Cooperative Institute for Marine and Atmospheric Studies

CIMAS

Final Report

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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 nine additional Florida and Caribbean University Partners (FAU, FIT, 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 I, II, III and IV) during the entire award period (July 1, 2010 to November 30, 2016) was $93.3M. Task I which includes not only Administration but also Research Infrastructure (ship-time, computing resource access etc.) and Education and Outreach was ca. $10.9M. The University of Miami contributed an additional $1.2 M towards Administration. Task II, which supports CIMAS employees conducting closely collaborative research off- campus was ca. $ 41.1M.

Individual research project funding (Tasks III and IV) totaled ca. $41.2M. The largest portions were the research projects within Themes 3 and 6 (Sustained Ocean and Coastal Observations & Ecosystem Management) which together account for 56%. The smallest portions were in Themes 5, 7 and 4 (Ecosystem Modeling & Forecasting Protection and Restoration of Resources, Ocean Modeling) which together account for only 17%. 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.

At the present time a total of 128 individuals at UM were directly provided salary support through CIMAS. Of the 128 research employees who received NOAA support, 64 worked at AOML, 29 at the SEFSC, 1 at RSMAS, 2 at NHC, 5 at the University of Puerto Rico and 6 in other locations. The remaining 21 were comprised of administrative staff, graduate and undergraduate students. The employees in the Research Associate and Research Scientist ranks have a diverse demographic profile. The population is 41% female. Foreign born individuals make up 45% of the total. The largest foreign sub-groups are Hispanics (20%), Asian and Pacific Islanders (12%). 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 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 the 2015-2016 time-frame there were 116 peer-reviewed publications and another 36 non-peer reviewed technical reports or other publications resulting from research projects conducted directly under our present Cooperative Agreement award number. Over the life of the award there were 60 peer-reviwed pubications and 25 non-peer reviewed technical reports or other publications. 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. A more detailed description of all the CIMAS projects can be found 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).

SOME RESEARCH HIGHLIGHTS

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

The Ocean, Coastal, and Estuarine Network for Ocean Acidification Monitoring
Our ocean acidification (OA) observing system is used to determine patterns and trends in key indicators of OA. Our data are used to evaluate changes in marine ecosystems and to develop management and mitigation strategies under ocean acidification conditions. We specifically focus our research in the Gulf of Mexico and East coast of the US. OA conditions are evaluated through surface measurements obtained from autonomous systems on 2 ships of opportunity (SOOP-OA), dedicated research cruises (the East Coast Ocean Acidification (ECOA) cruise, GOMECC-3 cruise next year) and by the continued development of the observing system. Ocean acidification is a consequence of the increase of CO_2 concentration in the water due to the burning of fossil fuels, cement production, deforestation, etc. and it can have significant impacts on shell fisheries and coral reef ecosystems.

Aquarius Reef Base Maintenance and Monitoring
Fear of predation influences food web structure on coral reefs (Laura Bhatti-Catano, PhD student, FIU). Predators can exert strong direct and indirect effects on ecological communities by intimidating their prey. The nature of predation risk effects is often context dependent, but in some ecosystems these contingencies are often overlooked. Risk effects are often not uniform across landscapes or among species. Indeed, they can vary widely across gradients of habitat complexity and with different prey escape tactics. These context dependencies may be especially important for ecosystems such as coral reefs that vary widely in habitat complexity and have species-rich predator and prey communities. With field experiments using predator decoys of the black grouper (*Mycteroperca bonaci*), the interactions between complexity interacts and predation risk that affect the foraging behavior and herbivory rates of large herbivorous fishes (e.g. parrotfishes and surgeonfishes) were studied across four coral reefs in the Florida Keys (USA). In both high and low complexity areas of the reef, the way in which herbivory changed with increasing distance from the predator decoy was studied to examine how herbivorous fishes reconcile the conflicting demands of avoiding predation vs. foraging within a reefscape context. With increasing risk, herbivorous fishes consumed dramatically less food (ca. 90%) but fed at a faster rate when they did feed (ca.

26%). Furthermore, fishes foraging closest to the predator decoy were 40% smaller than those that foraged at further distances. Thus, smaller individuals showed muted response to predation risk compared to their larger counterparts, potentially due to their decreased risk to predation or lower reproductive value (i.e. the asset protection principle). Habitat heterogeneity mediated risk effects differently for different species of herbivores, with predation risk more strongly suppressing herbivore feeding in more complex areas and for individuals at higher risk of predation. Predators appear to create a reefscape of fear that changes the size structure of herbivores towards smaller individuals, increases individual feeding rates, but suppresses overall amounts of primary producers consumed, potentially altering patterns of herbivory, an ecosystem process critical for healthy coral reefs.

Low resilience of Florida Keys coral reefs (Joseph R. Pawlik, University of North Carolina Wilmington). Coral reefs are economically important ecosystems that have suffered unprecedented losses of corals in the recent past. Why have Caribbean reefs in particular transitioned to coral-depleted systems and exhibited less coral resilience? A synthesis of recent research from diverse sources provides novel insights into the reciprocal interactions among sponges, seaweeds, and microbes. We propose that coral loss resulted in more abundant seaweeds that release dissolved organic carbon (DOC), which is consumed by sponges. Sponges return carbon to the reef but also release nutrients that further enhance seaweed growth. Both seaweeds and sponges compete for space with the remaining corals, and the cycling of carbon and nutrients alters microbial activity, with negative consequences for the coral microbiome. Adding to these interactions are geographic factors that enhance nutrients and DOC on Caribbean reefs, such as river discharge and windblown dust. Relatively higher abundances of sponges and the absence of phototrophic species suggest that sponge communities on Caribbean reefs have adapted to a different nutritional environment than is present elsewhere. This synthesis sheds new light on past hypotheses seeking to explain the disparity in the recovery of coral reefs across the tropics, provides new directions for research, and has implications for the conservation of Caribbean coral reefs that are related to fisheries and watershed management

Juvenile Sportfish Monitoring in Florida Bay, Everglades National Park
In Florida Bay there was an extreme hypersaline event in July 2015 where salinities were higher than every other year (up to 65.4) creating multiple fish kills (toadfish, mullet) and extensive seagrass die-off. There is a significant correlation with juvenile spotted seatrout, salinity, and seagrass percent cover.

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.

Caribbean Sea and Gulf of Mexico Bluefin Tuna Research
This work continues to improve the understanding of larval bluefin tuna distribution and ecology in the Gulf of Mexico and western Atlantic. This species is overfished, and economically valuable, however recruitment processes are generally poorly known. Year class strength is likely to be determined during early life, and so quantification of environmental variability and planktonic food

web effects on larval survival is critical. Our ongoing research project is the first to link larval distributions, feeding, growth and trophic interactions for the region. Results will facilitate better management of bluefin tuna, by enhancing knowledge of spawning behaviors and recruitment mechanisms.

Applying Bio-physical Monitoring and Capacity Assessments to Mesoamerican Reef Marine Protected Areas

This multi-year research focuses on monitoring larval and post-larval fish populations in the Mesoamerican region that are recruiting into MPAs. The goal is to fill data gaps and examine how these fishes are distributed and eventually develop comparisons between them. This barrier reef is the second largest in the world and houses ecologically and economically important species as well as increased anthropogenic pressures. The numerous marine protected areas and NGOs that conserve and manage the region are directly involved in the monitoring (via the ECOMEs) of their own areas which enriches the existing human capacity as well as generates a baseline for the development of a time series in a data pour region already vulnerable to a rapidly changing climate.

Use of a Biophysical Modeling Framework to Develop a Recruitment Index for Inclusion in Stock Assessments in the Gulf of Mexico and South Atlantic

Red snapper are a highly valued reef fish found throughout the Gulf of Mexico and southeastern U.S. Atlantic where they contribute to multibillion dollar fisheries. There is a paucity of published information documenting the occurrence, distribution and habitat preferences of red snapper juveniles in the southeastern U.S., and the probable source locations of recruits to the region are virtually unknown. We combine an individual-based larval transport model with an oceanographic hindcast model to understand sources and sinks of recruits in the region, and to develop indices of recruitment strength due to environmental factors. Our results suggest that connectivity of red snapper between the Gulf of Mexico and Atlantic regions is limited. These results have important implications for the expected recovery trajectories of the overfished red snapper population, and information on the environmental drivers of recruitment fluctuations can inform short-term projections of population dynamics.

Southeast Florida Coral Reef Fishery-Independent Assessment: Year 4

Understanding the distribution of coral reef fishes is critical for their management. We are establishing a baseline for status and trends of coral reef fishes from the northern Florida Reef Tract. The resulting data is of immediate societal relevance as it includes multiple commercially and recreationally important species. This information will support current coral reef management options being considered at the state and local levels in the near term and potentially assist with Marine Protected Area and other coral reef management options at the federal level in the future. Benthic habitat maps are used as the foundation for the sampling design to examine the issues of coral reef fish distribution, species-specific data relating to abundance and size structure, as well as assemblage structure and species richness. Variability of target species abundance is used to determine the number of visual census samples necessary for each strata included in the assessment. Sample sites are randomly selected within each strata. Distinct eco-regions are delineated based on habitat characteristics observed in the benthic habitat maps and confirmed during field sampling using a Reef Visual Census methodology. This research lends evidence to the claim that many commercially and recreationally targeted species are being over-exploited. This applies not only to legally-harvestable (sexually mature) size classes, but also to younger fishes that

have yet to contribute to the collective reproductive output of the species and therefore their ability to replenish local populations.

Examining the status and distribution of reef fish spawning aggregations in the Southeast Florida Coral Reef Initiative (SEFCRI) Region

The goal of this project was to 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 plan. In our efforts to attain that goal we have developed the first centralized repository for FSA reports in the South Florida region, and these data have also been included in an interactive Marine Spatial Planner (http://ourfloridareefs.org/tool/).

During the winter of 2015/16, an effort was initiated to characterize a historically known gag grouper spawning aggregation site near Boynton Beach, Florida. Sonar and 360 degree Remote Underwater Surveys, along with reports from collaborating divers, indicate that this particular aggregation did not form during the expected gag grouper spawning season of this year. Multiple mechanisms are possibly at work; the winter season was strongly influenced by El Nino weather patterns, and historically this site was subjected to heavy fishing pressure during the spawning season. While it is unclear why the aggregation has ceased to form, this observation warrants further investigation in the winter of 2016/17.

In addition to centralizing the local spawning aggregation reports for use by the SEFCRI working groups, data from the field effort in Jupiter, Florida have identified a link between water management strategies and the local reef fish communities. Major rainfall events, and the subsequent dumping of Lake Okeechobee in September, 2015 dramatically increased turbidity offshore near goliath grouper spawning sites. During that time, fish abundance as measured by acoustic survey was seen to decrease markedly. This human influenced disturbance potentially interfered with the spawning activity of an ESA listed species. The links between water and fisheries management are not immediately apparent, but these data offer insight into the relationship between two high priority topics in South Florida, and highlight considerations for future management actions.

Evaluation of ESA listed *Acropora* spp. Status and Actions for Management and Recovery

This ongoing project aims to document the long-term status of the remaining elkhorn coral populations in the upper Florida Keys and changes in the distribution of both elkhorn and staghorn corals. Elkhorn and staghorn corals are fast growing and structurally complex corals which provide coastal protection and habitat needed for several other economically important species. Specifically, this project documents the population trajectory (decline or recovery) of *Acropora* spp. populations in Florida and Curaçao, and identifies the cause(s) associated with these changes. These issues are addressed by focal, demographic monitoring of a subsample of the population and larger reef-scale distribution mapping. Mass bleaching events associated with warm thermal stress in both 2014 and 2015 affected the Florida Keys populations of these threatened coral species, and our established long term monitoring projects allowed us to evaluate the impact of these events. Natural recovery from stress events by Florida Keys elkhorn and staghorn corals is outpaced by increasing frequency and severity of stress events indicating an urgent need for recovery actions.

Defining Spawning Dynamics to Manage and Conserve Reef Fish Populations

Spawning aggregations of threatened or overfished groupers represent a focal point for exploitation but can equally serve management as a point to assess spawning stock health and recovery. The project team was able to continue long-term monitoring of three key species (red hind, black grouper and Nassau grouper) using a combination of high resolution passive acoustic monitoring and in-situ measurements of species abundance and size structure. Combined with past surveys, the results provide temporal patterns in aggregation periodicity, length structure and abundance, all of which are needed to assess current stock status. Results will lead to a predictive capacity to assess both the exact time of aggregation formation and how aggregation structure varies across aggregations within a single season.

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.

Synthesis of Information on Octocoral Biology, Ecology, and Fisheries in the South Atlantic in Support of Effective Management

A goal of this project was to provide the SAFMC, GMFMC, and FWC with the best scientific information to manage the octocoral fishery, with the least economic impact on the collectors who depend upon this resource for income. A major conclusion of the report is that the take of octocorals, below the 70,000 Federal Total Allowable Catch (TAC) or State of Florida quota per year threshold (a level that has never been reached), does not adversely affect the fishery. Florida Keys-wide abundance estimates presented for 15 octocoral species clearly documents that their populations are large (tens of millions to hundreds of millions, per species) and despite some fluctuations that are likely due to natural variation (along with sampling issues and taxonomic questions) are generally either stable or increasing. This result provides overwhelming evidence that current and projected collection levels are acceptable and that no octocoral species is over-collected. The scaling of quotas and landings at finer taxonomic resolution are not required. The numbers of colonies collected under the “other” and “purple” species groups represent 0.003% and 0.001% percent of their respective populations in the Florida Keys in 2009, respectively. Further, collectors rotate their collection sites and are selective about removing individual colonies that are size-appropriate and aesthetically pleasing for aquaria. These results also suggest that if demand for octocorals increases substantially, the 70,000 quota could reasonably be increased, assuming the reason for the increased demand could be rationally evaluated.

Targeted Products for Improving Ecosystem-Based Fishery Management in the Gulf of Mexico

This work addresses the broad need to develop statistical methodologies and information needs to support an ecosystem-based approach to fisheries. The work carried out will advance NOAA's integrated Ecosystem Assessment program, which is designed to make the management of marine resources more effective. The first component of this work is to continue the development of a trophic database for the Gulf of Mexico. This database is forming the basis for parameterization of an entire suite of ecosystem models (e.g., ATLANTIS, Ecopath/Ecosim, OSMOSE) which are currently in development in the Gulf. The second component of this work is to apply nonlinear time series forecasting methods to fisheries in the Gulf of Mexico. The nonlinear time series methods are being used to make short-term forecasts of the states of different components of the ecosystem, including physical dynamics and population abundances. Together, these two components are filling crucial gaps in existing research on ecosystem-based management in the Gulf of Mexico.

Developing a Decision-Support Tool for the Management of Clam Farms on the FL Gulf Coast

Our overall mission is to maintain and grow the economic impact of the hard clam aquaculture industry in Florida, to meet the increasing national and global demand for aquaculture products, and to respond to global climate change. Our program addresses the need for integrating a thorough understanding of the impacts of environmental variables and management decision on hard clam productivity. We are addressing this issue through the development of a preliminary decision-making tool for clam aquaculturists in the Gulf Coast of Florida. This will be the first such tool for the region and may eventually provide a tool to predict environmental factors that affect the sustainability and productivity of shell fish populations

Natural Resource Damage Assessment Plankton Processing

This project delves into the impacts of the 2010 Deepwater Horizon Oil Spill on larval fish that spawn in the Gulf of Mexico. Many of these species are commercially important for local fishermen, and also provide sources of food and are valuable exports. This work was designed to determine abundance and assemblage structure of these valuable species during and immediately after the DWH oil spill, and assess how these have and will change as compared to historical data. By adhering to these historical protocols, we can provide data which can in turn be compared to years of SEAMAP results. The FORCES Lab is honored to have been a part of the damage assessment for the historical event, and contribute towards a return of the ecosystem back to pre-spill status.

Coral Restoration and Recovery

Since the 1980's, coral populations, particularly elkhorn and staghorn, have suffered critical declines warranting their listing as threatened species. This project addresses various science needs to foster recovery, both via natural and proactive means. Basic life history information such as fertilization rates, larval duration, and timing of settlement competence can improve estimates of larval production and connectivity while the evaluation of success of elkhorn coral outplants, including their relative thermal tolerance can lead to improved population enhancement efforts. Unprecedented success in culturing larval recruits of *O.faveolata* beyond a couple months of age provide a step closer to using genetically diverse, sexually produced propagules in restoration/recovery actions for this imperiled species.

Husbandry and Outplanting of Relocated Acropora cervicornis from Miami Harbor

***Relocation of threatened staghorn corals (Acropora cervicornis) impacted by dredging activities at Miami Harbor*:** Coastal development and dredging activities, such as the dredging of the channel at Port of Miami, increase sedimentation rates and constitute a serious threat to coral reefs particularly for protected species such as the threatened staghorn coral, *Acropora cervicornis*. Therefore, prompt action was necessary to rescue and relocate imperiled corals to nearby protected coral nurseries to propagate new corals for use in restoration and mitigation activities. Over one year, >1,500 new corals were propagated within the nurseries and >600 were returned to local reefs significantly increasing local staghorn coral abundance and contributing to reef complexity and habitat. Such restoration activities are providing a sustainable source of corals for use in future outplantings and bridging spatial gaps between existing staghorn populations which will increase the potential for recovery.

Quantitative Tools to Study Individual to Population-Level Implications of Marine Animal Movement

We investigated the extent that the 2010 Deepwater Horizon oil spill potentially affected oceanic-stage sea turtles from populations across the Atlantic. Within an ocean circulation model, particles were backtracked from the Gulf of Mexico spill site to determine the probability of young turtles arriving to this area from major nesting beaches. Abundance of turtles in the vicinity of the oil spill was derived by forward-tracking particles from focal beaches and integrating population size, oceanic-stage duration, and stage-specific survival rates. Simulations indicated that 321,401 (66,199 – 397,864) green (Chelonia mydas), loggerhead (Caretta caretta), and Kemp's ridley (Lepidochelys kempii) turtles were likely within the spill site. These predictions compared favorably to estimates from in-water observations recently made available to the public (though our initial predictions for Kemp's ridley were substantially lower than in-water estimates, better agreement was obtained with modifications to mimic behavior of young Kemp's ridley turtles in the northern Gulf). Simulations predicted 75.2% (71.9-76.3%) of turtles came from Mexico, 14.8% (11-18%) from Costa Rica, 5.9% (4.8-7.9%) from countries in northern South America, 3.4% (2.4-3.5%) from the United States, and 1.6% (0.6-2.0%) from west African countries. Thus, the spill's impacts may extend far beyond the current focus on the northern Gulf of Mexico.

Linkages Between Coral Health and LBSP: Identifying Sub-Lethal Coral Response to Environmentally Realistic Nutrient Exposure

This project has examined key linkages between LBSP nutrient levels and coral health, aimed at informing management actions targeted at reducing the levels and impacts of LBSP. It encompassed a controlled tank experiment to assess the effects of environmentally-realistic levels of dissolved inorganic nitrogen (DIN) on coral health and function, allowing direct linkage of multiple coral health metrics with specific nitrate threshold levels over a six-month chronic exposure. This project has provided resource managers with experimentally determined thresholds of effect of elevated nitrate concentrations on coral health, applicable to planning and implementing LBSP action strategies.

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

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)

This work aims to investigate the impact of NASA Global Hawk UAS observations on the prediction of tropical cyclones in regional numerical models. 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. While no data assimilation leads to the failure to maintain an organized tropical system in the forecast, the addition of the standard manned aircraft observations results in a longer-lived tropical depression with a much improved track forecast. The further addition of the Global Hawk UAS observations improve the intensity forecast with a tropical storm that reaches peak intensity within 2-3 days much like the observed scenario.

Impact of Hyperspectral Sounder on Prediction of Tropical Cyclones

The geostationary hyperspectral sounder has the potential to improve hurricane track and intensity forecasts, but it is advantageous to evaluate its potential benefits prior to investing in its construction and deployment. To this end, we have conducted OSSEs to help determine the impact of this sounder on a realistic hypothetical tropical cyclone.

Reanalysis of the Atlantic Basin Tropical Cyclone Database in the Modern Era

This research will redefine the climatology of historical hurricanes from 1964, 1966-1969 as represented in HURDAT. The improved climatology is essential, both as a baseline for assessment of changes in hurricane numbers and intensities as the Earth warms, and for evaluating the contemporary hurricane threat in fields like windstorm underwriting or emergency management. The reanalysis synthesizes media accounts, historical records such as ship logs, archived meteorological observations, and synoptic-scale reanalyses in light of 21st century understanding to produce a new and improved HURDAT consistent with everything we know about past hurricanes. Since the hurricane record is noisy and episodically varying, extraction of every last bit of information from it is essential to formulation of rational responses to changing climate and evolving human and economic vulnerabilities.

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

This work supports efforts by NOAA to demonstrate and test a prototype UAS concept of operations that could provide valuable data for forecast models and help mitigate possible gaps in weather satellite coverage in the future. This project's efforts to optimize the use of UAS platforms like the Global Hawk that can continuously monitor TCs over extended periods of time will provide unprecedented opportunities to improve both forecasts and our general understanding of TC track, intensity change, and structure.

Near-automation of real-time airborne radar analysis onboard NOAA aircraft
With airborne Doppler radar providing the most widespread observations of the hurricane core at a 1.5km resolution, hurricane modelers have recognized the value of simulations being initialized at this fine resolution. Operationally, to simplify the task of submitting configuration parameters for each Doppler radar job, minimizing human error and maximizing timeliness, is the first step in the chain of delivering quality-controlled analysis in real-time within the time window offered by the NCEP Environmental Modeling Center.

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

Sustained and Targeted Ocean Observations for Improving Atlantic Tropical Cyclone Intensity and Hurricane Seasonal Forecasts
A study currently in preparation (Dong et al.) has addressed the impact of assimilating glider observations on the forecast of Hurricane Gonzalo (2014). The assimilation of underwater glider observations significantly improves pre-storm ocean thermal and saline structure for Hurricane Gonzalo (2014). The intensity forecast of Gonzalo is also greatly improved by assimilation of ocean observations, highlighting the importance of ocean initialization on coupled hurricane forecast.

The North American Multi-Model Ensemble (NMME) Intraseasonal-to-Interannual Prediction Experiment
NMME project has become an official operational NOAA product. Specific prediction research questions have examined the impact of coupled vs. prescribed SST in the predictability North American T2m and precipitation, and showed that coupling has a relatively small effect when compared to typical SST forecast errors. The project has also documented how initializing the atmosphere and land impact forecast skill over the US, and is a set of novel numerical experiments showed that La Nina may be more predictable than El Niño.

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, supported by this work, provides that single reference point used by the international community of ocean color satellite systems to tie these measurements together. This allows the ocean color record to be maintained over generations of satellite instruments to provide a data record suitable for studies of climate and ecological change. This calibration site is used by the international community, and is a key asset to the current NOAA satellite instrument, VIIRS on the Suomi NPP platform and the upcoming JPS-1 platform.

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

Coral Health and Monitoring Program (CHAMP)

Enochs and colleagues published a study describing a naturally acidified coral reef ecosystem at the remote island of Maug in the Commonwealth of the Northern Mariana Islands. This was the first time that scientists have seen a spatial shift from a healthy reef to an algae-dominated system, correlated with elevated CO_2. Both chemical and ecological gradients were quantified using a variety of advanced procedures including photo-mosaics, CT imaging of coral cores, and high-resolution SeaFET pH loggers. Together, these data provide insight into the influence of ocean acidification on reefs world-wide.

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.

The GO-SHIP Repeat Hydrography Program

The purpose of this program is to quantify changes in storage and transport of heat, fresh water, carbon dioxide (CO_2), oxygen, nutrients, chlorofluorocarbon tracers and related parameters in the world oceans. 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. Our contribution to the program addresses changes in the carbon system in the ocean. We achieve this by reoccupying select transects of the oceans on a decadal frequency to determine long-term changes. This type of sustained, repeat hydrographical cruises are currently the only way to sample the deep oceans and quantify changes in storage and transport with adequate precision and accuracy.

Western Boundary Time Series Project

The Western Boundary Time Series (WBTS) project maintains one of the longest time series of water mass and transport observations of key components of the global meridional MOC. Variations in the MOC have been shown in numerical climate models to be related to important societal quantities such as precipitation over the northern hemisphere, sea surface temperatures, and hurricane intensity. The WBTS project documents, through innovative uses of many different observational methods, the time variability of the warm upper and cold lower limbs of the MOC, which are carried, respectively, in the Florida Current and the Deep Western Boundary Current (DWBC). The project maintains daily observations of Florida Current and Deep Western Boundary Current transports as well as quarterly-to-annual ship sections to observe water property changes in both the Florida Straits and east of the Bahamas Islands. Research completed during

this period has found, among other things, that there is a lack of vertical coherence with the varying structure and transport of the Gulf Stream from the Straits of Florida to the Southeast Newfoundland Ridge (Meinen & Luther, 2016). Analysis of observations from three different dynamical regimes located along the Gulf Stream path showed that distinct upper and deep flows are incoherent at time scales of weeks up to two years. The implication of these results is that resolving the total Gulf Stream structure and flow requires full depth profiles, instead of using vertically-limited or remote observation.

Frajka-Williams et al. (2016) looked at the compensation between meridional flow components of the Atlantic MOC at 26ºN from ten years of observations. On the western boundary most of the interannual variability of the MOC can be traced to changes in isopycnal displacements, within the top 1000 m and below 2000m. This emphasizes the importance of deep boundary measurements, where substantial trends in isopycnal displacement are observed, to capture the variability of the Atlantic MOC.

PIRATA Northeast Extension (PNE)

The causes of observed boreal winter/spring sea surface temperature (SST) anomalies in the tropical North Atlantic between 1982 and 2015 were examined using a composite analysis of satellite and reanalysis data. Results show important damping of SST anomalies from wind-driven changes in mixed layer depth (MLD) and cloudiness-induced shortwave radiation in the deep tropics (5S–10N), in addition to the well-known positive wind-evaporation-SST and shortwave radiation-SST feedbacks between 5N–20 N. A robust influence of thermocline depth variations on SST is not found in the Intertropical Convergence Zone (ITCZ) region. For example, much stronger anomalies of wind stress, thermocline depth, and vertical turbulent cooling are found during a negative AMM event in 2009 compared to a positive event in 2010, despite SST anomalies of similar magnitude in the early stages of each event. Our results suggest that the preconditioning role of the winter cross-equatorial SST gradient may be a possible cause for this inconsistent relationship between thermocline depth and SST in the ITCZ region.

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

The broad scientific issue addressed by our work is air-sea CO_2 fluxes. The oceans absorb an estimated 30% of the anthropogenic CO_2 that would otherwise be stored in the atmosphere, thus increasing atmospheric levels of CO_2, which is why it is very important to be able to accurately determine the ocean-atmosphere exchanges. Our 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. We do this by providing 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). This collaborative program (led by Dr. Pierrot) of investigators at the NOAA laboratories AOML and PMEL, Columbia University, the University of Miami, and the Bermuda Institute of Ocean Sciences is the largest program of its kind in the world. This is a critical component of constraining the global carbon cycle which is of paramount importance for verification of climate frameworks such as proposed in COP-21.

Using SEDAR-assessed stocks to validate the accuracy of data-poor methods

The goal of this project is to determine suitable methods for the assessment of data poor fish stocks in the Southeast. Using SEDAR-assessed stocks to validate the suitability of data-poor methods no standout method could be found. The accuracy of all data-poor methods was poor, however DCAC-

based methods, DB-SRA-based methods, and SP-MSY stood out consistently as the highest performing methods out of all tested in both MSY and OFL scenarios. When input parameters suggested by the original papers describing DCAC and DB-SRA were used, DCAC produced estimates of OFL equivalent to those produced by DCAC informed with SEDAR input parameters. Overall, DCAC-based methods and SP-MSY may be most practical for management due to their precautionary performance and low data requirements.

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). Currently, we 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. The community composition, biodiversity, and interactions of the coral algal symbiont populations in the coral holobiont and of the microbial community populations in the coral microbiome have been implicated as major drivers influencing coral resiliency to environmental stress. We believe these data are fundamental to the discussion of timely questions about the role of ocean outfalls in the maintenance of coastal ecosystem health, in that it seeks to fill a major data gap in our nutrient and ocean current data in the area of interest.

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.cimas.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.

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 III non-NOAA, as described below.

Research in CIMAS under this CA was also carried out under Tasks III, Task III linked to CIMAS and Task IV non-NOAA. 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 linked to CIMAS 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 non-NOAA 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. At the end of this award period (2010-2016), there is a total of 128 research and 7 administrative persons were associated with CIMAS in various capacities. Of these, 107 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. Sixty-four (64) are located at AOML, 29 at the SEFSC, 1 at RSMAS, 2 at NHC. 6 work at distant NOAA facilities and 5 at UPR.

Table 1: CIMAS Research Personnel

Category	Number	BS	MS	Ph.D
Research Associate/Scientist	72	18	33	21
Part Time Research Associate/Scientist	6	1	2	3
Other Research Professional Category	3	1	1	
Postdoctoral Fellow	11			11
Research Support Staff	15			
Total (> 50% NOAA support)	**107**	**20**	**36**	**35**
Full Time Administrative Staff	5			
Task I Undergraduate Students	6			
Task I Graduate Students	10			
Visiting Scientist	7			
NOAA Association	64 - AOML 29 - SEFSC 1 - RSMAS 13 - (2) NHC, (5) UPR, (6) Other			
Obtained NOAA employment within the last year	3			

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 levels 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 11 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 three 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 “Department” 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 departments (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 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; Bonnie Ponwith, NMFS/SEFSC and R. Knabb, NWS/NHC), the Director of the NOAA CI Office: Candice Jongsma 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. Benjamin Kirtman, 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 thirtyeight 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 3 CIMAS employees transitioned to Federal position.

Demographics of CIMAS Employees

The CIMAS population is 59% male. Foreign-born individuals make up 45% of the personnel; of these Hispanics make up 20% of the ranks; Asian and Pacific Islanders, 12%. Only 2% 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 63. 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 10 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, 6 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 VII. Education and Outreach section) 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:

The total award funding from all sources totaled ca. $93.2M under the old 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
Year 5 Aditional	22,000	110,000	532,003	1,032,644	1,696,647
TOTALS	**10,910,640**	**41,127,921**	**35,384,993**	**5,856,849**	**93,280,403**

The sources of that funding are shown in Table 2 which indicates the average for the duration of the agreement. The major source of NOAA funding continues to be OAR which provided 53% of the total. NMFS, NESDIS, NOS contributed at 20%, 12%, and 6.6% respectively. "Other" accounts for 4%. The source of funding includes awards from NASA, NSF and private industry as well as sub-contractual awards from other universities to CIMAS investigators.

Table 2: Funding by Source

1 July 2010 - 30 November 2016		
Source	**Funding $M**	**% Total**
CRCP	0.06	0.4%
Dept of Defense	0.31	2.2%
Homeland Security	0.07	0.6%
NESDIS	2.36	12.0%
NMFS	3.81	20.0%
NOS	1.19	6.6%
NWS	0.31	2.0%
OAR	3.81	24.0%
OAR/AOML	4.46	23.0%
OAR/CPO	1.02	5.0%
OAR/OER	0.21	1.0%
Other	0.70	4.0%
GRAND TOTAL	**18.31**	**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 (including linked to CIMAS)** 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 non-NOAA funds 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 is 40% and for Task IV non-NOAA 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 for the total award period was $ 10.91M, in addition the University contributed about $0.24M per year for the Administration component. The distribution of NOAA Task 1 expenditures is shown in Figure 1. The category “Administration” 21% covers a portion of the salary of CIMAS staff including its Director and Associate Director. The category "Other" 13% 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 26% of the total. Temporary Staff accounts for 21% 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 11%.

Task I: General

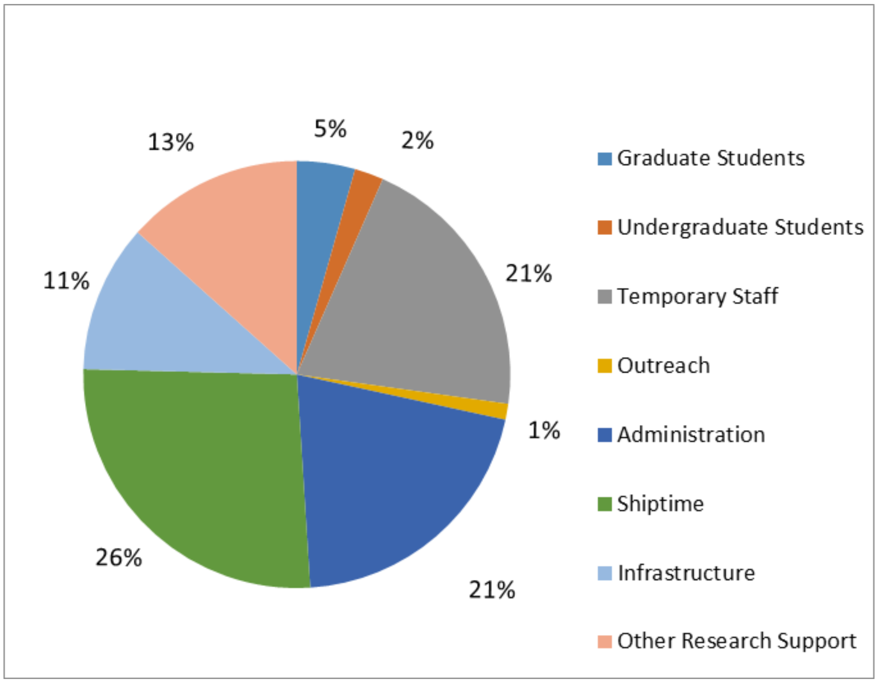

Figure 1: Distribution of Task1Funding

The funding provided for Task II employees totaled $41.1M over the total award. The distribution of these funds by employee category was reported every year during the duration of the award. The table below in Figure 2 indicates the existing distribution by category.

Task II: Employees by Category

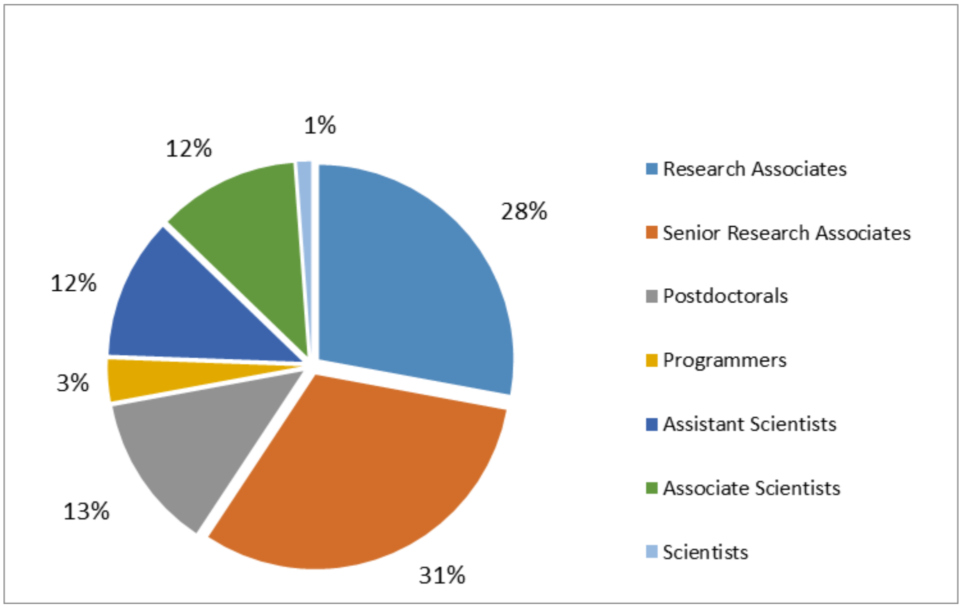

Figure 2: Distribution of Task 2: Funds by Employee Category

Funding by Theme

Project-specific research funding (Tasks III and IV) under the old CA totaled $41.2M as shown above in Table 1. Figure 3 shows the percentage of Task III funding expended upon each CIMAS Themes during the award period. Of total CIMAS research funds, Theme 3: Sustained Ocean and Coastal Observations continues to account for the largest portion of the funding 39%. The smallest portion of funding was in Theme 5: Ecosystem Modeling and Forecasting – 4%.

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 non-NOAA; 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

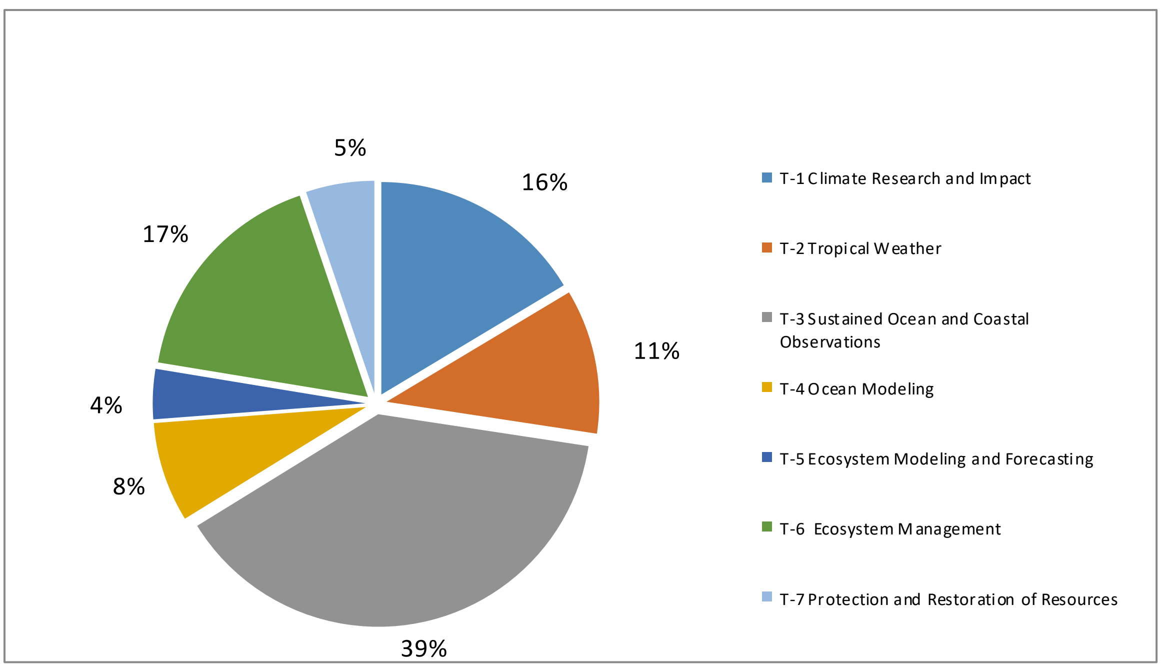

Figure 3: Percentage of Task 3 and Task 4 (Individual Research Project) funding per Theme

Table 3 below tabulates all projects (Task III) funded through the agreement totaling $25.2. These projects include Funding distributed through CIMAS to the Partner Universities during the performance period of this award (July 1, 2010 through November 30, 2016) of $5.6M or 23% of Task III.

	Table 3: NOAA Projects funded through the Main Award	
Principal Investigator	**Project Title**	**Funding Amount**
Ault, J	Florida Reef Track Fish Management and Assessment	$ 560,000
Ault, J	SEFCRI: Comprehensive Reef Fish Monitoring Program	$ 32,000
Babcock, E	Evaluation of Management Strategies for Fishery Ecosystems	$ 566,570
Babcock, E	Simulation of Management Strategies	$ 171,554
Babcock, E	Evaluation of Management Strategies for Fisheries Ecosystems	$ 308,507
Beron-Vera, F	Assessing Inertial Effects on Surface and Subsurface Drifting Buoy Motion	$ 65,362
Beron-Vera, F	Contribution to AOML Ocean Circulation Studies	$ 15,043
Beron-Vera, F	Monitoring of Surface and Subsurface Ocean Conditions during the period of April-October, 2010	$ 15,000
Capo, T	Assessment of Coral Reef Ecosystem Resilience Using Taxa-Specific Bleaching Thresholds	$ 10,000
Cherubin, L	Vieques sound and Virgen Passage Transport Study Modeling Component	$ 25,925
Criales	Florida Bay Pink Shrimp Project	$ 139,383
Die, D	Ecological Indicators for Water Management & Ecosystem Restoration of South Florida Estuaries	$ 142,850
Die, D	International Circle Hook Symposium	$ 45,000
Die, D	Targeted products for Improving Ecosystem-Based Fishery Management in the Gulf of Mexico	$ 156,397
Die, D	A Creel Survey of the Recreational (non-commercial), boat ramp-based Fisheries in St. Croix	$ 108,575
Elipot	High-Frequency Variability of Near-Surface Oceanic Velocity from Surface Drifters	$ 47,198
Enochs, I	Elucidating Net Ecosystem Prediction and Calcification at the Atlantic Ocean Acidification Testbed	$ 130,412
Evans, R	Developing the Operational Calibration/Validation Components for VIIRS SST Retrievals	$ 1,217,698
Gleason, A	Assessing the Location and Status of Reef Fish Spawning Aggregations in the Florida Keys	$ 47,375
Glynn, P	Climate Effects on Coral Reef Fishes	$ 60,500
Kamenkovich, I	Simulation of the Argo Observing System	$ 115,908
Kirtman, B	A North American Multi-Model Ensemble ISI Prediction Experiment	$ 120,000
Kirtman, B	CIMAS: Evolutionary Reinvention "Subcontract Awards to CIMAS University Partners - University of Florida"	$ 173,505
Kirtman, B	CIMAS: Evolutionary Reinvention "Subcontract Awards to CIMAS University Partners" Florida International University"	$ 2,407,560
Kirtman, B	CIMAS: Evolutionary Reinvention "Subcontract Awards to CIMAS University Partners: Florida State University"	$ 429,205
Kirtman, B	CIMAS: Evolutionary Reinvention "Subcontract Awards to CIMAS University Partners: NOVA Southeastern University"	$ 808,429
Kirtman, B	CIMAS: Evolutionary Reinvention "Subcontract Awards to CIMAS University Partners: University of Puerto Rico"	$ 77,000
Kirtman, B	CIMAS: Evolutionary Reinvention "Subcontract Awards to CIMAS University Partners: University of South Florida"	$ 1,718,187
Kirtman, B	NOAA Climate Test Bed (CTB) National Multi-Model Ensemble (NMME) Prediction System Phase 1 NMME Implementation Plan	$ 141,733
Kourafalou, V	Development of an Earth System Component for Medium-Range Predictability in Coastal Seas: Initial Application on Gulf of Mexico Harmful Algal Blooms and Hypoxian Episodes	$ 146,123
Kourafalou, V	Hydrodynamic Modeling in Support of the Oil Spill Response in the Gulf of Mexico	$ 185,086
Kourafalou, V	Ocean OSSE Development for Quantitative Observing System Assessment	$ 200,000
Langdon, C	Biogeochemical Measurements	$ 574,824
Langdon, C	Discrete Oxygen Measurements for East Coast Ocean Acidification Center	$ 35,000
Langdon, C	Oxygen Winkler Titrations in Support of the Deep Water Horizon Oil Spill Response	$ 10,048
Langdon, C	Potential for Recovery/Resilience of Corals and Algal Interference Under Climate Change	$ 148,288
Letson, D	Measuring the Value of Climate Variability on the Agricultural Sector	$ 132,784
Letson, D	Measuring the Value of Climate Variability on the Agricultural Sector: Climate Prediction and Applications Science Workshop	$ 15,000
Lirman, D	Biscayne Bay's Nearshore Submerged Aquatic Vegetation (SAV)	$ 358,024
Lirman, D	Husbandry and Outplanting of Relocated Acropora Cervicornis from Miami Harbor	$ 115,438
Luo, J	Comparative Analysis of Population Dynamics Using a Population Model that Explicity Considers Habitat (SEAPODYM) and one that does not (Stock Synthesis) for Atlantic Tuna	$ 93,902
Luo, J	Incorporating Hypoxia-based Habitat compression Impacts into Stock Assessment Process for Tropical Pelagic Billfish and Tuna	$ 53,434
Luo, J	Monitoring Shoreline Fish Assemblages of Biscayne and Florida Bays	$ 20,000
Luo, J	Spatial Analysis of Pop-up Satellite Archival Tag Data for Tuna and Istiophorid Billfishers incorporating Oceanographic Environmental Data and Considering the Implication of Climate Change	$ 17,493
Majumdar, S	Evaluating Global and Regional Observing System Simulation Experiments for Hurricanes	$ 102,367
Millero, F	CO2/Clivar Repeat Hydrography Program CO2 Science Team	$ 15,000
Millero, F	Surface Water pCO2 Measurements from Ships	$ 976,250
Minnett, P	Developing the Operational Calibration/Validation Components for VIIRS SST Retrievals	$ 162,750
Nolan, D	Development of Observation System Simulation Experiments for Unmanned Aircraft Systems in Hurricanes	$ 85,297
Nolan, D	Further Development of Observing System Simulation Experiments for Unmanned Aircraft Systems in Hurricanes	$ 74,960
Ortner, P	Ocean Conditions in the Gulf of Mexico	$ 70,000
Ortner, P	Oceanographic and Spectroscopic Sample Analysis Relating to the Deepwater Horizon Oil Spill	$ 80,089
Ortner, P	REPP-Connectivity-PR Connectivity of the PR-S.FL Coral Reef Ecosystem Complementary Technology Development and Augmented Summer 2014 Field Program	$ 250,000
Paris, C	Prioritizing Spawning Habitats in Terms of their Relative Contribution to Recruitment Success	$ 46,921
Paris, C	Use of a Biophysical Modeling Framework to Develop a Recruitment Index for Inclusion in Stock Assessments in the Gulf of Mexico	$ 43,786
Perez, R	Remote Sensing in Support of Climate Research	$ 584,130
Reid, P	Application and automation of Underwater Image Mosaics for Sampling, Characterizing, and Classifying Corals as Protected Stocks and Habitat	$ 140,203
Shay, N	Evaluation of Sea Surface Height Anomalies from the Cryosat-2 Mission to Enhance the NESDIS Operational Ocean Heat Content Product Suite	$ 99,998
Shay, N	Ingesting Sea Surface Height Anomalies from the Crysat-2 Mission to Enhance the NESDIS Operational Heat Content Product Suite	$ 59,900
Shay, N	Studies in Support of NOAA's Operational Ocean Heat Content Analysis for the South Pacific Ocean Basin	$ 150,000
Shay, N	Studies in Support of NOAA's Operational Ocean Heat Content Analysis Using Deep Water Horizon Measurements	$ 200,000
Shay, N	Upper Ocean Sampling of Currents and Salinity in the Loop Current to Monitor the Deep Water Horizon Oil Spill	$ 28,394
Shyu, M	Data Integration and Data Mining Support for Tropical Cyclone Integrated Observing System	$ 33,537
Shyu, M	System Support for the Development and Simulation of Tropical Cyclones in a Linux Cluster System	$ 33,537
Solis, D	Modeling Heterogeneous Production Processes in the GOM Red Snapper Fishery	$ 25,000
Voss, K	Developing a Low-Cost, In-Water Stereo-Video Camera for Use in Fishery-Independent Surveys	$ 43,173
Voss, K	Marine Optical Buoy (MOBY) Operations and Technology Refresh	$ 8,680,646
Voss, K	Marine Optical Buoy (MOBY) Operations Bridge Through NPP Launch	$ 1,259,858

Task III awards to CIMAS during the 2015-2016 reporting period where those projects were assigned a different award number (although they are "associated" with the overall Cooperative Agreement) are listed in Table 4.

Table 4: NOAA Projects with Individual Award Numbers

NA12OAR4310105	Criales, M	08/01/12 - 07/31/15	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	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
NA15OAR4590201	Dunion, J	09/01/15 - 08/31/17	Improvement to the Tropical Cyclone Genesis Index (TCGI)	$	27,251
NA14OAR4310193	Kirtman, B	08/01/14 - 07/31/17	Developing decision support tools for understanding, communicating and adapting to the impacts of climate on the sustainability of coastal ecosystem services	$	178,788
NA15NOS4510226	Lehenaff, M	09/01/15 - 08/31/17	Evaluation of Gulf of Mexico oceanographic observation networks, impact assessment on ecosystem management and recommendation	$	199,126
NA15OAR4590203	Nolan, D	09/01/15 - 08/31/07	Guidance on observational Understanding over the tropical Cyclone lifecycle	$	37,292
NA11NOS4780045	Ortner, P	09/01/11 - 08/31/17	2011 REPP -Understanding Coral Ecosystem Connectivity in the Gulf of Mexico-Pulley Ridge to the Florida Key	$	4,518,662
NA13OAR4310131	Perez, R	09/01/13 - 08/31/17	South Atlantic Meridional Overturning Circulation: Pathways and Modes of Variability	$	222,723
NA14NWS4680028	Zhang, J	08/01/14 - 07/31/17	Addressing deficiencies in forecasting tropical cyclone rapid intensification in HWRF	$	389,332
NA14OAR4830119*	Zhang, X	04/01/14 - 03/31/17	CIMAS Contributions to OAR disaster Recovery Act Project	$	1,035,877
*** Awards under the Disaster Relief Appropriation Act of 2013.**					

Task IV non-NOAA linked to CIMAS encompass project-specific research funding at CIMAS under the direction of CIMAS researchers. These projects supported by other funding sources including a NOAA project not linked to CIMAS are listed on table 5 below.

Table 5: Other Funded Projects

PI	Start/end date	Funding Source	Project Description
Annane, B	12/31/15 -12/30/19	Purdue	Assimilation of GNSS-R Delay-Doppler MAPS into Hurricane models
Dong, S	04/01/10 - 06/30/17	NASA	Investigating the Processes Contributing to the Salinity Differences Between Aquarius and In-situ Measurements
Dunion, J	01/01/04 - 12/31/16	U of Wisconsin	An Observational and Numerical Investigation
Goes, M	09/15/15 - 08/31/18	NSF	The Interannual Variability of the Brazil Current
Perez, R	04/18/14 - 04/17/17	NASA	Variability of the South Atlantic Subtropical Gyre
Perez, R	09/15/16 - 08/31/19	NSF	Extratropical Triggering of ENSO Events Through the Trade-Wind Charging mechanism
Shultzitski, K	09/01/15 - 08/31/17	NOAA	Measuring larval bluefin tuna growth to improve a fishery-independent index, and help resolve uncertainty with the stock-recruitment relationship
Volkov, D	08/05/13 - 08/04/17	NASA	The Mediterranean & Black Sea: Analysis of Large Sea level and.
Zhang, J	07/03/14 - 07/02/18	U of Washington	Calculating tropical Cyclone Inflow and Boundary Layer Proce

Conclusion

This is the final report for this award which covers the period of July 1, 2010 to November 30, 2016. Additonal projects were funded under this award during the period of July 1, 2015 through September 30, 2015. A no-cost extension was granted from October 1, 2015 through November 30 2016 (no funds were received during the NCE period).

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 Table 4. For Task III non-NOAA projects and NOAA funded projects not linked to CIMAS see Table 4. To avoid unnecessarily burdening the responsible principal investigators of such Task III and all Task III non-NOAA and non-CIMAS linked projects we did not require submission of a CIMAS specific report such as those included in Section VI.

VI. RESEARCH REPORTS

THEME 1: Climate Research and Impact

Coral Health and Monitoring Program (CHAMP)

Project Personnel: N. Amornthammarong, I.C. Enochs, R. van Hooidonk, P.R. Jones, X. Serrano, R. Carlton, M. Jankulak, G. Kolodziej and L. Valentino (UM/CIMAS); L.J. Gramer (UM/CIMAS, USF/FIO); K. Peebles (UM/RSMAS)

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

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

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To 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 1**:** Climate Research and Impact (*Primary*)
Theme 3**:** Sustained Ocean and Coastal Observations (*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 Unit: 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. In the past year, CHAMP's Coral Reef Early Warning System (CREWS) has continued its collaboration with the Caribbean Community Climate Change Centre (CCCCC) to deploy coral reef monitoring buoys and to collect, process, disseminate and archive their data. CIMAS personnel conducted a thorough analysis and reprogramming of a previously nonoperational buoy that is destined for deployment at Belize's Calabash Caye, and two new buoys were deployed off the north and south coasts of the Dominican Republic. Figure 1a shows the CWDR1 buoy being deployed at Catuan Wreck, near Boca Cheeca, D.R., and Figure 1b is a recent screencap of that buoy's data feed as accessed via the CHAMP Portal data query web site (http://www.coral.noaa.gov/champportal).

In addition to these new in situ data sources, this past year the CHAMP Portal also added a new source of remotely-sensed sea surface temperature (SST) data based on products produced by Remote Sensing Systems (www.remss.com). This newly-integrated SST data source allowed the CHAMP Portal to add 92 more 'virtual' stations, including several sites of interest in Cuban waters such as the Banco de San Antonio which serves as a sister sanctuary to NOAA's Flower Garden Banks and Florida Keys National Marine Sanctuary in the US.

The Acidification, Climate, and Coral Reef Ecosystems TEam (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.

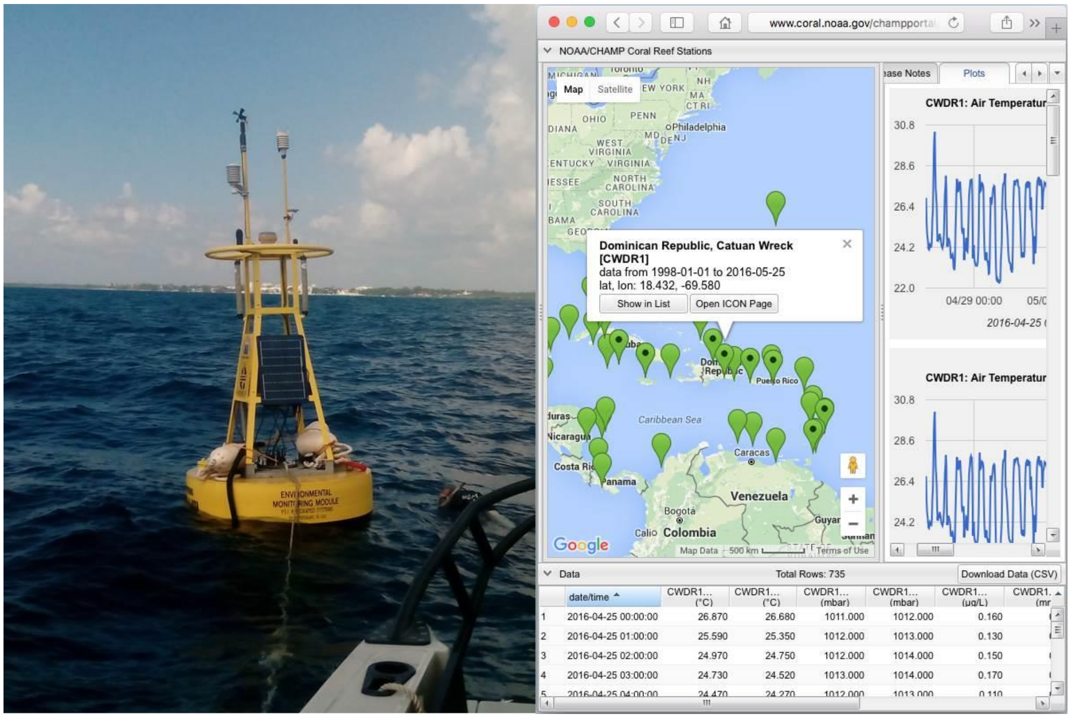

Figure 1: A) (left) shows the CWDR1 buoy being deployed at Catuan Wreck, near Boca Cheeca, D.R.; and B) (right) is a recent screencap of that buoy's data feed as accessed via the CHAMP Portal data query web site.

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 the Flower Garden Banks and in the Dry Tortugas. 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 in Panama as part of a collaboration with an NSF-funded study in the region.

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, Paul Jones, 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, monitoring coral symbiont communities, collection and processing of calibration/validation water samples, as well as electronics replacement and servicing of the MAPCO2 mooring.

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 completed coral reef monitoring associated with the Numeric Nutrient Criteria (NNC) study, involving monitoring three replicate reef sites at each of four reefs. Reef biometric data was generated using the EPA Stony Coral Rapid Bioassessment Protocol and the Periphyton Rapid Bioassessment Protocol to assess nuisance algal growth. Benthic surveys provide information on coral abundance and health using SCUBA-based in-situ measurements, as well as seasonal fluctuations in total benthic organismal abundance by analysis of photo-quadrats. 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.

CIMAS researcher Xaymara Serrano, in collaboration with NOAA/NMFS scientist Margaret Miller and RSMAS professor Andrew Baker, completed a series of laboratory-controlled experiments with larvae and newly-settled coral recruits from the species *Porites astreoides* and *Orbicella faveolata*, with the goal of investigating the effects of nutrient enrichment and elevated sea surface temperatures on the early life stages of these two species. Effects in symbiont community (identity and abundance), larval oxygen consumption, proportion settlement and larval survival of these two species were measured (Figure 2). A manuscript is currently being written summarizing the main findings from this study. Overall, results are expected to provide empirical evidence that might support the implementation of environmental policies aimed at improving water quality and maximizing reef resilience. Furthermore, because this research was undertaken using a species just listed as threatened under the ESA (*O. faveolata*), results are timely and relevant for the conservation and protection of this species.

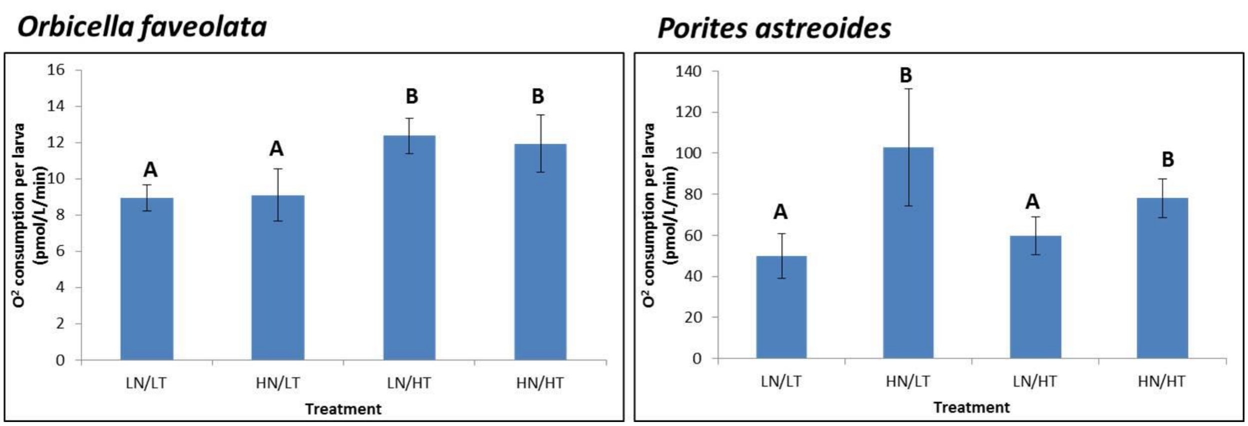

Figure 2: Respiration rates measured in *Orbicella faveolata* (left panel) and *Porites astreoides* (right panel) coral larvae after exposure to one of four experimental treatments: 27°C / 0.4 µM $NaNO_3$ (low nitrate and low temperature, denoted as LN/LT), 27°C / 14 µM $NaNO_3$ (high nitrate and low temperature, denoted as HN/LT), 31.5°C / 0.4 µM $NaNO_3$ (low nitrate and high temperature, denoted as LN/HT), and 31.5°C/ 14 µM $NaNO_3$ (high nitrate and high temperature, denoted as HN/HT). Different letters indicate significant differences among treatments.

Serrano also collaborated with scientists from the Department of Environment in the Cayman Islands and RSMAS professor Andrew Baker to investigate the genetic connectivity of corals between the Cayman Islands and among depths (shallow vs. deep) at each island. The two target coral species in this project were the broadcaster spawner *Montastraea cavernosa* and the brooding coral *Porites astreoides*. Data from this project is currently being analyzed to include in a manuscript. Overall, findings will help collaborators ensure that Marine Protected Areas in the Cayman Islands adequately protect important sources of larval recruits, maximize reef recovery, and prevent further habitat loss and degradation.

Local-scale projections of coral reef futures and implications of the Paris Agreement.
In the past Ruben van Hooidonk produced climate model-resolution (~1x1°) projections of the timing of annual severe bleaching (ASB) under the Representative Concentration Pathway emissions scenarios for all coral reefs in 2013 and 2014. These projections have informed global policy (they are cited in IPCC AR5) but are too coarse to inform conservation planning. To meet the need for higher-resolution projections, van Hooidonk generated statistically downscaled projections (4-km resolution) for all coral reefs. This research highlights the spatial patterns of these projections and evaluates the implications of the COP21 Paris Agreement for the projected timing of the onset of ASB; a point at which reefs are certain to change and recovery will be limited. These downscaled projections reveal high local-scale variation in ASB under RCP8.5 (a 'no climate policy' scenario). Timing of ASB varies >10 years in 71 of the 87 countries and territories with $\geq$500km^2 of reef area and some countries have far more relative 'climate winners' than other countries (Figure 3). These results indicate the projections warrant consideration in conservation and management planning at all spatial scales. Emissions scenario RCP4.5 represents lower emissions mid-century than will eventuate if pledges made following the 2015 Paris Climate Change Conference (COP21) become reality. RCP4.5 adds ~15 years on average before ASB occurs when compared to RCP8.5; however, >75% of reefs still experience ASB before 2070 under RCP4.5. Much greater emissions reductions are required than were pledged following COP21 to prevent the great majority of coral reefs from experiencing severe bleaching conditions annually this century.

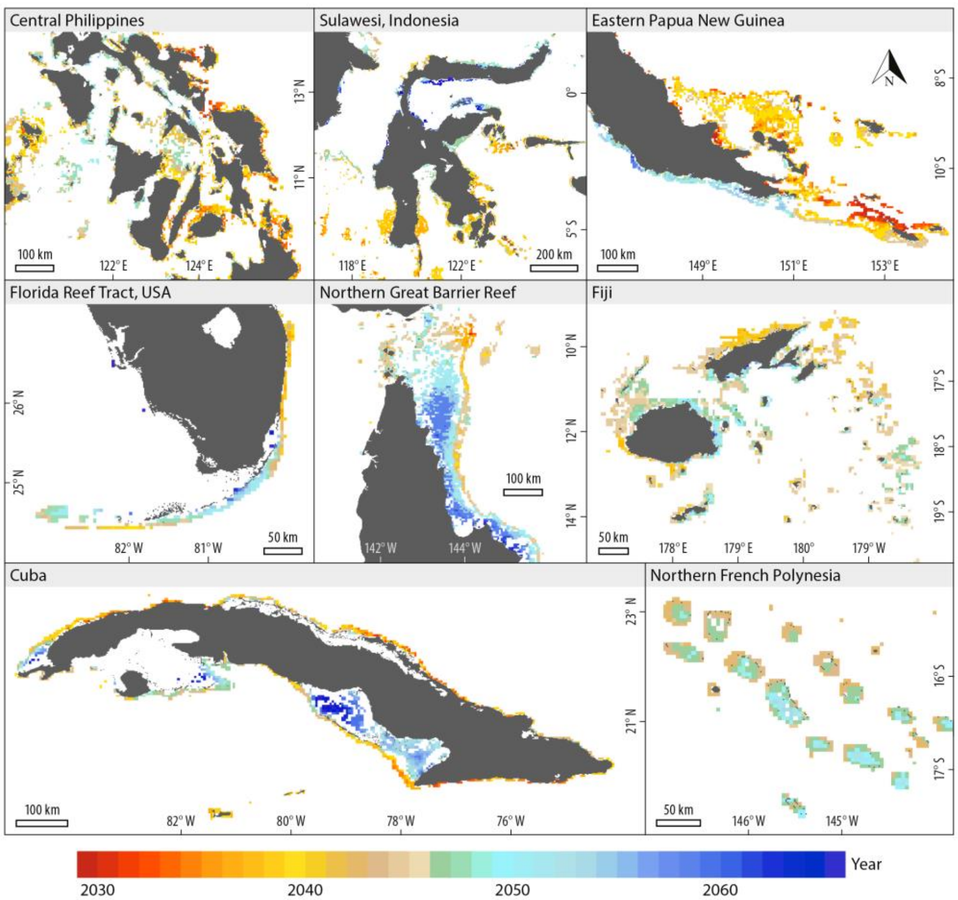

Figure 3: Statistically downscaled projections of the timing of the onset of annual severe bleaching (ASB) conditions under RCP8.5. These exemplify the high local-scale (10's of km) variation seen in projected ASB timing in most locations and, though atypical, the low variation seen in Northern French Polynesia.

This is a novel effort; these are the only downscaled projections produced to date for a marine ecosystem with a global distribution. The results will be shared as easy to use Google Earth files on NOAA's Coral Reef Watch website (http://coralreefwatch.noaa.gov/satellite/research/index.php) and the United Nations Environment Programme Live website (http://uneplive.unep.org/).

Since 2013, CIMAS researcher Lew Gramer has collaborated with Prof. Chuanmin Hu and Brian Barnes (University of South Florida) on final 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 (CNMI). These partners developed an algorithm to produce a proxy (Color Index or "CI") for "relative" in-water turbidity within shallow (<= 5 m) generally clear waters, using ocean color data from the MODIS and VIIRS instruments aboard polar-orbiting satellites. The algorithm was applied to twelve years of daily satellite overpasses in these three regions of particular interest for U.S. coral reef conservation. In prior years, customized ocean color data products were generated and analyzed 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 were previously extracted, with the goal of identifying locations for sensor deployment with maximal quantity and quality of concurrent satellite data. These satellite ocean color products were analyzed to understand the impact of the port of Miami dredging on turbidity plumes, and their impact on coral reefs. A paper was submitted by USF partners to the journal Remote Sensing of Environment. In 2015-2016, Gramer processed and analyzed high-resolution wave model products for the three regions, and found linear relationships between relative turbidity and wave action seasonally in southeast Florida and a portion of the coastline of the major island of American Samoa, Tutuila. Wave action did not explain significant events of relative turbidity at multiple sites within these two regions, nor was such a relationship apparent for any pixels analyzed within the CNMI (Figure 4). This together with the spatial placement of periodic events within each coastal region suggest that the satellite products do in fact allow frequent monitoring of in-water turbidity over these three disparate shallow coral reef systems.

Gramer also continued collaborations 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, were analyzed for the region, with continuous data covering all hurricanes and tropical storms that passed south Florida during the period. Analyses of summer periods between storms in prior years shows 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. Gramer analyzed data from cross-shore profiling sections of SE Florida shelf at depths from 20 to 360 m, covering the entire seasonal cycle, in cruises between 2006 and 2014. He found consistent linear relationships between temperature (T) below 24C and each of the three macronutrients, nitrogen, phosphorous, and silicates (Figure 5). Zero-intercept in all cases was between 24 and 25C, slope of robust regressions (R-squared of 0.7 or greater, $p<0.001$) was approximately -0.8 to -1.5 micromole / K for NOx and Si, and -0.06 to -0.09 for P (consistent with the Redfield ratio). No such relationship could be observed for ammonia or nitrite. Sea temperature and currents data from the array of moorings at depths of 11 to 140 m in the central SE Florida shelf over two years, and thirteen years of such data from the mooring at 11 m, showed episodic upwelling of water at initial temperatures less than 24C each summer analyzed, and currents data show that this cooler, nutrient-rich water reaches the 11 m isobath at final temperatures ranging from 21 to 27C, multiple times during two successive summers. The signature of

these upwelling events was then observed at 11 m during each of the other ten complete summer records available. Gramer also analyzed four years of sea temperature from partner moorings throughout the SE Florida shelf – from coastal waters of Miami-Dade north through Martin Counties, at a range of depths from 4 to 30 m. These data show cool temperature pulses (below 23 to as low as 10C) throughout the region during summer that cannot be explained by air-sea processes –indicative of upwelling events like those observed at the ocean current moorings in the central SE Florida shelf. These events are most intense and obvious in temperature records from the northern portion of SE Florida shelf (Palm Beach and Martin Counties), but are observed throughout the region every summer. Overall, this project has demonstrated that oceanic upwelling significantly cools the summer waters of SE Florida shelf every year, and appears to contribute of order 1000-3000 kg/m^3/year to total nitrogen and total silicates, 60-180 kg/m^3/year to total phosphorous. Distributed across the length of the SE Florida shelf, total volume of upwelled water at the 30 m isobath is of order 1 million m^3/year.

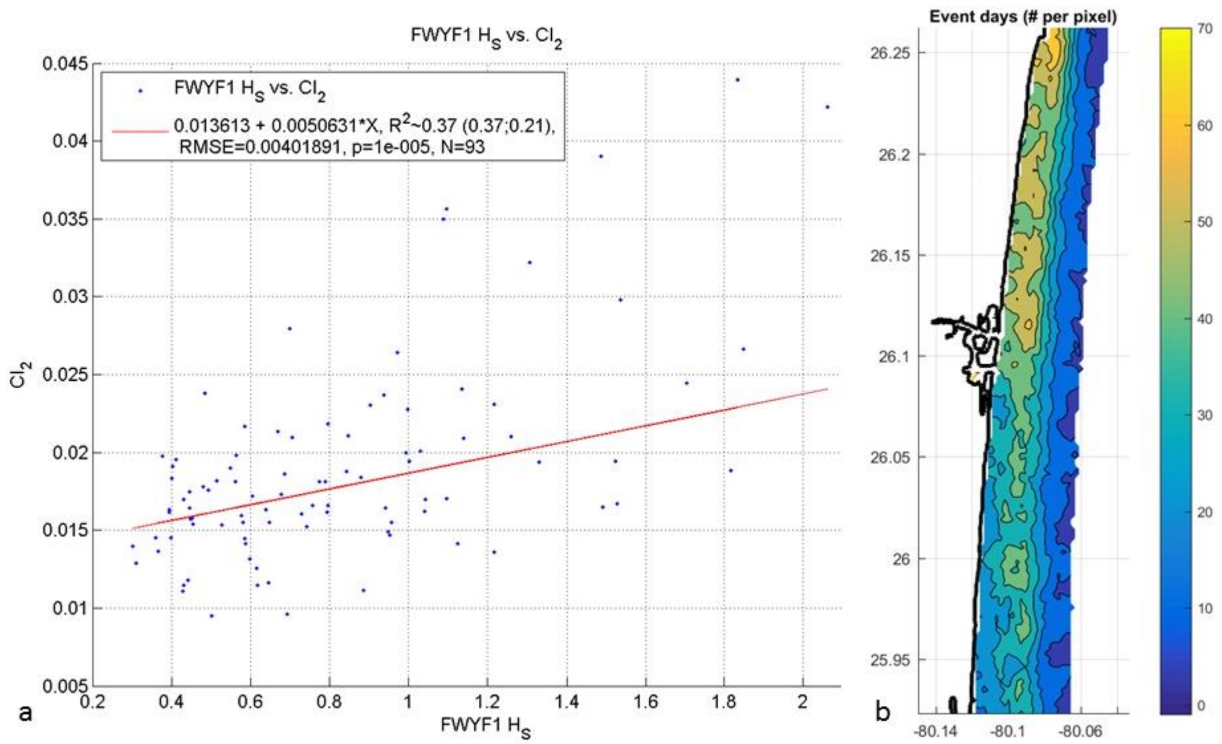

Figure 4: (a) Regression plot show robust linear relationship between Color Index (CI) at a pixel near Port of Miami and significant wave height (Hs) from the operational NOAA WaveWatch III model for the site. (b) Map showing incidence on southeast Florida shelf, of anomalously high relative turbidity (>93rd percentile CI pixel values) coincident with median or lower wave heights. Presence of anomalous, non-wave-related turbidity north of the Port Everglades channel suggests that sediments suspended in the water during Port dredging were advected northward on multiple occasions, and may have remained near the coast for 20 km or more as they moved.

The timing of southeast Florida upwelling events, outside of those associated with tropical cyclones, is generally not consistent with wind forcing (coastal Ekman flux divergence). Timing of events appears to be dependent on near-surface stratification, consistent with observations that these events do not occur during months when near-surface vertical-ocean mixing is most energetic, generally December, January, February, or March. Coincidence of events with periods of enhanced summer stratification in the shelf water column is in fact consistent with their being related to the breaking on the sloping shelf topography,

of either internal waves or of isotherms of the Florida Current. Frequency of summer upwelling appears to be similar everywhere. Intensity of upwelling, i.e., magnitude of cooling and nutrient influx, is dependent on local water depth and on geographic location: The higher end of the nutrient concentration ranges described above tends to be observed at the outermost reef line, and in the northernmost third of the SE Florida shelf; however, the lower end of these ranges encompasses the entire SE Florida shelf north of Biscayne Bay, to water depths as shallow as 5 m. This is a significant contribution to knowledge of the coastal environment in Florida, and will directly inform decisions related to the management of the reefs and potentially competing human uses in this region.

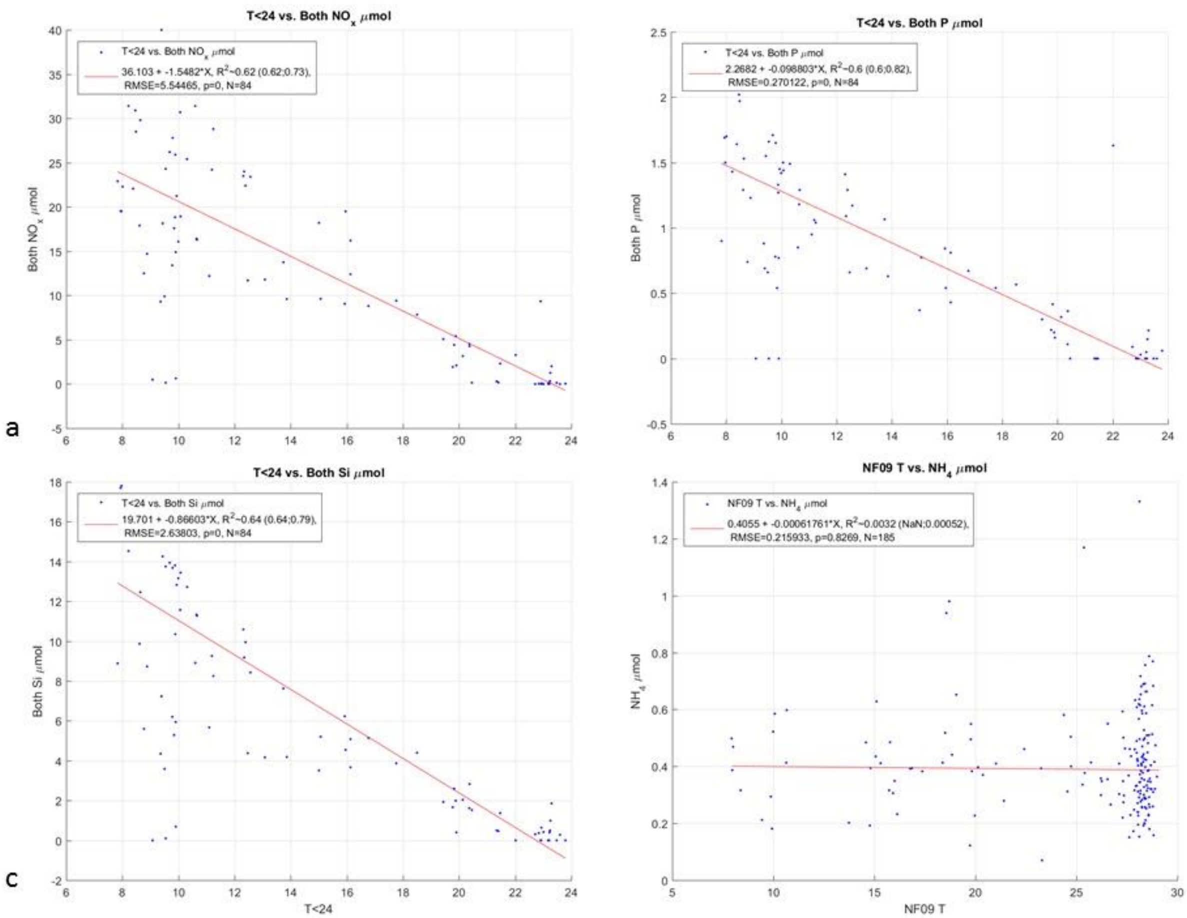

Figure 5: Scatter plots showing robust linear relationships between sea temperature below 24ºC and respectively, (a) nitrogen (NO_3^-), (b) phosphorous, and (c) silicates on the southeast Florida shelf. For comparison, (d) ammonia (NH_4) shows no relationship to sea temperature. Data gathered by cruises of the NOAA Florida Area Coastal Environment program, analyzed for the Gramer et al. upwelling study.

CIMAS scientist Dr. Natchanon Amornthammarong is developing novel instrumentation for in situ measurement of ocean properties: sea temperature, and dissolved nutrients in the nanomolar concentrations prevalent on coral reefs. For nutrients, Dr. Amornthammarong has developed a novel technology called the Autonomous Batch Analyzer (ABA). In situ sensors for ammonia measurement in natural waters have been built and field-tested using the ABA method. With its simple design, the system is robust, flexible, inexpensive, and requires minimal maintenance. Instrument packages are compact and

have low power consumption (less than 7.5 W), allowing them to be moored at depth on reefs or other generally oligotrophic coastal habitats, for periods of one month or longer. Packages can thus log nutrient concentrations, together with other standard variables (temperature, salinity, dissolved oxygen) at high frequency, up to four times per hour; sampling may also be programmed in response to detection of other environmental triggers, e.g., sea temperature or salinity change. This can allow research and management partners to document episodic or high-frequency fluxes to reef environments in situ, from both natural processes (diurnal and monthly tide cycles, upwelling, sediment resuspension, ground-water discharge) and anthropogenic sources - even at low concentrations that may be associated with non-local or far-field sources. The limit of detection is of order 10 nanomole (nM) for ammonia, with reproducibility 0.6% (n=10) at an ammonium level of 200 nM. In addition, the system produces a calibration curve by autodilution from a single stock standard solution with the same accuracy as traditional manual calibration methods. Representative field data and comparisons with standard EPA methods confirm the utility of the ABA for ammonia measurement. Instruments use low-cost components, allowing multiple packages to be built for projects that require resolving spatial as well as high-frequency temporal variability. Nitrate/nitrite and phosphate sensors are also under development based on the ABA method, and are expected to offer similarly low detection limits and high reproducibility for autonomous underwater deployments.

Dr. Amornthammarong is collaborating with Dr. Gramer on upwelling. It is considered critical to quantify uncertainty in the contribution of upwelling to nutrient dynamics on the southeast Florida shelf (see paragraphs above). Because of the episodic nature of upwelling on the shelf, directed boat observations of nutrient concentrations during multiple periods of upwelling during this project proved to be too logistically challenging. New technology developed at NOAA-OAR-AOML is being adapted to observe nanomolar in situ near-bottom nutrient concentrations at hourly frequency for deployments of one month or more at a time: this research has resulted in a viable sensor for the most volatile of the forms of available nitrogen, ammonia. Development and testing are ongoing to enable both nitrate and nitrite to be observed in this manner. This work is expected to result in deployment of sensors to simultaneously measure nitrate, nitrite, and ammonia during the upwelling season of 2016. Analysis of ocean currents and sea temperature data is also ongoing to distinguish upwelling mechanism between breaking of internal waves vs. onshore movement of Florida Current eddies and meanders; it will be important to distinguish between these two mechanisms, to make it possible to predict the potential impact of climate change scenarios on frequency and intensity of upwelling in this area.

Research Performance Measure: The CHAMP project addressed and met the defined objectives during 2015-2016 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. 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.

Western Boundary Time Series Project

Project Personnel: G. Berberian, R. Domingues, R. Garcia, S. Garzoli, J. Hooper, G. Rawson, R. Roddy and T. Sevilla (UM/CIMAS)

NOAA Collaborators: M. Baringer, Y-H. Daneshzadeh, S. Dong, 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.

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:

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. Regular 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 as well as on small boat charters. 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 http://www.aoml.noaa.gov/phod/floridacurrent (See Figure 1).

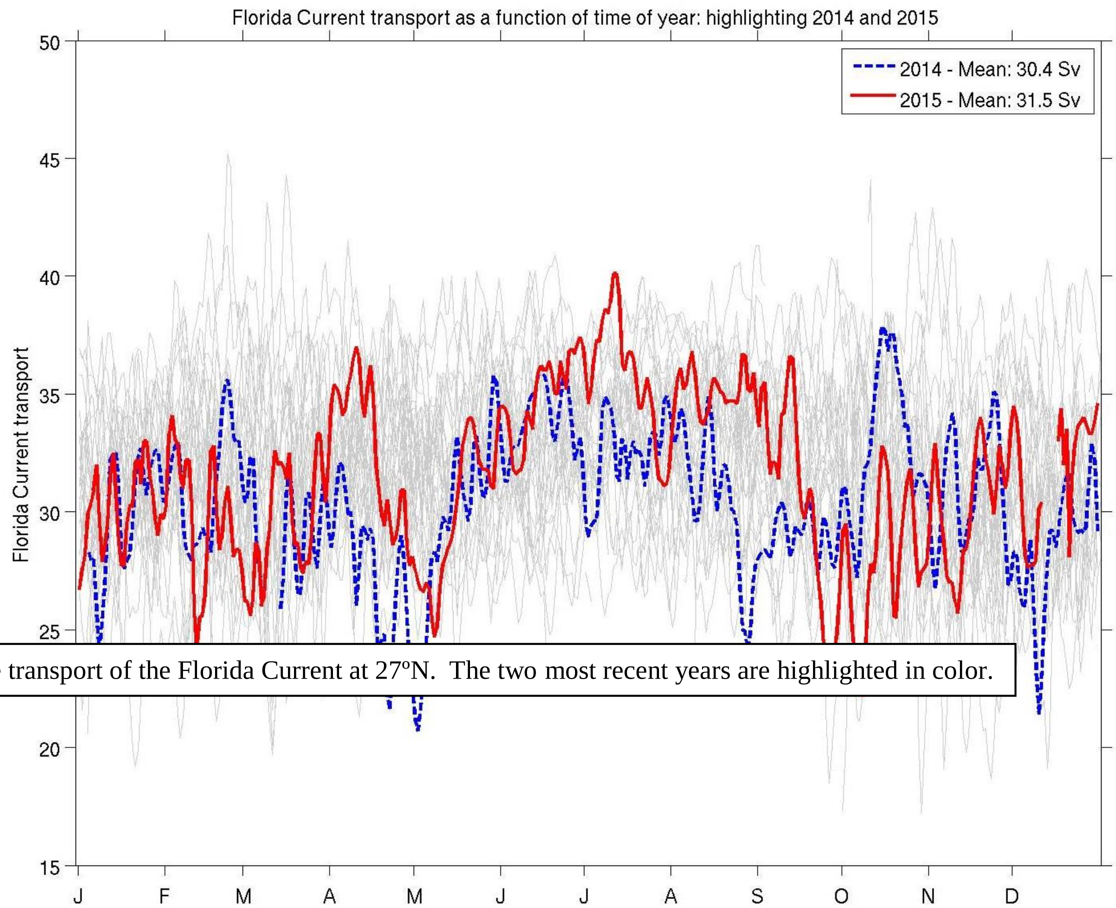

Figure 1: Volume transport of the Florida Current at 27ºN. The two most recent years are highlighted in color.

This project also ma
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Meridional Overturning Circulation Heat-flux Array experiment and the United Kingdom Natural 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 scientists from RSMAS/University of Miami and from the National Oceanographic Centre, Southampton (NOCS), United Kingdom.

Research Performance Measure: Most research goals were met during this last year. The scientific and support personnel continue to achieve the main project objectives – to maintain the continuity of this long-term data set and to continually improve the calibration of the data obtained. Several data reports with hydrographic data collected during cruises in the WBTS region were completed during this period.

Hurricane Risk to U.S. Offshore Renewable Energy Facilities

Project Personnel: S. Cocke, D.-W. Shin, (FSU); M. Powell (formerly NOAA, FSU)
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*:** To analyze vertical profile of hurricane wind near the hub height of turbines using GPS dropsondes and other sources of observational data; To use a catastrophe modeling approach to determine return periods of high hurricane winds.

CIMAS Research Theme:

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

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

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

Research Summary:

One of the primary aims of this project is to determine the vertical profile of winds in the lower hurricane boundary layer so that the risk of hurricane winds to offshore turbines can be estimated. Previous methods for estimating the vertical profile of winds, such as the IEC 61400-3 or the API RP 2A-WSD have known limitations and have not been validated against much of the recent GPS sonde data that has been collected by NOAA-AOML-HRD. We have been collecting and analyzing the HRD GPS dropsonde data sets. Presently we have access to the 1997-2005 dropsonde data, and HRD is currently processing the post-2005 data. Until the new data becomes available, we have done some preliminary analysis of the data which we currently have. The preliminary analysis is based on GPS sonde groups that were identified as shallow water sondes in the 2007 Joint Hurricane Testbed study. It is important to note that study was focused on surface layer properties and did not apply the resulting wind profiles to wind turbine rotor zones. In this study we apply the surface layer log-profile results to the full rotor zone and compare the observed hurricane profiles to those specified in various design condition standards documents.

We first analyze the GPS dropsonde data using the same profile method used in prior research (Powell et al., 2003; hereafter P2003), but focus on using sonde data that is over shallow water (less than 50 m depth) as this is more relevant to offshore turbines. As in P2003, the sonde data is binned in height (10 m intervals from 20 to 300 m, 20 m intervals from 300 to 500 m) and grouped in Mean Boundary Layer (MBL) wind speeds (10 m/s intervals). The MBL wind is defined to be the mean of the vertical profile of the wind in the lowest 500 m of the boundary layer. The approach of P2003 is to assume the wind follows a logarithmic profile in the vertical, and depends on roughness (drag coefficient). The dependence on roughness is important, as the roughness could change depending on sea state or upstream fetch. P2003 found that roughness appears to decrease with increasing winds above 33 m/s for open ocean. It is not known whether that will be the case for shallow water conditions.

The profile method of P2003 assumes that the surface layer (below 200 m) can be described by the bulk aerodynamic method. The friction velocity and surface roughness are found using a least squares linear regression for each MBL group (bin). The regression was done for the 20 to 160 m surface layer. The intercept is just the log of the roughness length, and the slope determines the friction velocity. Figure 1 shows the fitted profiles of the wind for each MBL group. We have further subdivided the data according to whether the flow was offshore, onshore and along shore. As expected, the roughness for offshore flow was higher than onshore flow, indicating the importance of fetch. The dependence of the drag coefficient on wind speed is not clear, as the data sample is rather small. We will reanalyze the data when more GPS sondes are processed, so that the results will be more robust.

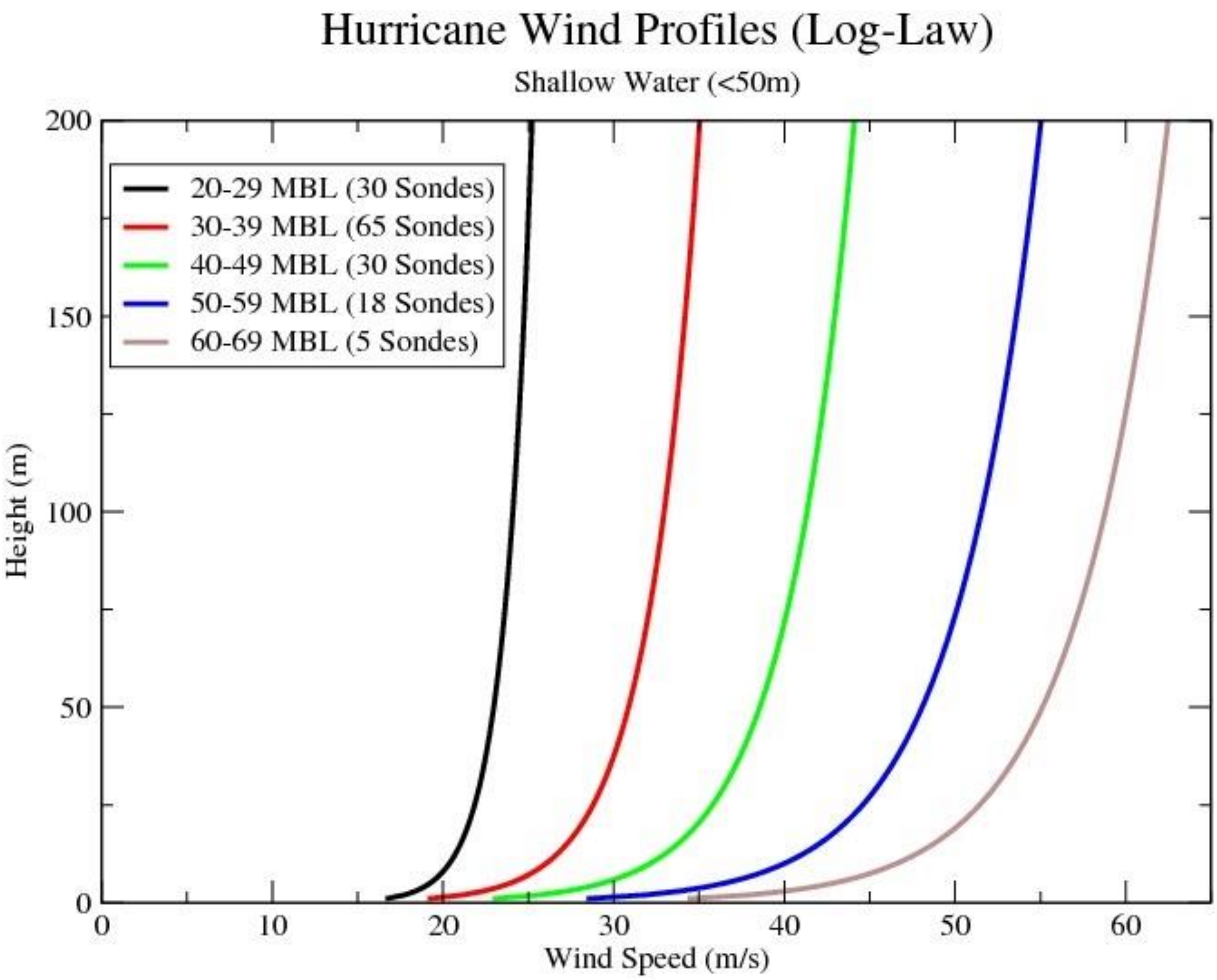

Figure 1: Fitted log-wind profiles for each MBL group.

Research Performance Measure: Significant progress has been made in analyzing some of the GPS dropsonde data. However, there has been a long delay in funds for the remaining fiscal year, and the project is temporarily stalled. We are eager to start moving forward again when the funding arrives.

Developing Decision Support Tools for Understanding, Communicating, and Adapting to the Impacts of Climate on the Sustainability of Coastal Ecosystem Services

Project Personnel: G.S. Cook, K.A. Kearney, P.B. Ortner and C. Quenée (UM/CIMAS)
NOAA Collaborators: C.R. Kelble (NOAA/AOML)
Other Collaborators: C. Carollo and D. Yoskowitz (Texas A&M – Corpus Christi); P. Fletcher (NOAA/Florida Sea Grant); D. Rudnick (US National Park Service)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives**:* To develop tools for understanding how pressures related to urbanization and climate change interact to impact ecosystem states, and how changes in these ecosystem states impact the production of ecosystem services and their economic value in coastal south Florida.

***Strategy**:* To accomplish these objectives we are using expert-opinion and matrix-based approaches to understand and rank predominant pressures, ecosystem states/habitat types, and ecosystem services in coastal south Florida. In a complementary analysis, we are coupling hydrodynamic-habitat suitability modeling with ecosystem services valuation (using meta-regression analyses) to predict how future changes in habitat areal abundance impact the future value of coastal ecosystem services.

CIMAS Research Theme:

Theme 1: Climate Research and Impact (*Primary*)
***Theme 6**:* Ecosystem Management (*Secondary*)
Theme 5: Ecosystem Modeling and Forecasting (*Secondary*)
Theme 7: Protection and Restoration of Resources (*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 1**:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems (Secondary)*

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

NOAA Funding Unit: OAR/CPO – Coastal Ocean and Climate Application
NOAA Technical Contact: Adrienne Antoine

Research Summary:

The primary objective of this research project is to develop decision support tools to explore the effect of urbanization on the resilience of ecosystem services under future climate change scenarios in coastal south Florida. 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. 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 (please see 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 pristine undeveloped central coast spanning from Rookery Bay in the north west through Florida Bay and Everglades National Park to the south and east.

To facilitate the development of integrated conceptual ecosystem models (ICEMs) for our three urbanization sub-regions spanning south Florida, we 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. Using expert-opinion polling 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).

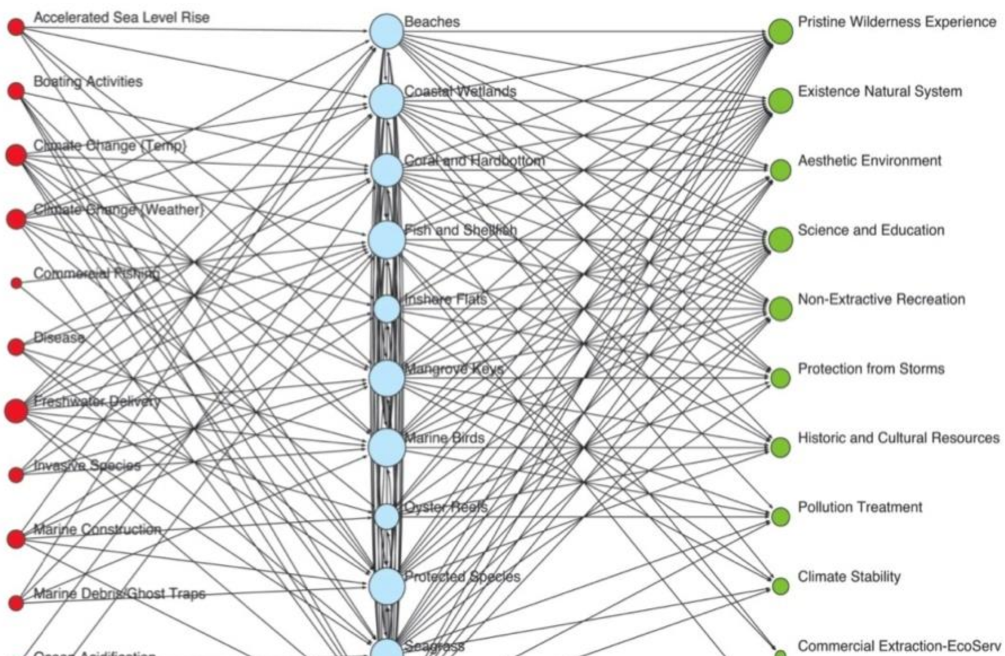

Figure 1: Ecosystem Pressure-State-Ecosystem Service network model for relatively pristine central study region (i.e. coastal Everglades National Park and Florida Bay). This model was constructed using regional expert opinion, and links various pressures, ecosystem states/habitat types, to a suite of 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 completed during year two of this study.

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. However, we have hired a replacement scientist who is taking over the hydrodynamic-habitat suitability empirical modeling component for our project. Before leaving Dr. Kearney developed 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, etc) associated with the suite of climate-related Pressures identified in our management engagement activities, with the distribution of key habitat types (e.g. spatial abundance of seagrass), and the generation of associated ecosystem services (e.g. recreational opportunities). 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.

