) and 32 vertical levels. It is forced at the surface by the Navy's high-resolution Coupled Ocean/Atmospheric Mesoscale Prediction System COAMPS (27 km, 3 hours). GoM-HYCOM is nested at the boundaries within the global operational HYCOM simulation at a daily rate. Forcing also includes realistic daily river discharge values from 15 major rivers in the U.S. part of the domain, while other rivers are represented by their monthly climatology. These attributes follow Schiller et al. (2011). Aspects of representation of coastal dynamics in regional modeling are included in Kourafalou et al. (2015).

To explore the value added from the simulation with the project developed high resolution GoM-HYCOM model, a comparison with another implementation of HYCOM in the GoM was performed. This other implementation (Le Hénaff et al., 2012) has several similar attributes, but two important differences: lower resolution (1/25° horizontally and 26 vertical layers) and climatological boundary conditions (daily updated, but perpetual year forcing). It was found that these were crucial differences, allowing the high resolution GoM-HYCOM to provide improved statistics on the realism of the Loop Current (LC) and associated eddy field. These features control mesoscale variability in the GoM, which is crucial for the correct representation of air-sea interactions at the regional scale, a key project objective.

Figure 1 shows the northern extension of the LC in both simulations. In addition to being on average more extended than in the 1/25° GoM simulation, the LC in the 1/50° simulation has usually shorter ring shedding periods. Observations indicate that the LC sheds anticyclonic rings at periods ranging from 2 to 18.5 months, with shedding occurring most frequently at 6, 9 and 11.5 months, with a lower peak at 17 months (Leben, 2005). In the 1/25° GoM HYCOM simulation, the shedding periods were rather large, from 17 to 19 months, with one exception at 3 months. These values were realistic, but they differed from the most commonly observed shedding frequencies (see Le Hénaff et al., 2012, for a discussion). In the new 1/50° simulation, the shedding periods are 11, 9, 15, and 7 months, which are closer to what observed values. In terms of northern extension, the average extension of the LC is 26.8° in the new 1/50° GoM simulation, close to the observed value of 26.2°. In addition to improved LC statistics with the 1/50° GoM HYCOM simulation, a data assimilation scheme has been recently implemented (following Halliwell et al., 2014). The scheme is based on sequential Kalman data assimilation, with an Ensemble Optimal Interpolation approach (Counillon and Bertino, 2009). Employing data assimilation is expected to provide further improvement on the model derived circulation fields.

The richness of the mesoscale field in the 1/50° GoM HYCOM simulation is illustrated on Figure 2, which presents the Sea Surface Salinity and Sea Surface Height fields. One clearly notices the mean LC and LC ring, which just detached, in lower salinity with respect to the rest of the basin. Fresher waters associated with the Mississippi River (MR) plume are also clearly noticeable close to the Mississippi Delta and on the neighboring continental shelf. In particular, the simulation shows a filament of fresher waters extending eastward along the continental shelf edge, part of which has been entrained southward between a small cyclonic eddy, sitting at the shelf edge, and the LC ring. A small cyclonic eddy, just east of the LC ring, presents notably fresher waters that come from that entrainment. Other small-scale cyclonic eddies are noticeable along the LC and the LC ring, in both SSH and salinity. The filament of fresher waters formed from the MR plume illustrates the realistic daily river forcing set up in the 1/50° simulation, which was another feature absent from the 1/25° simulation. In addition, the higher resolution simulation resolves the small scale features, especially small eddies at the shelf edge, which can participate in the export of the MR plume waters, as well as the rich frontal dynamics at the edge of the LC and LC rings.

2. Gulf of Mexico – North American Hydroclimate Teleconnections (B. Kirtman, E. Jung, I. Kamenkovich)

Part of the proposed research is to investigate how SST variability in the Gulf of Mexico (GoM) influences North American Hydroclimate. Our hypothesis is that GoM SST anomaly (SSTA) variability on monthly and seasonal time scales provides a source of warm season North American Hydroclimate. In particular, we simply ask: can GoM SSTA be used as a predictor of rainfall and/or convective available potential energy (CAPE) over North America during the warm season?

To test the above hypothesis we examine the relationship between GoM SSTA and North American Hydroclimate in the CCSM4 forecasts that are part of the North American Multi-Model Ensemble (NMME; Kirtman et al. 2014) seasonal prediction system. The objective of this part of the study is to investigate possible seasonal prediction of the probability of extreme weather in the United States. The analysis emphasizes the co-variability among extreme weather and environmental variables in observational estimates, and how well this co-variability is simulated and predicted within the context of a 30-year retrospective forecast experiment with CCSM4. Convective available potential energy (CAPE) and convective precipitation are used as a proxy of extreme weather over the USA, and SSTA over the Gulf of Mexico is used as an environmental predictor. Model predictability and prediction skill are assessed by saturation root-mean-squared-error (RMSE). The co-variability, which explain of 79-82 % of total CAPE-SST covariance and 50-52 % of total precipitation-SST covariance for the first leading components, are well captured by the forecasts, and show about four-to six months of predictability.

The predictability in the forecast is analyzed by comparing the correlations between area-averaged SSTA over the Gulf of Mexico (hereafter SST index) and convective precipitation (first row) and CAPE (second row) anomalies over the USA during MJJ over 1982-2011 for forecast initialized in May and for observational estimates (see Fig. 3). In the forecasts (left panels), positive correlation between the GoM SST index and CAPE over the USA is shown in the east of 102 °W with maximum correlation over Louisiana, Mississippi, Alabama, Georgia and Florida. In the observational estimates (right panels), positive correlations are found in the similar areas located along 30-40°N in the east of 102°W. The correlations are considerably weaker for convective precipitation, suggesting using CAPE as a proxy for extreme weather has better predictability.

3. Mesoscale variability and the air-sea interactions in the Gulf of Mexico (I. Kamenkovich, D. Putrasahan, B. Kirtman)

The analysis of the importance of oceanic mesoscale variability in the air-sea interactions over the Gulf of Mexico is carried out using two coupled atmosphere/ocean/ice simulations (see Kirtman et al. 2012 for detail). The first simulation (referred to as LRC) is a 155-year present-day climate simulation of the 0.5º atmosphere (zonal resolution 0.625º, meridional resolution 0.5º) coupled to ocean and sea-ice components with zonal resolution of 1.2º and meridional resolution varying from 0.27º at the equator to 0.54º in the mid-latitudes and with 42 vertical levels. The second simulation uses the same atmospheric model but coupled to 0.1º ocean and sea-ice component models and is referred to as HRC. The vertical levels in HRC are identical to LRC. The HRC simulation is eddy-resolving in the ocean – at least in the GoM. The atmospheric component is identical in both of these simulations and is based on the Community Atmospheric Model (CAM). The high-resolution simulation offers a unique opportunity to examine the importance of eddy advection for the upper ocean heat distribution, under an active atmosphere.

HRC simulations exhibit strong variability in the eastern part of the Gulf (Fig.4), where the Loop Current fluctuates between an "extended" state with the current reaching the northern part of the domain and a "retracted" state with the current flowing in the south of the Gulf. Mesoscale eddies that fill the domain include a large warm-core eddy that is shed by the Loop Current at the end of the extended state. In contrast, oceanic variability is weak in LRC and the low-resolution version of the Loop Current does not either change its position or shed eddies.

The analysis further demonstrates an important role of the oceanic mesoscale variability in air-sea interactions in the region. In particular, the correlation between the latent heat flux and surface temperature anomalies in HRC is large and positive in the vicinity of the Loop Current (Fig.5, left panel), but is negative in LRC (not shown). Since the coarse resolution in the latter simulation is typical for CMIP-class climate models, these results indicate a significant bias in their representation of the air-sea interactions.

We hypothesize that the difference between LRC and HRC is explained by the heat redistribution due to mesoscale eddies in the latter case, and this conclusion is supported by our preliminary results. In particular, a strong correlation between the latent heat anomalies and horizontal advection of heat in HRC (Fig.5, right panel) strongly suggests that the variability in the air-sea fluxes is driven by oceanic advection. If we define mesoscale temperature anomalies T' as deviations from a monthly mean <T>, T'=T-<T>, the correlations between the divergence of the corresponding "eddy" heat flux <**v**'T'> and latent heat anomalies become very similar to those in Fig. 5 (not shown). (Note that this definition of eddies includes short-term fluctuations of the Loop Current). In contrast, diffusion-based parameterization in LRC is clearly unable to capture these effects of mesoscale advection.

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FIGURES

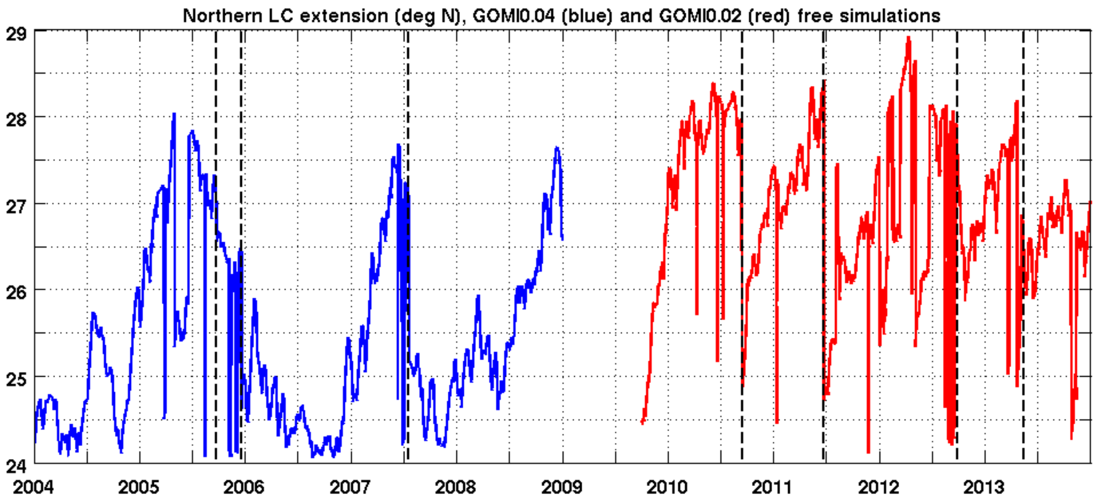

Figure 1: Maximum Loop Current extension (° latitude) from both GoM simulations (1/25° GoM HYCOM in blue, 1/50° GoM HYCOM in red).

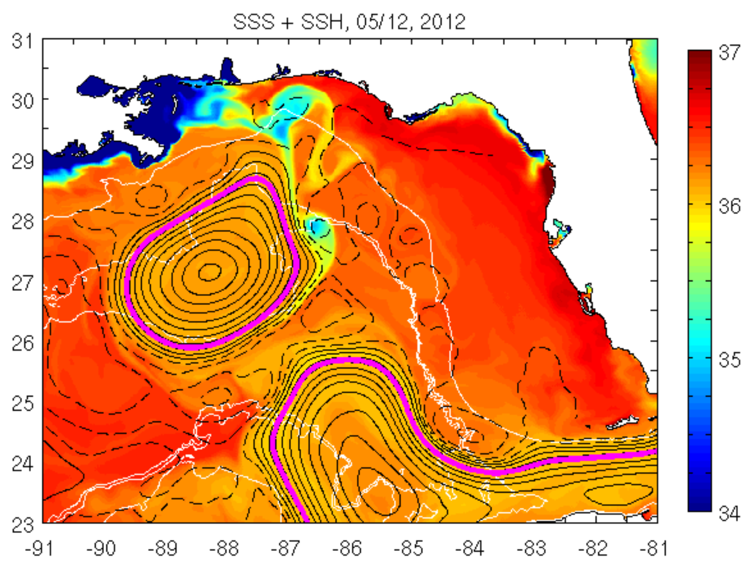

Figure 2: Sea surface salinity (colors, SSS) extracted from the 1/50° model simulation (zoom over the eastern GoM), on May 12, 2012 (free running simulation). Sea Surface Height (SSH) is in black contours (every 6 cm). Positive SSH with respect to the basin mean is in continuous lines, negative SSH is in dashed lines. The Loop Current is in magenta (SSH value of 17 cm over the basin mean, as defined by Leben (2005)). The white lines indicate the isobaths of 200, 2000 and 3000 m.

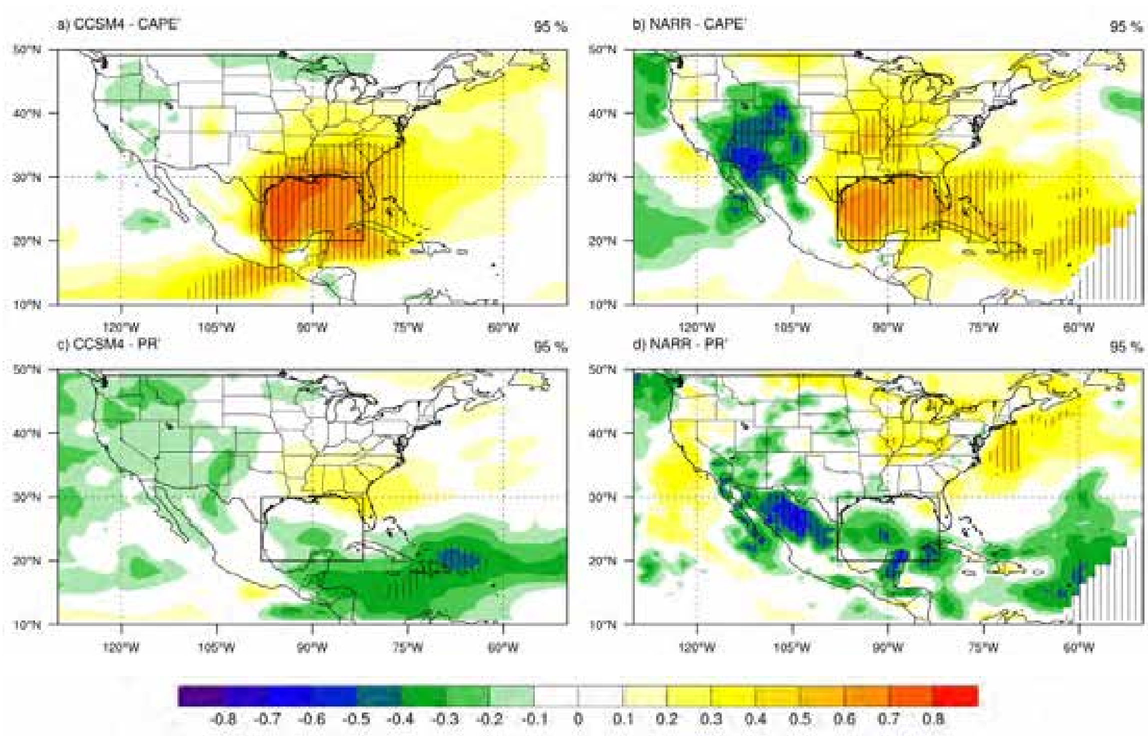

Figure 3: Correlations between area-averaged SST anomalies in the Gulf of Mexico (shown as black box) and (a, b; first row) CAPE and (c, d; second row) convective precipitation anomalies in the USA. Hashed areas indicate 95 % statistically significant. The correlations for the forecasts (left panel) and the observational estimates (right panels) are calculated for MJJ 1981-2011. The forecast with CCSM3 are initialized every 1 May of every year 1981-2011 and there are 10 member ensembles.

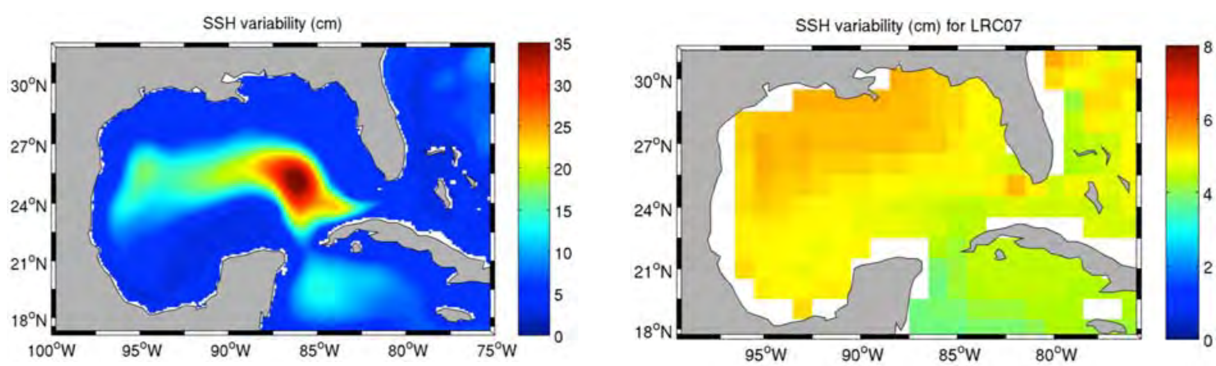

Figure 4: Standard deviation of the sea-surface height (SSH) anomalies in the HRC (left panel) and LRC (right panel) simulations. Units are cm. Note large values in the HRC simulation in the vicinity of the Loop Current.

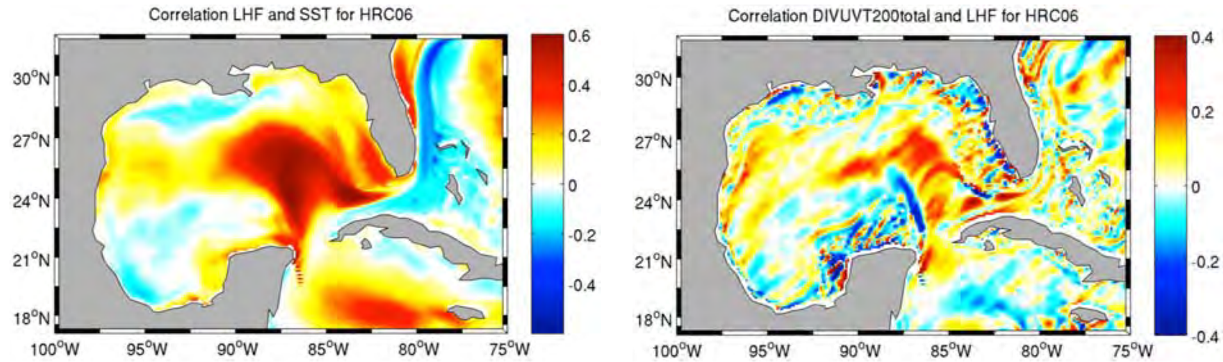

Figure 5: Relationship between air-sea fluxes and SST variability in the HRC simulation is illustrated by the correlations between the anomalies in the latent heat flux and: (a) SSTA (left panel) and (b) the divergence of the horizontal heat flux integrated over the top 200m (right panel). Note large values in the region where the Loop Current extends northward.

Highlights of Accomplishments

- New comprehensive Gulf of Mexico model at 1/50° (~2km) spatial resolution exhibits improved simulation of the Loop Current and its variability, as well as the richness of the mesoscale eddy field.
- Variability in the Gulf of Mexico SST anomalies (SSTA) on monthly and seasonal time scales provides a source of warm season North American Hydroclimate and can be used as a predictor of rainfall and/or convective available potential energy (CAPE) over North America during the warm season.
- Using CAPE as a proxy for extreme weather over the North America has better predictability than the convective precipitation.
- An important role of mesoscale oceanic processes in the air-sea interactions in GoM is demonstrated by contrasting climate simulations with and without explicit mesoscale variability.
- Oceanic redistribution of heat by mesoscale currents plays an important role in modulating air-sea interactions over the Gulf of Mexico.

Publications from the Project

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Budget for Coming Year

RSMAS/UM:

Salaries:	
Kamenkovich 0.9mo	$13,285
Kourafalou 1.75mo	$23,974
Graduate student 9.0mo	$25,003
Fringe Benefits	$8,122
Domestic Travel (2 trips)	$3,927
Other Direct Costs:	
Computer costs	$4,678
Publications	$2,000
Student Health Insurance	$2,538
Indirect Cost	$33,413
Tuition	$23,060
Total Cost	$140,000

NOAA/AOML:

M. Le Henaff, 3.8mo	$17,584
Fringe Benefits	$6,225
Indirect Costs	$6,190
Total Cost	$30,000

Future Work

Planned activities involve analysis of the air-sea interactions and upper ocean dynamics in the following comprehensive numerical simulations: (i) two coupled simulations with identical atmospheres, but different spatial resolution of oceanic components; (ii) high-resolution ocean-only model of the Gulf of Mexico (GoM). These activities are in progress and are expected to be completed during the final year of this project. Specific research tasks include:

- analysis of the modes of SST variability associated with GoM mesoscale circulations, and of their imprint on rainfall anomalies over the North America;
- analysis of the teleconnections between SST variability in GoM and the North America;
- examination of the importance of oceanic advection in heat distribution within the GoM, using comprehensive coupled and ocean-only simulations;
- studies of the importance of heat and mass transport through the Yucatan Channel and of the role of variability in the Caribbean Sea;
- studies of the role of small-scale eddies and topography in mesoscale variability and heat redistribution;
- analysis of the feasibility of capturing the effects of eddy redistribution in coarse-resolution climate models.

Severe Weather in the NMME

PI: Ben Kirtman

Final Report: 1 July 2014 - 31 March 2015

Grant Number: NA14OAR4830127

1. Introduction

The goal of the NMME (National Multi-Model Ensemble; Kirtman et al. 2014) expansion task is to evaluate and establish the prediction capabilities of high impact weather extremes out to several months by leveraging and enhancing the existing NMME system and data.

The NMME is aimed at developing a prediction system consisting of various US climate models to improve operational forecast skill on intraseasonal to interannual (ISI) time scales and to provide real-time forecasts and research data to the research and user communities. The NMME project is currently funded by NOAA, DOE, NASA and NSF. The daily and monthly NMME reforecast data will be archived at NCAR and available to the public.

While this activity will not be the primary focus of the HIWPP project, the HIWPP project will leverage the existing NMME resources and provide additional funding to enhance the NMME reforecast data with increased number of output variables and higher spatial/temporal intervals, as well as to support additional NOAA scientists to evaluate forecast capabilities and predictability of high-impact weather events, such as, hurricanes and tornadoes, out to several months based on the existing NMME models. The enhanced high-frequency NMME reforecast data will facilitate comparison of the existing NMME models and the new models under development in HIWPP. They will also increase the type of model outputs available to researchers and other customers and lay the groundwork for improving NMME-based high-impact at sub-seasonal time scales. Together with the other subprojects in HIWPP, the NMME expansion project will ultimately improve NOAA's forecast capabilities for high-impact weather across intraseasonal to seasonal time scales.

Objective: Assess severe weather environmental factors using NMME data

There is no current national capacity to provide skillful long-range severe weather outlooks. In response, a series of workshops were held to assess the current state of the science and to identify requirements to develop long-range severe weather outlook and attribution products that span the intraseasonal-to-seasonal timescales. Nascent efforts toward this goal are already underway and have demonstrated the potential for advancing our long-range prediction capabilities. Using observed relationships between large-scale environmental parameters and tornado occurrence, Tippet et al. (2012) demonstrate skill in predicting monthly tornado counts from the output of the NCEP Climate Forecast System (CFS).

This project will provide the basis for a more comprehensive model skill evaluation of factors that are critical to the long-range severe weather environment over the U.S. Chief among these are the El Nino Southern Oscillation (ENSO) phase transitions as captured by the Trans-Nino index (TNI), Gulf of Mexico SSTA, low frequency modes of North American low-level jet (NALLJ) variability, and thermodynamic and boundary condition fields important for supporting the severe weather environment (e.g., CAPE, helicity, soil moisture, etc.). A report will be produced on the analysis of these severe weather parameters in the reforecast datasets of all contributing NMME models to understand their skill in predicting the large-scale severe weather environments.

Objective: Using NMME Data to Improve Seasonal Hurricane Forecasts

An important collaborative element of this project is to ensure that NMME retrospective and real-time forecast data are available to the "Evaluation of NMME-based Hybrid Prediction System for Atlantic Hurricane Seasonal Activity" project lead by J. Schemm. The NMME-based hybrid prediction system is based on a multiple regression relationship established between the observed Atlantic hurricane seasonal activity and *predicted* circulation variables (i.e., from NMME forecasts). The predictors are forecasted wind shear over the main hurricane development region and preseason observed North Atlantic SST. The predictands are the seasonal total number of named storms and hurricanes, and the accumulated cyclone energy index. The hindcast period is 1982-2010 with initial condition month April, May, June and July, and the models included are CanCM3, CanCM4, CFSv2 and CCSM4. All forecast skill evaluations were cross validated. The effort during this reporting period was to ensure that all the retrospective and real-time forecast data was readily available to the Schemm team.

The hybrid NMME system demonstrates consider skill and will be provided to HSO forecasts in April 2015 for the 2015 May Outlook.

The proposed research will be carried out as part of the CIMAS program, and addresses the CIMAS climate variability theme in that the objectives examine how seasonal forecasts for the probability of high impact weather can be made.

2. Results and Accomplishments

To date the project has focused on:

1. How the NMME retrospective forecast with CCSM4 and CFSv2 (in collaboration with M. Tippett) capture the CAPE in the North American sector in comparison with observational estimates particularly forecast initialized in the beginning of May;

2. How well coupled modes of SST and convective rainfall over the North American are predicted in CCSM4 retrospective forecasts.
3. Gulf of Mexico SSTA composites of accumulated CAPE in observational estimates and CCSM retrospective forecasts

a. Cape Climatology

The first use we have examined is to compare the CCSM4 retrospective CAPE climatology with NARR (North American Regional Reanalysis) and with CFSv2 in collaboration with M. Tippett. Figure 1 show the retrospective CCSM4 forecast climatology for predictions initialized at the beginning of May and run out to one year. For comparison we show in Fig. 2 the CAPE climatology estimated from NARR. The Broad-brush characteristics of the CAPE monthly climatology for the observational estimates (NARR) are similar to the forecast climatology. The notable differences between the forecast CAPE climatology and the observational estimates are during the extended late spring early summer season (i.e., May-June-July-August). During MJJA the forecast CAPE climatology has much stronger signals extending into the central US.

This enhance CAPE during MJJA can also be detected in Figure 3 which shows the evolution of CAPE at 36N, 97.5W an arm site. Results from NCEP reanalysis are also included. For comparison we also show a similar calculation from CFSv2, CFSR, and two ARM site measurements in Fig. 4 (figure provided by M. Tippett). CFSv2 forecasts climatology also over-estimates CAPE relative to the NARR climatology, but both CFSv2 and CCSM4 are in better agreement with the ARM site measurements.

b. Preliminary Forecast Results

In order to begin our examination of the skill of the retrospective forecast experiments, we first analyze the co-variability between sea surface temperatures (SST) and North American convective precipitation. The motivation for this calculation is to diagnose whether there is coupled variability due to local SST variability (primarily in the Gulf of Mexico) that is related to convective precipitation over North America. A strong relationship that has similar spatial features in the observational estimates and the retrospective forecasts suggests potential predictability, and, most importantly, a mechanism for this predictability.

This coupled variability is diagnosed by calculating the Singular Value Decomposition (SVD) of the covariance matrix of SST anomalies and convective precipitation anomalies. The SVD analysis produces SST and convective precipitation patterns the co-vary.

Figure 5 shows the spatial pattern corresponding to the convective precipitation for the observational estimates (top row) from TRIMM and the retrospective forecasts (bottom row). The dominant first three singular vectors are show. Although not shown the SST anomaly patters for the observational estimates and the retrospective forecasts are very similar. The observational estimates are considerably noisier than the retrospective forecasts, but the first singular vector from both the observational estimates and the retrospective forecast have similar structures with positive convective precipitation anomalies over the southeast US co-varying with negative convective precipitation anomalies over the Gulf of Mexico extending into the southwest US. The first SVD patter from both the retrospective forecasts and the observations explains of 50% of the co-variability between the SST and the convective precipitation. Moreover, the pattern correlation between the observational spatial structure and the forecast spatial structure is 0.45 indicate significant similarity.

c. CAPE Composites with Gulf of Mexico SSTA

The objective of this study is to investigate possible seasonal prediction of the probability of extreme weather in the United States. The analysis emphasizes the co-variability among extreme weather and environmental variables in observational estimates, and how well this co-variability is simulated and predicted within the context of a 30-year retrospective forecast experiment with an atmosphere-ocean coupled model. Convective available potential energy (CAPE) and convective precipitation are used as a proxy of extreme weather over the USA, and sea surface temperature anomaly (SSTA) over the globe is used as the environmental variable that supports the seasonal predictability.

The emphasis on CAPE is based on two aspects. First, seasonal prediction systems have serious systematic biases in rainfall, which also lead to serious errors in the prediction of mean rainfall anomalies let alone predicting the potential changes in the probability of extreme weather. Second, CAPE has more robust large-scale drivers and hence more seasonal predictability. Moreover, CAPE is more directly link to changes in the chances of extreme weather as compared to seasonal mean rainfall.

While CAPE is a natural choice for predicting changes in the probability of extreme weather, it is a noise field, which complicates the analysis. Certainly, applying seasonal means will reduce the noisiness in the data, but will also limit our ability to detect features such as an early onset to the severe weather season. Here we advocate for the use of the accumulation of CAPE this has the advantage of daily resolution and is relatively smooth, but also avoids the difficulties of temporal filtering/smoothing in prediction mode. For example, Fig. 6 shows how the daily accumulation produces daily resolution but also a much more manageable field for analysis.

In terms of examining predictability, our preliminary analysis focuses on Gulf of Mexico composites of daily accumulation of CAPE (1 May – 30 September) over North America. Figure 7 shows the observational estimate of the composite from NARR and the composite from the 30-year CCSM4 retrospective prediction experiment. The model capture some elements of the observed spatial structure, but is somewhat weak in amplitude. Certainly, some of this weakness is due to using a 10 member ensemble from the prediction system. These results have been submitted for publication (Jung and Kirtman, 2015)

3. Publications from Project

Jung, E., and B. P. Kirtman, 2015: Can we predict high impact weather in the US? *Geophysical Research Letters*, (submitted).

4. Highlights

- Diagnosed CAPE climatology in observational estimates and multi-model retrospective forecast experiments
- Identified coupled SST-convective precipitation variability that has potential predictability. Comparison of these coupled modes in nature and the CCSM4 retrospective forecasts show substantive spatial similarities.

5. PI Contact Information:

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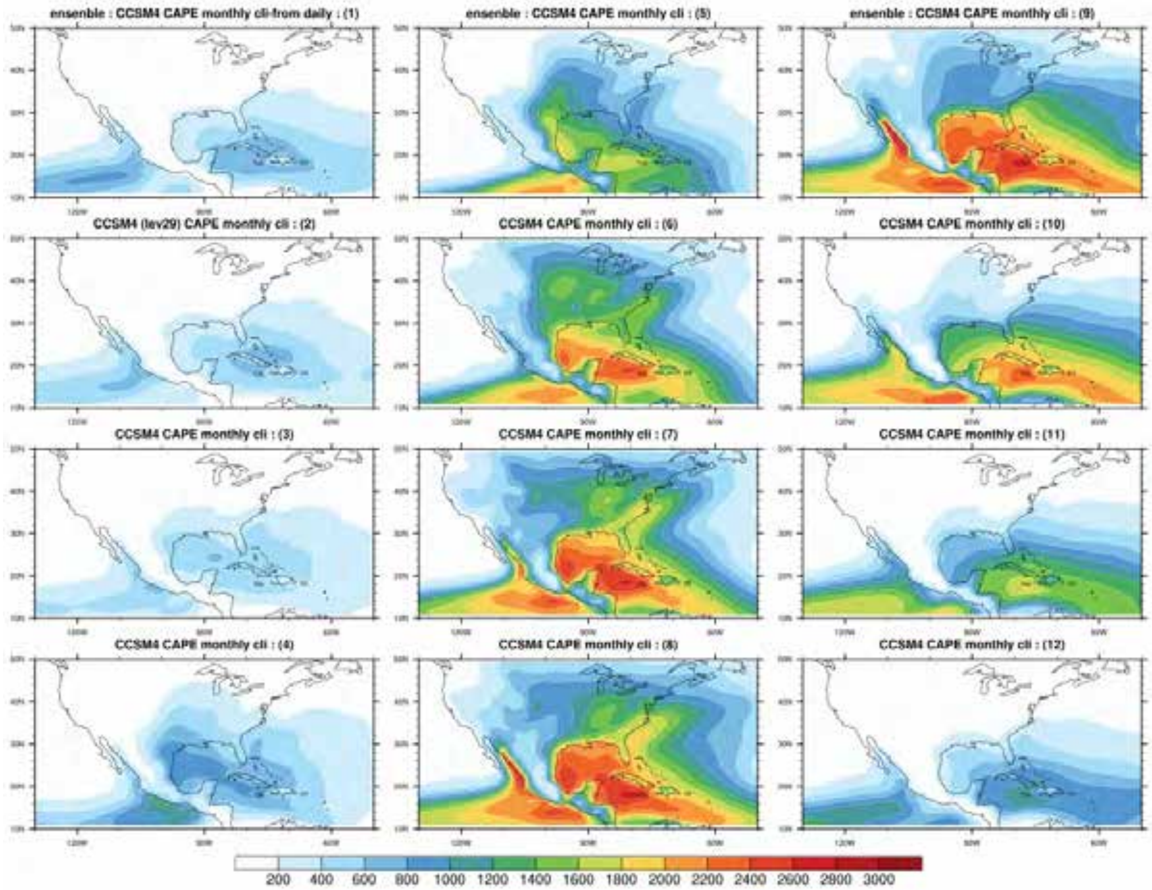

Figure 1: CCSM4 retrospective forecast CAPE monthly climatology. Forecasts are initialized at the beginning of May and there are 10 ensemble members. Month 1 corresponds to January; month 2 corresponds to February and similarly with the remaining months.

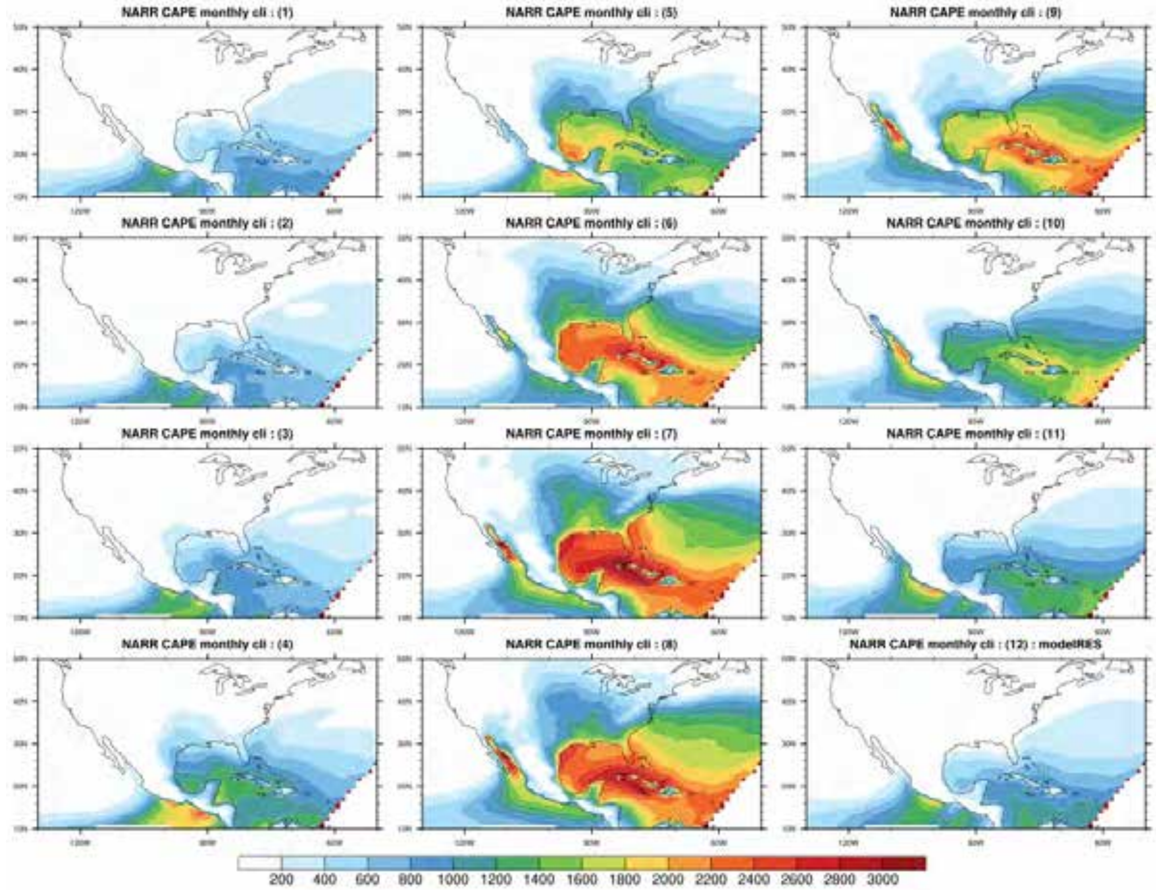

Figure 2: North American Regional Reanalysis CAPE monthly climatology. Month 1 corresponds to January; month 2 corresponds to February and similarly with the remaining months.

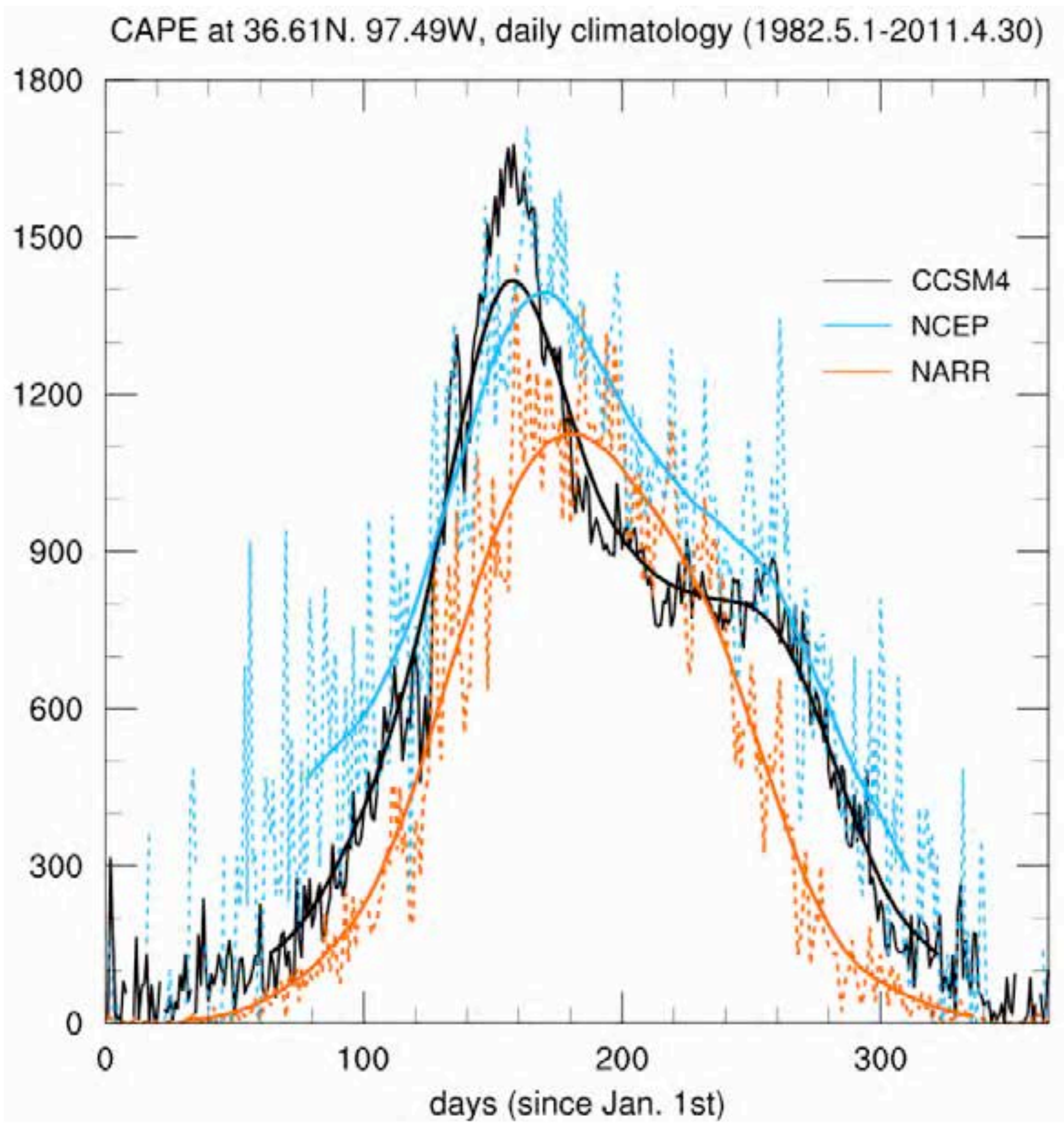

Figure 3: CAPE monthly climatology at the grid point nearest to the ARM site. The Black curve indicates CCSM4 forecast climatology, the blue curve is the NCEP climatology and the NARR data is in orange. The smoothed curves correspond to 30-day running means. Forecasts are initialized at the beginning of May and there are 10 ensemble members.

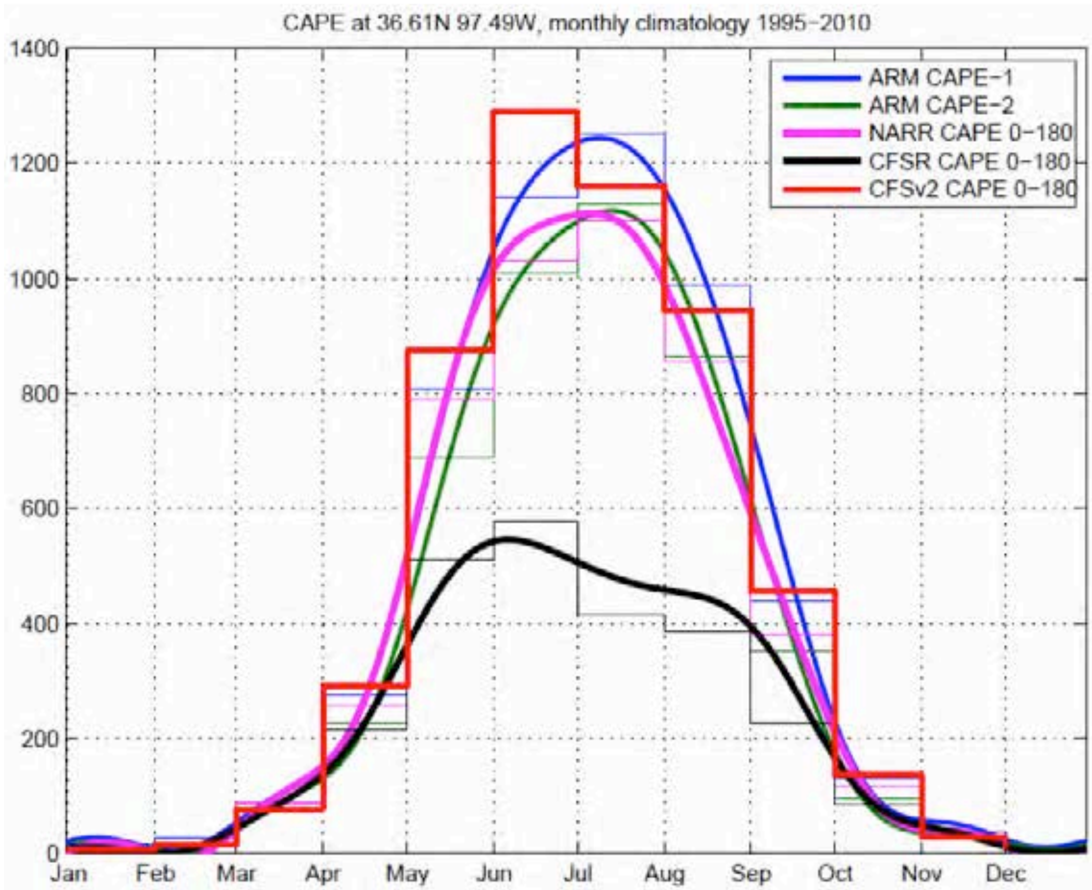

Figure 4: CAPE monthly climatology at the ARM site. The Black curve indicates CFSR, the red curve is the CFSv2 forecast climatology, the blue and green curves correspond to two estimates from the ARM site and the pink curve is the NARR estimate. The CFSv2 forecast data is monthly.

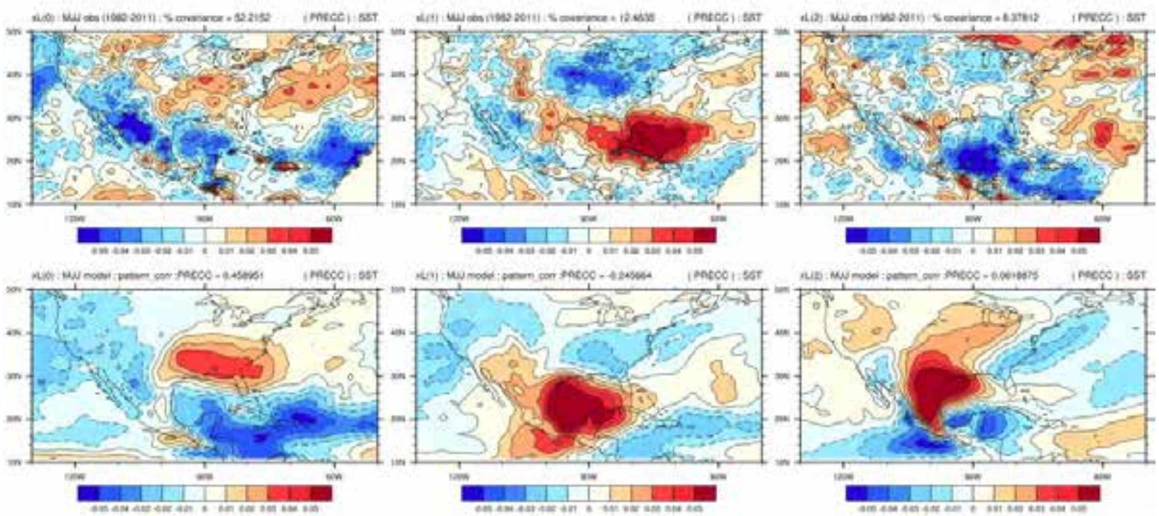

Figure 5: The spatial pattern corresponding to the convective precipitation for the observational estimates (top row) from TRIMM and the retrospective forecasts (bottom row) are shown. The dominant first three singular vectors are show from left to right.

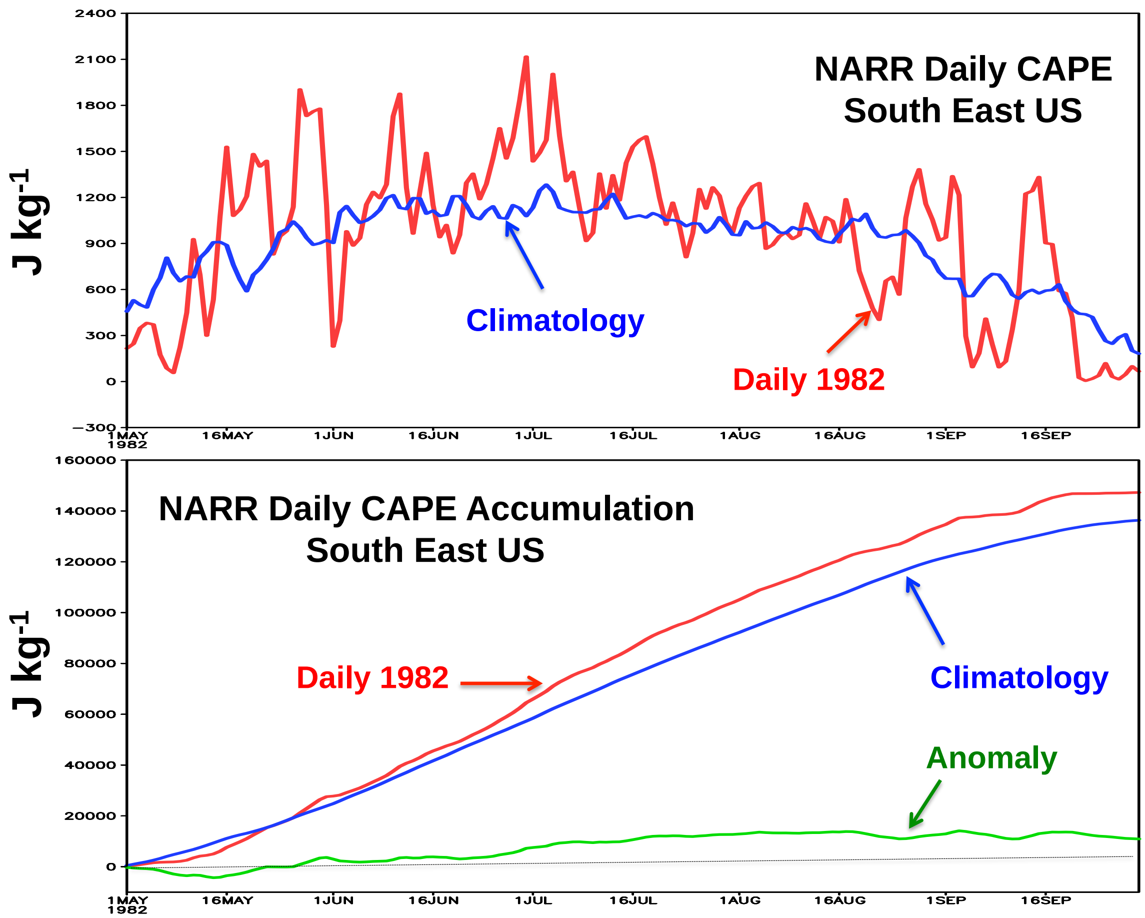

Figure 6: Area averaged CAPE (Southeast US) based on NARR data from 1 May 1982 to 30 September 1982. The top panel shows the raw NARR data in red and the 30 year climatology in blue. The bottom panel shows accumulated CAPE over the same region for 1 May 1982 to 30 September 1982 in red, climatology in blue and the anomaly in green.

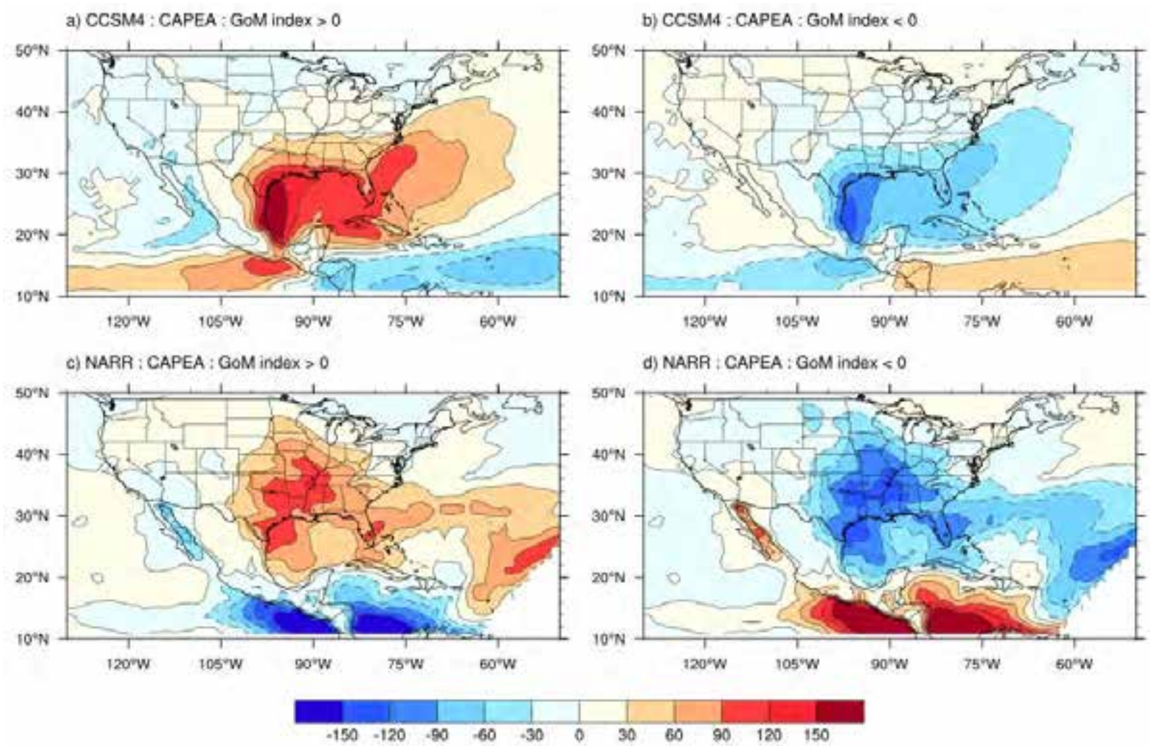

Figure 7: CAPE anomaly composite maps, associated with warm (left) and cold (right) SST anomaly in the Gulf of Mexico, in the CCSM4 (upper) and NARR (bottom). Composites are made from MJJ mean for the period 1982-2010. Unit of CAPE is J/kg.

Title: The North American Multi-Model Ensemble (NMME) Intraseasonal-to-Interannual Prediction Experiment

PI: Ben P. Kirtman (RSMAS)

Progress Report: May 1, 2014-April 30, 2015

Grant Number: NA12OAR4310089

1. Introduction

The research leverages an existing National Multi-Model Ensemble (NMME) team that has already formed and began producing routine real-time seasonal to interannual (ISI) predictions in August 2011, providing them to the NOAA Climate Prediction Center (CPC) on an experimental basis for evaluation and consolidation as a multi-model ensemble ISI prediction system. The experimental prediction system developed by this NMME team is as an “NMME of opportunity” in that the ISI prediction systems are readily available and each team member has independently developed the initialization and prediction protocol. We will refer to the NMME of opportunity as phase 1 NMME (or NMME-1).

The research activity is to develop a more “purposeful NMME” in which the requirements for operational ISI prediction are used to define the parameters of a rigorous reforecast experiment and evaluation regime. This will be phase 2 NMME (or NMME-2). The NMME team will design and test an operational NMME protocol that will guide the future research, development and implementation of the NMME beyond what can be achieved based on the phase 1 NMME project.

The proposed activity:

i. Builds on existing state-of-the-art US climate prediction models and data assimilation systems that are already in use in NMME-1 and ensure interoperability so as to easily incorporate future model developments.
ii. Takes into account operational forecast requirements (forecast frequency, lead time, duration, number of ensemble members, etc.) and regional/user specific needs. A focus of this aspect of the work will be the hydrology of various regions in the US and elsewhere in order to address drought and extreme event prediction.
iii. Utilizes the NMME system experimentally in a near-operational mode to demonstrate the feasibility and advantages of running such a system as part of NOAA’s operations.
iv. Enables rapid sharing of quality-controlled reforecast data among the NMME team members, and develop procedures for timely and open access to the data, including documentation of models and forecast procedures, by the broader climate research and applications community.

The activity also includes several NMME research themes:

i. The evaluation and optimization of the NMME system in hindcast mode (e.g., assessing the optimal number of ensemble members from each model, how to best combine the multi-model forecasts, sources of complementary prediction skill, etc.), methodologies to recalibrate individual dynamical models prior to combination, and provision of probabilistic quantitative (rather than categorical) information. There will also be a thorough evaluation of the forecasts across multiple time scales (e.g., variability beyond week two).

ii. Designing and evaluating a sub-seasonal (weeks 3 and 4) multi-model predictive protocol.

iii. The application of the NMME forecasts for regional downscaling and hydrological prediction.

2. Results and Accomplishments

a. NMME Data Production

- NMME team continues to meet monthly via telecom to address all science and data production issues
- NMME team now has a "data working group" to coordinate with NCAR on phase-II data serving
- All forecast providers (RSMAS/COLA/NCAR, GFDL, CMC, NASA) continue to submit real-time predictions on time all the time.
- IRI continues to upload and serve all real-time and retrospective data
- CPC continues to ingest data, produce graphical images of forecasts and skill assessments including probabilistic measures. CPC also developing evaluation of skill of real-time forecast.
- New monthly mean data (Tmin, Tmax, Z500, Soil Moisture, Runoff) are now routinely being provided to CPC and IRI from all forecast providers.
- Phase-II high frequency and additional fields data archive at NCAR is fully populated for CCSM4, GFDL-FLOR, CanCM3, CanCM4, GOES5, and CFSv2 is in progress.
- CCSM4 retrospective forecasts are completed and have been upload at NCAR phase-II data server
- CCSM4 sub-seasonal increased start frequency forecast have been completed.
- CFSv2 phase-II data conversion from GRIB2 to NetCDF4 is in progress

b. Land and Atmosphere Initialization in CCSM4

Several prediction experiments have been made with CCSM4 to investigate the role of land surface initialization in improve the forecast skill over North America. In particular, the experimental design follows the NMME forecast protocol implemented with CCSM4, but with the specific intent of separating remote responses from SSTA vs. land and atmosphere initialization in the forecast skill. Four experiments are described here:

(i) CAM4 (the atmospheric component of CCSM4) forecasts initialized in 1 May 1982-2010 are made with observed atmospheric and land initial conditions but with climatological SST.

(ii) CAM4 (the atmospheric component of CCSM4) forecasts initialized in 1 May 1982-2010 are made with observed atmospheric and land initial conditions but with observed SST.

(iii) CAM4 (the atmospheric component of CCSM4) forecasts initialized in 1 May 1982-2010 are made with climatological initial condition for the atmosphere and land and climatological SST.

(iv) CAM4 (the atmospheric component of CCSM4) forecasts initialized in 1 May 1982-2010 are made with climatological initial condition for the atmosphere and land and observed SST.

All of these forecast experiments are ten member ensembles. Comparisons isolate the relative roles of land and atmosphere initialization versus the remote response from SST. For example, comparing (i) vs. (iii) shows the skill from land and atmosphere initialization without the SSTA influence and comparing (ii) vs. (iv) shows the skill due to land and atmosphere initialization with SSTA influence. These comparisons are summarized in Fig. 1 and Fig. 2 and are being prepared for publication in Infanti and Kirtman (2015).

c. Comprehensive CCSM4 vs. CCSM3 hindcast quality comparison

To assess hindcast skill in CCSM3 and CCSM4 we use both deterministic and probabilistic methods, as this gives a more complete representation of the skill. We focus on hindcasts of sea surface temperature, precipitation, and 2-meter temperature. We form anomalies by removing the 1982-2010 climatology from each ensemble member for each forecast initialization period separately.

The initialization strategy developed for CCSM4 was specifically designed with the NMME forecast protocols in mind. This can be seen by the fact that the ocean, land and atmospheric initial conditions are taken from CFSR for both the retrospective forecast and the real-time forecasts. This is done so that CCSM4 can meet the on-time NMME protocol requirements and use state-of-the-art initial conditions. The approach has the added advantage that we can examine how using the same initial conditions with a very difference forecast tool (CFSv2 vs. CCSM4) affects the prediction. In contrast, the CCSM3 forecasts use climatological states for the land and atmosphere and an ocean-only data assimilation system for the ocean states.

To highlight the contribution from CCSM4 we show a brief comparison with CCSM3. Figure 3, for example, shows the T2m one season lead Ranked Probability Skill Score (RPSS) for forecasts initialized on 1 January and 1 June. Clearly, CCSM4 is out performing CCSM3. These results are being prepared for publication in Kirtman et al. (2015).

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Yeh, S.-W., B. P. Kirtman, J.-S. Kug, W. Park, and M. Latif (2011), Natural variability of the central Pacific El Niño event on multi-centennial timescales, *Geophys. Res. Lett.*, 38, L02704, doi:10.1029/2010GL045886.

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4. Highlights

- Continued real-time on time all the time forecasts

- BAMS paper describing overview of NMME project and skill evaluation
- NMME forecast data used in drought applications
- NMME phase-II retrospective forecasts with CCSM4 in production
- Evaluation of NMME forecast skill for Southeast US rainfall (J. Hydromet. Paper Infanti and Kirtman, 2013)
- Evaluation of NMME forecast skill with PMM as an ENSO Precursor (Larson and Kirtman, 2014)

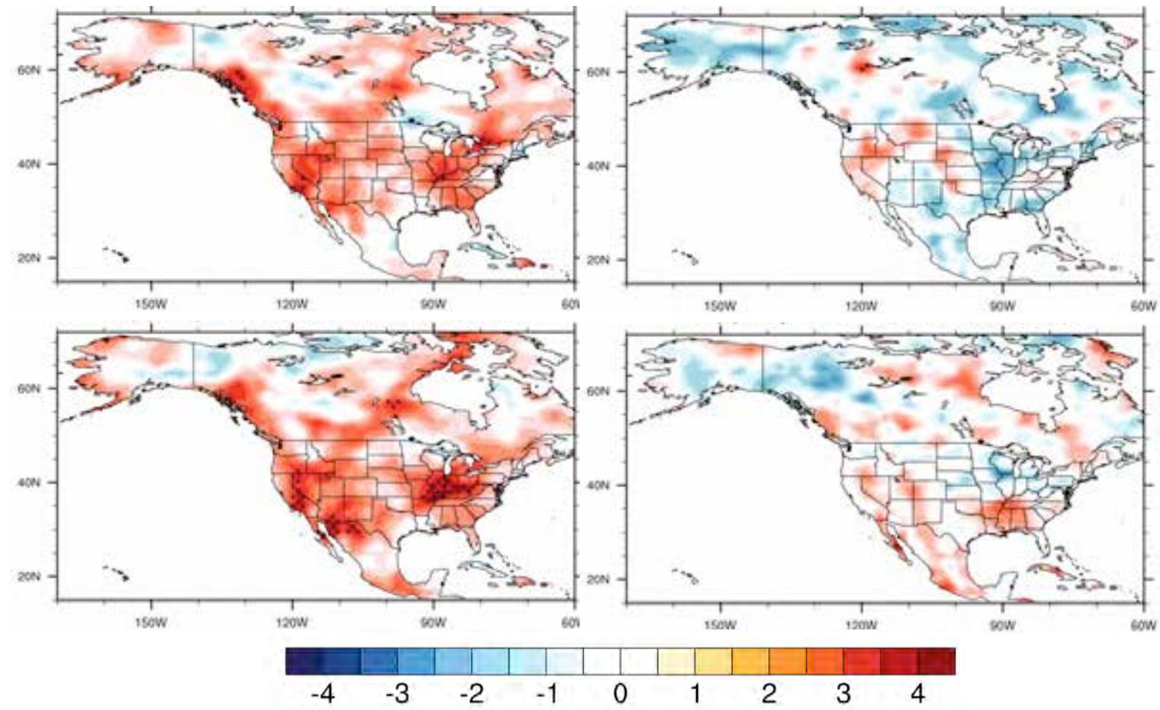

Figure 1: Z-statistic calculated from the correlation between “predicted” and observed precipitation. Results from experiment (i) in the upper left, experiment (ii) in the lower left, experiment (iii) upper right and experiment (iv) in the lower right.

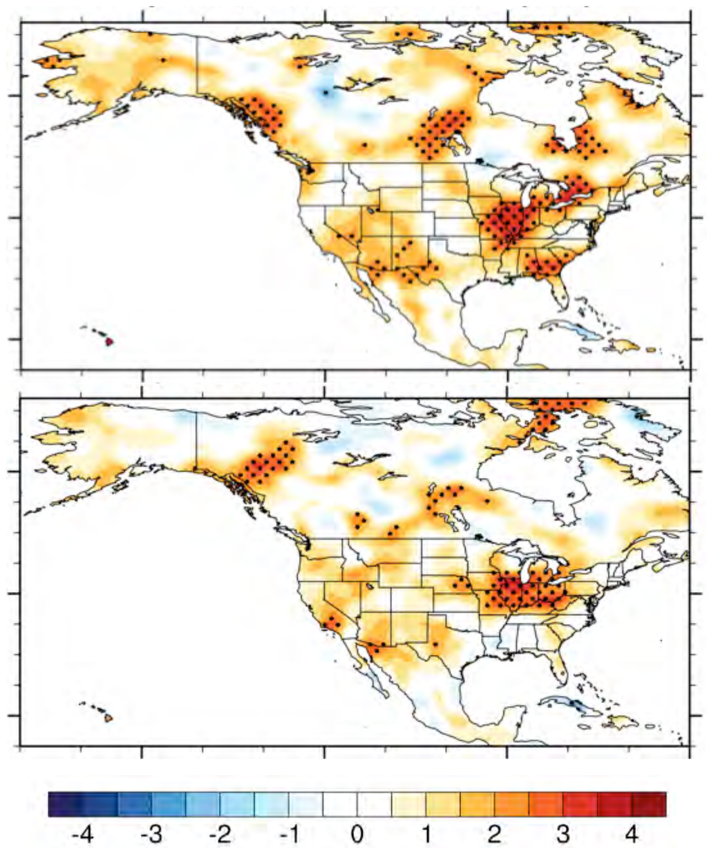

Figure 2: Difference in the Z-statistic. Top panel shows experiment (i) minus experiment (iii) and the bottom panel shows experiment (ii) minus experiment (iv). Stippling corresponds to 95% statistical significance.

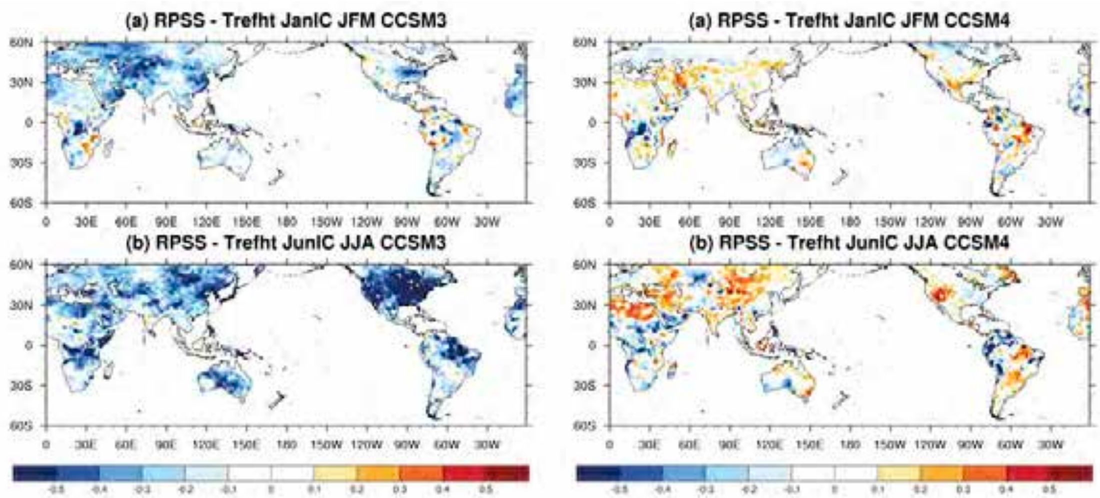

Figure 3: T2m one season lead Ranked Probability Skill Score (RPSS) for forecasts initialized on 1 January and 1 June. The results from CCSM3 are on the left and the results from CCSM4 are on the right.

Grant Number: NA13OAR4830224

Amount of Grant: Federal $1,301,395 Match $0 Total $1,301,395

Project Title: Extending the Gulf of Mexico OSSE system to the North Atlantic in support of development and demonstration of a relocatable ocean OSSE System

Grantee: University of Miami-RSMAS

Award Period: 10/01/2013 – 09/30/2015

Period Covered by this Report: 01/01/2015 – 03/31/2015

Objectives and Publications

Modelers based at University of Miami (UM)/RSMAS, NOAA/AOML/PhOD and the Cooperative Institute for Marine and Atmospheric Studies (CIMAS) have worked closely to develop a prototype system for ocean OSSEs (Observing System Simulation Experiments). This system has been initially applied and validated in the Gulf of Mexico (Halliwell et al., 2014a,b). The main objectives of this project are: a) to contribute toward a fully relocatable ocean OSSE system by expanding the Gulf of Mexico OSSE to the North Atlantic Ocean; b) demonstrate and quantify improvements in hurricane forecasting when the ocean component of coupled hurricane models is advanced through targeted observations and assimilation. As such, this project substantially addresses two of the three expected outcomes of Sandy Supplemental Projects with respect to hurricanes and other storms: (1) improve the Nation’s ability to observe coastal and oceanic conditions associated with these storms; and (2) improve NOAA’s capability to predict accurately future storms at longer lead times.

Methodology development and results are being shared between the UM/RSMAS and NOAA/AOML teams that collaborate in the project, within the Joint Ocean Modeling and OSSE Center (OMOC) which Dr. Kourafalou (PI) co-directs with Dr. Halliwell. The publication list so far includes nine refereed publications and eleven presentations in national and international conferences or research centers associated with ocean prediction:

Kourafalou, V.H., P. De Mey, M. Le Hénaff, G. Charria, C.A. Edwards, R. He, M. Herzfeld, A. Pasqual, E. Stanev, J. Tintoré, N. Usui, A. Van Der Westhuysen. J. Wilkin and X. Zhu, 2015. Coastal Ocean Forecasting: system integration and evaluation. *Journal of Operational Oceanography,* doi:10.1080/1755876X.2015.1022336.

Kourafalou, V.H., P. De Mey, J. Staneva, N. Ayoub, A. Barth, Y. Chao, M. Cirano, J. Fiechter, M. Herzfeld, A. Kurapov, A.M. Moore, P. Oddo, J. Pullen, A. Van Der Westhuysen and R. Weisberg, 2015. Coastal Ocean Forecasting: science drivers and user benefits. *Journal of Operational Oceanography,* doi:10.1080/1755876X.2015.1022348.

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Oke, P.R., G. Larnicol, E.M. Jones, V.H. Kourafalou, A.K. Sperrevik, F. Carse, C.A.S. Tanajura, B. Mourre, M. Tonani, G.B. Brassington, M. Le Hénaff, G.R. Halliwell, R. Atlas, A.M. Moore, C.A. Edwards, M.J. Martin, A.A. Stellar, A.Alvarez, P. De Mey, M. Iskandarani, 2015. Assessing the impact of observations on ocean forecasts and reanalyses: Part 2: Regional applications. *Journal of Operational Oceanography,* doi: 10.1080/1755876X.2015.1022080.

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Smith, S.R., K. Briggs, N. Lopez and V.H. Kourafalou, 2015. Numerical Model Evaluation Using Automated Underway Ship Observations. *J. of Atmospheric and Oceanic Technology* (Submitted).

Kourafalou, V.H., G. R. Halliwell, R.M. Atlas, H. Kang, M.F. Mehari, M. Le Hénaff, L.K. Shay, R. Lumpkin and G.J. Goni, 2015. North Atlantic OSSEs in support of improved hurricane forecasting: Nature Run evaluation. *American Meteorological Society 95th Annual Meeting*, Phoenix, AZ.

Halliwell, G.R., V.H. Kourafalou, R.M. Atlas, M.F. Mehari, H. Kang and M. Le Hénaff, 2015. North Atlantic OSSEs in support of improved hurricane forecasting: Impact of Ocean Observing System Enhancements. *American Meteorological Society 95th Annual Meeting*, Phoenix, AZ.

Le Hénaff, M., G.R. Halliwell, V.H. Kourafalou, L.K. Shay and R. Atlas, 2015. Evaluation of impact of DwH rapid-response surveys on numerical forecasts using Observing System Simulation Experiments, *Gulf of Mexico Research Initiative Conference*, Houston, TX.

Hole, L.R., M.H. Ghani, N. Wienders, V.H. Kourafalou, I. Fer, H. Kang, K. Drushka and D. Peddie, 2015. Using the CMR Sailbuoy for ocean shelf measurements. *Geophysical Research Abstracts,* vol. 17, EGU2015-4605, European Geophysical Union Assembly, Vienna, Austria.

Halliwell, G.R., A. Srinivasan, V.H. Kourafalou, H. Yang, D. Willey, M. Le Hénaff and R. Atlas, 2014. Rigorous Evaluation of a Fraternal Twin Ocean OSSE System for the Open Gulf of Mexico. *J. Atm. Ocean. Techn.* 31(1):105-130, doi: 10.1175/JTECH-D-13-00011.1.

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Ghani, M.H., L.R. Hole, I. Fer, V.H. Kourafalou, N. Wienders, D. Peddie, 2014. The SailBuoy remotely-controlled unmanned vessel: measurements of near surface temperature, salinity and oxygen concentration in the Gulf of Mexico. *Methods in Oceanography*, doi: 10.1016/j.mio.2014.08.11.

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Le Hénaff, M., G.R. Halliwell, V.H. Kourafalou, R. Atlas, 2014. Development of a Nature Run for a Gulf of Mexico OSSE system. *Ocean Sciences Meeting*, Honolulu, HI.

Halliwell, Jr., G.R., V.H. Kourafalou, M. Le Hénaff, and R. Atlas, 2014: OSSE evaluation of rapid-response airborne ocean observing strategies in the Gulf of Mexico. *18th Conference on Integrated Observing and Assimilation Systems for the Atmosphere, Ocean, and Land Surface, American Meteorological Society Annual Meeting*, Atlanta, GA.

Halliwell, Jr., G.R., V.H. Kourafalou, M. Mehari, H. Kang, M. Le Hénaff, and R. Atlas, 2014. Development, Evaluation, and Initial Applications of a new Ocean OSSE System based on HYCOM. Presentation at NRL-SSC.

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Kourafalou, V.H., 2014. Links between the Observing System Evaluation and Coastal and Shelf Seas task teams. GODAE OceanView Science Team annual meeting. Beijing, China.

Model simulations are taking place in the University of Miami's Center for Computational Science (CCS). In addition, a server system dedicated for this project has been purchased and work has been finalized on server set up for high performance computing. This includes ongoing tests for system optimization and storage integration to the CCS.

Task 1: Extending the OSSE system

The Task 1 OSSE system was originally validated over the open ocean within a Gulf of Mexico domain (Halliwell et al., 2014; 2015). For the Sandy Supplemental project, the system has been ported to an extended North Atlantic (ATL) domain (see details in previous Reports and Task 2). This large domain was chosen to contain the North Atlantic hurricane region and is situated far from open boundaries. Updated river inputs have been included for 172 rivers, with Amazon River parameterization as in Schiller and Kourafalou (2010).

Part of the work under this Task is to use the Gulf of Mexico as a test basin for various techniques and methodologies that will be extended to the ATL domain in Task 2 and Task 3. Work has been completed on the development of a new free-running model for the Gulf of Mexico (GoM), following work in Le Hénaff et al. (2012), but with a new high resolution configuration ($1/50^0$); this is an extension of the initial ocean OSSE system prototype (Halliwell et al., 2014; 2015), see previous Reports. This new model was initially implemented for free-running simulations (no data assimilation). During this last project period, data assimilation was also implemented, allowing further testing of the DA system employed in the ATL domain. Testing of model to data evaluation techniques (see Le Hénaff et al., 2012; 2014) are employed for Task3. In addition, this new domain is currently being used as a test basin for the implementation of tides in the OSSE system.

Task 2: Porting to a New Domain

For the extended North Atlantic domain, two new models have been set up: the Nature Run (NR) and the Forecast Model (FM). The NR is free-running and the FM is at first also run unconstrained and then it includes data assimilation. In this 6^{th} project period, the new FM configuration has been used (developed in the 5^{th} period), as it was proven to be superior to the initial FM (developed in the 4^{th} period). Evaluation has continued, exploring several data sets (see Table 1). In addition, both the FM and NR were extended to a sixth year (see Task 3). Comparison of 5-year and 6-year mean fields did not reveal strong differences. In addition, a new model has been evaluated through collaboration with the Naval Research Lab at Stennis Space Center. They provided archives from a global free-running model, which covered two simulation periods forced by two different Navy atmospheric models: 2008-2012 (forced by NOGAPS) and 2013 (forced by NAVGEM). We have evaluated these simulations as a possible candidate for a global NR that can be used both for the needs of this project and as a tool for carrying out this project's legacy into the future (global OSSEs). The evaluation was quite satisfactory. Examples are given in Figures 1-3, employing various mean field periods for the models. The 5-year and 6-year averages for the North Atlantic NR were found quite similar, while we opted to use only the 5-yr mean for the global model average, to be consistent with the same atmospheric model field (NOGAPS).

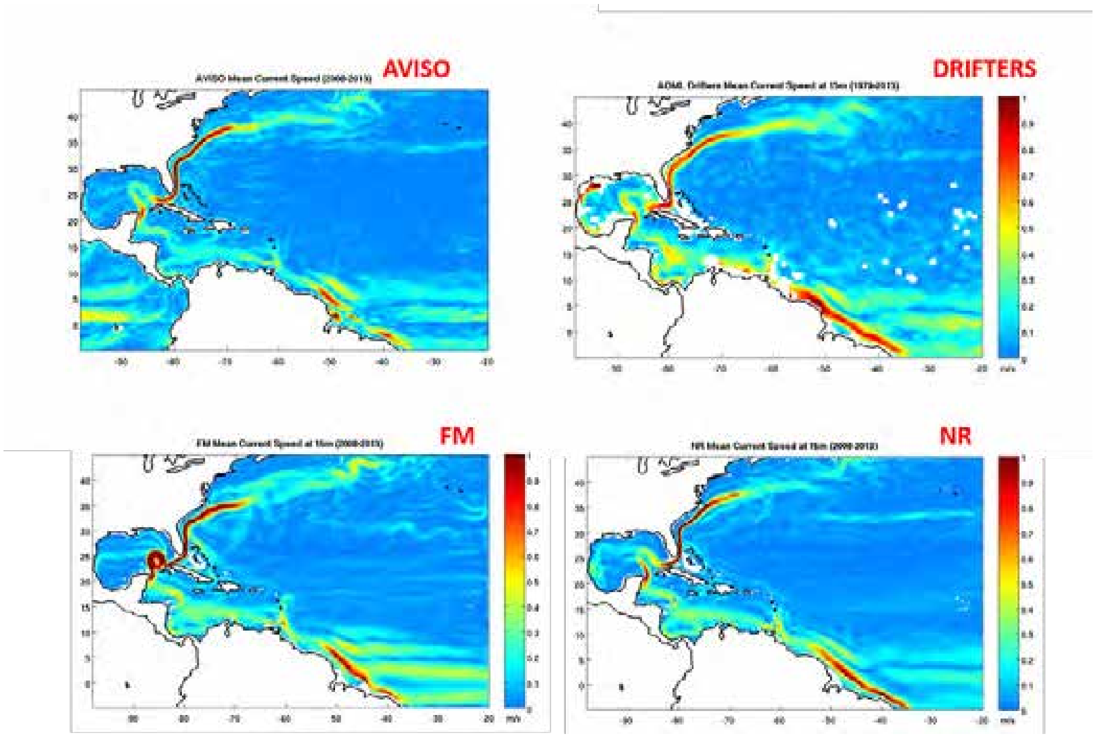


Figure 1: Surface current velocity comparison of FM, NR models (bottom) and data (AVISO climatology, upper left; Drifter climatology, upper right). Fields are 5-year mean (2008-2012).

Figure 1 shows a comparison of mean current speed from the FM and NR models (2008-2013 period) with fields from two different products: a) AVISO derived mean currents (2008-2013 period, same as for the models) and b) mean currents derived for a climatological drifter data set (1979-2013). We note that certain differences in the currents from the two data sets are not only due to the averaging period difference, but also to the direct character of drifter data vs. dependence on along-track satellite data for AVISO. Both models capture the data indicated current speed structure, including the distribution of gradients. The NR performs better than the FM in several areas, as in the Gulf of Mexico where the NR Loop Current has a better mean structure. In addition, the NR currents along the South American coast (dominated by the Brazil Current) are stronger, in agreement with the climatological drifter data set. The Gulf Stream extension is in better agreement with the AVISO data for both NR and FM models.

Figure 2 shows a comparison of Sea Surface Height (SSH) derived from AVISO data climatology to three NR simulations. Figure 3 shows a comparison of climatological (GDEM4 data) Sea Surface Salinity (SSS) to the same simulations, which are from the NRL global NR and from a 5-year and 6-year simulation of the ATL NR. The general structure of SSH and SSS features is similar between model simulations and data, revealing that the NR models have good skill in representing long term variability in the North Atlantic region. Notable differences are the higher SSH in the model fields for the Caribbean region and the weak Amazon plume in the global NR (which simply applies a bogus precipitation treatment of rivers, as compared to the careful parameterization of river plume dynamics in the ATL NR).

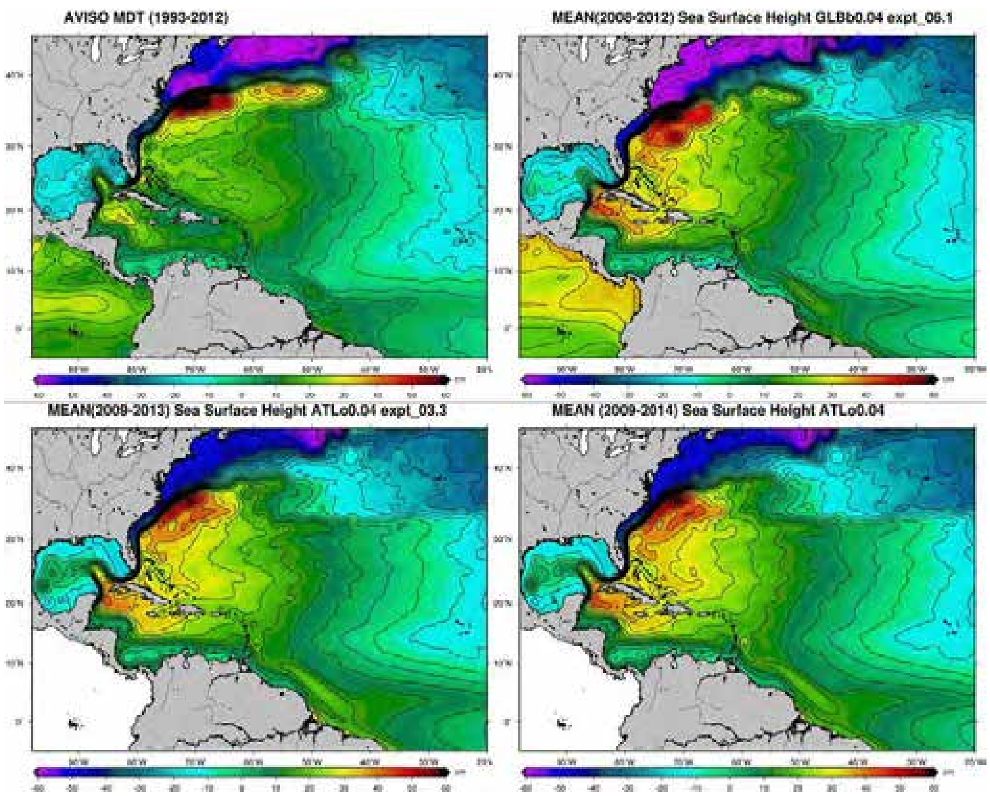


Figure 2: Sea Surface Height comparison of AVISO data (Mean Dynamic Topography over the period 1993-2012, upper left) to Sea Surface Height (SSH) for three NR simulations: global run (2008-2012 mean SSH, upper right); North Atlantic NR (2009-2013 mean SSH, bottom left); North Atlantic NR (2008-2014 mean SSH, bottom right).

<u>Task 3: The Atlantic Domain Nature Run</u>

The evaluation of the climatological realism of the Nature Run (NR) and the Forecast Model (FM) continues by using historical observations and ocean products obtained from available climatologies (as GDEM) and from AOML/PhOD and RSMAS/Univ. of Miami observing programs (see 4th Report). Synthetic observations are extracted from the NR to be used for OSSE experiments.

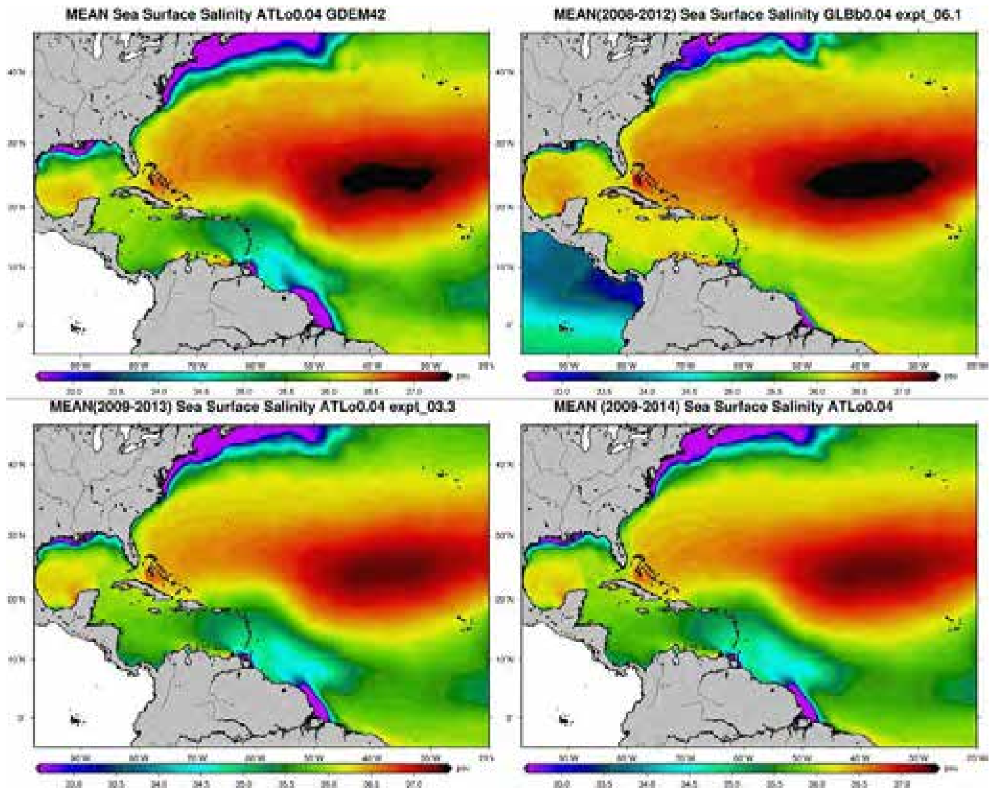


Figure 3: Sea Surface Salinity (SSS) comparison of GDEM4 climatology (upper left) to three NR simulations: global run (2008-2012 mean SSS, upper right); North Atlantic NR (2008-2013 mean SSS, bottom left); North Atlantic NR (2008-2014 mean SSS, bottom right).

An example of a series of quantitative analyses that have been employed for the NR evaluation is given in Figure 4. Time series of Sea Surface Temperature (SST) have been computed from the GHRSST data set and from the North Atlantic NR, averaged over each of 4 regions in the model domain: GS (Gulf Stream); AHW (Atlantic Hurricane East); AHE (Atlantic Hurricane East); EQ: Equator. The model exhibits remarkable skill in matching the magnitude and variability of the observed SST over the period 2008-2014. The comparison is weaker in the equatorial region, where the NR often appears cooler; this is due to the cooler waters entering from the southwestern boundary. However, the overall seasonal and inter-annual SST variability is also quite good in the equatorial region, closely following the observed distribution.

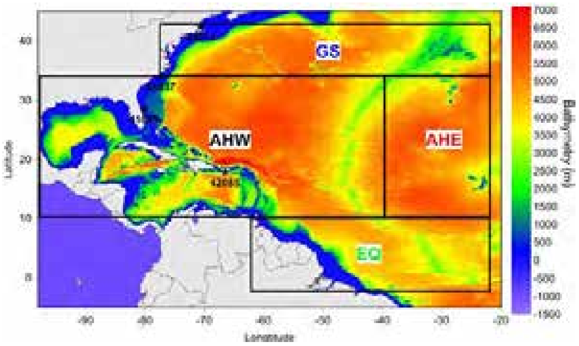
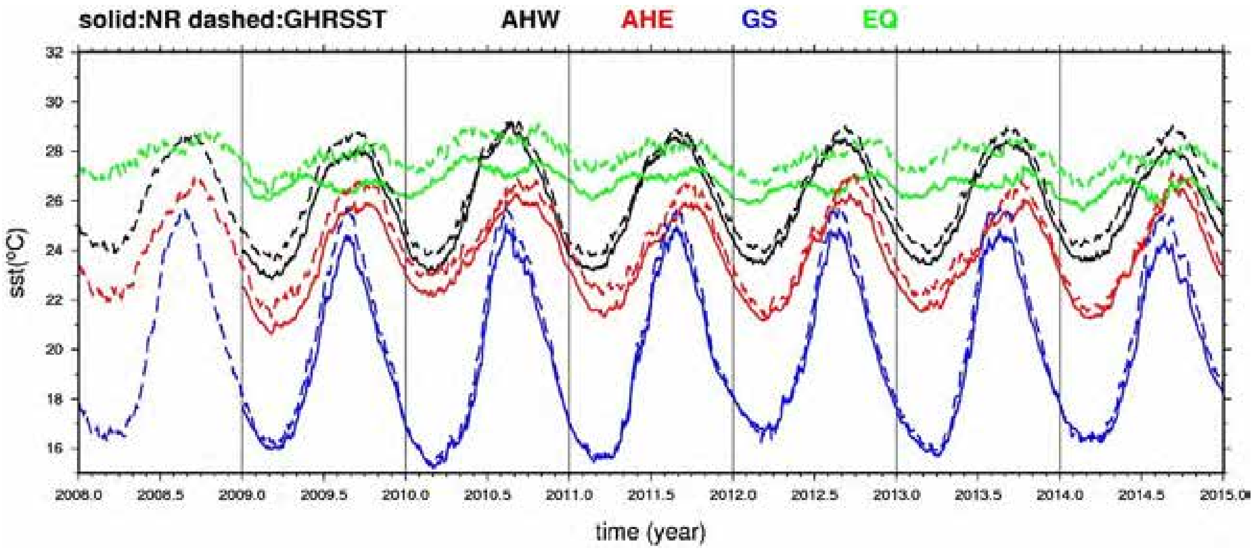


Figure 4: (upper left) North Atlantic NR model bathymetry with four study regions identified (see text for acronyms); (below) time series of NR model (solid lines) and GHRSTT data (dashed lines) averaged over each of the four study regions (line colors follow the colors identifying the study regions in the upper left panel).



Task 4: Observational analyses

The bulk of this work has been carried out. A comprehensive set of data sources within the North Atlantic model domain has been compiled and data have been suitably structured for use by the OSSE system (Table 1); see also 3d Report. These data are being used for the ongoing evaluation of the ATL OSSE system. Identical pairs of experiments continue to be performed that assimilate the same set of real (OSE) and synthetic (OSSE) observations, see examples in Figures 5-6. This evaluation results in continuous updates of the OSSE system toward improved results.

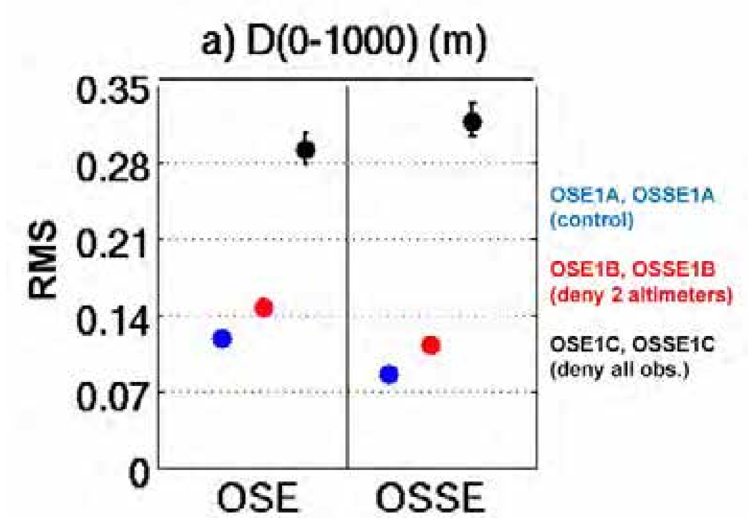


Figure 5: Results of an OSE/OSSE comparison where all observations were assimilated (blue), two altimeters were denied (red), and all observations were denied (black). OSE runs were evaluated against real Argo floats withheld from assimilation while OSSE runs were evaluated against synthetic floats simulated from the NR and also withheld from assimilation. Generally similar results are encouraging, although the OSSE runs indicate a larger impact of denying all observations.

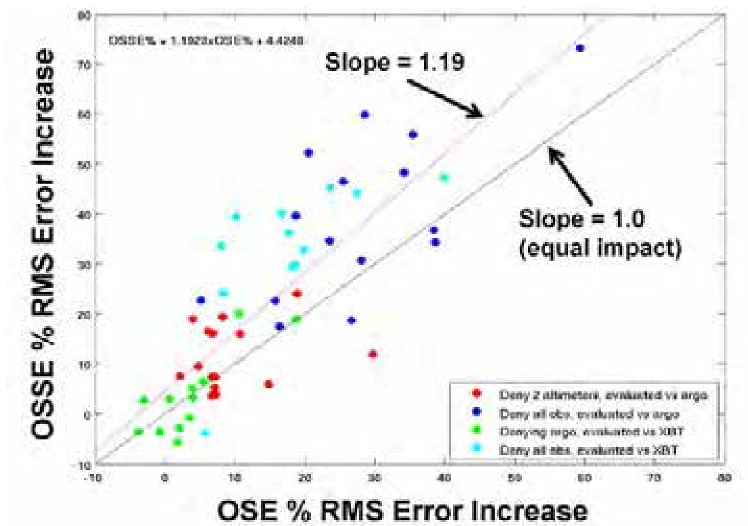


Figure 6: Synthesis of a large number of OSE/OSSE comparisons such as shown in Figure 1, but different model variables in different subregions of the Atlantic domain and denying different observing systems. Points are plotted as a function of OSE RMS error increase (abscissa) and OSSE error increase (ordinate). The slope of 1.19 demonstrates that the current configuration of the OSSE system tends to overestimate impacts by an average of ~20%.

References

Halliwell, G.R., A. Srinivasan, V.H. Kourafalou, H. Yang, D. Willey, M. Le Hénaff and R. Atlas, 2014. Rigorous Evaluation of a Fraternal Twin Ocean OSSE System for the Open Gulf of Mexico. *J. Atm. Ocean. Techn.* 31(1):105-130, doi: 10.1175/JTECH-D-13-00011.1.

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Table 1. Information on the data sets that have been compiled and are used by the OSSE system.

Data Type		Source	Variables	Temporal and Geographic Coverage/ Resolution	Usage
Altimeter	SARAL/Altika (al)	AVISO	SLA	20130314 - 20141023 Global Along Track	Assimilation
	Cryosat-2 (c2)	AVISO	SLA	20110128 - 20141023 Global Along Track	Assimilation
	Envisat (en)	AVISO	SLA	20040101 - 20101021 Global Along Track	Assimilation
	Envisat Extension (enn)	AVISO	SLA	20101026 - 20120408 Global Along Track	Assimilation
	Geosat Follow (g2)	AVISO	SLA	20040101 - 20080907 Global Along Track	Assimilation
	Haiyang-2A (h2)	AVISO	SLA	20140412 - 20141023 Global Along Track	Assimilation
	Jason-1 (j1)	AVISO	SLA	20040101 - 20081019 Global Along Track	Assimilation
	Jason-1 Geodetic (j1g)	AVISO	SLA	20120507 - 20130621 Global Along Track	Assimilation
	Jason-1 New Orbit (j1n)	AVISO	SLA	20090214 - 20120303 Global Along Track	Assimilation
	Jason-2 (j2)	AVISO	SLA	20081019 - 20131231 Global Along Track	Assimilation

	Topex/Poseidon New Orbit (tpn)	AVISO	SLA	20040101 - 20051008 Global Along Track	Assimilation
	MCSST	USGODAE	SST	20040106 - 20141231 Global	Assimilation
	GHRSST (v04 and v03)	JPL	SST	20080101 - 20141231 ATL domain (source global) 0.011 x 0.011	Evaluation
	NAVO (v1.0)	USGODAE	SST	20090101 - 20120612 Global 0.1 x 0.1	Evaluation
	Aquarius (v3.0)	PO.DAAC JPL	SSS	2011 - 2014 Global 1.0 x 1.0	Evaluation
In situ	Argo	USGODAE	Temp and sal	20040101 - 20141231	Assimilation/Evaluation
	Buoy	USGODAE	SST	20040101 - 20141231	Assimilation
	Drifter	USGODAE	SST	20040101 - 20141231	Assimilation
	Mooring	USGODAE	Temp and sal	20040101 - 20141231	Assimilation
	Shipobs	USGODAE	SST	20040101 - 20141231	Assimilation
	Tesac	USGODAE	Temp and sal	20040101 - 20141231	Assimilation
	Trak	USGODAE	Temp and sal	20040320 - 20111231	Assimilation
	XBT	USGODAE	Temp and sal	20040101 - 20141231	Assimilation/Evaluation
	AXBT (airborne)	HRD (AOML)	Temp	20100508 20100518 20100521 20100528 20100603 20100611 20100618 20100625 20100709	Assimilation

				20100909	
	AXCP (airborne)	HRD (AOML)	Temp, U and V	20100518 20100521 20100528 20100603 20100611 20100618 20100709	Assimilation
	AXCTD (airborne)	HRD (AOML)	Temp, sal and density	20100518 20100521 20100528 20100603 20100618 20100625 20100709	Assimilation
	Gliders	PHOD (AOML)	Temp and sal	20140715 - 20141119	Assimilation
	Buoy	National Data Buoy Center	Temp and sal	2009 to 2014 (hourly) Station data	Evaluation
Climatology	Drifter Current (v2.04)	AOML (Dr. Rick Lumpkin)	U,V and SST	1979 - 2013 (monthly and annual) Quasi-global 0.5 x 0.5	Evaluation
	GDEM4	Naval Oceanographic Office	Temp and sal	1900 to 2007 (monthly) ATL domain 0.04 x 0.04	Evaluation
	GDEM3	Naval Oceanographic Office	Bottom depth Temp and temp stdv Sal and sal stdv Sound speed	1900 to 2000 (monthly) Global 0.25 x 0.25	Evaluation
Other	All satellite merged	AVISO	MSLA	20080101 - 20131231 ATL domain 0.25 x 0.25	Evaluation
	Drifter and AVISO Current	Dr. Rick Lumpkin (AOML)	U,V and speed	20080101 - 20131231 ATL domain 0.25 x 0.25	Evaluation
	RSMAS	Dr. Nick Shay	h20, h26, mld	Jun 01 to Nov	Evaluation

			and ohc	30, 2009 to 2013 North Atlantic 0.25 x 0.25	
	AOML	Dr. Gustavo Goni and Dr. Marlos Goes	h26 and ohc	20080901 - 20120529 ATL domain 0.25 x 0.25	Evaluation

Note:

- All data are daily except climatology datasets.
- Airborne data are not continuous, only for the indicated dates
- GDEM3 and GDEM4 climatology is the result of profiles present during the period 1900 to 2000 and 1900 to 2007 respectively, i.e it is the result of sparse profiles during that period
- Drifter current climatology is also computed from the drifter data available from 1979 to 2013.