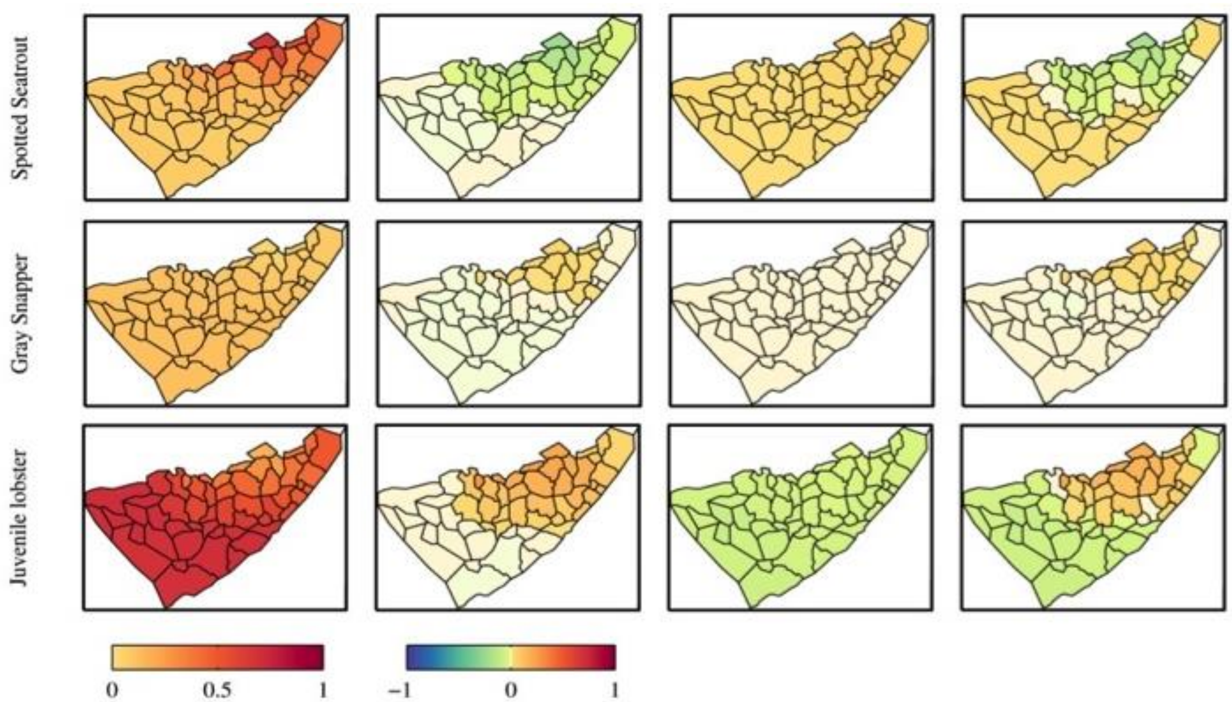

Figure 2: Habitat suitability models for spotted seatrout (*Cynoscion nebulosus*), gray snapper (*Lutjanus griseus*), and juvenile spiny lobster (*Panulirus argus*) in our relatively pristine central study sub-region. Figure panels depict (from left to right) habitat suitability for Flux Accounting and 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).

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 the quantification of ecosystem services for several of the key habitat types

found within our study region was initiated. The focus of this year was on the development and testing of the meta-regression model.

The meta-regression analysis was tested on counties in our study areas (Table 1). 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. It is possible the differences in values in this exercise are driven by a combination of the areal extent of coastal marshes and population density.

Table 1: Value of ecosystem services provided by coastal marshes calculated using 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).

Research Performance Measure: All major research objectives are being met. We have had not had any major deviations from our proposed workplan, and we anticipate the same outcomes as predicted originally.

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Global Drifter Program

Project Personnel: S. Dolk, R. Perez, 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 1*:** Climate Research and Impacts

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 AOML's DOC, which coordinates drifter deployments, 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.

The AOML's DAC is responsible for processing data from all drifters in the project. This specific program focuses 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.

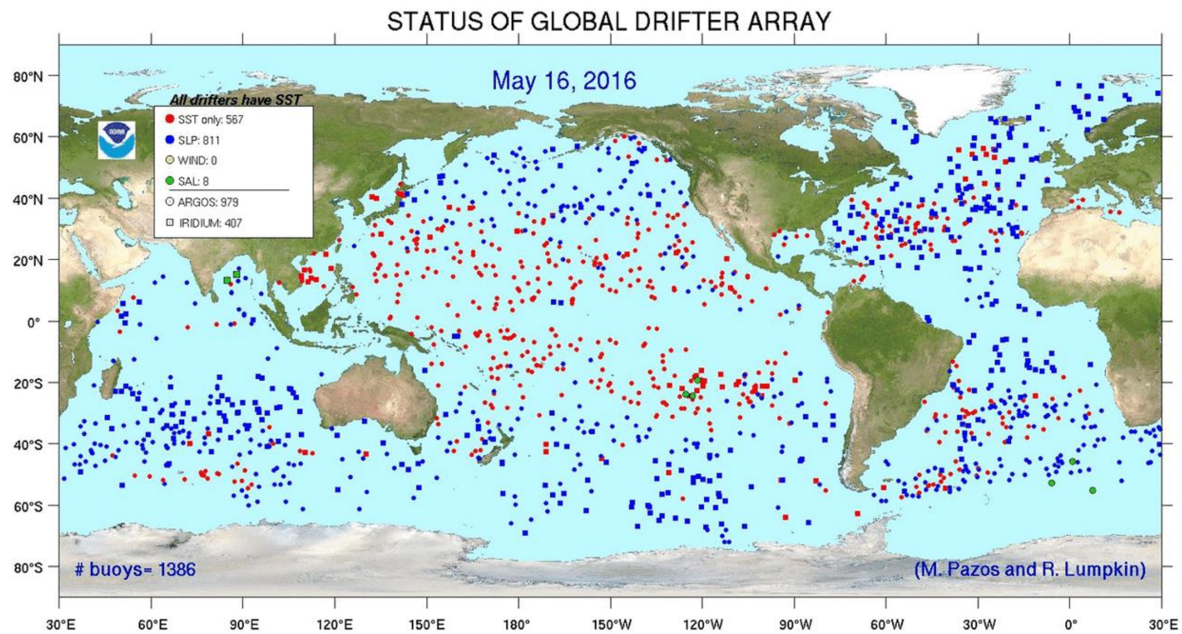

Figure 1: Status of the Global Drifter Array (updated weekly)

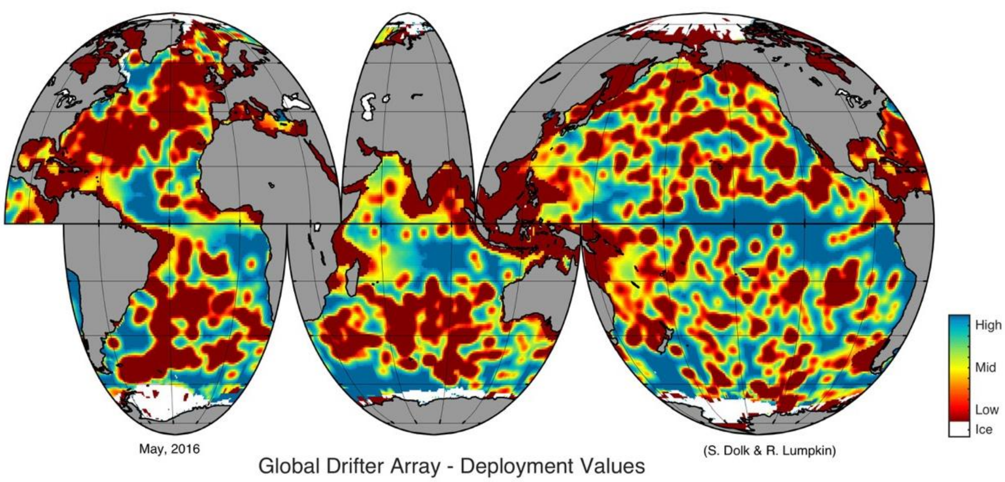

Figure 2: Deployment Value Map(s) (updated monthly)

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

A new hourly global surface drifter dataset was generated this year by S. Elipot (UM/RSMAS), with collaboration from R. Lumpkin, R. Perez, and other researchers (Elipot et al., 2016). This global dataset provides a new tool for the study of relatively small-scale oceanic processes. The hourly product is freely available via the Data Assembly Center of the Global Drifter Program (http://www.aoml.noaa.gov/phod/dac/dacdata.php).

Southwest Atlantic Meridional Overturning Circulation ("SAM") Project

Project Personnel: R. Garcia, S. L. Garzoli, and R.C. Perez (UM/CIMAS)
NOAA Collaborators: S. Dong, C.S. Meinen, P. Pena, U. Rivero, and R. Smith (NOAA/AOML)
Other Collaborators: I. Ansorge (University of Cape Town, South Africa); E. Campos and O. Sato (University of Sao Paulo, Brazil); M.P. Chidichimo and A. Piola (Naval Hydrographic Service and University of Buenos Aires, Argentina); S. Speich (École Normale Supérieure, France)

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/COD
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, precipitation patterns, and hurricane intensification in the Atlantic. These changes have strong societal impacts both in the region and around the globe. 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.

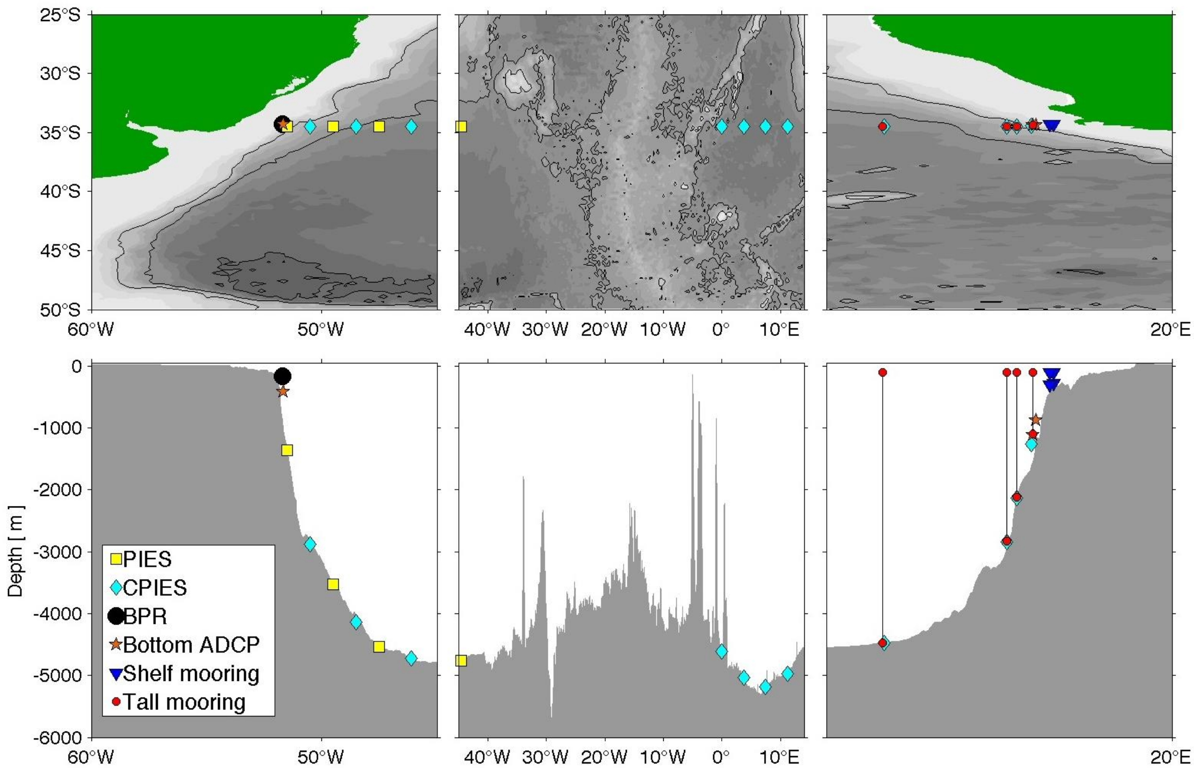

Figure 1: Map indicating the location (top panel) and the vertical distribution (bottom panel) of the four NOAA PIES making up the SAM array at 34.5°S; also shown are the Brazilian CPIES deployed in December 2012, the Brazilian coastal moorings deployed in December 2013, the French CPIES deployed in September 2013, and the South African moorings which were added in September 2014.

Research Performance Measure: Ship time issues in 2015 resulted in only limited PIES data being available during the year. Because of the data limitations, science analysis has focused on combining existing SAM data with other data sets in the region (e.g., Argo, GO-SHIP) as well as numerical models to focus on the larger picture of MOC pathways in the South Atlantic (Garzoli et al., 2015). Project PIs are collaborating with international researchers on manuscripts describing the variability of the Brazil Current along 34.5°S using data from the SAM PIES and Brazilian CPIES, as well as data from Argentinian and Brazilian hydrographic surveys. Project PIs are also leading and co-authoring manuscripts describing the variability in extended time-series of the DWBC and AMOC volume transport from the combined international observed arrays along 34.5°S. Results from several analyses were presented at the IUGG General Assembly in Prague (Czech Republic) in June-July 2015, at the UK RAPID – US AMOC International Science meeting in Bristol, UK in July 2015, at a capacity building meeting (COCOA) in Southampton, UK in July 2015, at the SAMOC VI workshop and 2016 Ocean Science meeting in New Orleans in February 2016.

The North American Multi-Model Ensemble (NMME) Phase-2: Deployment, Operation and Seasonal Prediction Science

Project Personnel: B.P. Kirtman (UM/RSMAS/CIMAS)
NOAA Collaborators: H. van den Dool (NOAA/CPC); J, Huang (NOAA/CPO)
Other Collaborators: B, Denis (Environment Canada); W. Anderson (GFDL); J. Tribbia (NCAR); S. Pawson (NASA/GSFC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To deploy the NMME-Phase II Seasonal System into NCEP operations and of establishing the terms of operation following deployment to satisfy both service and research purposes for the operational phase.

***Strategy*:** To continue producing real-time CCSM4 forecasts on time all the time, lead the overall NMME science team in collaborative research and the investigate the skill and predictability of the NMME system with particular focus on CCSM4.

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/CPO
NOAA Technical Contact: Annarita Mariotti

Research Summary:

The research is a continuation an existing National Multi-Model Ensemble (NMME) team producing operational seasonal to interannual (ISI) predictions. The project includes both basic and applied prediction research, and the production of real-time, on-time all the time operational prediction with CCSM4.

a) NMME Operational Activities

- NMME Partnership Agreement signed by all parties (May 2016).
- NMME team continues to meet monthly via telecom to address all science and data production issues
- CESM retrospective forecasts have been completed and evaluated and the system is being considered for the operational production suite
- 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 are now routinely being provided to CPC: Winds for hurricane seasonal outlook, and sea-ice extent and thickness for skill assessment
- Phase-II high frequency and additional fields continue to accumulate at the NCAR data server (see table 1 for details).

TABLE 1: NMME Phase-II data published as of March 9, 2016.

NMME Phase-II Data Archive Overview: Mar 9, 2016

Archive Data by Variable and Model

	CCSM4		CESM1	CFSV2		CanCM3	CanCM4	FLORB	GEOS5
Variable	Daily	3hr	Daily	Daily	6hr	Daily	Daily	Daily	Daily
TAS	⦸	✔	EX	P	✔	✔	✔	✔	✔
TA	✔	⦸	EX	P	✔	✔	✔	⦸	✔
TASMIN	✔	⦸	EX	P	✔	✔	✔	✔	✔
TASMAX	✔	⦸	EX	P	✔	✔	✔	✔	✔
PR	⦸	✔	EX	EX	✔	✔	✔	✔	✔
PSL	✔	⦸	EX	EX	✔	✔	✔	⦸	✔
UA	✔	✔	EX	EX	✔	✔	✔	⦸	✔
VA	✔	✔	EX	EX	✔	✔	✔	⦸	✔
G	✔	⦸	EX	EX	✔	✔	✔	⦸	✔

✔ Complete
EX Expected (not yet published)
P In Progress
⦸ Not Expected

- CFSV2 daily complete Apr 30, 2016
- CESM1 daily complete May 31, 2016

b) Prediction and Predictability of Land and Atmosphere Initialized CCSM4 Climate Forecasts over North America

To understand the contribution of land and atmosphere initialization to seasonal forecasts we consider the atmospheric component of CCSM4 coupled to the land component (CAM4-CLM4) with prescribed data ocean/ice.

We compare 2 experiments, as follows:

1. No-Init: 30-year simulation where monthly climatological SST and sea ice coverage from observational estimates are prescribed.
2. LA-Init: Initialized hindcasts (1982-2009; 10-member ensembles) using observed atmospheric and land states (initialization strategy discussed below). Prescribed climatological SST and sea-ice as above.

Though we refer to experiment 2 as a “hindcast” as it uses initial data identical to fully coupled CCSM4 hindcasts, SST and sea ice are prescribed from 1982-2001 climatology using Hadley Centre Global Sea Ice and Sea Surface Temperature (HadISST) data. Thus, this experiment emphasizes atmosphere and land initialization in the absence of SST or sea-ice anomalies.

Our analysis (see Fig. 1) highlights the influence of land and atmosphere initialization on monthly deterministic prediction skill and predictability, isolating this influence from SSTA constructive or destructive interference by prescribing climatological SSTs. On monthly time-scales, there is a

significant increase in precipitation skill over North America at lead 0 mainly due to atmospheric initialization (larger prediction skill is found in the first two weeks after initialization, not shown). 2-meter temperature monthly prediction skill is similarly increased at lead 0, with positive influence of land surface initialization on skill in the remaining 2 months in summer. These results are discussed in detail in Infanti and Kirtman (2016), and are part of Infanti's Ph. D. (May 2016).

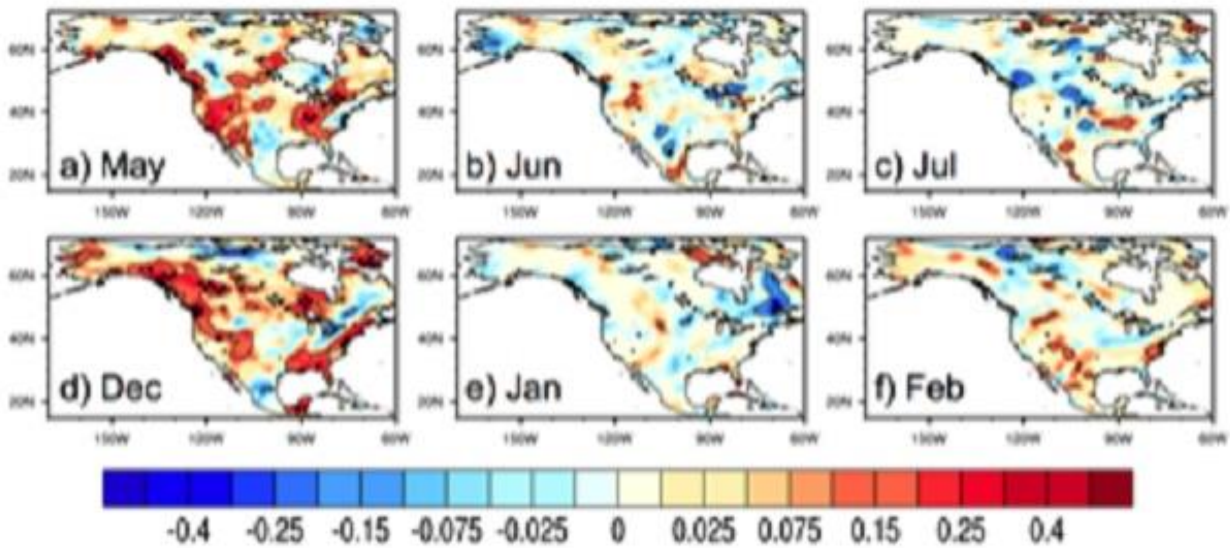

Figure 1: Difference in anomaly correlations for precipitation (anomaly correlation for LA-Init minus NoInit). Stippling (contours) indicate significance of difference at 99% (95%) confidence level based on Monte Carlo estimation of significance. (a) – (c) May initialized hindcasts verifying in May, Jun, Jul (or NoInit verifying in May, Jun, Jul). (d) – (e) Dec initialized hindcasts verifying in Dec, Jan, Feb (or NoInit verifying in Dec, Jan, Feb).

c. An alternate approach to ensemble ENSO forecast spread: Application to the 2014 forecast

Many dynamical forecast models predicted a 2014 El Niño event. Yet despite the moderate sea surface temperature (SST) warming that was observed, the 2014 forecast is often described as a "busted" forecast. The question that arises is of practical importance—was 2014 actually a bust or is the usual method of calculating ensemble spread (defined below) underestimating forecast uncertainty and by extension, affecting the retrospective evaluation of El Niño–Southern Oscillation (ENSO) predictions?

For example, Figs. 2c and 2d show the CCSM4 March initialized Niño-3.4 anomaly forecasts with 10 ensemble members (gold), ensemble mean (black solid), forecast spread (grey polygon), and the observed Niño-3.4 index from the National Center for Environmental Prediction Climate Prediction Center (CPC; black dashed). To be clear, "forecast spread" is computed from the actual CCSM4 initialized forecasts, whereas "expected spread" is the proposed supplemental spread discussed below. The 2015 observed Niño-3.4 evolution falls within the forecast spread is on track to verify, albeit the final amplitude may vary from that predicted by this particular model (2.33°C in December). On the other hand, observed 2014 Niño-3.4 sits well below the forecast spread and verifies at 0.78°C as compared to the ensemble mean forecast of 1.67°C. So was 2014 a "bust" or does 0.78°C fall within the expected spread generated via noise-driven processes in CCSM4, despite the December forecast spread spanning only 1.16–2.17°C?

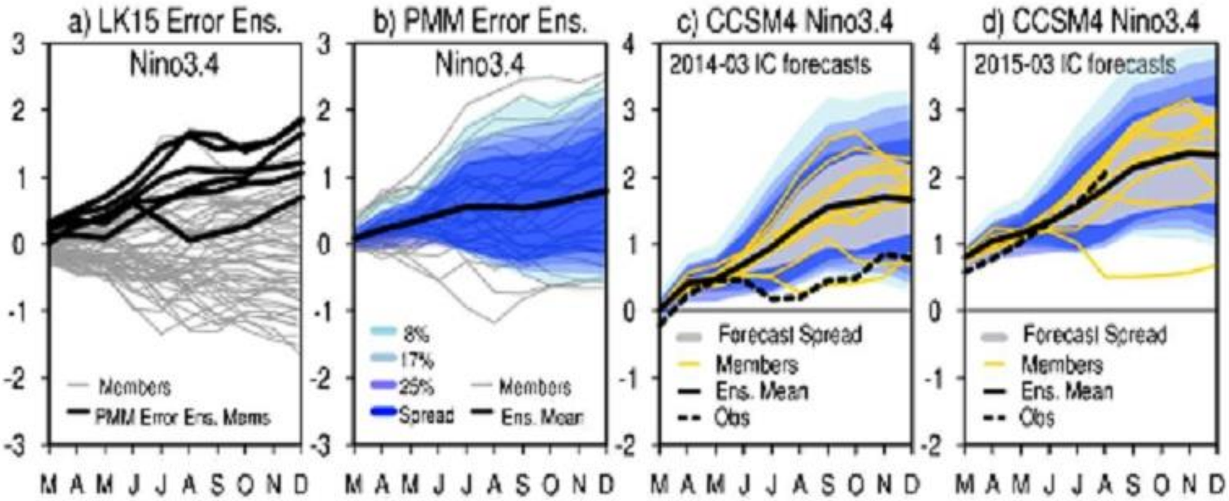

Figure 2: (a) Niño-3.4 SST error swath for the March error growth ensemble in Larson and Kirtman [2015]. Black bold curves indicate the six members whose ocean initial conditions are used in the PMM error ensemble. (b) Niño-3.4 error swath, ensemble mean, spread, and uncertainty thresholds for the PMM error ensemble. Uncertainty thresholds are calculated by averaging the most extreme three, six, and nine warm or cold members corresponding to 8%, 17%, and 25%, respectively. (c) 2014 CCSM4 March initialized Niño-3.4 forecasts from the NMME, forecast spread (grey polygon), ensemble mean (black solid), observations (black dashed), and expected spread and uncertainty thresholds from Figure 1b. (d) Same as Figure 1c but for the 2015 forecasts.

The present study expands on the Larson and Kirtman (2015, J. Climate; LK15) experimental design to produce an expected noise-driven spread for the March initialized 2014 and 2015 CCSM4 NMME predictions of December Niño-3.4. The initial conditions of both forecasts contain Pacific Meridional Mode (PMM) SST signatures and predict December El Niño. A PMM error growth ensemble is constructed from six ensemble members that originally bias warm in the LK15 March error ensemble, each also having PMM-like errors in the initial conditions. The constructed ensemble is essentially a sensitivity test, pairing each base ocean with six different atmospheric noise initial conditions.

We are not suggesting that a new error ensemble must be constructed for each actual forecast but merely demonstrating that the expected spread from initial SST errors with similar structures as the March 2014 and 2015 initial conditions used in the real-time CCSM4 NMME forecasts is large for longer lead times. In fact, the spread in the PMM error ensemble (Figure 2b) is similar to that in the original LK15 March error ensemble (Figure 2a), suggesting that the expected spread is similar for differently constructed noise-driven error ensembles, as long as the initial conditions are ENSO-independent. Thus, the spread of the LK15 ensembles suffice as a benchmark for expected spread from noise-driven processes alone in CCSM4. In this case, more information is gained by using ocean base members with PMM-like initial errors, including that the presence of PMM-like perturbations in March can increase the probability that El Niño will occur (i.e., the warm bias), but does not guarantee it due to the large sensitivity of the coupled system to perturbations in March (i.e., large expected spread).

These results are discussed in detail in Larson and Kirtman (2015), and are part of Larson's Ph. D. (May 2016).

Research Performance Measure: The CCSM4 forecast produced and delivered to CPO on time all the time. Published paper on seasonal predictability.

Predicting the Potential Impact of Climate Change on the Intra-Americas Sea Under IPCC Climate Change Scenarios

Project Personnel: Y. Liu and R. Domingues (UM/CIMAS)
NOAA Collaborators: S.-K. Lee and G.J. Goni, (NOAA/AOML); J.T. Lamkin, W. Ingram and M. Schirripa (NOAA/SEFSC)
Other Collaborators: B.A. Muhling (Princeton U); 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* (*Primary*)

***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 - 27ºC. 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; 2016). 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 Multidecadal 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.

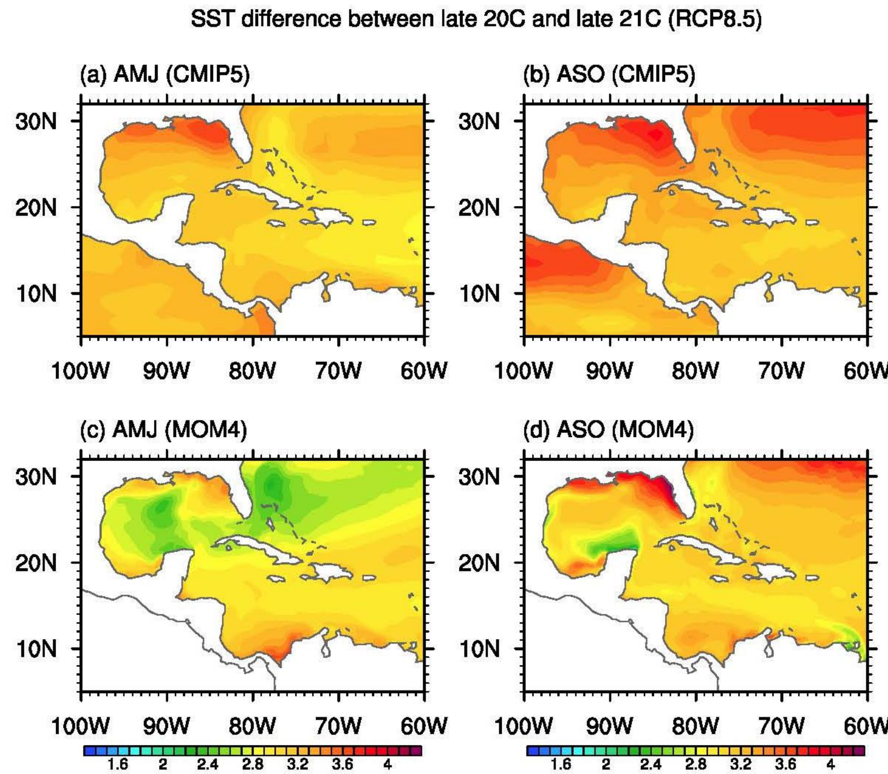

Figure 1: SST difference in the IAS between the late 21st century (2090 ~ 2098) and late 20th century (1990 ~ 1998) for (a) the boreal spring months of AMJ and (b) the boreal summer months of ASO obtained from the weighted ensemble of 18 CMIP5 models simulations under the historical and RCP8.5 scenario, (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.

Another paper entitled "Variability of preferred environmental conditions for Atlantic bluefin tuna (*Thunnus thynnus*) larvae in the Gulf of Mexico during 1993-2011" by Domingues et al (2016) is published 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.

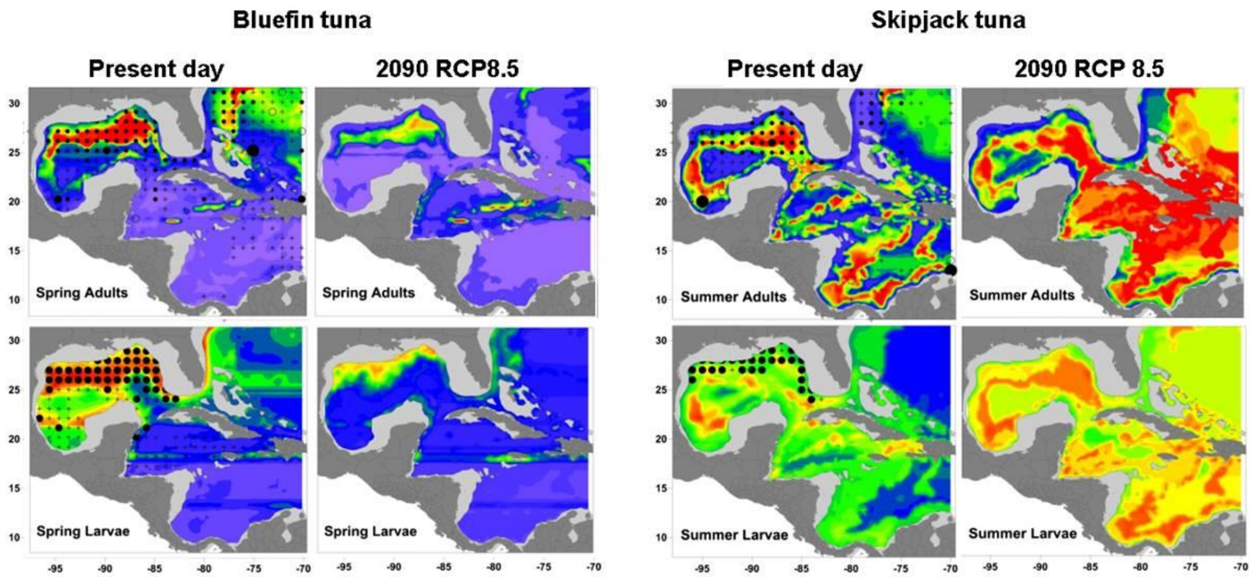

Figure 2: (a) Kriged predicted probabilities of occurrence for adult (1990 – 2009) and larval (2000 – 2013) BFT during spring (contours). (b) Kriged predicted probabilities of occurrence for adult (1990 – 2009) and larval (2000 – 2013) skipjack during summer (contours). Results are shown for the 2000s, 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.

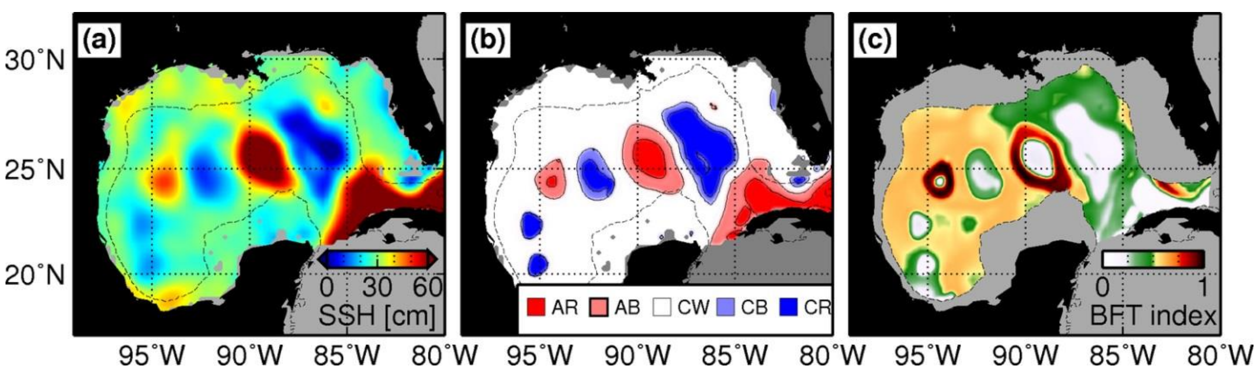

Figure 3: Maps for May 20, 1998 of: (a) Sea Surface Height; (b) type of mesoscale features; and (c) BFT_Index. Overlaid in the maps is the 200 m isobath (dashed line). In (b), AR refers to anticyclonic region, AB to anticyclonic boundary, CW to common waters, CB to cyclonic boundaries and CR to cyclonic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

Real-time computation and distribution of the BFT_index and derived parameters is currently being carried out by NOAA/AOML. For more information, please visit:
http://www.aoml.noaa.gov/phod/research/ecosystems/fisheries/bft_monitoring.php

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. Five papers have been published.

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

Project Personnel: V. Misra and D. Zierden (FSU)

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 (*Primary*)
***Theme 6*:** Ecosystems Management (*Secondary*)

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

NOAA Funding Unit: OAR/CPO
NOAA Technical Contact: Caitlin Simpson, CSI/RISA Program

Research Summary:
The impact of an extreme case of irrigation on the Southeastern United States
Selman and V. Misra
The impacts of irrigation on Southeast United States (SEUS) diurnal climate are investigated using simulations from a regional climate model. An extreme case is assumed, wherein irrigation is set to 100% of field capacity over the growing season of May through October. Irrigation is applied to the root zone layers of 10-40cm and 40-100cm soil layers only. It is found that in this regime there is a pronounced decrease in monthly averaged temperatures in irrigated regions across all months. In non-irrigated areas a slight warming is simulated. Diurnal maximum temperatures in irrigated areas warm, while diurnal minimum temperatures cool. The daytime warming is attributed to an increase in shortwave flux at the surface owing to diminished low cloud cover. Nighttime and daily mean cooling result as a consequence repartitioning of energy into latent heat flux over sensible heat flux, and of a higher net downward ground heat flux. Excess heat is transported into the deep soil layer, preventing a rapidly intensifying positive feedback loop. Both diurnal and monthly average precipitations are reduced over irrigated areas at a magnitude and spatial pattern similar to one another. Due to the excess moisture availability, evaporation is seen to increase, but this is nearly balanced by a corresponding reduction in sensible heat flux. Concomitant with additional moisture availability is an increase in both transient and stationary moisture flux convergences. However, despite the increase, there is a large-scale stabilization of the atmosphere stemming from a cooled surface.

The sensitivity of Southeastern United States climate to varying irrigation vigor
Selman and V. Misra
Four regional climate model runs centered on the Southeast United States (SEUS) assuming a crop growing season of May through October are irrigated at 25% (IRR25), 50% (IRR50), 75% (IRR75) and 100% (IRR100) of the root zone porosity to assess the sensitivity of the SEUS climate to irrigation. A fifth run, assuming no irrigation (CTL), is used as the basis for comparison. Across all IRR runs, it is found that there is a general reduction in seasonal mean precipitation over the irrigated cells relative to CTL. This manifests as an increase in dry (0-1mm/day) days and reduction in > 1 mm/day rainfall events. A comparative moisture budget reveals that area-averaged precipitation over the irrigated cells displays a reduction in precipitation and runoff in IRR100 with a weaker reduction in IRR25. This is despite an increase in vertically integrated moisture convergence and local evaporation. We find that irrigation increases the lower atmospheric stability, which in turn reduces the convective rainfall over the irrigated areas.

Seasonally averaged temperatures reduce over irrigated areas, with the intensity of the reduction increasing with irrigation vigor. This is largely attributed to a repartitioning of sensible heat flux into latent heat flux. There is also however a small increase of heat flow to deeper soil layers. Precipitation ahead of transient cold fronts is also reduced by irrigation as they pass over irrigated cells, owing to the increased stability in the lower troposphere. The intensity of this precipitation reduction becomes more

intense as irrigation vigor increases. Lastly, heat waves in the SEUS are reduced in intensity over irrigated cells.

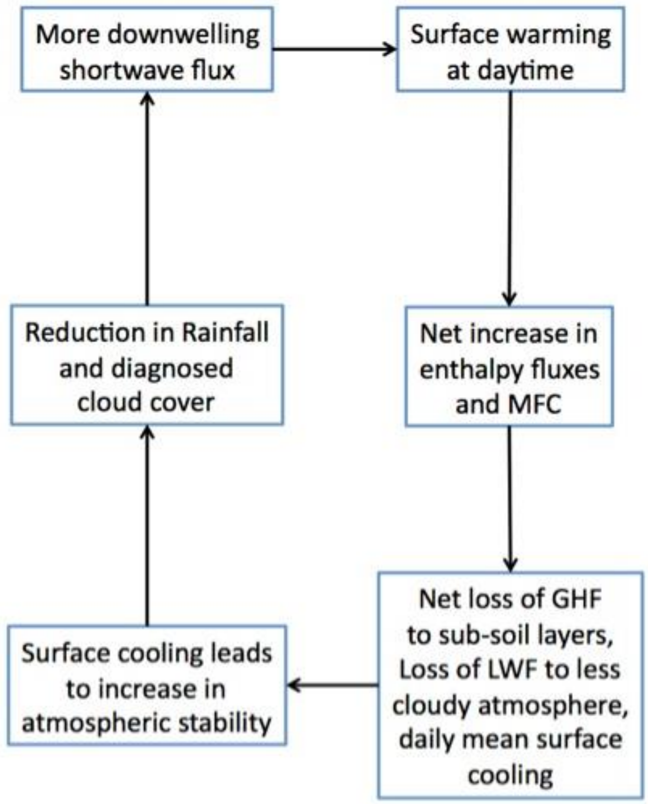

Figure 1: Schematic diagram depicting the thermodynamic feedback loop forced by irrigation in the southeastern US farm areas. Moisture flux convergence, ground heat flux and latent heat flux are abbreviated as MFC, GHF and LHF.

Research Performance Measure:

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 presenting 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). The webinars are hosted by Auburn University and held bi-weekly in times of drought, or monthly otherwise.
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, including 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.
7. Steering committee member for the NIDIS ACF Pilot strategic plan, including attending a strategic planning meeting October 12-13, 20-16 in Auburn, Alabama.

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 & 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 Program
NOAA Technical Contact: Robbie Hood (NOAA 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, theTWiLiTE 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.

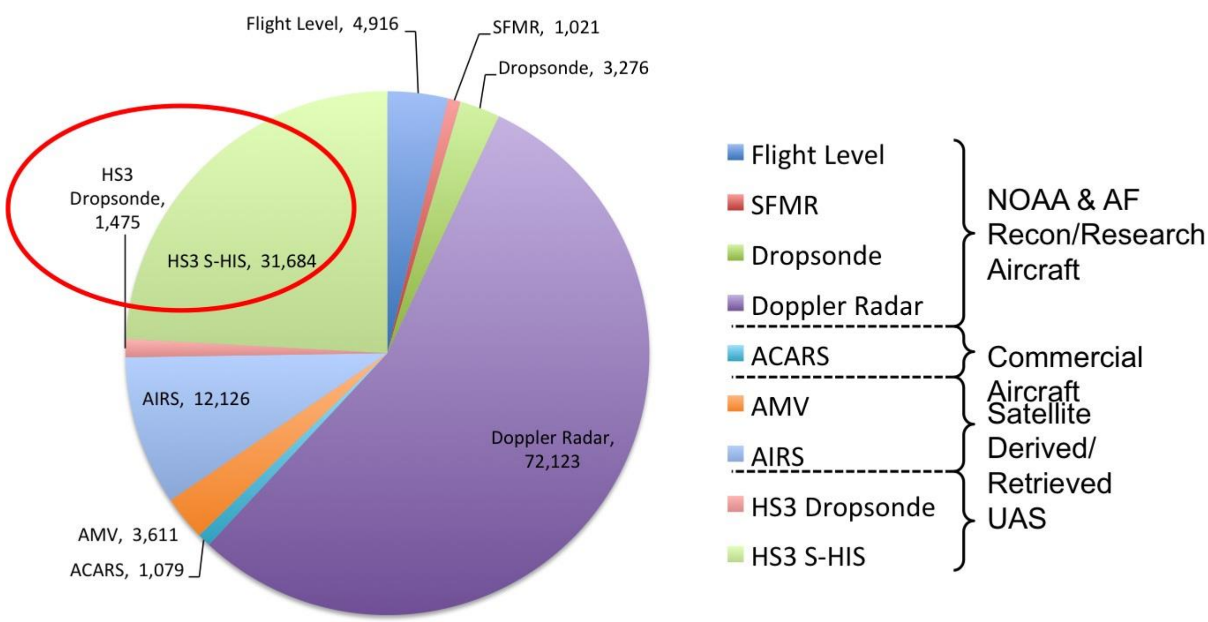

Figure 2: The distribution of all available observation platforms and the number of observations from each as assimilated in HEDAS for Tropical Disturbance Gabrielle at 7 September 2013 18 UTC.

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.

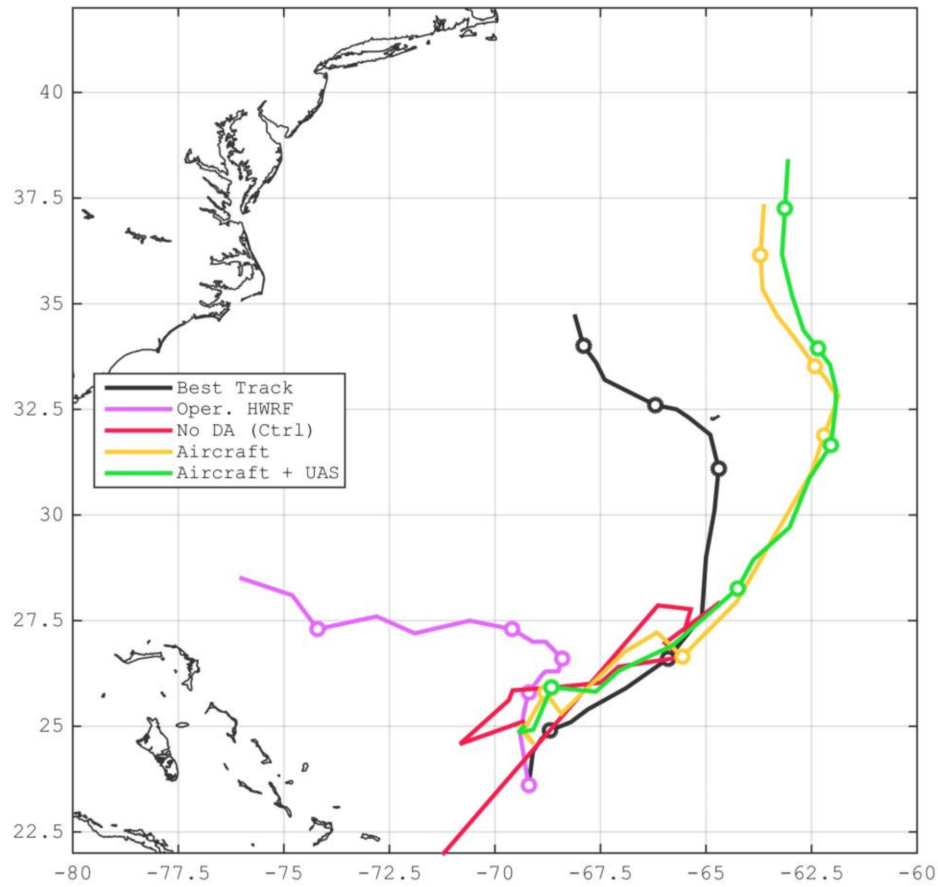

Figure 3: Track forecasts initialized at 7 September 2013 18 UTC for control (no data assimilation, red), as well as initialization from HEDAS analysis with standard observations (yellow) and all (standard plus UAS) observations (green). The corresponding operational HWRF forecast is shown in purple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

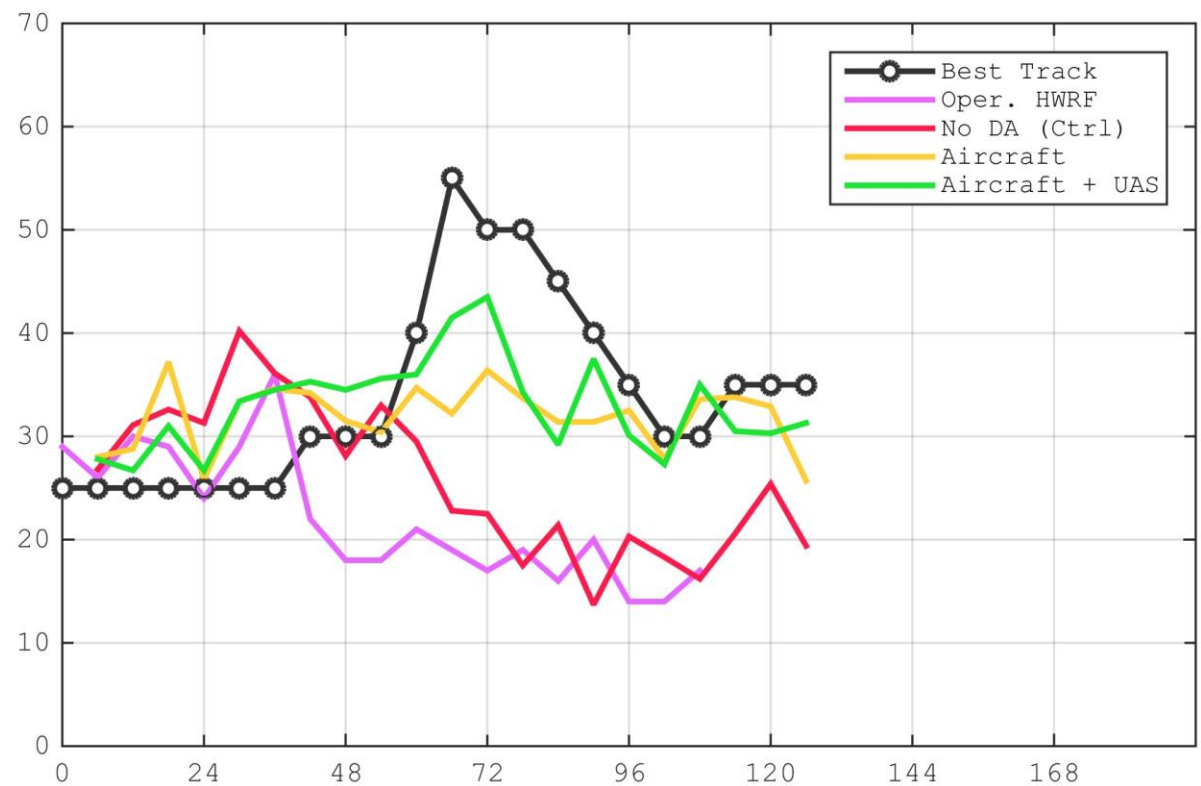

Figure 4: As in Fig. 3 but for intensity (maximum 10-m wind speed, knots).

Research Performance Measure: All major objectives were met on schedule and this project is completed.

Impact of Hyperspectral Sounder on Prediction of Tropical Cyclones

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

Long Term Research Objectives & 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.

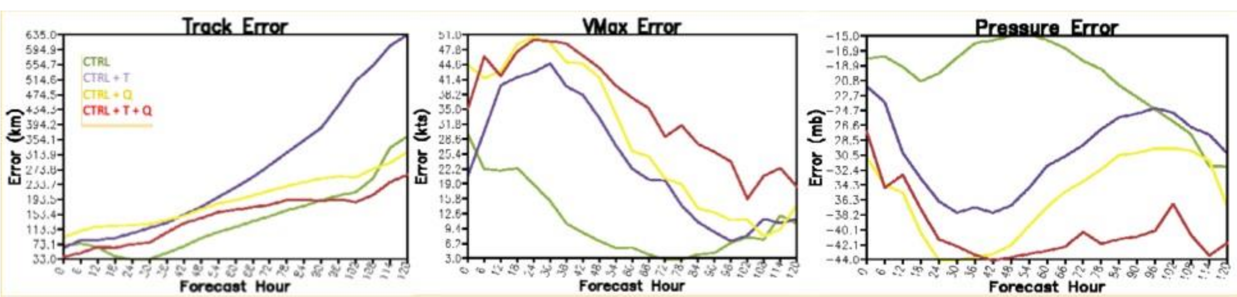

Figure 1: (a) Average error over 17 cycles. Position (track) error in km (b) Average error over 16 cycles. Minimum central pressure error in hPa. (c) Average error over 16 cycles. Maximum 10m wind speed error in kts.

Several experiments were conducted to determine the importance of variable type (temperature only, moisture only, or a combination of the two) on TC track and intensity forecasts. Data assimilation techniques were also explored, varying the frequency at which observations were provided for the analyses. Results show that the assimilation of both temperature and moisture improve the short term track forecasts (~12 hours). However, the short term forecasts of maximum wind improve when only temperature observations are assimilated. When cycling is increased from six to one hourly, temperature only observations provide the largest improvement to the intensity analysis, but that improvement is

quickly lost (within 6-12 hours) and leads to a degraded forecast. The assimilation of both temperature and moisture also provides a slight improvement to both short term track and intensity forecasts. Upon comparing the relative humidity analyses from the 6 hourly and the 1 hourly experiments to the Nature Run, it revealed the 1 hourly cycled experiment is over saturating the storm environment possibly leading to a degraded forecast.

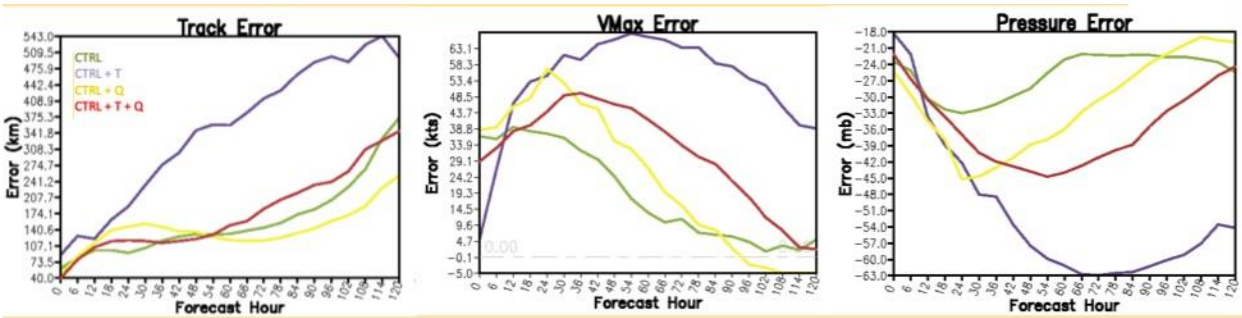

Figure 2: (a) Average error over 97 cycles. Position (track) error in km (b) Average error over 16 cycles. Minimum central pressure error in hPa. (c) Average error over 16 cycles. Maximum 10m wind speed error in kts.

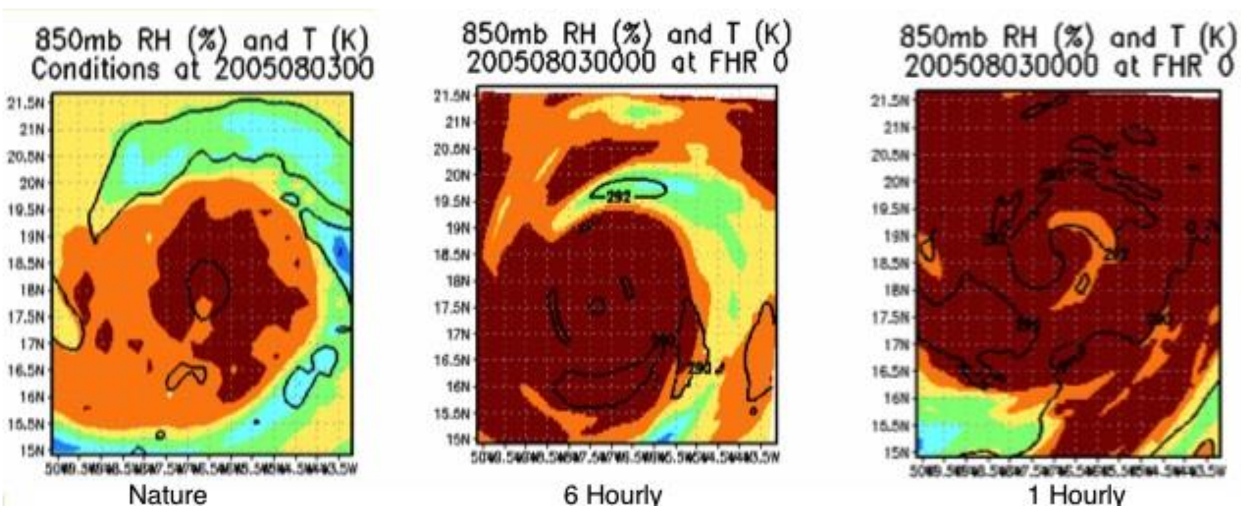

Figure 3: 850mb relative humidity and temperature analyses on 00UTC August 03 from the Nature Run (left), 6 hourly experiment (middle), and 1 hourly experiment (right).

Research Performance Measure: The research program was completed on schedule.

Reanalysis 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)

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 - *Society is prepared for and responds to weather-related events* (*Primary*)

***Goal 3*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts* (*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 1964, 1966, 1968 and 1969 are complete. We expect to have 1967 done by the end of June. A summary of significant results since July of 2015 follows:

The hurricane season of 1966 was active 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.

The 1967 hurricane season was below average, but similar to 1960 and 1992, it had an intense and deadly hurricane. Hurricane Beulah crossed the Caribbean Sea and Gulf of Mexico making landfall in Hispaniola, the Yucatan peninsula and near the Mexico-Texas border. The main development region between Africa and the Lesser Antilles was quite active, with the formation of six tropical cyclones. Doria was a long-lasting hurricane near the east coast of the United States that made landfall in the mid-Atlantic as a tropical storm on a rare southward track. Fern quickly intensified in the Bay of Campeche but weakened to a tropical storm before making landfall in western Mexico. Edith was a weak tropical storm that formed east of the Lesser Antilles and dissipated over the eastern Caribbean Sea. Ginger was a rare tropical storm that formed between Africa and the Cape Verde Islands and moved northward, quickly weakening over the cooler waters. Chloe was a long-lived Cape Verde hurricane that remained over the ocean until impacting France as a weak extratropical cyclone. Arlene was an early season Cape Verde system that reached hurricane intensity over the north Atlantic and did not affect land. Heidi and the non-developing tropical depressions in HURDAT are still pending reanalysis.

Figure 1: Satellite image of Hurricane Gladys on October 17, 1968 over the eastern Gulf of Mexico, captured by the NASA Apollo 7.

The 1968 hurricane season was about average with most of the tropical cyclone activity developing over the western Atlantic. Hurricanes Abby and Gladys and Tropical Storm Candy made landfall in the United States. The hurricane season had an active start with three tropical cyclones developing in June. Dolly developed near South Florida but turned to the northeast and passed close to the Outer Banks as a minimal hurricane. Tropical Storm Edna was the only tropical cyclone to develop between Africa and the Lesser Antilles, and was never a threat to land. Frances was a weak tropical storm that developed north of the Bahamas and moved away from the United States, briefly threatening Bermuda. HURDAT originally indicated that a subtropical cyclone formed over the western Atlantic in September. The data available suggests that the system was a hurricane and this is one of the most significant changes for this season. A

couple of new tropical storms were added and the most significant impacted New England, but the damage was minimal. 1968 is one of the few seasons on record not to feature a major hurricane.

The 1969 hurricane season was one of the most active seasons on record, but similar to 2004, the first named storm did not develop until late July. Many of the tropical cyclones were long-lived and most stayed over the ocean. Camille was the most intense tropical cyclone of the season, making landfall in the United States as a category 5 hurricane causing significant damages and deaths. Two named tropical cyclones made landfall in Caribbean. Francelia was a category 2 hurricane when it hit Belize in early September and Martha was an atypical hurricane, forming in the southern Caribbean Sea in November. Martha was the first tropical cyclone on record to hit Panama. Hurricane Laurie formed in the western Caribbean Sea and reached peak intensity in the central Gulf of Mexico, where it made a clockwise loop and weakened before impacting southern Mexico. Hurricane Gerda formed near South Florida and accelerated to the northeast reaching major hurricane intensity off Cape Cod before hitting eastern Maine as a weakened system. Hurricane-force winds were experienced in Nova Scotia but the damages were minor. Hurricane Holly formed east of the Lesser Antilles but dissipated before being a threat to land. Inga was one of the longest-lived cyclones on record, forming east of the Lesser Antilles and dissipating northeast of these islands. Five systems of at least tropical storm intensity formed while Inga was still active, four dissipating before Inga died. Kara formed north of the Greater Antilles and moved toward the western Atlantic. Satellite and synoptic data suggests that it acquired subtropical characteristics between the United States and Bermuda. The system intensified into a hurricane as it moved away from land into the north Atlantic. Jenny and a subtropical storm that developed in the eastern Gulf of Mexico were the only systems with winds of at least tropical storm intensity to impact Florida. The subtropical Atlantic was very active this year with the development of five tropical cyclones, two reaching hurricane intensity.

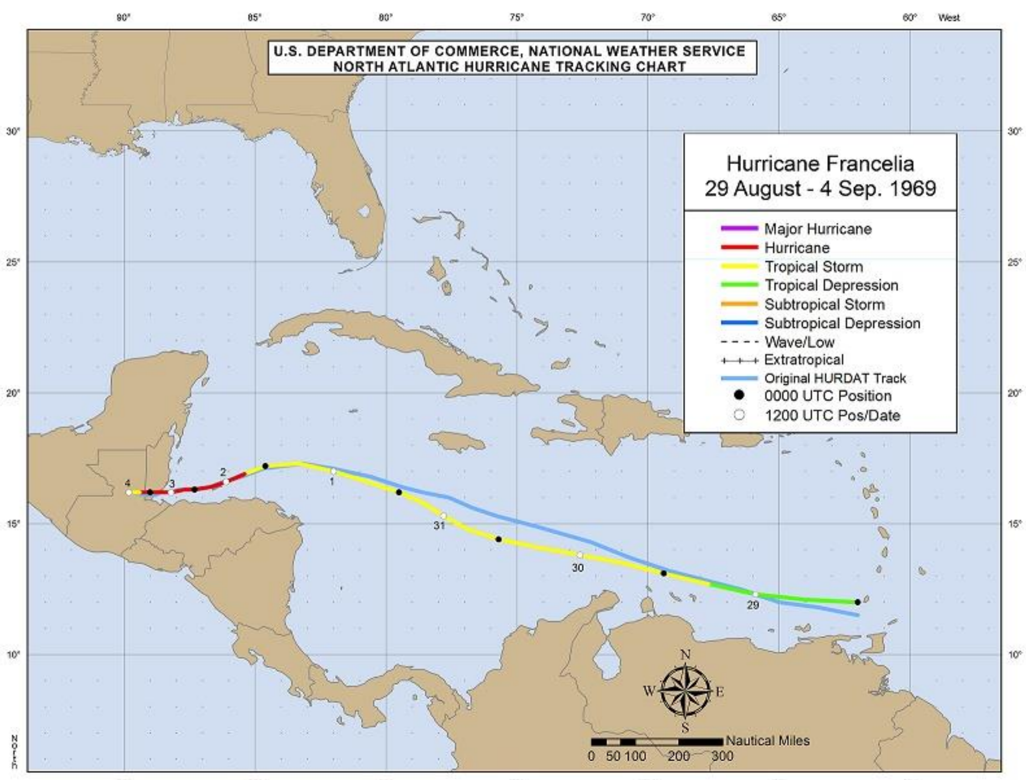

Figure 2: Original and revised track of Hurricane Francelia of 1969, illustrating changing assessments of track due to reanalysis based on the data available.

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 storm' positions, intensities, and structure. He also took the lead on the 1964 hurricane season revisions. The 1964 season operationally featured 12 tropical storms, 6 hurricanes, and 6 major hurricanes. Following reanalysis, a new storm was added; the revised total for the season is 13 tropical storms, 7 hurricanes, and 5 major hurricanes—an above-average year. The most notable storms were Hurricane Cleo, a long-lived major hurricane that caused tremendous loss of life in Haiti and significant damage in the Miami metropolitan area, and Hurricane Dora, another long-lived major hurricane that caused widespread flooding in northern Florida and produced hurricane-force winds in Jacksonville, Florida–the first known instance of such on record in the city.

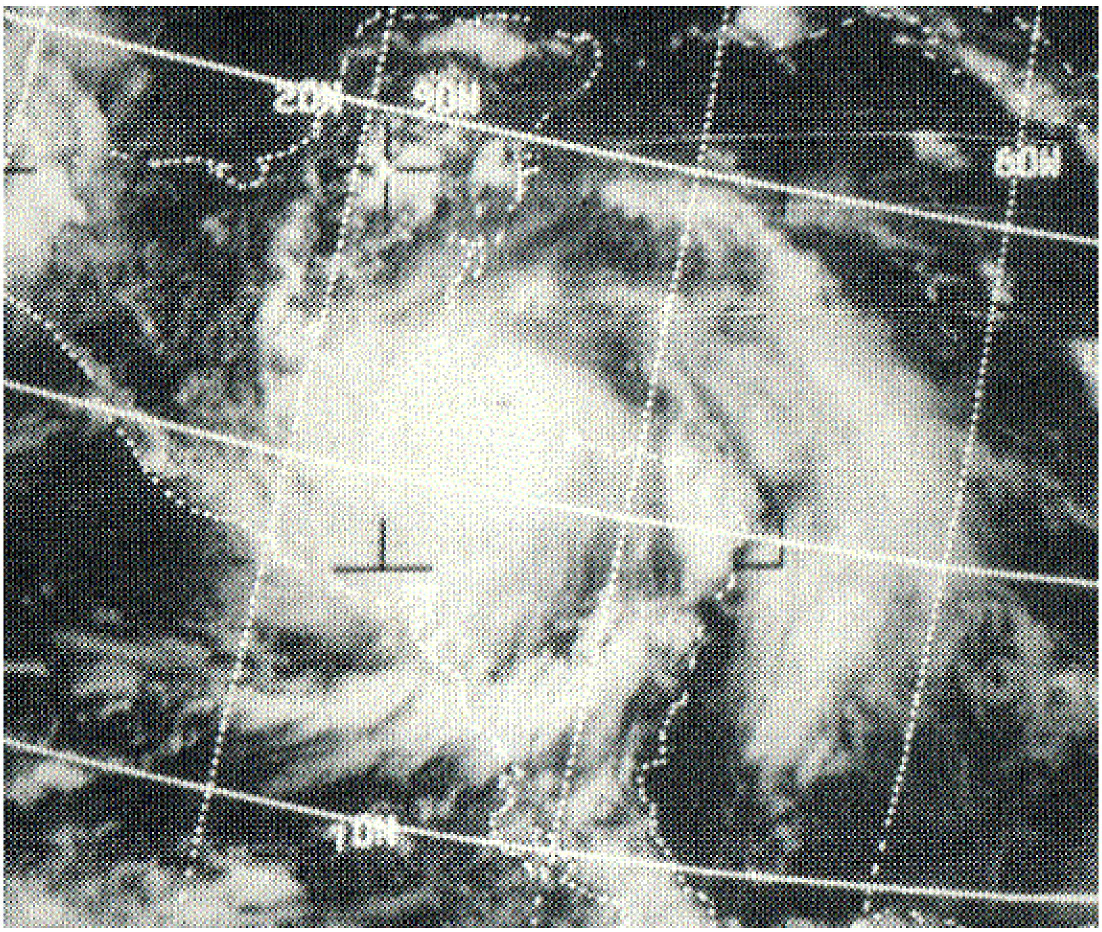

Figure 3: ESSA IX showing Hurricane Francelia on September 2, 1969 affecting the Bay Islands of Honduras on its way to Belize.

Research Performance Measure: The reanalysis of the 1967 hurricane season should be complete in June. By the end of 2016, we are expecting to have completed the reanalysis of the hurricane seasons of 1970-1972. 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, H. Christophersen, B. Dahl, B. Klotz, K. Sellwood and J. Zhang (UM/CIMAS)
NOAA Collaborators: R. Atlas, S. Aberson and M. Black (NOAA/AOML)
Other Collaborators: L. Bosart and R. Torn (SUNY-Albany)

Long Term Research Objectives & Strategy to Achieve Them:

***Objectives*:** To support the NOAA Sensing Hazards with Operational Unmanned Technology (SHOUT) 2015 and 2106 hurricane field campaigns, evaluate the impacts of UAS in-situ and remote sensing observations that are collected during SHOUT on tropical cyclone analyses and forecasts, and investigate signals of the tropical cyclone diurnal cycle in model simulations.

***Strategy*:** Participate in SHOUT field campaign efforts by providing mission science and GPS dropwindsonde processing support, as well as designing flight tracks for the Global Hawk aircraft. Conduct Observing System Experiments (OSE) and Observing System Simulation Experiments (OSSEs) using data from Global Hawk field missions and utilizing NOAA/AOML/HRD's in-house HEDAS. Perform experiments using a version of the idealized Hurricane Weather Research and Forecasting (HWRF) simulation system to characterize the formation and evolution of the tropical cyclone diurnal cycle.

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 Program
NOAA Technical Contact: Robbie Hood, NOAA UAS Program

Research Summary:

The NOAA UAS program successfully conducted its 2015 SHOUT hurricane field program and will utilize the Global Hawk Unmanned Aircraft System (UAS) again in 2016 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, a microwave sensor for detecting 3-dimensional temperature, moisture and precipitation through the hurricane's upper-level cirrus clouds, and a dual frequency Doppler radar for detecting 3-dimensional winds in the hurricane environment. The project team has provided and will continue to provide a combination of on-site and remote mission science and real-time GPS dropwindsonde processing support during SHOUT Global Hawk missions and will also help design aircraft flight tracks that optimally sample the TC inner core and its surrounding environment. To address this latter effort, the project team is working with the NOAA Environmental Modeling Agency (EMC) to generate 80-member HWRF ensemble forecasts for TCs of interest during SHOUT. These forecasts will be used to calculate optimal GPS dropwindsonde target locations for various forecast lead times during potential periods when the GH would be flying. This output will be used to generate real-time analyses and made available to SHOUT mission scientists to plan Global Hawk flight patterns and GPS dropwindsonde sampling strategies.

The potential for UAS assets to improve hurricane analyses and forecasts is evaluated by investigating the impact of Global Hawk dropwindsondes for vortex-scale hurricane data assimilation in NOAA's Hurricane Ensemble Data Assimilation System (HEDAS). We first carried out some case studies. Two dates from Hurricane Edouard (2014) were chosen for these case studies. In the first case (15 September 0600 UTC), Global Hawk dropwindsondes provided exclusive inner-core observations, while in the second case (16 September 1800 UTC), Global Hawk dropwindsondes coexisted in the inner core with an extensive suite of observations from other aircraft yet remained somewhat exclusive in the near environment (Fig. 1).

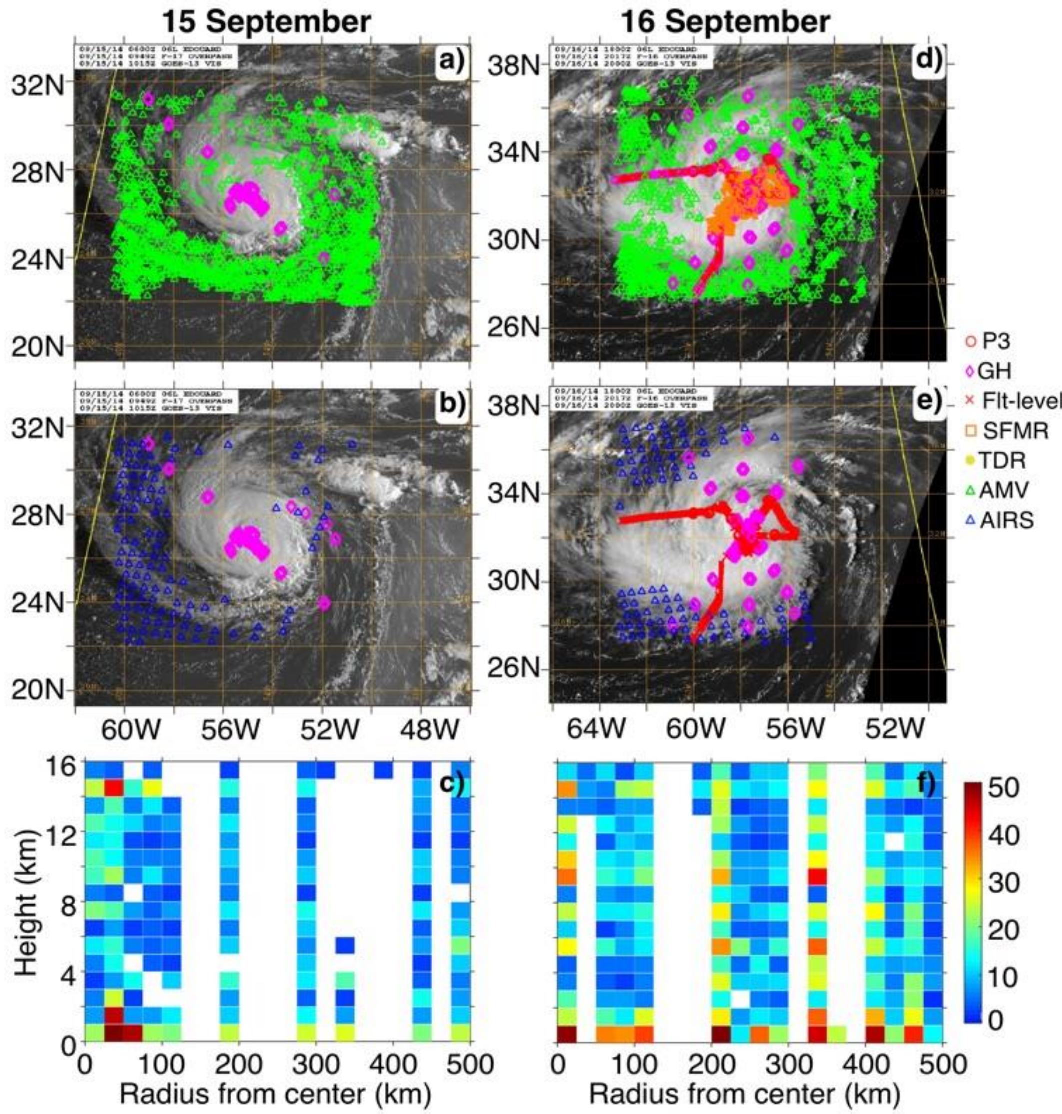

Figure 1: Spatial distribution of assimilated observations overlaid on visible cloud imagery for the experiment All (including all available observations) centered at 6 UTC on 15 September (left panel) and at 18 UTC on 16 September (right panel) for (a,d) wind observations and (b,e) thermodynamic observations. Visible imagery courtesy of Naval Research Laboratory, Monterey, CA. (c,f) Density distribution of the assimilated GH observations (purple diamonds in the top and middle panels) in a radius-height coordinate at every 25 km in radius and 1 km in height.

Large impacts are observed on model kinematic and thermodynamic analyses in the inner-core region of the storm on 15 September when Global Hawk dropwindsondes were assimilated. This leads to a better representation of the storm structure such as warm core anomaly, primary and secondary circulation, etc. Consequently, this contributes to a positive intensity forecast for the 15 September case (Fig. 2). Meanwhile, for the 16 September case, we notice that analysis increments from assimilating Global Hawk dropwindsondes exist both in the inner core and near the environment of the storm, although they are not as large in magnitude as the first case, as an extensive suite of observations from other aircraft and satellite retrievals may have already contributed to the improved analysis. Nonetheless, the assimilation of Global Hawk dropwindsondes leads to a consistent track improvement up to 5 days (Fig. 2). Our initial study presents promising results for incorporating Global Hawk to mitigate the possible observation gaps from NOAA P-3 or satellite observations (e.g., AIRS), and additional advantages even in the presence of satellite observations or reconnaissance observations.

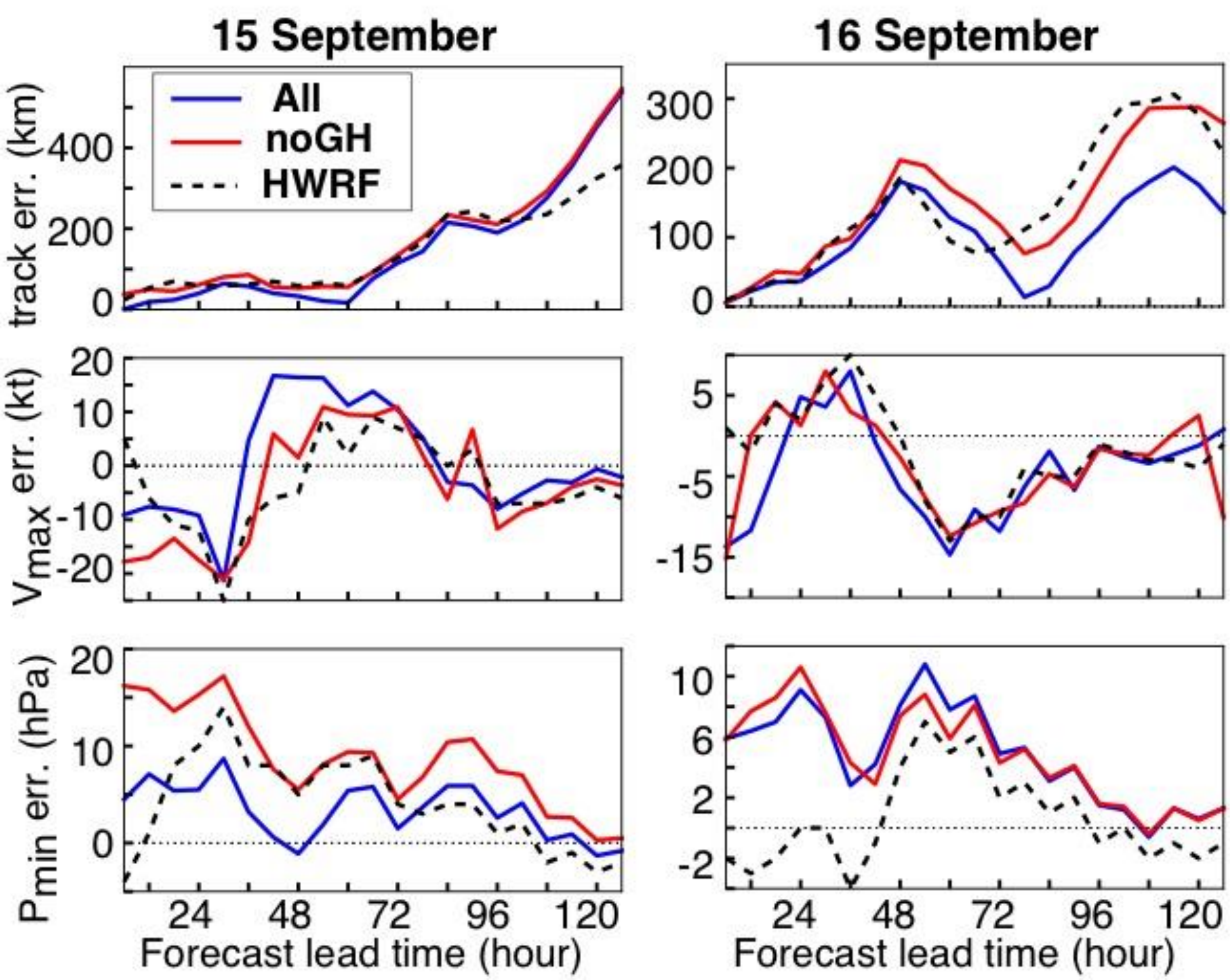

Figure 2: Track error (unit: km), the maximum sustained 10-m wind speed error (v_{max}, unit: kt), and the minimum sea level pressure error (P_{min}, unit: hPa) compared to the best track at every 6 hours from the 124-hour deterministic forecasts of the experiments All (blue solid lines) and noGH (red solid lines), and corresponding operational HWRF forecast (black dashed lines) at 6 UTC 15 September (left panel) and 18 UTC 16 September 2014 (right panel).

We also assessed the impacts of assimilating Global Hawk remote sensing observations, and in particular, retrievals from the Scanning High-resolution Interferometer Sounder (SHIS) instrument. This is an instrument that measures emitted thermal radiation at high spectral resolution for infrared radiation and is similar to the AIRS instrument on NASA's Aqua satellite but capable of sampling at much higher spatial resolution. One case study at 0600 UTC on 12 September 2014 of Hurricane Edouard demonstrates that the assimilation of SHIS retrievals alone leads to similar impacts as assimilating AIRS retrievals and Global Hawk dropwindsonde observations combined, i.e., a consistent positive impact on the track forecasts (Fig. 3). The assimilation of AIRS, Global Hawk dropwindsonde thermodynamic observations and SHIS retrievals together shows the largest impacts on both track and intensity forecasts (Fig. 3), as well as initial analysis fields. This initial assessment of the remote sensing observations onboard Global Hawk suggests that targeting with UAS or recon aircraft should be designed to complement the coverage of available satellite data, which could potentially enhance the impact substantially in some cases. These results also demonstrate the importance of the availability of high-resolution thermodynamic observations in the hurricane inner core.

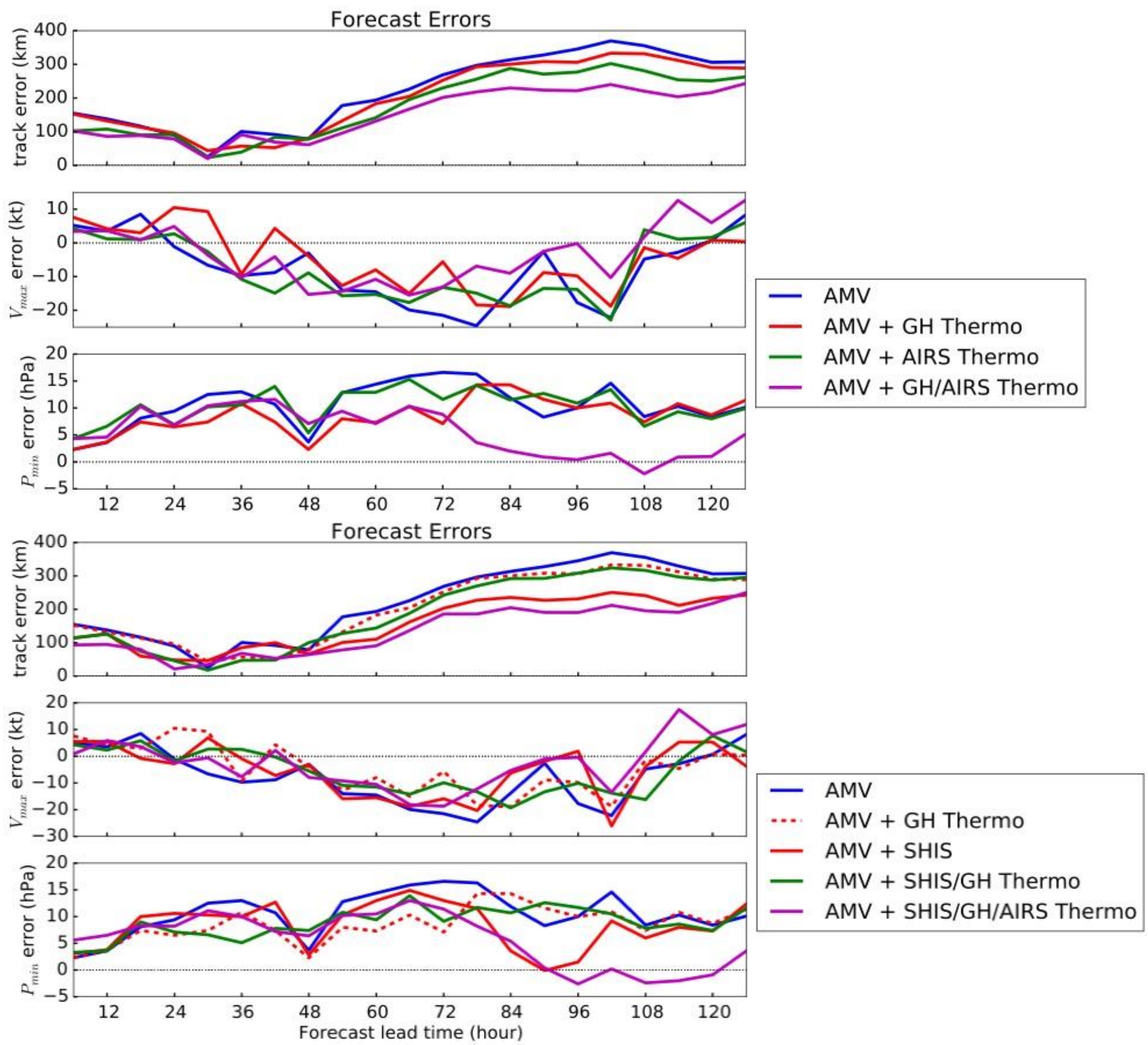

Figure 3: Deterministic forecast errors compared to the best-track at 6 UTC on 12 September, 2014.

HEDAS was also utilized to evaluate the impact of assimilating observations taken using UAS technology on TC surface wind structure. These types of surface wind analyses have the potential to provide important information about the strength, extent and location of the strongest winds within a TC, which can then be used for planning, safety, and insurance mitigation purposes. Two observing system experiments (OSEs) were conducted, one for a well observed storm and another when the primary source of observations was the NASA WB-57 being flown by the Office of Naval Research's TC Intensity (TCI) field campaign. The second experiment was the first time that high-altitude Yankee dropwindsondes and surface wind observations from the Hurricane Imaging Radiometer (HIRAD) have been assimilated into a numerical model. For this purpose, the observation processing capability within HEDAS was extended to be able to utilize these new observation types.

For each experiment two analyses were created, one in which only the conventional data were assimilated and a second where both conventional and UAS data types were assimilated. For the first experiment, the case selected was 2014 Hurricane Edouard verifying at 1800 UTC on 16 September. Both HEDAS analyses for this case capture the secondary wind maxima, the significant wind radii and eye diameter well. However, the addition of UAS dropsondes provides a better analysis of the secondary eye-wall structure seen in the observations (Fig. 4). Although neither analysis contains wind speeds as high as the officially reported intensity at this time, they are consistent with the maximum of the observed winds and are also consistent with the drop in intensity, which is expected during an eyewall replacement cycle. In this case, HEDAS appears to do a good job of representing the state of the vortex at the time it was observed. Although there were plentiful conventional observations at this time, there was still additional benefit derived from including the UAS observations.

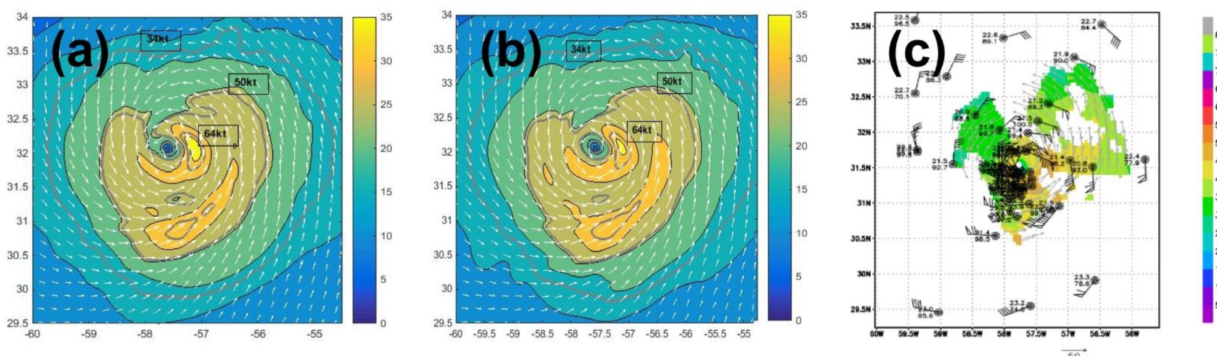

Figure 4: HEDAS surface wind speed analysis for Hurricane Edouard (2014). (a) Conventional observations only; (b) conventional observations plus Global Hawk dropsondes; and (c) P-3 Doppler radar and dropwindsonde observations at 500 m. This is the lowest level for which radar data are available.

The second case, 2015 Hurricane Joaquin, verifying at 18 UTC on 02 October, is one for which unmanned aircraft have the potential to provide the greatest benefit. At this time none of the NOAA aircraft were available, Joaquin was a category-3 major hurricane and the forecasts differed greatly between the operational models. In this case the location of the storm over the many small islands of the Bahamas and the limited number of independent observations made evaluating the surface structure more difficult. Comparing the two HEDAS analyses above the surface at 500 m with the information given by U.S.A.F. vortex messages and with the NHC best track report, we can see that the addition of the UAS observations produces a more realistic wind field than the conventional data alone (Fig. 5). Without these observations the storm is too large, too strong and does not have the wind maximum in the correct location. The official maximum wind estimate was 110 kt while the analysis without NASA WB-57 observations has winds in excess of 135 kt, a difference of two Saffir Simpson scale categories. The analyses which included the TCI observations has maximum wind speeds of 98 kt which keep it a

category-2 storm, which is consistent with the maximum observed winds of 107 kt on the eastern side. Additionally, the analysis with the TCI data produces a smaller storm, although the radius of maximum wind is still greater than the 15-km value given in by the best track. Both analyses contain the observed eastward extension of the 35-kt wind radius. Although this is only a single case it suggests that both the HIRAD and Yankee dropwindsonde observations are capable of adding value to the analysis of TC winds within the HWRF model.

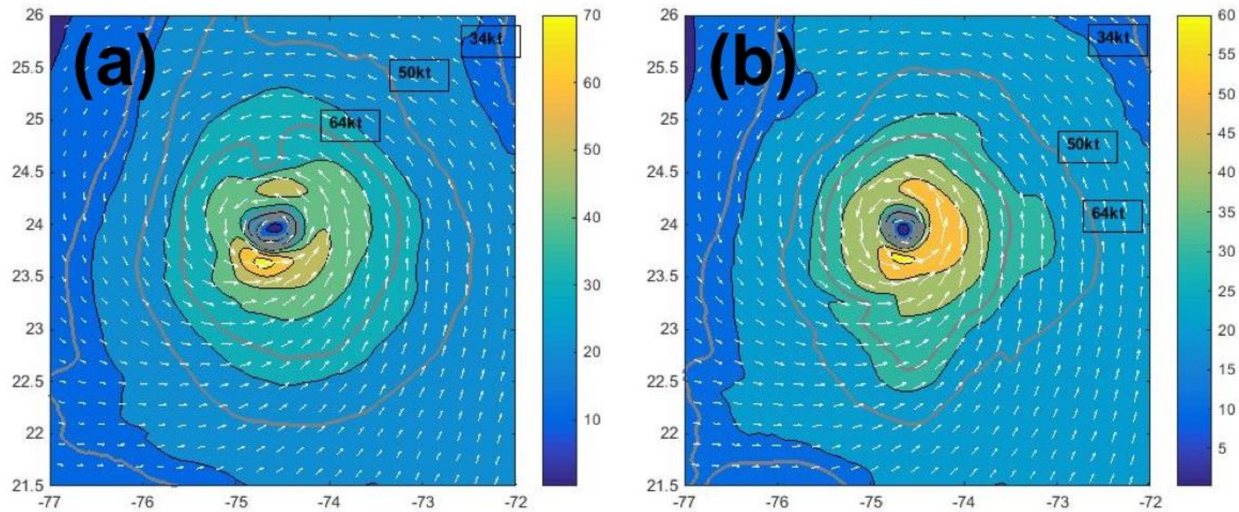

Figure 5: HEDAS 500-m wind speed analysis for Hurricane Joaquin (2015). (a) Conventional observations only; (b) conventional observations plus TCI dropwindsondes and HIRAD surface winds.

Observing system simulation experiments (OSSEs) are also being conducted to assess how altering the Global Hawk sampling pattern for a given mission impacts the forecast after the data are assimilated. The data are generated by sampling the Nolan et al. (2013) nature run with the aircraft simulation code developed at AOML and then assimilated with HEDAS. The first of these experiments compares two different Global Hawk flight tracks that occur in conjunction with the flight of a NOAA P-3 aircraft. Adding Global Hawk dropwindsondes improves the structure and intensity of the storm in the final analysis after data assimilation compared to using NOAA P-3 dropwindsonde, flight-level, and SFMR data alone (Fig. 6). The location of the improvement was shown to be sensitive to the placement of the dropsondes, which depends both on the flight pattern itself and the timing of the flight relative to the window during which data are assimilated into the model. The impact of shifting the timing of the flight pattern is currently under further investigation.

As part of the assessment of the TC diurnal cycle, a version of an idealized HWRF simulation system was modified to give the user control over the development and progression of the diurnal cycle. This idealized model framework incorporates several standard features, including the GFDL radiation scheme and three nested domains with 27, 9, and 3 km horizontal resolution, respectively. Three simulations were executed, which all experienced very weak vertical wind shear (1.4 m s^{-1}), high SSTs (30.9 °C), and had an initially strong but slowly moving (west at 2.1 m s^{-1}) category 3 hurricane with radius of maximum wind of 44 km. Our experiments include a control simulation that is allowed to run for seven days with no modifications to the standard radiation setup, a day only experiment that keeps the solar zenith angle constant at 1600 UTC (1200 local time, 20°N, 75°W), and a night only experiment that keeps the solar zenith angle constant at 0400 UTC (0000 local time).

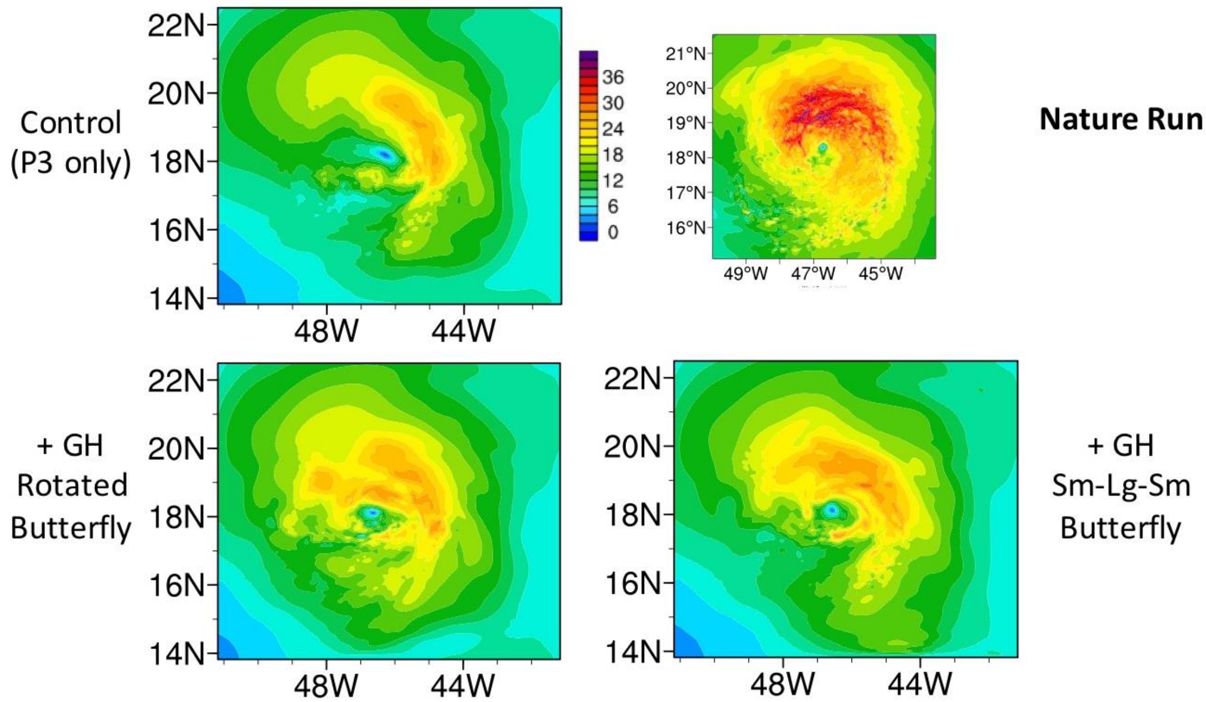

Figure 6: HEDAS surface wind speed analyses are compared when only P-3 observations are assimilated (Control) versus two types of Global Hawk flight patterns (rotated butterfly and small-large-small butterfly). For reference, the plan view of surface wind speed in the Nature Run (truth reference) valid at the same time is also shown.

The diurnal cycle appears in several fields within the model, one of which is the upper-level radial wind. Examining this field for the night and day only experiments, which are shown in Fig. 7, several differences are clearly depicted. With the night only experiment (left panel), the outflow is weakened considerably, especially near the end of the simulation period. The hurricane outflow slightly intensifies around 96 hours, but overall, this pattern is not conducive for any further intensification. For the day only experiment (right panel), the diurnal signature is again not present, but the radial wind pattern remains fairly constant in magnitude throughout the forecast period. In theory, a fairly strong outflow signature aloft would be conducive for intensification or at least maintenance of the vortex, but the intensity trace (not shown) indicates that the presence of a diurnal cycle provides the best mechanism for this process.

Research Performance Measure: This project is in the year-2 phase of a proposed 3-year effort. Objectives that focus on the providing SHOUT hurricane field program support were successfully completed in 2015 and are planned for 2016. In 2015, real-time objective guidance using HWRF model ensemble information was successfully implemented to help plan NOAA SHOUT Global Hawk flight tracks and GPS dropwindsonde sampling strategies in and around TCs and improve model forecasts of storm track and intensity. This effort will be also carried out again during the 2016 SHOUT hurricane field campaign. Studies of the formation and evolution of the TC diurnal cycle have begun and will continue during the year-2 and 3 phases of this project.

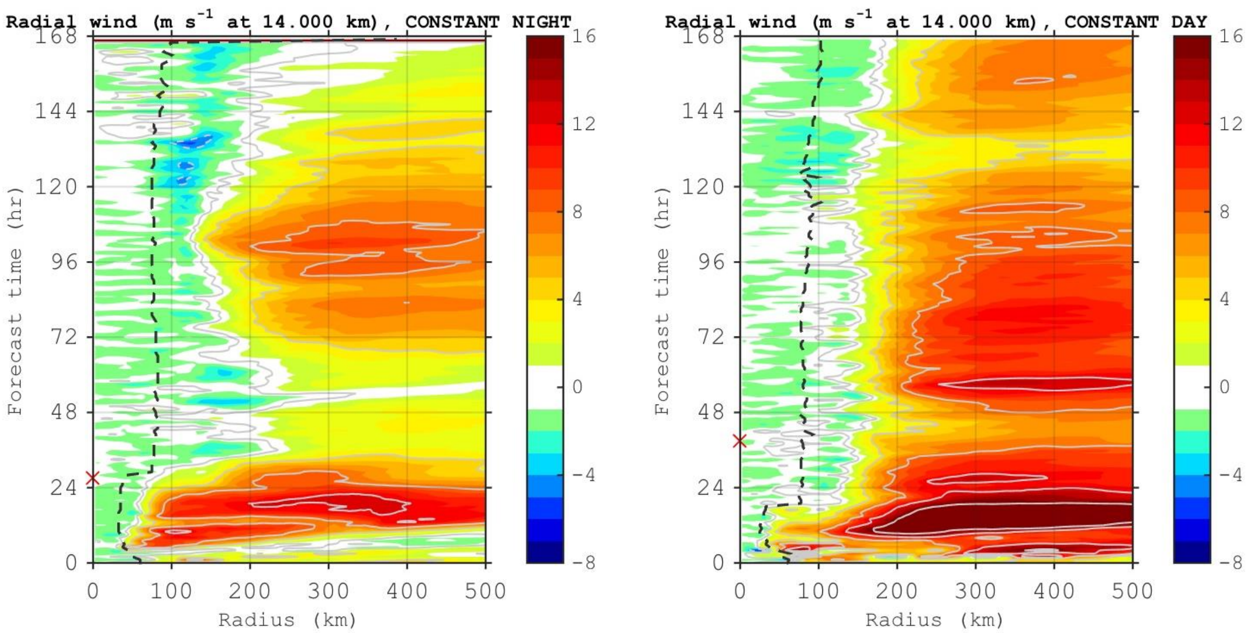

Figure 7: The 14 km radial wind (m s^{-1}) in the experiments for night only (left) and day only (right) are provided as a function of radius (km) and forecast time (hours). The red 'X' indicates the hour at which the solar zenith angle was set to a constant value. Positive values indicate winds moving away from the vortex center.

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Near-Automation of Real-Time Airborne Radar Analysis Onboard NOAA Aircraft

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

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.

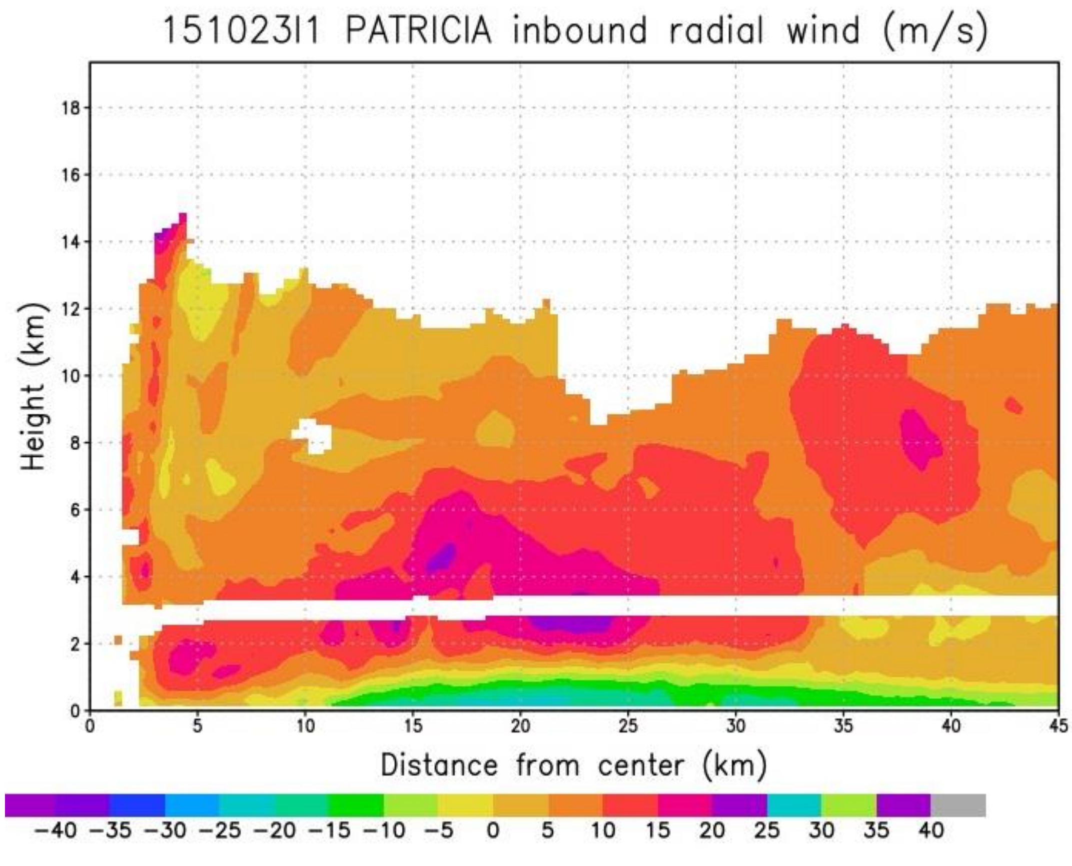

Figure 1: Inbound radial winds of Hurricane Patricia, October 23, 2015. X-coordinate is distance from storm center and y-coordinate is height above sea surface.

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 NOAA AOC (Aircraft Operations Center) 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.

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.

To facilitate NCEP being warned that Doppler radar data is to be included for one of their established daily HWRF runs, operators can now issue a trigger from the ground identifying the new storm event.

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

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Ingesting Sea Surface Height Anomalies from the Cryosat-2 Mission to Enhance the Nesdis Operational Ocean Heat Content Product Suite

Principal Investigators: L.K. (Nick) Shay (UM/RSMAS)
Other Collaborators: E. Maturi and D. Donahue (NOAA/NESDIS)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: While the Cryosat-2 altimetry mission primarily focuses on polar sea ice, its use in mesoscale oceanography has been somewhat limited given it 369-day repeat track. Cryosat-2 can operate in three modes: Synthetic Aperture Radar (SAR); SAR interferometric; and, a low-resolution sea surface height anomaly (SSHA) mode similar to other altimetry satellites. In this low resolution mode, the SSHA data are a key component in calculating the daily ocean heat content (OHC) product operationalized for three basins, North Atlantic, and North and South Pacific Oceans at NOAA/NESDIS. Despite the unusual repeat track, Cryosat-2 can provide data coverage in limited areas of the ocean due to its specific orbit characteristics. Here, the inclusion of the Cryosat-2 SSHA data is assessed from March 2013 to August 2015 when combined with other altimetry missions such as Jason-2 and SARAL.

***Strategy*:** Cryosat-2 SSHA data were evaluated for filling in gaps to assess possible improvements to the OHC product suite that currently uses both Jason-2 and SARAL mission data. The OHC product was calculated with and without Cryosat-2 to assess its impact on the product suite. Central to this objective is that isotherm depths (20 and 26ºC), ocean mixed layer depth, and OHC were carefully evaluated from *in-situ* data from floats, drifters, expendable bathythermographs (XBT) transects, long-term Pirata and TAO moorings and airborne AXBTs, and AXCTDs as discussed in the report to NESDIS listed below.

CIMAS Research Theme:

***Theme 2*:** Tropical Weather;
***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: NOAA/NESDIS
NOAA Technical Contact: Eileen Maturi

Research Summary:
Using the three daily systematically merged regional temperature and salinity climatologies for the North Atlantic (Meyers et al., 2014: SMARTS); North Pacific (McCaskill et al., 2016: SPORTS) and the South Pacific (SPOC), the addition of Cryosat-2 to the operational OHC product for NOAA/NESDIS was investigated. Using data from March 2013 to August 2015, the ingesting of the Cyosat-2 data reduced the mapping errors using the Mariano and Brown (1992) objective analysis approach (Figure 1). The SSHA root-mean square differences of Cryosat-2 mission at cross-over points (within a few kilometers) of either a Jason or SARAL track were determined using +/- 1, 3 and 5-day intervals and found to be approximately 8 to 9 cm in all three basins. The lower root-mean square differences were obtained with the +/- 1-day interval. Moreover, the OHC root-mean square differences calculated with and without Cryosat-2 were found to be insignificant (e.g., within 1 to 2 kJ cm^{-2}). Notwithstanding, some mapped areas did suggest more OHC variability due in part to the dynamic nature of the ocean in those regimes. Thus, adding the additional altimeter data from Cryosat-2 did not degrade the product suite while lowering the mapping errors. Potential follow-on missions using the same radar altimeter technology are already in production. Understanding the limitations involved with a multi-mode mission is important to explain how this new wave of radar altimeters can be used in the future of sensing the open ocean from space (for more details see the NESDIS report of Shay et al. (2016) listed below).

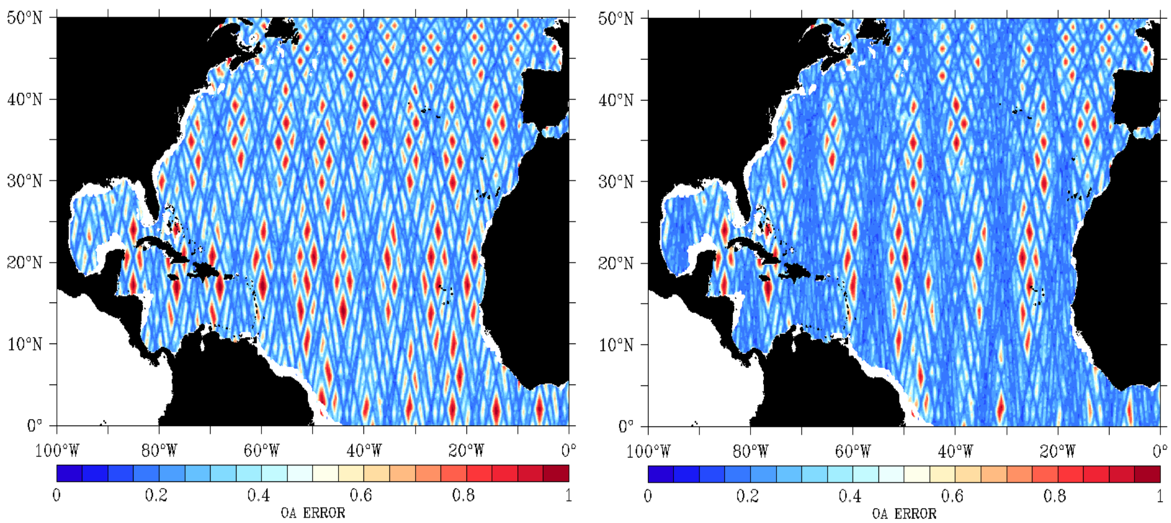

Figure 1: Mapping error from Objective Analysis of SSHA product in the North Atlantic for May 31, 2015 in the left panel: Jason-2 and SARAL and the right panel: Jason-2, SARAL, and Cryosat-2

Research Performance Measure: Sources and sinks of oceanic heat content have been shown to improve the forecasting of hurricane intensity in both statistical and dynamical coupled forecast models at the National Centers. A key element of the daily OHC mapping requires multiple satellite altimeters to resolve both warm and cold oceanic structures that often lie in front of developing or mature hurricanes. Over a two-and-a-half-year period, ingesting of the Cryosat-2 mission data to the NESDIS product suite reduced the SSHA mapping errors while not degrading the OHC signals in three basins. By comparing the various SSHA from multiple missions into the product suite, Cryosat-2 data also improved the characterization of the isotherm and mixed layer depths as well as the OHC. With the ingesting of Cryosat-2 data, OHC uncertainties were reduced when compared to coincident ocean measurements. Thus, the Cryosat-2 data are now entrained into the daily NOAA NESDIS product suite aimed at improved intensity forecasting at the National Centers.

Addressing Deficiencies in in Forecasting Tropical Cyclone Rapid Intensification in HWRF

Project Personnel: J. Zhang, 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 underprediction 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 HWRF ensemble forecasts 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). Feedbacks are sent to HWRF model developers for improvement of the model physics. The result from this project led to improvement in the boundary layer parameterization scheme in HWRF.

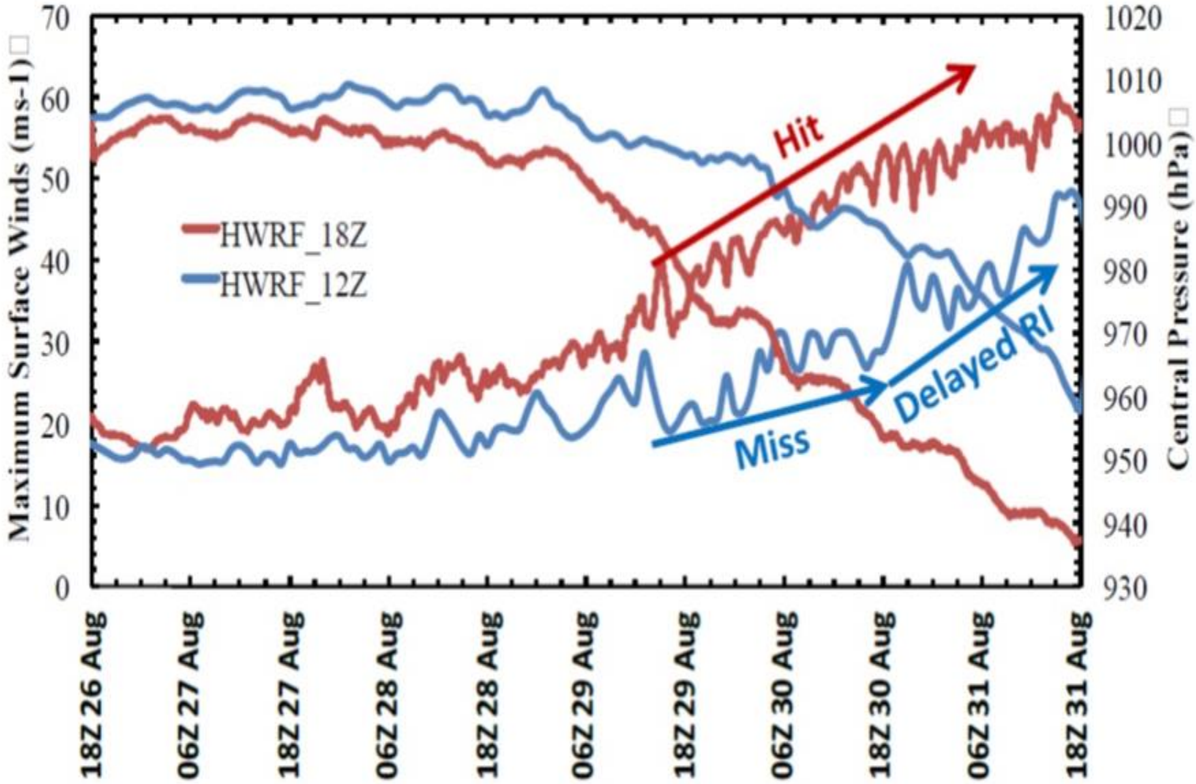

Figure 1: Time series of minimum central pressure and maximum 10-m winds for the Hit (i.e., 18 UTC 26 August initial time; red) and Miss (i.e., 12 UTC 26 August initial time; blue) HWRF forecasts.

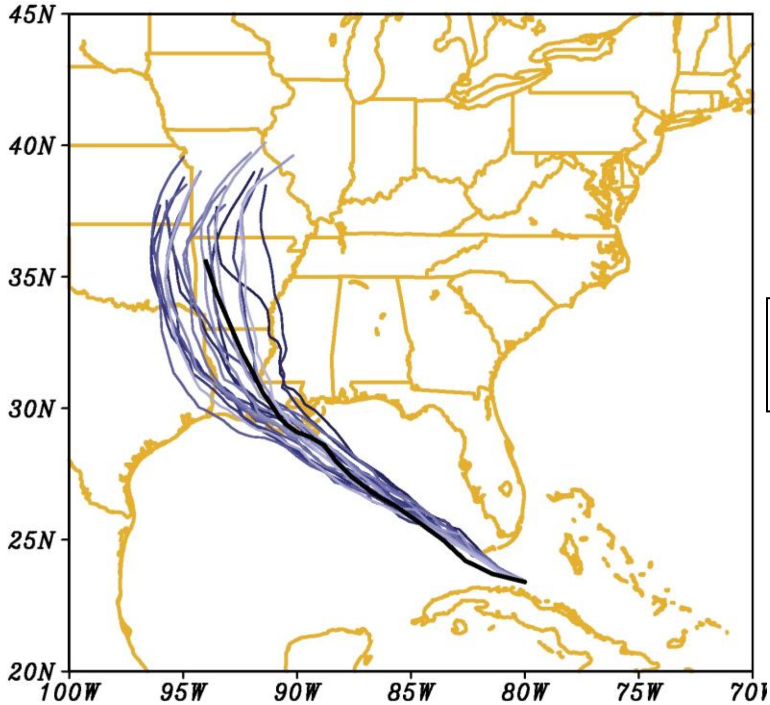

Figure 2: Storm tracks from HWRF ensemble forecast of Hurricane Isaac (2012).

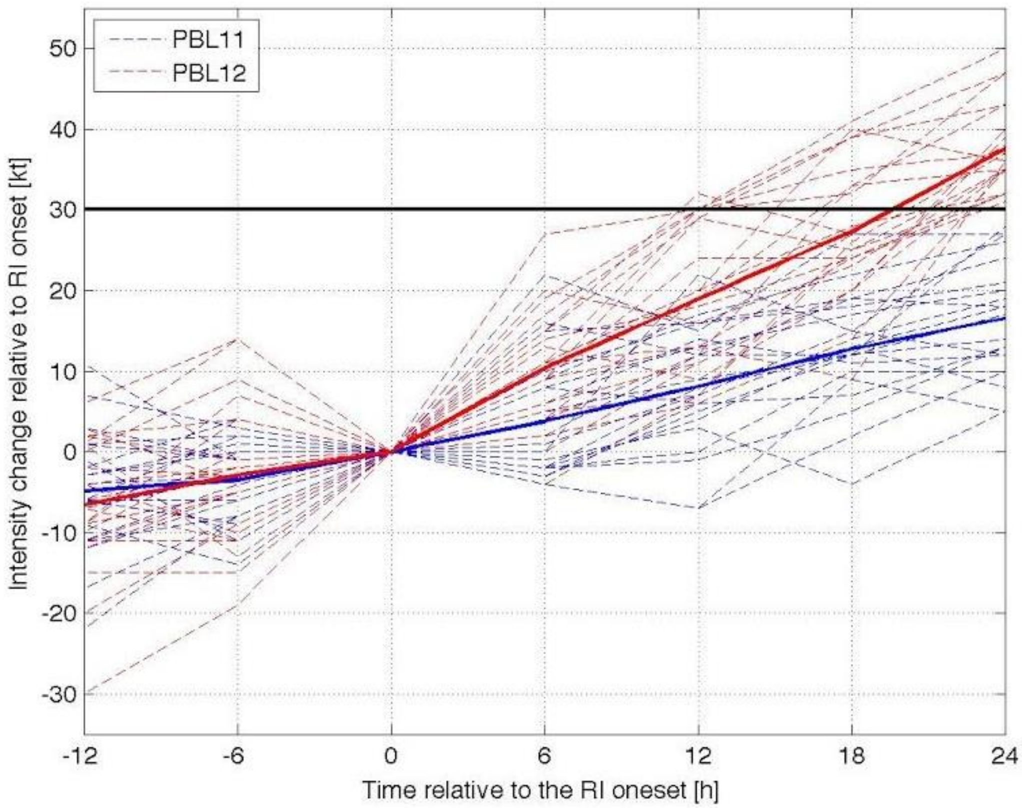

Figure 3: Plot of intensity change in kt for PBL11 (blue) and PBL12 (red) HWRF forecasts as a function of time relative to the onset of RI events that are seen in PBL12 not in PBL11. Note that the boundary layer vertical diffusion in HWRF was upgraded based on aircraft observations for PBL12.

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

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Developments in the High-Impact Weather Prediction Project (HIWPP)

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

Long Term Research Objectives and Strategy to Achieve Them:
***Objectives*:** To create a multi-scale hurricane prediction system working at cloud-resolving 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 the NEMS framework.

***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:

As of the end of 2015, all major technical milestones of the HIWPP project have been achieved, excepting comprehensive testing and evaluation-- a task that is recommended to be merged with the on-going HNMMB R2O efforts at EMC (HNMMB is a potential replacement for the operational GFDL hurricane model). It should also be noted that there were few land-falling storms in the 2015, the seasons on which much of the developmental efforts were focused. The defined milestones and their respective dates of completion are shown in Table 1.

Table 1: Milestones of the HIWPP project and their completion date.

Milestone	Completed
✓ Configuration & Testing	Dec 2014
✓ HWRF Physics Transitions	Sept 2014
✓ Idealized Framework	April 2015
✓ HWRF Vortex Tracker	Jun 2015
✓ HWRF Vortex Initialization & Cycling	Dec 2015
Semi-Real-time Testing	On-going
Multi-Season Testing, Verification, Rainfall Evaluation	Postponed due to lack of HPC

The NMMB system for Hurricanes, "HNMMB", is a regional hurricane prediction model developed to fulfill the goals and requirements of the *Hurricane Nest Project*, a subcomponent of HIWPP. The system operates within the framework of the NOAA Earth Modeling System (NEMS), combining the dynamical core of the Nonhydrostatic Multiscale Model on the B-grid (NMMB) with hurricane-specific components adopted from the Hurricane Weather Research & Forecasting (HWRF) model. These components include a physics suite tailored for the hurricane problem, the HWRF storm-tracking algorithm, the HWRF vortex cycling and initialization routine for multiple storms, and the capability to model idealized tropical cyclones. The model currently operates at a resolution of 18 km for the fixed outer domain, with resolutions of 6 km and 2 km, respectively, for the storm-following, telescopic nested pairs. The system is version-controlled on the SVN repository, and is scripted to run from a single input file. An automated suite of advanced diagnostic tools is included, which is called at the completion of

each forecast cycle and uploads plots, data, and other forecasting tools directly to the HNMMB website at 'www.storm.aoml.noaa.gov/hnmmb'.

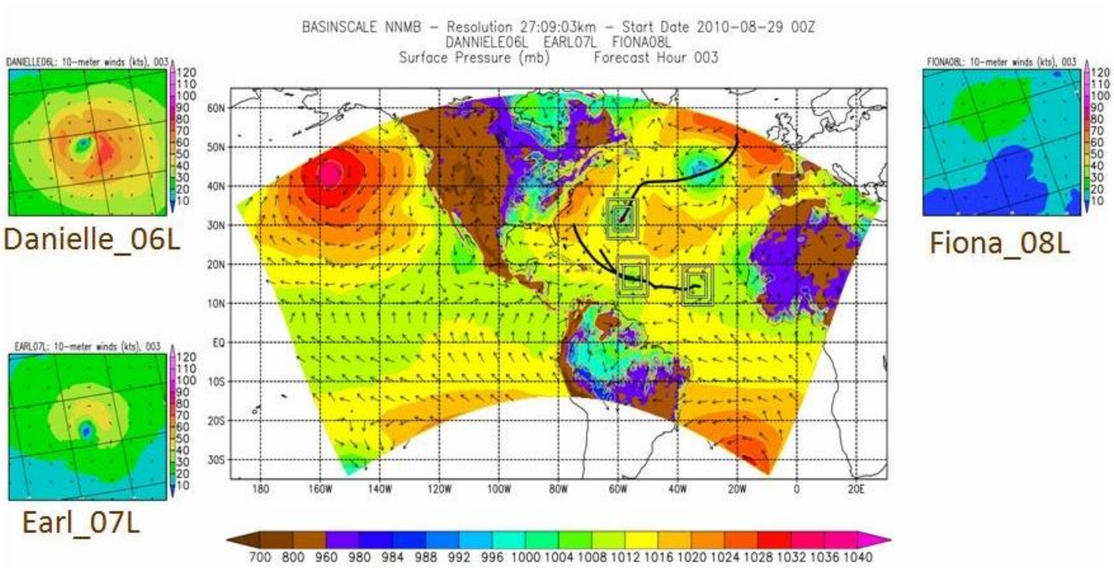

Figure 1: Plot of surface pressure and wind speeds from the region HNMMB model showing multiple nests for Hurricanes Danielle, Earl, and Fiona at 00z on Aug 28, 2010.

In addition to the regional model described above, a 'proof-of-concept' global model with multiple storm-following nests has also been achieved. With the global system, the HIWPP goal of a global-to-local scale hurricane prediction system operating at ~3 km resolution has been demonstrated and validated in a laboratory environment. Future advancements necessary for the HNMMB system to become operational include the addition of ocean coupling and data assimilation. Multi-season testing, verification, and rainfall evaluation are on-going at EMC.

Research Performance Measure: All objectives have been met or are on track. See details in Table 1.

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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, F. Marks, S. Goldenberg, T. Quirino (AOML/HRD); Q. Liu, S. Trahan and Z. Zhang (NCEP/EMC)

Other Collaborators: Da-Lin Zhang (U. Maryland/Dept. Atmos. & Ocean Sci.); Ligia Bernardet (DTC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To develop multiple sets of movable multi-level nesting modeling system based on operational HWRF.

***Strategy*:** To possibly transition from research to operation

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: Daniel Melendez

Research Summary:
I. 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*.

II. 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.

Verifications
III.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.

III.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 Franklin). 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.

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

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.

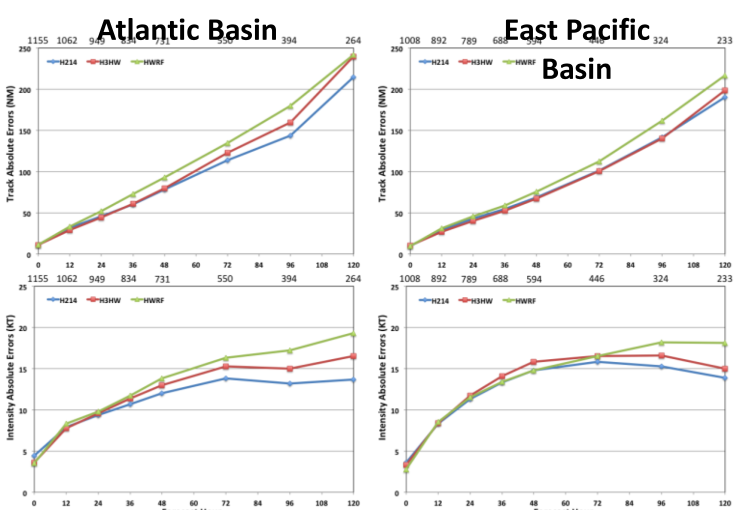


Figure 1: Verification of the 2013 basin-scale HWRF Forecasts (H3HW, red), real-time operational HWRF (HWRF, green), and 2014 operational HWRF (H214, blue) (2011-2014).

III.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.

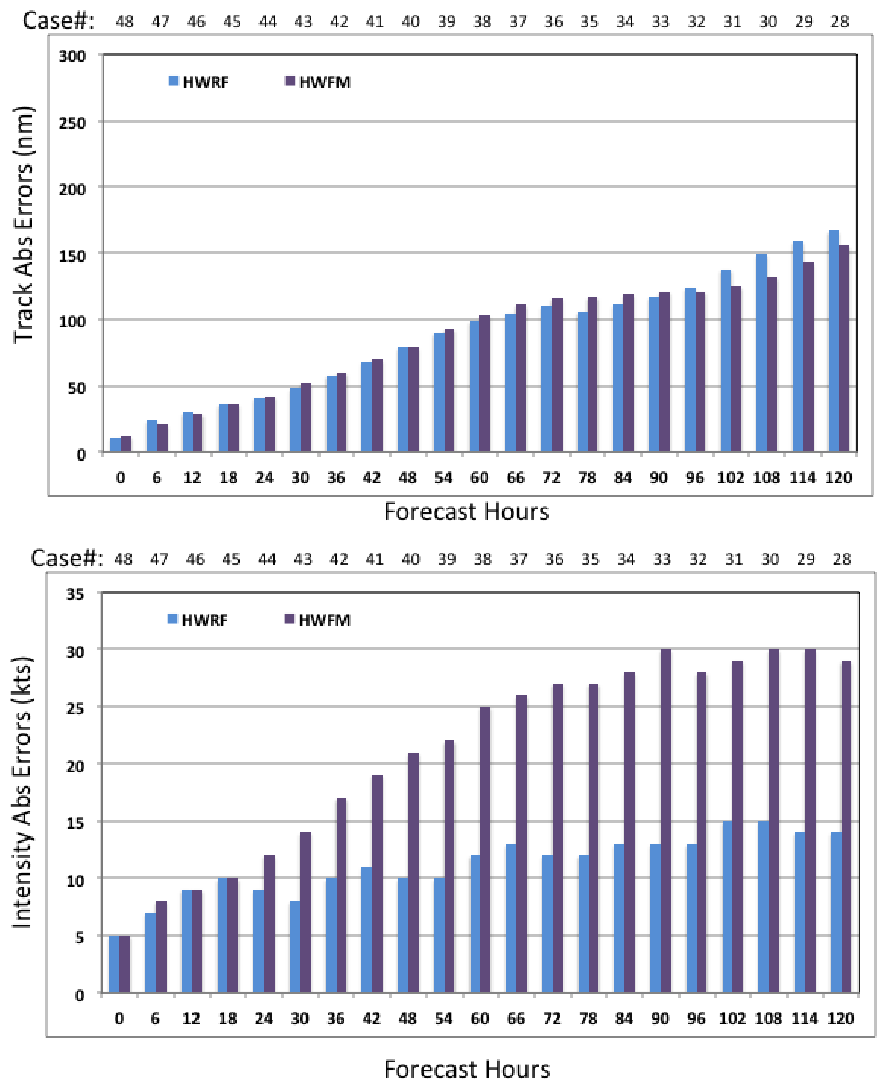


Figure 2: Track and intensity forecast verification of Hurricane Leslie. (a). Track; (b). Intensity.

Research Performance Measure: 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.

Services to Support the Hurricane Forecast Improvement Project

Project Personnel: X. Zhang, A. Aksoy, J. Zhang, G. Alaka, H. Chen, R. Gall, B. Klotz, J. Delgado, K. Sellwood and R. St. Fleur (UM/CIMAS)
NOAA Collaborators: S.G. Gopalakrishnan, F. Marks, S. Goldenberg, T. Quirino (AOML/HRD); Q. Liu, S. Trahan, Z. Zhang and V. Tallapragada (NCEP/EMC)
Other Collaborators: M. Boothe and M. Montgomery (NPS)

Long Term Research Objectives and Strategy to Achieve Them:
***Objectives*:** To develop multiple sets of movable multi-level nesting modeling system based on operational HWRF.
***Strategy*:** To possibly transition from research to operation.

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: Shannon Louie

Research Summary:
1. HWRF model development
An experimental HWRF basin-scale system developed in AOML/HRD and UM/CIMAS was operated during 2013-15 hurricane seasons. The 2013 version ran retrospective and real-time forecasts for 2012-14 seasons. The 2014 version caught up all operational HWRF model developments then developed and tested multiple-storm initialization. 2015 version transferred all developments into operational HWRF Python script-based implementation. All ATCF files were sent to TCMT for independent evaluation during the HFIP demo period. All real-time forecast products are available at HRD product website: http://storm.aoml.noaa.gov/basin.

The modeling group at HRD and CIMAS started the transition of the basin-scale HWRF development to operation during the project period. We had transferred all our scripts and codes developed for the basin-scale HWRF system to DTC. DTC converted the basin-scale HWRF ksh-based implementation into the 2015 operational python script-based implementation. The modeling group closely collaborated with DTC and EMC teams to assure the smooth and effective transition. The first version of the basin-scale HWRF system based on the python scripts implementation succeeded in 2015 HFIP demo season.

PI and collaborators constantly upgraded the basin-scale HWRF system during the project period. We had the following major activities:

- Developed the end-to-end basin-scale HWRF system under the operational HWRF framework;
- Tested the basin-scale HWRF system in real-time during the project demo period (1 August-1 November);
- Completed all storm forecasts during 2012-13 seasons and selected storm forecasts in 2011 by using 2013 version of the basin-scale HWRF system;
- Fixed bugs in the operational HWRF framework during the development of the basin-scale HWRF system, the details were documented in quarterly report during the project period;

- Extended functionalities for the basin-scale HWRF system implementation in the operation HWRF framework;
- Implemented the HRD post-processing and graphics system in the basin-scale HWRF system during the real-time and retrospective forecasts;
- Established the basin-scale HWRF product website and products;
- Implemented verification software in the basin-scale HWRF system;
- Transferred forecast products to support HFIP genesis project by NPS group;
- Started forecast assessments on significant storms: Isaac, Leslie, Sandy, Ingrid, Gabrielle, Edouard, Erika, Joaquin, and Patricia;
- Started retrospective forecasts of 2015 version of the basin-scale HWRF system for 2012-15 seasons;
- Geared up for the research to operation transition of the basin-scale HWRF system.

2. Evaluating model physics

PI (Jun Zhang) led the model physics evaluation component of this project. We conducted three 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.

For model evaluation purpose, we first organized and analyzed the observational data for model evaluation purposes and to test different metrics for evaluating the inner core structure of tropical cyclones. We built observational data sets with two resources (i.e., the post-processed Doppler radar and dropsonde data). 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. Following our work on axisymmetric hurricane structure before this project, dropsonde data were grouped the dropsonde data relative to the environmental wind shear. New algorithms were developed 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}.

Results mentioned above along with other observational analyses have been presented by PI and collaborators at the HFIP meetings and AMS conferences. Our results have been also selected by HFIP team leaders and presented in the annual HFIP review meetings. Besides the above-mentioned work on observational-data maintenance and analyses, we explored methods for comparing TCs in numerical models to the observational composites that we have developed. We coordinated with the HWRF team members from EMC and HRD to obtain hurricane simulations using the 2012 version of the operational HWRF model.

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). 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:

$$K_m = k\,(u_*/\Phi_m)\,Z\,\alpha\,(1 - Z/h)^2, \quad (1)$$

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).

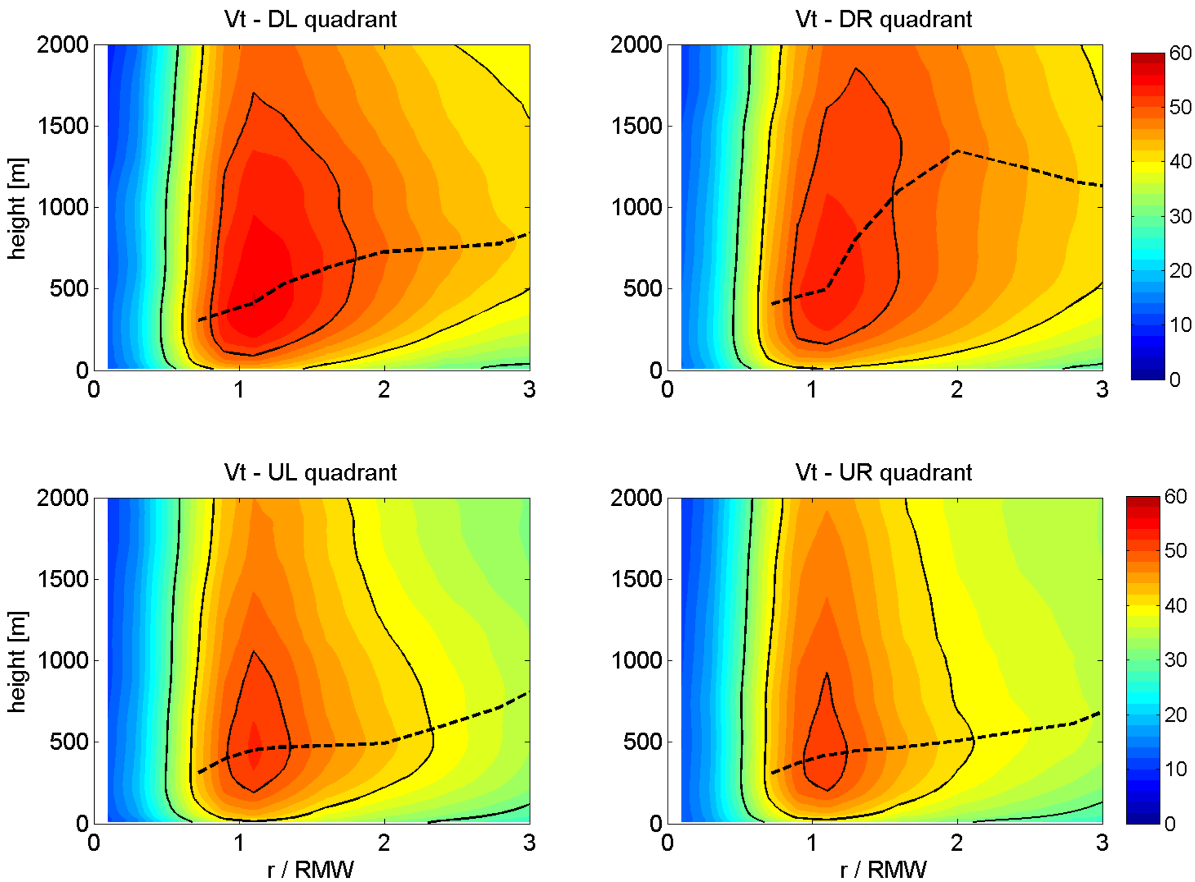


Figure 1: Composite analysis result of the relative tangential wind velocity as a function of altitude and the normalized radius to the storm center for the four quadrants relative to the shear direction. The thick black lines in each panel are the 30, 40 and 50 m s^{-1} contours. The black dashed line in each panel depicts the height of the maximum tangential wind speed varying with radius.

A total of 122 simulations of 4 hurricanes (Hurricanes Bill, Earl, Karl and Irene, see Fig. 2 for storm tracks) were conducted for PBL11 and PBL12 by the operational HWRF center (EMC). 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		2010/09/14/18Z	2010/09/18/06Z
Irene	34	2011/08/20/18Z	2011/08/29/00Z

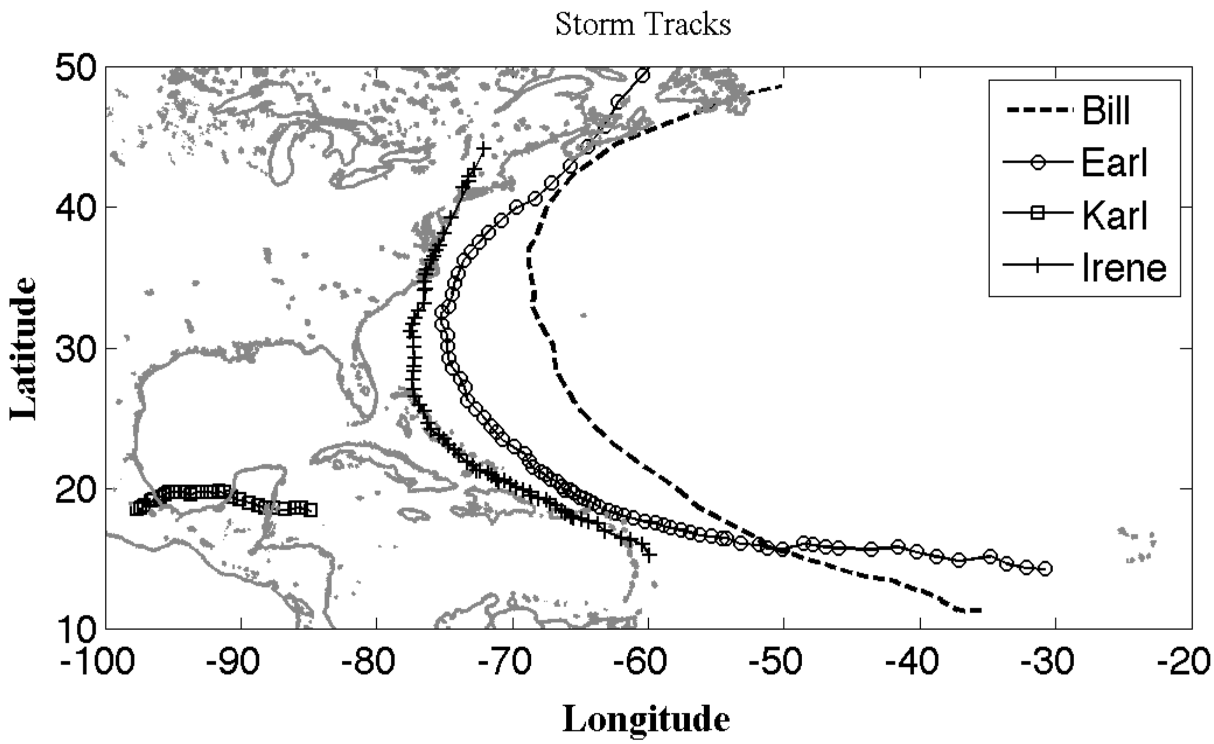


Figure 2: Best tracks of Hurricane Bill(2009), Earl(2010), Karl(2010), and Irene(2011).

The absolute errors of track and intensity forecasts for PBL11 and PBL12 runs are shown in Figure 3, 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.**

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 4 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 to be ~37 km (Only forecast times where there are SFMR data are used in the analyses). 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.

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 5 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.

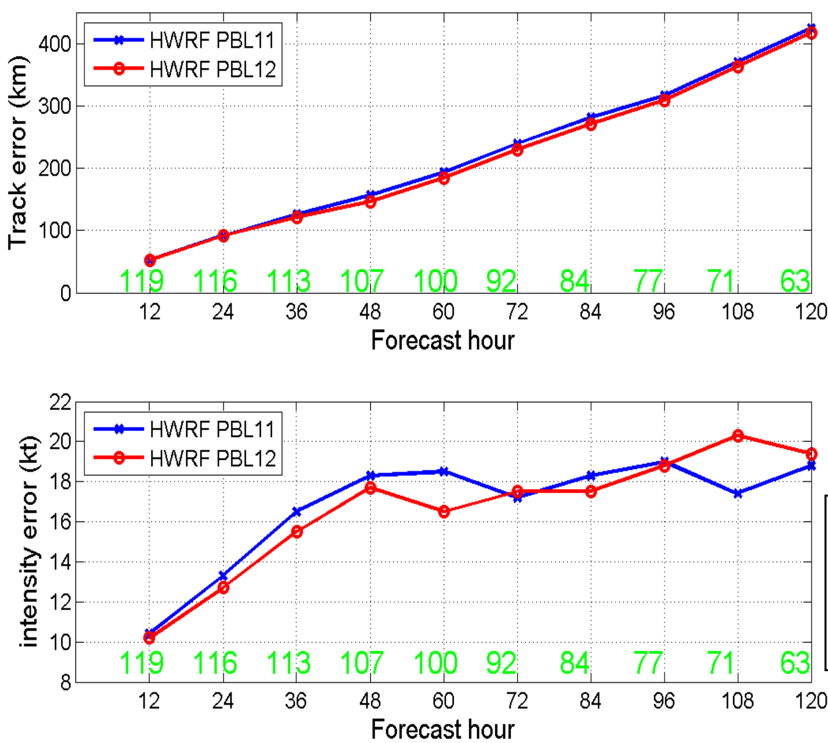


Figure 3: Absolute errors of track (upper panel) and intensity (lower panel) forecasts of the two sets of HWRF simulations of 4 hurricanes listed in Table 1.

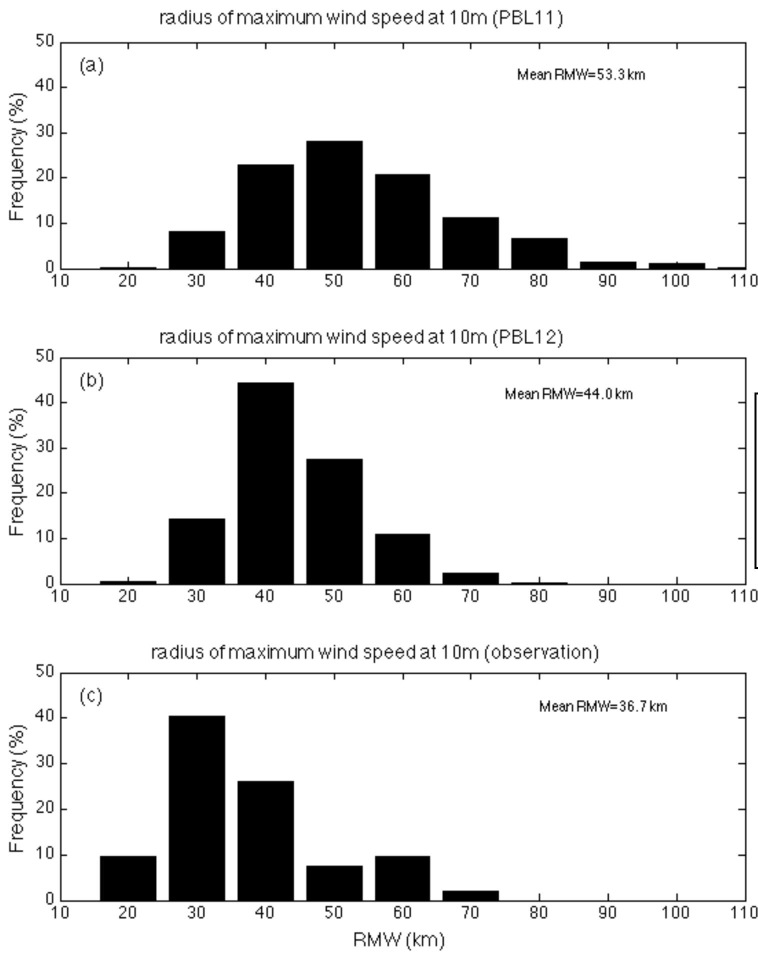


Figure 4: Frequency distribution of simulated radius of maximum wind speed at 10m for HWRF forecasts with PBL11 (upper panel), PBL12 (middle panel) and observations (lower panel).

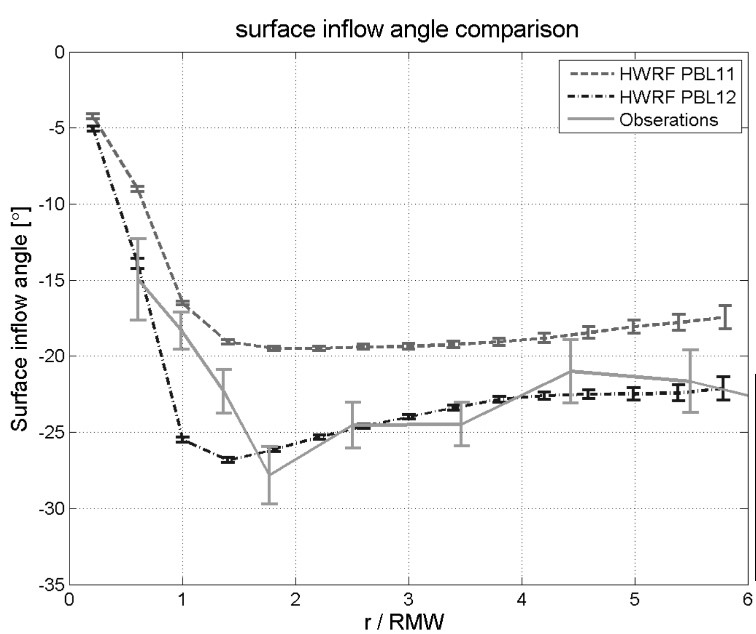


Figure 5: Plot of surface inflow angle as a function of radius to the storm center normalized by the radius of maximum wind speed. Vertical bars show the 95% confidence interval. The observation curve is from Zhang and Uhlhorn (2012).

Figure 6a-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 6d-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.

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 7 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 8 is a schematic diagram summarizing the difference in storm structures between PBL11 and PBL12 forecasts (Zhang et al. 2015). 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.

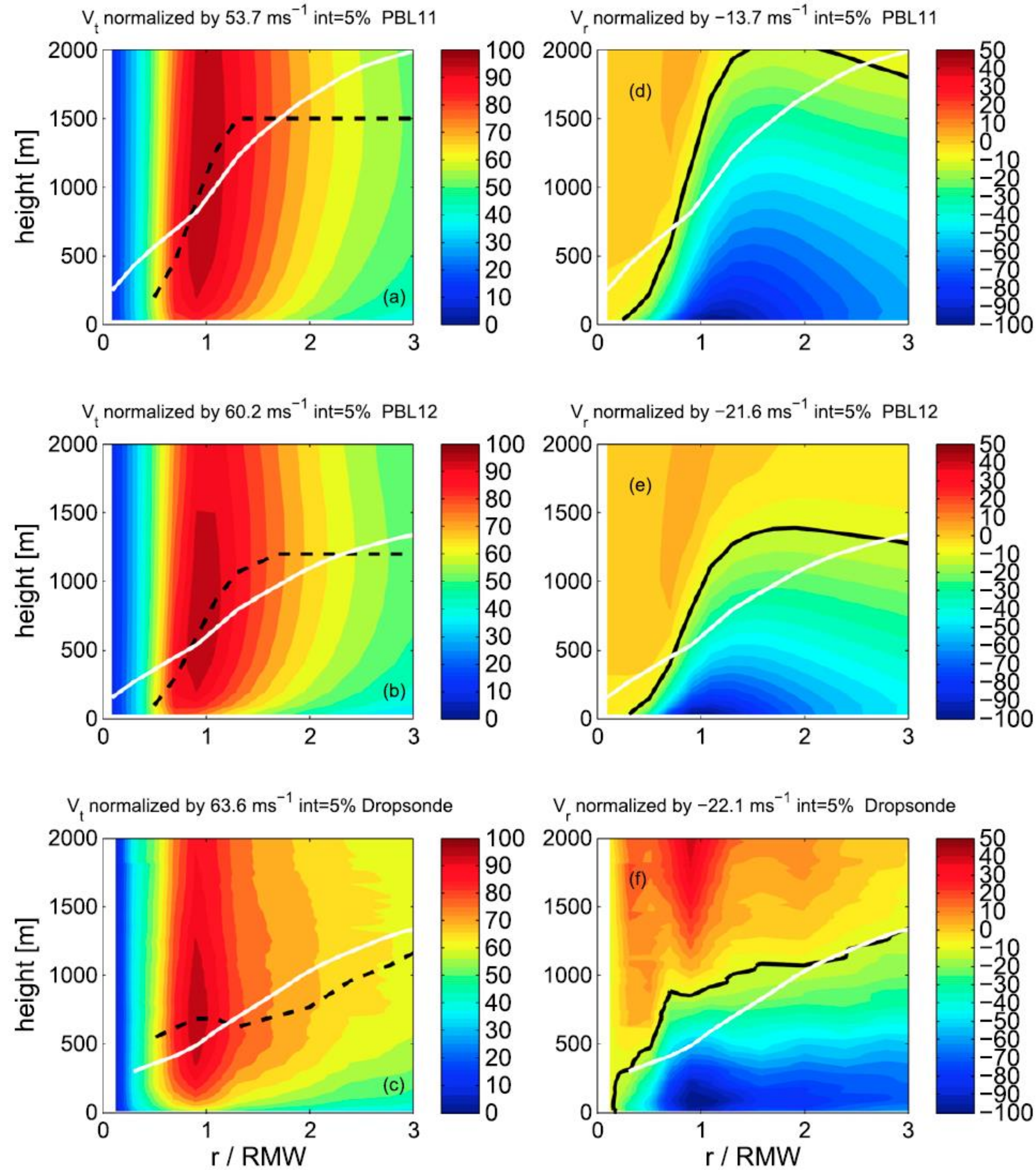


Figure 6: Plots of tangential wind (left) and radial wind (right) as a function of r/RMW and height. The upper panels are for PBL11, the middle panels are for PBL12, and the lower panels are for sonde composites from Zhang et al. (2011a). The dashed line represents the height of the maximum tangential wind speed and the solid line represents the inflow layer depth.

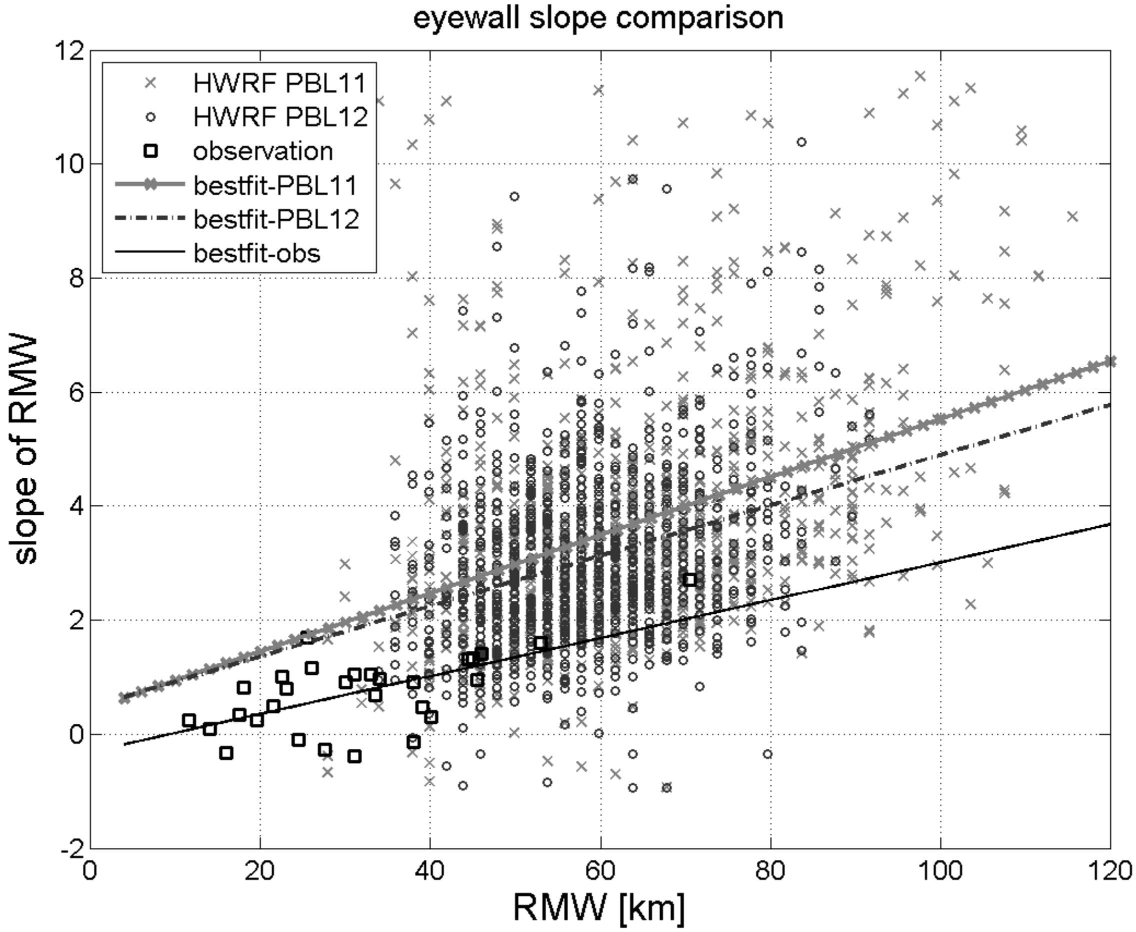


Figure 7: Plot of the slope of the RMW as a function of RMW at 2 km for PBL11 and PBL12. The observed relationship from Doppler radar data given by Stern and Nolan (2009) is also shown.

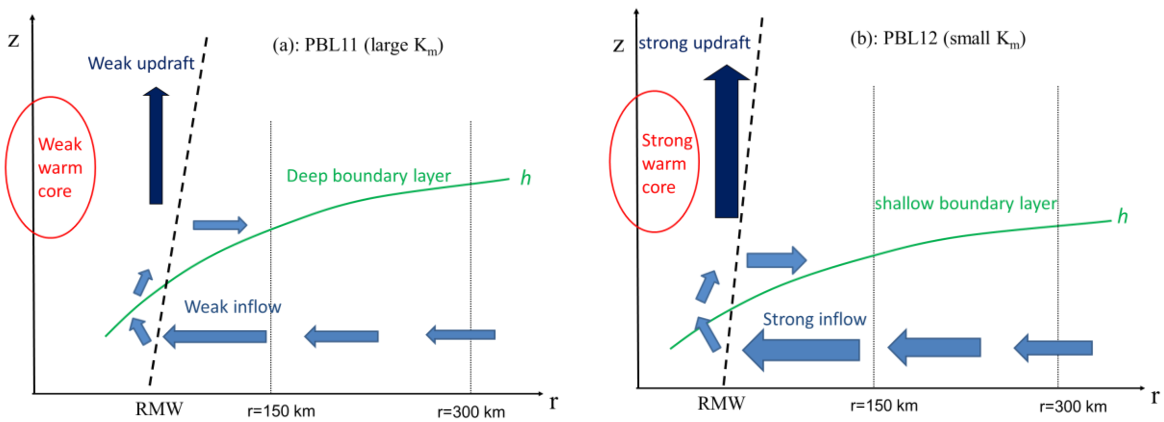


Figure 8: A schematic diagram summarizing the different structures in the PBL11 (a) and PBL12 (b) composites. The thickness and length of the arrow is correlated with the strength of inflow, outflow or updraft. The boundary-layer height (h) is denoted by the green line in each panel.

PI (Jun Zhang) also investigated the effect of horizontal diffusion on hurricane intensity change and structure using idealized HWRF simulations (Zhang and Marks 2015). We conducted 23 experiments by varying L_h from 0 to ~5000 m. Note that we ran all the experiments with the same initialization and physics options except for varying L_h. We found that the simulated hurricane intensity change is sensitive **to the setup of L_h in that the storms intensify faster for smaller L_h (Fig. 9). We found also that the** simulated maximum intensity is sensitive to the L_h used in the parameterization of horizontal turbulent fluxes, in particular for L_h<2000m.

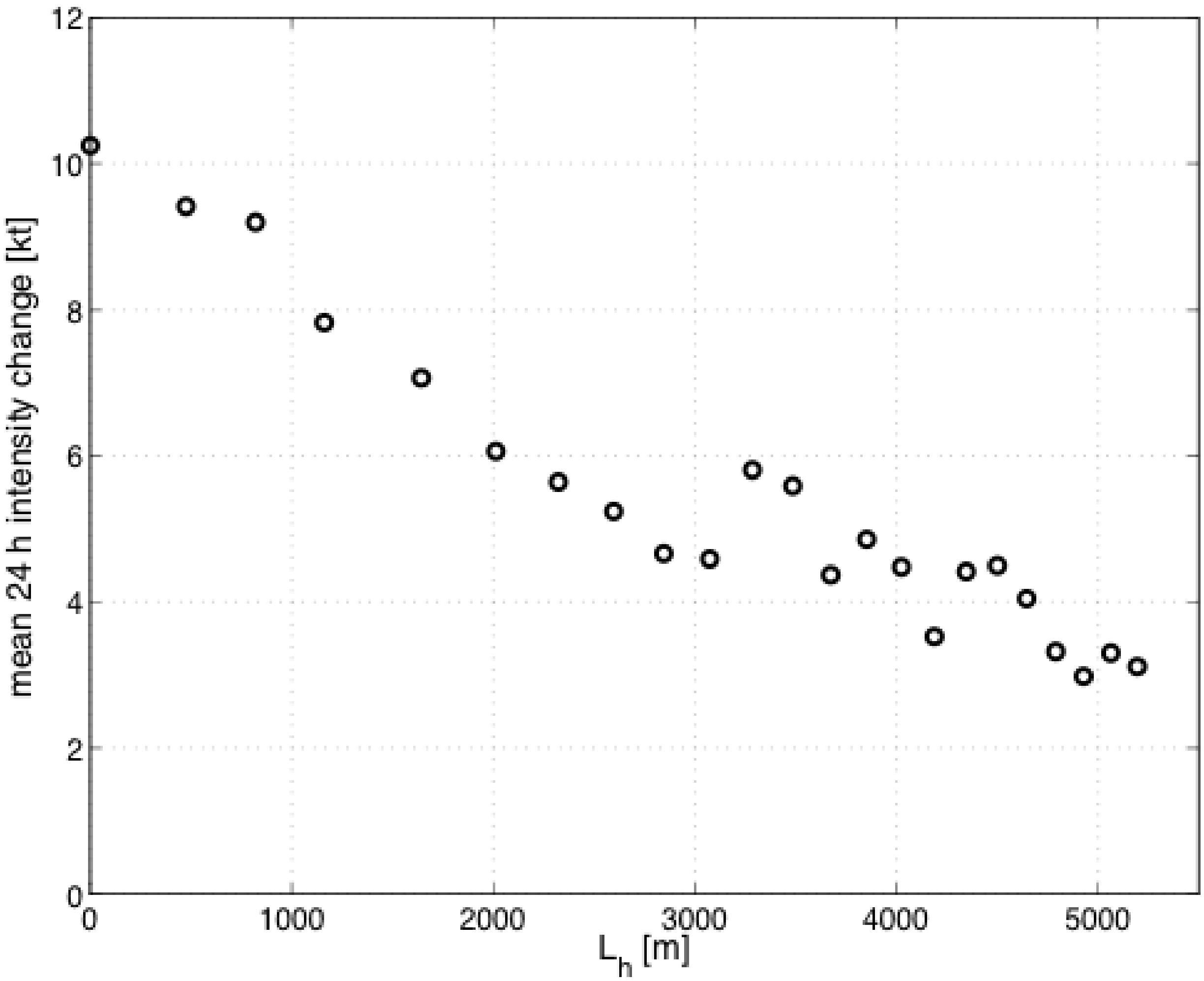


Figure 9: Plot of the mean 24 h intensity change in kt as a function of L_h.

The sensitivity experiments also demonstrate that the simulated storm structures such as the size of the storm, the kinematic boundary layer height, and eyewall slope are sensitive to L_h. But L_h has little impact on the magnitude of surface inflow angle and thermodynamic mixed layer height. **Figure 10** shows an example of the storm size as a function L_h.

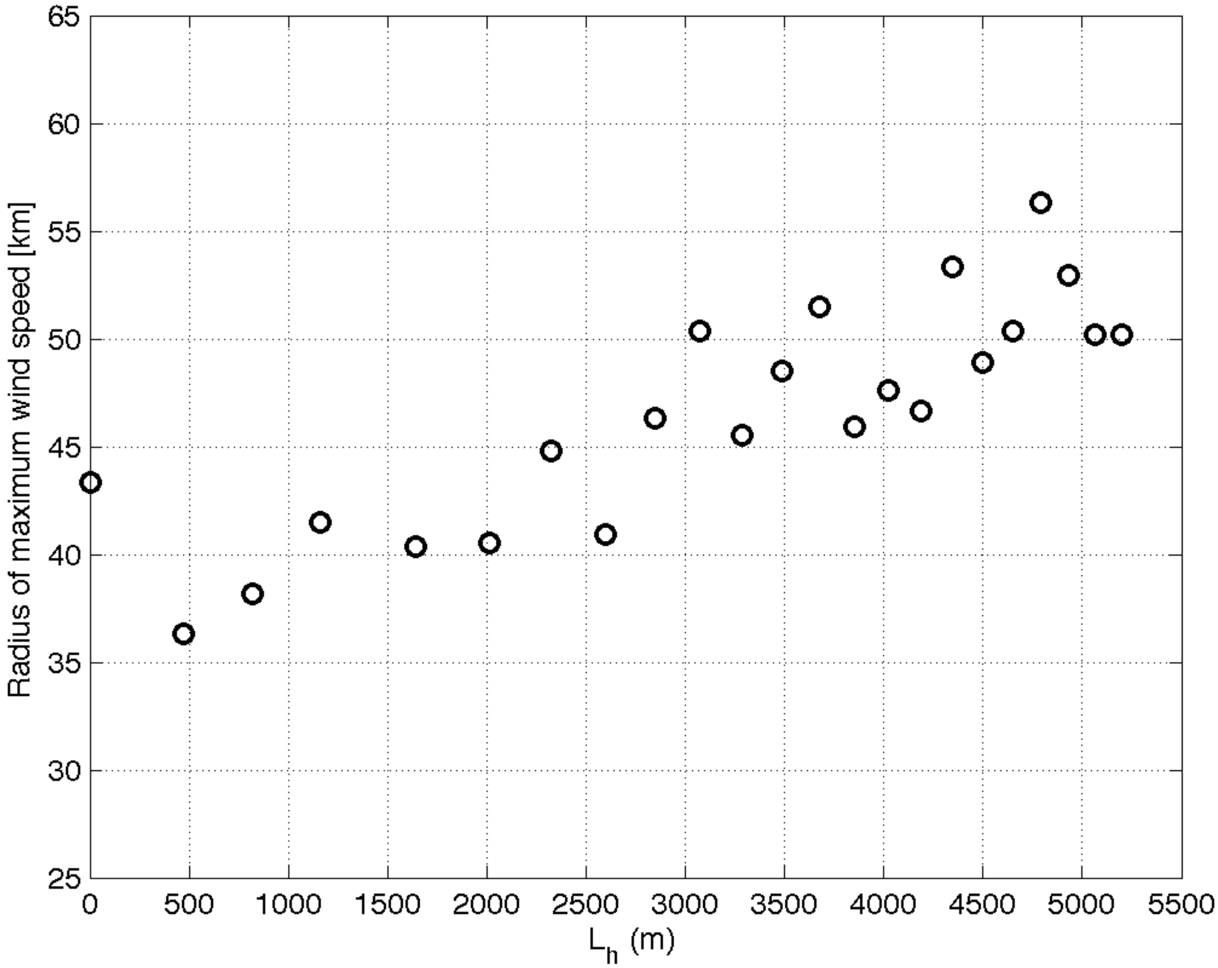


Figure 10: Radius of maximum azimuthally-averaged tangential velocity (RMW) at 2 km altitude as a function of horizontal mixing length (L_h). Each data point represents RMW averaged over the last 12 h of the five-day simulations.

Angular momentum budget analyses indicate that both the mean advection and eddy advection terms are affected by the setup of L_h. When L_h is smaller, the radial convergence of angular momentum is larger both within and above the boundary layer, which leads to a faster spin-up of the vortex. Both the axisymmetric and asymmetric vertical advection of angular momentum plays an important role in spin-up the vortex above the boundary layer and they are larger for smaller L_h. The eddy radial advection of angular momentum plays an important role in spin-up of the low-level vortex inward from the radius of the maximum wind speed when L_h is small (Fig. 11).

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.

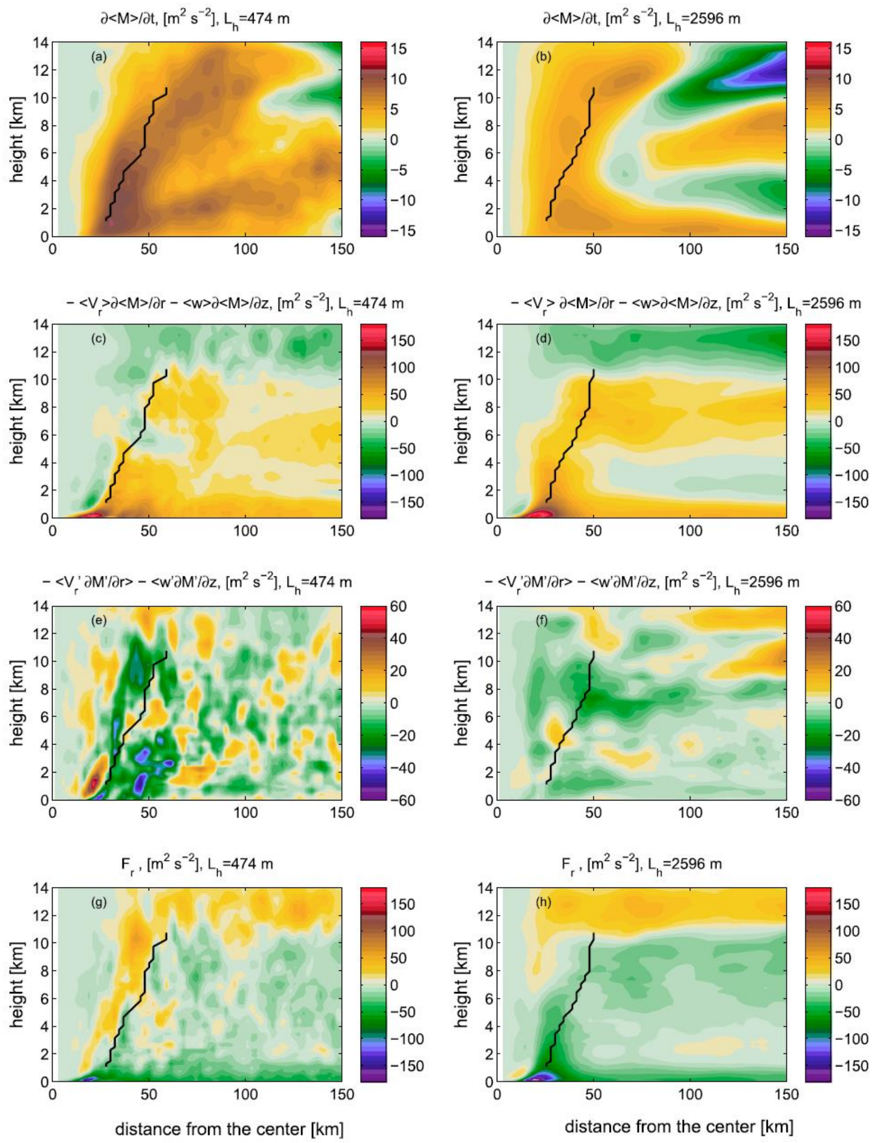


Figure 11: Radius–height plots of the terms in the azimuthally averaged absolute angular momentum(hMi) budget for simulations with Lh 5 (left) 474 and (right) 2596m during a period of rapid intensification (between 24 and 36 h). These budget terms include (a),(b) the local rate of change of (hMi); (c),(d) the total mean advection; (e),(f) the sum of the eddy transport of (hMi); and (g),(h) the friction term Fr. The black line represents the radius of maximum azimuthally averaged tangential wind speed.

3. Hurricane observation program and activities

3.1 Observation

During the 2013-15 Hurricane Field Program observational team under HFIP's support collected numerous data through missions of NOAA's NOAA42/43, NOAA49, and NASA's Global Hawk NA872. The observational team consisted of employees from HRD and CIMAS employees from CIMAS. The team set up the schedules to ensure all flights were covered. The data collected by missions and by storms are summarized in Table 2 and 3. The team collected data from 20 different storms, 57 missions by NOAA42/43, 44 missions from NOAA49, and 10 missions from NA872.

Table 2: Summary of missions during 2013-15 hurricane season

YEAR	STORM NAME	AIRCRAFT	FLIGHTS	DATA TYPES COLLECTED		
2013	GABRIELLE	NOAA42/43	3	HDOBS	DROPS	TDR
2013	GABRIELLE	NOAA49	2	HDOBS	DROPS	
2013	GABRIELLE	NA872	1		DROPS	
2013	INGRID	NOAA42/43	5	HDOBS	DROPS	TDR
2013	INGRID	NOAA49	3	HDOBS	DROPS	TDR
2013	KAREN	NOAA42/43	4	HDOBS	DROPS	TDR
2013	KAREN	NOAA49	1	HDOBS	DROPS	TDR
2013	OCEAN HEAT	NOAA42	1	HDOBS	DROPS	
2014	ARTHUR	NOAA42/43	5	HDOBS	DROPS	TDR
2014	ARTHUR	NOAA49	4	HDOBS	DROPS	TDR
2014	BERTHA	NOAA42/43	5	HDOBS	DROPS	TDR
2014	BERTHA	NOAA49	2	HDOBS	DROPS	TDR
2014	CRISTOBAL	NOAA42/43	8	HDOBS	DROPS	TDR
2014	CRISTOBAL	NOAA49	2	HDOBS	DROPS	TDR
2014	CRISTOBAL	NA872	2		DROPS	
2014	DOLLY	NA872	1		DROPS	
2014	EDOUARD	NOAA42/43	10	HDOBS	DROPS	TDR
2014	EDOUARD	NOAA49	1	HDOBS	DROPS	TDR
2014	EDOUARD	NA872	4		DROPS	
2014	GONZALO	NOAA43	3	HDOBS	DROPS	TDR
2014	ISELLE	NOAA49	3	HDOBS	DROPS	
2014	JULIO	NOAA49	1	HDOBS	DROPS	
2014	SIMON	NOAA49	2	HDOBS	DROPS	TDR
2014	ANA	NOAA49	4	HDOBS	DROPS	
2015	GUILLERMO	NOAA49	3	HDOBS	DROPS	
2015	DANNY	NOAA43	5	HDOBS	DROPS	TDR
2015	DANNY	NOAA49	3	HDOBS	DROPS	TDR
2015	ERIKA	NOAA43	5	HDOBS	DROPS	TDR
2015	ERIKA	NOAA49	3	HDOBS	DROPS	TDR
2015	ERIKA	NA872	2		DROPS	
2015	JOAQUIN	NOAA49	4	HDOBS	DROPS	TDR
2015	OHO	NOAA49	2	HDOBS	DROPS	
2015	PATRICIA	NOAA43	3	HDOBS	DROPS	TDR
2015	KATE	NOAA49	3	HDOBS	DROPS	TDR

The observation team processed dropsonde and SFMR data for NOAA's missions as well as NASA's Global Hawk unmanned aircraft. The team also remotely processed the Tail Doppler Radar (TDR) data from missions and ensured that the quality controlled data was transmitted to NCEP in time to be assimilated into the HWRF model. All of the NOAA dropwindsonde data were organized by mission and storm name. The quality-controlled data were made available to the research community via the AOML web site retrospectively (http://www.aoml.noaa.gov/ hrd/data_sub/hurr.html) and ftp server in near real

time. In addition to the raw data and ASPEN output a number of additional products were created to allow for easier use of the data. A catalogue file was created for the high frequency processed data and the tempdrop messages were compiled into a single document for each flight with added headers to help match each message with its original data file. Additionally, the tempdrop messages were decoded, sorted by altitude and written out as plain text for the user's convenience. K. Sellwood monitored the availability of these high quality in-situ observations and the processing and archiving of data for assimilation using HEDAS in near real time during the 2013-15 hurricane season. The observation processing code was updated to allow the assimilation of cloudy radiances using canonical correlation analysis (Steward 2013). This is an important step towards filling data gaps over the TC vortex when there is no aircraft reconnaissance. *All of the observation processing code used in HEDAS has been committed to the repository on jet and is now available for use by the research community.*

Table 3: Mission summary by storm name during the project period.

YEAR	STORM NAME	P-3 FLIGHTS	G-IV FLIGHTS	GLOBAL HAWK
2013	GABRIELLE	3	2	1
2013	INGRID	5	3	0
2013	KAREN	4	1	0
2014	ARTHUR	5	4	0
2014	BERTHA	5	2	0
2014	CRISTOBAL	8	2	2
2014	DOLLY	0	1	1
2014	EDOUARD	10	1	4
2014	GONZALO	3	0	0
2014	ISELLE	0	3	0
2014	JULIO	0	1	0
2014	SIMON	0	2	0
2014	ANA	0	4	0
2015	GUILLERMO	0	3	0
2015	DANNY	5	3	0
2015	ERIKA	5	3	2
2015	JOAQUIN	0	4	0
2015	OHO	0	2	0
2015	PATRICIA	3	0	0
2015	KATE	0	3	0
TOTAL	20	57	44	10

3.2 Products of Model Diagnostics

A set of graphical products was created in order to evaluate the ability of HWRF to represent TC vortex scale characteristics and processes that can be validated by observations. How well the model represents boundary layer structure is one important aspect. Figure 12 illustrated the R-Z mean structure of the wind field in the boundary layer in the HWRF model using two different boundary layer schemes. Looking at the model data in this way allows us to compare the model with observations and work toward improving this specific area of the model code. Another type of products is the TC vortex responding to environmental shear effect. The shear effect is important both for forecasting and understanding how the TCs intensify. A number of products which illustrate the TC vortex relative to shear direction were also created. Figure 13 gives an example of the asymmetric near surface winds and location of strong

convection relative to the storm motion and environmental shear. The code and the corresponding scripts to produce these and other graphics were completed and ready to be incorporated into the existing diagnostic package. The statistics of TC vortex structures represented by the model is also an important diagnostic products as it allows us to identify potential biases in the model. A set of 140 cases has been compiled where there is NOAA P-3 TDR data available at HWRF initial forecast times. We compared the radial location of the maximum TC wind in the model with the observations to determine whether the model has a tendency to produce too large of a storm. A subset of these cases was selected by comparing with the HEDAS initial condition. The products can determine whether assimilation of data near the TC center location improves the wind structure and whether it can be maintained throughout the forecast. The statistics of such a products from the basin-scale HWRF model is underway. The products developed from this project can be transferred to operational applications.

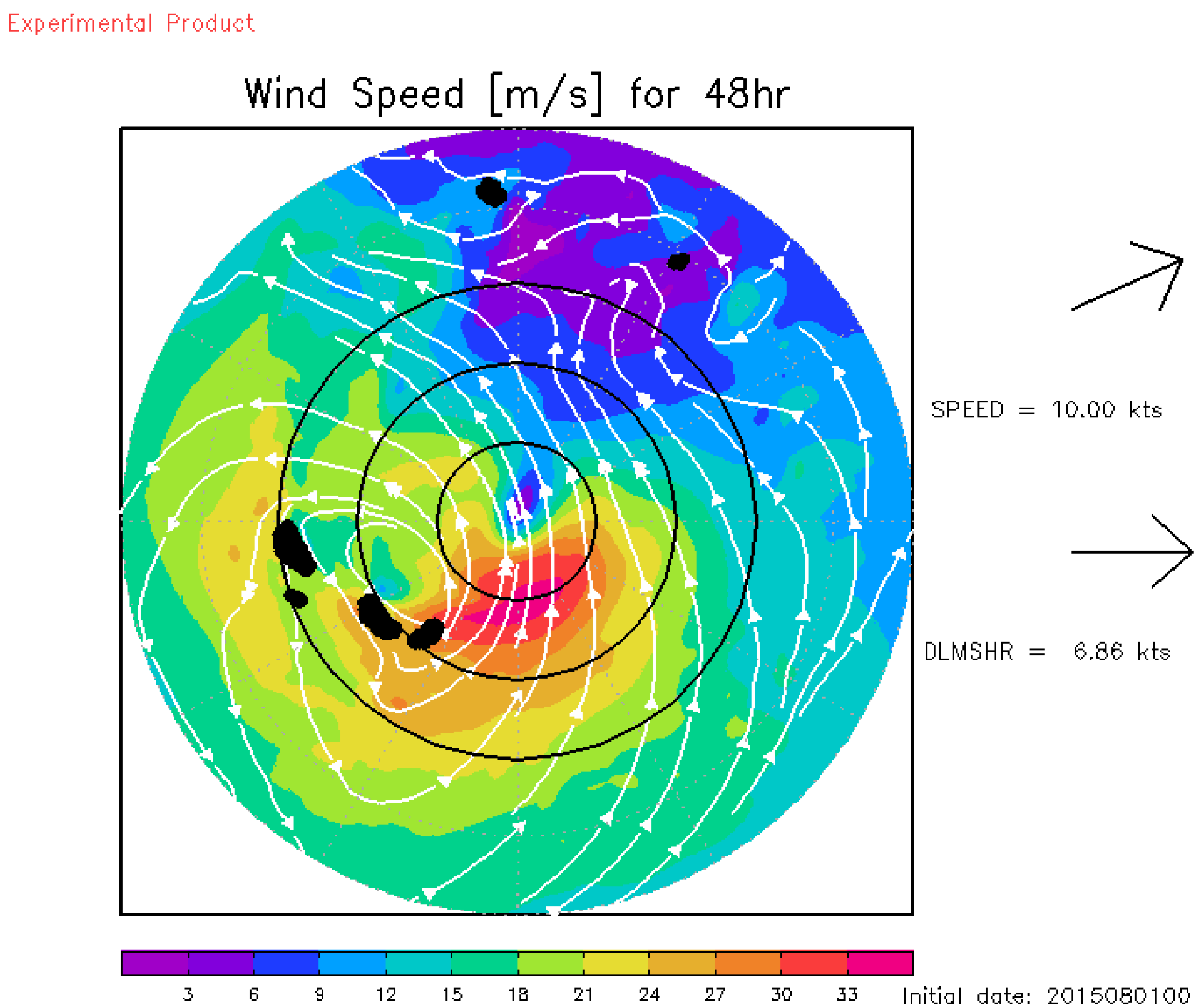


Figure 12: Example of 10-meter wind speed (shaded contours), asymmetric flow (streamlines) and location of strong convective activity (black shading. The rings give the radius of maximum wind speed in multiples of 1, 2 and 3. The wind fields have been rotated so that the shear vector points to the right and the storm motion has been removed. The shear and storm motion vectors are given on the right side of the figure.

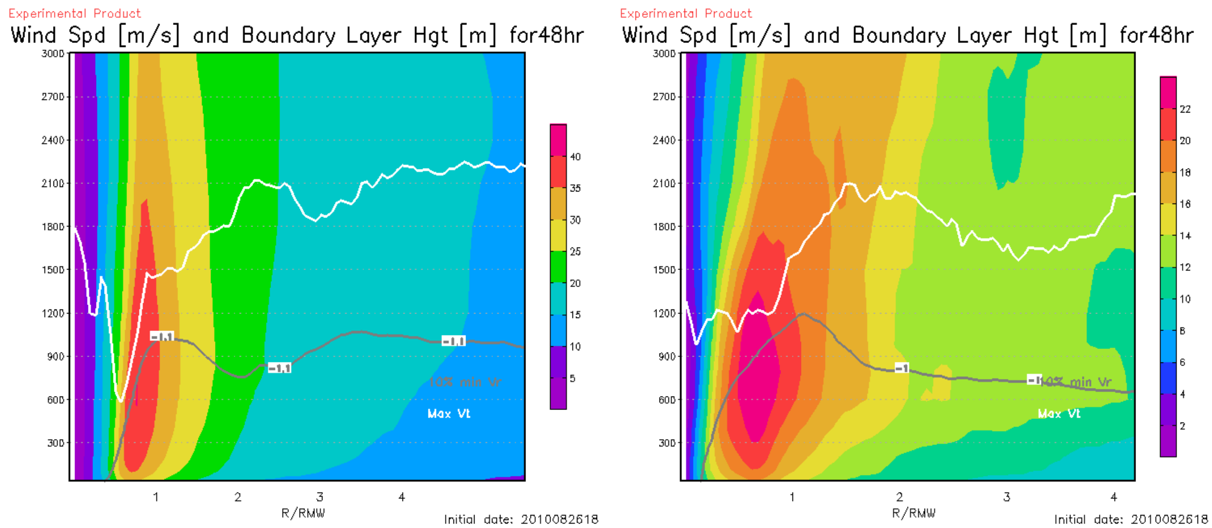


Figure 13: Mean tangential wind speed for HWRF Basin scale forecast of hurricane Earl initialized 18Z 08/28/2010 with HWRF (left) and NEMS (right) boundary layer physics packages. The height of the boundary layer defined as 10% of maximum surface inflow and maximum tangential wind speed is given by the black and white contours.

Previous reports have discussed specifics related to improving the observations of surface winds from the NOAA and Air Force Reserve (AFRC) SFMR platforms. These data were collected during NOAA's IFEX annual field program and by extent during the AFRC reconnaissance missions. The previous reports have stressed the importance of how improved data can have positive impacts on data assimilation and ultimately the HWRF forecast. This report again focuses on the benefits of the revised (and currently operational) SFMR data, with a broader discussion of the 2015 season. The 2015 Atlantic season was relatively quiet, but there were several NOAA and AFRC missions into tropical storms such as Ana and Erika as well as into hurricanes Danny, Joaquin, and Kate. Additionally, several flights were conducted into the record-breaking, major hurricane Patricia, which made landfall in Mexico as a category 5 hurricane.

The first step in the examination of the 2015 data is to follow previous methodologies and compare the wind speeds against the available co-located GPS dropsonde winds. These wind speeds are adjusted to the surface from a mean wind within the lowest 150 m as described in the peer-reviewed literature. While the number of pairs is relatively low (143 points), the performance of the SFMR wind speeds reflects the described improvement to the algorithm. Based on a linear regression fit to the paired data shown in Fig. 14, the variance explained by the relationship of the two wind speeds is 93% with a root-mean squared error (RMSE) of 3.3 m/s. This RMSE is further reduced from the values provided in the refereed documentation.

One of the drawbacks to the previous version of the SFMR algorithm was a high wind speed bias in rain, especially at the lower wind speeds. Although, there were not many instances of heavy rain (rain rate > 20 mm/h) in this dataset, the results indicate a similar RMSE to that of the all rain cases. While this is by no means a statistically significant result, it hints at the idea that the revised algorithm indeed provides improved measurements within the full wind speed spectrum and within rain. This is an important result for using such data in a model or data assimilation framework

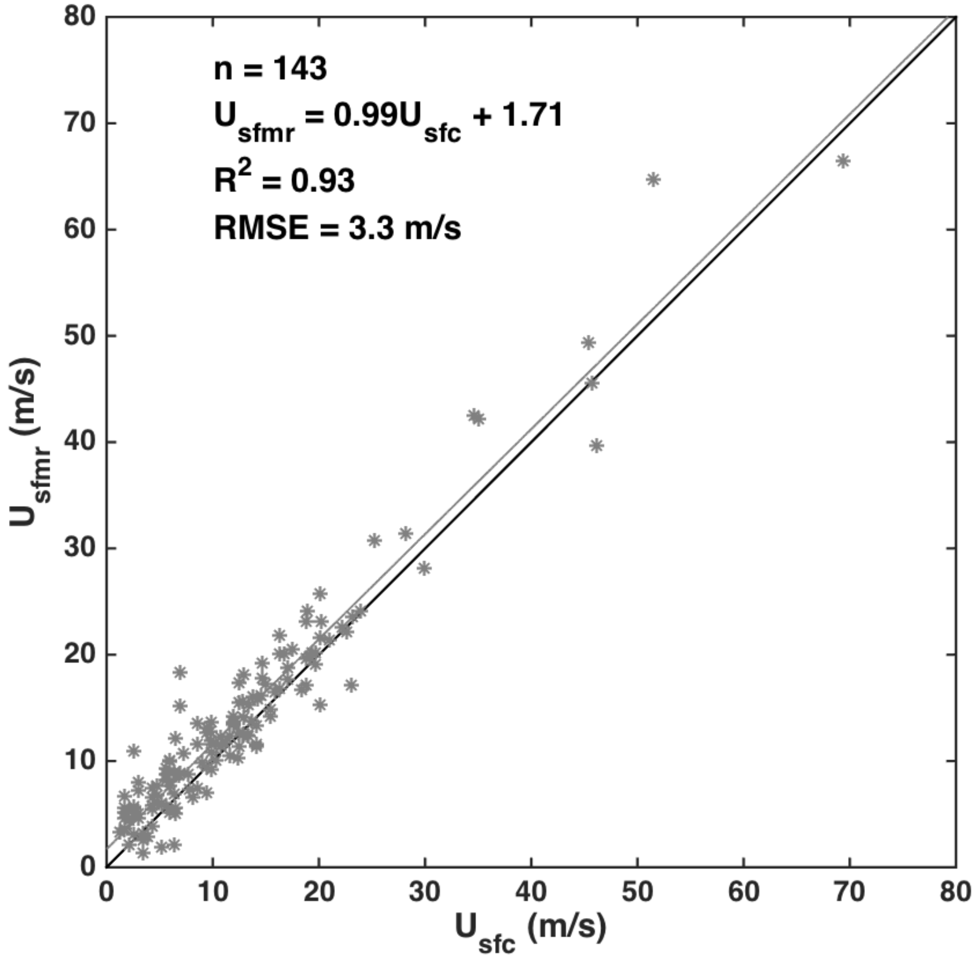


Figure 14: Plotted are the SFMR surface wind speeds (U_{sfmr}) as a function of GPS dropsonde surface-adjusted wind speed (U_{sfc}). Various statistical values related to the linear regression fit are provided as well.

Finally, it is necessary to discuss the importance of the SFMR data collected in Patricia. This hurricane was extremely hard to predict due to its rapid intensification and compact inner core structure. The SFMR on both reconnaissance aircraft collected wind speeds in excess of 90 m/s (> 175 kt), which the operational prediction models were not able to resolve well. For this reason, it is clear that there is still much improvement needed in our understanding of rapidly intensifying storms so as to improve their prediction. Using the SFMR data has proven to be helpful both to operational forecast centers such as NHC as well as to those frameworks that assimilate them.

4. Data Assimilation and Observing Strategy (PI: Altug Aksoy)

4.1. Retrospective Vortex-Scale Data Assimilation Experiments with HEDAS

Using the latest 2015 version of HEDAS, the DA has been running a large sample of retrospective experiments to evaluate the impact of various observing systems. In this version of HEDAS, the latest available HWRF code is used with restart capability. The number of retrospective experiments that have so far been carried out is is shown in Table 4 below:

Table 4: Number of cases carried out in the HEDAS retrospective experiments for each type of experiments (shown in various columns).

Storm Name (Year)	Control (No DA)	All Obs	No Doppler	No G-IV Doppler	No AMV
Earl (2010)	11	11	11	0	11
Katia (2011)	1	1	1	1	1
Isaac (2012)	22	27	22	10	3
Leslie (2012)	3	3	1	0	0
Sandy (2012)	11	17	11	6	11
Ingrid (2013)	9	9	9	3	9
Arthur (2014)	12	16	12	5	12
Bertha (2014)	8	8	8	2	8
Iselle (2014)	3	3	3	3	3
Julio (2014)	1	1	1	1	1
Edouard (2014)	8	8	8	2	8
Guillermo (2015)	1	1	1	1	1
Danny (2015)	6	8	8	4	0
Erika (2015)	15	15	15	6	15
Joaquin (2015)	3	3	3	3	3
Patricia (2015)	3	3	3	0	0
Kate (2015)	0	4	0	0	0

In "Control", no data assimilation is carried out. In "All Obs", all available observations are assimilated. In "No Doppler", all available observations are assimilated except those from all NOAA aircraft Doppler radar instruments. In "No G-IV Doppler", all available observations are assimilated except those from the NOAA G-IV Doppler radar instrument only in the cases that had the NOAA G-IV aircraft making Doppler radar measurements. In "No AMV", all available observations are assimilated except the satellite Atmospheric Motion Vectors (AMVs).

As this large experiment is still ongoing (with 505 experiments completed as of the writing of this report), a complete and comprehensive set of results is not yet available. In Fig. 15, a preliminary analysis of impact of assimilating Doppler radar observations on the NOAA aircraft (NOAA P-3s and NOAA G-IV) is provided.

The results so far suggest that the Doppler radar observations have a positive impact on intensity forecasts during the first 48 hours of forecasts. In terms of the track forecasts, positive impact is seen at longer lead times, generally beyond 60 hours of forecast. It is encouraging to see that Doppler radar observations have positive impact on both track and intensity, albeit at varying forecast lead times.

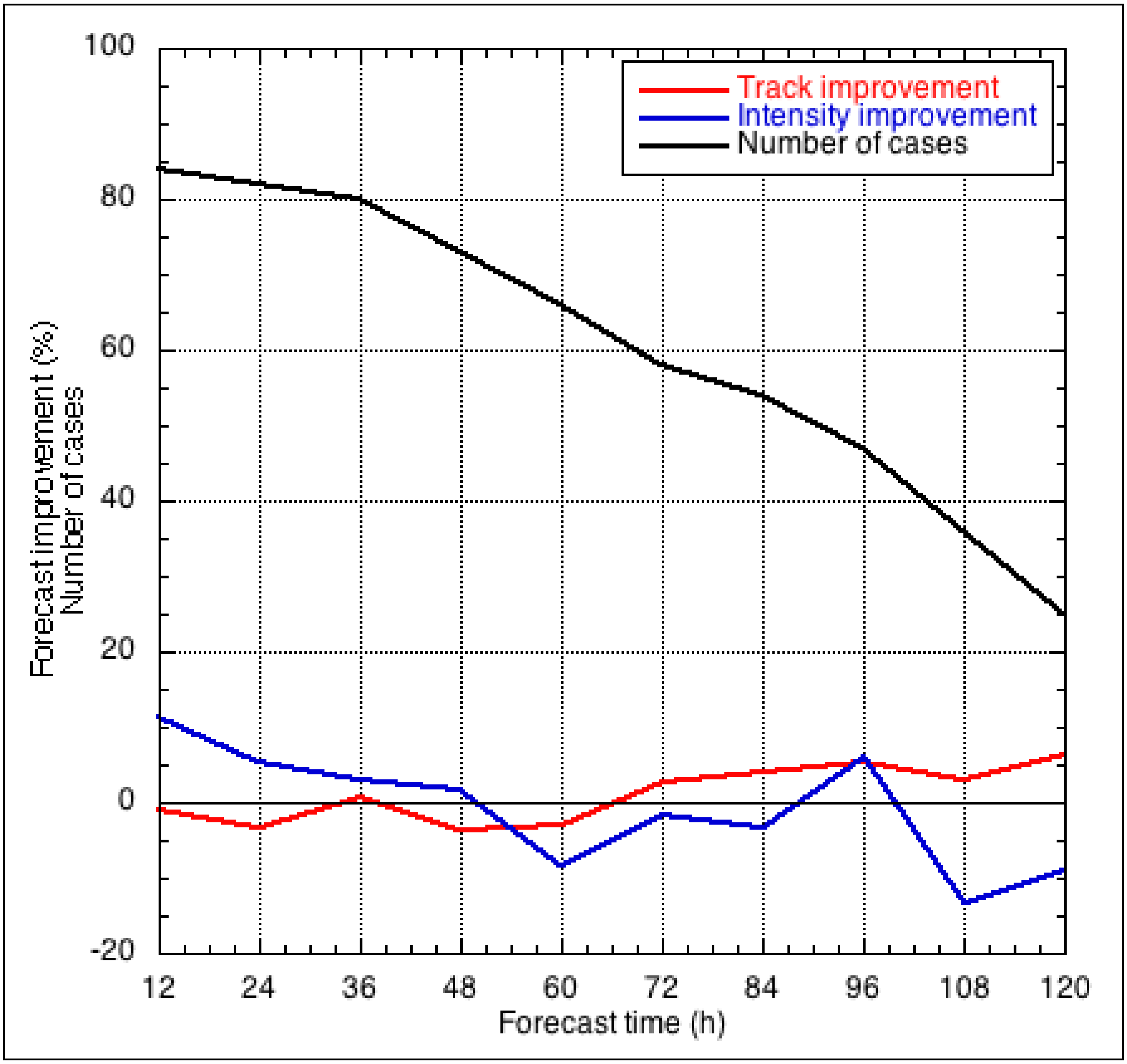


Figure 15: Impact of assimilating NOAA aircraft Doppler radar observations on HWRF forecasts initialized with HEDAS analyses. Impact is shown as percentage improvement with positive numbers indicating positive impact from Doppler radar observations. Track improvement is shown in red and intensity improvement is shown in blue. The number of cases considered in these calculations is shown in black.

4.2. Impact of Global Hawk Dropwindsonde Observations in Vortex-Scale Tropical Cyclone Data Assimilation & Forecasts

Experiments have been carried out to investigate the impact of the Global Hawk dropwindsonde observation in vortex-scale data assimilation using HEDAS. For this purpose, two case studies have been performed for Hurricane Edouard (15 Sep 2014 00Z and 16 Sep 2014 18Z). For both of these case studies, two experiments are carried out assimilating all aircraft data including the Global Hawk vs. no Global Hawk.

In the 15 Sep case, the Global Hawk dropsondes were the only source of observations besides satellites, whereas in the 16 Sep case, a multitude of aircraft missions were carried out, including two NOAA P-3, Air Force C-130, and NASA Global Hawk. The location and distribution of the observations in these two cases is shown in Figure 16. It is evident that on 15 Sep 00Z, the Global Hawk dropsondes are the only data source in the inner core of Hurricane Edouard. Meanwhile on 16 Sep 18Z, due to the existence of the large volume of inner-core data from other aircraft, the Global Hawk appears to be more prominent in the near environment of Hurricane Edouard. This difference between the two cases regarding the spatial distribution of Global Hawk observations is expected to have a significant impact on their impact on the respective HEDAS analyses and the subsequent HWRF forecasts.

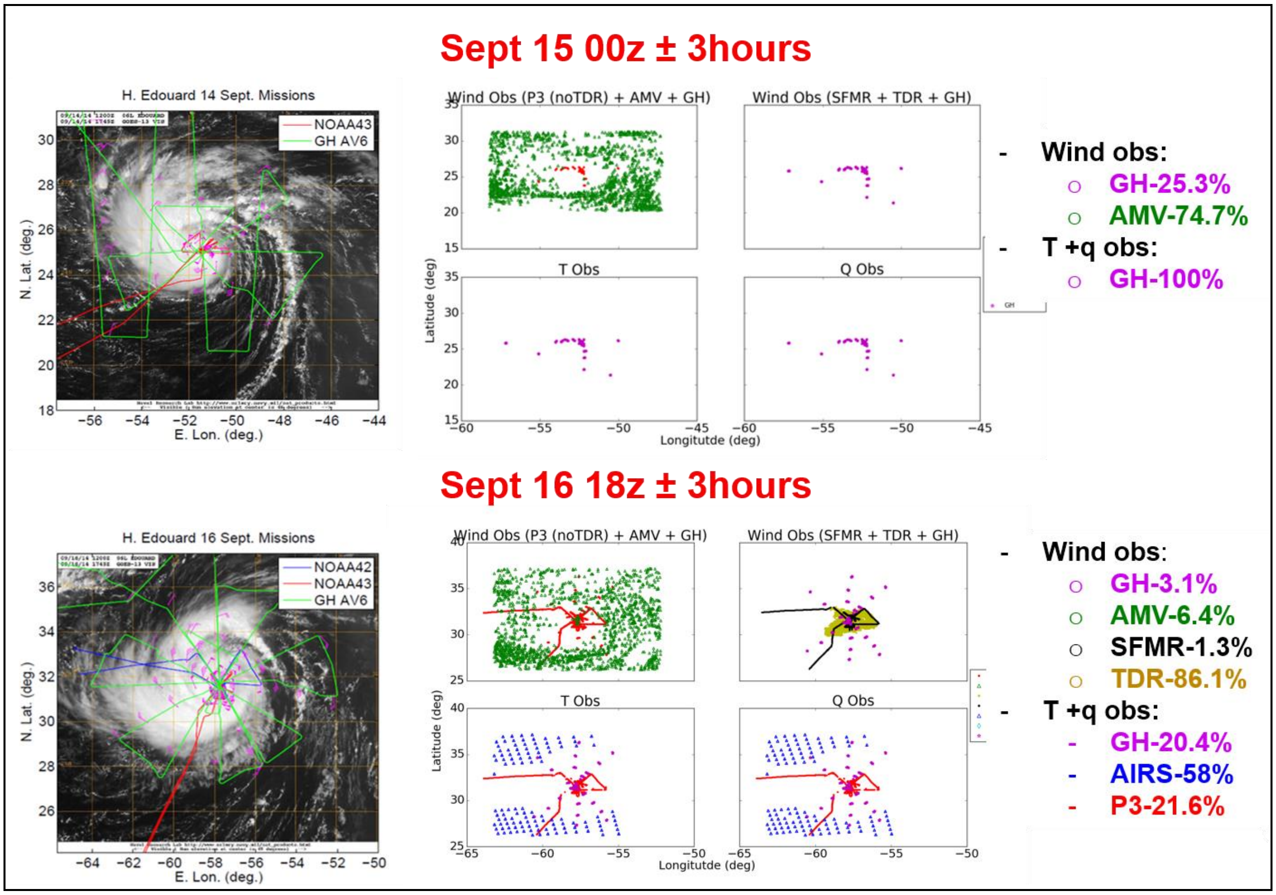


Figure 16: Comparison of the location and distribution of all observations evaluated/assimilated for the Hurricane Edouard cases 15 Sep 2014 00Z and 16 Sep 2014 18Z.