Project Title: **Toward developing a seasonal outlook for the occurrence of major U.S. tornado outbreaks**

PIs: Sang-Ki Lee[1,2] (Lead PI), Scott J. Weaver[3], Robert. M. Atlas[2], Chunzai Wang[2] and David B. Enfield[1,2]
Institutions: [1]University of Miami/CIMAS
[2]NOAA/AOML
[3]NOAA/CPC
Report Year: FY2015 (Progress Report)
Grant#: NA12OAR4310083

1. Results and Accomplishments

Recent tornado outbreaks over the U.S. have caused devastating societal impacts with significant loss of life and property, prompting the need to identify and understand long-term climate signals that may provide seasonal predictability for intense tornado outbreaks over the U.S. Currently, seasonal forecast skill for intense U.S. tornado outbreaks has not been demonstrated. Therefore, the main goals of this project are (1) to refine the recently identified potential predictive skill provided by the TNI, (2) to explore other long-term climate signals that can provide additional predictability in seasonal and longer time scales, and (3) to evaluate and potentially improve seasonal forecast skill for intense U.S. tornado outbreaks in the NCEP Climate Forecast System version 2 (CFSv2).

In order to achieve these goals, the PIs have engaged in the following three major areas of research in FY2015:

1) **Spring persistence, transition, and resurgence of El Niño**
2) **Probability of US regional tornado outbreaks and its link to springtime ENSO phase evolution and North Atlantic tripole SST variability**
3) **Organized climate and severe weather workshop (March 11-12, 2015)**

Here, we briefly describe results on these three tasks.

1.1. Spring persistence, transition, and resurgence of El Niño

In *Lee et al*. (2013), we identified a link between U.S. tornado outbreaks and one particular pattern of springtime ENSO phase, namely a positive phase of Trans-Niño. In *Lee et al*. (2014a), we explored the onset, decay, transition and resurgence phases of ENSO in spring and their impacts on springtime US rainfall variability. In this study, we further attempted to objectively identify and explain the spatio-temporal evolution of inter-event El Niño and La Niña variability in the tropical Pacific for the entire lifespan from onset to decay.

The inter-El Niño variability is captured by two leading orthogonal modes, which explain more than 60% of the interevent variance. The first mode illustrates the extent to which warm SST anomalies (SSTAs) in the eastern tropical Pacific (EP) persist into the boreal spring after the peak of El Niño. Our analysis suggests that a strong El Niño event tends to persist into the boreal spring in the EP, whereas a weak El Niño favors a rapid development of cold SSTAs in the EP shortly after its peak (Fig. 1a and 1b). The second mode captures the transition and resurgence of

El Niño in the following year. An early-onset El Niño tends to favor a transition to La Niña, whereas a late-onset El Niño tends to persist long enough to produce another El Niño event. The spatiotemporal evolution of several El Niño events during 1949–2013 can be efficiently summarized in terms of these two modes, which are not mutually exclusive, but exhibit distinctive coupled atmosphere-ocean dynamics.

We also applied the same methodology to explore inter-event La Nina variability to find that the first EOF mode of inter-La Niña variability describes El Niño transitioning to a 2-year La Niña and a 2-year La Niña transitioning to El Niño (Fig. 1c and 1d).

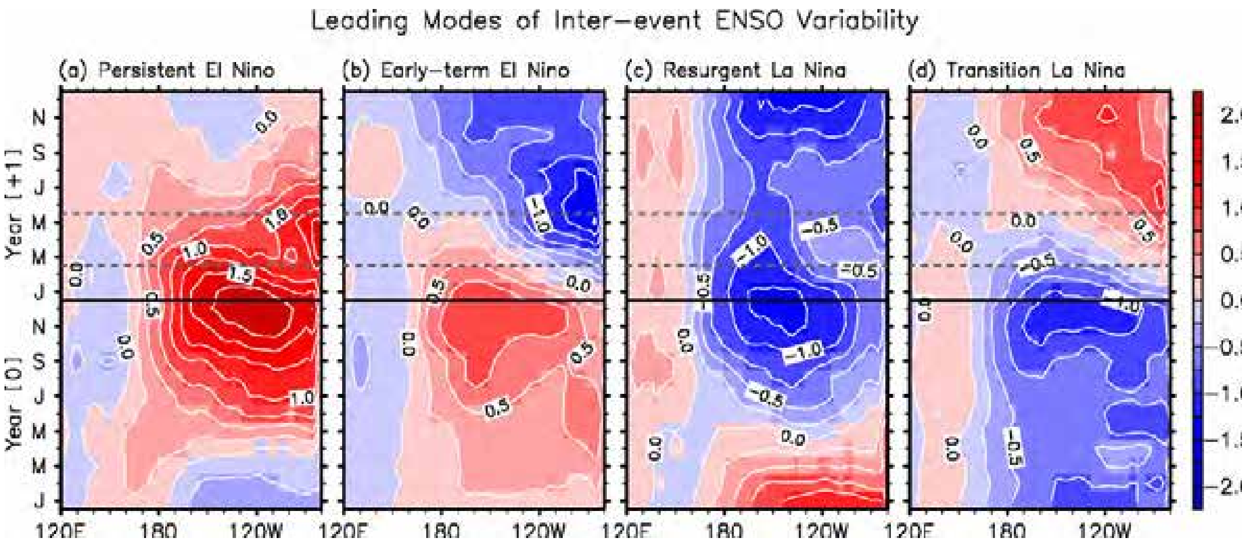

Figure 1. Four leading patterns (Time-longitude plots) of spatio-temporal ENSO evolution identified in *Lee et al*. (2014b), namely (a) persistent El Niño, (b) early-terminating El Niño, (c) resurgent La Niña, and (d) tranistioning La Niña.

This work was published in December 15, 2014 issue of Geophysical Reseaerch Letters (GRL). This paper contributes to our MAPP project in two ways. First, this study provides an objective way to characterize various patterns of springtime ENSO phase evolutions by using only two leading modes. Second, the two leading modes of inter-ENSO variability may help us to identify precursors to springtime ENSO phase evolution and associated teleconnection to the US. (i.e. seasonal prediction of springtime ENSO phase evolution).

Lee, S.-K., P. N. DiNezio, E.-S. Chung, S.-W. Yeh, A. T. Wittenberg and C. Wang, 2014b: Spring persistence, transition and resurgence of El Nino. Geophys. Res. Lett., 41, 8578-8585, doi:10.1002/2014GL062484. http://www.aoml.noaa.gov/phod/docs/2014GL062484.pdf

References:
Lee, S.-K., R. Atlas, D. B. Enfield, C. Wang and H. Liu, 2013: Is there an optimal ENSO pattern that enhances large-scale atmospheric processes conducive to major tornado outbreaks in the U.S.? J. Climate, 26, 1626-1642, doi:http://dx.doi.org/10.1175/JCLI-D-12-00128.1

Lee, S.-K., B. E. Mapes, C. Wang, D. B. Enfield and S. J. Weaver, 2014a: Springtime ENSO phase evolution and its relation to rainfall in the continental U.S. Geophys. Res. Lett., 41, 1673-1680, doi:10.1002/2013GL059137.

1.2 Probability of US regional tornado outbreaks and its link to springtime ENSO phase evolution and North Atlantic tripole SST variability

The main objective of this study is to further advance our scientific understanding on the relationship between the springtime ENSO phase evolution and U.S. tornado outbreaks to move forward with the ultimate goal of developing a seasonal outlook for U.S. tornado outbreaks. To achieve this objective, we first present a new metric that measures the probability of localized tornado outbreaks. Then, we use that metric to explore the probability of tornado outbreaks in various regions of the US under four dominant phases of springtime ENSO evolution recently identified in *Lee et al*. (2014b) (see section 1.1) and to explain the associated atmospheric dynamics. Here, we also have a new finding that the North Atlantic tripole sea surface temperature (SST) variability is linked to U.S. regional tornado outbreaks in early spring (not shown here).

Probability of US regional tornado outbreaks

One of the important tasks of this project is to explore a potential seasonal outlook for US tornado outlook. To develop such a seasonal outlook, we need to understand what we can and cannot predict on seasonal time scale. First, tornadogenesis is basically a mesoscale problem that requires overlap of very specific and highly localized atmospheric conditions. Therefore, it is not expected to be adequately captured by large-scale and long-term averaged atmospheric processes. In other words, a seasonal outlook cannot pinpoint exactly when, where and how many tornadoes may strike. Instead, a seasonal outlook may be able to predict what regions are more vulnerable to, or more likely to experience, a tornado outbreak before the tornado season (March - June) begins.

Therefore, to move forward with our goal to develop a seasonal outlook for U.S. tornado outbreaks, we propose a new index, *probability of regional tornado outbreak*, which can be used as a seasonal tornado outlook metric. This new index measures the probability that a localized tornado outbreak may occur in a predefined region. There are four steps to compute the probability of US regional tornado outbreaks.

Step-1) First, for each month and year, we count the number of F1 - F5 tornadoes within a 200 km radius from the center of each 1°×1° grid points in the US.
Step-2) For each grid point and each calendar month, we sort the number of tornadoes and compute the upper tercile value.
Step-3) Next, we identify an outbreak if the number of tornadoes within the 200 km radius exceeds its upper tercile for each calendar month.
Step-4) For a subset of data, we count the number of outbreak years and then perform a Chi-square test of 90% significance.

Fig. 2 shows the climatological mean number of tornadoes within 200 km radius, the threshold for outbreak and the probability of US regional tornado outbreaks for March, April and May, obtained by using the steps described above.

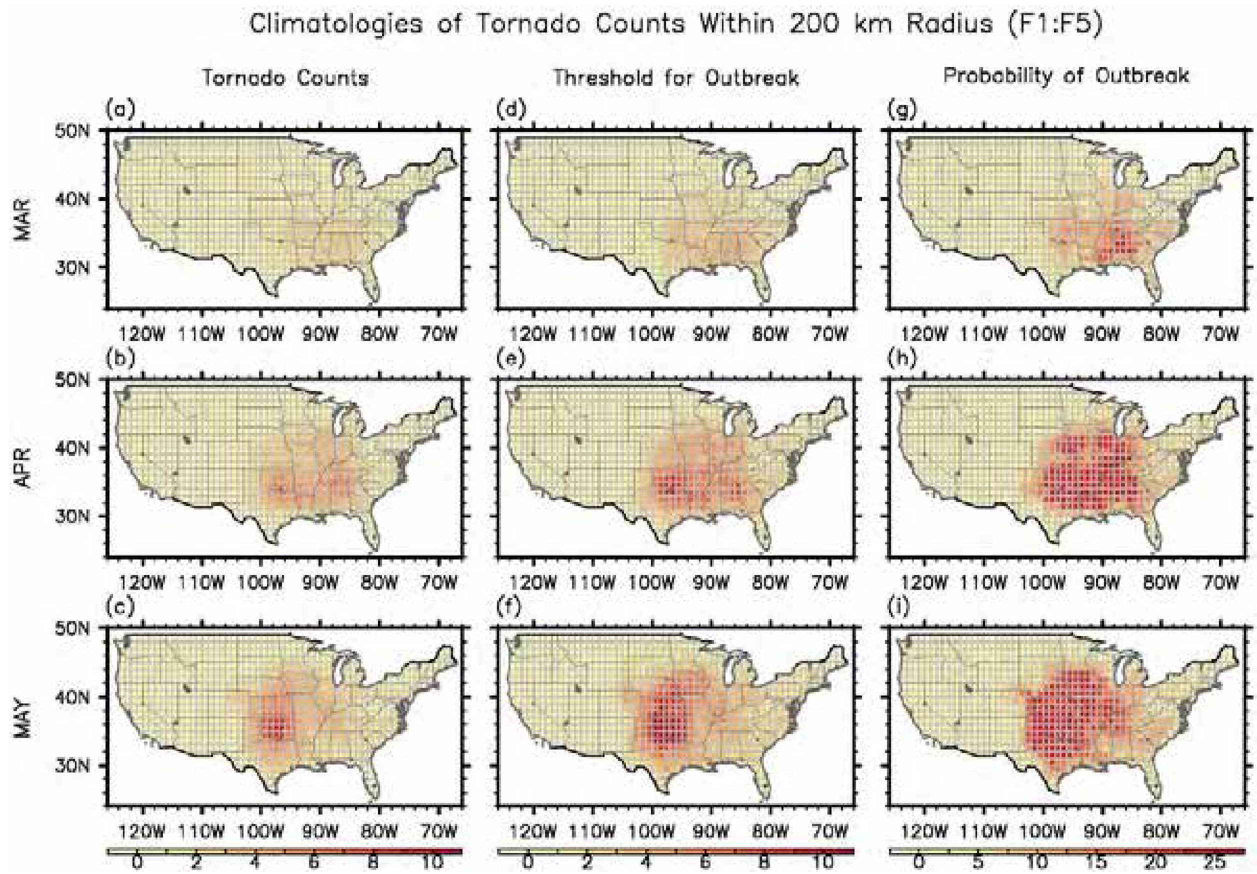

Figure 2. (Left panels) The climatological number of tornadoes within 200 km radius, (Mid paneles) the threshold for outbreak and (Right paneles) the probability (%) of US regional tornado outbreaks for March, April and May, obtained by using the four steps described above.

<u>*Springtime ENSO phases and their links to US regional tornado outbreaks*</u>

Fig. 3 shows the global SST anomalies during the four dominant phases of ENSO (i..e, persistent El Nino, early-terminating El Nino, resurgent La Nina and tranisitoning La Nina), and the corresponding probability of regional tornado outbreaks in April. The black dots in the right panels indicate that the signal is above 90% significance level.

As shown in Fig. 3e, the probability of regional tornado outbreak during the persistent El Nino years is reduced overall along the so-called tornado alley, but slightly increased over Lousiana, Alabama, Mississippi and Florida. However, it is important to note that the reductions over the tornado alley are not statistically significant. What this may mean is that although the chance for outbreak reduces overall in some US regions during the peristent El Nino years, it is statistically indistinguishable from that during the normal years. <u>This result has a very important implication for the future development of a seasonal severe weather outlook</u>. The early-terminating El Nino cases are characterized by a weak El Niño transitioning to a La Niña event. This case is characterized by a rapid development of cold SST anomalies in the EP shortly after the peak season (Figs. 1b and 3b). During the early-terminating El Nino years, the probability of outbreak is minimally affected overall. However, the probability increases significantly over Texas.

During the persistent La Nina years (Figs. 1c and 3c), the probability of outbreaks increases significantly by 20 ~ 30% in a wide region over the Central and Southeast US states, including Illinois, Kenturky, Virginia and North Carolina. It is intersting to note that the South US states (Texas, Oklahoma Kansas, Arkansas, Lousiana and Mississippi) are not much affected during the persistent La Nina years. During the transitioning La Nina years (Figs. 1d and 3d), the cold SST anomalies in CP are almost completely dissipated in the spring, while warm SST anomalies emerge quickly in EP. The probability of regional tornado outbreaks somewhat reduces over Lousiana, Mississippi, Alabama and Georgia, but greatly and significantly increases over Oklahoma and Kensas (20 ~ 30%).

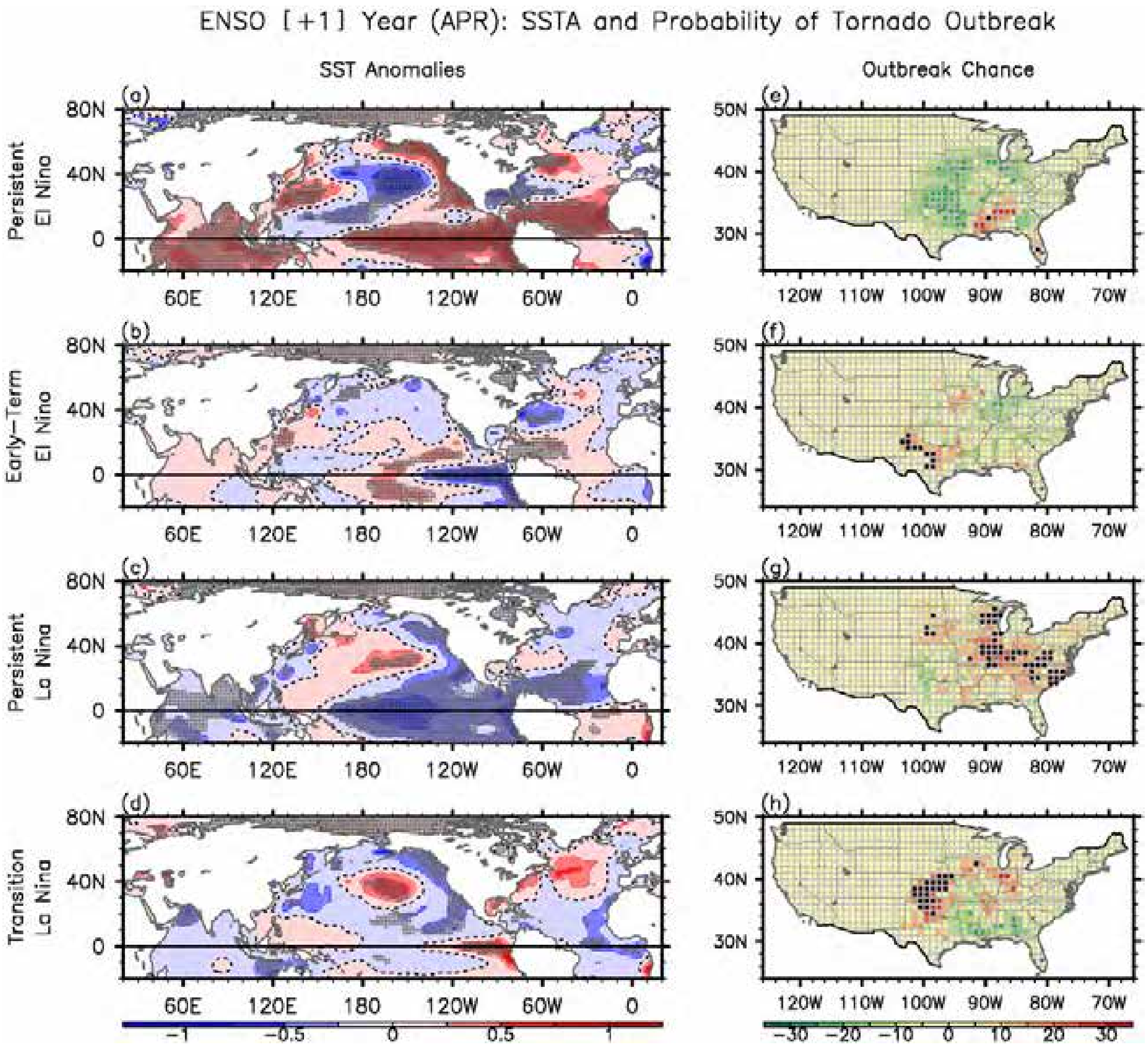

Figure 3. Global SST anomalies during the four dominant phases of ENSO (i.e, persistent El Nino, early-terminating El Nino, resurgent La Nina and tranisitoning La Nina), and the corresponding probability (%) of regional tornado outbreaks in April. The black dots in the right panels indicate that the signal is above 90% significance level.

Springtime atmospheric anomalies linked to resurgent and transitioning La Nina

To better understand the significantly increased probability of regional tornado outbreak during the resurgent and transitioning La Nina years, atmospheric anomalies during those years are shown in Fig. 4.

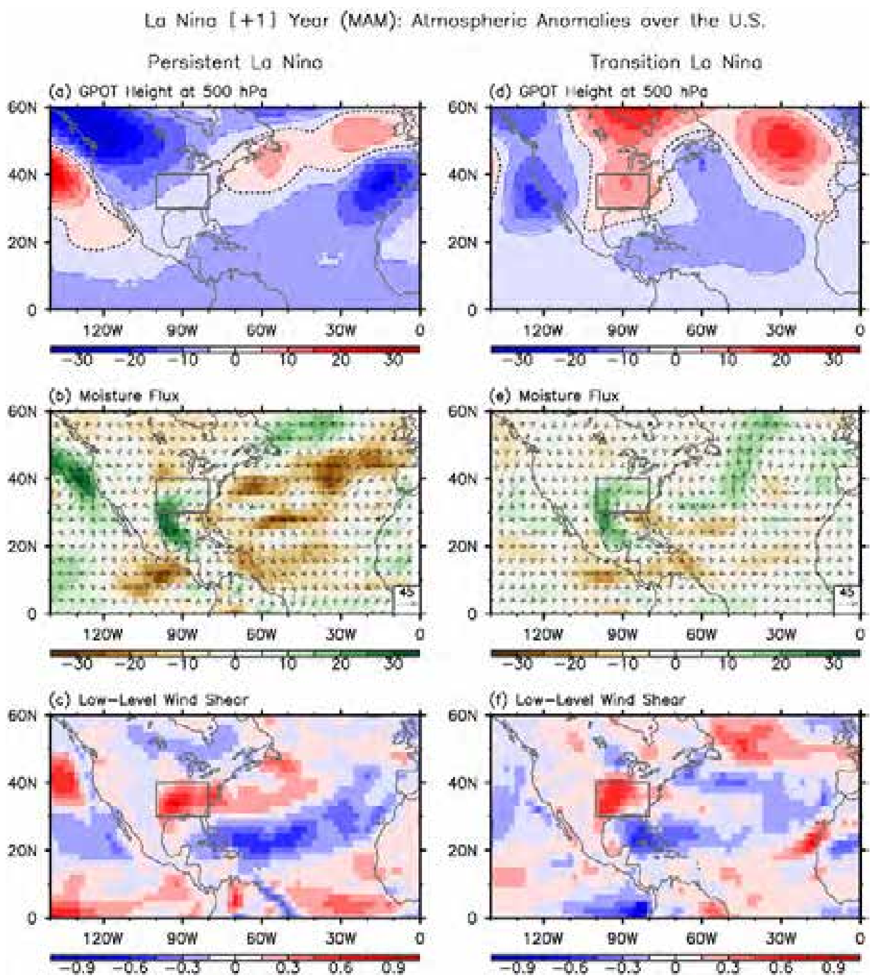

Figure 4. Geopotential height anomalies at 500 hPa, vergially integrated moisture transport anomalies and low-level wind shear anomalies (850 - 1000 hPa) during the resurgent La Nina years and transitioning La Nina years in March-April-May (MAM) derived from the 20th Century Reanalysis (20CR). The unit is *gpm* for the geopotential height, $kg\ m^{-1}\ s^{-1}$ for the moisture transport, and $m\ s^{-1}$ for the wind shear.

During both the resurgent and transitioning La Nina phases, the low-level wind shear is much increased in the east of the Rockies, and the moisture transport from the Gulf of Mexico to the US increases. Therefore, the atmospheric conditions under the resurgent and transitioning La Nina phases are favorable for tornado outbreaks in the US.

The results shown in this report will be summarized and submitted for a publication. The focus of our work during the rest of FY2015 will be developing a statistical-dynamic seasonal tornado outlook. The new index proposed here, *probability of regional U.S. tornado outbreak*, will be used to achieve that goal.

1.3 Climate and severe weather workshop

Summary

Scott Weaver (co-PI from CPC) and Gregory Carbin (SPC) co-organized the Climate and Severe Weather workshop (CSWW) at the NOAA Center for Weather and Climate Prediction (NCWCP) in College Park, MD on March 11-12, 2015. The workshop was designed to advance the goal of establishing long-range (i.e., > 1 week) operational severe weather outlooks by enhancing research and development activities, and strengthening partnerships for transitioning research to operations through a multi-institutional collaborative outlook process. The CSWW is the third in a series of workshops on long-range severe weather outlooks. It is the first to include specific discussion and recommendations of how scientific advances in climate and severe weather research may be brought to bear on long-range NOAA operations and applications.

Participants included those from various NOAA/NCEP and NOAA/OAR centers (SPC, CPC, and AOML), NOAA's Climate Program Office, and the academic research community. A key outcome is the recommendation that three severe weather outlooks be developed as a function of varying lead-times. These include separate outlooks for the seasonal, monthly, and weeks 1-4 time horizon. While the continued development of these outlooks will require additional resource commitments from NOAA and other funding agencies, it was widely agreed that experimental implementation could begin in FY 2016.

The CSWW organizing committee proposed 4 goals for consideration at the workshop. Research on the climate and severe weather connection has been rapidly advancing over the last few years. As such, these goals reflect the desire to assess the latest state-of-the-art science and develop a strategy for initiating and strengthening the R2O and O2R paradigms in the long-range severe weather context.

The workshop featured four sessions, which included scientific presentations spanning numerous topics and timescales. Session 1 provided an overview of NOAA climate programs and examples of current operational climate outlook frameworks. Sessions 2 and 3 were oriented toward current understanding of sub-seasonal and seasonal variability of severe weather, respectively, including linkages to climate variability modes (i.e., MJO, GWO, ENSO) and modeling tools for their prediction. Session 4 targeted regional variability and high resolution modeling approaches. The CSWW agenda, list of attendees, and scientific presentations may be found here:
http://www.spc.noaa.gov/misc/CSWW-2015/

Outcomes and Recommendations

The participants discussed implementation planning for operational severe weather outlooks beyond week-1. In particular, it is recommended that three severe weather outlooks be developed as a function of lead-time. These include separate outlooks for the seasonal, monthly, and weeks 1-4 time horizons. While some overlap in severe weather definitions and presentation format may occur, it was decided that some aspects will be unique to the particular lead time of the outlook

Partnerships for scientific research and product dissemination
A critical aspect to the success of this endeavor is to nurture shared activities among the NOAA/NCEP centers (i.e., CPC and SPC), NOAA/OAR labs (i.e., NSSL and AOML) and the academic research community. Despite the optimistic appraisal among the CSWW participants regarding the potential for skillful long-lead severe weather outlooks, it is paramount to understand that forecast improvements and related scientific advances ultimately depend on increased resource support from climate programs engaged in advancing scientific research and development activities. Given that gaps remain in understanding the climate and severe weather linkage and developing applied forecasting techniques, it is necessary that both basic and applied research continue in earnest, focusing on statistical and dynamical modeling, improved diagnostic understanding, and applied research on methods to blend models into useful guidance products.

2. Highlights and Accomplishments

The three highlights of our research during FY2015 are listed below.

1) We proposed an objective way to characterize various patterns of springtime ENSO phase evolutions by using only two leading inter-event EOF modes. The four dominant ENSO phases identified in our study (i.e, persistent El Nino, early-terminating El Nino, resurgent La Nina and tranisitoning La Nina) may help us to identify precursors to springtime ENSO phase evolution and associated teleconnection to the US. (i.e. seasonal prediction of springtime ENSO phase evolution).
2) During the resurgent La Nina years, the probability of outbreaks increases significantly by 20 ~ 30% in a wide region over the Central and Southeast US states. Durign the transitioning La Nina years, the probability of regional tornado outbreaks somewhat reduces over Lousiana, Mississippi, Alabama and Georgia, but greatly and significantly increases over Oklahoma and Kensas (20 ~ 30%).
3) Scott Weaver co-organized the Climate and Severe Weather workshop (CSWW) to advance the goal of establishing long-range (i.e., > 1 week) operational severe weather outlooks. A key outcome is the recommendation that three severe weather outlooks be developed as a function of varying lead-times. It was agreed that experimental implementation could begin in FY 2016.

3. Publications

During FY2015, we have published one paper in the Geophysical Research Letters. We also have two papers in-preparation or in-revision:

Lee, S.-K., P. N. DiNezio, E.-S. Chung, S.-W. Yeh, A. T. Wittenberg and C. Wang, 2014: Spring persistence, transition and resurgence of El Nino. Geophys. Res. Lett., 41, 8578-8585, doi:10.1002/2014GL062484. http://www.aoml.noaa.gov/phod/docs/2014GL062484.pdf

Lee, S.-K., S. J. Weaver, R. Atlas, C. Wang and D. B. Enfield, 2015: Probability of US regional tornado outbreaks and its link to springtime ENSO phase evolution and North Atlantic tripole SST variability. In-preparation.
Riddle, E., S. J. Weaver, Lee, S.-K., R. Atlas, and C. Wang, 2015: Simulation of North American low-level jet variability in the NCEP Climate Forecast. In-revision.

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5. Future Work

1) For our future work, we will complete our effort to explore springtime ENSO phase evolution and its relation to the probability of regional U.S. tornado outbreak. The results shown in this report will be submitted for a publication.
2) The main focus of our work during FY2015 will be developing a statistical-dynamic seasonal tornado outlook. The new index proposed here, *probability of regional U.S. tornado outbreak*, will be further used to achieve that goal.
3) Partnership Building: The PIs will continue to build relationships with partners in the federal government and academia to align research priorities effectively toward developing long-range severe weather outlooks.

Quarterly Project Report to OAR

Award Number: NA14OAR4830103
Project Title: CIMAS Contributions to OAR Disaster Recovery Act Projects
Grantee: Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami FL
Research Period: January 1, 2015 – March 31, 2015
Lead CIMAS PI: Sang-Ki Lee

1. Goals and objectives

The present project aims to make use of new observation technology to improve the understanding of air-sea interaction for extreme weather events for the ultimate goal of improving tropical Atlantic intensity and track forecasts and seasonal outlooks. Using observations and numerical experiments, the project also aims to assess the value of current observational efforts and to propose improvements in how ocean and atmospheric observations need to be carried out in order to improve forecasts and outlooks. With these goals in mind, this project concentrates on three tasks to be carried out in close collaboration with NOAA AOML scientists.

1) Observing System Experiments (OSE and OSSE) in support of Data Gap Mitigation; Lead PI: Dr. Robert Atlas, NOAA/AOML
2) Sustained and Targeted Ocean Observations for Improving Atlantic Tropical Cyclone Intensity and Hurricane Seasonal Forecasts; Lead PI: Dr. Gustavo Goni, NOAA/AOML
3) The Impact of Emerging Observing Technologies on Future Predictions of Hurricane Structure and Intensity Change; Lead PI: Dr. Joseph Cione, NOAA/AOML

A site visit in January 2015, reviewed the administrative and scientific progress for the project for 2014. The summary of our research progress made for the period of January 1 – March 31, 2015 is described below for the three tasks:

2. Progress summary

<u>Task-1: Observing System Experiments (OSE and OSSE) in support of Data Gap Mitigation;</u> Lead PI: Dr. Robert Atlas, NOAA/AOML

The primary objective of this project is to formally establish a laboratory activity for the quantitative assessment of observing systems, in order to enable the most cost-effective decisions relating to the JPSS data gap, as well as other proposed changes to the global observing system. The capability to be established will include the potential to conduct Observing System Experiments (OSEs) and Observing System Simulation Experiments (OSSEs) to quantitatively assess the value of either existing or future observing systems. The existing global OSSE capability will be significantly upgraded. In addition, limited OSSEs using current OSSE systems, and limited OSEs will be performed.

(1) Project staffing

One additional new team member has been added since the last quarterly report. At JCSDA, thru ESSIC, the new team member is Yan Zhou. Yan has a new PhD from U. of Maryland/College Park. Yan's thesis, under the supervision of Eugenia Kalnay, focused on methods to correct for inhomogeneities in reanalyses. Yan's research interests include ensemble and variational data assimilation methods, their applications to satellite retrieval and radiance observations, numerical model prediction, validation and bias estimation, and climate change and variability.

(2) Resources and infrastructure

Nature runs

Legal issues involved in acquiring the ECMWF T1279 NR is the subject of continuing discussions between NOAA Office of the General Counsel and ECMWF. The time for delivery continues to be uncertain. As reported previously, the 7km-CS NR (2-year, 7 km, non-hydrostatic, now denoted G5NR) has been released by NASA GMAO. The team has completed preliminary validation and calibration activities. Access to data and documentation are all at

- http://gmao.gsfc.nasa.gov/projects/G5NR/

Preliminary OSSEs with the ECMWF T511 NR, are now complete. HWRF OSSEs and other experiments continue based on the high resolution hurricane NR, denoted HNR1 here, produced by Nolan et al. (2013). The project's main focus for the G5NR is the Aug-Sep 2006 period which contains a number of tropical cyclones, including AL08 of 2006 which makes landfall about 30 miles west of Mobile Bay as a Cat 3, borderline Cat 4 storm. Figure 1 shows AL08 and gives an indication of the detail and realism of the G5NR.

Data assimilation system (inc. forecast models)

All experiments will make use of versions of operational systems, including the GFS and HWRF forecast models and the GSI, EnKF and hybrid EnKF/GSI analysis systems. This approach leverages the R2O/O2R resources of the JCSDA. Some experiments also make use of the HEDAS developed at AOML. O2R activities have succeeded at installing the new NCEP system on JIBB and S4. This system, which went operational in Jan 2015, includes data assimilation (DA) at T574 and forecasts at T1534 resolution. Both the GSI and EnKF run at the same DA resolution. In addition an R&D version of the operational system at reduced resolution with T670 for the GFS and T254 for the DA that should allow more efficient (quicker, less storage) experiments is used by the project. All of these configurations have been tested within our OSSE setting. Experiment with real data for 2005 and 2014 are used to prepare diagnostic data sets which are used to create the simulated data with the correct coverage, and for calibrating the OSSE systems.

Observing systems

The proposed observing systems of most interest are the Geo-HSS and GNSS/RO. JCSDA has secured separate funding to conduct parallel experiments for a Geo-MW sensor (microwave sensor in geostationary orbit). CIMSS has produced Geo-AIRS data for a GOES east satellite location on the 7-km grid for the two-month Aug-Sep 2006 study period from the G5NR. The new bending angle GNSS/RO software has been integrated into the observation simulation software and is expected to be implemented in the future versions of GSI. All existing observations have been simulated for parts of the Aug-Sep 2006 study period, based on the 2014 actual observations. Because we are interested in a potential data gap, observations from U.S. afternoon polar orbiters are not included. Software is being refined to simulate a constellation of 5 Geo-HSS instruments with IASI characteristics.

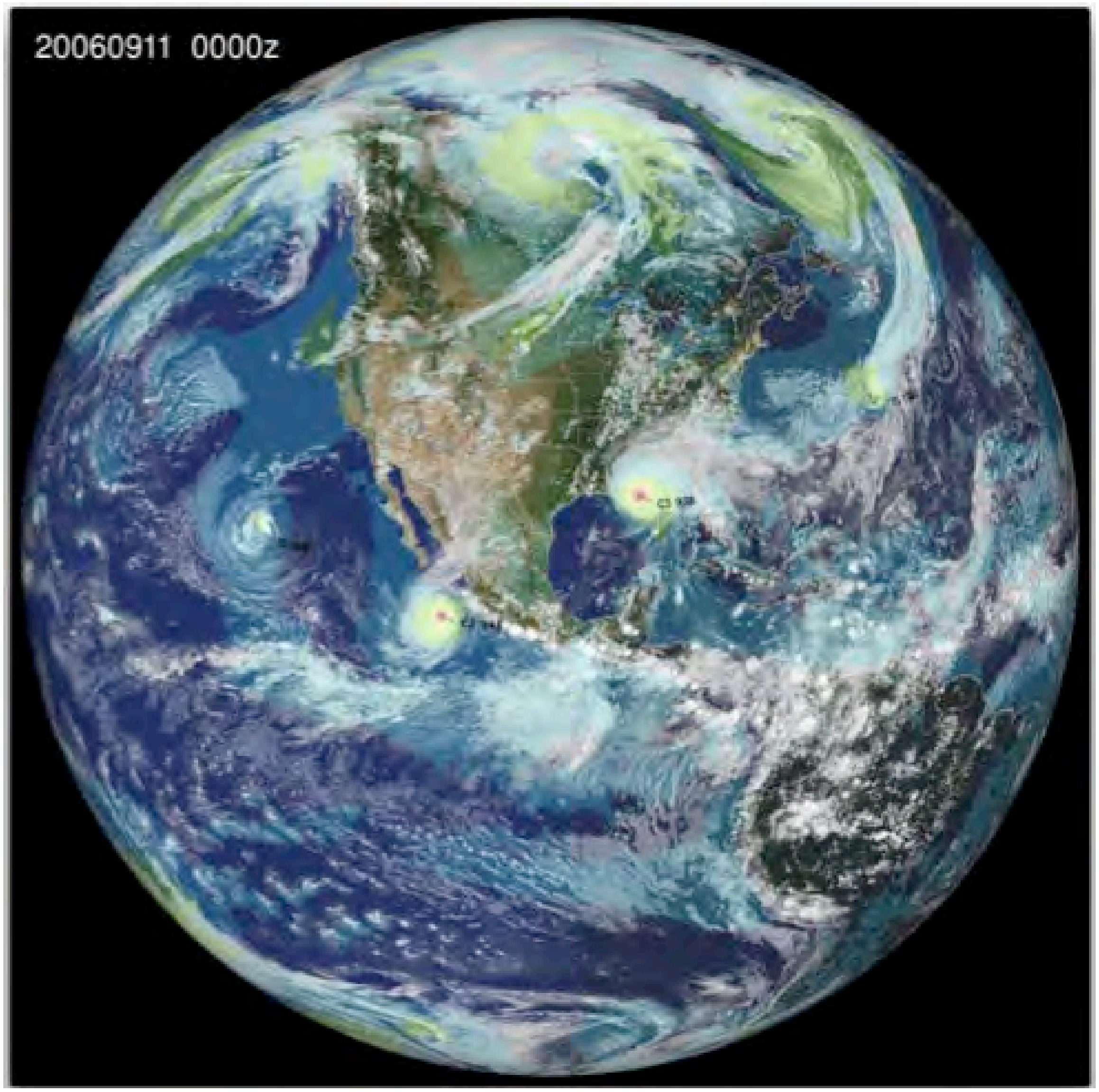

***Figure 1**. A top down view in the visible (i.e., as seen from space) of the G5NR at 00 UTC 11 Sep 2006. An additional color overlay indicates wind speed. At this time two major hurricane are present. One is making landfall on the Gulf Coast and the second is south of Baja California. The labels indicate that at this time they are both Cat 3 hurricanes with a central pressure of 938 and 941 hPa respectively.*

<u>*Computer resources*</u>

Computer resources include the Jet and Zeus supercomputers utilized by AOML and ESRL, the JIBB supercomputer used by JCSDA, and the S4 supercomputer used by JCSDA and CIMSS. A new computer named Thea is now being used by some team members. Thea is an upgrade for Zeus, which will be retired later.

Team members
The team includes staff from AOML/CIMAS, JCSDA, ESRL, and CIMSS. Also StormCenter is a subcontractor to AOML.

(3) Current progress

As reported last quarter, several team members attended and presented results at the AMS Annual Meeting in Phoenix this January. These presentations are now available online.

AOML/CIMAS

- The focus is on predictability (also called spin-down) experiments to better understand some issues related to the HWRF DA. For example, in Fig. 2, with excellent data GSI produces a weaker vortex at the surface, but after 6-h, the storm has regained its surface characteristics.

JCSDA

- Testing of system components for the OSSEs using the new OSSE system is complete. Comparison of real data T1534 and T670 experiments show that the main features of the analyses and forecasts are similar, but that the higher resolution system is more accurate. We will use the T670 setup as a pathfinder in our work and repeat critical experiments at higher resolution.
- JCSDA is now tuning the simulated observation errors using a calibration approach that compares (O-B) (i.e, 6-h forecast errors or innovations) statistics in real data experiments and in the OSSE. The Geo-HSS OSSEs are anticipated to begin shortly, but a great deal of ground work is necessary.
- An OSSE package for public release is being refined.

ESRL/GSD

- Work is focused on the GNSS/RO data simulation and OSSEs. The GNSS/RO OSSEs will be conducted in collaboration with JCSDA. A first experiment will use the same CTRL case as the Geo-HSS.

CIMSS/U. Wisconsin

- The CIMSS satellite orbit simulator has been expanded to include many other instruments. CRTM will be used together with the orbit simulator to simulate radiance measurements from existing satellite sensors.
- To diagnose previous findings that GEO AIRS shows improvements after 30 hours of forecast but not earlier, a bracketing experiment with perfect (no error) observations was performed. It is found that both the GEO AIRS and the CTRL (radiosonde only) experiments show comparable track forecast as the no error experiment for the first 30 hours of the forecast.
- A new relocation technique of hurricane called parcel displacement method was developed from the Lagrangian viewpoint.

StormCenter

- Prototyping of MP2 user interface is complete.
- MP2 now can access project experiments on JIBB, S4, and Storm, as well as the G5NR and MERRA reanalysis on Discover.
- StormCenter is finishing up a batch facility for MP2 and documentation to act as a user's guide.

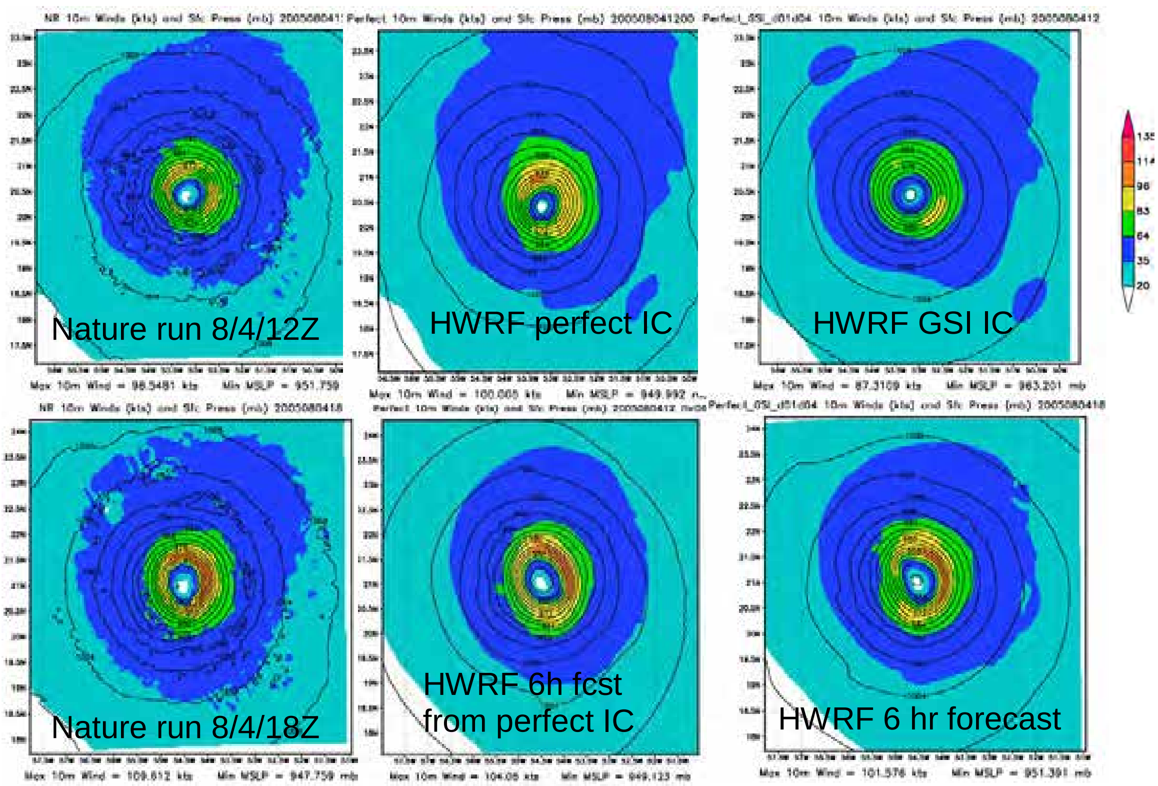

Figure 2*. 10m winds (kts) shaded and MSLP (mb) contoured. Sample analysis and 6 hour forecast from 12 UTC Aug 04. Left column shows the 3 km domain from HNR1; center column shows 3 km domain from HWRF cold start run that used HNR1 as initial and boundary conditions; right column shows HWRF cycled run with analysis provided by GSI assimilating perfect data from HNR1 27 km and 1 km domains and GFS background and boundary condition.*

(4) Planned activities

- Finish calibration of the G5NR OSSE system for study period Aug-Sep 2006.
- Begin T670 CTRL and Geo-HSS experiments.
- Complete preparations for the T670 GNSS/RO experiments.
- Continue predictability experiment for the HWRF DA system.
- Tune GNSS/RO error statistics for the HWRF system, and re-run GNSS/RO hurricane OSSEs.
- Preform Geo-HSS HWRF OSSEs using new retrievals created by J. Susskind.
- Test new parcel displacement hurricane relocation technique in the QuickOSSE framework.

(5) Observing System Experiments Acronyms

AIRS	Atmospheric Infrared Sounder
AL08	Atlantic hurricane 8
AMS	American Meteorological Society (Boston)
AOML	Atlantic Oceanographic and Meteorological Laboratory (Miami FL)
CIMAS	Cooperative Institute for Marine and Atmospheric Studies (Miami FL)
CIMSS	Cooperative Institute for Meteorological Satellite Studies (Madison WI)
CS	cubed sphere
CTRL	Control Experiment
DA	data assimilation
ECMWF	European Center for Medium-Range Weather Forecasting
ESRL	Earth System Research Laboratory (Boulder CO)
ESSIC	Earth System Science Interdisciplinary Center (University of Maryland, College Park)
EnKF	ensemble Kalman filter
G5NR	GMAO 7-km (1⁄16 x 1⁄16°) resolution NR
GEO	geostationay Earth orbit
GEOS	Goddard Earth Observing System
GFS	Global Forecast System
GMAO	Goddard Modeling and Assimilation Office
GNSS	global navigation satellite system
GOES	Geostationary Operational Environmental Satellite
GSI	Grid point Statistical Interpolation
Geo-AIRS	geostationary instrument with AIRS characteristics
Geo-HSS	geostationary hyper-spectral sounder
HEDAS	Hurricane Ensemble Data Assimilation System
HNR1	first hurricane NR (00 UTC 29 Jul – 00 UTC 11 Aug 2005)
HSS	hyper-spectral sounder
HWRF	Hurricane Weather Research and Forecasting (model)
IASI	Infrared Atmospheric Sounding Interferometer
JCSDA	Joint Center for Satellite Data Assimilation
JIBB	JCSDA in a Big Box (NASA Goddard Space Flight Center)
JPSS	Joint Polar Satellite System
LEO	low Earth orbi
MERRA	Modern-Era Retrospective analysis for Research and Applications
MP2	Multi-Plot II
MSLP	mean sea level pressure
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NR	nature run
O2R	operations to research
OSE	observing system experiments
OSSE	observing system simulation experiments
PI	principal investigator
QOSAP	Quantitative Observing Systems Assessment Program

R&D	research and development
R2O	research to operations
RO	radio occultation
S4	Supercomputer for Satellite Simulations and Data Assimilation Studies (Space Science and Engineering Center at the University of Wisconsin-Madison)
T1279	new ECMWF NR, operational as of 26 January 2010 (10 km)
T1534	GFS operational as of Jan 2015 (9 km). Analysis uses T574L64.
T254	GFS operational as of 10/29/2002 12Z (53 km)
T511	"old" NR, T511L60 operational as of 21 November 2000 (26 km)
T574	GFS operational as of 07/28/2010 12Z (23 km)
T670	new GFS research model resolution (20 km). Analysis uses T254L64
UTC	Universal Time Coordinated
WRF	Weather Research and Forecasting (model)

Task-2: Sustained and Targeted Ocean Observations for Improving Atlantic Tropical Cyclone Intensity and Hurricane Seasonal Forecasts; Lead PI: Dr. Gustavo Goni, NOAA/AOML

This work will implement a pilot array of two Seagliders to carry out sustained and targeted upper-ocean profiling of temperature (T), salinity (S), and current velocities (u,v) in the Atlantic Warm Pool region. The proposed work will provide 4,500 to 5,500 profile observations per year during the two-year study obtained from two Seagliders that will be deployed in the Caribbean Sea and north of Puerto Rico. Data will be transmitted in realtime into the GTS, and will be used by scientists involved in this and all other projects that utilize GTS profile data. In this work, each Seaglider will provide data of approximately 2,700 profiles per year. The main objectives of the proposed work are to implement upper ocean observations from Seagliders, to evaluate their impact on and to improve: (1) hurricane intensity forecasts and (2) hurricane seasonal forecasts; using a combination of these new sustained observations, targeted observations, data analysis, and current NOAA operational forecast models.

(1) Project update:

The second year AOML underwater glider mission started with new oxygen sensors

On February 5, the second year AOML underwater glider mission started with the deployment of two gliders in the Caribbean Sea, south of Puerto Rico, from the R/V La Sultana of the University of Puerto Rico Mayaguez (UPRM). For this mission, a new sensor to measure dissolved oxygen concentration was installed on both gliders. Grant Rawson (CIMAS/PHOD), Julio Morell and Luis Pomales (UPMR) led the field efforts, while Francis Bringas (PHOD) and Walt McCall (NDBC) led the ground piloting efforts, together with Ricardo Domingues (CIMAS/PHOD). The deployment was, however, cancelled and the gliders were recovered on February 6 in order to correct some firmwear issues related to the new oxygen sensors installed in both gliders. Both gliders were successfully re-deployed on February 6. The two gliders transected a region in the eastern Caribbean Sea providing approximately 3000 profile observations of temperature, salinity, oxygen and surface and depth-average current velocities until their recovery in April 27, 2015. Data from this mission has been transmitted to the GTS and modeling centers to better initialize the upper ocean conditions in this area for seasonal forecast of the Atlantic Warm Pool.

The underwater gliders sucessfully recovered from the Carribbean Sea

The two gliders were sucessfully recovered from the Caribbean Sea on April 27, 2015. Walt McCall (NDBC) led the ground piloting efforts. Julio Morell and Luis Pomales (UPRM) and Ricrdo Domingues (CIMAS/PHOD) led the field efforts. Currently, the underwater glider mission is in an intercessional period for planing the next deployment and for reviewing various aspect of the glider mission during the previous deployments.

Seaglider data website updated

Seaglider data website was updated to provide dissolved oxygen profiles from the newly installed oxygen sensors. The updated website also provide surface current and depth-averged current in near-real time.

Project Home:
http://www.aoml.noaa.gov/phod/goos/gliders/index.php
Latest Observations
http://www.aoml.noaa.gov/phod/goos/gliders/observations.php
All Observations:
http://www.aoml.noaa.gov/phod/goos/gliders/past_observations.php
Temperature, Salinity and Dissolved Oxygen profiles
http://www.aoml.noaa.gov/phod/goos/gliders/view_profiles.php
Glider-derived ocean currents
http://www.aoml.noaa.gov/phod/goos/gliders/ocean_currents.php
Previous mission (July – Novermber 2014)
http://www.aoml.noaa.gov/phod/goos/gliders/previous_missions.php
Data access:
http://www.aoml.noaa.gov/phod/goos/gliders/data.php
FAQ:
http://www.aoml.noaa.gov/phod/goos/gliders/faq.php
Picture Gallery:
http://www.aoml.noaa.gov/phod/goos/gliders/gallery.php

The role of Atlantic warm pool on Hurricane Edouard's (2014) rapid intensification identified

A set of experiments were conducted to investigate the sensitivity of Hurricane Edouard's (2014) forecast to Atlantic warm pool using an uncoupled high resolution (3 km) HWRF model. Five days forecasts were performed from 00 UTC Sep. 12 with the prescribed SSTs derived from Fleet Numerical Meteorology and Oceanography Center (FNMOC) high resolution ocean analysis for US Global Ocean Data Assimilation Experiment (GODAE) and Generalized Digital Environment Model (GDEM) climatology at September. The atmospheric initial condition and lateral boundary conditions were derived from Global Forecast System (GFS). Besides the year 2014, the FNMOC SST from previous years 2010 - 2013 at the same date and time were used to replace the 2014 FNMOC SST.

In Figure 3, the prescribed SSTs from different experiments show large variation in terms of Atlantic warm pool's location, size and strength. In 2014 and 2012, the Atlantic warm pool was strong and extended farther east to Sargasso Sea while much weaker warm pool retreated back to the west in 2013 and 2011. GDEM September climatology missed the warm pool completely in the region of interest. The track forecasts of Hurricane Edouard from all six experiments show similar moving directions during most of the forecast hours (Figure 3). A larger impact from the location and size of Atlantic warm pool is observed on the intensity forecasts compared to the track (Figure 4). Three different groups are identified in the minimum sea level pressure prediction. Stronger storms are predicted with larger warm pools (year 2014 and 2012) which are closer to the best track. The SSTs with smaller warm pools lead to weaker storms. SST in the year 2010 has a relatively medium warm pool and an intensity forecast between the strong and weak storms.

These experiments will be extended with the fully coupled HWRF-HYCOM model to investigate the role of warm pool in high resolution simulation of tropical cyclones.

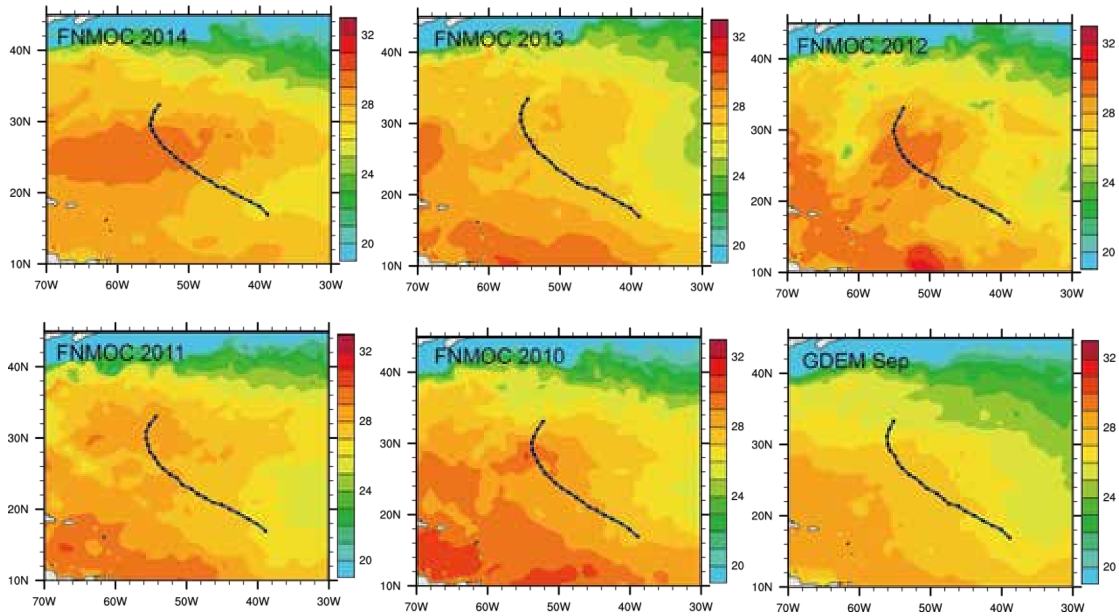

***Figure 3**. Prescribed SSTs for different experiments overlapped with 120 hours track forecast for each individual experiment (starting from 00 UTC Sep. 12 2014 plotted every 6 hours).*

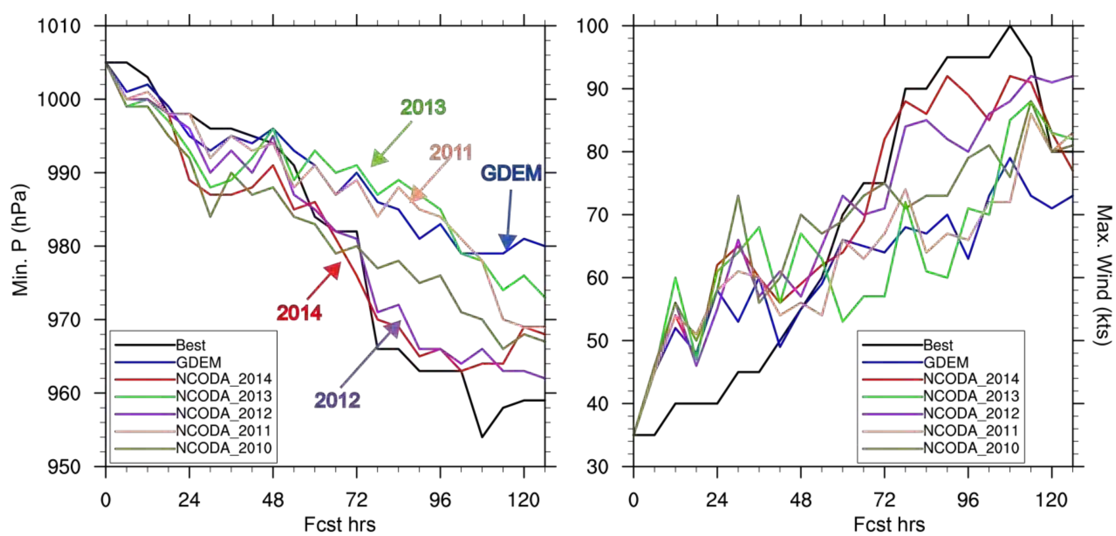

***Figure 4**. 120 hours minimum sea level pressure (left) and maximum surface wind forecasts (right) for Hurricane Edouard.*

Task-3: The Impact of Emerging Observing Technologies on Future Predictions of Hurricane Structure and Intensity Change; Lead PI: Dr. Joseph Cione, NOAA/AOML

The primary objective of this project is to evaluate and assess the benefits of using new and emerging technologies consisting of aircraft-deployed low altitude unmanned aircraft systems (UAS) and Doppler wind lidar (DWL) profiling systems to better predict tropical cyclone intensity change through evaluation of and improvements to the physical routines used within NOAA's operational Hurricane Weather Research Forecast (HWRF) model based on these novel observations. Currently, detailed analyses of temperature, moisture and wind below 500m are very limited due to the fact that the primary source of data in this region of the storm is from point-source GPS dropsonde measurements. Improvements to observing this area is critical since it's where energy is exchanged with the ocean and where the winds directly impact lives and property. Moreover, recent analyses from modeling and observational studies have shown a strong sensitivity to initial conditions, especially for atmospheric moisture at low levels within the storm environment. In order to address this critical data void, this project will test and evaluate UAS and DWL emerging technologies to assess how observations from each platform may complement and enhance existing data coverage within the tropical cyclone boundary layer and ultimately lead to improved forecasts of intensity change.

This funded effort will extend and leverage existing OAR and Hurricane Forecast Improvement Project (HFIP) sponsored observing programs to evaluate novel technologies, instruments and observing platforms that provide improved kinematic and thermodynamic observations within the atmospheric boundary layer of tropical cyclones. Focus will be directed toward collecting data capable of evaluating and improving tropical cyclone predictions through better defining of the initial atmosphere and ocean, removal of model biases, and improved atmospheric physics characterization and parameterization. The primary scientific objectives to achieve them are listed below:

- Significantly Enhance Atmosphere/Ocean Boundary Layer Observations
- Evaluate HWRF and POM Hurricane Structure
- Improve HWRF and POM Model Physics (Part I)
- Improve HWRF and POM Model Physics (Part II)
- Establish an 'Optimal Mix' for Hurricane Boundary Layer Observations

(1) Project update:

Project update for January 1, 2015 – March 31, 2015:

1) Project (green)
- Presented Coyote UAS Hurricane Edouard (2014) analyses at The Interdepartmental Hurricane Conference held in Jacksonville, FL (February 2015)
- Began preliminary comparison of Coyote UAS pressure, wind temperature data collected in Hurricane Edouard with measuremtns collected by NOAA P-3 aircraft (GPS sondes and Tail Doppler Radar winds) (March 2015)

2) Budget (green)
- There is no issue or new development with this category.

3) Administrative (green)
- There is no issue or new development with this category.

Accounting for the influence of feeding success on the growth and survival of bluefin tuna larvae in stock assessment efforts

Principal Investigators:

Barbara Muhling, Cooperative Institute for Marine and Atmospheric Studies, University of Miami

Joel Llopiz, Woods Hole Oceanographic Institution

Final Report, November 2014

Introduction

Atlantic bluefin tuna (BFT) are found in sub-tropical, temperate and sub-arctic habitats throughout the North Atlantic Ocean. Two stocks are recognized by the International Commission for the Conservation of Atlantic Tunas (ICCAT): eastern and western. The stocks are nominally delineated by a north-south boundary at 45°W. However, considerable mixing of the stocks occurs, with adults of both eastern and western stocks feeding and migrating throughout the north Atlantic (Block et al., 2005).

Despite this wide-ranging behavior, and in contrast to many tropical tunas, BFT show strong spawning site fidelity. The eastern stock spawns only in the Mediterranean Sea during summer; and the western stock in the Gulf of Mexico (GOM) and immediate surrounds during spring. These spawning grounds are characterized by warm (>20°C) near-surface waters, low surface chlorophyll and deep chlorophyll maxima (Muhling et al., 2013). Once hatched, pelagic larvae grow quickly, reaching up to 7mm in length after one week (Brothers et al., 1983). However, growth and potentially survival vary widely among individuals during the larval phase, and also among years (Tanaka et al., 2006). The contribution of feeding success to this variability in growth, survival, and ultimate recruitment is not currently known.

Despite various management measures, the western BFT stock is still considered to be overfished, and subject to overfishing. However, considerable uncertainty exists with respect to this evaluation. The most problematic knowledge gap is the lack of understanding of the stock-recruitment relationship. This relationship describes the mathematical association between the number of spawning fish in a population, and the number of young fish they produce. The most recent assessment from ICCAT considers two potential forms of the SRR, resulting in two recruitment scenarios for the western Atlantic BFT stock: “low” and “high” (Fig. 1).

- The low recruitment scenario assumes that an unspecified change in environmental conditions since 1970 will prevent high levels of recruitment from occurring in the future, even if the stock is rebuilt.
- The high recruitment scenario assumes that as stock biomass increases, recruitment will increase accordingly. As a result, the high levels of recruitment observed during the 1970s may be possible in the future.

There is currently insufficient evidence to favor one scenario over the other. This is highly problematic, as under the low

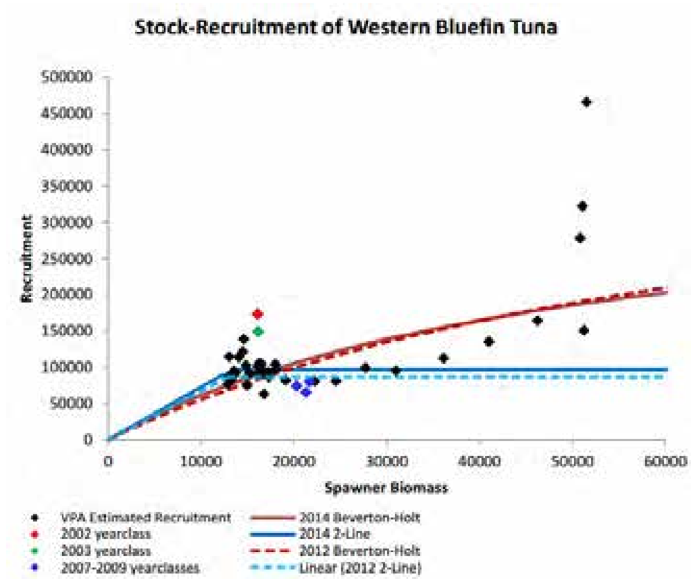

Figure 1: Spawner-recruit relationships from the 2014 stock assessment. The two-line model (blue) represents the low recruitment scenario; the Beverton-Holt model represents the high recruitment scenario (red) (Lauretta et al., 2014)

scenario, the stock is currently above biomass levels that can support maximum sustainable yield. Under the high recruitment scenario, the stock is still heavily overfished, and will not recover within the timeframe of the current rebuilding plan. The central questions which must be addressed in order to improve the western Atlantic BFT stock assessment therefore relate to drivers of recruitment. Recruitment in other scombrid species has been associated with larval feeding, growth and predation processes, suggesting a link with zooplankton communities (Marguiles, 1993; Robert et al., 2008). Published studies (Llopiz et al. 2010, Llopiz & Hobday, 2014) show that larval BFT are highly selective feeders, and that feeding success is not related to ambient primary productivity levels. Instead, the abundance of specific planktonic prey and predator species is likely to be of key importance.

This project therefore aimed to improve understanding of larval BFT feeding and diets in the GOM, with implications for growth, survival and recruitment. Our objectives were to:

1) Examine preserved BFT larvae from several sampled years for:
    a. Feeding success (gut fullness)
    b. Prey item assemblages
2) Characterize diets by size class
3) Determine environmental correlates and spatiotemporal predictive models of:
    a. Feeding success
    b. Prey item assemblages
4) Determine relationships between feeding behavior and daily growth
5) Link larval ecology to observed recruitment variability

Methods

<u>Biological Samples</u>

280 larval bluefin tuna were analysed for gut contents analysis at Woods Hole Oceanographic Institution (WHOI) (Table 1). In addition, 54 zooplankton samples were analysed from the 2012 cruise. These were from a fine mesh (200μm) net towed between the surface and 10m depth, and thus represent the only available information on prey fields collected in the same vertical strata occupied by larval BFT.

Year	**Larvae Provided**	**Subset Examined**	**Other Samples**
2003	236	60	
2011	100	100	
2012	121	121	54 Zooplankton samples

Larval BFT were sourced from bongo and neuston net tows for 2003 and 2005, and from S-10 net tows for 2011 and 2012 (see Habtes et al., 2014 for sampling net descriptions).

<u>Feeding Analyses</u>

Larvae selected for dissection were measured for both standard and lower jaw lengths. All prey were then removed from stomachs, enumerated, and identified to the lowest taxonomic level possible. Feeding success was defined as the proportion of daytime-collected larvae with at

least one prey item in their guts. Gut fullness was calculated using standard conversion factors, and a size-corrected index of gut fullness following Sponaugle et al. (2009).
Zooplankton assemblages were determined for 54 stations from 2012: 36 stations where BFT larvae were collected, and 18 nearby negative stations. Assemblages were compared among positive and negative stations, and between zooplankton samples and gut contents, to determine feeding selectivity.

<u>Data Analyses</u>

Several indices of BFT larval feeding were available from the gut contents analysis:

- Feeding success
- Gut fullness
- Prey composition

Permutational non-parametric analysis of variance (Permanova) in Primer-6 software (Anderson, 2001) was used to define spatial and interannual variability in these indices. Multivariate ordination techniques, such as Canonical Analysis of Principal Coordinates (CAP) were used to visualize results, and to highlight ontogenetic shifts in prey types. For 2012 only, zooplankton assemblages from plankton samples were compared between positive and negative BFT stations, using Permanova. Feeding selectivity was examined by comparing the percent composition of zooplankton taxa from BFT guts vs. zooplankton assemblages from the surrounding water column.

In addition, connections between the oceanographic environment and feeding indices were investigated using distance-based linear models (Distlm), also in Primer-6. These models quantified the contribution of environmental variables to spatial and temporal variability in gut fullness, and prey composition. Environmental variables were sourced from *in situ* CTD casts, satellites and the HYCOM GOM ocean model. Remotely sensed and modeled variables were extracted for each sampling time and location using the Marine Geospatial Ecology toolbox for ArcGIS (Roberts et al., 2010).

During 2012, 100 larval BFT were aged using daily otolith increments. Using gut contents data for this year only, the ability of gut fullness and prey composition to predict recent daily growth was investigated.

Results

<u>Feeding success</u>

The mean daytime feeding incidence among larvae from all years was 96.9%. Feeding incidence of daytime collected 2-4mm larvae was 79.2%, in 4-6mm larvae it was 96.9%, and in larvae >6mm, feeding incidence was 100%. Similarly, the index of gut fullness increased with larval size (Fig. 2). Of all the explanatory variables considered, length was the strongest determinant of gut fullness (R^2 = 0.16, $p<0.001$). When combined with day of the year, geostrophic current magnitude, surface temperature and temperature at 100m depth in a Distlm, the R^2 value increased to 0.25.

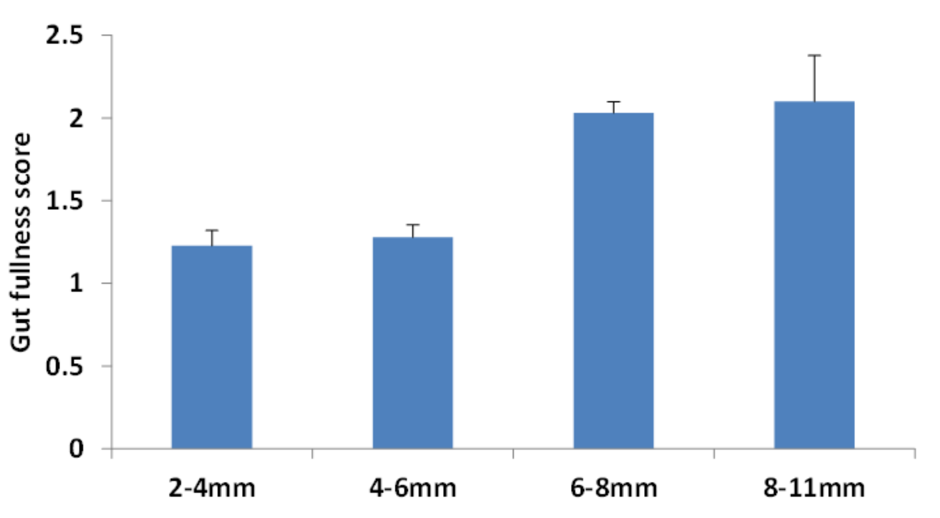

Figure 2: Mean index of gut fullness for larvae from all years, by size class.

Larval diets

Gut contents of larvae <6mm were dominated by copepod nauplii (Fig. 3). Larger larvae feed more heavily on appendicularians and cladocerans. 6.7% of larvae 6-8mm were piscivorous, increasing to 66.7% for larvae >8mm. Larvae consumed prey across a variety of sizes, however mean prey length increased with larval length (Fig. 4).

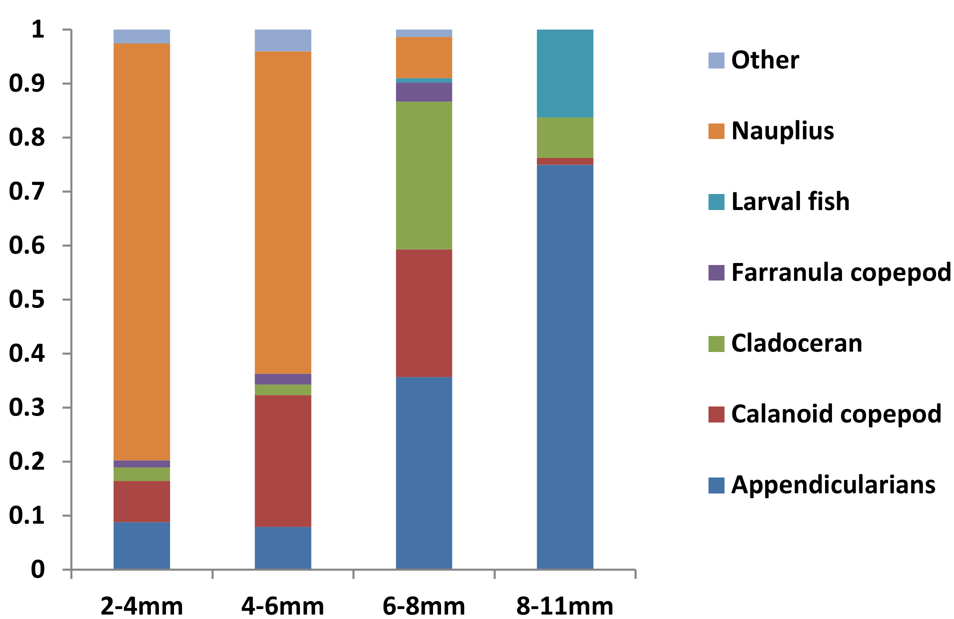

Figure 3: Diet composition of larval BFT from all years, by size class.

A Permanova including larval size class and year of capture showed that both variables had a significant effect (p<0.001), and that the interaction between the two factors was also significant (p=0.003). Pairwise tests highlighted significant differences in diets among 2-4mm and 406mm larvae from 2003 vs. 2011, and significant differences in diets for 6-8mm larvae among all years (Table 2). No differences were found in diets of larvae >8mm, however sample sizes in this size class were low.

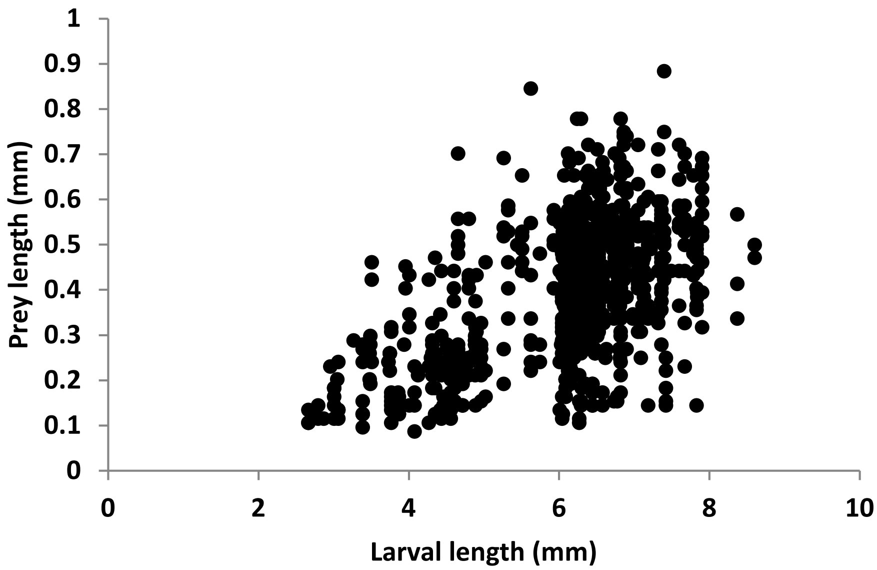

Figure 4: Larval prey sizes by larval length.

Table 2: Results of pairwise Permanova among years within size classes. Significant results at p<0.05 are highlighted.

Size Class	Comparison	t-statistic	p-value
2-4mm	2003 vs. 2011	1.6733	0.033
2-4mm	2003 vs. 2012	0.9942	0.386
2-4mm	2011 vs. 2012	1.8636	0.002
4-6mm	2003 vs. 2011	1.5703	0.068
4-6mm	2003 vs. 2012	1.8514	0.021
4-6mm	2011 vs. 2012	2.0268	0.016
6-8mm	2003 vs. 2011	3.009	0.001
6-8mm	2003 vs. 2012	2.3909	0.001
6-8mm	2011 vs. 2012	2.9317	0.001
8-11mm	2003 vs. 2011	1.2101	0.314
8-11mm	2003 vs. 2012	0.72817	1
8-11mm	2011 vs. 2012	0.6367	0.52

The observed differences in diets by size class were primarily due to a switch from nauplii for larvae <6mm to appendicularians and *Evadne* cladocerans at >6mm (Fig. 5).

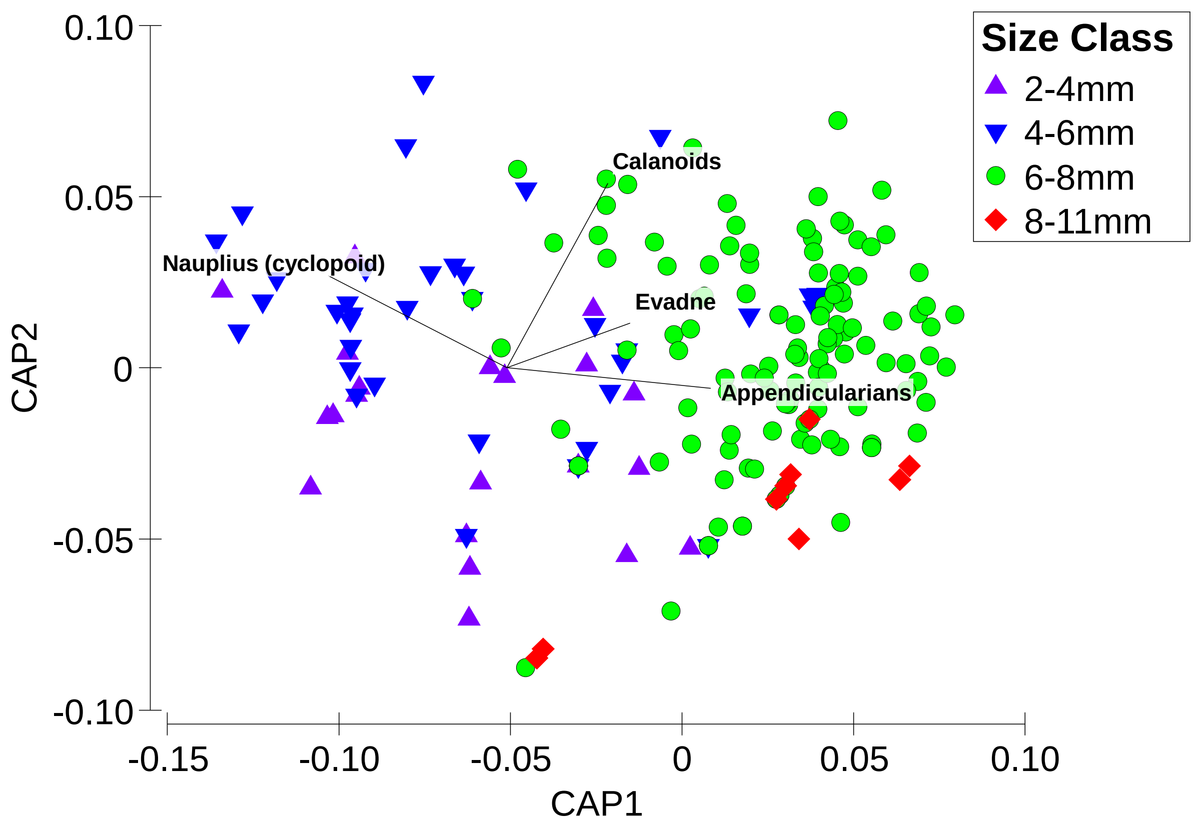

Figure 5: Canonical Analysis of Principal Coordinates (CAP) among diets of larvae of different size classes.

The differences in diets of similarly sized larvae among years was driven by an increased incidence of nauplii in 2012, higher prevalence of cladocerans in 2003 and 2012, and higher incidence of appendicularians in 2011 (Fig. 6).

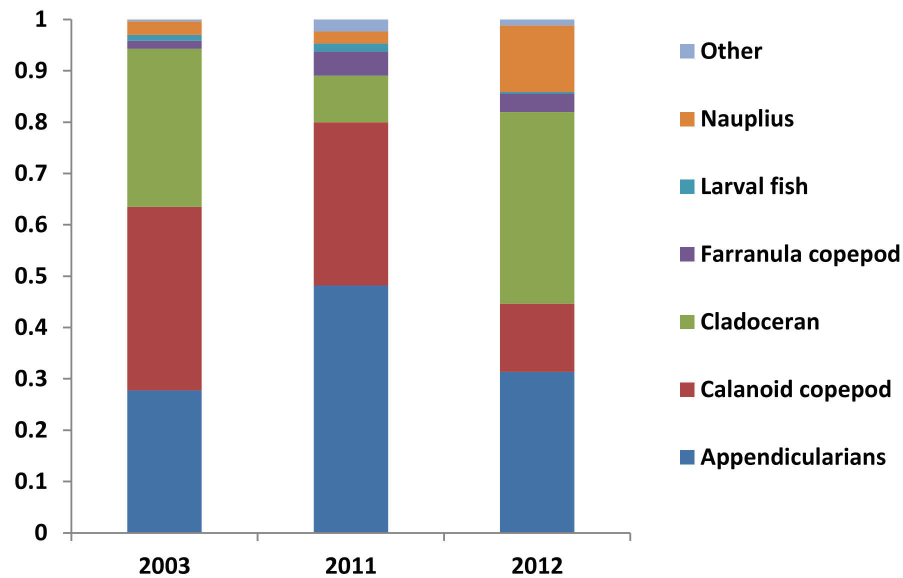

Figure 6: Diet composition of 6-8mm larvae among the three years sampled

Environmental Effects

A Distlm showed that while larval length was the most important determinant of larval diets, environmental variables were also significant. Marginal tests for all predictor variables were significant at $p<0.05$, with the exception of salinity at 100m (Table 3). The best final model included all variables except surface salinity, and explained 27% of the total variability.

Table 3: Results of Distlm model using environmental variables and length to predict diet composition.

Variable	**F-statistic**	**p-value**	**Proportion of Variance**
Day of the year	4.6744	0.002	0.024
Sea surface height	2.6646	0.023	0.014
Length	31.509	0.001	0.140
AVISOVel	5.032	0.001	0.025
SST	5.5828	0.001	0.028
T100	2.8061	0.02	0.014
SSS	3.3557	0.007	0.017
S100	1.5596	0.193	0.008
Chl Satellite	7.1797	0.001	0.036

Zooplankton assemblages

2012 Zooplankton assemblages were significantly different between positive and negative BFT stations (Permanova: p=0.006). Positive stations had higher densities of Calocalanus, Corycaeus and Evadne, while negative stations had more copepodites, nauplii and Farranula (Fig. 7).

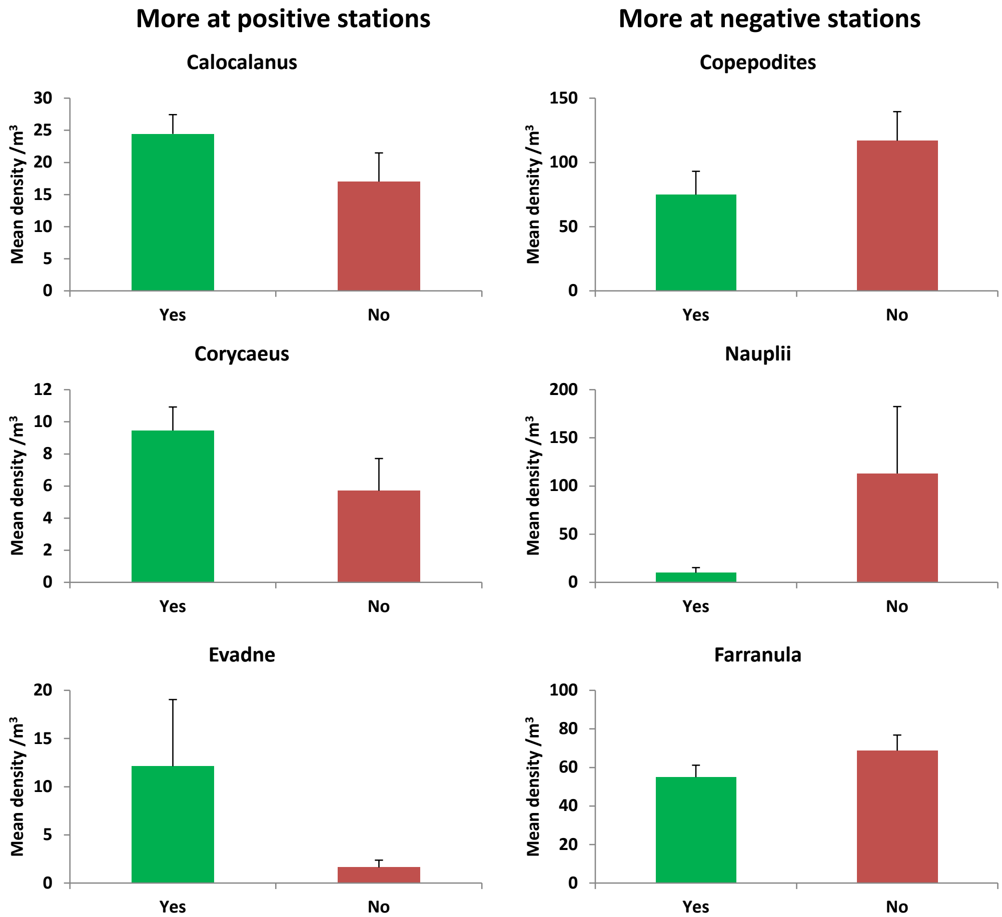

Figure 7: Mean densities (/m^3) of zooplankton taxa between stations negative and positive for BFT larvae.

Cluster analysis with a similarity profile (Simprof) test divided zooplankton assemblages into 6 distinct groups. These groups generally followed water mass structure in the GOM, with assemblages "c" and "d" associated with a region of higher surface chlorophyll west of 90°W (Fig. 8).

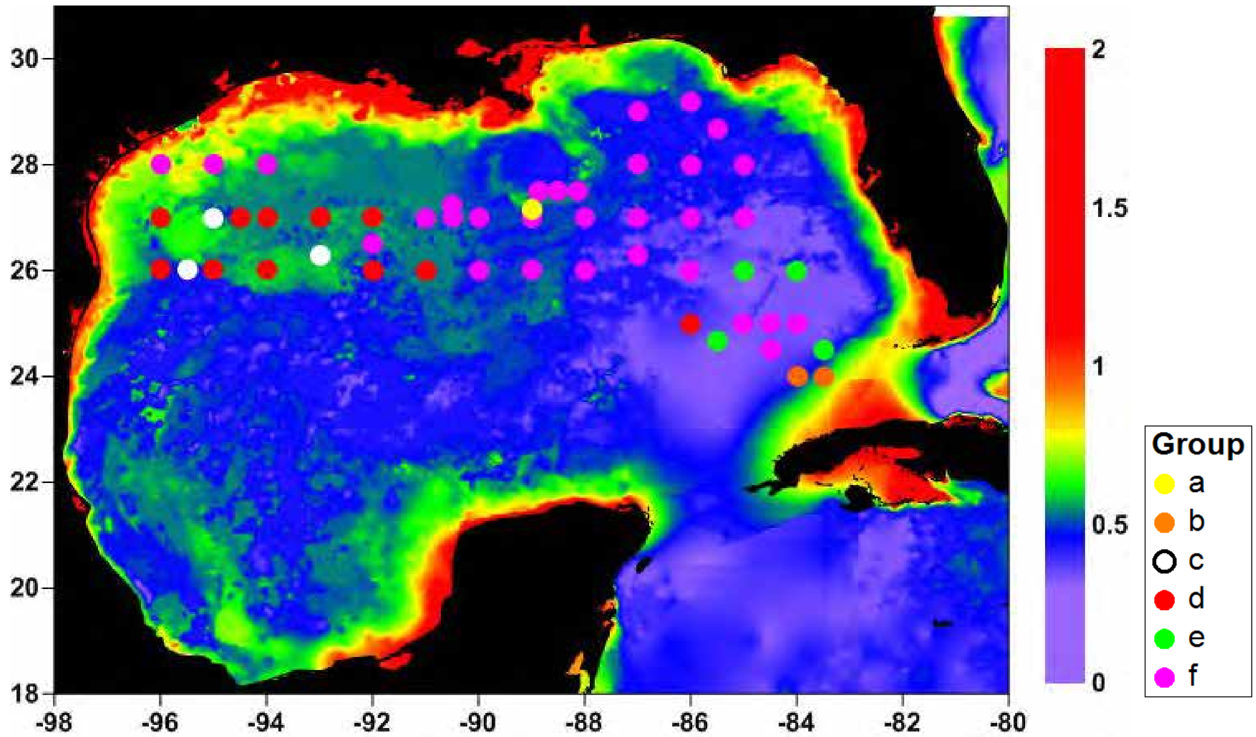

Figure 8: Zooplankton assemblage groups from cluster analysis overlaid on surface chlorophyll (mg/m3) from the MODIS Aqua satellite. A weekly composite covering May 13th – 19th, 2012, is shown.

Feeding selectivity of 2012 BFT larvae was assessed by comparing zooplankton assemblages between gut contents and the ambient water column. Larval guts had higher proportions of *Evadne* cladocerans and appendicularians, and lower proportions of calanoid copepods and *Farranula*, suggesting active selection of cladocerans and appendicularians (Fig. 9).

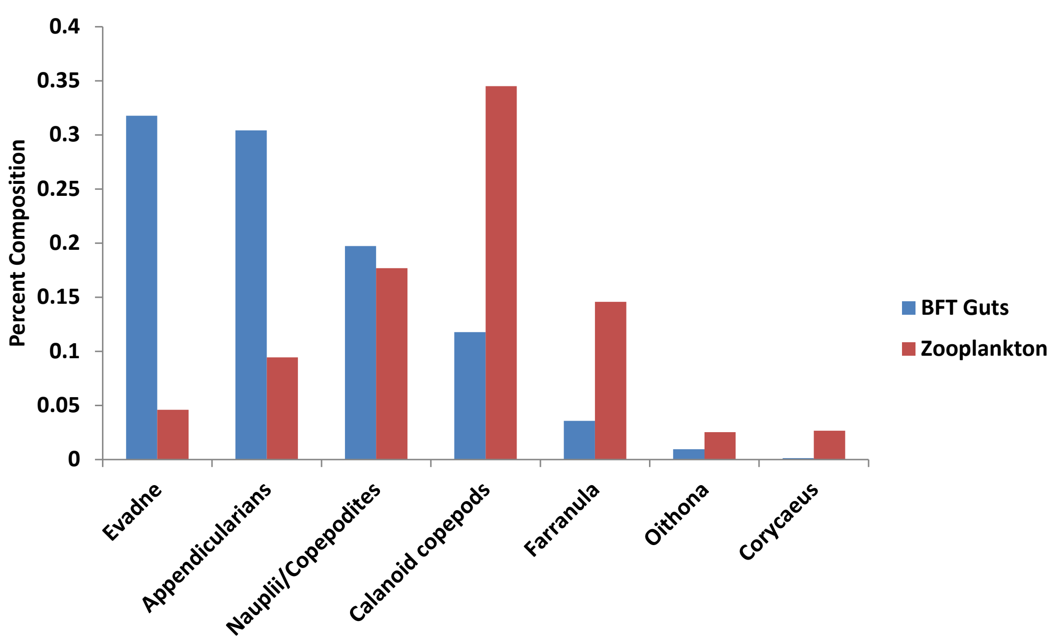

Figure 9: Feeding selectivity for BFT larvae collected in 2012.

Of the 6 assemblage groups identified for the 2012 zooplankton samples, group "f" was characterized by the higher abundances of nauplii, appendicularians and cladocerans (Fig. 10). Stations characterized by this zooplankton assemblage were likely more suitable for BFT larval feeding, despite being characterized by low surface chlorophyll (Fig. 9).

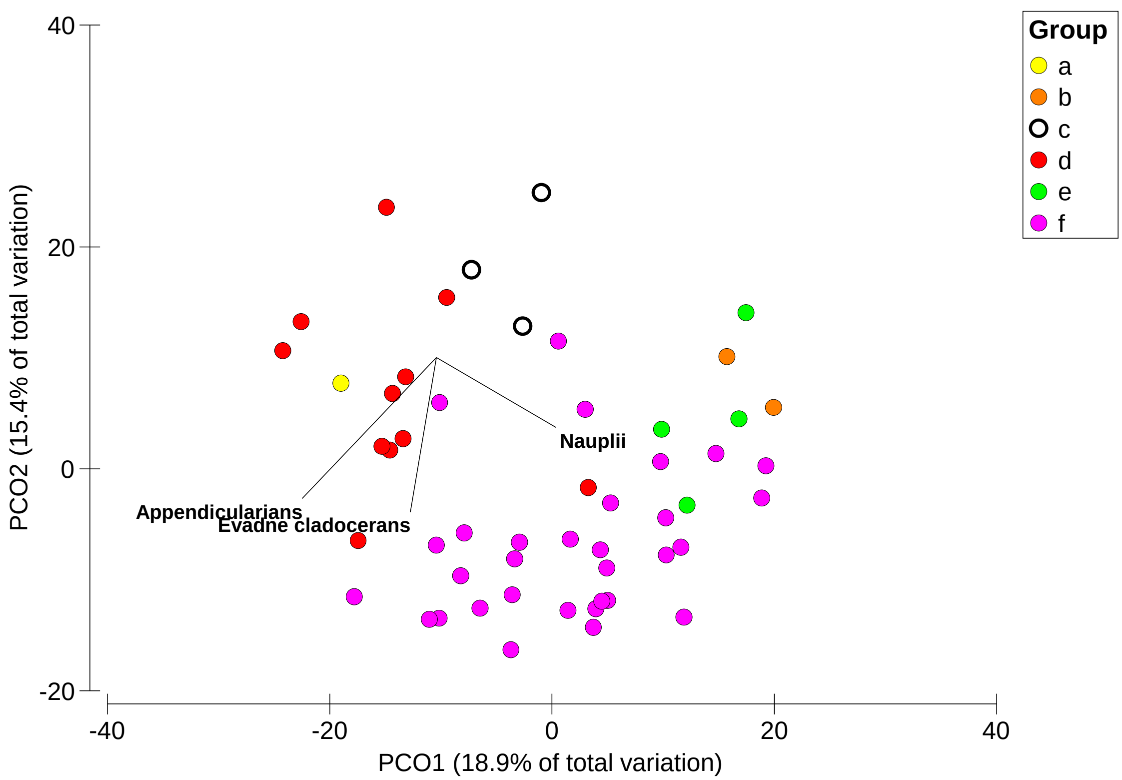

Figure 10: Principal Coordinates Analysis (PCO) of 2012 zooplankton samples, showing cluster groups.

<u>Comparison with aged larvae</u>

28 larvae from 2012 had both gut contents and aging analyses completed. Gut fullness and diet composition were correlated with recent (3 day) growth for these larvae, as measured by otolith increment width. Neither diet metric was significantly correlated with recent growth at $p<0.05$.

Conclusions and Management Implications

Larval BFT from the years 2003, 2011 and 2012 were successfully examined as proposed during this project. Indices of larval feeding success and prey selectivity were prepared for GOM larvae for the first time, significantly improving our current understanding of larval ecology. Specialized plankton tows completed during the spring 2012 cruise also resulted in the availability of prey field samples, which historically have rarely been collected in the GOM.

Several additional relevant research activities were completed as part of this project. The first was the participation of both PIs in a NOAA larval tuna ecology cruise in the GOM for 4 weeks during May, 2014. This cruise included participants from multiple US and international agencies, and allowed the use of cutting-edge technologies to examine the spawning grounds and ecology of BFT in the GOM. In addition, preliminary results were presented at the September 2014 ICCAT BFT species group meeting in Madrid, Spain. An ICCAT SCRS paper was prepared, and was made available to all members of the species group, which included delegates from countries around the North Atlantic, and Mediterranean Sea. Lastly, results from the project were presented at an annual NASA-funded workshop in Miami in December 2013, which focused on climate changes impacts on Atlantic tunas and billfishes. A final update will be presented at the December 2014 workshop.

Results from this project will contribute to the understanding of larval BFT ecology. As drivers of recruitment for BFT are currently not well understood, this area of research is of significant interest to stock managers. Our results show that larval BFT feeding is specialized, and variable among years. Feeding success was generally high, with most daytime-collected larvae having food in their guts. Larvae also appeared to actively select for prey organisms characteristic of oligotrophic environments. There was significant interannual variability in diets among larvae of similar sizes, however the impacts of this variability on growth, survival and recruitment remain uncertain. An ontogenetic shift in diet composition occurs at ~4mm, when larvae switch from nauplii to larger zooplankters. At lengths >6mm, larvae become piscivorous, which likely constitutes another dietary specialization allowing for fast growth in oligotrophic environments. This ecology is distinct from most temperate fish species. Preliminary results for 28 larvae from 2012 show no effect of feeding on larval growth. However, future research will expand this analysis to cover multiple years and locations.

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ANNUAL PROGRESS REPORT

A. Grant Number: **NOAA NA11NOS4780045**

B. Amount of Grant: **Year 4 Total - $1,087,467**

C. PROJECT TITLE: 2011 REPP- UNDERSTANDING CORAL ECOSYSTEM CONNECTIVITY IN THE GULF OF MEXICO-PULLEY RIDGE TO THE FLORIDA KEYS

D. Grantee: **University of Miami, RSMAS, MBF**

E. Award Period: From: **September 1, 2011** To: **August 31, 2016**

F. Period Covered by this Report: From: **June 1, 2014** To: **May 31, 2015**

G. Summary of Progress and Expenditures to Date:

l. **Work Accomplishments:**

a. Brief summary of progress (Note: progress is reported below by sub-group designation):

Program Management (PM) (PIs R.K. Cowen, P.B. Ortner, S. Pomponi)

Program Management activities were focused on three main actions:

1) Complete planning and oversight of Cruise 3 conducted August 14-28, 2014 (results reported below in Community Structure section)
2) Planning and completion of 4th All-PI meeting held in Miami on Dec 2-3, 2014 (for Agenda see Appendix A). The primary tasks were to discuss:
    a. Results from the August 2014 cruises;
    b. Improving communications between project subgroups by beginning to present science outputs from this project.
    c. Planning for the upcoming (and last) field season, including identifying sampling priorities for both locations and species (see Table below for list of taxa collections to date);
    d. Initial efforts of the Decision Support Tool subgroup on database development to collate existing datasets;
3) Meet with the Sab to update on all activities (several members of SAB attended the full PI meeting) – agenda also included in Appendix A.
4) Preliminary planning for Cruise 4 activities to be conducted in June and August 2015 on two separate vessels (*M/V Spree* – 19-29 June 2015, *R/V F.G. Walton Smith* – 22 August – 4 Sept 2015).

<u>Summary of meeting results:</u>

A brief overview of discussion topics are given below focusing on the opportunities (and need) for synthesis activities (here initially focusing on scientific analyses and publication) and various Working Group outputs/products (and necessary steps) needed for the DST:

1. Synthesis activities
    a. Expected (part of the proposed outcomes)
    b. Opportunistic
        i. **Role of currents influencing nutrients/plankton to PR**
            1. Water mass sources (determined from models, drifter analysis) – i.e. inner, mid, outer West FL shelf, Loop;
            2. Nutrients/plankton associated with different water masses
            3. Relate to findings at PR – planktonic fish ecologies
            4. Possible contributors – Villy, Josefina O., Su/Esther, RKC – ISIIS.
        ii. **Meta-analysis of scaling of population structure**
            1. Use all taxa within PR
            2. Include data from other studies within WNA waters
            3. Key drivers – PLD, Pop size, propagules behavior, longevity
            4. Possible contributors – All pop gen PIs, possible biophys modeling
        iii. **FW lens** – expand beyond Villy et al ms – (which identifies conditions that created large lens during non-flood periods).
            1. What is range of potential – e.g. model using same physical conditions but start with flood conditions
            2. What could be the potential effect
                a. Plankton (evidence, deviation from norm)
                b. Coral impact - Duration of low salinity
            3. Obvious other implications – clear pathway for oil connection
            4. Possible contributors – Villy, ISIIS, Coral people?
        iv. **Compare mesophotic environments throughout WNA and through time**
            1. Pulley Ridge, other GOM sites, Puerto Rico
            2. Community descriptors – percent coverage, dominant taxa, etc.
            3. Possible contributors – Reed et al, Appeldoorn, Rene Garcia,
        v. Claire suggested that her modeling now incorporates temp mediated larval survival, could also look at eddy fields to evaluate larval condition along transport path
            1. This would require empirical data input from Sponaugle/Shulzitski, others.

2. DST Discussion – Steps to providing DST with the necessary information and data outputs form the PR project to meet their mission:

   Overall, each working group needs to:
   **Review their proposed outputs
   **Identify nature of products (e.g. maps, tables, verbal analysis, etc.)
   **Report/provide these to DST WG

Steps to assist in this effort:
1. Establish WG – Leads of each sub-project to coordinate with DST, + Ryan, Ortner, possibly Reed.
   a. Have WG re-read whole Proposal (especially DST section)
2. Review options for:
   a. Full PR data archive
   b. Products (per sub-group outputs above)
   c. Consider science/data presentation consultant
   d. Other possible products per SAB?
3. DST will be essentially a data portal with cover website with brief project description

Summary Table of taxa/samples collected through August 2014

	Pulley Ridge				**TER**			
Taxa	2012	2013	2014	Pulley Total	2013	2014	TER Total	Grand Total
Chlorophyta								
Halimeda sp.	15	33	36	84	22	20	42	126
Chordata								
Epinephelus morio		28	16	44	34	14	48	92
Holocentrus rufus		4		4	54	2	56	60
Pterois volitans		3	36	39	1		1	40
Stegastes partitus	36	35	60	131	26	27	53	184
Cnidaria								
Agaricia sp.	30	37	84	151	10	14	24	175
Montastraea cavernosa	13	28	26	67	10	35	45	112
Porifera								
Xestospongia muta	39	20	57	116	9	17	26	142
Grand total	**133**	**188**	**315**	**636**	**166**	**129**	**295**	**931**

Physical Oceanography (PO)

Cruise 3 (C3) work by the PO subgroup was related to: a) the August 2014 cruise and analysis of C3 field data; and b) simulations with the extended high resolution model to support the biophysical modeling and to analyze data findings related to an intrusion of Mississippi waters around the study area.
The participant contributions were as follows:

NOAA-AOML (PIs G. Halliwell and R. Smith): fieldwork related to the August 2014 cruise and data analysis;

UFL (PI A. Valle-Levinson): data analysis of Y3 (2014 field) data

UM/RSMAS (PI V. Kourafalou): simulations with the extended Florida Straits, South Florida and Florida Keys (FKEYS) model; analysis of results and preparation of model outputs for the biophysical modeling group; combination of modeling and cruise data to study an intrusion of Mississippi waters around the study area during August of 2014.

<u>Fieldwork</u> (NOAA-AOML and UFL):

C3 PO mooring fieldwork activities included the turn-around of moored instrumentation at all three sites maintained by the project (Fig. 1). Acoustic Doppler current profilers (ADCP) and temperature/salinity recorders deployed in 2012, and serviced in 2013, were successfully recovered during the project's June 2014 research survey aboard the M/V *Spree*. Concurrent with these recoveries, new instruments were deployed at each site, extending the current velocity and temperature/salinity time-series into the summer of 2015, when all project moorings and associated instrumentation will be recovered (final recoveries are planned for August 2015). This long record will allow a synthesis of circulation variability over several years. First findings (Figs. 2-8) are as follows.

Between August 2012 and mid November 2012, currents at Pulley Ridge were influenced by a young Loop Current, which promoted on shelf flow and across-shelf flow east towards the Dry Tortugas. Following this period, cyclonic eddy circulation (~mid November 2012 through ~mid March 2013) resulted in weaker current velocities across the region. Beginning in ~mid March 2013, the Loop Current front once again moved over the Pulley Ridge. This direct influence of the Loop Current persisted until the beginning of December 2013. The configuration of the Loop Current during this period promoted strong off-shelf flow and strong across-shelf flow towards the Dry Tortugas. In this mode, physical connectivity between Pulley Ridge and the Dry Tortugas may be increased.

While currents observed at the two Dry Tortugas moorings were typically weaker than those recorded at Pulley Ridge, noticeable increases in flow moving off-shelf along the bottom were measured at both PO-A and PO-B mooring sites, between mid-March 2013 and the beginning of October 2013. Both the cyclonic eddy circulation off the Dry Tortugas, situated with a center of circulation to the southeast of the moorings in the Straits of Florida, and the close proximity of the Loop Current front contributed to this increased off-shelf flow. Following this period, the Loop Current front moved to the southwest in association with a Loop Current Eddy ("ring") shedding event. As a result, the cyclonic circulation between the northern front of the current and the Florida Keys shelf break elongated across the region driving strong along-shelf flow towards Pulley Ridge.

The above sequence is also illustrated in the satellite images depicted in Fig. 9. From approximately mid-February 2013 through the end of November 2013, the Loop Current front was in close proximity to Pulley Ridge. During this period, the current had often a direct influence on water flow across Pulley Ridge. This close proximity is apparent in the color gradients of the September and November ocean color images and from the noticeable increase in current velocities at the PO-C mooring site (Fig. 4), over the 9.5-month timespan. Beginning in December 2013 through the end of the moored record, the Loop Current front moved toward the southwest in association with a ring separation event.

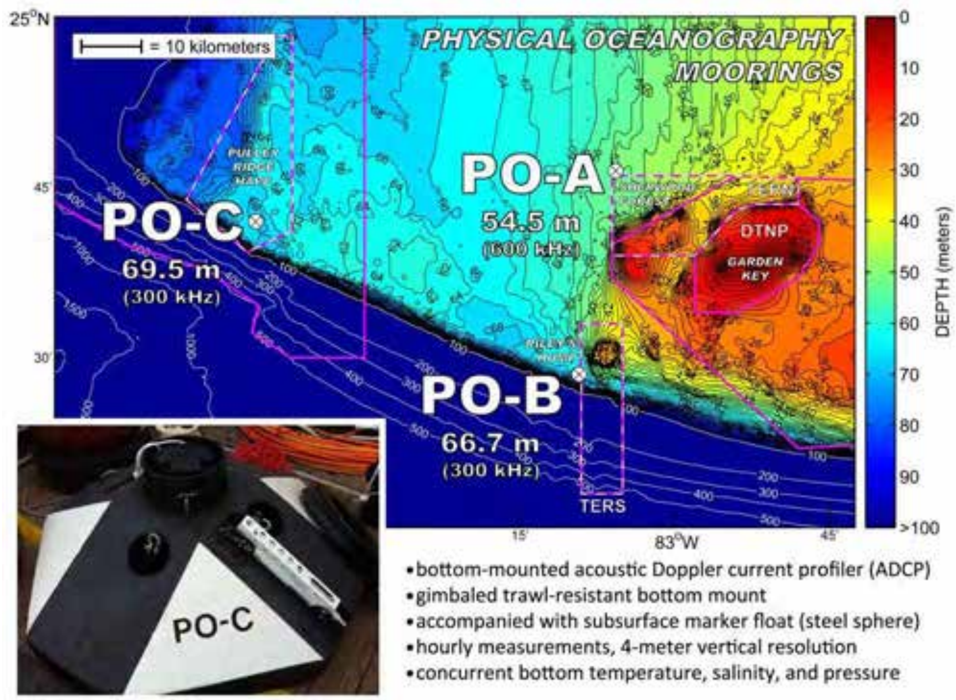

Figure 1. Pulley Ridge and Dry Tortugas Physical Oceanography (PO) mooring description and site locations.

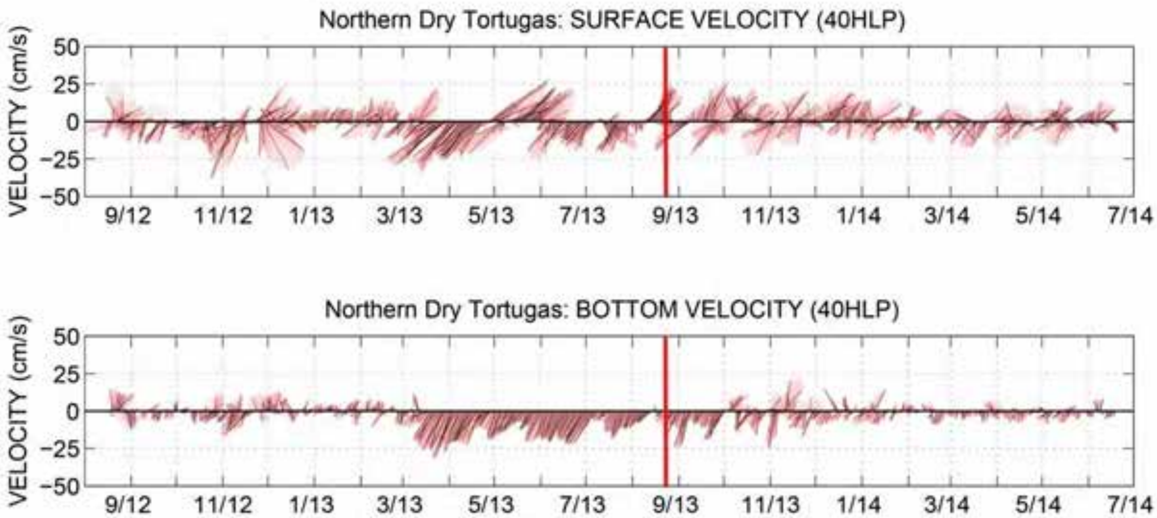

Figure 2. Surface and bottom current velocity time-series for mooring site PO-A, located in the northern Dry Tortugas (bottom depth: 54.5 m). Hourly data are 40-hour-low-pass (40HLP) filtered (shown in red). Black vectors are the same filtered data, plotted once daily for clarity. The red vertical line indicates the summer 2013 instrument exchange.

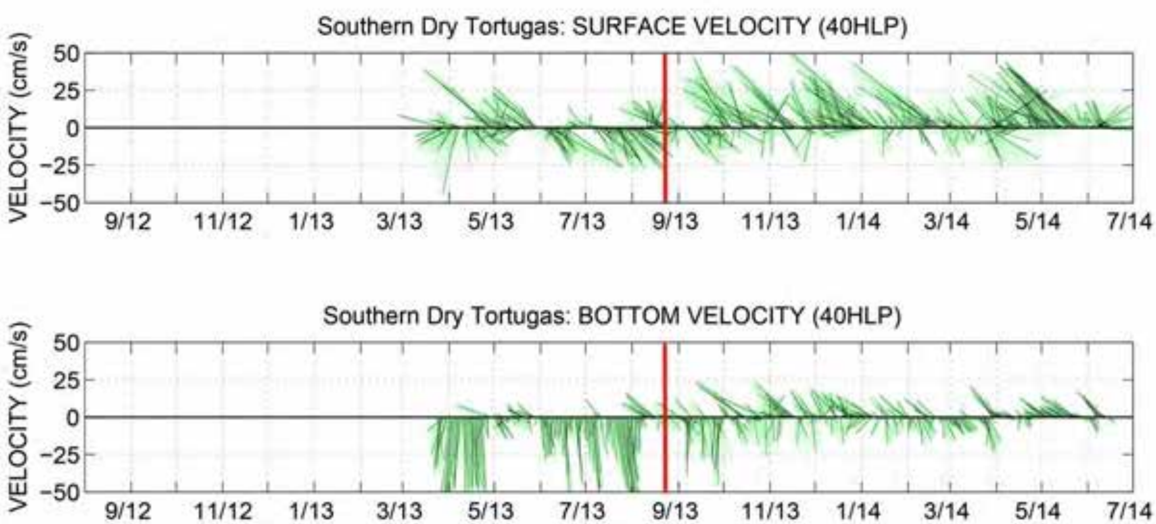

Figure 3. Surface and bottom current velocity time-series for mooring site PO-B, located in the southern Dry Tortugas (bottom depth: 66.7 m). Hourly data are 40-hour-low-pass (40HLP) filtered (shown in green). Black vectors are the same filtered data, plotted once daily for clarity. The red vertical line indicates the summer 2013 instrument exchange.

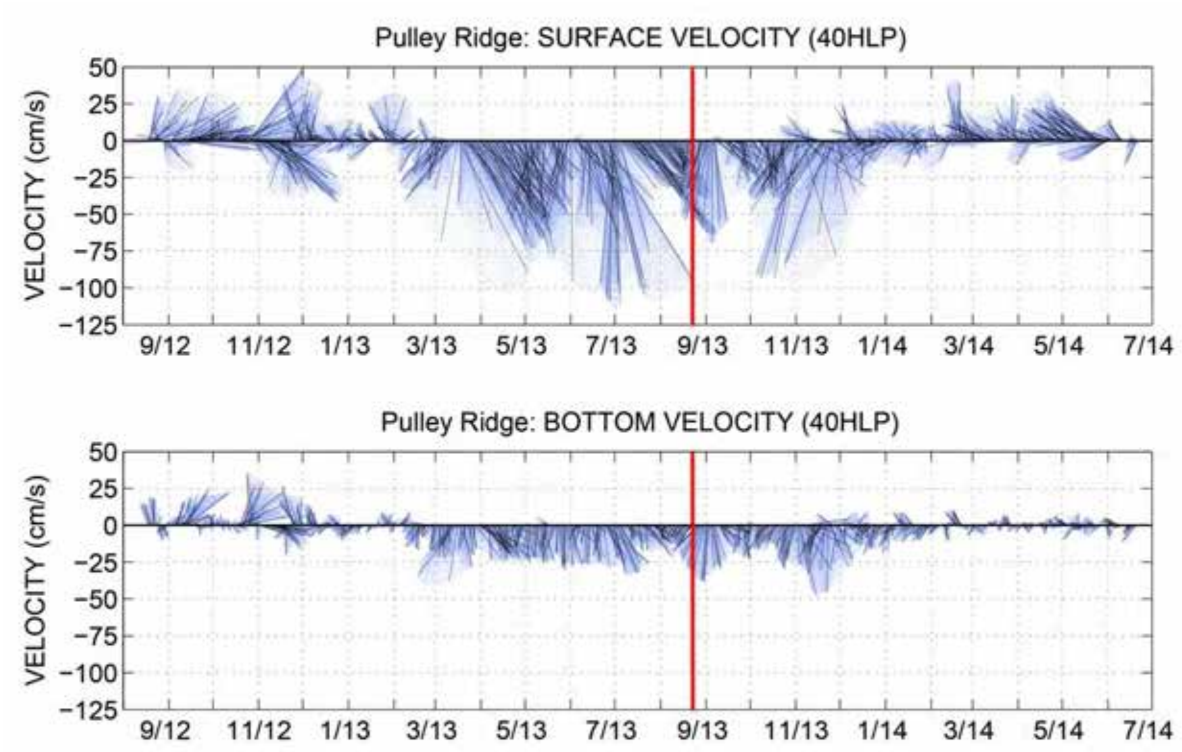

Figure 4. Surface and bottom current velocity time-series for mooring site PO-C, located at Pulley Ridge (bottom depth: 69.5 m). Hourly data are 40-hour-low-pass (40HLP) filtered (shown in blue). Black vectors are the same filtered data, plotted once daily for clarity. The red vertical line indicates the summer 2013 instrument exchange.

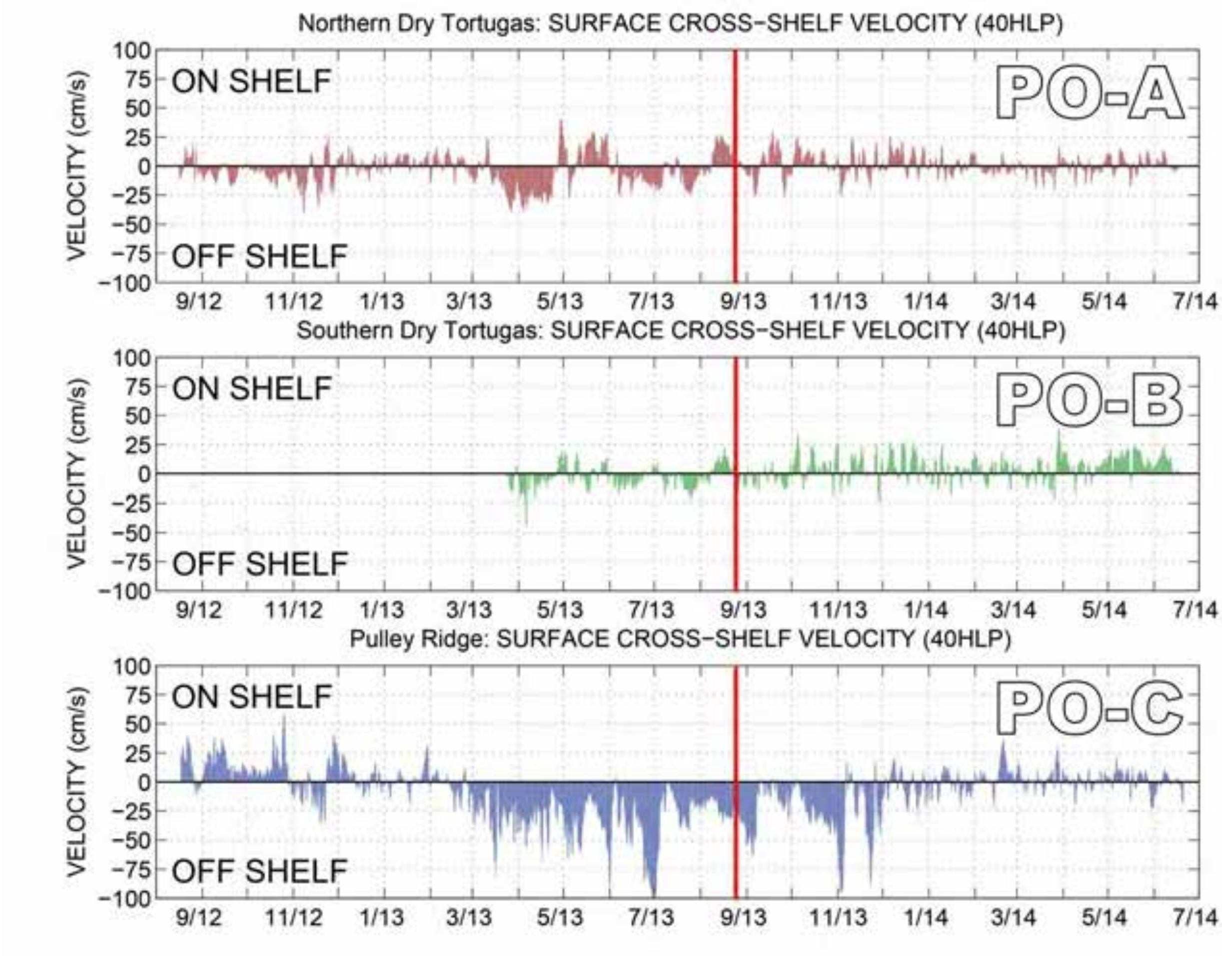

Figure 5. Cross-shelf velocity component of surface flow at each PO mooring site. Hourly data are 40-hour-low-pass (40HLP) filtered. Black vectors are the same filtered data, plotted once daily for clarity. The red vertical line indicates the summer 2013 instrument exchange.

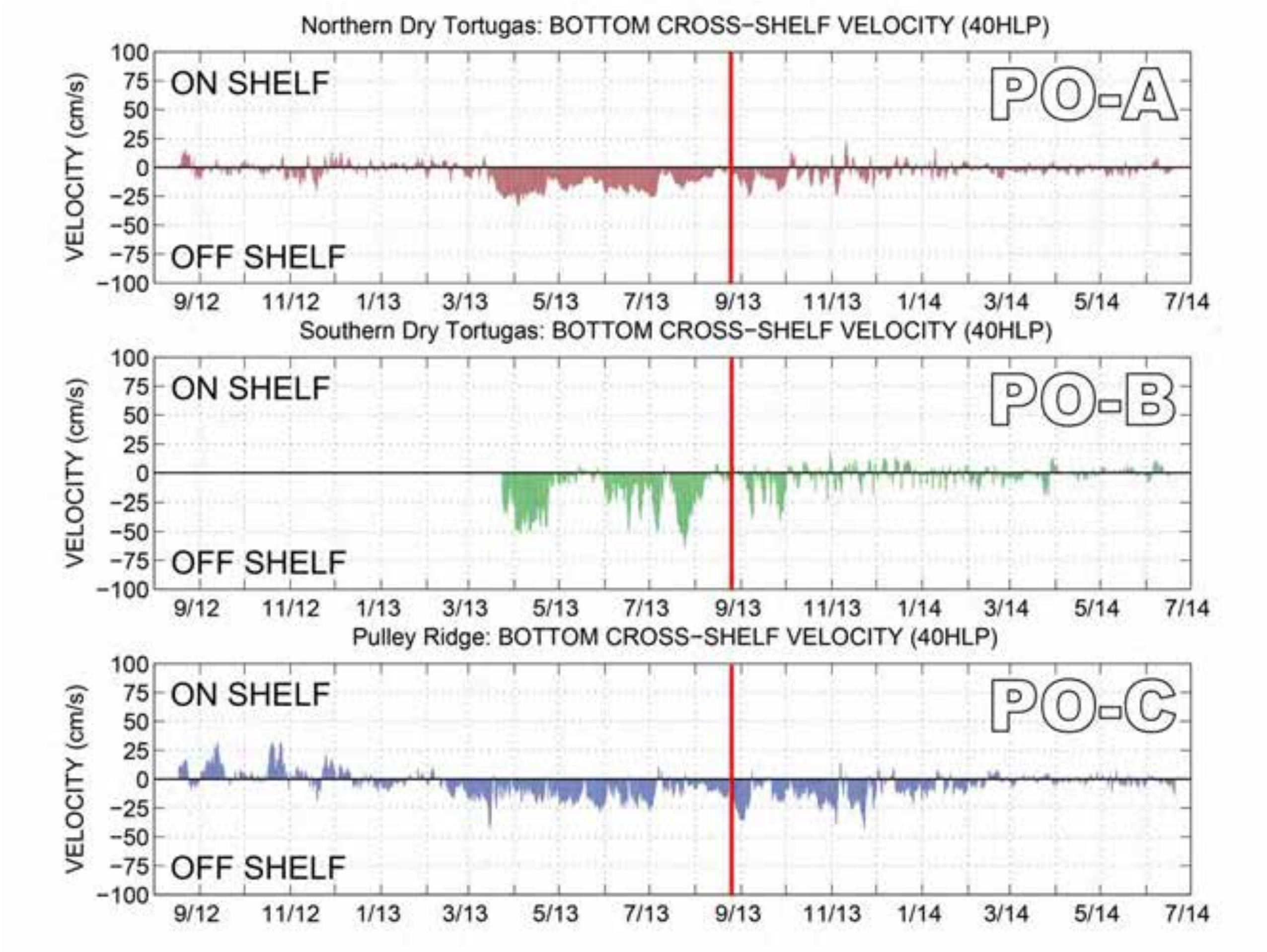

Figure 6. Cross-shelf velocity component of bottom flow at each PO mooring site. Hourly data are 40-hour-low-pass (40HLP) filtered. Black vectors are the same filtered data, plotted once daily for clarity. The red vertical line indicates the summer 2013 instrument exchange.

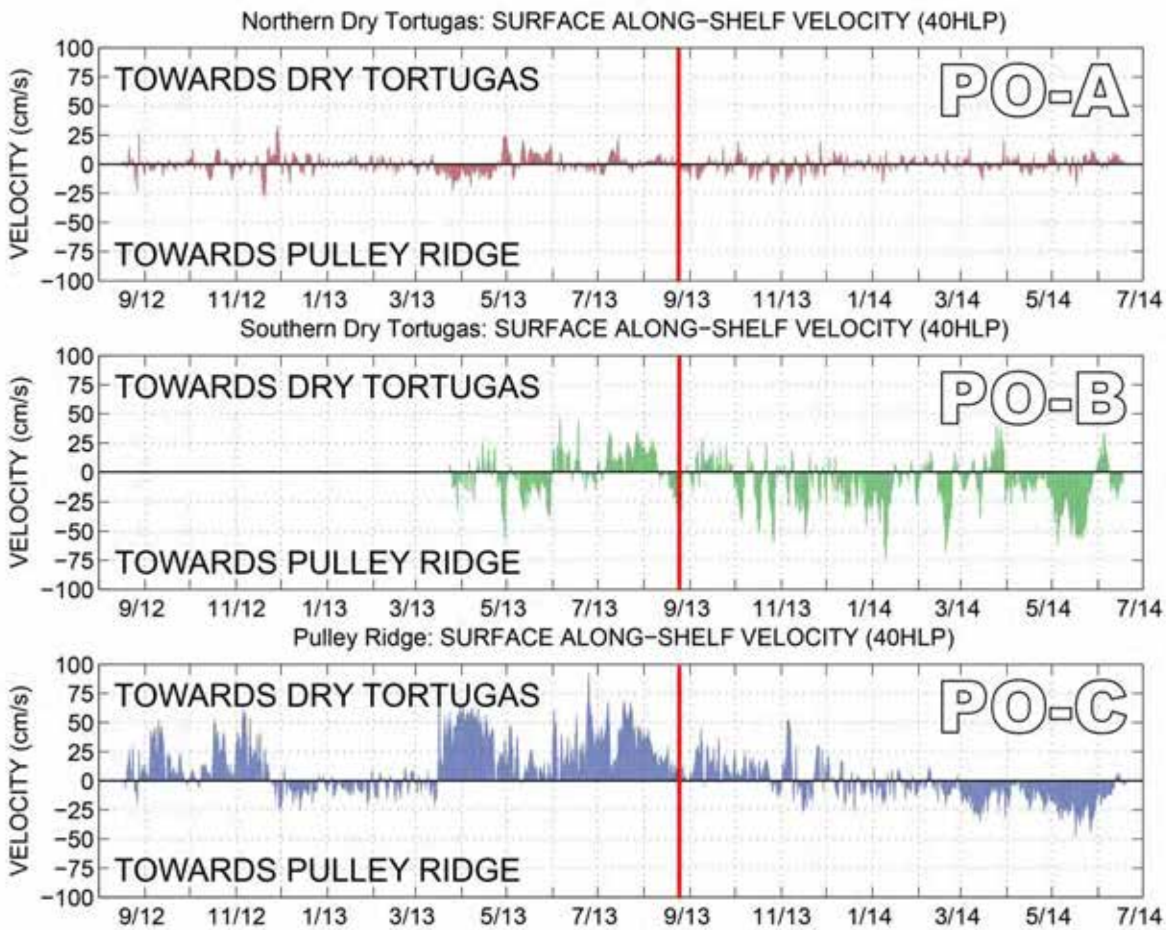

Figure 7. Along-shelf velocity component of surface flow at each PO mooring site. Hourly data are 40-hour-low-pass (40HLP) filtered. Black vectors are the same filtered data, plotted once daily for clarity. The red vertical line indicates the summer 2013 instrument exchange.

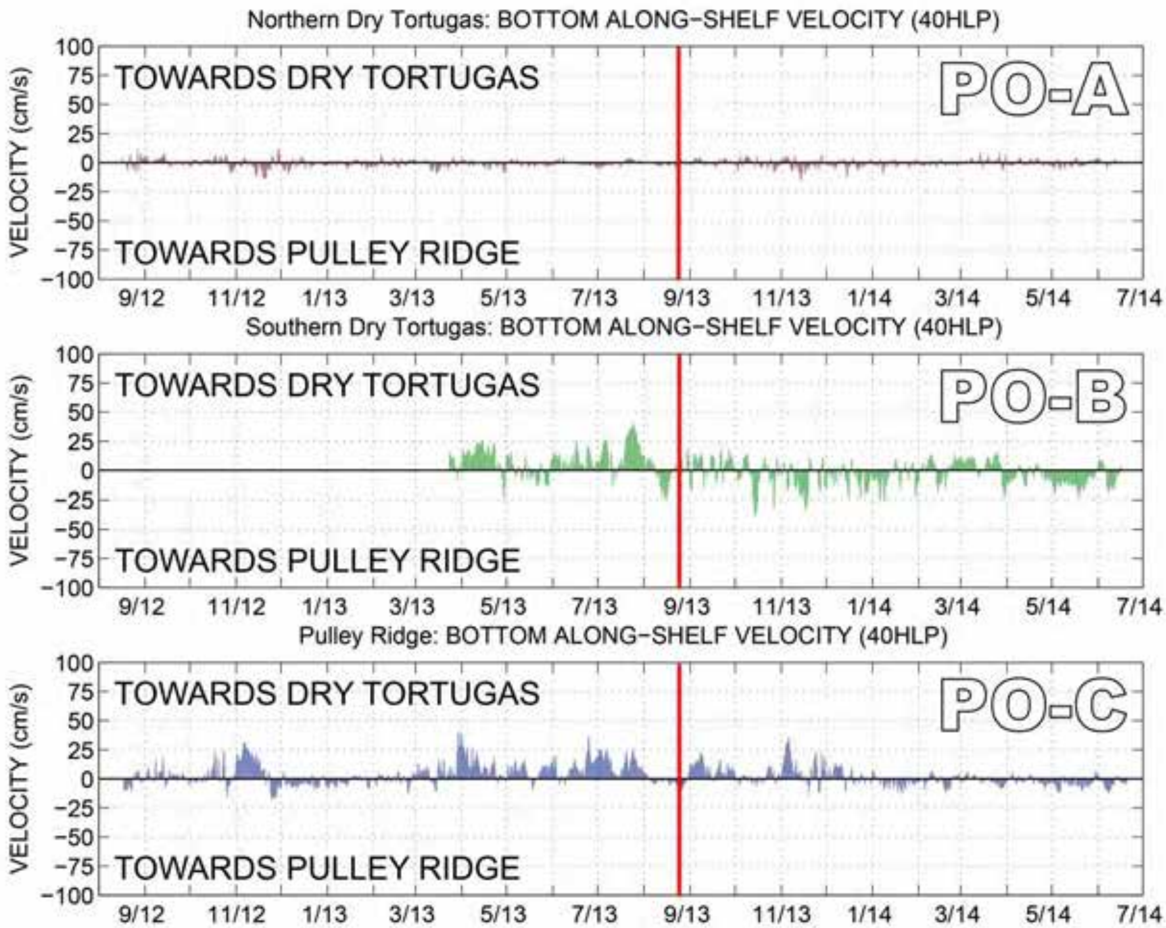

Figure 8. Along-shelf velocity component of bottom flow at each PO mooring site. Hourly data are 40-hour-low-pass (40HLP) filtered. Black vectors are the same filtered data, plotted once daily for clarity. The red vertical line indicates the summer 2013 instrument exchange.

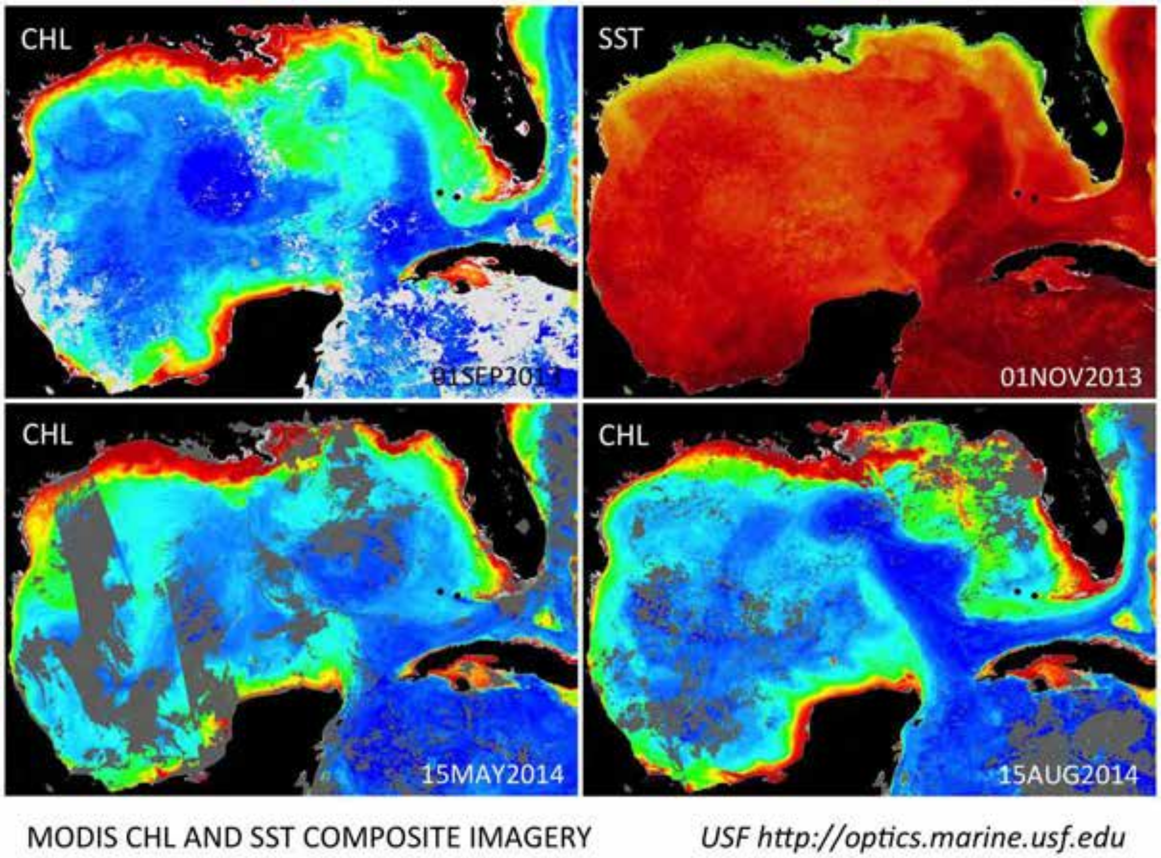

Figure 9. Gulf of Mexico (GOM) composite ocean color images for selected dates in 2013 and 2014. The location of Pulley Ridge and the Dry Tortugas are indicated with black dots.

The Spatial structure of modes 1 and 2 is shown in Fig. 10, employing a complex empirical orthogonal function (CEOF) analysis on the data from March to July of 2013. This is the period with common coverage for the 3 instruments during the first deployment. The spatial structure illustrates dominant profiles of velocity at the three sites. Profiles are shown by their separate components (left panels) and in vector form (right panels). Mode 1 explains 61% of the variability and mode 2 explains 18%. This means that 79% of the time, i.e. the contribution by modes 1 and 2, the subtidal flow was unidirectional throughout the water column at the 3 sites. The actual sign of these flows is given by the temporal variations of the modes, which are shown in Fig. 11. For instance, a profile with a negative north component, combined with negative temporal variations, indicates positive flows associated with that mode. The strongest southward pulses of mode 1 occurred at the end of March and in late July. This was when the flow was strongest toward the south at Pulley Ridge. Weakest southward flow component for mode 1 at Pulley Ridge appeared in late April, late May, and early August. This analysis will allow us to focus in particular events when the flow was toward the shelf or toward the Florida Current.

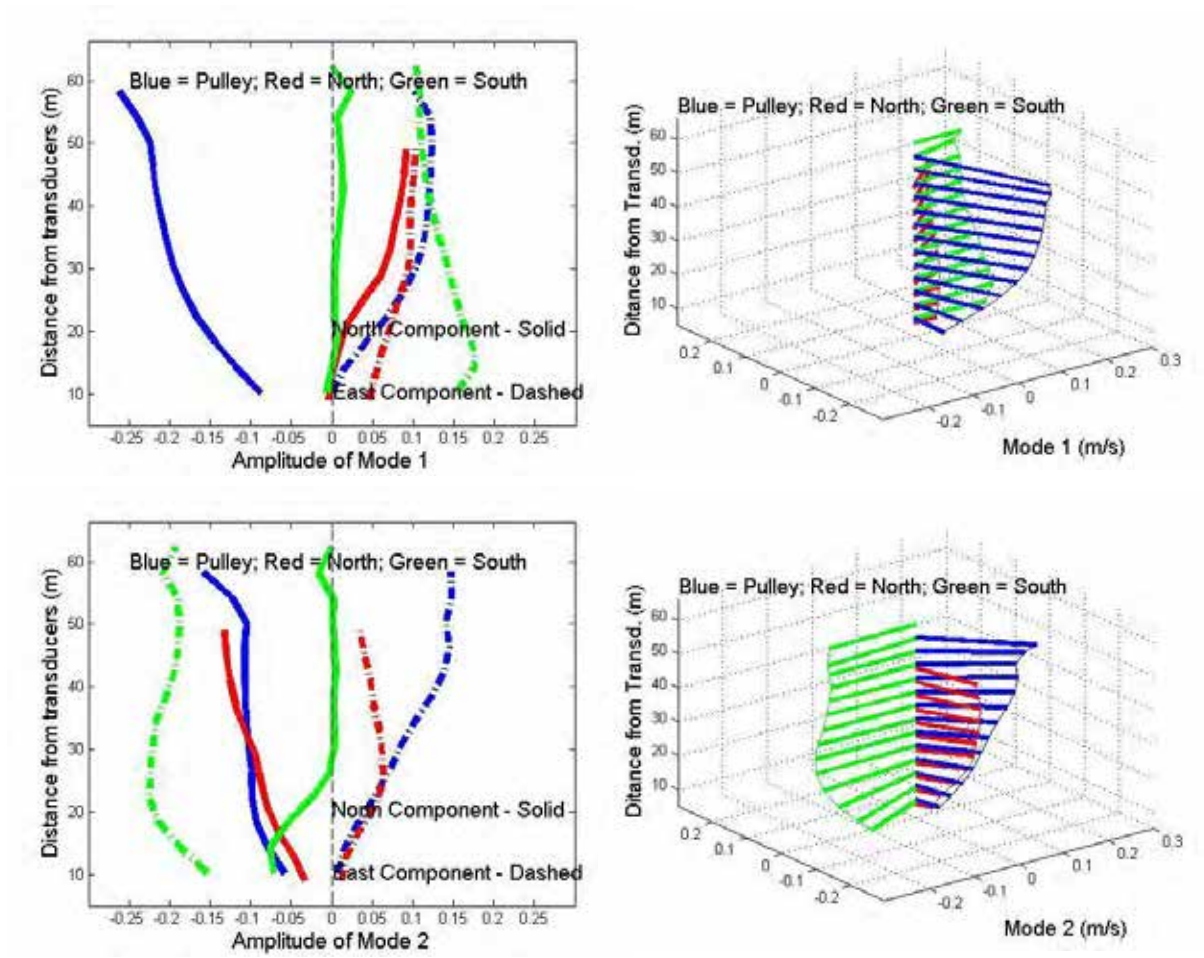

Figure 10. Spatial structure of modes 1 (left) and 2 (right) of complex empirical orthogonal function (CEOF) analysis on the data from March to July of 2013.

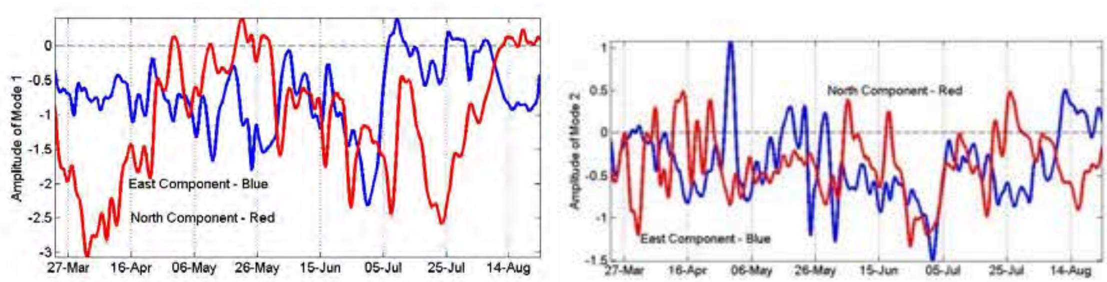

Fig. 11. Temporal variations of subtidal flows for complex empirical orthogonal function (CEOF) modes 1 (left) and 2 (right). When the signal is negative, it means that the mode 1 represents flow moving southward and westward.

Modeling (UM/RSMAS):

Simulations with the high resolution (1/100°, ~900 m) Florida Straits, South Florida and Florida Keys (FKEYS) HYCOM model continued, covering several years (through 2014). Model archives were provided to the biophysical modeling group and led to the first biophysical modeling study on the connectivity between the mesophotic Pulley Ridge reef and the shallow Florida Keys reefs (Vaz et al., in review). In addition, the physical modeling focused on the study of a unique event further connecting the two reef systems under study to the remote Mississippi Delta.

During the summer 2014 cruise to the Pulley Ridge area, the R/V Walton Smith encountered unusually fresh waters over the southwestern part of the West Florida Shelf (WFS). Examination of Ocean Color maps from remote sensing indicates that these fresher waters originate from the Mississippi Delta. We have investigated this event, which strongly impacted the water characteristics in the study area, by employing the FKEYS-HYCOM model, which was extended to cover both the Pulley Ridge and Dry Tortugas study areas for the needs of this project. In order to fully simulate the Mississippi pathways, we have also employed a new implementation of the HYCOM model covering the entire GoM at 1/50° (~1.8 km) resolution (development through ancillary NOAA project). This GoM simulation uses a 2 km grid with 32 vertical levels, adapted from a regional implementation of HYCOM in the Northern GoM dedicated to the study of the MR plume (Schiller et al., 2011). The GoM simulation is nested into the global HYCOM operational simulation run at the Navy Research Laboratory, using daily fields. In order to accurately simulate Mississippi pathways, this is the only GoM model that also incorporates realistic river forcing, using daily discharge values from U.S. Geological Survey (USGS) and detailed plume dynamics based on Schiller and Kourafalou (2010) and Schiller et al. (2011). A data assimilation scheme (following Halliwell et al., 2014) constrains the Loop Current/Florida Current system variability.

This GoM HYCOM simulation is very suited for examining the initial expansion of the Mississippi River waters. Figure 1 illustrates this export of low-salinity waters originating from the Mississippi Delta area in the summer 2014. In June, the fresh water pool extends eastward along the northern GoM continental shelf. In July, this plume extends southward following the edge of the WFS, while fresher water from the Mississippi Delta area is also entrained offshore along a Loop Current ring that just detached. In August, this ring re-attaches to the LC, and fresher waters of Mississippi origin are entrained along the LC, joining the initial plume extending along the WFS. This large plume is then entrained toward south Florida along the LC. Under the influence of frontal cyclonic eddies at the edge of the LC, part of this plume is advected onto the southwestern corner of the WFS, in the area of Pulley Ridge. The data-assimilative 1/50° GoM HYCOM simulation has proven useful to understand the mechanisms affecting the MR plume export from the Northern GoM to South Florida.

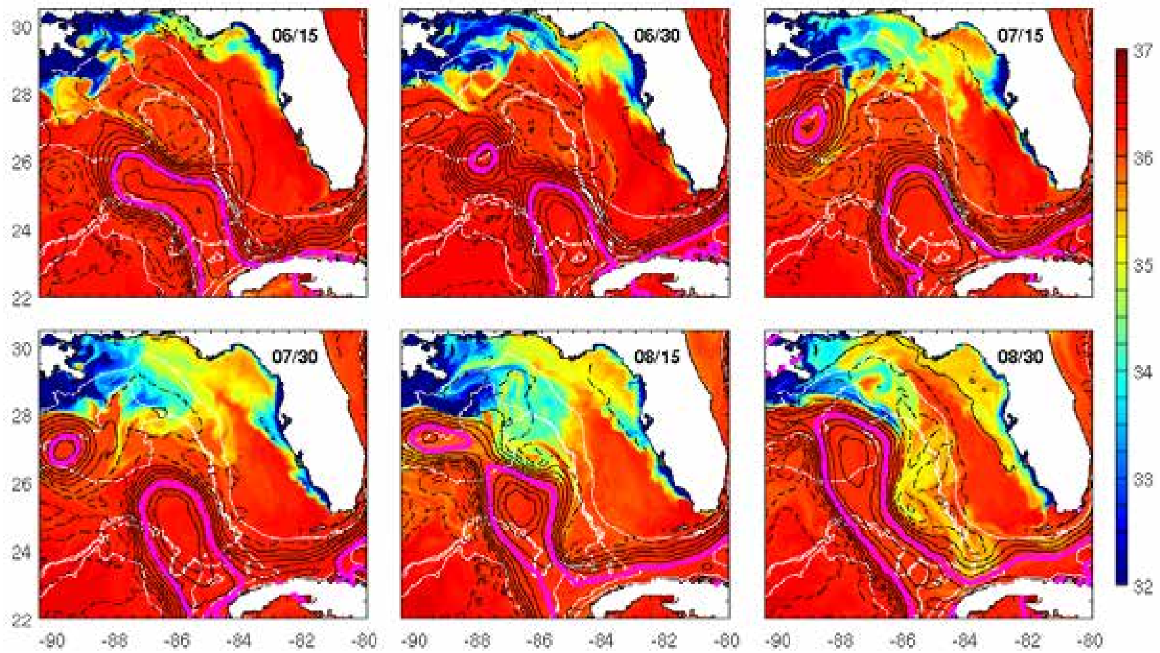

Figure 1: Sea surface salinity (colors, SSS) extracted from the assimilative 1/50° model simulation (zoom over the eastern GoM), from June 15 to August 30, 2014. In black contours is the Sea Surface Height (SSH) every 6 cm. Positive SSH with respect to the basin mean is in continuous lines, negative SSH is in dashed lines. The Loop Current is in magenta (SSH value of 17 cm over the basin mean, as defined by Leben, 2005). The white lines indicate the isobaths 200, 2000 and 3000 m.

As the low-salinity waters of Mississippi origin approach the Pulley Ridge and the Dry Tortugas, the higher resolution FKEYS simulation was employed to investigate how such an intrusion influences the reef areas under study. As seen on Figure 2, the FKEYS simulation shows, in the second part of the cruise (August 18 to 28, 2014), a sea surface salinity distribution along the Florida Reef Tract and on the WFS that is generally fresher than for the earlier cruise period (August 13 to 18); this is consistent with ship-board observations. The FKEYS simulation reveals that a frontal eddy located southwest of the WFS allowed the transfer of substantially fresher waters of Mississippi origin onto the continental shelf and the reef tract. The eddy impact was followed by easterly winds, which corroborated the advection of such low-salinity waters onto the Florida Keys Reef Tract.

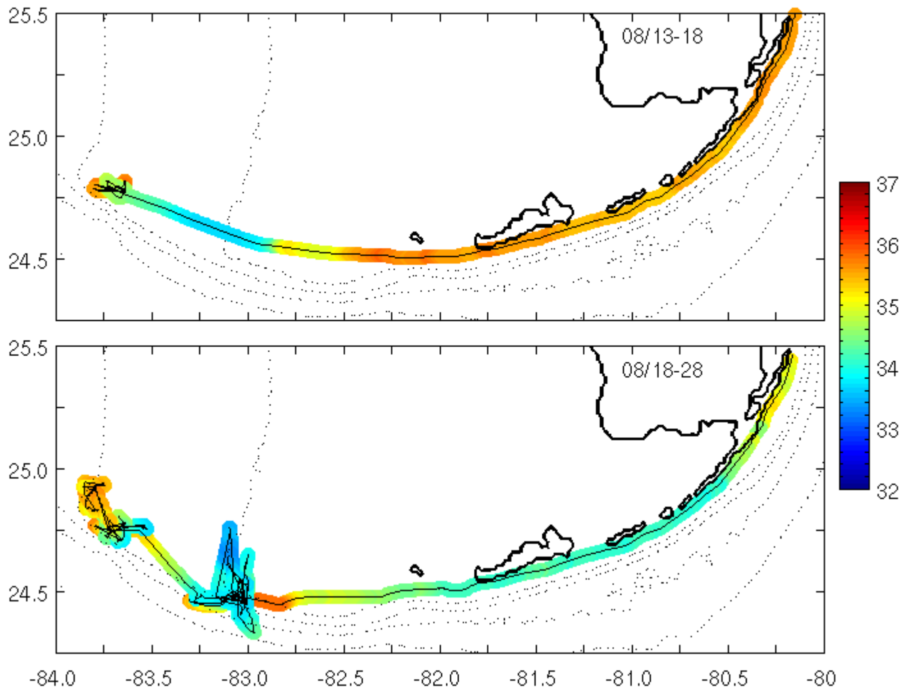

Figure 2: Sea surface salinity (colors, SSS) extracted from the FKEYS 1/100° model simulation (zoom over the Florida Keys) along the R/V Walton Smith cruise track, from August 13 to 18 (top), and August 18 to 28 (bottom), 2014. The black dotted lines indicate the isobaths 50, 100, 200, 500, 2000 and 3000 m.

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Biophysical Modeling

Empirical Data (Sponaugle and Cowen)

Progress during 2014 focused on quantifying bicolor damselfish, *Stegastes partitus,* reproductive output. The goals of this work were to assess differences in reproductive investment across depth strata, and to provide reproduction data for biophysical models.

Methods

Stegastes partitus collections occurred during peak spawning in the lower Florida Keys at "shallow", upper shelf (US, <10 m deep) and "deep", lower shelf (LS, >20 m) sites for one week each in July and August of 2014 to supplement collections that occurred in 2013. In addition *S. partitus* were collected aboard the *R/V Spree* during June 2014 at mesophotic depths (M, ~60-70 m) at Pulley Ridge. Collections targetted female fish of reproductive age, and their ovaries were preserved in formalin for ovary weights, oocyte counts, and histological staging.

Gonadosomatic index (GSI, ratio of ovary weight to fish weight) was calculated for each female fish as a rough measure of reproductive investment. To further address differences in reproduction, batch fecundity was assessed using the gravimetric method that involves counting oocytes in a weighed portion of the fish ovary and then multiplying by the total weight of the ovary (Murua et al. 2003). To include only late-stage oocytes in fecundity counts, a grid was overlaid on an image of histological sections, and each oocyte located at the intersection point of the grid was measured and staged (Fig. 1). Oocytes were grouped into 8 histological stages, in order from early to late development; (1) CN=chromatin nucleolar, (2) PN=perinucleolar (3) CA= *cortical alveolus*, (4) PY=primary yolk, (5) SY=secondary yolk, (6) TY=tertiary yolk, (7) MNS=migratory nucleus, (8) HO=hydrated oocyte. Histological stages were used to calculate the ratio of late-stage yolked oocytes to total oocytes and the proportions were applied to oocyte counts to include only late-stage oocytes in batch fecundity estimates. The measured area of histological oocyte stages were also compared amongst depth strata. In addition, based on histological sections, ovaries with post-ovulatory follicles and atresia were excluded from the batch fecundity analysis.

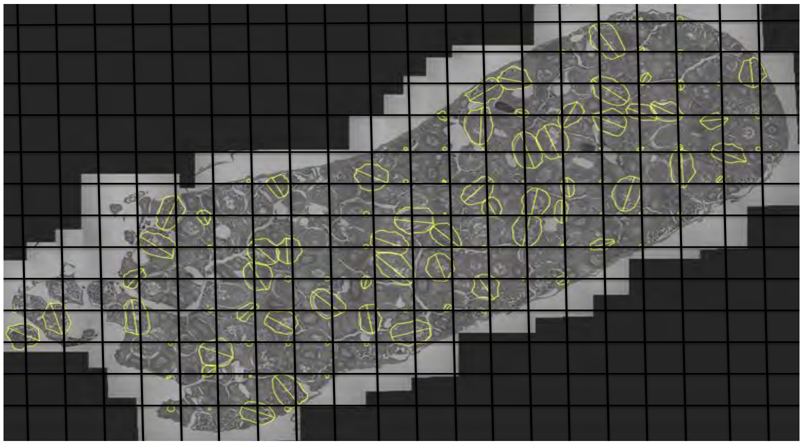

Fig. 1. Grid overlay of histological section of *S. partitus* ovary. Ooctes located at the intersection points (yellow outline) were measured and staged.

Results

Analyses included fish that were collected during peak spawning between the full moon and last quarter moon. Fecundity calculations were limited to fish ovaries with late stage oocyte development, and no evidence of recent post-ovulatory follicles or atresia, resulting in different sample sizes depending on the analysis (Table 1).

Table 1. Sample sizes of total collections, GSI analysis, and fecundity calculations.

Strata	N total	N GSI	N fecundity
Upper shelf	61	48	17
Lower shelf	38	27	9
Mesophotic	33	12	8

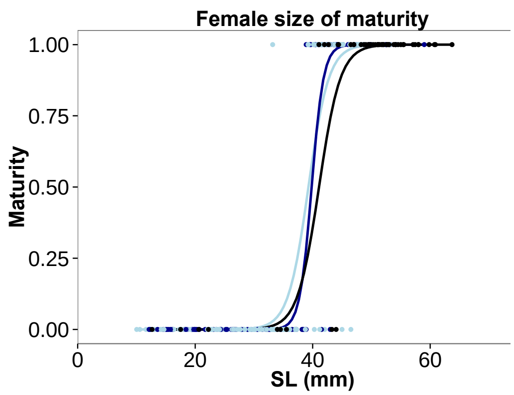

Figure 2. Probability of maturity for female fish based on standard length (SL). Logistic regression P>0.05.

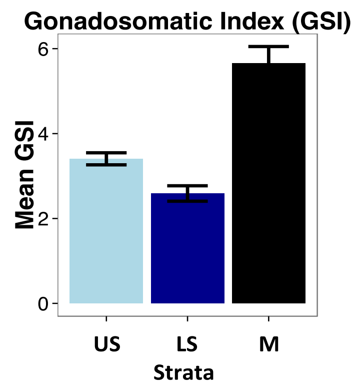

Figure 3. Mean GSI index (±SE) between depth strata. (ANOVA p<0.01; Tukey LS<US<M).

There were no differences in the size of maturity for *S. partitus* regardless of collection depth, with a consistent maturation of 55% maturity at 40 mm standard length (Fig. 2). GSI index showed significantly higher reproductive investment for mesophotic reef fish. However, the relationship between depth and GSI index was not linear, with the lowest GSI index found on lower shelf reefs (Fig. 3). In accordance with differences in GSI index, mesophotic reef fish also had the highest batch fecundity even after accounting for differences in body size. However, US and LS fish did not have significant differences in batch fecundity (Fig. 4). Mesophotic fish also had larger oocytes for most developmental stages compared to US and LS fish, revealing higher fecunding and potentially higher condition larvae (Fig. 5). The results of these analyses suggest relatively high reproductive investment and high fcundity for *S. partitus* fish populations at Pulley Ridge. These results will be combined with demographic results reported last year and ongoing efforts to estimate population abundances across the Florida Keys to produce an esitmate of total Keys-wide reproductive output. Fecundity calculations in conjunction with fish size distributions and population densities across depth strata can be used to refine the biophyscial population connectivity model for Pulley Ridge and the Florida Keys.

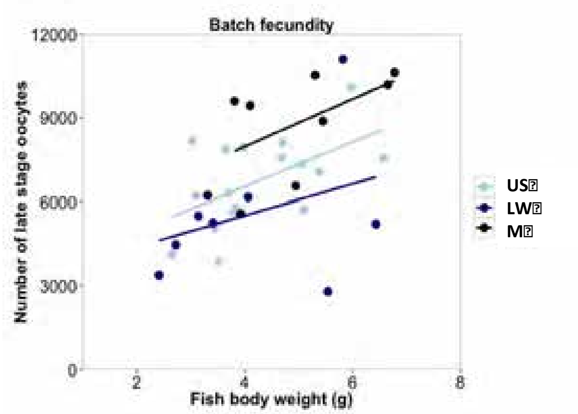

Figure 4. Batch fecundity based on fish body weight. (ANCOVA p<0.05; Tukey US=LS, LS=M, M>LS).

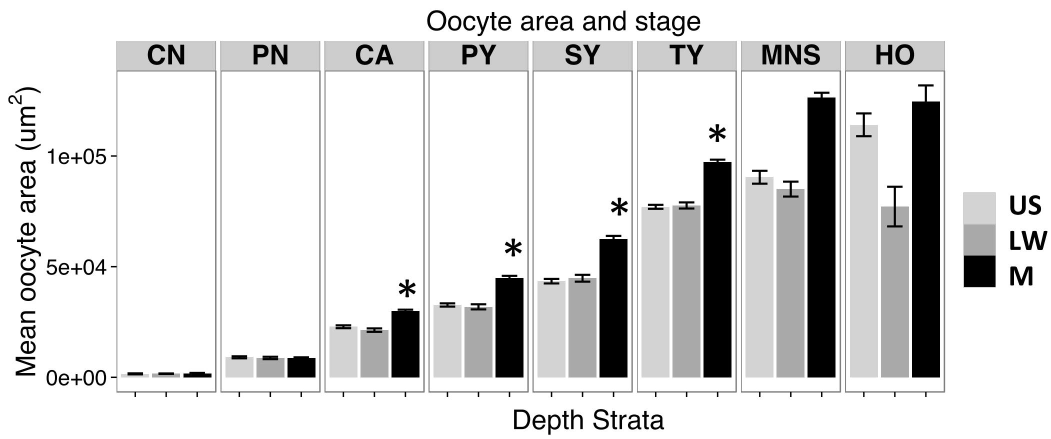

Figure 5. Oocyte area. An asterisk denotes significance ($p<0.05$) for ANCOVA with fish weight as a covariate.

Numerical Modeling (Paris and Olascoaga)

During 2014 biophysical modeling activities were focused on the 3-dimentional analysis of connectivity for the bicolor damselfish *Stegastes partitus* larvae between Pulley Ridge and the Florida Keys and on expanding the analysis by simulating long-term connectivity of Pulley Ridge with other reefs in the Gulf of Mexico region:

i) configuring the CMS to simulate dispersal of *Stegastes partitus,* running experiments and analyzing connectivity output based on 8 years of simulations (2004-2008, 2012-2015);

ii) finding underlying physical mechanisms of dispersal. For this purpose we used different metrics, such as the latitudinal position of the Florida Current, Sea Surface Height (SSH) anomalies, Lagrangian Coherent Structures (LCSs), Okubo-Weiss parameter, and velocity field evolution.

Results on general connectivity patterns and mechanisms for *S. partitus* between Pulley Ridge and the Florida Keys were submitted to *Continental Shelf Research* and are currently under review. A second manuscript using a multi species approach on the connectivity of Pulley Ridge with the shelf-break reefs located in the northern Gulf of Mexico and the Yucatan peninsula is in preparation. The main findings reported in the two manuscripts are presented in this report.

<u>Methods</u>

Multi-scale simulations rely on nested hydrodynamic models covering the study domain with different horizontal resolutions. The various resolutions are needed to capture the spatial-temporal scales of circulation influencing larval dispersal in the region. The highest resolution model, 1/100 degrees (~900 m), covers the Florida Keys (FKeyS-HYCOM, c.f. Kourafalou and Kang, 2012, 79-83.4°W 22.8-26.1° N). Daily hindcast from the GoM- and Global-HYCOM and 6 hourly for the FKeyS-HYCOM from

2004 to 2008 are used in the experiments.

Vertical connections between shallow and mesophotic coral reefs are quantified by a three dimensional (3D) version of the CMS seascape module described in Paris *et al.* (2013). This novel 3D seascape module allows CMS users to configure spawning and settlement areas at discrete depths (**Fig. 6**); settlement only occurs if a larva is found within both vertical and horizontal boundaries of a polygon during its competency period (i.e., between its minimum and maximum pelagic larval duration or PLD). We define three vertical strata encompassing from shallow water to mesophotic reefs (0 to 20m, > 20m to 40m, and > 40m to 80m). Spawning occurs on a daily frequency at 51 sites, and the number of particles released is scaled using observations of lunar cyclic spawning (Sponaugle *et al.* 2012). Larvae are competent to settle 20 days after hatch and were tracked for a maximum PLD of 32 days following Sponaugle *et al.* (2012). Specific traits of *S. partitus* larvae incorporated in the model are ontogenic vertical migration (OVM) and a daily mortality rates measured *in situ* by Paris-Limouzy (2001). The full simulations include 1825 spawn events where more than 100 million larvae are tracked.

To understand the spatial-temporal patterns of variation of the connectivity between Pulley Ridge, Dry Tortugas and the Florida Keys, we use time series and spectral analyses. We calculate the energy density spectra using a Fourrier Fast Transform method (FFT), smoothed by a Hamming window with 365 points, i.e. one year. The Empirical Orthogonal Functions (EOF) of the anomalies of larval export from Pulley Ridge is also calculated using the single value decomposition (SVD) method (Emery and Thompson, 2003).

Results and Discussion

Connectivity Between Pulley Ridge and the Florida Keys

Larvae released at Pulley Ridge are exported to the Florida Keys reef tract, throughout all strata considered in the simulations, suggesting vertical transport (**Fig. 7**). Connectivity of *S. partitus* larvae from Pulley Ridge to the Florida Keys is transient, whereby periods with high settlement alternate with periods with no settlement. In addition, these connections vary spatially and temporally (**Fig. 7**). During events where a large number of larvae successfully settle, most settlement occurs on reefs closer to Pulley Ridge, particularly Dry Tortugas and Marquesas Islands. Indeed, the probabilistic matrix for the entire study period (2004 to 2008) reveals that larvae released at Pulley Ridge present a high likelihood of settling at all strata the Western Florida Keys (**Fig. 8**). On the contrary, self-recruitment at Pulley Ridge is estimated around 30%, and its reefs appear to receive limited *S. partitus* larval subsidies from the Florida Keys. These results indicates that the region might rely on local replenishment to support its population of *S. partitus,* or can receive additional larval subsidies from other regions, such as the shelf-break reefs located in the northern Gulf of Mexico.

Spatial and Temporal Scales of Connectivity

The elevated energetic peaks over some regions indicate larger settlement variability (**Fig. 9a**). A notable high energetic power spectrum is found for settlement in the Western Keys. Most variability occurs at high frequencies of periods less than 30 days reflecting the lunar cycle periodicity of *S. partitus* spawning. On the lower frequency band, peaks at 90, 72 and 60 days are related to physical transport mechanisms (e.g., seasonal of winds and variability of the local circulation, variations of the Florida Current front intensity and position) and a peak at 10 days is likely related to mesoscale eddy activity. Indeed, the spectral analysis of the anomaly of the latitudinal position of the Florida Current front reveals similar peaks at 60 and 10 days, reinforcing the assumption the Florida Current underlays some of the observed variability in settlement (**Fig. 10c**).

The first mode of the EOF explains 40% of the settlement variability, while the second and third modes explain 23% and 8%, respectively (**Fig. 9a**). The magnitude of these 3 major EOF modes is larger over the shallow (<20m) and mid-depths (20-40m) of the Western Keys, corroborating expected high variability of settlement (Fig. 4a, 5a). Specific settlement events are explained by distinct modes, as illustrated by the four events highlighted on figure 10b.

Both the first and the third EOF modes are related to settlement on Dry Tortugas, while the second EOF mode is related to settlement on the Western Keys. Although EOFs are useful to represent patterns of a variable distributed over a large area for a long period, it is not always possible to relate individual EOF modes to specific physical processes. Here, the fact that different modes explain the variability of settlement peaks occurring at distinct geographical areas, suggests that separate physical mechanisms could regulate successful connections between Pulley Ridge and the Florida Keys. To evaluate this hypothesis, we investigate dispersal pathways and flow characteristics on these events. Settlement events explained by the first and third EOF modes are analyzed together, while the second EOF mode is analyzed separately. The following spawning dates are used in our analysis, since most of their settlement variance was explained by a EC mode (in chronological order): i) first mode: 1/25/2005, 5/29/2006, and 8/18/2006; ii) second mode: 6/27/2006, 12/1/2007, and 1/1/2008 iii) third mode: 1/20/2005, 1/24/2005, and 3/27/2008. In the following sections, results are shown from the following spawning events (as noted on **Fig. 10b**): E1 (1/25/2005), E2 (5/29/2006), E3 (12/1/2007), and E4 (1/1/2008).

Larval Dispersal Pathways and Flow During High Connectivity Events

The dispersal pathways following spawning are highly variable, even for spawning days explained by the same mode (**Fig. 11a,c,e,g**). Generally, larvae spawned during events explained by the first and third modes tend to be transported initially in the northwestern direction, towards the Southwest Florida Shelf, while larvae spawned during events explained by the second mode are transported southward, and towards the Florida Keys. On events E1 and E2, both the velocity fields and the LCSs show the Loop and Florida Currents flowing closer to the Pulley Ridge and the Florida Keys than during spawning events E3 and E4, when the Florida Current is located to the south of the Florida Keys. On events E1 and E2 a cyclonic eddy over the Dry Tortugas region is evident on the averaged velocity fields.

Distinct patterns of dispersal emerged during the settlement period (**Fig. 11a,b,d,f**). During their competency period, larvae spawned on events explained by the first and third mode concentrate around the Western Florida Mid-Shelf and the Dry Tortugas region, mostly north of Pulley Ridge (i.e., latitude higher than 24.4°N). On the contrary, the pathways of the second mode settlers were spread south of the Florida Keys (i.e., south of 24.4°N), particularly in the Marquesas Islands and the Lower Keys.

Averaged velocity fields and LCS also corroborate these findings. The LCSs fields calculated for settlement days of spawning events of the first and third modes (**Fig. 12b,d**) show attracting LCSs over the region of Dry Tortugas, and also distributed close to the Atlantic Florida Keys Shelf. The LCSs are following the main curvature of the local bathymetry, indicative that the Florida Current is close to the reefs. Such circulation patterns are favorable for the retention of larvae over the Dry Tortugas and the Western Florida Keys. Alternatively, attracting LCSs during settlement of larvae spawned during the second mode (**Fig. 12e,f**) show the presence of mesoscale features, which propagate along the Straits of Florida and the Florida Keys. A concentration of attracting LCSs near the downstream reefs of the Western Keys is in agreement with high settlement expected on these reefs and dates (**Figs. 7,10b**). From the LCSs fields it was also possible to infer that the Florida Current was retreated to southern positions during these two events (E3,E4).

Interactions of Flow and Biological Traits Shaping Settlement and Connectivity

The position at which the meandering Florida Current front approaches the Florida Keys and the Atlantic Florida Keys Shelf varies seasonally and inter-anually (Kourafalou and Kang, 2012). Settlement peaks occur when the Florida Current front reaches a southern position near the western edge of the Florida Keys, therefore allowing remotely generated eddies to propagate along the reefs, aiding with entrapping and transporting larvae to settlement grounds. Both locally and remotely generated eddies can have their dissipation or growth enhanced by interactions with the topography of the Florida Straits, and by latitudinal variations of the Florida Current (Kourafalou and Kang, 2012). In our study we observed that the elongation of the cyclonic eddies as they moved towards shallower bathymetry enhanced a counter current flowing along the Florida Keys, which further favored settlement. This is apparent in the trajectories of larval settlers during settlement on two events (E3 Dec/01/2007 and E4 Jan/01/2008, **Fig. 12f,h**). Yet, the Florida Current front variability is not a good predictor of settlement. We found no significant correlation between the time series of the latitudinal variations of the Florida Current front (Kourafalou and Kang, 2012), and larval export from Pulley Ridge, up to a lag of 15 days. This result corroborates with the transient nature of connections between Pulley Ridge and the Florida Keys, indicating that episodes of high connectivity resulted from rare optimal conditions created by a combination of physical and biological mechanisms. Connectivity would depend on a match-mismatch of favorable oceanographic conditions with the phenology of the target species. The "match-mismatch" hypothesis was put forward by Cushing (1969) between the food and the timing of first feeding for fish larvae. Here we find that the physical conditions present after spawning and during the early stages of larvae (about 10 days) are critical to realized connectivity and thus to reproductive success.

Not only the remote circulation favor connectivity between Pulley Ridge and the Florida Keys, but local circulation mechanisms also play an important role. Circulation features occurring over the broad Southwest Florida Shelf sections were particularly important to enhance settlement on Dry Tortugas. Larvae spawned at Pulley Ridge during northward flow events are transported over the mid-shelf where a balance between buoyancy and wind-driven flows drive the transport (Weisberg *et al.*, 2005; Kourafalou *et al.,* 2009; Liu and Weisberg, 2012). Southward flows occur on the mid shelf during both events, aiding the dispersal of Pulley Ridge larvae towards Dry Tortugas. Once near Dry Tortugas, larvae benefit from the persistent eddy activity (Lee and Williams, 1999; Kourafalou and Kang, 2012) to be retained long enough, until they reach their competency period and settle.

The dispersal pathways revealed by the modeling outline the importance of the eddying flow for increasing connectivity, as per the initial work of Paris-Limouzy *et al.* (1997). This is indeed supported by the findings of energy peaks at frequencies related to mesoscale activity on the spectral analysis of daily settlement (Fig. 4a,b). It has been long suggested that eddies could aid reef fish settlement in the region, which has been confirmed by *in situ* observations (Lee *et al.,* 1992; Limouzy-Paris *et al.,* 1997; Lee and Williams, 1999; Sponaugle *et al.,* 2005). However, eddies occurring in the study region might have different origins, do not present a clear temporal or spatial pattern, and vary in number, strength, and characteristics in scales from days to years (Kourafalou and Kang, 2012). In this context, the timing of spawning can be determinant on the outcome of a larval cohort and could also bring food the larvae for better survival (Cushing 1969). This has also been suggested by *in situ* observations in South Florida (Sponaugle *et al.,* 2005) and in modeling studies for other regions presenting high eddy variability (Karnauskas *et al.,* 2011; Vaz *et al.,* 2013). The present study however, sheds a new light on this subject by exploring vertical connections. Here, we find that the co-occurence of larval vertical migration and mesoscale circulation is not only an effective transport mechanism to connect fragmented coral reef habitat distributed over a large geographic region, but also to aid connections between reefs located at different depths. This result serves to better understand the role of mesophotic reefs in increasing shallow water reefs resiliency. Moreover, our simulations indicate that populations of *S. partitus* at Pulley Ridge can be sustained by self-recruitment (**Fig. 8**). The region might also receive *S. partitus* larval subsidies from reefs outside of the study region, particularly other reefs in the Western Florida Shelf. This scenario deserves future investigation, and it is the aim of our next paper.

Preliminary results of wide connectivity of Pulley Ridge with GoM reefs

To investigate other possible origin for *S. partitus* larvae recruiting at Pulley we backtracked larvae released from Pulley Ridge for periods of 25 to 60 days, spawned along the first 60 meters of the water column. We used velocities from the GoM HYCOM from 2004-2008. The general pattern of transport is similar for all periods and depths of release, as illustrated by the pdfs of larvae released at 40m and tracked for 35 days (**Fig. 13**). The most likely origin of Pulley Ridge are the Western Keys, including Dry Tortugas, and the Western Florida Shelf. Transport from the Yucatan peninsula could also be a possibility. The depth of release or time of dispersal did not seem to significantly affect the results (**Fig. 14**).

Integration of results

The next step is to configure a multi-species model to simulate connectivity from reefs in the northern Gulf of Mexico shelf break, particularly focusing in the protected areas and Habitats of Particular Concern (HPCs). We will use data from Pulley Cruises to simulate species-specific spatial production and settlement at Pulley Ridge and data from SEAMAP Reef Fish Survey (NOAA - NMFS - SEFSC) to configure the Florida Big Bend and Desoto Canyon reefs.

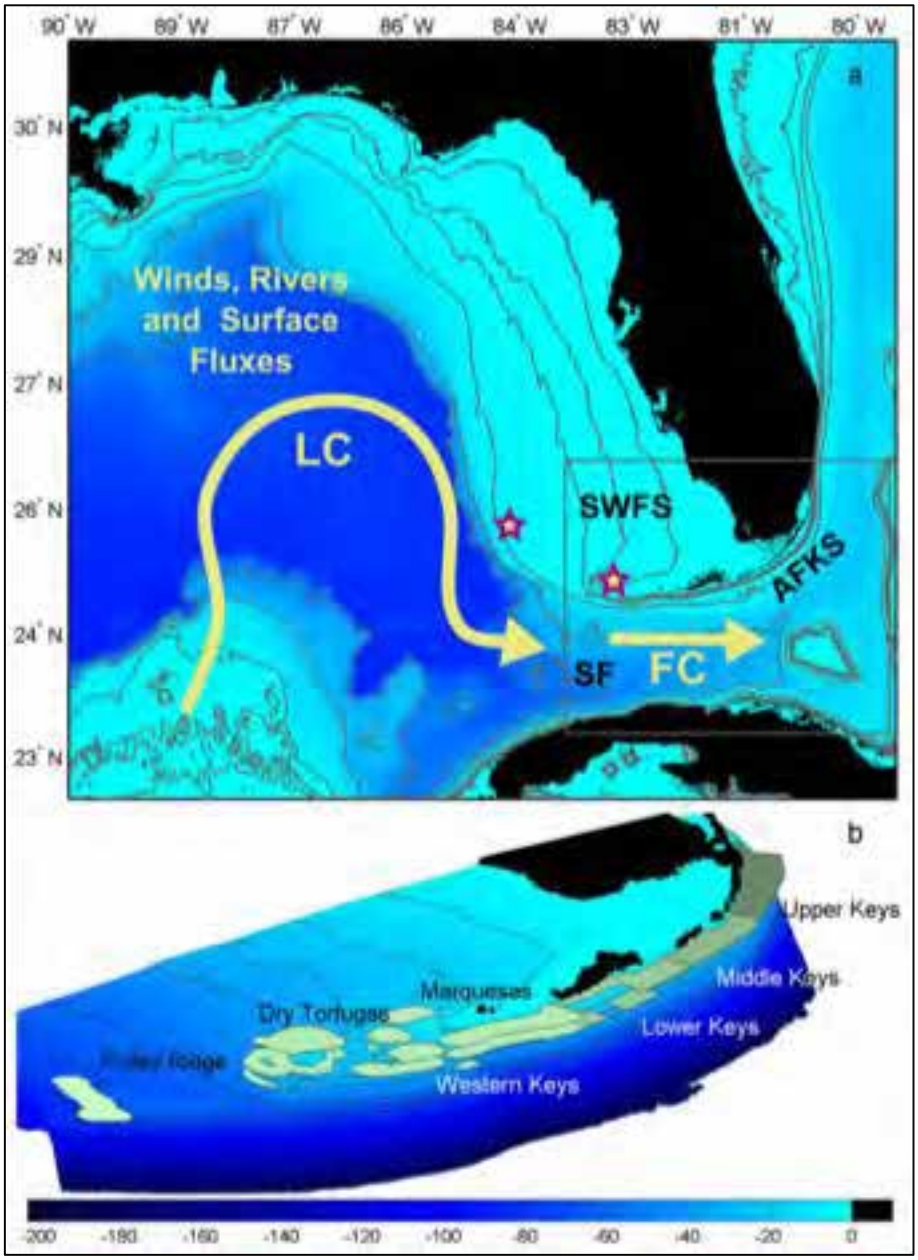

Figure 6. Study area: (a) Major circulation forcing and bathymetry of the Southwest Florida Shelf (SWFS), the Atlantic Florida Keys Shelf (AFKS), the Straits of Florida (SF), the Pulley Ridge and the Dry Tortugas (red stars); the grey box delineates the high resolution (~1 km) hydrodynamic model (FKeys-HYCOM, Kourafalou and Kang 2012) domain. (b) Three-dimensional view of the settlement habitat of the biophysical model (Connectivity Modeling System, Paris *et al.* 2013) composed of three depth strata, i.e., shallow (0-20m), mid (20-40 m), and deep (40-80m), whereby the deep strata represent the mesophotic reefs. The color gradient of the strata represents the subdivisions from the Upper Florida Keys (darker colors) to Pulley Ridge (lighter colors).

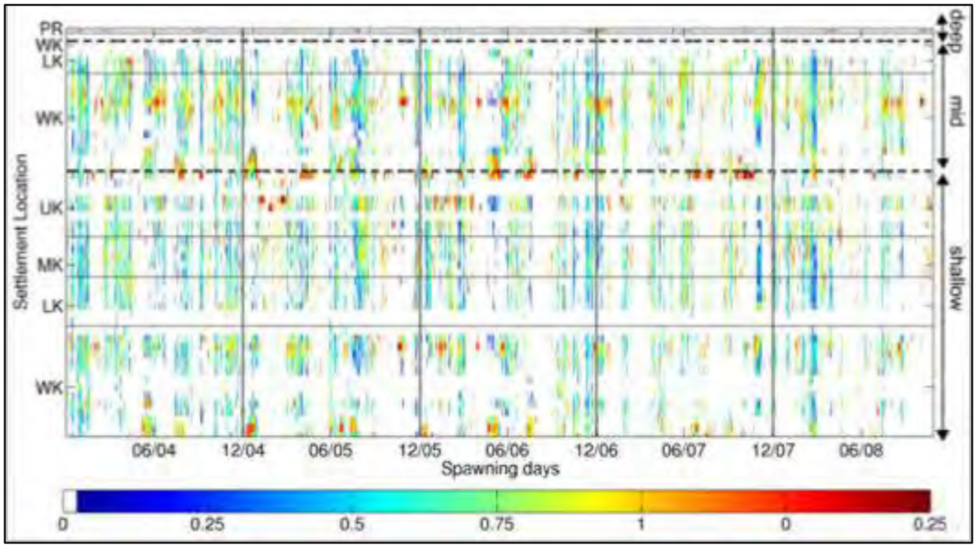

Figure 7. Daily probability of *Stegastes partitus* larval connectivity between Pulley Ridge (3 reef polygons or nodes herein in the 60-80 m strata) and the Florida Keys, where WK = Western Keys (25 nodes), LK = Lower Keys (10 nodes), MK = Middle Keys (5 nodes), UK = Upper Keys (8 nodes), PR = Pulley Ridge. Virtual larvae are released in the biophysical model at the mid depth of each PR node from 2004 to 2008. The color of each node represents the daily probability of settlement. Dashed lines delineate different depth strata (i.e., shallow = 0-20 m, mid = 20-40m, deep = 40-80 m).

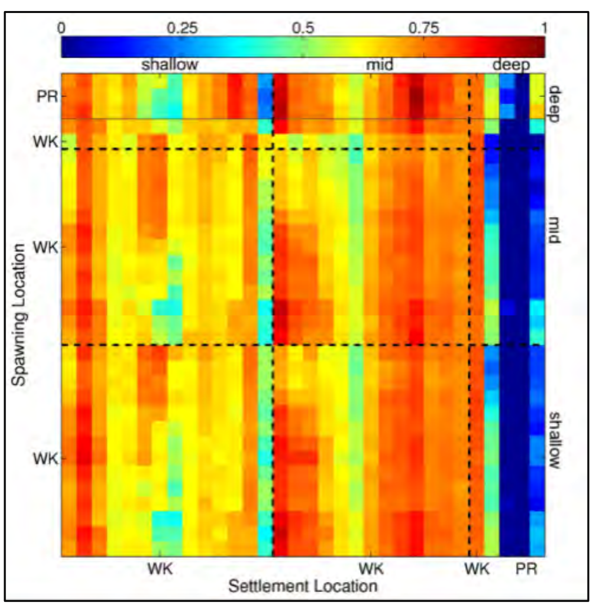

Figure 8. Three-dimensional connectivity matrix between mesophotic and shallow reef ecosystems: Probabilistic of *Stegastes partitus* larval connectivity released at Pulley Ridge (PR) and in the Western Florida Keys (WK). The matrix is based on 1,825 daily spawn events from 2004 to 2008. The color code represents the probability that an individual larva released at a spawning location (Y-axis)

arrives at a settlement location (X-axis). Dashed lines delineate different depth strata (i.e., shallow = 0-20 m, mid = 20-40m, deep = 40-80 m).

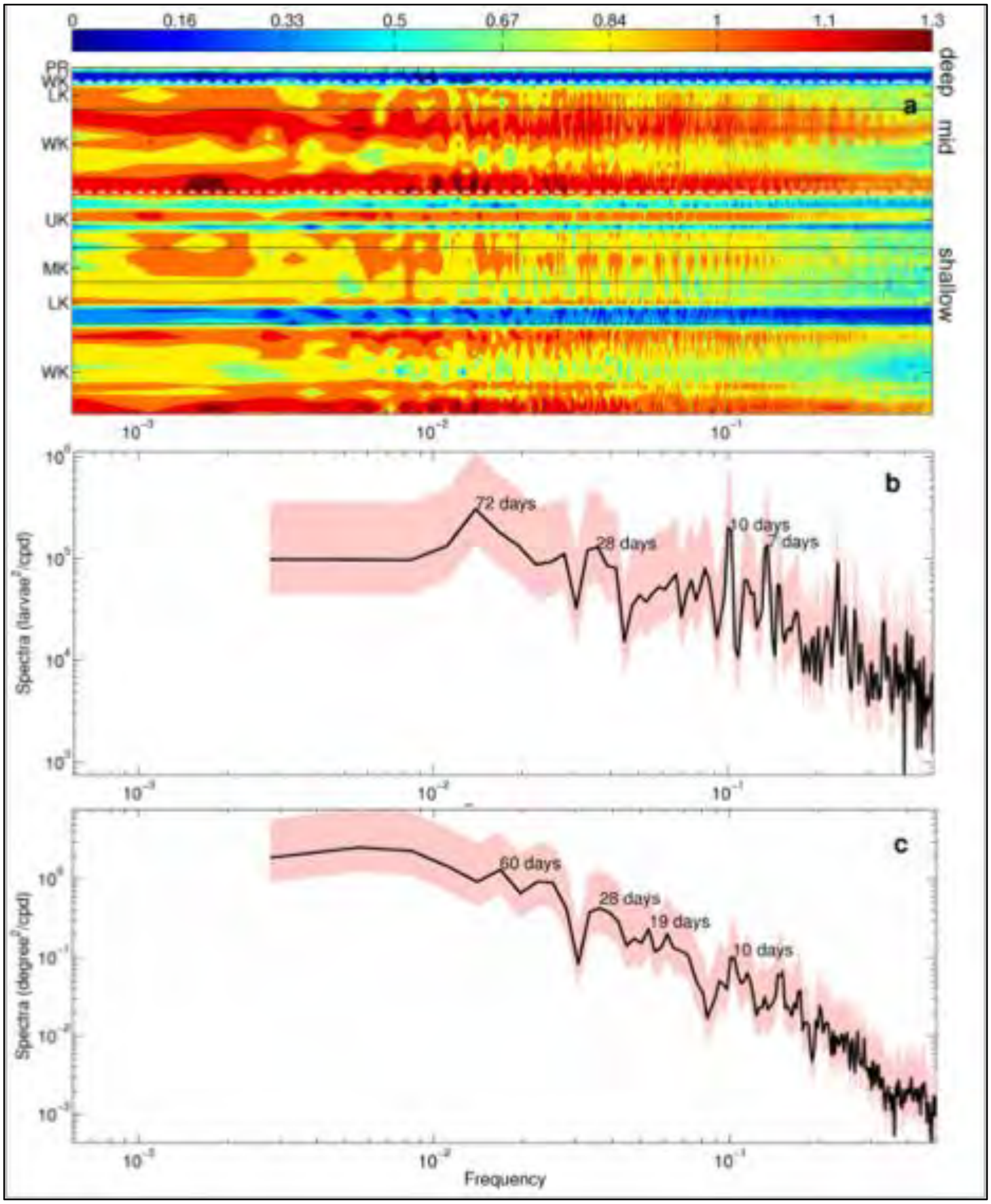

Figure 9. Spectral analysis of (**a**) the spatial settlement of *Stegastes partitus* larvae from daily releases from 2004-2008 at Pulley Ridge (PR), (**b**) of the temporal spawning of successfully settled larvae from PR and (**c**) of the zonal position of the Florida Current Front for 2004-2008 along 83° W. Shaded areas on (b) and (**c**) represent the

95% confidence interval. WK = Western Keys; LK = Lower Keys; MK = Middle Keys; UK = Upper Keys; PR = Pulley Ridge. White dashed line in (a) delineates different depth strata (i.e., shallow = 0-20 m, mid = 20-40m, deep = 40-80 m).

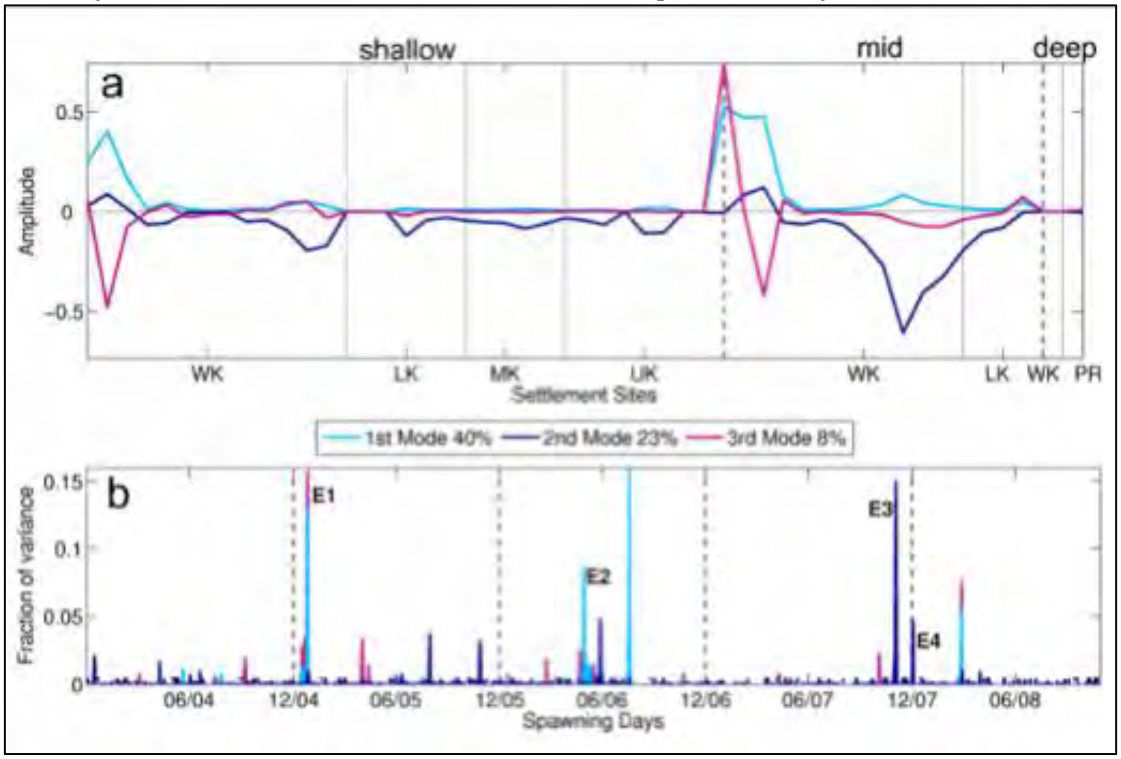

Figure 10. (**a**) Spatial distribution of the first, second, and third modes EOFs relative to the daily export of successful *Stegastes partitus* larvae from Pulley Ridge (PR). (**b**) Temporal distribution of settlement variance explained. Settlement events explaining most variability are marked E1-E4. WK = Western Keys; LK = Lower Keys; MK = Middle Keys; UK = Upper Keys; PR = Pulley Ridge. Grey dashed lines delineate different depth strata (i.e., shallow = 0-20 m, mid = 20-40m, deep = 40-80 m).

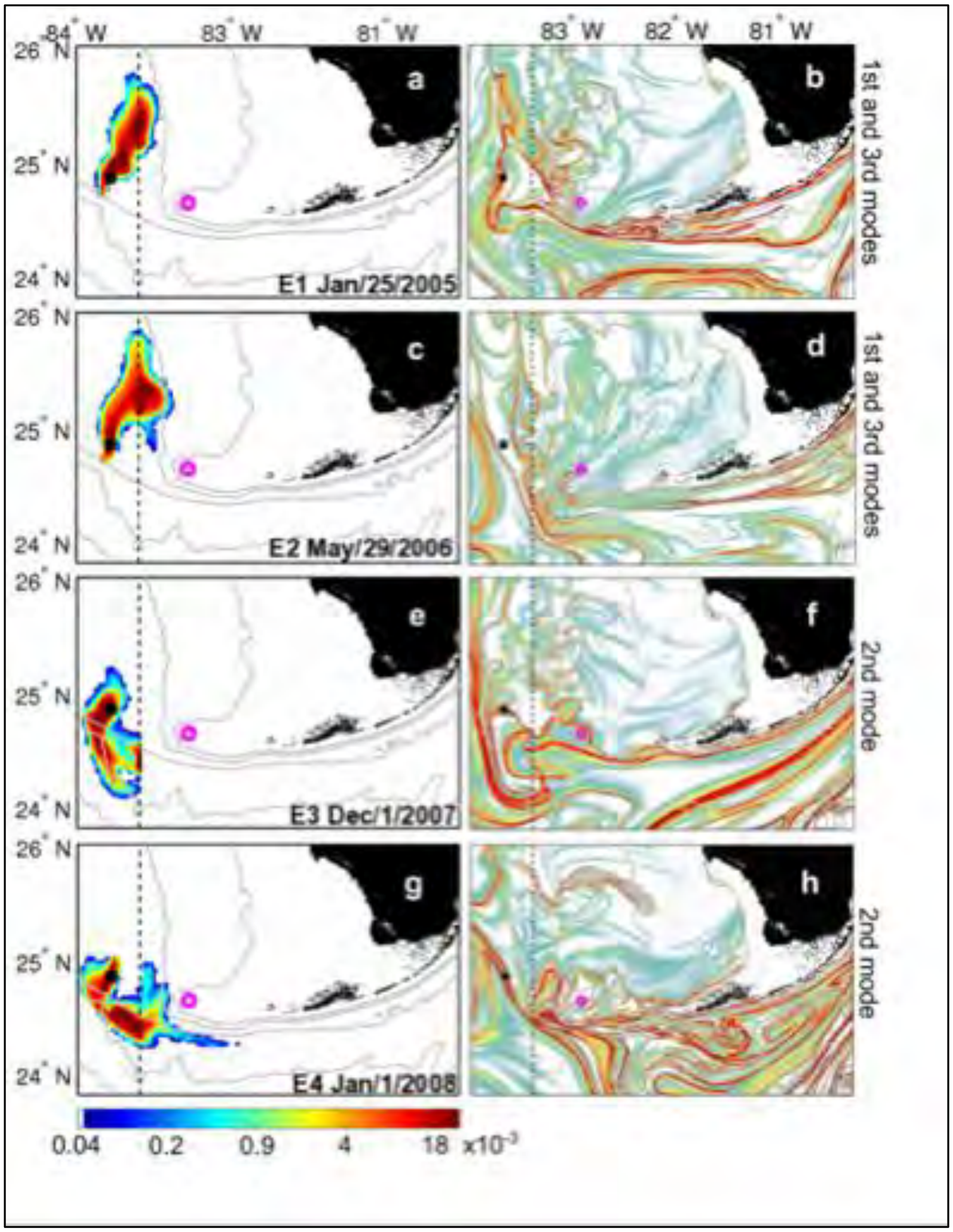

Figure 11. Simulated *Stegastes partitus* larval pathways and flow characteristics during spawning for four settlement events. Left column (**a,c,e,g**): probability density function (PDF) of larval trajectories calculated over 10 days after larval release of successful larvae. Right column (**b,d,f,h**): attracting Lagrangian Coherent Structures (LCSs) obtained from Finite-Time Lyapunov Exponents (FTLE). The four settlement events, namely E1 = Jan/25/2005, E2 = May/29/2006, E3 = Dec/01/2007, and E4 = Jan/01/2008, correspond to high settlement pulses identified on figure 9.

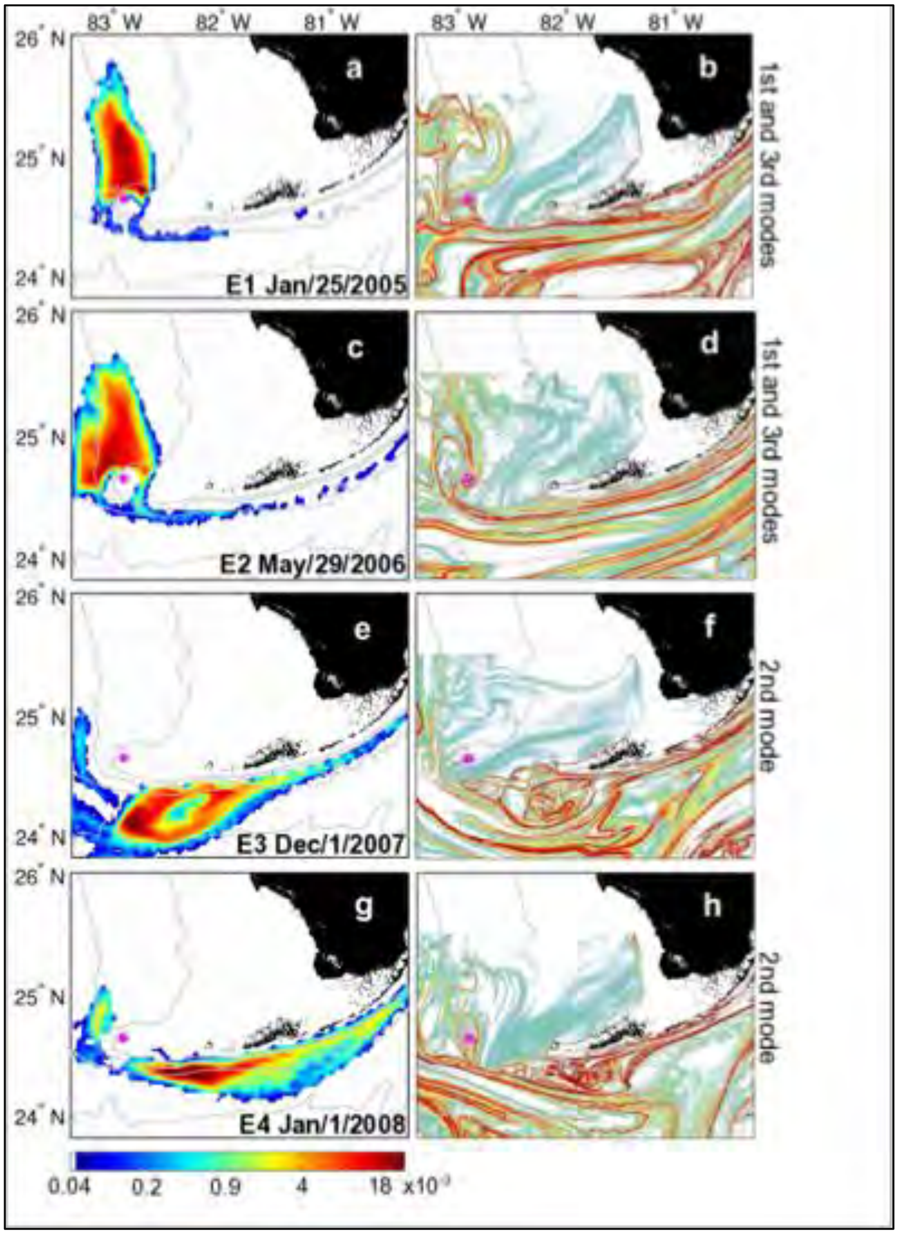

Figure 12. Larval pathways and flow characteristics during four settlement events. Left column (**a,c,e,g**): probability density function (PDF) of larval trajectories calculated over 12 days before the end of the pelagic larval duration. Right column (**b,d,f,h**): attracting Lagrangian Coherent Structures (LCSs) obtained from Finite-Time Lyapunov Exponents (FTLE). The four settlement events, namely E1 = Jan/25/2005, E2 = May/29/2006, E3 = Dec/01/2007, and E4 = Jan/01/2008, correspond to high settlement pulses identified in figure 4. (FTLE).

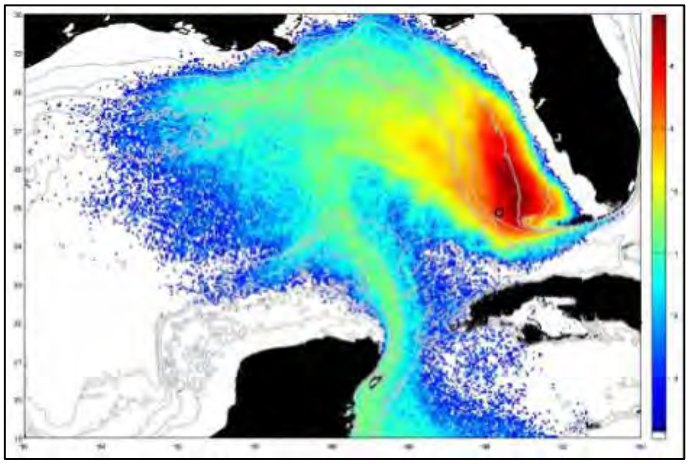

Figure 13. Larval pathways of larvae released at Pulley Ridge (40 meters depth) and backtracked for 35 days. The larval pdfs are calculated for daily releases from 2004 to 2008.

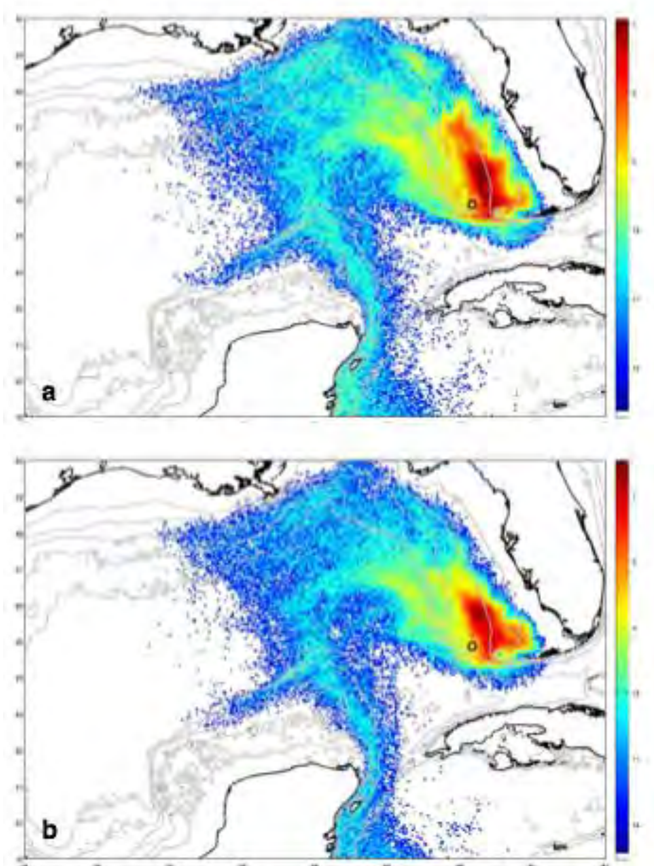

Figure 14. Larval pathways of larvae released at Pulley Ridge at, a) 10 meters depth and b) 60 meters depth and backtracked for 35 days. The larval pdfs are calculated for daily releases for 2007.