A comparison of the final HEDAS analyses between these two experiments is presented in Figs. 17-19 for 10-m wind speed, temperature, and specific humidity, respectively. In general, the impact of the differences in the spatial distribution of the Global Hawk observations between the 15 and 16 Sep cases becomes distinct in these analyses. For the 15 Sep case, the main impact from the Global Hawk dropsondes observations is clearly seen in the inner core of Hurricane Edouard. Meanwhile, for the 16 Sep case, the impact in the inner core is rather limited whereas a greater impact spread out to the near environment is evident in all fields. As discussed before, this is mainly because the wind analysis is dominated by a plethora of Doppler radar wind observations from the P-3 tail Doppler radar instruments.

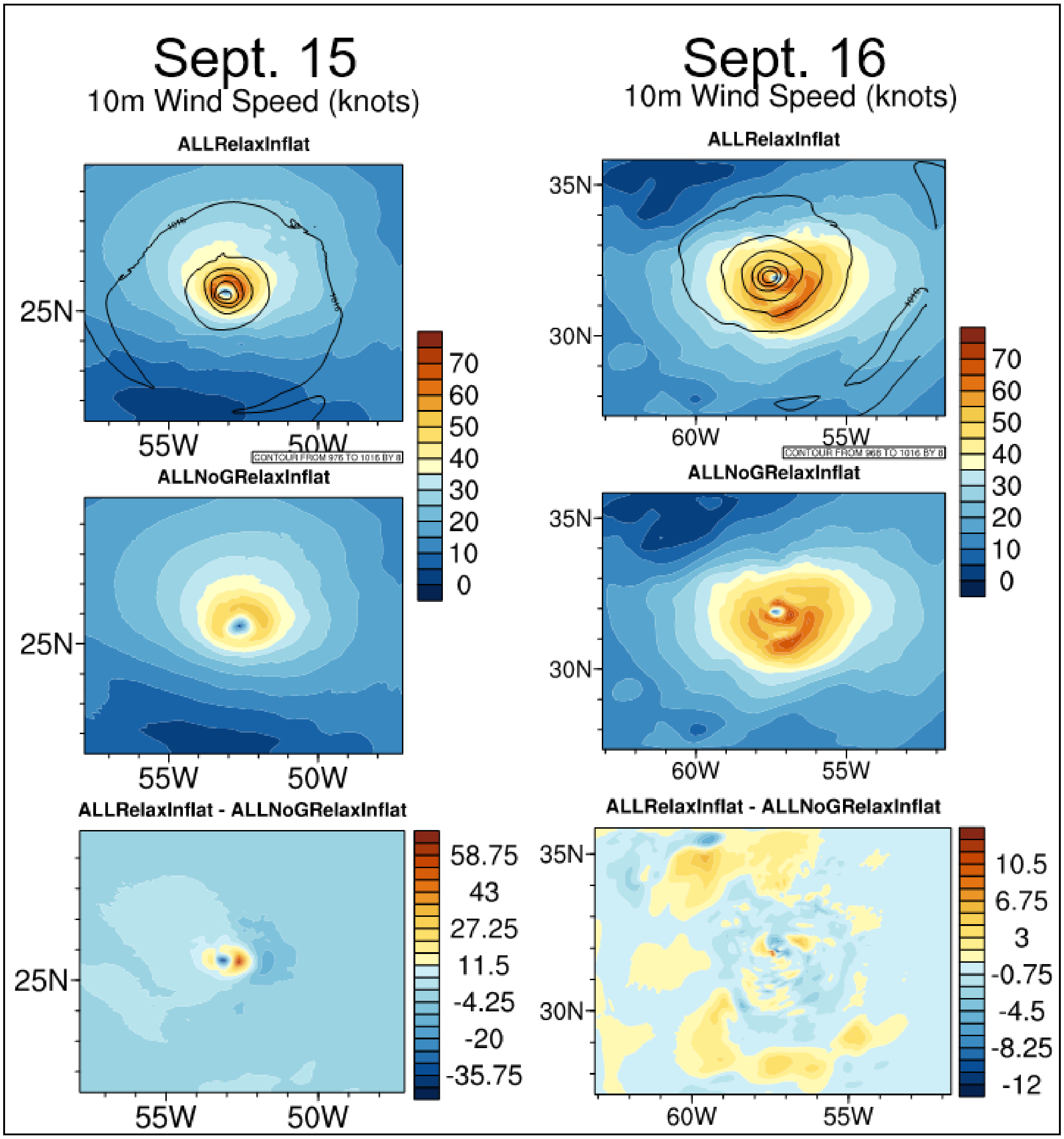


Figure 17: Comparison of HEDAS analyses when all aircraft data are assimilated ("ALL", top row) vs. when Global Hawk data are not assimilated ("ALLNoG", middle row). The difference fields are also shown in the bottom row. The field shown is 10-m horizontal wind speed (shaded). 15 Sep 00Z analyses are shown on the right and 16 Sep 18Z analyses are shown on the left.

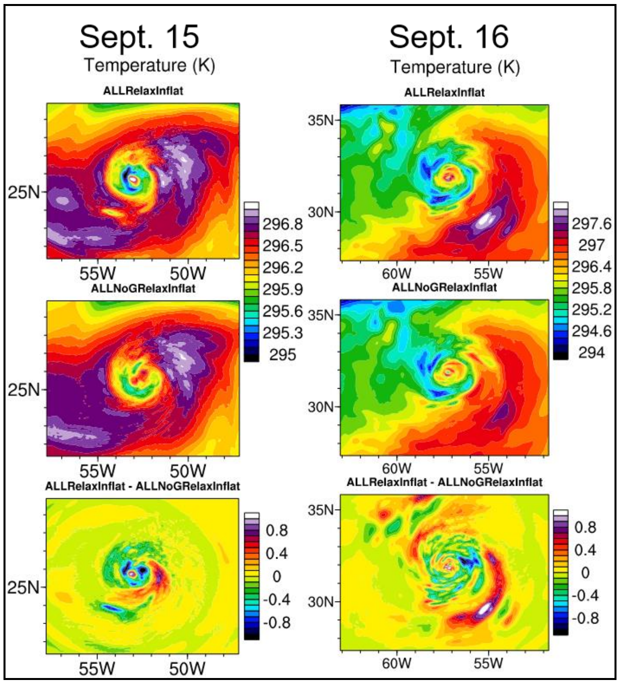


Figure 18: Same as Fig. 17, but for temperature at 500 m elevation.

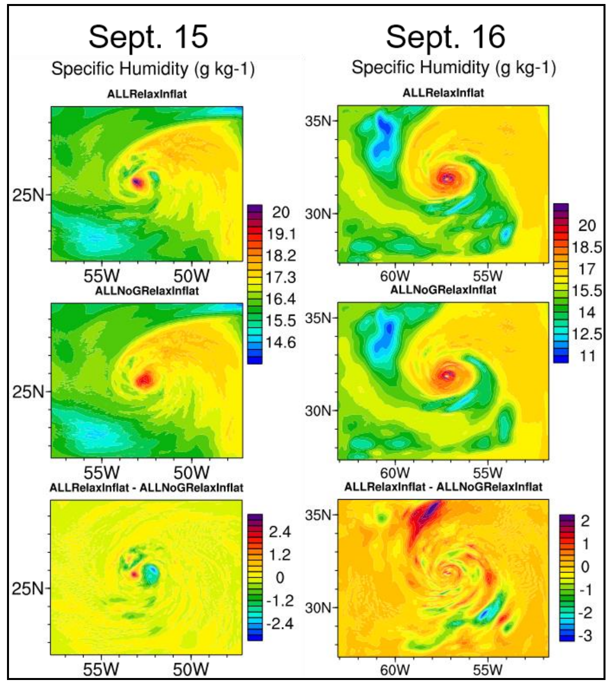


Figure 19: Same as Fig. 17, but for specific humidity at 500 m elevation.

When these analyses are used to initialize deterministic HWRF forecasts, it is observed that forecast performance is indeed dependent on where spatially the Global Hawk observations are dominant (Fig. 20). In the 15 Sep 00Z case, where the Global Hawk observations have the greatest impact on analysis in the inner core of Hurricane Edouard, both intensity and MSLP forecasts are positively impacted, with the most distinct and consistent impact being in MSLP. Meanwhile, in this case, impact on the track forecast is minimal in the short range and becomes slightly positive after 84 h lead time. Conversely, in the 16 Sep 18Z case, where the Global Hawk observations have the greatest impact on analysis in the near environment of Hurricane Edouard, the evident forecast impact clearly shifts to the track of the storm as the improvement in track forecast error gradually and consistently increases with increasing lead time to more than 100 km by the 5-day lead time. Meanwhile, forecast performance for intensity and MSLP is similar among the three forecast scenarios shown, suggesting that the lack of impact from the Global Hawk observations on the inner core structure is likely the reason.

These preliminary results suggest that the Global Hawk dropsonde observations have the potential of improving both the track and intensity of a hurricane, depending on how they are combined with observations from other observing platforms. When the Global Hawk is the primary source of data in the inner core, positive impact on intensity can be expected through improved analyses of the vortex-scale storm structure. When the Global Hawk flies in conjunction with other aircraft that collect high-density observations in the inner core, positive impact can be expected on the track forecasts through improved analyses of the near environment of storms.

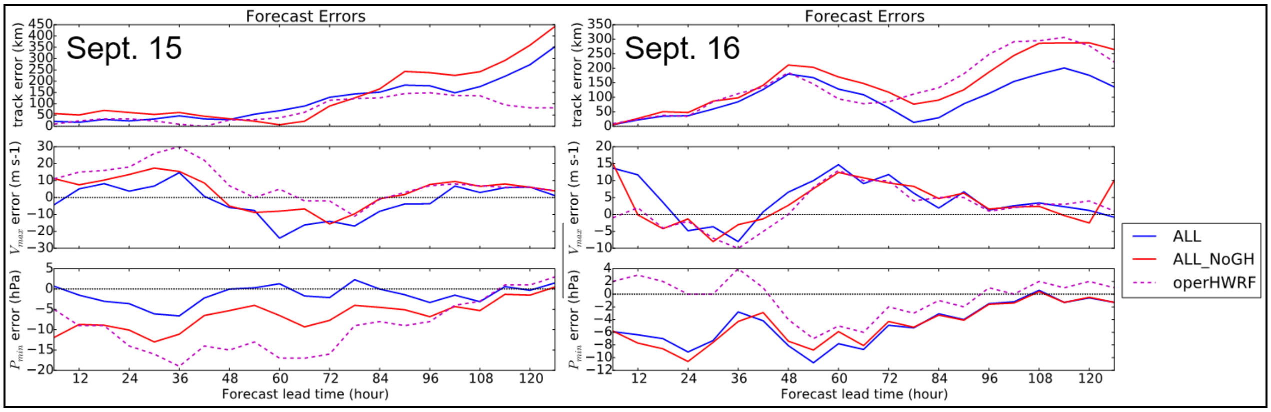


Figure 20: Track (top), intensity (middle), and MSLP (bottom) forecast error for the Hurricane Edouard forecast initialized on 15 Sep 2014 00Z (left) and 16 Sep 2014 18Z (right) for initializations using the HEDAS analyses with (blue) and without (red) the Global Hawk dropsonde data assimilated. For comparison, the forecast errors from the operational HWRF are also shown in dotted purple.

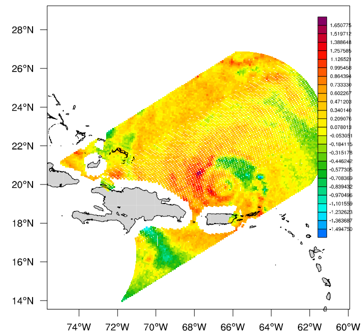
4.3 Assimilation of Satellite Radiance Observations Using the CCV Concept

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. This work is still ongoing as of the end of 2015. The following is a brief description of the CCV methodology:

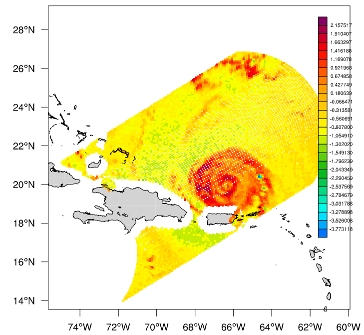
Satellite observations of cloudy (and especially precipitating) scenes contain large, irreducible uncertainty arising from particle shape and size distributions, dielectric constant of cloud ice, and surface emissivity. Since these uncertainties cannot be modeled with a single call to a radiative transfer 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. 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 21 below 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

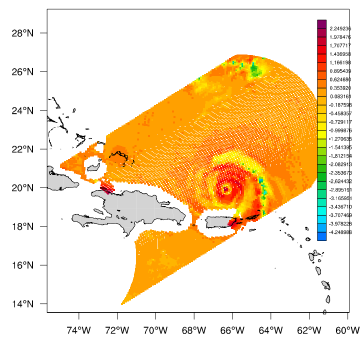
measure of uncertainty; the largest contribution for each CCV (as measured by the model CCV) is described. The fourth CCV has a low R^2 value and would therefore be discarded.



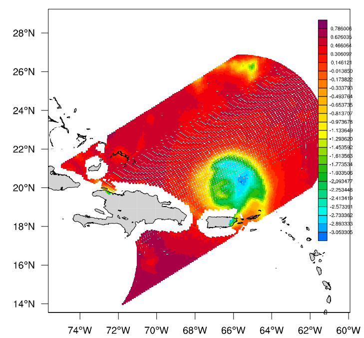
(A) CCV #1, fluffy cloud ice



(B) CCV #2, rain and humidity



(C) CCV #3, non-precip. liquid cloud



(D) CCV #4, pristine cloud ice

Figure 21: Demonstration of how the Canonical Correlation Vectors are spatially distributed in a sample Hurricane Earl case and how they correlate to various microphysical species observed in the atmosphere.

4.4. Using the HEDAS Preprocessing Platform to Disseminate High-Resolution Vortex-Scale Observations to the Hurricane Research Community

The HEDAS observation processing system has been modified to enable the generation of a simple medium to distribute all of the vortex-scale observations (manned/unmanned aircraft, ACARS, AMVs, AIRS & GPS-RO retrievals, and RAOBS) within a pre-specified time window and distance from a specific instance of a storm. We hope that this medium will be useful in hurricane model evaluation efforts. The advantage here will be that all of the above mentioned observations will be placed in a single file in simple ASCII format so that modelers who do not have detailed knowledge about observations and observation file formats can use any of these observations with relative ease. We continue to add new vortex-scale observation types and platforms to our processing capability. During the year of 2015, we have added the Global Hawk and Coyote unmanned aircraft observing platforms into our portfolio.

5. Verification

We completed preliminary assessment of forecasts on Hurricane Joaquin from the 2015 version of basin-scale HWRF system. The initial evaluation indicated that the basin-scale HWRF system performed pretty well although the system is still under development (Figure 22). The verification shows Joaquin's track forecast skill is superior or comparable to operational HWRF and close to GFS across the forecast hours while the intensity forecast skill is above 25% except at 12h and 120h forecast times as operational HWRF's.

The verification of the 2013 version of the basin-scale HWRF system were documented in TCMT verification report (https://www.rap.ucar.edu/projects/tropical-cyclone-research-model-testing-evaluation-tcmt). Further verification of the 2015 basin-scale HWRF is underway.

6. Highlights of Transition

HFIP team at HRD and CIMAS worked closely with EMC and DTC teams to assure the transition. Here are a few highlights of transitions:

- The code of multiple level nests on multiple storms transferred
- Multiple storm initialization transferred
- Storm prioritization scripts transferred
- Physics diagnostics applied in operational HWRF improvement (vertical diffusion)
- HEDAS applied on NOAA Sensing Hazards with Operational Unmanned Technology (SHOUT) project
- TDR data real-time application in operational HWRF system

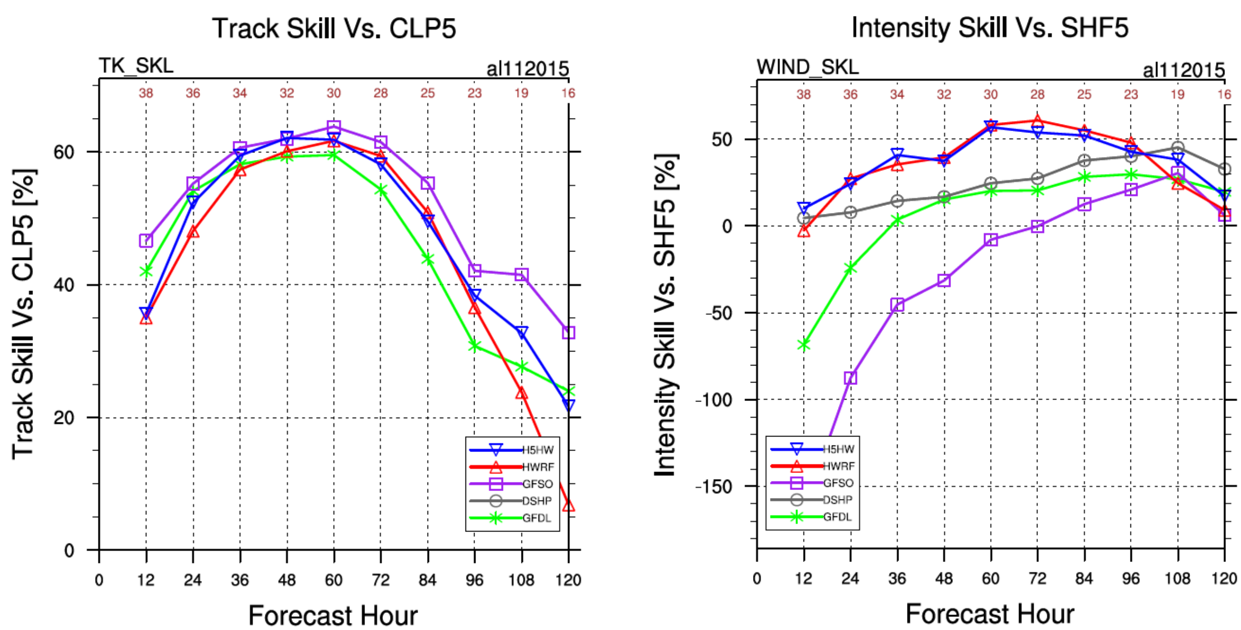
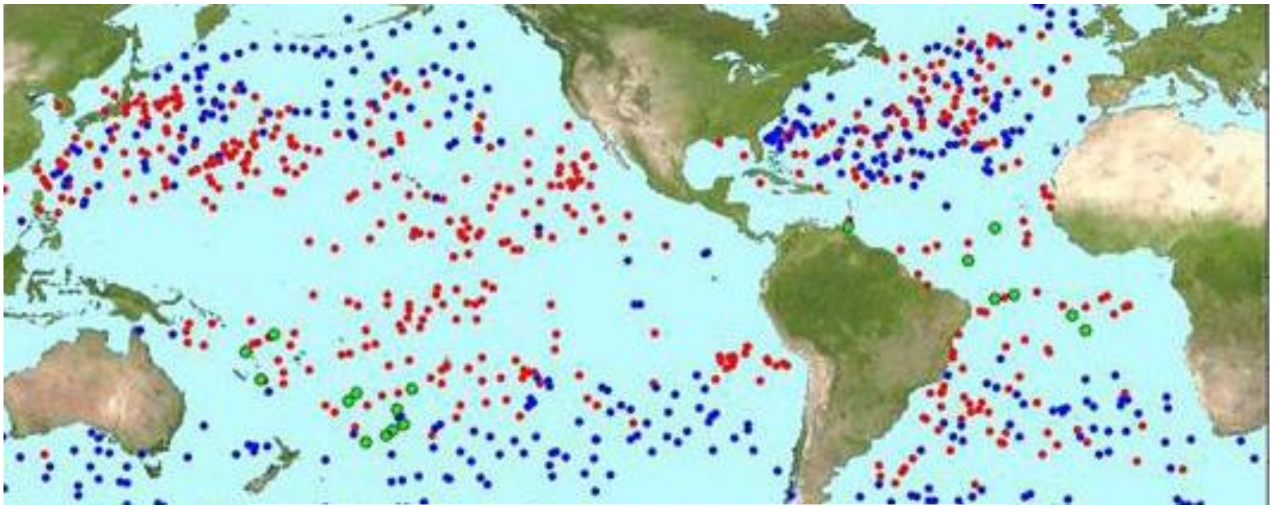


Figure 22: Hurricane Joaquin verification. Track skill is scaled by CLIPER5 (Climatology and Persistence track model) and intensity by SHIFOR5 (Climatology and Persistence intensity model). H5HW: basin-scale HWRF; HWRF: NCEP operational HWRF; GFS0: NCEP operational global model; GFDL: GFDL operational regional hurricane model; DSHP: SHIPS with inland decay statistical-dynamical intensity model.

Research Performance Measure: All research goals were met.



RESEARCH REPORTS

THEME 3: Sustained Ocean and Coastal Observations

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

Project Personnel: L. Barbero, D. Pierrot, K. Sullivan, Y. Liu and R. van Hooidonk (UM/RSMAS/CIMAS)
NOAA Collaborators: R. Wanninkhof and S.-K. Lee (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*

NOAA Funding Unit: OAP/OAR
NOAA Technical Contact: Dr. Libby Jewett, OAP/OAR

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. All data from these analyses have been submitted to data repositories and made publicly available.

During the performance period the first ECOA cruise along the East coast of the US took place (Figure 1). The data have already been quality checked and sent to NOAA's NCEI (National Center for Environmental Information) (formerly NODC). The comprehensive determination of inorganic carbon system parameters provides needed inputs to determine the aragonite saturation state.

As part of the OA effort we have established 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 has been made possible by the large increase of observational data that have been obtained from the ship of opportunity programs run by our group (Figure 2).

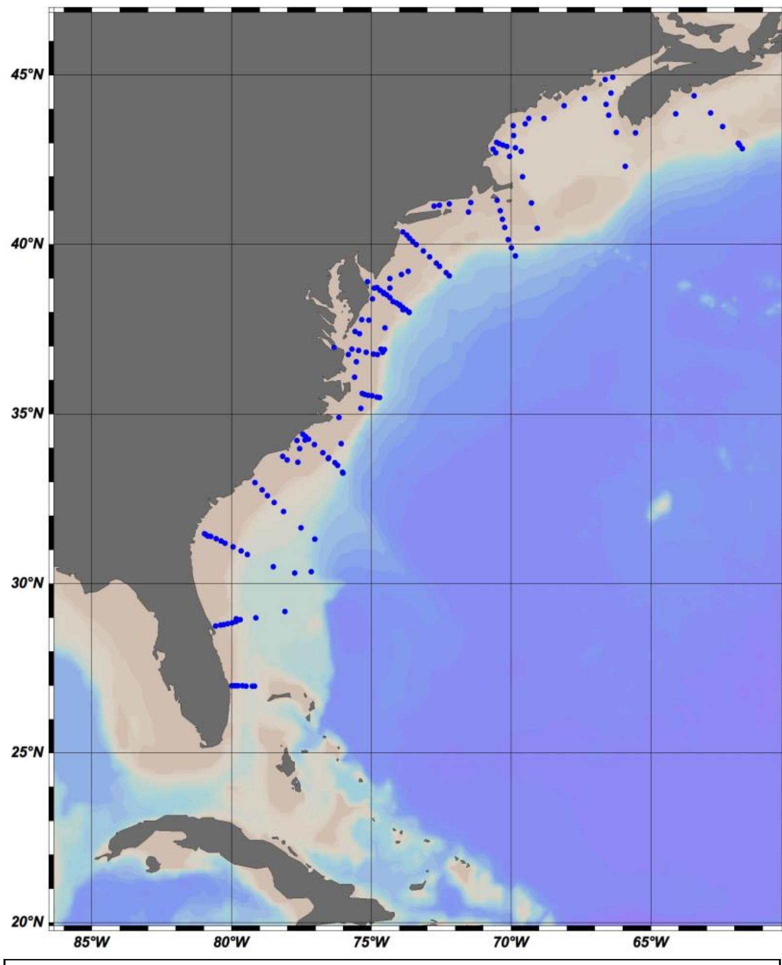


Figure 1: Map of the stations occupied during the ECOA-1 cruise. In total, 163 stations were sampled.

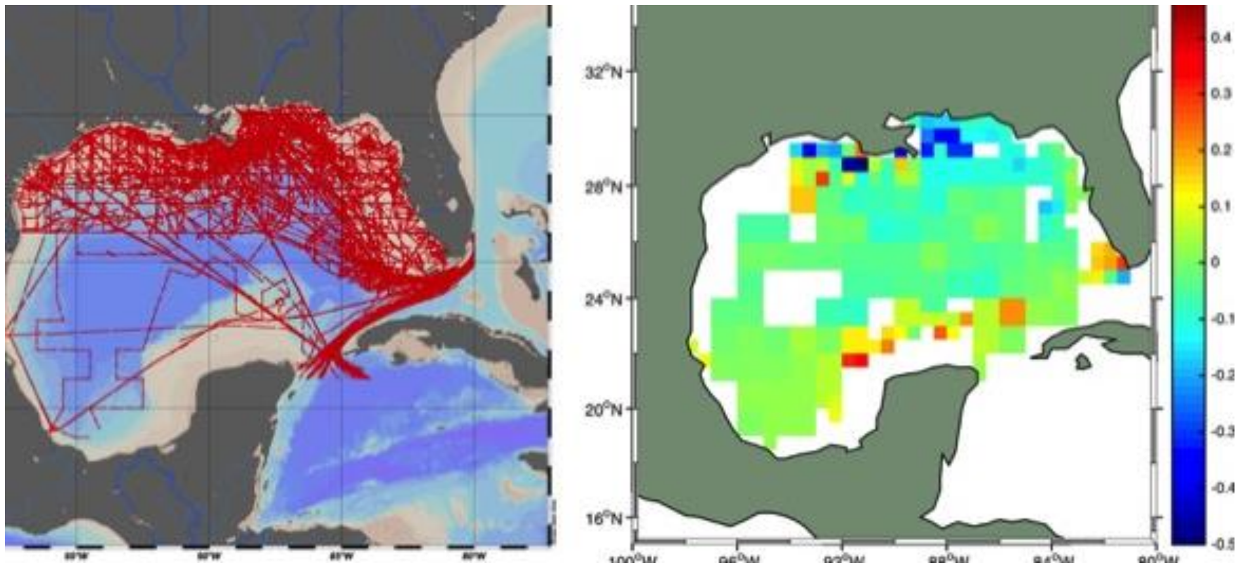


Figure 2: Left) Map of cruise tracks in the Gulf of Mexico where surface pCO_2 measurements have been gathered. Over 2/3 of these data (>500K data points) have been obtained by our group. Right) Climatological air-sea CO_2 fluxes (mol C/m^2y) in the Gulf of Mexico for the month of April calculated using our pCO_2 measurements and monthly CCMP winds. The influence of the Mississippi river influx on the fluxes is apparent.

Research Performance Measure: Provide quality-controlled data that are used to determine patterns and rates of OA in the realm. The data from the cruises have been submitted on time to the NCEI and were released to the public in 2016.

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The GO-SHIP Repeat Hydrography Program

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

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: *An informed society anticipating and responding to climate and its impacts*

NOAA Funding Unit: COD/CPO
NOAA Technical Contact: Dr. Kathy Tedesco, NOAA CPO

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 July 2015 the Pacific meridional P16N transect from 20 ˚S to 56 ˚N was completed in full. In February-April 2016 the Indian meridional transects I08S and I09N were completed (Figure 1).

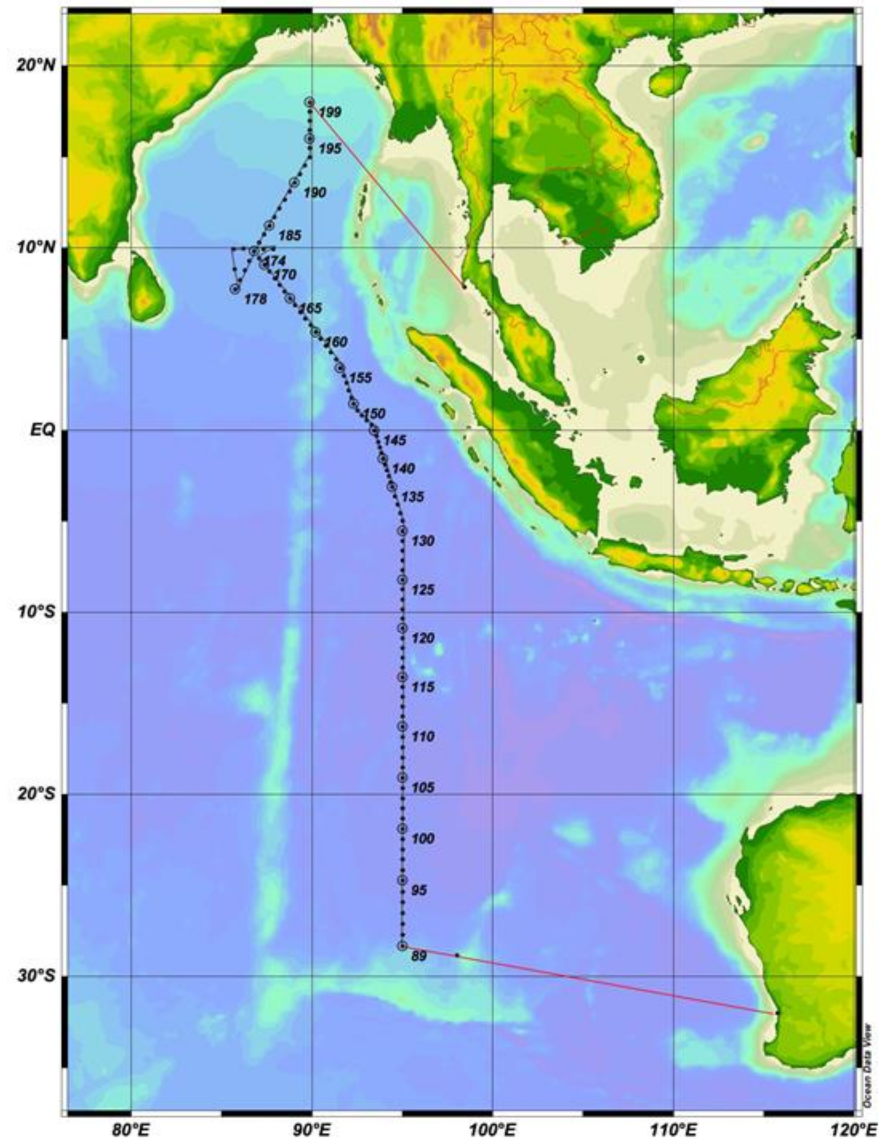

Figure 1: Track of the 2016 GO-SHIP I09N cruise in the Indian Ocean, departing from Fremantle (Australia) and arriving in Phuket (Thailand).

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/CO2 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-2016 we completed one meridional section in the Pacific Ocean, P16N, and two meridional sections in the Indian Ocean from 60 ˚S to 18 ˚N called I08S and I09N with full physical and chemical characterization of over 110 water column profiles. Dr. Leticia Barbero was chief scientist on I09N (Figure 1). CIMAS project personnel and NOAA collaborators were responsible for CTD, ADCP, O_2, nutrients, and inorganic carbon measurements.

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-16 of completing the re-occupation of the I08S and I09N cruises was met.

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PIRATA Northeast Extension

Project Personnel: S. Dolk, R.C. Perez and E. Valdes (UM/CIMAS)
NOAA Collaborators: R. Lumpkin, C. Schmid, G. R. Foltz (NOAA/AOML); P. Freitag, M. McPhaden, M. Strick, L. Stratton (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* (*Primary*)
Goal 2**:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events* (*Secondary*)

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.

CIMAS and AOML personnel participated in the PNE cruise aboard the NATO ship NRV Alliance this past November-December 2015. Claudia Schmid (AOML) served as Chief Scientist, with scientific support provided by Shaun Dolk, Erik Valdes, and Thomas Sevilla (CIMAS), as well as scientists from NOAA/PMEL and the Aerosols and Ocean Science Expeditions (AEROSE) team. A University of Miami/RSMAS graduate student, Michael Cohen, and a volunteer, Vera Schmid-Dannert, also participated in the cruise. Four PNE buoys were recovered and redeployed, and an additional T-FLEX mooring (part of the validation process as the array transitions from ATLAS moorings to T-FLEX moorings) was recovered. Conductivity-temperature-depth (CTD) casts were conducted at 41 stations. Two expendable bathythermograph (XBT) experiments were performed to improve the quality of the XBT data. Planning is underway for the January-February 2016 PNE cruise aboard the NOAA R/V Ronald H. Brown.

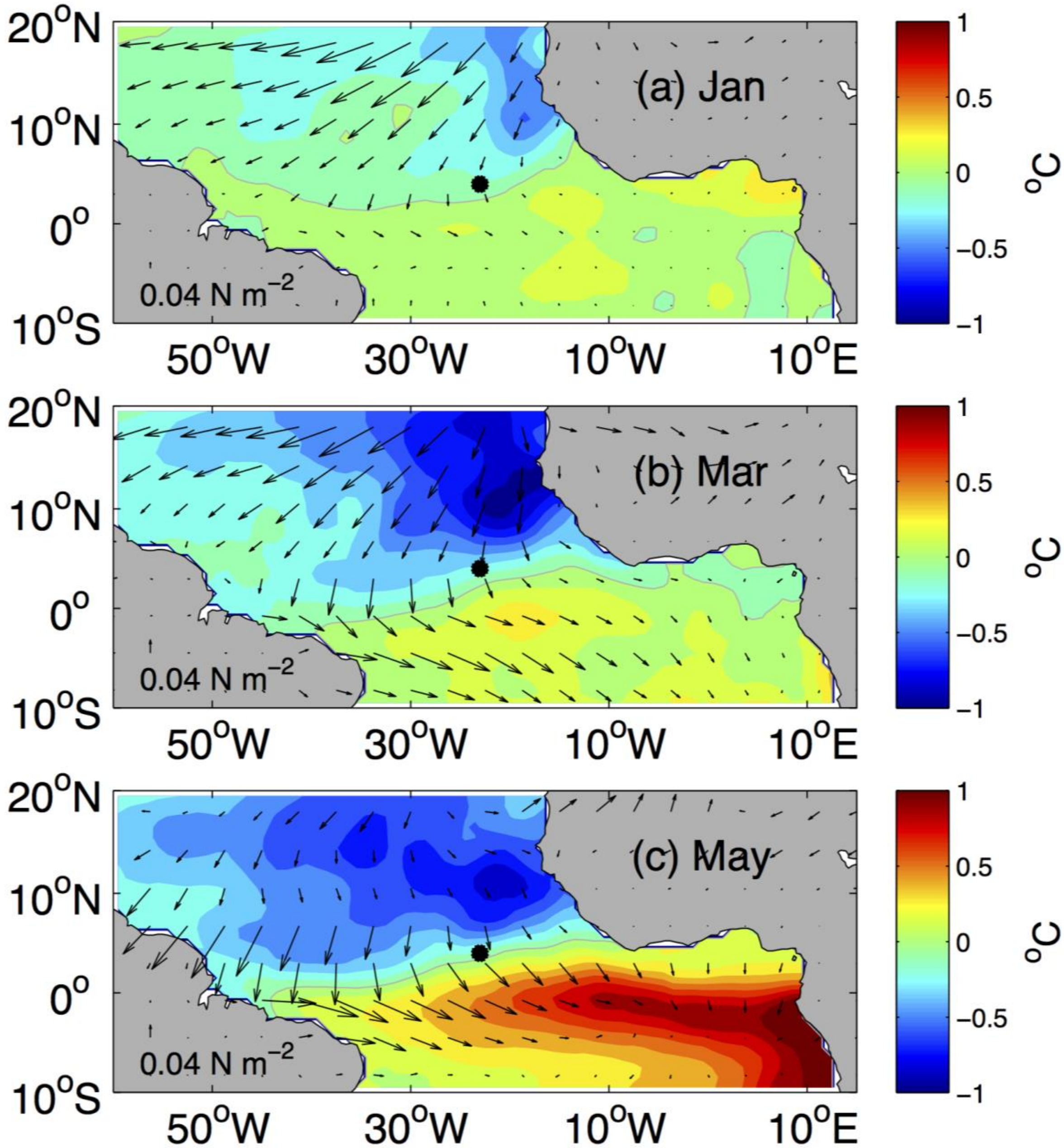

Figure 1: Composite maps of Atlantic Meridional Mode (AMM, anomalous cross-equatorial SST gradient in the Atlantic) events during January, March, and May for 1982-2014. Signs shown are for typical AMM negative events. (a) SST anomalies (shaded) and wind stress anomalies (vectors). (b) rainfall anomalies (shaded).

Research Performance Measure: All major objectives are being met. One PNE-related paper was submitted to the Journal of Climate (Rugg, Foltz, and Perez, 2016). The lead author of this paper was an undergraduate NOAA Hollings Scholar, Allyson Rugg. Allyson interned with Gregory Foltz and Renellys Perez at AOML in June-July 2015, and presented her results at the 2016 AMS (January 2016) and AGU Ocean Sciences (February 2016) meetings.

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

Project Personnel: R. Domingues, G. Rawson, T. Sevilla and J. Dong (UM/CIMAS)
NOAA Collaborators: G. Goni, S.-K. Lee, F. Bringas, G. Halliwell and U. Rivero (NOAA/AOML); R. Bouchard (NOAA/NWS)
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* (*Primary*)

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

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

Research Summary:

Tropical Cyclones (TC) are very often observed to travel and intensify over areas in the Tropical North Atlantic Ocean and in the Caribbean Sea, which are generally characterized by large upper-ocean heat content. Yet, no sustained ocean observation efforts were in place in these areas, which have been very poorly sampled during past decades. To address this lack of observations, NOAA/AOML proposed a multi-institution effort to implement a pilot network of Underwater Gliders. An underwater glider is an autonomous underwater vehicle (AUV, Figure 1) that uses small changes in buoyancy together with wings to propel itself by converting vertical motion into horizontal motion. These vehicles can be configured with customized oceanographic sensors and thanks to a very small consumption of energy, they are able to measure several ocean parameters during a period of weeks or months along thousands of kilometers.

Figure 1: CIMAS / AOML's Underwater gliders aboard R/V La Sultana from University of Puerto Rico Mayaguez.

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: (i) enhance our knowledge about the role that the ocean plays in the intensification of TCs; (ii) and to assess the impact of underwater gliders ocean observations on the TC intensity and seasonal forecasts. To accomplish this, a pilot network of underwater gliders was implemented in July 2014. To date, **four glider missions** have been successfully completed with the collection of over **9,000** temperature and salinity profiles.

During July 1st, 2015 – June 30, 2016, two underwater glider missions were successfully carried out: one during the 2015 Hurricane Season from July-November, 2015, and another mission off-Hurricane Season, from March – June, 2016. The mission during Hurricane Season 2015 (Figure 2a) took place between July 15 – August 11, 2015, and ended with the collection of 2,690 temperature, salinity, and dissolved oxygen profiles, including observations collected for ocean conditions under Tropical Storm Erika (2015). The mission off-Hurricane Season (Figure 2b) took place from March 10 – June 2, 2016, and ended with the collection of over 1,450 temperature, salinity, and dissolved oxygen profiles. Data collected by the underwater gliders were made available in real-time through AOML website (http://www.aoml.noaa.gov/phod/-gliders) and through the Global Telecommunications System (GTS). Data were also distributed through NOAA Integrated Ocean Observing System - IOOS (http://www.ioos.noaa.gov/).

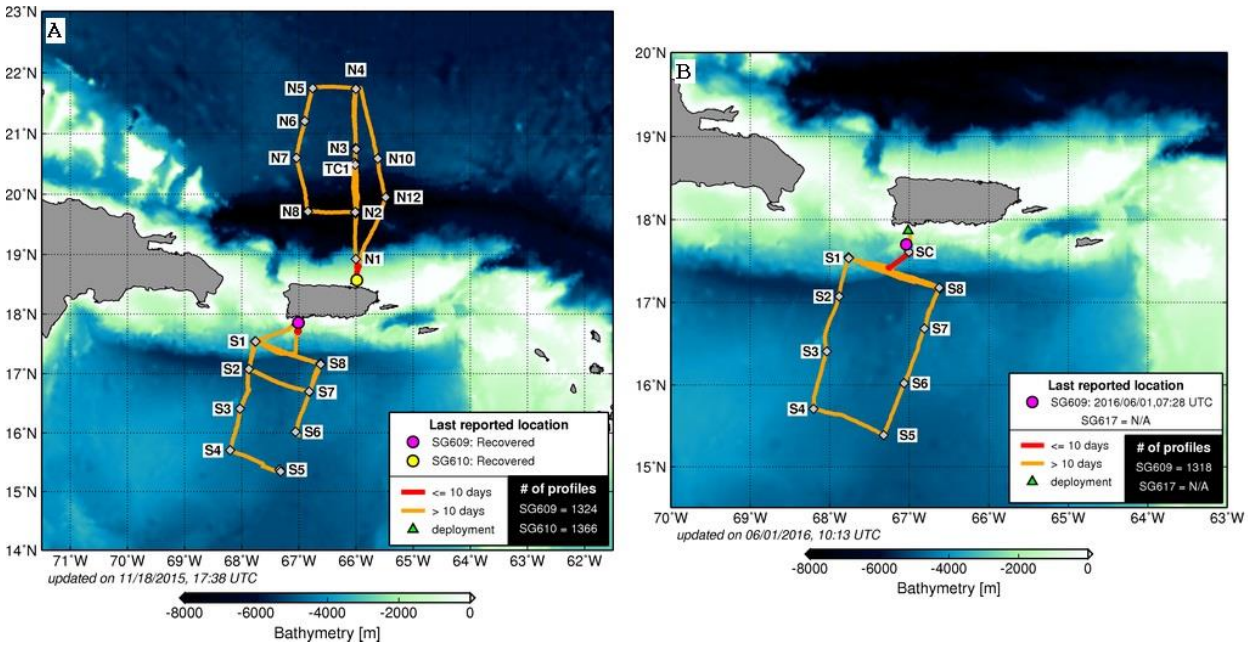

Figure 2: Track travelled by two underwater gliders during (A) the Hurricane Season (July-November) mission from 2015, and (B) during the off-Hurricane Season (March-June) mission from 2016.

Before the July 2015 deployment, tests were conducted on the gliders to determine the cause of voltage drops in the secondary battery pack. The battery packs were removed from the gliders and an electrical load applied and recorded in order to measure the performance of the batteries. It was determined that the batteries performed as expected and the characteristics of lithium battery voltage drop is what we were experiencing during the mission. The main reason it was not seen in previous missions is because the gliders were switched to a bused 15V system from a 24V/10V system. The provided the glider team an additional learning experience about the power draw and reserve energy of the gliders. Additional spare parts were also purchased before the off-Hurricane Season deployment, including hull sections, transducers, GPS, and Electronic assemblies to prolong the usable life of the glider systems and prevent downtime.

During the 2015 Hurricane Season mission, glider SG609 had an encounter with a shark and sustained some damage to wings and hull (Figure 3). In December 2015 the glider was refurbished and the shark damage was repaired. This included removing a shark tooth from the fiberglass fairing, replacing a wing, potting the holes in the fiberglass and re-painting portions of the glider. The glider was deployed in March 2016 without issues.

Figure 3: (right) Shark tooth embedded on body of the glider. (left) Damage on SG609 after the shark encounter.

In June 2016, Glider 610 was converted into a pumped CTD system from the passive CT sail. Glider 609 will remain as a CT sail system in order to carry out comparison studies of the pumped vs passive systems. Both gliders were also upgraded to include a WetLabs Fluorometer which measures Chlorophyll A, CDOM, and backscatter in the 700nm wavelength. Each channel is significant in it's own right but combined the channels can be used to detect the presence of crude oil in the water column.

Science Update

During July 1st, 2015 – June 30, 2016, the scientific advances from this project were geared towards (i) enhancing our knowledge about the role that the ocean plays in the intensification of TCs; (ii) and on assessing the impact of underwater gliders ocean observations on the TC intensity and seasonal forecasts.

Observational component

In one study published on Geophysical Research Letters (Domingues et al., 2015), researchers from AOML, CIMAS, and their colleagues at the University of Puerto Rico Mayaguez and at the Environmental Modeling Center, identified the importance of salinity effects in reducing the upper-ocean cooling during Hurricane Gonzalo (2014) using the observations collected by one glider. Hurricane Gonzalo formed on October 12, and traveled within 85 km from the location of the glider situated north of Puerto Rico on October 14 (Figure 4a). At that stage, Hurricane Gonzalo was a category 3 hurricane with maximum sustained winds of 115 mph. Observations collected before, during, and after the passage of this hurricane were analyzed to help improve understanding of the upper-ocean response to hurricane winds and of the ocean recovery after the passage of the storm. The study revealed that salinity conditions below the surface of the ocean created a barrier against the strong wind forcing of the hurricane, which in oceanographic terms is simply named as a “barrier layer”. The presence of this barrier layer prevented the strong mixing forced by the hurricane. As a consequence, cooling of surface waters (Figure 4b) was small

(~0.4ºC) compared to cooling forced by other hurricanes with similar strength in areas where the barrier layer was not present. This is important because the small cooling of surface waters may have favored the intensification of Gonzalo. In fact, a second study (Goni et al., 2015) revealed that Hurricane Gonzalo continued to intensify until it reached maximum intensity as a category 4 Hurricane.

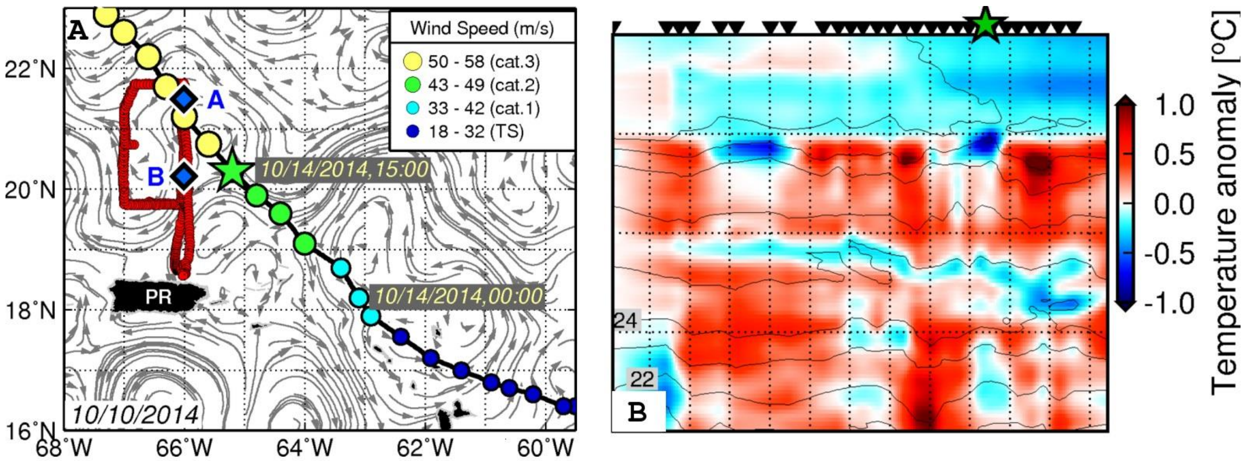

Figure 4: (A) Track followed by the glider (red points) north of Puerto Rico (PR) during July-November 2014, overlaid on altimetry-derived geostrophic currents. During October 8-28, the glider sampled ocean conditions between sites A and B (blue diamonds). The track of Hurricane Gonzalo is shown by colored circles (every 3hrs). The star highlights the closest location of the hurricane with respect to the glider. (B) Temperature anomalies in the upper 200m at site B during October 13-15, 2014, with respect to initial conditions in this location.

The study by Domingues et al., (2015) further revealed that salinity effects observed in the real ocean were not properly represented in one of the ocean models that is used for hurricane forecast, the HYbrid Coordinate Ocean Model (HYCOM) coupled to the Hurricane Weather Research Forecast model (HWRF), HWRF-HYCOM. As a consequence, HWRF-HYCOM overestimated the surface cooling forced by winds of Hurricane Gonzalo, which ultimately caused an underestimation in the intensity forecast of Gonzalo. Identifying such discrepancies and understanding the mechanism behind them is one way for improving tropical cyclone intensity forecasts. The study concludes that "a better model representation of salinity conditions may improve simulations of the ocean response and future hurricane forecasts in this region, given the important role of salinity suggested by the observations analyzed in this study". Results presented in this study emphasize the value of underwater glider observations for improving our knowledge of how the ocean responds to tropical cyclone winds and for tropical cyclone intensification studies and forecasts.

Modeling component

The modelling component of this project aims to investigate the impact of ocean observation assimilation, especially underwater gliders assimilation, on hurricane forecast using a high resolution coupled atmospheric-ocean numerical model system. A study currently in preparation (Dong et al., in preparation) has addressed the impact assimilating glider observations on the forecast of Hurricane Gonzalo (2014). Hurricane Gonzalo (2014) is first simulated with a high resolution Hurricane Weather and Research Forecast (HWRF)-Hybrid Coordinate ocean model (HYCOM) coupled forecast system. The ocean initial conditions are from the forecast-data assimilation system maintained by NOAA/AOML. The conventional ocean observations are assimilated daily from 00 UTC March 15 of 2014 throughout 00 UTC October 13 2014. The T/S data from two underwater gliders were assimilated from 00 UTC July 15 to 00 UTC October 13 2014. Only the glider T/S data collected close to 00 UTC of each day were

assimilated. All the ocean data assimilation is performed with the ocean forecast only. An ocean forecast from 2009 to 2014 without any observation assimilated is denoted as NODA as the benchmark experiment. Three data assimilation experiments were designed to examine the impact of assimilating underwater glider T/S data and conventional observations, denoted as GLID, CTRL and ALL (Table 1). After the initialization of both atmospheric and ocean models, the 126 hours coupled forecast started from 00 UTC October 13 to 06 UTC October 18, covering most of the life cycle of Gonzalo as a hurricane.

Table 2: Experiments Assimilating Different Ocean Observations

Experiment Name	Obs assimilated/Remark
NODA	No obs
GLID	Two underwater gliders
CTRL	Conventional ocean obs (Jason altimeter, MCSST, AXBT, AXCTD etc.)
ALL	Gliders+conventional ocean obs

The pre-storm ocean profile has a mixed layer with around 55 m depth and an SST of 29 ºC (Figure. 5a). The temperature profile of NODA has a shallow mixed layer of 10 m deep and shows negative bias across the upper 150m depth of the ocean. SST is 0.2 ºC colder than observed (Figure 5a). The assimilation of glider observations in GLID improves the thermal structure by reducing the bias throughout most of the upper 150 m depth (Figure 5a). The SST of GLID is warmer than observed by 0.3 ºC. The bias is always below 0.4 ºC between 60 to 120 m and increased to 1 ºC down to 150 m. The temperature profile of CTRL is similar to GLID above the MLD base but has bias always higher than 0.5 ºC from 60 m to 150 m, which suggests the assimilation of conventional observations also improves the pre-storm thermal structure of this region but not as much as assimilating the glider observation. The assimilation of additional glider observation data based on conventional observations further improves the initial thermal structure: the mixed layer depth of ALL is around 30 m, deeper than CTRL (Figure 5a). The bias is further reduced over most of the upper 150 m depth compared to CTRL.

The observed subsurface salinity quickly increases from the surface to a local maximum at 20 m (Figure 5b). NODA underestimates the salinity with negative bias over 0.5 from 20 m down to 150 m depth. The assimilation of glider T/S data in either GLID or ALL limits the negative bias down to 0.2 (Figure 5b). The conventional observations also help to reduce the error but not as much as the assimilation of glider observation. The salinity of ALL is very close to the observation from 20 to 105 m with near-zero errors (Figure 5b).

During the 126 hours forecast, the predicted track is close to the best track and shows little sensitivity to different ocean initial conditions. On the other hand, the assimilation of conventional ocean observations significantly improves Gonzalo’s intensity forecasts (Figure 6) by reducing the averaged absolute error of minimum sea level pressure and maximum surface wind 47% and 46% respectively. The predicted storms initialized from ocean conditions with conventional ocean observations assimilated (CTRL) are category 3 and closer to the best track, compared to a category 2 storm predicted in NODA. The assimilation of underwater glider observations shows marginal impact (Figure 6). The improvement on Gonzalo’s intensity forecast is partly from a stronger surface enthalpy heat flux induced by the warmer upper ocean condition, especially after 36 hours.

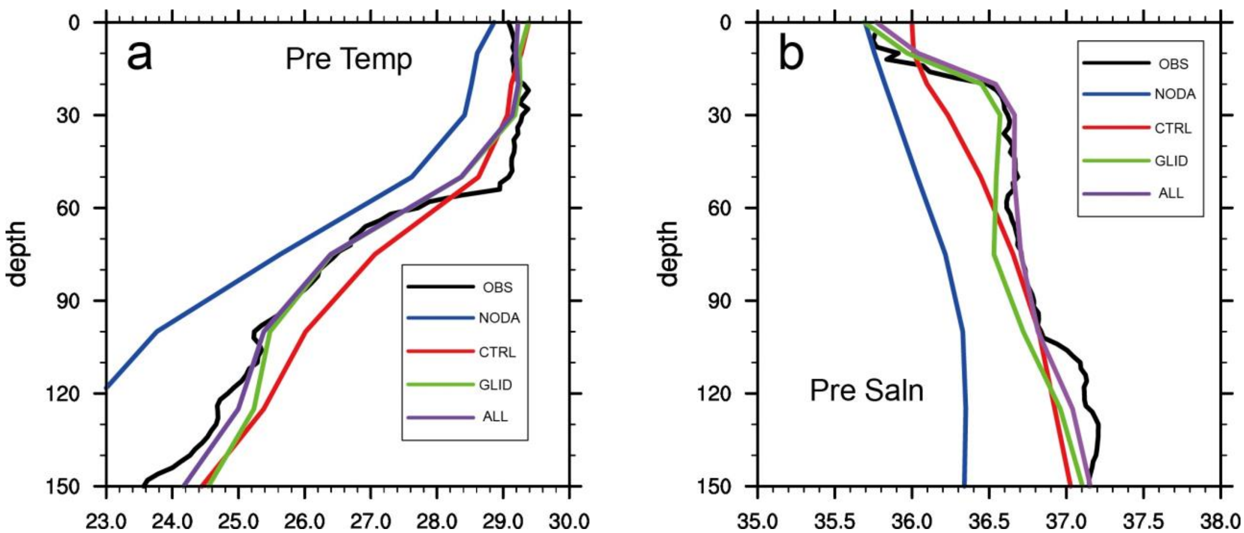

Figure 5: (a) Temperature and (b) salinity profiles at 00 UTC October 13 2014 from four experiments, compared to the glider observation.

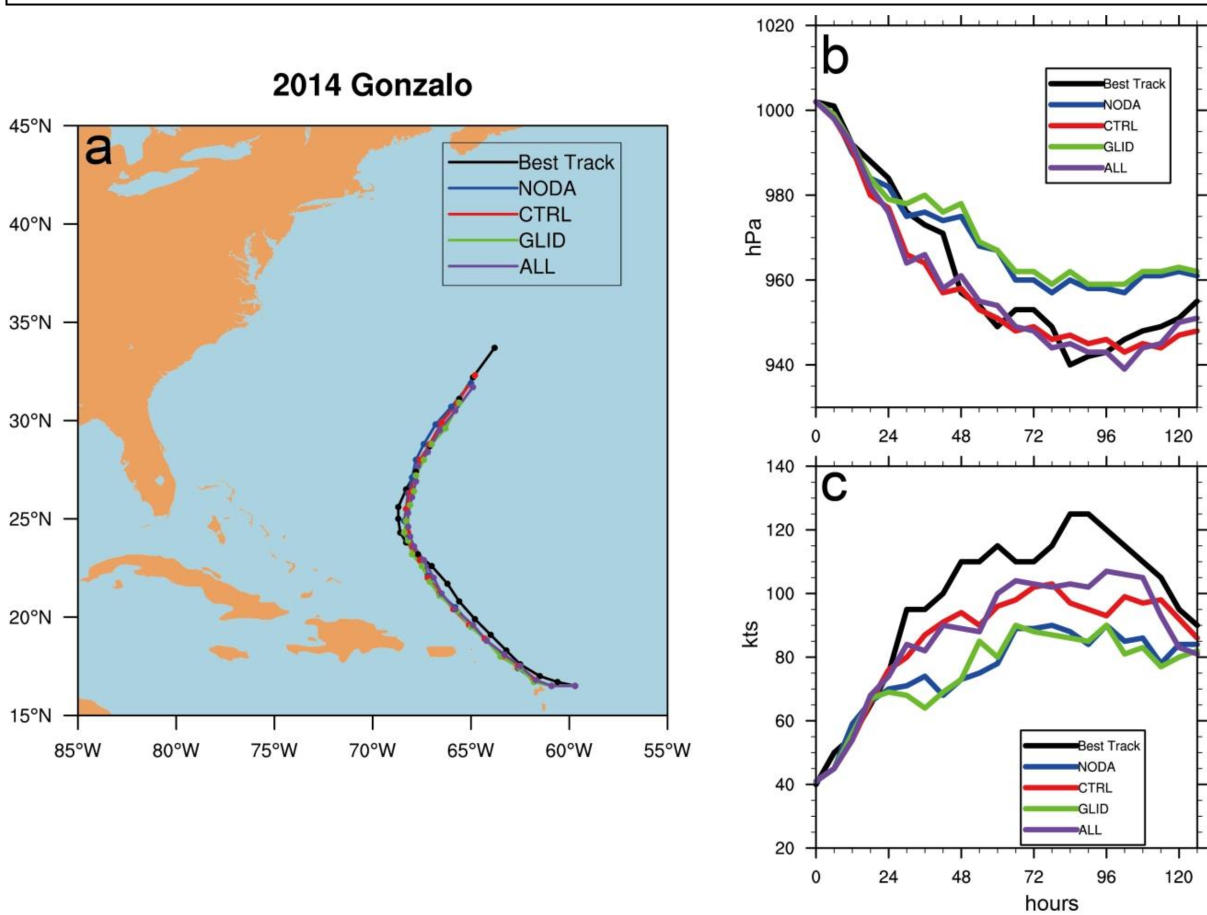

Figure 6: (a) Hurricane Gonzalo's track forecast, (b) minimum sea level pressure (center pressure), and (c) maximum wind forecasts, along with the best track data.

In summary, the assimilation of underwater glider observations significantly improves pre-storm ocean thermal and saline structure for Hurricane Gonzalo (2014). The intensity forecast of Gonzalo is also greatly improved by assimilation of ocean observations, highlighting the importance of ocean initialization on coupled hurricane forecast.

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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Ship of Opportunity Program

Project Personnel: C. Gonzalez, Z. Barton, R. Domingues, M. Goes, H. Lopez, J. Christophersen, G. Rawson, R. Roddy, P. Halsall, T. Sevilla, D. Volkov and R. Sabina (UM/CIMAS)

NOAA Collaborators: S. Dong, G. Goni, M. Baringer, F. Bringas, P. Pena, A. Stefanick, J. Farrington, J. Harris, U. Rivero and Y-H. Daneshzadeh (NOAA/AOML)

Other Collaborators: J. Trinanes (U. 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 the long-term mean and variability of major ocean currents, and of the transport of mass, heat, and freshwater 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* (*Primary*)

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

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

Research Summary:

The global atmospheric and oceanic data from Ships Of Opportunity Program (SOOP) provides key observations for understanding long-term changes in climate. The XBT Network is component of SOOP that supports the design, implementation, maintenance, evaluation, and data acquisition, transmission, and distribution of a network of eXpendable BathyThermographs (XBTs) that obtains temperature profiles along fixed predetermined transects. 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 transport of heat, mass, and freshwater, b) assessing variability of boundary currents, and c) contributing with approximately 15% of the global upper ocean heat content data. Deployments are carried out from a network of cargo vessels, cruise ships, and research vessels. Transects are repeated several times per year, to measure the water temperature from the sea surface to a maximum depth of usually 850m.

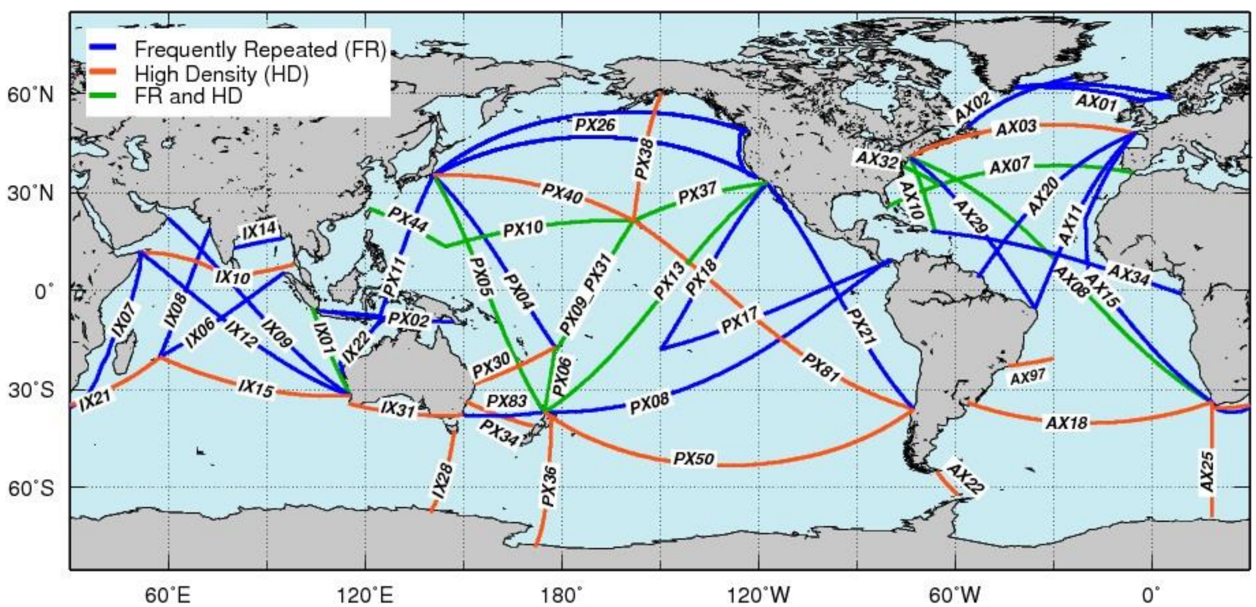

Figure 1: OceanObs09 XBT transects recommended by the scientific community to be occupied in frequently repeated mode (FR, in blue), high density mode (HD, in orange) or both (in green).

The XBT network currently in place has been recommended by the international scientific community during the OceanObs99 and OceanObs09 meetings (Figure 1), and discussed during the four XBT science meetings that have already taken place since 2011. NOAA/AOML is involved with the deployment of approximately 8000 XBTs 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.*

NOAA/AOML currently maintains, exclusively or as part of international and/or multi-institutional collaborations, the following transects (Figure 2) in High Density mode: AX01, AX02, AX07, AX08, AX10, AX18, AX20, AX22, AX25, AX32, AX97, MX01, MX02, and MX04. NOAA/AOML 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 the main ocean currents and the upper thermal structure in the Pacific Ocean.

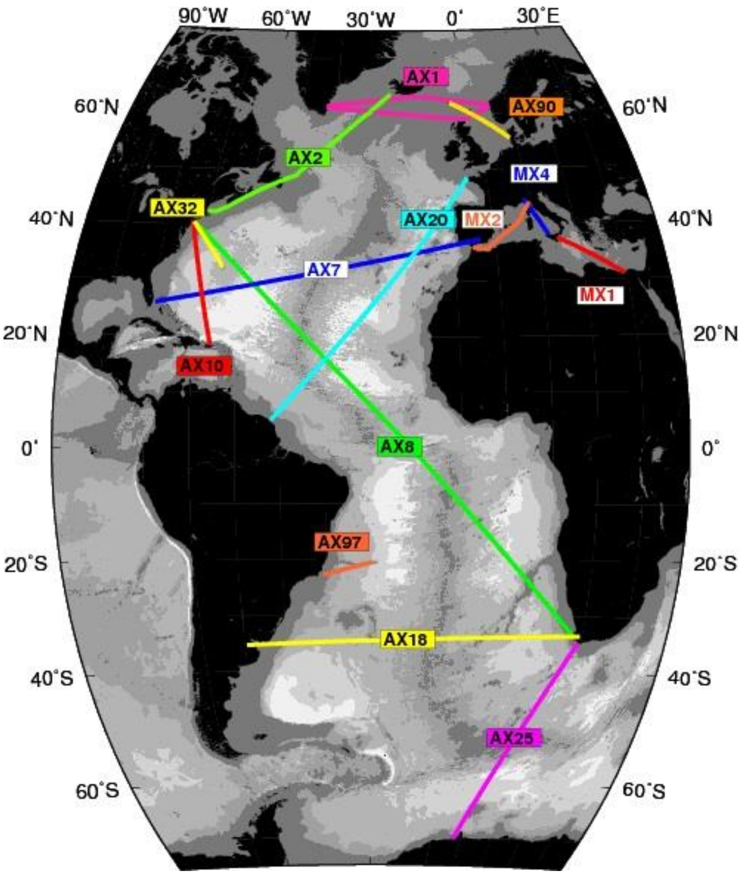

Figure 2: Location of the 4 High Density XBT transects (AX07, AX08, AX10, and AX18) maintained solely by NOAA/AOML, and the 7 transects (AX01, AX02, AX20, AX25, AX32, AX90, AX97, IX01, IX12, IX28, MX01, MX02, and MX04) maintained by NOAA/AOML in collaboration with the University of Paris, IRD/France, NOAA/NEFSC, University of Cape Town, Federal University of Rio Grande, Australia's Bureau of Meteorology and CSIRO, and ENEA/Italy.

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 ocean currents correspond to 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 3 shows the location of XBT deployments by the international community during calendar year 2015 **(total of 17,043 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 (Figure 4).

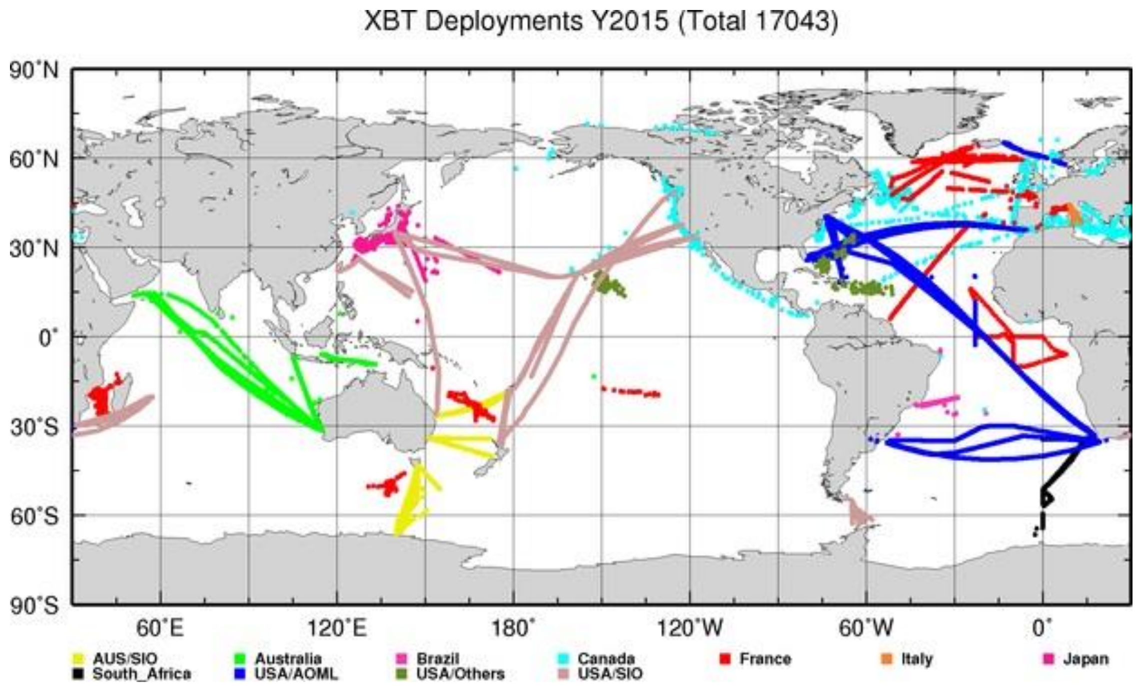

Figure 3: Locations of XBT deployments by AOML and the international community during calendar year 2015.

The data obtained though this project are distributed into the GTS within 24 hours of their acquisition, providing critical input for weather and climate forecasts models and scientific applications. Data are also 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/*.

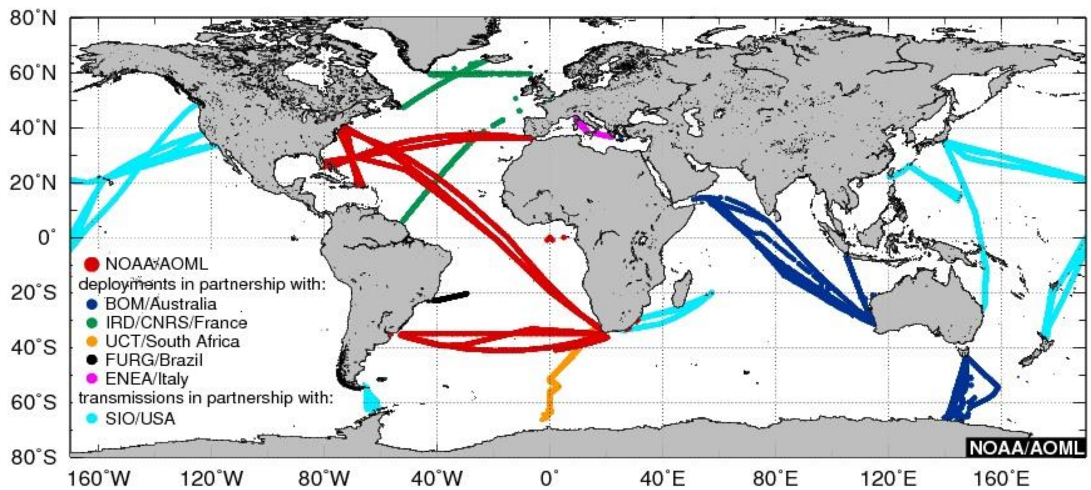

Figure 4: Location of the AOML XBT deployments and AOML-supported XBT deployments/transmissions during FY2015 carried out by AOML or in partnership with national and international collaborators.

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.

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 5), and AX07 in the North Atlantic (Figure 6).

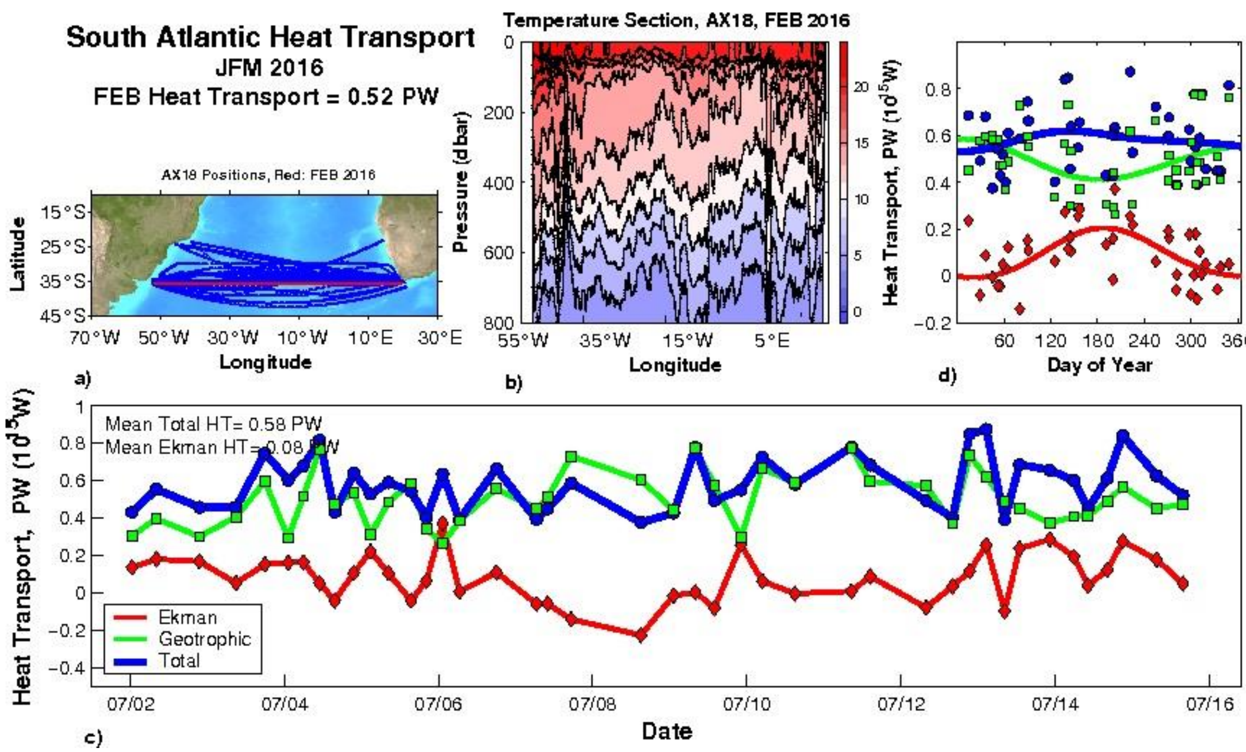

Figure 5: South Atlantic MHT calculated using data from the AX18 high density XBT transect, which runs from the Rio de la Plata region to South Africa.

During FY2015, AOML also continued the TSG operation in support of pCO_2 operations. During this period AOML received, processed, and distributed TSG data from 7 ships of the SOOP (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 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 8 million TSG records were processed at AOML during FY2015 (Figure 7), and distributed through several data centers. The operation of TSG equipment is performed with the SEAS software.

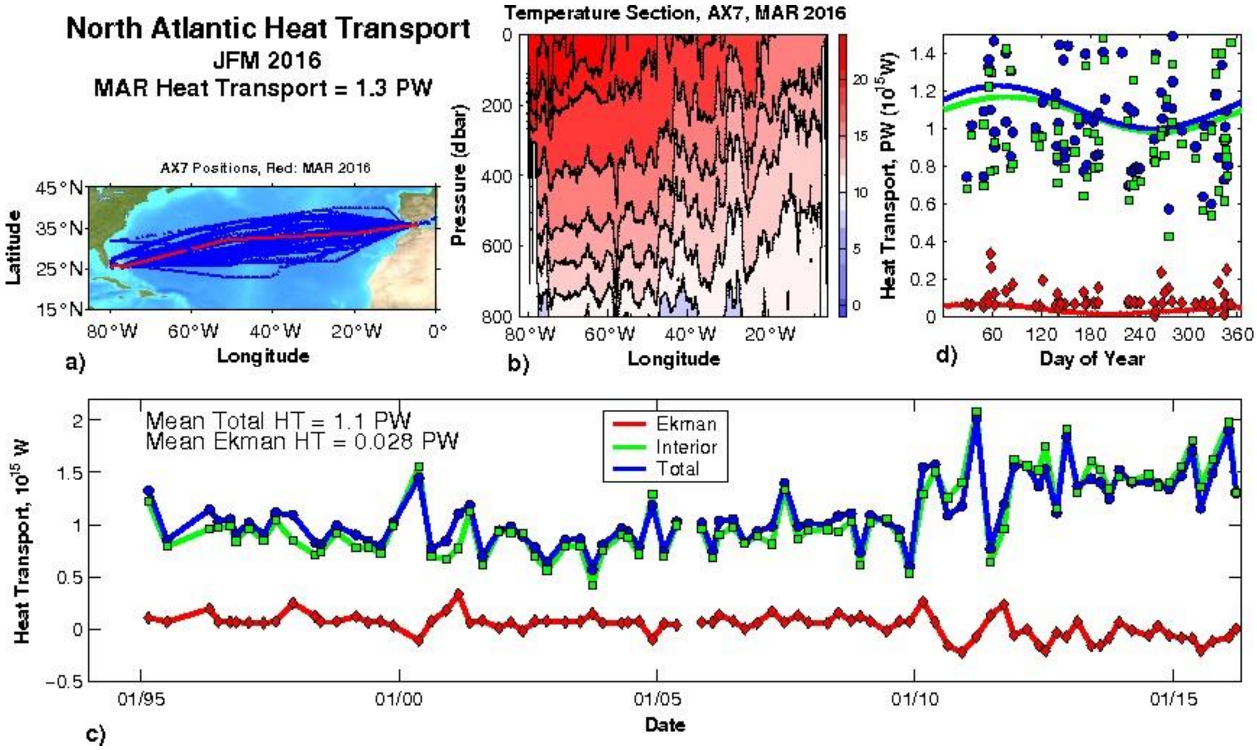

Figure 6: North Atlantic MHT calculated using data from the AX07 high density XBT transect, which runs from Florida, USA, to Gibraltar.

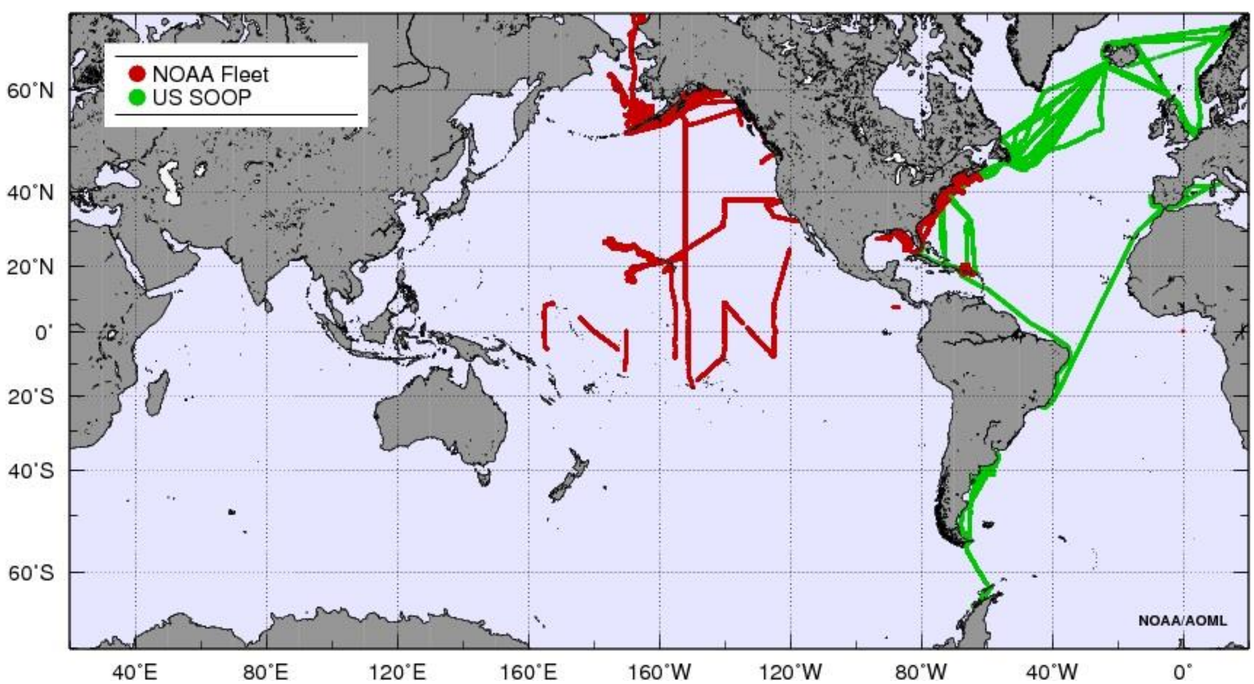

Figure 7: Locations of TSG records received, processed, and distributed by AOML during fiscal year 2015.

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 a proprietary XBT data acquisition device, which aims to improve current methods for acquiring data, while reducing associated costs of operations. The new instrument called Real-time Data Acquisition Device performs the same operations as the MK-21 by Lockheed Martin. Production cost for the current Real-time Data Acquisition Device prototype is less than $100 per unit, which may potentially translate in a major savings of operating costs, given that each MK21 unit costs approximately $8,000.

(ii) Multiple tests of a new Linux-based computer system to deploy and monitor XBTs during a cruise with Amverseas. This new system has proven more stable than windows-based operating systems. Once the testing phase is over, it will be assessed as an alternative to windows-based operating systems where needed. The new setup also includes the newly developed Ethernet DAQ Mk21 from Sippican. This is currently the only sippican-supported version of the XBT acquisition hardware.

(iii) Updates in software used for real-time monitoring of XBT transects. The software decodes the binary files from a FTP server transmitted via Iridium, and is able to identify problems during cruises like gaps between deployments and equipment failures. This software is currently used by NOAA/AOML to identify issues with the data and to support riders.

(iv) A new software package used for quality control of XBT data. Quality control proceedures were updated and translated from FORTRAN to PYTHON. The new software aims to simplify troubleshooting, maintenance, and accessibility, while still complying with requirements to transmit in BUFR formatted files to GTS.

(v) Updates in the AMVERSEAS software used for data acquisition. Updates included implementing the command-dispatcher module Remote Command System, which will increase the flexibility of AMVERSEAS, and including a Distance Drop Plan in the XBT Program, which simplifies the sampling setup for the rider.

(vi) A sea trial was performed to test the new accuracy of the Enhanced XBT (EXBT) probes during the PIRATE Northeast Extension 2015 cruise. A series of 40 EXBTs was deployed to examine the gain in temperature and depth accuracy of the new probes. These probes include a new thermistor parameterization, and a tighter weight tolerance for the weight variability of the probes noses. Preliminary results show that the new probes improved the median temperature accuracy (Figure 8).

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

(a) Dong et al. (2015a): 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 also showed strong interannual variations in subsurface temperatures (Figure 9). 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.

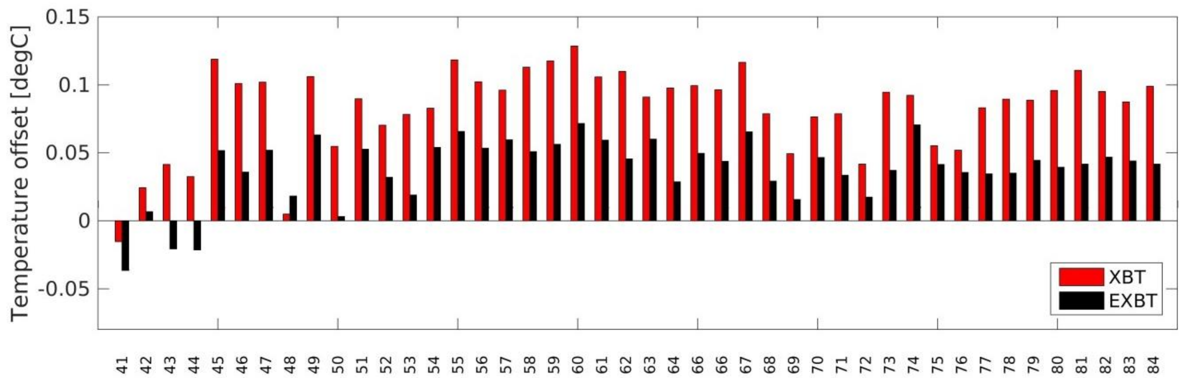

Figure 8: Temperature offset (deg C) calculated between the XBTs and CTDs profiles deployed during the PNE 2015 experiment. Red bars are for the uncalibrated thermistors, and black bars are for the post-calibrated thermistors.

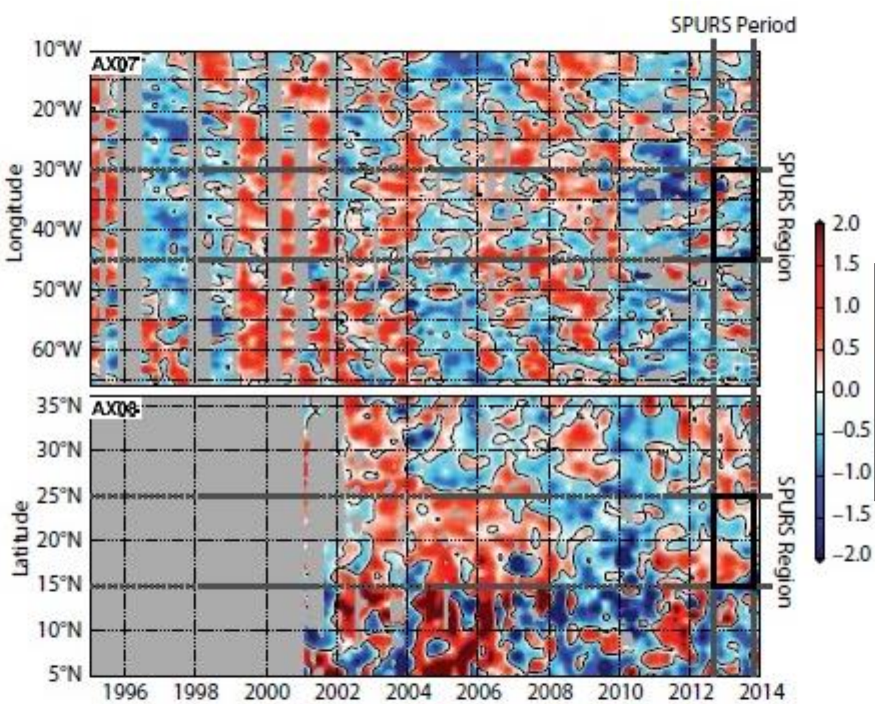

Figure 9: Hovmoller diagram of subsurface temperature anomalies at 100 m depth from XBT transects AX07 (top panel) and AX08 (bottom panel). Black boxes indicate the SPURS-1 period/region.

(b) Dong et al., (2015b): Altimetry-derived synthetic temperature and salinity profiles between 20°S and 34.5°S are used to estimate the Meridional Overturning Circulation (MOC) and meridional heat transport (MHT), which are assessed against estimates obtained from expendable bathythermograph (XBT) measurements. Consistent with studies from XBTs and Argo data, both the geostrophic and Ekman contributions to the MOC exhibit 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 34.5°S. The dominance of the geostrophic and Ekman components on the interannual variations in the MOC and MHT varies with time and latitude (Figure 10), with the geostrophic component being dominant during 1993–2006 and the Ekman component dominant between 2006 and 2011 at 34.5°S.

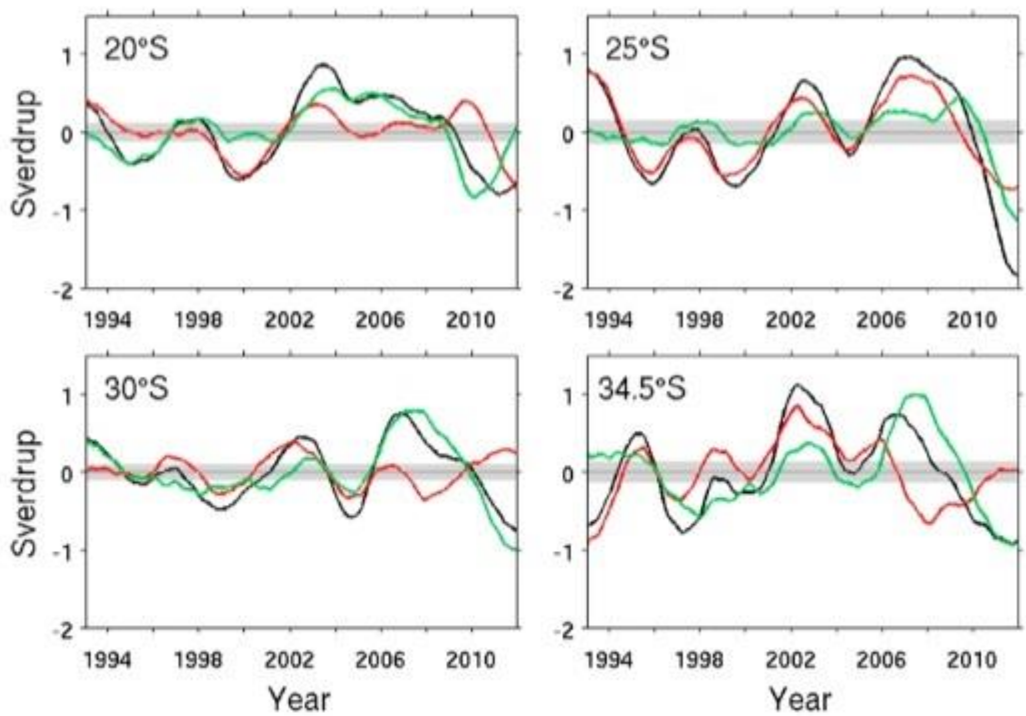

Figure 10 – Interannual variations of the MOC (black) and contributions from the geostrophic (red) and Ekman (green) components at 20°S, 25°S, 30°S, and 34.5°S, respectively. The gray shading denotes the range where anomalies are not significantly different from zero.

(c) Lopez et. al. (2016): This study presents a physical mechanism on how low-frequency variability of the South Atlantic meridional heat transport (SAMHT) may influence decadal variability of atmospheric circulation. A multicentury simulation of a coupled general circulation model is used as basis for the analysis. The highlight of the findings herein is that multidecadal variability of SAMHT plays a key role in modulating global atmospheric circulation via its influence on interhemispheric redistributions of momentum, heat, and moisture. Weaker SAMHT at 30°S produces anomalous ocean heat divergence over the South Atlantic, resulting in negative ocean heat content anomalies about 15–20 years later. This forces a thermally direct anomalous interhemispheric Hadley circulation, transporting anomalous atmospheric heat from the Northern Hemisphere (NH) to the Southern Hemisphere (SH) and moisture from the SH to the NH, thereby modulating global monsoons. Further analysis shows that anomalous atmospheric eddies transport heat northward in both hemispheres, producing eddy heat flux convergence (divergence) in the NH

(SH) around 15°–30°, reinforcing the anomalous Hadley circulation. The effect of eddies on the NH (SH) poleward of 30° depicts heat flux divergence (convergence), which must be balanced by sinking (rising) motion, consistent with a poleward (equatorward) displacement of the jet stream. A schematic diagram showing the mechanism uncovered by this study is shown in Figure 11. This study illustrates that decadal variations of SAMHT could modulate the strength of global monsoons with 15–20 years of lead time, suggesting that SAMHT is a potential predictor of global monsoon variability. A similar mechanistic link exists between the North Atlantic meridional heat transport (NAMHT) at 30°N and global monsoons.

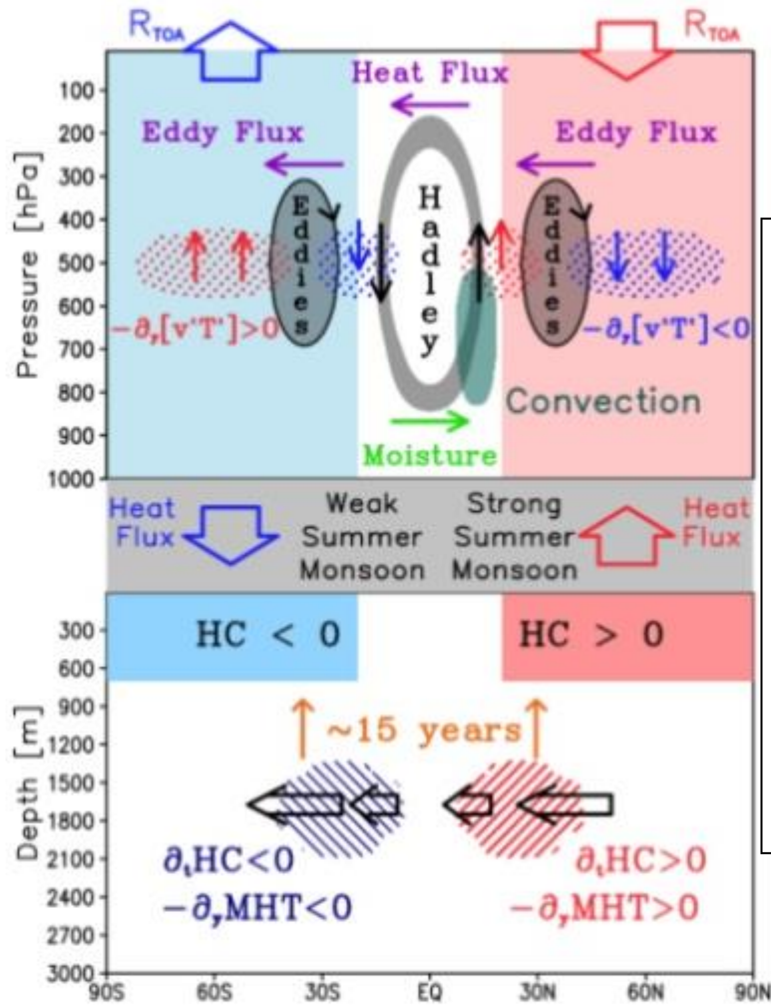

Figure 11 – Schematic diagram of the role of weaker-than-normal MHT in the anomalous atmospheric circulation at 15-20 years lead-time. Weakened MHT is shown by thick lack arrows on the bottom panel. Negative (positive) tendency in heat content is labeled by dark-blue (red) hatching. There is negative (positive) heat content in the SH (NH) about 15-20 years after the heat transport anomaly labeled here by blue (red) rectangle. Anomalous Hadley circulation is labeled by gray oval a counterclockwise circulation. Moisture and heat fluxes are shown by green and purple arrows, respectively. The TOA and surface radiative fluxes are shown by thick red and blue arrows. Purple arrows depict atmospheric eddy heat transports. Eddy forced vertical motion is shown by red and blue stipples.

(d) Lima et al. (2016): This study assesses the structure and variability of the BC across the nominal latitude of 22ºS using data from the high density XBT AX97 transect and from three numerical ocean models with data assimilation (HYCOM-NCODA, GLORYS2V3 and FOAM). These Ocean Forecasting and Analysis Systems (OFAS) are able to capture the mean observed features in the 22°S region, showing a BC core confined to the west of 39°W and an Intermediate Western Boundary Current between the depths of 200 and 800 m (Figure 12). However, the OFAS tend to overestimate the mean BC geostrophic baroclinic volume transport across the AX97 reference transect, and underestimate its variability. The OFAS show that the coastal region between the coastline and the western edge of the AX97 transect plays an important role in the mean BC total

transport, contributing to up to 30% of its value, and further confirming that this transport is not sampled by the XBT data. In order to understand the variability of the BC, a statistical classification of the BC is proposed, with the creation of three different scenarios.