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Genetic Connectivity

Epinephelus morio **(Red Grouper) Connectivity Assessment** PI:

M. Shivji, Post-doc: A. Bernard

Sample Collections

A total of 304 red grouper samples have been collected and genotyped for this project (Figure 1). Samples from Pulley Ridge and the Dry Tortugas were collected as part of the Year 2 and 3 cruises (Year 2: Pulley Ridge, n = 28; Dry Tortugas, n = 34; Year 3: Pulley Ridge, n = 16, Dry Tortugas, n = 13).

For comparative regional connectivity analyses and since red grouper are currently managed as two distinct units within US waters (Gulf of Mexico vs. western Atlantic, with a stock boundary occurring at the US Highway 1 in the Florida Keys), tissue samples were also collected from individuals caught at other locations, including: the Florida Keys (~ 10 kilometers north of Marathon Key, FLK, *n* = 35 (samples kindly provided by Bob Ellis, FSU)), the Florida shelf of the Eastern Gulf of Mexico, *n* = 51 (samples kindly provided by NOAA), the waters of the Campeche Bank, Mexico, *n* = 78 (samples kindly provided by commercial fishers), and from the waters of the Western North Atlantic (*n* = 49, spanning from the coast of Florida to North Carolina).

Laboratory molecular analyses

All red grouper samples were genotyped at 13 microsatellite loci cross-amplified from three other grouper species: 11 of these markers were developed for *Epinephelus striatus* (Nassau grouper) (Bernard et al. 2012), one for *Mycteroperca bonaci* (black grouper) (Zatcoff et al. 2002), and one for *Mycteroperca microlepis* (gag grouper) (Chapman et al. 1999; Zatcoff et al. 2004). Despite using markers from non-red grouper species, the microsatellites showed high levels of polymorphism (number of alleles per locus ranged from 3 to 33 (mean = 15.23), and power analyses performed using the program POWSIM (Ryman and Palm 2006) indicated that the markers were sufficiently variable to infer even low levels of genetic population structure using varying sampling regimes (Figure 2). Across all three assayed sampling regimes, the power to detect significant structure using these markers and sample sizes was high (>0.8), when divergence was at F_{ST} = 0.0015 or higher. The proportion of significant detections dropped significantly for all three sampling regimes at F_{ST} <0.001 (Fig. 2).

Statistical analyses of Population Differentiation

Multilocus genetic analyses of the red grouper samples showed high levels of connectivity and no statistical population differentiation across the surveyed geographic range. Population-level pairwise F_{ST} values show low and non-significant levels of differentiation among the six *a priori* defined collection sites (Table 1). When collection sites were pooled into three distinct locations corresponding to the US Western North Atlantic, US Eastern Gulf of Mexico, and Campeche Bank, Mexico, still no evidence of pairwise genic or genotypic differentiation was found (P>0.05). Similarly, when collection sites were pooled to correspond to two broad regions (i.e., pooled US Western North Atlantic vs. pooled Gulf of Mexico), no genic or genotypic differentiation was found (P>0.05).

Individual-based Bayesian clustering analyses of genotypes (Structure; Pritchard et al. 2000) were consistent with the population pairwise F_{ST} analyses, indicating high levels of connectivity (single genetic population) across all sampling sites (highest probability of K=1; Figure 3).

All the laboratory work for the red grouper is completed. Further statistical analyses for manuscript development will occur in the forthcoming year of this project.

Table 1. Pairwise F_{ST} values for each red grouper *a priori* defined population (upper triangular matrix) and associated *P*-values (lower triangular matrix).

Collection Site	WNA	CB	DT	FLK	GOM	PR
WNA	--	0.0008	-0.0003	0.0020	-0.0013	-0.0040
CB	0.81	--	-0.0011	0.0036	-0.0011	0.0003
DT	0.80	0.50	--	-0.0004	-0.0021	-0.0023
FLK	0.68	0.21	0.79	--	0.0012	-0.0016
GOM	0.51	0.55	0.77	0.46	--	0.0000
PR	1.00	0.68	0.84	0.86	0.23	--

Abbreviations: WNA, western North Atlantic; CB, Campeche Bank; DT, Dry Tortugas; FLK, Florida Keys; GOM, western Florida shelf of the Gulf of Mexico; PR, Pulley Ridge

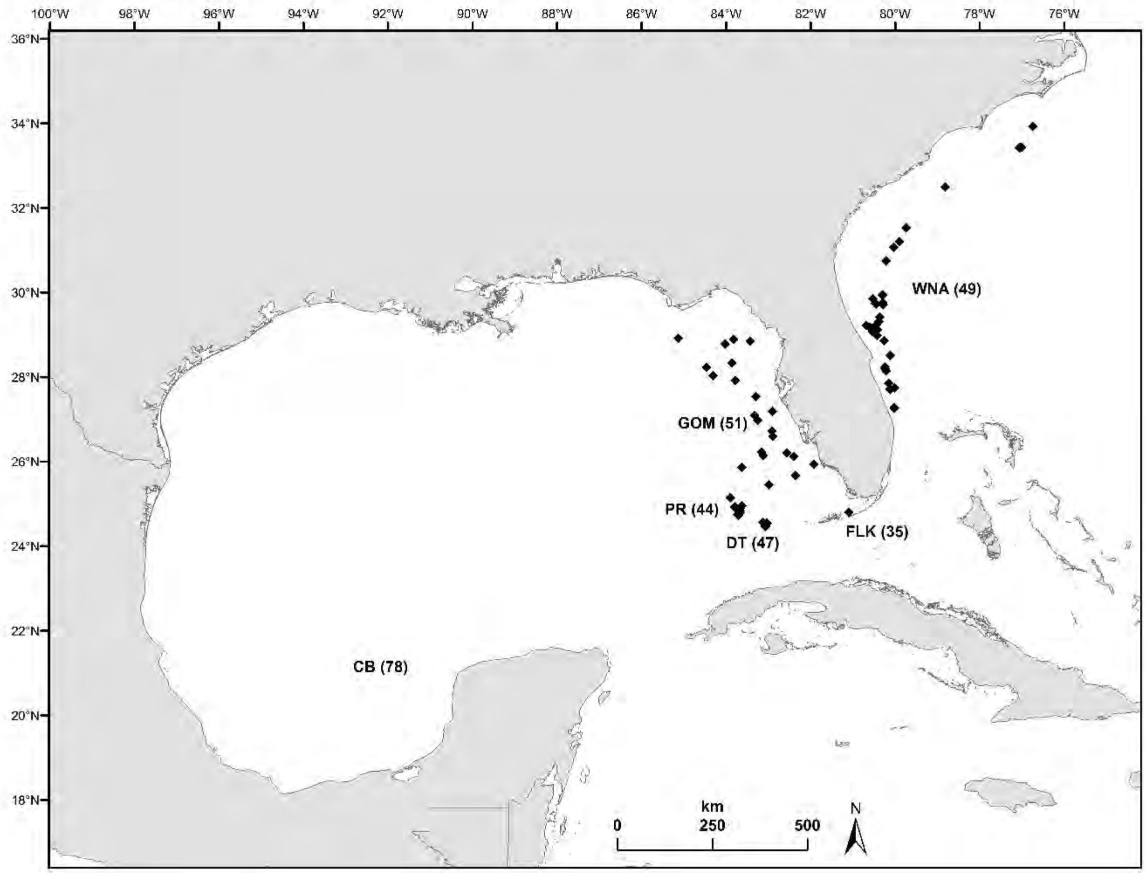

Figure 1. Map of red grouper collection locations. Abbreviations: FL Keys, Florida Keys; DT, Dry Tortugas; GOM, Gulf of Mexico Western Florida Shelf; CB, Campeche Bank, Mexico; PR, Pulley Ridge.

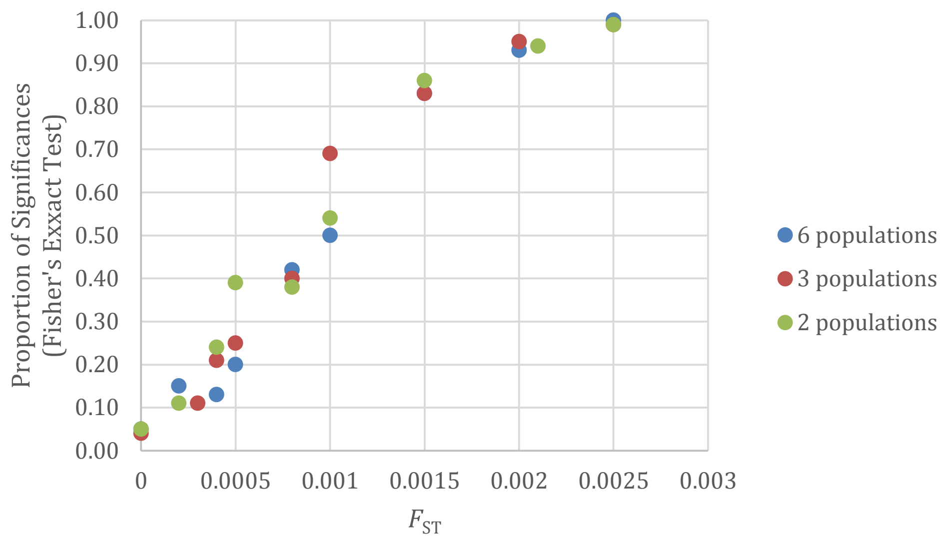

Figure 2. PowSim results depicting the simulated proportion of significant outcomes of Fisher's exact test vs. the identified level of genetic differentiation (F_{ST}) assuming an effective population size (N_E) of 10000 across three different sampling regimes. Regime 1): the six *a priori* defined populations; Regime 2): three populations consisting of the western North Atlantic (WNA), US Gulf of Mexico (USGOM), and the Campeche Bank (CB); Regime 3): two populations consisting of the WNA and the Gulf of Mexico (US and Mexico sampling sites in GOM combined).

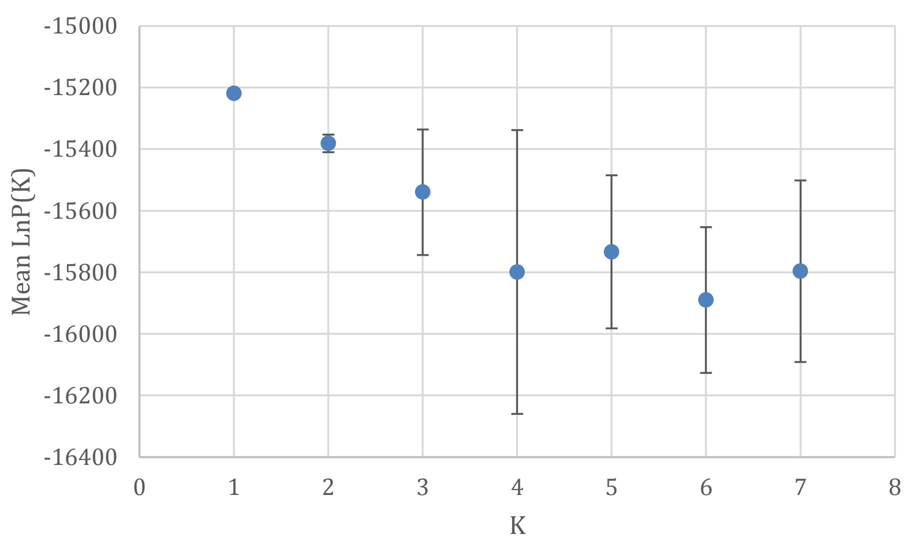

Figure 3. Structure output of the mean estimated Ln Probability of Data: LnP(D) (± std. dev.) vs. cluster number (*K*) (*K* = 1-7) across five independent runs (100 000 burn-in, 100 000 MCMC iterations) assuming the *locprior* model and correlated allele frequencies.

Xestospongia muta (Giant barrel sponge) Connectivity Assessment

Sample Collections

- A total of 116 samples of the giant barrel sponge were collected from Pulley Ridge by the project cruises across three years of sampling (2012, *n* = 39; 2013, *n* = 20; 2014, *n* = 57).

- A total of 26 samples were collected from the Dry Tortugas by the project cruises (2013, n = 9; 2014, n = 17); these will be combined with 52 samples collected from the Dry Tortugas independently by our lab.

- A total of 11 samples were collected from the Flower Garden Banks National Marine Sanctuary in 2013 (courtesy of L. Rocha & M. Bernal, California Academy of Sciences).

Laboratory molecular analyses

Ten highly polymorphic microsatellite markers have been isolated, developed, and optimized for assessing connectivity patterns of the giant barrel sponge (Richards et al. *In Prep*). Genotyping of samples is on-going. All laboratory work on the sponge is expected to be completed by the end of 2015.

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II. M.F. OLEKSIAK PROGRESS REPORT

PI: M. Oleksiak

Connectivity between Pulley Ridge and the Florida Keys

FISHES – Lionfish

FIELD COLLECTION OF SAMPLES

Due to the lack of available *T. bifasciatum* samples from Pulley Ridge (species originally proposed), we switched to lionfish, *Pterois volitans,* a more abundant species collected on Pulley Ridge.

Lionfish are native in the Indonesian-Island Pacific region. However, they are an invasive species whose distribution initiated in Southern Florida in 1985. By 2001 lionfish had a wide spread distribution along the Atlantic Coast of North America (Schofield 2009, Schofield 2010); by 2005 they were well established in the Bahamas; in 2009 they began to spread throughout the Florida Keys and by 2010 they were wide spread through the Gulf of Mexico including Pulley Ridge (Schofield 2009, Schofield 2010). This rapid expansion from a relatively few individuals requires high density genetic sampling to identify sufficient genetic markers to resolve the distribution and connectivity among populations. To accomplish this we applied Genotyping by Sequencing (GBS) (Elshire, Glaubitz et al. 2011).
Lionfish samples were collected between June 2013 and February 2015 from thirteen locations along the eastern and western Florida coasts to the Texas Gulf Coast (Table 1). These thirteen locations were from two regions: Atlantic and Gulf of Mexico (Fig 1).

ONGOING GENETIC ANALYSES

Genomic DNA was isolated from all samples and Genotyping by Sequencing (GBS) was preformed as described (Elshire, Glaubitz et al. 2011) using the restriction enzyme ApeKI. The GBS library was sequenced using two Illumina HiSeq 2500 lanes with a 75 bp single end read (Elim Biopharmaceuticals, Inc.). The UNEAK GBS analysis pipeline, TASSEL (Bradbury, Zhang et al. 2007) was used to call single nucleotide polymorphisms (SNPs) using Bowtie (Langmead B., Trapnell, C. 2014)). In total, 404,254 SNPs were identified across 229 samples. We removed SNPs in which observed heterozygosity significantly exceeded expected heterozygosity ($p < 0.01$) because these are likely to represent paralogs (alignment between dublicate genes at different chromosomal positions). After filtering so that all all SNPs occur in 80% of individuals and all individuals have at least 50% of SNP, we retained 187 individuals and 6,364 SNPs.

RESULTS:

The genomic analyses of the lionfish populations have just begun. Initial analyses suggest a complex admixture population with most of the variation within populations (AMOVA, (Excoffier, Laval et al. 2005). The genetic distances among populations initially suggest little difference between Pulley Ridge and the Dry Tortugas. We are exploring higher resolution approaches to better understand the connectivity and invasion of lionfish.

Figure 1. Lionfish Collection Sites.

Table 1. Lionfish Collection Information.

Location	Date (Month-year)	N individuals	Lat	Long	Depth (m)	Storage
North East, FL		10	30.29	-80.82		EtOH
Cape Canaveral, FL		6	28.04	80.09	27	EtOH
Ft. Pierce, FL		5	27.38	-79.82	24	EtOH
Biscayne National Park, FL	Feb-15	38	25.40	-80.10	4-36	Chaos
Islamorada, FL	Feb-15	30	24.88	-80.65		Chaos
Dry Tortugas, FL	Jun-13	19	24.60	-83.88	62	EtOH
Pulley Ridge	2014	26	24.80	-83.70	62	EtOH
Tampa,FL	May-14	19	28.08	-84.36	34	EtOH
Apalachicola, FL	Mar-14	19	31.80	86.86	35	EtOH
Alabama Shelf, AL (West FL)	Sep-14	20	29.61	-88.10	39	EtOH
Mississippi Delta, LA (Further West	Jul-13	10	29.10	-88.73	44	EtOH

FL)						
Flower Garden Banks,TX	Feb-15	10	27.87	-93.80	24	Frozen
Galveston, TX (Even further West)	Aug-14	17	28.36	-94.16	27	EtOH

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III. A. BAKER PROGRESS REPORT

PI: Andrew Baker

Population Genetics of Reef Corals

To date we have analyzed a total of 380 samples of *Montastraea cavernosa* and 484 samples of *Porites astreoides* to analyze patterns of genetic connectivity between the Upper and Lower Florida Keys, Pulley Ridge (*M. cavernosa*) and the Flower Garden Banks (both species). This analysis includes 13 of the 41 samples of *M. cavernosa* collected from Pulley Ridge during cruises prior to 2014. Some of these results have now been published (Serrano et al. 2014 in *Molecular Ecology*), and a second manuscript is in the final stages of preparation (Serrano et al. for *Scientific Reports*). A recap of these findings, and the citations for outputs to date, are included at the end of this section.

We are currently finalizing the hire of a postdoc who will be responsible for analysis of remaining Pulley Ridge samples (and the upcoming 2015 samples to be collected from the Dry Tortugas by divers aboard the R/V Spree). This postdoc, co-supervised by Dr. Margi Oleksiak, will also be responsible for population genetic analysis of select fish species.

Collection and analysis of new samples
During the 2014 cruise an additional 134 coral samples were collected, including 61 samples of *M. cavernosa*, and 73 samples of agariciid lettuce corals (in the genera *Agaricia, Leptoserism* and *Undaria*). These samples were transported to Harbor Branch in August 2014 and delivered to the University of Miami for analysis in February 2015. These samples, in addition to the 45 samples of agariciid coral collected prior to 2014, are currently being extracted under the direction of Dr. Xaymara Serrano, a former student on the project (and now a postdoc at NOAA no longer being paid by the Pulley Ridge project). Dr. Oleksiak and I are currently finalizing the hire of a new postdoc who will apply Genotyping-by-Sequencing (GBS) to analyze all *M. cavernosa* samples, and develop and apply GBS to the agariciid corals. GBS analyses of the agariciid corals will involve investigating species boundaries in this group and developing molecular diagnostics to help distinguish these species. The postdoctoral position has been offered to a well-qualified applicant in Australia, and an equally suitable candidate in Spain is our back-up choice.

Funding
We have worked with Sponsored to re-budget our allocated funds (taking account of budgetary cuts in prior years) to allow the upcoming hire of the postdoc, who will then be able to analyze all project samples. In anticipation of this, our burn rate this year has been low.

RECAP OF SPECIFIC FINDINGS TO DATE

Montastraea cavernosa
Samples from the Upper and Lower Keys displayed significant structure with depth, with ~57% and ~90% of the individual colonies at deep depths (≥25 m) assigned to the deep cluster (depicted in yellow, Figures 2 and 3), respectively. Conversely, Dry Tortugas samples consisted of a single panmictic population across depths, with 81-99% of the colonies assigned to the shallow cluster (depicted in blue, Figure 1). Interestingly, all individuals from FGB were strongly assigned to the shallow cluster present in Florida (>70% probability of membership), despite its depth (20-30 m) and distance (>1,300 km). In contrast, all individuals from PR were strongly assigned to the deep cluster present in Florida (≥90% probability of membership), **strongly suggesting that Pulley Ridge is directly connected to the deep population in FL** and therefore connectivity with the shallow population (if any) occurs via stepping-stone dispersion.

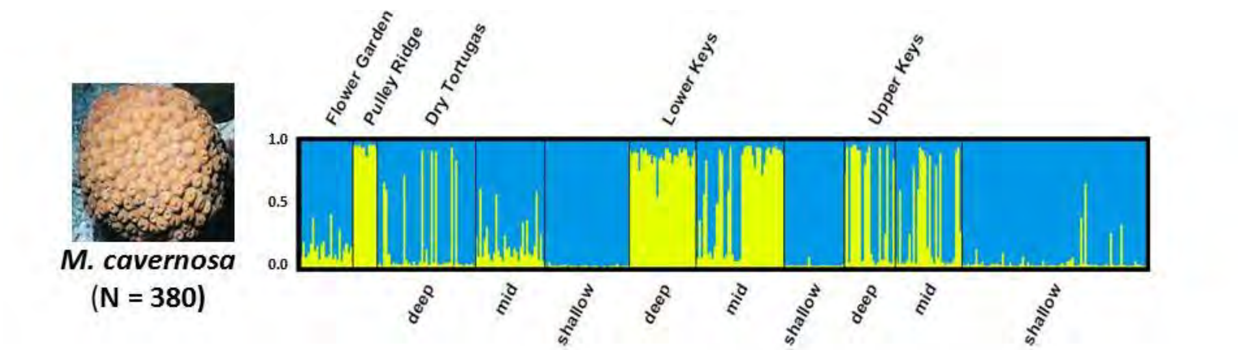


Figure 1: Results of STRUCTURE analysis of *Montastraea cavernosa* samples showing that **Pulley Ridge samples belong to the same population as deep sites in the Florida Keys**, whereas samples from the Flower Garden Banks belong to the same population as shallow sites in the Florida Keys.

Porites astreoides:

No samples of *P. astreoides* have yet been collected from PR due to its extreme rarity at this location. Within Florida (FL), the largest significant differentiation with depth occurred in the Upper Keys, where 79% of the individual colonies at intermediate and deep depths (≥15 m) were assigned to the deep cluster (depicted in yellow, Figure 2). The Flower Garden Banks (FGB) appears to be partially isolated from Florida, as most individuals are strongly assigned (>70% probability of membership) to a third cluster (depicted in pink, Figure 2), despite the presence of a few individuals with high probabilities of membership to either the shallow or deep clusters present in FL.

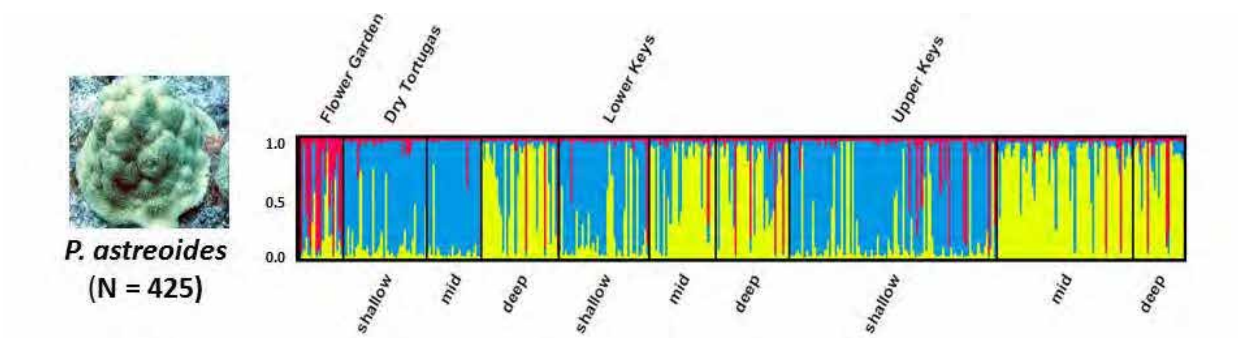


Figure 2: Results of STRUCTURE analysis of *Porites astreoides* samples showing that **samples from the Flower Garden Banks are distinct from Florida populations** and suggesting a lack of effective connectivity. *P. astreoides* is very rare/absent at Pulley Ridge and hence not sampled.

Together, these findings suggest that within Florida, differentiation occurs by depth in both species, although the transition is shallower for *P. astreoides*. However, differentiation also occurs with geographic location (FGB vs. FL) for *P. astreoides*. These findings also suggest that FGB is highly connected to the shallow FL *M. cavernosa* population, albeit partially isolated from FL in the case of *P. astreoides.* One possible explanation is that currents favor long-distance dispersal during the expected annual mass spawning season of *M. cavernosa*, but may be less favorable earlier in the year when *P. astreoides* begins its monthly planulation. Alternatively, the potentially shorter pelagic duration for brooding species like *P. astreoides* could result in higher recruitment within FGB rather than long-distance dispersal.

Modeling coral connectivity between Florida and the Flower Garden Banks: Implications for Pulley Ridge

In collaboration with Drs. Claire Paris and Dan Holstein we used biophysical modeling to assess whether connectivity between the FGB and the Florida Keys (if any) is expected to occur through one or multiple generations, and whether differences in reproductive season and pelagic larval duration (PLD) of *M. cavernosa* and *P. astreoides* could affect connectivity between these two locations (Serrano 2013). Backtracking results for *M. cavernosa* suggest that particles released from a broad area of shallow habitat in the lower Keys and eastern Gulf of Mexico can potentially disperse to the Upper Keys given a 30-day PLD. In contrast, none of the *P. astreoides* backtracking scenarios from the Upper Keys, or the forward tracking from FGB, showed evidence of an overlap among these regions after a maximum PLD of 10 days. Together, findings reveal significant differences in the potential for dispersal and connectivity for *M. cavernosa* compared to *P. astreoides,* as indicated by our genetic data. In all three regions in FL, a much greater potential for dispersal from the GOM region was observed for *M. cavernosa*. Based on these results, we hypothesize that connectivity between the FGB and shallow sites in FL may occur for *M. cavernosa* through the northern GOM region, either over a few generations, or directly by a few rare recruits. Conversely, the lack of overlap between any of the backtracking or forward tracking trajectories for *P. astreoides* suggest little or no connectivity between the FGB and FL, as indicated by our genetic data. However, it is possible that effective connectivity among these regions may occur through a different oceanographic route, perhaps east and south in the GOM, along the Yucatan peninsula. Furthermore, based on the modeling outputs observed for *P. astreoides* it appears likely that there might be more connectivity between FL and PR than that observed between sites in FL and FGB, based on the fact that backtracking results from the Keys suggest PR is well within the PLD envelope.

Differential patterns of connectivity between FGB and FL coral species are of potential interest in the context of the Deepwater Horizon blow out; **we are currently using these data as justification for physiological investigations of oil and dispersant on both coral larvae and adult corals.**

Population Dynamics

No Report

<u>Community structure</u>
(PIs M. Dennis Hanisak, John Reed, Stephanie Farrington (HBOI-FAU), Stacey Harter, and Lt. Heather Moe (NMFS/Southeast Fisheries Science Center)

Objective - Characterize MCEs: To locate, characterize, and determine the distribution of MCEs in the study area

Most of our effort this year was the execution of the August 2014 Pulley Ridge cruise and analyses from the 2012-2014 cruises. Significant progress was made as follows.

2014 Cruise (Cruise No. WS1412, R/V Walton Smith, August 14-28, 2014)

1) Conduct survey transects by ROV to quantify benthic habitat and organisms, and identify suitable specimen collection sites
24 dives with the Mohawk ROV were conducted, with 59 hours of total bottom time and 4,914 images (mostly for quantitative analyses). 27 sites (random blocks, with 5 ROV transects each) were surveyed: 17 sites in the Pulley Ridge area (3 immediately west of the Main Ridge, 7 east of the Main Ridge, 4 on West Ridge, and 3 in "Pulley Basin" (the flat area between the Main Ridge and West Ridge) and 10 sites in the Tortugas area (2 near Miller's Ridge and 8 west of the Sanctuary border. Table 1 and Figures 1-3 provide dive locations and other information for the ROV surveys.

Overall, the 2014 sites on Pulley Ridge had low coral coverage, with the exception of the 3 blocks immediately west of the Main Ridge and those in Pulley Basin; the former in particular are noteworthy due to the large number of small recruits and large expanses of *Agaricia*, unlike anything we saw in our 2012 and 2013 cruises. The sites in the Tortugas were dominated by soft bottoms, with a lot of algal coverage, but we did find several quite nice reefs, with relatively high coral coverage (especially *Monastraea* spp.); most noteworthy was Block 46, just outside the sanctuary border. Table 2 summarizes the overall benthic characterization of the 2014 sites.

2) Conduct CTD profiles at three physical oceanography moorings in the vicinity of the Dry Tortugas and at Pulley Ridge
CTD casts were made at all three physical oceanography moorings [north Tortugas site (TERN), south Tortugas site (TERS), and east of Pulley Ridge (PR)].

3) Conduct sampling with larval fish light traps
The larval fish light traps were successfully deployed on moorings and recovered at Pulley Ridge (4 nights) and in the Tortugas area (3 nights).

4) Capture in situ, real-time images of marine zooplankton with the ISIIS (In Situ Ichthyoplankton Imaging System):
The ISIIS was deployed four times, three successfully (there was a connection problem during the first drop), with the two successes at Pulley Ridge and one in the Tortugas area. A second deployment planned for the Tortugas was scrubbed due to a mechanical problem could not be resolved at sea.

5) Deploy fish traps, with red grouper the primary target
Fish traps were deployed 10 nights, with 214 fish collected, including 25 red grouper, 1 black grouper, and 3 red hind.

6) Deploy drop cameras for comparative analyses of fish observed with ROV sampling
Seven successful deployments (5 drops per deployment) were made with the drop cameras.

7) Deploy seepage meters to obtain ground water samples
Four successful deployments (2 sites per deployment) were made.

8) Deploy satellite-tracked drifting buoys (drifters)
Three drifters were deployed at the CTD sites, as requested by the Physical Oceanography team.

9) Data base and data entry
All cruise data were entered at sea into our database, which we modified to include all of the additional sampling done by Florida State University Fish Group (fish traps, drop cameras, and seepage meters).

10) Dissemination as a NOAA signature cruise
We were again invited by NOAA to be a signature cruise (the Coral Ecosystem Connectivity 2014 expedition) for the Ocean Exploration website. We provided cruise-related materials and submitted 10 blogs while at sea, followed by a Mission Summary (http://oceanexplorer.noaa.gov/explorations/14pulleyridge/logs/logs.html.)

Data Analysis

We have completed quantitative analysis of fish populations, benthic marcrobiota, and habitat for the 2012-2014 ROV dives. We completed a taxonomic photo album of benthic macrobiota photographed during the 2012-2014 cruises. These images included macroalgae; sessile invertebrates – coral, gorgonacea, soft coral, Antipatharia, non-coral Cnidaria, Porifera, Bryozoa, Ascidiacea; and mobile invertebrates – Annelida, Arthropoda, Mollusca, and Echinodermata. These images were utilized in the point count analysis of the quantitative photographic transects.

Data for these three cruises on the R/V *Walton Smith* have been compiled in two cruise reports previously submitted during this year:

1) A combined 2012-2013 Cruise Report, *Characterization of the Deepwater Benthic Habitat and Fish Assemblages from ROV Transects on Pulley Ridge and Tortugas during 2012 and 2013 Cruises* was submitted October 1, 2014 (Farrington et al. 2014).

A total of 42 1-km x 1-km random blocks (28 for Pulley Ridge, PR, and 14 for Tortugas area, T) were analyzed from 44 ROV dives, covering 45.45 km (PR = 32.6 km; T = 12.83 km), at depths from 94.5 m to 23.1 m (PR = 94.5 m - 60.3 m; T = 58 m - 23.1 m). A total of 99.75 hours (PR = 74.5; T = 24.5) of ROV video were recorded and 7,563 *in situ* digital images were taken which included quantitative transect images (7,336), general habitat images, and species documentation images.

All fish were identified for each ROV dive to species level and counted. The total distance (km) of each dive was used to calculate the linear density (# individuals km^{-1}) of each fish species. A total of 111 fish taxa were identified from both Pulley Ridge and Tortugas dives in 2012 and 2013. The most common species included sharpnose puffer, cherubfish, reef butterflyfish, yellowtail reeffish, sunshinefish, purple reeffish, squirrelfish, wrasse bass, orangeback bass, chalk bass, greenblotch parrotfish, and bicolor damselfish. Unfortunately, lionfish were also abundant, mostly associated with red grouper burrows, and present in 72% of the blocks. A total of 703 lionfish were counted over both years. Fifteen species of commercially and recreationally important grouper and snapper species were counted (total 681 individuals). The dominant species were vermilion snapper (428), black grouper (13), graysby (19), mutton snapper (41), red grouper (88), and scamp (56).

Quantitative phototransects were conducted during each ROV dive with a digital still camera pointing straight down (or perpendicular to the substrate as possible) with parallel lasers (10 cm) for scale. In general, digital images were taken every 30 seconds within the 100-m transects throughout the dive. Percent cover of substrate type and benthic macrobiota was determined by analyzing the quantitative transect images with Coral Point Count with Excel extensions (CPCe 4.1©, Kohler and Gill 2006). Fifty random points overlaid on each image were identified as substrate type and benthic taxa. Substrate categories included: soft bottom (unconsolidated sand, mud) and hard bottom, which was subdivided into rock (pavement, boulder, ledge), rock rubble/cobble (generally, 5-20 cm diameter), and bare dead coral plate. All benthic macrobiota (usually >3 cm) were identified to the lowest taxa level possible.

A total of 216 benthic biota taxa were identified from Pulley Ridge and 196 taxa from Tortugas transects. These included 102/60 taxa, respectively, of Porifera, and 47/54 Cnidaria which included 32 Scleractinia, 27 Alcyonacea (gorgonacea), and 4 Antipatharia. The density and diameter of plate corals (*Agaricia* sp., *A. fragilis*, *A. lamarcki/grahamae*, *Leptoseris cucullata* and *Montastraea cavernosa*) were calculated for all the Pulley Ridge transect photos for both 2012 and 2013 cruises. Mean percent cover of plate corals was 0.55% and mean density was 0.54 colonies m^{-2}. The southern part of the Main Pulley Ridge had the greatest coral cover (1.69%) and density (3.66 colonies m^{-2}). What is chilling is the apparent loss of coral cover over the past 10 years. Surveys conducted by USGS in 2003 documented a mean coral cover on Pulley Ridge of 11.90%, with a maximum of 23.23% in the central region of the ridge. By 2013, we report an average coral cover of 0.85%, and a maximum of 5.62% (Block 18). The overall mean coral cover went from 11.90% to 0.85% which is a 92.8% loss of coral cover in 10 years! At this time we cannot say with certainty the cause of this loss.

On a positive note, a large number of the corals are relatively new recruits: 47.7% were <5 cm in diameter, and 35.4% were 5-9 cm.

2) The 2014 Cruise Report, *Characterization of the Mesophotic Benthic Habitat and Fish Assemblages from ROV Dives on Pulley Ridge and Tortugas during 2014 R/V Walton Smith Cruise*, was submitted on April 3, 2105 (Reed et al. 2015).

In 2014 a total of 24 ROV dives surveyed 27 random blocks (17 blocks in PR and 10 in Tortugas (Table 2). The 24 ROV dives covered 25.68 km (PR = 15.52 km; T = 10.16 km), at depths from 27 to 115 m (PR = 64-87 m; T = 27-115 m). A total of 59 hours of ROV video were recorded and 5,323 *in situ* digital images were taken which included quantitative transect images (4,323), general habitat images, and species documentation images.

All fish were identified for each dive to species level and counted. The total distance (km) of each dive was used to calculate the linear density (# individuals km^{-1}) of each fish species. A total of 116 fish taxa were identified from both Pulley Ridge and Tortugas dives in 2014.

A total of 197 benthic macrobiota were identified from the quantitative image analysis at Pulley Ridge and Tortugas. The most diverse taxa by far were sponges (78 taxa). The other sessile benthic taxa included 18 Chlorophyta, 7 Rhodophyta, 6 Phaeophyta, 27 Scleractinia (hard corals), 19 gorgonian octocorals, 5 Antipatharia, Bryozoa, and Ascidiacea; mobile invertebrates included Annelida, Mollusca, Arthropoda, and Echinodermata. Coverage of biota at Pulley Ridge was dominated by various algae (51.42% cover). Coralline red algae (up to 63% cover) and the lettuce-like green algae *Anadyomene menziesii* (10.1%) were the most common.

The diversity of the scleractinian coral fauna at these mesophotic reef sites is quite rich; a total of 27 coral species were identified at all sites. The dominant species at PR included *Agaricia fragilis, A. lamarcki/grahamae, A. undata, Helioseris cucullata* (previously *Leptoseris cucullata*), *Madracis aurentenra*, *M. formosa, M. decactis*, and *Oculina diffusa*. As pointed out above, in the previous cruises of 2012 and 2013 we found that the overall average coral cover dropped from 11.90% (USGS 2003 data) to 0.85% (2012-2013 data) which is a 92.8% loss of coral cover in 10 years within the Pulley Ridge Habitat Area of Particular Concern (PRHAPC). However, in 2014 more blocks were added outside of the PR HAPC and to the west of the main Pulley Ridge to fill in the relatively unstudied West Ridge, and for the first time, areas of the Central Basin where we discovered some of the highest coral cover that we have seen to date in our cruises. The density in the Central Basin was 5.58 colonies m^{-2}; Block 83, which is outside the PR HAPC, had the greatest density of all the blocks with 17.05 colonies m^{-2}. *Agaricia* spp. had the greatest density of 16.82 colonies m^{-2}. A great majority of these were small plate agariciid coral so it appears that the coral is growing back from whatever die-off occurred after 2003.

At the Tortugas, mesophotic patch reefs were discovered inside three blocks, and an extensive fringing reef was surveyed just west of the North Tortugas Ecological Reserve (TER). Hard corals averaged 3.22% cover on these reefs, and comprised 3.96% cover on the fringing reef (Block 46) and 2.51% on the patch reefs. Gorgonians averaged 9.62% cover, sponges 5.44%, and algae 4.53%. All of these sites are outside of the boundaries of the Florida Keys National Marine Sanctuary (FKNMS) and the TER.

Table 1. ROV dive sites during 2014 R/V *Walton Smith* cruise (Site Number = Day-Month-Year-Site).

Site Number dd-mm-yy-#	Method	Latitude (On Bottom)	Longitude (On Bottom)	Latitude (Off Bottom)	Longitude (Off Bottom)	Depth Range (m)	Distance (km)	Block Number	Bottom Time (h:mm)
16-VIII-14-1	ROV 14-01	24.8163	-83.7326	24.8099	-83.7274	78 - 80	0.88	Block 25	2:27
16-VIII-14-3	ROV 14-02	24.7872	-83.7316	24.7795	-83.7294	78 - 82	0.89	Block 29	1:55
17-VIII-14-1	ROV 14-03	24.7841	-83.6602	24.7773	-83.6552	68.5 - 70.3	0.91	Block 27	2:39
17-VIII-14-3	ROV 14-04	24.8144	-83.6380	24.8079	-83.6373	67.3 - 69.4	0.73	Block 23	1:56
18-VIII-14-1	ROV 14-05	24.7871	-83.7139	24.7939	-83.7200	79 - 80.5	0.97	Block 28	1:56
18-VIII-14-4	ROV 14-06	24.7068	-83.6497	24.7124	-83.6497	64.7 - 65.5	0.62	Block 32	1:50
19-VIII-14-1	ROV 14-07	24.7572	-83.7249	24.7538	-83.7326	74 - 76.4	0.87	Block 30	2:44
20-VIII-14-1	ROV 14-08	24.9176	-83.8035	24.9308	-83.7895	78.8 - 81	2.04	Block 35 & 34	4:29
20-VIII-14-4	ROV 14-09	24.9095	-83.8082	24.8349	-83.8173	78.4 - 82.5	1.25	Block 36	2:10
20-VIII-14-5	ROV 14-10	24.8940	-83.8229	24.8269	-83.8269	80 - 82.5	0.79	Block 37	1:30
21-VIII-14-1	ROV 14-11	24.8321	-84.7819	24.8270	-83.7841	80.8 - 83.2	0.62	Block 76	2:49
21-VIII-14-2	ROV 14-12	24.8294	-83.8022	24.8239	-83.8116	80.1 - 81.9	1.12	Block 77	1:49
21-VIII-14-3	ROV 14-13	24.8391	-83.8295	24.8350	-83.8366	83 - 87	0.85	Block 79	2:19
22-VIII-14-1	ROV 14-14	24.7543	-83.7583	24.7576	-83.7756	77 - 78.6	1.79	Block 31 & NR-82	3:52
22-VIII-14-3	ROV 14-15	24.7617	-83.7866	24.7672	-83.7944	81.7 - 83.5	0.99	NR-Block 83	1:45
22-VIII-14-4	ROV 14-16	24.7110	-83.6543	24.7098	-83.6557	64 - 66.5	0.20	Block 32	0:31
23-VIII-14-1	ROV 14-17	24.4784	-83.2425	24.4868	-83.2433	83 - 112	0.94	Block 75	2:20
23-VIII-14-2	ROV 14-18	24.4689	-83.2126	24.4756	-83.2127	82.5 - 115.2	0.75	Block 74	2:35
24-VIII-14-2	ROV 14-19	24.5344	-83.0236	24.5490	-83.0423	27.5 - 31.8	2.49	Block 68 & 66	3:39
24-VIII-14-4	ROV 14-20	24.5242	-83.0023	24.5285	-83.0101	31 - 32.5	0.92	Block 61	1:37
25-VIII-14-1	ROV 14-21	24.5689	-83.0644	24.5805	-83.0697	31.2 - 32.2	1.39	Block 69	1:44
25-VIII-14-2	ROV 14-22	24.5947	-83.0944	24.6015	-83.1009	31.9 - 34.5	1.00	Block 63	1:58
25-VIII-14-3	ROV 14-23	24.6305	-83.1042	24.6371	-83.1033	27 - 30.8	0.74	Block 46	1:14
26-VIII-14-1	ROV 14-24	24.5218	-82.9970	24.5045	-82.9981	30 - 33	1.93	Block 67 & 70	2:34

Table 2. Percent cover (CPCe Point Count) of benthic macrobiota and bare substrate for ROV sites surveyed at Pulley Ridge and Tortugas during 2014 R/V *Walton Smith* cruise.

Region	No. Blocks	% Bare Hard	% Bare Soft	% Human	% Biota	Grand Total	Depth Range (m)

		Bottom	Bottom	Debris			
Pulley Ridge	**16**	**34.03%**	**11.27%**	**0.01%**	**54.68%**	**100.00%**	**61.6 - 86.1**
Main Ridge-South	1	46.22%	0.15%	0.00%	53.63%	100.00%	72.2 - 76.3
Off Main Ridge	4	46.45%	30.55%	0.00%	23.00%	100.00%	61.6 - 69.5
Central Basin	8	31.79%	8.42%	0.01%	59.77%	100.00%	72.2 - 86.1
West Ridge	3	29.82%	10.84%	0.00%	59.34%	100.00%	76.7 - 85.3
Tortugas	**10**	**19.74%**	**58.75%**	**0.02%**	**21.49%**	**100.00%**	**22.9 - 114.8**
Reef	4	17.75%	49.27%	0.01%	32.97%	100.00%	27-32.5
Hard Bottom	2	61.47%	33.76%	0.08%	4.69%	100.00%	79.2 - 114.8
Soft Bottom	4	0.83%	80.77%	0.00%	18.40%	100.00%	30.0-34.5
Grand Total	**26**	**28.54%**	**29.53%**	**0.01%**	**41.92%**	**100.00%**	**22.9-114.8**

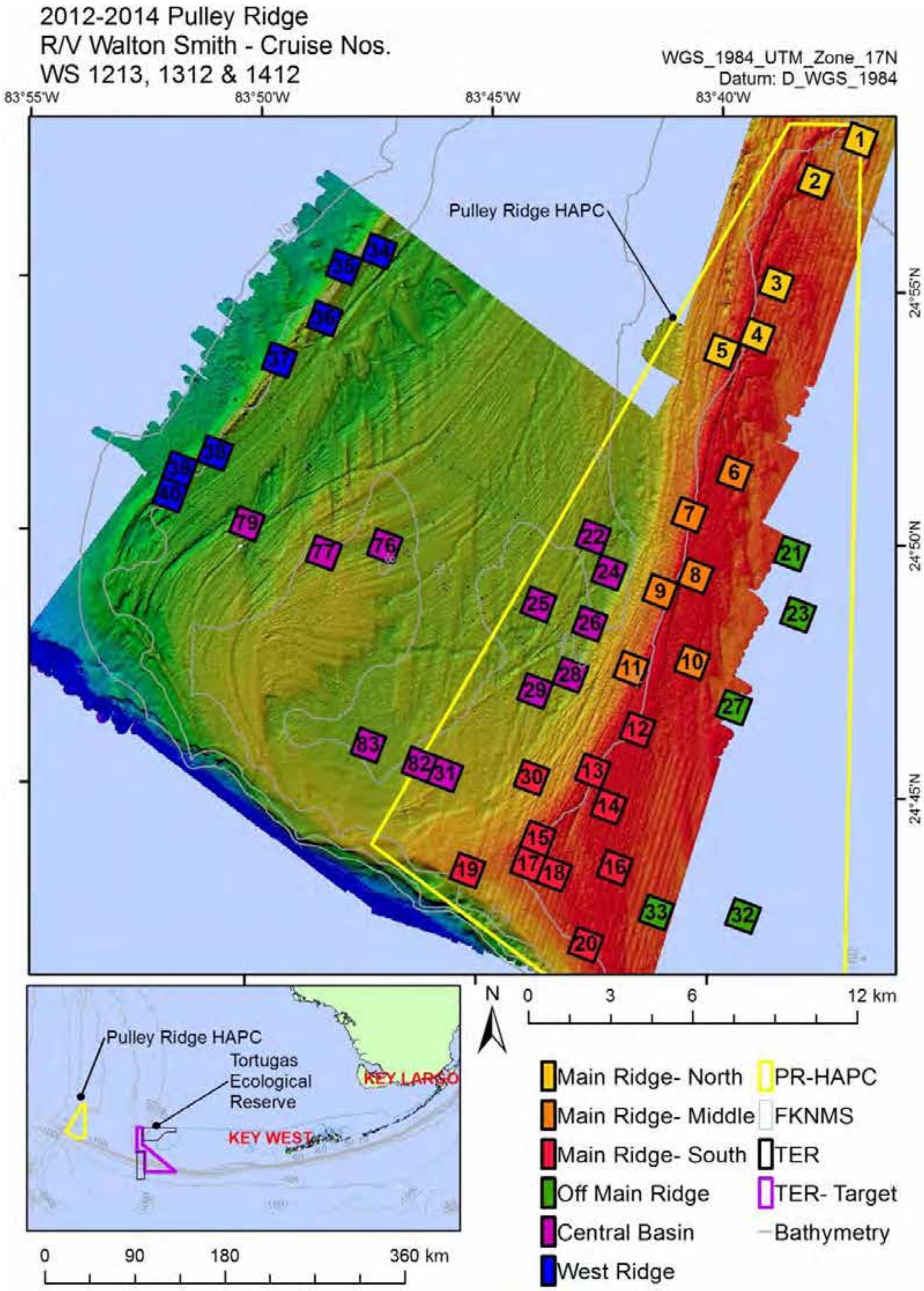


Figure 1. Random Blocks from 2012-2014 R/V *Walton Smith* cruises showing habitat zones based on multibeam map and ROV dives. Pulley Ridge Habitat Area of Particular Concern (PR HAPC) boundaries in yellow. Background map: Naar, D.F. 1999. Multibeam Bathymetry Survey, USF.

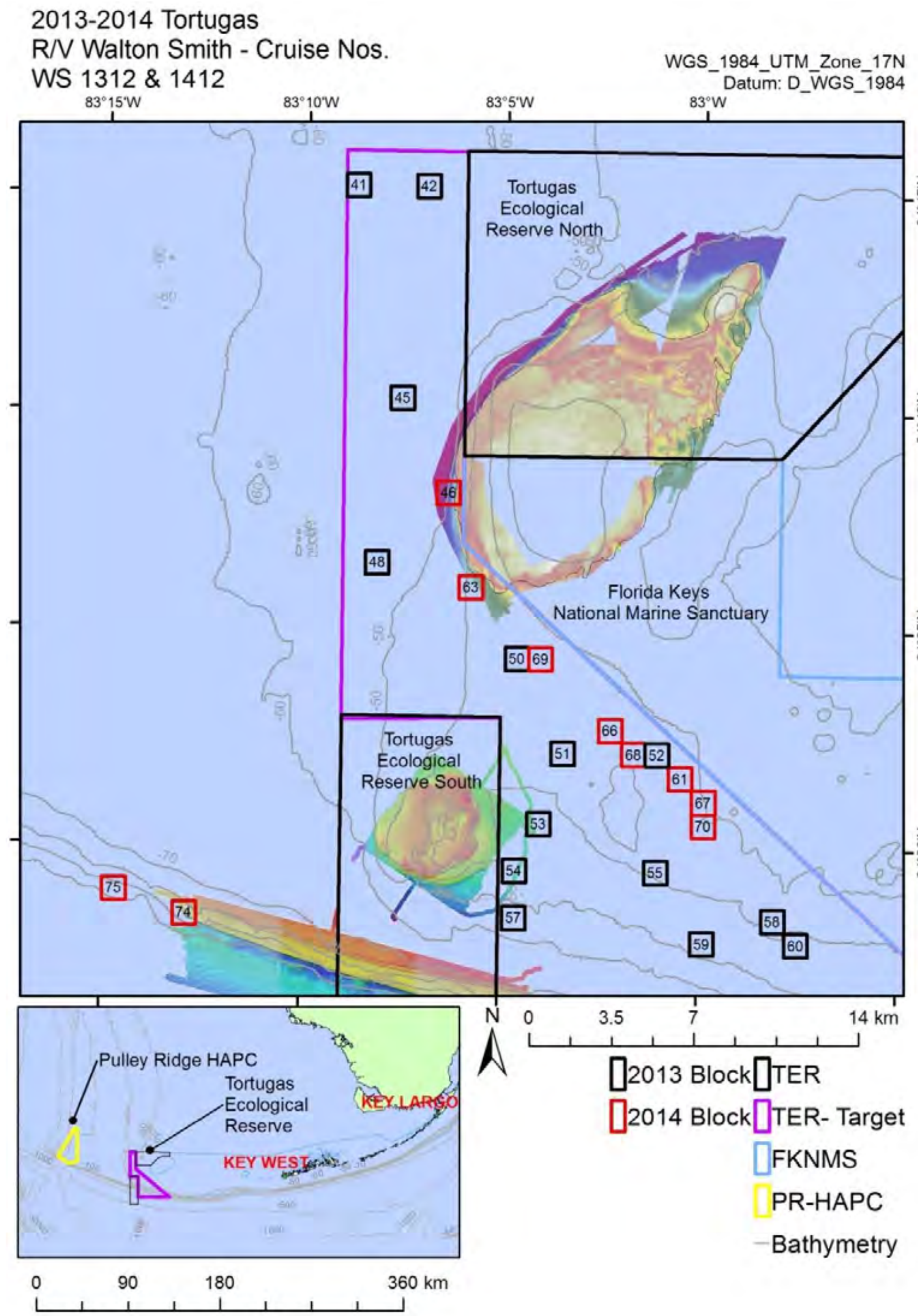


Figure 2. Random 1 km x 1 km blocks surveyed at Tortugas by ROV during the 2013-2014 R/V *Walton Smith* cruises. Blocks surveyed during the 2014 cruise are in red. All sites are outside of the boundaries of the Tortugas Ecological Reserves (TER) and the Florida Keys National Marine Sanctuary (FKNMS). Background maps: Miller's Ledge – Robertson E. 2002. Multibeam Bathymetry Survey, USF, 2002; TER – Donahue S. 2011. Multibeam Bathymetry Survey, NF-11-06-FKNMS.

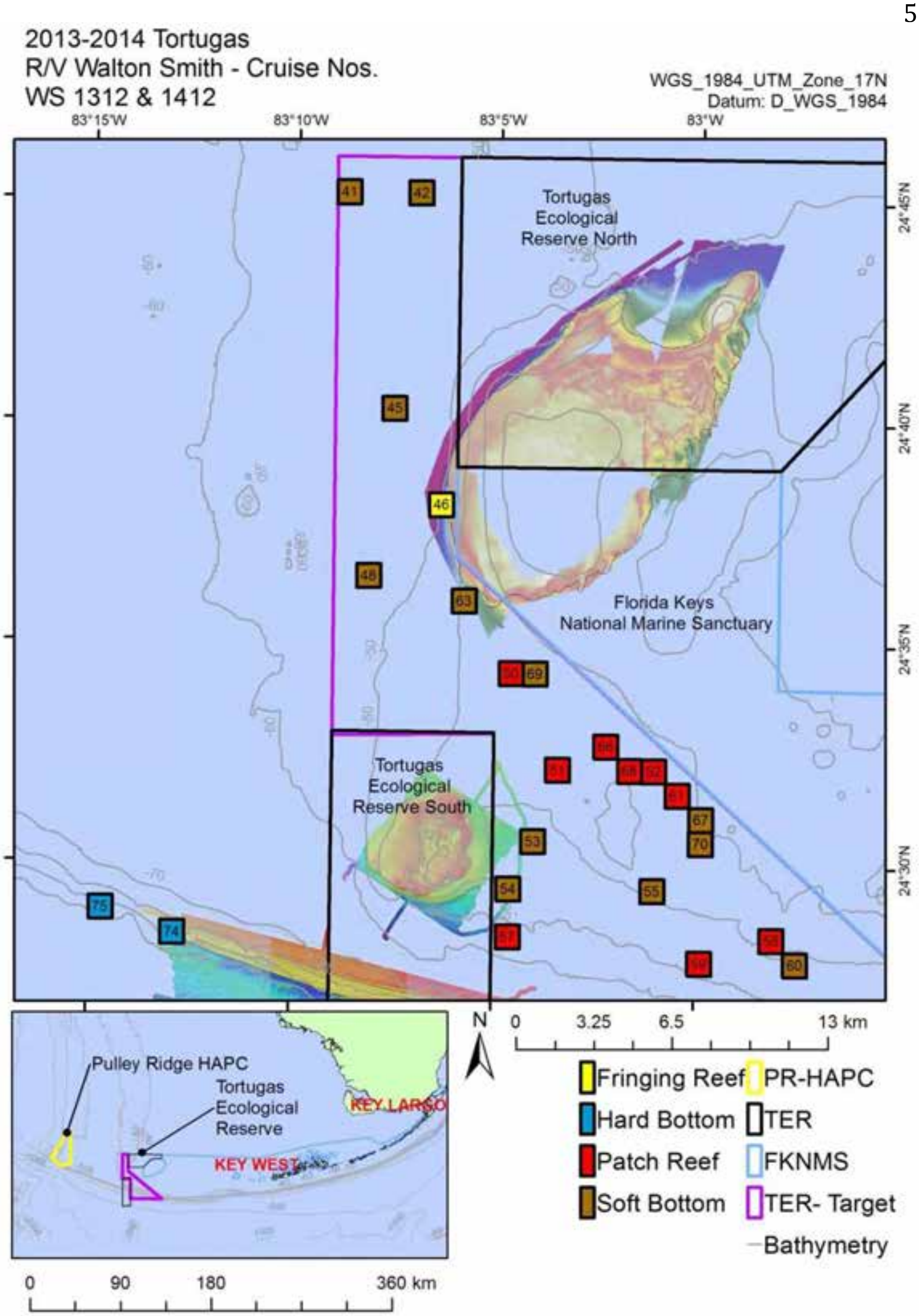


Figure 3. Random Blocks from 2013-2014 R/V *Walton Smith* cruises showing habitat zones based on multibeam maps and ROV dives. Background maps: Miller's Ledge – Robertson E. 2002. Multibeam Bathymetry Survey, USF, 2002; TER – Donahue S. 2011. Multibeam Bathymetry Survey, NF-11-06-FKNMS.

3) We have acquired and analyzed historical images taken by Continental Shelf Associates (CSA) at a site on Pulley Ridge for a Mineral Management Survey-sponsored project conducted in the early 1980s on the Southwest Florida shelf.

CSA used a "camera sled" consisting of a video, still camera, lights, and strobe that were attached to a pan & tilt unit mounted within a rectangular steel cage constructed of ~1" angle iron. The video camera was pointed forward at an oblique angle to seafloor and during the quantitative surveys a Benthos still camera was aligned perpendicular to the seafloor and shot photos down through the bottom of the sled.

Earlier this year, we acquired the imagery and digitized the old CSA photos from their Site 29 on Pulley Ridge and quantified benthic coverage similar to what we have done for our 2012-2014 cruises. Also, we were able in our May 2015 CIOERT cruise to run transects at the old CSA site with the Mohawk ROV. Our initial analysis of the 1981 images was similar to what CSA had calculated for the MMS report in 1982; the results indicate a decline of *Agaricia* from 9.2% in 1981 to 0.32% in 2015, consistent with our analyses of the USGS data. These data will be included in our overall analysis of the benthic community at Pulley Ridge, which will be done after our final cruise for this project in August-September 2015.

Bioeconomics
(PI: David Die; co-PI: Mahadev Bhat; Research Associate: Nadia Seeteram)

The socio-economic analysis component of the project started only during the 3rd year of the project. For this phase of the project, our goal is to analyze the economic impacts of expanding HAPC or other sanctuary regulations in the Pulley Ridge and Dry Tortugas regions of Southwest coast of Florida. This analysis requires us to first understand the size of the current commercial fishing operations by gear and species. This will allow us to trace the regulation-induced impacts on different types of fishing and non-fish businesses in the region. We initiated three different activities during the year.

First, we worked with Dr. David R. Gloeckner, Chief of the Fishery Monitoring Branch, NOAA Fisheries Southeast Fisheries Science Center, and the representative of their contracting firm, Mr. Brett Pierce, to extract fisheries data from the NMFS Vessels Monitoring Data System and other economic data for the study region. This data mining was a time consuming process which required developing lengthy data processing codes and ensuring that the confidentiality of the vessels operating in the region was not compromised. The data to be processed included several variables: species- and gear-wise catch from six specific NMFS data regions of the study area, number of trips, landings by major ports of the Southwest coast of Florida, dockside prices, and other economic fishery input data. At the time of this report, the data has been extracted and is being reviewed by the Dr. Gloeckner for confidentially compliance before the final data release.

We also acquired commercially available regional input-output economic modeling software along with the economic data, called IMPLAN (IMPact for PLANing). The model consists of data on industry by industry regional economic transactions (total industry purchases, output, income payment, exports, taxes and regional consumption). The purpose of this model is to look at the impacts of changes in management-induced fishery catch by species and gear types on the economies of the eight counties along the Southwest coast Florida. Each county model consists of more than 200 economic sectors. For the purpose of our analysis, we needed to map fishery-relevant input and output economic sectors to the default economic sectors of IMPLAN. We have developed a customized industry-by-industry template of about 25 economic sectors. This process allows us to reduce the original IMPLAN model of each county with over 200 sectors to a smaller and more manageable 25 by 25 economic input-output model. Once we acquire the NMFS data, our next step would be to map the fishery catch data of various Pulley Ridge regions to specific county level IMPLAN input-out models and then simulate the effects of various policy-relevant changes on the county and west coast regional economies.

Finally, we have developed a 15-page survey instrument for evaluating the perception of commercial fishers relating to proposed expansion of HAPC regulations in the Pulley Ridge area. We have completed the IRB process at Florida International University. We are currently administering a pilot survey. Also, we consulted with Ms. Beth Dieveney and Mr. Scott Donahue of the Florida National Marine Sanctuary Program to make sure that the survey instrument accurately reflects the current and proposed regulations. We also contacted the President of the commercial fisheries association in Key West and other fishery scholars (e.g., Dr. Manoj Shivalani) during the development of this survey for inputs and suggestions. After the pilot survey is completed, we will soon launch the actual survey online using Qualtrics.

Decision Support Tool

Activities during current funding period

We have begun work on the primary aim of the DST component; i.e., construction of the Decision Support Resource (DSR - originally called the Decision Support Toolkit - DST). The DSR will be a multi-tier, web-based search application that will present a comprehensive view to decision makers, researchers and the general public for exploring and accessing information collected and generated by the entire project. The DSR will integrate project information at both the dataset level (e.g., all data collected during a specific cruise, or generated by a specific model run) and the level of individual observations (e.g., a specific *in situ* observation of a red grouper). Integration at the dataset level will provide users with the ability to compare datasets and select those that may contain complementary information for use in analysis. Integration at the level of individual observations will enable users to download subsets of data, and also enable us (the DST component) to produce graphical presentations (e.g., maps, charts) and summary statistics to aid decision makers in making use of project data.

Key to enabling this integration is the definition and annotation of metatdata at both of these levels (dataset and observation). In support of this objective we have drafted initial metadata annotation conventions and are using (and revising) these to annotate datasets from Harbor Branch (data contained in the HBOI At Sea Database; John Reed - P.I.) and simulation output produced by the Connectivity Modeling System (Clair Paris - P.I.). We are also evaluating assigning Archival Resource Keys (ARK)[1] and/or Digital Object Identifiers (DOIs)[2] to datasets (and subsets), which will provide permanent URL references for these data that can be used for citation in journal articles and other applications where data provenance is important.

We have also begun development of the DSR, beginning with features to support annotation, search and access to datasets. The architecture of the DSR is highly influenced by work done by the University of Miami Center for Computational Science (CCS), Software Engineering Group on other projects involving the integration of scientific data from multiple sources[3], as well as the display and exploration of geographically linked information[4]. The DSR will built using open source technology, allowing sharing and reuse of the system/framework and code. The DSR is being built as a multi-tier, web-based application [Fig1]. The three core tiers (i.e., presentation, service and storage) standard for this type of architectural approach will be implemented using: 1) A combination of HTML and Javascript (jQuery[5] and AngularJS[6]) at the presentation layer; 2) Both Java-based servlets (deployed on Apache Tomcat[7]) and Javascript services (deployed on node.js [8]) at the service tier; and 3) A storage tier built using a combination of PostgreSQL/PostGIS [9, 10] and MongoDB [11].

The first internal release of the DSR, with features for dataset annotation and search, is currently planned for July 2015. This will be an alpha release used to help continue to elite features from the Pulley Ridge project P.I.s that will be incrementally added to enhance the system prior to an initial public release in the Fall. The system will continue be enhanced with new features and data throughout the remainder of the project.

An important recent addition to the project team has been the hiring of Chance Scott, who had been contributing to the project as a graduate student (part-time), but is now a full-time member of the project. Mr. Scott is a graduate of the University of Miami M.A. program in Geography and Regional Studies. While not a software developer, Mr. Scott's expertise in both the analysis of spatial data and the use of GIS systems will prove invaluable in helping with the integration of datasets, as well as the production of other materials for use in visualization (e.g., maps and raster images).

We also recently purchased an additional 28 terabytes of storage space for use by the project.

Planned activities
As stated above we have begun construction of the DSR, with internal releases beginning in July. We will be following an incremental, iterative (agile), development strategy resulting in regular incremental releases (approximately every 4-6 weeks). Initially these releases will be made available to the project internally, and then made publicly available after internal review. We will continue development of the DSR both by adding application features and new data for the remainder of the project.

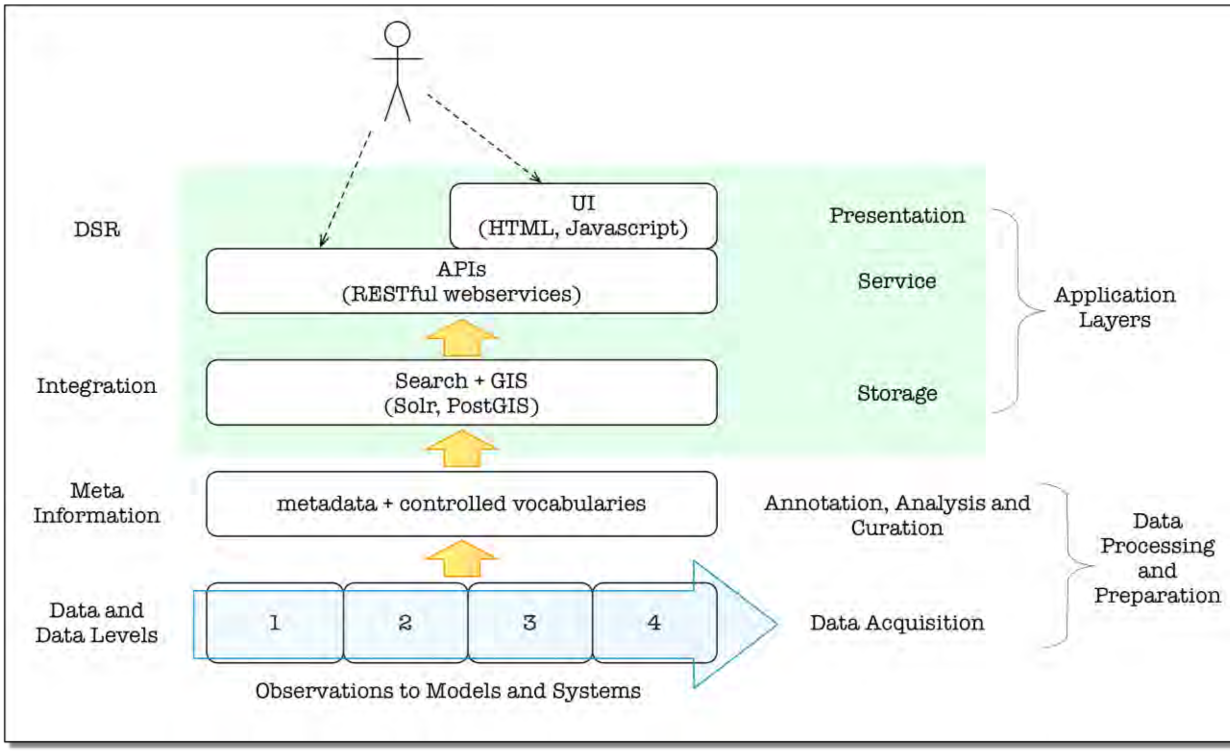


Figure 1: Component level diagram for the Decision Support Resource

Reference List

1. **Archival Resource Key** [http://en.wikipedia.org/wiki/Archival_Resource_Key]

2. **Digital object identifier (DOI)** [http://en.wikipedia.org/wiki/Digital_object_identifier]

3. **LIFE** [http://life.ccs.miami.edu]

4. **MAP: Miami Affordability Project** [http://comte.ccs.miami.edu/housing/]

5. **jQuery** [http://www.jQuery.com]

6. **AngularJS** [https://angularjs.org]

7. **Apache Tomcat** [http://tomcat.apache.org]
8. **node.js** [https://nodejs.org]
9. **PostgreSQL** [http://www.postgresql.org]
10. **PostGIS** [http://postgis.refractions.net]
11. **MongoDB** [http://www.mongodb.org]

Management Application (MA)

During this last project period we have lost a member of our Stakeholder Advisory Board (SAB) reflecting changes in assignment on the agencies part. We have yet to identify a suitable replacement for Alyssa Dausman of USGS however given the participation of Cathy Tortucci this might be moot.

We invited any members able to join us to attend the December 2-3 2014. All-PI meeting held in Miami after which we held an SAB meeting at CIMAS (See Appendix A for the Agenda and Appendix B for the attendee list). Those present already attended in person and many of the others attended electronically using GOTOMEETING. We reported the results of the August cruise and discussed at length not only the progress made to date but the exciting opportunity afforded us with the supplementary technology development funding provided by OAR and the additional shiptime provided by OER. The question focused upon was how to best capitalize upon these. We requested the SAB's advice on what particular products or outcomes would be most useful to their organizations and the following was provided:

1) A benthic ROV survey of the wider Habitat Area of Particular Concern (HAPC) area around the central polygon we have focused upon (and making these data available as quickly as possible even if high level -e.g., coral cover, bottom type, readily identifiable species or taxa) would be especially useful to the GFMC. The GFMC is interested in knowing if the current HAPC boundaries need to be expanded. There criteria for expansion is presence of coral.
2) A benthic ROV survey just outside the southwest corner of the North Tortugas Reserve would be useful to the Florida Keys National Marine Sanctuary.
3) Our methods of integration and analysis of video taxa identification, biophysical modeling and larval connectivity quantification (best proven practices) would be useful to the South Atlantic Fishery Management Council with respect to their own marine protected area process; and
4) Genetic analytical approaches to establishing larval sources is highly relevant to both Fishery Management Councils and the National Marine Sanctuary office.

Items (1) and (2) have been incorporated into our current cruise planning for this season. We had one RV/WALTON SMITH cruise in May 2015 and have another in August 2015. In June 2015 we will have an RV/SPREE technical diving cruise. We

have yet to provide (no specific requests have been made) our methods of integration and analysis to the SAFMC nor our genetic analytical methods to either the FMCs or NMS office. On the other hand we were specifically requested to assist the FKNMS with respect to their need to develop a Draft Environmental Impact Statement for extension of potential boundary extension with respect to the DTER and the HAPC at Pulley Ridge. We provided relevant and useful information in precisely the form requested. Moreover our FKNMS SAB member was very helpful to us in obtaining for the first time a permit to collect in Dry Tortugas North Ecological Reserve and collecting *Agaricia* spp. therein will be a major objective of the June technical diving cruise. Last we were approached and have agreed to make a presentation on the project and its results to the August 18 FKNMS Advisory Council meeting and a member of our Program Management team will make herself available to do so (S. Pomponi). Most recently on the cruise taken this May as part of our technology development supplement, not only did the technologies we were able to test perform admirably (side scan AUV and sampling "platform" for ROV) but the team discovered a deep water reef providing grouper, tilefish and snapper habitat just outside of the FKNMS. See http://www.fau.edu/hboi/cioert/cioert_at_sea.php
These data were immediately provided to the NMS and the FKNMS.

2. Applications:

Provide a brief summary of work to be performed during the next year of support, if changed from the original proposal; and indication of any current problems or unusual developments that may lead to deviation of research directions or delay of progress toward achieving project objectives.

The main emphasis of our work over the next year will be to conduct the August-September 2015 cruise, the last one planned for this project, to complete the characterization of community structure at Pulley Ridge and nearby mesophotic system, per the proposal, and analyses of data from that and previous cruises. In addition, the added collection capabilities of the ROV will be used on the 2015 cruise in order to confirm species identifications of many of the species in our quantitative images.

Samples from the previous and upcoming SPREE cruises will be disseminated to the relevant laboratories for genetic and reproductive biology studies. Time required for full analysis will vary by taxa/laboratory (in part due to timing of funding availability, and in part due to change in targeted taxa).

We have had to accommodate significant budget reductions in the planning and execution of this projects goals. Specifically, we have had to eliminate the proposed 3rd year of work for the Population Dynamics team as well as the Decision Support Tool (DST) team in order to help meet our field program goals. The FY13 deferment and 25% cut to the overall plan is costing the team key access to population/fishing data on fish species for input to the DST. Further, with this delay in funding to the DST team, our final output products will likely be delayed, thus we will likely require a no-cost extension of 1 or 2 years.

a. Outputs

i. New fundamental or applied knowledge

Reed J.K., S. Farrington, S. Harter, H. Moe, D. Hanisak, and A. David. 2015. Characterization of the mesophotic benthic habitat and fish assemblages from ROV dives on Pulley Ridge and Tortugas during 2014 R/V *Walton Smith* cruise. Report to NOAA Office of Ocean Exploration and Research, and NOAA Deep Sea Coral Research and Technology Program. HBOI Technical Report Number 157.

Farrington, S., J. Reed, H. Moe, S. Harter, D. Hanisak, and A. David. 2014. Characterization of the Mesophotic Benthic Habitat and Fish Assemblages from ROV Dives on Pulley Ridge and Tortugas during 2012 and 2013 R/V *Walton Smith* Cruises. NOAA CIOERT Cruise Report. Report to NOAA-NOS-NCCOS. 44 pp. HBOI Technical Report Number 147.

Reed, J.K. and S. Farrington. 2014. Photo album and taxonomy of benthic macrobiota from 2012-2013 ROV dives on Pulley Ridge mesophotic reef. 69 pp. HBOI Technical Report Number 149.

Reed, J.K. and S. Farrington. 2014. Photo album and taxonomy of benthic macrobiota from 2012-2013 ROV dives on Tortugas mesophotic reef. 37 pp. HBOI Technical Report Number 150.

Reed, J.K. and S. Farrington. 2014. A proposal to the Gulf of Mexico Fishery Management Council for the expansion of the Pulley Ridge HAPC boundaries. Report to GOMFMC. HBOI Technical Report.

Reed, J.K. and S. Farrington. 2014. A proposal to the Gulf of Mexico Fishery Management Council for the expansion of Florida Keys National Marine Sanctuary boundaries. Report to FKNMS. HBOI Technical Report.

Reed, John K., Stephanie Farrington, Dennis Hanisak, Kevin Rademacher. 2012. NOAA SEADESC Level I Report for the 2012 Pulley Ridge Cruise, August 14-25, 2012, R/V Walton Smith and UNCW Superphantom ROV. Report to NOAA-NOS-NCCOS, 57 pp.

Reed, John K., Dennis Hanisak, Stephanie Farrington, Kevin Rademacher. 2012. Preliminary cruise report, "Connectivity of the Pulley Ridge - South Florida Coral Reef Ecosystem: Processes to Decision-Support Tools". 2012 Pulley Ridge Cruise, August 14-25, 2012, R/V Walton Smith and UNCW Superphantom ROV. Report to NOAA-NOS-NCCOS, 66 pp. HBOI Miscellaneous Contribution Number 824.

New fundamental or applied knowledge in these reports:

The cruises to date have resulted in a rich set of new data discovering and characterizing mesophotic reef sites on Pulley Ridge and within the Pulley Ridge HAPC.

These data will be useful for site selection, habitat characterization, and coral health assessment by the UM-REPP Connectivity Pulley Ridge project in planning and executing the 2014 sampling cruises.

ii. Scientific publications

Ault, J.S., S.G. Smith, J.A. Browder, W. Nuttle, E.C. Franklin, G.T. DiNardo, and J.A. Bohnsack. 2014. Indicators for assessing the ecological and sustainability dynamics of southern Florida's coral reef and coastal fisheries. Ecological Indicators 44:164-172 http://dx.doi.org/10.1016/j.ecolind.2014.04.013

Le Hénaff, M., V.H. Kourafalou, R. Dussurget and R. Lumpkin, 2014. Cyclonic activity in the eastern Gulf of Mexico: characterization from along-track altimetry and *in situ* drifter trajectories. *Progress in Oceanography*. pp. 120-138, doi: 10.1016/j.pocean.2013.08.002.

Kourafalou V.H., P. De Mey, M. Le Hénaff, G. Charria, C.A. Edwards, R. He, M. Herzfeld, A. Pasqual, E. Stanev, J. Tintoré, N. Usui, A. Van Der Westhuysen, J. Wilkin and X. Zhu, 2015. Coastal Ocean Forecasting: system integration and validation*. Journal of Operational Oceanography*, doi:10.1080/1755876X.2015.1022336.

Vaz, A.C., C.B. Paris, M.J. Olascoaga, V.H. Kourafalou, and H. Kang (Submitted). The perfect storm: match-mismatch of bio-physical events drives larval reef fish connectivity between Pulley Ridge and the Florida Keys. *Cont. Shelf Res.*

Serrano X, Baums I, O'Reilly K, Smith T, Jones R, Shearer T, Nunes F, Baker AC (*in press*) Geographic differences in vertical connectivity in the Caribbean coral *Montastraea cavernosa* despite high levels of horizontal connectivity at shallow.

Sponaugle, S. 2015. Recruitment of coral reef fishes: linkages across stages. *In*: C. Mora (ed), Ecology of fishes on coral reefs. Cambridge University Press

Shulzitski K., S. Sponaugle, M. Hauff, K. Walter, E. D'Alessandro, and R.K. Cowen. 2015. Close encounters with eddies: oceanographic features increase growth of larval reef fishes during their journey to the reef. Biology Letters 11: 20140746

Serrano XM (2013) Horizontal vs. vertical connectivity in Caribbean reef corals: Identifying potential sources of recruitment following disturbance. Ph.D. dissertation, University of Miami. *Open Access Dissertations,* paper 1101.

Serrano X, Baums I, O'Reilly K, Smith T, Jones R, Shearer T, Nunes F, Baker AC (2014) Geographic differences in vertical connectivity in the Caribbean coral *Montastraea cavernosa* despite high levels of horizontal connectivity at shallow depths. *Molecular Ecology* 23 (17): 4226–4240

Serrano X, Baums IB, Smith TB, Jones RJ, Shearer TL, Baker AC (prepared for submission to *Scientific Reports*) Long distance dispersal, vertical gene flow and depth zonation of algal symbionts in the Caribbean brooding coral *Porites astreoides*.

Mignard C. 2014. Characterizing biodiversity of fish communities in support of the evaluation of new marine management alternatives for the Pulley Ridge. MSc Thesis, Universite Pierre et Marie Curie, Paris, France.

iii. Patents
iv. New methods and technology
v. New or advanced tools (e.g. models, biomarkers)

The models being developed and refined for this project (notably the Physical Oceanographic circulation model (eFKEYS) and the Particle dispersal model (CMS)) are novel, very high resolution models that will be valuable tools for managers and scientists interested in connectivity pathways throughout the GOM and Florida Straits region (and beyond). Once the CMS model is validated with genetic studies, it will be readily available to the management process (per C. Paris). The CMS model is being utilized in the modeling presentations listed below.

vi. Workshops
vii. Presentations

Sponaugle, S., C.B. Paris, K.D. Walter, V.H. Kourafalou, E. D'Alessandro, 2014. Observed and modeled larval settlement of a reef fish to the Florida Keys. Ocean Sciences Meeting, Honolulu, HI.

Vaz AC, Paris CB, Holstein DM, Olascoaga MJ 2014. Simulating mesophotic to shallow reef connectivity considering three-dimension coral ref habitats, *Ocean Sciences Meeting, Honolulu, HI.*

Paris CB (**2014**) Biophysical Models: Tracking Invisible Larval Pathways from Spawning to Recruitment, *AFS 144 Annual Meeting, August 17-21, Quebec*

Sagarese S, Tetzlaff J, Bryan M, Schirripa MJ, Karnauskas M, Gruss A, Paris CB, Zapfe G (**2014**) Incorporating integrated ecosystem assessment products into Stock assessments for the Gulf of Mexico: a case study for gag grouper, natural mortality, and recruitment, *AFS 144 Annual Meeting, August 17-21, Quebec*

Karnauskas M, Walter JF, Paris CB (**2014**) Improving estimates of recruitment strength in stock assessments via a biophysical modeling framework, *AFS 144 Annual Meeting, August 17-21, Quebec*

Lindo-Atichati D, Vaz AC, Karnauskas M, Paris CB (**2015**) Estimating oil exposure of red snapper and gag grouper during the DWH blowout, *Oil Spill and Ecosystems Science Conference*, Feb 16-19, Houston (Poster)

Paris CB (**2015**) Modeling larval life in moving fluids: hydrodynamics, cues, and navigation, *Physics/Ecosystems Interactions, Gordon Research Conference*, June 7-12, Biddeford, ME

viii. Outreach activities/products (e.g. website, newsletter articles)

b. Management outcomes - I. Management application or adoption of:

i. New fundamental or applied knowledge

ii. New or improved skills

iii. Information from publications, workshops, presentations, outreach

Products

Data from the above cruise reports will be important for managers and scientists within NOAA Fisheries, the Gulf of Mexico Fishery Management Council, The Florida Keys National Marine Sanctuary, NOAA Deep Sea Coral Research and Technology Program, and NOAA Mesophotic Reef Ecosystem Program.

In December 2014, the data compiled from our cruises to Pulley Ridge, including CIOERT cruises of 2010 and 2011 (FloSEE I and II), and the UM cruises of 2012-2014, were presented to the advisory panel of the Gulf of Mexico Fishery Management Council, as a proposal to extend the boundaries of the Pulley Ridge HAPC to the west to include the coral rich Central Basin and the West Ridge. Also our data compiled on the mesophotic reefs at Tortugas in 2013-2014 were presented to the Florida Keys National Marine Sanctuary as a proposal for extending the boundaries of the sanctuary to include these areas.

A final cruise for this research project is planned for August-September 2015. Once that is completed, a final report will compile the data from all four cruises and compare to previous research. Ultimately these data from the various cruises will be used to characterize and document the habitat, benthic communities, and fish populations inside and outside the Pulley Ridge HAPC and between the North and South Tortugas Ecological Reserves. These data may then be compared to future research cruises to better understand the long-term health and status of these important mesophotic ecosystems. These data will be of value to the regional Fishery Management Councils, NOAA Fisheries, NOAA Mesophotic Reef Ecosystem Program, NOAA Deepsea Coral Research and Technology Program (DSCRTP), NOAA Coral Reef Conservation Program (CRCP), and NOAA Marine Sanctuaries for management decisions on these habitats and managed key species.

iv. New or improved methods or technology

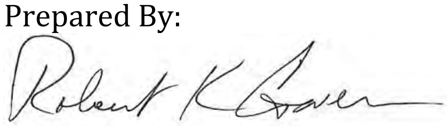
v. New or advanced tools

The project has completed three field seasons and is still processing the samples collected. Even so, we have been interacting with the FKNMS, and have provided them with an analysis of existing information to help them identify the ecological boundaries that their Advisory Council should consider for a potential Sanctuary expansion. As the project continues to progress, we fully expect there to be additional management related outcomes in the out years (several examples are given in this report of activities during this last year). A unique aspect of our project is a Stakeholder Advisory Board, a collaboration of federal, state, and nongovernmental stakeholders, to help guide outputs and ensure their utility for resource managers. The Stakeholder Advisory Board has representatives from: the Bureau of Ocean Energy Management, Everglades and Dry Tortugas National Parks, Florida Fish and Wildlife Research Institute, Gulf Coast Ecosystem Restoration Task Force, Gulf of Mexico Fishery Management Council, The Nature Conservancy, NOAA National Marine Fisheries Service's Southeast Fisheries Science Center, NOAA National Marine Fisheries Service's Southeast Regional Office, NOAA Office of National Marine Sanctuaries, NOAA Office of Ocean Exploration and Research, and South Atlantic Fishery Management Council. The goal of this study is to not only provide a better understanding of the underlying processes that regulate Pulley Ridge and whether Pulley Ridge helps sustain the coral reef communities in the Florida Keys and Dry Tortugas, but also help determine if the area would benefit from further protection.

c. Management outcomes - II. Societal condition improved due to management action resulting from output; (examples: improved water quality, lower frequency of harmful algal blooms, reduced hypoxic zone area, improved sustainability of fisheries)

d. Partnerships established with other federal, state, or local agencies, or other research institutions (other than those already described in the original proposal).

Prepared By:



Signature of Principal Investigator Date: June 30, 2015

NOAA COP Annual Progress Report Form

Agenda
Pulley Ridge – All-PI meeting
December 2-3, 2014
RSMAS – Map and Chart Room, Library

Day 1 (Tuesday)

A. Welcome (R. Cowen)	0900
B. Introductions (Everyone - again)	0915
C. Overview of Previous Year activities (Cowen)	0930
a. Annual Report	0945
b. Cruise 3 –	
i. Sampling plan	
ii. Cruise participation	
Coffee Break	1015
iii. Cruise results (Dennis Hanisak/John Reed)	1030
iv. Technical Diving – results/issues (Rick Gomez)	
v. Samples collected	
Lunch Provided (1.5 hrs)	1200
D. Scientific results – preliminary	
a. Physical Oceanography –	1300
b. Bio-physical modeling	1330
c. Community Structure	1400
d. Genetics -	1430
Coffee Break	1500
e. Fish -	1530
f. BioEconomics -	1600
g. DST –	1630
h. Synthesis and needs	1700
Ice Breaker (RSMAS Patio)	**1730**

Day 2 (Wednesday)

E.	Start – Plan for the day, housekeeping (Cowen)	0900
F.	Continue – Synthesis discussion	0915
G.	Planning for Year 4 Cruise (Cowen)	1000

Coffee Break 1030

H.	General Discussion	1100

All-PI mtg adjourned - Lunch 11:30

Stakeholder's Advisory Board (SAB) Mtg

1200-2:30 pm

Change location – CIMAS Conference Room

Lunch Provided

1) Brief Review of PI Meeting Highpoints (for those unable to attend)
2) Response to Website for Summer Cruise
3) Cruise Plan for this Coming Year
4) Funding Challenge (Shiptime/Personnel) Given Stretch to Six Years
   Changes Instituted as a result

Project: **South Atlantic Meridional Overturning Circulation: Pathways and Modes of Variability**

PIs: Renellys C. Perez[1], Ricardo P. Matano[3], Silvia L. Garzoli[1]
Collaborator: Rym Msadek[3]
Institutions: [1]University of Miami/CIMAS, NOAA/AOML
[2]Oregon State University/CEOAS
[3]UCAR, NOAA/GFDL
Report Year: FY2014 (Annual Progress Report)
Grant #: NA13OAR4310131

1. Project Overview

Previous observational and modeling efforts on the meridional overturning circulation (MOC) have been focused on the North Atlantic and the Southern Oceans, which are the main sites for deep-water formation. To understand the feedbacks between the North Atlantic and the Southern Oceans we need to improve our understanding of the pathways of the upper and lower limbs of the MOC in the South Atlantic (SA) Ocean, which are the most important links between them. The SA is not just a passive conduit for the transit of remotely formed water masses, but actively influences them through air–sea interactions, mixing, subduction, and advection.

As part of the project we are 1) characterizing the pathways of the upper and lower limb of the MOC in the SA and identifying the dynamical mechanisms that control these pathways, 2) identifying the natural modes of variability in the SA and their impact on the MOC, and 3) determining the response of the SA pathways to predicted climate change scenarios and assessing the impact of this response on the MOC. Our research is focused on the analysis of state-of-the-art eddy-permitting and eddy-resolving NOAA/GFDL climate model simulations, non-eddying Coordinated Model Intercomparison Project and Intergovernmental Panel on Climate Change Fifth Assessment Report models including the NOAA/GFDL coarse resolution models (CM2.1, CM3), global ocean circulation models, process-oriented numerical experiments using regional ocean models, and global in-situ and satellite observations.

2. Results and Accomplishments

2.1 Fate of Deep Western Boundary Current

During the first year of our project, we examined the fate of the Deep Western Boundary Current (DWBC) in the SA (Garzoli et al., 2014). In this study, historical and new observations including hydrographic sections, Argo data (Figure 1) and chlorofluorocarbon measurements, were examined together with two different analyses of a global ocean-only numerical model (OFES: OGCM For the Earth Simulator) to trace the pathway of the DWBC through the SA. When the very energetic, eddying DWBC reaches the Vitória-Trindade Ridge (~20°S), the flow branches due to conservation of potential vorticity. Both observations (Figure 1) and OFES model analyses (Figure 2) indicate that the main portion of the flow continues along the continental shelf of South America in the form of a strong reformed DWBC, while a smaller portion, about 20%, is advected towards the interior of the basin. It is hypothesized that this eastward motion results from eddy thickness flux divergence due to overlying Agulhas Ring decay and enhanced mixing caused by the energetic eddy field at the Vitória-Trindade Ridge. Strong westward propagation observed throughout the basin is hypothesized as a mechanism by which the DWBC reforms along the western boundary south of the Vitória-Trindade Ridge (i.e., there is interaction between the mean flow and westward propagating Rossby Waves).

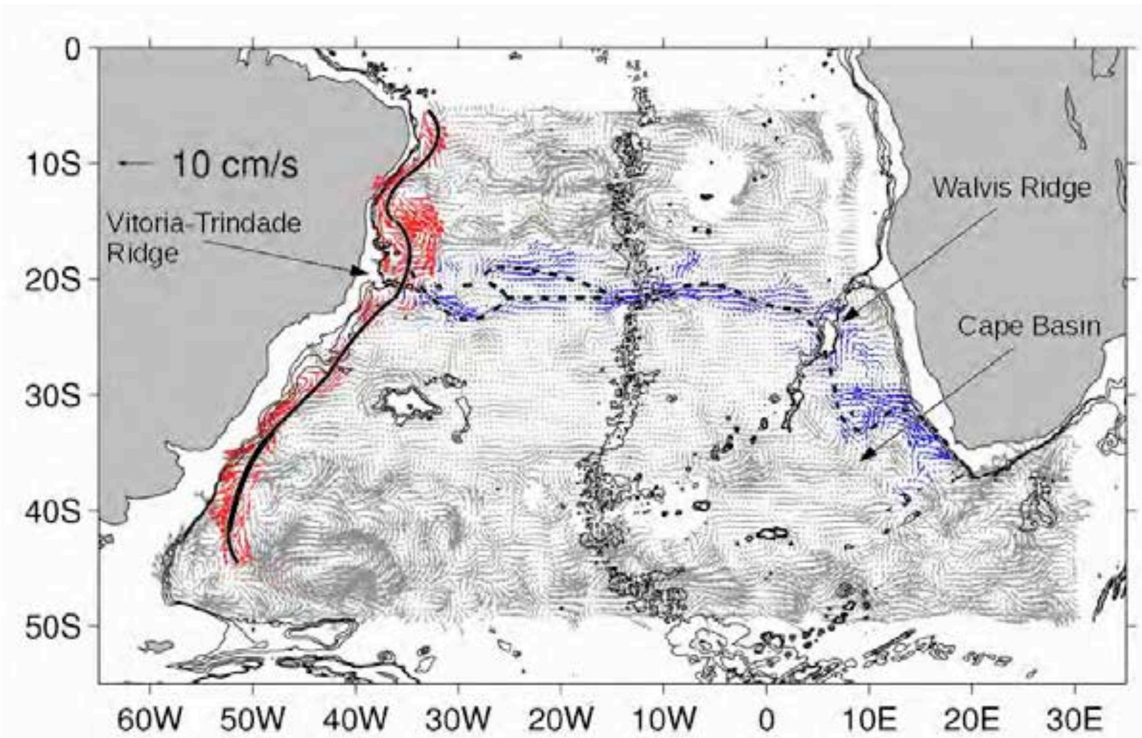


Figure 1. Velocity field at 2000 dbar derived from Argo data. Red highlights the strong southward flow along the western boundary; blue indicates the eastward velocity originating near the Vitória-Trindade Ridge. Black lines: 2000, 2500 and 3000 m isobaths. Solid curves highlight the pathways of the DWBC along the South American coast. Dashed lines indicate regions where the pathway is less well developed as it moves to the interior of the basin.

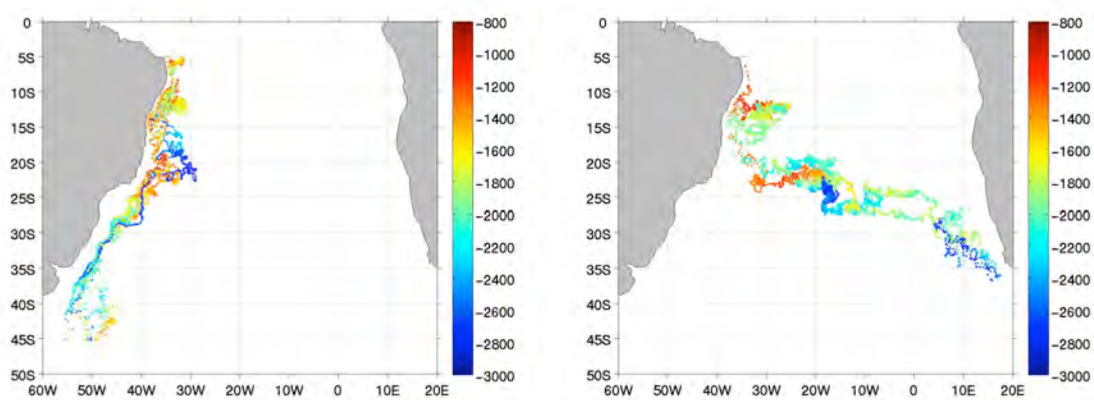


Figure 2. Examples of the two main pathways for the NADW derived from synthetic floats launched along 5°S between 1000 and 3500 m depth in the OFES model. The left panel shows examples of trajectories of 71% of the synthetic floats along the western boundary; the right panel shows examples of the trajectories of 21% of the floats heading towards the Cape Basin. The color shading indicates the depth of the float.

2.2 Process-oriented Numerical Experiments

We have also developed a nested model of the South Atlantic circulation using the Agrif version of the Regional Ocean Modeling System (Combes and Matano, 2014). In this model setup a high-resolution "child" model is embedded into a coarser resolution "parent" model. The parent grid extends 360° in the longitude and from Antarctica to 15.2°N, it has a spatial resolution of 1/4° and 40 vertical levels with enhanced resolution at the surface. The child grid, which is centered on the subtropical gyre, extends from 70°W to 52°W and from 47°S to 8°S and has a spatial resolution of 1/12° (Figure 3). The bottom topography is a smoothed version of ETOPO1 (1/60° resolution), to prevent from horizontal pressure gradient errors. The model equations are based on an upstream third-order advection scheme, in which the diffusion of tracers (Temperature and Salinity) is split from the advection term and where diffusion is represented by a biharmonic diffusivity satisfying the Peclet constraint. The model uses the KPP scheme for vertical mixing in the surface boundary. The model includes a 23,000 m^3s^{-1} discharge from La Plata River (~34.4°S) and the M2 tidal component. At the surface, the model is forced by the ERA-Interim data set from 1979 to 2012 with a spatial resolution of 0.75°. A bulk formulation derives the surface wind stress, heat and freshwater fluxes from the 3 days averaged ERA-Interim 2-meter air temperature, relative humidity, precipitation, 10-meter wind amplitude, short wave and long wave radiation. Because of large errors over coastal upwelling regions, we use climatology short and long wave radiation from the COADS data set. At the northern open boundary of the parent grid (~15°N), we impose a modified radiation boundary condition with nudging to the monthly mean climatology provided by the Simple Ocean Data Assimilation model [SODA]. The SODA model also provides the initial condition.

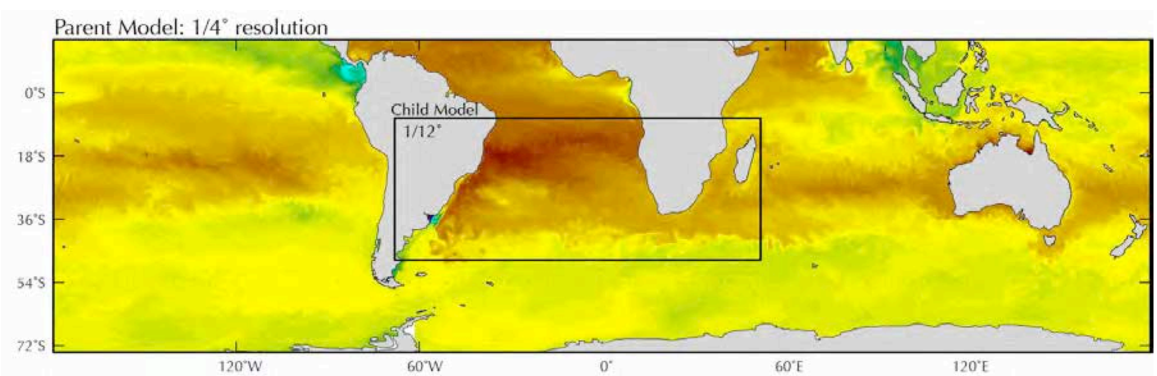


Figure 3. Snapshot of the sea surface salinity in the nested model configuration implemented for this project. The "parent" grid has a horizontal resolution of ¼°, the "child" grid has a horizontal resolution of 1/12°.

In addition to the model development during the first year of our project we completed two numerical simulations. The first simulation, which is our benchmark, was conducted using the model configuration described above. This experiment was spun-up for 20 years and run in a diagnostic mode for another 20 years. This experiment will be used to investigate the sensitivity of the South Atlantic circulation (surface, intermediate and deep) to changes in the model configuration (e.g., bottom topography, wind stress forcing, mixing parameterization, etc.). Preliminary assessment of slightly modified version of this model shows good agreement with observations (Combes and Matano, 2014; Matano et al., 2014). To determine the pathways of the main water masses in the South Atlantic we released passive tracers at different density levels of the model. Figure 4, for example, shows a snapshot of a tracer distribution after 4 years of its release. This particular tracer was released at the Agulhas Retroflection region and shows the pathways of the Indian Ocean waters in the South Atlantic. Note, in particular, the persistence of the Agulhas eddies throughout the basin. Many of these eddies can be tracked until they impinge on the eastern boundary of South America and, on occasion, to the Brazil/Malvinas Confluence.

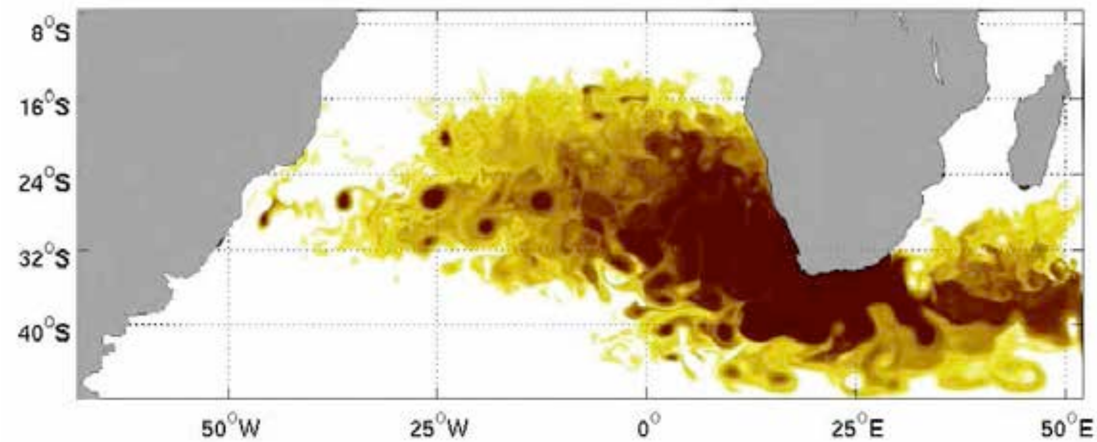


Figure 4: Snapshot of the surface distribution of a passive tracer released at the Agulhas Retroflection Region.

Figure 5 shows a snapshot of a passive tracer released in the northwestern corner of the child model and at NADW levels. There are offshore extrusions of NADW in the proximities of 10°S, 20°S and 45°S. The most remarkable is the one observed near 20°S, which is the approximate location of the Vitória-Trindade Ridge, because there is no clearly defined offshore mean flow in this location. That is, apparently, the offshore detrainment of the deep waters in this location is a largely eddy-driven process. The question, therefore, is whether these eddies driving this outflow are produced locally (e.g., through interaction between the western boundary current and the Vitória-Trindade Ridge) or are the deep-ocean expression of surface eddies.

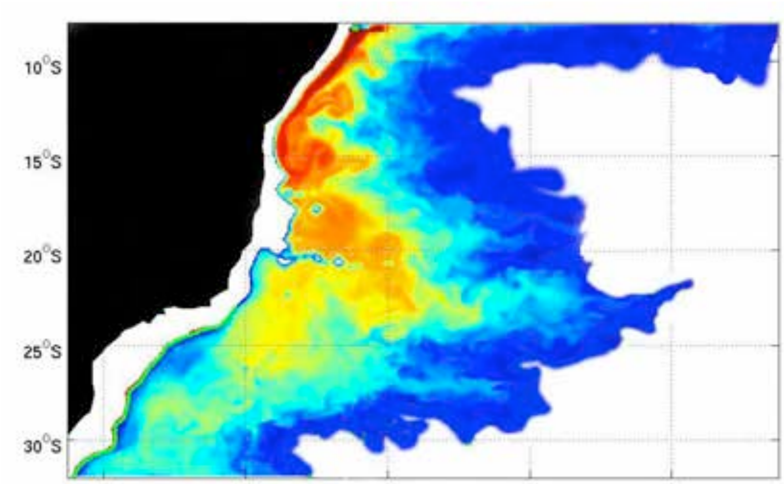


Figure 5: Snapshot of the distribution of passive tracer released at 2000 m in the benchmark experiment.

We are presently running a suite of sensitivity experiments to test the sensitivity of the South Atlantic's water mass pathways to local and remote forcing. In our first sensitivity experiment, which is underway, we “removed” the Vitória-Trindade Ridge to test the sensitivity of the NADW pathways to the existence of this morphological feature. This experiment is still under development but preliminary analysis shows a reduced offshore spreading pattern of NADW (Figure 6) although a substantial portion of the NADWs is still detrained in the offshore direction at this particular location. However, we still cannot conclude because the spin-up of the simulation is not complete.

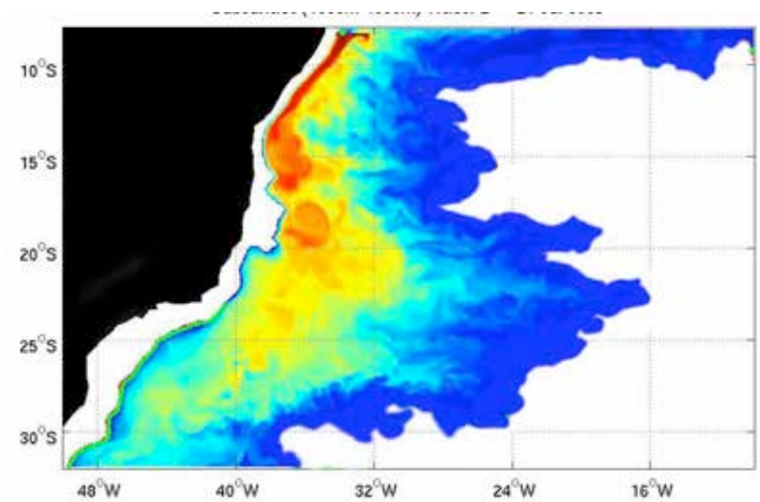


Figure 6: Snapshot of the distribution of passive tracer released at 2000 m in a sensitivity experiment in which the Vitoria-Trinidade Ridge was removed.

2.3 Analysis of MOC variability in the SA on seasonal timescales

Lastly, in the first year of the project we analyzed the sensitivity of the seasonal cycle of the maximum northward volume transport by the MOC to wind forcing at the latitudes of the RAPID/MOCHA array (nominally 26.5°N) and the developing SAMBA array (nominally 34.5°S) using observations and NOAA/GFDL numerical simulations. Observations of the MOC seasonal cycle are obtained from the RAPID/MOCHA array along 26.5°N, and from Argo and SCOW (Scatterometer Climatology of Ocean Winds) measurements along 34.5°S. The NOAA/GFDL simulations include the state-of-the-art eddy-permitting NOAA/GFDL climate model simulations (CM2.5 and its ocean-only counterpart) and a non-eddying IPCC AR4 simulation (CM2.1). The CM2.1 and CM2.5 coupled climate simulation that we considered in this analysis are forced with present-day conditions. The ocean-only version of CM2.5 is forced with normal year seasonal cycle wind forcing from the Common Ocean-ice Reference Experiment (CORE) documented in Large and Yeager (2004). Years 21-30 from the NOAA/GFDL simulations are compared with similarly long observational records collected at those two latitudes and a two-layer idealized ocean model (Zhao and Johns, 2014) forced with the winds produced by the coupled climate or used to drive the ocean-only simulations.

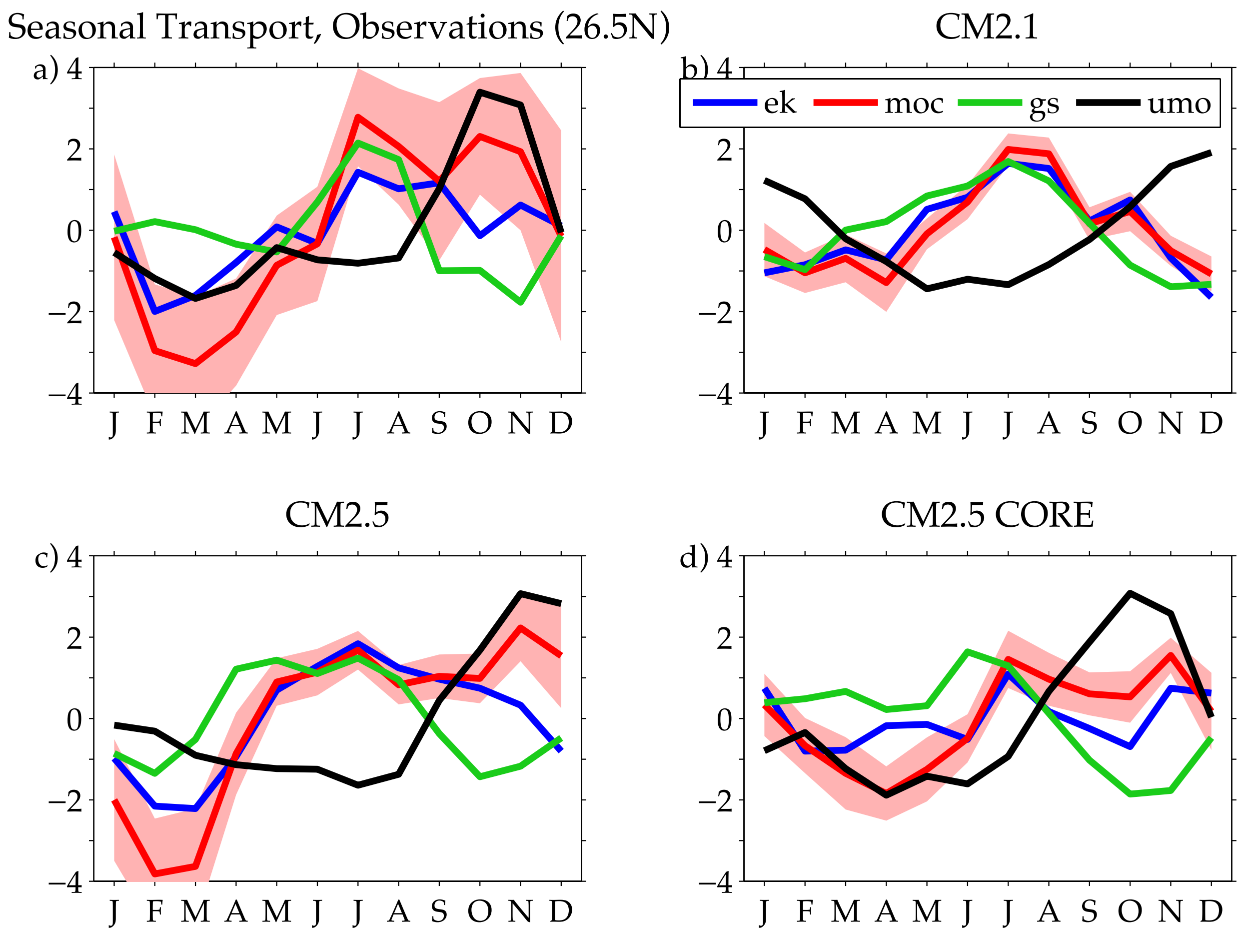


Figure 7: Seasonal cycle of MOC volume transport along 26.5°N for (a) RAPID/MOCHA observations collected during 2004 and 2011 and three GFDL simulations: (b) CM2.1, (c) CM2.5, and (d) CM2.5 CORE. Red lines indicate the total MOC seasonal cycle. Blue, black, and green lines indicate the Ekman (ek), Upper Mid Ocean (umo), and Gulf Stream (gs) components of the MOC seasonal cycle, respectively. Upper Mid Ocean transport is a proxy for the geostrophic transport between Abaco and the eastern boundary. Red shading corresponds to standard errors of total MOC, which are computed as the standard deviation of monthly values divided by the square root of the number of years sampled.

Observation-based estimates of the seasonal cycle of volume transport by the MOC (Figure 7a and 8a) show that both geostrophic and wind-driven Ekman components contribute to the seasonal cycle in observations. The peak of geostrophic and wind-driven Ekman seasonal cycles each align with one of the two peaks in the total seasonal cycle at 26.5°N, but this alignment is not evident at 34.5°S. The model simulations are able to reproduce the observed total MOC seasonal variations at 26.5°N (Figure 7b,c,d, red lines). However, none of the model simulations are able to reproduce the observed geostrophic seasonal variations at 34.5°S (Figure 8, black lines) leading to an overly strong total MOC seasonal cycle (Figure 8b,c,d red lines). This indicates, that the weak seasonal cycle of the geostrophic component in the models does not depend on coupling or horizontal resolution. Sensitivity to resolution, however, will be explored further using the even higher resolution (1/10°) NOAA/GFDL CM2.6 simulation.

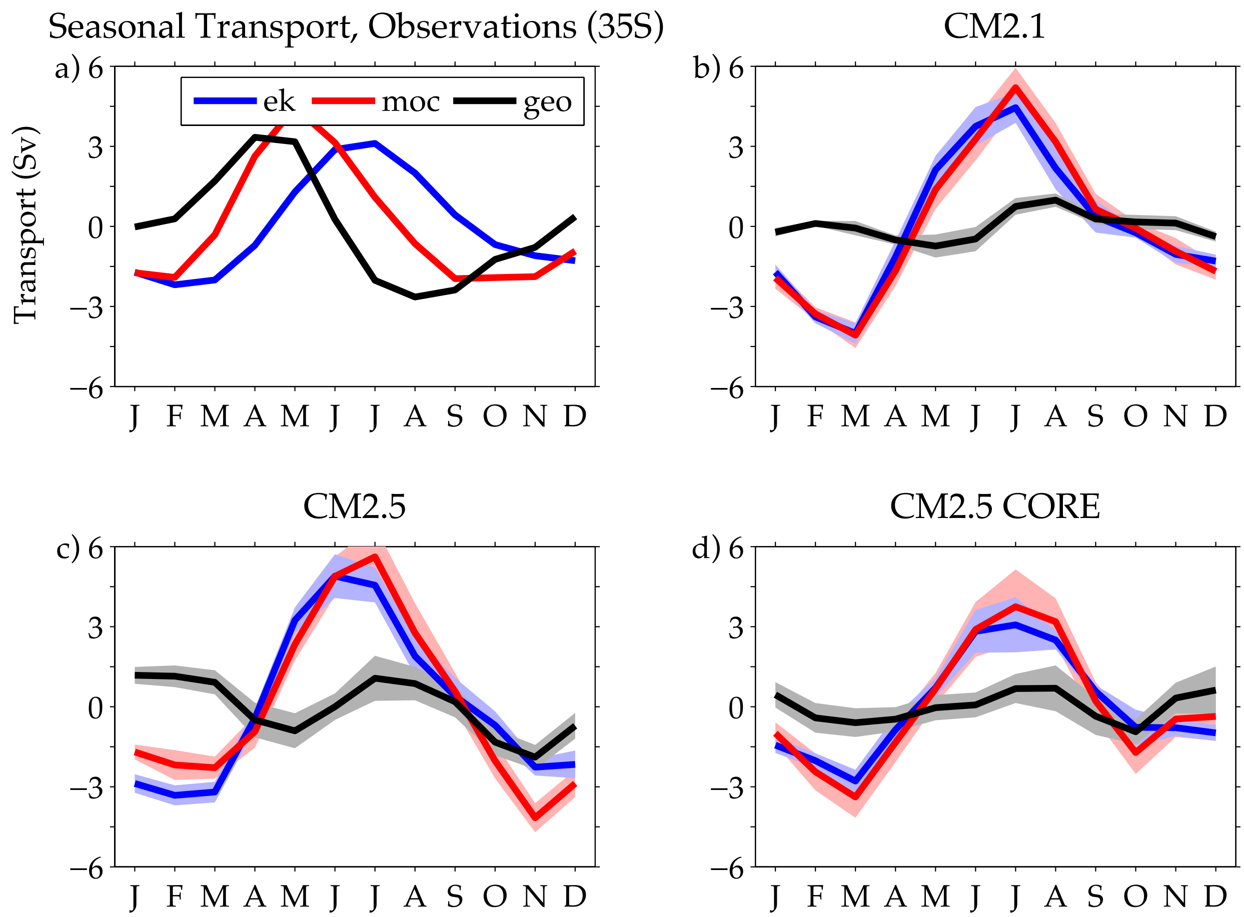


Figure 8: Seasonal cycle of MOC volume transport along 34.5°S for (a) Argo observations (Dong et al., 2014) and three GFDL simulations: (b) CM2.1, (c) CM2.5, and (d) CM2.5 CORE. Red lines indicate the total MOC seasonal cycle. Blue and black lines indicate the Ekman (ek) and geostrophic (gs) components of the MOC seasonal cycle, respectively. Shading corresponds to standard errors, which are computed as the standard deviation of monthly values divided by the square root of the number of years sampled.

At 34.5°S, the models have very different wind stress curl seasonal cycles when compared to SCOW near the eastern and western boundaries (not shown), which can have a strong impact on the geostrophic component of the MOC which responds to the zonally integrated wind stress curl across the basin (e.g., Kanzow et al., 2010). Using a two-layer idealized ocean model (Zhao and Johns, 2014) forced by the SCOW, CM2.5 and CM2.5 CORE winds, we have explored the possible causes for this discrepancy between models and observations (Figure 9). Although there are phasing differences between the Argo and the SCOW-forced 2-layer model geostrophic seasonal cycles (Figure 9d), we found that the amplitudes were quite similar and produced in-phase MOC seasonal cycles (Figure 9a).

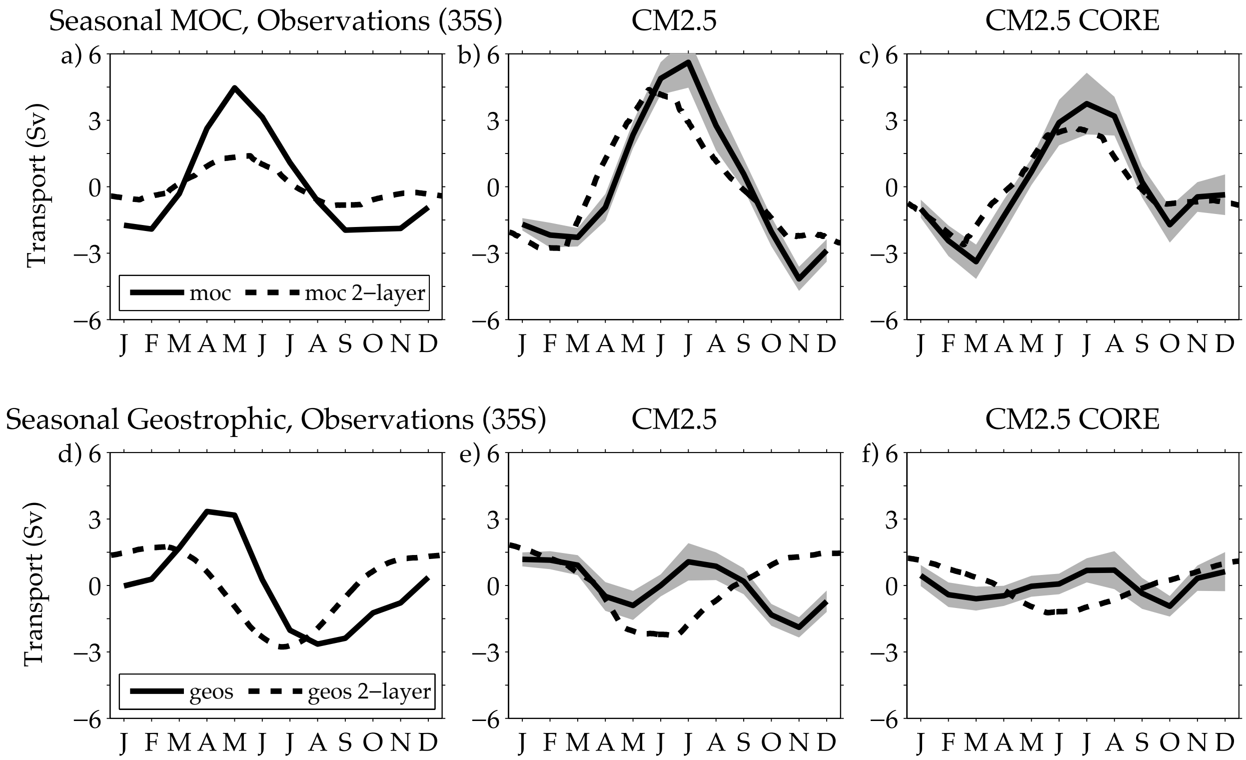


Figure 9: Seasonal cycle of MOC transport along 34.5°S for a) observations, b) CM2.5 and c) CM2.5 CORE simulations (solid lines), and for the corresponding 2-layer idealized model (dashed lines). Panels (a)-(c) show the total MOC seasonal cycle, and panels (d)-(f) show the geostrophic component of the MOC seasonal cycle.

The CM2.5 and CM2.5 CORE 2-layer geostrophic and total MOC seasonal cycles are very similar to those produced by the fully-coupled and ocean-only models themselves, suggesting that the differences in the geostrophic seasonal cycles may in fact be due to differences in the model and observed wind stress curl seasonal cycles – or the way that information is transmitted into the interior in the models. As future work we will examine whether the weak geostrophic seasonal cycle in the coupled model, ocean-only, and idealized 2-layer simulations in the SA is due to excessively strong baroclinicity below the surface mixed layer in the models as suggested by Dong et al. (2014, under revision for GRL).

3. Publications Related to the Project

*(PI/Collaborator names in **bold**)*

Ansorge, I. J., M. O. Baringer, E. J. D. Campos, S. Dong, R. A. Fine, **S. L. Garzoli**, G. Goni, C. S. Meinen, **R. C. Perez,** A. R. Piola, M. J. Roberts, S. Speich, J. Sprintall, T. Terre, and M. A. Van den Berg, 2013. Basin-wide oceanographic array bridges the South Atlantic. *Eos, Transactions, American Geophysical Union*, **95(6)**: 53-54, doi:10.1002/2014EO060001.

Combes, V., and **R. P. Matano**, 2014. A two-way nested simulation of the oceanic circulation in the Southwestern Atlantic. *J. Geophys. Res. Oceans*, **119**, doi:10.1002/2013JC009498.

Garzoli, S. L., S. Dong, R. Fine, C. Meinen, **R. C. Perez**, C. Schmid, E. van Sebille, and Q. Yao, 2014. The fate of the Deep Western Boundary Current in the South Atlantic. *Deep Sea Res.*, submitted.

Matano, R. P., V. Combes, A. R. Piola, R. Guerrero, E. D. Palma, P. T. Strub, C. James, H. Fenco, Y. Chao, M. Saraceno, 2014. The Salinity Signature of the Cross-Shelf Exchanges in the Southwestern Atlantic Ocean: Numerical Simulations. *J. Geophys. Res. (Oceans)*, submitted.

Meinen, C. S., S. Speich, **R. C. Perez**, S. Dong, A. R. Piola, **S. L. Garzoli**, M. O. Baringer, S. Gladyshev, and E. J. D. Campos, 2013. Temporal variability of the Meridional Overturning Circulation at 34.5°S: Results from two pilot boundary arrays in the South Atlantic. *J. Geophys. Res.*, **118(12)**, 6461-6478, doi:10.1002/2013JC009228.

4. PI/Collaborator Contact Information

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Progress (Quarter 2: FY 2015): Evolving Data Fields For Use in OSSE Modeling
NOAA/CIMAS Grant: NA13OAR4830217
Lynn K. Shay (UM/RSMAS)

A paper describing the hurricane Isaac data was again reviewed (accepted subject to a minor revision) and we have revised it accordingly. The paper will be resubmitted for publication in the *Journal of Physical Oceanography*. This data set is available for the OSSE modeling studies. Oceanic expendables were deployed during hurricane Edouard from the NOAA WP-3Ds in September 2014 have been processed. The preliminary analysis of that data set has been completed as reported in a recent poster paper at the Office of the Federal Coordinator 69^{th} Interdepartmental Hurricane Conference in Jacksonville in early March. These data will also be used in the OSSE modeling studies by Halliwell and others.

Activity:

Development of a long-term, homogenized upper tropospheric water vapor data set from satellite microwave radiances

NOAA OAR Climate Program Office
NOAA Award NA10OAR4310120

PI: Brian J. Soden b.soden@miami.edu
Co-I: Eui-Seok Chung echung@rsmas.miami.edu
Collaborator: Viju John viju.john@metoffice.gov.uk

Final Progress Report

In the first year of funding we performed a systematic intercomparison of the infrared and microwave upper tropospheric water vapor radiances. This resulted in two publications: In John et al. (2011), we use microwave retrievals of upper tropospheric humidity (UTH) to estimate the impact of clear-sky-only sampling by infrared instruments on the distribution, variability and trends in UTH. On monthly scales, maximum clear sky bias is up to 30%RH over convectively active areas. The magnitude of the bias shows significant correlations with UTH itself and also with the variability in UTH. We also show that IR-sampled UTH time series has spuriously higher interannual variability and smaller trends compared to microwave sampling.

This paper was followed up by Chung et al. (2011) which focused on the implications of the IR dry bias for model evaluation. We introduced a new method for evaluating the water vapor distribution which combines both IR (HIRS 6.7 μm) and microwave (SSM/T-2 183.31±1 GHz channel) radiances and is much less sensitive to tropospheric temperature biases. The geographical distribution of the humidity is found to exhibit a close association with the 500 hPa vertical pressure velocity, suggesting that model biases in tropical upper tropospheric relative humidity can be attributed to errors in simulating the intensity of large-scale tropical circulation.

In the second year of funding we constructed and analyzed an intercalibrated and drift adjusted archive of 183 GHz water vapor absorption band measurements from Advanced Microwave Sounding Unit-B (AMSU-B) and Microwave Humidity Sounder (MHS) onboard polar orbiting satellites and document adjustments necessary to use the data for long-term climate monitoring. A method for the limb correction of the satellite viewing angle based upon a simplified model of radiative transfer was developed to remove the scan angle dependence of the radiances. Biases due to the difference in local observation time between satellites and spurious trends associated with satellite orbital drift were then diagnosed and adjusted for using synthetic radiative simulations based on ERA-Interim reanalyses. The adjusted, cloud-filtered and limb-corrected brightness temperatures were then intercalibrated using zonal-mean brightness temperature differences. It is found that these correction procedures significantly improve consistency and quantitative agreement between microwave satellite records of upper and middle tropospheric water vapor. The resulting radiances are converted to estimates of the deep-layer mean upper and middle tropospheric relative humidity, and then used to examine the long-term trend of upper tropospheric relative humidity from reanalysis datasets and coupled ocean-atmosphere models. These results are described in Chung et al. (2013a).

In the third year of funding, we evaluated the diurnal variations of upper tropospheric humidity in five different reanalysis datasets (Chung et al., 2013b). All reanalysis datasets reproduce the day/night contrast of upper tropospheric humidity and the land/ocean contrast in the diurnal amplitude. The satellite measurements indicated a slightly later diurnal minimum over land relative to most reanalyses and the microwave satellite measurements, indicate that cloud masking of the infrared radiances may introduce a small (~ 3 hr) bias in the phase. One reanalysis exhibits a substantially different diurnal cycle over land which is inconsistent with both infrared and microwave satellite measurements and other reanalysis products. This product also exhibits a different covariance between vertical velocity, cloud water and humidity than other reanalyses, suggesting that the phase bias is related to deficiencies in the parameterization of moist convective processes.

We also assessed the quality of global radiosonde measurements tropospheric humidity in Moradi et al. (2013). Satellite observations from three water vapor channels sensitive to the microwave frequencies at 183.31±1, 183.31±3, and 183.31±7 GHz were used to investigate the quality of humidity measurements from operational radiosonde sensors in upper-, middle-, and lower-troposphere. The radiosonde data were partitioned into 32 groups based on sensor type. First, the satellite brightness temperatures (Tb) were simulated using radiosonde profiles and a radiative transfer model, then the radiosonde simulated Tb's were compared with the observed Tb's from the satellites. The day and night data were examined separately to see the effect of daytime radiation bias on the sonde data. Overall, in the upper troposphere, Russian sensors show a large systematic wet bias but a small random error. Vaisala sensors have a small systematic dry bias and also a relatively small random error in the UT. Other sensors including, Chinese, Indian and the U.S. sensors, have a dry bias that is accompanied with a large random error in the UT. Overall, Vaisala sensors perform better than other sensors through the troposphere with the smallest random error and systematic biases. The Russian sensors have a large systematic wet bias in UT, but they perform very good in LT. The sensors with a large random bias, Chinese, Indian and the U.S. sensors, are not suitable for UT studies as they fail to respond to humidity changes in upper and even middle-troposphere. Because of the large differences between different radiosonde sensors, it is essential for UTH studies to only use the data measured using a single type of sensor at any given station. If multiple sensor types are used then it is necessary to consider the bias between sensor types and its possible dependence on humidity and temperature.

In the fourth year of funding, we have used this climate-quality satellite data set to quantify the decadal trends in upper, middle and lower tropospheric humidity. We used coupled ocean-atmosphere model simulations under different climate forcing scenarios to investigate satellite-observed changes in global-mean upper tropospheric water vapor. Our analysis demonstrates that the upper tropospheric moistening observed over the period 1979–2005 cannot be explained by natural causes and results principally from an anthropogenic warming of the climate. By attributing the observed increase directly to human activities, this study verified the presence of the largest known feedback mechanism for amplifying anthropogenic climate change. A version of this paper is currently under review at the Proceedings of the National Academy of Science (Chung et al., 2014).

In the final year of the extension for this grant we have used the intercalibrated humidity data sets from AMSU-B to examine the influence of mid-tropospheric relative humidity (MTH) on tropical cyclone development and intensification (Chung and Soden, 2015). Our analysis reveals spatially coherent changes in MTH over the tropical North Atlantic that are highly correlated with variations in accumulated cyclone energy (ACE). Fewer storms are generated in dry years and those that do form tend to originate outside of the driest regions. In contrast, genesis locations in humid years are more evenly distributed across the Atlantic main development region (MDR) with a substantially higher percentage of storms developing into hurricanes. The driest years tend to be systematically less active in terms of ACE, storm duration, and number of storms compared to neutral years; whereas neutral and wet years tend to show similar level of activity. The MTH anomalies over the MDR are shown to persist for up to 6 months prior to the start of the North Atlantic hurricane season, suggesting that MTH information may also be useful for improving seasonal prediction of the Atlantic tropical cyclone activity.

Publications:

Chung, E.S., B. J. Soden, J. Schmetz, and B.J. Sohn, 2011: Model simulated humidity bias in the upper troposphere and its relation to the large-scale circulation, *J. Geophys. Res*, **116,** D10110, doi:10.1029/2011JD015609.

Chung, E.S., B.J. Soden and V.O. John, 2013a: Intercalibrating microwave satellite observation for monitoring long-term variations in upper and mid-tropospheric water vapor, *J. Atmos. Ocean. Technol*., **30**, 2303-2319.

Chung, E-S., B.J. Soden, B.J. Sohn, J. Schemtz, 2013b: An Assessment of the Diurnal Variation of Upper Tropospheric Humidity in Reanalysis Datasets, *J. Geophys. Res*. **228**, 3425-3430.

Chung, E-S, B.J. Soden, B.J. Sohn, and L. Shi, 2014: Upper tropospheric moistening in response to anthropogenic warming, *Proc. Nat. Acad. Sci*. **111**, 11636-11641.

Chung, E-S, and B.J. Soden, 2015: A Satellite-based Analysis of Mid-Tropospheric Humidity and Atlantic Tropical Cyclone Activity, submitted *J. Climate*.

Johns, V.O., and co-authors, 2011: Clear-sky sampling biases in satellite infra-red estimates of upper tropospheric humidity and its trends, *J. Geophys. Res*., **116**, D14108, doi:10.1029/2010JD015355.

Moradi, I., R. Ferraro, B. Soden, and P. Arkin, 2013: Assesing the quality of humidity measurements from global operational radiosondes, accepted *J. Geophys. Res*.

HFIP proposal final Report

(Award number NA12NWS4680004)

Title: Advanced model diagnostics of tropical cyclone inner-core structure using aircraft observations

PIs: Jun Zhang, David Nolan and Sylvie Lorsolo (no longer a co-PI after year 1)
Collaborators: Robert Rogers, Paul Reasor
HWRF team collaborators: S. Gopalakrishnan, Xuejin Zhang, Vijay Tallapragada, Young Kwon, Weiguo Wang, and J.-W. Bao

The goal of this proposal is to evaluate model performance using diagnostic tools that will help improve the prediction of TC intensity by the operational HWRF model. The present proposal has two main objectives:

1) *To generate composites of multiple types of aircraft observations from HRD's extensive aircraft database and model simulations.*
2) *To create metrics to quantitatively evaluate deficiencies and biases in the inner-core structure.*

The work proposed in this project (with 2 year duration) consists of three main tasks: 1) analysis and compositing of observational and model datasets; 2) design of metrics for inner-core structure evaluation and quantitative assessment of HWRF performance; 3) transition of the diagnostic software and report of model biases, deficiencies, and error statistics to EMC and/or National Hurricane Center (NHC) operations.

In year 1 we proposed to organize and analyze the observational data for model evaluation purposes and to test different metrics for evaluating the inner core structure of tropical cyclones. We built an observational data base with two resources (i.e., the post-processed Doppler radar and dropsonde data). The axisymmetric structures of the vortex-scale, convective-scale and boundary layer were summarized in our recently published papers (Lorsolo et al. 2010; Zhang et al. 2011a; Rogers et al. 2012). Our observational analysis results regarding the axisymmetric boundary layer structure have been shared with our EMC collaborators, Young Kwon and Weiguo Wang, who will work with the PI closely to evaluate and improve the planetary boundary layer (PBL) scheme in the operational HWRF model.

The observational data were composited with respect to storm intensity, change in intensity and shear direction and magnitude so that model diagnosis may take into account these criteria. Differences of boundary-layer structures between strong and weak storms are documented by Zhang et al. (2011a). Detailed analyses on the surface inflow angle structure are reported by Zhang and Uhlhorn (2012). Work has been done to document differences based on observations in the inner-core structure of tropical cyclones that are intensifying compared with those that are remaining steady-state (Rogers et al. 2013). Asymmetric votex-scale structures relative to the environmental vertical wind shear have been documented by Reasor et al. (2013). The asymmetric boundary-layer structure in relation to the environmental vertical wind shear is summarized by Zhang et al. (2013). Below we show examples of our analyses.

The improved dropsonde database allows us to study the asymmetric boundary layer structure in addition to our previous work on the axisymmetric boundary layer structure with focus on boundary layer height scales (Zhang et al. 2011). We have grouped the dropsonde data relative to the environmental wind shear. New algorithms have been written to rotate the droposnde locations in the coordinate system relative to the environmental vertical wind shear which is obtained from the Statistical Hurricane Intensity Prediction Scheme (SHIPS) database. Asymmetric boundary layer height analyses in four quadrants (downshear-left, downshear-right, upshear-left and upshear-right) have been conducted. Figure 1 shows results for diagnosing the height of the maximum tangential wind speed (h_{vtmax}) in different quadrants relative to the shear direction, showing the downshear-right quadrant has highest h_{vtmax}.

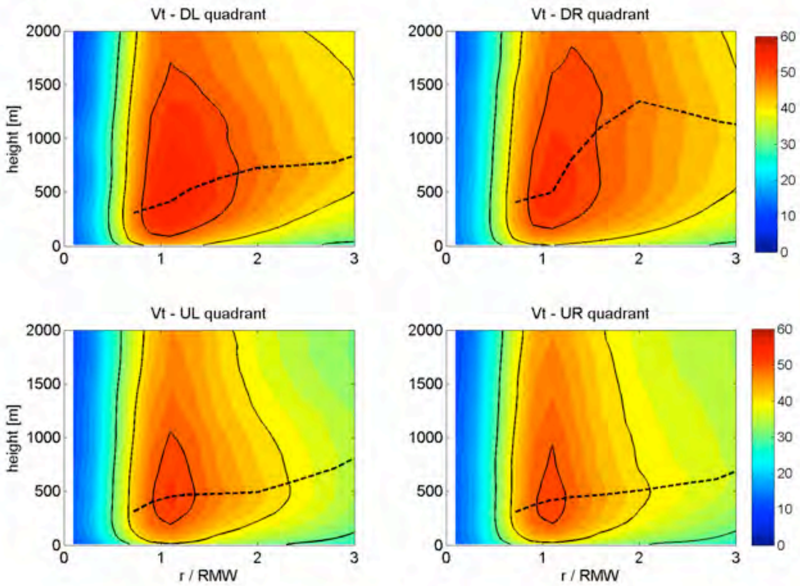

Fig. 1: Composite analysis result of the relative tangential wind velocity as a function of altitude and the normalized radius to the storm center for the four quadrants relative to the shear direction. The thick black lines in each panel are the 30, 40 and 50 m s^{-1} contours. The black dashed line in each panel depicts the height of the maximum tangential wind speed varying with radius.

A composite of radar analyses from TC's of hurricane strength that were intensifying (RI; defined as an intensification rate corresponding to at least 20 kt over the subsequent 24 h from the Best Track at the time of the radar analysis) was constructed and compared with a composite from TC's that were remaining steady-state (SS; defined as an intensification rate of +/- 10 kt/24 h). A total of 40 eyewall passes from 14 separate WP-3D flights in 8 different TC's comprised the composite, while a total of 53 eyewall passes from 14 WP-3D flights in 6 different TC's comprised the SS composite.

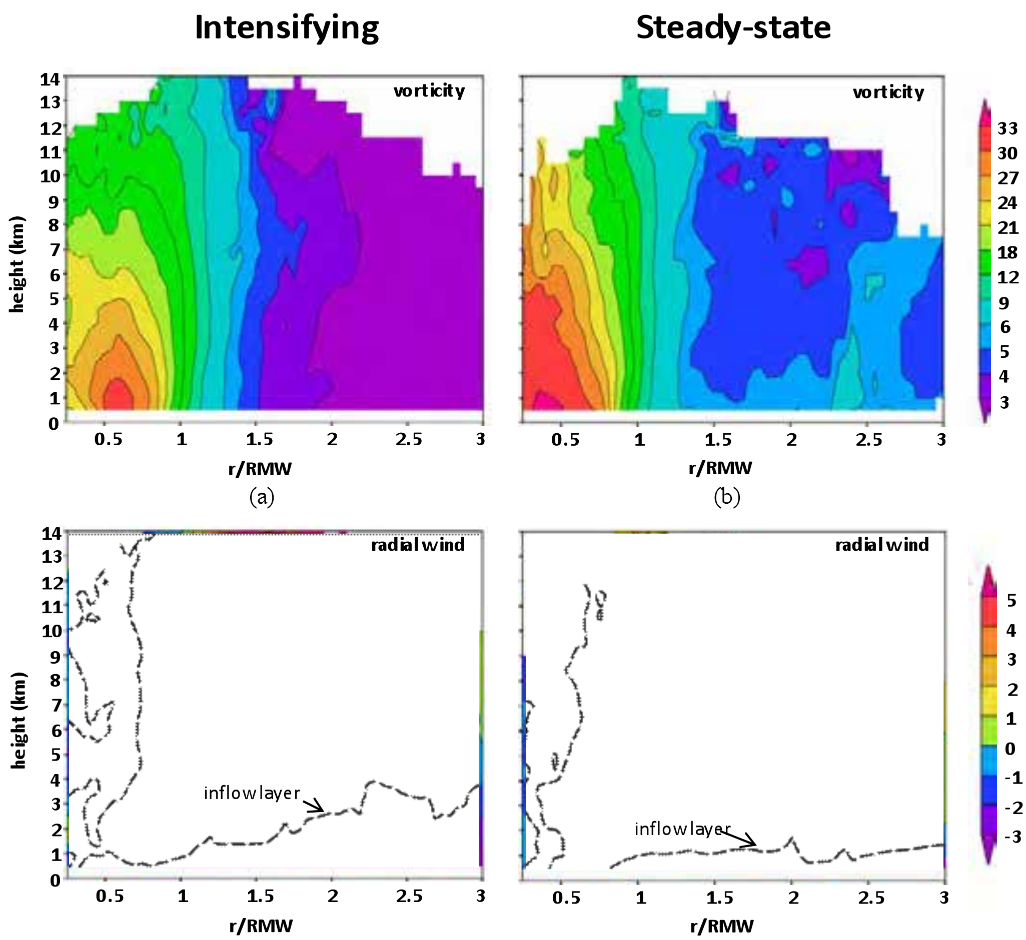

Fig. 2: Composite mean plots of axisymmetric vertical vorticity (x 10^{-4} s^{-1}) for (a) intensifying TC's; (b) steady-state TC's. Composite mean plots of radial wind (m s^{-1}) for (c) intensifying TC's; (d) steady-state TC's. All composites plotted as a function of normalized radius r and height AGL. Data from a minimum of 7 radar analyses are required for plotting.*

Figure 2 shows composite mean plots of axisymmetric vorticity and radial wind for each of the composites. Statistically-significant differences (at the 95% confidence level) were identified for these fields. For example, intensifying storms showed a ring-like vorticity structure inside the RMW compared with steady-state storms, which showed a more monopolar structure, consistent with that shown in Kossin and Eastin (2001). Additionally, intensifying storms showed a more rapid decrease in axisymmetric vorticity with radius outside the RMW, with values in the 2-3 x RMW radial band ~50% less than that seen in the steady-state storms. For radial flow, the strength of the radial inflow outside the RMW (i.e., in the 1.5-2.5 x RMW radial band) for the intensifying TC's is about twice that for the steady-state TC's (note that, since these analyses only extend down to 500 m AGL, the true measure of the peak inflow is not capable of being sampled, as indicated in Lorsolo et al. (2010) and Zhang et al. (2011). Additionally, the depth of the inflow layer is much larger for intensifying TC's than for steady-state TC's. The differences between intensifying and steady-state TC's as shown by comparing airborne observations will be used to guide an examination of composites of HWRF forecasts to see if the model can produce similar distinctions in inner-core structure.

Results mentioned above along with other observational analyses have been presented by PIs and collaborators at the HFIP meetings and AMS conferences. Our results have been also selected by HFIP team leaders and presented in the 2012 annual HFIP review meeting. In summary, our observational work following our proposal work plan has been successfully completed by the end of year 1.

Besides the above-mentioned work on observational-data maintenance and analyses, in year 1 we explored methods for comparing TCs in numerical models to the observational composites that we have developed. For this purpose we have firstly used the output of a research-quality, high resolution TC simulation developed for another NOAA-supported research project. Given its high resolution and advanced physical parameterizations, this simulation provides something of an "upper-bound" to what can be expected from the operational forecast models. The structures of the TC in simulations in two different resolutions have so far been compared to observationally-developed pressure-wind relationships of Knaff and Zehr (2007), the boundary layer wind field composites of Zhang et al. (2011a), the vertical structure composites of Stern and Nolan (2009), and the diurnal pulsations of the upper-level outflow that was recently identified by Jason Dunion of CIMAS/NOAA/HRD. We found that 3km to 1 km resolution change leads to significant improvements in inner-core size (Fig. 3) and eyewall slope. We also found that boundary layer profiles are not improved by horizontal resolution, and only slightly improved by increased vertical resolution (Fig. 4). The results of this analysis were presented at the HFIP regional modeling review meeting and will be documented by Nolan et al. (2013).

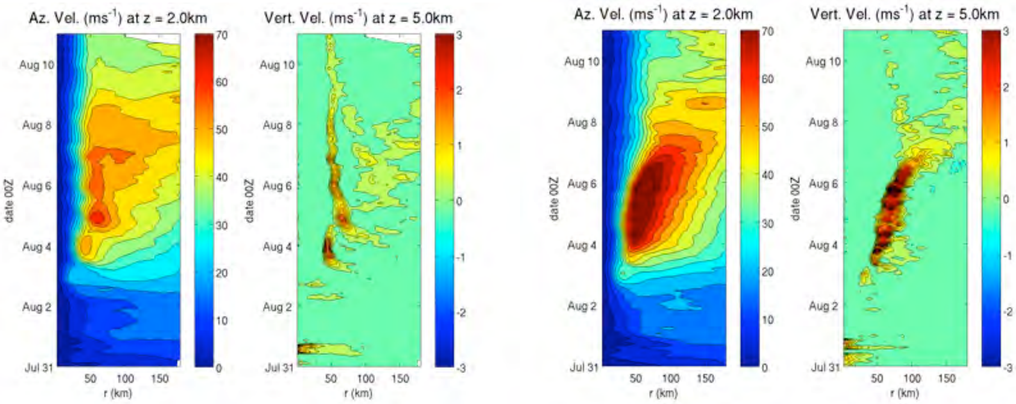

Fig. 3: Radius-time Hovmoller diagrams from the hurricane nature run using 1km resolution (left) and 3km resolution (right). In the 3km simulation, the eyewall is too large, too wide, and its size increases steadily with time.

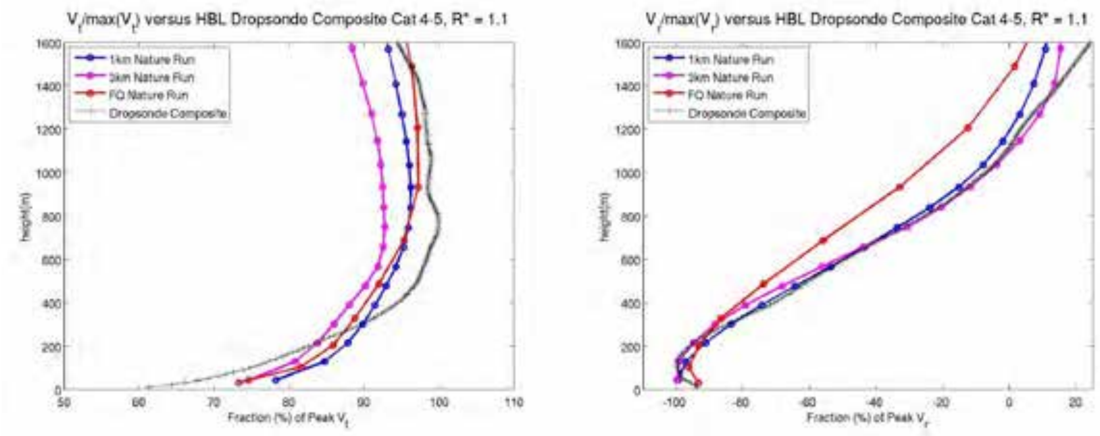

Fig. 4: Composite analysis result of the relative tangential wind velocity as a function of altitude and the normalized radius to the storm center for the four quadrants relative to the shear direction. The thick black lines in each panel are the 30, 40 and 50 m s^{-1} contours. The black dashed line in each panel depicts the height of the maximum tangential wind speed varying with radius.

In year 2, we focused on model evaluation using the observational data we built in year1. We coordinated with the HWRF team members from EMC and HRD to obtain hurricane simulations using the 2012 version of the operational HWRF model. We first tested our proposed metrics for TC structures using HWRF simulations of Hurricane Earl (2010). Metrics in terms of boundary layer height scales using the Earl simulation with nearly perfect tack and intensity forecast are tested, including the height of maximum wind speed and the inflow layer depths. We have also tested metrics in terms of the vortex scale structures using the Earl run. While testing the structural metrics, we also evaluated the effects of vertical eddy diffusivity on simulated structure. Figure 5 shows the track and intensity forecasts of two simulations initialized on 27 August 2010 at 12 Z for Hurricane Earl (2010).

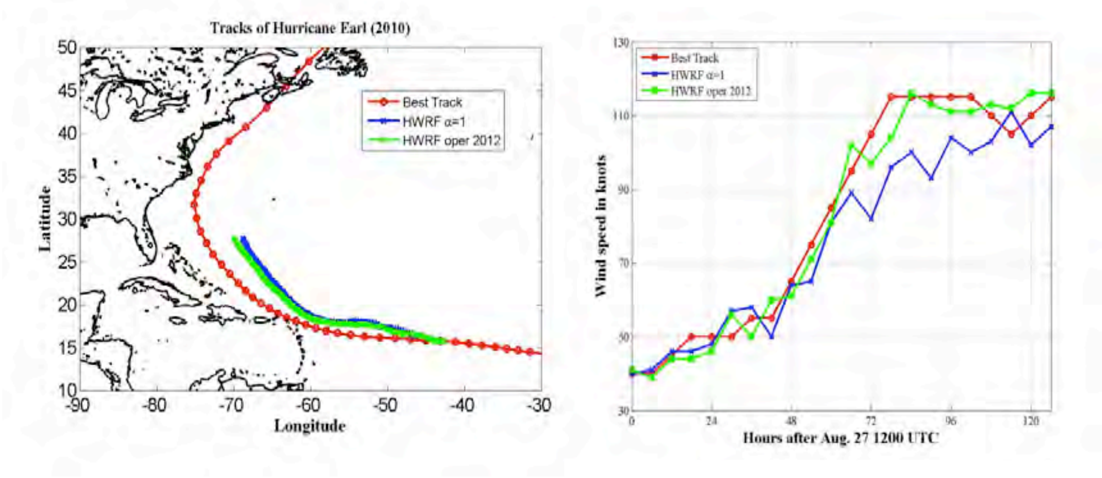

Figure 5: Intensity forecast of Hurricane Earl (2010) simulated using the 2012 version HWRF model with initialization at 12Z on August 27 using two different PBL physics, one following the 2012-version HWRF setup and the other following the 2011-version HWRF setup (see text for details).

The same initial vortex was used in these two simulations, but with two different PBL physics, one using the 2012-version HWRF PBL physics setup (alpha=0.5), and the other using the 2011-version HWRF setup (alpha =1) for the vertical eddy diffusivity using Eq. 1 in the form of:

$$K_m = k\,(u_*/\Phi_m)\, Z\, \alpha\, (1 - Z/h)^2, \qquad (1)$$

where k is the Von Kármán constant (k = 0.4), u_* is the surface frictional velocity scale, Φ_m is the stability function evaluated at the top of the surface layer, Z is the height above the surface, and h is the PBL height. In neutral conditions, which is usually valid in the hurricane boundary layer, $\Phi_m = 1$. The values of K_m used in the 2012-version HWRF (referred to as control run hereafter) are closer to observed ones given by Zhang et al. (2011b), compared to the 2011-version HWRF (referred to as large K_m run hereafter) as illustrated by Gopalakrishnan et al. (2013). It appears that the simulated tracks for the two simulations are close to each other but the intensity forecasts are different (Fig. 5). The control run (alpha=0.5) has a better intensity forecast after 68 hours after the initial time.

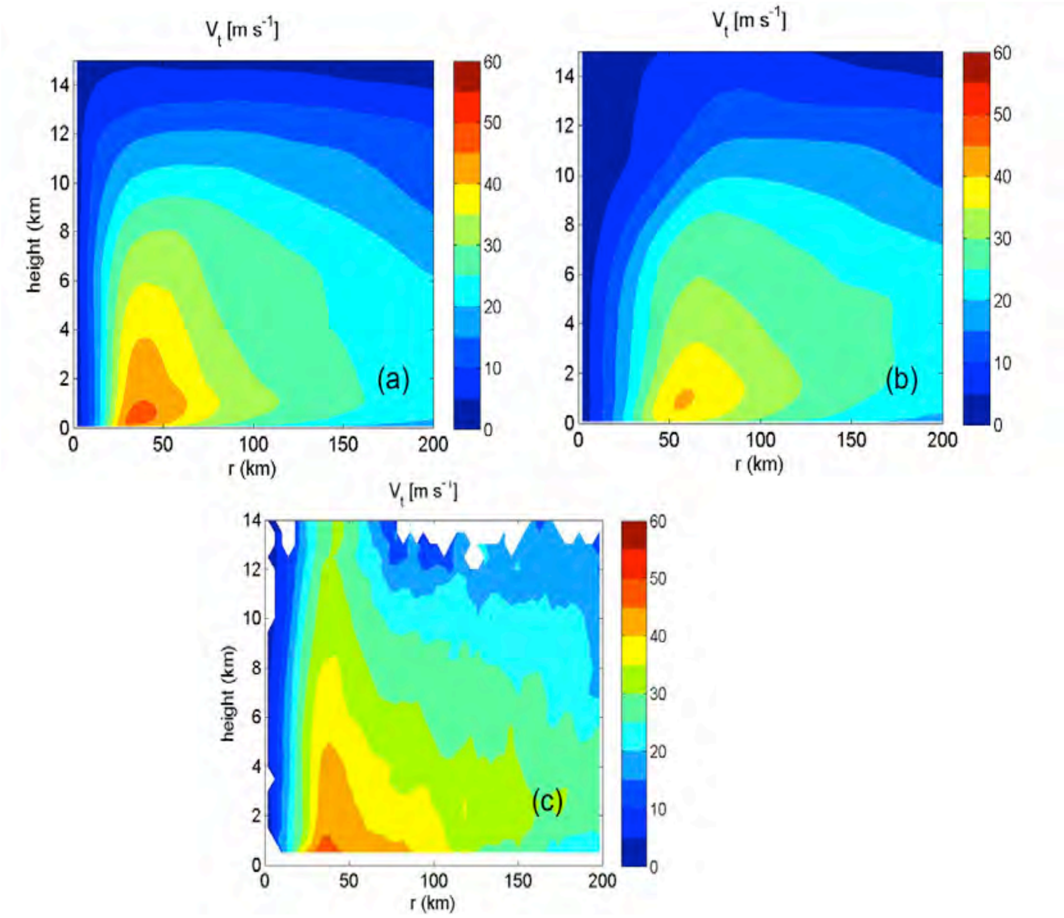

Figure 6: Azimuthally averaged tangential wind (Vt) from (a) the control run, (b) the large Km run between 56 and 68 hour forecast time periods, and (c) Doppler radar data taken from the same period.

Figure 6a and b show how the axisymmetric tangential wind (V_t) averaged during the period between 56 and 68 h differs for the control run and large K_m run, respectively. Figure 9c shows the Doppler radar observed V_t during the same period. There are some differences in the primary circulation between the two runs. For example, the peak of the tangential wind speed is larger in the control run than that in the large K_m run. It is also found that the peak axisymmetric tangential wind speed in the control run is closer to the observed (Fig. 6c). Furthermore, the size of the storm as indicated by the radius of the maximum wind speed (RMW) in the control run is approximately 40 km, which is much smaller than that (52 km) in the large K_m run, but is consistent with the radar data. These results are consistent with those found in the idealized simulations using HWRF by varying K_m as reported by Gopalakrishnan et al. (2013), i.e., that reducing K_m tends to make a more intense and smaller vortex.

After the successful tests we made using a case study on the structural metrics we developed based on observations, we conducted composite analysis for multiple HWRF forecasts. Our work has focused on evaluating the structural differences between two sets of simulations with: 1) PBL scheme as in the operational HWRF model (referred to as PBL12 hereafter), and 2) PBL scheme as in the 2011 version HWRF (PBL11 hereafter). In the 2011-version HWRF, α =1 (Eq. 1), while the 2012-version HWRF used α =0.5. The values of K_m used in PBL12 are closer to the observed values reported by Zhang et al. (2011b) as illustrated in detail by Zhang et al. (2012) and Gopalakrishnan et al. (2013).

A total of 122 simulations of 4 hurricanes (Hurricanes Bill, Earl, Karl and Irene, see Fig. 7 for storm tracks) were conducted for PBL11 and PBL12. These simulations were run in a cycling mode every 6 hours in the same manner as in the operational HWRF forecasts. Each cycle generates a five-day forecast. The number of cycles for each storm depends on its lifetime. Table 1 summarizes the storm information along with the number of cycles of simulations and starting time of the first and last cycles.

Table 1: Summary of storm information and HWRF simulations.

Storm name	Number of cycles of simulations	Starting time of the first cycle	Starting time of the last cycle
Bill	33	2009/08/15/18Z	2009/08/23/18Z
Earl	40	2010/08/25/18Z	2010/09/04/12Z
Karl	15	2010/09/14/18Z	2010/09/18/06Z
Irene	34	2011/08/20/18Z	2011/08/29/00Z

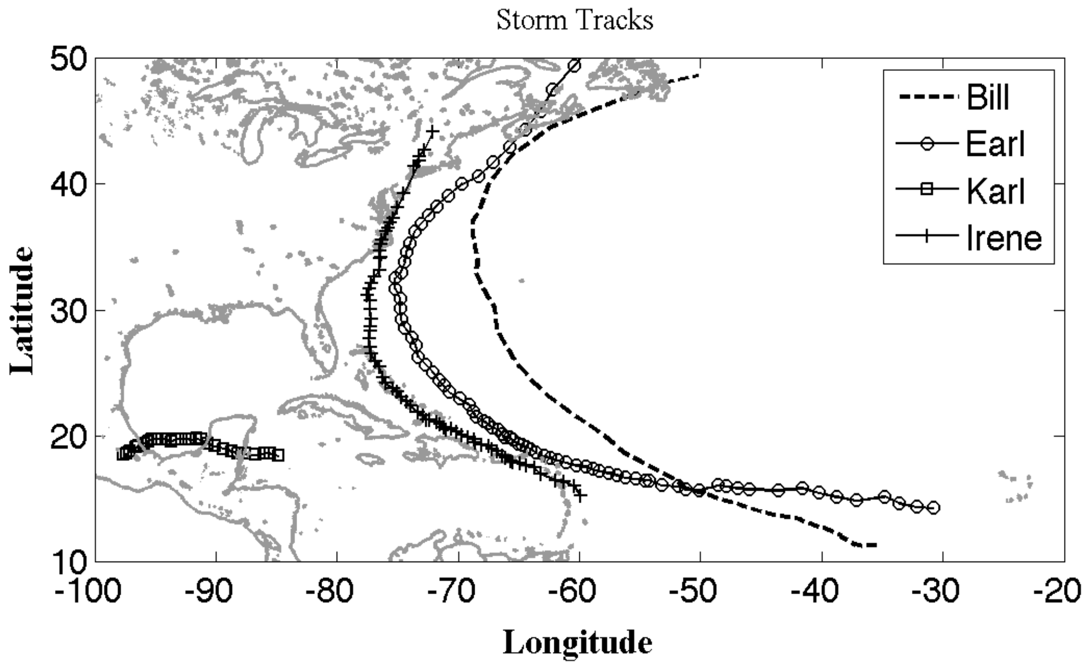

Figure 7: Best tracks of Hurricane Bill (2009), Earl (2010), Karl (2010), and Irene (2011).

The absolute errors of track and intensity forecasts for PBL11 and PBL12 runs are shown in Fig. 8, which were derived by comparing the simulated track and intensity to the best track data from the National Hurricane Center (NHC). The number of cases in the above verification every 12 hours is also plotted. It appears that the track forecast is improved in the PBL12 run compared to the PBL11 run (Fig. 2a) although the improvement is relatively small (< 4%). On the other hand, the intensity forecast is improved (~6% on average) from PBL11 to PBL12, especially before 72 hours. Note that this improvement is purely due to the improvement of the PBL physics. In the verification of the 2012 version HWRF compared to 2011 version HWRF reported recently by Tallapragada et al. (2014), the improvements in track and intensity forecasts include also the effect of increasing model horizontal resolution from 9km to 3km for the finest nest.

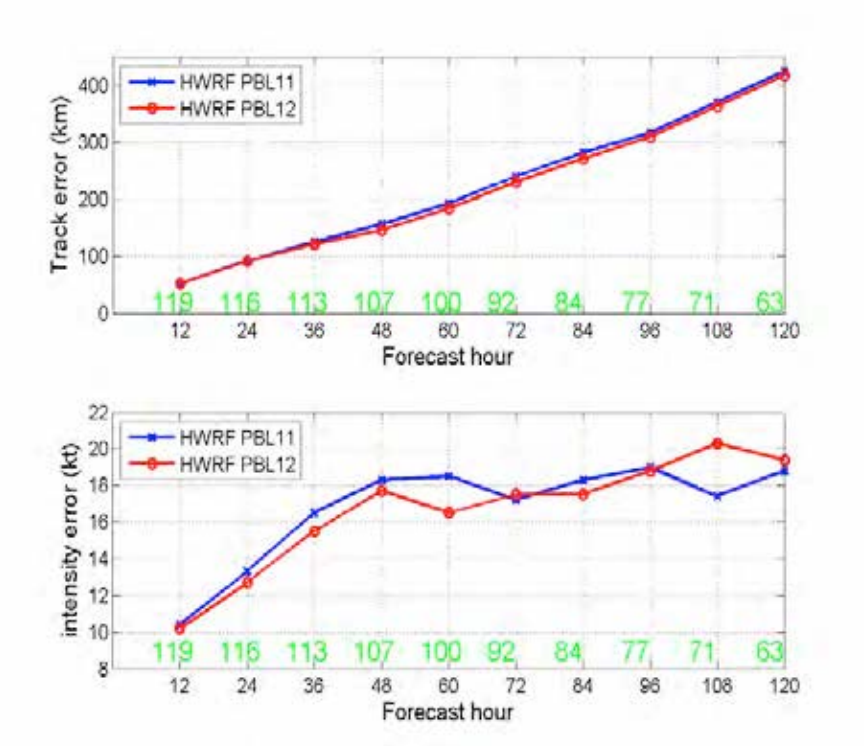

Figure 8: Absolute errors of track (upper panel) and intensity (lower panel) forecasts of the two sets of HWRF simulations of 4 hurricanes listed in Table 1.

Next, we present results of the composite analyses of the PBL11 and PBL12 runs in comparison with observational composites in terms of structural metrics that include the size of the storm, surface inflow angle, PBL height, and eyewall slope, etc. Figure 9 shows the frequency distribution of the radius of the RMW at 10m for the PBL11 and PBL12 composites. It clearly demonstrates that the mean size of the simulated storms in the PBL11 composite is substantially larger than that in the PBL12 composite, with a mean difference of ~ 10 km. Estimates of RMW from the Stepped Frequency Microwave Radiometer (SFMR) data in these storms showed the mean RMW for these four storms[1] to be ~37 km. These values are closer to those of the PBL12 composite (~44 km) than the PBL11 composite (~53 km), indicating that the PBL12 physics improves forecasts of storm size.

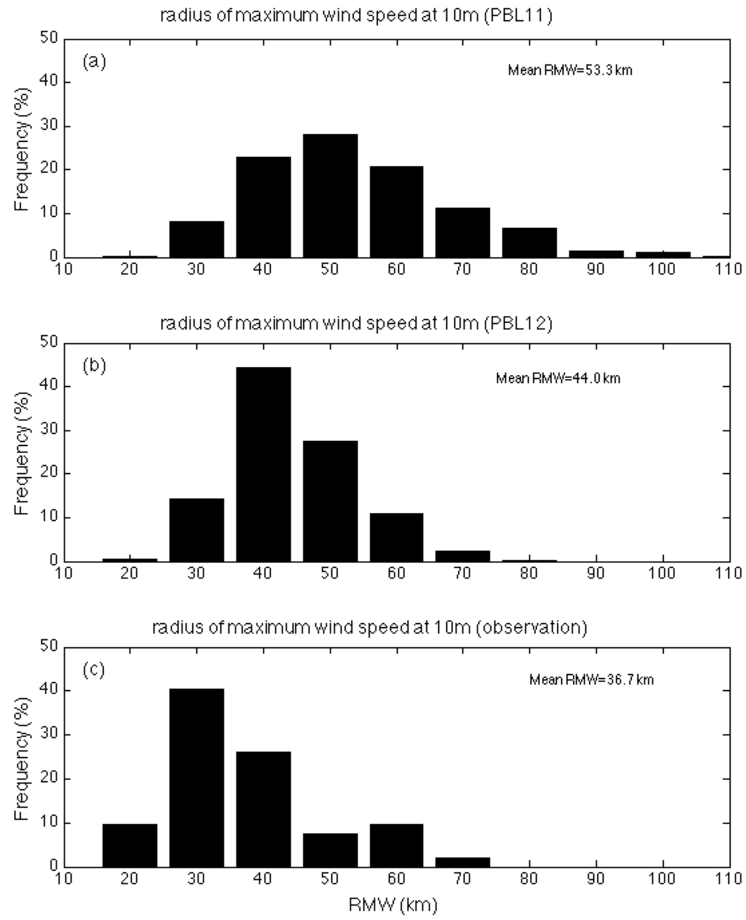

Figure 9: Frequency distribution of simulated radius of maximum wind speed at 10m for HWRF forecasts with PBL11 (upper panel), PBL12 (middle panel) and observations (lower panel).

Hurricane surface inflow angle is an important dynamical parameter which represents the relative strength between the radial wind velocity and tangential wind velocity. Since air parcels move from the ambient region to the storm center following the inflow trajectory, how the inflow angles vary with the distance to the storm center is tied to the energy exchange near the air-sea interface thus is important for hurricane intensification. Here we compare the radial distribution of the surface inflow angles for the PBL11 and PBL12 runs and compare the composite results with observations based on the GPS dropsonde data as reported by Zhang and Uhlhorn (2012). Figure

[1] Only forecast times where there are SFMR data are used in the analyses.

10 illustrates that the simulated surface inflow angle and its radial variation in the PBL12 run is very close to the observations. However, the magnitude of the surface inflow angle in the PBL11 run is significantly smaller than observed values, although the trend of variation of inflow angle as a function of radius is similar to that in observations. Again, this result shows that results of the physics upgrade in the 2012-version HWRF are very encouraging.

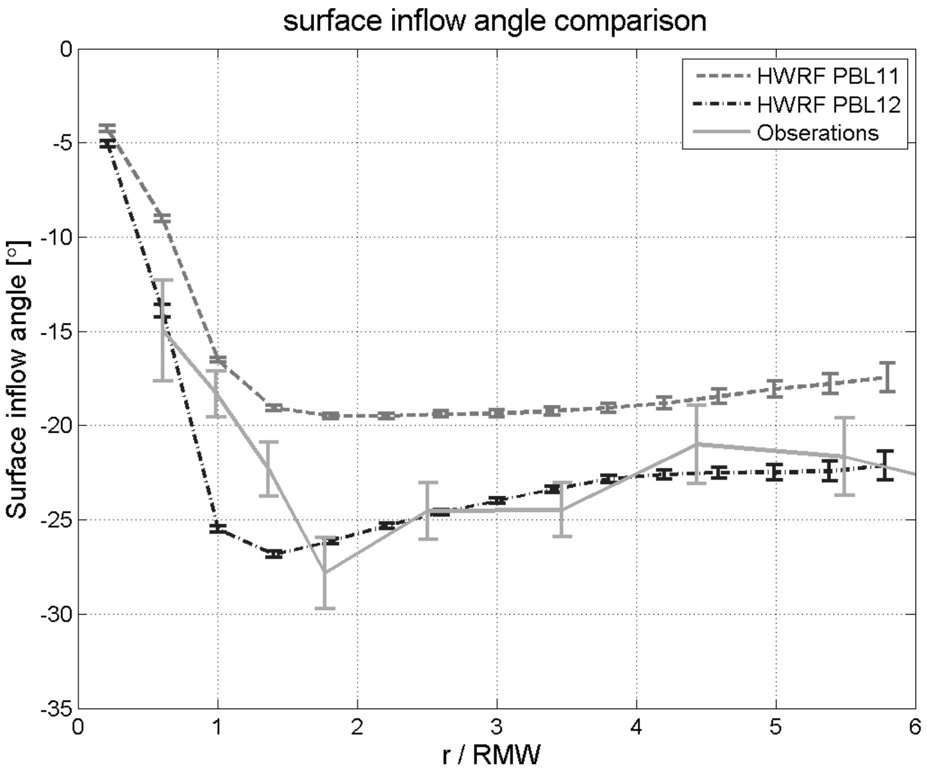

Figure 10: Plot of surface inflow angle as a function of radius to the storm center normalized by the radius of maximum wind speed. Vertical bars show the 95% confidence interval. The observation curve is from Zhang and Uhlhorn (2012).

Figure 11a-c, respectively, show the tangential wind speed as a function of r* and z for PBL11, PBL12, and sonde composites. The dashed line in each panel represents h_{vtmax}. Firstly, it shows that h_{vtmax} in the PBL12 run is much closer to observations than that in the PBL11 run. At the eyewall region (r*=1), the observed h_{vtmax} is ~600m, but h_{vtmax} in the PBL11 run is ~1000m. Secondly, both PBL11 and PBL12 runs captured the trend of decrease of hvtmax with decreasing radius especially close to the eyewall region. This behavior is captured in the PBL12 run for a larger radial distance than in the PBL11 run (i.e., r*<1.8RMW in PBL12 versus r*<1.2 in PBL11). The PBL12 run also shows a broader vortex than the PBL11 run, again more consistent with observations. In the outer radii (r*>1.5), h_{vtmax} in the PBL12 run is much higher than that in the observation, which is the remaining model deficiency.

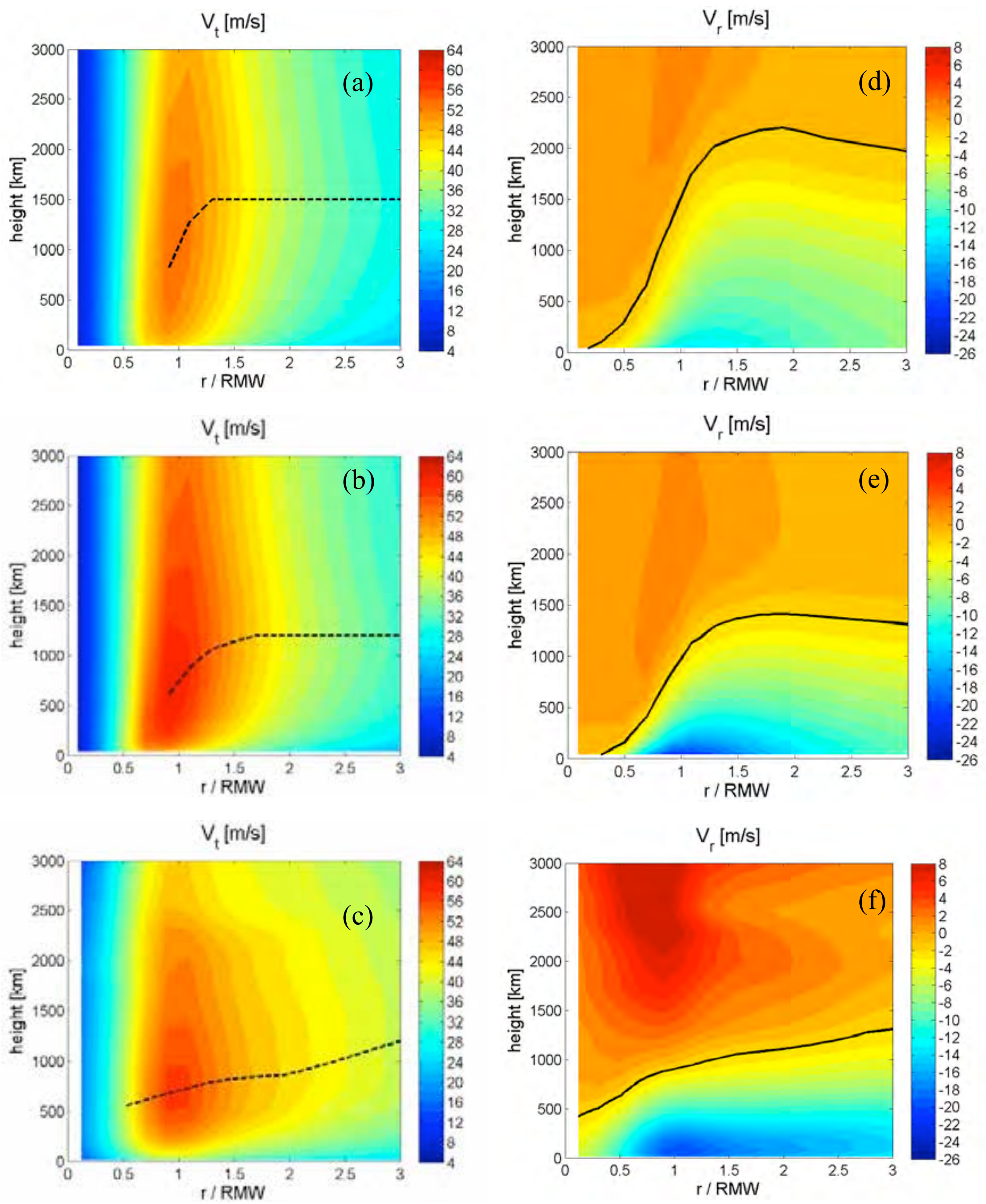

Figure 11: Plots of tangential wind (left) and radial wind (right) as a function of r/RMW and height. The upper panels are for PBL11, the middle panels are for PBL12, and the lower panels are for sonde composites from Zhang et al. (2011a). The dashed line represents the height of the maximum tangential wind speed and the solid line represents the inflow layer depth.

Figure 11d-f, respectively, show the radial wind speed as a function of r* and z for PBL11, PBL12, and sonde composites. The solid line in each panel shows the inflow layer depth (h_{inflow}). The result of h_{inflow} is similar h_{vtmax}, with h_{inflow} in the PBL12 run being much closer to observations than that in the PBL11 run. At the eyewall region (r*~1), the observed h_{inflow} is ~800m, but h_{inflow} in the PBL11 run is ~1200m which is significantly deeper than that in the PBL12 run and the observed value. Both PBL11 and PBL12 runs captured the trend of decrease of h_{inflow} with decreasing radius same as in the observation. Both runs also captured the feature of h_{vtmax} being within the inflow layer consistent with observations. Furthermore, the magnitude of the peak radial wind speed in the PBL12 run is much closer to the observed value than that in the PBL11 run. The radial inflow in the PBL11 run is too weak compared to observations. It is noticed also that h_{inflow} in the outer radii (r*>1.5) is higher than that in the observation, suggesting further improvement in the model physics is needed.

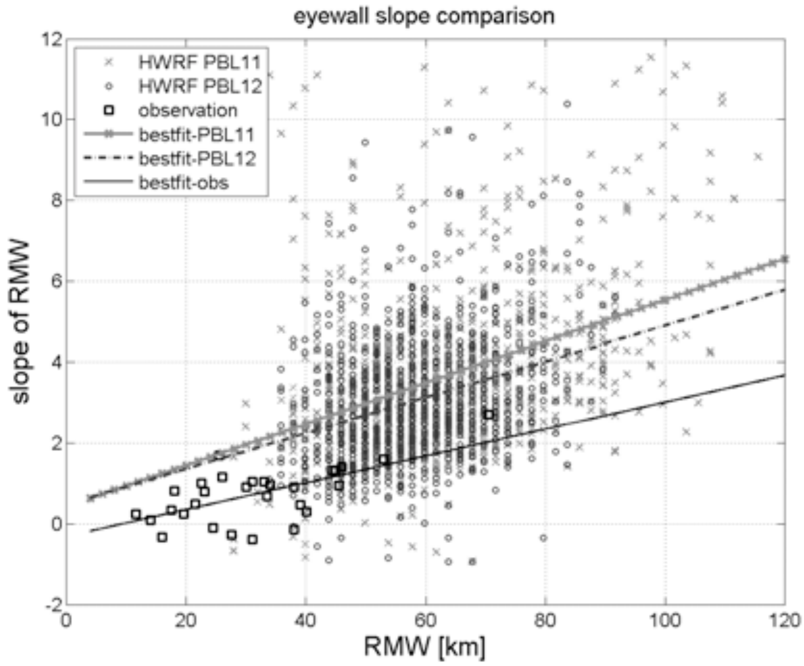

Figure 12: Plot of the slope of the RMW as a function of RMW at 2 km for PBL11 and PBL12. The observed relationship from Doppler radar data given by Stern and Nolan (2009) is also shown.

Using these two sets of simulations, we also tested another important structural metric, eyewall slope. The eyewall slope defined as the slope of the RMW is one of the important parameters that represent the vertical structure of a hurricane and is tied to hurricane dynamics. Following Stern and Nolan (2009), we use the RMW at 2 km when testing the relationship between the eyewall slope and the storm size. We calculated the eyewall slope using the azimuthally averaged tangential wind for each forecast time for the two set of runs. Figure 12 shows the slope of the eyewall as a function of RMW for the PBL11 and PBL12 runs. The updated observational data from Stern and Nolan (2009) are also shown. It is encouraging to see that both PBL11 and PBL12 runs show the increase of eyewall slope with increasing RMW, consistent with observations. However, the magnitude of the simulated eyewall slope in both runs is significantly larger than that in observations. We noticed somewhat improvement in the eyewall slope and RMW relationship for larger RMW (i.e., RMW>40 km) in the PBL12 run compared to the PBL11 run, but this improvement is small. Nolan et al. (2013) found that model resolution is also responsible for improving the eyewall slope representation in the WRF-ARW model simulation of a nature run. Their WRF-ARW simulations also showed larger eyewall slope than observations. Our result indicates that the vertical diffusion may not be the main factor influencing the eyewall slope structure. Further improvement in the vertical wind structure in HWRF is recommended.

Our work further emphasizes the importance of aircraft observations in model diagnostics and development, endorsing the developmental framework for improving the physical parameterizations in hurricane models as proposed recently by Zhang et al. (2012), which is also supported by this project. Figure 13 is a schematic diagram summarizing the difference in storm structures between PBL11 and PBL12 forecasts. With smaller vertical diffusion in the boundary layer, the simulated storms are stronger and have smaller size, shallower boundary layer, stronger inflow in the boundary layer, stronger outflow above the boundary layer, stronger updrafts in the eyewall, stronger warm core and smaller eyewall slope.

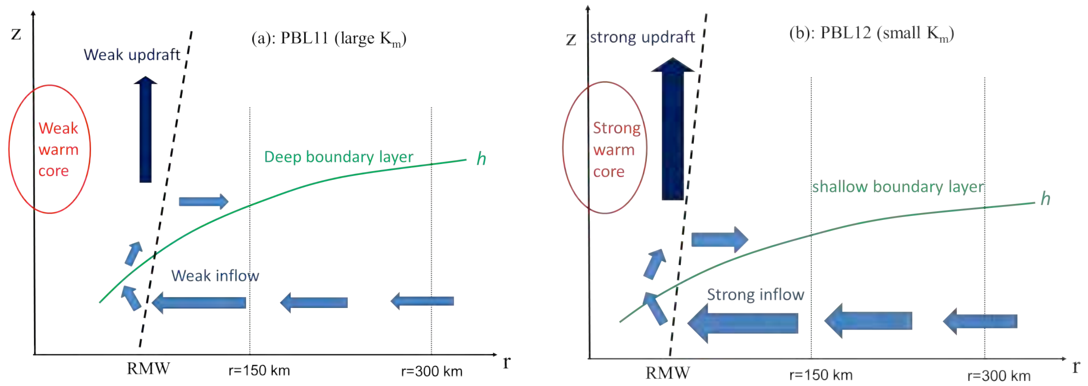

Figure 13: A schematic diagram summarizing the different structures in the PBL11 (a) and PBL12 (b) composites. The thickness and length of the arrow is correlated with the strength of inflow, outflow or updraft. The boundary-layer height (*h*) is denoted by the green line in each panel.

This model physics improvement framework of Zhang et al. (2012) consists of four main steps: 1) model diagnostics, 2) physics development, 3) physics implementation and 4) further evaluation. Here we show that this framework is successful for improving the boundary layer physics of the HWRF model. This framework should be able to guide model development for other hurricane models as well.

Besides the work mentioned above, the PI (Jun Zhang) is also part of the microphysics team the HFIP lead (Frank Marks) put together to evaluate microphysics schemes in HWRF and in charge of analyzing the high-altitude dropsonde data from the G-IV aircraft to evaluate the thermal structure in idealized HWRF simulations. Results are presented at the modeling group meetings and Monthly science meetings of HRD. PI (Jun Zhang) also investigated the effect of horizontal diffusion on hurricane intensity and structure using idealized HWRF simulations. We have submitted a paper (Zhang and Marks 2015) to Monthly Weather Review. He also worked closely with HWRF developers at EMC and ESRL to evaluate the impact of the other boundary layer scheme (TKE-type MYJ scheme) on intensity and structure simulations and presented results at EMC's weekly meeting. These work including summarizing the model composite study were conducted within the year of extension after year 2 with no cost.

Above all, all the proposed tasks in our proposal have been successfully completed at the end of this project. We want to acknowledge HFIP and HWRF team for supporting our work.

References (PIs' publications as part of this proposal are in bold):

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Lorsolo, S., J. A. Zhang, F.Marks, J. Gamache, 2010: Estimation and Mapping of Hurricane Turbulent Energy Using Airborne Doppler Measurements. *Mon. Wea. Rev.*, **138**, 3656–3670.

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Progress Report (May 2015)

Re: Award number NA14NWS4680028

Title: Addressing deficiencies in forecasting tropical cyclone rapid intensification in HWRF

PIs: Jun Zhang, David Nolan and Hua Chen

Collaborator: Robert Rogers

HWRF team collaborators: Sundararaman G.Gopalakrishnan and Vijay Tallapragada

The goal of this project is to evaluate and improve the performance of the HWRF model in forecasting rapid intensification (RI) of tropical cyclones. The main objectives of this project are:

1) To identify key physical processes associated with RI using HWRF forecasts and the hurricane nature runs.
2) To quantitatively evaluate deficiencies and biases in inner-core structure and environmental conditions associated with RI forecasts by the HRWF model.

Our proposed work in year 1 is focused on selecting and analyzing two cases of excellent RI forecasts (Hit) and one case with RI miss (Miss) from HWRF forecast. We also plan to analyze the nature run simulated using the WRF-ARW model to document key physical processes associated with RI. In addition, composite analysis approach will be explored using the HWRF retrospective forecasts to prepare for our proposed work in year 2.

As stated in our last round progress report, we have identified one "Hit" case, the HWRF forecast of Hurricane Earl (2010) initialized at 18 UTC on 26 August (Chen and Gopalakrishnan 2015). The "Miss" case is also identified, which is the HWRF forecast of Hurricane Earl (2010) initialized at 12 UTC on 26 August. The time series of the minimum central pressure and maximum 10-m wind speed for these two cases are shown in Fig. 1.

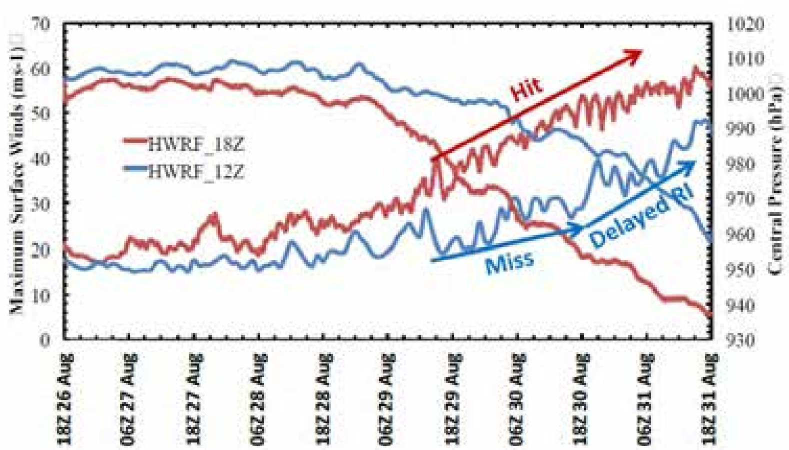

Figure 1. Time series of minimum central pressure and maximum 10-m winds for the Hit (i.e., 18 UTC 26 August initial time; red) and Miss (i.e., 12 UTC 26 August initial time; blue) HWRF forecasts.

In recent months, we have continued our analyses of the 3-km HWRF forecast of Hurricane Earl (i.e., the Hit case) with a focus on determining the relationship between different modes of precipitation and RI in the model. Figure 2 shows an image of TRMM TMI 37 GHz brightness temperatures, a channel that emphasizes emission and is indicative of rainfall in the lower troposphere, at 0413 UTC 28 August, i.e., about 24 h prior to the onset of RI (Stevenson et al. 2014, Rogers et al. 2015). A "ring" of elevated emission and low-level rainfall is apparent at this time. This ring has been noted to be a robust precursor to the onset of RI in observational studies (e.g., Kieper and Jiang 2012). A plot of 3-h time-averaged reflectivity at 2 km altitude from the HWRF forecast initialized at 18 UTC 26 August (Fig. 2b) shows a similar area of elevated reflectivity which may depict the ring-like structure similar to that seen in the satellite image. This represents shallow to moderate precipitation, consistent with the patterns noted in Kieper and Jiang (2012). Such shallow precipitation will be associated with a shallow layer of diabatic heating (not shown).

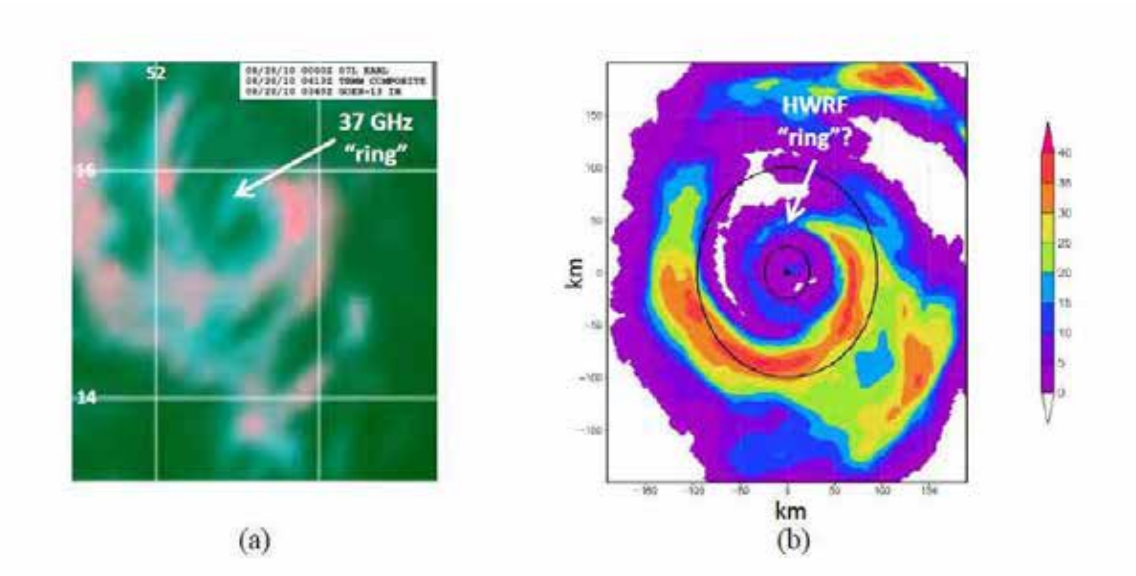

Figure 2. (a) Plot of 37 GHz TRMM composite image for Tropical Storm Earl valid 0413 UTC 28 August; (b) Reflectivity (shaded, dBZ) averaged over a 3-h window between 12:30 and 15:30 UTC 28 August from 3-km HWRF forecast initialized at 1800 UTC 26 August. Circles in (b) denote 25- and 100-km radii.

A plot of the top of the 0.5 g/kg hydrometeor surface, equivalent to a ~20 dBZ radar echo top, is shown in Fig. 3 during the time of the ring-like structure in the HWRF forecast shown in Fig. 2b. There are some areas where the 0.5 g/kg hydrometeor surface extends up to above 14 km altitude, indicative of deep convection. However, those towers are > 100 km from the center at this time, and they are outside the RMW. The ring-like structure is characterized by hydrometeor tops extending to 2-4 km altitude near the center, with some tops extending to 8-10 km by 15 UTC 28 August. This represents shallow to moderate precipitation, consistent with the patterns noted in Kieper and Jiang (2012). Such shallow precipitation will be associated with a shallow layer of diabatic heating. By contrast to the times ~12 h prior to onset shown in Fig. 3, hydrometeor tops for the time period marking the onset of RI (Fig. 4) show that tops exceed 14-16 km over a widespread region on the east and southeast sides of the storm. Some of these tops are within 50 km of the center, inside the RMW. This is consistent with the convective bursts documented in observations of the onset of Earl's RI (Stevenson et al. 2014, Rogers et al. 2015).

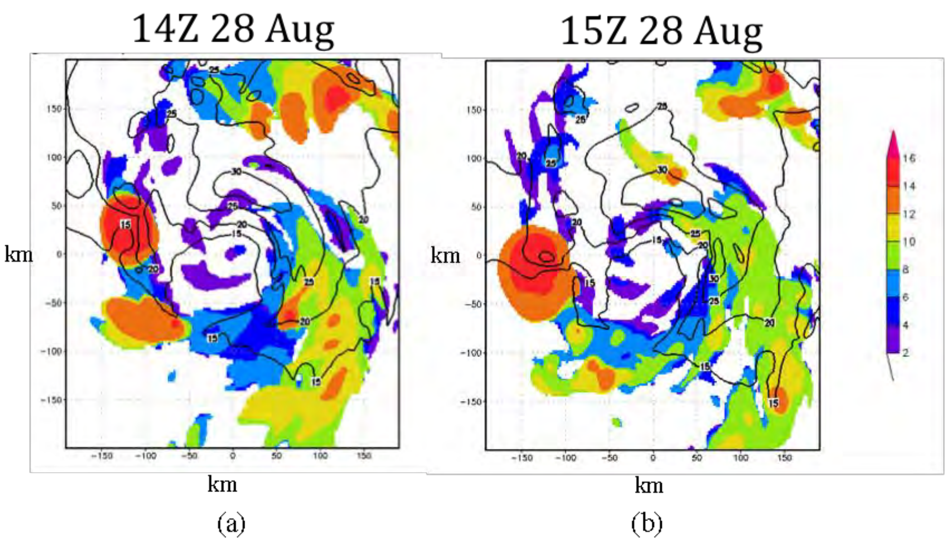

Figure 3. (a) Top of the 0.5 g/kg hydrometeor surface in HWRF forecast (shaded, km) and wind speed at 2-km altitude (contour, m/s) valid 14 UTC 28 August; (b) As in (a), but for 15 UTC 28 August.

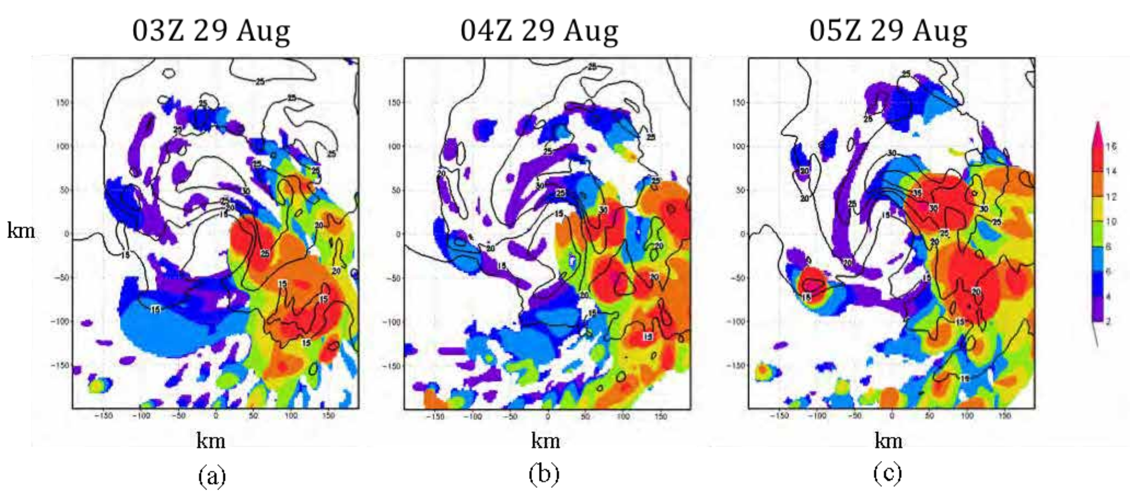

Figure 4. (a) Top of the 0.5 g/kg hydrometeor surface in HWRF forecast (shaded, km) and wind speed at 2-km altitude (contour, m/s) valid 03 UTC 29 August; (b) As in (a), but for 04 UTC 29 August; (c) As in (a), but for 05 UTC 29 August.

While the presence of deep convection seems to be associated with the immediate onset of RI in the model, that does not mean that the shallow/moderate convection seen ~12 h earlier did not play a role. Recent work has identified an alternate, boundary-layer mechanism that explains the onset of RI. Miyamoto and Takemi (2015, under review at JAS) has proposed that RI begins once the radius of maximum convergence (RMC) in the boundary layer approaches the low-level RMW, resulting in an axisymmetrization of convection and eyewall formation. They argue that, since the RMC scales with the vortex Rossby number, the RMC approaches the RMW as the vortex slowly intensifies and the Rossby number increases. Figure 5 shows a time-radius Hovmoller of axisymmetric PBL convergence and tangential wind at 2-km altitude for the HWRF forecast of Earl. As the RMW contracts, the RMC does approach the RMW, and it is nearly at the RMW at the RI onset time of ~06 UTC 29 August. The ring-like structure seen in the HWRF forecast at 12-15 UTC 28 August may also be explained by this ring of high PBL convergence. The RMC at this time is ~50 km, which is consistent with the radius of the ring of shallow precipitation seen in the plot in Fig. 2b. So the ring identified in 37 GHz microwave imagery may simply reflect the presence of a region of enhanced PBL convergence associated with an intensifying vortex, and may not necessarily indicate that RI is imminent. How this could serve as a precursor for RI, and whether cases that do not undergo RI also produce this structure, is still under investigation.

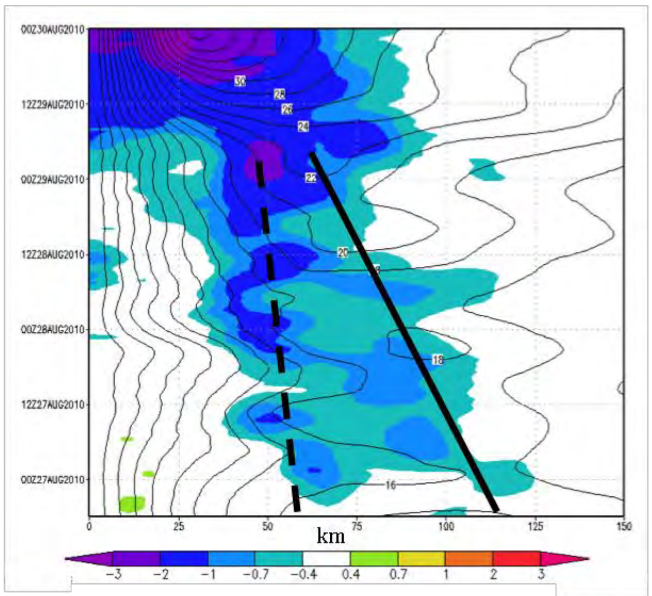

Figure 5. Time-radius Hovmoller of azimuthally-averaged divergence in the 0.25-1 km layer (shaded, x 10^{-4} s^{-1}) and wind speed at 2-km altitude (contour, m s^{-1}). Fields are smoothed over a 3-h period to reduce convectively-induced anomalies. Thick solid line denotes approximate radius of maximum winds; thick dashed line denotes approximate radius of maximum convergence.

Part of this continuing investigation will involve comparing the “Hit” forecast of RI, indicated by the 18 UTC 26 August forecast shown here, with a “Miss” forecast of RI, indicated by the delayed onset of RI produced by the 12 UTC 26 August HWRF forecast (Fig. 1). Does the Miss forecast show a similar ring-like structure at around the same time as the Hit forecast? Does it show a ring at the same RI-relative time (i.e., ~24 h prior to RI onset)? Given that the shear environment of the Miss and Hit forecasts are different, as shown in the previous report, how are the structures of the vortices (e.g., vertical tilt) different between the runs at the time of the observed RI onset? These questions will be pursued in the coming months.

The results from previously HFIP-funded project of the PIs showed that the boundary layer physics has an important role in intensity and structure forecasts by comparing HWRF forecasts with two different boundary layer physics toobservations (Zhang et al. 2015). We analyzed a total of 122 HWRF forecasts of 4 hurricanes (Hurricanes Bill, Earl, Karl and Irene) with 1) the PBL scheme as in the 2012 operational HWRF model (referred to as PBL12 hereafter), and 2) the PBL scheme from the 2011 version HWRF, using the larger value of K_m (PBL11 hereafter). We found that the improvement of the vertical diffusion in the boundary layer scheme led to improvements in track and intensity forecasts of the HWRF model. We also found substantial improvements in the simulated storm size, surface inflow angle, near-surface wind profile and kinematic boundary layer heights in simulations with the improved physics, although we only found minor improvements in the thermodynamic boundary layer height, eyewall slope, and the distributions of vertical velocities in the eyewall.

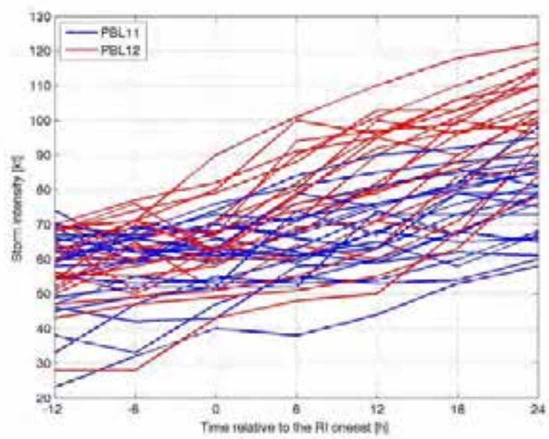

Figure 6: Plot of the storm intensity in kt for PBL11 (blue) and PBL12 (red) forecasts. Only forecasted RI events in PBL12 but not in PBL11 are shown.

To achieve the objectives of the current HFIP-funded project on RI, we have further analyzed the two sets of HWRF forecasts with different vertical diffusion profiles. We aim to understand if the boundary layer physics also affects the intensity change and RI forecasts. Figure 6 shows the 24 h intensity change from the PBL11 and PBL12 forecasts, only for the cases where RI events are captured by PBL12 but not by PBL11. Here RI event is defined following the definition from Kaplan et al. (2010) of RI as a 24 h increase in wind speed of 30 knots. Following the methodology we used in our previous HFIP-funded project (Zhang et al. 2015), we use structural metrics in a composite framework to conduct model diagnostics to compare RI and non-RI events. The goal is to investigate how inner-core structure difference is related to different intensity change due to different boundary layer physics. In recent months, we have investigated the axisymmetric boundary layer structure with focus on the boundary layer height scales. These height scales include the height of the maximum tangential wind speed (h_{vtmax}), the depth of the inflow layer defined as the height of 10% peak inflow (h_{inflow}), and the thermodynamic mixed layer depth defined either as 1) the height where the difference of virtual potential temperature (θ_v) and the mean of θ_v over the lowest 150m equals 0.5 K

(Z_{id}), or 2) the vertical gradient of θ_v equals 3K/km (Z_{ig}). Here we evaluate these four boundary layer height scales in the model composites from PBL11 and PBL12. To get meaningful comparisons in h_{vtmax} and h_{inflow}, we normalized V_t and V_r by their maximum values in both the PBL11 and PBL12 composites at the on-set of the RI event. Azimuthally averaged fields will be presented as a function of radius normalized by RMW (r*=r/RMW) and of dimensional height (z).

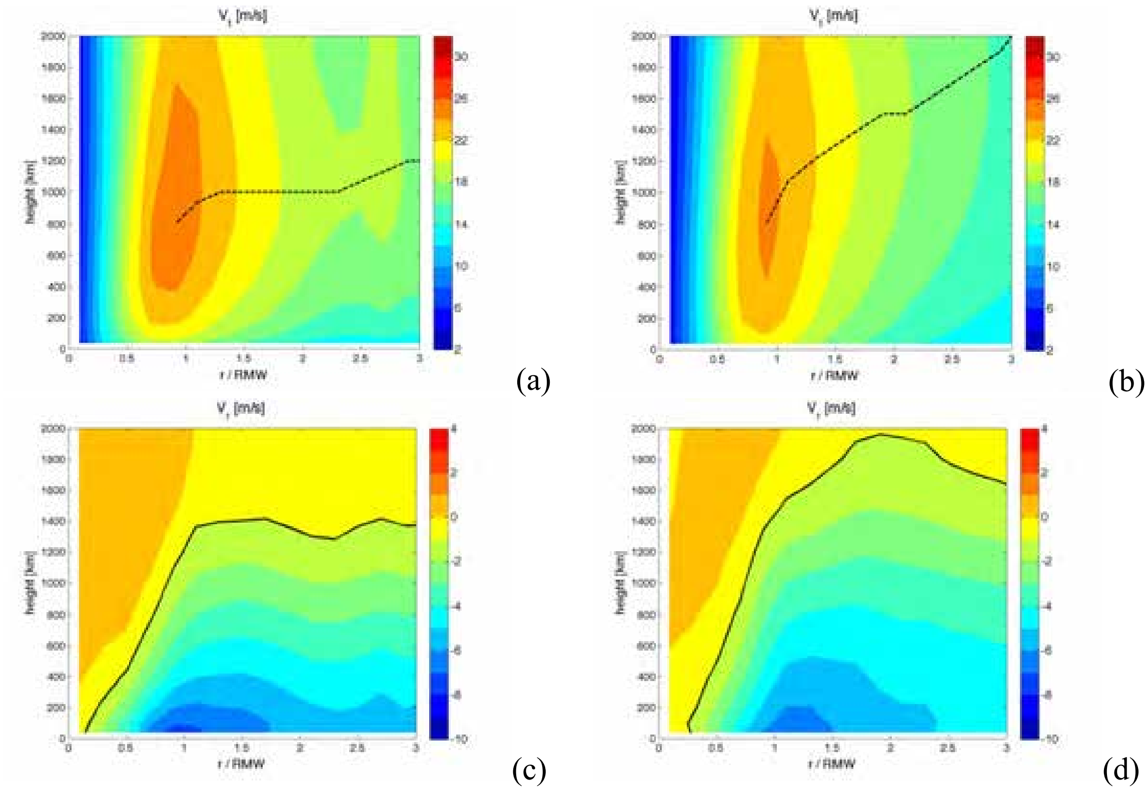

Figure 7: Plots of tangential velocity (a and b) and radial velocity (c and d) as a function of height and radius (r) normalized by the radius of maximum wind speed (RMW) at 2 km. The left panels are for PBL12 and the right panels are for PBL12 composites. The dashed line represents the height of the maximum tangential wind speed and the solid line represents the inflow layer depth.