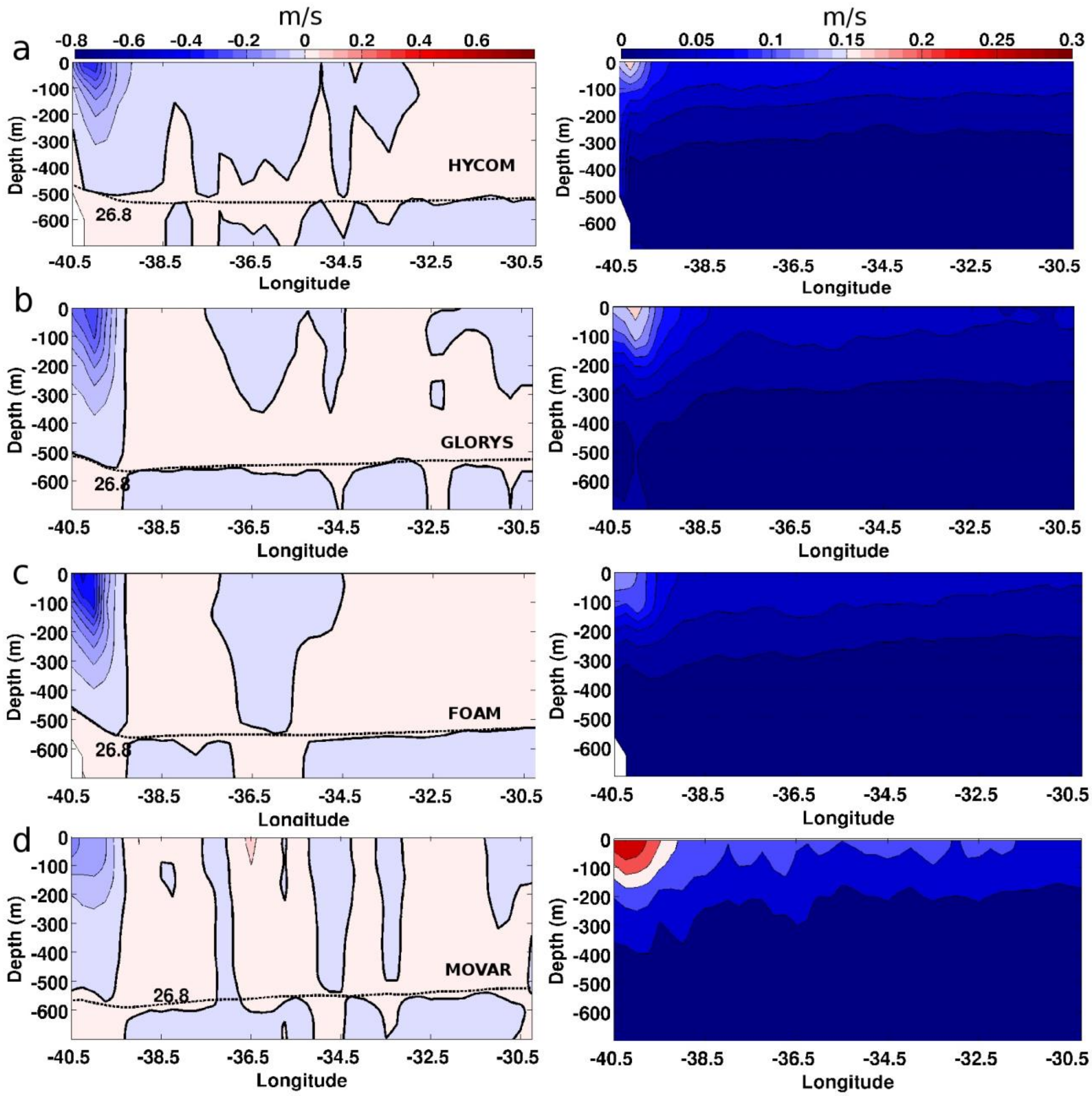

Figure 12 - Mean cross-sectional component of the baroclinic velocity (left panels) and associated standard deviation (right panels) for the OFAS and MOVAR at the AX97 reference transect for the whole period (2004-2012). The OFAS are represented in the vertical panel panels from top to bottom in the following sequence: (a) HYCOM (b) GLORYS and (c) FOAM. (d) Same distribution for MOVAR during the cruise periods. Units are in m/s, with negative (positive) values indicating a southward (northward) flow. A solid bold line represents the zero contour of the velocity. The reference level of no motion is the σ_θ = 26.8 kg/m3. A black dashed line in the left panels represents the mean depth of this isopycnal, for each data.

(e) Bringas et al. (2015): Expendable bathythermographs (XBTs) are probes widely used to monitor global ocean heat content, variability of ocean currents, and meridional heat transports. In the XBT temperature profile, the depth is estimated from the time of descent in the water using a fall-rate equation. There are two main errors in these profiles: temperature and depth errors. The reduction of error in the estimates of the depth allows a corresponding reduction in the errors in the computations in which XBTs are used. Two experiments were carried out to study the effect of the deployment height on the depth estimates of Deep Blue XBT probes. During these experiments, XBTs were deployed from different heights. The motion of the probes after entering the water was analyzed to determine the position and the velocity of the probes as a function of time, which was compared to that obtained using the Hanawa et al. fall-rate equation. Results showed a difference or offset between the experimentally observed depths and those derived from Hanawa et al. This offset was found to be linked to the deployment height. To eliminate the offset in the fall-rate equation for XBTs deployed from different heights, a methodology is proposed here based on the initial velocities of the probes in the water (or deployment height). Results indicate that the depth estimates in the profiles need to be corrected for an offset, which in addition to having a launch height dependence is time dependent during the first 1.5 s of descent of the probe in the water, and constant after that.

(f) Cheng et al., (2015): Recommendations for correcting biases in XBT data, and the impact on applications and ongoing research to improve the quality of future XBT data are provided. eXpendable BathyThermograph (XBT) data were the major component of the ocean temperature profile observations from the late 1960s through early 2000s, and XBTs still continue to provide critical data to monitor surface and subsurface currents, meridional heat transport, and ocean heat content. Systematic errors have been identified in the XBT data, some of which originate from computing the depth in the profile using a theoretically- and experimentally derived fall rate equation (FRE). After in-depth studies of these biases and discussions held in several workshops dedicated to discuss XBT biases, the XBT science community met at the Fourth XBT Science Workshop and concluded that XBT biases consist of: 1) errors in depth values due to the inadequacy of the probe motion description done by standard FRE, and 2) independent pure temperature biases. The depth error and temperature bias are temperature dependent and may depend on the data acquisition and recording system. In addition, the depth bias also includes an offset term. Some biases affecting the XBT-derived temperature profiles vary with manufacturer/probe type and have been shown to have a time dependence. Best practices for historical XBT data corrections, recommendations for future collection of metadata to accompany XBT data, impact of XBT biases on scientific applications, and challenges encountered are presented in this manuscript. Analysis of XBT data shows that, despite the existence of these biases, historical XBT data without bias corrections are still suitable for many scientific applications, and that bias corrected data can be used for climate research.

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.

Aquarius Reef Base Maintenance and Monitoring

Project Personnel: J.W. Fourqurean, T.A. Potts and M.R. Heithaus (FIU)

Long Term Research Objectives and Strategy to Achieve Them:

Objectives: To continue supporting maintenance and monitoring of the Aquarius undersea laboratory and provide stewardship of NOAA-owned Aquarius related equipment while developing a new business model that will support marine ecosystem research, coral reef and ocean observations, advanced undersea technology testing, diver training, education and outreach missions.

Strategy: To transition personnel, assets and operating protocols from UNCW and reinvest in a new shore base of operation to allow successful completion of the 2013 American Bureau of Shipping annual survey and to limit corrosion and similar damage in line with historical trends of the NOAA-owned facility. Concurrently, to develop a stable business model that relies on users to pay the expenses associated with research, teaching and training activities at Aquarius Reef Base.

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 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/OER
NOAA Technical Contact: Karen Kohanowich

Research Summary:

In FY2013, FIU received two awards in the amount of $600,000 and $500,086. Funds were used to actively maintain the Aquarius habitat and related systems in accordance with Planned Maintenance System Requirements in order to meet standards for annual American Bureau of Shipping certification.

To meet the stewardship mandate, FIU transitioned personnel, assets and protocols from the program's prior host institution, the University of North Carolina Wilmington. This included hiring necessary staff to complete maintenance tasks, revising the FIU Diving Operations Manual and updating the Aquarius Habitat Operations and Procedures Manual for saturation diving.

FIU invested in a new, commercially zoned shore facility in Islamorada, Florida to provide a staging location for offshore operations. This facility includes deep-water dockage for five university vessels, workshops for dive equipment maintenance, staff offices, training conference room, telemetered command center for Aquarius saturation diving, and a media production area for facilitating live broadcasts.

FIU also implemented a new business model that relies upon external funding to cover operating costs in support of marine ecosystem science projects and extreme environment training operations. This business model consists of user-levied day rates, grants and sponsorships. To date, 22 projects were conducted or will be completed by the end of 2016 (Table 1). Planning efforts with customers from academia,

government, industry and the private sector with projects consistent with the CIMAS research themes are currently ongoing.

Figure 1: FIU Aquarius undersea laboratory.

Table 1: Missions conducted at Aquarius Reef Base: 2013-2016

Year	Title	PI Institution
2013	Sponges on Florida coral reefs: Anthropogenic changes	UNCW
	Optical methods for monitoring coral health	UCSD
	Sea Test II (NEEMO 17)	NASA
	Predation and herbivory in coral reef environments	FIU
2014	Sponges on Florida coral reefs: Anthropogenic changes	UNCW
	Human Universe	BBC
	Catlin Seaview Surveys of Conch Reef and Upper Keys reefs	Catlin
	Mission 31	Bonnet Rouge
	NEEMO 18	NASA
	NEEMO 19	NASA
	SRDD-1 – Saturation dive training	USN
	SRDD-2 – Saturation dive training	USN
2015	Sponges on Florida coral reefs: Anthropogenic changes	UNCW
	Impacts of sharks on coral reef ecosystems	FIU
	NEEMO-20	NASA
	SRDD-1 – Saturation dive training	USN
	SRDD-2 – Saturation dive training	USN
2016	Sponges on Florida coral reefs: Anthropogenic changes	UNCW
	SRDD-1 – Saturation dive training	USN
	SRDD-2 – Saturation dive training	USN
	NEEMO-21	NASA
	Impacts of sharks on coral reef ecosystems	FIU

Figure 2: NASA astronauts use a Deep Worker submersible as part of the NASA Extreme Environment Operations Mission.

Figure 3: FIU scientists use a Pulsed Amplitude Modulation fluorometer to measure photosynthetic efficiency of corals during Mission 31.

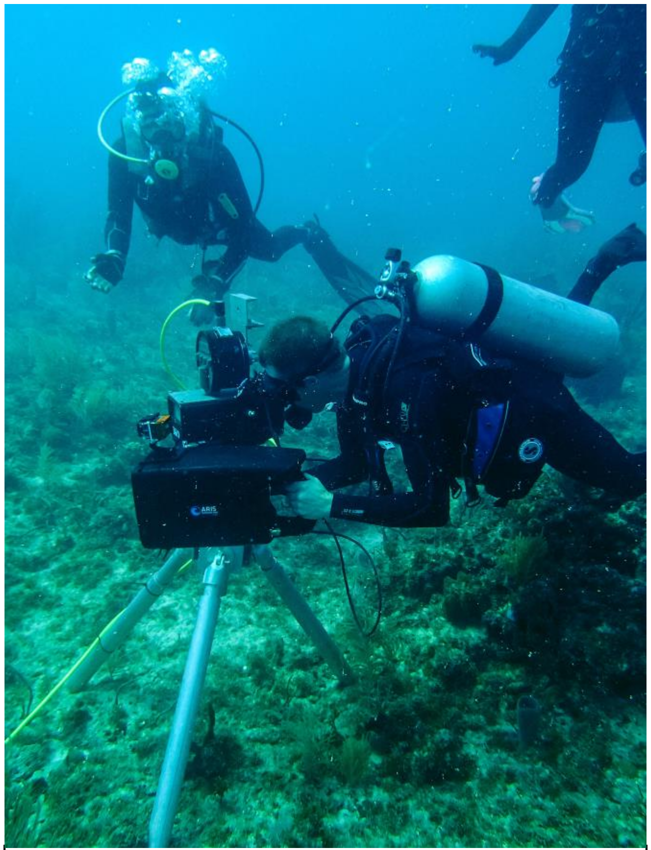

Figure 5: FIU students conduct a mid-mission Skype virtual field trip aboard Aquarius with elementary school students in Pennsylvania.

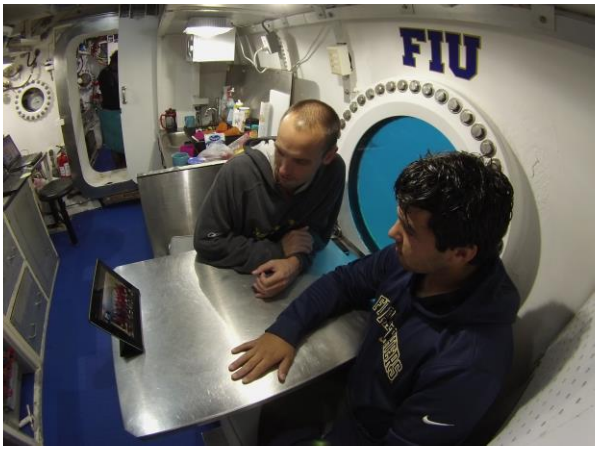

Figure 4: FIU researchers set up sonar during "Impacts of sharks on coral reef ecosystems" mission.

Research Performance Measure: The project successfully met the original objectives for safety, compliance and use of Federal assets. Currently, all assets of the program (boats, the LSB, and the habitat) are being maintained to specifications as outlined in the approved Planned Maintenance System Requirements

Florida Area Coastal Environment (FACE) Program

Project Personnel: M. Gidley, I. Enoch and P. Jones (UM/CIMAS)

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

Long Term Research Objectives & 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* (*Primary*)

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

NOAA Funding Unit: OAR and CRCP

NOAA Technical Contact: Craig McLean

Research Summary:

The FACE/NNC 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. Last year, we initiated a project with the Florida Department of Environmental Protection to develop numeric nutrient criteria for the coastal ocean. The project included 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 were conducted in conjunction with parallel coral reef survey cruises conducted by Dr. Paul Jones and Dr. Ian Enochs also at CIMAS/AOML. Some 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 redundancy analysis plot showing relationships between environmental parameters and community structure. Figure 3 is a heatmap plot showing relationships of bacterial and fungal community composition to source communities. Figure 4 shows ADCP results for all twelve cruises from the deep-water current profiler. Figure 5 is a comparison of health vs. bleached coral species at four sample sites. This project concluded in November 2015.

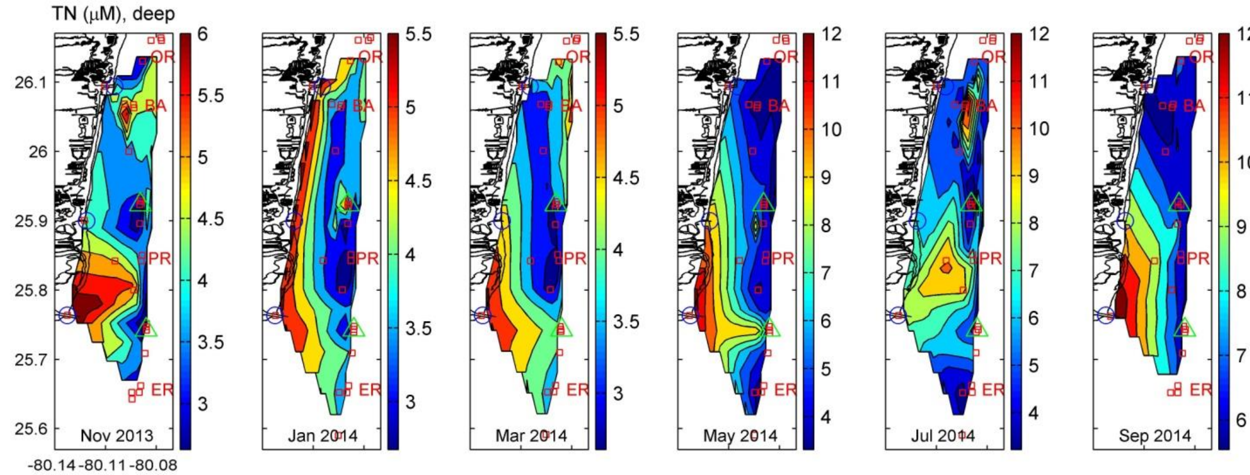

Figure 1: Contour plots of total nitrogen (TN) from near-bottom water samples obtained during six cruises from November 2013 through September 2014. Note evidence of plume from the Port of Miami inlet. Sample sites are denoted by red squares, treated-wastewater outfalls (Miami-North and Miami-Central)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

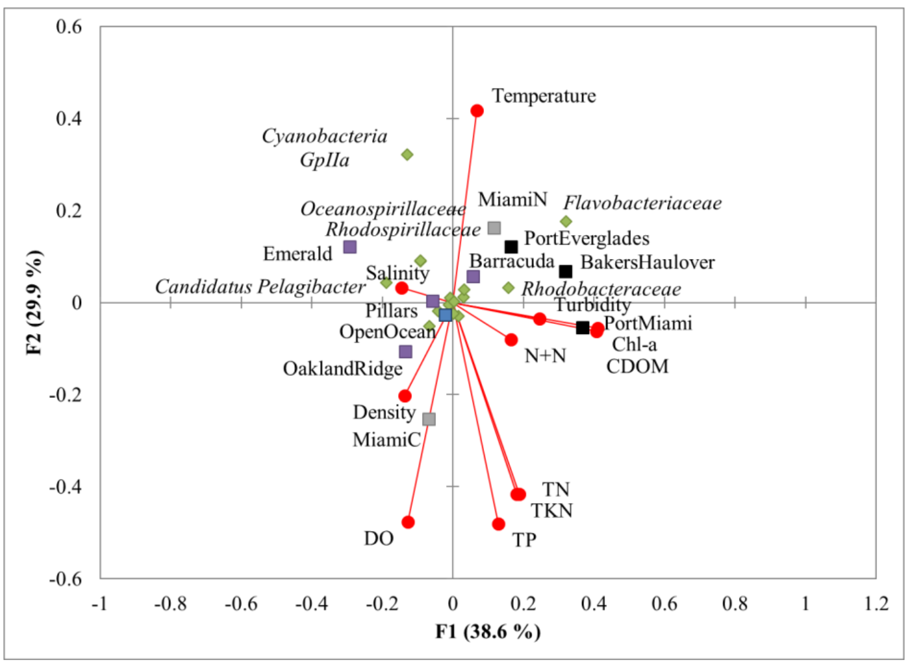

Figure 2: Redundancy Analysis Plot for samples collecting during a FACE NNC cruise relating physicochemical parameters, sample site locations, and distributions of the 15 most abundant bacterial families among water samples. For clarity, families that clustered around the origin are not shown. Colors denote sample type: purple – reef water; blue – open ocean; black – inlets; gray – outfalls. Redundancy analysis revealed that the majority of abundant families were poorly related to physicochemical parameters. Coral tissue samples were more strongly associated with increased abundances of *Bacillaceae* and *Hahellaceae* while inlet samples were associated with greater abundances of *Flavobacteriaceae* and *Rhodobacteraceae*. Abundances of *Cyanobacteria* group II were also associated with reef water samples. Little separation was observed between open ocean and outfall samples, which

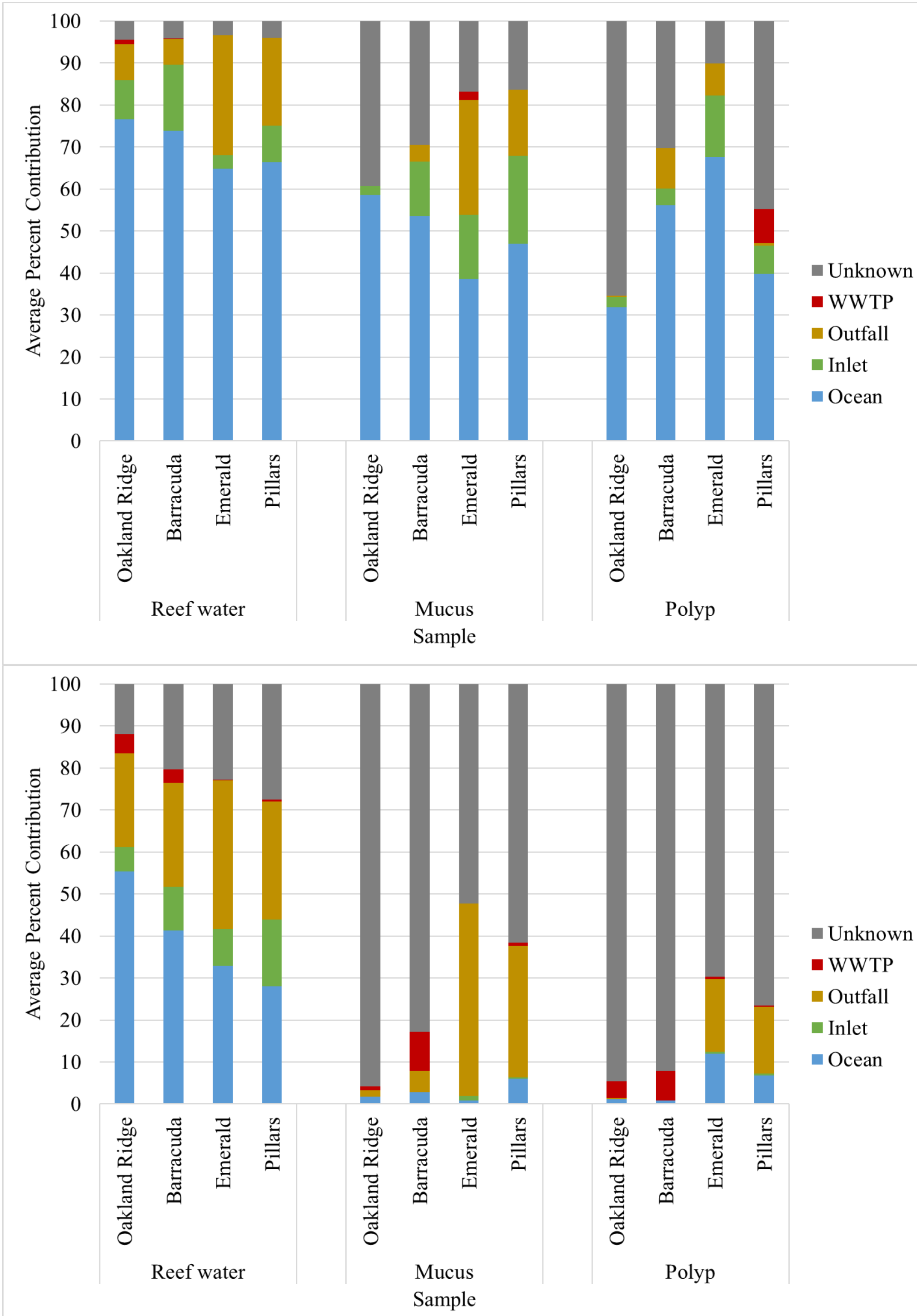

Figure 3: Heat Map Plot showing percent of (Top) bacterial community composition and (Bottom) fungal community composition attributable to specific source communities as determined by SourceTracker software. Among Land-Based Sources of Pollution (LBSP), outfall communities had the greatest influence on community composition among reef water and mucus samples, followed by communities from inlet sample.

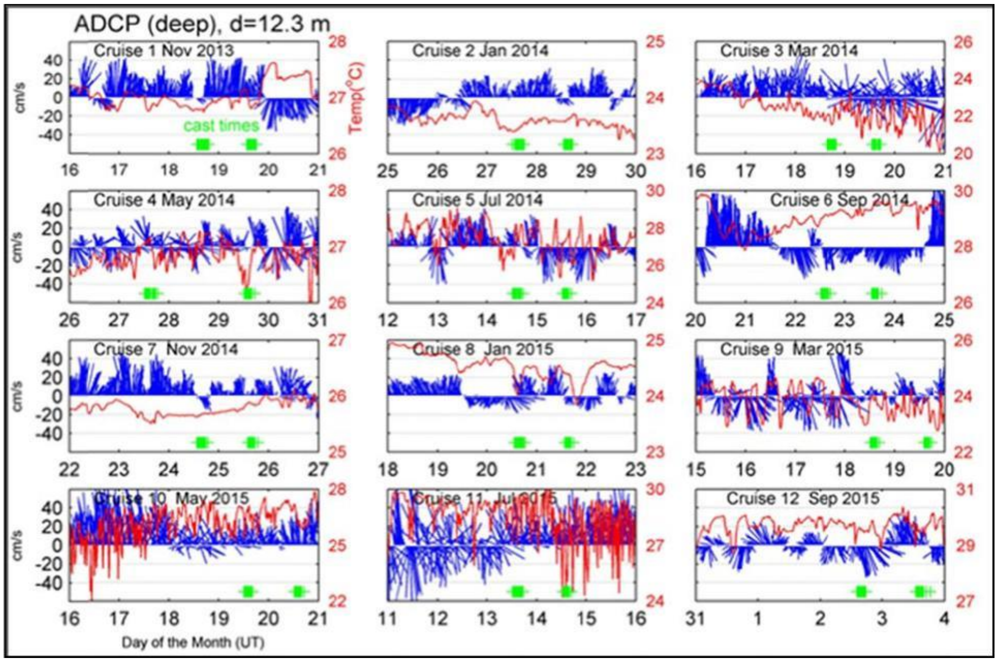

Figure 4: Ocean current and direction measurements from the deep-water ADCP for the twelve cruises. Current direction (oceanographic convention) is indicated by the angle of the blue stick (north is up); current velocity is denoted by the length of the stick as denoted by left vertical axis. The ADCP temperature is given by the red line and is denoted by the right axis. Cruise cast time are shown by the green '+' signs. All times are UT.

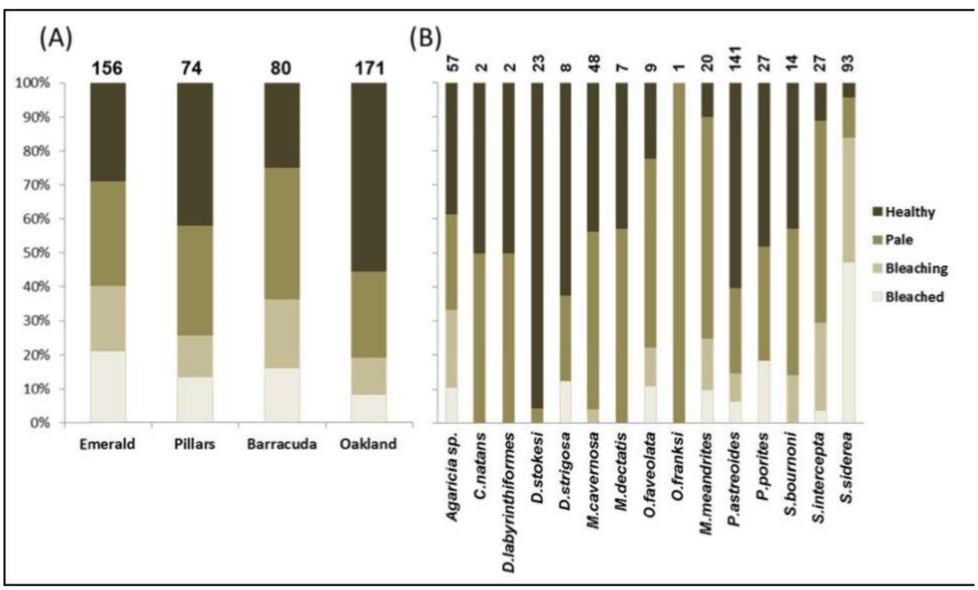

Figure 5: The distribution of healthy, pale, bleaching and bleached corals surveyed in September 2014, displayed as a percentage of (A) the total number of colonies surveyed at each reef, and (B) the total number of colonies of each particular species. Numbers at the top of the bars refer to the N of each category. For the categories of bleaching severity: "Healthy" refers to colonies displaying no change in usual pigmentation; "Pale" colonies exhibited a lower than usual color intensity; "Bleaching" colonies had very pale to almost colorless tissue; "Bleached" colonies had clear/colorless tissue.

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 final reports have been 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).

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Quantifying the Contribution of Upwelling to LBSP on SE Florida Reefs by Sub-Watershed (NSU Contribution)

Project Personnel: A.V. Soloviev (NSU); L. Gramer (UM/CIMAS)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To quantify the long-term 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 produced 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:

During the first year of the project, we provided a data report and data, which represented an approximately 14-year data set collected from multiple ADCP moorings. The first year report discussed data from bottom mounted ADCP at an 11-m isobath on the Dania Beach shelf which had an approximately 14-year record. In the first year report, we also discussed a four-year data set collected from a subsurface ADCP mooring located at a 244-m isobath and an Acoustic Wave and Current Profiler (AWAC) system. The AWAC system was used to collect data off the Dania Beach shelf at the 11-m isobath for approximately two months. The data from all three moorings were preliminarily processed 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.

Negative values for cross shelf velocity associated with upwelling events were observed during hurricane events. Analysis of several hurricanes, conducted in collaboration with Dr. Lew Gramer, revealed temperature drops of greater than 2°C near shore, due to associated upwelling events.

Most of the work was accomplished during Year 1. A no cost extension for Year 2 was arranged in order to publish the data and technical report (Soloviev et al. 2015) on the *NOAA Coral Reef Information System (CoRIS) Geoportal* (http://data.nodc.noaa.gov/coris/library/NOAA/CRCP/project/789/CRCP_789_Product_1435_NSUOC_data_report.pdf). During Year 2, we also analyzed observations of southward flow on the coastal western flank of the Florida Current (Fig. 1). The analysis has resulted in the manuscript of a paper Soloviev et al. (2016), which is now under review in Deep-Sea Research.

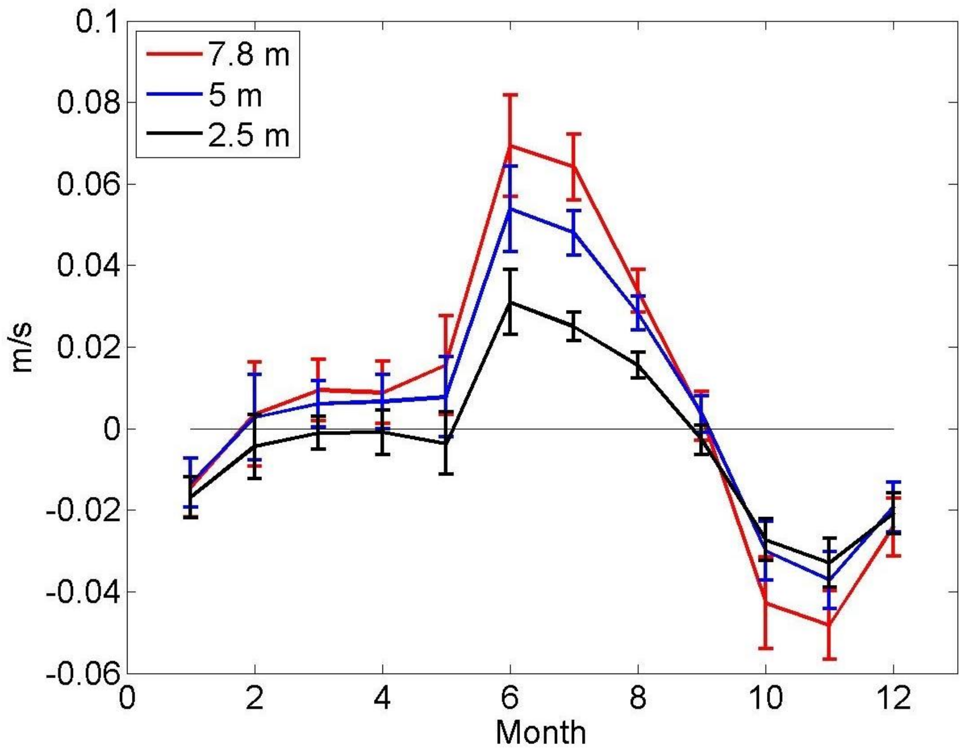

Figure 1. Seasonality of the northward current velocity component at the 11-m isobath mooring (26.073°N, 80.101°W): Monthly mean current climatology produced by averaging over thirteen years of data with 68% confidence intervals. In the calculation of error bars, we assumed that monthly averages from each year were statistically independent. In the legend 7.8 m, 5 m, and 2.5 m refer to height above the bottom. (Sloviev et al., submitted to DSR.)

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 on the NOAA Coral Reef Information System (CoRIS) Geoportal. We collaborated with Dr. Lew Gramer to validate analysis of in situ records for ocean currents and available temperature measurements. Based on the data presented in the technical report, we analyzed mechanisms, frequency, and inshore circulation directly or indirectly associated with upwelling events on the Southeast Florida shelf. A related paper titled "Southward Flow on the Western Flank of the Florida Current" has been submitted to Deep-Sea Research by A.V, Soloviev, A. Hirons, C. Maingot, C.W. Dean, R. E. Dodge, A.E. Yankovsky, J. Wood, R. H. Weisberg, M.E. Luther, and J.P. McCreary.

Investigation of the Movement of Adult Billfish in Potential Spawning Areas

Project Personnel: J. Hoolihan (UM/CIMAS); J. Luo (UM/RSMAS)
NOAA Collaborators: C. Brown and E. 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 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 analyzed data garnered from pop-up satellite archival tags (PSATs) to understand behavior and movement of large pelagic predators PSATs use light-based geolocation methods to estimate movement tracks of tagged fish. There are inherent restrictions to this method that limit accuracy to around 60 nm. Latitudinal points are particularly difficult to determine. Further processing using Kalman, bathymetric, and sea-surface temperature (SST) filtering improves track estimates. One problem with estimating tracks in tropical areas is that SST is often uniform across large areas, reducing its usefulness as a filtering tool. To address this, we used ocean heat content (OHC), a habitat metric that is a fundamental part of hurricane intensity forecasting. Combining PSAT data with OHC in an optimization framework substantially improved geoloca-

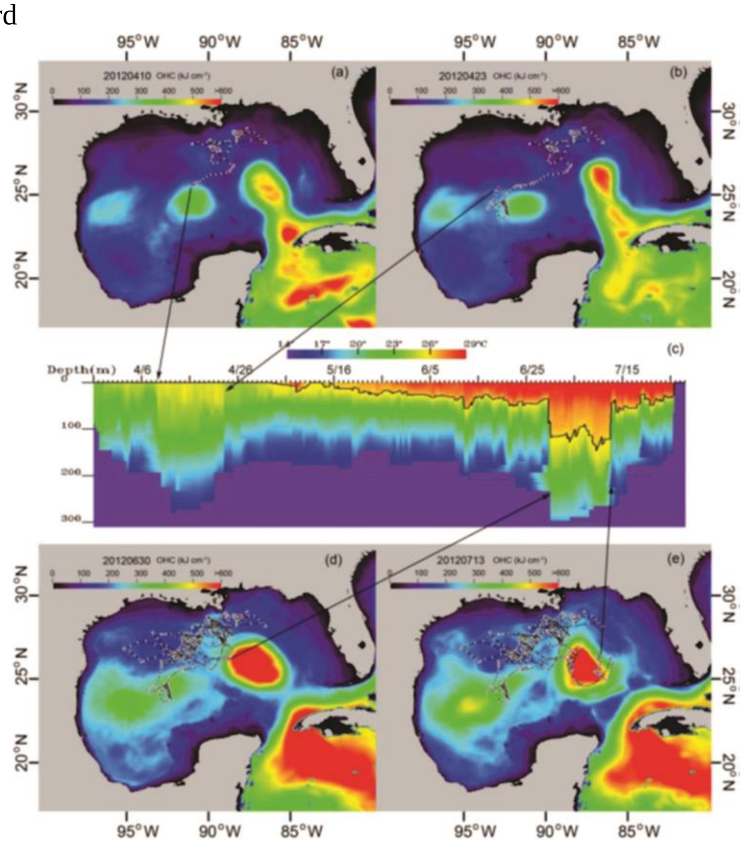

Figure 1: OHC refined movement track of a yellowfin tuna in the Gulf of Mexico. (a) Track position overlain on the OHC map for April 10, 2012. (b) Track position overlain on the OHC map for April 23. (c) PDT from the tagged yellowfin tuna. (d) Track positions overlain on OHC map for June 30. (e) Track positions overlain on OHC map for July 13. Reprinted from PLOS ONE| DOI: 10.1371/journal.pone.0141101 October 20, 2015.

tion estimates previously based on SST (Luo et al., 2015); and, provided the first quantitative evidence showing many of our PSAT monitored fishes associating with ocean fronts and eddies (Figure 1).

In 2016, a study was undertaken to determine the maximum size and longevity attained by blue marlin *makaira nigicans*. Blue marlins are large, long-lived, vagile, predatory billfish inhabiting tropical and subtropical waters worldwide. They represent an economically important recreational fishery, and are overexploited as bycatch by commercial longline fleets targeting swordfish and tunas (Anon. 2011). The most recent assessment results reported by the International Commission for the Conservation of Atlantic Tunas (ICCAT) indicates the Atlantic blue marlin stock is below B_{MSY} and that fishing mortality is above F_{MSY} (Anon. 2011). Improved stock assessment methods are needed to ensure the conservation of this species. Accurate estimates of population age-structure and fish growth rates are fundamental for advanced stock assessment methods. These estimates have typically been difficult to attain for billfishes due small sample sizes, lack of very young and very old individuals, and problems associated with interpreting growth annuli present in hard parts.

We have at our disposal high resolution photomicrographs of anal fin spine cross sections from Atlantic blue marlin (n = 1620) gathered from Venezuelan fisheries. Further, an additional 64 samples that require sectioning and imaging are available at the Southeast Fisheries Science Center (SEFSC) Miami lab. Within these collections are over 20 very large individuals ranging from about 800 to 1300 lbs. whole weight. In total, this sample set represents an unprecedented number from which to estimate growth rates, maximum size and longevity. Capture location, sex, and lower jaw-fork length are known for nearly all these fish. We are currently in the process of evaluating and assigning age estimations to these samples (Figure 2).

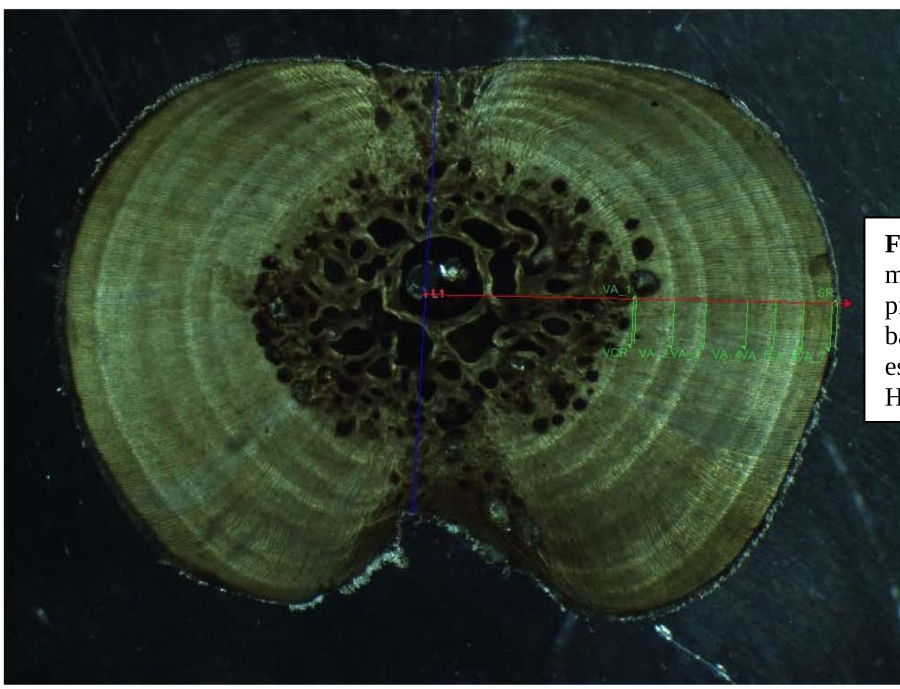

Figure 2: Cross section of blue marlin anal fin spine showing presumptive annual growth bands used for age and growth estimations (*photo by* J. Hoolihan).

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) Many joint authored (NOAA/RSMAS) peer review papers have resulted over the last few years. Those from 2015-2016 are listed in the Publications section of this report. Others can be accessed at:
http://www.sefsc.noaa.gov/fisheriesbiology.jsp

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

NOAA Funding Unit: NOAA/NESDIS
NOAA Technical Contact: Menghua Wang

Research Summary:

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

- Collected water samples to determine chlorophyll *a* concentrations, CDOM absorption, and particle absorptions. These data have been and will be used to evaluate VIIRS performance in coastal waters.
- Participated in the cruise survey onboard the NOAA ship Nancy Foster to collect bio-optical data in the South Atlantic Bight and Bahamas in December 2015. 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.
- Attended NOAA JPSS/VIIRS team meeting in August 2015 and reported progress.
- Evaluated performance of SeaWiFS, MODIS, and VIIRS performance as a function of viewing angle. In general, cross-sensor discrepency increases when viewing angle from one of the sensors exceedes 50 degrees (Barnes and Hu, 2016).
- Developed and validated a new algorithm to detect and quantify a harmful algal bloom in CDOM-rich waters using VIIRS measurements in the absence of a fluorescence band (Qi et al., 2015). The approach was originally developed for Tampa Bay, but it was found applicable in coastal waters off Suwannee estuary where CDOM is very high and traditional blue/green band ratio algorithms are not applicable. The red/green band ratio avoids the interference of CDOM to first order, and therefore shows much improved performance for VIIRS.
- We also devoted efforts to work on oil spills using VIIRS. Wang and Hu (2015) developed a technique to delineate oil slicks from noisy VIIRS imagery by combining image filters and morphology operators. Sun and Hu (2016) compared hundreds of VIIRS and MODIS images collected over the same locations within 2-3 hours, and determined the sun glint threshold required to observe thin oil films in both VIIRS and MODIS imagery. Fig. 1 shows two pairs of examples where in one case oil slicks are detected by VIIRS but not by MODIS, and in the other case oil slicks are detected by MODIS but not by VIIRS. Such a discrepancy is due to the sun glint strength on different images, a result of different solar/viewing geometry. From statistics of hundreds of image pairs, the sun glint strength required to

observe thin oil slicks has been determined to be > 10^{-6} sr^{-1} for VIIRS and > 10^{-5} sr^{-1} for MODIS. VIIRS imaging bands tend to be more sensitive in detecting oil slicks than MODIS imaging bands.

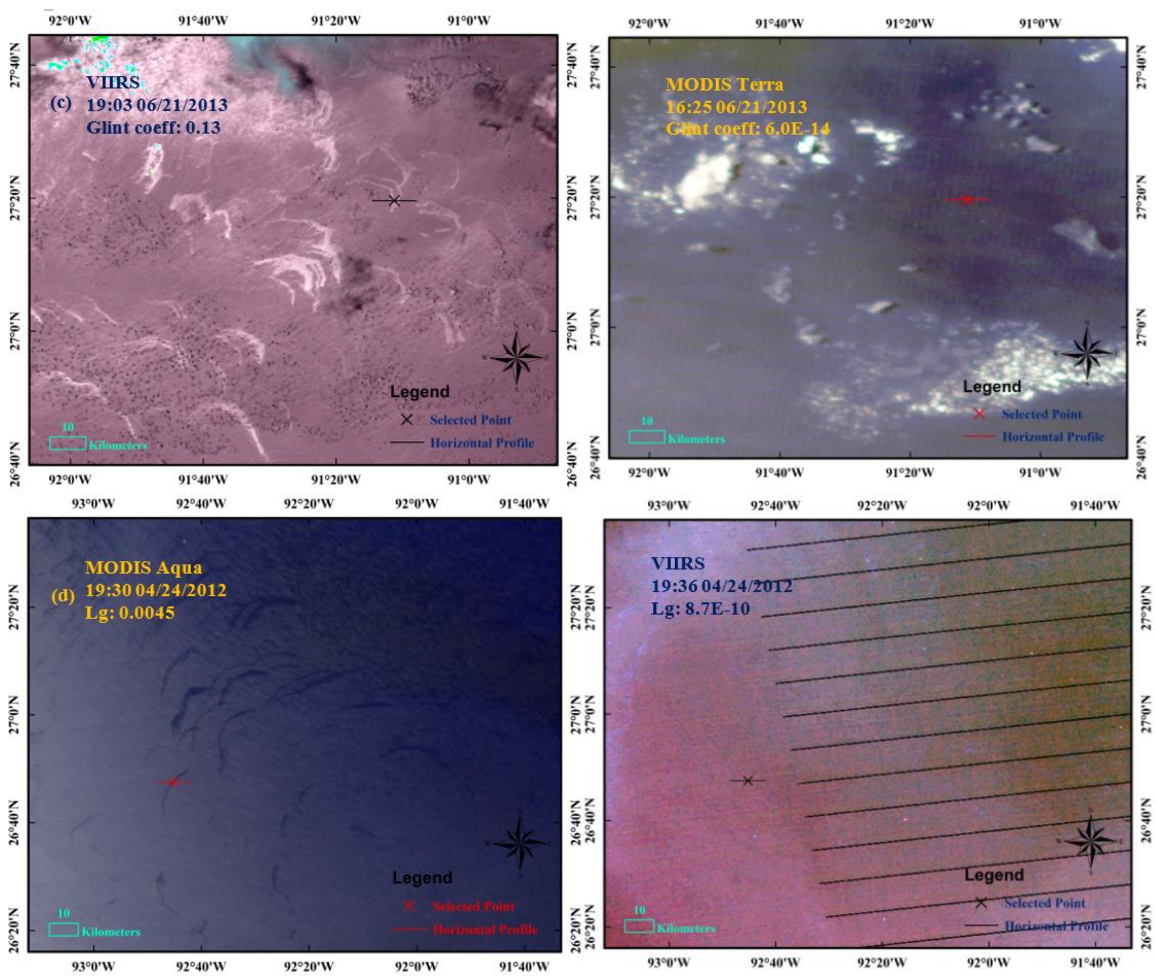

Figure 1: Surface oil slicks detected by VIIRS and MODIS. Top: detected by VIIRS but not by MODIS on the same day; Bottom: detected by MODIS but not by VIIRS on the same day. The key parameter to determine the detectability is sun glint strength. Figure from Sun and Hu (2016).

Research Performance Measure: The accomplishments have met the original objectives.

Biogeochemical Measurements

Project Personnel: C. Langdon (UM/RSMAS), G. Berberian (UM/CIMAS)
NOAA Collaborators: M. Baringer (NOAA/AOML)

Long Term Research Objectives and Strategy to Achieve Them:

***Objective*:** To determine the changing oxygen content of the global ocean and to use the change in oxygen to constrain the changes in CO_2 inventory due to formation and breakdown of organic matter so as to obtain the changes due to anthropogenic factors by difference.

***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*

NOAA Funding Unit: CPO/COD
NOAA Technical Contact: Kathy Tedsco

Research Summary:

The Biogeochemical Measurements project funds my involvement (dissolved oxygen) in the Global Ocean Ship-based Hydrographic Investigation Program (GO-SHIP). The objective is to re-occupy select hydrographic sections to quantify change storage and transport of heat, fresh water, carbon dioxide, oxygen nutrients, chlorofluorocarbon tracers and related parameters. The program began in 2003. In 2015 the Pacific meridional P16N section from 20°S to 56°N was completed in full.

One of the main objectives of the program is to determine where and how much excess atmospheric CO_2 is entering the ocean on decadal time scales. Key to achieving this objective is assessing changes in the ocean's biogeochemical cycle that also impact the CO_2 inventory. The uptake of excess CO_2 by the ocean is the total observed change in CO_2 inventory plus/minus changes due to formation/breakdown of organic matter estimated from changes in oxygen, NO_3 and PO_4.

During FY-2015 we completed a meridional section in the Pacific from 20°S to 56°N of over 200 water column profiles. My group performed a total of 5,400 high precision oxygen measurements. Figure 1 shows how the apparent oxygen utilization (AOU) of the central Pacific along the 152W section has changed over the period 2006 to 2015. Shown in green are areas where oxygen content has shown little change and conditions are still healthy for marine life. Areas in green and yellow have experienced an increase in AOU (decrease in oxygen content) of 40-60 μmol/kg. Areas in red have experienced an AOU increase of 150 μmol/kg. Shown in blue near the equator are areas where the AOU has decreased (oxygen content has increased) in the last nine years. The oxygen levels at a density of 26.5 in the north Pacific at latitude 40-45N were previously observed to have decreased relative to 1991 (Mecking et al., 2008; Sabine et al., 2008). The data from this most recent cruise indicate that the AOU has continued to increase. 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 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.

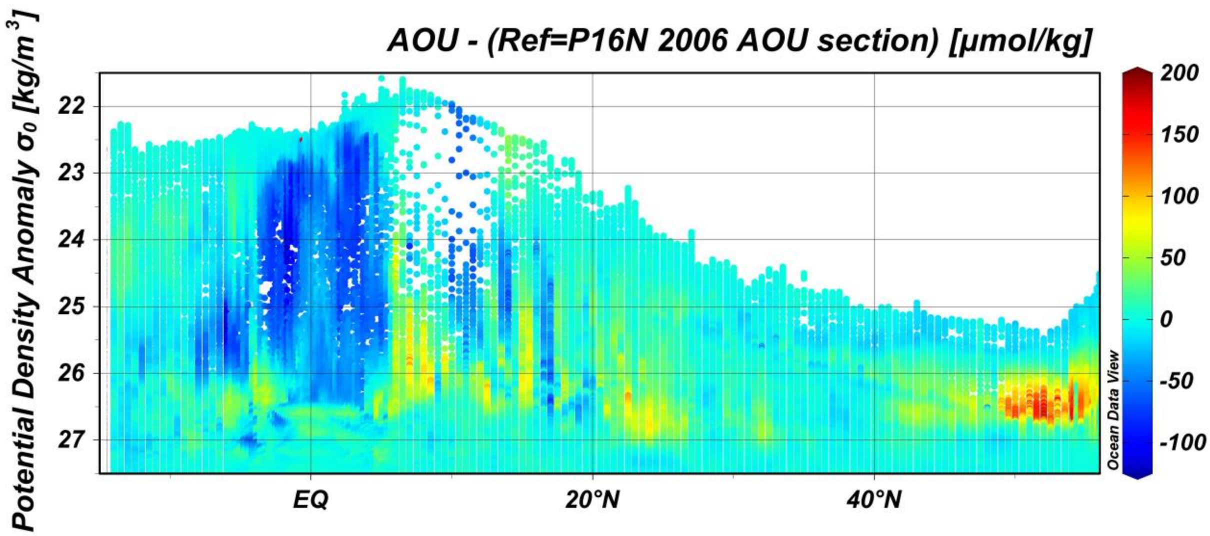

Figure 1: Section through the Pacific along 152W showing how the apparent oxygen utilization has changed dramatically between 2015 and 2006 decreasing in the equatorial Pacific and increasing the north Pacific (50-56° N).

Research Performance Measure: The repeat hydrographic sections are progressing according to the timeline provided by the GO-SHIP plan (http://www.go-ship.org). All data have been quality controlled and archived with CCHDO (http://cchdo.ucsd.edu/) within the six-months of completion of the cruise. The performance measure for FY-15 of completing the re-occupation of the P16N cruise and archiving the data was met.

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Discrete Oxygen Measurements for East Coast Ocean Acidification Center

Project Personnel: C. Langdon (UM/RSMAS)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To determine where and how much the near shore waters of the US East coast are becoming acidified both due to update of excess CO2 from the atmosphere and as the result of hypoxia caused by eutrophication.

***Strategy*:** Carry out hydrographic surveys along the east coast of the US at regular intervals (2007, 2012 and 2015).

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: OAP

NOAA Technical Contact: Libby Jewett and Dwight Gledhill

Research Summary:

The first East Coast Ocean Acidification Cruise (ECOA-1) was completed in May-June 2015. The effort was in support of the coastal monitoring and research objectives of the NOAA Ocean Acidification Program (OAP). The cruise was designed to obtain a snapshot of key carbon, physical, biogeochemical parameters and production rates as they relate to ocean acidification (OA) in the coastal realm. This was the third comprehensive occupation of the coastal waters, with the first occurring in 2007, and the second in 2012. The previous efforts were named the Gulf of Mexico and East Coast Carbon (GOMECC) cruises I and II. During each of these cruises key knowledge and data gaps were realized including: 1) a need to sample contributing Scotian Shelf and Labrador Slope waters, 2) a need to sample closer to the coast in order to better understand the effects of land fluxes on OA and 3) the need to characterize biological rate processes that affect distributions of carbonate parameters.

Our efforts are intended to complement mooring time series and other regional OA activities. The cruise included a series of transects complemented by lines laid out approximately parallel to the coast. A comprehensive set of underway measurements were taken between stations along the entire transect (Figure 1). Full water column CTD/rosette stations were occupied at 163 specified locations. A total of 15 scientists from UNH, UDEL, Princeton, ODU, and AOML/NOAA participated in the 34-day cruise, which departed from Newport, RI, on 19 June, and arrived on schedule in Miami, FL on 24 July.

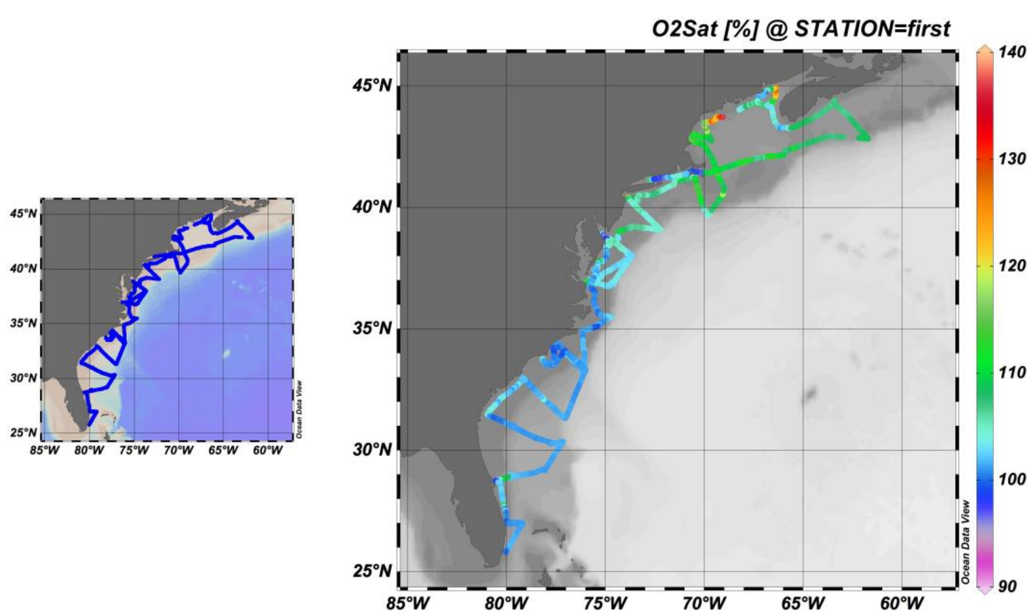

Figure 2: ECOA cruise track on the left and surface plot of percent oxygen saturation along the cruise track on the right.

A total of 1100 discrete oxygen analyses were performed. These data were used to calibrate the oxygen sensor on the CTD. An additional 125 analyses were performed on sea water drawn from the ship's uncontaminated sea water line. These data were used to calibrate a second oxygen sensor the Uni of Delaware group was using to obtain a continuous record of the surface water along the ship track. These data will be used by the UDel group to obtain an estimate of primary productivity based on the oxygen supersaturation corrected for physical effects based on Argon supersaturation.

Figure 1 shows the 2015 ECOA cruise track and a plot of how oxygen saturation varied along the track. This track repeats lines that were obtained in 2007 and 2012 during the GOMECC 1 and 2 cruises. The data do not reveal any regions of significant oxygen under-saturation that would be indicative of hypoxia related acidification at the time of the cruise. It could be that the hypoxia is only found up in the estuaries or that hypoxic conditions did not exist at the time of this cruise. We did observe high oxygen supersaturation in the Gulf of Maine and this is a consistent feature that was also observed during the 2007 and 2012 cruises indicating that these water are highly productive during the summer months.

The data from this cruise are available at http://www.aoml.noaa.gov/ocd/gcc.

Research Performance Measure: Program attained all its goals on schedule (field work completed according to plan and data archived within one year of cruise completion).

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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.

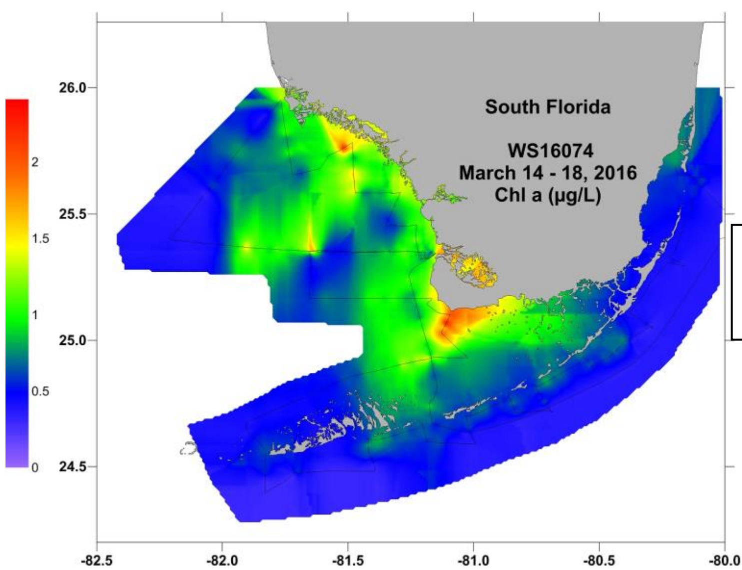

Figure 1: Chlorophyll a contour of South Florida coastal waters showing a harmful algal bloom on the northernmost transect

Research Performance Measure: All major research objectives are being met on schedule. The emphasis during this report period (1 October 2015 – 30 June 2016) has been on data collection and processing, 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.

Juvenile Sportfish Monitoring in Florida Bay, Everglades National Park

Project Personnel: L. Visser, I. Zink and T. Creed (UM/CIMAS)
NOAA Collaborators: J. Browder 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 3*:** Sustained Ocean and Coastal Observations (*Primary*)
***Theme 5*:** Ecosystem Modeling and Forecasting (*Secondary*)
***Theme 6*:** Ecosystem Management (*Tertiary*)
***Theme 7*:** Protection and Restoration of Resources (*Tertary*)

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 2015. 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 some of 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. In 2014 there were significantly less spotted seatrout collected than any other year sampled. The year 2015 had the highest recorded salinities in Florida Bay during the entire sixteen-year sampling period, and there were subsequent fish kills and seagrass die-offs in parts of Rankin and west sub-regions.

Three sub-regions showed juvenile spotted seatrout population inversely correlated with salinity, but the West did not. 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 such as seagrass percent cover and diversity. This could be in part, because the salinities in the west are more stable.

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 (Fig 1). 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.

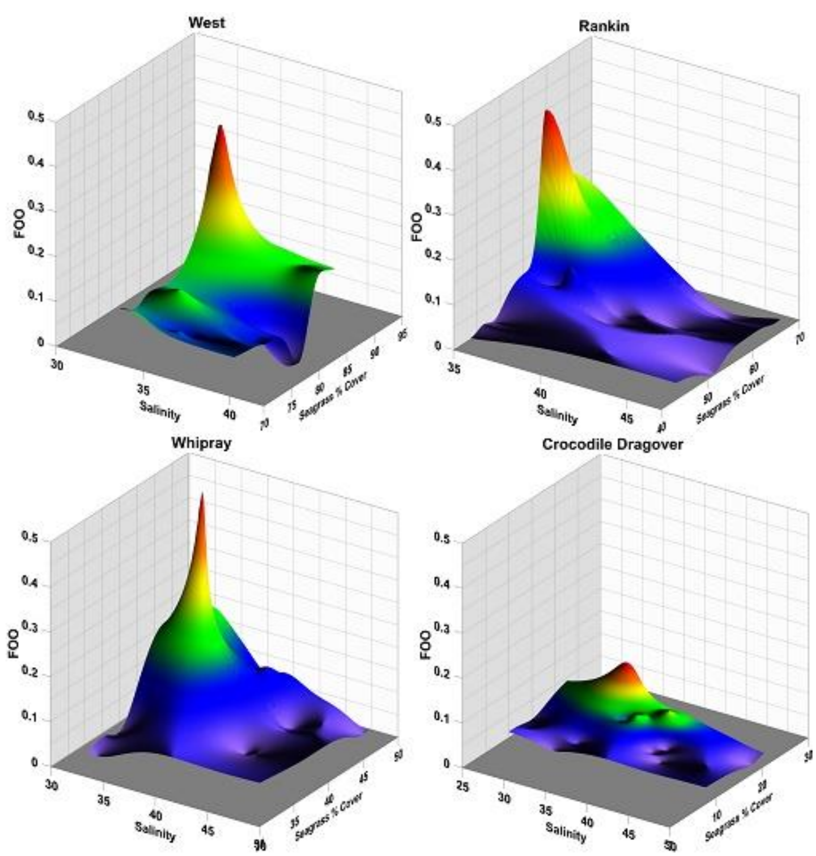

Figure 1: Contour plots depict the relationship between the juvenile spotted seatrout population, salinity, and seagrass within each sub-region of Florida Bay. Spotted seatrout occur more frequently with lower salinities and higher seagrass percent cover.

A logistic regression was employed on the data collected from 2004 to 2010 to quantify the impact of salinity and 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, the 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: 1) We have quantified a significant relationship with juvenile spotted seatrout to salinity that has allowed for the development of a testable hypothesis 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 2015 System Status Report, indicating that this project is contributing to science-based management within CERP. 2) 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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Surface Water Partial Pressure of CO_2 (pCO_2) Measurements from Ships

Project Personnel: Denis Pierrot, K. Sullivan and L. Barbero (UM/CIMAS); F.J. Millero and R.J. Woosley (UM/RSMAS)
NOAA Collaborators: R. Wanninkhof and G. Goni (NOAA/AOML)
Other Collaborators: T. Takahashi (LDEO); N. Bates (BIOS)

Long Term Research Objectives and 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 thirteen 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 and to date has sold 60 units worldwide. 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, was released in September 2015 (Fig. 1). Efforts to produce SOCAT version 4 are underway with a release in the summer of 2016.

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 ships *Equinox* and *Allure of the Seas* and the container ship *Skogafoss* have been 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.

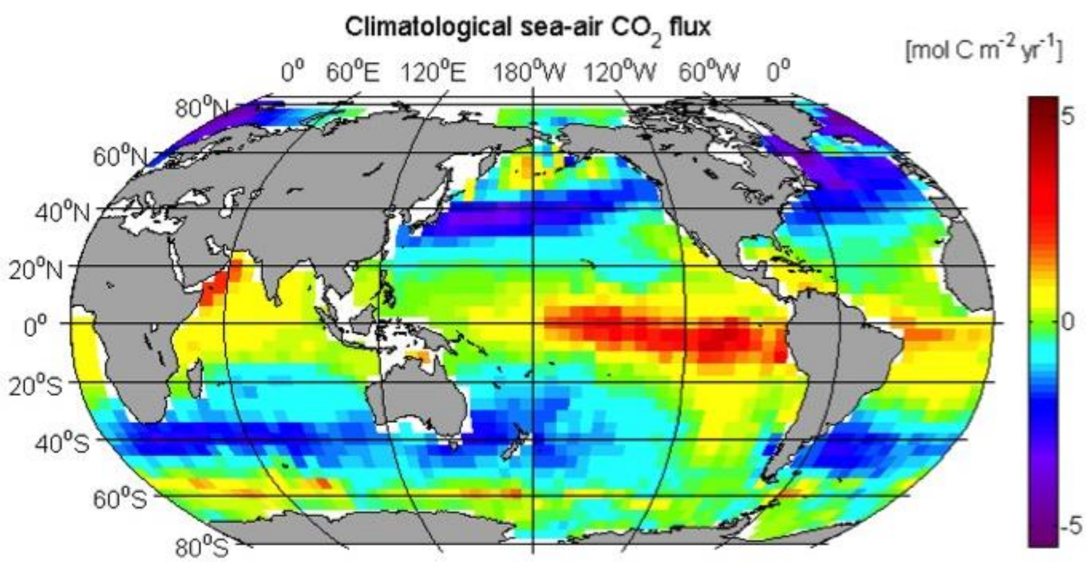


Figure 1: Climatological sea-air CO_2 fluxes (mol C / m^2 y) centered on the year 2005, computed using SOOP pCO_2 measurements and interpolated CCMP winds.

Taro Takahashi, Lamont-Doherty Earth Observatory of Columbia University (LDEO), Palisades, NY 10964:

About 9 peta-grams of carbon in the form of CO_2 are emitted annually into the atmosphere by various human activities, affecting the Earth's climate. About 2 peta-grams of carbon are absorbed annually by the global oceans, thus slowing the rapid accumulation of CO_2 in the atmosphere. The equatorial waters are major CO_2 source emitting about 0.7 Pg C/yr. This is counteracted by the two major sinks located over colder ocean regions: a 1 Pg C/yr sink centered around 40ºS in the southern hemisphere and a 0.7 Pg C/yr sink centered around 40ºN in the northern hemisphere. It is important to know how these CO_2 source and sink areas are changing in response to climate change.

The partial pressure of CO_2 (pCO_2) in seawater is a measure of chemical driving force for sea-air CO_2 gas exchange. The net sea-air CO_2 flux is governed primarily by the wind speed and pCO_2 difference between seawater and air. The primary objective for our proposed investigation is to observe and document a long-term change in ocean pCO_2 in different areas. Its seasonal change and interannual variation need to be characterized. Because of the importance of the high latitude areas as sinks for atmospheric CO_2, the Lamont field program is focused on the measurements of surface water pCO_2 in the high latitude Southern Ocean and the Arctic Ocean. Combination of the new data with our data accumulated since 1957 will yield a reliable estimate for multi-decadal mean rate of change in the oceanic CO_2 sink flux. Approximately 10 million pCO_2 measurements made to date have been assembled and archived at the Carbon Dioxide Information and Analysis Center (CDIAC), Oak Ridge, TN, for public access (Takahashi et al., 2016). The results are used to test and validate Ocean General Circulation models (OGCM) coupled with biogeochemistry models for the future prognosis for atmospheric CO_2 levels (e.g. Landschützer et al., 2015).

Nicholas Bates, Bermuda Institute of Ocean Sciences (BIOS):

The contribution of the Bermuda Institute of Ocean Sciences (BIOS) to the SOOP project has an overarching objective of supporting the measurements of seawater and atmospheric pCO_2 measurements on two vessels, the UNOLS research vessel R/V *Atlantic Explorer*, and the merchant vessel M/V *Oleander*. The primary aim of this effort is focused on improving scientific understanding of the time and spatial variability of air-sea gas exchange of CO_2 in the subtropical gyre of the North Atlantic Ocean, across the Gulf Stream and Middle Atlantic Bight (MAB) of the Eastern Seaboard, but also with research cruises to the seas north of the Caribbean (Puerto Rico, Bahamas) and occasional cruises to the U.S. continental shelf (e.g., Florida to Maryland).

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

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

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

Long Term Research Objectives & 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 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
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 float. Recently new deep profiling Argo floats, capable of diving and recording temperature and salinity down to 6000 m depth have been deployed and are now part of the Argo array.

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:
- 377 floats were deployed by the USA institutions.
- 65 of these floats were deployed jointly by AOML and CIMAS.
- 2,464 US floats actively reported data during this period.
- 83,855 profiles approximately have been distributed on Global Data Centers.
- 67,467 profiles were sent to GTS by the US DAC where 84% of them were distributed during the first 24 hours since the profiles were obtained.

Changes in the quality control/file production include:

- Improvements in producing the Real-time Profile NeCDF files, and compliance with the ARGO Users Guide v3.03. Production of NetCDF files for both Meta files and Technical files were finalized and User Manual v3.1 meta and tech files are being produced operationally.
- Development of the final element, Trajectory files, is nearing completion and is expected to be added to the operational processing in a matter of weeks. The traj files will also be v3.1.
- Preliminary addition of Bio-ARGO files for profiles (BR files), meta files (Bmeta) and trajectory files (Btraj) have been added to the main program.
- Extensive changes were made to nearly all software elements to accommodate new functions of the software as well as transition to a new computer. Efficiency gains in processing (and also in hardware capabilities) allowed us to run the operational system more frequently, and adjustments were necessary as additional runs were added.
- Netcdf Trajectory Software package was developed. It is being tested and will be moved to production soon.
- Meta and Technical Netcdf Software package is developed, tested and operational

In addition to the changes in the quality control/product in software, improvements were made in the areas of:

- A system to process incoming meta data to improve the time the new floats are introduced to the operational processing system and consequently speed the availability of their data in the distribution sites for the National Weather Service and research community.
- Implementation of numerous changes and additions, and transition to a new computer required extensive modification of the scripts that control the operational processing.
- Changes were made to improve the method used to prepare input files for the QC process.
- Modification and testing of existing programs to migrate from "ftp" to "ftps" for data transmission to the National Weather Service.
- Software was implemented to distribute real-time profiles (NetCDF 3.1 version) to the GDAC (Global Data Centers) in BUFR format via GTS (Global Telecommunications System)
- A system for archiving inactive floats data is under development.

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.
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.

Results from scientific studies that used Argo data:

Meridional volume and heat transports at four different latitudes (20S, 25S, 30S, and 35S) are estimated using Argo observations, sea surface heights, and winds in the years 2000-2015. The variability and co-variability of meridional volume and heat transports are analyzed at these latitudes and compared with that from global numerical ocean models with data assimilation. Meridional volume and heat transports correlate strongly at all the four latitudes. For every 1 Sv increase in the meridional volume transport about 0.046 PW increase in meridional heat transport is observed at 25S, 30S, and 35S. More heat about 0.056 PW is transferred further north across 20S for the same increase in the meridional volume transport. Meridional volume transport exhibits strong annual cycles both in the observations and in the models. However, the timing of

the maxima and minima and the amplitude of the annual cycles are different in the observations and models.

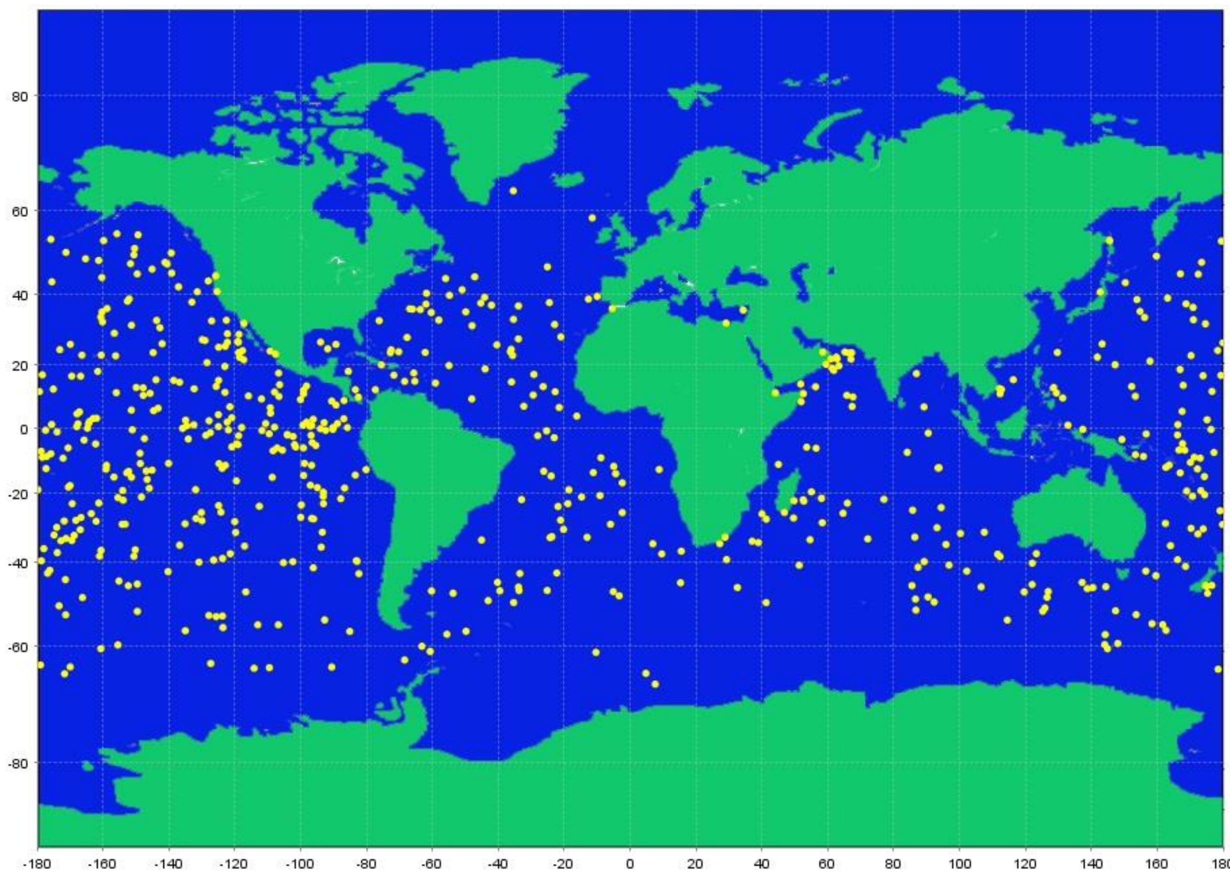


Figure 1: Location of US Argo floats in May 2016.

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

Remote Sensing in Support of Climate Research

Project Personnel: S-K. Lee and M. Goes (UM/CIMAS),
NOAA Collaborators: Gustavo J. Goni (NOAA/AOML)
Other Collaborators: J.A. Trinanes (University of Santiago de Compostela)

Long Term Research Objectives & 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 1*:** 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 NOAA/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. AOML has managed the CoastWatch Caribbean regional node since 2000; it serves as a pathway for accessing near-real-time and science-quality data and products such as sea surface temperatures, ocean color, winds, and sea surface height anomalies. The node was expanded few years later to include the Gulf of Mexico. In 2015, the Atlantic OceanWatch node was created at AOML, with Gustavo Goni and Joaquin Trinanes serving as node manager and operations manager, respectively. The new framework expands the capabilities of the CoastWatch node, as well as the range of its products, to include larger areas, focusing on both near-real-time and historical datasets and developing new technologies for data sharing and visualization.

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 and the development of operational products from the real time telemetry received through the X&L-Band antenna recently installed at AOML, which is managed by UW-Madison/SSEC. 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.

The processing and creation of products from the Visible Infrared Imaging Radiometer Suite (VIIRS) on S-NPP required the installation and configuration of the International Polar Orbiter Processing Package (IPOPP) and the Community Satellite Processing Package (CSPP). These products are currently being integrated within our data distribution schema (Figure 1). Besides the data from the station in Miami, VIIRS data is also being pulled from the satellite receiving station in Mayaguez, Puerto Rico, expanding the geographical coverage.

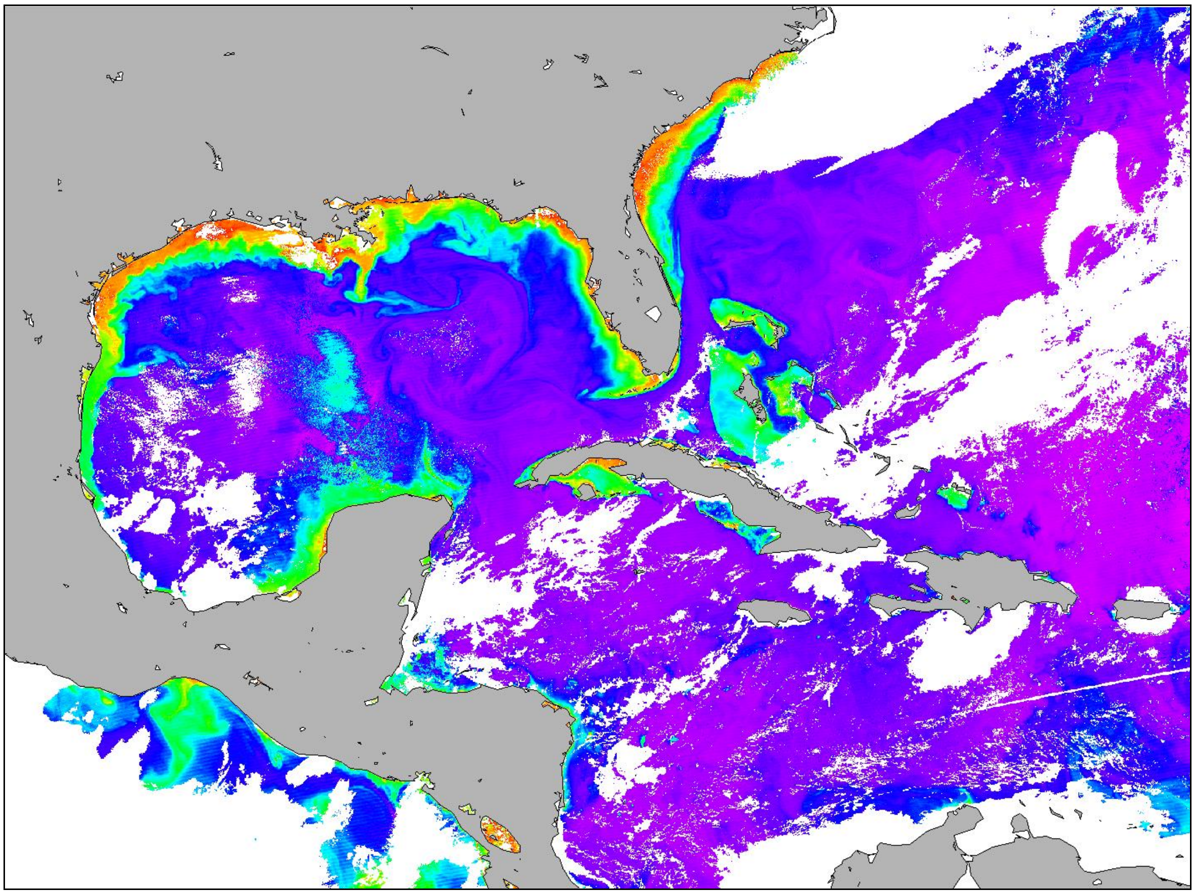


Figure 1: 750-m Chlorophyll-a field from VIIRS/S-NPP created in near-real-time using in-house processing.

A new study published in the journal Nature Microbiology highlights how emerging, devastating outbreaks of Vibrio infection in Latin America might be linked to El Niño. Vibrios are rod-shaped bacteria present in the marine environment that proliferate in warm and low-salinity seawater. In the U.S. alone, Vibrio infections cause an estimated 80,000 illnesses and 100 deaths annually. There are many species of Vibrio, the best known being V. cholerae, V. vulnificus, and V. parahaemolyticus. During the last three more significant El Niño episodes (1990-1991, 1997-1998 and 2010), new Asian variants of pathogenic Vibrio have emerged in Latin America (Figure 2). They include a variant of V. cholerae, which resulted in more than 13,000 deaths in Peru in 1990, and two variants of V. parahaemolyticus, which triggered widespread gastrointestinal illness associated with contaminated shellfish in 1997 and 2010. We observed that declared illnesses caused by waterborne bacteria reported in Latin America

moved in tandem with where and when warm El Niño waters made contact with the land. Whole-genome sequencing of bacterial strains suggest there may indeed be a link between organisms that cause illness in Asia and those that emerge in Latin America, in particular, Peru and Chile. Other authors involved in the study include Drs. Jaime Martinez-Urtaza of the UK's University of Bath, Narjol Gonzalez Escalona of the US Food and Drug Administration, and Craig Baker-Austin of the UK's Centre for Environment, Fisheries and Aquaculture Science. The Atlantic OceanWatch node at AOML routinely generates and distributes operational global vibrio risk fields using remote sensing and models as primary inputs.

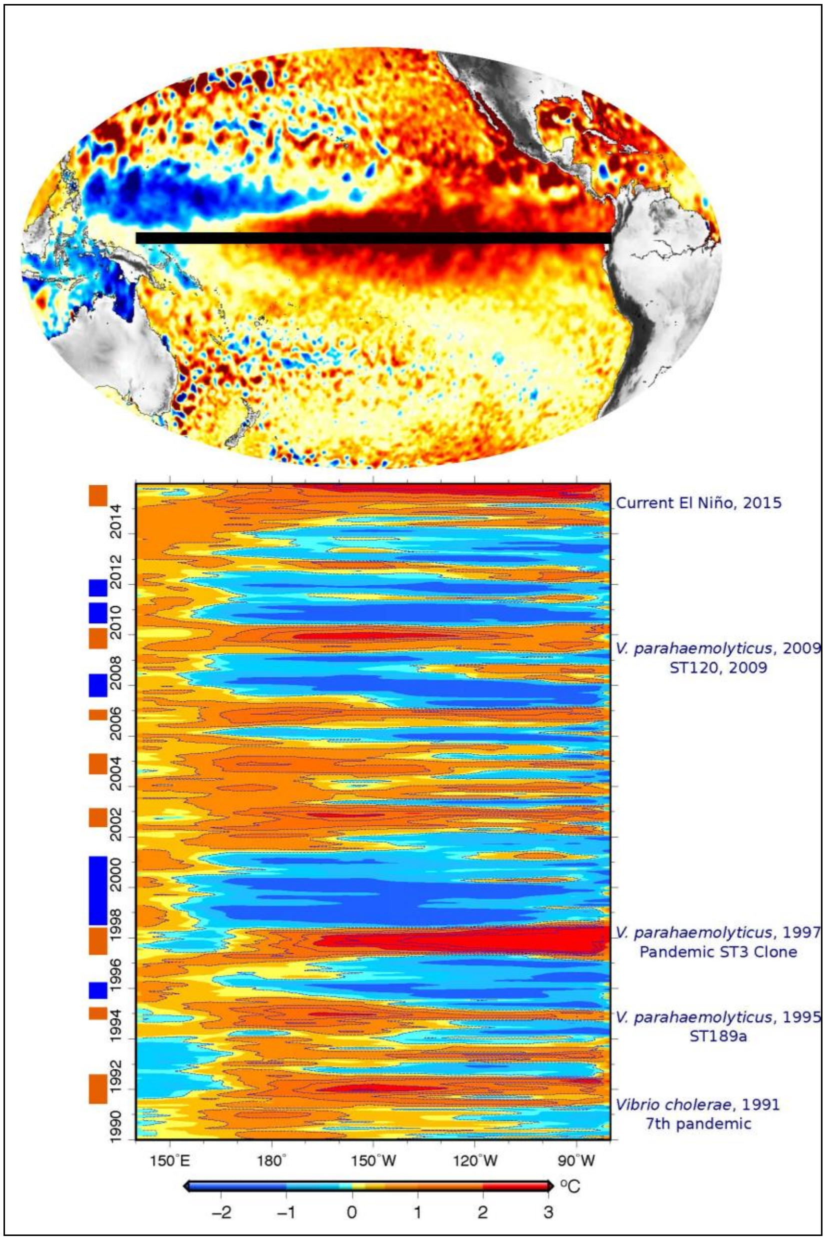


Figure 2: Correlation between El Niño and the emergence of new Vibrio infections in South America (Martinez-Urtaza et al, 2016).

On January 27th-29th, we organized and hosted the 17th CoastWatch/OceanWatch Science Workshop. Presentations highlighted the large suite of products distributed by the CoastWatch/OceanWatch programs, while subsequent discussions brought greater awareness of the robust frameworks and methodologies for satellite data processing, and of robust approaches to identify, understand, support, and meet user needs and requirements. This workshop highlighted the importance of regular, direct interaction between node managers to improve the program's objectives and quality of its products, as well as provide a common ground for sharing expertise and knowledge. Presenters and remote participants also recognized AOML's role in organizing and leading the workshop; they expressed confidence in meeting the challenges posed by a new generation of satellites, the advent of new technologies for data management and processing, and an increasing need for international cooperation and compulsory data quality requirements.

Other activities related to this project include the processing of wind datasets to assess the carbon fluxes at regional scales in the Gulf of Mexico and other parts of the globe (e.g. Greenland), and the migration of the global flux and regional ocean acidification processing to VM. For fluxes studies, techniques were developed and implemented to collocate in-situ data Southern Ocean with high resolution SST data from MODIS and VIIRS.

The online data visualization package has been improved with new features. It supports datasets from external servers, additional baselayers and protocols. The current release adds Climate Data Records (CDRs) from the National Centers for Environmental Information, and multiple satellite layers from NASA, served through Web Map Tile Services (WMTS). This effort expands including the development of mobile applications for Android and IOS.

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.

Europe's Copernicus program relies on data from a constellation of satellites, the Sentinels, which will provide global monitoring capabilities. Currently, 4 satellites of this constellation are in orbit: S-1A&B (radar imagery), S-2A (high resolution multispectral) and S-3A (sea surface height, sea surface temperature and ocean color). NOAA is testing and assessing European Space Agency data distribution framework and the quality of the products being provided. From the perspective of our CoastWatch/OceanWatch node, S-1 SAR data has multiple applications (such as oil detection, coastal winds from flux studies, waves, sea ice) and advantages, such as its all-weather capability. We have developed software to select, download and process S-1 data and are working on developing similar routines for S-3A. They will allow us to access S-3A products in real-real-time from ESA and EUMETSAT servers once this satellite is commissioned.

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.

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 & 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 and follow on JPS platforms. 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 its 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.

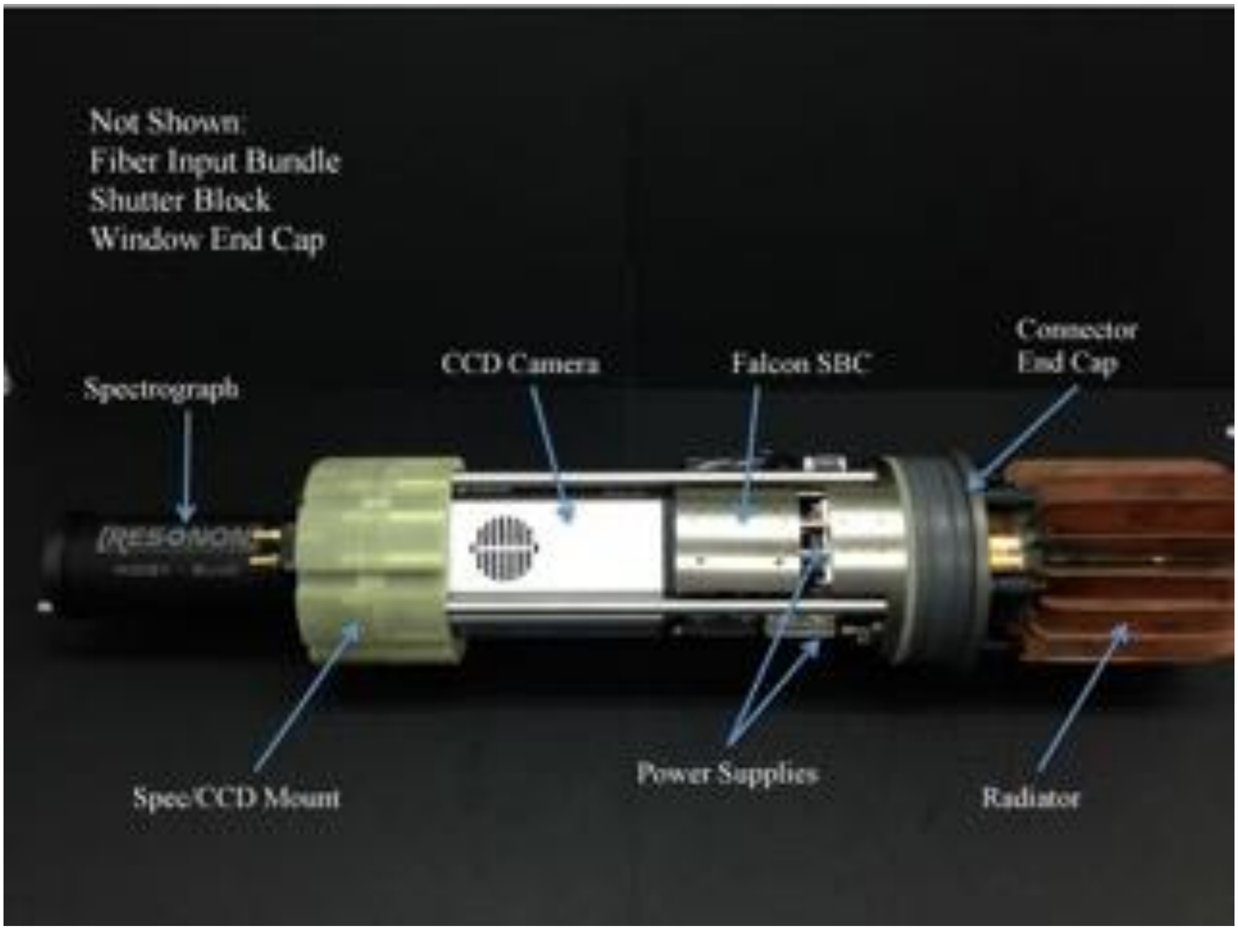
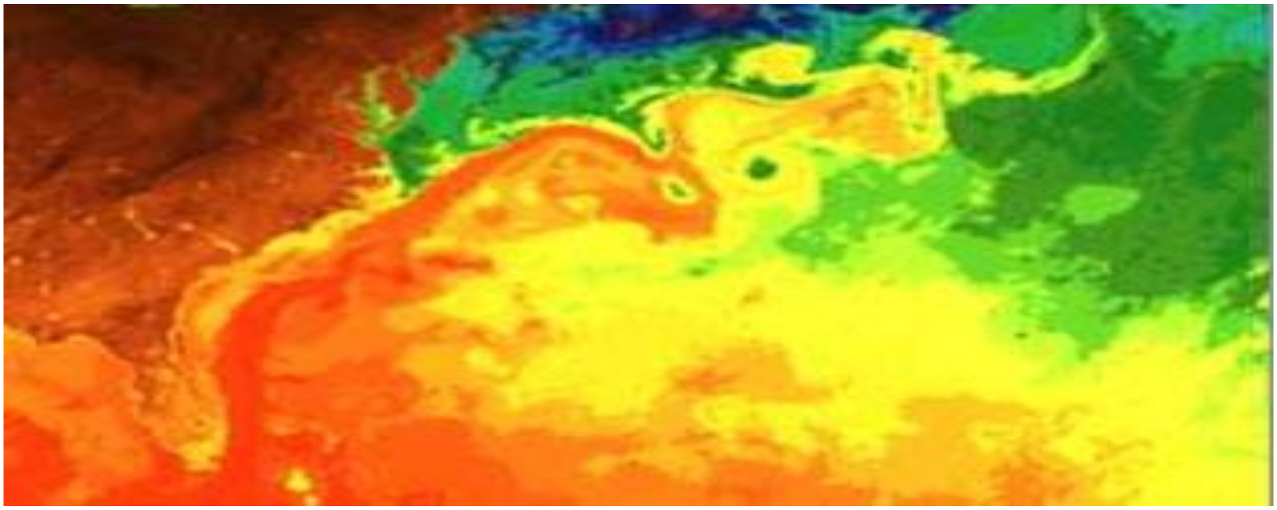


Figure 1: A picture of the new blue wavelength in-line spectrometer for MOBY-Refresh, with major components labeled. This system allows multiple light measurements to be made simultaneously, with 1 nm spectral resolution over a range from 350- 700 nm. The fiber input comes in from the left, through the spectrograph, whose image is displayed on the CCD camera and collected by the single board computer.

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. In addition, we have been making progress on the MOBY-Refresh effort. During the last year we have installed the new, modern control system for MOBY, and have begun characterization of the new optical spectrometers that will be installed in this system to replace the old optical system. Our first trial deployment of the blue spectrometers will occur at the end of June 2016.



RESEARCH REPORTS

THEME 4: Ocean Modeling

Variability and Coherence of the Atlantic Meridional Overturning Circulation

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

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:
The goal over the first year of this project was to establish a baseline evaluation of the high-resolution eddy-resolving global HYCOM simulations in representing the circulation of the Southern Atlantic Ocean. We documented that the model represents the magnitude and vertical structure of the trans-basin

AMOC at 34.5°S, the transport and the horizontal/vertical structure of the Antarctic Circumpolar Current (ACC) through the Drake Passage at 65°W, and the net transport across 20°E, and used the model results to explore the source of the upper AMOC water and the modification the water mass in this region.

In the first part of year 2, we examined the coherence of the AMOC variability. We found that on seasonal time scale (Figure 1), the variations are high and coherent from 35°S to ~15°N. In the North Atlantic, the variations are also coherent from 65°N to near 20°N, this coherence is similar to the results based on basin-scale Atlantic model. In the area from 15°N to 20°N the variation is generally weaker and the phase of the variation changes. On interannual and longer time scale (Figure 2), the variation is generally weaker and there is not a clear pattern for the first 4 years. From 2008 to 2013, however, the variation is significantly more coherent from 35°S to about 35°N with generally similar variation phase, and further to about 60°N with a shift in the variation phase. It is also clear that the AMOC transport is higher in 2003-2008 than 2009-2013 throughout the whole Atlantic domain.

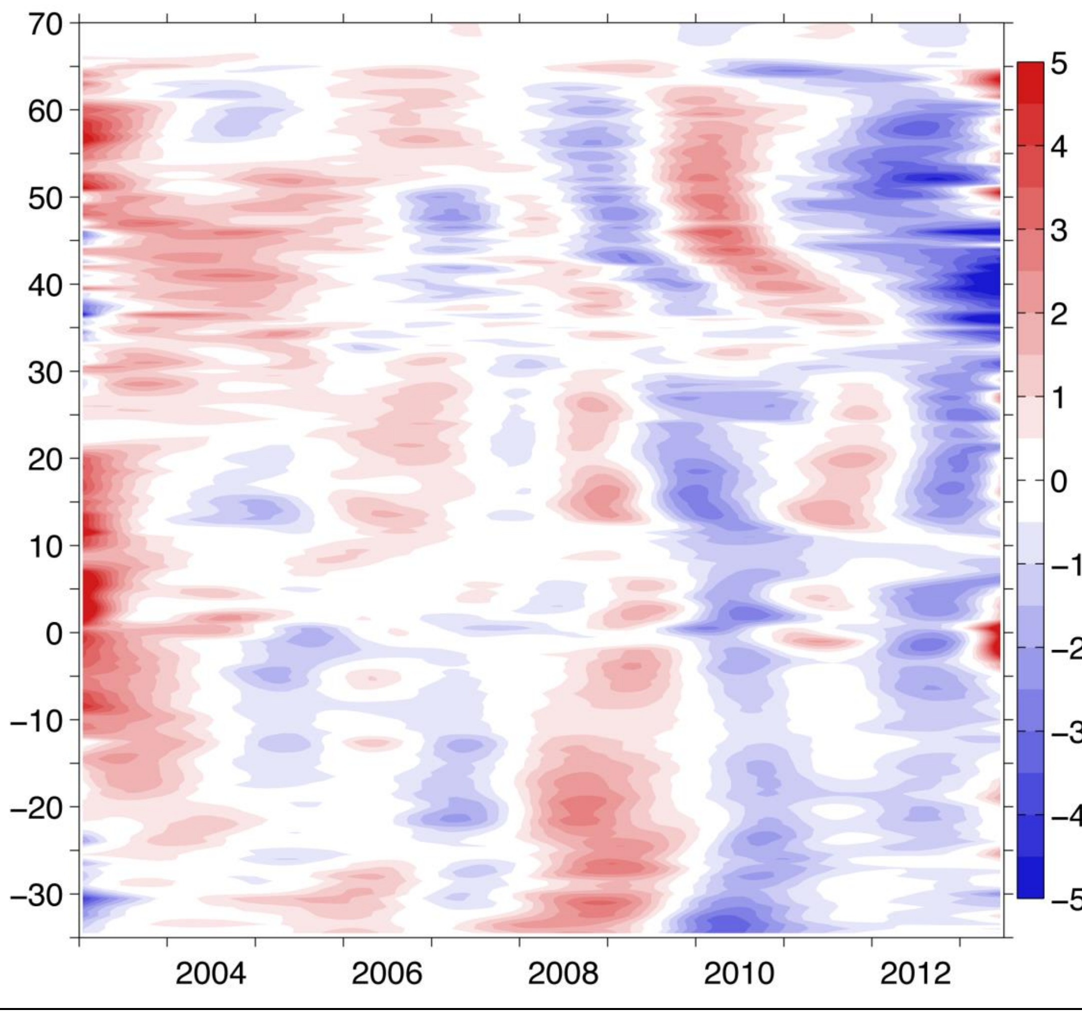


Figure 1: Latitudinal distribution of the modeled AMOC variations on seasonal time scales, determined from decomposing the AMOC transport time series (at each latitude) using the ensemble empirical mode decomposition (EEMD); see Xu et al. (2014) for details.

We are currently preparing a manuscript that summarizes these research results based on the existing 10-year long model simulation (2003-2012). Separately, we are working on a long-term (1958-2015) global simulation at 1/12° resolution in order to study the coherence and variability of the AMOC on decadal-to-interdecadal time scales. Results from this new simulation will be compared to a) similarly configured global simulation with a resolution of 0.72°, which is the resolution used in most of the current climate models; as well as to b) similarly configured global simulation with same horizontal resolution and atmospheric forcing but using the NEMO ocean model in the DRAKKAR project.