Both PBL11 and PBL12 forecasts reproduce the trend of decrease toward the center of h_{vtmax} and h_{inflow}. Both forecasts also captured the feature of h_{vtmax} being within the inflow layer. It is evident from Fig. 7 that both h_{vtmax} and h_{inflow} in PBL11 are much higher than those in PBL12. The tangential wind speed at the outer radii (r*>1.5) is generally larger in PBL12 than in PBL11, although the peak tangential wind speed is similar (Fig. 7a and b). The peak inflow in PBL12 is found to be stronger than that in PBL11 (Fig. 7c and d). The thermodynamic mixed layer depths (Z_{id} and Z_{ig}) are similar between PBL11 and PBL12. Interestingly, Z_{id} and Z_{ig} are slightly higher in PBL12 than in PBL11, although the difference is not significant. Both forecasts captured the trend of decrease of mixed layer depth with decreasing radius. The main difference between PBL11 and PBL12 is found near the surface where the surface layer is much more unstable in PBL12 than in PBL11, indicating more surface enthalpy fluxes are supplied to the system in PBL12 than in PBL11.

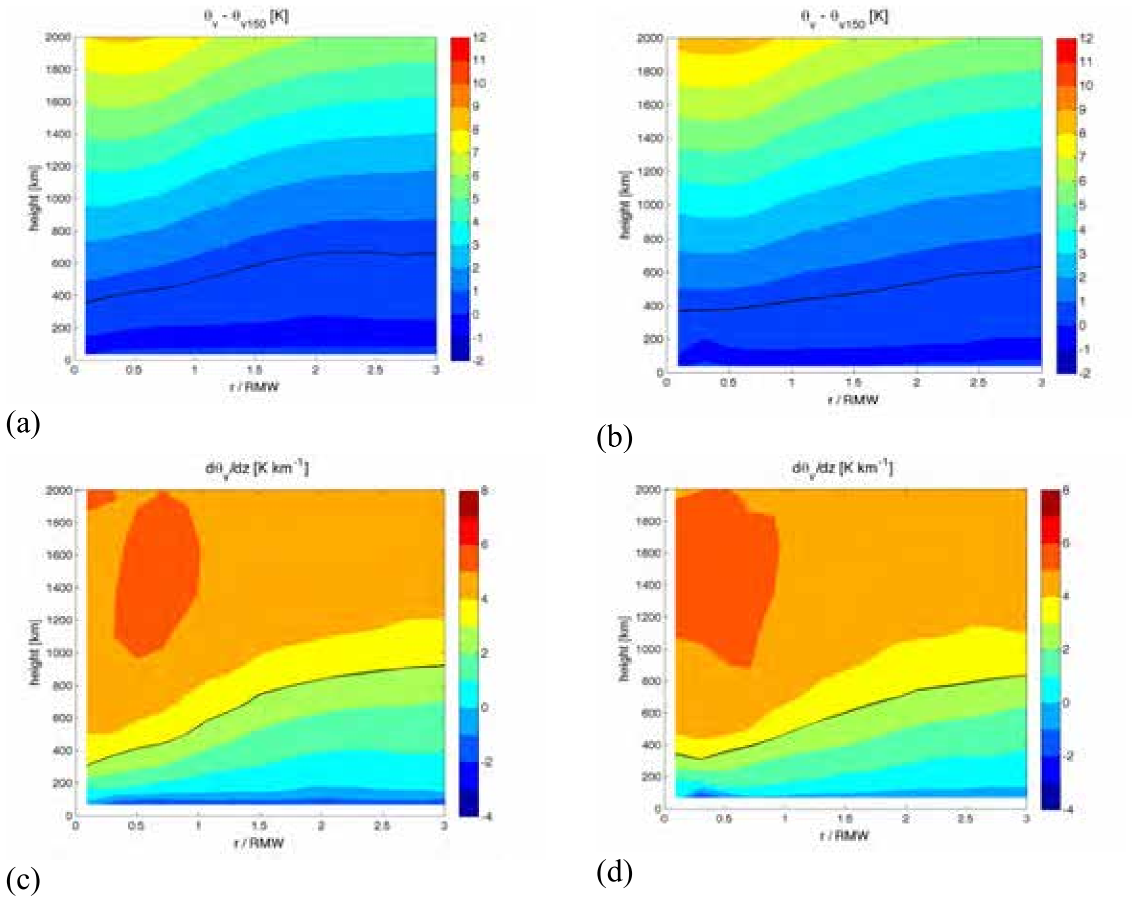

Figure 8: Plots of the difference of theta-v and the mean of the lowest 150m data (a and b) and vertical gradient of theta-v (c and d) as a function of r/RMW and height. The left panels are for PBL11 and the right panels are for PBL12. The solid line represents the mixed layer depth.

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Project Final Report

(Report period: 1/01/2012-12/31/2014)

Project Name: Development of Multiple Moving Nests Within a Basin-Wide HWRF Modeling System (NOAA Award: NA12NWS4680007)

Principal Investigator: Xuejin Zhang (U. Miami/RSMAS/CIMAS)

Co-PI: Da-lin Zhang (U. Maryland/Dept. Atmos. & Ocean Sci.)

PI and Co-PI officially started the project on January 1, 2012. In University of Miami, Dr. X. Zhang leads the project. PI has established regular communication and discussion with collaborators of EMC and HRD, and UMD/DAOS co-PI.

I. Scientific progress highlights

I.1. Research to Operation transition: PI, collaborating with HRD scientist Thiago Quirino, EMC scientists Qingfu Liu, Samuel Trahan, and Zhan Zhang, and CIMAS staff Russell St. Fleur, completed the development of the basin-scale HWRF system. *The system source code was committed to DTC repository and the nesting code was transited in the operational HWRF system in 2012. The entire basin-scale HWRF system including automation scripts was transferred to DTC in 2014 for possible research-to-operation transition and public release.*

I.2. Real-time and retrospective experimental forecasts: The basin-scale HWRF system conducted HFIP stream 2.0 real-time forecasts for 2013 and 2014 hurricane seasons and retrospective forecasts for 2011-12 season in the Atlantic and East Pacific basins basin with 2013 version basin-scale HWRF system. The total cycles were 706, 1026, 745, and 648 for 2011, 2012, 2013 and 2014 seasons respectively. Real-time forecast and diagnostic products were archived at HRD real-time experimental forecast products website: https://hwrf.aoml.noaa.gov/realtime. Retrospective products are archived on HRD data portal and jet mass storage. They are available by request.

I.3. Verifications

I.3.1 The basin-scale HWRF modeling system: The basin-scale HWRF system utilized GFS analyses and forecasts as its input. Initializing multiple vortexes was based on operational HWRF's vortex initialization procedure (Tallapragada et al. 2014, http://www.dtcenter.org/HurrWRF/users/docs/scientific_documents/HWRFv3.6a_ScientificDoc.pdf). The first guess fields, initial conditions and lateral boundary conditions were generated from the same GFS system including its hybrid ensemble DA system during 2011-2014 seasons. The analyses and real-time forecasts or re-forecasts were used. The data were then transferred to ESRL's supercomputer JET by EMC's HWRF group. The model configuration and its counterpart configurations of the 2013 and 2014 version operational HWRF were summarized in Table 1.

I.3.2. Methodology and results: We also obtained ATCF files of 2011-2014 seasons from the operational HWRF and the 2014 pre-implementation retrospective and real-time forecasts. The HWRF forecast system replaced the 2012 operational HWRF on 2 July 2013 on operational supercomputer in NCEP's operational center (Personal communication with Frankline). Therefore, we only use 2013 ATCF file forecast tracks after 2 July 2013 in this verification. The verification results are shown in Figure 1. In general, basin-scale HWRF forecast statistically better tracks (5-10% improvement) comparing to operational HWRF in both the Atlantic and E. Pacific basins during four seasons. Intensity forecasts show constant 5% or more improvement in the Atlantic basin while slightly inferior forecasts (< 5%) in the E. Pacific basin in the first 72 hours then better in the 96-120 hours. The verification results further suggest that the oceanic effect on intensity should be taken into account if the storm moves slowly in the forecast.

Further verifications were done after 2014 season. The results indicate 2014 operational HWRF further improved track forecasts another ~5% (Figure 1) especially in day 4 and 5. This indicates the basin-scale HWRF can be further improved after other components in the system are improved such as land surface physics, ocean coupling, and initialization including large-scale environment and inner core. All of these components are not implemented in the basin-scale HWRF system yet. The research is beyond the scope of this research project.

I.3.3 Model improvement direction: The intensity errors were noticeably reduced in both basins compared to 2014 operational HWRF. The difference of the two systems is the ocean coupling in term of physical processes. The basin-scale HWRF system does not have ocean coupling while operational HWRF system couples with 3-D Princeton Ocean Model. The basin-scale HWRF system is fed by GFS Sea Surface Temperature (SST), which is provided by Reynolds 1.0°×1.0° weekly SST analysis (Reynolds & Smith, 1994). The weekly averaged SST smoothed the significant upwelling cooling effect over the storm passage corridor. The absence of oceanic effect in basin-scale HWRF system significantly degrade the intensity forecasts of the slow moving TC such as Leslie although it generated similar or better track forecasts (Figure 2). We will further quantify how significant the ocean effects are in the forecast model by mining this three-year dataset.

I.3.4 Broad impacts: PI and other scientists at HRD: S. G. Gopalakrishnan, H. Chen, P. Reasor, F. Marks, and S. Goldenberg are mining the massive datasets focusing on several research directions: Hurricane Sandy track and intensity evolution and its mechanism, shear-related hurricane structure, forecast track and intensity verification, and storm-storm interaction and forecast application (Xu et al., 2013). Naval Postgraduate School professor M. Montgomery and his team applied the basin-scale forecasts on genesis prediction in 2013-14 season and support HRD IFEX map discussion.

II. Publications related to this project

Xu et al. (2013) investigated the storm-storm interaction in HWRF. The study shows changing the intensity of TS Bopha has significant effects on simulating TY Saomai's intensities, structures, and tracks. It suggests a significant relevance for operational intensity forecasts under active binary TC interaction with current basin-scale HWRF system.

Da-Lin Zhang et al. (2015) studied the sensitivity of hurricane intensity forecasts to different distributions of vertical grid resolution in idealized framework. The research provides the theoretical evidence that the enhancing the vertical grid resolution in HWRF results in the substantial improvement of forecasts in 2013 basin-scale HWRF and 2014 operational HWRF.

Goldenberg et al. (2015) systematically documented the significance of the triply nested HWRF through the track and intensity verification.

X. Zhang et al. (2015) documented the algorithm of triple nests in HWRF system and provided track and intensity verifications of the basin-scale HWRF system forecasts in 2011-2014 seasons.

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Xu, H., Xuejin Zhang, X. Xu, 2013: Impact of Tropical Storm Bopha on the Intensity Change of Super Typhoon Saomai in the 2006 Typhoon Season. Adv. in Meteorology, Vol. 2013, http://dx.doi.org/10.1155/2013/487010.

Zhang, D.-L., L. Zhu, X. Zhang, and V. Tallapragada, 2015: Sensitivity of idealized intensity and structures under varying background flows and initial vortex intensities to different vertical resolutions in HWRF. *Mon. Wea. Rev.* 914-932.

Zhang, X., S. G. Gopalakrishnan, S. Trahan, T. S. Quirino, Q. Liu, and V. Tallapragada, 2015: Representing Multi-scale Interactions in HWRF Modeling System: Design of Movable Nests and Forecast Verification. Wea. Forecasting., (in review, manuscript available at request).

	2103 operational HWRF	2013 basin-scale HWRF	2014 operational HWRF
Domain	27 km: 77.58° × 77.58° 9 km: 10.56° × 10.2° 3 km: 6.12° × 5.42°	27 km: 178.20° ×77.58° 9 km: 10.56° × 10.2° 3 km: 6.12° × 5.42°	27 km: 77.58° × 77.58° 9 km: 10.56° × 10.2° 3 km: 6.12° × 5.42°
Model top	50 hPa	2 hPa	2 hPa
Vertical levels	42	61	61
Vortex initialization	Modified Vortex Initialization at 3 km, with 30°×30° analysis domain and GSI DA	Modified Vortex Initialization at 3 km, with 30°×30° analysis domain and No GSI DA	Modified Vortex Initialization at 3 km, with 30°×30° analysis domain and hybrid DA
Cycling	Only 3 km domain and No GSI DA	Only 3 km domain and No GSI DA	Cycling and GSI DA
Ocean coupling	27-9 KM: Yes 3 KM: No, Downscaled	No coupling	27-9 KM: Yes 3 KM: No, Downscaled
Physics scheme			
Microphysics	Modified Ferrier (High Resolution)	Modified Ferrier (High Resolution)	Modified Ferrier (High Resolution)
Radiation	GFDL	GFDL	GFDL
Surface	GFDL	GFDL	GFDL
PBL	2013 GFS	2013 GFS	2013 modified GFS
Convection	SAS (High Resolution), No CP (3 km), Shallow Convection	SAS (High Resolution), No CP (3 km), Shallow Convection	SAS (High Resolution), No CP (3 km), Shallow Convection
Land surface	GFDL Slab	GFDL Slab	GFDL

Table 1. Summary of HWRF system configuration and physics schemes

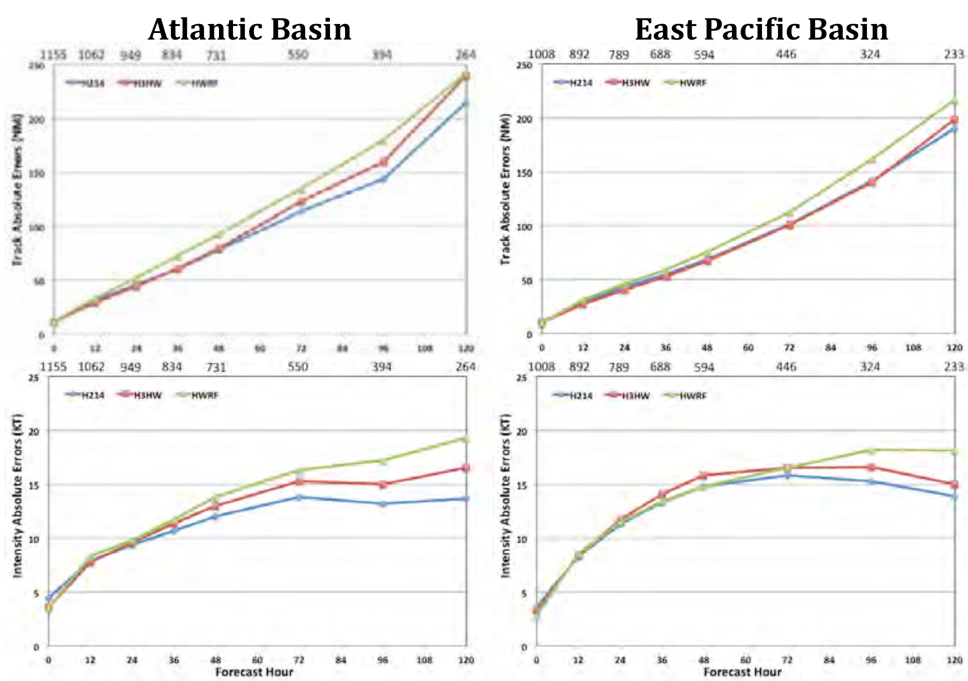

Figure 1. Verification of the 2013 basin-scale HWRF Forecasts (H3HW, red), real-time operational HWRF (HWRF, green), and 2014 operational HWRF (H214, blue) (2011-2014).

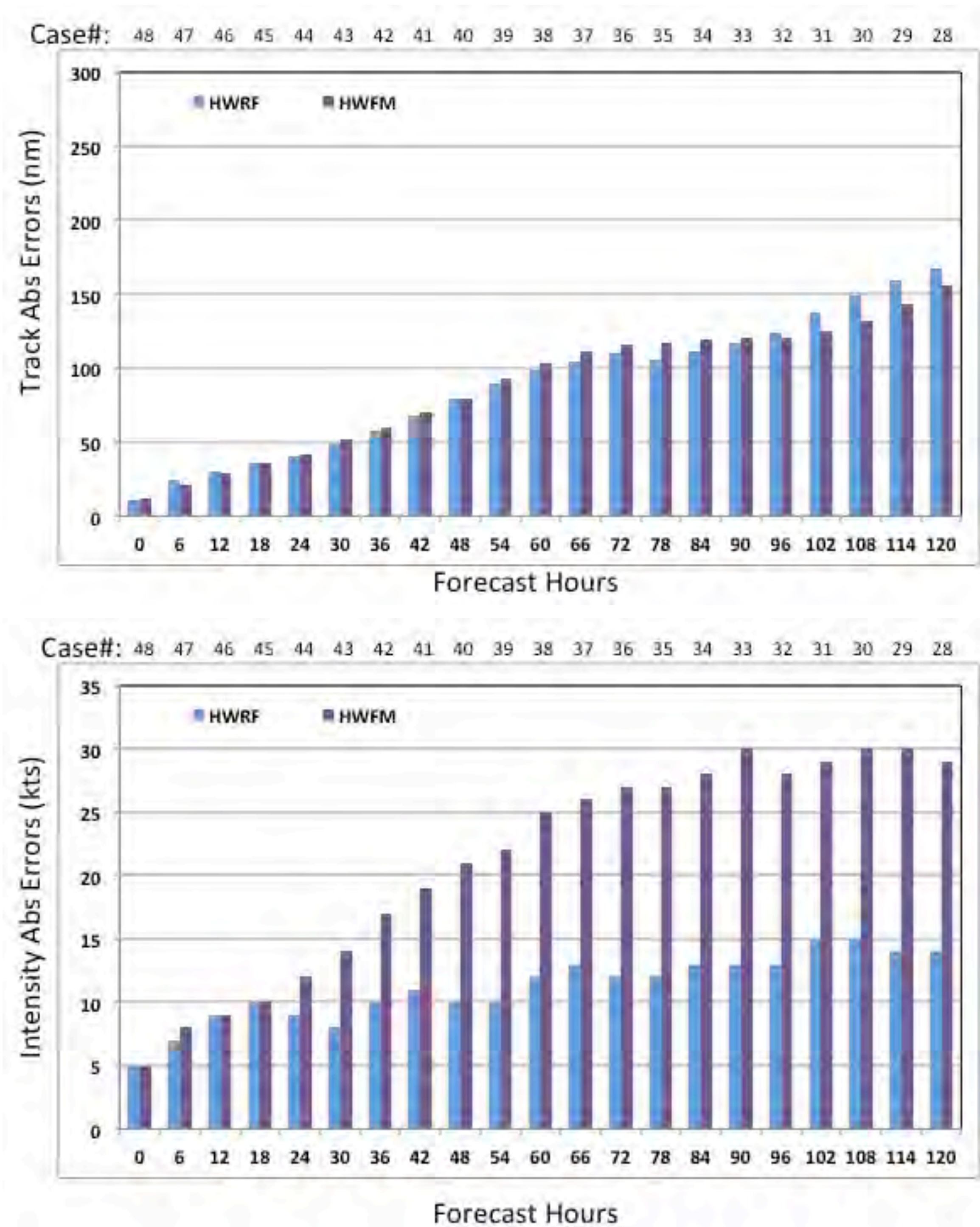

Figure 2. Track and intensity forecast verification of Hurricane Leslie. (a). Track; (b). Intensity.

Project Progress Report
(Report period: 1/01-3/31/2014)

Project Name: Services to Support the Hurricane Forecast Improvement Project (Award Number: NA13OAR4830232)

Principal Investigator: Xuejin Zhang (U. Miami/RSMAS/CIMAS)

Co-PI: Altug Aksoy & Jun Zhang (U. Miami/RSMAS/CIMAS)

Research Staff: Robert Gall, Bradley Klotz, Kathryn Sellwood, and Russell St. Fleur
PI and Co-PI officially started the project on October 1, 2013 in University of Miami. Dr. X. Zhang leads the project. PI has established regular communication and discussion with collaborators at HRD and EMC.
Collaborators: S. G. Gopalakrishnan, T. Quirino, F. Marks, S. Goldenberg, J. Delgado, HRD IFEX team (AOML/HRD); V. Tallapragada, Q. Liu, Z. Zhang, and S. Trahan (EMC/HWRF team)

I. Scientific Progress
1. HWRF model development

PI and collaborators started upgrading basin-scale HWRF system to 2015 operational HWRF. We have the following major activities in this quarter:

- Transfer whole 2014 basin-scale HWRF system to DTC and closely work with DTC to assure the equivalent conversion from the ksh scripts of 2014 basin-scale HWRF to the Python scripts in order to conform with the 2015 operational HWRF implementation;
- Test idealized capability of the 2015 operational HWRF and evaluate the related physics with idealized framework; Further analysis on different experiments is underway
- Work with EMC scientist, Dr. Dmitry Sheinin, and URI scientist, Dr. Biju Thomas, on upgrading the ocean coupler and ocean initialization for basin-scale HWRF implementation
- Test the effect of NOAH land surface model (LSM) replace GFDL slab LSM in basin-scale HWRF; the retrospective experiments are underway
- Review and upgrade the basin-scale HWRF products; Product website are underway.

Table 1 shows the difference of the 2015 basin-scale HWRF. The major upgrade is the 2015 basin-scale HWRF will be a fully coupled land-atmosphere-ocean system. For the first time, the basin-scale HWRF system not only has full capability of the operational HWRF system but also advances capability that can forecast multiple storms within multiple basins or single basin e.g. Atlantic basin or East Pacific basin, with a fully coupled multiple oceans. The development provides the potential transition from research to operation in 2016.

	2015 Operational HWRF	2013 Basin-scale HWRF	2015 Basin-scale HWRF
Domain	18 KM: 77.58° x 77.58° 6 KM: 12.66° x 12.18° 2 KM: 7.90° x 7.06°	27 KM: 178.20° x77.58° 9 KM: 10.56° x 10.2° 3 KM: 6.12° x 5.42°	27 KM: 178.20° x 77.58° 9 KM: 12.66° x 12.18°§ 3 KM: 7.90° x 7.06°
Model top	2 hPa	2 hPa	2 hPa
Vertical levels	61	61	61
Vortex initialization	Vortex Initialization at 2 km	Vortex Initialization at 3 km	Vortex Initialization at 3 km
Data assimilation	Hybrid DA + HWRF ensemble DA for TDR	No GSI DA	Hybrid DA¶
Cycling	Storm component cycling within 30°x30° analysis domain	Storm component cycling within 30°x30° analysis domain	Storm component cycling within 30°x30° analysis domain
Ocean coupling	18-6 KM: Yes 2 KM: Downscaled	No coupling	27-9 KM: Yes 3 KM: Downscaled
Physics Scheme			
Microphysics	Modified Ferrier-Aligo (High Resolution)	Modified Ferrier (High Resolution)	Modified Ferrier-Aligo (High Resolution)
Radiation	RRTMG(SW,LW)	GFDL	RRTMG (SW,LW)
Surface	GFDL	GFDL	GFDL
PBL	2015 GFS	2013 GFS	2015 GFS
Convection	SAS, No CP (2 KM), Shallow Convection	SAS, No CP (3 KM), Shallow Convection	SAS, No CP (3 KM), Shallow Convection
Land surface	NOAH LSM	GFDL Slab	NOAH LSM

§ : The domain size may be changed in order to obtain better scalability
¶: May explore the independent basin-domain DA if satellite project get funded, not priority before HFIP demo season

Table 1. Comparison of model configurations among 2013 and 2015 basin-scale HWRF systems and 2015 operational HWRF.

2. Evaluating model physics

PI (Jun Zhang) continued model physics evaluation work using HWRF retrospective simulations and observational data. We focused on evaluating the structural differences between two sets of HWRF simulations with: 1) PBL scheme as in the operational HWRF model (referred to as PBL12 hereafter), and 2) PBL scheme as in the 2011 version HWRF (PBL11 hereafter). We aim to further investigate the effect of the observation-based upgrades of the PBL physics in HWRF in 2012 and after on the simulated hurricane intensity and structure. We used structural metrics to do model evaluation. These metrics include the size of the storm and surface inflow angle, boundary layer height scales, eyewall slope, warm core structure and distribution of the vertical velocity. We have presented model evaluation results in our previous reports.

In recent months, we evaluated the impact of boundary layer physics in terms of vertical eddy diffusivity on the shape of wind profile in the surface layer. According the traditional Moninon-Obukhov similarity theory, the surface layer wind should follow the logarithmic relationship with height if turbulent fluxes are constant with height in the surface layer under neutral condition. Figure 1 compares the vertical wind profiles in the layer from the lowest model level (~30m) to 600m for 4 radial locations (r^*=1, 1,5, 2 and 2.5) from the PBL11 and PBL12 composites. Mean wind profiles from the dropsonde composite of Zhang et al. (2011) are also shown. It appears that the wind speed increases with height more quickly in the PBL12 composite than in the PBL11 composite, indicating the near-surface vertical wind shear is stronger in the PBL12. The observed wind profiles have relatively larger wind shear and are quantitatively closer to those in the PBL12 composite. Both model simulations and observations indicate a logarithmic wind profile above the lowest model level. This result is consistent with the modification made to the vertical diffusion in the boundary layer scheme as follows: 1) the model dynamics ensures that the momentum flux or the stress (τ/ρ) is near-constant in the lower part of the boundary layer and equal to its surface value, which is determined by the surface layer parameterization (i.e., $\tau = \rho\, u_*^2$); 2) the boundary-layer parameterization implies that this stress is equal to $K_m \partial u/\partial z$ and for $z << h$, $K_m \approx \alpha k u_* z$; 3) putting these together, $\partial u/\partial z = u_*/(\alpha k z)$, which solves to give a logarithmic layer, $u = u_*/(\alpha z)\log(z/z_0)$ where z_0 is the roughness length. The classic log layer is retrieved only when $\alpha = 1$, and the effect of using $\alpha < 1$ is to increase the shear near the surface. As α=0.5 is used in PBL12 while α=1.0 is used in PBL11, the shear near the surface in the PBL12 composite is larger than that in the PBL11 composite.

Furthermore, PI (Jun Zhang) has been continuously evaluating the impact of horizontal diffusion on hurricane intensity and structure in HWRF simulations using idealized simulations. We found that the peak intensity is more sensitive to L_h for smaller values of L_h (Fig. 2). When L_h increases to the model horizontal resolution (3 km) and larger, the peak intensity becomes less sensitive to L_h. This behavior indicates that the effect of L_h on simulated peak intensity is larger when L_h is smaller than the model's horizontal resolution of the inner nest grid scales.

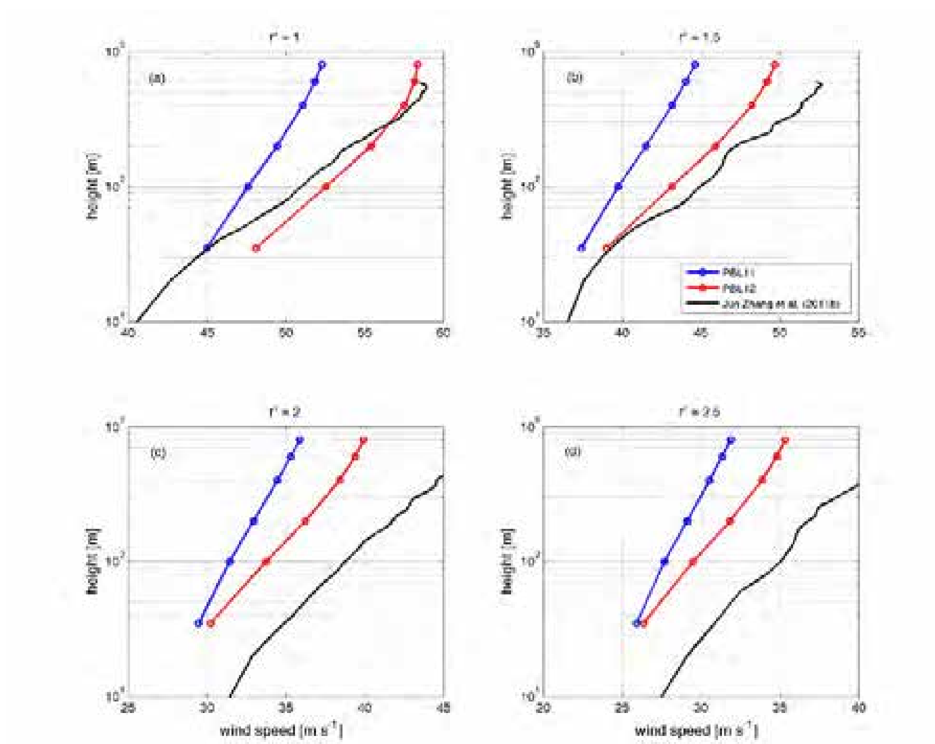

Figure 1. Plots of vertical wind profiles in the layer between the lowest model level and 600 m from the PBL11 and PBL12 composites at found radial locations r*=1 (a), r*=1.5 (b), r*=2 (c) and r*=2.5 (d). The mean wind profile from the dropsonde composite of Zhang et al. (2011) is also shown.

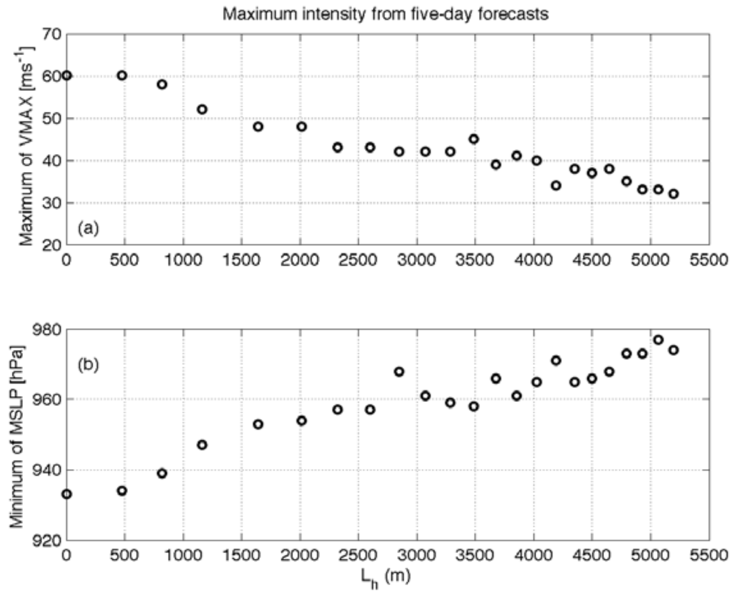

Figure 2. Simulated maximum intensity in terms of maximum wind speed (a) and minimum sea level pressure (b) during each five-day simulation as a function of horizontal mixing length (L_h). Here VMAX is defined as the maximum 10-m wind speed at each forecast hour, and MSLP is the minim sea level pressure.

Other sensitivity experiments have also been run using HWRF to test the impact of model horizontal resolution on simulated hurricane intensity and structure. The results of the sensitivity experiments will be included in a paper be submitted to Weather and Forecasting led by the other PI (Xuejin Zhang).

3. Hurricane observation program and activities

- All the 2014 USAF dropsonde data has been quality controlled, organized by flight and Storm name and made available to the scientific community via public FTP server and the AOML web site.
- Additional files have been created to make the data more user friendly. The individual tempdrops messages are concatenated into a single file for each flight along with additional metadata for each message. The tempdrop messages are also decoded into an easy to read ascii table format for each flight.
- Observation processing for the HEDAS data assimilation system has been updated for 2015 and is ready to be implemented for the 2015 season and RDITT HWRF runs.
- HEDAS satellite simulation code has been upgraded to get 37GHZ brightness temperatures and produce graphics using the Polarization Correction Technique (PCT). The PCT plots allow for the visual assessment of the microphysics and are used operationally to predict rapid intensification (Fig 3) This graphic can be directly compared with actual satellite data products which are available in real time.
- Work has started to develop new diagnostic quantities and graphics for the basin scale HWRF

- Work is underway to update the observation processing code to use cloudy radiances from satellite observations in HEDAS.

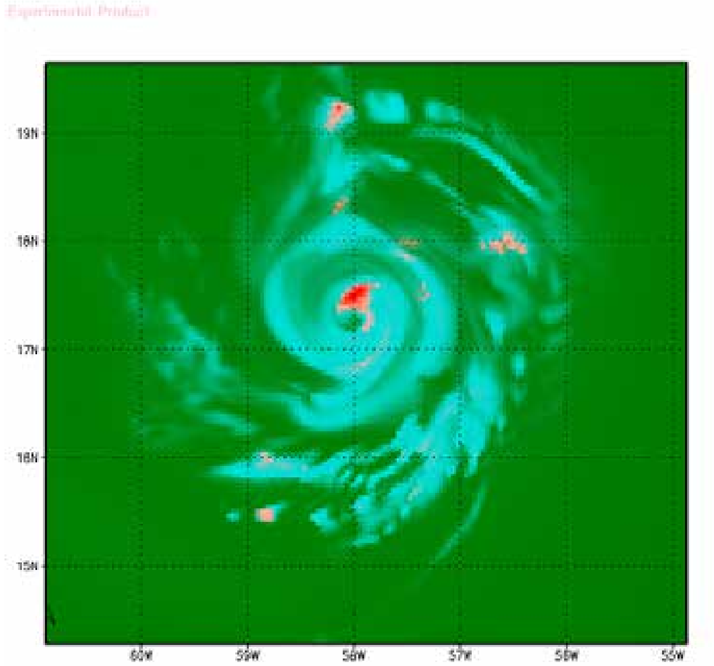

Figure 3. Simulated 37GHZ brightness temperature using the Polarization Correction Tecnique. A cyan colored ring about the center has been shown to be correlation with hurricane intensification. The pink/red colors indicate deep convection/ice concentration.

4. Data Assimilation and Observing Strategy (PI: Altug Aksoy)

The DA group has finally managed to modify the HEDAS scripts to work with the latest HWRF version with restart capability. This version of HWRF was obtained from NCEP/EMC, but had some changes that required modification of the HEDAS scripts. We now have a complete end-to-end HEDAS system and we have begun to run retrospective experiments to evaluate the impact of various observing systems. The retrospective experiments that we have planned to run are shown in table 2.

In addition to the retrospective runs we are currently carrying out, during the 2015 hurricane season, we are planning to run the HEDAS All Obs (HEAD) experiment in real time on Jet. The other experiments will be run in parallel in the research queue, resources permitting. In 2015, our new innovation in HEDAS is the assimilation of all-sky radiance observations. For this purpose, we are collaborating with NASA/JPL researchers to incorporate radiance operators based on the canonical correlation vector (CCV) concept. The following is a brief description of the CCV methodology:

Satellite observations of cloudy (and especially precipitating) scenes contain large, irreducible uncertainty arising from particle shape and size distributions, dielectric constant of cloud ice, and surface emissivity. Since these uncertainties cannot be modeled with a single call to a radiative transfer model, and calculating enough multiple radiative transfer calls per observation to capture the uncertainty would be cost prohibitive, we instead take the approach of using statistics to extract the maximally certain information from the observations.

Experiment	Description
HEDAS Control (HECT)	No vortex-scale data assimilation. HEDAS ensemble is spun up from the GFS ensemble for the duration of a typical HEDAS experiment (8 hours), but no DA is carried out.
HEDAS All Obs (HEAD)	All available vortex-scale observations are assimilated in HEDAS. Observations assimilated are: (1) P-3 TDR, flight level, dropsonde, SFMR; (2) G-IV TDR and dropsonde; (3) Air Force flight level, dropsonde, SFMR; (4) Global Hawk dropsonde; (5) ACARS commercial aircraft obs; (5) AMVs; (6) AIRS clear-air thermodynamic retrievals; (7) GPS-RO thermodynamic retrievals.
HEDAS No Doppler (HEND)	All available vortex-scale observations except for all P-3 and G-IV TDR observations are assimilated.
HEDAS No G-IV Doppler (HENG)	All available vortex-scale observations except for only G-IV TDR observations are assimilated.
HEDAS No AMV (HENA)	All available vortex-scale observations except for AMV observations are assimilated.
HEDAS Radiance (HERA)	All available vortex-scale observations as described in HEAD plus satellite all-sky radiance observations are assimilated.

Table 2. Experiment descriptions

From a training database calculated offline of collocated model and radiative transfer calculations representative of the uncertainty, we seek the combinations of directions in the observation and model variable spaces that are optimally certain but mutually uncorrelated. In the statistical community, this method is known as canonical correlation analysis and has been called "double-barreled principal component analysis." The general approach of using combinations of channels goes back to very first attempts to assimilate satellite data, but our method lets the data speak for itself about the optimal channel combination that is the least sensitive to those uncertainties, and we have a direct measure of the remaining uncertainty. We then project along these canonical correlation vectors using a non-linear fit to improve the fit along the tails. Because the inclusion of radically different statistics leads to a smearing of the signal, we first cluster the observations using k-means clustering. This automatically chooses a given number of regions; in our case, with four regions, clustering automatically chooses the eye, convective regions, anvil region, and outer clear as the best four regions. We compute separate statistics for each of these areas. Finally, we have found it is necessary to deconvolve the observations to put them onto the same resolution in order to maximize the effectiveness of using the observations. We believe many of these techniques will be useful for any attempt at assimilating all-sky radiances, not just our own CCV approach. This approach will be attempted for radiance observations from a variety of satellite including AIRS, AMSU/B, TMI/GMI, and a host of scatterometers.

Figure 4 shows the canonical correlation vector (CCV) observations for TRMM/TMI. Each CCV (as shown in different panels) chooses different features that are mutually uncorrelated and comes with a measure of uncertainty; the largest contribution for each CCV (as measured by the model CCV) is described. The fourth CCV has a low R^2 value and would therefore be discarded.

5. HFIP Project Management

Dr. R. Gall's management activities included:

- Finished a preliminary draft of the 2014 HFIP Annual Plan. The draft is complete and is now out for review by the HFIP community.
- Continued some administration of the HFIP computer system. This activity is being transferred to Vijay.
- Advise on various HFIP programs with Vijay Talapragada and Fred Toepfer.
- Participating in NGGPS (Next Generation Global Prediction System) core selection.
- Continued to participate the HFIP every other week telecon.
- Travel: None this quarter

6. References

Zhang, J. A., R. F. Rogers, D. S. Nolan, and F. D. Marks, 2011: On the characteristic height scales of the hurricane boundary layer. *Mon. Wea. Rev.*, **139**, 2523-2535.

II. Management activities and issues

1. New hiring: Dr. G. Alaka joined CIMAS Nov. 4, 2014. He will focus on verification and large-scale diagnostic study and model sensitivity on land surface model. HFIP paid Dr. Alaka full-time start January 1, 2015.
2. Dr. R. Gall reduced his commitment to 20% and continue to help manage the HFIP project from January 1, 2015
3. X. Zhang and J. Delgado participated AMS annual meeting in Phoenix, AZ and present two talks about the basin-scale HWRF model. They also participated "Python in Climate and Meteorology" short courses for beginner and advanced users.

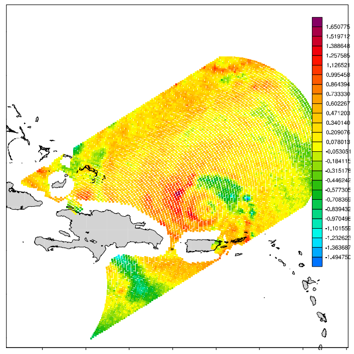

Figure 4. The canonical correlation vector (CCV) observations for TRMM/TMI.

Project Progress Report
(Report period: 1/01-3/31/2015)

Project Name: CIMAS Contributions to OAR Disaster Recovery Act Projects (NOAA Award: NA14OAR4830119)

Principal Investigator: Xuejin Zhang (U. Miami/CIMAS)

Collaborators: S. G. Gopalakrishnan, T. Quirino and J. Cione (AOML/HRD); T. Black and M. Pyle (NCEP/EMC/Mesoscale Modeling Branch); V. Tallapragada (NCEP/EMC/HWRF team)

Contractors: Teraflux Inc (J. Prusa), Itri Corp

PI and collaborators officially started the project on April 1, 2014. Dr. Zhang leads the project representing CIMAS in University of Miami. PI has established regular communications and discussions with collaborators at HRD and EMC, and contractors. Dr. J. Prusa visited HRD every week to discuss project progress and issues. Drs. Gopalakrishnan and T. Quirino lead development efforts at HRD.

I. Scientific Progress (Written by Prusa, Quirino, and Diaz)

The relationships/summaries of the work completed to the proposal tasks/rationale are noted below. HRD modeling group short slide presentations directly relevant to the HIWPP project are also attached at the end of this report. They give a weekly timetable of developments in this quarter.

(I) Advancements to the NMMB end-to-end automation system.

Proposal task(s)/rationale: this work aligns closely with the proposal rationale to:

• optimize the NMMB/NEMS to run on state of the art computer systems

• create low latency tools to collect, access, extract, and evaluate high-resolution information

Development details: We have further enhanced the shell-script based system capable of performing automated forecasts of the NMMB model. Various bug fixes were made to improve the stability of the system. In addition, complex portions of the code were refactored to modularize the framework and facilitate future code reuse. Various processes were setup to transfer, in real-time, the diagnostic plots generated automatically by the end-to-end system workflow to the AOML/HRD website. Support for single-domain forecasts was also added to the workflow. This required modifications both to the post-processing scripts and also to the automated job submission system in order to support cold-start, single domain forecasts. In addition, support for the creation of a cycling directory structure was added in order to support the HWRF initialization process that was ported to the NMMB model. Finally, the complete end-to-end system was ported to the Theia cluster. At this stage, the NOAA Jets, Zeus, and Theia clusters are supported seamlessly by our end-to-end NMMB system.

(II) Advancements to the initialization of the global nested NMMB configurations.

Proposal task(s)/rationale: this work aligns closely with the proposal rationale to:

• optimize the NMMB/NEMS to run on state of the art computer systems

• create low latency tools to collect, access, extract, and evaluate high-resolution information

Development details: The process of initializing global, nested configurations of the NMMB model requires the generation of high-resolution terrain data spanning the entire globe. This is a very slow process due to some known and severe scalability constraints in the geogrid.exe program of the NPS initialization package. For example, the processes takes on average 60 minutes in NOAA's Jets cluster for a standard 27:09:03km resolution forecast. In order to circumvent geogrid.exe's server scalability constraints, we designed an algorithm that parallelizes the global, high-resolution terrain data generation process by splitting the globe into patches that are processed independently and then later combined into a single globe-spanning terrain data set. Essentially, this development added an indirect IO parallelization capability to geogrid.exe. As a result, the initialization process decreased from 60 minutes to 5 minutes in experiments performed in the Jet's cluster – an order of magnitude enhancement.

(III) Porting all NMMB developments to the Theia cluster.

Proposal task(s)/rationale: this work aligns closely with the proposal rationale to:

- optimize the NMMB/NEMS to run on state of the art computer systems
- create low latency tools to collect, access, extract, and evaluate high-resolution information

Development details: In order to make use of the newly available Theia resources toward the accomplishment of our HIWPP milestones, all developments related to the NMMB model were ported to the Theia cluster. This was a painstaking process that involved modifications of various programs and scripts to support the new Theia cluster and its modern set of developmental software. In the process, our group identified issues both in the setup of some developmental software available in Theia and also on the configuration of the batch system. We promptly informed the Theia cluster administrators of these issues in hopes they could be addressed as soon as possible and facilitate the transition efforts of other groups to Theia. The NMMB model was successfully ported to Theia after issues with the setup of the netCDF module were identified and addressed. To port the NPS initialization package, we modified the ungrib.exe program, which is responsible for decoding the GFS model data used in the generation of model initial and boundary conditions, to support the latest MPI standards relating to the invocation of MPI collective subroutines. We also fixed various memory access violation bugs in the ungrib.exe program that were exposed via compilation with the latest version of the Intel compiler available in Theia. Furthermore, our end-to-end NMMB automation system was further developed to support the new Theia cluster. Processes were setup to provide an automated and real time inflow of GFS data, official forecast tracks, and diagnostic predictors into the Theia cluster. This was done to support the automated generation of diagnostic graphics by the post-processing workflow of our end-to-end NMMB system. Finally, we thoroughly tested the entire workflow of our end-to-end NMMB system in the Theia cluster to ensure that all components were working properly.

(IV) Setting up the Hurricane NMMB SVN repository

Proposal task(s)/rationale: this work aligns closely with the proposal rationale to:

- optimize the NMMB/NEMS to run on state of the art computer systems

• create low latency tools to collect, access, extract, and evaluate high-resolution information

Development details: We worked closely with EMC to setup the Hurricane NMMB repository. This repository will hold all HIWPP related collaborative developments to the NMMB model and related components. We committed all of our developments to the repository, including the complete end-to-end NMMB automation system, the Parallel/MPI Diapost post-processing developments, and the AOML/HRD's NEMSIO2NETCDF converter. HRD's NMMB and NPS developments undertaken over the past year were already previously committed to EMC's Subversion repository.

(V) Development of idealized tropical cyclone capability in NMMB

Proposal task(s)/rationale: this work aligns with the proposal task to develop an idealized tropical cyclone capability for NMMB–NEMS. This capability is important for rigorous testing of the HNNMB, i.e, the hurricane NMMB.

Development details: This development recently achieved the milestone of a 27/9/3 forecast to 126 hr of an idealized storm in a 75^{o} x 75^{o} domain for d01 with moving d02 and d03. The initial wind field was specified with a 20 ms^{-1} maximum wind at a radius of 90 km. At 126 hrs the idealized storm was a hurricane with an eye ~ 15 km in diameter. Remaining issues are focused on the resetting of lateral and surface boundary conditions for $t > 0$ to those of the initialization. These are anticipated to be resolved soon at which point the ideal code development will be sent to the Hurricane NMMB SVN repository, completing this proposal task.

(VI) Scalability test for Basin-Scale NMMB at uniform 3km resolution

Proposal task(s)/rationale: this work aligns closely with the proposal rationale to optimize the NMMB/NEMS to run on state of the art computer systems

Development details: Problems using both NPS and NMMB for grid resolutions of 3 km or finer were identified. At this resolution, a basinscale domain ~ 175 x 79 deg (~ 6500 x 3000 grid) cannot be initialized by the four NPS executables (ungrib.exe, geogrid.exe, metgrid.exe, and nemsinterp.exe) within the standard 8 hour wallclock limit typical for NOAA machines. A current workaround suitable for research is to run each executable by itself. The complete NPS initialization requires ~ 12 hrs. The time integration with NMMB currently fails, however. Preliminary investigation suggests the problem is insufficient memory for the ~ 3900 cores used for this run.

(VII) HIWPP related presentations and workshops.

Proposal task(s)/rationale: this work aligns closely with the proposal rationale to:

• optimize the NMMB/NEMS to run on state of the art computer systems

• create low latency tools to collect, access, extract, and evaluate high-resolution information

Development details: On April 1st, 2015, AOML/HRD presented at the EMC's Annual NMMB Workshop. This invited talk related all of HRD-EMC's collaborative NMMB model developments undertaken over the past year under HIWPP support. In addition, AOML/HRD hosted the 1st Annual HIWPP Workshop from April 21st to 23rd. This workshop brought together all of the teams supported under HIWPP and NGGPS. The various teams provided updates on their developments undertaken during the first year of HIWPP support. As a result, various useful scientific discussions ensued.

II. **UAS project activities**:

1) Material, shipping and NRE tasks for preparation of Coyote C048 for FY15 clear air flight.
2) Satellite communication sim card and data charges for the Coyote METOC/Hurricane UAS FY14 flights.
3) Labor and project management charges by contractor.

III. Management Activities

Dr. S. Diaz travelled to NCEP to learn NMMB initialization in January.

APPENDIX II

Task IV Projects

PI	Start/end date	Funding Source	Project Description
Dong, S	07/01/14 - 06/30/17	NASA	Investigating the Processes Contributing to the Salinity Differences Between Aquarius and In Situ Measurements
Dunion, J	07/01/12 - 06/30/16	NASA	Utilizing NASA Reconnaissance Assets to Investigate Hurricane Upper-level Warm Core Evolution, Inner Core Pulsing, and Near-Environment Moisture Interactions
Dunion, J	01/01/14 - 12/31/14	UW *	An Observational and Numerical Investigation of Energy
Ortner, P	01/24/09 - 12/31/15	RCCL	Explorer of the Seas oceanographic and meteorological sampling: the next generation fully-automated ship-of-opportunity and beyond
Ortner, P	10/01/14 - 09/30/17	NSF***	Development of an Autonomous Ammonium Fluorescence Sensor (AAFS) and a Total Dissolved Inorganic Carbon Analyzer for Natural Waters
Perez, R	10/01/10 - 09/30/15	NSF	Global Impacts of Eddies on Inertial Oscillation of the Mixed Layer
Perez, R	04/18/14 - 04/17/17	NASA	Variability of the South Atlantic Subtropical Gyre
Volkov, D	08/05/13 - 08/04/17	NASA	The Mediterranean & Black Sea: Analysis of Large Sea Level Anomalies
Volkov, D	09/10/13 - 09/09/14	NASA	Investigating the Variability of Sea Level in the Sub-Artic Sea
Williams, D	01/15/15 - 12/31/15	NSF **	Surviving Climate Change
Zhang, J	07/03/14 - 06/02/15	U of W *	Calculating tropical Cyclone Inflow and Boundary Layer Processes from Ocean Vector Wind Remote Sensors

* Report submission is not required ** New award ***Inter-Agency collaboration (NSF/ONR/NOAA)

Annual Progress Report

1) **Project Title:** *Investigating the Processes Contributing to the Salinity Differences between Aquarius and in situ Measurements*
2) **PI:** Shenfu Dong
3) Period covered by the report: 07/01/2014 – 06/30/2015 (Year 1).
4) Institution: Cooperative Institute for Marine and Atmospheric Studies, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149.
5) Grant number NNX14AI85G

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1. Introduction

Small changes in ocean temperature and salinity can have large effects on global ocean circulation and water cycle. Compared to temperature, salinity has received much less attention, mainly because salinity measurements are not as abundant and because ocean salinity is generally perceived to have no direct influence on ocean-atmosphere interaction. However, through the modification of oceanic density fields, salinity can impact ocean circulation and mixing, which, in turn, affects ocean temperature. Thus, salinity can play a substantial role in ocean-atmosphere interaction and the global climate system.

Sea surface salinity (SSS) measurements from dedicated Aquarius satellite are a great tool to study the global hydrological cycle and, thus, advance our understanding of the Earth's climate system as a whole. Prior to their application in climate studies, space-borne SSS measurements need to be compared with *in situ* salinity in order to assess the accuracy of remote sensing products and, ultimately, to improve the satellite SSS retrieval algorithms. This project is targeted specifically to (1) validate the Aquarius SSS retrievals, and (2) investigate the surface salinity stratification in the upper 5 m of the ocean. In particular, we aim to explore the effect of salinity differences at the two measurement depths on the salinity differences between Aquarius and Argo.

The project includes deployment of an array of drifters in different regions: the eastern tropical Pacific (low salinity, high precipitation, negative SSS difference between Aquarius and Argo), the subtropical South Pacific (high salinity, high evaporation, negative SSS difference), and the South Atlantic (high salinity, high evaporation, positive SSS difference). The unique aspect of this deployment is that each drifter will be equipped with two conductivity/temperature probes at 15-20 cm and 5 m depth. These drifters are specifically designed for this project. The drifter records provide a valuable data set to validate Aquarius SSS retrievals and to improve our knowledge of the near-surface salinity structure.

As part of the validation of Aquarius retrievals and a demonstration of its capabilities and utility for oceanographic studies, along-track Aquarius data are used for the determination of the Antarctic Circumpolar Current (ACC) salinity fronts between Africa and Antarctica. The obtained surface salinity fronts are coupled with fronts obtained from concurrent satellite measurements of sea surface temperature and sea surface height, and from temperature and salinity profiles along an XCTD section in the Southern Ocean. This not only assesses the quality of Aquarius data, but for the first time illustrates the distinction between the variability of salinity and temperature fronts at the surface.

The research activities that have been carried out during the period covered by the report are:

1. Purchase, test, and deploy salinity drifters;
2. Determination of the Antarctic Circumpolar Current fronts from sea surface salinity, sea surface temperature, and sea surface height;
3. Analysis of Agulhas rings.

During the first year, progress has been made in all three areas mentioned above and our research is advancing according to the proposed schedule. In addition to the research activities of the proposed work, we also contributed to the special issue in TOS Oceanography for SPURS (Dong et al., 2015), which was the first dedicated field program for Aquarius mission.

2. Narrative of the accomplishments and first science results

2.1 Salinity Drifters

Our proposed work relies on the deployment of eight drifters, four supported by NASA, with the remaining four contributed by NOAA/AOML. Fortunately, NOAA/AOML agreed to contribute another four drifters based on panel suggestions. We have increased the number of drifters in the eastern tropical Pacific from four to six, and in the subtropical South Pacific and the South Atlantic from two to three. We have postponed the drifter deployment for the eastern tropical Pacific to the 2016-2017 to be aligned with SPURS II experiment. The six drifters for the other two regions were purchased in 2014. They were tested at NOAA/AOML. Three of them were loaded on the VOS ship for XBT PX08 line for the South Pacific deployment in March. One was already deployed on April 10, 2015 and the remaining two drifters will be deployed during the northbound leg after we determine if the first drifter is working properly. The reason to deploy the drifters in the South Pacific during this time of the year is to catch the raining season when strong surface stratification is expected. We are currently looking into the research cruises and VOS ships in the South Atlantic for the drifter deployments.

Measurements from those drifters will be analyzed in the remainder of year 1 and year 2 to examine the salinity differences between 15 cm and 5 m depths, and the potential causes for the differences. As our preliminary analysis, we examined the salinity differences between Aquarius along track data and surface salinity from Argo floats. Different from recent study by Drucker and Riser (2014) who suggested that the wind speed does not play a role in the salinity differences between Aquarius and Argo globally, our examination in the subtropical South Pacific shows that there is a statistically significant correlation between wind speed and salinity differences. The different results may be due to the focus of the study region. Drucker and Riser (2014) focused on global scale, relationship between salinity differences and parameters might be masked out by the strong dependence of salinity differences on sea surface temperature, whereas our examination is localized for the subtropical South Pacific region. Further detailed analysis will be performed.

2.2 Determination of the Antarctic Circumpolar Current fronts

During the first year of the proposed research we started identifying the major ACC fronts using satellite altimetry SSH data and performed a preliminary comparison of the identified time-mean frontal positions with space-borne SST and SSS data. To locate the ACC fronts from SSH data we followed the concept, proposed by Sokolov and Rintoul (2007, 2009), that each front (aligned with strong SSH gradients) can be successfully labeled by a single SSH contour. We used the methodology described in Volkov and Zlotnicki (2012), which finds fronts by integrating the squared SSH gradient along the contours of constant SSH value. In essence, for a set of SSH contours $i=1,2,\ldots,n$ we estimate the root-mean-square of the along-contour SSH gradient: $R(\nabla\eta_i) = \sqrt{L^{-1}\oint(\nabla\eta_k)^2 dl}$, where $(\nabla\eta_k)^2$ is the square of the absolute SSH gradient at point k of the contour and L is the length of the contour. Peaks in $R(\nabla\eta_i)$, defined as local maxima relative to the neighboring values, correspond to oceanic fronts usually associated with local maxima in SSH gradients.

Displayed in Figure 1a is $R(\nabla\eta_i)$ computed for the time mean (2012-2014) SSH field and over the longitudinal band between 0 and 50°W, which is the domain of our proposed investigation. The identified fronts are then plotted over the time mean map of the absolute SSH gradient along with the contours of SSH (Figure 1b).

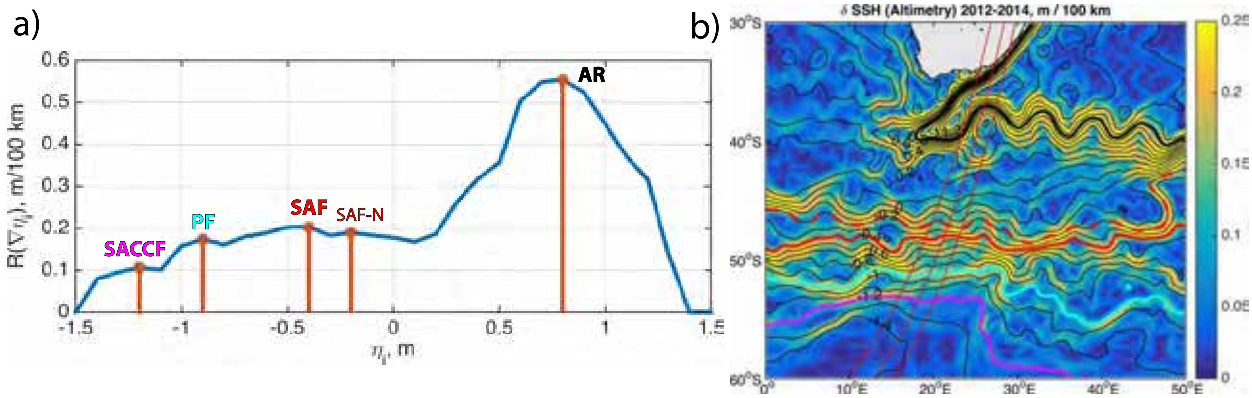

Figure 1. (a) Root-mean-square (m per 100 km) of the along contour SSH gradients. The contours are marked by SSH labels on the horizontal axis. Vertical lines indicate the locations of fronts between 0 and 50°W, defined as local maxima. Red lines show the Aquarius descending tracks. Abbreviations: AR – Agulhas Retroflection, SAF – Sub-Antarctic Front, SAF-N – northern Sub-Antarctic Front, PF – Polar Front, and SACCF – South ACC Front.

One can see that the fronts generally align with the SSH gradients reasonably well. The strongest gradients are associated with the Agulhas Retroflection (AR) region and with the Sub-Antarctic Front (SAF). It should be noted that the identified fronts correspond to single contours, while the frontal areas are usually broader. This is especially obvious in the SAF region. The SAF in Figure 1b may be viewed as consisting of several braches. Our methodology detects two main branches: the northern branch (SAF-N) and the SAF itself. The Polar Front (PF) is also well defined and can traced across the entire domain (cyan curve in Figure 1b).

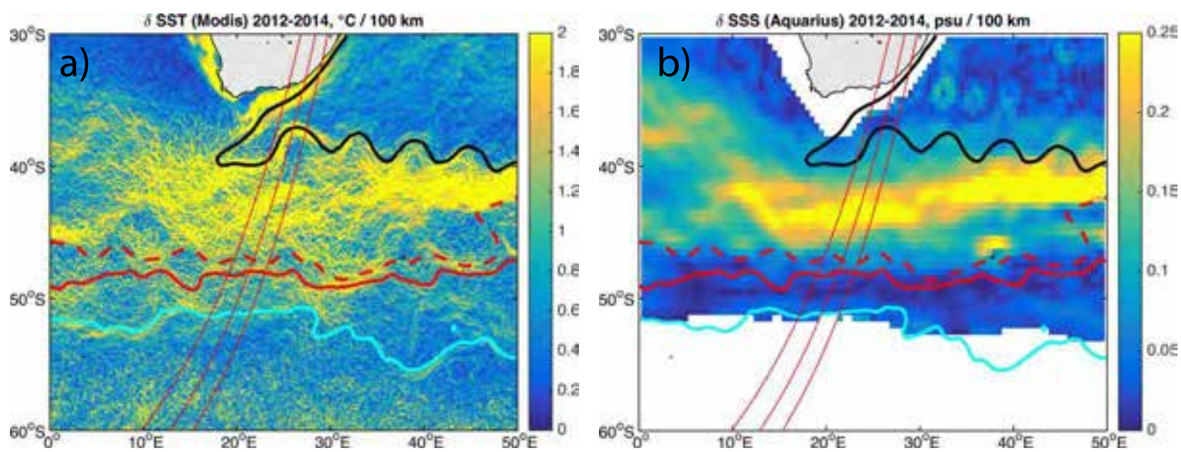

Figure 2. The horizontal absolute gradients of (a) SST from Modis (°C/100 km) and (b) SSS from Aquarius (psu/100 km, gridded product). The AR (black), SAF-N (dashed red), SAF (red), and PF (cyan) as identified in Figure 1 are shown.

The fronts defined by the SSH gradient criteria are overlaid on the concurrent horizontal gradients of SST from Modis (Figure 2a) and SSS from Aquarius (Figure 2b). One can see that the broad band of the largest SST gradients observed between 40°S and 45°S is not associated with any SSH front. There is a good match between the SSH and SST gradients in the Agulhas Retroflection and to a smaller extent along the SAF and PF. None of the defined fronts matches with the observed gradients of SSS, computed from the gridded Aquarius data. However, the band between 40°S and 45°S, similar to SST, is also characterized by strong SSS gradients. The absence of dynamic SSH fronts in this area suggests that the effect of temperature gradients here is compensated by salinity gradients. This is the area where both temperature and salinity strongly increase northward leading to positive (increasing northward) thermosteric sea level gradient and negative halosteric sea level gradient.

We have verified the aforementioned suggestion with an optimized solution of the ECCO2 (Estimating the Circulation and Climate of the Ocean, Phase II) model. For this we calculated the steric, thermosteric, and halosteric contributions to the meridional sea level gradient (Figure 3). Although there are some discrepancies between the model and observations, the compensation between the thermosteric and halosteric contribution between 40°S and 45°S is well simulated. It is also seen that the SAF mainly reflects the meridional temperature gradient, while the PF is equally contributed by the meridional temperature and salinity gradients.

In conclusion, we have performed a preliminary analysis of the time mean frontal location in our study region. In the following work, we will use the Aquarius data along the tracks plotted in Figures 1-3. The along-track data provide better spatial resolution and we expected that coupled to SSH and SST data it might be useful for detecting the location of the PF.

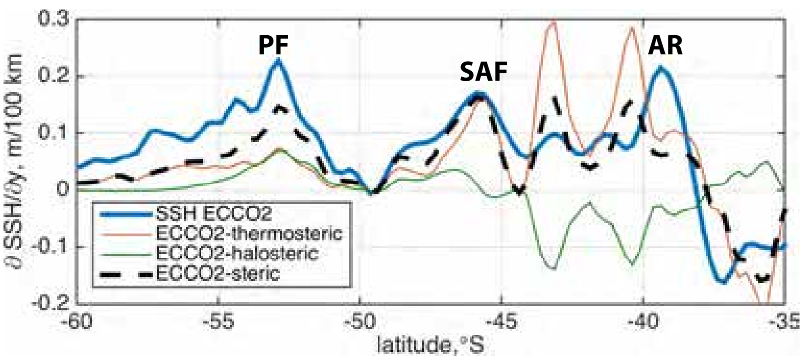

Figure 3.
The meridional gradients of SSH (blue), steric (dashed black), thermosteric (red), and halosteric (green) sea level from the ECCO2. Prior to computing the gradients the data are averaged over 10°-25°W.

2.3 Analysis of Agulhas rings

We have conjectured that coherent Agulhas rings can provide a mechanism for the observed differences between Aquarius and Argo salinity measurements. This conjecture was built on a bias of Argo float sampling toward coherent rings. We have proposed to test our conjecture by identifying coherent rings from altimetry data and determine the number of Argo floats trapped within these rings compared to that attracted into incoherent rings (identified as regions where vorticity dominates over strain).

This year we have provided theoretical support for our conjecture by showing that heavy (light) objects are attracted (repelled) by coherent material eddies (Beron-Vera et al., 2015). We have also completed a detailed survey of coherent Agulhas rings (Wang et al., 2015). The survey was done applying recent techniques from nonlinear dynamical systems data that enable objective detection of rings with coherent material boundaries. We detected 1 to 4 rings yearly from altimetric SSH data over 1992-2014 with diameters ranging from 40 to 280 km. A total of 23 eddy cores of about 50 km in diameter and with 9 at least 30% of their contents traceable into the Indian Ocean were found to travel across the subtropical gyre with minor filamentation.

With the coherent ring survey completed, we have started to analyze the Argos float database. We plan to do this along with the analysis of Aquarius data over the overlapping period.

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NASA Hurricane Science Research Program (HSRP)
Grant Number: NNX12AK63G
Year-2 Progress Report
July 1, 2014 – June 30, 2015

Utilizing NASA Reconnaissance Assets to Investigate Hurricane Upper-level Warm Core Evolution, Inner Core Pulsing, and Near-Environment Moisture Interactions

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Year-3 Goals (01 July 2014 – 30 June 2015):

1. The proposal team will collaborate with NASA HS3 science team members to design aircraft flight patterns for the 2014 Atlantic Hurricane season that will optimize sampling of the TC inner core and near-environment by available aircraft assets (e.g. the Global Hawk, NOAA P-3s and NOAA G-IV). These aircraft experiments and modules will be designed help facilitate the main objectives of this project and the HS3 mission;
2. Finish data analysis and finalize satellite algorithm modification implementations;
3. Recruit new graduate student and conduct new analyses suggested by the findings from the original analyses; Co-PI and graduate student continue to coordinate research efforts with the PI and other Co-PIs;
4. Present and publish results;

Year-2 Accomplishments

1. Goal 1: Aircraft Mission Design and Real-Time Mission Support

i. Real-Time Global Hawk GPS Dropsonde Processing Support

PI Dunion was a member of the 2014 HRD Global Hawk GPS dropsonde processing team to support the HS3 objective of quality controlling GPS dropsonde data and transmitting that information in real-time during several missions into tropical cyclones (TCs), TC remnants, and the Saharan Air Layer. PI Dunion supported this effort by processing and transmitting GPS dropsondes in real-time during several 2014 HS3 missions and conducted these tasks both remotely and on-site at NASA Wallops.

ii. Satellite Data and Product Support

Leading up to and during the operational field phase of HS3 in 2014, the daily mission planning, forecast, and flight support teams once again made extensive use of real-time satellite-based data and products derived at CIMSS. These products were made available over a dedicated web site, with selected products transmitted directly to the HS3 Mission Tools Suite (MTS). Some examples of critical mission support datasets for science include the hourly atmospheric motion vectors, upper-level diagnostic products, analyses of vertical wind shear, and objective intensity estimates. Two CIMSS satellite-based products were extensively used to help guide the Global Hawk missions and reduce the flight hazard risk. The Tropical Overshooting Tops (TOT) product was used to identify active convective cells overshooting the local equilibrium layer. Turbulence is often associated with these features, so the product was used during the missions to avoid those areas. The second product was a cloud-top height analysis produced by an advanced satellite-based algorithm (ACHA), updated to indicate cloud-top heights in pressure-altitude coordinates.

New product displays were introduced this year to further assist with Global Hawk mission monitoring. The first was a higher spatial resolution ACHA image for the area surrounding the Global Hawk that was transmitted directly to the HS3 Mission Tools Suite. The second was 3-h animation of the Global Hawk flight. An example of this can be found at: http://cimss.ssec.wisc.edu/goes_r/proving-ground/nhc/ot/Dolly_GH_animation_example.html. These animations enhanced the mission scientist's ability to follow the Global Hawk and assess trends in the cloud-top heights, TOTs and lightning in its path. Examples below.

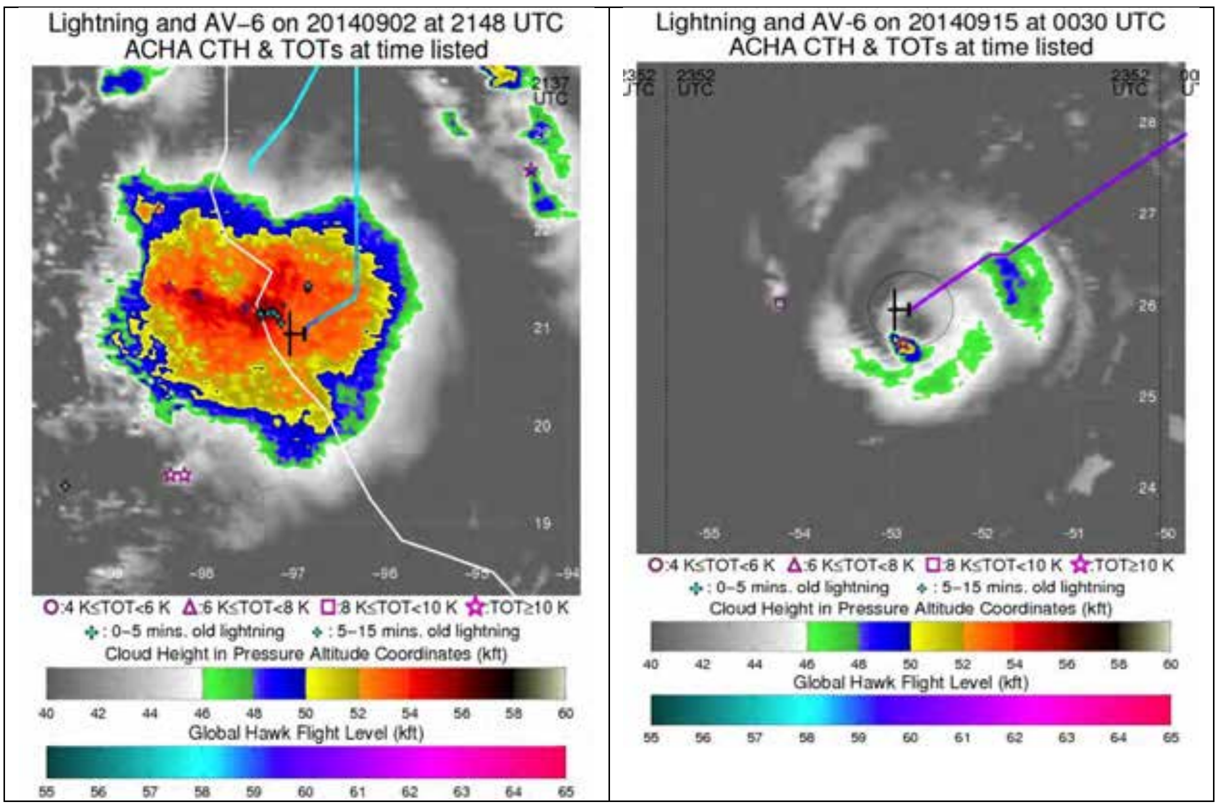

Fig. 1 High-resolution ACHA cloud top heights with current lightning and TOTs during TC Dolly on Sept 2 (left), and TC Edouard on Sept 15 (right), but in GH-centric coordinates. The GH and its recent (past 3-h) flight track is plotted over the images.

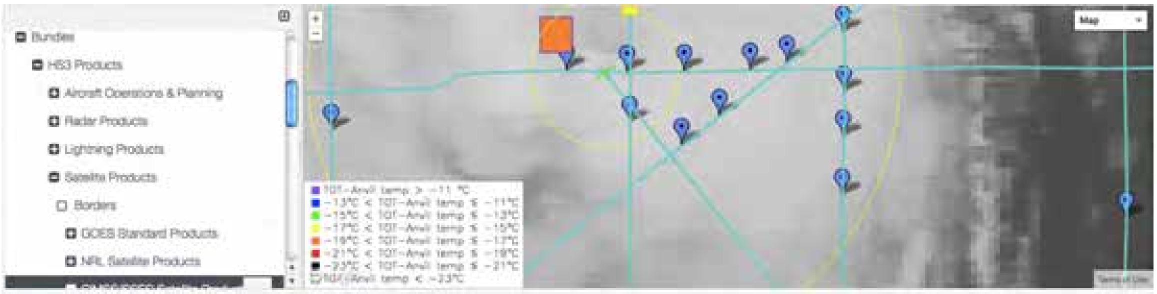

Fig. 2 Screen shot of THE MTS display in real time showing an example of the GH flying through the core region of TC Edouard towards an indicated TOT (orange square), which it diverted around.

iii. Real-time Forecasting and Mission Science Support

Team members Sarah Griffin, Derrick Herndon and John Sears from UW-CIMSS all provided forecasting support at Wallops during the 2014 HS3 field campaign. PI Dunion and Co-PI Velden acted as a mission scientists at NASA Wallops. Additionally, PI Dunion coordinated HS3 missions with NOAA IFEX G-IV and P-3 research missions and helped facilitate daily inter-agency telecons.

2. Goal 2: *Continue primary science objective investigations*

i. Utilize NASA Global Hawk dropsonde data with nearly coincident satellite microwave sounder observations from SSMIS, S-NPP, ATMS and AMSU to compare observed tropical cyclone warm core anomaly structures.

Work this period focused on anlaysis of the HS3 Global Hawk (GH) research flights into Hurricane Edouard. Specifically, data from the three missions on September 14, 16 and 17-18. On each of these missions, the GH conducted multiple transects of Edouard deploying dropsondes both in the environment and the inner core of the TC. Analysis of this dropsonde data permits an evaluation of the TC warm core structure of a strong TC with unprecedented detail.

Analysis Methodology

Continuous transects that crossed the TC center were selected and used to produce cross sections of the observed dropsonde temperatures at 25 mb intervals starting from the ~75 hPa flight level. In some cases the transects did not always extend fully into the environment. In addition, it was noted that some of the dropsondes at the end points of the transects (waypoints) did not appear respresentative of the environment and produced spurious temperatures. These data are included in the calculation of the TC warm anomaly (temperature at center dropsonde – environment temperature). So in order to improve the fidelity of the environmental temperatures, soundings from the 1-degree Global Data Asssimliation System (GDAS) at 8 points surrounding (and outside) of the TC core were combined with the two transect end point dropsonde data to create a mean environmental temperature. Fig. 3 shows the location of the GH transect throgh Hurricane Edaourd and the GDAS grid points used to create a warm core cross-section on September 14, 2014.

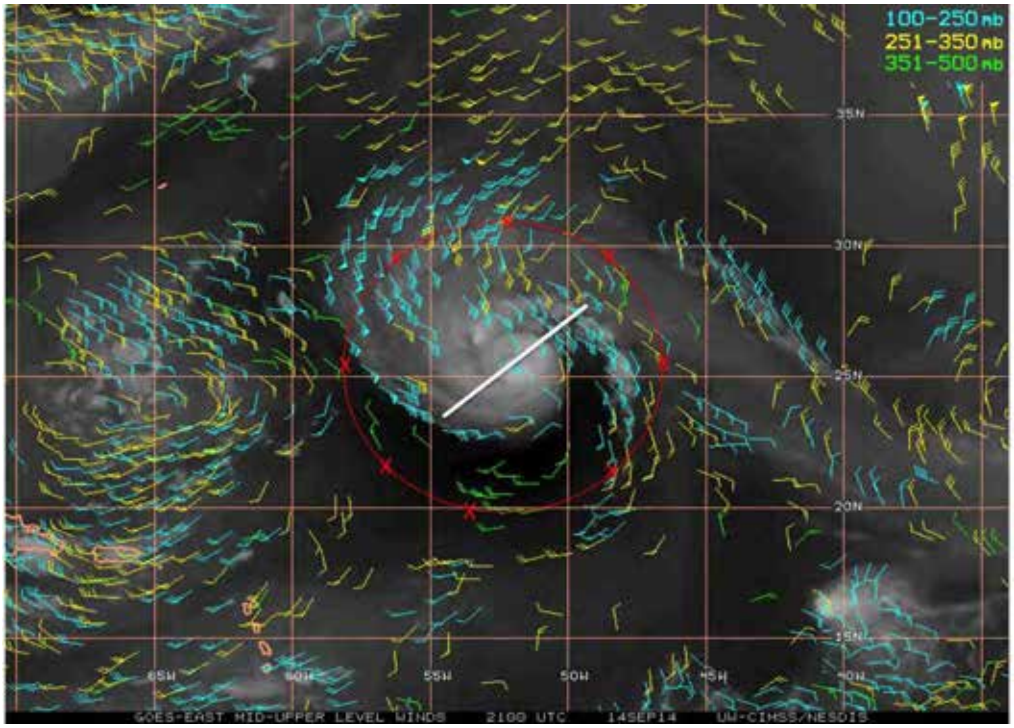

Fig. 3: GOES water vapor imagery showing Hurricane Edaourd on 14 Sep 2014 2100 UTC. UW-CIMSS water vapor atmopsheric motions vectors, location of the GH transect (white line), and the GDAS model grid points (red x) used to create a cross-section on 14 Sep 2014 are overlayed on the image.

Figure 4 shows the location of the GH transect (white line) and the GDAS points (red x) used to create a cross-section on September 16, 2014.

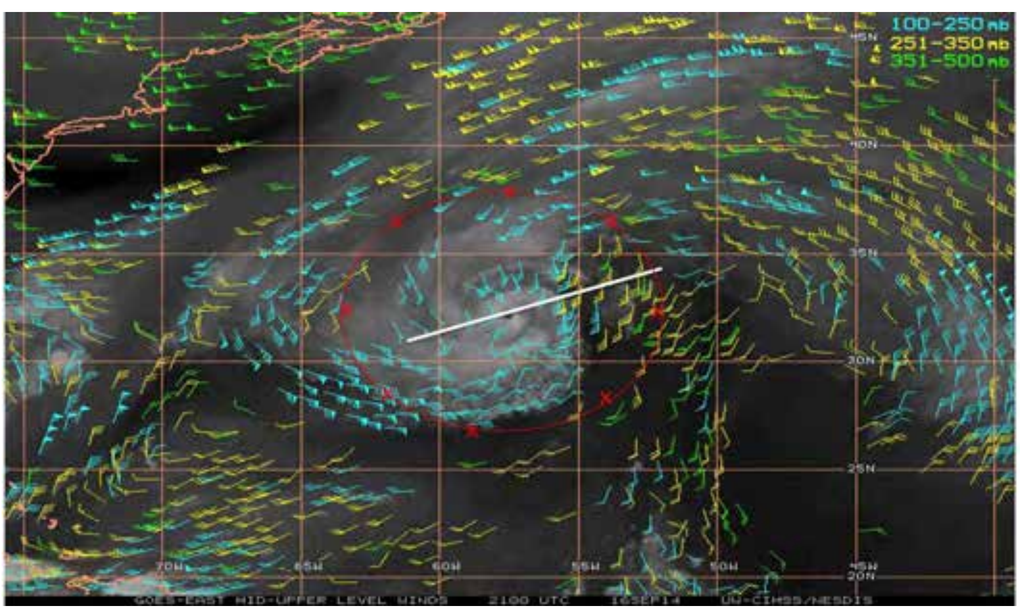

Fig. 4: Same as in Fig. 3, except for 16 Sep 2014 2100 UTC.

Figure 5 shows observed GPS dropsonde temperature anomalies on September 14th at 2103 UTC and September 16th at 2214 UTC (upper panels), and AMSU-derived Tb anomalies for NOAA-18 on September 14th 1912 UTC and NOAA-15 September 16th at 2025 UTC (lower panels). The TC warm core anomalies are depicted by the darker green to red colors. While the distance across the cross sections is nearly the same, note that the TC core is not centered in the AMSU swaths, thus the anomaly maxima are offset relative to the respective GPS dropsonde anomalies.

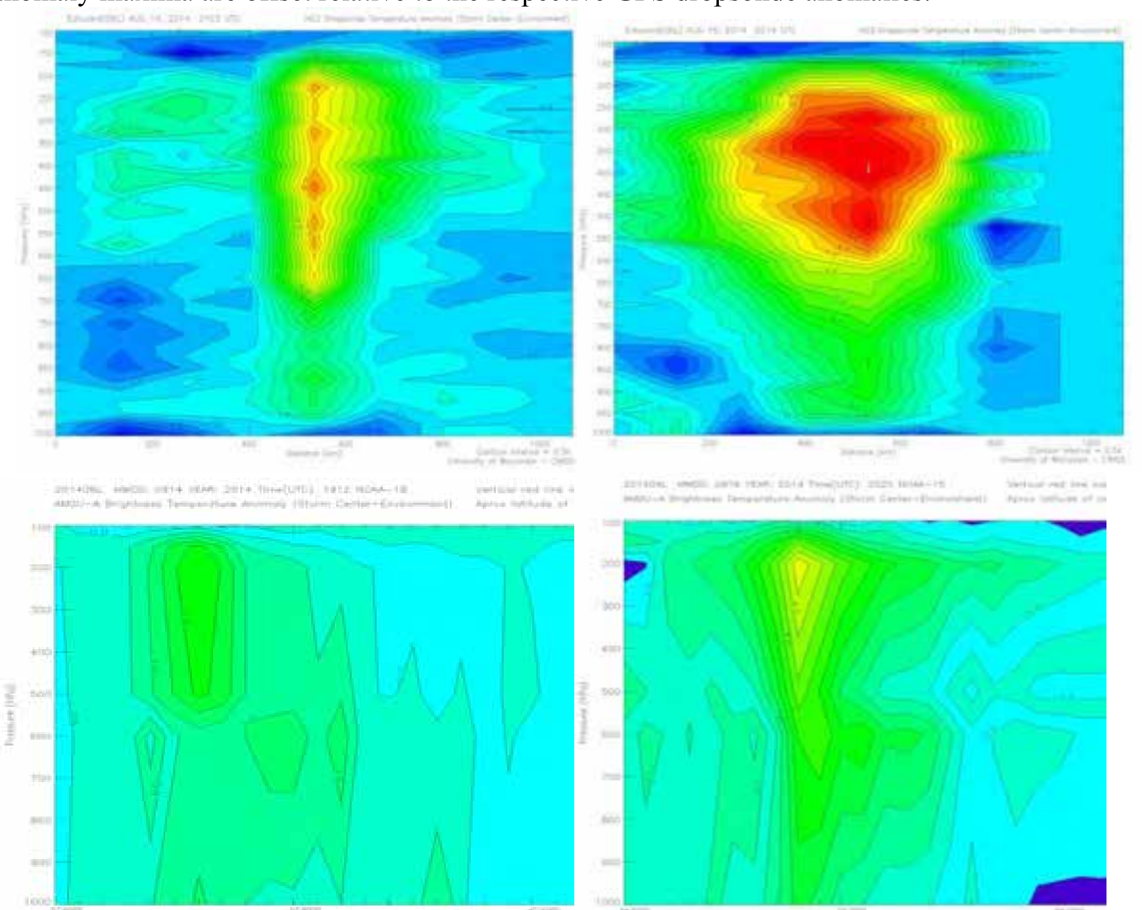

Fig. 5: Observed GPS dropsonde temperature anomalies on September 14th at 2103 UTC and September 16th at 2214 UTC (upper panels), and AMSU-derived Tb anomalies for NOAA-18 on September 14th 1912 UTC and NOAA-15 September 16th at 2025 UTC (lower panels). The TC warm core anomalies are depicted by the darker green to red colors.

Comparing the observed anomalies to the satellite-derived anomalies permits an evaluation of the sub-sampling issues associated with the relatively coarse resolution of the microwave sounders. While it is impossible for the sounder to completely resolve the magnitude of the TC warm core, we are primarily interested in calibrating and documenting the instrument's response with the observed values. On September 14th AMSU does not capture the moderate warm anomaly very well, likely a result of the small core of Edouard at this time. Some evidence of the warm anomaly exists above 600 hPa because the outward-sloping eyewall results in a larger eye at upper levels, partially mitigating the instrument resolution (the spatial FOV resolution is more coarse near the scan edge for this AMSU pass where the TC center is located). The observed anomaly on the 14th shows several localized maxima, however, because the center GPS dropsonde was close to and at times within the inner edge of the TC eyewall, these maxima could be a result of the GPS dropsonde falling in and out of the tight inner warm core gradient.

On Sept 16th both the observed anomaly from the GH and the AMSU-derived anomalies are larger in magnitude and horizontal extent than on the 14th (Fig. 5). The center GPS dropsonde on the 16th was very near the center of the eye at this time. The core anomaly shows two distinct maxima with one near 350 hPa and the other near 525 hPa, and a less distinct third maximum near 250 hPa. The AMSU vertical weighting functions are much coarser than the 25 hPa vertical resolution of the dropsonde cross sections shown here. Nevertheless, there is some indication of two maxima in the AMSU anomaly cross-section with the primary peak near 200-250 hPa and a secondary around 600 hPa.

In both cases the AMSU warm anomaly magnitudes appear to be 3-4 times less than what is observed in the GPS dropsonde profiles. Continued analysis of the GPS dropsonde data and comparisons to the other sounder instruments is ongoing. Although the ATMS orbit geometry was unfavorable for most of the GH transects for Edouard, SSMIS data is available. While Edouard is probably the most interesting case, transects of weaker Cristobal are also available.

ii. Examine the tropical cyclone diurnal cycle in storms flown during the HS3 campaign.

Figure 6 shows the tracks for Global Hawk and two NOAA P-3 missions flown into Hurricane Edouard on 16 Sep 2014. The Global Hawk pattern was planned by PI Dunion and was designed as a storm relative rotated butterfly pattern that included several crossings of the eye and inner core region, as well as sampling of the surrounding environment out to ~R=450 km.

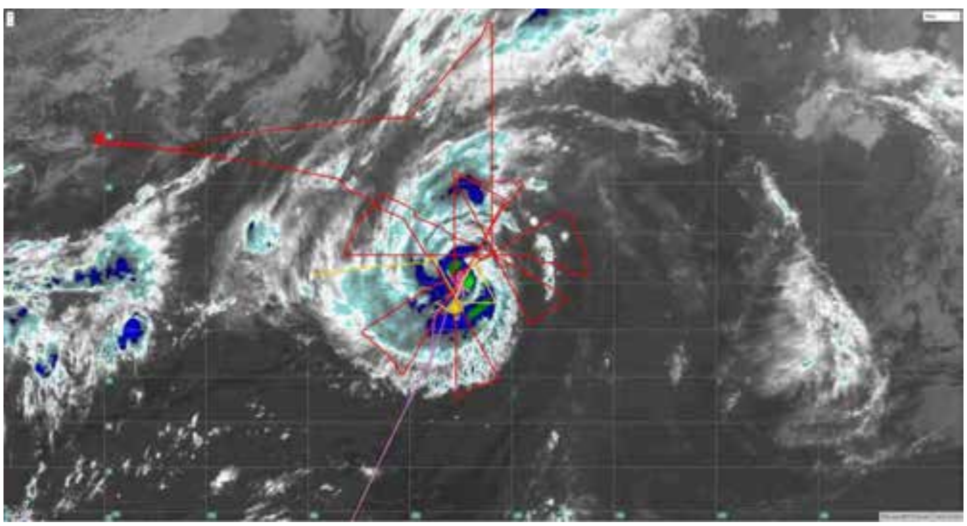

Fig. 6: Flight tracks for aircraft missions flown into Hurricane Edouard on 16 Sep 2014. The red, yellow, and purple curves denote the tracks for the Global Hawk, NOAA-42 P-3, and NOAA-43 P-3 respectively.

PI Dunion has begun examining GPS dropsonde composites from the Global Hawk and NOAA P-3 Edouard missions that were flown on 16 Sep 2014. Figure 7 shows an analysis of 650 hPa RH and indicates that dry mid-level air (i.e. 30-50% RH) was surrounding the TC (~R=300-350 km), particularly in the western, and southern semicircles. Although the inner core of Edouard appeared to be fairly moist inside of ~R=200 km, the surrounding dry air that was sampled was ~10-40% dryer than the typical moist tropical sounding found in the Atlantic (Dunion 2011). Figure 7 also shows a composite of 200 hPa radial winds that was derived from the Global Hawk GPS dropsonde data. This plot indicates that although the radial outflow was well established in the northern and southern semicircles of Edouard, it was relatively inhibited in the eastern and western semicircles with some upper-level inflow even suggested on the east side of the storm.

Ongoing efforts will include performing an in-depth analysis of the mid-level moisture and upper outflow patterns associated with Edouard and investigating possible links between the Edouard's TC diurnal cycle and changes in the observed upper-level outflow patterns that were observed by the Global Hawk GPS dropsonde data.

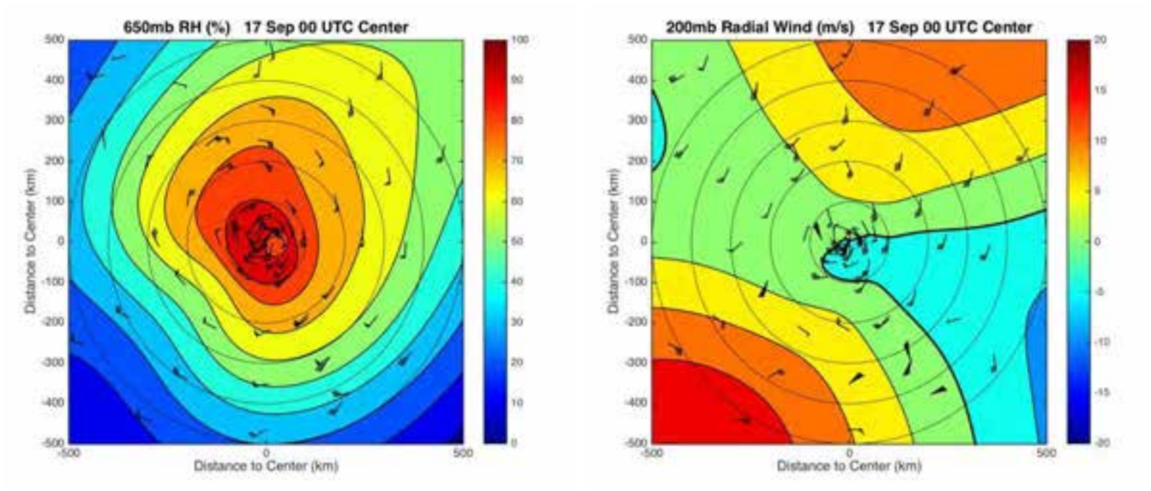

Fig. 7: Composite fields of (left) 700 hPa RH (%) and (right) 200 hPa radial wind (Vr) created from GPS dropsondes launched from the Global Hawk and two NOAA P-3s. For Vr, the storm motion has been removed from the analysis. GPS dropsonde winds are overlaid on both plots and are valid for the respective levels and black range rings denote distances from the storm center at 100 km intervals.

3. Goal 3: *Tropical Convective System Phase Space*

The tropical convective system (TCS) phase space provides a diagnostic summary of the mesoscale-alpha structures of a TCS and the environment in which the TCS is embedded. Used in conjunction with model forecast data, the TCS phase space allows for quick identification of TCSs which may be of interest to field campaigns, such as HS3, due to their potential to undergo tropical cyclogenesis. The phase space also allows for easy comparison between models, ensemble members, or consecutive model runs providing additional information on the reliability of the forecasts in support of the decision making process.

The phase space is composed of a number of metrics; FIGURE displays six metric sets of interest to the formation of a tropical cyclone and the temporal evolution of those metrics for a nondeveloping east Pacific TCS as forecast by the NCEP GFS (initialized at 0000 UTC 27 April 2015). These metrics include three structural (top row) and three environmental metrics (middle row). The key structural metrics are the distance from the 850-hPa center to the 500-hPa center (left), the mean intensity of the flow (center), and the organization of the flow (right). These three metrics describe the formation of a vertically-aligned, warm-core vortex with an intense quasi-axisymmetric primary circulation. The environmental metrics are the volume-averaged relative humidity (left), the shallow-layer (850-500-hPa) vertical wind shear (center), and the deep-layer (850-200-hPa) vertical wind shear (right). Two shear metrics are included to better describe the nature of the vertical shear profile as a large deep-layer shear may be indicative of strong outflow, in which case the deep-layer shear may have large values while the shallow-layer shear has near-zero values. The inclusion of moisture provides information on the favorability of the environment to sustained deep convection. Additionally, work is underway to design a metric to measure the direction of dry air relative to the system center in order to better explore the interaction of the vertical wind shear and the moisture gradient.

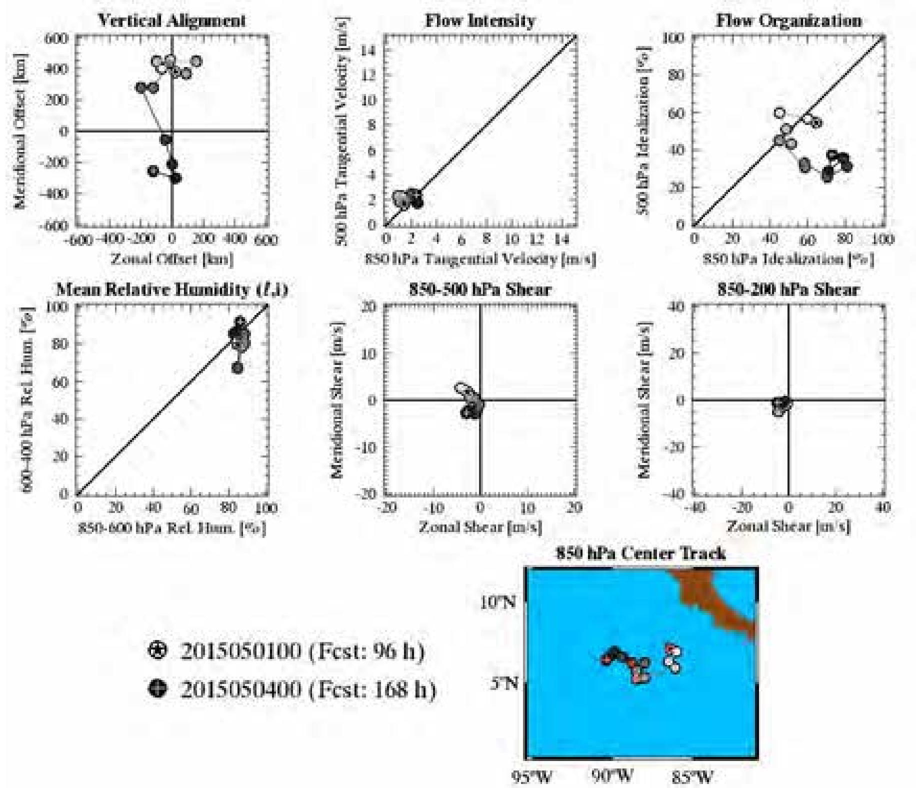

Fig. 8: Example TCS phase space diagram for a nondeveloping east Pacific TCS forecasted by the NCEP GFS initialized at 00 UTC 27 April 2015. The temporal evolution of the phase space metrics are represented by the phase space trajectories with shaded circles positioned at three-hour intervals. The initial time of the trajectory (f=96 hours, verifying at 00 UTC 1 May 2015) is indicated by the black star on a white background and the final time (f=168 hr, verifying at 00 UTC 4 May 2015) by the white plus on a black background. Darker shading indicates later times in the trajectory. The 850-hPa center position is indicated on the map with the day of month in red on each 00 UTC position.

4. Goal 4: *Presentations of Science Results*

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Grant Project Cover Sheet

Submitting Organization:	University of Miami Rosenstiel School of Marine and Atmospheric Science		
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Address:	4600 Rickenbacker Cswy		
City:	Miami	**State:**	**Florida**
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Project Title: The next generation fully, automated Ships of Opportunity and OceanScope Testbeds

Ocean Fund Project Status Report – April 2015

Following is a brief overview of our status with respect to implementing the current "three year" phase in our long term collaborative project with RCL (specifically RCCL and now Celebrity). This phase commenced with the 2013 funding received at the end of that calendar year. The plan in our funded three year proposal was to maintain/upgrade the *Explorer*, complete installation of all systems excepting ADCP aboard *Allure of the Seas*, install next generation new equipment (full OceanScope complement including ADCP) aboard *Equinox* during her scheduled Spring 2014 dry-dock in Cadiz and possibly move the full set of upgraded equipment from *Explore*r *of the Seas* to another vessel. This has been substantially modified over time as described below to reflect a series of unanticipated events. This has involved additional travel/logistical costs as well as outside vendor engagement with respect to software and equipment refurbishment. Moreover the project completion date will have to be extended from January 2016 to at least April 2016. This extension will not incur any additional costs to RCCL. We appreciate both RCL management's understanding and the recent efforts to accelerate funding transfers to the degree possible including enabling payment of the 2014 $250K increment. The invoice for the remaining $250K (of the $650K three year total) is attached to this status report.

Celebrity Equinox

As reported last July, some of the installation was not completed as planned despite considerable prior collaboration between Celebrity Marine Operations and RSMAS over the months prior to the dry-dock., during the dry-dock in Cadiz and during the subsequent legs when she went back into service. The present status and plans are follows

a. The next generation AMOS that was installed is now working well and our primary technician on the software required is back on board and working on the project despite the amputation of his leg. Fortunately most of his work can be done remotely thanks to corporate IT;
b. Meteorological data from the ship is being received but we have yet to work out a system with the ship to determine which anemometer (they have two) is being polled and furnished to us. The ship did not permit our meteorological system to be installed on the mast as planned deeming the mounting point insufficiently robust and a possible safety issue. A more robust housing has been found (and an alternative more robust entire unit was located) and we plan to install this during one of her stateside port stops;
c. The site-to-site VPN (RSMAS server) was updated to include the both M-AERIs and all devices aboard were added to the AnyConnect VPN thanks to corporate IT assistance. Our access to the remote help desk was finalized for minor changes and requests;
d. The M-AERI presently on *Equinox* was swapped for a newly calibrated unit during a November 10-21 *Equinox* cruise and is working well. The M-AERI project requires the ships's meteorological measurements, beginning in November, 2014, and continuing until a dedicated meteorological sensors are installed;
e. The ADCP transducer/deckbox/sea chest/ADU-800 GPS along with tools and the aforementioned meteorological system was offloaded November 21 in Fort Lauderdale and returned to our marine technical group for transfer to *Allure of the Seas* during her drydock (see below).

   A pCO2 system was installed in February and is working well after some initial difficulties.

This was an extension to our original plan but enable us to obtain critical data in the Caribbean despite the decommissioning of the *Explorer* since the *Allure* is not yet on line.

Allure of the Seas

a. a. The latest generation M-AERI Installation is complete on *Allure of the Seas* and the ship has modified the railing around the instrument on Deck 14 to discourage access by guests. Some minor work remains with respect to the clear panels surrounding the unit. The M-AERI device has been added to our site-to-site VPN (RSMAS server) and to the AnyConnect VPN (web based) by corporate IT and is functioning well. The M-AERI project requires the meteorological measurements, beginning in August, 2014, and continuing until a dedicated meteorological sensors are installed;

b. The next generation AMOS system installed last year was refurbished by our marine technical and will be relocated to the bow space just aft of the bulbous bow during the April 5 cruise prior to the May drydock in Cadiz. Good locations were found for both the AMOS itself and the ancillary pCO2 project which also requires a clean air intake; and, UniStrut provided to the ship's engineer. It will be welded in place prior to April 5.

c. An ideal location (good interior access and sufficiently flat hull section) was also located for the ADCP sea chest and we think we will be able to repurpose the sea chest constructed for *Equinox. Allure of the Seas* (not *Equinox*) will become the second fully OceanScope equipped (ADCP, AMOS, MAERI and pCO2) vessel in our fleet.

d. We are working closely with William Spence, ship manager, with regard to all of the above issues and he has told as that he has reason to be believe that he will receive DNV approval of the ADCP sea chest (the more challenging issue).

e. The ADCP will installed and the AMOS connected to the seawater intake during the drydock. Both Peter Ortner, overall project PI, and Richard Findley, head of the RSMAS Marine Technical Group, will be in Cadiz in May to oversee and assist in this process.

Explorer of the Seas

a. The first generation M-AERI was removed some time ago.
b. The second generation AMOS (and pCO2 aboard) continued in operation through an early February cruise after which all equipment on board was readied for removal by RSMAS personal who conducted one last calibration mission. It was all removed prior to the dry dock passage excepting the ADCP's.
c. There are two ADCP's aboard the *Explorer*. They will be removed during her haulout in Cadiz in March. RSMAS personnel will supervise. The larger (an oval 38kHz unit that has yielded invaluable data) is still operational._The smaller 150kHz ADCP unit will be sent to the manufacturer for refurbishment. We will need to locate a replacement lower frequency unit. For maximum flexibility our new sea chest designs accommodate alternative transducer sizes (the smaller 150/75 and the larger 75/38) but only for the newer circular (not oval) units.
d. At a minimum the 150kHz unit will be removed. The larger can be left in place (along with its cable) and brought back into service when/if *Explorer* routes warrant such an investment.

Liberty of the Seas

a. *Liberty of the Seas* has been selected to receive as much of the *Explorer of the Seas* hardware as is readily salvageable and compatible with the new AMOS system including the 150kHz ADCP transducer. We had considered *Summit* and *Freedom* however after discussion with RCL leadership elected to go with the newer vessel.

b. The plan will be to install two sea chests (dual purpose/dual frequency) and the hull penetrations and shutoff valves required by the AMOS during her dry dock in February 2016. As much work as possible will be done prior to February 2016 but the system cannot be fully installed and operational until at least April 2016.

OceanScope Progress

a. A new software system (UHDAS) which is a modification of the software developed for UNOLS research vessels is being modified for use on commercial vessels as part of OceanScope. This would become the standard on all the RCL vessels. The cost for developing this software will be split with GSO/URI ($25K each). We had not originally budgeted for this, however, we were able to accommodate this purchase within our present budget. The contracts were issued in March 2015 and the work will be completed by next Fall.
b. Dr. Ortner was invited to LSU Dept of Oceanography to speak on OceanScope as a Distinguished Visiting Fisheries Scientist in early March.
c. Dr. Ortner (through CIMAS) received $200K/per annum for sensor development with respect to incorporating miniature biomedical sensors for O2, pH and Conductivity into dropped probes which is intended for incorporation into the automated XBT launchers to be installed on RCCL and other OceanScope vessels.

Development of an Autonomous Ammonium Fluorescence Sensor (AAFS) and a Total Dissolved Inorganic Carbon Analyzer for Natural Waters

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NSF Award Number: 1434228

CIMAS Research Theme:
***Theme 3*:** Sustained Ocean and Coastal Observations

Link to NOAA Strategic Goals:
***Goal 1*:** Healthy Oceans – *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*
***Goal 4*:** Resilient Coastal Communities and Economies – *Coastal and Great Lakes communities that are environmentally and economically sustainable*

Funding source: National Ocean Partnership Program (ONR and NSF) and NOAA/OAR Ocean Acidification Program

NOAA Technical Contact: Molly Baringer

LONG-TERM GOALS

Our goal are to improve analytical methodologies with respect to nutrient and ocean carbon cycle parameters and to implement technologies that can be deployed on diverse platforms in diverse applications: specifically, nutrient sensors that can be be deployed for periods of up to a month aboard ships, moorings or drifting buoys or used as a component in lowered, towed or autonomous oceanographic instrument packages for vertical profiling and dissolved inorganic carbon analyzers that can be used aboard ship or back in the laboratory that have accuracy and precision comparable to the more complex and expensive methods currently employed.

TECHNICAL OBJECTIVES

(1) Our first objective is to develop a robust, relatively simple, inexpensive, low power and compact instrument with a detection limit in the nM range and a sampling frequency of at least 4 samples per hour for ammonium determination. Robustness, simplicity, low construction cost, lower power and small size are the practical desiderata for commercial application. Commercialization and the reduced costs that can result are essential to permit wider application throughout the oceanographic community.

(2) Our second objective is to develop dissolved inorganic carbon instrumentation that shares the same coulometric principle as the SOMMA system and has a similar precision and accuracy. However, the system is much simpler and able to autonomously measure eight discrete samples with absolutely no attention.

APPROACH AND WORK PLAN

(1) For the ammonium sensor, our approach has been to first design, assemble and demonstrate engineering prototypes suitable for bench-top laboratory use, then take these aboard ship and once we have achieved the key design objectives test these first in an ongoing sampling program at coastal sewage outfalls along the east coast of Florida and second underwater by deploying at a CREWS (The Coral Reef Early Warning System) station. Once we have achieved (and verified in the field) all our basic design objectives we will then concentrate upon further miniaturizing, reducing power consumption as much as possible and re-packaging for the possible alternative applications. These last efforts will be facilitated by the large and diverse South Florida user community and the related instrument development activities occurring both at UM/CIMAS and AOML. The key person in the initial step is Dr. Amornthammarong while Drs. Ortner, and Hendee, while assisting in these initial steps, will take a much larger role with regard to underwater deployment and field testing.

(2) With respect to the dissolved inorganic carbon analyzer, a syringe pump equipped with a zero-dead volume syringe and a 12-port distribution valve are being used to precisely dispense a dense acid brine solution and seawater samples into the stripper in contrast to the multiple solenoid valves and thermostat-regulated pipette used in SOMMA. Waste remaining in the stripper is automatically withdrawn by a peristaltic pump after each analysis. Again laboratory testing and performance are the first steps followed by analysis of diverse field samples collected from Flower Garden Banks, TX; Delaware Bay and Delaware River, DE; and Shark River, Everglades, FL.

WORK COMPLETED

(1) An autonomous analyzer for the measurement of ammonium in marine waters

Since the project started, progress has been rapid and numerous advances made with regard to the basic mechanics of the instrumentation. First an effective, simple mixing chamber was designed that could be used in conjunction with a syringe pump for flow analysis. Second a new design of fluidic system was developed incorporating this mixing chamber, the Autonomous Batch Analyzer (ABA) system, and the ABA was repeatedly tested in the field (on a ship, at a coastal inlet, etc.). Both have been described in the peer-reviewed literature (Amornthammarong *et al*., 2010 and 2011).

Building upon these advances, a submersible, battery-powered system is being constructed (Figure 1). The electrical port provides access to data logger, communication and battery modules. This will either be self-contained and submersible or be incorporated into larger integrated buoy or moored system for longer deployment periods or to take advantage of pre-existing data communication channels where realtime data is required. We are using an Arduino Uno microcontroller in lieu of the original electronic circuit of a Kloehn syringe pump. The present system consumes only 7.5 W (max). Normally, Kloehn syringe pumps consume 40 W (max). Furthermore using the Arduino Uno microcontroller means a cooling fan is no longer needed. Both stepper motors controlling the selection valve and the syringe are also is also modified to be fully automated.

Figure 1. Submersible, solar-powered system for *in-situ* ammonium measurement in natural waters.

RESULTS

Representative results obtained during earlier field tests and laboratory applications were provided in prior annual reports. Most recently the system was tested for 20 days from September 23 to October 12, 2013 near a Land/Ocean Biogeochemical Observatory (LOBO) station at Harbor Branch Oceanographic Institute (HBOI), Florida Atlantic University for near real-time ammonium concentration measurement every 30 minutes in the Indian River Lagoon (IRL). The entire results of the operation plotted with daily precipitation are shown in Figure 2. As in prior deployments in the Intercoastal Waterway in Ft. Lauderdale, much higher concentrations of ammonium were observed immediately right after a heavy rain prior to the deployment. In the first four days period a strong diurnal pattern was apparent. The ammonium concentrations of the period are plotted with chlorophyll data retrieved from the LOBO station (Figure 3). The result shows that ammonium concentrations were low when chlorophyll concentrations were high and vice versa.

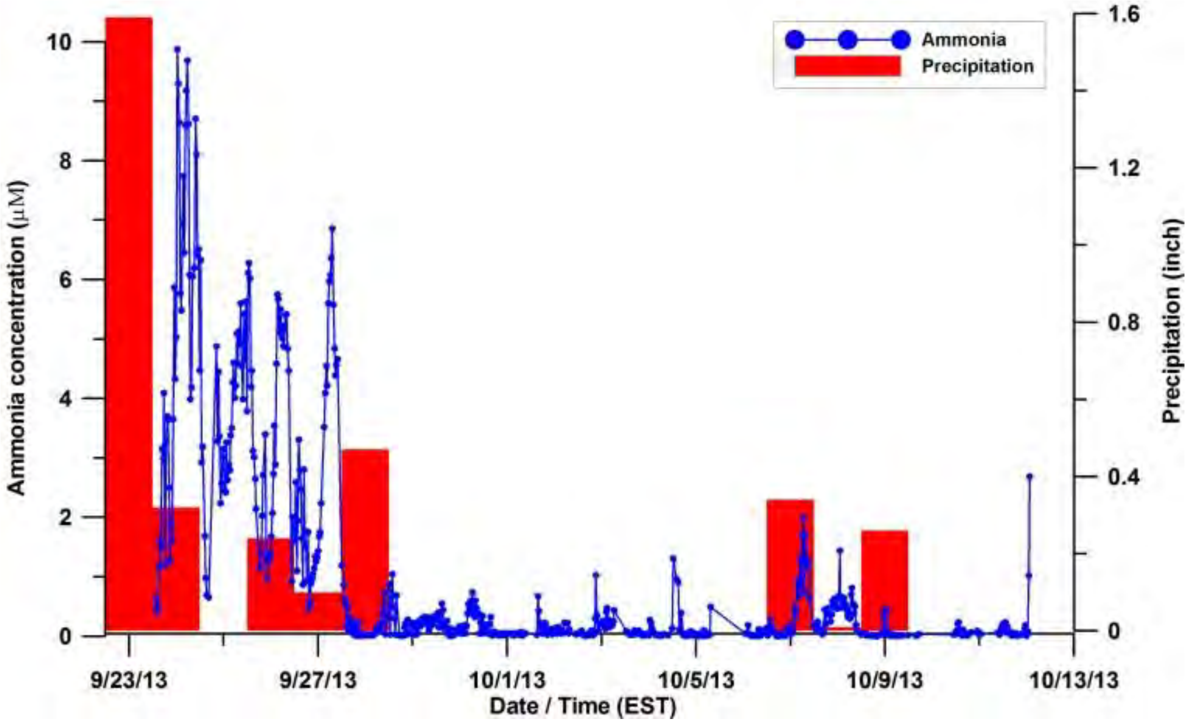

Figure 2. Measurements of ammonium in the surface waters of the Indian River Lagoon, Florida, at the pier of the Harbor Branch Oceanographic Institute, Florida Atlantic University from September 23 to October 12, 2013 (plotted with daily precipitation).

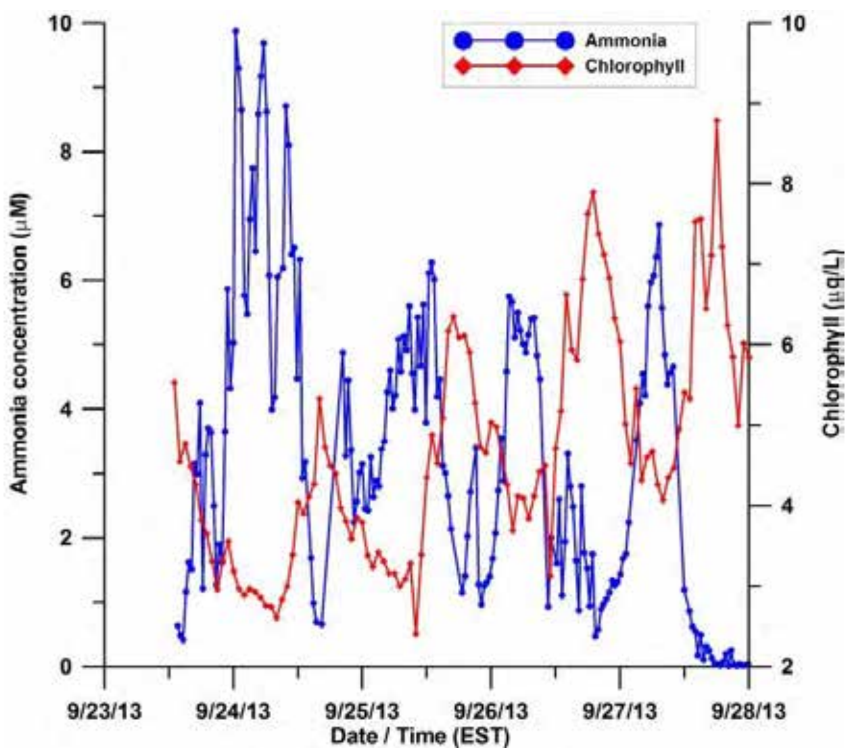

Figure 3. Effect of ammonium concentrations on chlorophyll concentrations.

When the ammonium concentrations of the first four days period are plotted with current direction as shown in Figure 4, it suggests that the source of the ammonium was north of the measurement point. Moreover, when the ammonium concentrations are plotted with conductivity (Figure 5), the result shows that ammonium concentrations were high when conductivity was low and vice versa. It suggests that ammonium may come from freshwaters.

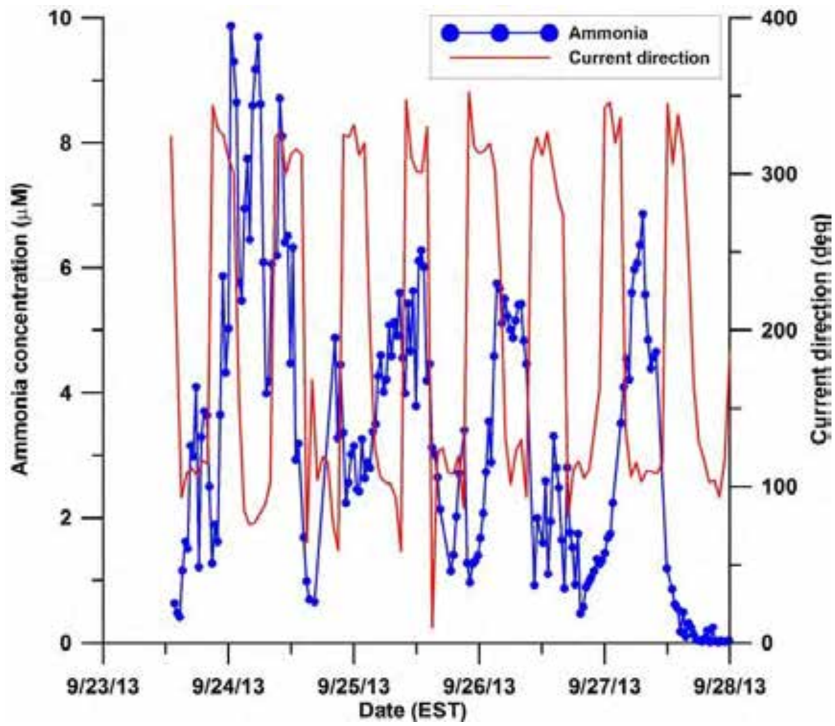

Figure 4. Ammonium concentrations are plotted with current direction.

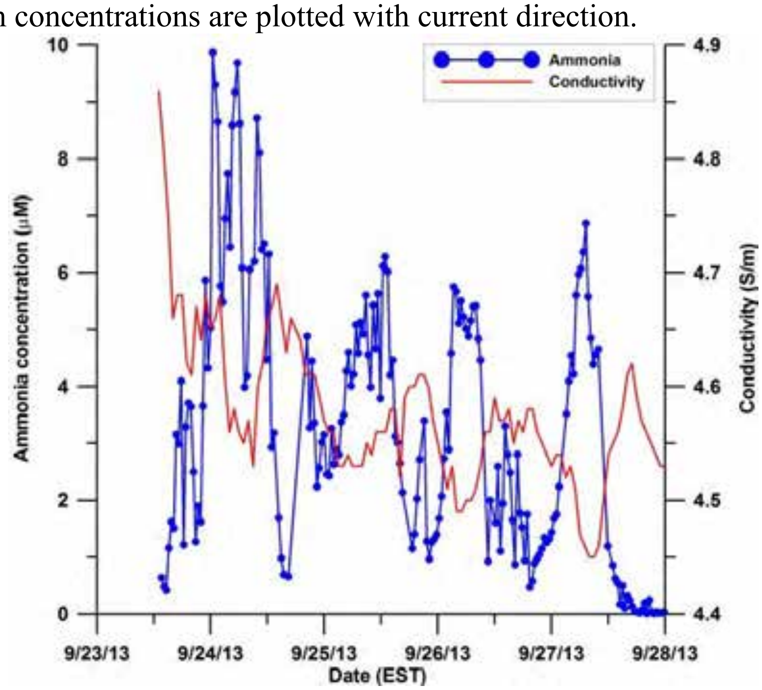

Figure 5. Ammonium concentrations are plotted with conductivity.

To compare the system with prior FAU/HBOI results, the ammonia analyzer was deployed at the same location for a week from June 16 to 23, 2014. The results of the operation plotted against the results obtained by the EPA standard method upon discrete samples are shown in Figure 6. The discrete samples were collected in sequential triplicate at ca. same time and then measured by an autoanalyzer (Seal Analytical AA3 HR). The two methods agreed well except at the first sampling point. That said, discrete ammonia samples typically exhibit large variability.

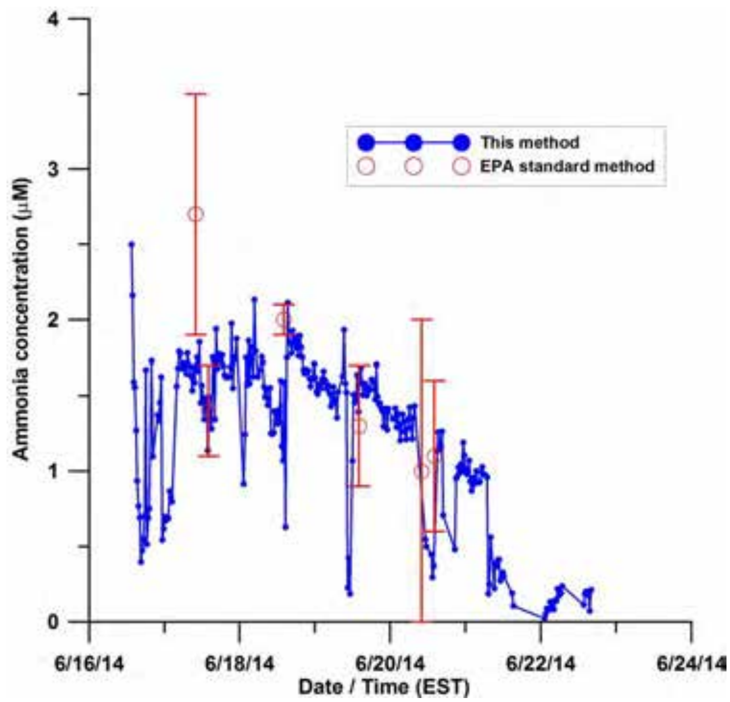

Figure 6. Intercomparison data with the EPA standard method. The system was deployed at the Indian River Lagoon from June 16 to 23, 2014.

(2) A simplified coulometric method for multi-sample measurements of total dissolved inorganic carbon concentration in marine waters

Dissolved inorganic carbon (DIC) is defined as the sum of the concentrations of dissolved CO2, carbonic acid, bicarbonate, and carbonate. DIC concentration, [DIC], is reported as micromoles carbon per kilogram of seawater (umol kg^{-1}). Seawater [DIC] typically range from 1800 to 2300 umol kg^{-1}, but can reach 4300 umol kg^{-1} in extreme marine environments (e.g. the Black Sea). For investigating the oceanic component of the global carbon cycle the consensus analytical goal is 0.05% for accuracy and precision, or $\pm$1.0 umol kg^{-1} for seawater. The "Standard Operating Procedure" described by Dickson *et al.* is based upon coulometry. A commercial system based upon this approach, the Single Operator Multi-parameter Metabolic Analyzer (SOMMA), has become the accepted method of automated DIC measurement within the oceanographic community. Moreover, while the SOMMA system (or the very similar VINDTA-3D system) can achieve accuracy < 1 umol kg^{-1}, or < 0.06% in most ocean environments, their operating protocol is complex and a highly trained operator is essential. Accurate measurements depend upon highly precise dispensing of a known volume of seawater into the stripper where the seawater is acidified. Sample throughput is comparatively limited.

The instrument we have developed shares the same coulometric principle as the SOMMA system and has a similar precision and accuracy. The solution-dispensing method is adapted from a commercially available DIC analyzer (LI-7000, Apollo Scitech), but the dispensed volume is increased 25-fold thereby decreasing uncertainty in the dispensed volume. Waste remaining in the stripper is automatically withdrawn by a peristaltic pump after each analysis. The system is called the Multi-sample Automated Natural-water Analyzer dubbed MANA by Dr Rik Wanninkhof, NOAA.

A schematic diagram and summary of the system are given in Figure 6. The 12-way syringe pump (55023, Norgren Kloehn) equipped with 25 mL capacity zero dead volume syringe (with 48 000 step resolution), seven sample bottles, and a CRM bottle are all installed in a modified thermostat-regulated cooler (P-85 Krusader, Koolatron), maintained by thermostat at 22.0 ^{o}C (the lowest controllable temperature achievable in the laboratory). Figure 7(a) shows all the components of the system and 7(b) shows the inside of the thermostatically regulated cooler in which the syringe pump and eight sample bottles are housed.

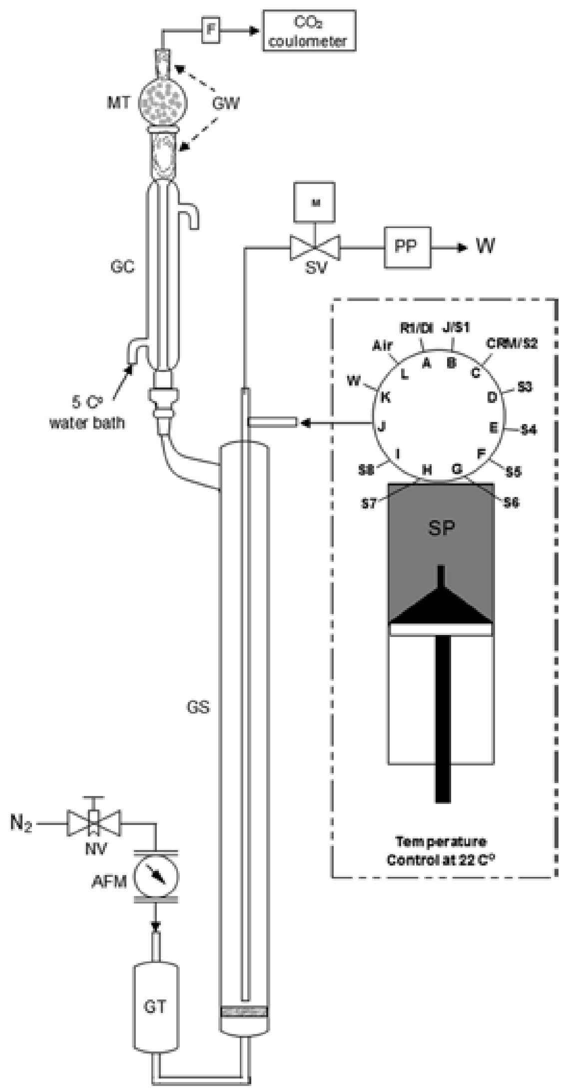

Figure 6. A schematic diagram of the multi-sample automated naturalwater analyzer (MANA). Acronyms: NV, needle valve; AFM, air-flow meter; GT, glass trap; GS, glass stripper; GC, glass condenser; MT, moisture trap; GW, glass wool; F, PTFE 0.2 mmfilter; SV, pinching valve; PP,

peristaltic pump; SP, 12-way syringe pump equipped with 25 mL zero dead volume syringe; W, waste; R1/DI, acid solution or deionized water; J, junk or low nutrient seawater solution; CRM, certified reference materials; S1–S8, samples.

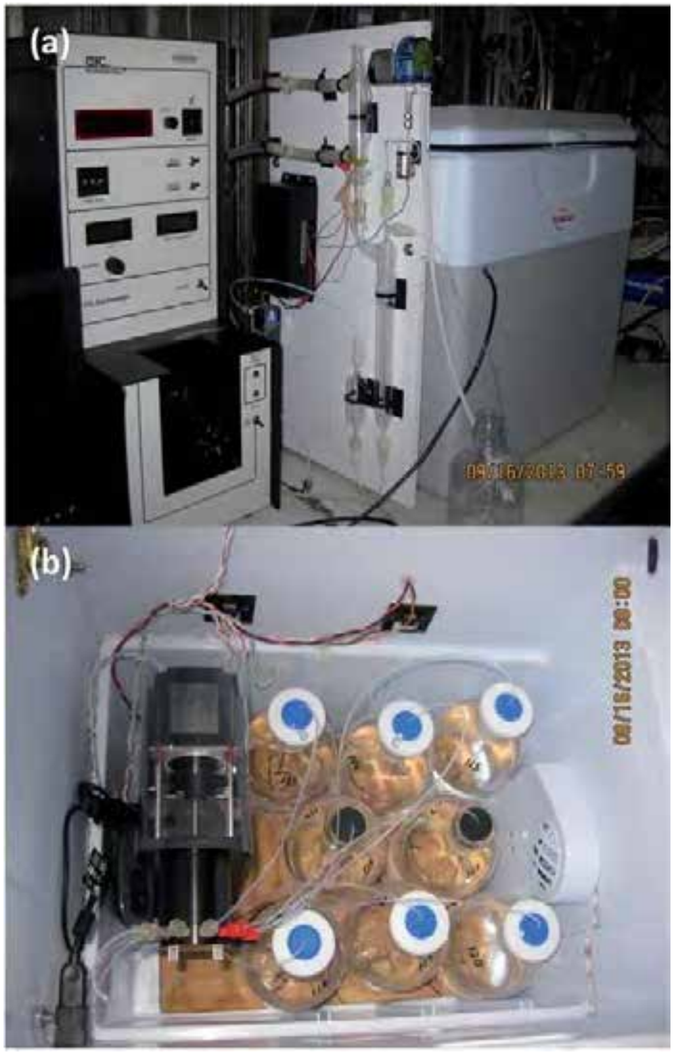

Figure 7. (a) The Multi-sample Automated Natural sample Analyzer (MANA). (b) The interior of the temperature regulated chamber housing the syringe and sample bottles.

The system response was linear [y = (2347.9 $\pm$ 64.5)x, y = system response (count), x = percent of LNSW] over a range of 50–100% LNSW diluted by deionized water, with a correlation coefficient (R^2) of 0.9992. Reproducibility was tested by injecting LNSW 14 times in succession. The mean value measured was 2012.5 umol kg^{-1} with a precision of 0.022%. The accuracy of the system was tested by injecting CRMs, and then calculated [DIC] by using the calibrated volume of the syringe, which was calibrated every time the syringe was changed. The average offset of calculated [DIC] from CRM reported by the Scripps Institution of Oceanography of the University of California was 1.2 umol kg^{-1} (n = 9). Field samples were then tested in a number of contexts and the system compares favorably with the SOMMA system in both accuracy and precision but has considerable operational advantage.

The differences are given in the Table below which is reproduced from our recent publication (Amornthammarong *et al,* 2014).

Table 5 Comparison of SOMMA and MANA

Features	SOMMA	MANA
Solution-delivery mechanics	Multiple solenoid valves and a glass pipette, which make the system complex and delicate	A syringe pump equipped with a distribution valve. The system is simpler, more rugged and easier to operate
Calibration system	Gas loop and CRM. The gas loop calibration system also causes the complexity of the system	CRM only same as VINDTA 3D.[25] This causes the systems much simpler and need only one gas (carrier gas)
Waste removal from stripper	Uses gas pressure which can cause leakage of acid waste. Moreover a small amount of waste can be left inside stripper	Uses a peristaltic pump, that can completely draw down waste with little chance of any leakage
Sample injection	Operator needs to change the sample bottles to make repeated measurements	Autonomously measures up to eight samples
Sample volume	Hard to change	Easy to change. This can be useful for very high [DIC] sample measurement
Cost	Relatively high and no longer commercially available	Significant lower component costs and not commercially available

IMPACT AND APPLICATIONS

Economic Development

The ammonium sensor system being developed will have broad applicability as a research tool in biological oceanography but with respect to economic implications it also has wide market potential for regulatory-required monitoring of ammonium. Such monitoring has become part of the permitting process for municipal and regional waste water treatment facilities throughout the U.S. Moreover, the basic design we have pioneered through the ABA system can be adapted to automating other wet chemical reactions such as nitrate, nitrite and phosphate, etc. further extending the commercialization potential of this NOPP-supported research and development project.

The dissolved inorganic carbon analyzer that we have developed will greatly reduce operator intervention for investigating the oceanic component of the global carbon cycle. Given the recognized economic significance of ocean acidification, we anticipate this too will be rapidly commercialized although its use will likely be restricted to the scientific community unless there is a significant change in the regulatory environment.

Science Education and Communication

With respect to science education the primary relevance will be incorporation of the system (and the measurements it permits) in graduate theses and dissertations within the marine science community. When the development and testing is complete we will be able to deploy such an instrument to monitor in situ ammonium in the coastal and ocean water column to study the variable influx of this rapidly assimilated nutrient that is associated with migration of zooplankton populations in benthic communities (including coral reefs), zooplankton and mesopelagic fish vertical migration, grazing by schooling herbivorous fishes and intermittent physical processes such as breaking internal waves, wind-mixing etc.

In addition data streams from contexts of local political significance (e.g. documenting the extent of pollution associated with individual point sources like sewage outflows or groundwater springs could be useful for public outreach and education.

TRANSITION TO OPERATIONS

Economic Development

Contacts have already been established (and interest expressed) by commercial instrument manufacturers.

Quality of Life

The ammonium instrument has already been used in the Florida Area Coastal Environment (a federal/state/private industry partnership) to monitor surface concentrations of ammonium in the coastal waters of the Florida Keys and south-eastern coastal waters with respect to point sources like inlets adjacent to population centers and sewage outfalls and in the Indian River Lagoon in the context of a major state-federal ecosystem restoration effort in that lagoon.

RELATED PROJECTS

NONE

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Preview of Award 1031278 - Annual Project Report

Cover

Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	1031278
Project Title:	Collaborative Research: Global Impacts of Eddies on Inertial Oscillations of the Mixed Layer
PD/PI Name:	Renellys C Perez, Principal Investigator Rick Lumpkin, Co-Principal Investigator
Recipient Organization:	University of Miami Rosenstiel School of Marine&Atmospheric
Project/Grant Period:	10/01/2010 - 09/30/2015
Reporting Period:	10/01/2013 - 09/30/2014
Submitting Official (if other than PD\PI):	Renellys C Perez Principal Investigator
Submission Date:	09/29/2014
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Renellys C Perez

Accomplishments

*** What are the major goals of the project?**

This project aims to improve estimates of the wind-driven near-inertial energy flux into the interior ocean. This is being undertaken by analyzing the inertial oscillations recorded by NOAA's Global Surface Drifter data set, in conjunction with numerical modeling. The hypothesis is that the global near-inertial energy flux from the mixed layer to the interior is substantially shaped and accelerated by interactions with the mesoscale eddy field. This collaborative project involves researchers in Seattle, Miami, and London with expertise in oceanographic observations, modeling, and theory, as well as in statistical time series analysis. The strategy of the Miami component of this project has been to first create and then refine analysis tools that have been tested on small observational data sets before proceeding to the global analysis.

*** What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?**

Major Activities: Here we report on the drifter dataset improvement component of the project by the Miami group, comprised of PIs R. Perez and R. Lumpkin and UM/RSMAS collaborator S. Elipot, in year 4 of the project. NOAA/AOML produces and distributes the surface drifter dataset that is being utilized by this project.

Efforts this year by the Miami group have centered on developing a global *hourly* drifter product from Argos satellite-tracked surface drifters. We are evaluating the optimum method to interpolate the uneven drifter position fixes to uniformly sampled *hourly* positions and velocities by working on a subset of surface drifters that have been equipped with Global Positioning System (GPS). We began with the simplest approach of linear interpolation in longitude-latitude space and are in the process of evaluating errors resulting from higher order interpolation schemes (i.e. regression estimators with variable polynomial order and observational window length). Having dual hourly Argos and GPS fixes allows for a rigorous examination of the errors associated with each interpolation schemes. The resulting scheme will be applied globally and the global *hourly* drifter product will yield a better understanding of the distribution and characteristics of high frequency motions in the upper ocean, with focus on near-inertial waves, diurnal and semidiurnal tides, and submesoscale motions. The global drifter program will be transitioning to hourly GPS fixes transmitted via Iridium satellite over the next year, and this hourly interpolated product will be allow for connection of the pre- and post-Iridium record with a characterization of how the errors have changed over time.

Efforts by the Seattle group are ongoing to develop optimized techniques to identify the near-inertial component of the motion potentially in the presence of background vorticity in the drifter product (reported separately by Seattle group).

Specific Objectives:

Significant Results: A PI meeting was held in February 2014 during the 2014 Ocean Sciences Meeting in Honolulu, HI. Based on recommendations made during this meeting, we are actively developing an *hourly* drifter product from Argos satellite-tracked surface drifters. This work follows the necessary drogue reclassification effort that was completed last year (detailed in Lumpkin et al., 2013). The updated raw-drifter data set was used to study the circulation in the tropical Atlantic in Perez et al. (2013). Results from Perez et al. (2013) were presented by R. Lumpkin at the October 2013 TAV/PIRATA meeting in Venice, Italy and by R. Perez at the 2014 Ocean Sciences Meeting.

Key outcomes or Other achievements:	A PI meeting was held in February 2014 during the 2014 Ocean Sciences Meeting in Honolulu, HI. Based on recommendations made during this meeting, we are actively developing an *hourly* drifter product from Argos satellite-tracked surface drifters. This work follows the necessary drogue reclassification effort that was completed last year (detailed in Lumpkin et al., 2013). The updated raw-drifter data set was used to study the circulation in the tropical Atlantic in Perez et al. (2013). Results from Perez et al. (2013) were presented by R. Lumpkin at the October 2013 TAV/PIRATA meeting in Venice, Italy and by R. Perez at the 2014 Ocean Sciences Meeting.

*** What opportunities for training and professional development has the project provided?**

The development of the new high resolution drifter data set is being led by early career research scientist R. Perez, and has involved collaboration with another early career research scientist S. Elipot. R. Perez participated in several K-12 outreach events at UM/RSMAS, NOAA/AOML, and local schools. R. Lumpkin collaborated with authors from NOAA's ClimateWatch Magazine to create an article about the Global Drifter Program (http://www.climate.gov/news-features/climate-tech/doing-their-part-drifter-buoys-provide-ground-truth-climate-data).

*** How have the results been disseminated to communities of interest?**

A PI meeting was held in February 2014 during the 2014 Ocean Sciences Meeting in Honolulu, HI. Based on recommendations made during this meeting, we are actively developing an *hourly* drifter product from Argos satellite-tracked surface drifters. This work follows the necessary drogue reclassification effort that was completed last year (detailed in Lumpkin et al., 2013). The updated raw-drifter data set was used to study the circulation in the tropical Atlantic in Perez et al. (2013). Results from Perez et al. (2013) were presented by R. Lumpkin at the October 2013 TAV/PIRATA meeting in Venice, Italy and by R. Perez at the 2014 Ocean Sciences Meeting.

The 6-hourly global drifter data set and monthly drifter climatology have been made publically available at the following site: http://www.aoml.noaa.gov/phod/dac/index.php.

Papers analyzing the 6-hourly global drifter data set and monthly drifter climatology have been published in/submitted to various scientific journals: Journal of Geophysical Research, Journal of Atmospheric and Oceanic Technology, Oceanography, and Climate Dynamics.

*** What do you plan to do during the next reporting period to accomplish the goals?**

In year 5, rigorous examination of the errors associated with each Argos interpolation schemes will continue. Once the optimal technique has been identified, it will be applied globally to the drifter data set. The global drifter program will be transitioning to hourly GPS fixes transmitted via Iridium satellite over the next year, and this hourly interpolated product will be allow for connection of the pre- and post-Iridium record with a characterization of how the errors have changed over time. The global *hourly* drifter product will then be used to develop a better understanding of the distribution and characteristics of high frequency motions in the upper ocean, with focus on near-inertial waves, diurnal and semidiurnal tides, and submesoscale motions.

We will also work with the Seattle group to develop an *hourly* drifter product with explicit near-inertial component in year 5.

Products

Books

Book Chapters

Conference Papers and Presentations

Inventions

Journals

Hormann, V., R. Lumpkin, and R. C. Perez (2013). A generalized method for estimating the structure of the equatorial Atlantic cold tongue: Application to drifter observations. *J. Atmos. Oceanic Technol.*. 30 1884. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1175/JTECH-D-12-00173.1

Lumpkin, R. and G. Johnson (2013). Global Ocean Surface Velocities from Drifters: Mean, variance, ENSO response, and seasonal cycle. *J. Geophys. Res. Oceans*. 118 2992. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1002/jgrc.20210

Lumpkin, R., and P. Flament (2013). On the extent and energetics of the Hawaiian Lee Countercurrent. *Oceanography*. 26 (1), 58. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:http://dx.doi.org/10.5670/oceanog.2013.05

Lumpkin, R., S. Grodsky, M.-H. Rio, L. Centurioni, J. Carton, and D. Lee (2013). Removing spurious low-frequency variability in surface drifter velocities. *J. Atmos. Oceanic. Technol.*. 30 (2), 353. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1175/JTECH-D-12-00139.1

Perez, R. C., V. Hormann, R. Lumpkin, P. Brandt, W. E. Johns, F. Hernandez, C. Schmid, and B. Bourles (2013). Mean meridional currents in the central and eastern equatorial Atlantic. *Clim. Dyn.*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1007/s00382-013-1968-5

Licenses

Other Products

Other Publications

Patents

Technologies or Techniques

Thesis/Dissertations

Websites

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Perez, Renellys	PD/PI	1
Lumpkin, Rick	Co PD/PI	1

Full details of individuals who have worked on the project:

Renellys C Perez
Email: rcperez@miami.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: The development of the new high resolution drifter data set is being led by R. Perez.

Funding Support: NSF

International Collaboration: Yes, United Kingdom
International Travel: No

Rick Lumpkin
Email: Rick.Lumpkin@noaa.gov
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: R. Lumpkin is the head of the Global Drifter Program at NOAA/AOML, and is actively involved in the development of the new high resolution drifter data set with R. Perez.

Funding Support: NOAA

International Collaboration: Yes, United Kingdom
International Travel: No

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
Earth Space Research	Other Nonprofits	Seattle, WA
Northwest Research Associates	Other Nonprofits	Seattle, WA
University of Miami	Academic Institution	Miami, Florida

Full details of organizations that have been involved as partners:

Earth Space Research

Organization Type: Other Nonprofits
Organization Location: Seattle, WA

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: The project is a collaboration between researchers in Seattle (Northwest Research Associates and Earth Space Research), Miami, and London

Northwest Research Associates

Organization Type: Other Nonprofits
Organization Location: Seattle, WA

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: The project is a collaboration between researchers in Seattle (Northwest Research Associates and Earth Space Research), Miami, and London.

University of Miami

Organization Type: Academic Institution
Organization Location: Miami, Florida

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: S. Elipot is an Assistant Scientist at the University of Miami/RSMAS and is involved as a collaborator on this project.

What other collaborators or contacts have been involved?

NO

Impacts

What is the impact on the development of the principal discipline(s) of the project?

The global *hourly* drifter product developed by this project will yield a better understanding of the distribution and characteristics of high frequency motions in the upper ocean, with focus on near-inertial waves, diurnal and semidiurnal tides, and submesoscale motions.

What is the impact on other disciplines?

The global *hourly* drifter product developed by this project will be made publically available and can be used for a variety of applications, as is already the case for the 6-hourly drifter product and drifter climatology produced by the R. Lumpkin's group.

What is the impact on the development of human resources?

The development of the new high resolution drifter data set is being led by early career research scientist R. Perez, and has involved collaboration with another early career research scientist S. Elipot. R. Perez participated in several K-12 outreach events at UM/RSMAS, NOAA/AOML, and local schools. R. Lumpkin collaborated with authors from NOAA's ClimateWatch Magazine to create an article about the Global Drifter Program (http://www.climate.gov/news-features/climate-tech/doing-their-part-drifter-buoys-provide-ground-truth-climate-data).

What is the impact on physical resources that form infrastructure?
Nothing to report.

What is the impact on institutional resources that form infrastructure?
Nothing to report.

What is the impact on information resources that form infrastructure?
Nothing to report.

What is the impact on technology transfer?
Nothing to report.

What is the impact on society beyond science and technology?
Nothing to report.

Changes/Problems

Changes in approach and reason for change
Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them

A no cost extension is requested to complete the generation of hourly interpolated drifter product, and publish results on the analysis of the quality controlled fields.

Changes that have a significant impact on expenditures
Nothing to report.

Significant changes in use or care of human subjects
Nothing to report.

Significant changes in use or care of vertebrate animals
Nothing to report.

Significant changes in use or care of biohazards
Nothing to report.

Annual Progress Report

1) **Project Title:** *Variability of the South Atlantic Subtropical Gyre*
2) **PI:** Renellys C. Perez
3) Period covered by the report: 4/17/2014 – 02/17/2015 (Year 1).
4) Institution: Cooperative Institute for Marine and Atmospheric Studies, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149.
5) Grant number NNX14AH60G

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Project team: Renellys C. Perez (Programmer: Qi Yao; Collaborators: Shenfu Dong, CIMAS/UM and NOAA/AOML; Rym Msadek, UCAR and NOAA/GFDL)

Introduction

The rate at which heat is transported northward *vs.* stored by the South Atlantic subtropical gyre is of great importance, as the gyre plays a significant role in the establishment of oceanic teleconnections, and changes occurring in the South Atlantic alter the Atlantic Meridional Overturning Circulation (AMOC). Substantial changes in the circulation of Southern Hemisphere subtropical gyres have previously been inferred from satellite measurements and *in situ* hydrographic and near-surface velocity measurements. A decadal expansion and strengthening (or spin-up) of the Southern Pacific subtropical gyre was detected in the mid 1990s to mid 2000s, which was linked to a southward shift and intensification of the Southern Hemisphere westerlies associated with anthropogenic increases in ozone-depleting gases and CO_2. Understanding of changes observed in the South Atlantic subtropical gyre lags that of the South Pacific gyre.

As part of this project, the time-variability of the South Atlantic subtropical gyre is being investigated through analysis and interpretation of satellite and *in situ* data, synthesis products, and ocean-only and coupled climate models. The overall goals of this project are two-fold: a) to describe the evolution of the South Atlantic subtropical gyre over the past two decades in the surface and intermediate waters; and b) to improve our understanding of the mechanisms that control the variability of the South Atlantic subtropical gyre, and the currents that delineate the boundaries of the gyre, on interannual to decadal timescales. Specifically, we will characterize the time-varying components of the Brazil Current, South Atlantic Current, Benguela Current, Agulhas leakage, and South Equatorial Current, and ascertain whether the primary mechanisms and sources responsible for the variability of each of those currents are the same as the mechanisms that govern the gyre variability. This work is done in collaboration with Rym Msadek at NOAA/GFDL and Shenfu Dong at UM/CIMAS.

The research activities that have been carried out during the period covered by the report are:

1. Analysis of observed sea surface height (SSH) and surface current anomalies in the South Atlantic subtropical gyre between 20°S and 55°S;
2. Analysis of observed property changes in the South Atlantic subtropical gyre and on the western boundary along 34.5°S.

During the first year, progress has been made in both of the areas mentioned above and our research is advancing according to the proposed schedule. R. Perez and S. Dong are coauthors on several abstracts for presentations at the IUGG/IAPSO meeting in Prague, Czech Republic in June 2015. These talks are focused on the variability of the southward flowing Brazil Current and southward flowing Deep Western Boundary Current as estimated from *in situ* measurements collected from two overlapping arrays of moorings and shipboard surveys along 34.5°S. These talks are related to research activities 1 and 2. The programmer funded with partial support under this grant, Qi Yao, retired at the end of 2014. Another programmer at NOAA/AOML has been selected to assist us with our efforts for the remainder of the grant. R. Perez has also obtained access and begun processing output from NOAA/GFDL ocean-only and coupled climate simulations in collaboration with R. Msadek. These model simulations will be used in the remainder of year 1 and year 2 to examine the variability of the Brazil and Benguela Currents, the subtropical gyre, and their impact on AMOC on seasonal to interannual timescales, and compare with available observations.

Narrative of First Science Results

Observed SSH and surface current anomalies in the South Atlantic subtropical gyre

We have begun analyzing large-scale changes in the South Atlantic subtropical gyre between 20°S and 55°S using altimetric SSH anomaly (SSHA) fields distributed by AVISO (http://www.aviso.oceanobs.com) and near-surface currents derived from a synthesis of drifter velocities, altimetry and wind products (Lumpkin and Garzoli, 2011). The multi-satellite AVISO SSHA product is available daily on a 1/4° spatial grid from January 1, 1993 to December 31, 2013. Poleward of 2.5° latitude, the drifter-altimetry synthesis produces snapshots of currents at 15-m depth that are derived from weekly AVISO SSHA fields on a 1/3° spatial grid. Future work in collaboration with Rick Lumpkin will update the surface velocity product to match the daily and 1/4° spatial resolution of the new AVISO product.

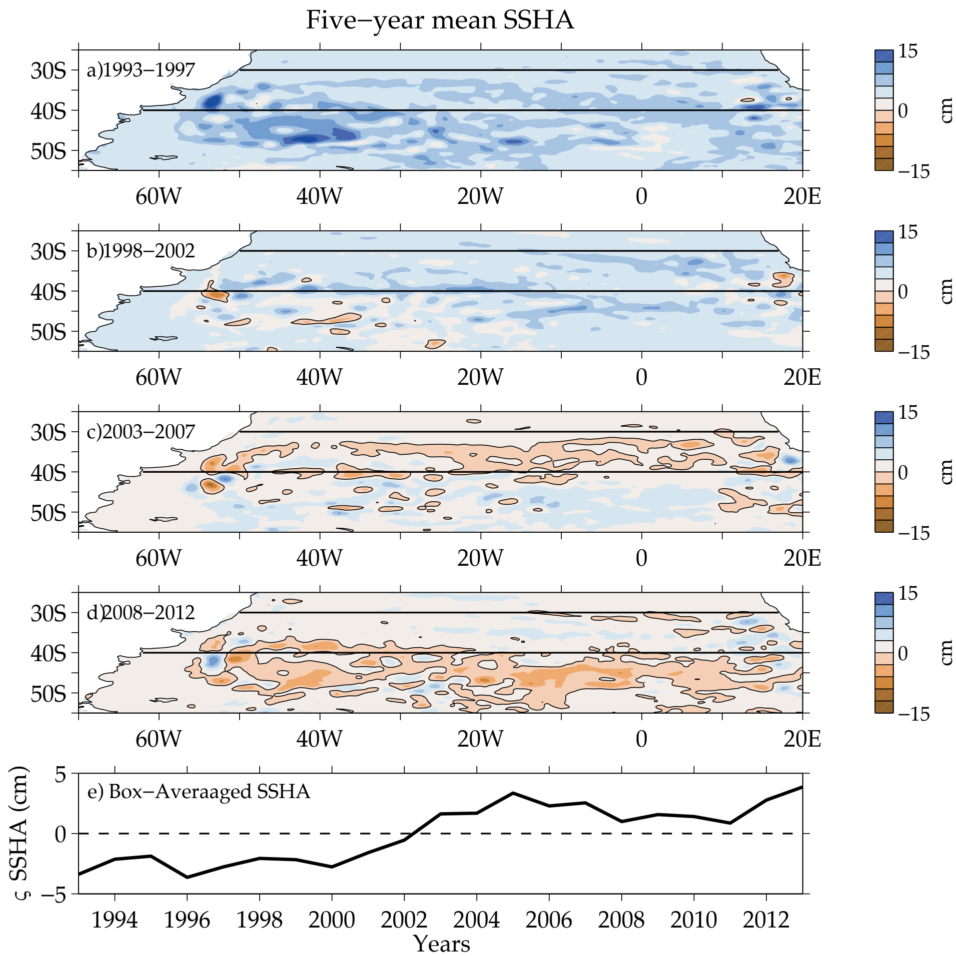

Figure 1. (a)-(d) Five-year mean AVISO SSHA (relative to the 1993-2013 mean) over the South Atlantic subtropical gyre. Black line shows the region bounded by 30°S and 40°S over which the box-averaged annual SSHA time series plotted in (e) is computed.

Figure 1 demonstrates how successive five-year means of SSHA have changed over the past two decades. Consistent with previous studies (e.g., Roemmich et al., 2007) that reported an increase in SSHA in the South Pacific subtropical gyre of up to 12 cm between 1993 and 2003, the average SSHA in the South Atlantic between 30°S and 40°S increased by up to 7 cm between 1993 and 2005 (Figure 1e). Since then, SSHA in this region dropped by approximately 2.5 cm between 2005 and 2011, and subsequently increased by 3 cm. Note, the temporal evolution of annual SSHA is very similar when averaged between 20°S and 55°S (not shown).

Analysis of surface current anomalies during the same time period demonstrates that the southward flowing Brazil Current increased in strength (negative velocity anomaly) between 1993 and 2002 between 15°S and 30°S consistent with the gyre increasing in strength (Figure 2). In the following decade, the Brazil Current weakened (positive velocity anomaly) in the following decade consistent with the gyre decreasing in strength (Figure 2). The northward flowing North Brazil Current was also observed to increase in strength (positive velocity anomaly) between 1998 and 2012 and the boundary between the North Brazil and Brazil Currents shifted southward. The amount of water transported northward by the North Brazil Current can influence the strength of AMOC in the Northern Hemisphere, and we will quantify this relationship in year 2.

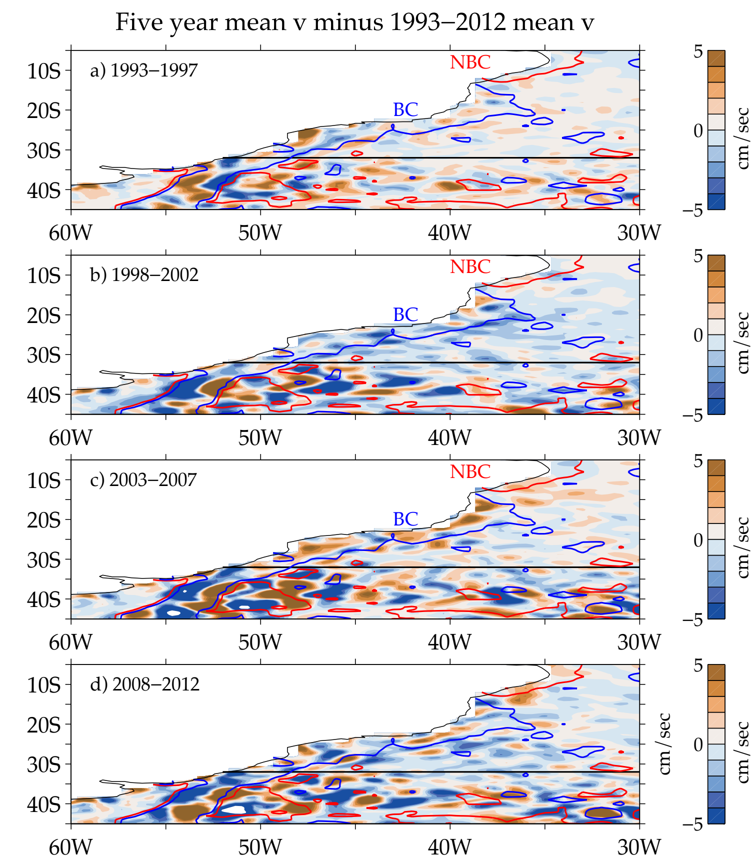

Figure 2. Five-year mean meridional velocity estimated from the Lumpkin and Garzoli (2011) drifter-altimetry synthesis, with 1993-2012 mean meridional velocity subtracted (color shading). The blue (red) contour line indicates 5 cm/sec southward (northward) flow in the 1993-2012 mean, and these contours delineate the mean locations of the Brazil Current (BC) and North Brazil Current (NBC). The black horizontal line identifies the latitude 32ºS.

Observed property changes in the South Atlantic subtropical gyre and on the western boundary

We have analyzed large-scale changes in the upper ocean temperature structure in the South Atlantic subtropical gyre using the Roemmich and Gilson (2009) gridded Argo data set and Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) SST fields distributed by Remote Sensing Systems (http://www.ssmi.com). The Argo data set is available as monthly temperature and salinity fields from January 1, 2004 to December 31, 2013 on a 1° horizontal grid (http://sio-argo.ucsd.edu/RG_Climatology.html) from the surface down to 2000 m. TMI SST daily (3-day running average) fields are available from January 1, 1998 to December 31, 2014 on a 0.25° spatial grid.

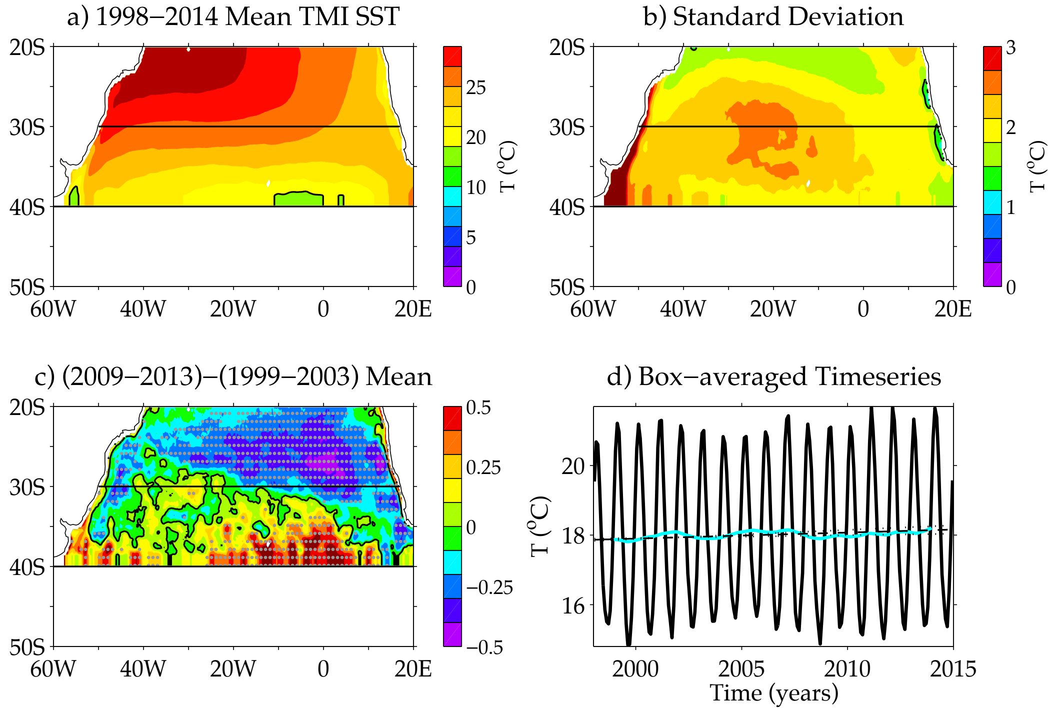

Figure 3. Spatial structure of 1998-2014 TMI SST (a) mean and (b) standard deviation estimated from TMI SST monthly averages. (c) Difference between two five-year means separated by a decade: 2009-2013 and 1999-2003. (d) Temporal evolution of the box averaged (region bounded by 30ºS and 40ºS) SST (black-line) with 2-year low-pass filtered time series overlaid (cyan line). Linear fit (dashed line) and 95% confidence limits (dotted lines) are also overlaid.

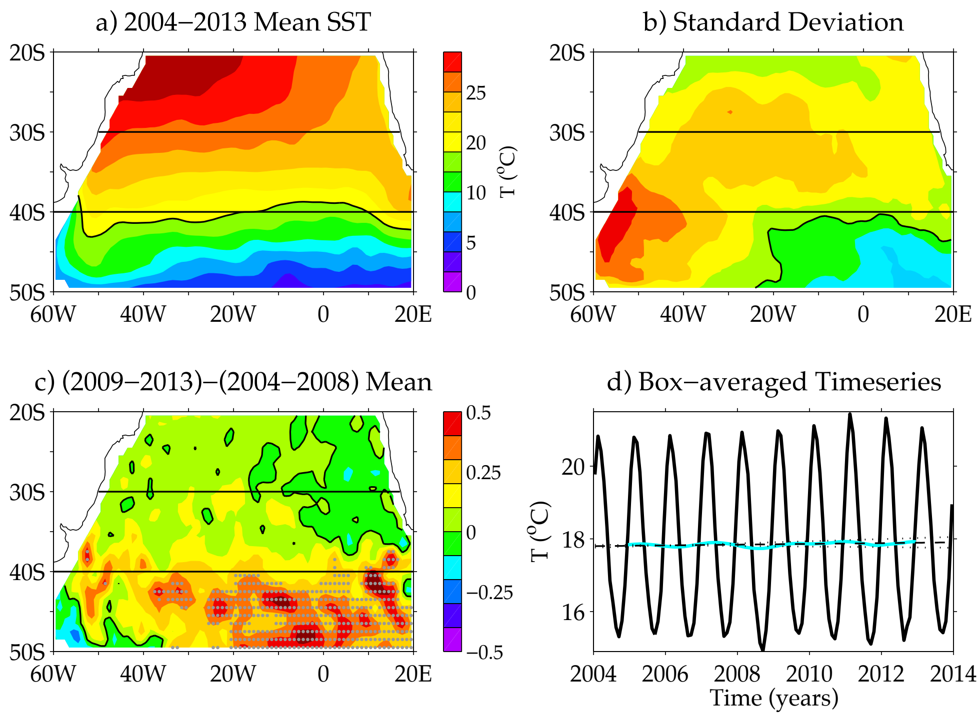

Figure 4. Spatial structure of 2004-2013 Argo SST (a) mean and (b) standard deviation estimated from Argo SST monthly averages. (c) Difference between two succesive five-year means: 2009-2013 and 2004-2008. (d) Temporal evolution of the box averaged (region bounded by 30ºS and 40ºS) SST (black-line) with 2-year low-pass filtered time series overlaid (cyan line). Linear fit (dashed line) and 95% confidence limits (dotted lines) are also overlaid.

From this analysis, we have observed large-scale changes in surface (Figure 3 and 4) and subsurface temperatures (Figure 5) over the South Atlantic subtropical gyre. At the surface, TMI SST shows large variability over the South Atlantic subtropical gyre between 25°S and 40°S (Figure 2) with the large decadal increase between 2009-2013 and 1999-2003 observed south of 30°S (Figure 3c). From the shorter Argo record, warming between 2009-2013 and 2004-2008 is largest south of 35°S (Figure 4c). Note the Argo SST structure north of 40°S matches TMI SST structure during this decade (not shown). SST trends are positive and significant at the 95% level for the full TMI record (slope: 0.0144°C/decade), and are positive but not significantly different from zero for the Argo record (slope: 0.0088°C/decade). We found very weak (but significant) positive subsurface warming trends below 500 m (i.e. depths for which temperatures are no longer strongly impacted by strong seasonal forcing and have weak seasonal cycles). For instance, at 1000 m depth subsurface temperatures have increased by (slope: 0.003°C/decade) between 2004 and 2013, and the warming trend approaches surface warming values (slope: 0.0075°C/decade) between 2008 and 2013 (Figure 5d). Subsurface warming is most pronounced near the western boundary just north of 40°S and eastern boundaries in Agulhas eddy corridor.

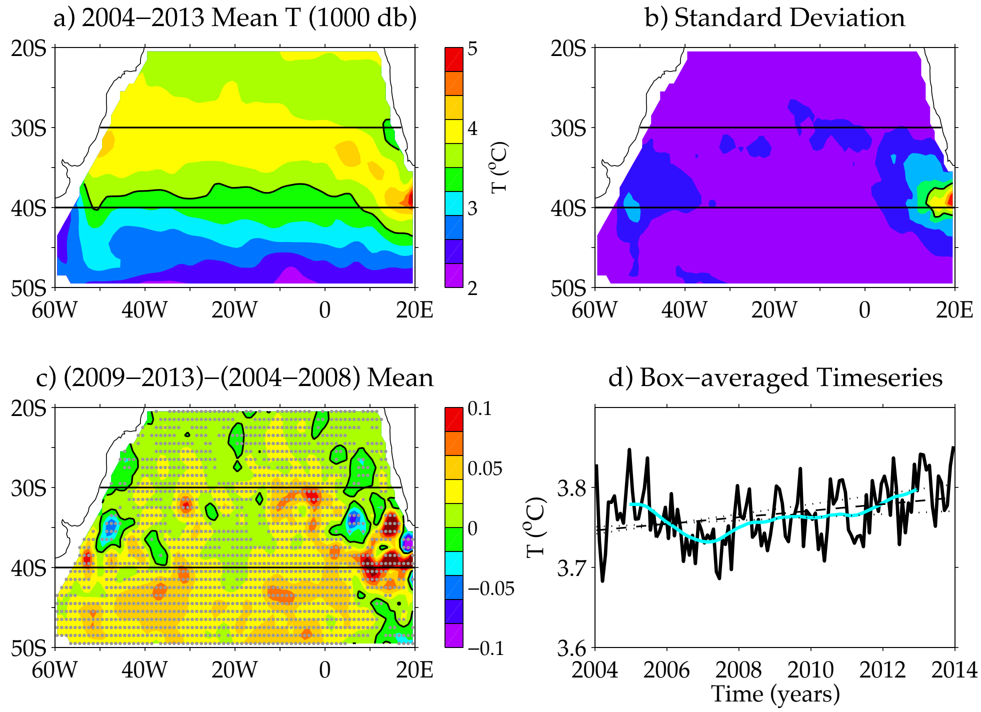

Figure 5. Same as Figure 4 but for 1000 m Argo temperatures.

The evolution of temperature and salinity inferred from the four inverted echo sounders equipped with pressure sensors (PIES) moorings deployed at 34.5°S as part of the Southwest Atlantic MOC (SAM) project (Meinen et al., 2012, 2013) has also been analyzed using daily data from March 2009 to September 2014. Site A, B, C, D are located at 51.5°W, 49.5°W, 47.5°W, and 44.5°W. Shown in Figures 6 and 7 are the temporal evolution of temperature and salinity anomalies (relative to a seasonal cycle computed from the five-year record), respectively, for the SAM moorings. Based on the SAM estimates, there are alternating one to two-year periods with positive temperature and salinity anomalies followed by periods of negative temperature and salinity anomalies. These anomalies can extend from the surface down to 800-1000 m of depth.

Temperature and salinity are derived from the PIES vertical acoustic travel times measurements using climatological (i.e. mean) hydrographic relationships. These mean T-S relationships only capture the dominant mode of variability inherent in the data. Because of this, the reconstructed temperature and salinity fields may not properly reproduce the more complex time-varying vertical structure (i.e. surface intensification) of temperature and salinity that may occur in the real ocean. We found through comparison with Argo and World Ocean Atlas (WOA) seasonal cycles that SAM-derived temperature and salinity underestimate the seasonal variability in the upper 300 m of the water column (not shown). Our next plan is to examine the SAM and Argo interannual temperature and salinity anomalies to examine the upper-ocean structure of these alternating warming/salinification vs. cooling/freshening events in the upper 1000m of the water column.

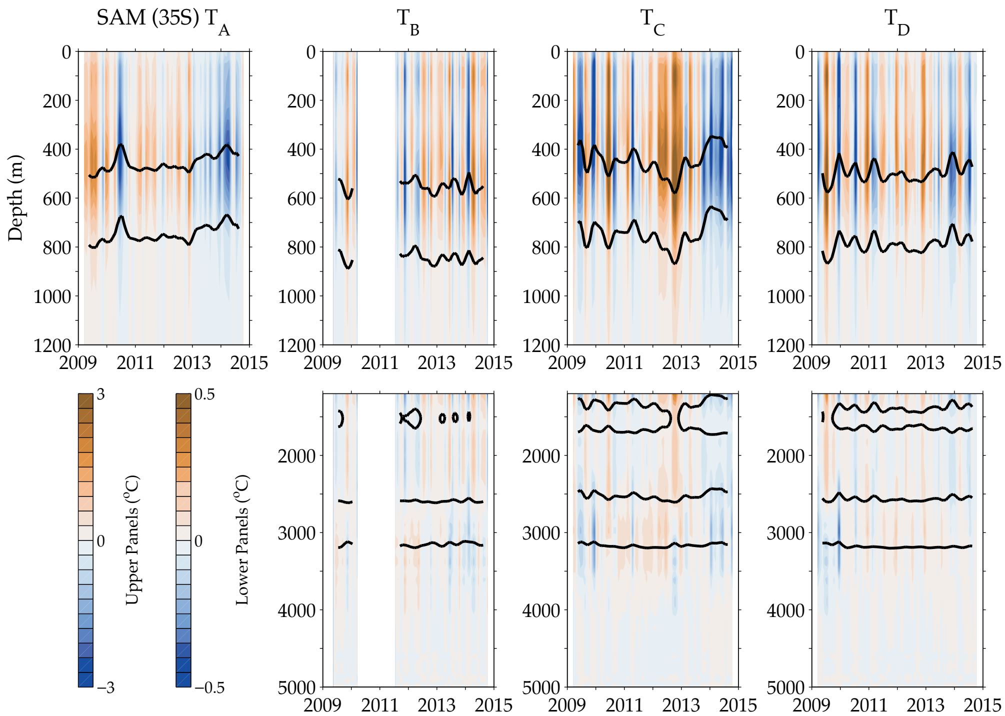

Figure 6. Color Shading: temperature anomalies (relative to a seasonal cycle computed from the five-year record) inferred from the SAM mooring measurements at sites A, B, C, and D along 34.5ºS. Note different color shading and y-axis stretching for top and bottom panels. Black contours show 6-month low-passed isotherms (5º and 10ºC in the upper panels; 2º, 3º and 5ºC in the lower panels).

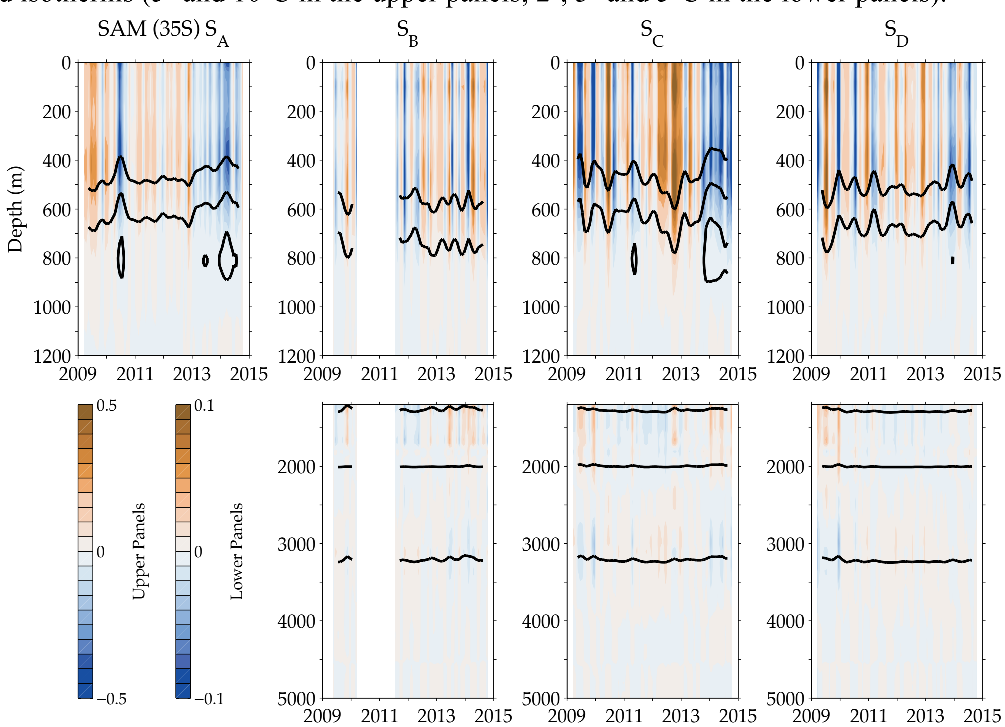

Figure 7. Same as Figure 6 except for salinity anomalies. Black contours show 6-month low-passed isohalines (33.9, 34.25, and 34.4 in the upper panels; 34.25, 34.4, and 34.8 in the lower panels).

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Annual Progress Report – Year 2

- **Project Title**: *Mediterranean and Black Seas: Analysis of Large Sea Level Anomalies*
- **PI**: Denis Volkov
- Period covered by the report: **06/01/2014 – 05/10/2015** (Year 2)
- Institution: Cooperative Institute for Marine and Atmospheric Studies, University of Miami
- **Grant Number**: NNX13AO73G

PI: Denis Volkov
Associate Scientist, Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami, Florida.
Contact address: 4600 Rickenbacker Csw, Miami, FL 33149
.

Project team: Felix Landerer (Co-I, Jet Propulsion Laboratory)

1. Introduction

The primary objectives of this research are: i) to understand what caused the unprecedented sea level rise in the Mediterranean and Black seas in 2010 and 2011 and to analyze large anomalies observed during other periods, ii) to determine the relative contribution of steric and mass effects to the sea level variability in the region on a broad spectrum of time-scales, iii) to quantify the influence of atmospheric circulation in the subtropical North Atlantic on sea level in the Mediterranean Sea, iv) to investigate the role of the total freshwater balance in forcing the changes of sea level, and v) to establish the statistical and dynamical relationship between the sea level fluctuations in the Mediterranean and Black seas.

The research objectives that were fulfilled during the period covered by this report include:

1. We have used GRACE measurements in combination with precipitation and evaporation data from an atmospheric re-analysis to derive the Danube River runoff;
2. We have performed a comprehensive analysis of sea level budget of the Black Sea;
3. We have linked the large scale atmospheric processes over the North Atlantic and Europe, terrestrial water storage over the southern Europe, and sea level in the Black Sea;
4. We have established a statistical relationship between the large scale atmospheric circulation over the North Atlantic and sea level in the Mediterranean and Black Seas;
5. We have initiated work on understanding the dynamical relationship between sea level in the eastern Mediterranean and Black Seas

The science results were published in Climate Dynamics (Volkov D.L., and F.W. Landerer, 2015: Internal and external forcing of sea level variability in the Black Sea, *Clim. Dyn*., doi:10.1007/s00382-015-2498-0) and presented at the OSTST 2014 meeting in Konstanz (Germany).

2. Narrative of the accomplishments and science results

2.1. The Danube discharge derived using GRACE data

Terrestrial water storage (*TWS*) over a particular time interval Δt (for GRACE data Δt =1 month) is the time-integral of terrestrial precipitation (*P*) and evaporation (*E*) integrated over the Black Sea drainage basin with an area A_{DB} and the river discharge (Q_R) into the Black Sea:

$$TWS = \frac{1}{A_{DB}} \int (P - E - Q_R) dt \qquad (1).$$

GRACE provides monthly mean *TWS* anomalies. Using the estimates of P and E provided by an atmospheric re-analysis product (we used ERA-Interim re-analysis product, www.ecmwf.net), Q_R can be derived as a residual of equation (1).

Due to measurement uncertainties and monthly discretization of *TWS*, the approximation of its time derivative can introduce considerable high-frequency artifacts (Landerer et al. 2010) in the month-to-month variability of river discharge based on the GRACE *TWS* and the ERA-Interim *P* and *E* data, making these estimates less reliable. Indeed, the monthly time series of the Danube discharge provided by GRDC (Global Runoff Data Centre, www.bafg.de/GRDC/) and those derived from GRACE and ERA-Interim products are not well correlated (not shown), although yearly averages are well correlated (r = 0.8; Figure 1). Additionally, the annual Danube discharge obtained from GRACE and ERA-Interim data (124 km^3 $year^{-1}$) is strongly underestimated compared to the time-mean of the GRDC data (225 km^3 $year^{-1}$). This bias possibly arises because ERA-Interim underestimates precipitation and overestimates evaporation over some parts of Europe as reported earlier (e.g. Szczypta et al. 2011). Nonetheless, the comparison in Figure 1 demonstrates the potential utility of the GRACE data for recovering the inteannual variability of river discharge into the Black Sea, but a bias correction of about 100 km^3 $year^{-1}$ is necessary when the ERA-Interim P – E is used.

Figure 1. *The yearly averages of the Danube discharge provided by GRDC and obtained using the GRACE terrestrial water storage (red curve) and the ERA-Interim terrestrial precipitation and evaporation data (black curve) over the Danube discharge area. The dots indicate data points and the dashed line is a linear interpolation to fill the 2009 gap in the GRDC data. Note that despite the bias, the combination of GRACE and ERA-Interim data captures the interannual discharge variability fairly well.*

We are currently extending the analysis of the basin discharge from the Danube to the entire Black Sea and Mediterranean drainage areas, using the budget from GRACE TWS and P-E as described in Eq. 1. Preliminary results show that for the Black Sea, the total drainage area discharge is highly correlated with that of the Danube River. This is not surprising given that the Danube is the dominating discharge contributor for the Black Sea. For the Mediterranean discharge area (which includes the entire Nile basin), the basins discharge estimated from Eq.1 yields large interannual variations, and most notably an apparent persistent decline of discharge since 2008 compared to the 2002 – 2008 period. We note that this apparent discharge change is to a large degree precipitation-driven. Given the known biases of ERA-Interim P-E over the Danube basin, it is not clear that all these signals are indeed real. This analysis is ongoing and will be completed in the current work year.

2.2. The Black Sea level budget

The variability of sea level (η) in the Black Sea can be approximated as follows:

$$\frac{\partial\eta}{\partial t} \cong \frac{\partial\eta_T}{\partial t} + \frac{1}{A_{BS}}(Q_R + Q_P - Q_E - Q_B), \quad (2)$$

where η_T is the thermosteric sea level, Q_R is river discharge, Q_P is precipitation, Q_E is evaporation, Q_B is the net volume flux through the Bosphorus Strait, and A_{BS} is the area of the Black Sea (including the Sea of Azov). Equation (2) does not include the contributions of the halosteric sea level change and groundwater supply. Using salinity fields from an ECCO2 (Estimating the Circulation and Climate of the Ocean, Phase 2) ocean data synthesis product (http://ecco2.jpl.nasa.gov/), we found that the contribution of the halosteric sea level to the total sea level variability is very small (not shown) and can be neglected at the time scales considered. The contribution of groundwater is also very likely not significant. Assuming that heat transported by rivers and through the Bosphorus is also small, the time change of the thermosteric sea level is approximately determined by the net surface heat flux, Q_{NET} (positive downward):

$$\frac{\partial\eta_T}{\partial t} \cong \frac{\alpha Q_{NET}}{\rho C_p}, \quad (3)$$

where $\alpha = 1.3 \times 10^{-4}$ K^{-1} is the thermal expansion coefficient, ρ (= 1018 kg m^{-3}) is the Black Sea water density, and C_P (= 3990 J kg^{-1} K^{-1}) is the seawater specific heat capacity.

The seasonal cycle of the sea level budget components (in cm/month) is displayed in Figure 2. The standard deviation of the seasonal cycle of the Black Sea η is 2.8 cm, which is nearly 3 times smaller than the standard deviation of the total η (7.7 cm). The seasonal maximum of the Black Sea η ($\partial\eta/\partial t$) is observed in June (April-May), while the secondary peak takes place in January (December) (Figure 2a). The seasonal maximum of η in June is mainly caused by the river discharge (blue curves) that peaks in April-May and by evaporation (red curve) that is at a minimum in April. The seasonal cycle of the river discharge is presented for both, the sum of the six major rivers over the 1952-1985 period (dashed blue curve) and the reconstructed discharge (solid blue curve), which appear to be very close. The contribution of precipitation (green curve) is smaller, but important, because it is responsible for the secondary maximum of η in January. The seasonal amplitude of the thermosteric sea level (dashed black curve) computed using (3) is about 1 cm, and the seasonal maximum occurs in August.

The integral effect of freshwater fluxes and the net surface heat flux is shown in Figure 2b (blue curve). The seasonal amplitude of the associated sea level change is two times greater than the seasonal amplitude of $\partial\eta/\partial t$. This difference must be compensated by the outflow through the Bosphorus Strait (red curve), making the reasonable assumption that the impact of halosteric sea level variability and heat fluxes through river mouths and the Bosphorus Strait are negligible. The outflow in Figure 2b is computed as a residual of the other known terms in equation (1). A caveat of this estimate is that uncertainties in the river runoff and surface freshwater and heat fluxes are also dumped to the outflow. The maximum outflow of about 28 km^3/month equivalent to 6 cm/month sea level change occurs in April-May, while in September-October the net inflow of 9.5 km^3/month balances the sea level decrease due to the negative fresh water flux when evaporation exceeds the sum of precipitation and river discharge.

The annual mean fresh water flux into the Black Sea obtained from ERA-Interim precipitation and evaporation data and river discharge from the DT dataset is about 150 km^3/year, which is balanced by nearly the same outflow. This estimate is two times smaller than the Black Sea outflow of 300 km^3/year documented by Ünlüata et al. (1990). However, seasonally biased ADCP (Acoustic Doppler Current Profiler) measurements in the Bosphorus Strait carried out from September 2008 to February 2009 revealed a mean net outflow of over 110-120 km^3/year (Jarosz et al. 2011), while the range of the variability exceeded 2000 km^3/year. Unfortunately we cannot estimate the outflow for exactly the same time interval, because river discharge data are missing in 2010. But using climatological values from September to February we estimate the outflow of about 85 km^3/year, which is below the estimate of Jarosz et al. (2011). The annual mean river discharge is 302 km^3/year, which is close to the 350 km^3/year reported by Ünlüata et al. (1990) taking into account that we used only five major rivers. On the other hand, compared to Ünlüata et al. (1990), the ERA-Interim precipitation is underestimated (~240 km^3/year vs 300 km^3/year) and evaporation is overestimated (~390 km^3/year vs 350 km^3/year). This can be the reason why the outflow is underestimated in our study.

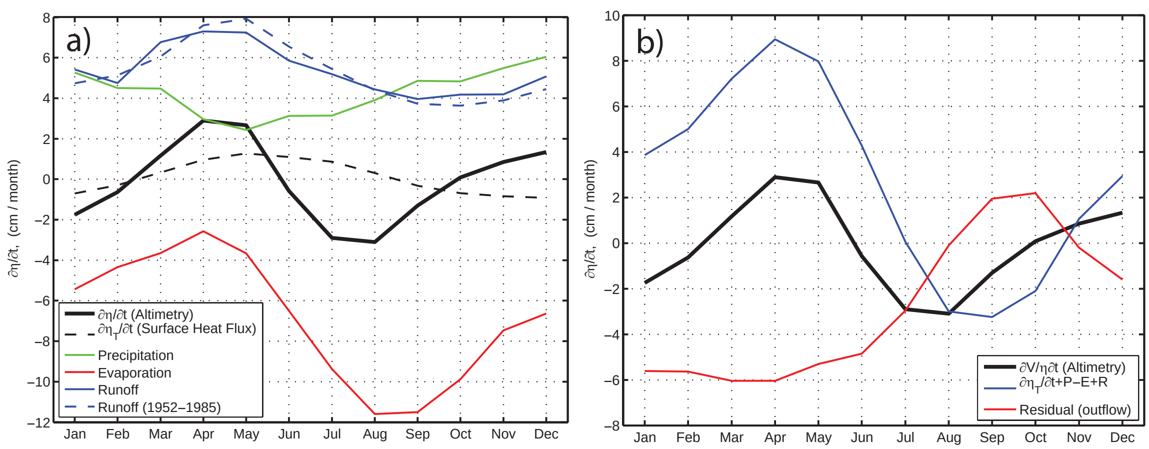

Figure 2. *The seasonal cycle (monthly mean climatology) of SLA change components in the Black Sea: (a) the total SLA change (bold black), SLA change due to surface heat flux (dashed black), SLA change due to precipitation (green), SLA change due to evaporation (red), SLA change due to river discharge (blue), SLA change due to river discharge over the 1952-1985 period when the discharge data of 5 largest rivers (Danube, Dnepr, Dnestr, Don, Kuban) are available (dashed blue); (b) the total SLA change (bold black), the integral SLA change due to surface heat flux, precipitation, evaporation and river discharge (blue), and the residual SLA change mainly due to the Bosphorus Strait outflow (red).*

The sea level record at the Tuapse tide gauge (Russia) appears to be a good proxy for the basin-averaged sea level variability in the Black Sea. From this record, we can extend the analysis back to 1979, which is the first year of the ERA-Interim product. The correlation coefficient between the concurrent satellite altimetry sea level averaged over the Black Sea and the Tuapse tide gauge record is 0.83, while the correlation coefficient between their time derivatives is 0.76 (blue and black curves in Figure 3a). When the monthly mean climatology is subtracted from both time series (Figure 3b), the correlation between them remains high: r = 0.82 for the sea level time series and r = 0.72 for their time derivatives. The sum of the thermosteric sea level variability and the freshwater components (red curves in Figure 3) is significantly correlated with the time-derivative of the Tuapse tide gauge record (black curves in Figure 3): r = 0.64 for the initial records and r = 0.43 for the nonseasonal records. However, not all the nonseasonal variability is accounted for by the sum of the thermosteric sea level change and fresh water fluxes. The difference can be due to both the variability of the outflow and errors in the data we used for the budget estimates.

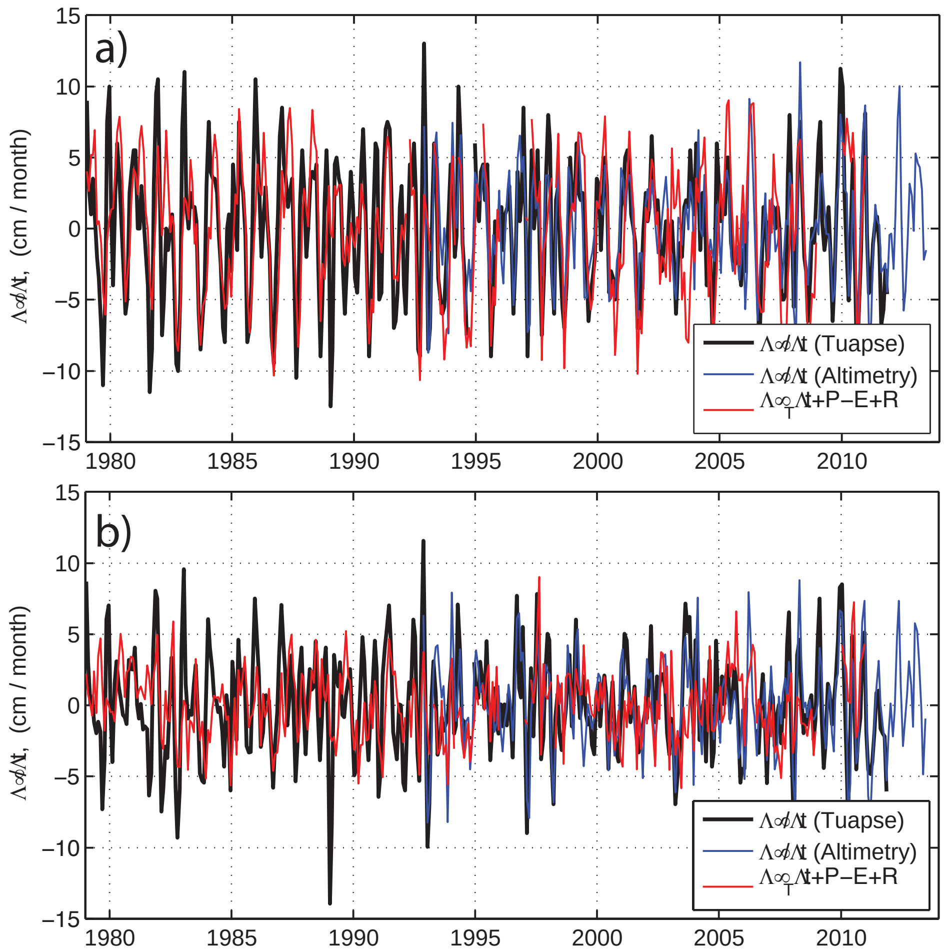

Figure 3. *The time series of the time change of SLA components (cm/month) in the Black Sea: the total SLA change inferred from the Tuapse tide gauge record (black), the total SLA change inferred from satellite altimetry (blue), the integral SLA change due to surface heat flux, precipitation, evaporation and river discharge (red). (a) Seasonal cycle is present and (b) seasonal cycle is removed.*

The contribution of the thermosteric sea level variability to the nonseasonal $\partial\eta/\partial t$ in the Black Sea is negligible (Figure 4, green curve). The largest $\partial\eta/\partial t$ contribution comes from other internal processes: precipitation and evaporation (Figure 6, red curve) together explain 20% of the nonseasonal $\partial\eta/\partial t$ variance. The contribution of the river discharge to the variability of $\partial\eta/\partial t$ is less evident, because it does not explain any $\partial\eta/\partial t$

variance. However, occasional peaks in $\partial\eta/\partial t$ coincide with peaks in the river discharge. Since no river discharge data are available at the end of 2009 and after December 2010, we cannot verify the role of river discharge in generating the observed large anomalies in February 2010, January 2011, and April 2013 independently from GRACE terrestrial water storage data. However, anomalies in Q_P–Q_E (Figure 4, red curve) do not seem to have sufficient magnitude to explain the observed sea level rise; they are also mostly negative. This implies – albeit indirectly – that river discharge and processes that are able to reduce the Black Sea outflow are more likely factors that generated the observed fluctuations.

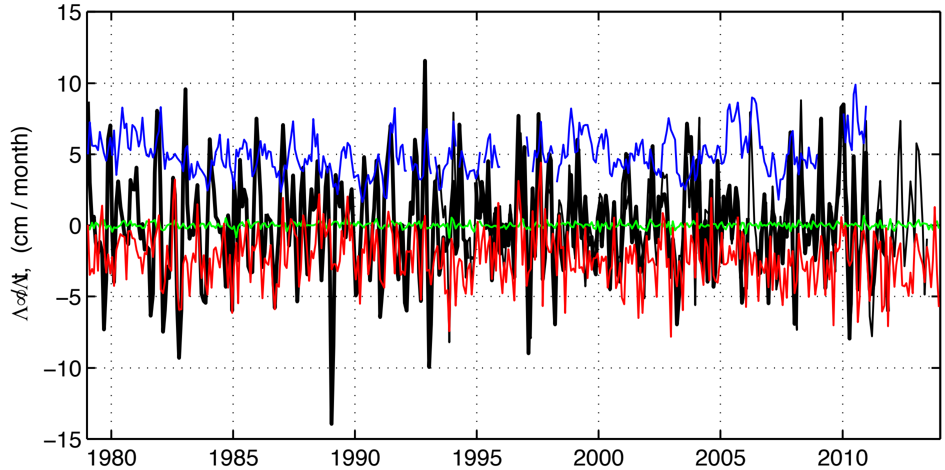

Figure 4. *The time series of the time change of the nonseasonal SLA components in the Black Sea: the total SLA change inferred from the Tuapse tide gauge record (solid black), the total SLA change inferred from satellite altimetry (thin black), the integral SLA change due to precipitation and evaporation (red), the SLA change due to river discharge (blue) and net surface heat flux (green).*

2.3. Large-scale atmospheric processes and terrestrial water storage

In the progress report for Year 1, we showed that because river discharge plays an important role in the Black Sea level budget, the nonseasonal variability of sea level anomaly (SLA) in the Black Sea is linked to water storage over the Black Sea drainage basin observed by GRACE. River discharge into the Black Sea is a residual of terrestrial water storage, precipitation, and evaporation over the Black Sea drainage basin. Hence, it depends on large-scale atmospheric processes. To identify the large-scale atmospheric processes linked to the sea level variability in the Black Sea, here performed the Coupled Empirical Orthogonal Functions (cEOF) analysis of *TWS* and sea level pressure (*SLP*) over the eastern side of the North Atlantic and Europe (Figure 5). The cEOF analysis identifies the temporally co-varying spatial patterns that explain most of the squared covariance between the field pairs (Bretherton et al. 1992). The temporal evolution of these patterns is demonstrated by two coupled Principal Component (cPC) time series for each field. We considered only the first cEOF modes (cEOF-1) that explain most of the squared covariance.

The cEOF-1 mode of *SLP* and *TWS* fields explains 80% of the squared covariance (Figure 5). It exhibits a di-pole SLP pattern with one center located in the eastern North

Atlantic near the Azores and another center in the Nordic Seas to the north of Iceland (Figure 5a). This pattern is correlated with an out-of-phase water storage variability highlighting a contrast between southern and northern Europe (Figure 5b). The correlation coefficient between the cPC-1 of *SLP* and *TWS* is 0.54. The low *SLP* anomalies over the eastern North Atlantic are associated with an increase of *TWS*, while the high *SLP* anomalies are related to a decrease of *TWS* in southern Europe, in particular over the Balkans.

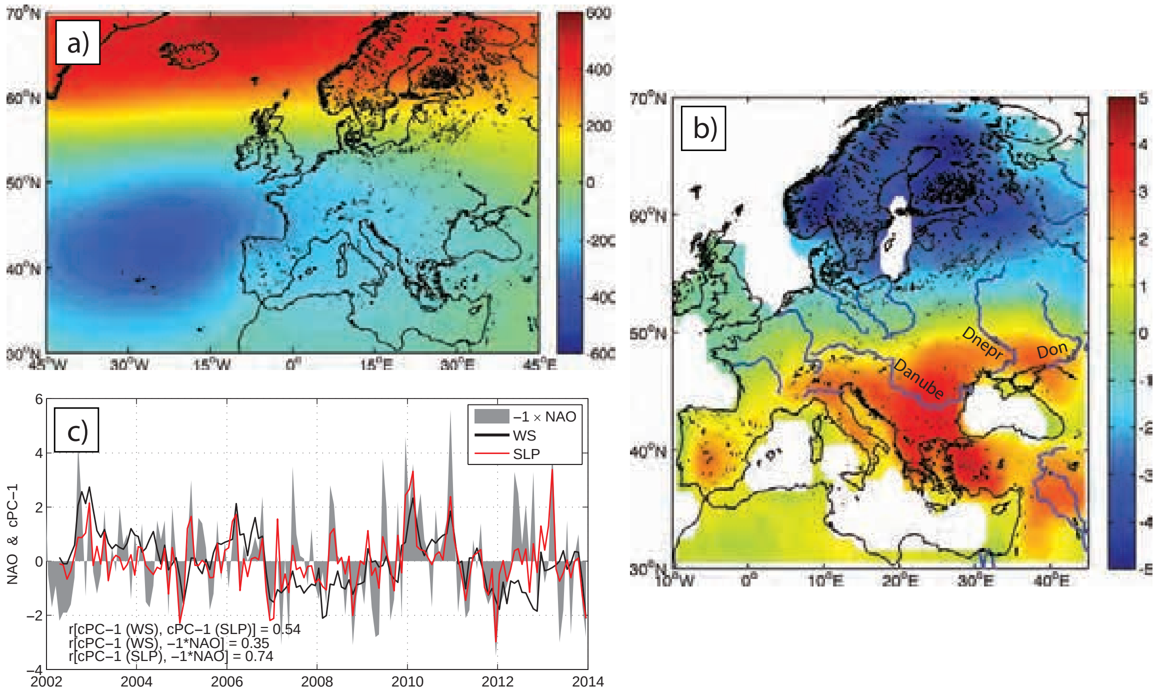

Figure 5. *The cEOF-1 of ERA-Interim SLP and GRACE TWS, shown as regression maps of (a) SLP and (b) S projected on (c) cPC-1 of SLP (red curve) and cPC-1 of TWS (black curve), respectively. The units are in Pa per standard deviation for SLP and cm per standard deviation for TWS. The NAO index multiplied by –1 is shown in (c) by the gray area.*

The cEOF-1 spatial patterns of *SLP* and *TWS* are in accordance with the North Atlantic Oscillation (NAO), which is a measure of the *SLP* difference between the Azores maximum and Icelandic minimum (Hurrell 1995). Stanev and Peneva (2002) reported a negative correlation between the NAO index and river discharge into the Black Sea. The correlation coefficient between the cPC-1 of *SLP* (red curve in Figure 5c) and the monthly NAO index (grey area in Figure 5c) is – 0.74, while the correlation between the cPC-1 of *TWS* and the monthly NAO index is much lower (r = –0.35), but still significant. During times of a high/low NAO index, the axis of the maximum moisture transport shifts northward/southward across the Atlantic and extends over northern/southern Europe and Scandinavia/Mediterranean Sea. The divergence of moisture transport determines the excess of precipitation over evaporation. As a result, wetter/drier conditions occur over southern Europe and the Mediterranean during the low/high NAO index, while drier/wetter conditions take place over northern Europe. The obtained result suggests that the observed variability of *TWS* over the Black Sea drainage basin is directly linked to large-scale atmospheric processes, modulated by the NAO. Therefore, here we note that the observed maxima of *TWS* in winters 2009/2010 and 2010/2011 are related to strongly negative NAO indices (Figure 5c).

2.4. Large-scale atmospheric circulation and sea level

Displayed in Figure 6 is the result of the coupling of *SLA* with *SLP* and wind speed. The cEOF-1 mode explains 92% of the squared covariance between the *SLA* and *SLP* fields. The regression map of SSH exhibits a basin-scale oscillation pattern that extends over the entire Mediterranean and Black Seas (Figure 6a). The *SLA* pattern in the Mediterranean Sea is similar to the one reported earlier by Landerer and Volkov (2013). By including the Black Sea in the cEOF analysis, we observe that the Black Sea is the region where the maximum fluctuations of *SLA* in relation with the large-scale *SLP* fluctuations take place. If the cEOF analysis is conducted for $\partial\eta/\partial t$ and *SLP* (not shown), then the Black Sea stands out as the only region where $\partial\eta/\partial t$ is statistically related to *SLP* changes. This is expected due to the observed time lag between the basin-averaged sea levels in the Black and Aegean Seas (reported after the Year 1). With regard to the Mediterranean, the barotropic response of the Mediterranean sea level to wind forcing near the Strait of Gibraltar (Landerer and Volkov 2013) is so fast that it is shown to be simultaneous in monthly data.

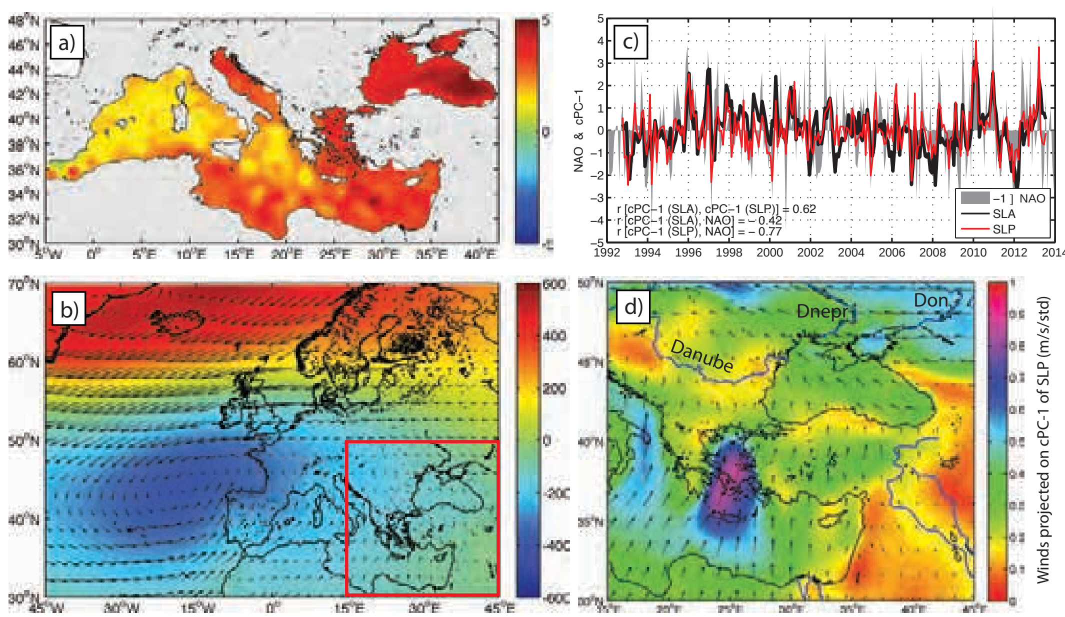

Figure 6. *The cEOF-1 of satellite altimetry SLA and ERA-Interim SLP, shown as regression maps of (a) SLA and (b) SLP projected on (c) cPC-1 of SLA (black curve) and cPC-1 of SLP (red curve), respectively. The units are in cm per standard deviation for SLA and Pa per standard deviation for SLP. The NAO index multiplied by –1 is shown in (c) by the gray area. Regression map of the ERA-Interim winds projected on cPC-1 of SLP fields is shown by wind vectors in (b) and its zoom-in on the eastern Mediterranean and Black Sea along with the absolute wind strength (color) are shown in (d). The units of wind vectors are in m/s per standard deviation.*

The regression map of *SLP* demonstrates a di-pole oscillating pattern (Figure 6b), similar to cEOF-1 mode of *SLP* coupled to the terrestrial water storage (Figure 5a). The correlation coefficient between the cPC-1 time series of *SLA* and *SLP* is 0.62 (Figure 6c). Large synoptic fluctuations of cPC-1 of *SLP* in winters 2009/2010, 2010/2011, and 2012/2013 are correlated with corresponding fluctuations of cPC-1 of *SLA*. The correlation coefficients between the cPC-1 of *SLP/SLA* and the monthly NAO index is –0.77 / –0.42, which indicates that sea level in both the Mediterranean and Black Seas is linked to the NAO. The influence of the NAO on the Mediterranean sea level over longer time scales has been related to the atmospheric pressure loading and also to the local changes in precipitation and evaporation (Tsimplis and Josey 2001). The NAO has also been found to indirectly affect the synoptic variability of the Mediterranean sea level (Landerer and Volkov 2013). Our results here demonstrate that the NAO impact is also relevant for the synoptic variability of sea level in the Black Sea.