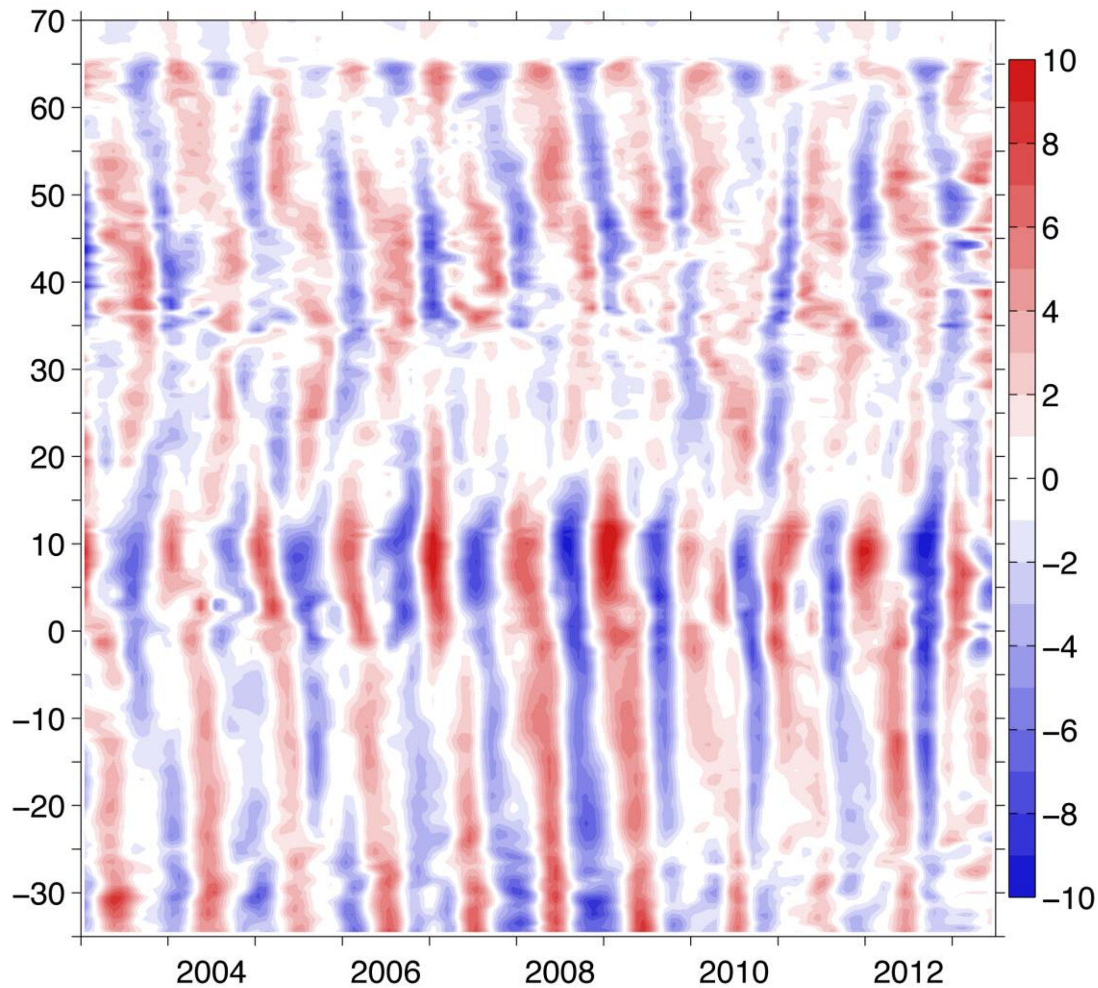


Figure 2: The same as in Figure 1 but for interannual time scales.

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, and working on the 2nd year objective, which is to perform a multi-decadal integration of the global simulation at 1/12°.

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, H.-S. Kang and I. Androulidakis (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 GoM 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 validated with several observations (eg. work in this project at Smith et al., 2016); through an ancillary NOAA project, it has been expanded to include the entire GoM. For the purposes of this study, additional work on river plume dynamics has been performed on the full GoM implementation, 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 (Le Hénaff and Kourafalou, 2016).

Processes influenced the spreading of Mississippi waters (a large source of nutrients, linked to hypoxia episodes) have been studied in detail. In particular, baseline river discharge and flooding conditions have been simulated, characterizing the similarities and differences on the transport and fate of the riverine waters that are of low salinity and high nutrient content. An example is given in Figure 1, where the

distribution of density anomaly is shown, as computed for baseline and flood conditions (Androulidakis et al., 2015). The prevailing buoyancy-driven patterns show influence on surrounding areas towards Louisiana-Texas (LATEX shelf, "downstream" for river plume development) and Mississippi-Alabama-Florida (MAFLA shelf, "upstream" for river plume development) in both cases. However, the influence toward the LATEX shelf prevails in the baseline, while the tendency toward MAFLA substantially increases during flooding conditions. These process oriented studies are important as a basis for the complex biophysical simulations that follow.

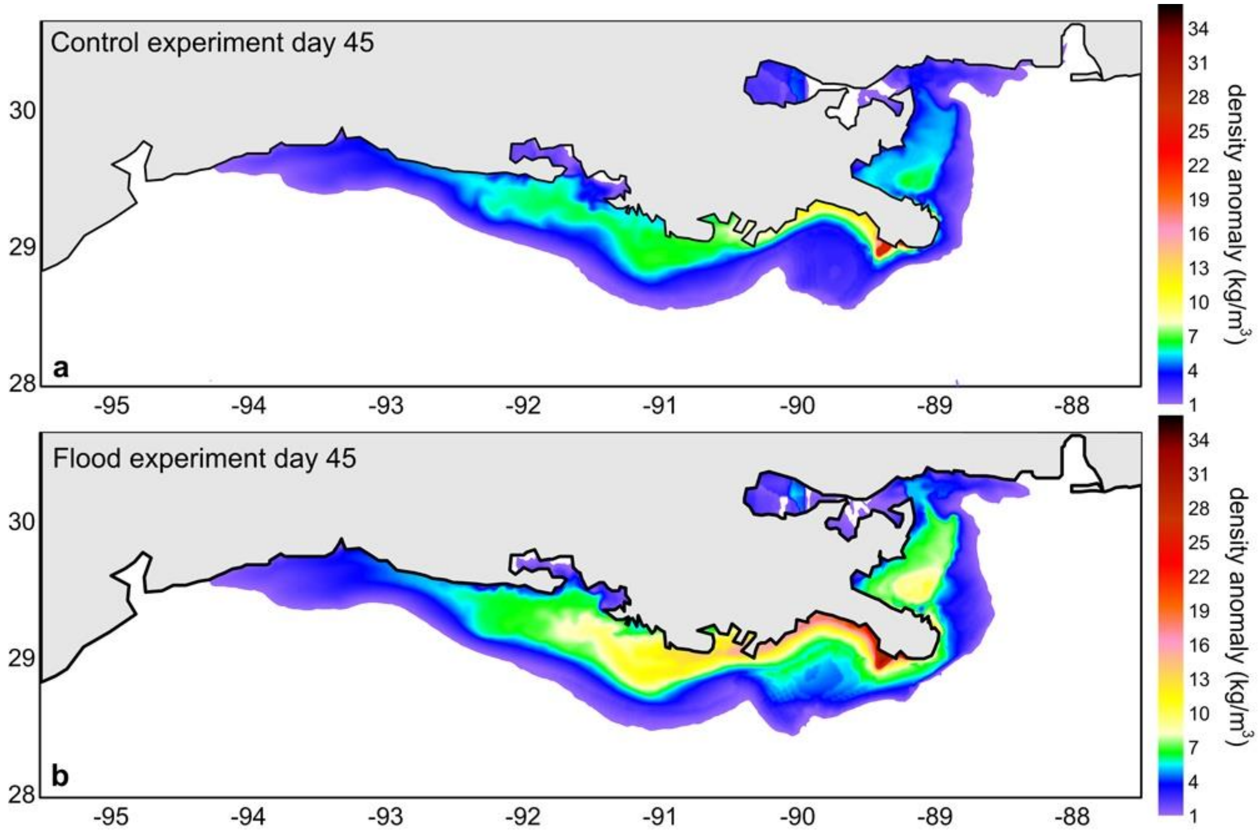


Figure 1: Distribution of density anomaly (kg/m^3) from a baseline (upper) and flooding (lower) experiment on the transport and fate of Mississippi River waters; the density anomaly is a proxy for the influence of riverine waters in the surrounding shelf areas.

The HYCOM hydrodynamic model was coupled with the Carbon, Silicate, Nitrogen Ecosystem (CoSiNE) model. This work has been mainly carried out by NRL (UM sub-contract), in collaboration with RSMAS and AOML. The coupled model has been applied on the entire GoM, first at a lower resolution of 1/25^0 (NRL GoM-HYCOM setup); coupled simulations have been performed at NRL, with the physical results compared to data validated simulations performed at RSMAS. The comparisons show that the results were generally reproduced and matched; improvements are in progress, both in the biological parameters and transitioning to the higher resolution (1/50^0) GoM-HYCOM model developed at RSMAS. The biophysical coupling effort has first focused on the NPZD (Nutrients Phytoplankton Zooplankton Detritus) model representation of the biological processes, so the mechanics of the various elements (input fields, IC/BC, parameters, parallelization) are in place before the much more sophisticated and involved ecosystem within CoSiNE is implemented. As an initial step, a passive tracer (i.e. no biology right-hand-side) simulation was performed using a plankton tracer. The coupling implementation was found to work properly as the tracer was clearly advected (and diffused) by the

physical model. Then, the biological processes were added and a fully coupled HYCOM and CoSiNE model code was developed. Figure 2 shows an example of a coupled simulation for the entire Gulf of Mexico (a zoom in the Northern Gulf is shown). This is the first time that HYCOM has been coupled with a comprehensive nutrient transport model, resulting in a modeling tool that can have broad applications in the scientific community. The hydrodynamic simulations used are currently free-running (ie no data assimilation). An ancillary project under the RESTORE act is already implementing the coupled model for Observing System Simulation Experiment (OSSEs), using the methodology framework 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).

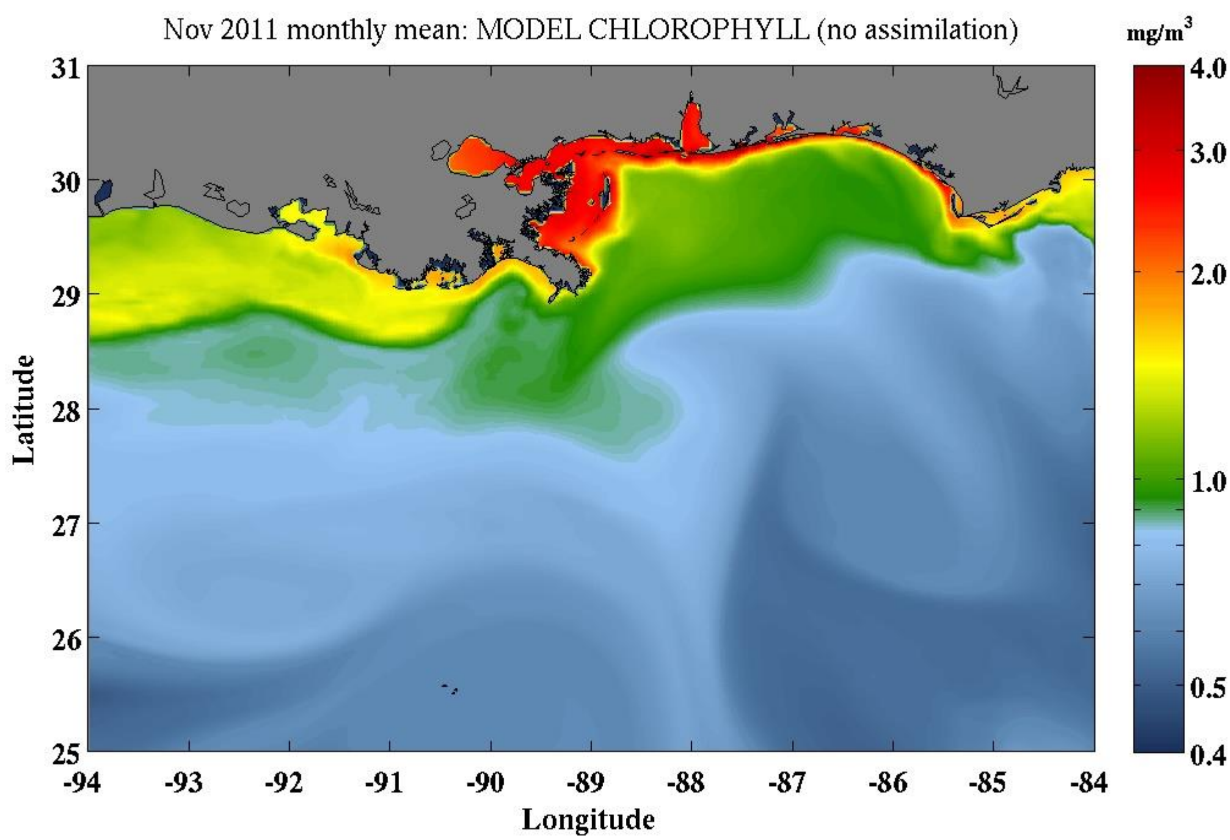


Figure 2: Chlorophyll distribution around the Mississippi Delta from the coupled HYCOM-CoSiNE simulation (based on a free-running HYCOM implementation in the GoM); monthly mean for November 2011.

Research Performance Measure: All major objectives have been met.

Ocean OSSE Development for Quantitative Observing System Assessment

Project Personnel: V. Kourafalou, H.-S. Kang and I. Androulidakis (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).

Two forecasting models have been developed within the North Atlantic OMOC OSSE domain. The first one (developed during the last reporting period) has very high resolution ($1/100^0$, ~900m) and covers both coastal and deep sea areas, over a limited domain within the Gulf of Mexico covering the deep Florida Straits and all shelf and coastal areas around South Florida, the Florida Keys, northern Cuba and the western Bahamas. This is a free-running model (no data assimilation), that has been publicly serving 7-day forecast fields for the last year. The second one (developed during the current reporting period) includes the entire Gulf of Mexico (GoM), with the data assimilation scheme adopted by OMOC. The domain is also high resolution ($1/50^0$, ~1.8 km) and both models use the HYbrid Coordinate Ocean Model (HYCOM) code. This GoM-HYCOM model is the highest resolution currently available for near real-time forecasting. We 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 global HYCOM model on $1/12^0$ grid; data are hosted at FSU/COAPS. Boundary conditions are updated daily from the global HYCOM model, up to a 7-day period. Maps for Sea Surface Height (SSH), Sea Surface Temperature (SST), temperature at 50m and surface currents are being publicly displayed.

An example of GoM-HYCOM forecast fields is displayed in Fig. 1. The initial and 7th forecast day are given for Sea Surface Height (SSH) and near-surface currents (only a few velocity vectors plotted to indicate the circulation that accompanies the SSH changes; more detailed surface currents are displayed on accompanying web pages, see link under "Outreach"). The initial GoM state was dominated by a detachment process of an anticyclonic Loop Current (LC) Eddy (LCE), partially under the influence of a cyclonic LC Frontal Eddy (LCFE) immediately north of the Yucatan Strait. The model predicted the change in LCFE orientation and size and the subsequent re-attachment of the LCE to the main LC body. Predicting the LC variability, which is dominated by the LCE separation process, is crucial for predicting the circulation in the GoM and monitoring the connectivity of remote GoM ecosystems. Further improvements are in progress, through advancing the data assimilation scheme. These activities are under our ocean modeling and OSSE framework, which allows the advancement of strategies for observing system design and quantitative evaluation of observing systems, by quantifying the improvement of model forecasts through the assimilation of specific observations.

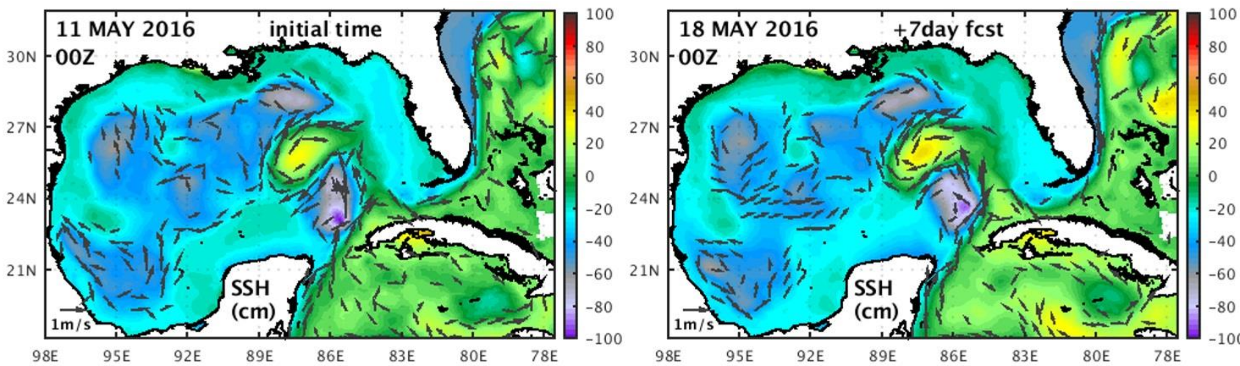


Figure 1: Sea Surface Height and near surface currents (only a few vectors are plotted for clarity) from the GoM-HYCOM forecast modeling system. Example is for the initial and 7th-day forecast, starting from 18 May, 2016.

Research Performance Measure: All major objectives have been met.

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South Atlantic Meridional Overturning Circulation: Pathways and Modes of Variability

Project Personnel: R.C. Perez, S.L. Garzoli and R. Garcia (UM/CIMAS)
NOAA Collaborators: C.S. Meinen and S Dong (NOAA/AOML)
Other Collaborators: R. Msadek (CERFACS/CNRS); R.P. Matano (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 Atlantic Meridional Overturning Circulation (AMOC) in the South Atlantic.

***Strategy*:** 1) To characterize the pathways of the upper and lower limb of the AMOC 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 AMOC. 3) To determine the response of

the South Atlantic pathways to predicted climate change scenarios and assess the impact of this response on the AMOC.

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: Sandy Lucas

Research Summary:
Previous observational and modeling efforts on the Atlantic meridional overturning circulation (AMOC) 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 AMOC 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 AMOC 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 AMOC, and 3) determining the response of the South Atlantic pathways to predicted climate change scenarios and assess the impact of this response on the AMOC. 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.

In work led by R. Matano to characterize the leading modes of low-frequency variability of the South Atlantic circulation in the SODA analysis product, we computed empirical orthogonal function (EOF) modes of the model's sea surface height (SSH) and sea surface temperature (SST) fields as well as of its forcing field (wind stress, wind stress curl and freshwater fluxes). The dominant model of low-frequency variability is an inter-decadal variation of the subtropical gyre. The dynamical manifestations of the Brazil-Malvinas Confluence and the Agulhas Retroflection variability appear in the second and third mode. The structure of the wind stress curl show changes related mostly to the first SSH mode. The lack of significant correlation between the SSH and wind curl for the second and third modes indicates that these patterns are more influenced by the internal variability of the geostrophic flow. There are significant correlations between SSH and SST anomalies, suggesting that an important portion of the SST variability are driven by advective effects associated with the geostrophic circulation. Our analysis also shows a strong correlation between the AMOC and the meridional heat transport (MHT) in the South Atlantic, with a latitudinal volume and heat increase that is close to observations. The anomalies and the meridional gradient of the AMOC and MHT appear stronger during El Niño years and weaker during La Niña ones.

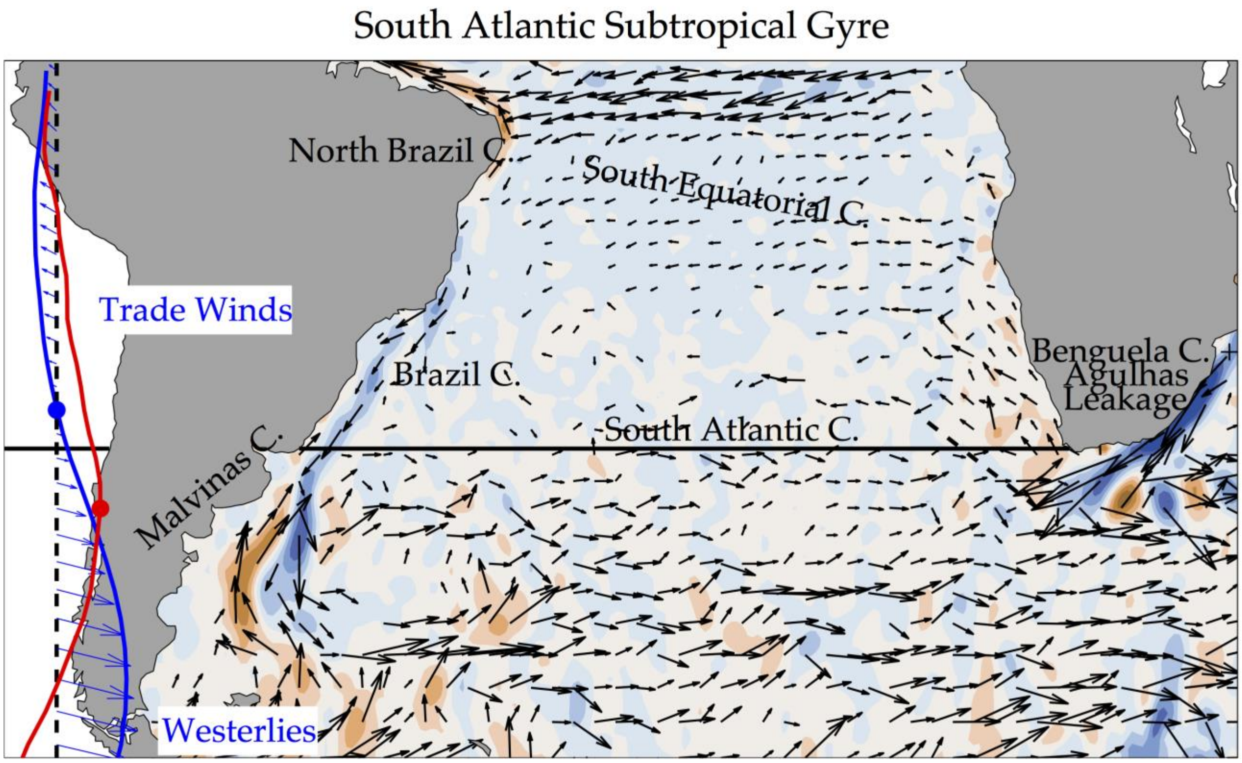
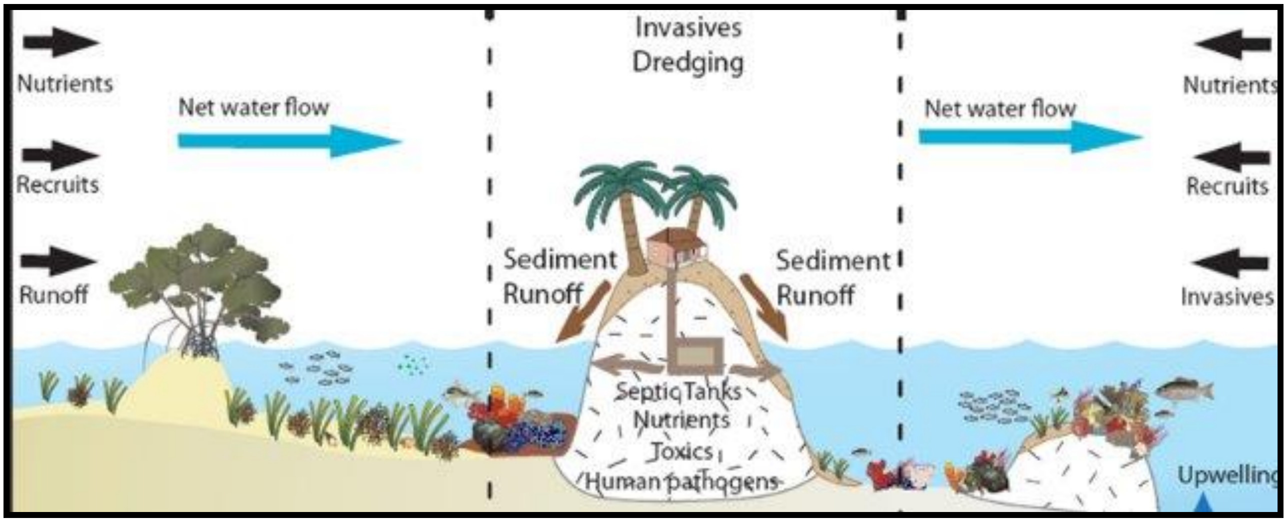


Figure 1: Map of mean near-surface currents delineating the boundaries of the South Atlantic subtropical gyre generated from the Lumpkin and Johnson (2013) drifter climatology. Color shading: meridional velocity (blue indicates southward and brown indicates northward). Vectors show horizontal currents with magnitudes in excess of 10 cm/sec. Blue vectors: Mean wind stress from NCEP reanalysis averaged across the basin, blue curve: mean zonal wind stress, red curve: mean wind stress curl. Labels indicate the major wind (blue) and circulation (black) features.

A parallel study is being led by R. Perez using observed SSH anomalies (SSHA) from AVISO, as well as, simulated SSHA from NOAA/GFDL's CM2.5 simulation forced with COREII atmospheric forcing and their ECDA analysis product to study the low-frequency variability of the South Atlantic circulation and its impact on AMOC in the South Atlantic. Much of our analysis confirms the SODA results described above, specifically the observed and simulated variability in the South Atlantic is dominated by steadily increasing sea level increase across the entire basin, while the interannual to decadal (and in the models multidecadal) subtropical gyre changes are the next largest source of variability. SSHA trends and the modes of variability create zonal density gradients across the basin, and impact the strength and structure of the boundary currents and AMOC. The western boundary currents (i.e., the southward flowing Brazil Current and northward flowing North Brazil Current) are particularly influenced by the first mode of variability of the gyre such that the magnitudes of their transports increase when the first mode of SSHA increases. These gyre scale changes significantly influence the strength of the AMOC in the South Atlantic. Specifically, the AMOC volume transport is strengthened when the first mode is positive, with largest transport increases found to the north of the South Atlantic subtropical gyre (north of 15°S). Increasing AMOC anomalies between 35°S and 15°S suggest interaction between the gyre circulation and AMOC on interannual to multidecadal time scales.

In work led by R. Matano, we continued using our regional eddy-resolving (1/12˚) ROMS simulations of the tropical and subtropical South Atlantic. Previously, we reported the finding of a strong correlation between the time variability of the surface, westward mean flow generated by the passage of Agulhas eddies and the time variability of the deep eastward current that detrains North Atlantic Deep Water (NADW) from the western boundary region. Our analysis indicated that these mean flows (westward at the surface and eastward at NADW levels) are in thermal wind equilibrium and, therefore, are a manifestation of the same dynamical phenomena (Agulhas eddies). To investigate the causality of such equilibrium we conducted process-oriented experiments in a flat-bottomed basin with different formulations of the density structure. These experiments, which are in progress, aim to discriminate the role of bottom topography and inter-ocean density fluxes in the coupling between the upper and deep circulation. In collaboration with R. Perez, the co-variability of the surface westward and deep eastward flows are being examined in several of the NOAA/GFDL simulations, as well as, gridded Argo-altimetry velocity products.

Research Performance Measure: Progress has been made in all of the areas mentioned above and research objectives are being met. Research findings were presented at the UK RAPID – US AMOC International Science meeting in Bristol, UK in July 2015, and at the 2016 Ocean Sciences meeting in New Orleans, LA in February 2016.



RESEARCH REPORTS

THEME 5: Ecosystem Modeling and Forecasting

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.

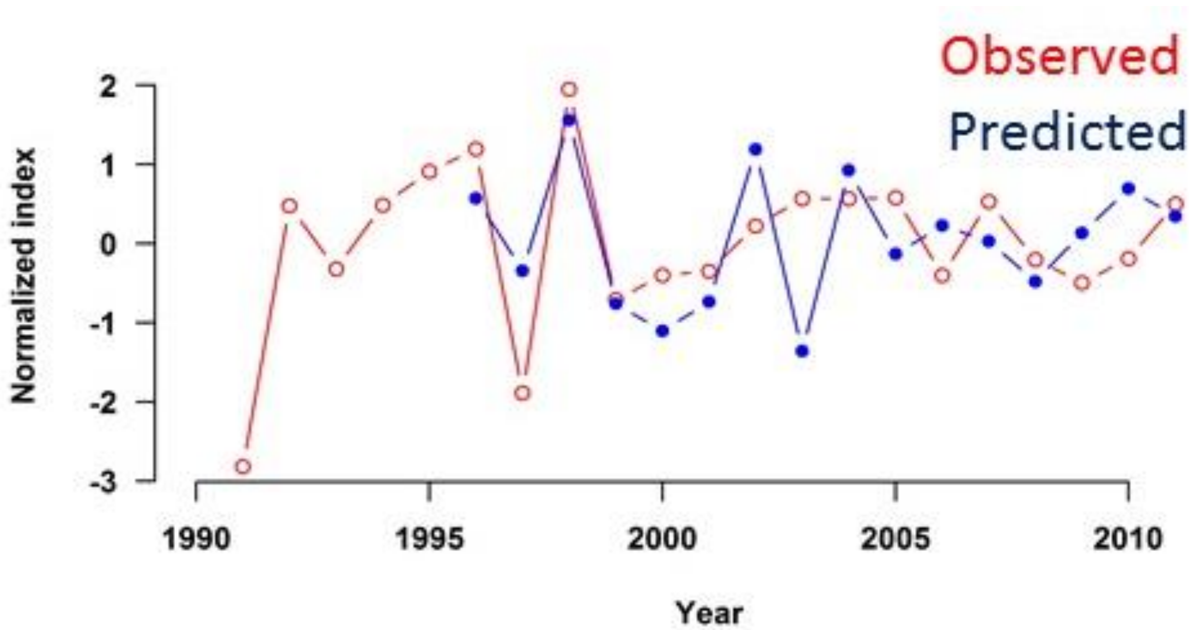


Figure 1: An example of time series forecasting using a technique known as empirical dynamic modeling.

Research Performance Measure: Final report. This project was 9 months in duration, 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 as part of a study on the environmental effects on abundance, and 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.

Applying Bio-physical Monitoring and Capacity Assessments to Mesoamerican Reef Marine Protected Areas

Project Personnel: E. Malca, (UM/CIMAS); Eloy Sosa-Cordero, Laura Carrillo-Bibriezca, Lourdes Vasquez-Yeomans, (ECOSUR); María José González (MARfund)
NOAA Collaborators: John Lamkin, Trika Gerard (NOAA/SEFSC)

Long Term Research Objectives and 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: NMFS/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 fourth activity in the series (titled Connectivity Exercises or "ECOME" was carried out simultaneously in multiple marine protected areas (MPAs) during the new moon: September 9-17, 2015 along the Mesoamerican Barrier Reef to collect larval and juvenile reef fishes. At least 37 people representing 10 MPAs from the 4 countries in Mesoamerican Reef region participated in the field exercises. A new MPA joined the Connectivity network: Bacalar Chico Marine Reserve located in Northern Belize.

A final report for ECOME 1-4 was completed during Spring 2016. This report compiled the results of over and captured lessons learned from the project. It was distributed to local MPA managers in the Mesoamerican Region. Many of the managers also and carried out the field exercises and all MPAs provided their datasets to compile the report.

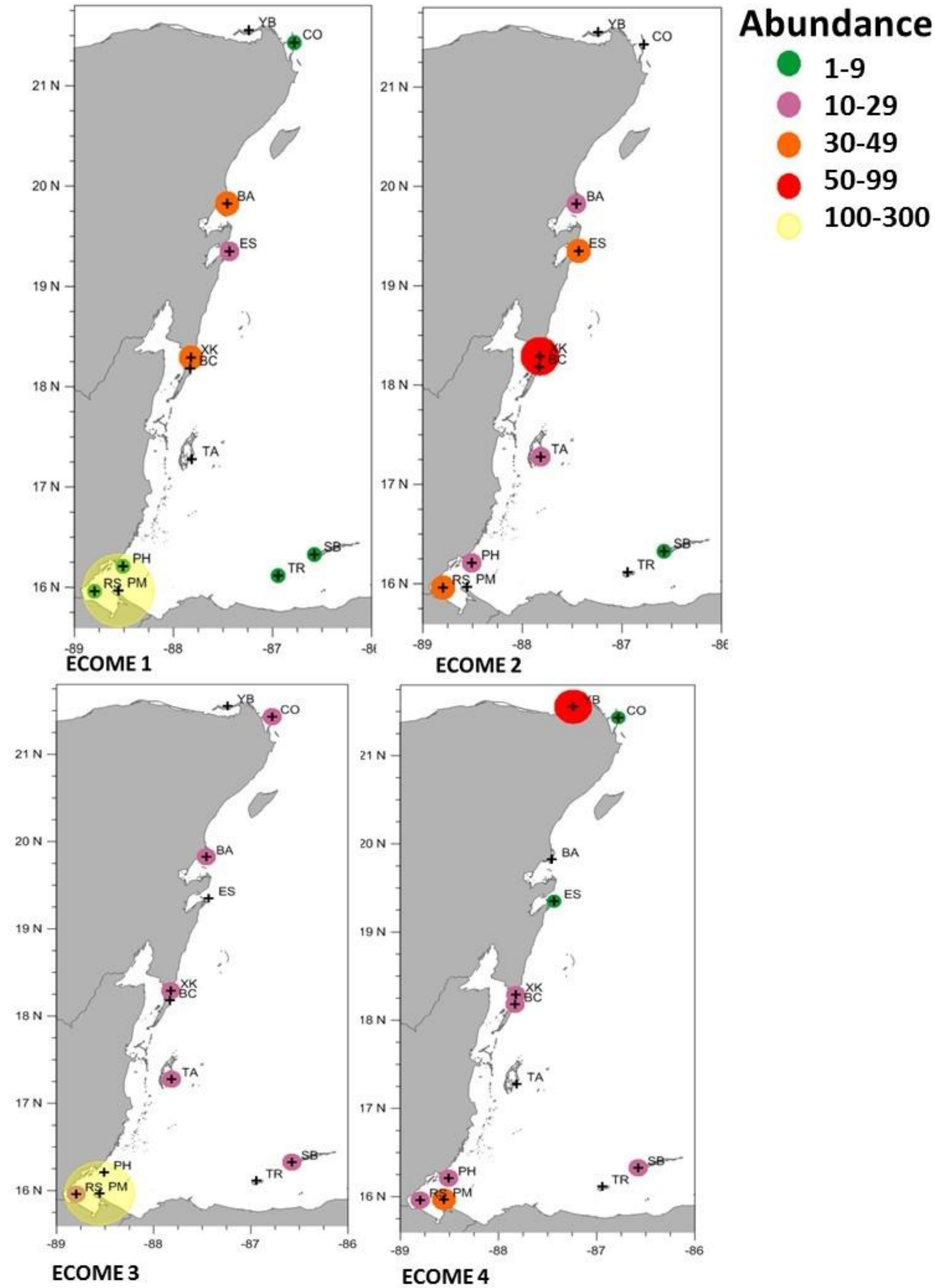


Figure 1: Abundance of larval and post-larval fishes along the Mesoamerican Barrier Reef during the four ECOME monitoring activities in 2010-2015.

Figure 2: Regional and local managers and scientists participated in the 3rd Connectivity workshop in Cancun, Mexico during July 2016.

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. During the year, members of the "Connectivity Network" carried out several informal training events within the region to augment additional monitoring sites for the ECOME exercises. For example, during ECOME 4, the Sartaneja Alliance for Conservation and Development received training to carry out the next ECOME exercise. A fifth ECOME is planned to monitor summer spawners recruiting into MPAs during the new moon in September 2016.

Results from the Connectivity Exercises (ECOME) were presented to local and regional managers during "the 3rd Workshop in Connectivity" carried out in Cancun, Mexico July 12 and 13, 2016. Representatives from each of the four countries attended and funds were allocated to replenish or outfit new collecting equipment as well as temperature sensors to continue monitoring the region.

Use of a Biophysical Modeling Framework to Develop a Recruitment Index for Inclusion in Stock Assessments in the Gulf of Mexico and South Atlantic

Project Personnel: C.B. Paris and A. Vaz (UM/RSMAS)
NOAA Collaborators: M. Karnauskas, T. Kellison and K. Shertzer (NOAA/SEFSC)
Other Collaborators: R. He (North Carolina State University); S. Lowerre-Barbieri (Florida Fish and Wildlife Conservation Commission)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To identify sources of larval red snapper recruits to the southeastern U.S. Atlantic red snapper stock and understand likely areas of age-0 settlement in the region. To estimate the expected recruitment strength of southeastern U.S. Atlantic red snapper due to environmental factors.

***Strategy*:** To incorporate biological information and physical oceanographic information in a bio-physical modeling framework in order to simulate the expected trajectories of red snapper eggs/larvae spawned in the Gulf of Mexico and southeastern U.S. Atlantic regions.

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:

Red snapper are a highly valued reef fish found throughout the Gulf of Mexico and southeastern U.S. Atlantic regions. The goal of this project is to use a combination of recently-developed hydrodynamic ocean and biophysical modeling approaches to simulate recruitment events of red snapper, *Lutjanus campechanus*, in the Gulf of Mexico and U.S. Atlantic. We combine an individual-based larval transport model (Connectivity Modeling System; Paris et al. 2013) with an oceanographic hindcast model (Regional Ocean Modeling System; Shchepetkin and McWilliams 2005), to understand sources and sinks of recruits in the region, and to develop indices of recruitment strength. This combined effort will lead to the development of a powerful recruitment forecasting tool for the region.

Particle releases representing red snapper eggs/larvae are carried out from known spawning locations, with the number of particles per location and time scaled to the percent spawning fraction determined from biological data sets. Particles are then tracked through time and space, given realistic parameterized biological behavior, and the oceanographic conditions specific to each year. Successful settlers are those particles that reach settlement habitat within the given pelagic larval duration. The relative number of successful settlers each year then represents the expected recruitment trends due solely to environmental and oceanographic factors. The successful larval trajectories, given the biological constraints described above, are used to understand the probable settlement locations of age-0 red snapper in the southeastern U.S. Atlantic region, and also to identify the probable source locations of these recruits.

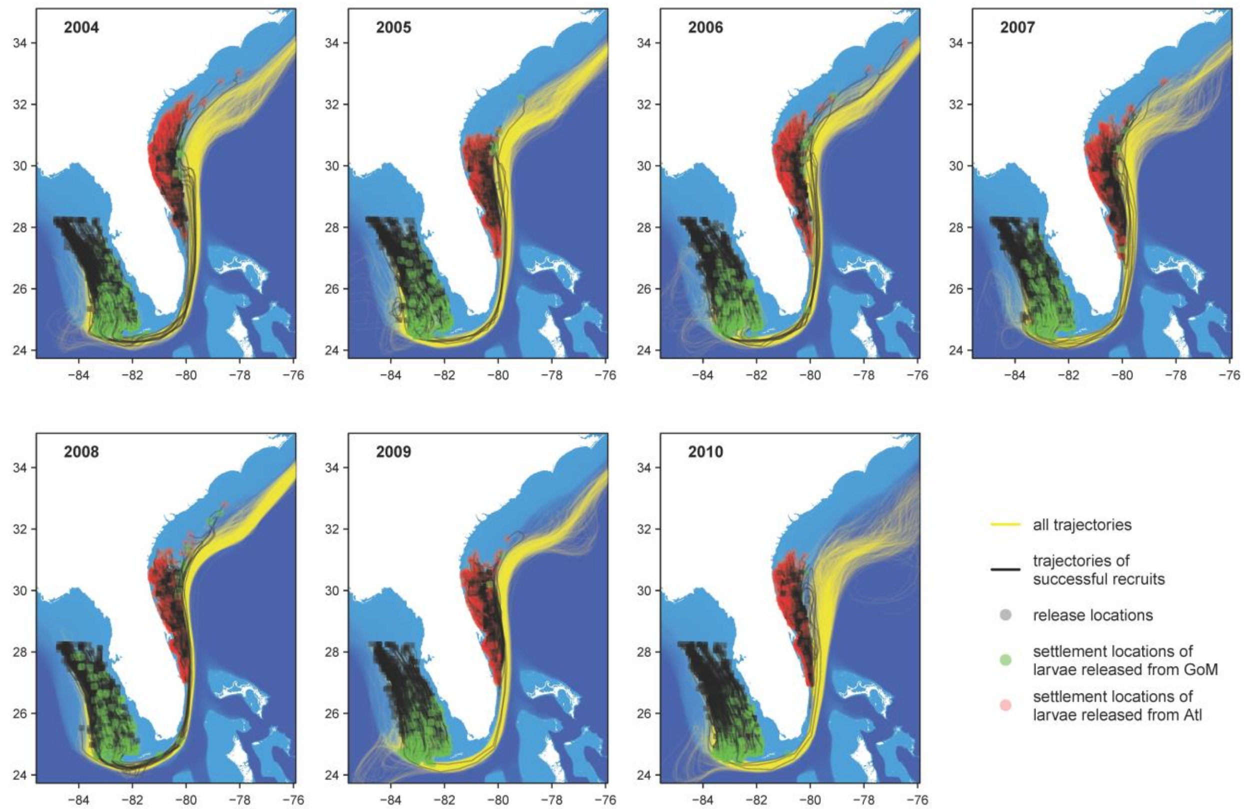


Figure 1: Simulated red snapper larval trajectories for the Gulf of Mexico and southeastern U.S. Atlantic, showing for individual years the respective source and settlement locations for larvae released from each region.

Research Performance Measure: The SABGOM oceanographic model was converted into the format necessary for incorporation into the biophysical model (Connectivity Modeling System). Simulations were first carried out for larval releases in the Gulf of Mexico to compare the estimated larval trajectories from SABGOM with those from an alternative ocean model, the HYCOM 1/25 degree Gulf of Mexico Analysis. Further simulations were carried out to estimate the relative success rates of red snapper larvae spawned in the Gulf of Mexico and southeastern U.S. Atlantic in recruiting to the Atlantic, using the SABGOM model. Preliminary estimates show that the Gulf of Mexico is not a significant source of red snapper larvae to the Atlantic, and that larvae in both regions are largely self-recruiting to their respective regions (Figure 1). Within the Gulf of Mexico, only spawning locations located south of approximately Tampa Bay are potential source locations for recruits in the southeastern U.S. Atlantic. This project is a component of a larger multi-institutional project that will continue throughout the next year. Work with external collaborators is ongoing to: 1) understand the differences in trajectories produced from the two alternative oceanographic models, 2) refine the simulations with incorporation of further biological data, and 3) write up results for publication. The portion of this project which was funded under the CIMAS Award is complete.

Caribbean Sea and Gulf of Mexico Bluefin Tuna Research

Project Personnel: L. Rasmuson, K. Shulzitski, E. Malca, S. Privoznik, A. Shiroza, J. Mostowy, K. Doering, A. Spera, J. Suca and A. Ender (UM/CIMAS)
NOAA Collaborators: J. Lamkin, T. Gerard and A. Zygas (NOAA/SEFSC)

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: NMFS/SEFSC
NOAA Technical Contact: Theo Brainerd

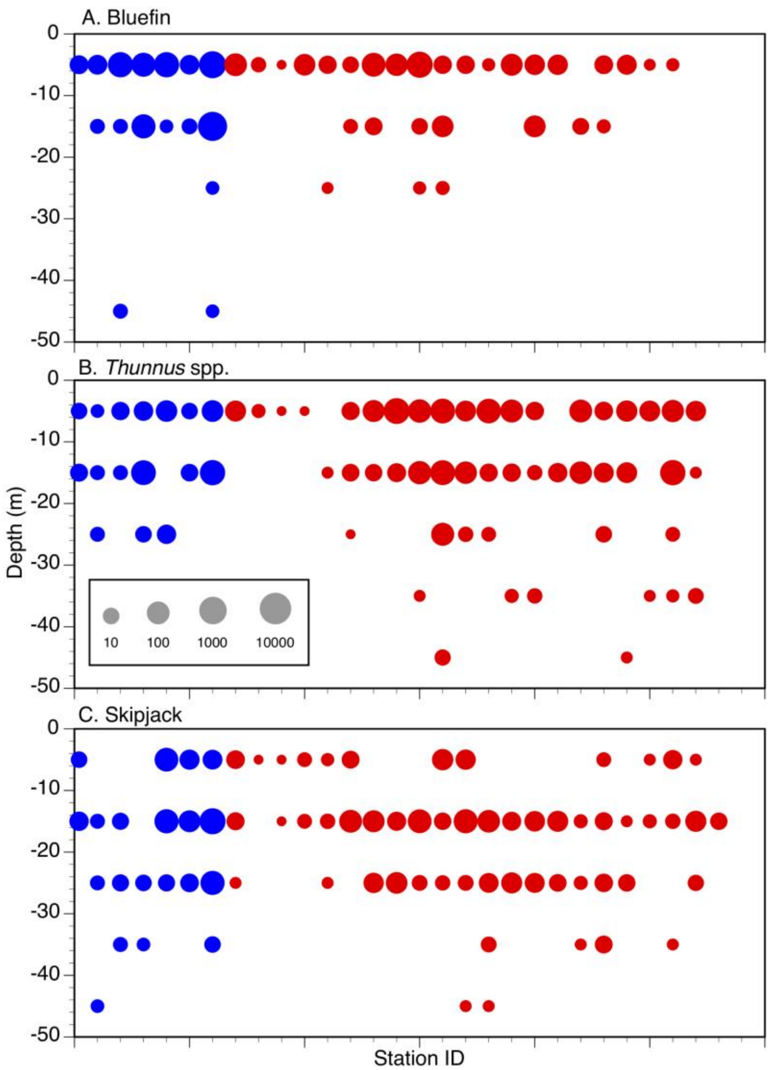
Research Summary:

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, Cuba and north of the Bahamas. In 2016, we focused our sampling efforts our sampling efforts on unique circulation features near the Loop Current and south of Cuba.

The 2016 research cruise conducted intensive sampling of circulation features, collecting and preserving larvae for studies of growth, isotopic trophodynamics, condition and feeding patterns. A comparison between sampling gears was conducted to provide a correction factor the NOAA-led annual spring survey, which was completed on the NOAA ship Oregon II. Scientists from UM/CIMAS, NOAA-SEFSC, NOAA-AOML, WHOI, City University of New York, IEO (Instituto Español Oceanográfico, Spain), National Research Institute of Far Seas Fisheries (Japan), Centro de Investigaciones Pesqueras (Cuba), GEOCUBA Marine Studies (Cuba), and El Colegio de la Frontera Sur - ECOSUR (México) participated during the research cruise. The NOAA research vessel Nancy Foster was used for the 29 days of sampling completing 64 stations (including 3 stations that were sampled continuously for 24 hours).

Similarly, to cruises completed in previous years (2009-2015), physical data from CTD casts, and biological data from plankton net tows were collected *in situ*. This year at select stations, the ship remained at a specific station (based on the regional oceanography) for 24-hrs and conducted repeated plankton tows in order to better understand how patterns change over the course of a day. We collected vertically stratified plankton tows in order to let us better understand where in the water column larvae are located. Samples were sorted at sea and subsets of larvae were either frozen separately in liquid nitrogen for tissue stable isotope analyses or frozen in pure ethanol to preserve high quality DNA for next-generation sequencing. 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.

These results suggest that spawning of bluefin tuna is more restricted in time and space than for other Atlantic tunas, including congeners. Bluefin were most prevalent in the upper 20 m of the water column where as other species are more dispersed throughout the water column (Fig. 1). For our targeted 24-hr studies, it appears that lobster larvae are most abundant on the edges of oceanic circulations. All of the samples have been preserved, and will be used for future ecological studies.



Research Performance Measure: The research program is on schedule. This year's (NF1602) cruise was successfully completed on June 5, 2016; sample processing has started and sorting will begin shortly. Last year's cruise (NF1502) has been completely sorted and identification of larval bluefin tuna and other species of interest has been completed. For the trophodynamics sub-project, frozen samples of ichthyoplankton, mesozooplankton, microzooplankton and phytoplankton 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, and all larvae from 2013 and 2014 have also been aged. Lastly, 54 larval Skipjack tuna (*Katsuwonis pelamis*) have been aged for a multi-species comparison.

Figure 1: Vertical distribution of three different groups of tuna larvae.

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)
Other Collaborators: M. Feeley (NPS), A. Acosta(FWRI)

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 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* (S*econdary*)

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 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, 208 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.

Research Performance Measure: Divers conducted photo-documentation, RVC fish surveys, and habitat assessments at 208 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, 932 dives were needed to complete the 2015 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, in 2014, 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. This year,

the R-package and an accompanying data sever went live and was distributed to all partners, collaborators and scientists.

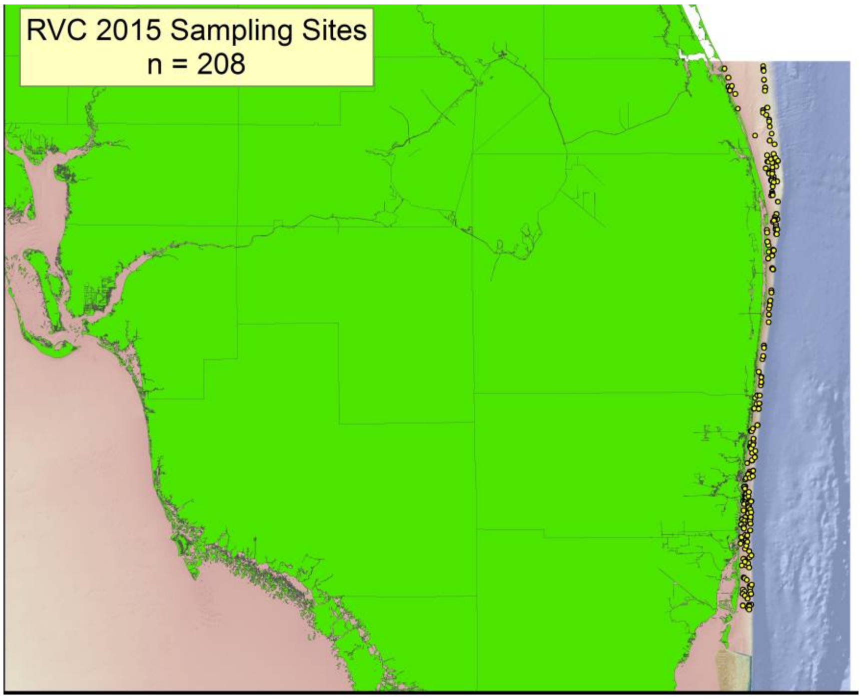


Figure 1: Sampling site locations for 2015 in the Florida domain.

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Ecology of Forage Fishes in the Arctic Nearshore

Project Personnel: K.M. Boswell (FIU)

NOAA Collaborators: R. Heintz and J. Vollenweider (NMFS/AKFSC/ABL)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** The goal of this project was to develop a detailed characterization of nearshore Arctic fish communities and their habitats in order to better understand the ecological function of the coastal habitats fringing the Arctic Large Marine Ecosystem. Our approach was to characterize Arctic fish communities in nearshore habitats by observing seasonal changes in the communities in a variety of habitats near Pt. Barrow, Alaska and relating those changes in local environmental conditions.

***Strategy*:** Through a series of weekly surveys during the ice free periods in 2013 and 2014, we characterized the nearshore fish community structure and demographic patterns among dominant species, examined the feeding ecology and energetics of nearshore fish species, used stable isotopes to elucidate food web interactions, characterized the shallow water habitats with an autonomous vessel and examined the meteorological and oceanographic forcing between the Elson Lagoon and Beaufort Sea water masses. In generalx the occupants of the nearshore habitats of the Arctic, near

Barrow, are strongly influenced by the physical and meteorological processes that dominate this region. The regulation of sea ice in the nearshore and overall climatic forcing during the ice-free period appear to play a deterministic role in the species present, their energetic content, prey availability and food-web interactions. As expected there was a direct linkage between the meteorological conditions (i.e., wind speed, direction and pressure) and the magnitude and direction of the flow between the Lagoon and Beaufort Sea habitats. Reversals in meteorological condition yielded rapid reversals in flow between water masses.

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: AKFSC
NOAA Technical Contact: Ron Heintz

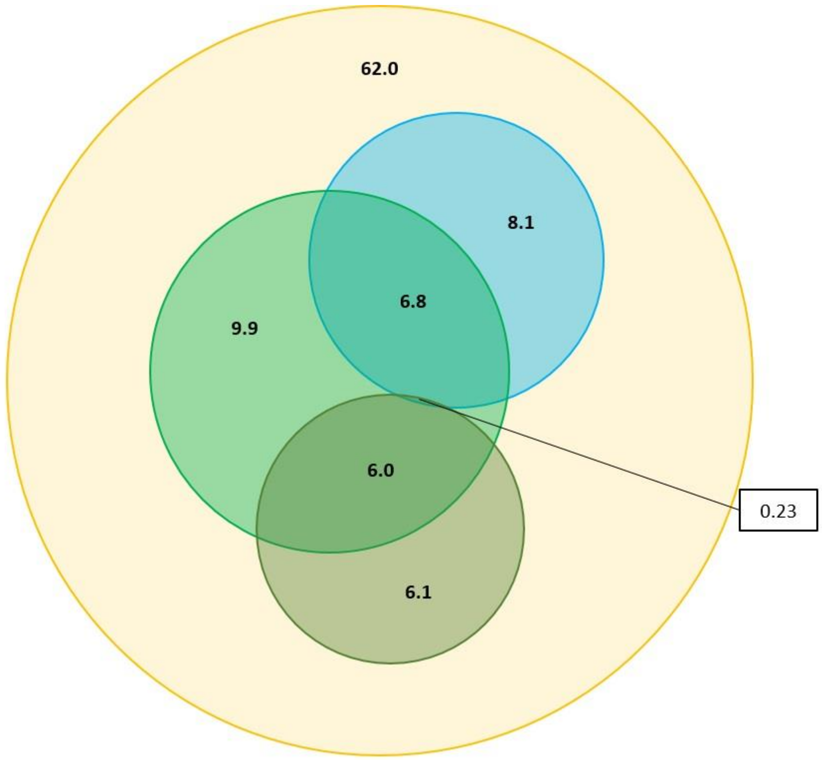
Research Summary:

As Arctic climate change continues and anthropogenic pressures increase it is imperative that a detailed baseline is established of the state of Arctic marine ecosystems before the impacts of these threats manifest further. To date, little is known about the functionality and structure of nearshore habitats and the communities within them. A multi-faceted approach was used to investigate the nearshore ecosystems around Point Barrow in order to gain a better understanding of how these imminent threats may affect the Arctic nearshore.

Building on the work of Johnson and Thedinga (2012), we established 12 sampling stations along the shorelines of the Chukchi Sea (n = 5), Beaufort Sea (n = 3), and Elson Lagoon (n = 4). These sampling stations were sampled by means of beach seines every week for 6 weeks during the shift from ice-covered to open-water at the beginning of summer (July 14th – August 23rd). Fish were enumerated and processed for stable isotope analysis. A multivariate and multiscaled approach were used to identify patterns that can function as a baseline for future monitoring efforts.

Research Performance Measure:

The objectives were: ***(1) To understand the abundance and distributions of communities in the three habitats that were sampled.*** We examined community structures across multiple spatial and temporal scales to identify patterns and limitations in fish distribution. ***(2) To understand what physical and environmental variables drive changes in community structure.*** We used multivariate Canonical Correspondence Analysis (CCA) models in variance partitioning to identify the variables that explain most of the variation in community composition. ***(3) To understand how Arctic nearshore foodwebs are structured and to identify major sources of carbon across the three sampled habitats.*** Stable isotope analysis of Nitrogen and Carbon were used on the most abundant species to understand how foodwebs are structures in all three habitats, as well as identify differences in carbon sources.



CCA	Model Equation	Constrained Inertia	Unconstrained Inertia	Percent Explained (%)	P value
[1]	E	1.8518	6.0877	**23.32**	0.001
[2]	S	1.0133	6.9261	**12.76**	0.007
[3]	T	1.2386	6.7008	**15.6**	0.001
[4]	E-S	1.3561	5.5701	17.08	0.001
[5]	E-T	1.2946	5.4063	16.31	0.001
[6]	E-(S+T)	1.6647	4.0412	**9.85**	0.001
[7]	S-E	0.5176	5.5701	6.52	0.002
[8]	S-T	0.9949	5.7059	12.53	0.001
[9]	S-(E+T)	0.4827	4.9236	**6.08**	0.001
[10]	T-E	0.6814	5.4063	8.58	0.001
[11]	T-S	1.2202	5.7059	15.37	0.001
[12]	T-(E+S)	0.6465	4.9236	**8.14**	0.001
Total Variance Explained:		**[1]+[7]+[12]**	**0.3798**	Unexplained Variance:	**0.6201**
		[2]+[4]+[12]	**0.3798**		
		[3]+[5]+[9]	**0.3799**	Total Inertia:	**7.9394**

Figure 1: A proportional representation of partitioned variance explained by ENV (green), SPT (grey) and TMP (blue) of the total variance in the community composition matrix (ASP, orange). Numbers on the diagram represent the % of variance in ASP explained by each portion of the ven diagram. More than half of the variance explained by ENV is also explained by SPT and TMP. However, SPT and TMP have almost no overlap (0.23 %). The results of variance partitioning are displayed in the table below the figure. Variance is represented by the sum of eigenvalues in constrained models (inertia). The total inertia in the ASP matrix was 7.9394. In the rows where the sum of constrained and unconstrained inertia does not equal 7.9394, the difference is what has been partialled out. The proportion of variance explained by each model is given in percents.

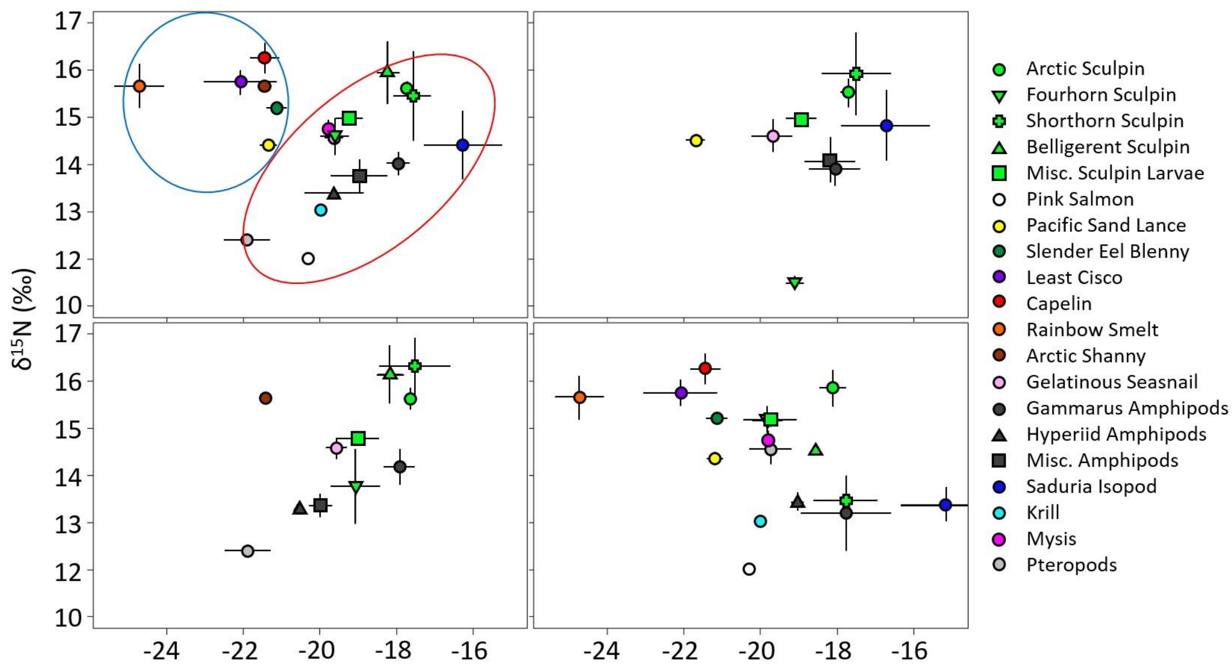


Figure 2: Stable isotope biplots of all samples (A), Beaufort Sea (B), Chukchi Sea (C), Elson Lagoon (D). Different colors represent different species groups. Points with the same color represent similar species, and shapes differentiate between them. Error bars represent standard error for $\delta^{13}C$ (x-axis) and $\delta^{15}N$ (y-axis).

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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 (FIU); D. Burkepile (UC Santa Barbara)

NOAA Collaborators: C. Taylor (NOS/NCCOS), 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 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 field survey incorporating hydroacoustics, divers, and stationary video camera deployments was developed to investigate the reported spawning locations. Field observations and compiled reports have been 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: Theo Brainerd

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 12 reef fish aggregations from 7 species were identified by resource users, extracted from the existing literature, and working relationships were built with local recreational users 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 identified peak reproductive periods for a range of species, providing important insight into the seasonality of FSA formation (Figure 1).

In the 2015/2016 period, additional reports were gathered from various sources and several of the reported aggregations were investigated further. Hydroacoustic surveys, along with 360-degree Remote Underwater Video surveys (360 RUV's), and diver visual surveys were performed at eight goliath grouper spawning sites in the Jupiter, Fl region to characterize the temporal and spatial nature of goliath aggregation behavior, and the reeffish community response to aggregation activity between July and November 2015. To address reports of a cubera snapper aggregation in the Homestead, Fl region, trip reports consisting of landings, fishing pressure, and reproductive organ state were gathered from a collaborating commercial charter fisherman between July and September. Additionally, hydroacoustic and 360 RUV's were performed at a historically recognized gag grouper aggregation site in the Boynton Beach, Fl region to assess the status of the reported aggregation between January and March 2016.

While the task of implementing dedicated field efforts to survey every reported aggregation is logistically infeasible, collaborating resource users can offer a wealth of knowledge and act as agents in the field to relay real-time information to researchers. Based on real-time information from resource users, a directed field effort can then be implemented to characterize and assess the status of the identified aggregations. This process of gathering information and developing a response program ensures the most effective use of resources, and is essential to future FSA research (Figure 2).

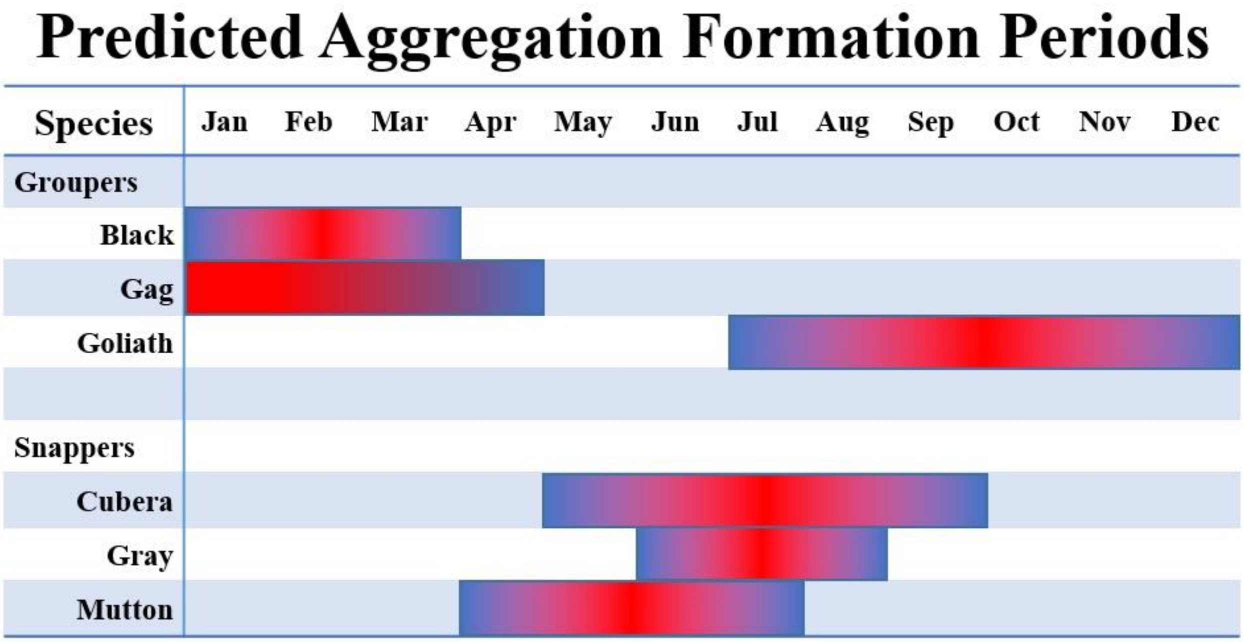

Figure 1: Seasonality of FSA formation for select species throughout the Caribbean as described in available literature, and by experienced resource users. Red areas represent estimated peaks in spawning activity.

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 these objectives, we have compiled a geospatial database consisting of 13 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 (Figure 2); and relayed this information to the SEFCRI working groups for the development of their regional management plan and Marine Spatial Planner (http://ourfloridareefs.org/tool/). Unfortunately, field efforts and user reports from both the gag grouper and cubera snapper aggregations suggest that they did not form during their respective spawning seasons in 2015/2016. Additional field efforts are required in upcoming seasons to confirm that these aggregations still occur, and the dynamic between researchers and resource users must be improved to expedite the exchange of information.

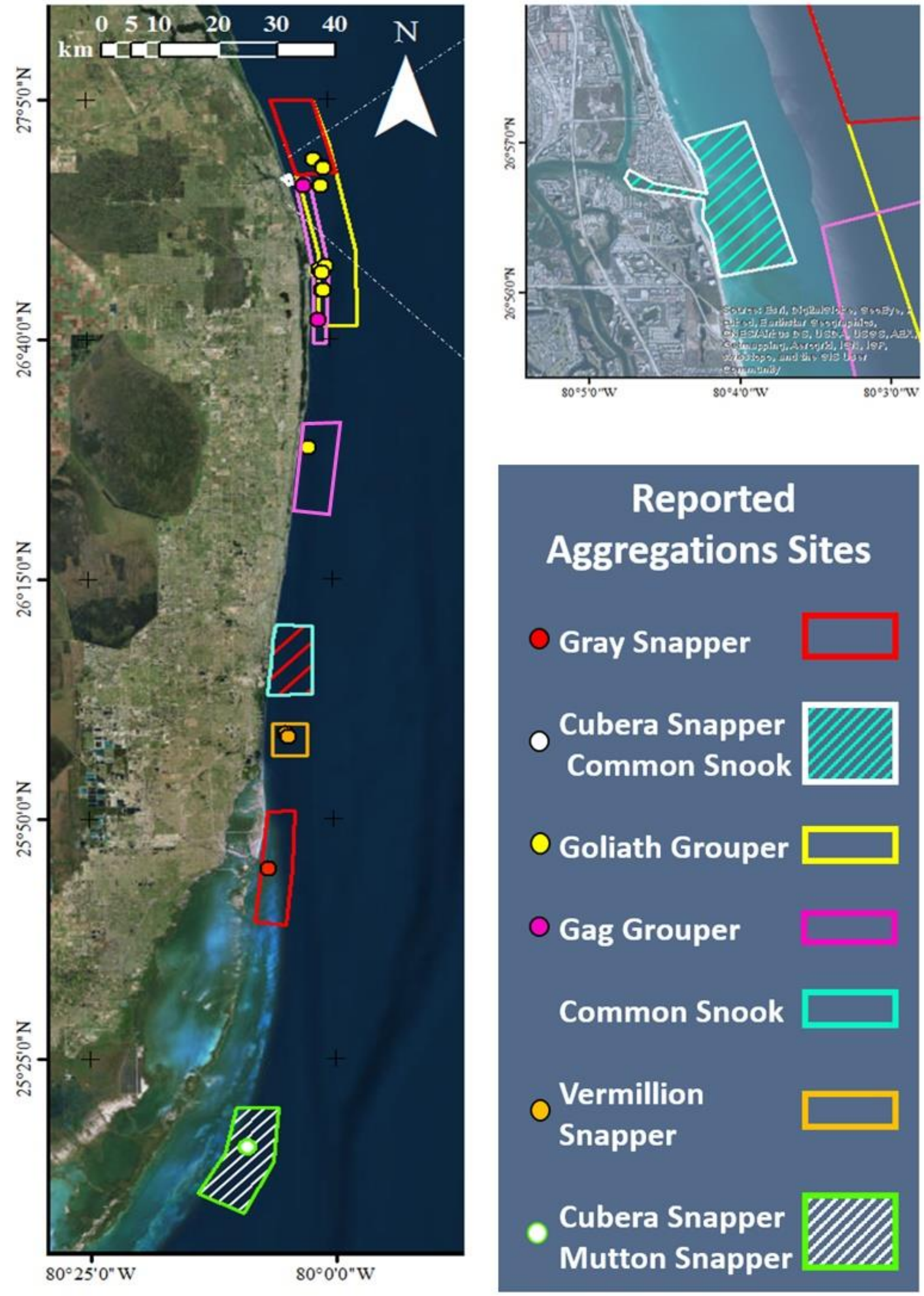

Figure 2: Reported aggregation sites were presented to the SEFCRI-TAC for the development of their regional resource management plan and Marine Spatial Planner (http://ourfloridareefs.org/tool/). Polygons are representative of a generalized aggregation area, while points relate to specifically identified aggregation locations.

Gulf of Mexico Integrated Ecosystem Assessment

Project Personnel: G.S. Cook, A. Gruss, K.A. Kearney, W. Harford and C. Quenée (UM/CIMAS)

NOAA Collaborators: C.R. Kelble (NOAA/AOML); M. Karnauskas, M. Schirripa and M. McPherson (NOAA/SEFSC); M. Jepson (NOAA/SERO)

Other Collaborators: 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 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, protection from storms, and buffers to pollution. These benefits, often described as ecosystem services, are one of the reasons that coastal communities are some of the fastest growing population centers in the nation, and the world. 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 coastal communities. To protect human communities in coastal regions will require an understanding of how these complex human-natural systems interact with one another, and multi-sector ecosystem-based management approaches that both protect and sustain marine ecosystems and the services they provide.

The Gulf of Mexico (GoM) is vital to the economic health of our nation. More than 8 million jobs exist in the coastal counties of the GoM, contributing between $5-6 billion annually to the US Treasury. From a biological standpoint this region also plays a critical role. There are over 15,000 species inhabiting the GoM, generating more than 1 billion pounds of commercial seafood, 44% of the US marine recreational catch, and comprising half of the nation's coastal wetlands. However, the footprint of the GoM extends well beyond the coastal waters of Texas, Louisiana, Mississippi, Alabama, and Florida. Through its upstream linkages it impacts and is impacted by 31 of the 50 states comprising the greater Gulf of Mexico

watershed. Clearly, sustaining the resilience of this marine ecosystem and the services it provides is vital to our nation and its economy.

Since the GoM is a vast and complex large marine ecosystem we have taken a scaled approach to exploring how this social-ecological system is structured and how it functions. At smaller geographic scales we are working with multiple 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 along the southeast Florida coast (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 a shift in composition of fishery landings in the GoM in the late 1970s that 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 provide recommendations on how resource managers can adjust to various climate regimes in the broader Gulf of Mexico.

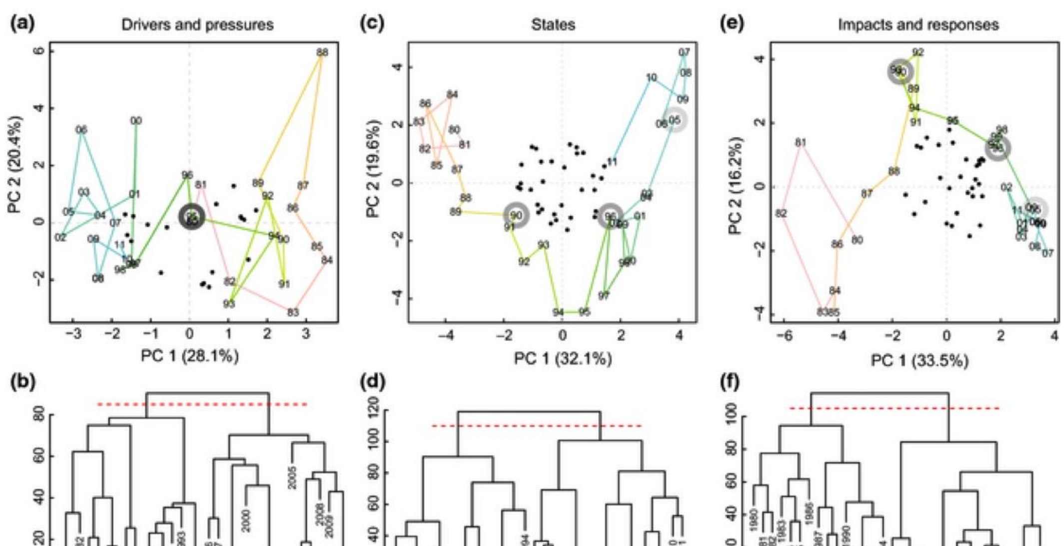

Figure 1: Multivariate analyses of three groups of ecosystem indicators: drivers and pressures (a, b), states (c, d), and impacts and responses (e, f). Top row (a, c, e): Yearly scores of first two principal components are plotted, based on principal components analysis (PCA) of ecosystem indicator values 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.

We used simulated management strategy evaluation to confront the effects of uncertain future occurrences of red tide-induced natural mortality on fishery harvests. The red tide dinoflagellate *Karenia brevis* episodically causes mortality to harvested fish stocks in the eastern Gulf of Mexico. Faced with the unpredictability of these natural mortality events, we evaluated whether and how precautionary harvest control rules (HCRs) or reactionary HCRs could lead to improvement in achieving fishery management objectives. Precautionary HCRs were those that reduced catches as an anticipatory means of mitigating possible future biomass declines, while reactionary HCRs relied on post-event responsiveness through catch adjustments to mitigate episodic natural mortality increases. We found that both precautionary and reactionary HCRs can lead to achievement of management objectives under sporadic and uncontrollable natural mortality increases. However, reactionary HCRs require timely management interventions and accurate assessment of fish stock status to produce benefits similar to those produced by precautionary HCRs. As ecosystem-based management becomes prominent in U.S. marine resource policy, management strategy evaluation can contribute to integrated ecosystem assessment. Integrated ecosystem assessment follows a spectrum of approaches from fishery-focused models to holistically-focused assessments of cumulative pressures on ecosystem services. At one end of this spectrum, our single-species approach incorporates environmental interactions into decision-support tools for fishery management.

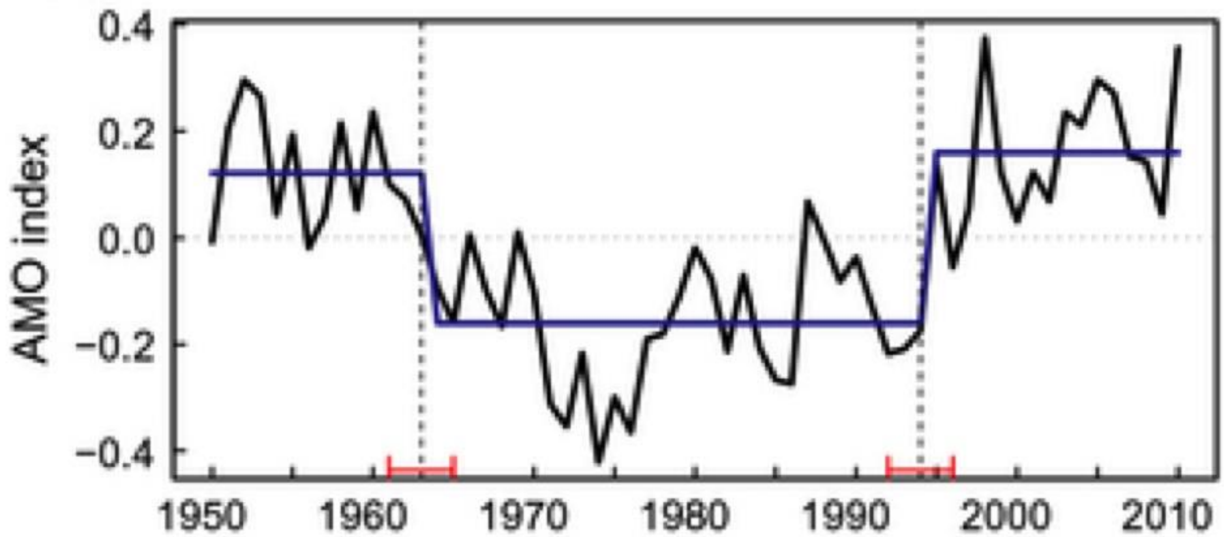

Figure 2: Time series of the Atlantic Multidecadal Oscillation (AMO), with significant breaks and their confidence intervals identified using a sequential F-test algorithm.

Through these projects we provide complementary frameworks for exploring and characterizing the various pressures threatening the sustainability of ecosystem services in coastal south Florida and the Gulf of Mexico large marine ecosystem. 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.

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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Targeted Products for Improving Ecosystem-Based Fishery Management in the Gulf of Mexico

Project Personnel: D. Die and X. Zhang (UM/RSMAS)
NOAA Collaborators: M. Karnauskas, C. Porch and M. Schirripa (NMFS/SEFSC)
Other Collaborators: J. Simons and H. Liu (Texas A&M)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** 1) To explore the utility of nonlinear time series (NLTS) models for forecasting stock abundance of fish populations in the Gulf of Mexico. 2) Support the development of a publically-available trophic database for the Gulf of Mexico

***Strategy*:** 1) To conduct NLTS analysis on abundance time series for East and West Gulf red snapper; to understand whether East and West stocks are dynamically coherent; to examine possible associations between the stock trends of Gulf red snapper and other relevant species and environmental variables. 2) 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; edit and test all extracted data that is loaded into the GoMexSI database; and continue to refine and enhance the GoMexSI database and webpage interface.

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 nonlinear time series modeling portion of this work is nearing completion, with a final publication in review. We found that fisheries-independent indices, representing age classes that have not yet recruited to the fishery, display higher dimensionality than fisheries-dependent indices. This result suggests that

for the heavily exploited Red snapper, fishing has reduced the number of important processes controlling the population. Also of note, we observed lower dimensionality and higher predictability of abundance indices of the eastern subpopulation of red snapper, which has historically undergone heavier fishing pressure than the western subpopulation. Additionally, two indices in the Eastern Gulf demonstrated significant nonlinearity, consistent with the notion that fishing can intensify nonlinear fluctuations in fish abundance, as subtle changes in fishing behaviors by fleets have dramatic influences on the fisheries.

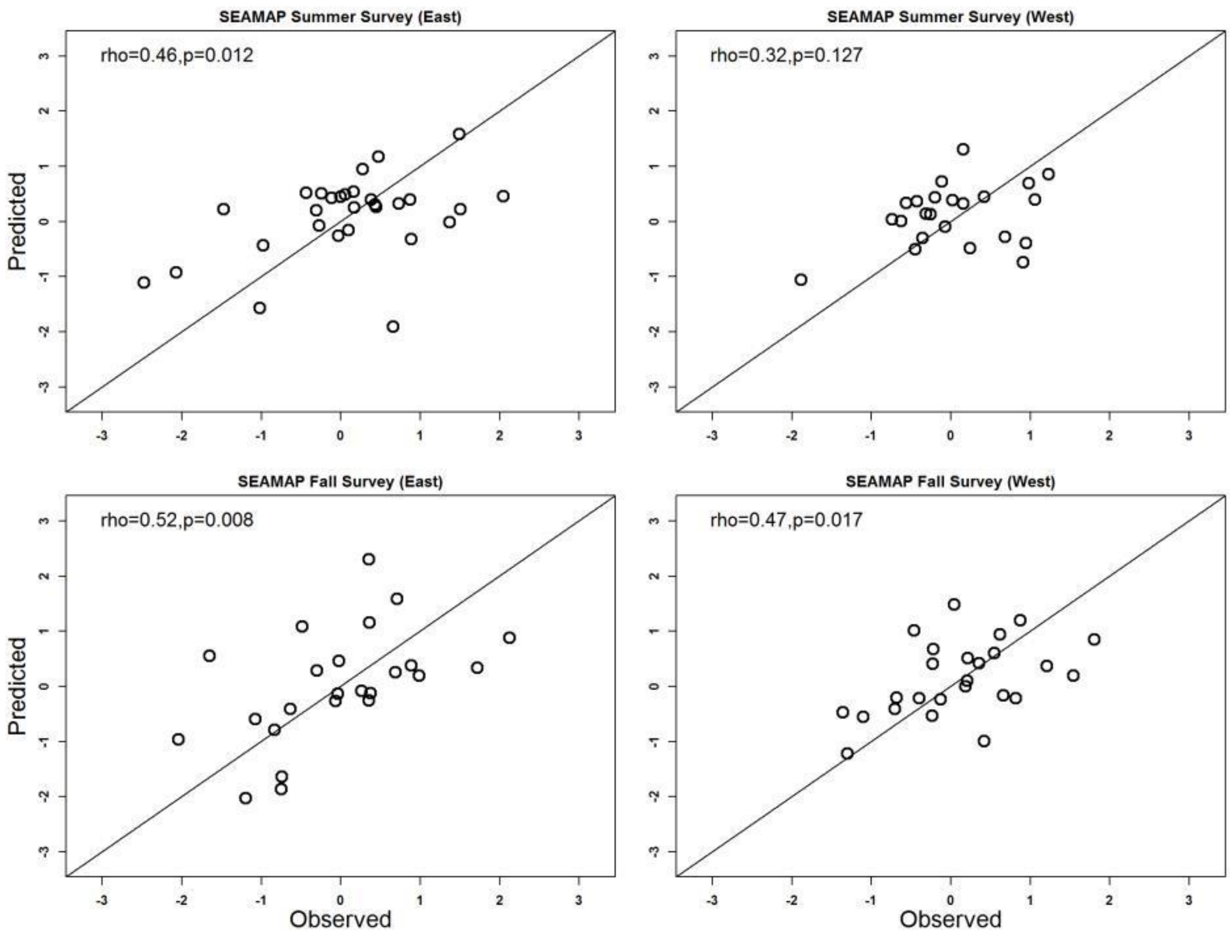

Figure 1: Performance of nonlinear time series forecasts of fishery-independent indices of Red snapper abundance from SEAMAP surveys, for East (left column) and West (right column) subpopulations, and summer (top row) and fall (bottom row) surveys.

The second component of this project is the Gulf of Mexico Species Interaction (GoMexSI) database, 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 approximately 800 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 approximately 200 (25%) of these references, which represent 122 unique data sources. Including all prey items, we have identified, and have in the database, 1,744 unique interactors. There are currently 74,649 lines of species interaction data in the GoMexSI database, of which 14,048 were extracted as a result of this CIMAS project. These data come from all over the Gulf and its estuaries (Figure 2). 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.).

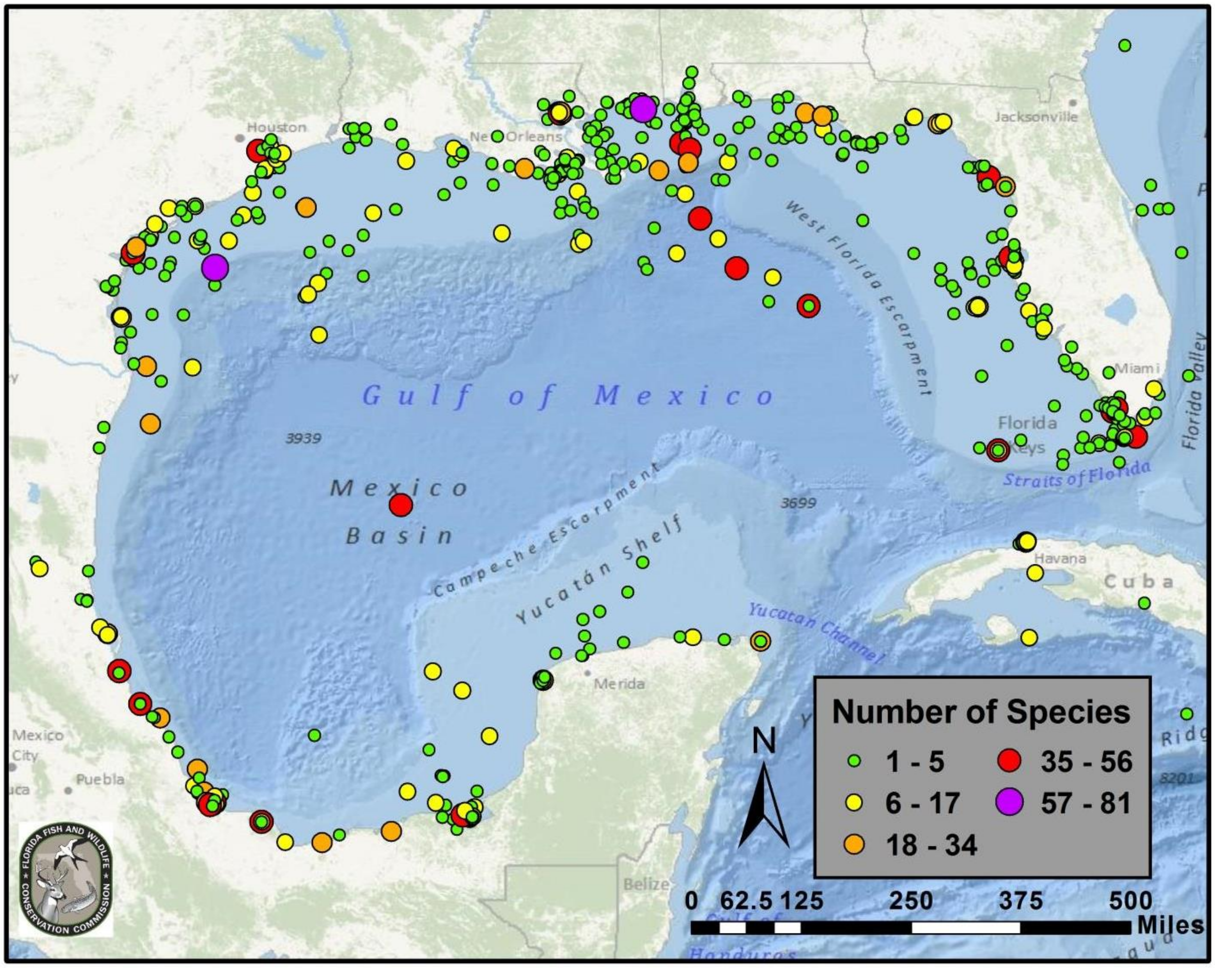

Figure 2: Map showing the location of the centroids of 747 of the nearly 800 fish diet references we have obtained from the Gulf of Mexico, with the size and color scale of the point giving an indication of the number of fishes examined for diet.

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).

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

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 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 2).

Research Performance Measure: All objectives for this project are complete, with exception of two remaining peer-reviewed publications, which are being prepared for submission at this time.

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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, L.M. Rutten (NSU)

NOAA Collaborators: J. Schull (NOAA.SEFSC); A. David (NOAA/SEFSC, Panama City Lab)

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.

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) NOAA Technical Memorandum that is in review; and 3) a website that includes project materials, photographs, and more that is published at www.florida-octocorals.org.

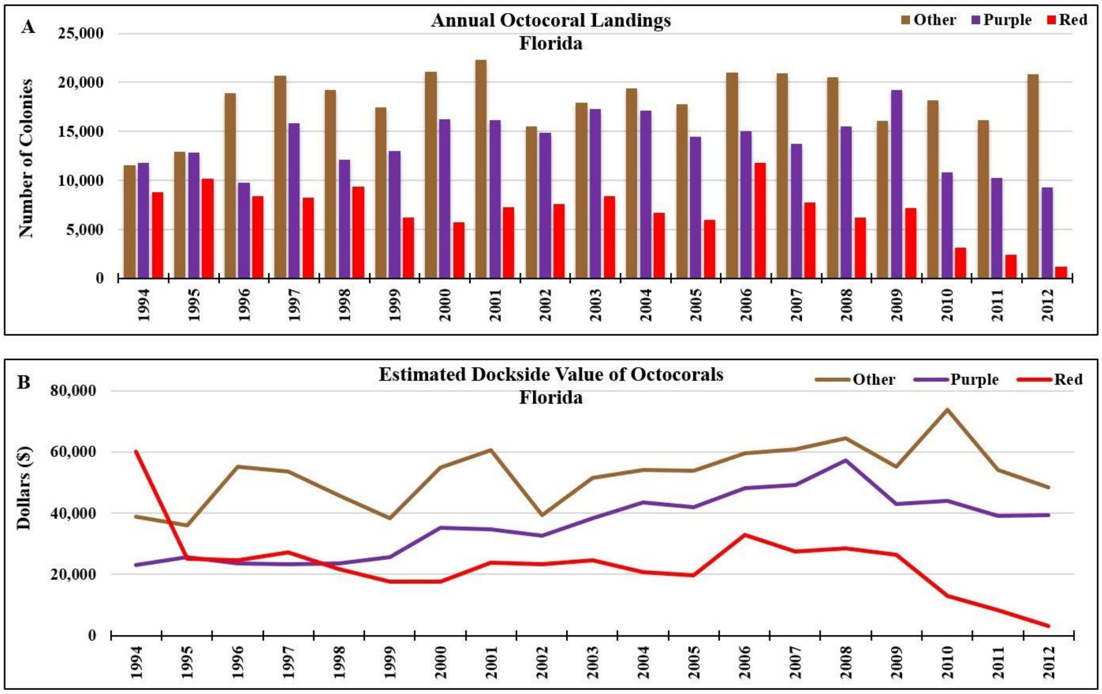


Figure 1: (A) Annual octocoral landings and (B) dockside value of octocoral species groups (other, purple, and red) in State and Federal waters off Florida, 1994-2012 (unpublished commercial octocoral collection data from FWC).

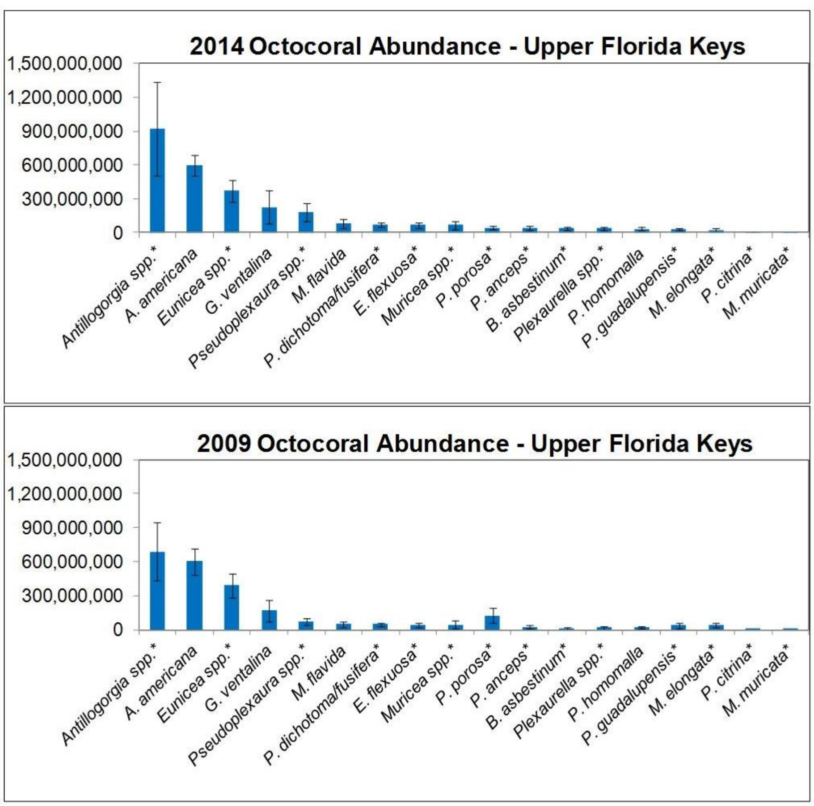


Figure 2: Octocoral abundance in the upper Florida Keys (Carysfort, northern Key Largo to Alligator Light, Upper Matecumbe Key), based upon surveys during 1999-2002, 2005, 2009, and 2014. Species are ranked along the x-axis from high-to-low based upon 2014 data. Error bars represent 95% confidence intervals. Octocoral species or genera targeted in the octocoral fishery are indicated with an asterisk (*).

Net Revenues of the Federal Fin-Fish Commercial Fisheries in the Gulf of Mexico

Project Personnel: E. Overstreet (UM/CIMAS)
NOAA Collaborators: C. Liese (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:

With the departure of another contracted employee in June 2015, the contractor assumed additional duties relating to the management of two economic data collections. Validations have been created to clean the already collected economic data. These validations were also implemented in the database to ensure a higher quality of the economic data being reported to the coastal logbook database. The contractor is also working on creating automated reports which summarize various commercial fishery segments of the Gulf of Mexico and the South Atlantic; equations to estimate net revenues for these segments have been built and are being tuned.

The attached figures are examples of the output being generated by the one of the automated reports. Both figures are for estimated revenue of reef fish fisheries managed by the Gulf of Mexico Fishery Management Council (SOI).

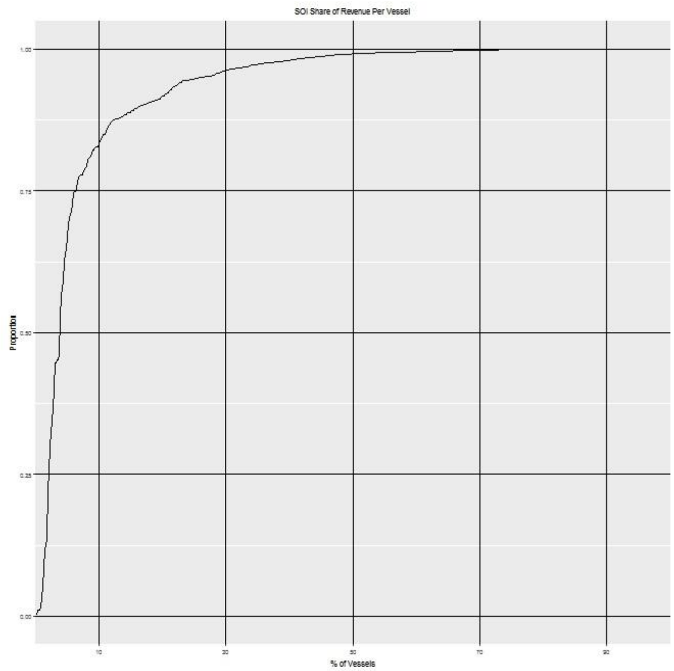


Figure 1: A graph showing the SOI share of estimated revenue per vessel. Vessels were arranged based on an increasing SOI share. Where the horizontal dashed line intersects the curve indicates the percent of vessels where the percent of SOI share was 50% or less.

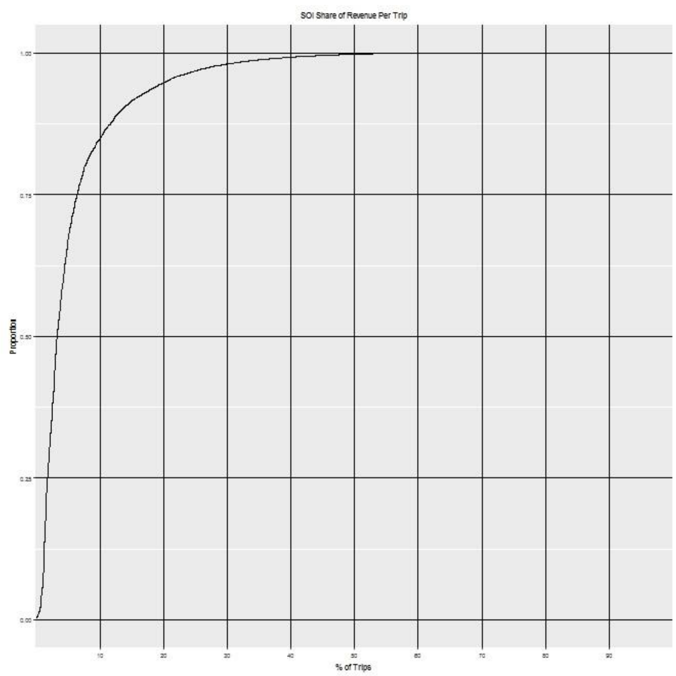


Figure 2: A graph showing the SOI share of estimated revenue per trip. Trips were arranged based on an increasing SOI share. Where the horizontal dashed line intersects the curve indicates the percent of trips where the percent of SOI share was 50% or less.

Research Performance Measure: Progress is being made toward economic analysis of economically and statistically meaningful sub-populations of the SE federal fin-fisheries (including at the trip- and annual/vessel-levels). The quality of the ongoing data collection has been significantly improved.

Support for the Marine Resource Assessment Program at the University of South Florida College of Marine Science

Project Personnel: E. Peebles and 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 under the "MRA Core Courses" heading in Section VII: Education and Outreach. 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,

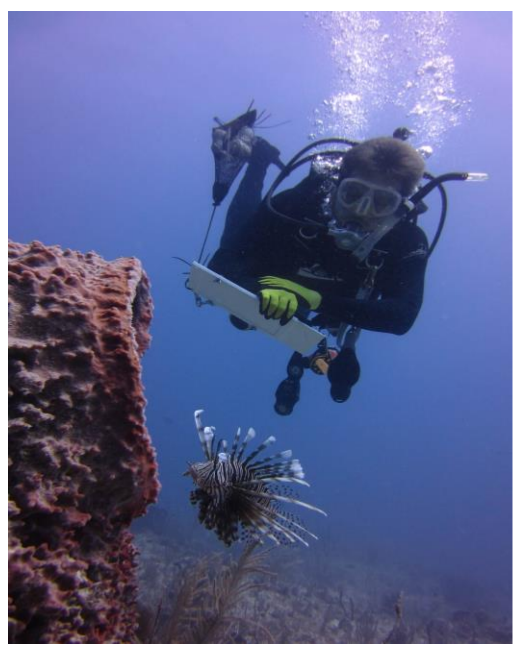


Figure 1: USF MRA faculty member Dr. Chris Stallings conducting a lionfish survey in Biscayne Bay, Florida.

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.

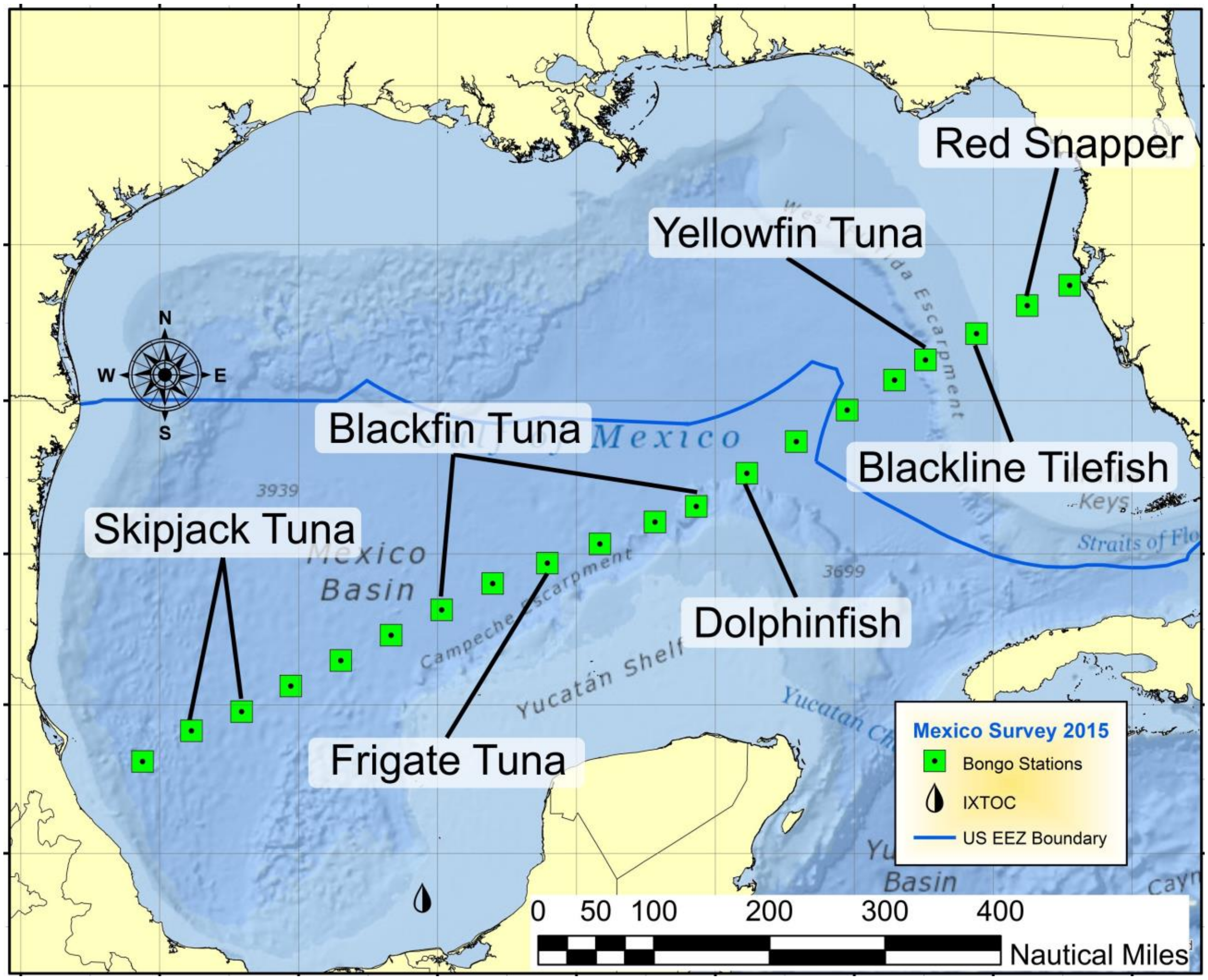


Figure 2: Selected fish-egg identifications based on DNA barcoding by USF MRA faculty Drs. Ernst Peebles and Mya Breitbart. This Fall, 2015, cross-Gulf transect took advantage of a return trip from MRA-related work in Mexico that was being conducted by USF MRA faculty member Dr. Steve Murawski. A total of 19 egg species have been identified from this series of 20 plankton samples.

There are currently 27 fulltime USF-CMS students participating in the MRA program, with 8 being Master's students and 19 being doctoral students. The present award provides fellowships for 5 of the 27 students; all 5 are doctoral students. The remaining 22 MRA students work as Graduate Assistants on research grants and compete for internal and external graduate fellowships.

Figure 3: Reef fish collected for fecundity analysis by USF MRA faculty and students (Ernst Peebles 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. 4). 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.

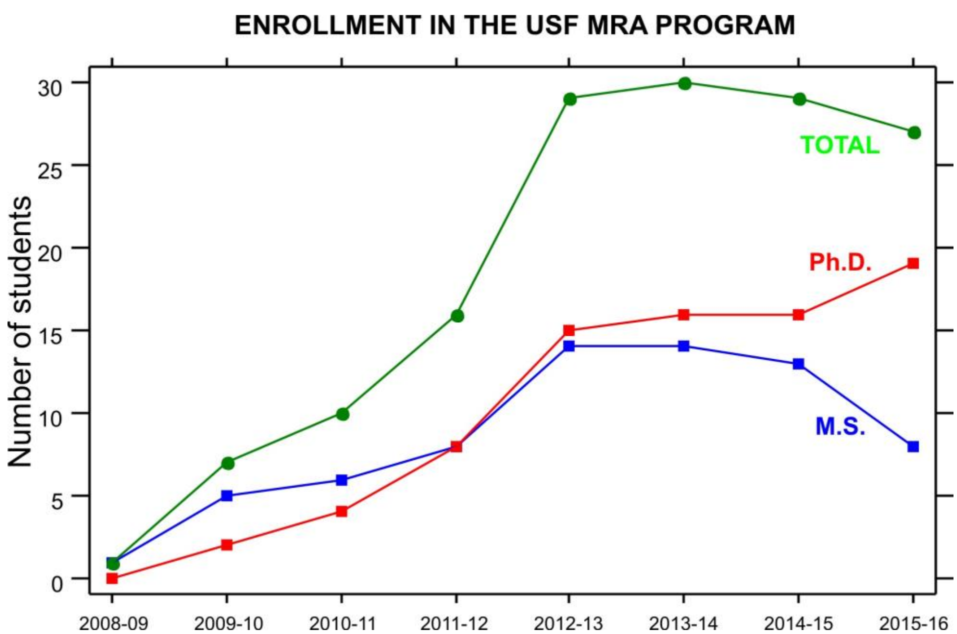


Figure 4: Enrollment in the USF-CMS Marine Resource Assessment (MRA) program by type of student and academic year.

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 (63%) or pursue a doctoral degree (25%). 12% have left the field.

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 Unified Data Processing system (UDP) and pelagic individual fish weight data for entry in the Pelagic Weigh-out Receipt (PWR) system, including efforts to improve compliance and quality control; 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).

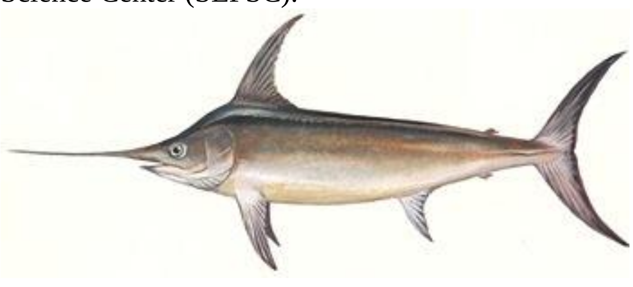


Figure 1: *Xiphias gladius*, the swordfish (www.safmc.net**).**

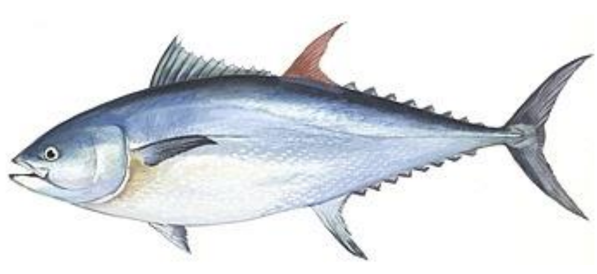
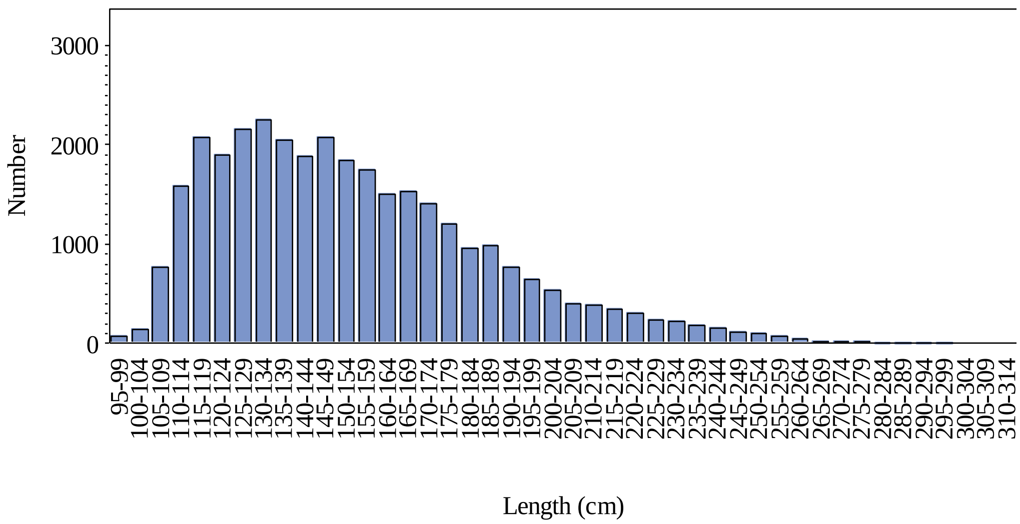


Figure 2: *Thunnus thynnus*, the Atlantic bluefin tuna (www.safmc.net**).**

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, previously held in the Domestic Longline System (DLS), is now processed within UDP to better integrate catch and effort data. This integration allows for automated reports used in annual ICCAT assessments, further streamlining the assessment process.

A)



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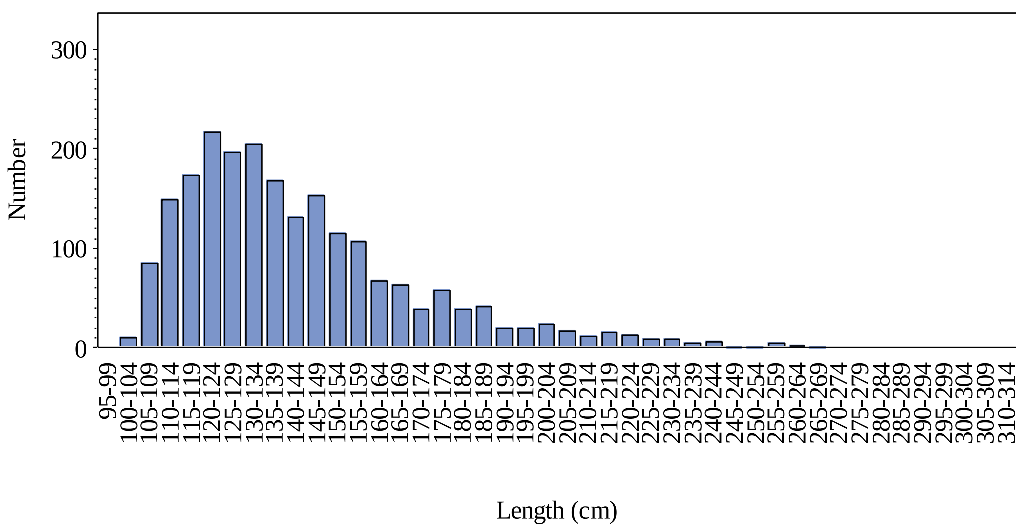

Figure 3: Length frequency (lower jaw fork length, in cm) of swordfish caught in commercial (A) longline and (B) hand gear fisheries obtained from catch as size (CAS) data reported to the Pelagic Longline program for 2014.

Research Performance Measure: One hundred twenty-nine validations designed to improve logbook data quality have been integrated into UDP. One hundred twenty vessels have been contacted about missing or invalid information submitted on logbooks for 429 distinct trips since 1 July 2015.

Southeast Florida Coral Reef Fishery-Independent Assessment: Year 4

Project Personnel: R.E. Spieler, K. Kilfoyle, B.K. Walker (NSU); J. Blondeau (UM/CIMAS)
NOAA Collaborators: 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, DERM)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** The goal of the FIA is continued implementation of a statistically robust, habitat-based, tiered protocol to assess coral reef fish populations in the southeast Florida coral reef segment. This project not only expands upon the previous Reef Visual Census (RVC) work done in the SEFCRI region (Kilfoyle et al., 2014), but also ongoing work in Biscayne National Park (BNP), the Florida Keys National Marine Sanctuary (FKNMS) and Dry Tortugas National Park (DTNP) to include fishery-independent data collections along the entire Florida coral reef tract. By using equivalent methods, the FIA and RVC will provide statistically comparable data for reef fish along the entire Florida Reef Tract (Dry Tortugas to St. Lucie Inlet). The FIA will inform the current state-led Local Action Strategy (LAS) efforts which are implementing conservation and management actions on coral reefs within state waters off southeast Florida.

***Strategy*:** The FIA project contains 4 primary tasks: 1) project planning and update of sampling design, 2) fieldwork, 3) data analysis, and 4) report writing. 1) SEFCRI partner agencies have hired and trained NSU personnel to conduct the fishery-independent assessment of the southeast Florida region and refine subsequent sampling designs using the previous three years' worth of data; 2) NSU will conduct field sampling using the RVC protocol at sites identified with the statistical methods used in the previous FIA designs. 3) NSU will perform an analysis of the data collected to provide statistically robust trends of reef fish size, distribution and abundance within each mapped habitat and for the entire region. 4) NSU will provide the raw data and analyses to NOAA at the end of the full 5-year project in 2017.

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/NOS/CRCP
NOAA Technical Contact: Dana Wusinich-Mendez

Research Summary:

From June through the end of October 2015 we performed visual census surveys of coral reef fish abundance and species richness during the course of >500 individual dives at 130 sampling stations. A further 300 survey dives at 79 sampling stations were completed by partner agencies (FWC, FDEP-CRCP, Miami-Dade County/DERM, Broward County/DERD), with methodology training, logistical coordination assistance, and data collection oversight provided by NSU (with assistance from NOAA-SEFSC support staff). FWC sampled all sites in the far northern portion of the survey domain: Martin County. Broward County sampled a small selection within Broward County. FDEP-CRCP and Miami-

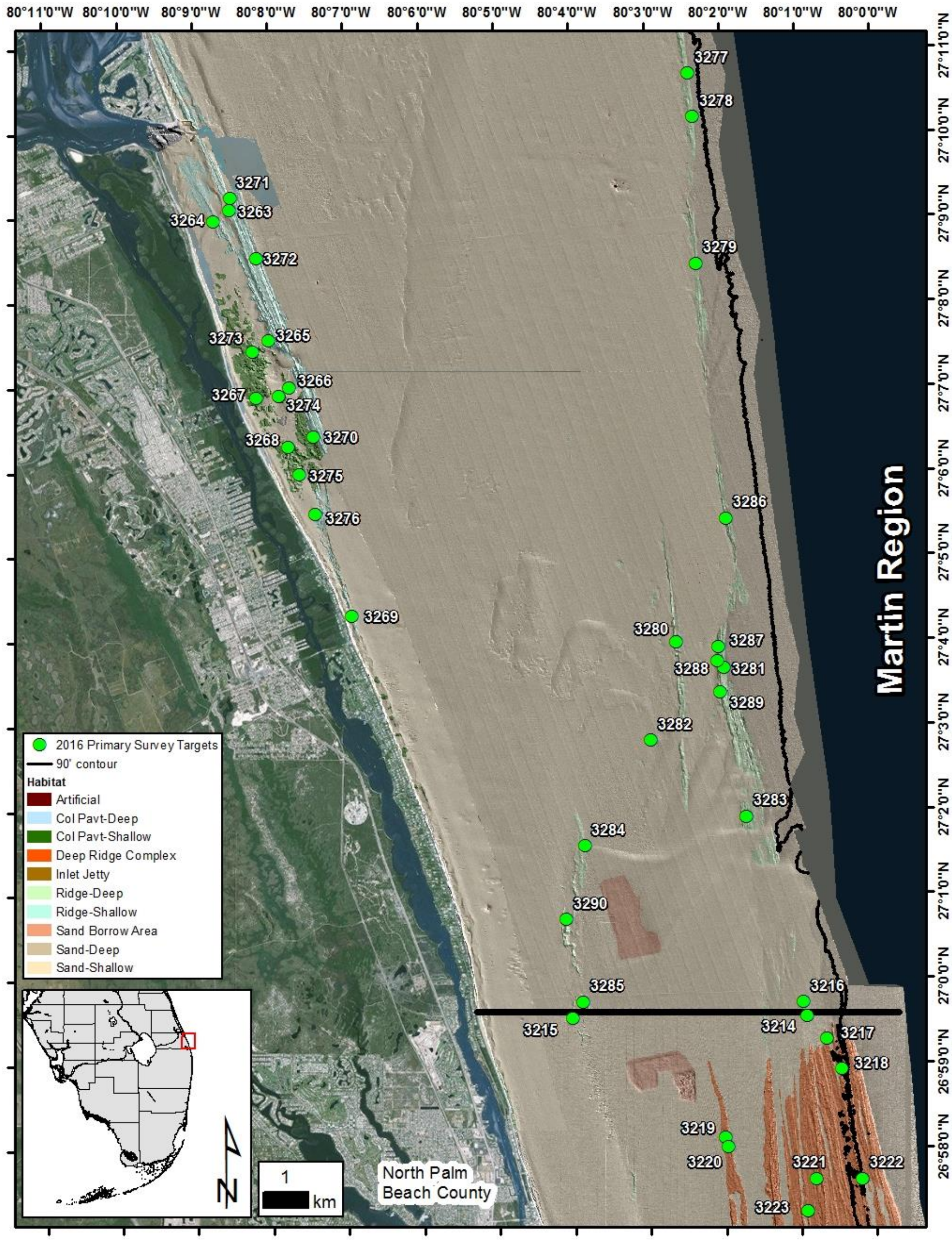

Figure 1: Site maps for Martin region.

Dade County/DERM both collected the majority of the sites in the far southern portion of the survey domain, mainly sites south of Haulover Inlet. NSU sampled all remaining sites from Jupiter Inlet to Government Cut.

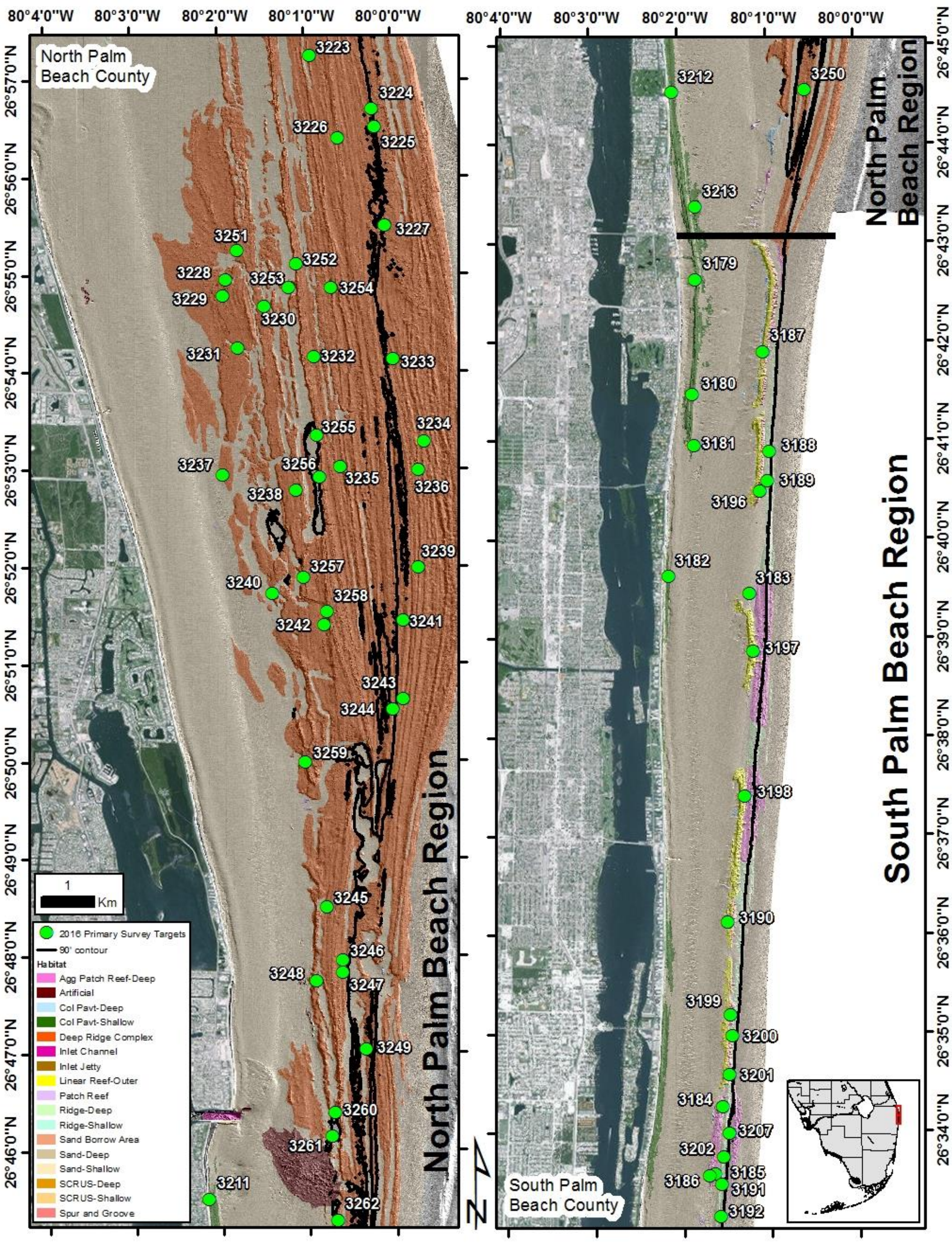

Figure 2: Site maps for North and South Palm Beach regions.

With all four years of data combined, >692,500 individual fishes were counted, representing >300 species domain-wide. With each year of sampling, new species are added to the master RVC species list that was informed by previous Florida Keys and Dry Tortugas datasets. New additions from year 4 include: Pacific Orbicular Batfish (*Platax orbicularis*), Southern Stargazer (*Uranoscopus y-graecum*), Bantam Bass (*Parasphraenops incisus*), and Bank Butterflyfish (*Prognathodes aya*).

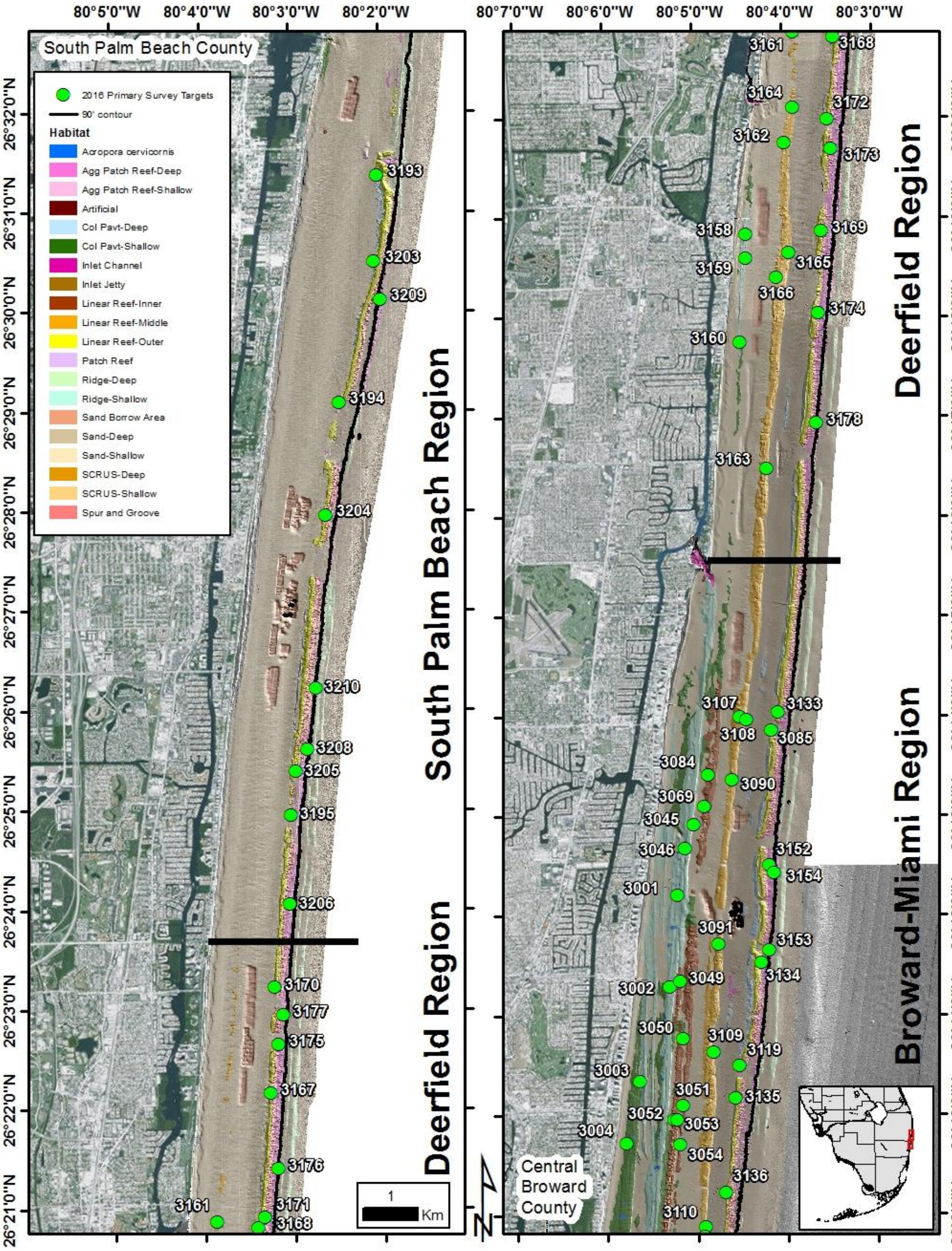

Figure 3: Site maps for South Palm Beach, Deerfield, and Broward-Miami regions.

In November 2015, all data entry was completed and proofed for errors by each individual survey diver. This was immediately followed by a rigorous quality assurance/quality control procedure with assistance from NOAA-SEFSC support staff. Following that, in early 2016, the process of creating an analysis-ready dataset was initiated, along with getting the data into a format that could be used to further refine the survey design and perform the sample allocation procedure. The analysis-ready dataset was completed in the spring, and field sampling for the 2016 season began in May.

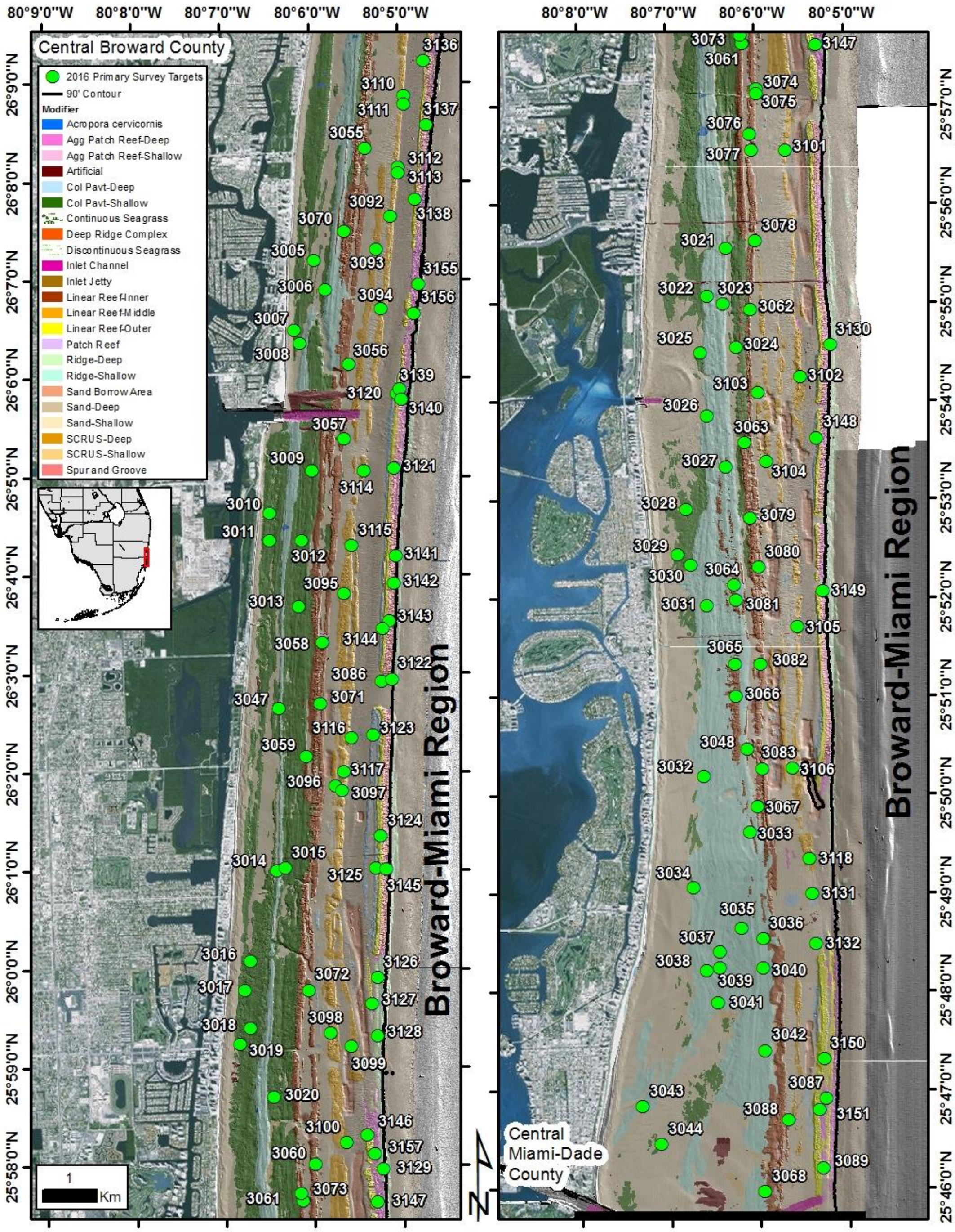

Figure 4: Site maps for Broward-Miami regions.

Research Performance Measure: The FIA Year 4 project was completed as scheduled. The sample allocation was based on NSU completing surveys at 100 out of an estimated total of 224 sites likely to be surveyed throughout the entire SEFCRI survey domain by the combined efforts of NSU and the other partner agencies that contributed with *pro-bono* support. NSU completed surveys at 130 out of a total of 209 sites that were surveyed by all parties (62%).

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 evaluate reef-scale changes in distribution and abundance of elkhorn and staghorn corals.

***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) Reef-scale surveys to re-assess *Acropora* spp. population in areas surveyed in 2006. 3) Periodic assessments of other Caribbean *Acropora* spp. populations. 4) In 2014 and 2015, successive warm-stress-induced mass bleaching events were 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 twelfth year of thrice yearly surveys in the upper Florida Keys and tenth 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). To evaluate larger scale changes in distribution of *Acropora cervicornis* and *A. palmata*, selected reef sites were surveyed by a snorkeler who marked locations of each *Acropora* spp. colony. Initial surveys were conducted in 2006, and selected sites were resurveyed at for comparison in 2014 and 2015.

During summer 2015, we observed bleaching among the upper Florida Keys *A. palmata* population for a 2nd consecutive year. Bleaching response varied between sites but was remarkably consistent with the response observed at these sites during the 2014 bleaching event. Temperature sensors deployed at each site documented daily average water temperatures that were slightly lower than 2014 however the duration of elevated/stressful temperatures (>31 ºC) was longer in 2015 than 2014. Overall, we estimate that approximately one third of live tissue area of the focal *A. palmata* population was lost during each bleaching event (i.e. between our planned seasonal surveys in June and February of the following year),

or 50% loss between spring 2014 (prior to 2014 bleaching) and spring 2016 (following both bleaching events). In 2005, the upper Florida Keys populations suffered similar losses associated with the 2005 hurricane season, and recovery was only minimal over the ~ decade prior to the recent bleaching events.

Based on low resolution reef-scale surveys, *A. palmata* showed a small but negative trend in density between 2006 and 2014. Over this same time period, *A. cervicornis* increased in density at sites where active population enhancement (by Coral Restoration Foundation) has occurred and decreased at sites where it has not. Both species decreased in density (regardless of restoration efforts) between 2014 and 2015 following the 2014 bleaching event.

While the Florida Keys reefs have experienced moderate bleaching events in the past decade, this is the first severe bleaching event to affect local *A. palmata* since the 1998 El Niño-associated bleaching event (Miller et al. 2002).

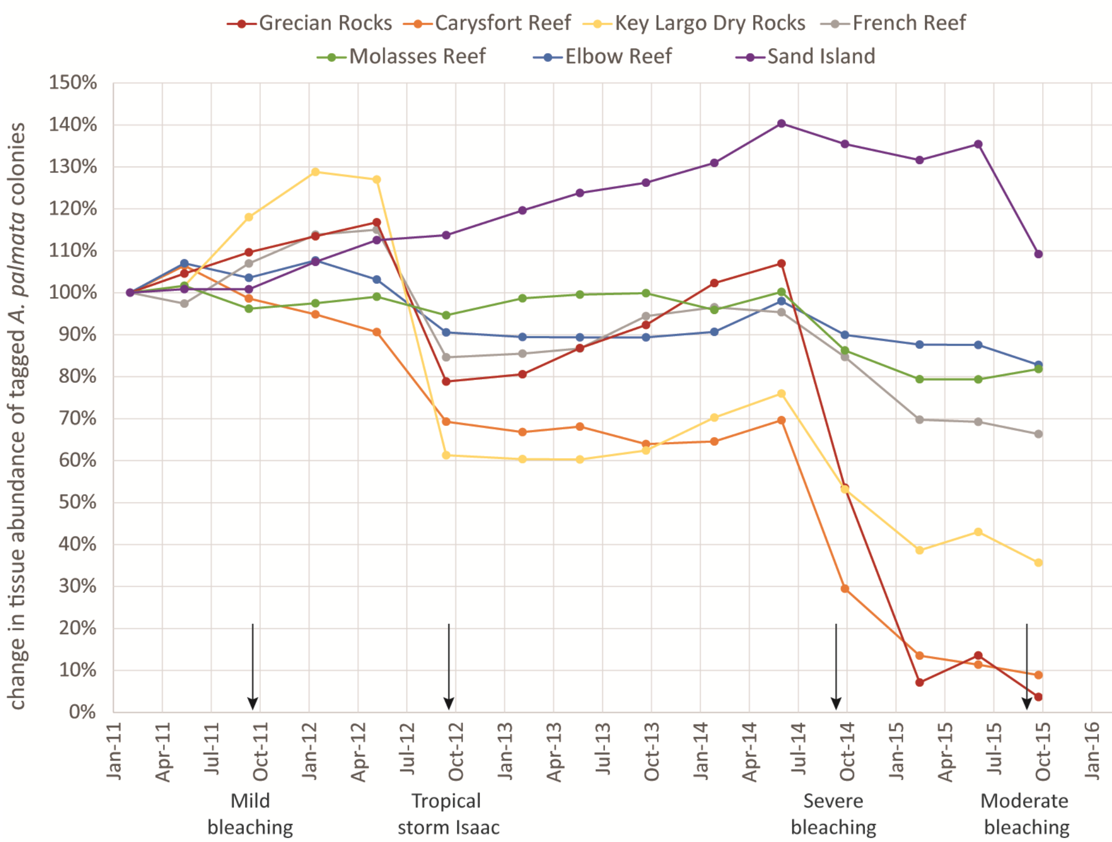

Figure 1: Relative change in live tissue abundance of tagged *Acropora palmata* colonies in upper Florida Keys monitoring plots expressed as a percentage of the 2010 abundance.

Research Performance Measure: All planned monitoring surveys of the Florida Keys sites were conducted as scheduled with two additional (unplanned) surveys conducted in the Florida Keys during fall 2015 to fully document the second bleaching event affecting the population. In 2015, 16 reef-scale surveys were conducted for comparison to 2014 and 2006 surveys. Manuscripts for both survey components are in prep for peer-reviewed publication.

RESEARCH REPORTS

THEME 7: Protection and Restoration of Resources

Using SEDAR-Assessed Stocks to Validate the Accuracy of Data-Poor Methods

Project Personnel: R. Ahrens (UF)
NOAA Collaborators: Jim 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 3**:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

NOAA Funding Unit: OAR/CIPO
NOAA Technical Contact: Elizabeth Perez

Research Summary:
Many marine fish stocks in the Southeast do not have sufficient data to allow for traditional stock assessments to be conducted. While these 'data-poor' stocks are present in all regions of the United States, 75% of stocks and stock complexes in the Southeast can be considered data-poor: they have only catch history data available to inform management reference points such as legally-required Annual Catch Limits (ACLs). Such limited data also cannot produce informed estimates of maximum sustainable yield (MSY), nor generate accurate overfishing limits (OFLs). However, data-poor stock assessment methods

such as depletion-corrected average catch (DCAC) and depletion-based stock reduction analysis (DB-SRA) do exist and have been used to produce reference points for a number of data-poor Pacific stocks, but have not yet been applied to stocks in the Southeast. This study compares MSY and OFL estimates from Southeast Data, Assessment, and Review (SEDAR) stock assessments to those produced by data-poor methods for the same stocks, using the same SEDAR-sourced data, in order to determine the accuracy of the data-poor methods at estimating MSY and OFL for stocks in the Southeast. Three forms each of DCAC and DB-SRA, two surplus production methods (SP-MSY and SP-SRA), and an additional mean length-based method (FDem ML) were tested.

Based on this analysis, there is no stand-out method when considering assessments of data-poor stocks in the Southeast. In spite of relative poor performance in accurately replicating reference points from full stock assessments, DCAC, DB-SRA, and SP-MSY (Figure 1) may still be preferable to scalar methods, which have been shown to provide poor bases for management when stocks are below *BMSY*, a level at which data-poor stocks in the Southeast almost certainly are given the region's characteristics. In terms of demonstrated overall appropriateness, DCAC-based methods tend to produce the most precautionary OFLs and therefore may be the most useful methods to consider against the use of traditional scalar methods. SP-MSY, with its moderate trend of underestimation and very light data requirements, may be a better alternative for the most data-poor of stocks in the Southeast. DB-SRA-based methods could also be considered for data-poor Southeastern stocks, however their imprecision and higher data requirements lessen their appeal when viewed in light of DCAC-based methods, which are more precise and precautionary, and SP-MSY, which has very similar overall accuracy to DB-SRA-based methods. If catch-at-length data is available, Fdem ML may be a potential option, but it does not perform as well overall as depletion-based methods and requires additional inputs. Obtaining standardized input data for data-poor stocks should be a priority of stock assessment scientists. That may entail shifting focus towards the use of data-borrowing methods and improving the quality of the data we already have for data-rich stocks so that it can be used in methods such as SP-MSY.

DCAC using the surrogate input parameter values recommended by the original publications describing DCAC and DB-SRA may also be a viable and precautionary data-poor method for many stocks in the Southeast, especially for those stocks with life histories that are somewhat similar to groundfish (Figure 2). More congruent performance to SEDAR-informed models beyond DCAC, and perhaps even more accuracy, may be achieved if a set of surrogate parameters are developed specifically for regional and life history groups within the Southeast. It may ultimately be more economical and efficient to develop specified surrogate parameters than to spend resources trying to improve the available data for multitudes of individual stocks.

When assigning data-poor methods to real-world data-poor stocks, the amount of risk managers are willing to assume relative to the achievement of stated goals for a stock should be the first consideration. For some data-poor stocks, a high risk of overexploitation may be unacceptable for cultural, ecological, or economic reasons, and a method with demonstrated precision and precautionary tendencies–in this case, DCAC-based methods–should be employed. In other cases, where the main goal of management is solely the procurement of consumable biomass and there is no indication that overexploitation presents a significant and continuing risk to this goal, or the risk is viewed as acceptable in order to achieve this goal, less precise methods such as SP-MSY and DB-SRA-based methods can be utilized. Ergonomically, SP-MSY may be the most appropriate method for Southeastern data-poor stocks due to its extremely low and obtainable data needs and its acceptable accuracy relative to other methods. In some cases, especially for stocks in the Caribbean, there may not even be enough information available or able to be borrowed to inform SP-MSY, let alone depletion based methods. For such stocks, scalar methods will have to remain the default management strategy, and will likely remain as the default methods even for stocks that can go through other methods if the results of scalar methods align more closely with those stocks' management goals. While no single data-poor method can serve as a panacea to the issues facing stock assessments for

data-poor stocks in the Southeast, given their performance relative to other data-poor stock assessment methods, DCAC-based methods, SP-MSY, and DB-SRA-based methods should be recognized as useful tools for stock assessment scientists when faced with setting catch limits for data-poor Southeastern stocks. Additionally, until Southeast-specific parameters are developed, the use of DCAC with the surrogate input parameter values tested in this analysis may be a viable, albeit last-resort, option for developing catch targets for Southeastern stocks that have no data other than a time series of catch.

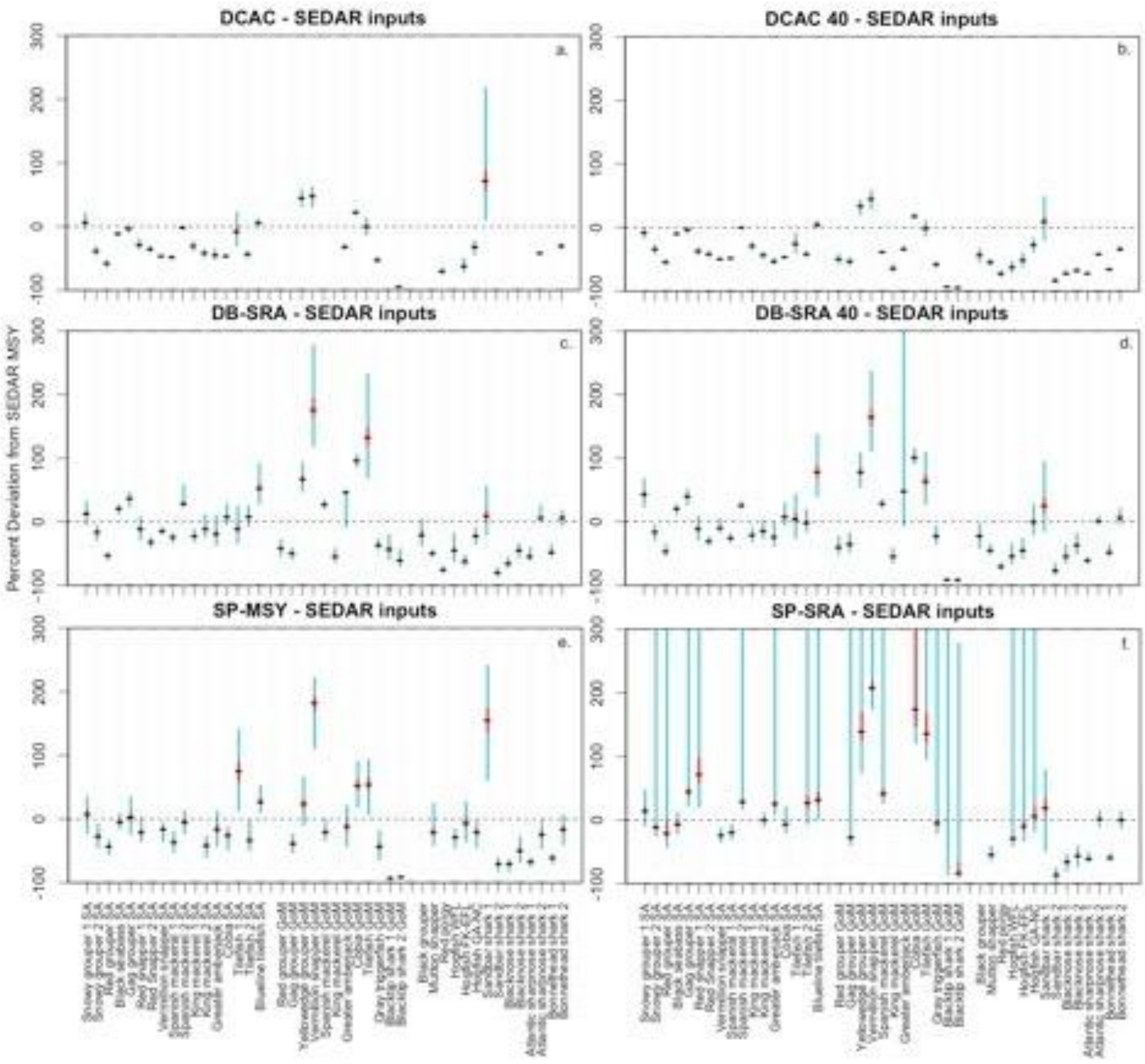

Figure 1: Percent deviation of medians and confidence intervals of MSY estimate distributions produced by each method from the SEDAR MSY value for each stock, where (a) is DCAC, (b) is DCAC 40, (c) is DB-SRA, (d) is DB-SRA 40, (e) is SP-MSY, (f) is SP-SRA, and (g) is Fdem ML. Medians are represented by black lines, the 80% confidence interval is represented by the blue region, and the 20% confidence interval is represented by the red region. The dotted lines represent 20% deviation around the SEDAR OFL value.

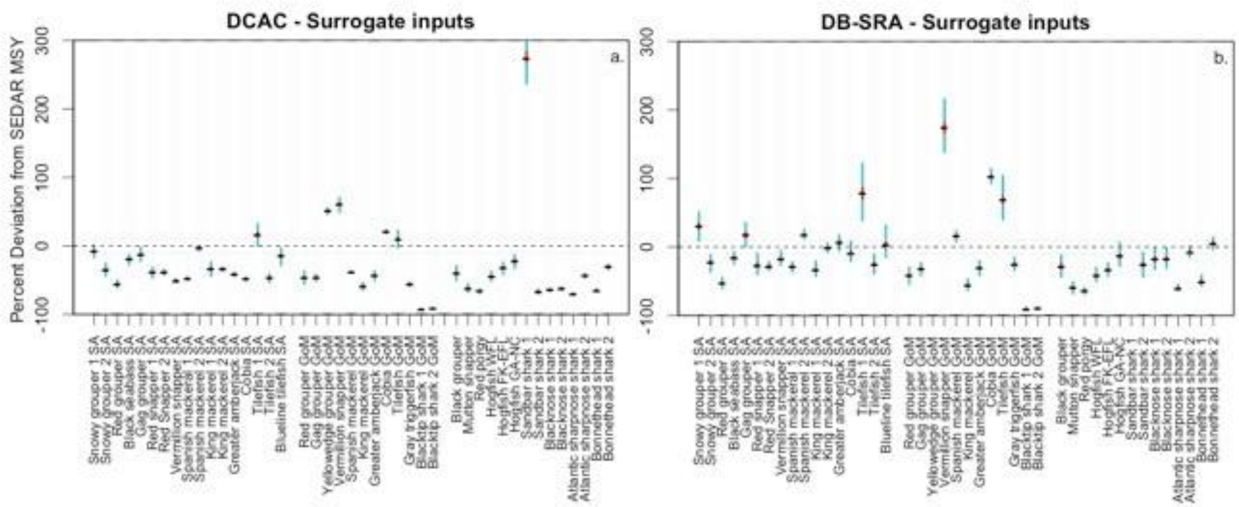

Figure 2: Percent deviation of medians and confidence intervals of MSY estimate distributions produced by each method from the SEDAR MSY value for each stock, where (a) is DCAC and (b) is DB-SRA. Medians are represented by black lines, the 80% confidence interval is represented by the blue region, and the 20% confidence interval is represented by the red region. The dotted lines represent 20% deviation around the SEDAR OFL value.

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 master's thesis had been completed and defended. A rough draft of the scientific publication is anticipated to be completed by early winter of 2016.

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Defining Spawning Dynamics to Manage and Conserve Reef Fish Populations

Project Personnel: R. Appeldoorn and Michelle Schärer (U. Puerto Rico, Mayaguez)
NOAA Collaborators: R. Hill (NMFS/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** To characterize the temporal dynamics and population structure of grouper spawning aggregations in Puerto Rico.

***Strategy*:** To use passive acoustic monitoring and in situ assessments (numbers, size) to continue long-term monitoring of known aggregations to determine seasonal dynamics and population composition.

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:
From December 2015 through July 2016 grouper spawning aggregations were monitored at four sites within the Mona Passage (Figure 1), targeting primarily four species: red hind (*Epinephelus guttatus*), Nassau grouper (*E. striatus*), yellowfin grouper (*Mycteroperca venenosa*) and black grouper *(M. bonaci*). Activities variously included deployment/recovery of DSG passive acoustic recorders (Figure 2), field surveys and data processing. All DSG recorders functioned properly and the data files recovered during these deployments have been processed to convert them from dsg to .wav format for subsequent processing. All data will be analyzed to determine the presence of species specific courtship associated sounds (CAS) in each file of 20 seconds duration with a 5-minute interval throughout the complete deployment. The analysis of the complete acoustic dataset will be conducted in MATLAB with a new algorithm developed by Florida Atlantic University (L. Cherubin). Figure 3, from 2015 data, illustrates the results of the processed data for red hind at the Abrir la Sierra site.

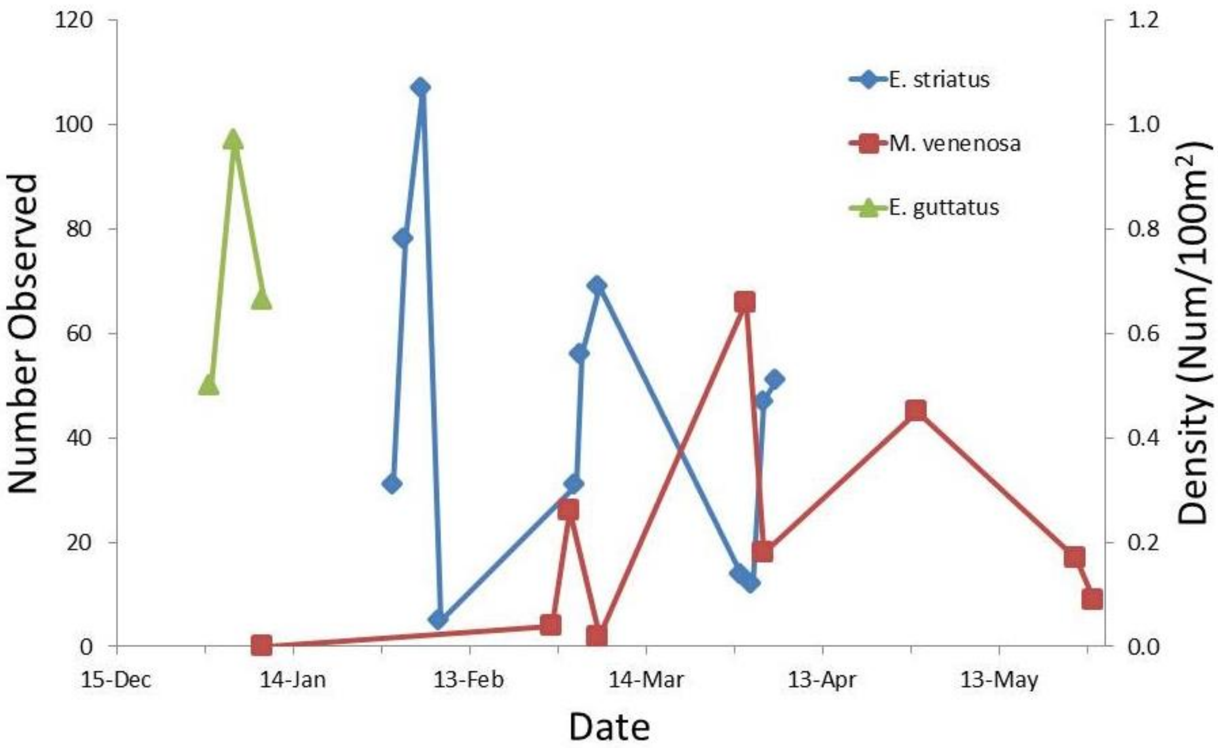

Figure 1: Map of the study area, showing Mona Island, Bajo de Sico and Abrir la Sierra. Boxes indicate the seasonally closed areas protecting spawning aggregations.

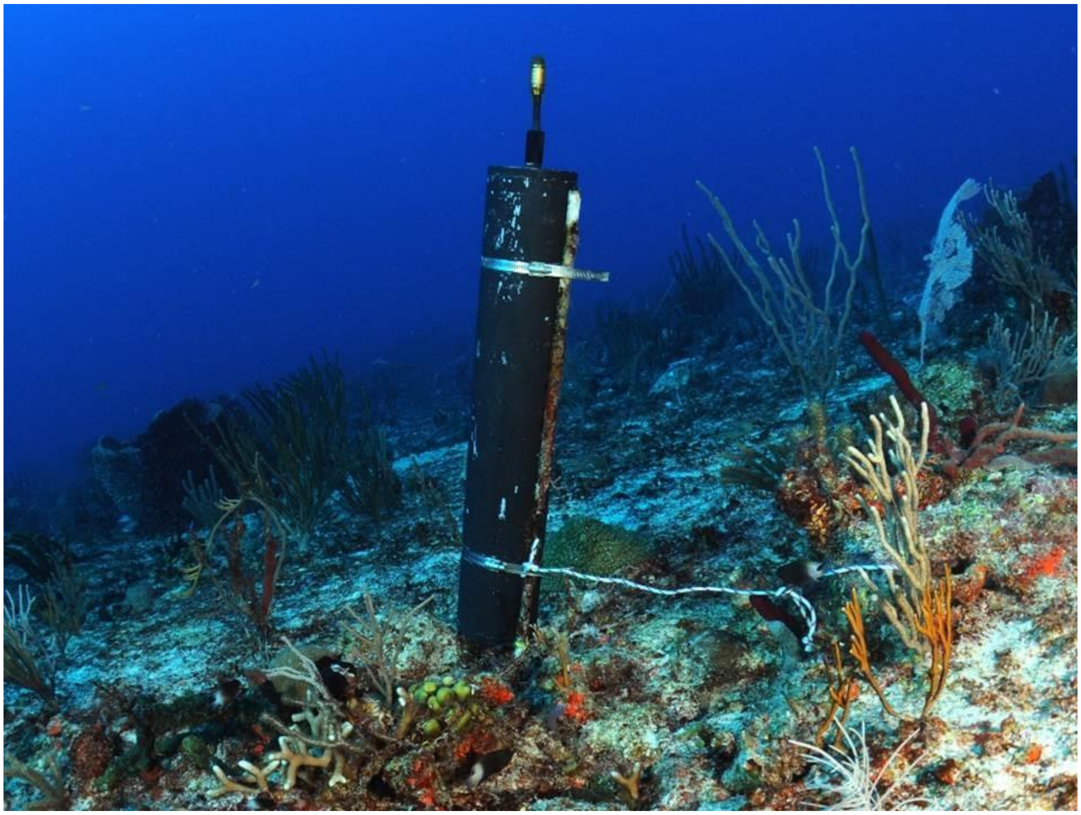

Figure 2: Deployment of a DSG sound recorder on the seafloor (photo by J. Zegarra).

Surveys were conducted to estimate abundance and size structure of fish aggregated to spawn at the three sites. At Bajo de Sico, 16 surveys over 11 dates were conducted using CC-rebreather and technical dives to collect data. The maximum count of fish observed on any survey per day is presented as the maximum count per day (Figure 4). All surveys at Bajo de Sico were conducted with red laser calipers and video to estimate the total length of each Nassau grouper. Image extraction of fish from the video files is completed, and these will be analyzed to obtain length-frequency distributions. The color phase, distended abdomen and estimated length for each grouper will be noted per survey, and these data will be compared between days after the full moon for each monthly spawning peak. These data indicate the proximity to spawning for the fish aggregated at each peak.

Mona Island surveys were conducted to assess black and yellowfin grouper. Thirteen surveys were conducted over 11 days of sampling. The behavior of these fishes precluded the approach by divers with laser calipers, so total length of each individual was estimated visually. Figure 4 shows the maximum number of fish observed per day.

At Abrir La Sierra, red hind could only be surveyed during the late January - early February aggregation (3 days) due to weather. Figure 4 shows the aggregation peaked during that time.

Research Performance Measure: The original objectives were met. However, total number of days sampling were reduced during some aggregation times due to bad weather. In addition, the laser caliper method for measuring fish length was not possible with the two *Mycteropera* species, so less precise visual estimates of length were used.

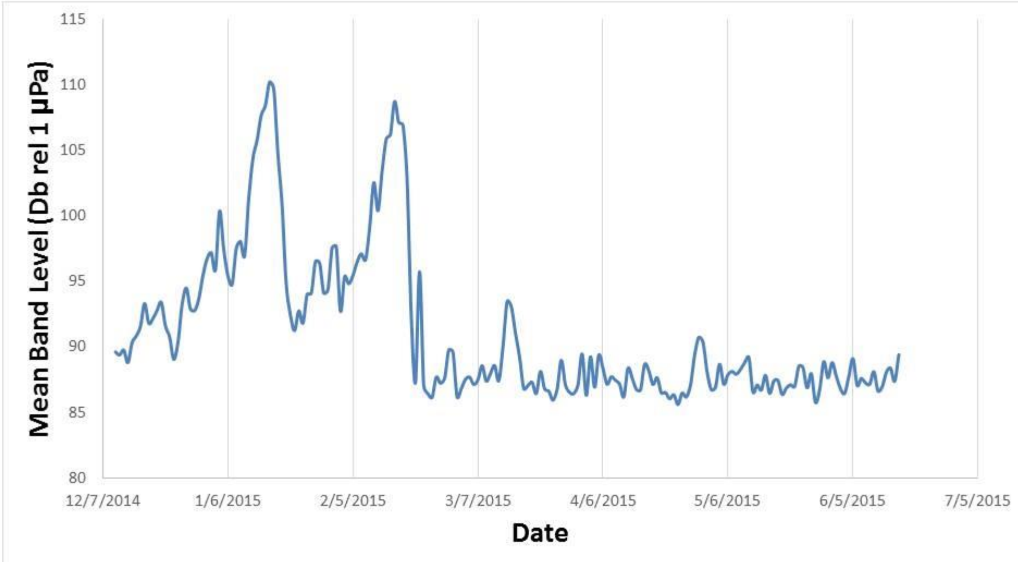

Figure 3: Mean band (sound pressure) level recorded in 2015 at the red hind spawning aggregation site at Abrir la Sierra, Puerto Rico. The graph shows the increased rate of courtship associated sound production during the two large aggregations that peaked mid-January and mid-February. Only a minor peak occurred in mid-March, suggesting that there were few red hind at the site that month.

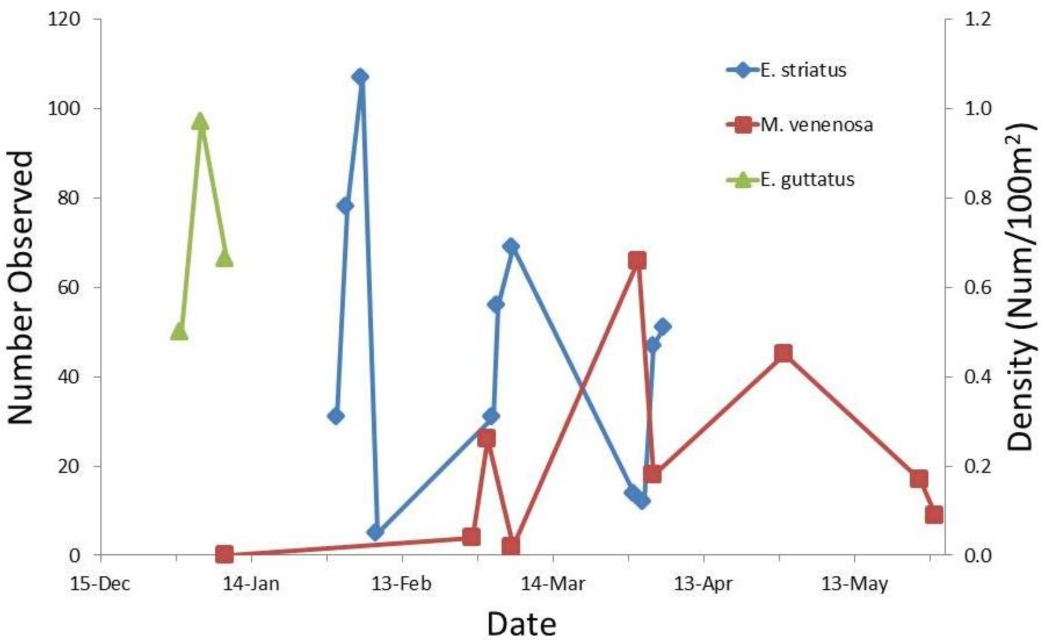

Figure 4: Maximum number of fish observed at the Bajo de Sico (Nassau grouper) and Mona Islands (yellowfin grouper) sites and density observed at Abrir la Sierra (red hind) during underwater surveys. Surveys were timed to capture the increase, peak and decline of each monthly aggregation, but sampling was occasionally limited by bad weather or boat problems. Nassau grouper were observed to aggregate at the beginning of February, March and April, with the most fish observed in February. Yellowfin grouper were observed aggregating at the very end of February, March and April, that is, one month later than Nassau grouper. Red hind peaked at the beginning of January; the February aggregation could not be sampled.

Developing a Decision-Support Tool for the Management of Clam Farms on the FL Gulf Coast

Project Personnel: S. Baker, Leslie Sturmer and Paul Suprenand (UF)
NOAA Collaborators: J. Berkson (NOAA/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.

This study evaluated water quality data (temperature, salinity, and dissolved oxygen concentrations) from two aquaculture use areas in Cedar Key, Florida spanning from 2002 through 2013, and collected *in situ* using data sondes. Water quality was 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 designated as periods when one or more water quality variables remained outside of *M. mercenaria's* optimal physiological range, based on published studies. Optimal physiological ranges led to the development of an Environmental Assessment Index (EAI), which considered relationships between water quality variables and the duration of a suboptimal water quality event. Water quality data were then analyzed to characterize relationships between water quality variables and a suite of regional environmental variables ranging from wind direction to nearby river gage heights. These relationships were used to develop mathematical models for predicting temperatures,

salinities, dissolved oxygen concentrations at clam aquaculture use areas, and the EAI for three subsequent days from a selected start date of a suboptimal water quality event. Mathematical modelling included Redundancy Analysis (RDA), AutoRegressive Integrated Moving Average (ARIMA) models, Trigonometric, Box–Cox transform, ARIMA error correction, Trend, and Seasonal components (TBATS) models, and a Generalized Additive Models (GAMs), with and without Principal Component Analysis (PCA). GAM equations for each water quality variable provided a method for estimating missing water quality values, which could be combined with real-time *in situ* measurements made by the National Oceanic and Atmospheric Administration (buoys) or the United States Geological Survey's (river gages). Ultimately, water quality predictions are intended to enhance current online water quality information made available to clam farmers for making decisions related to aquaculture planning and management.

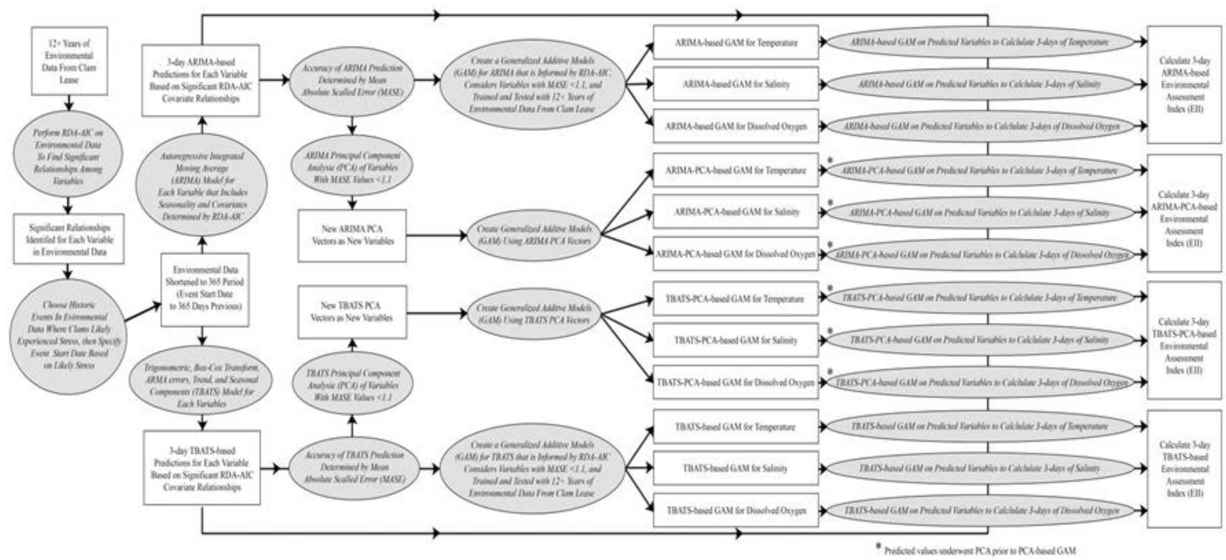

Figure 1: Flow diagram detailing mathematical model developments using AutoRegressive Integrated Moving Average (ARIMA) models, Trigonometric, Box-Cox Transform, ARMA errors, Trend, and Seasonal Components (TBATS) models, principal component analysis (PCA), and generalized additive models (GAM) to calculate Environmental Impact Index (EII) values.

Research Performance Measure: Our performance measures were 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 was obtained and formatted for use. Available data was synthesized and the key variables in mortality events were identified. A predictive model of clam mortality risk was developed using the key variables identified and incorporating the uncertainty in the system. A pilot risk management tool was developed. 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.

The present study is the first to use multiple sets of predictive mathematical models for predicting water quality in shellfish aquaculture. The present study's unique mathematical models predicting temperature, salinity, dissolved oxygen concentration, and EAI can be an important tool for Cedar Key clam farmers. These models synergistically predict future water quality in clam aquaculture use areas and could be used to alert farmers of potential suboptimal water quality events. The decision-support model developed in the present study can be integrated into the existing online interface to include real-time calculations of EAI to express the degree of potential clam stress, as well as to predict the value of each water quality

variable and resulting EAI values over the next three days. These potential enhancements to the online interface may provide a basis for making decisions regarding clam crops, hence the ‘decision-support’ term, which includes deciding when and where to plant seed (young clams) and/or to harvest clams in aquaculture use areas. Furthermore, the methods applied in the present study are highly transferable to other industries, organisms and locations, as well as use in identifying the minimum set of observational data needed to forecast environmental susceptibility.

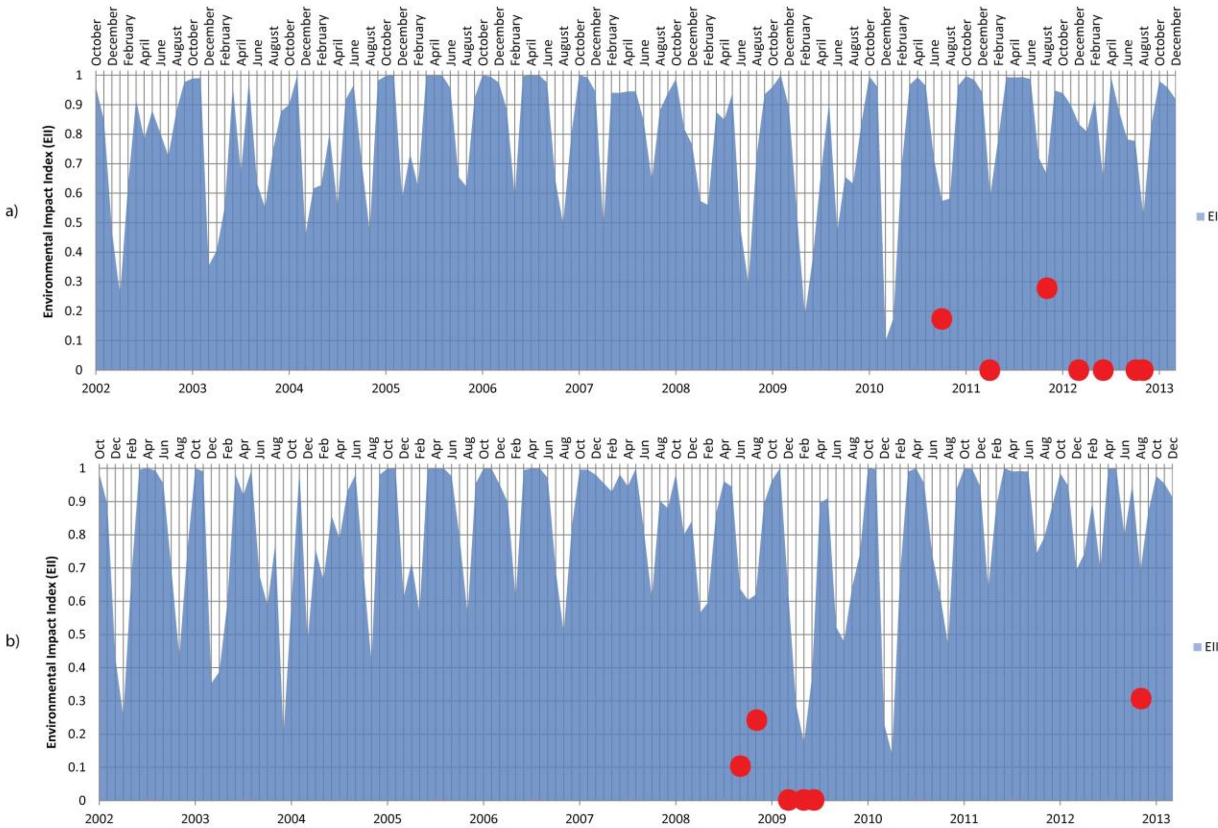

Figure 2: Calculated temporal Environmental Impact Index (EII) values from 2002 to 2013 for a) Gulf Jackson, and b) Dog Island. Red points are the months and lowest values in current study’s recent events when EII fell below 0.30.

Marine Mammal Research and Stranding Response

Project Personnel: L. Aichinger Dias (UM/CIMAS),
NOAA Collaborators: 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 and writing of scientific reports. 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 (small and large), management of data and samples collected and writing of scientific reports. 4) To respond and coordinate response actions during cetacean strandings dead or alive in the US Southeast Region. 5) 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:

After the pre-assessment phase in which, time sensitive data was collected during and immediately following the DWH oil spill, injury assessment studies were implemented to determine whether natural resource injuries have or might result from the spill. A comprehensive restoration plan for the Gulf was developed (Programmatic Damage Assessment and Restoration Plan-PDARP), which included several documents outlining potential impacts of the DWH oil spill on natural resources in the Gulf. Dias produced and co-authored two technical reports in support of the PDARP: 1- Evidence of marine mammals' direct exposure to petroleum products during the Deepwater Horizon Oil Spill in the Gulf of Mexico, and 2- Distribution and Abundance of Cetaceans in the Northern Gulf of Mexico. The first report documented several cetacean species swimming through oil and with oil on their bodies by means of photographs and field observations collected during NOAA/NRDA projects (Figure 1). In the latter report, aerial and ship-based survey data over a 20-year span indicated the distribution, abundance and density of whales and dolphins in the Gulf of Mexico.

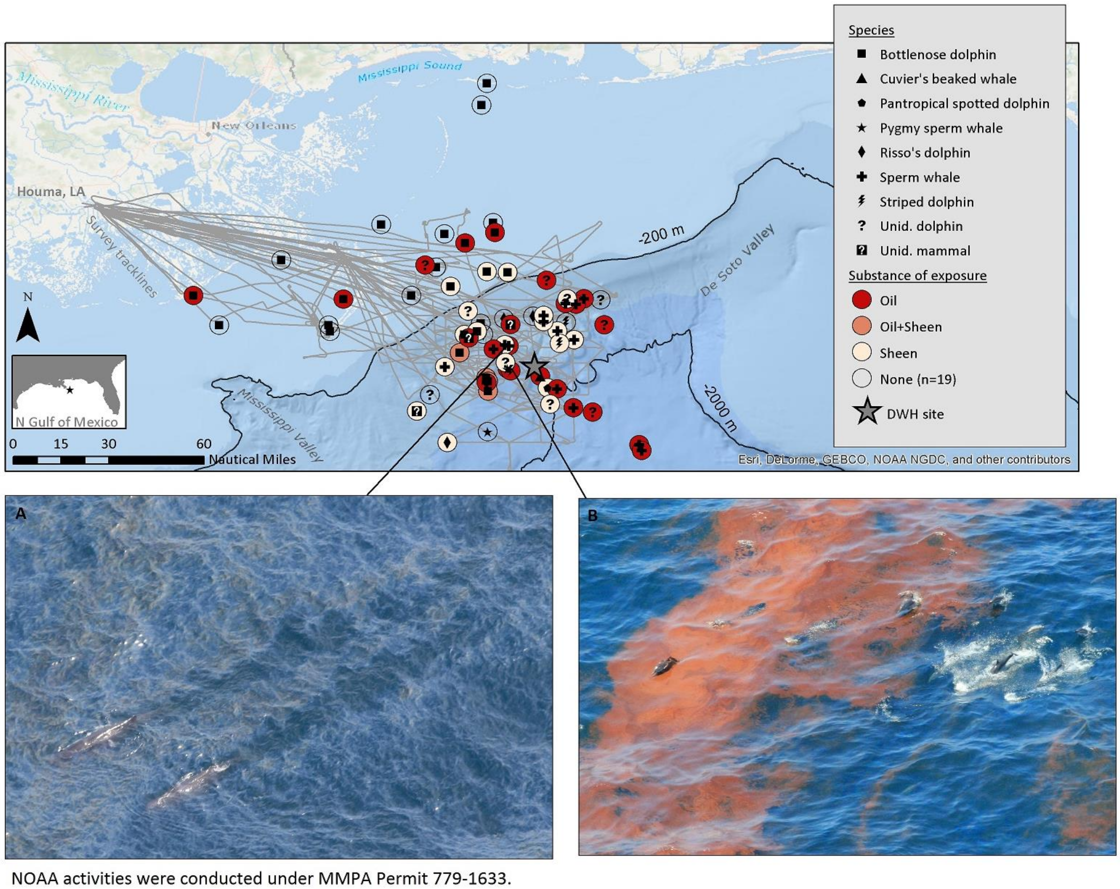

Figure 1: Marine mammal sightings in the presence or absence of petroleum products and survey tracklines during the Helicopter Survey. A: sperm whales swimming through oil, 28 April 2010, photo by NOAA; B: striped dolphins swimming through oil, 29 April 2010, photo by NOAA. (Unid. -unidentified).

In addition to writing reports related to the DWH oil spill, Dias participated in the 2015 Southeast Fisheries Science Center (SEFSC) research cruise on board the *NOAA Ship Gordon Gunter*. This survey was conducted along the continental shelf and shelf-break waters in the northeastern Gulf, with the main objectives to: 1- collect biopsy samples of bottlenose (*Tursiops truncatus*) and Atlantic spotted (*Stenella frontalis*) dolphins and, 2- deploy acoustics tags on Bryde's whales (*Balaenoptera edeni*). During this cruise, Dias worked as the data and sample manager and also assisted in writing scientific reports.

Dias also participated in the long-term monitoring of bottlenose dolphins (*T. truncatus*) in Biscayne Bay as a photographer. Off-season Dias assisted in project planning and scientific permit renewal.

Research Performance Measure: all objectives were completed on time. 1) Managed data and wrote two technical reports for the Offshore Marine Mammal Injury Assessment under the NRDA PDARP (see publications below). 2) Worked as a marine mammal observer and managed data and samples collected during the 2015 SEFSC research cruise in the Gulf of Mexico. During this project, more than 3,500 km of survey effort were performed, 332 cetacean sightings recorded, 222 biopsy samples collected and one acoustic tag deployed. 3) Assisted with North Atlantic Right Whale (*Eubalaena glacialis*) satellite tagging attempt in northern Florida. 4) Audited the Introduction to Geographic Information System (GIS) class at RSMAS during one semester. 5) Assisted in project planning and development for the Biscayne

Bay Photo-ID project also working as a photographer during two field seasons. 6) Managed evidentiary images (photographs) of stranded cetaceans from the Northern Gulf of Mexico Marine Mammal UME and associated legal deliverables, totaling nearly 300 GB of data. 7) Validated historical stranding records. 8) Trainings accomplished: 24-hour Hazardous Waste Operations and Emergency Response (HAZWOPER); Department of Transportation/ International Air Transport Association Hazardous Material Shipping (DOT/IATA).

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Coastal Fisheries Logbook Program

Project Personnel: J. Diaz (UM/CIMAS)
NOAA Collaborators: D. Gloeckner, M. Judge, 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*:** 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 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.

Research Performance Measure: Our objective, the monitoring of compliance by fisherman by the timely submission of data, has been successfully accomplished.

2016 SE COASTAL FISHERIES TRIP REPORT FORM **Use Black Ink only !** Version Date 03/15

OMB Control No. 0648-0016 Expiration Date: 08/31/2016

Signature:	Phone No.: ( ) -	Schedule No. *NMFS Use Only*
Vessel Name:	Trip Start Date: MM DD YY	County or Parish: State :
Vessel No.:		Dealer Name:
Operator Name: please print	Trip Unload Date:	SE Federal Dealer Number:
Operator Number: (if known)	Days at Sea: No. of Crew:	State Trip Ticket No.:
		Check box if landings sold to multiple dealers: ☐ Yes

GEAR SECTION: See Instructions on Page 2. Check gear box and fill in all the boxes below.

Traps **(T)** ☐Fish ☐Other		Longline**(L)**☐ PLL ☐Bottom ☐Other		Gill Net **(GN)** ☐Drift ☐Anchor ☐Strike ☐Other		Hook & Line ☐(H) Hand ☐(E) Bandit ☐(TR) Trolling ☐(B) Buoy		Divers ☐(S) Spear ☐(P) Power		Other Gear **(O)**	
Total # Trap Hauls		# Sets		# Sets		# Lines		# of Divers		Type	
# Traps Used		# Hooks per Line		Length (yards)		# Hooks per Line		Total Hrs Fished		Total Hrs Fished	
Trap Soak Time (hrs)		Set Soak Time (hrs)		Depth (yards)		Total Hrs Fished		*SE VTR #:*	**R**16100001		
Total Soak Time (hrs)		Total Soak Time (hrs)		Set Soak Time (hrs)		Date Received: *NMFS use only*					
Mesh: x / x		Length (miles)		Mesh:							

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**.

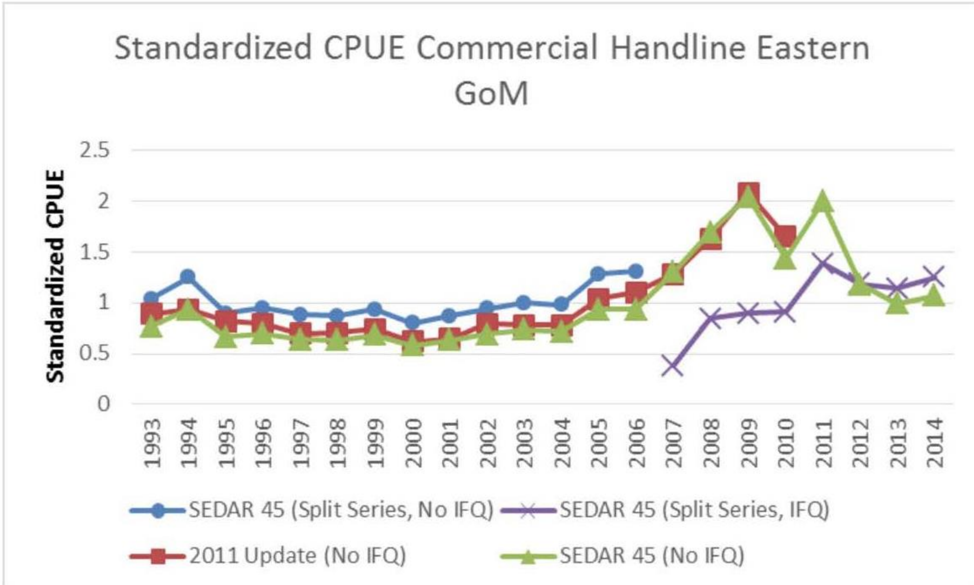
	Species Name	Code	Gutted-lbs	Whole-lbs	Gear	Area	Depth		Species Name	Code	Gutted-lbs	Whole-lbs	Gear	Area	Depth
	Amberjack-Great	1812	#	#			'	PORGY	Jolthead	3312	#	#			'
	Amberjack-Lesser	1815	#	#			'		Knobbed	3308	#	#			'
	Almaco	1810	#	#			'		Red	3302	#	#			'
	Banded Rudder	1817	#	#			'		Whitebone	3306	#	#			'
	Crevalle	0870	#	#			'	SHARK	Blacknose	3485	#	#			'
	Cobia	0570	#	#			'		Blacktip	3495	#	#			'
	Dolphin Fish	1050	#	#			'		Bonnethead	3483	#	#			'
GROUPER	Black	1422	#	#			'		Bull	3497	#	#			'
	Gag	1423	#	#			'		Dogfish, Smth	3511	#	#			'
	Warsaw	4740	#	#			'		Finetooth	3481	#	#			'
	Red	1416	#	#			'		Lemon	3517	#	#			'
	Scamp	1424	#	#			'		Sandbar	3513	#	#			'
	Snowy	1414	#	#			'		Sharpnose, Atl	3518	#	#			'
	Yellowedge	1415	#	#			'	SNAPPER	Blackfin	3757	#	#			'
	Yellowfin	1426	#	#			'		Lane	3761	#	#			'
	Hind, Red	1413	#	#			'		Mangrove	3762	#	#			'
	Hind, Rock	1412	#	#			'		Mutton	3763	#	#			'
	Hind, Speckled	1411	#	#			'		Queen	3770	#	#			'
GRUNT	Bluestriped	1444	#	#			'		Red	3764	#	#			'
	French	1445	#	#			'		Silk/Yelloweye	3758	#	#			'
	White	1441	#	#			'		Vermillion	3765	#	#			'
	Margate	1442	#	#			'		Yellowtail	3767	#	#			'
	Margate, Black	1443	#	#			'		Triggerfish, Gray	4561	#	#			'
	Grunts, Unc.	1440	#	#			'		Triggerfish, Ocean	4562	#	#			'
	Hogfish	1790	#	#			'		Triggerfish,Queen	4563	#	#			'
	King Mackerel	1940	#	#			'		Tilefish, Gray	4474	#	#			'
	Spanish Mackerel	3840	#	#			'		Tilefish, Golden	4470	#	#			'
	Wahoo	4710	#	#			'		Sea Trout, White	3455	#	#			'
	Black Sea Bass	3360	#	#			'		Little Tunny	4653	#	#			'
	Bluefish	0230	#	#			'		Barracuda	0180	#	#			'
	Blue Runner	0270	#	#			'		Hake	1550	#	#			'

TRIP EXPENSE SECTION: MANDATORY FOR SELECTED VESSELS. See Instructions on Pages 3-4.

Owner Operated? Yes ☐ No ☐	Gallons of Fuel Used on This Trip	Price per Gallon $.	Bait Expense $ .00 / Ice Expense $ .00
Grocery Expense $ .00		Misc. Trip Expenses $ .00	IFQ Allocation Purchased for This Trip $ .00
Has the payment for your catch been determined? Yes ☐ No ☐	If Yes: Total Trip Revenue $ .00		Total Payment to **HIRED** Crew and Captain $ .00

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.



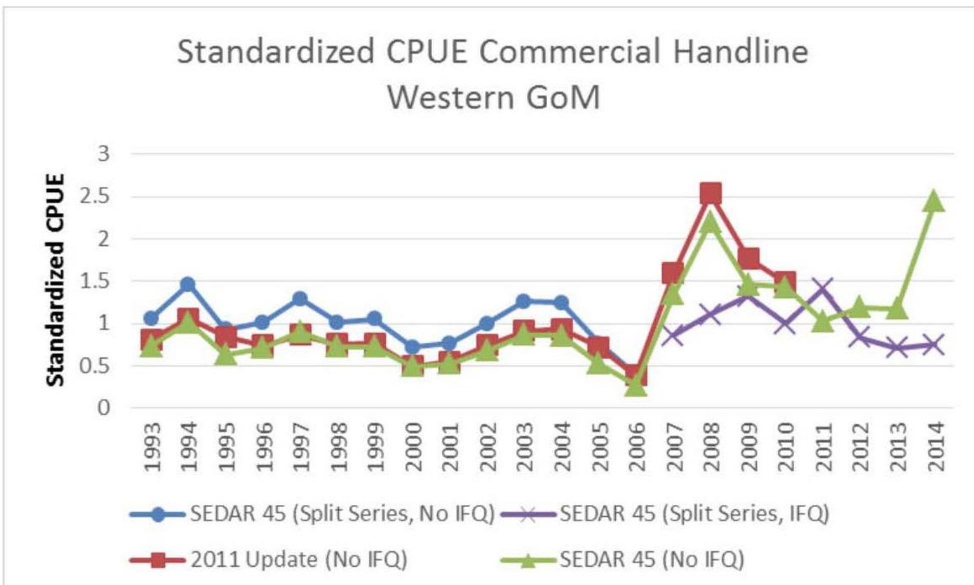


Figure 2: The recent SEDAR45 utilized a standardized commercial logbook catch per unit effort in the U.S. Gulf of Mexico. Figure 2 shows the standardized catch-per-unit effort (CPUE) for the commercial handline fishery in the eastern (top panel) and western (bottom panel) Gulf of Mexico. In the 2011 update (red lines) no factor was included in the standardization process to account for the implementations of red snapper IFQs in 2007. Given that red snapper IFQs may impact vermilion snapper CPUE (due to potential changes in targeting behavior), it was deemed inappropriate to continue to ignore the IFQ variable. To account for red snapper IFQs, the commercial CPUE indices were truncated in 2006 (blue lines) assuming no IFQ variable and a new timeseries was begun in 2007 (purple lines) with the IFQ variable included. The non-truncated timeseries with no IFQ variable (green lines) is shown for comparison to the 2011 update indices. The truncated timeseries with no IFQ show similar patterns to the 2011 update, while the new IFQ timeseries, not surprisingly, show different trends from the 2011 update. Since 2007, the western stock has been relatively stable, whereas the eastern stock has shown a generally increasing trend that has leveled off over the last three years. All indices are normalized to their mean.

Mandatory Ship Reporting System

Project Personnel: R. Domingues (UM/CIMAS)
NOAA Collaborators: G. Goni, F. Bringas, J. Harris and J. McKeever (NOAA/AOML)
Other Collaborators: P. Chinn (Contractor)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** Contribute with conservation efforts towards the northern right whale 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 opted for transitioning 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 **8,300** reports. 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.

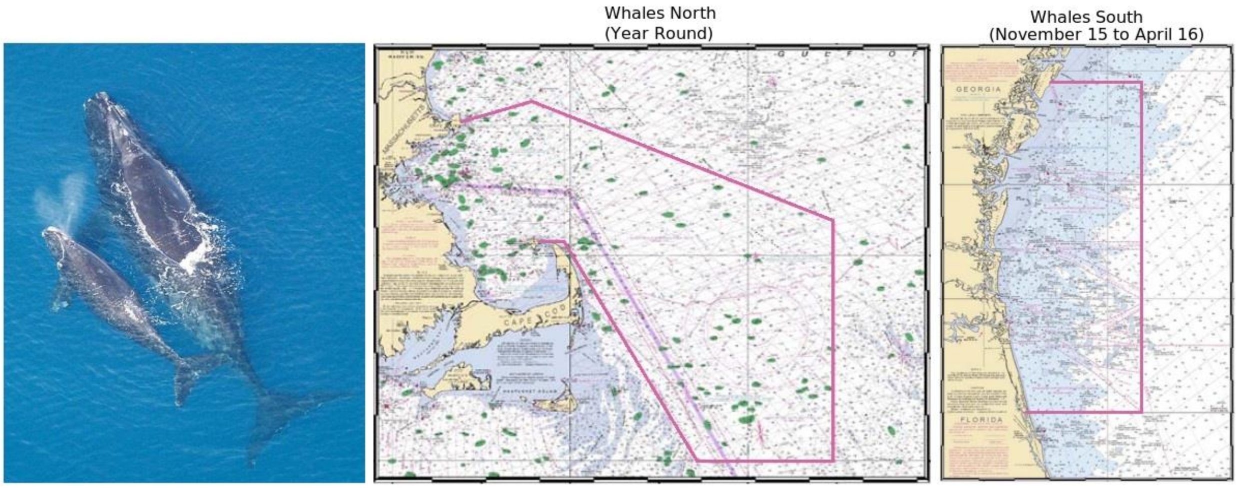


Figure 1: (left) North Atlantic right whale with calf. The (center) Whales North and (right) Whales South reporting areas along the east coast of United States within the Mandatory Ship Reporting system. The reporting requirements for each area are emphasized above the maps.

Research Performance Measure: All planned goals were met during this year. During the period between July 1, 2015 and June 30, 2016, the MSR hosted at AOML has received and processed more than 3,500 reports. Ships reporting to the MSR were provided with an automated response message containing information on how to avoid collisions with whales, including the location of the latest whale sightings.

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Husbandry and Outplanting of Relocated Acropora cervicornis from Miami Harbor

Project Personnel: D. Lirman and S. Schopmeyer (UM/RSMAS)
NOAA Collaborators: T. Moore and M. Miller (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** Rescue, propagate, and relocate staghorn corals (*Acropora cervicornis*) exposed to increased sedimentation stress and mortality due to dredging operations at the Port of Miami/Miami Harbor.

***Strategy*:** 1) Collect staghorn colonies threatened by sedimentation stress near the Port of Miami; 2) Fragment these colonies into small (10-20 cm) fragments; 3) Deploy the staghorn fragments onto our propagation structures in the UM nurseries found within Miami-Dade County; 4) Track growth and survivorship of fragments during the grow-out nursery phase; and 5) Outplant POM fragments/colonies onto natural reefs within Miami-Dade County.

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* (*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:

Colonies of *A. cervicornis* were located within the dredge area between 10/27/14 and 11/08/14 and healthy colonies or portions of the colonies were harvested. Corals remained shaded and in seawater during transport to two University of Miami (UM) *Acropora* nurseries within Miami-Dade County at: (1) Key Biscayne Nursery; and (2) Bowl Nursery. Corals were deployed onto suspended mid-water coral trees constructed of PVC and fiberglass and maintained in accordance with the nursery's best husbandry practices. Coral trees were anchored using duckbill anchors driven into the sand and corals were hung from the fiberglass arms using crimped monofilament. Coral trees are cleaned monthly to remove fouling organisms such as hydroids, algae, sponges, and gastropods, and are repaired as needed.

After collection, the colonies from Miami Harbor were re-fragmented to create smaller units (10-20 cm) that were placed on our PVC trees at our two nurseries: Key Biscayne (n = 979 fragments) and the Bowl (n = 80 fragments). Mean fragment size at the time of deployment at the nurseries (Oct-Nov 2014) was 17.6 (0.9) cm, with fragments ranging from 4.5 cm to 46 cm in total linear extension (TLE). Once at the nurseries, the staghorn fragments experienced very low initial mortality (3.7%), indicating that the collection, storage, and transfer methods were highly efficient and that the nursery environments are adequate for the survivorship and growth of Miami Harbor coral collections. Corals were monitored and a subset of corals were measured for TLE and overall health every 3 months.

Fragments were monitored on July 16th, 2015. Very low mortality (4.2%) was observed since corals were installed within the coral nurseries and macroalgal or tunicate overgrowth were the dominant causes of mortality. April 2015). Most fragments were alive with healthy coloration and very little partial mortality (1.3 $\pm$ 0.8% of the aggregate coral tissue showing signs of recent partial mortality). Mean fragment size increased to 106.4 (5.1) cm and the mean number of branches per fragment increased to 21.8 (1.2) (Fig. 1). Mean daily growth rates calculated for tagged fragments were 0.42 (0.02) cm per day, representing a projected mean annual growth rate of 154.5 (8.5) cm per year for each fragment.

Due to the bleaching event recorded in Florida in the 2015 summer, the coral nursery was surveyed regularly during Aug-Oct to document bleaching prevalence. While some very minor paling was observed on a small number (< 25 out of > 900) of the colonies growing on the top branches of a couple of the nursery trees, no evidence of bleaching was documented and the POM fragments showed to be resilient to this disturbance while located at the nursery.

Outplanting of POM corals began on September 2, 2015 with approval by NOAA and FWC. To date, POM corals have been outplanted to six sites in Miami-Dade County including Miami Beach Plot 2 (N 25.835; W 80.106), Fowey (N 25.588; W 80.104), North Emerald (N 25.675; W 80.097), Barge Site (N 25.676; W 80.101), Emerald (N 25.674; W 80.097), and Divers Paradise (N 25.676; W 80.100). Outplanting was concentrated on reefs where no significant bleaching of wild staghorn colonies was observed.

Figure 1: Rescued fragments of *Acropora cervicornis* from the Port of Miami a) immediately after installation in UM coral nurseries and b) ten months after installation.

POM corals were outplanted onto natural reefs in Miami-Dade County using the methods developed and published by the *Acropora* restoration program. Corals collected from the nursery trees were transported to the selected sites and attached to the bottom using masonry nails, epoxy, and plastic cable ties (Fig. 2). Corals were deployed in clusters of 20-50 corals at a spacing of 50-100 cm between outplants. A total of 921 POM corals have been outplanted to date, including corals collected from all trees at the Key Biscayne nursery which represent collections from different areas of the POM impact area and potentially distinct genotypes. The average TLE of outplants was 162.5 cm (range 48 - 220 cm).