As discussed above, the variability of *TWS* over the Black Sea drainage basin – and thus also river discharge – is one of the important sources for sea level anomalies in the Black Sea. Another mechanism can be linked to wind forcing that can impact the Black Sea outflow. Displayed in Figure 6b is the regression map of ERA-Interim winds projected on cPC-1 of *SLP* (Figure 6c, red curve); Figure 6d shows a zoom-in for the eastern Mediterranean and the Black Sea region. The displayed wind pattern is in accordance with the low NAO index and features weak westerly winds over the North Atlantic Ocean. During the times of low/high NAO, the northeastward/southwestward wind anomalies occur near the Strait of Gibraltar. These wind anomalies contribute to the along-strait wind that leads to barotropic fluctuations of the Mediterranean sea level (Landerer and Volkov 2013; Fukumori et al. 2007). At the same time, the NAO also determines the strongest meridional wind anomalies over the eastern Mediterranean and along the Aegean Sea (Figure 6d): the low/high NAO is associated with a strong northward/southward wind over the Aegean Sea and an increase/decrease of sea level in the Black Sea. Strong winds are able to significantly reduce the Black Sea outflow or even reverse the net volume flux (Jarosz et al. 2011). Thus, our analysis suggests that the NAO-modulated wind over the Aegean Sea may be another factor that influences the variability of sea level in the Black Sea at both the synoptic and interannual time scales.

2.5. Dynamical relationship between the Mediterranean and Black Seas elevations (in progress)

Along with establishing the statistical relationships, presented in the previous sections, we have started to investigate how sea level changes over the eastern Mediterranean, in particular over the Aegean Sea, affect the sea level variability in the Black Sea. It has been perceived that the Black Sea level variability is a function of the basin's freshwater budget and, therefore, a possible response of the Black Sea elevation to the sea level variability in the Mediterranean basin has not been considered. During the course of our study, using satellite altimetry data we have shown that the nonseasonal records of sea level in the Aegean and Black Seas are significantly correlated (Volkov and Landerer, 2015; also see the progress report for Year 1). It appears that the maximum cross-correlation is observed when the Black Sea level lags behind the Aegean Sea level by about 20 days. Our initial proposal was to use dedicated sensitivity experiments to explain this time lag. However, similar response of one basin to changes in the other basin connected to the first basin by a strait has been investigated in other regions using analytical model (e.g. Garrett, 1983, Candela et al., 1989; Johns and Sofianos, 2012). Therefore, we decided to first explore the capability of an analytical model to explain the observed time lag between the Aegean and Black Seas. This work is in progress and the results will be reported after Year 3.

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Volkov D.L., and F.W. Landerer, 2015: Internal and external forcing of sea level variability in the Black Sea, *Clim. Dyn*., doi:10.1007/s00382-015-2498-0

Title of Grant / Cooperative Agreement:	Investigating the variability of sea level in the sub-A
Type of Report:	Summary of Research
Name of Principal Investigator:	Denis Volkov
Period Covered by Report:	01/24/2011 - 06/30/2014
Name and Address of recipient's institution:	University of Miami, Rickenbacker Csw, Miami FL, 3
NASA Grant / Cooperative Agreement Number:	NNX13AM36G

Reference 14 CFR § 1260.28 Patent Rights *(abbreviated below)*
The Recipient shall include a list of any Subject Inventions required to be disclosed during the preceding year in the performance report, technical report, or renewal proposal. A complete list (or a negative statement) for the entire award period shall be included in the summary of research.

Subject inventions include any new process, machine, manufacture, or composition of matter, including software, and improvements to, or new applications of, existing processes, machines, manufactures, and compositions of matter, including software.

Have any Subject Inventions / New Technology Items resulted from work performed under this Grant / Cooperative Agreement?	No	Yes
If yes a complete listing should be provided here: Details can be provided in the body of the Summary of Research report.		

Reference 14 CFR § 1260.27 Equipment and Other Property (abbreviated below)
A Final Inventory Report of Federally Owned Property, including equipment where title was taken by the Government, will be submitted by the Recipient no later than 60 days after the expiration date of the grant. Negative responses for Final Inventory Reports are required.

Is there any Federally Owned Property, either Government Furnished or Grantee Acquired, in the custody of the Recipient?	No	Yes
If yes please attach a complete listing including information as set forth at § 1260.134(f)(1).		

Attach the Summary of Research text behind this cover sheet.

Reference 14 CFR § 1260.22 Technical publications and reports (December 2003)
Reports shall be in the English language, informal in nature, and ordinarily not exceed three pages (not counting bibliographies, abstracts, and lists of other media).

A Summary of Research (or Educational Activity Report in the case of Education Grants) is due within 90 days after the expiration date of the grant, regardless of whether or not support is continued under another grant. This report shall be a comprehensive summary of significant accomplishments during the duration of the grant.

Summary of Research

- **Project Title**: *Investigating the variability of sea level in the sub-Arctic and Arctic seas*
- **PI**: Denis Volkov
- Period covered by the report: 01/24/2011 – 06/30/2014
- Institution: JIFRESSE, University of California Los Angeles, Box 957228, Los Angeles, California 90095-7228.
- **Grant Number**: NNX13AM36G

PI: Denis Volkov, Associate Scientist

During the first 2 years of performance was at Joint Institute for Regional Earth System Science and Engineering, University of California Los Angeles.

Now at Cooperative Institute for Marine and Atmospheric Studies, University of Miami, 4600 Rickenbacker Causeway, Miami FL 33149.

Project team: Felix Landerer (Co-I, Jet Propulsion Laboratory), Isabelle Pujol (Collaborator, C.L.S. Space Oceanography Division, Toulouse, France).

1. Overview

This is the summary of research for all years of performance. In the fall 2013 we submitted a summary of research after the project was closed at the University of California Los Angeles and transferred to the University of Miami, where it runs until 09/09/2014. That summary covered the period 01/24/2011 – 01/24/2013. The present summary, therefore, contains the previous summary plus a description of what was done over the 01/24/2013 – 06/27/2014 period.

The primary objectives of this project are i) to determine the recent (from 1993 to present) dynamics of sea level in the Arctic and sub-Arctic seas, ii) to estimate the contribution of steric and ocean mass effects to the observed changes of sea level, and iii) to understand the dynamical and thermodynamics factors responsible for the observed variability of sea level. The project uses space-borne observations of sea surface height (SSH) and the Earth's gravity field (GRACE), available tide gauge records, in situ measurements (drifters and hydrographic surveys), atmospheric re-analyses, and an ECCO2 (Estimating the Circulation and Climate of the Ocean, Phase 2) ocean data synthesis product.

The research activities that were carried out during the period covered by this summary are

- The validation of available satellite altimetry data in the region using available tide gauge and surface drifter data;
- The optimization of ocean gravity measurements by GRACE;
- Determination of steric and mass changes;
- Analysis of sea level time series;
- Presentation and publication of results.

During the course of the project we have exceeded our initial expectations and made progress in each activity mentioned above. Our work resulted in 5 publications in referred journals:

i. The regional validation of the available altimeter products that was carried out during the first year of the project in collaboration with Dr. I. Pujol from C.L.S. Space Oceanography Division, demonstrated that the available satellite altimetry is already of adequate quality to study the regional variability of sea level on the time scales from mesoscale eddy processes to interannual variability. A manuscript dedicated to the validation activities performed during the first year was published this year in Journal of Geophysical Research - Oceans [*Volkov and Pujol*, 2012].

ii. During the cause of our study we discovered a cyclonic propagation of sea surface height anomalies in the Lofoten Basin of the Norwegian Sea and we explored the nature of the observed phenomenon. This research was carried out in collaboration with scientists from St. Petersburg State University (Russia). The results were published in Geophysical Research Letters [*Volkov et al.,* 2013a].

iii. In a manuscript, published in Continental Shelf Research [*Volkov et al*., 2013b], we studied the role of the net surface heat flux, wind forcing, and oceanic advection on the regional sea level variability in the Barents Sea. We assessed the contributions of interannual, annual and higher frequency sea level variability, discussed the role of barotropic and baroclinic changes, and identified the mechanisms that drive the variability.

iv. In a manuscript, published in Journal of Geosphysical Reseach – Oceans [*Volkov and Landerer*, 2013), we studied the nonseasonal variability of the Arctic Ocean mass by combing satellite altimetry, satellite gravimetry (GRACE), and ocean data systhesis (ECCO2) data. Particular attention was paid at estimating the relative contributions of wind forcing and fresh water fluxes and identification of the sources that contributed to the record-high Arctic Ocean mass anomaly in February 2011.

v. In a follow-on study [*Volkov*, 2014], strong correlation between the nonseasonal GRACE and satellite altimetry data was found in the Nordic and Barents seas, which suggested a possibility of using the longer altimetry records in these areas as a proxy for the nonseasonal sea level variability over the entire Arctic. This study identified the dominant pattern of the nonseasonal atmospheric pressure variability that drives strong zonal wind anomalies over the northeastern North Atlantic associated with the nonseasonal sea level anomalies in the Nordic seas. Our results show that wind-driven northward Ekman transport anomalies in the northeastern North Atlantic may induce coherent changes of sea level across the entire Arctic Ocean.

The results of the project were presented at Ocean Surface Topography Science Team 2011 and 2013 meetings, at 2011 and 2012 AGU Fall meetings, Ocean Sciences and EGU 2012 meetings, and at 20 Years of Progress in Radar Altimetry Symposium in 2012.

2. Narrative of the accomplishments and science results

2.1 Validation of satellite altimetry data (D. Volkov and I. Pujol)

The use of altimetry data in the sub-polar and polar regions has been limited due to temporally sparse altimetry measurements, and the inhibiting effect of sea ice cover on sea level retrieval. Up to this date, all validation studies have been carried out only for the low and mid-latitudes. Therefore, the quality of the high latitude altimetry records remains uncertain. Recent advances in the processing of geophysical data records, obtained from altimetry satellites, have made available more SSH data at high latitudes. In the first year of the project we carried out the first validation of the state-of-the-art gridded satellite altimetry product[1] in the Nordic (Greenland, Icelandic, and Norwegian), Barents, and Kara seas. We assessed the quality of the product by comparing altimetry measurements with those collected by tide gauges and surface drifters. The location of tide gauges used in this study is shown in Figure 1 and drifter trajectories are shown in Figure 2.

[1] The altimetry product was produced by SSALTO/DUACS and distributed by AVISO with support from CNES.

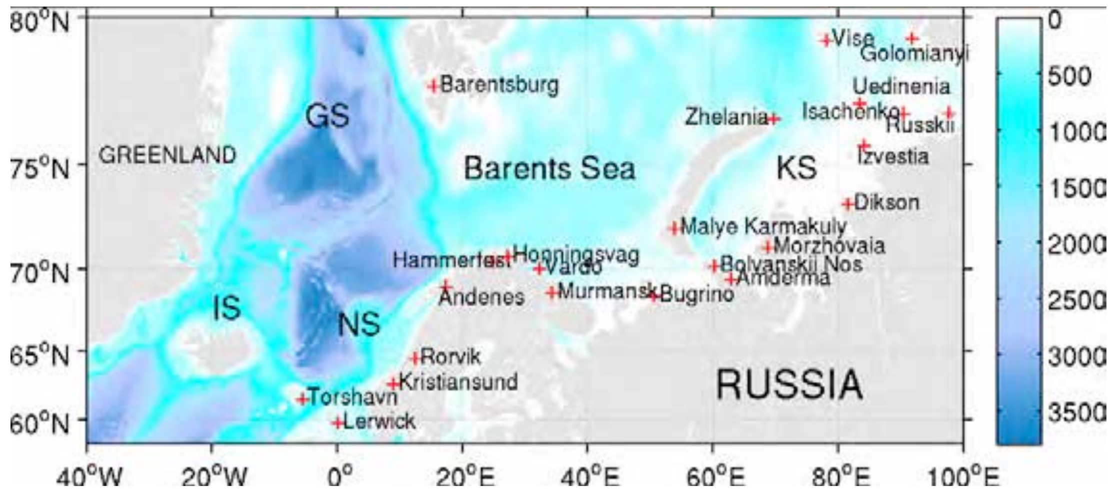

Figure 1. *Map of the study region with bottom topography and the locations of tide gauges.*

The comparison with tide gauge records corrected for the inverted barometer (IB) and glacial isostatic adjustment (GIA) demonstrated that the altimetry data are robust in most coastal areas of the study region (Table 1). The IB correction has a prominent effect on the variability of the tide gauge time series bringing them significantly closer to the corresponding SLA time series. The impact of the GIA correction on the RMS difference between the altimetry and tide gauge records is found to be small.

In the Norwegian and Barents seas the RMS difference between the altimetry and tide gauge measurements is generally about 3 cm. This estimate is similar or lower than those reported in the earlier studies focused on lower latitudes [e.g. *Pascual et al.*, 2009]. The discrepancy between the altimetry and tide gauge records increases in the Barents and Kara seas (going eastward). At the majority of tide gauges located in these regions, the RMS difference is about 5-7 cm. Because satellite altimetry is more accurate away from the coast, the best match in the Kara Sea is usually observed at the tide gauges located on small islands. We conclude that the altimetry data in these shallow regions of the Barents and Kara seas could be contaminated by the aliasing from the residual tidal and high frequency signals. The quality of some tide gauge records is found to be suspect. Therefore, one needs to be cautious when interpreting the tide gauge time series in the region. The seasonal cycle is the major signal in the monthly altimetry and tide gauge records and can be used as a diagnostic of altimetry data. We compared the amplitudes and phases of the seasonal cycle of SSH estimated from the altimetry and tide gauge data. The amplitudes and phases are found similar at most locations (Table 2). The annual phases agree to within 1 month or better. Analyzing the seasonal cycle in the altimetry and tide gauge records at lower latitudes, *Vinogradov et al.* [2010] reported the same difference. Along the Norwegian coast the annual phases are identical.

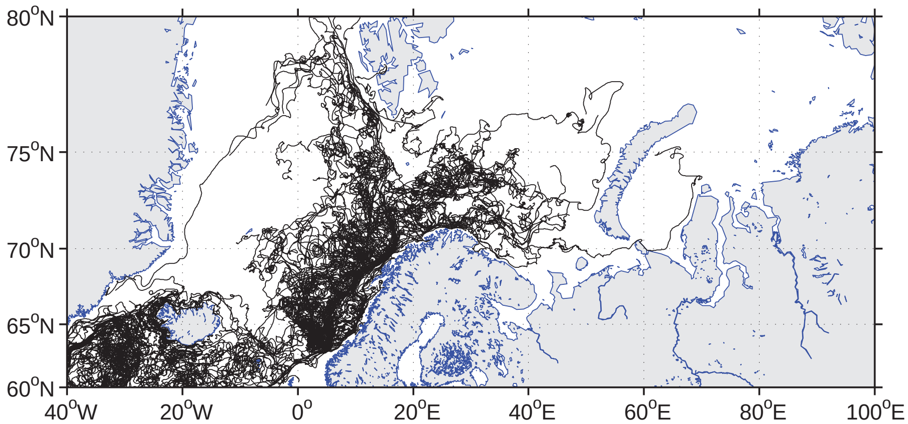

Figure 2. *The trajectories of surface drifters present in the region from January 1993 to December 2010.*

Table 1. *Comparison between the monthly tide gauge records and altimeter MSLA interpolated to the location of tide gauges in terms of standard deviations and root-mean-square (RMS) differences. The comparison is conducted only for the tide gauges that have overlapping records with altimetry. The IB correction for the tide gauge data was calculated using the ERA-Interim SLP. The time mean sea level, computed over the overlapping records, was subtracted from both the tide gauge and altimeter data. Abbreviations: ALT – altimeter data, TG – raw tide gauge records, (TG-IB) – tide gauge records corrected for IB, (TG-IB-GIA) – tide gauge records corrected for IB and GIA.*

Tide Gauge Station	*Number of overlapping records*	*Standard deviation of SLA*				*RMS of SLA differences*		
		ALT	*TG*	*TG-IB*	*TG-IB-GIA*	*ALT-TG*	*ALT-(TG-IB)*	*ALT-(TG-IB-GIA)*
Torshavn	144	5.5	8.1	6.0	5.8	6.9	2.3	2.2
Lerwick	157	6.2	9.6	6.9	6.8	6.2	1.9	1.9
Kristiansund	204	5.9	12.5	8.9	8.9	8.8	3.9	3.9
Rorvik	205	7.0	12.5	8.5	8.5	8.1	3.3	3.1
Andenes	200	7.0	12.4	7.5	7.4	8.0	2.9	3.1
Hammerfest	198	6.1	12.4	7.7	7.7	8.2	3.2	3.2
Honningsvag	200	6.5	11.9	7.0	7.0	7.4	2.9	2.8
Barentsburg	168	4.3	11.8	9.5	9.6	11.3	8.0	8.0
Barentsburg[1]	91	4.8	8.7	6.6	6.5	7.3	4.0	4.0
Vardo	187	6.8	11.8	7.5	7.4	7.6	3.1	3.1
Murmansk	186	6.2	12.0	9.2	9.2	9.1	6.6	6.6
Zhelania	17	4.6	13.6	11.8	11.8	11.8	10.9	10.8
Bolvanskii Nos	12	7.4	15.0	8.8	8.8	6.7	4.7	4.7
Amderma	142	8.0	14.2	11.7	11.8	9.2	7.4	7.5
Amderma[2]	142	8.0	13.0	10.1	10.1	8.0	5.8	5.8
Morzhovaia	6	10.4	21.8	22.7	22.7	6.4	6.0	6.0
Dikson	16	11.6	16.0	13.8	13.8	11.1	10.7	10.7
Izvestia CIK	85	8.1	12.8	10.1	10.1	6.8	5.3	5.3
Isachenko	5	7.1	14.3	10.8	10.8	4.4	4.6	4.6
Uedinenia	8	6.4	16.0	12.6	12.5	8.8	6.3	6.3
Vise	81	4.3	12.7	10.6	10.6	9.1	6.8	6.9
Golomianyi	60	4.2	9.7	6.3	6.3	7.7	6.2	6.3

[1]*Only data from 2002 to 2009 inclusive are considered.*
[2]*The 1992-2010 linear trend has been removed from the tide gauge data.*

Table 3. *Comparison of amplitudes (cm) and phases (months of the annual maxima) of the seasonal cycle estimated from the altimetry and tide gauge data.*

Tide Gauge Station	Altimetry		Tide Gauge	
	A	*φ*	*A*	*φ*
Torshavn	6	Sep	6	Sep
Lerwick	7	Nov	8	Nov
Kristiansund	7	Nov	10	Nov
Rorvik	8	Nov	9	Nov
Andenes	8	Nov	8	Nov
Hammerfest	7	Nov	8	Nov
Honningsvag	7	Nov	8	Nov
Barentsburg	4	Sep	6	Oct
Vardo	7	Nov	8	Nov
Murmansk	7	Nov	7	Oct
Bugrino[1]	8	Dec	6	Nov
Malye Karmakuly[1]	6	Nov	4	Oct
Zhelania	4	Nov	5	Dec
Bolvanskii Nos	7	Dec	11	Dec
Amderma	10	Nov	11	Oct
Morzhovaya[1]	11	Nov	9	Oct
Dikson[1]	7	Oct	4	Sep
Izvestia CIK	9	Oct	9	Nov
Isachenko[1]	6	Nov	5	Nov
Uedinenia[1]	7	Nov	6	Nov
Russkii[1]	5	Nov	3	Nov
Vise	4	Oct	6	Oct
Golomianyi	2	Nov	3	Nov

[1]The amplitude and phase of the seasonal cycle in tide gauge data are computed using the time interval shown in Table 1.

One of the major climate-related concerns for the society is the rise of sea level. Comparisons of linear trends derived from two independent observational systems, i.e. tide gauges and altimetry, and may shed some light on the quality of observations. The comparison of linear trends revealed substantial differences at most locations that can be regarded as a measure of uncertainty. A comparison of trends obtained from tide gauge records and SSH anomalies interpolated to the locations of tide gauges is presented in Table 3. In the Kara Sea, the linear trends in the tide gauge data were estimated using both the entire records from January 1993 and the July through September averages. Only the tide gauges with relatively long records in 1993-2009 (at least 15 years) are considered. Although the trends agree in sign, the difference between them at most locations is substantial. The best agreement is observed at Kristiansund, Hammerfest, and Honningsvag tide gauges in the Norwegian Sea, where the difference between trends does not exceed 1 mm/year. The worst agreement is observed at Barentsburg and Amderma. Overall, we conclude that the sea level rise by 3-4 mm/year along the Norwegian coast appears to be robust with an uncertainty of about 1-2 mm/year. On the other hand, the present rates of sea level change in the northern part of the Greenland Sea and in the coastal areas of the Barents and Kara seas remain largely uncertain.

Table 3. *Comparison of linear trends (mm/year) estimated from the altimetry and tide gauge data. JAS means July through September average.*

Tide Gauge Station	*Time Interval Used*	*Trend in Altimetry Data*	*Trend in Tide Gauge Data*
Torshavn	Jan 1993 - Dec 2007	3.8	6.5
Kristiansund	Jan 1993 - Dec 2009	3.5	3.5
Rorvik	Jan 1993 - Dec 2009	4.4	1.8
Andenes	Jan 1993 - Dec 2009	4.3	2.3
Hammerfest	Jan 1993 - Dec 2009	4.0	3.2
Honningsvag	Jan 1993 - Dec 2009	4.0	2.9
Barentsburg	Jan 1993 - Dec 2009	1.8	4.8
Barentsburg	Jan 2002 - Dec 2009	-0.7	-4.1
Vardo	Jan 1993 - Dec 2009	4.1	2.5
Murmansk	Jan 1993 - Dec 2009	3.8	5.2
Amderma	Jan 1993 - Dec 2009	-	12.8
Amderma[1]	JAS 1993 - JAS 2009	3.3	13.9
Izvestia TSIK	Jan 1993 - Dec 2009	-	3.1
Izvestia TSIK[1]	JAS 1993 - JAS 2008	1.7	4.2
Vise	Jan 1993 - Dec 2008	-	0
Vise[1]	JAS 1996 - JAS 2007	0	2.2
Golomianyi	Jan 1993 - Dec 2008	-	1.6
Golomianyi[1]	JAS 1993 - JAS 2008	1.6	5.7

[1]The linear trend is computed using July through September averages.

The comparison with surface drifter data has provided support for the realistic representation of surface circulation by satellite altimetry in the region. The general patterns of circulation observed by altimeters and drifters are similar. Displayed in Figure 3 are the drifter and altimetry geostrophic velocity observations averaged over all measurements falling into 1°×1° bins and the difference between them. There is a good agreement in spatial patterns of the velocities (Figure 3, top and middle plots). One can observe the Norwegian Current that splits into the North Cape Current that enters the Barents Sea and the West Spitsbergen Current that heads towards the Fram Strait following the bottom topography. The East Greenland Current is also resolved by both the altimetry and the drifter observations. In some places altimetry appears to somewhat underestimate the velocities (Figure 3, lower plots). In most energetic regions the short-term variability is adequately resolved by the altimetry measurements. However, altimetry appears to somewhat underestimate the surface velocities. This is probably because the drifter data are not as much filtered as the altimetry data.

The RMS differences between the drifter (corrected for Ekman currents) and altimetry velocities are presented in Figure 4. Depending on local ocean dynamics the values in most areas range between 7 and 15 cm/s. In the areas of low variability the RMS differences usually do not exceed 7 cm/s. In energetic regions, such as the Lofoten Basin in the Norwegian Sea and the East Greenland Current, the RMS differences may reach 20 cm/s. These estimates are comparable to those estimated by *Pascual et al.* [2006 and 2009] at lower latitudes. We demonstrated that drifter trajectories are in a good agreement with altimetric SSH and its mesoscale variability. The time series of the *U* and *V* components (Figure 5) demonstrate a rather good agreement between the altimetry data and the drifters. Even the short-term variability is adequately resolved by the altimetry measurements. However, the drifter data manifest stronger variability, probably because they are not as much filtered as the altimetry measurements.

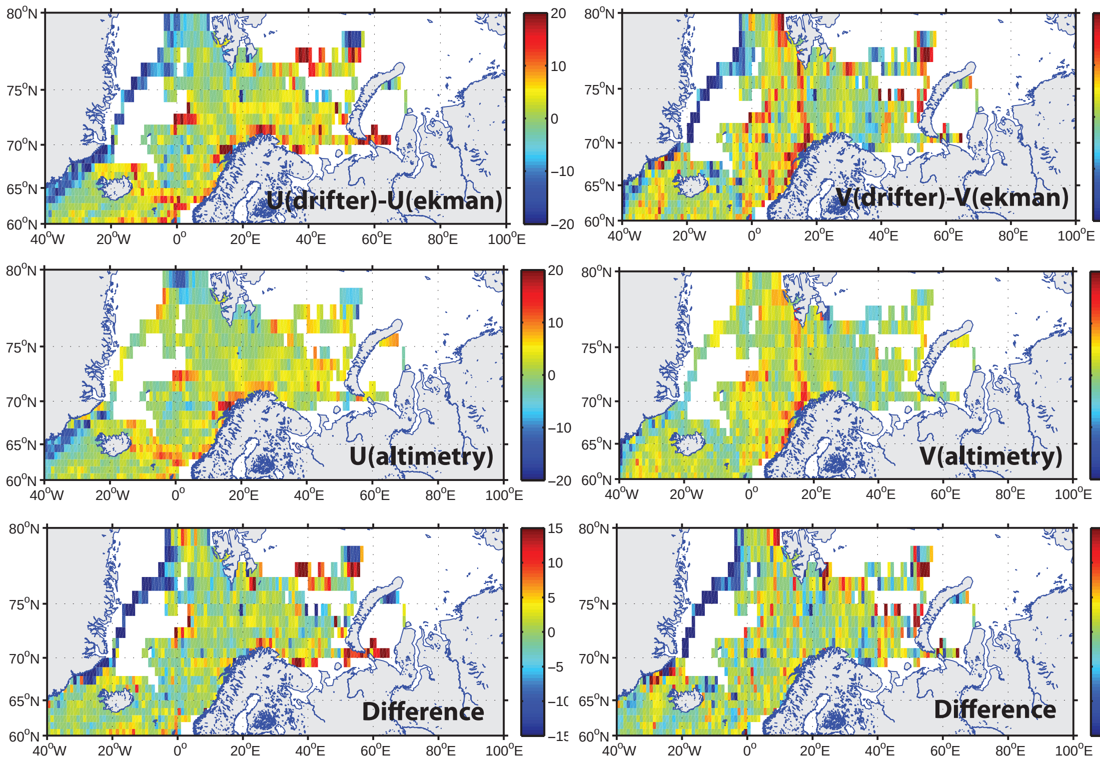

Figure 3. *The time mean U and V components of the drifter (top) and altimetry (middle) velocities averaged over 1°×1° bins, and the difference between them (bottom). The drifter velocities were corrected for Ekman currents. The altimetry data were interpolated at the trajectories of drifters.*

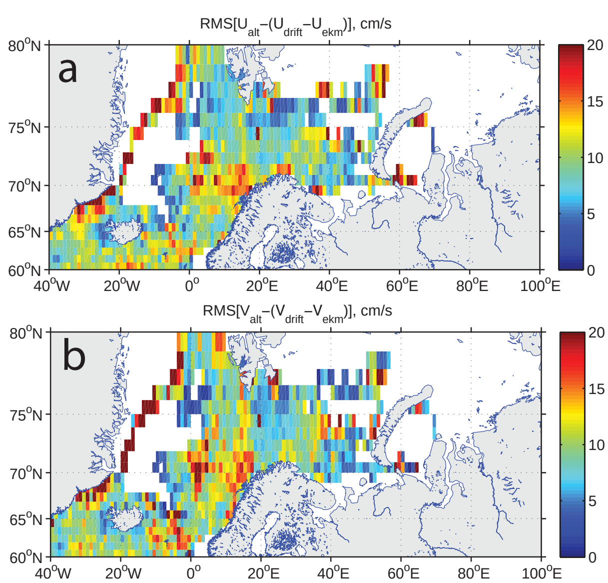

Figure 4.
The RMS of the differences (cm/s) between the altimetry and drifter U (a) and V (b) velocity components computed over 1°×1° bins. The altimetry data were interpolated at the trajectories of drifters. The drifter velocities were corrected for Ekman currents.

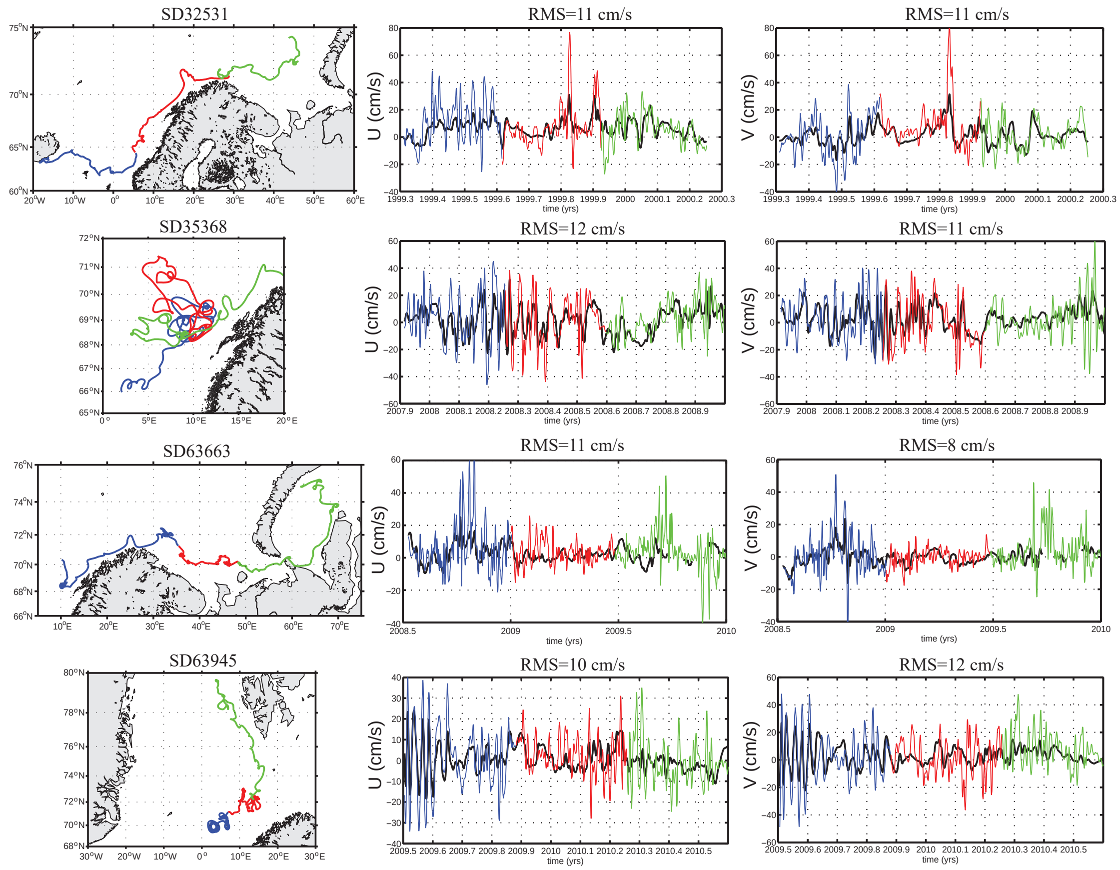

Figure 5. *The along-trajectory drifter (color curves) and altimetry (black curves) U and V velocities for 4 drifters. The color in the drifter trajectories and velocities is used to highlight different time intervals. The drifter velocities were corrected for Ekman currents. The RMS of the difference between the altimetry and drifter velocity components is shown.*

2.2. Optimization of ocean gravity measurements from GRACE (F. Landerer)

In 2012, the GRACE project reprocessed the entire GRACE time-variable data set and released the so-called 'RL05' data. Updates in the processing scheme included improvements in the Level-1 data as well as the GRACE satellite's orbits. In addition, the ocean de-aliasing model (OMCT) was updated to a newer version to improve the removal of sub-monthly mass variations in the monthly GRACE solutions. As of Nov-2012, Release-05 data encompassed the period from 01-2003 through 09-2012 (RL04 processing was discontinued after Apr-2012). The optimization of GRACE ocean mass (or bottom pressure, p_b) variations for the study region included the assessment & evaluation of the following processing steps: (i) spectral truncation & de-striping, (ii) spatial smoothing, (iii) land-leakage corrections.

Mass variations over land contaminate the mostly weaker ocean signals, and thus must be removed before assessing near-coastal bottom pressure. Two principal approaches to implement the three processing steps mention above are (1) to apply explicit post-processing filters on the spherical harmonic gravity coefficients, or (2) to apply spatial and temporal constraints in the derivation of the monthly gravity field from GRACE's Level-1 data (the so-called 'mascon' approach).

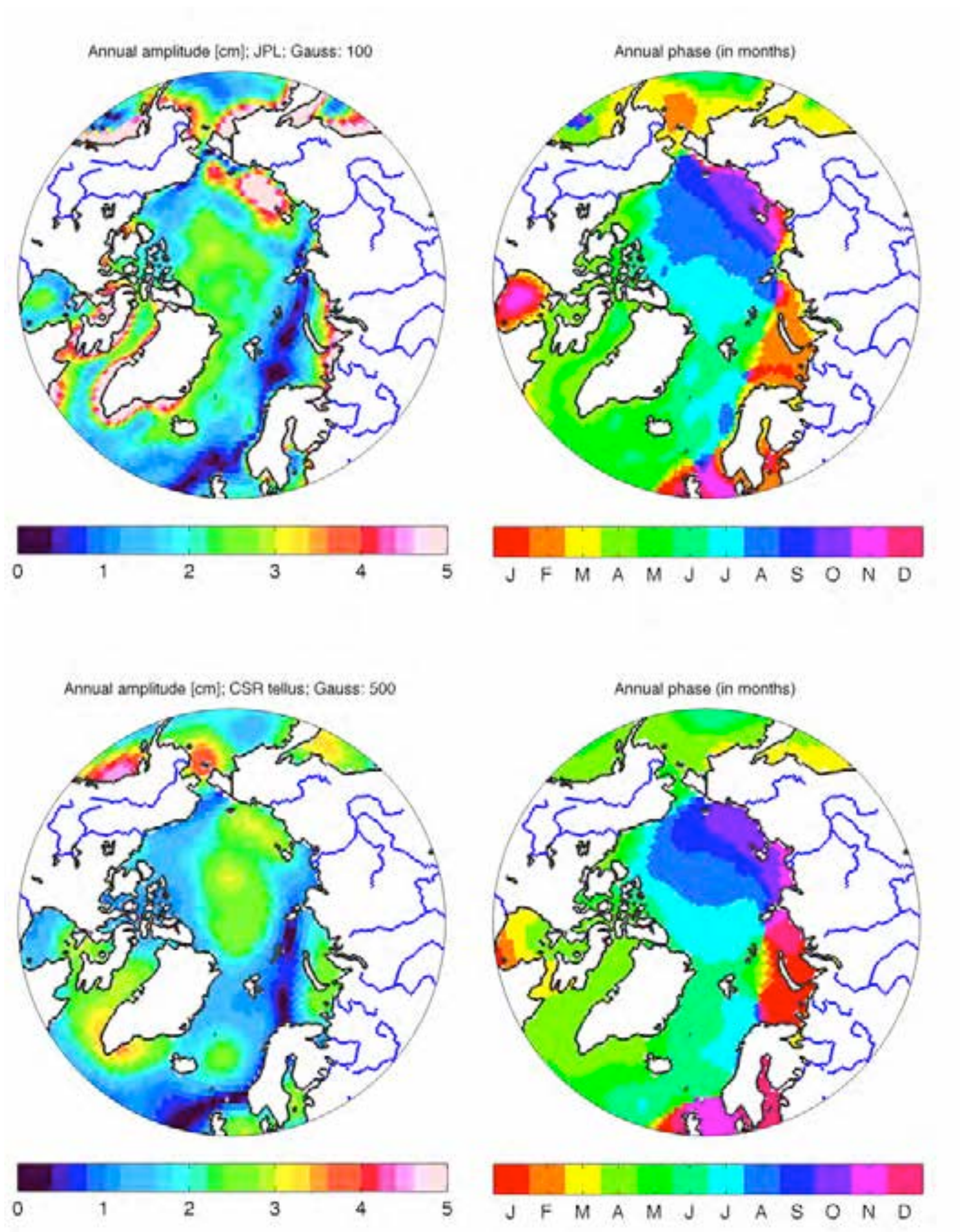

Figure 6. *Annual amplitude (left column; cm) and phase (right column, in month of year) of bottom pressure changes from GRACE JPL mascons (top), and CSR-RL05 Tellus (with 500km smoothing).*

Figure 6 compares the annual cycle amplitude and phase of the conventional GRACE p_b and the newer mascon solutions. Due to the smoothing and post-processing filters, the seasonal amplitudes in the conventional fields are much reduced, and also distorted in their shape. The phase information, on the other hand, is similar (Figure 6, right column). After experimenting with several post-processing filter combinations, and different smoothing radii, we have determined that a smoothing radius of at least 300 km is necessary to reduce striping artifacts in the conventional GRACE fields if the spatial structure of the p_b variations is analyzed (for a basin-mean analysis, this requirement can be relaxed – see below). With such a smoothing radius, however, smaller spatial scales cannot be resolved. The 'mascon' approach, on the other hand, does not need this level of smoothing, and can hence resolve smaller features. In Figure 6, a striking difference between the conventional and newer 'mascon' p_b fields are the high seasonal amplitudes on the East Siberian shelf in the mascon data. We hypothesize that this feature is a real signal, related to regional wind-stress forcing, and to some extent also to river discharge from the big Eurasian catchment basins. As of 01/2103, a preliminary analysis of the nature and associated dynamics of this signal in combination with wind-stress data (from re-analysis) indicated that these 'mascon' features on the shelf areas are real, and further investigations were thus initiated.

In a further evaluation, we compared GRACE against in-situ bottom pressure recorders (BPRs) in Fram Strait (Figure 7). A total of 6 BPRs recorded p_b in Fram Strait (just West of Spitsbergen) between 2003 and 2009 (albeit not simultaneously). We combined the BPRs (between 2-6 stations at any one time) into one array, and computed the correlation with GRACE p_b in the Nordic Seas and Arctic ocean (Figure 7). The col-located GRACE data has a correlation of 0.6, with similar values throughout most of the interior Arctic Ocean as well as the GIN Seas. This correlation is consistent with a basin-wide, homogeneous mode of bottom pressure change (or ocean mass) change, which we plan to examine further. While the correlation patterns for the conventional spherical harmonic GRACE fields yield similar correlation values, the RMS difference between GRACE and in-situ BPRs is somewhat lower for the 'mascon' fields, although this difference is likely not significant. Overall, we found that the newer 'mascon' fields provide an improved spatial representation and accuracy of bottom pressure in the study area. In addition, our analysis also yielded important feedback to the JPL-mascon inversion process for the accurate formulation and application of constraints.

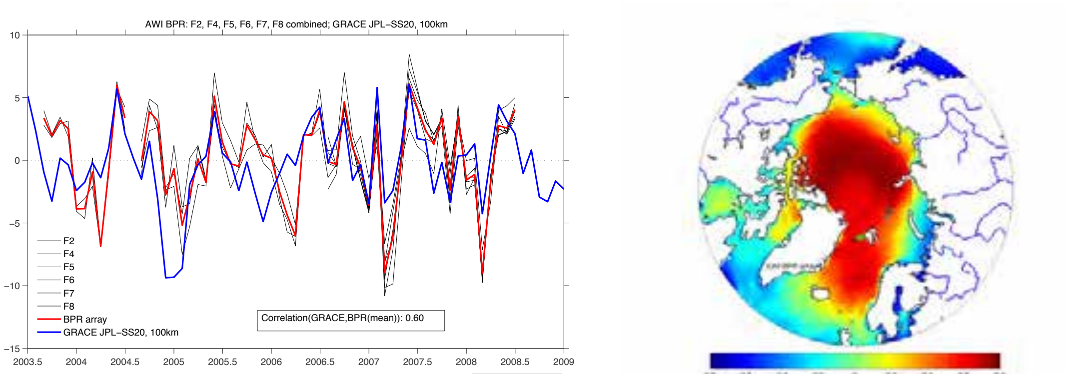

Figure 7. *Bottom pressure changes from in-situ BPR instruments in Fram Strait (source: AWI) and GRACE. The individual BPR records (thin black lines) are combined into one BPR array (red line; Note that instrument coverage varies from 2 to 6 simultaneous records). The correlation between GRACE bottom pressure (chosen to be a 2x2 degree square centered over the BPR array) and the BPR array is 0.60.*

2.3. Topographic Rossby waves in the Lofoten Basin of the Norwegian Sea (D. Volkov, T. Belonenko, V. Foux)

The Lofoten Basin (LB) is a topographic depression of about 3,250 m deep, situated in the Norwegian Sea and bounded by the Vøring Plateau in the south, Mohn's Ridge in the northwest, and the Eurasian continental shelf in the east (Fig. 8a). Being a transit area for the warm and saline Atlantic Water on its way to the Arctic Ocean, it plays an important role in sustaining the Meridional Overturning Circulation for it is a region where the Atlantic Water loses its heat to the atmosphere, mixes with surrounding water, and thus, undergoes transformation necessary for deep water formation that takes place in the adjacent Greenland Sea. In satellite altimetry maps, the LB appears as a "hot spot" of the Nordic seas. We observe the largest standard deviation of SSH reaching about 15 cm in the center of the basin (Fig. 8a).

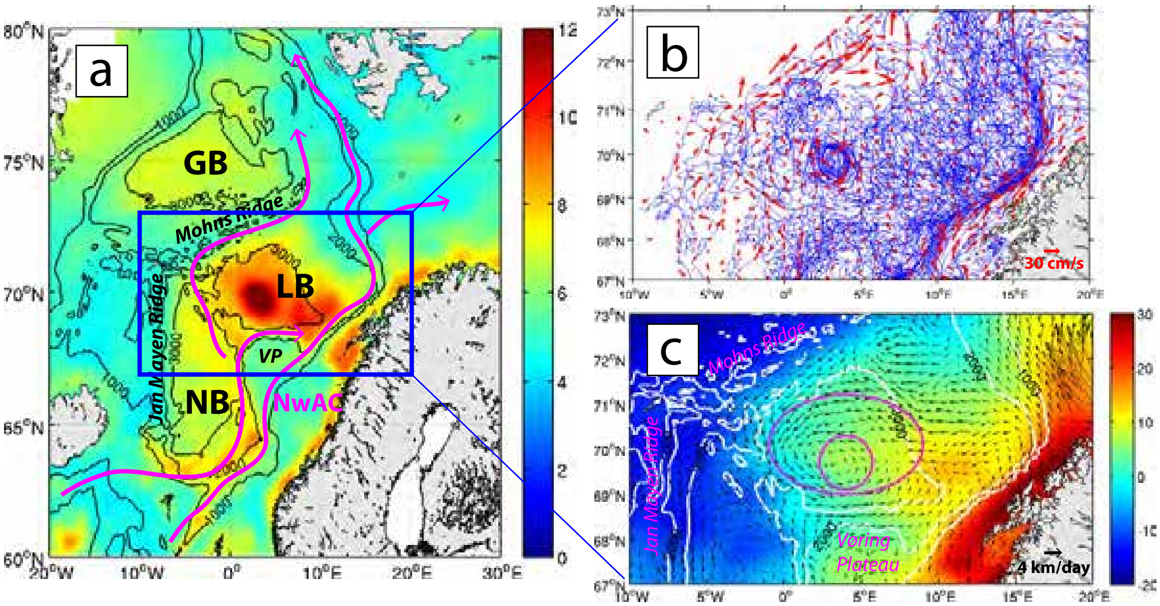

Figure 8. (a) Standard deviation of SSH (cm) in the Nordic seas. Abbreviations: GB - Greenland Basin, LB - Lofoten Basin, NB - Norwegian Basin, NwAC - Norwegian Atlantic Current, VP - Vøring Plateau. The study region is bounded by the blue rectangle. (b) Trajectories of 100 surface drifters (blue curves) that were present in the study region from September 1996 to August 2010 and their geostrophic velocity vectors (red arrows) averaged over 1°×0.25° (longitude × latitude) bins. (c) MDT_CNES_CLS09 mean dynamic topography (color, cm) and the velocities of eddy propagation (arrows). Two ellipsoidal contours, along which the time-distance diagrams are plotted and wavenumber-frequency spectra are computed, are shown.

Using ERS-1/2 and Envisat satellite altimetry measurements and a space-time lagged correlation analysis of sea surface height (SSH) fields we discovered a cyclonic propagation of the synoptic-scale sea surface height anomalies around the center of the LB (Fig. 8c). Surface drifter trajectories do not reveal an associated coherent near-surface cyclonic flow suggesting that the propagating signals have a wavelike nature, at least in the upper ocean (Fig. 8b). Using a Complex Singular Value Decomposition analysis we identified a di-pole and a quadri-pole wave modes rotating around the center of the LB and showed that these modes together explain most of the variance of the high-pass filtered SSH (signals with periods longer than 6 months were removed) (Fig. 9).

In order to investigate the properties of the observed wavelike propagation in more detail, we analyzed the wavenumber-frequency spectra of the high-pass filtered SSH along two elliptical contours (shown in Figs. 8a and 9) around the center of the LB (Fig. 10). As can be seen, most spectral energy of the cyclonically propagating waves is concentrated at the wavelengths of about 500 km (wavenumber = 0.002 km^{-1}). The frequency of the waves is more variable and their phase speeds range from about 2 to 10 km/day.

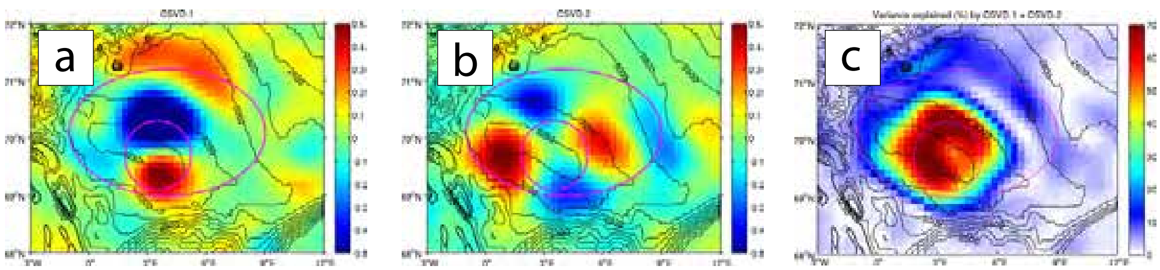

Figure 9. *Spatial patterns of CSVD-1 (a) and CSVD-2 (b), shown as correlation maps; variance explained by SSH reconstructed with CSVD-1 and CSVD-2 (c). Two ellipsoidal contours, along which the wavenumber-frequency spectra are computed, are shown.*

Then we proceeded with testing a hypothesis that the observed propagation is a manifestation of topographic Rossby waves. Variations in topography may lead to the concentration of wave energy in certain regions or wave trapping. We analyzed the linearized barotropic potential vorticity equation in polar coordinates centered on the LB. The solution to this equation was sought as an azimuthally propagating wave. After some mathematical manipulations, we derived two dispersion relations for both the di-pole and the quadri-pole wave modes:

$$\sigma_s\left\{\begin{matrix} s=1 \\ s=2 \end{matrix}\right\} = \frac{\omega}{2\pi} = \left\{\begin{matrix} \beta_e/(3.1\pi)^2 l \\ 4\beta_e/(5.3\pi)^2 l \end{matrix}\right\},$$

where s is the azimuthal wavenumber (s=1 for the di-pole and s=2 for the quadripole modes), ω is the wave frequency, $l = 1/\lambda$ is the wavenumber (λ is the wavelength), $\beta_e = H\frac{\partial}{\partial r}\left(\frac{f}{H}\right)$ is an equivalent beta effect, H is depth, r is the distance between the center of wave rotation and the maximum/minimum SSH value at the crest/trough of the wave, and f is the Coriolis parameter. Using the dispersion relations and absolute β_e =0.1 × 10^{-10}, 0.5 × 10^{-10}, and 1 × 10^{-10} s^{-1} m^{-1}, representative for the LB, we overlaid the theoretical dispersion curves for the di-pole (solid) and quadri-pole (dashed) waves on the wavenumber-frequency spectra (Fig. 10). It appeared that most of the observed spectral energy falls within the bounds set by the theoretical dispersion curves. The dispersion analysis, therefore, supports our hypothesis that the observed cyclonic propagation of SSH anomalies in the LB is a manifestation of topographic Rossby waves. In the following year of the project we intend to investigate the sensitivity of the observed waves to the variability of the Norwegian Atlantic Current and wind forcing.

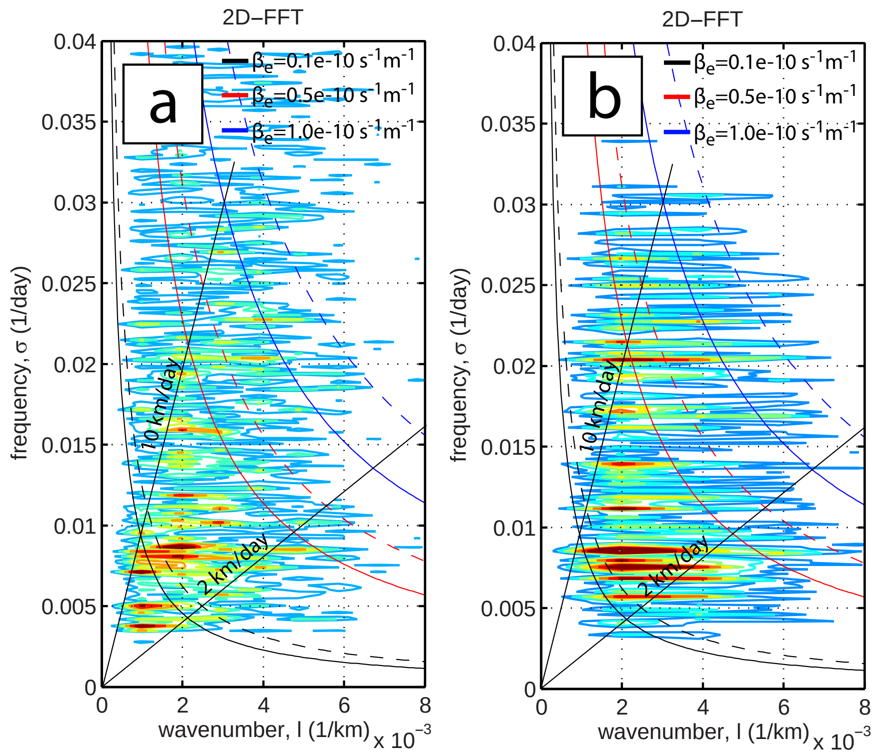

Figure 10. *Amplitudes of 2D Fast Fourier transforms (wavenumber-frequency spectra) of the high-pass filtered SSH (m^2×km×7 days) along the external (a) and internal (b) ellipsoidal contours. Color contours start at 400 m^2×km×7 days and the separation between them is 200 m^2×km×7 days. The dispersion curves are plotted for the di-pole (solid) and quadri-pole (dashed) modes, and for β_e =0.1 × 10^{-10} (black), 0.5 × 10^{-10} (red), and 1 × 10^{-10} s^{-1} m^{-1} (blue).*

2.4. The genesis of sea level variability in the Nordic and Barents seas (D. Volkov, F. Landerer, S. Kirillov)

The Barents Sea (BS) is the only shelf sea of the Arctic Ocean that is mostly ice-free all year round, thus permitting regular satellite altimetry measurements. Coupling these measurements to GRACE and hydrography data, when measurement and processing errors are minimized, allows the determination of the sea level budget components. We have conducted one of the first analyzes of the local sea level budget using the combination of space borne and in-situ observations as well as a high-resolution ocean data synthesis product. Hereafter, we use the following nomenclature for sea level anomaly (SLA) components: the total sea level anomaly (SLA_T), the mass-related sea level anomaly (SLA_M), the steric sea level anomaly (SLA_S), the thermosteric sea level anomaly (SLA_{TS}), and the halosteric sea level anomaly (SLA_{HS}).

Using satellite altimetry and GRACE observations, we have presented the first observational evidence of the relative importance of the mass-related changes of sea level in the BS (Figure 11). We have shown that the non-seasonal mass-related changes of sea level are responsible for the large part (up to 50%) of the non-seasonal sea level variability in the BS. Significant contributions of the mass-related sea level variability, of the same magnitude or larger than the steric sea level variability, are also observed at interannual time scales. The difference of two GRACE data releases, however, highlights existing uncertainties, probably related to the processing algorithms of GRACE measurements and uncertainties in the high-frequency de-aliasing models used to estimate monthly GRACE gravity fields.

We have shown that the recently released GRACE RL05 data attenuates the annual cycle signal compared to the previous RL04 release. By comparing the difference between the annual cycles of the altimetric SLA_T and GRACE-derived SLA_M to the hydrography-derived annual cycle of SLA_S and the ECCO2-derived annual cycles of SLA_M and SLA_S, we have concluded that RL04 gives a more realistic result in the BS than the newer RL05. In terms of the non-seasonal variability, the standard deviation of the difference between the RL04 and RL05 time series, averaged over 25°W-45°W and 73°N-77°N, is 1.5 cm. These comparisons indicate that the uncertainties in GRACE data are still rather large and regional validation of GRACE products is warranted.

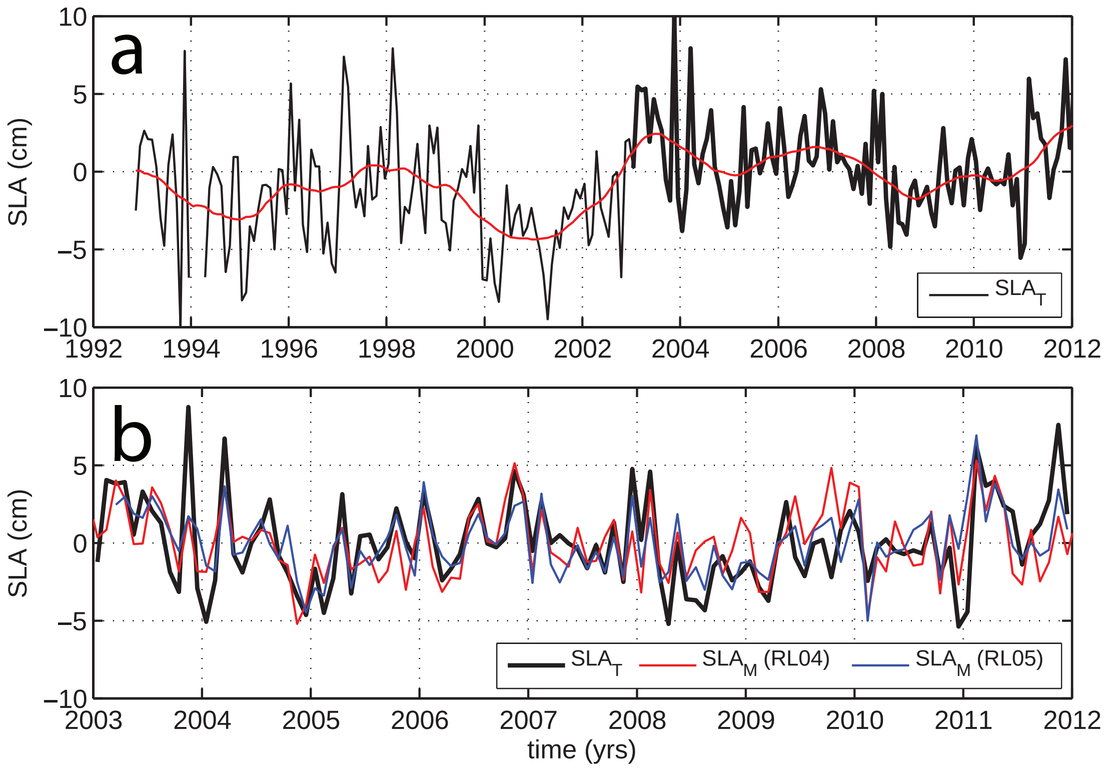

Figure 11. *(a) The non-seasonal SLA_T from satellite altimetry for the 1992-2011 time period (black) and it yearly running mean (red); (b) the de-trended time series of the non-seasonal SLA_T (black) versus SLA_M from GRACE RL04 (red) and RL05 (blue) products for the 2003-2011 time period. The time series are averaged over 25°W-45°W and 73°N-77°N.*

The phase of the annual cycle of SLA_T exhibits a distinct difference of 1-3 months between the BS and the neighboring Norwegian and Greenland seas (Figure 12b). The annual cycle of SLA_T is the interference of the annual cycles of SLA_M and SLA_S. The analysis of GRACE observations shows that the annual maximum of SLA_M (from RL04) lags behind the annual maximum of SLA_T by three months (Figure 13a). This suggests that the local importance of the mass-related sea level variability can be responsible for the observed phase difference between the BS and Nordic seas. To investigate this question in more detail, we have analyzed the mechanisms of the annual cycle in the ECCO2 model. It turns out that the phase of the annual cycle of SLA_S from ECCO2 is distributed rather uniformly over the BS and the Nordic seas (Figure 14f). This rules out the possibility of the phase difference caused by the anomalous advection or the spatial variations in the net surface heat flux. The phase difference between the BS and the Nordic seas is seen only in the annual cycle of SLA_M (Figure 14e).

The amplitude of the annual cycle of SLA_S, obtained as the difference between the altimetric SLA_T and GRACE-derived SLA_M, is about twice greater than the annual cycle of SLA_S, calculated from hydrographic data (Figure 13). This discrepancy is most likely caused by errors in GRACE data. We have demonstrated that the uncertainty of GRACE data, estimated as the difference between the two recent GRACE products, is rather large. The use of different time intervals for the satellite- and hydrography-based estimates of the annual cycle should not have a great impact. We have shown that the parameters of the annual cycle did not change much over the period of hydrographic surveys, considered in this study. In the ECCO2 model, the annual cycle of SLA_M in the central part of the BS is of about the same magnitude as the annual cycle of SLA_S. The amplitude and phase of the annual cycle of SLA_S in the model are rather close to the estimates, obtained from hydrography.

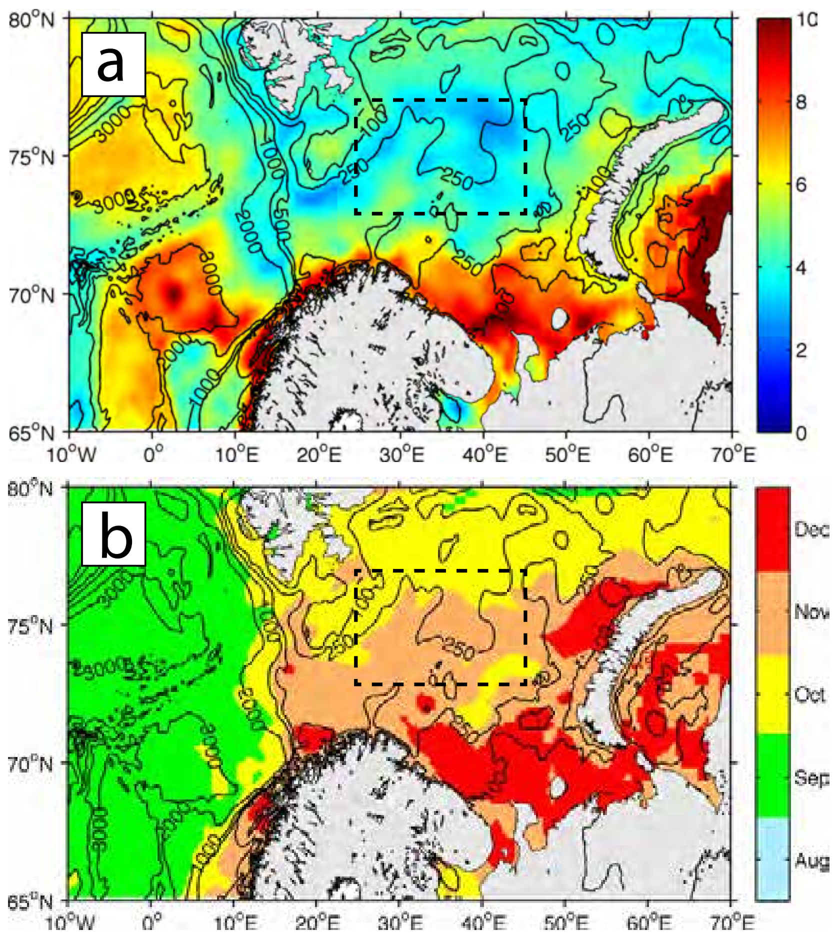

Figure 12. *(a) Amplitude (cm) and (b) phase (month of the annual maximum) of the annual cycle of altimetric SLA_T computed from the 1993-2011 monthly mean climatology. The dashed rectangle bounds the area used for averaging the time series.*

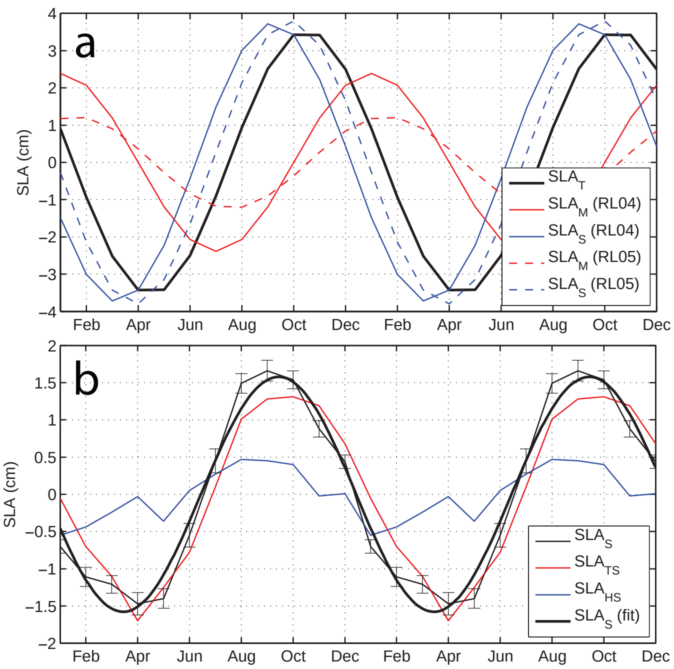

Figure 13. *(a) Annual cycles of SLA_T from satellite altimetry (black), SLA_M from GRACE RL04 (solid red) and RL05 (dashed red), and SLA_S, computed as the difference between SLA_T and GRACE-RL04 SLA_M (solid blue) and between SLA_T and GRACE-RL05 SLA_M (dashed blue). The time series of SLA_T and SLA_M are averaged over the 25°W-45°W and 73°N-77°N area (dashed rectangles in Figure 4 a and b). (b) Monthly mean climatology of steric (thin black), thermosteric (red), halosteric (blue) sea level anomalies, and the annual cycle of SLA_S (bold black), computed from hydrography data for the time period of 1950-1995 over the 25°W-45°W and 73°N-77°N area. The error bars show the standard errors on the determination of the monthly mean values at 95% confidence level.*

Because the mass-related variability of sea level dominates in the BS, we have analyzed the barotropic vorticity balance in order to investigate the mechanisms of the barotropic variability in more detail. The barotropic vorticity equation for the depth-integrated flow is expressed as follows:

$$\frac{\partial \zeta}{\partial t} + \mathbf{u}\nabla\zeta + \beta v - \frac{\zeta + f}{H}\left(\frac{\partial \mathrm{SLA_M}}{\partial t} + \mathbf{u}\nabla H\right) = \frac{1}{\rho}\nabla\times\left(\frac{\boldsymbol{\tau}}{H}\right) - D \qquad (1),$$

where H is depth, $\mathbf{u}(u,v)$ is the depth-integrated velocity vector, f is the planetary vorticity, $\zeta = \partial v/\partial x - \partial u/\partial y$ is the relative vorticity, $\beta = \partial f/\partial y$, $\boldsymbol{\tau}(\tau_x, \tau_y)$ is the wind stress vector, ρ is density, and D - dissipation. The left side of the equation (1) represents the sum of the time change of the relative vorticity, the advection of the relative vorticity tendency, the advection of planetary vorticity, (in brackets) the vortex stretching term and the topographic term (representing the flow over the varying topography). The right side of equation (1) contains forcing: the wind stress term and dissipation. The terms of the equation (1) were averaged over Region-2 shown in Figure 15.

Neglecting the impact of fresh water fluxes to and from the BS, the variability of SLA_M is driven either by wind or by vorticity fluxes. We have shown that the advection of the relative vorticity tendency and the advection of planetary vorticity do not significantly influence the variability of SLA_M. What does drive the variability of SLA_M

in the central part of the BS is the combined effect of wind forcing balanced by the flow over the varying bottom topography (topographic influence) and dissipation (Figure 16). The variability of wind stress curl over the BS forces water to flow in or out of the area thus changing the area-averaged sea level. With regard to the annual cycle, this means that the time-integrated cyclonic (anticyclonic) anomaly of wind stress observed in winter (summer) months (Figure 16) leads to a decrease (increase) of sea level in the BS that reaches a minimum (maximum) in May-June (November-December) (Figure 17a), i.e. several months after the actual maximum (minimum) in the wind stress curl anomaly, which is consistent with Ekman dynamics.

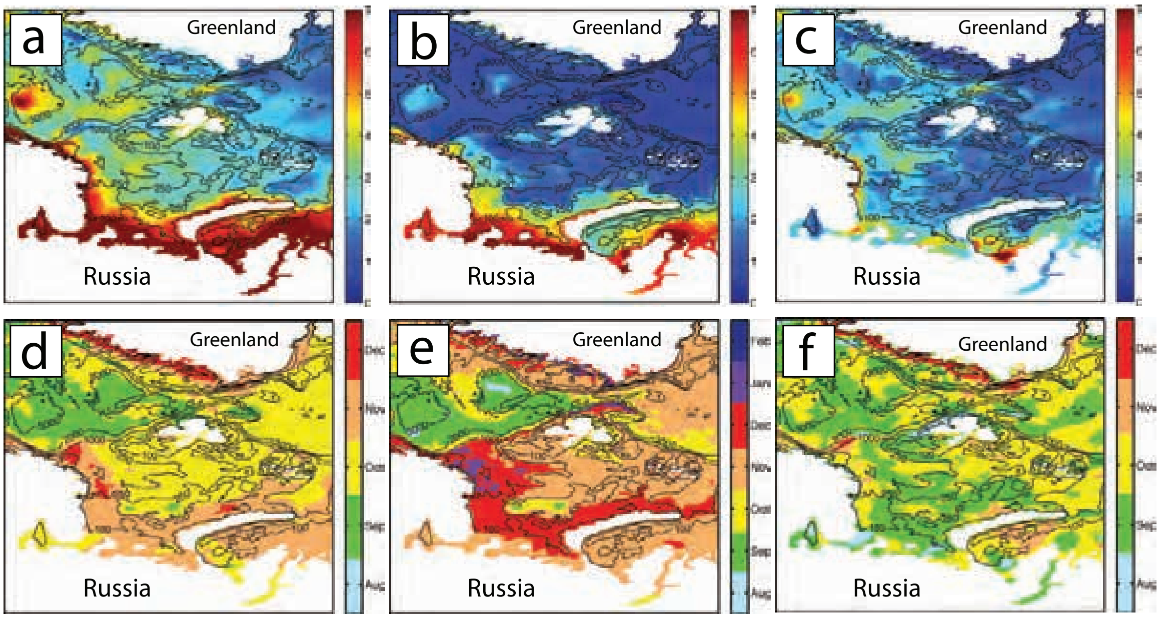

Figure 14. *The amplitudes (upper plots) and phases (lower plots) of the annual cycle of* SLA_T *(a and d),* SLA_M *(b and e), and* SLA_S *(c and f), obtained from the ECCO2 output. Bottom topography is shown for 100, 250, 1000, 2000, and 3000 m.*

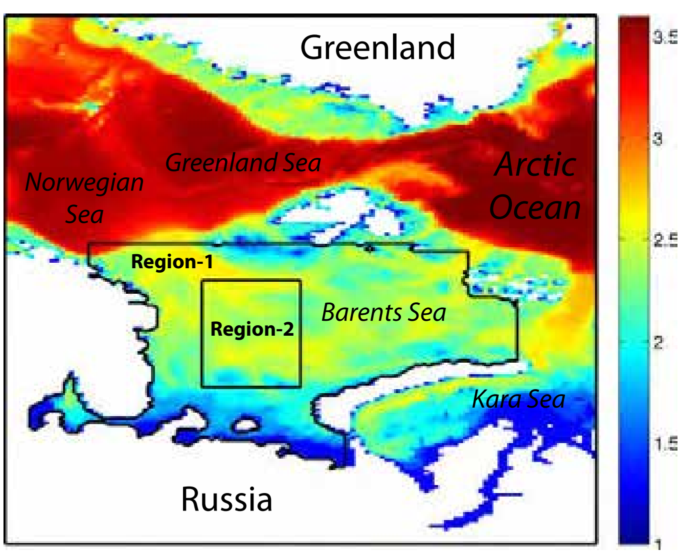

Figure 15. *The truncated ECCO2 model domain that we used in this study. Color shows the* $\log_{10}$ *of depth and two black contours bound the areas, over which averaging of quantities was performed: the entire Barents and White seas (Region-1) and the central part of the Barents Sea (Region-2).*

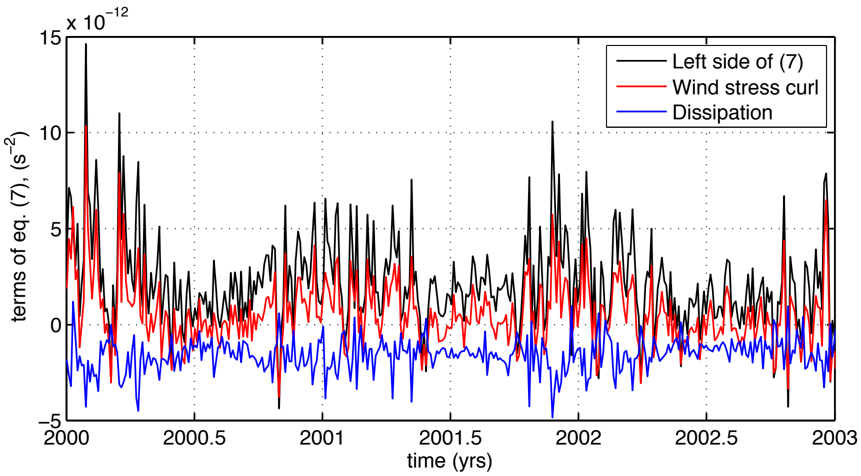

Figure 16. *Components of the barotropic vorticity budget averaged over Region-2 (Figure 15): the sum of the left side terms of Eq. (1) (black), the wind stress term (red), and the dissipation term (blue).*

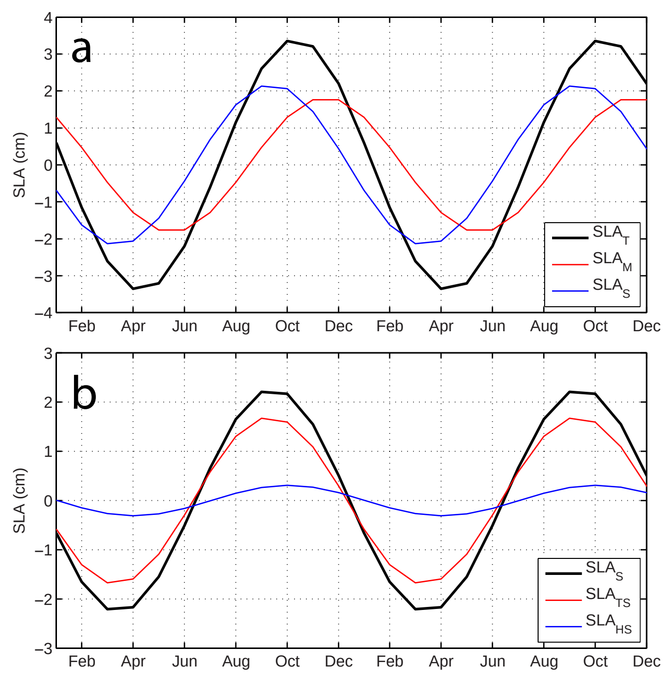

Figure 17. *(a) Annual cycles of SLA_T (black), SLA_M (red), and SLA_S (blue), and (b) annual cycles of SLA_S (black), SLA_{TS} (red), and SLA_{HS} (blue) from ECCO2 model. The time series are averaged over Region-2 (Figure 15).*

Using hydrography and the ECCO2 output we have estimated the contributions of the thermosteric and halosteric effects to the variability of sea level in the entire BS. As expected, the largest contribution of the thermosteric sea level in the BS is observed along the main paths of the AW advection: the North Cape Current and the Norwegian Coastal Current. The halosteric effects dominate in the southeastern, eastern, and northern parts of the BS, subject to the seasonal formation and melt of sea ice and to the river runoff. In terms of the annual cycle in the center of the BS, both the hydrography and ECCO2 data show the dominance of the thermosteric sea level with a maximum in the fall when the heat contents of the water column reaches it highest value. The amplitude of the annual cycle of SLA_{HS} is about 3 times smaller than the amplitude of the annual cycle of SLA_{TS} (Figure 13b). The annual maximum of the SLA_{HS} takes place at approximately the same time (August for hydrography and October for ECCO2), so that both signals complement each other. The halosteric sea level peaks along with the fresh water content due to the ice melt, continental runoff, and decreased salinity transport from the Norwegian Sea.

Using the ECCO2 output we have determined the relative contribution of the net surface heat flux and the lateral advection of heat to the variability of the thermosteric sea level (Figure 18). The variability of SLA_{TS} is dominated by the seasonal signal and, as expected, most of the variability is explained by heat exchange with the atmosphere. The contribution of heat advection to the annual cycle of SLA_{TS} is small. However, heat advection becomes important at the interannual time scale, when its contribution is equal or exceeds the contribution of the net surface heat flux. This means that the variability of the AW inflow into the BS on the interannual time scale can greatly influence the oceanographic conditions of the region, in particular, the regional extent of sea ice cover.

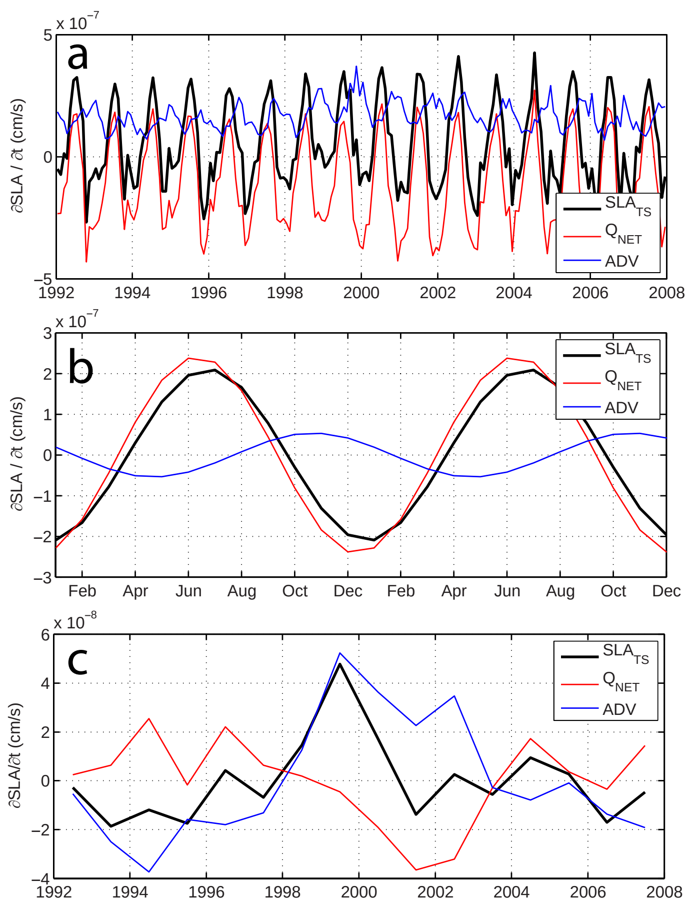

Figure 18. *The time change of the thermosteric sea level (black), thermosteric sea level due to the net surface heat flux (red), and thermosteric sea level due to the lateral advection (blue): (a) the monthly time series, (b) annual cycle, and (c) yearly averages. The time series shown are averaged over Region-1 (Figure 15).*

2.5. Nonseasonal fluctuations of the Arctic Ocean mass (OcM) observed by the GRACE satellites (D. Volkov, F. Landerer)

The Arctic OcM variations observed by GRACE in 2003-2012 feature strong non-seasonal fluctuations on time scales from 2 to 6 months. The basin-averaged OcM measurements exhibited a record high anomaly of about 4 cm above the 2003-2012 average in February 2011 (Figure 19).

Coupling satellite measurements of OcM with wind stress, we have found that the zonal wind pattern is correlated with a di-pole pattern of OcM change (Figure 20). When westerly winds intensify/reduce over the North Atlantic at about 60°N and over the Russian continental shelf break, OcM decreases/increases in the Nordic seas and in the central Arctic, and increases/decreases over the Russian Arctic shelf, consistent with Ekman dynamics. The time evolution of this pattern is related to the AO index.

The basin-wide OcM changes in the Arctic Ocean are correlated with the northward wind near its gateways: low/high OcM anomalies in the Arctic Ocean are associated with northward wind anomalies over the northeastern North Atlantic and Nordic seas, and over the Bering Sea (Figure 21). This variability pattern is responsible for the record high anomaly observed in February 2011. We conclude that the meridional wind anomalies over the Nordic seas can modulate the strength of the East Greenland and West Spitsbergen currents, and eventually the transport across the Fram Strait, via Ekman dynamics. The low/high Arctic OcM anomalies correspond to the negative/positive anomalies of the wind stress curl over the North Atlantic, just south of 65°N (Figure 22). This suggests that associated anomalies in Sverdrup transport can influence the southern boundary of the Nordic seas and, thus, be one of the possible mechanisms for the wind-driven non-seasonal fluctuations of the Arctic OcM. Demonstrating the great utility of the GRACE observations, we have also revealed associated changes in the large-scale ocean circulation. The cyclonic/anticyclonic circulation anomaly with an anomalous outflow/inflow through the Fram Strait is associated with the low/high Arctic OcM (Figure 23).

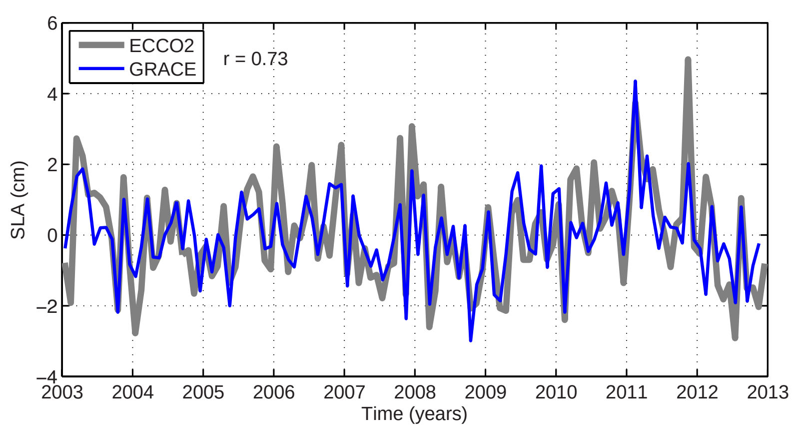

Figure 19. *The basin-averaged non-seasonal OcM from GRACE (blue) and from ECCO2 model (gray). Note that the large signal in November 2011 is likely real, but was not observed with GRACE due to an instrument outage between November 17 and December 12. Accounting for this outage largely removes the peak from the model estimate. For a monthly GRACE-OcM estimate, the 1-sigma uncertainty is about 9 mm, based on Wahr et al. [2006].*

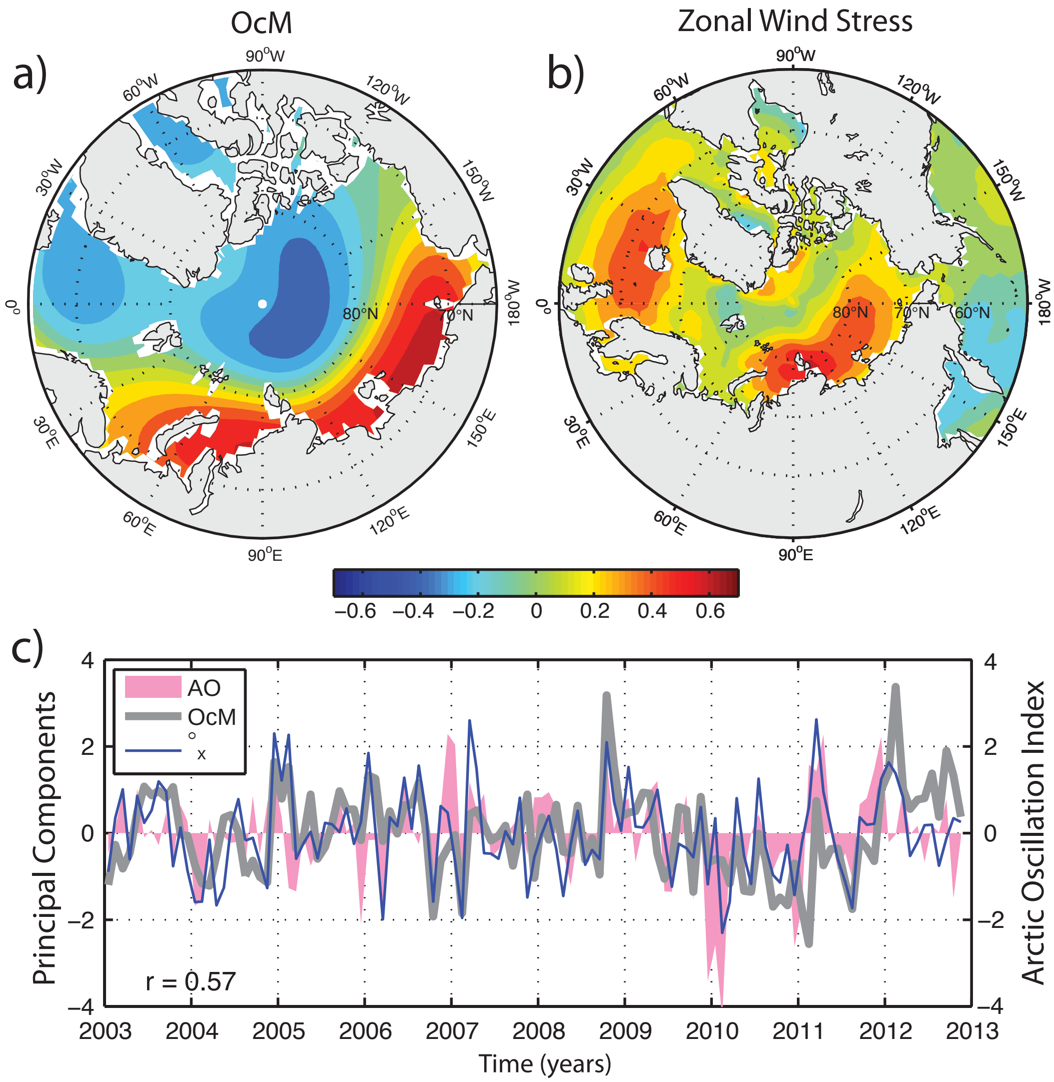

Figure 20. *The spatial patterns (a, b) and the principal component (PC) time series (c) of the first coupled EOF of the Arctic OcM and zonal wind stress (τ_x). The spatial patterns are shown as heterogeneous correlation maps: (a) the correlation between the PC-1 of τ_x and OcM field and (b) the correlation between the PC-1 of OCM and τ_x field. The Arctic Oscillation index is shown by the pink-shaded area in (c) plot.*

The basin-wide fluctuations of OcM, and the record high anomaly in particular, are well simulated by the ECCO2 model. The model also simulated a somewhat larger anomaly in November 2011, which is likely to be real, but not resolved by GRACE due to an instrument shutdown at around the same time. Based on ECCO2 model output, we conclude that the contribution of fresh water fluxes is negligible on non-seasonal time scales, and most of the OcM variability is explained by the net horizontal transports that mostly represent the wind-driven redistribution of water (Figure 24a).

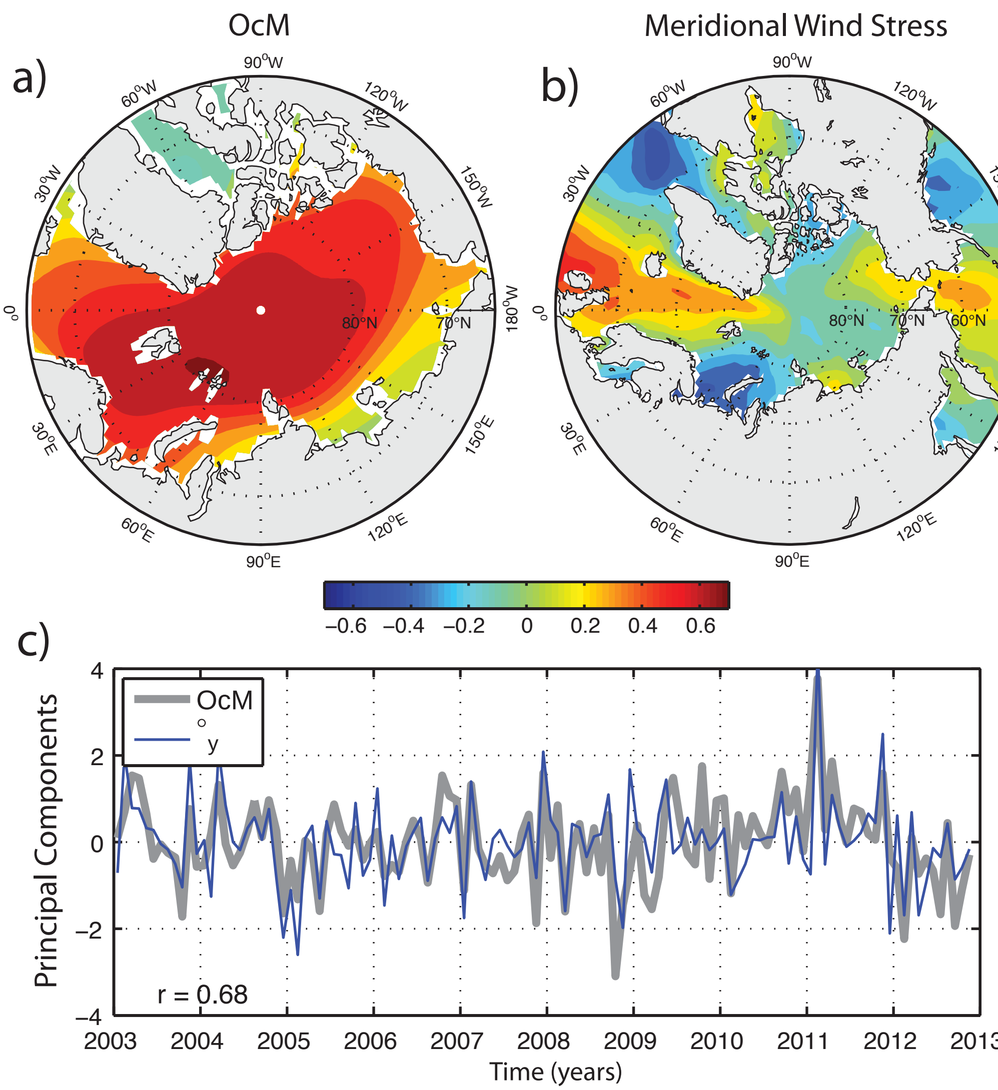

Figure 21. *The spatial patterns (a, b) and the principal component (PC) time series (c) of the first coupled EOF of the Arctic OcM and meridional wind stress (τ_y) The spatial patterns are shown as heterogeneous correlation maps: (a) the correlation between the PC-1 of τ_y and OcM field and (b) the correlation between the PC-1 of OcM and τ_y field.*

Although the Bering Strait transport usually compensates for the Atlantic transport anomalies, most of the variability of the Arctic OcM is driven by the variability of non-compensated transport across the Atlantic sector (Figure 24b). However, we have shown that the contribution of the Bering Strait transport was significant for both of the large Arctic Ocean mass anomalies in February and in November of 2011, when it did not compensate for the Atlantic transport anomalies (Figure 25). We suggest that during winter months, when the shallow northern part of the Bering Sea is covered with sea ice, the northward wind anomalies by the means of Ekman transport can affect the strength of the Kamchatka and the Bering Slope currents and lead to the divergence or convergence of water in the northern part of the Bering Sea, which controls the net transport across the Bering Straight.

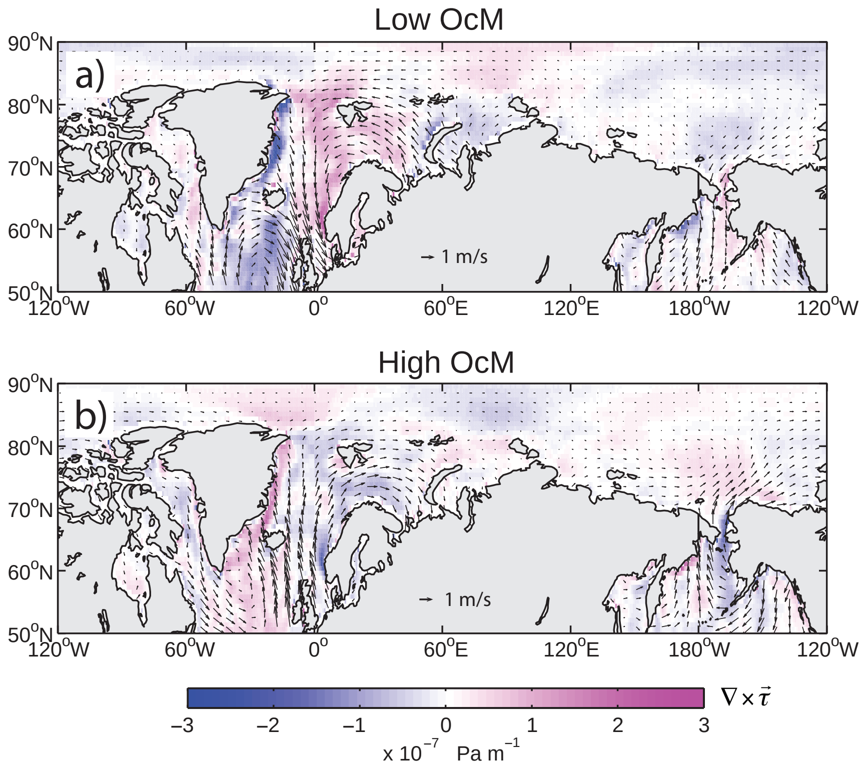

Figure 22. *The 10 m height wind vectors and wind stress curl (color) averaged over the period of low (a) and high (b) OcM anomaly, i.e. when OcM in Figure 2 is less than -1 cm and greater than 1 cm, respectively.*

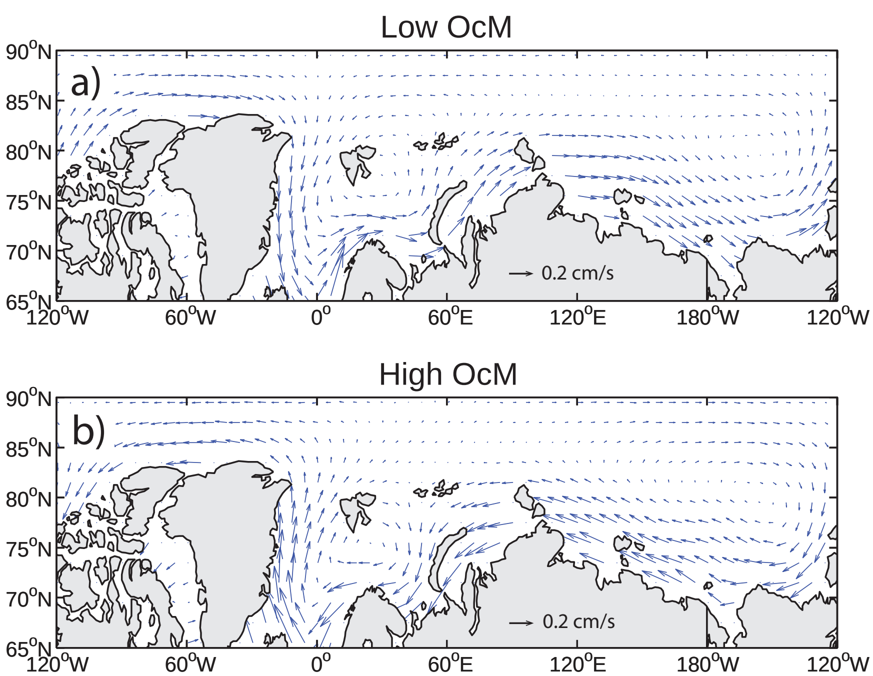

Figure 23. *The geostrophic velocity vectors, calculated from GRACE OcM anomalies and averaged over the period of low (a) and high (b) OcM anomaly, i.e. when OcM in Figure 2 is less than -1 cm and greater than 1 cm, respectively.*

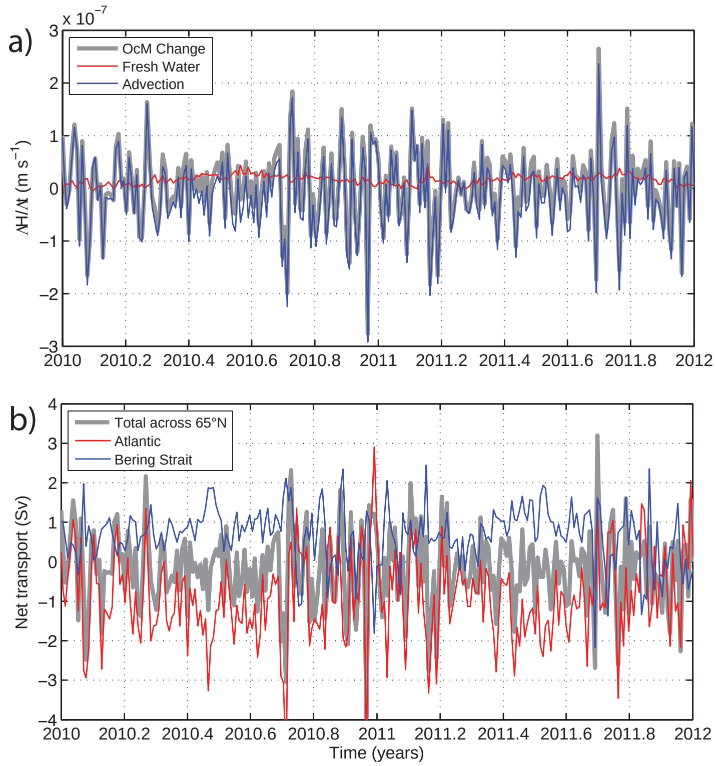

Figure 24. *(a) The time change of the Arctic OcM (gray), the net transport across 65°N scaled by the ocean area north of this latitude (blue), and fresh water fluxes (red); (b) net transport in Sverdrups (1 Sv = 10^6 m^3 s^{-1}): total across 65°N (gray), across 65°N in the Atlantic Ocean (red), and through the Bering Strait (blue).*

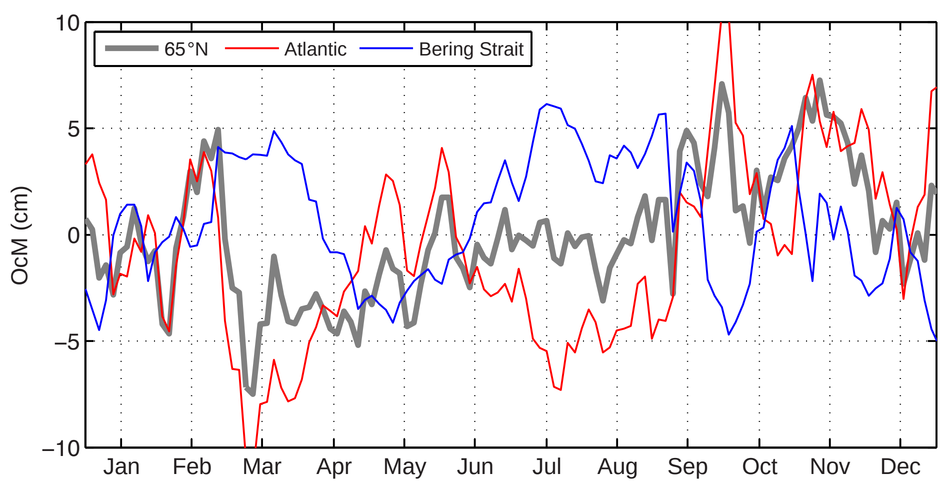

Figure 25. *The de-trended cumulative sums of the total (gray), Atlantic (red), and Bering Strait (blue) net transport anomalies in 2011, scaled by the Arctic Ocean area and multiplied by the time interval (3 days) to obtain equivalent sea level in centimeters. The tick marks of x-axis correspond to mid-month dates.*

2.6. Do the North Atlantic winds drive the nonseasonal variability of the Arctic Ocean mass and sea level? (D. Volkov, GRL, 2014)

The GRACE satellites have observed coherent basin-wide changes of the nonseasonal OcM extending across the deep parts of the Arctic Ocean and the adjacent Nordic seas. The existing explanation of the nonseasonal basin-wide OcM changes as being due only to the meridional wind anomalies over the Nordic seas is not complete and an external forcing mechanism should also be relevant. The basin-wide coherency of the nonseasonal OcM variability and the strong correlation between the nonseasonal OcM and SSH over the Nordic and Barents seas allows using the longer satellite altimetry records as a proxy for the nonseasonal SSH in the Arctic Ocean. Coupling the nonseasonal SSH variability to atmospheric forcing shows that positive/negative SLP anomalies are correlated with positive/negative SSH anomalies in the Nordic seas. This is partly because of the associated local Ekman convergence/divergence. On the other hand, a dipole oscillation pattern of SLP drives strong zonal wind anomalies over the northeastern North Atlantic correlated with the nonseasonal SSH variability in the Nordic seas. The variations of zonal wind cause the northward Ekman transport anomalies that modify the net transport across the boundary between the northeastern North Atlantic and the Nordic seas. The results of this study demonstrate that the Ekman transport anomalies over the northeastern North Atlantic are very important for driving the nonseasonal, including interannual, variability of the Arctic OcM and SSH. This study complements previous research [*Volkov and Landerer*, 2013; *Peralta-Ferriz et al*., 2014] and extends it by using longer (compared to GRACE) satellite altimetry observations, identifying a new mechanism for the Arctic OcM/SSH variability, and establishing relationship between the interannual changes of the Arctic OcM/SSH and wind forcing. This study is also a basis for a proposal that is being submitted to 2014 NASA Physical Oceanography program.

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