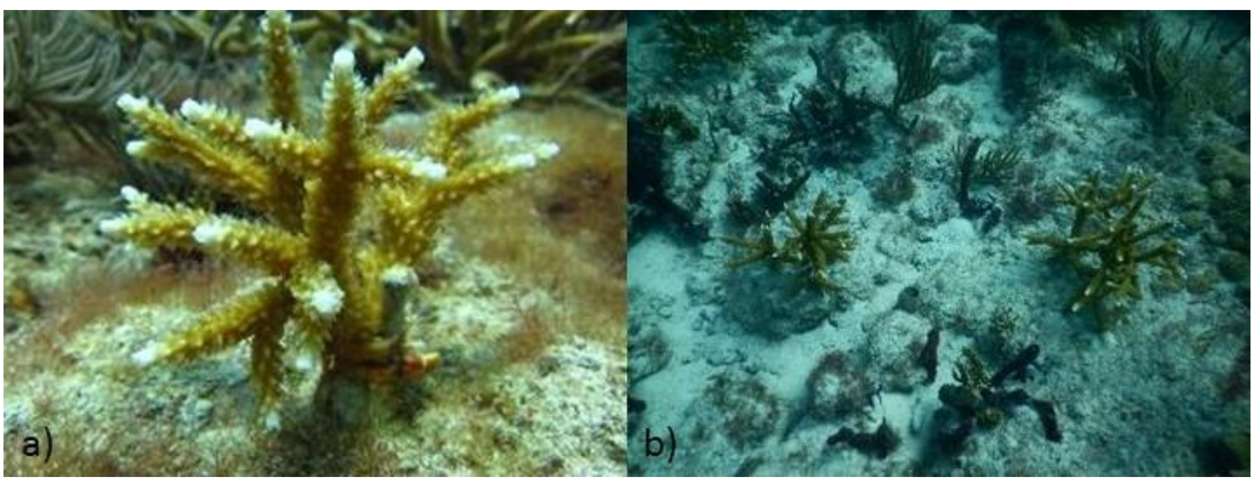

Figure 2: Healthy colonies of *Acropora cervicornis* one month after outplanting to local Miami-Dade County reef.

These sites were surveyed 1-2 months after outplanting to document survival and bleaching prevalence and impacts. Survival of staghorn outplants has been very high (> 90%). Some partial to full bleaching was observed in late September 2015, but > 75% of corals exhibit normal coloration. There has been some evidence of some partial mortality caused by predation (mostly by *Coralliophila*), but predation only affected < 10% of colonies. No evidence of active disease has been recorded among the outplanted corals. Corals will continue to be monitored as per SAL permit requirements by FWC.

Research Performance Measure: Corals were successfully rescued from the negative impacts of dredging at the Port of Miami and over 1,000 fragments were installed within UM coral nurseries. The corals experienced very low mortality and were successfully propagated over the course of one year to create healthy corals for outplanting onto local reefs in Miami-Dade County as part of species recovery programs for the threatened species *Acropora cervicornis*.

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Incorporating Hypoxia-Based Habitat Compression Impacts into the Stock Assessment Process for Tropical Pelagic Billfishes and Tunas

Project Personnel: J. Luo (UM/RSMAS); J.P. Hoolihan and D. Die (UM/CIMAS)
NOAA Collaborators: E.D. Prince (NOAA/SEVSDF)
Other Collaborators: M. Paunder and C. Phillip (Goodyear)

Long Term Research Objectives and Strategy to Achieve Them:
***Objectives*:** To investigate how vertical temperature structure of the ocean and the minimum DO level affect the vertical distribution of the fish, which lead to the change in their interaction with fishing gear.
***Strategy*:** To use satellite tagging data, oceanographic data, fishing gear distribution data and computer modeling to study the interaction of fish and fishing gears.

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 2*:** Weather-Ready Nation - *Society is prepared for and responds to weather-related events* (*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:
CPUE standardization function (CSF) is depended on the vertical hook distribution, the vertical Δt fish distribution, the depth of $\leq$3.5 ml/L Do distribution (DO_{dep}), and the depth of Δt distribution (DT_{dep}). If we hold the hook distribution and Δt fish distribution constant, we can determine the effect of DO_{dep} and the depth of Δt. Figure 1 and 3 show the CSF decreases as DO_{dep} and $DT10_{dep}$ increase. At shallow (<50 m) DO_{dep} and $DT10_{dep}$, CSF values are constantly high indicating intense squeezing effect of low DO and shallow thermocline. As DOdep and DT10dep increase beyond 50 m, the CSF becomes more variable. This is due to the presence of the interaction term between DOdep and DT10dep, and also because CSF is derived from all Δts (Δt1 to Δt10). Comparing the two species, the yellowfin tuna has much large CSF range from 0.5 to 1.78 (Figure 1) in comparison to that of blue marlin, from 0.8 to 1.25 (Figure 3). This may reflect that yellowfin tuna is distributed over a larger range of depths than blue marlin. Thus, it is

much more likely to be squeezed by decreasing DO and Δt depths. Mean annual CPUE indices were calculated using the GLM delta method, which partitions variance in two components: Firstly the proportion of positive catches and, secondly, the positive catches (Lo et al. 1992)). The annual mean nominal CPUE indices (Figure 2A and Figure 4A) were calculated on nominal CPUE data by areas inside or outside the OMZ. It is clear that the choice of areal strata can have an effect on CPUE calculation. For example, yellowfin tuna annual mean nominal CPUE indices (Figure 2A) inside the OMZ are about twice the value of indices of the outside before 1970, and after 1970 the outside CPUE indices are about twice of the inside. For blue marlin, annual mean nominal CPUE indices outside OMZ are about 2-4 times greater than that of inside OMZ for the entire period from 1956 to 2013. The annual mean standardized CPUE indices were all reduced for all zones (Figure 2b,c,d, Figure 4b,c,d). For both yellowfin tuna and blue marlin, CPUE standardization results in greater changes in the nominal CPUEs trends from inside the OMZ than changes for nominal CPUE trends outside OMZ (Figure 5). Comparing by species, yellowfin tuna has a greater change in the CPUE trend than blue marlin. Averaged over the years, yellowfin nominal CPUE indices reduced by 44% inside the OMZ and 30% outside the OMZ, while blue marlin nominal CPUE indices only reduced by 19% inside the OMZ and 14% outside the OMZ.

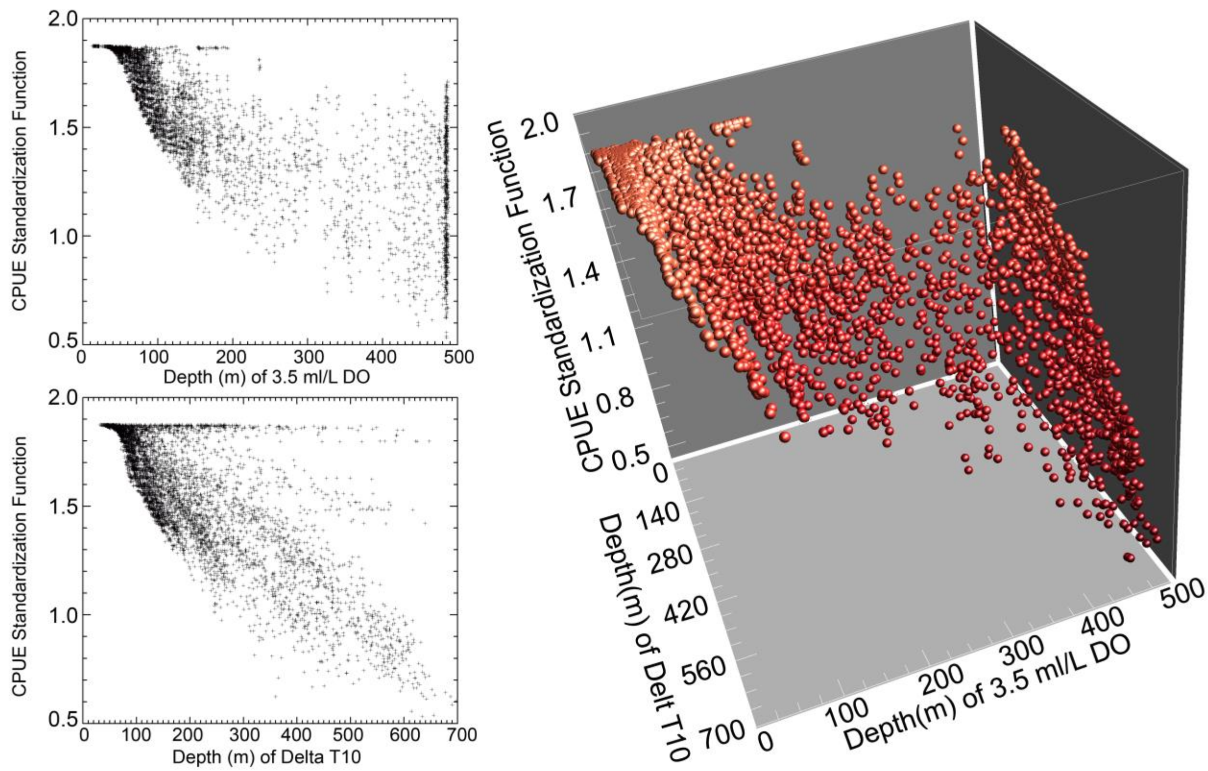


Figure 1: CPUE standardization function of yellowfin tuna derived from yellowfin tuna PSAT data, vertical LL hook distribution, depth of $\leq$3.5 ml/L dissolved oxygen, and depth of Δt10 in tropical Atlantic Ocean.

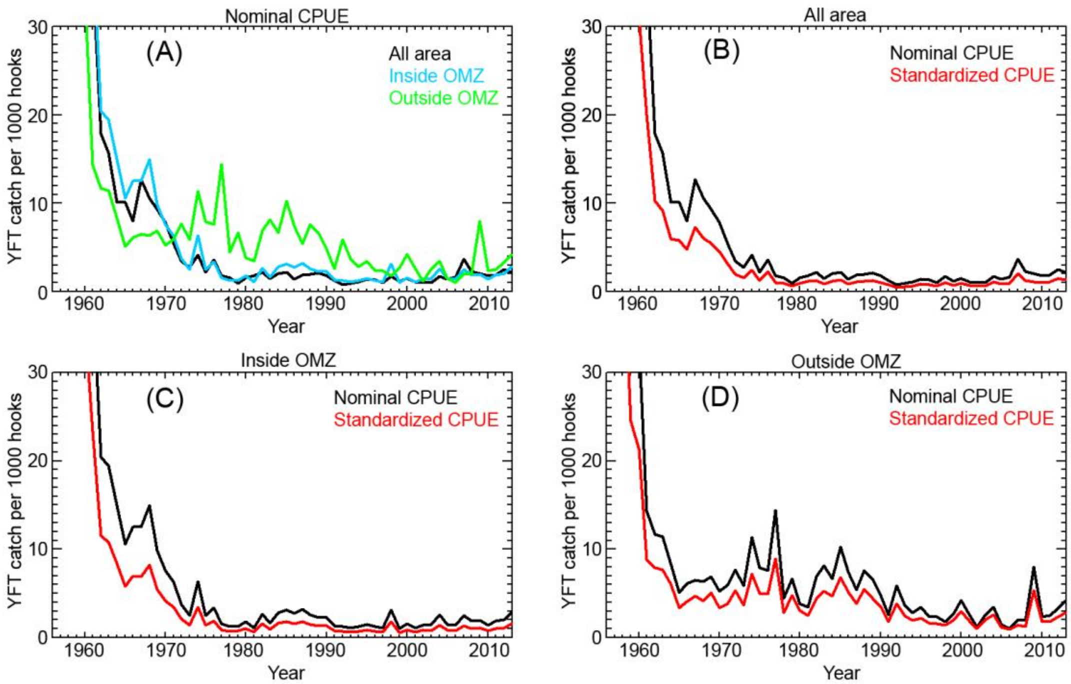


Figure 2: Mean CPUE indices of yellowfin tuna for the tropical Atlantic Ocean. A) Annual mean CPUE indices based on nominal CPUE for all areas (black line), inside OMZ (blue line) and outside OMZ (green line). Comparison of nominal (black line) and standardized (red line) annual mean CPUE indices are shown for all area (B), inside OMZ (C), and outside OMZ (D).

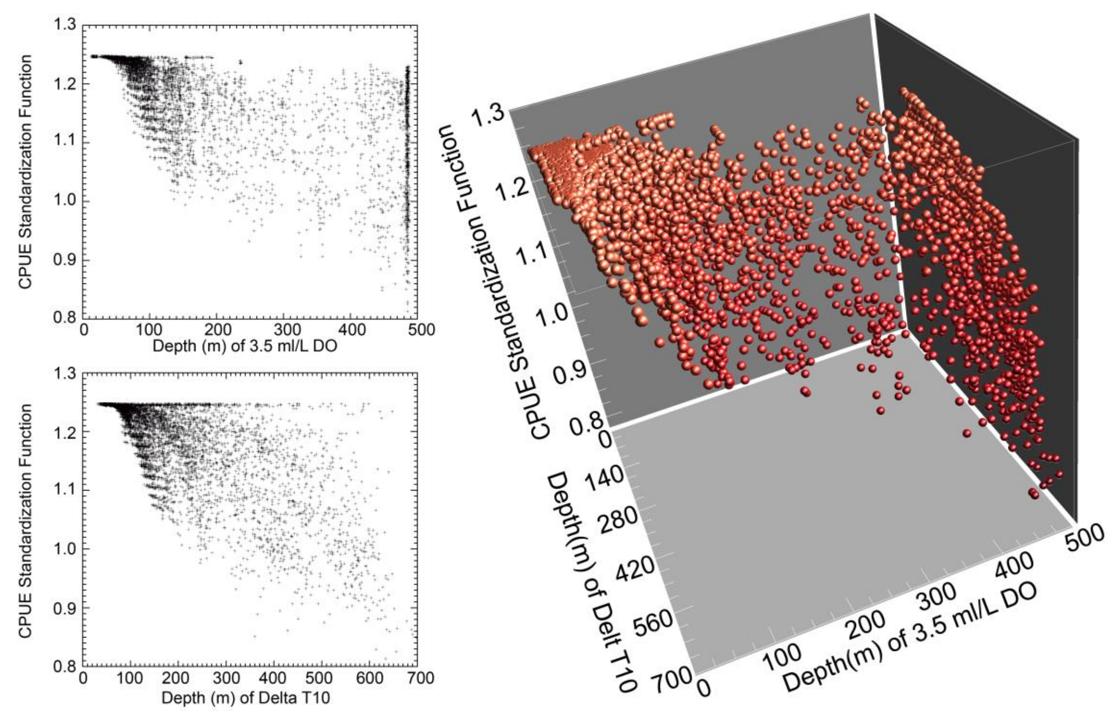


Figure 3: CPUE standardization function of blue marlin derived from blue marlin PSAT data, vertical hook distribution, depth of $\leq$3.5 ml/L dissolved oxygen, and depth of Δt10 in tropical Atlantic Ocean.

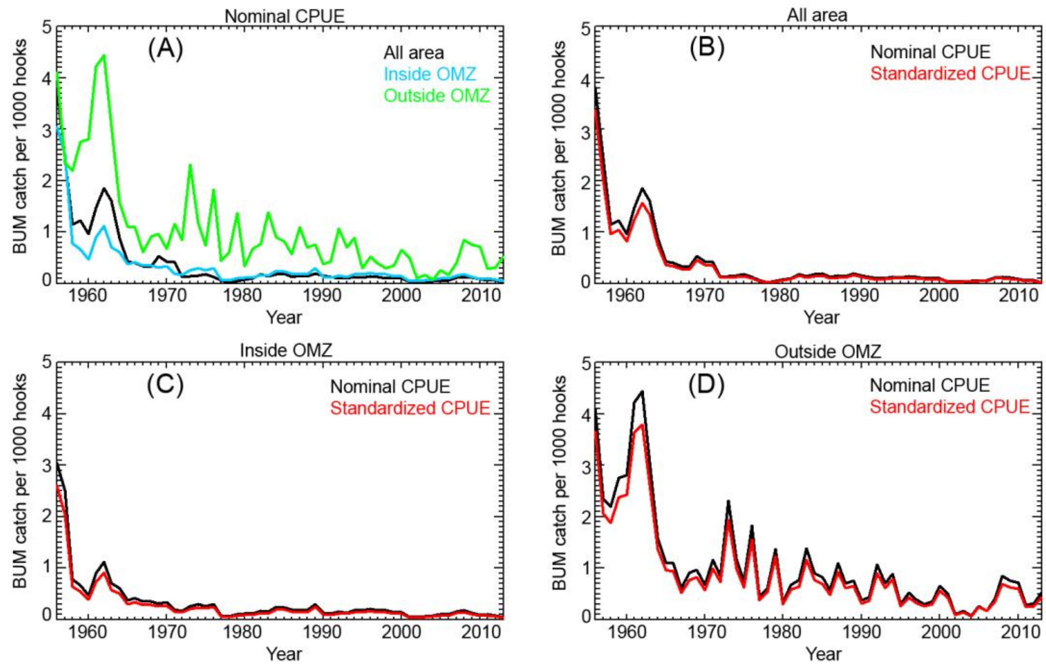


Figure 4: Mean CPUE indices of blue marlin for the tropical Atlantic Ocean. A) Annual mean CPUE indices based on nominal CPUE for all area (black line), inside OMZ (blue line) and outside OMZ (green line). Comparison of nominal (black line) and standardized (red line) annual mean CPUE indices are shown for all area (B), inside OMZ (C), and outside OMZ (D).

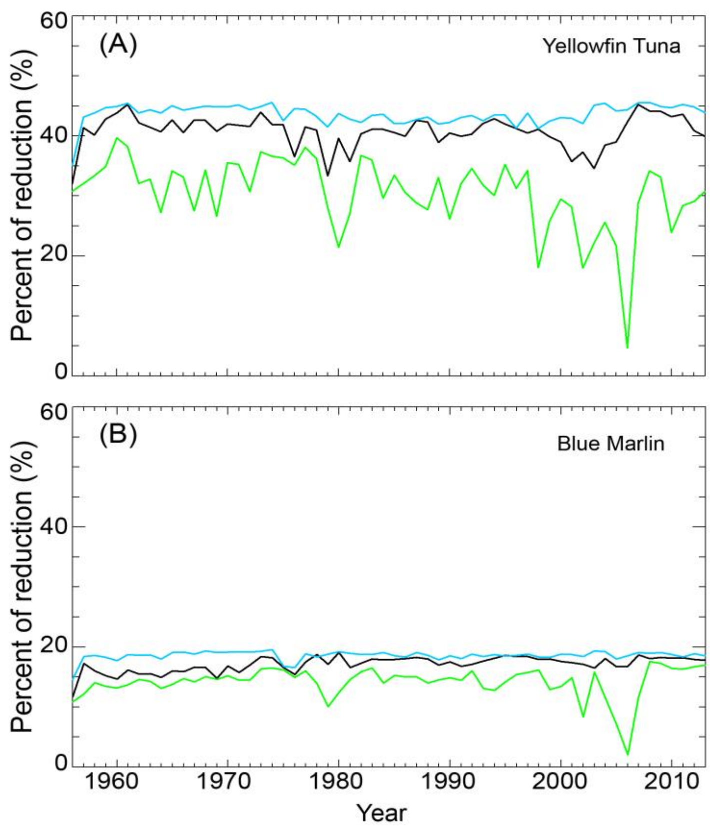


Figure 5: Percent of reduction comparing annual mean standardized CPUE indices to annual mean nominal CPUE indices for yellowfin tuna (A) and blue marlin (B) for inside OMZ (blue line), outside OMZ (green line), and the combined (black line).

Research Performance Measure: This project accomplished more than the original objectives.

Coral Restoration and Recovery

Project Personnel: R.E. Pausch, A.J. Bright and D.E. Williams (UM/CIMAS)
NOAA Collaborators: M.W. Miller (NOAA/SEFSC)
Other Collaborators: Coral Restoration Foundation, 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, we completed a second year of intensive genet-specific spawning observations for *O. faveolata* at Horseshoe reef. Eight of 28 genets under observation failed to spawn over the 6 expected nights (August 6-8 and September 3-5). We also completed focused experiments documenting larval duration, survivorship, and competency curves over time for these two species. Overall, *A. palmata* shows peak settlement at day 8-9 following spawning, at which time approximately 75% of the larval cohort remained alive. For *O. faveolata*, settlement response is well-developed earlier, by day 4-5, though only about 50-60% of *O. faveolata* fertilized embryos survived this long. As part of a collaborative effort with Mote Tropical Marine Research Lab, we had unprecedented success this year in culturing post-settlement *O. faveolata*, with over 8000 polyps (recruits) thriving at the Mote facility into spring 2016 (Fig 1). This provides opportunity to experiment with using these larval recruits for reef population enhancement in the coming year
.

We implemented a new experiment under another project component evaluating aspects of outplant design for cultured fragments of elkhorn coral (*A. palmata*). This experiment, initiated in May 2015, was designed to compare the performance of four different genetic individuals across distinct habitat types (fore-reef versus patch reef; three sites each). Preliminary results of this experiment provide definitive evidence that the four genetic individuals tested show marked variation in their thermal bleaching tolerance during the high temperature stress experienced during summer 2015 (Fig 2). This is important knowledge on a climate-resilience trait for this keystone reef-building coral.

Figure 1: *Orbicella faveolata* recruits settled from larvae in Aug 2015 and cultured in collaboration with Mote Tropical Research Lab. An unprecedented 8000 recruits of this threatened species are thriving in lab culture over six months. (Photo credit: C. Page).

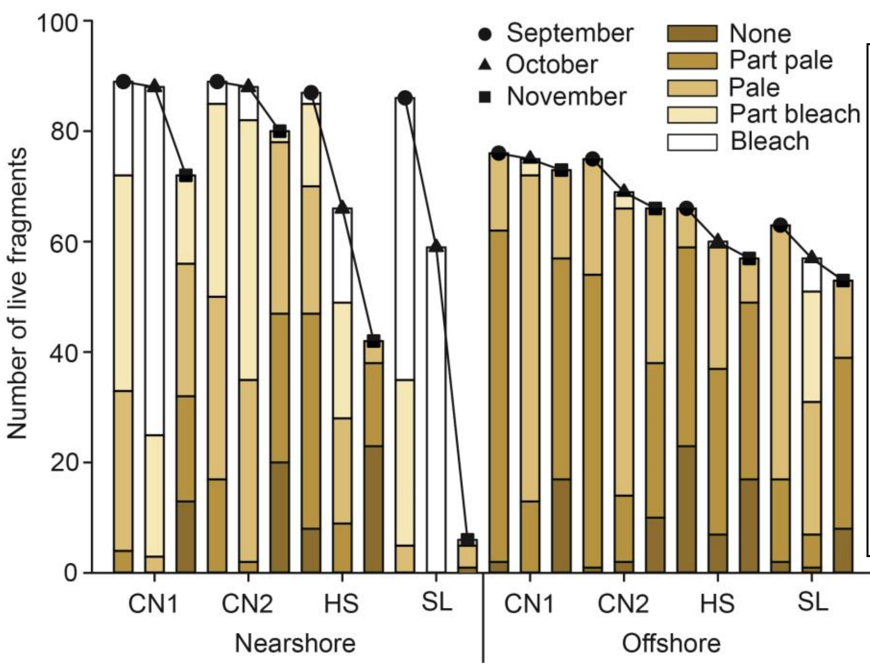


Figure 2: Bleaching score composition of *Acropora palmata* outplanted fragments in Sept, Oct. and Nov 2015. Fragment genotype and habitat treatments are shown on the x-axis. Bleaching was substantially worse in the nearshore patch reef (compared to offshore reef) habitat. Also, the SL genotype showed much higher bleaching susceptibility in both habitats than the other three genotypes, which translated into high mortality in the patch reef habitat.

Research Performance Measure: Intensive field work is involved with each project component. We were successful in implementing the second *A. palmata* outplant experiment as planned (May 2015) and were successful in performing spawning and larval experiments in Aug-Sept 2015.

Natural Resource Damage Assessment Plankton Processing

Project Personnel: S. Privoznik, A. Ender, A. Jugovich, K. Doering, E. Keister, T. Morrell, A. Shiroza and J. Mostowy (UM/CIMAS)
NOAA Collaborators: J. Lamkin and Trika 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 FORCES (Fisheries Oceanography for Recruitment, Climate, and Ecosystem Science) laboratory at the NOAA/NMFS Southeast Fisheries Science Center, Miami Lab is assisting in 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.

Research Performance Measure: The large volume of samples generated in response to the DWH was divided into prioritized Tiers among the multiple institutions to facilitate processing and data acquisition. The SEFSC Miami Lab has processed a total of 1,970 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 117,419 larval fish, from 612 samples, to the lowest possible taxonomic levels. 100% of sorted and identified samples at NOAA SEFSC Miami Lab have been entered into the online database shared by the NRDA labs. 100% of samples sorted and identified have been labeled and sent to the DWH Plankton Assessment Archive.

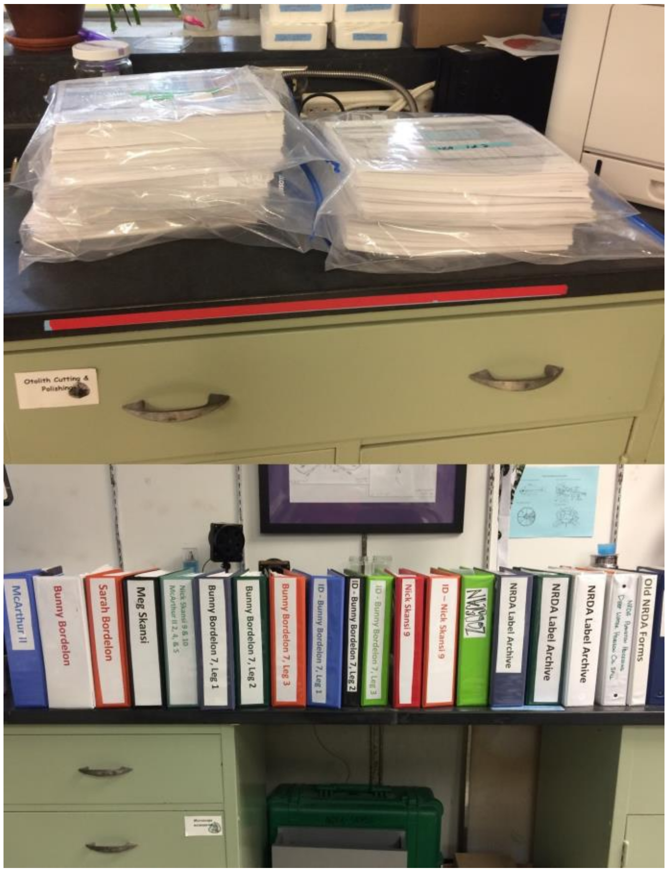


Figure 1: Upon completion of the multi-year plankton processing project, the necessary sample archiving resulted in hundreds of Chain of Custody forms (top) and dozens of binders of datasheets and forms (bottom).

Figure 2: The FORCES Lab was pleased to share their contribution to the DWH Damage Assessment with NOAA deputy administrator VADM Brown in March 2016.

Quantitative Tools to Study Individual to Population-Level Implications of Marine Animal Movement

Project Personnel: N. Putman (UM/CIMAS)
NOAA Collaborators: P. Richards (NOAA/SEFSC); G. Goni (NOAA/AOML)

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*)

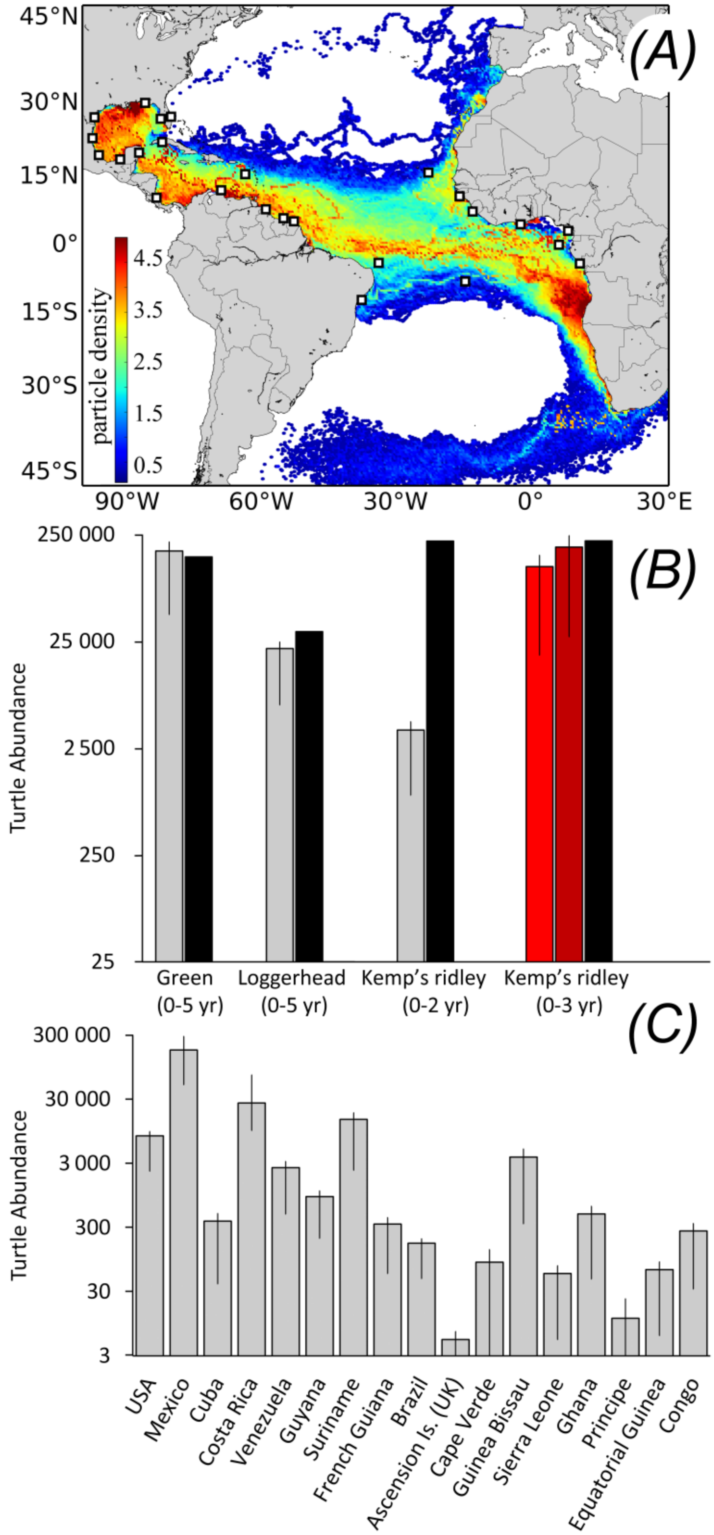
***Goal 3*:** Climate Adaptation and Mitigation - *An informed society anticipating and responding to climate and its impacts* (*Secondary*)

NOAA Funding Unit: NMFS/SEFSC; OAR/AOML
NOAA Technical Contact: Theo Brainerd; Molly Baringer

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 fishes. At the beginning of April his project transitioned from being housed at the SEFSC (under the mentorship of Dr. Paul Richards) to AOML (under the mentorship of Dr. Gustavo Goni).

Research Performance Measure: Research performance is measured in terms of peer-reviewed publications produced. A manuscript showing how demographic information can be layered into models of physical transport to estimate abundance of juvenile turtles at the site of the DWH spill was published in *Biology Letters*. Other publications include identifying physical transport mechanisms that influence the genetic population structure of sea turtle foraging grounds and sensory basis by which turtles can re-locate small oceanic islands for nesting.



We investigated the extent that the 2010 Deepwater Horizon oil spill potentially affected oceanic-stage sea turtles from populations across the Atlantic. (A) Within an ocean circulation model, particles were backtracked from the Gulf of Mexico spill site to determine the probability of young turtles arriving to this area from major nesting beaches (white squares). Abundance of turtles in the vicinity of the oil spill was derived by forward-tracking particles from focal beaches and integrating population size, oceanic-stage duration, and stage-specific survival rates. (B) Simulations indicated that as many as 213,248 green (Chelonia mydas), 24,646 loggerhead (Caretta caretta), and 243,804 Kemp's ridley (Lepidochelys kempii) turtles were likely within the spill site (grey bars). These predictions compared favorably to estimates from in-water observations recently made available to the public (black bars). Though our initial predictions for Kemp's ridley were substantially lower than in-water estimates, better agreement was obtained with modifications to mimic behavior of young Kemp's ridley turtles in the northern Gulf (red bars). (C) Simulations predicted 75.2% (71.9-76.3%) of turtles came from Mexico, 14.8% (11-18%) from Costa Rica, 5.9% (4.8-7.9%) from countries in northern South America, 3.4% (2.4-3.5%) from the United States, and 1.6% (0.6-2.0%) from west African countries. Thus, the spill's impacts may extend far beyond the current focus on the northern Gulf of Mexico.

Application and Automation of Underwater Image Mosaics for Sampling, Characterizing, and Classifying Corals as Protected Stocks and Habitat

Project Personnel: P. Reid and B. Gintert (UM/RSMAS; A. Gleason (UM/Physics)
NOAA Collaborators: M. Miller and B. Vargas-Angel (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** Our long-term research objectives are to improve the management of populations of scleractinian corals that are protected under the Endangered Species Act and also to understand how the structure provided by certain species of branching corals can serve as the basis of essential habitat for stocks of reef fish.

***Strategy*:** Our strategy to achieve these long-term objectives is to improve measurements of coral abundance, condition, and habitat quality through a combination of underwater image mosaics, which provide spatially explicit maps at the coral colony level, automated image classification, which will enable processing of many sites over time, and correlation of habitat metrics extracted from the classified mosaics with fish census data.

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/ASTWG
NOAA Technical Contact: George Cutter

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. There are strong legal mandates for ongoing coral species and reef habitat assessments or status reviews under both the Magnuson-Stevens and the Endangered Species Act (ESA) contexts. Understanding the habitat characteristics that define EFH, and the coral stocks that create them, are critical components to improved fishery stock assessment and management.

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 suffer at least 4 limitations:

a) labor intensive.
b) same methods not applicable in all areas or to all species.
c) measurements are not necessary comparable from place to place.
d) demographic measurements are not always compatible with the objective to measure corals as EFH. In other words, to get at both corals as stocks and habitat, two methods are often necessary.

The goal of this project was to test the ability of underwater landscape mosaics to address these four limitations of coral surveys. The first three limitations have been addressed in this project through automated image analysis and new techniques for creating mosaics of very large areas from underwater images, both of which reduce field labor and increase objectivity in data analysis. The automated analysis showed strong promise for detecting *Acropora spp.* in underwater images (Fig. 1). Data acquisition with

multiple cameras decreased survey time and changes to our code increased the area that can be stitched together (Figs. 2, 3). The fourth limitation has been addressed by correlating features measured from the mosaics, such as percent live coral cover, with an in situ measurement known as total linear extension (TLE), which has been shown to correlate with apparent thresholds in fish habitat function.

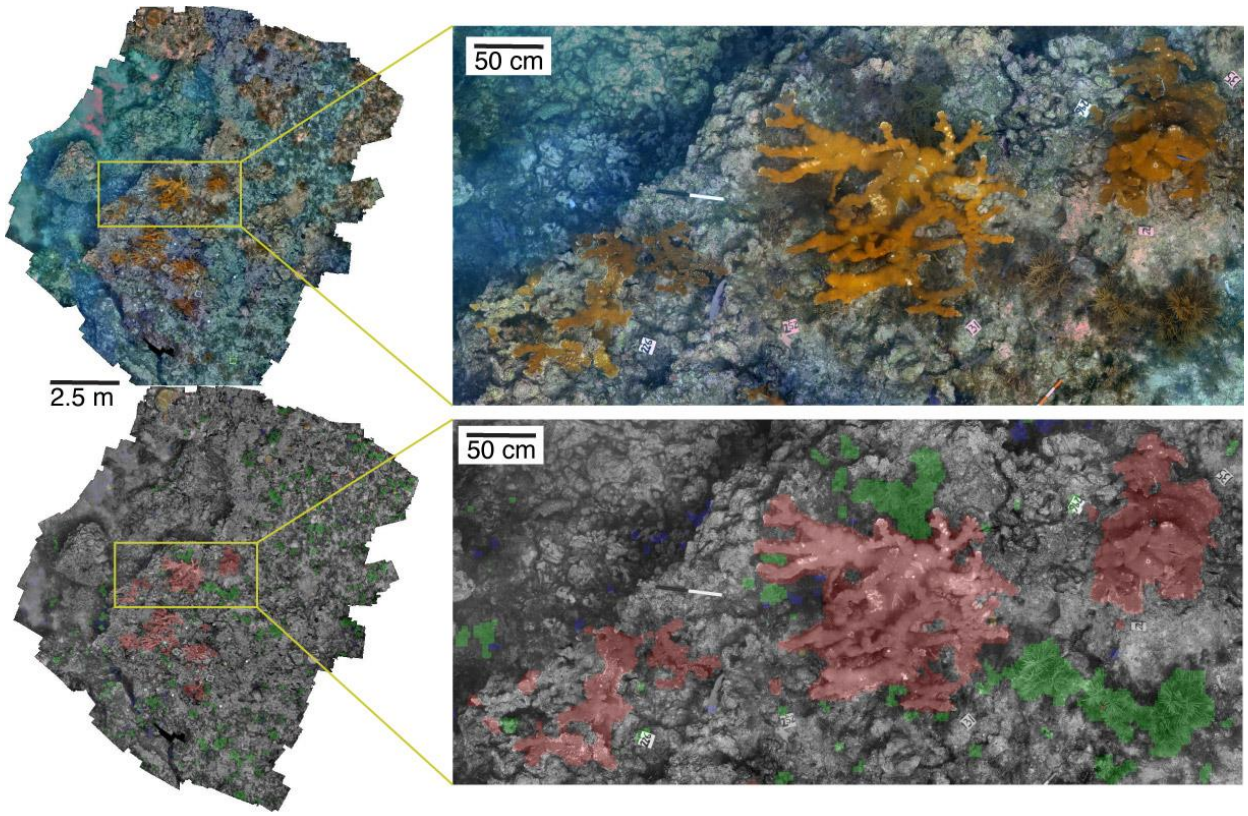


Figure 1: Example of classification results. Top left: an underwater image mosaic from a plot near Molasses Reef, FL, containing several colonies of *A. palmata*. Bottom left: same mosaic as the top panel but converted to greyscale. Pixels classified as *A. palmata* are tinted red, pixels classified as gorgonians tinted green. Panels on the right side show zoomed-in subsets of the mosaic (top) and classified mosaic (bottom). Note how the classifier works using both color and texture; much of the *A. palmata* colonies are a distinctive bright orange, but there are portions of some colonies that are the same shade of brown as the gorgonians. Nevertheless, these areas were properly classified.

Research Performance Measure: The project had three performance objectives:

1) Evaluate a current state-of-the-art benthic classification algorithm in multiple habitats and for several ESA-listed or proposed coral species (part A). Improve our existing benthic classification algorithm (part B). Part A for this objective has been achieved using data from several sites with *Acropora palamata* in the Florida Keys (Fig. 1). Part B for this objective has been investigated using a new algorithm.
2) Increase the area that can be rapidly mosaicked. This objective has been achieved by using multiple GoPro cameras mounted in an array to acquire data simultaneously. Our mosaicking code was also modified to work with this configuration. Dozens of datasets have been successfully processed using this technique (Figs. 2, 3).

3) Increase sampling accuracy and efficiency of coral condition and EFH using biological metrics derived from underwater image mosaics. Objective 3 was achieved by demonstrating that diver-based measurements of total linear extension for *A. cervicornis* colonies correlated with both 2-D size measurements and percent live coral cover as measured from the mosaics.

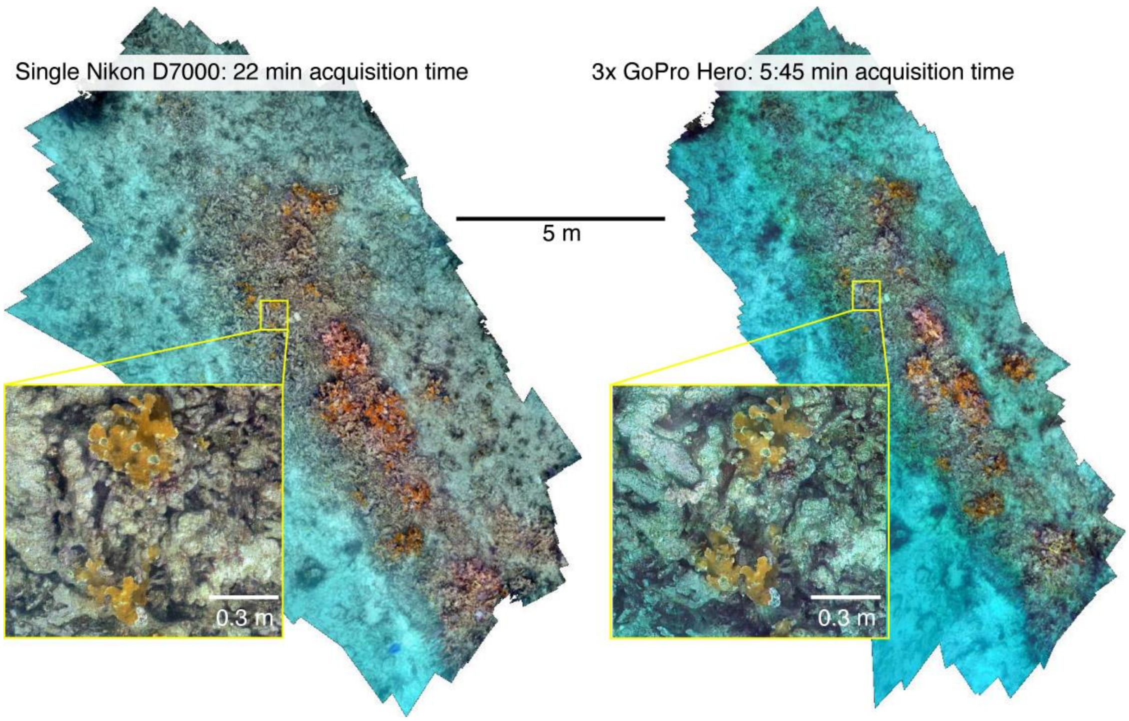


Figure 2: Comparison of two mosaics; one made with a single camera (left) and one made with an array of 3 cameras deployed on a pole. The same diver acquired data for both, and both datasets produced very similar results. The single-camera mosaic (left) covers a slightly larger area, but took almost 4 times as long to acquire.

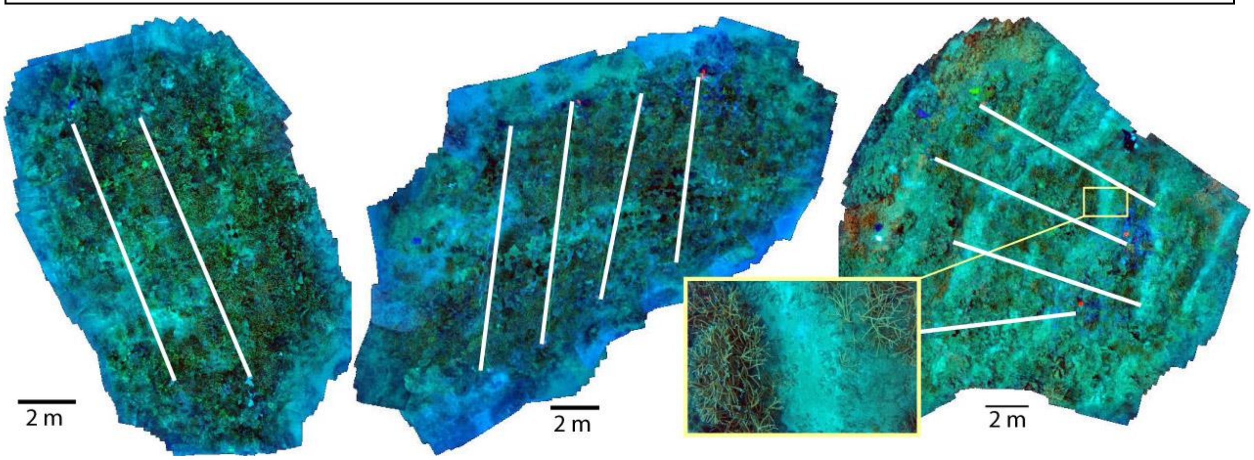


Figure 3: Three sample mosaics from the Puerto Rico dataset acquired in summer 2014. Each mosaic covers approximately 100 m^2 and required about 12 minutes to collect the raw images using an array of 4 cameras. We also collected in situ colony size/condition and fish abundance/diversity data from replicate 10 m^2 transects within each of these areas for cross-calibration with these meso-scale mosaics. The extent of the transects themselves are highlighted here as white lines drawn on top of the mosaics.

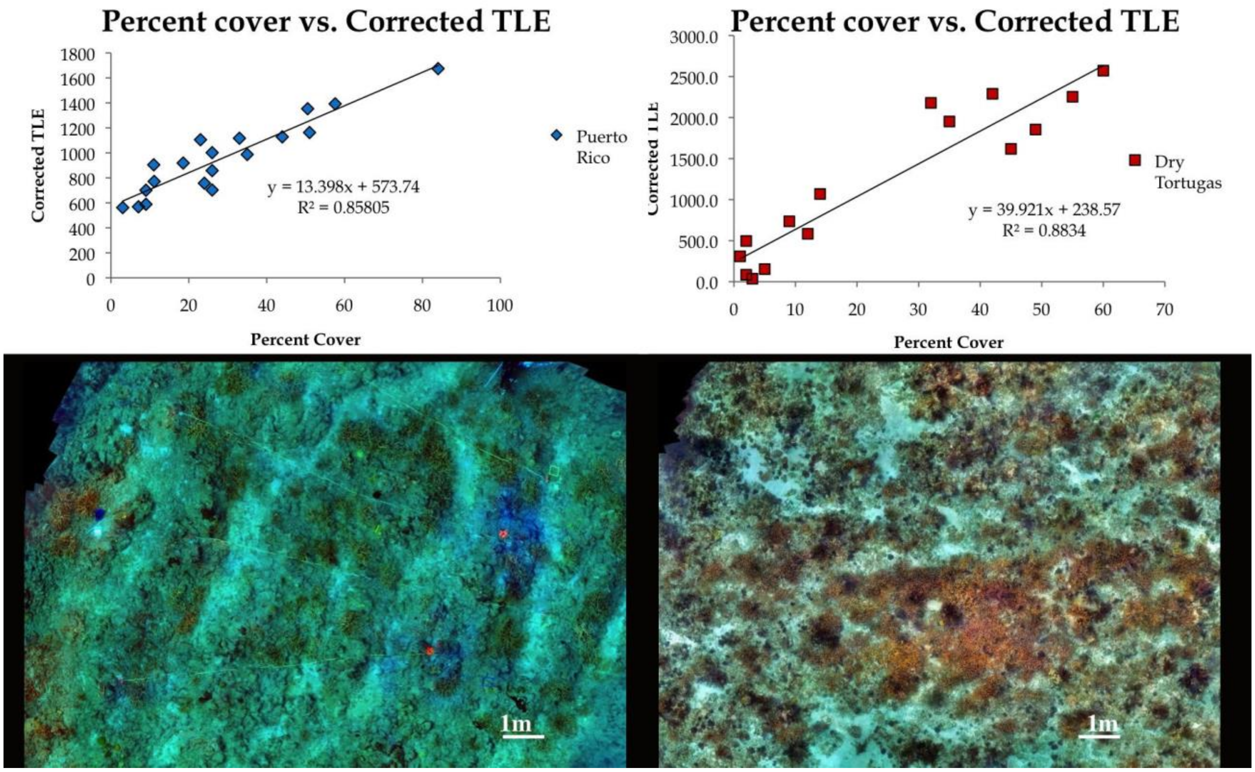


Figure 4: Correlation between percent benthic cover of live *Acropora cervironis* derived from the mosaics and total linear extention (TLE) of *A. cervicornis* branches measured in by divers at these sites. TLE has been shown to correlate with apparent thresholds in fish habitat function. These data suggest that habitat function may be able to be assessed directly from the imagery, thereby reducing the need for time-consuming *in situ* TLE measurements and providing objective data that can be compared across regions and among research groups.

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Linkages Between Coral Health and LBSP: Identifying 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: 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 dissolved inorganic nitrogen (DIN) is 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 sub-lethal 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.

This project was designed to examine linkages between LBSP nutrient levels and coral health: specifically reduced, mean, low-, mid-high- and high-nitrate conditions and the concomitant sub-lethal health effects measured by coral growth, PAM fluorometry, and histological 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 use of multiple complimentary metrics for coral health assessment in response to target nitrate levels permits identification of overall sub-lethal coral response to elevated nitrate concentrations. 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. 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 this work included a six-month laboratory dose response experiment to determine the effects of environmentally-realistic levels of DIN on coral health and function. Target concentrations (0.1, 0.3, 1.0, 4.0, and 8.0 µm) were determined from water quality data obtained by AOML-FACE, SECREMP, and other available water quality monitoring data. Colony fragments from 5 colonies each of *Montastraea cavernosa, Porites astreoides, Porites divaricata, and Siderastrea siderea*, were exposed for six months to five concentrations of nitrate. Four independent replicates of each concentration were maintained (replicates are individually temperature controlled and independently dosed). Each replicate contained five fragments of each species (one fragment from each colony). To link coral physiological performance to exposure over time, the maximum quantum yield of PSII photochemistry of each coral was monitored bi-weekly with a submersible pulse amplitude modulated fluorometer (PAM). To assess growth rate and calcification response, buoyant weight measurements of each coral were conducted bi-weekly. Color/condition and mortality of each coral was assessed weekly. Water quality parameters, including ammonia, nitrite, nitrate, phosphate, pH, alkalinity, salinity and temperature were monitored regularly. At the conclusion of the exposure, 25% of each coral was fixed for histological and ultrastructural analysis to quantify tissue condition, and zooxanthellae density. An additional 25% of each coral was preserved for future geochemical calibration studies of temperature and nutrient proxies. The remaining portion of the coral was returned to the land-based nursery at Nova Southeastern University. 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 will facilitate prediction of future coral health and coral reef condition, providing missing information for definitively linking terrestrial pollutants with coral degradation.

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* (*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. Sub-lethal indicators of coral heath demonstrated significant impacts to coral health over time during the 6-month chronic exposure period.

Offshore nitrate concentration data was compiled 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 were 0.1 µM (lower than the mean), 0.3 µM (the mean), 1.0 µM (low-high), 4.0 µM (mid-high), and 8.0 µM (high) nitrate. Actual mean exposure concentrations were 0.21, 0.29, 0.96, 3.39 and 6.04 µM nitrate.

All data were tested for normality (Brown–Forsythe) and homoscedasticity (Komolgorov–Smirnov/Lilliefors) and transformed to meet these assumptions where applicable, or nonparametric methods were used. Tukey's HSD test (parametric) or multiple comparisons (nonparametric) was used for post hoc analysis. All statistical tests were performed using STATISTICA 12. <u>Mortality (Fig. 1):</u> Percent mortality of each species was compared between treatments after 2, 4 and 6 months of exposure using Kruskal-Wallis ANOVA on ranks (α=0.05) and Multiple Comparisons post-hoc analysis. For *M. cavernosa*, *P. divaricata*, and *S. siderea*, no significant differences in mortality between treatments were found during the exposure ($p>0.05$). For *P. astreoides*, significant concentration effects on mortality were found at 4 mo ($p=0.0053$) and 6 mo ($p=0.0147$) of exposure, but post-hoc analysis could not resolve specific treatment differences. <u>Color/Condition score (Fig. 2):</u> Mean color/condition score was compared between treatments after 2, 4 and 6 months of exposure using Kruskal-Wallis ANOVA on ranks (α=0.05) and Multiple Comparisons post-hoc analysis. For *M. cavernosa* and *S. siderea*, no significant differences in color/condition score between treatments were found during the exposure ($p>0.05$). *P. astreoides*, significant concentration effects on color/condition were found at 4 mo ($p=0.0458$) and 6 mo ($p=0.0167$) of exposure, but post-hoc analysis could not resolve specific treatment differences. Similarly, for *P. divaricata*, significant concentration effects were found at 6 mo ($p=0.0404$) of exposure, but post-hoc analysis could not resolve specific treatment differences. <u>Photosynthetic efficiency (Fig. 3):</u> Mean PSII quantum yield (F_v/F_m), and mean growth rate (mg/d) of each species were compared between treatments after 2, 4 and 6 months of exposure using Kruskal-Wallis ANOVA on ranks (α=0.05) and Multiple Comparisons post-hoc analysis. For *P. astreoides*, no significant differences in photosynthetic efficiency between treatments were found during the exposure ($p>0.05$). For *M. cavernosa*, *P. divaricata*, and *S. siderea*, significant treatment effects were found at 2, 4 and 6 mo of exposure ($p<0.05$). In *M. cavernosa*, F_v/F_m of the 6.04 µM exposed corals was significantly less than the 0.21 µM and 0.96 µM after 2 mo of exposure; after 4 mo of exposure, the 6.04 µM exposed corals had a significantly lower F_v/F_m than the 0.21 µM and 0.29 µM corals; after 6 mo of exposure, the 3.39 µM and 6.04 µM exposed corals had a significantly lower F_v/F_m than the 0.21 µM corals. In *P. divaricata*, F_v/F_m of the 6.04 µM exposed corals was significantly less than 0.21 µM corals after 2 mo; after 4 mo, F_v/F_m of the 6.04 µM corals was

significantly lower than the 0.21 µM corals; and after 6 mo, F_v/F_m of the 3.39 µM and the 6.04 µM corals was significantly lower than the 0.21 µM corals. In *S. siderea*, F_v/F_m of the 6.04 µM exposed corals was significantly lower than the 0.21 µM corals after 2 mo; after 4 mo, F_v/F_m of the 6.04 µM corals was significantly lower than the 0.21 µM and 0.29 µM corals; and after 6 mo, F_v/F_m of the 6.04 µM corals was significantly lower than the 0.21 µM corals. Growth rate (Fig. 4): Mean growth rate was compared between treatments after 2, 4 and 6 months of exposure using One-way ANOVA (α=0.05) and Tukey's HSD post-hoc analysis. For *P. astreoides* and *P. divaricata*, no significant differences in mean growth rate between treatments were found during the exposure ($p>0.05$). For *M. cavernosa*, growth rate in the 6.04 µM exposed corals was significantly less than the 0.21 µM corals at 4 mo of exposure. In *S. siderea*, growth rate was significantly less in the 6.04 µM corals compared to all other concentrations at after 2 and 4mo of exposure; after 4 mo, growth rate in the 3.39 µM corals was also significantly less than in the 0.21 and 0.29 µM corals. After 6 mo, growth rate was significantly less in the 3.39 and 6.04 µM corals compared to the lower concentrations, and growth rate in the 0.96 µM corals was significantly less in the 0.21 and 0.29 µM corals Histology: Coral tissues were assessed for quantitative changes in overall tissue characteristics, individual cell types, and degeneration of tissues. Digital micrographs were calibrated in Image J, and tissue and cellular characteristics were measured on screen. Area of the epidermis and gastrodermis in the coenenchyme (the common mesenchymal tissue that links colonial polyps in corals) was determined by tracing the edge of each layer along a 100-mm contour length (5/sample), and the area of mucocytes and granular amoebocyte cells was determined by tracing the cell margins. These measurements were then used to quantify the relative surface area per contour length for each metric. To compare histological characteristics, one-way ANOVA (α=0.05) and Tukey's HSD post-hoc analysis was used to compare mean area (mean of corals of each species per tank) between treatments at the end of the 6 month exposure. For *M. cavernosa*, significant treatment effects were found for epidermal tissue area ($p=0.002$); mean EP tissue area in the 3.39 and 6.04 µM corals was significantly less than in the 0.21 and 0.96 µM corals. For *S. siderea*, significant treatment effects were found for epidermal tissue area, zooxanthellae density, and gastrodermal mucocyte area ($p<0.05$). Mean EP tissue area in the 6.04 µM corals was significantly less than in the 0.21 µM corals. Mean gastrodermal mucous area in the 0.21 µM corals was significantly greater than in the 0.29, 0.96, and 6.04 µM corals, and mean zooxanthellae density was significantly lower in the 0.21 µM corals compared to the 0.29 and 0.96 µM corals. Threshold determination: The median effect concentration (EC50) for each species was calculated from mean color/condition scores with Graphpad Prism 6.0. The median inhibition concentration (IC50) for each species was calculated from mean photosynthetic efficiency measurements with Graphpad Prism 6.0. The mean EC50 for all species was 3.797 ± 0.724 µM nitrate, and the mean IC50 was 0.952 ± 0.116 µM nitrate (mean ±SE).

Overall, this research indicates that chronic, 6 mo exposure to elevated nitrate concentrations significantly affected mortality in *P. astreoides*, but not in *M. cavernosa*, *P. divaricata*, or *S. siderea*, but post-hoc analysis could not resolve specific treatment differences. Color/condition was significantly affected in both *Porites* species, but not in in *M. cavernosa* or *S. siderea*, however post-hoc analysis could not resolve specific treatment differences. Photosynthetic efficiency was significantly reduced after 2 mo if exposure in *M. cavernosa*, *P. divaricata* and *S. siderea* but not in *P. astreoides*. Growth rate was significantly reduced after 4 mo of exposure in *M. cavernosa* and after 20 mo of exposure in *S. siderea*. The mean median effect concentration for all species tested based on color/condition score was 3.78 µM nitrate, indicating that exposure to this concentration of nitrate for 6 mo will effect 50% of the population. The mean half-maximal inhibitory concentration for all species tested based on photosynthetic efficiency was 0.95 µM nitrate, indicating that, exposure to this concentration of nitrate for 6 mo will reduce photosynthetic efficiency by 50% in these species.

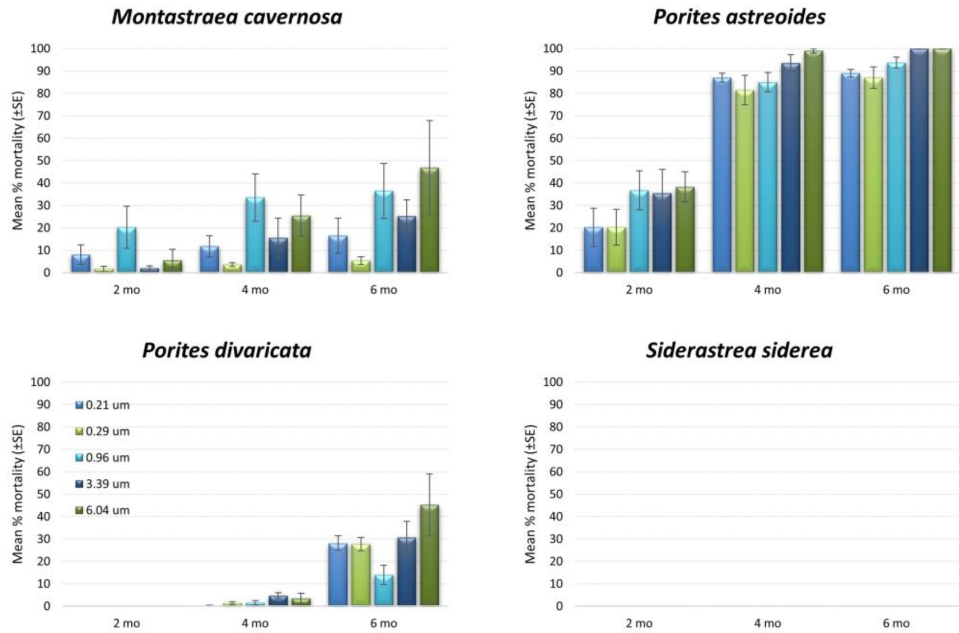


Figure 1: Mean % mortality **(**mean ± SE) of experimental corals after 2 months, 4 months, and 6 months of exposure for each species. Significant treatment effects, if any, are indicated by a red asterisk above the specific exposure time period.

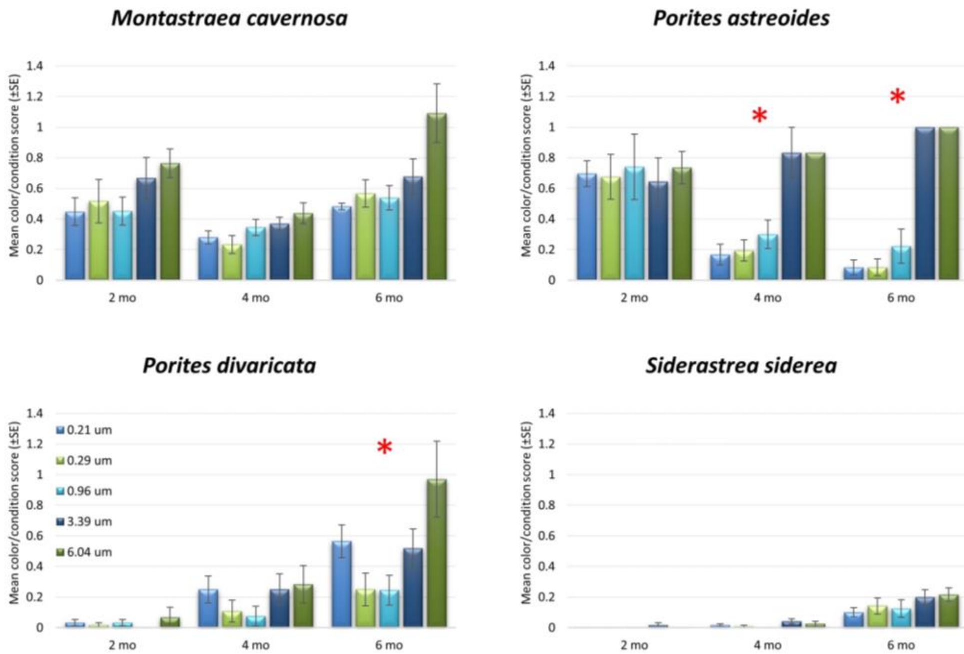


Figure 2: Mean color/condition score **(**mean ± SE) of experimental corals after 2 months, 4 months, and 6 months of exposure for each species. Significant treatment effects, if any, are indicated by a red asterisk above the specific exposure time period.

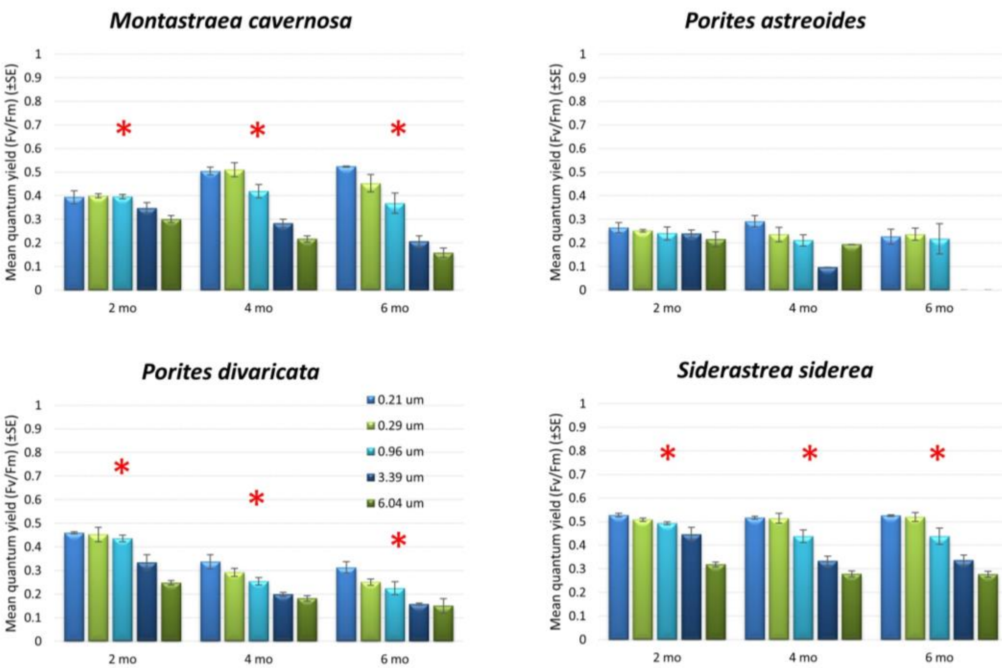


Figure 3: Mean PSII quantum yield [Fv/Fm = (Fm − Fo)/Fm; mean ± SE] of experimental corals after 2 months, 4 months, and 6 months of exposure for each species. Significant treatment effects, if any, are indicated by a red asterisk above the specific exposure time period.

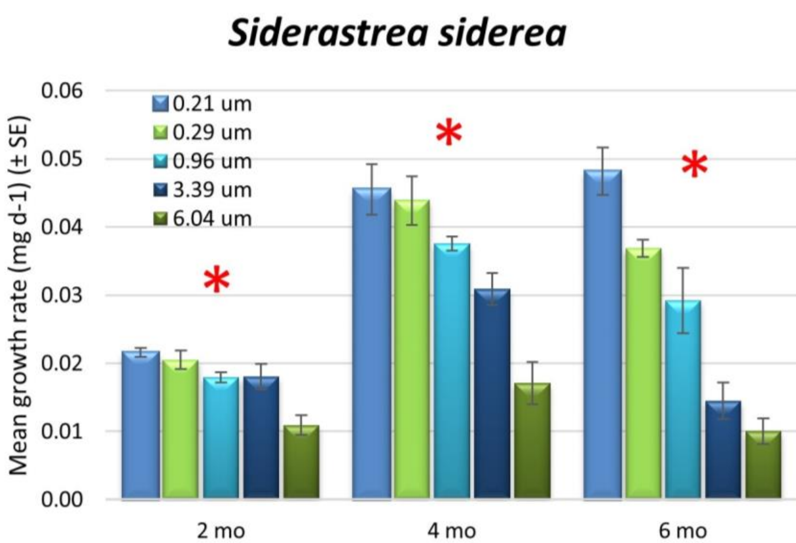


Figure 4: Mean growth rate (mg/d) **(**mean ± SE) of *Siderastrea siderea* after 2 months, 4 months, and 6 months of exposure. Significant treatment effects, if any, are indicated by a red asterisk above the specific exposure time period.

Research Performance Measure: This was a 2-year project, and due to processing delays, the project was not funded until late in the first year. After the initial delay, the project proceeded on time. We have successfully completed the experiments and analysis, and have determined sub-lethal threshold concentrations of effect for environmentally realistic levels of nitrate.

Marine Mammal Research

Project Personnel: J. Wicker (UM/CIMAS),
NOAA Collaborators: L. Garrison, A. Martinez, J. Contillo and J. Litz (NOAA/SEFSC)

Long Term Research Objectives and Strategy to Achieve Them:

***Objectives*:** 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. 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. 2) To support the West Florida Bottlenose dolphin Cruise by collecting biopsy samples, photographic data, acoustic data and visual data. 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 (*Primary*)
***Theme 3*:** Regional Coastal Ecosystem Processes (*Secondary*)

Link to NOAA Strategic Goals:

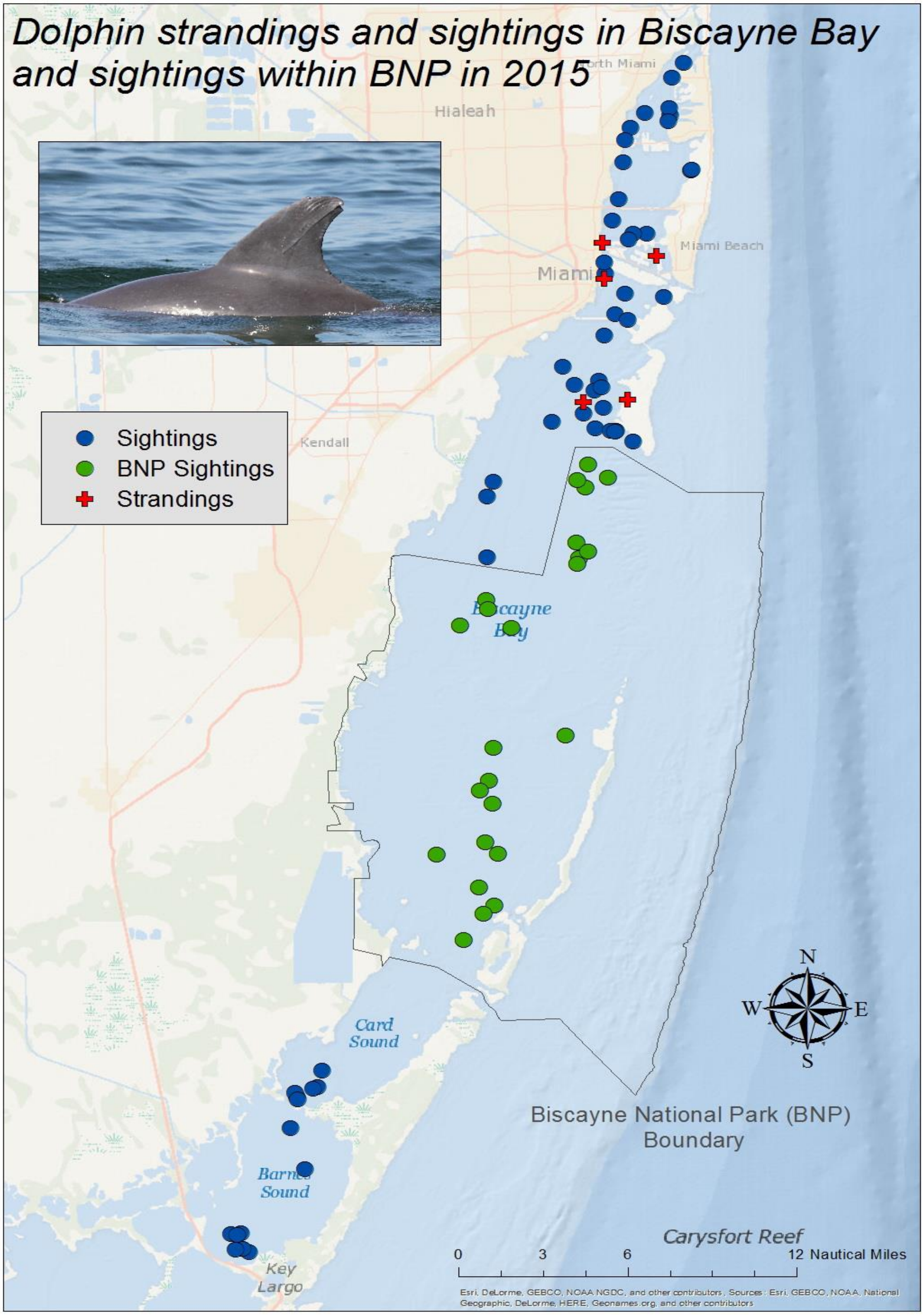
***Goal 3*:** Healthy Oceans - *Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems*

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. I have supported research projects in the Gulf of Mexico and Atlantic Ocean resulting in over 332 marine mammal sightings, 222 biopsy samples, and 3,500 (km) of visual survey effort. The summer 2015 West Florida Bottlenose dolphin Cruise assessed the abundance, habitat and spatial distribution of Bottlenose/Atlantic spotted dolphins through visual and passive acoustic monitoring, 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/FPC onboard NOAA ship Gordon Gunter during the marine mammal large vessel survey during the summer of 2015. 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 through SE United States.


Dolphin strandings and sightings in Biscayne Bay
and sightings within BNP in 2015
Sightings
BNP Sightings
Strandings
Hialeah
Miami Beach
Miami
Kendall
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Biscayne National Park (BNP)
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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)

This course was taught for the fourth time during Fall 2015 by Christopher Stallings and Ernst Peebles of USF-CMS. (8 students and one visiting-scientist auditor – 0% agency)
USF students: Krista Abbott, Kristie Armas, Megan Hepner, Alexander Ilich, Brianna Michaud, Tess Rivenbark, Kelly Vasbinder, Julie Vecchio
Florida FWC students: none
NOAA students: none

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)

This course was taught for the fourth time during Spring 2016 by David Jones of USF-CMS (6 students; 0 agency employees)

USF students: Kate Dubickas, Christian Gfatter, Brianna Michaud, Kelly Vasbinder, Julie Vecchio, Elizabeth Simpson
Florida FWC students: none
NOAA students: none

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

This course was taught for the second time during Spring 2016 by Cam Ainsworth of USF-CMS (8 students, including 3 agency employees – 38% agency).

USF students: Elizabeth Simpson, Brianna Michaud, Kaitlyn Colna, Kelly Vasbinder, Melissa Rohal
Florida FWC students: Brittany Combs, Ben Kurth
NOAA students: Walter Ingram (audited)

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)

This course was taught for the second time during Fall 2015 by David Jones of USF-CMS (8 students, including 3 agency employees – 38% agency)

USF students: Erin Cuyler, Christian Gfatter, Kate Dubickas, Brianna Michaud, Jen Granneman
Florida FWC students: Brittany Combs, Mike Murphy
NOAA student: Nic Alvarado

MRA Graduates (All Years)

Claire Crowley (M.S., Spring 2012); employed by FWC FWRI
Catherine (Bruger) Hayslip (M.S., Fall 2013); left the field
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); left the field
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 as assistant professor at the University of the Virgin Islands
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
Brock Houston (M.S., Summer 2015, employed as sales engineer at YSI Instruments)
Sheri Huelster (M.S., Summer 2015, employed as project scientist at Cardno)
Orian Tzadik (Ph.D., Fall 2015, employed by FWC FWRI)

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. Dr. Tzadik graduated in Fall 2015 and is now employed at FWC FWRI.

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 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 to 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 150 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.

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 2015, more than 120 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. Beth Babcock, the UM P.I. of the Living Marine Resources Cooperative Science Center (LMRCSC) and of the collaboration of Dr. David Die CIMAS Associate Director who serves as UM representative in the LMRCSC science committee. 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, CIMAS supports the activities of the LMRCSC by funding part of the research and studies of the LMRCSC students who are housed at RSMAS. Moreover, the participation of US Caribbean universities in CIMAS benefits the LMRCSC by enhancing the recruitment of a diverse student body. Currently the program funds two PhD students and funded an additional MSc student earlier in the 2015 academice year.

Public Outreach and Informal Educational Activities Associated with Specific CIMAS Research Projects

CIMAS sponsored five climate education workshops covering the basics of climate in terms of understanding how greenhouse gases affect global climate, sea level rise, sea-ice concentration and thickness, land ice cover and the Earth's albedo. Elements of ecosystem science were also covered. The workshops included a total 133 attendees and also showcased how CIMAS science contributes to understanding climate variability and change. The workshop attendees were polled to assess how the training contributed to their understanding of climate - across all the workshops 68% of the participants felt "empowered to learn more about climate change."

In addition, CIMAS projects have their own specific outreach components, listed in the section below according to project names:

Western Boundary Time Series Project

- C. Meinen was interviewed over the phone by a reporter for Science magazine on the latest updates to the Meridional Overturning Circulation ("MOC") arrays in the Atlantic on Tuesday, April 26, 2016.

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, Jan. 15. Dr. Mark Powell was one of three presenters.
- Dr. Mark Powell conducted a review of the IEC international standard for relevance to Hurricane Design conditions. March 2015.

Developing Decision Support Tools for Understanding, Communicating, and Adapting to the Impacts of Climate on the Sustainability of Coastal Ecosystem Services

- G. Cook - 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.
- Project personnel conducted three separate Expert Opinion Polling sessions throughout South Florida, engaging managers and stakeholders to better the conceptual models that had been devised.

Coral Health and Monitoring Program (CHAMP)

- A study by Enochs and colleagues was covered in the popular media by The Miami Herald, Bradenton Herald, Environmental Monitor, Gizmodo.com, IFLScience.com, Climate Wire, Yahoo News, TorontoStar.com, ScienceDaily.com, among others.
- Media coverage of Xaymara Serrano's *Porites astreoides* paper published in 2016:
  UM Press release:
  http://www.rsmas.miami.edu/news-events/press-releases/2016/um-researchers-found-shallow-water-corals-in-florida-are-not-related-to-the/
  WLRN radio interview:
  http://wlrn.org/post/floridas-coral-getting-help-hundreds-miles-away
- Ruben van Hooidonk gave a presentation "the importance of coral reef conservation" at a TEDx event organized by the Dutch consulate, September 23, 2015.

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 including My Brothers Keeper in March 2016, and co-mentored a NOAA Hollings scholar during the summer of 2015.
- R. Perez, E. Valdes, R. Lumpkin, and M. Pazos participated in Bring Your Child to Work Day.

Southwest Atlantic Meridional Overturning Circulation ("SAM") Project

- C. Meinen was interviewed over the phone by a reporter for Science magazine on the latest updates to the Meridional Overturning Circulation ("MOC") arrays in the Atlantic on Tuesday, April 26th, 2016.
- S. Garzoli and R. Perez are involved in the MPOWIR (Mentoring Physical Oceanography Women to Increase Retention) organization.

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.

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

- AOML Open house in May 2015 where we set up a station to explain ocean acidification to students from local schools, boy and girl scouts and general audience.

Gulf of Mexico Integrated Ecosystem Assessment

- 2015 Review Panel for NOAA Ernest F. Hollings and Educational Partnership Program Undergraduate Scholarship Programs.

Aquarius Reef Base Maintenance and Monitoring

- K-12 Outreach:

  Virtual Field Trips conducted aboard Aquarius: 124 venues; 12,194 students
  Aquarius shore base field trips: 302 students
  Aquarius Teacher Under the Sea program: Five K-12 teachers joined FIU scientists as they studied the impacts of sharks on coral reef ecosystems. Teachers engaged in immersive research and developed educational outreach programs and lesson plans.

- Undergraduate Programs:
  Scientific Research Diver Certificate Program: 21 students
  FIU School of Journalism and Mass Communication: 19 students

- Public Awareness
  Sea-Space Initiative, Washington DC (panel)
  Lunar Surface Applications, Kennedy Space Center, FL (panel)
  Mandela Washington Fellowship at FIU, Key Largo, FL (visiting fellows)

Florida Area Coastal Environment (FACE) Program

- Included in several Science Café presentations - Centers for Ocean Sciences Education Excellence - Florida

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

- A two-day workshop was held March 19th and 20th, 2015 at the Cooperative Institute of Marine and Atmospheric Studies, Rosenstiel School of Marine & Atmospheric Science, University of Miami. 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 and also ~10 people via webinar.

Synthesis of Information on Octocoral Biology, Ecology, and Fisheries in the South Atlantic in Support of Effective Management

- A website (www.florida-octocorals.org) was constructed that provides all the project results in a user-friendly manner.

Defining Spawning Dynamics to Manage and Conserve Reef Fish Populations

- Presentation of project objectives and results at the 157th meeting of the Caribbean Fishery Management Council, August 23. 2016, San Juan, PR.

Reanalysis of the Atlantic Basin Tropical Cyclone Database in the Modern Era

- Delgado, S., 2015: Reanálisis de HURDAD, VIII Congreso Cubano de Meteorología, Havana, Cuba (Talk given 2 Dec. 2015).
- Delgado, S., 2016: Reanalysis of the 1951-1959 Atlantic hurricane seasons, American Meteorological Society, San Juan, PR (Talk given 19 April 2016).
- Landsea, C.W., and Delgado, S., 2016: Hurricanes of Extraordinary Size: 1956's Greta, 1962's Ella, and 2012's Sandy, American Meteorological Society, San Juan, PR (Talk given 19 April 2016).
- Mock, C.J., Landsea, C.W., and Delgado, S., 2016: The Atlantic Hurricane Seasons of 1837 and 1838, American Meteorological Society, San Juan, PR (Talk given 19 April 2016).
- Moses, B., 2016: Re-Analysis of the 1964 Atlantic Hurricane Season, American Meteorological Society, San Juan, PR (Poster presented 21 April 2016).

The GO-SHIP Repeat Hydrography Program

- D. Pierrot, R. Wanninkhof, and C. Langdon are actively involved in the international coordination and data quality control of efforts such as GO-SHIP repeat hydrography.
- J.-Z. Zhang is actively involved in the Joint IOC-ICES Study Group on Nutrient Standards (SGONS)

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.
- 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.

PIRATA Northeast Extension

- S. Dolk mentored 2 high school students, from MAST Academy, for summer internships during the summer of 2015.

- G. Foltz and R. Perez mentored a Hollings Undergraduate Scholar, Allyson Rugg, from May 26, 2015 to July 27, 2015.

Surface water partial pressure of CO_2 (pCO_2) measurements from ships

- D. Pierrot, L. Barbero and K. Sullivan participated in the AOML Open house in May 2015 where a station was set up to explain the CO_2 system in the ocean to students from local schools, boy and girl scouts and the general audience.

Ocean OSSE Development for Quantitative Observing System Assessment

- Weekly 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_GULF_OF_MEXICO_high_resolution

Targeted Products for Improving Ecosystem-Based Fishery Management in the Gulf of Mexico

Through the funding from this project and others we have been able to continually update and improve the GoMexSI webpage. We recently released GoMexSI ver 2.0, which features the Vision, and Goals and Objectives of the GoMexSI project, along with a link to the latest GoMexSI video "No Guts, No Data, No Glory".

Within the webpage there are three query pages, a Taxonomic Query that allows one to search for predator/prey information on a selected taxa, the Spatial Query page which allows one to search for predator/prey information in a selected area of the Gulf, and the Exploration Mode which presents the unique predators above and the unique prey below the selected organism, now with the option to open an additional window for a selected organism from the displayed predators and prey. The maps that can be displayed by clicking on **Map** now have the polygon for which the centroid is representative, and the Spatial Query page now displays the centroid of all available data references in the database. The raw data from the Taxonomic and Spatial queries are available as a csv file download.

Another section of the webpage presents summary information about the Texas Coastal Fish Gut Round-up which was an effort to collect under-represented fishes in the database from off the coast of Texas working with charter boats and head boats operating out of ports O'Connor, Aransas and Mansfield. Included in this section is a list of targeted species, project partners, a summary of the species captured and stomachs taken, and some background information.

A GoMexSI News section provides the text and links to various news stories that have covered aspects of the GoMexSI project. Additionally, links to the GoMexSI Facebook page and GoMexSI Twitter account are provided.

Developing a Decision-Support Tool for the Management of Clam Farms on the FL Gulf Coast

P. Suprenand participated as a Lecturer at ClimEco5 in Natal, Brazil, in August 2016. ClimEco5 is an interdisciplinary summer school offered by IMBER, Integrated Marine Biogeochemistry and Ecosystem Research. Students and early-career researchers in natural and social sciences learn practical ways of dealing with challenges arising from working across social and natural sciences disciplines and communicating with decision makers. Suprenand served on a team of multidisciplinary experts to share perspectives and approaches to marine science and, in doing so, shared the development and results of this project.

Caribbean Sea and Gulf of Mexico Bluefin Tuna Research

- Undergraduate students, Justin Suca and Alina Spera, from the University of Miami's RSMAS participated in the project in research cruises, sample and laboratory processing. 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 Miami, FL, and Cozumel, Mexico with overall 100 people touring the research vessel and its facilities.
- In Havana, Cuba the Nancy Foster hosted a delegation from the US Embassy where the ambassador learned about our ongoing research in Cuba.

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

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.marine.usf.edu/ainsworthecology/
- http://www.marine.usf.edu/fishecology/

Evaluation of ESA listed Acropora spp. Status and Actions for Management and Recovery

- Poster presentation "Ecology and recovery of *Acropora palmata*: ecosystem architect and climate sentinel" for 2016 NOAA SEFSC Ecosystem Science Review.

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
- Detailed information about the Mandatory Ship Reporting system at AOML/PhOD website: http://www.aoml.noaa.gov/phod/research/ecosystems/msr/

Coral Restoration and Recovery

- This project served as the internship project for NOAA Hollings Scholar, Michael Connelly.
- D. Williams and M. Miller presented research results to managers and staff of Florida Keys National Marine Sanctuary, 28 Sept 2015.
- Research results were summarized at the SEFSC Ecosystem Science Review, March 2016.

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

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 except one annual in-person meeting, which was held on April 18, 2016, all meetings are conducted as teleconferences via GOTOMEETING.

COUNCIL OF FELLOWS

FELLOWS	**AFFILIATION**
Dr. John Baldwin	**Florida Atlantic University**
Dr. Manhar Dhanak	Florida Atlantic University
Dr. Marguerite Koch	Florida Atlantic University
Dr. Tristan Fiedler	**Florida Institute of Technology**
Dr. Kevin Johnson	Florida Institute of Technology
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. David Letson	University of Miami/RSMAS
Dr. Sharan Majumdar	University of Miami/RSMAS
Dr. Richard Appeldoorn	**University of Puerto Rico**
Dr. Gary Mitchum	**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. Benjamin Kirtman, Director	UM/CIMAS
***Ex Officio*:**	
Dr. David Die, Associate Director	UM/CIMAS

EXECUTIVE ADVISORY BOARD

Institutional Representatives

Ms. Camille Coley	Florida Atlantic University
Dr. Andrés G. Gil	Florida International University
Dr. Gary Ostrander	Florida State University
Dr. Robert Atlas	NOAA/AOML, Director
Dr. Bonnie Ponwith	NOAA/Southeast Fisheries Science Center
Dr. Richard Knabb	NOAA/National Hurricane Center
Dr. Richard Dodge	NOVA Southeastern University
Dr. Winfred M. Phillips	University of Florida
Dr. Nilda E. Aponte	University of Puerto Rico
Dr. Jacqueline E. Dixon	University of South Florida
Dr. Richard Nemeth	University of the Virgin Islands
Dr. Roni Avissar	UM/RSMAS Dean

Ex Officio Members

Dr. Candice Jongsma	NOAA CI Program Office
Dr. Benjamin Kirtman	UM/CIMAS
Dr. David Die	UM/CIMAS

IX. AWARDS AND HONORS

Coral Health and Monitoring Program (CHAMP)

- Ian Enochs received the CIMAS Outstanding Scientific Performance Award (2015).
- Xaymara Serrano awarded a Ford Foundation Doctoral Fellowship (2015).
- Ruben van Hooidonk received the Sustainability Award from the Netherland America Foundation and Royal Dutch Airlines (KLM).

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

- J. 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*."
- NASA Group Achievement Award (2016): NASA Severe Storms Sentinel (HS3) Project.

Ingesting Sea Surface Height Anomalies from the Cryosat-2 Mission to Enhance the NESDIS Operational Ocean Heat Content Product Suite

- Lynn K. (Nick) Shay received the Richard H. Hagemeyer Award from NOAA's Office of the Federal Coordinator for Meteorology at the 2016 Interdepartmental Hurricane Conference.

Services to Support the Hurricane Forecast Improvement Project

- Xuejin Zhang, NOAA Team Member of the Month (May 2013)
- Federal Employee of the Year (Scientific), Team member, 2014
- S. Gopalakrishnan, F. Marks, T. Quirino, V. Tallapragada, DOC Gold Medal 2015
- Xuejin Zhang and Jun Zhang, CIMAS Gold Medal Award, 2015

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

- Gustavo Goni, Francis Bringas, George Halliwell, Richard Bouchard (NWS) were awarded the **NOAA Bronze Medal Award** for the rapid and successful implementation of an array of underwater gliders geared towards Caribbean Sea and Tropical Atlantic hurricane research and forecasts.

Gulf of Mexico Integrated Ecosystem Assessment

- Kelble (NOAA/AOML), Karnauskas (NOAA/SEFSC) and Schirripa (NOAA/SEFSC) 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

Defining Spawning Dynamics to Manage and Conserve Reef Fish Populations

- R. Appeldoorn recognized for research contributions in coral reefs and related fisheries by the US Coral Reef Task Force at its 34th Meeting, October 2015, Puerto Rico.

Support for the Marine Resource Assessment Program at the University of South Florida College of Marine Science

- Claire Crowley – William Hogarth Marine Mammal Fellowship (USF CMS)
- Lindsey Dornberger – Garrels Memorial Fellowship in Marine Science (USF CMS)

X. POSTDOCTORAL FELLOWS AND GRADUATE STUDENTS

CIMAS-Supported Postdoctoral Fellows and Graduate Students

Postdoctoral Fellows

Alaka, Ghassan
Chen Leighton, Hua
Christophersen Hui
Council, Elizabeth
Forrestal, Francesca
Jones, Paul
Liu, Yanyun
Lopez, Hosmay
Majumder, Sudip
Putman, Nathan
Rasmuson, Lief
Serrano, Xaymara

Graduate Students

Task I

Bouck, David
Komisarjevsky, Nicholas
Morrris, John
Pritchard, Edward
Savoi, Caitlyn
Zink, Ian

Task III

Employees

Domingues, Ricardo
Gramer, Lewis J.
Jugovich, Amelia

Other Participants in CIMAS Projects

Postdoctoral Fellows

Barnes, Brian
Bell, Ray
Combes, Vincent
Infanti, Johnna
Jung, Ensuil
Larson, Sarah

Other Participants in CIMAS Projects Cont'd

Min, Dughong
Putrasahan, Dian
Siqueira, Leo
Suprenand, Paul
Stefanova, Lydia
Vaz, Ana

Graduate Students

Arcodia, Marybeth
Bhatti-Catano, Laura
Barton, Mark
Binder, Benjamin
Bouck, David
Brecicka, Rebecca
Chacin, Dinorah
Chen, Gino
Cheng, Yu
Clouse, Kimberly
Cohen, Michael
Cortezi, Matheus
Crowley, Claire
Dean, Cayla W.
Denson, LaTreese
Dornberger, Lindsey
Duke, Mara
Duran, Alain
Espitia, Paola
Ferrá-Elias. Angela
Fisco, Dana
Garcia, Jaaziel
Grasso, Peter
Grasty, Sarah
Gray, Alisha
Gravinese, Philip
Groenen, Danielle
Groves. Caroline
Habtes, Sennai
Hall, Brittany
Harms, Chelsea
Hayslip, Catherine
Helms, Charles
Herdter, Elizabeth
Houston, Brock
Huelster, Sheri
Infanti, Johnna
Jermain, Robert
Kelly, Elizabeth
Knowles, Morgan
Kotkowski, Rachel
Kramer, Samantha
Larson, Sarah
Li, Yen Ling.
Olinger, Lauren
Olsen, Emily
Olson, Jack
Palko, Diane
Patranella, Allison
Perryman, Holly A.
Peter, Szandra
Pomales, Luis
Rolls, Holly
Rudzin, Johnna
Sanchez, Phillip
Sauls, Beverly
Selman, Christopher
Shantz, Andrew
Snyder, Susan
Spathias, Hanae
Stocker, Joshua
Sun, Shaojie
Tuohy, Evan
Turner, Nicholas
Tzadik, Orian
Valla, Daniel
Vara, Mary Janine
Williams, Sky
Zayas, Carlos
Zenone, Aubrey
Zhang,Wei

XI. RESEARCH STAFF

Aguilar, Sandra	Senior Research Associate III
Aichinger Dias, Laura	Research Associate III
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 II
Berberian, George	Research Associate II (PT)
Blondeau, Jeremiah	Senior Research Associate II
Bright, Allan	Senior Research Associate I
Bucci, Lisa	Senior Research Associate I
Carollo, Cristina	Assistant Scientist
Casey, Sean	Associate Scientist
Chen, Hua	Postdoctoral Associate
Christophersen, Hui	Postdoctoral Associate
Christophersen, Johnathan	Research Associate II
Councill, Elizabeth	Postdoctoral Associate
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	Senior Research Associate I
Domingues, Ricardo	Research Associate III
Dunion, Jason	Senior Research Associate III
Enochs, Ian	Associate Scientist
Festa, John	Senior Research Associate III (PT)
Forrestal, Francesca	Postdoctoral Associate
Forteza, Elizabeth	Research Associate III
Gall, Robert	Scientist (PT)

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.	Assistant Scientist
Halliwell, Vicki	Senior Research Associate III
Halsall, Patrick	Research Associate II
Harford, William	Assistant Scientist
Hoffman, Ross	Scientist (PT)
Hoolihan, John	Scientist
Hooper, James	Senior Research Associate I
Jankulak, Michael L.	Systems Administrator
Jones, Paul	Postdoctoral Associate
Jugovich, Amelia	Research Associate I
Klotz, Bradley	Senior Research Associate II
Ko, Mu-Chieh	Senior Research Associate I
Kolodziej, Graham	Research Associate II
Le Henaff, Matthieu	Assistant Scientist
Liu, Yanyun	Postdoctoral Associate
Lopez, Hosmay	Postdoctoral Associate
Majumder, Sudip	Postdoctoral Associate
Malca, Estrella	Senior Research Associate I
Martin, Shannon	Associate Scientist
Mears, Norris Patrick	Research Associate I
Mehari, Michael	Senior Research Associate I
Nair Jayalekshmi	Research Associate III
Otero, Sonia	Senior Research Associate II
Overstreet, Elizabeth	Senior Research Associate II
Pausch, Rachel	Research Associate I
Perez, Renellys	Associate Scientist
Pierrot, Denis P.	Associate Scientist
Privoznik, Sarah	Research Associate II
Putman, Nathan	Postdoctoral Associate

Quenee, Charline	Research Associate I
Rasmuson, Leif	Postdoctoral Associate
Rawson, Grant T.	Research Associate III
Roddy, Robert	Research Associate III (PT)
Ryan, Kelly	Sr. Research Associate II
Sabina, Reyna	Research Associate III (PT)
Sellwood, Kathryn J.	Research Associate III
Serrano, Xaymara	Postdoctoral Associate
Sevilla, Thomas	Electrical Engineer
Shideler, Allison	Senior Research Associate II
Shiroza, Akihiro	Senior Research Associate I
Shulzitski, Kathryn	Assistant Scientist
Sprehn, Charlotte	Senior Research Associate I
St. Fleur, Russell	Programmer, Intermediate
Stevens, Sabrina	Senior Research Associate I
Sullivan, Kevin F.	Senior Research Associate III
Teare, Paul	Research Associate II
Valdes, Erik	Research Associate III
Valentino, Lauren	Senior Research Associate I
van Hooidonk, Ruben	Assistant Scientist
Visser, Lindsey	Research Associate III
Volkov, Denis	Associate Scientist
Wicker, Jesse A.	Research Associate III
Williams, Dana E.	Associate Scientist
Zhang, Jun	Associate Scientist
Zhang, Xuejin	Associate Scientist

XII. VISITING SCIENTISTS

Dr. Nancy Maynard – October 1, 2012 (to continue through June 2017)
NASA Emeritus
NASA Goddard Space Flight Center
Greenbelt, MD

Dr. Erlend Moksness – September 4, 2015
Regional Research Director
Institute of Marine Research (IMR)
Norway

4 September, 2015 – "*Bilateral Collaboration Between Cuba and Norway for the Development of and Capacity Building in Numerical Models Addressing Regional Ocean Circulation, Oil-Drift and Biophysical Interaction in a Changing and Varying Climate"*

Dr. Tom Carruthers – August 30 – September 3 and November 2 – 6, 2015
University of British Columbia
Fisheries Centre Aquatic Ecosystems Research Laboratory (AERL)
Vancouver, BC, Canada

30 August – 3 September, 2015 – "*Lead a demonstration workshop for the DLM tool and engage in general discourse and collaboration building with researchers in CIMAS and NOAA/AOML"*
2 – 6 November, 2015 – "*Participate in NOAA SEDAR Data Limited Assessment Workshop*"

Dr. Julian Heming – March 14 – 17, 2016
UK Met Office
Fitzroy Road
Exeter Devon, United Kingdom

17 March, 2016 – "*Tropical Cyclone Predictions from the Met Office Global Model: A Brief History and Recent Developments*"

Dr. Dusanka Zupanski – March 28, 2016
Zupanski Consulting, LLC
Fort Collins, CO

28 March, 2016 – "*Theoretically Advanced, Yet Computationally Efficient Data Assimilation and Forecasting Method"*

Dr. Brad Beechler – March 29, 2016
Vaisala, Inc.
Boulder, CO

29 March, 2016 – "*Object-Based Data Assimilation: Strategies and Technologies"*

Dr. Jason Sippel – March 30, 2016
NCEP/EMC
College Park, MD

30 March, 2016 – "*The Challenges in Developing the Operational HWRD FA System: What I've Learned After 1.5 Years at EMC*"

Prof. U.C. Mohanty – June 6 – 10, 2016
School of Earth Ocean and Climate Sciences
Indian Institute of Technology Bhubaneswar
A2-708, Toshali Bhawan, Satya Nagar
Bhubaneswar-751007, Odisha, India

7 June, 2016 – "*Recent Developments in the Prediction of Tropical Cyclones in the North Indian Ocean*"

XIII. PUBLICATIONS

Table 1: Publication Record 2015-2016 for Cooperative Agreement NA10OAR4320143

	Institute Lead Author	NOAA Lead Author	Other Lead Author
	2015-2016	**2015-2016**	**2015-2016**
Peer Reviewed	60	11	45
Non-Peer Reviewed	25	7	4

Refereed Journal Articles

Abarca, S.F., M.T. Montgomery, S.A. Braun, and J.P. Dunion (2016), On the secondary eyewall formation of Hurricane Edouard (2014), *Mon. Wea. Rev*., doi:10.1175/MWR-D-15-0421.1 2016.

Adam T.C., M. Kelley, B.I. Ruttenberg, and D.E. Burkepile (2016), Groups of roving midnight parrotfish (Scarus coelestinus) prey on sergeant major damselfish (Abudefduf saxatilis) nests, *Marine Biodiversity*, 1-2, doi: 10.1007/s12526-016-0475-4.

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