

CIMEC

Cooperative Institute for Marine Ecosystems and Climate

Scripps Institution of Oceanography, UCSD
California State University Los Angeles
Humboldt State University
University of California Davis
University of California Los Angeles
University of California Santa Barbara
University of California Santa Cruz

PROGRESS REPORT 2015-2016





CIMEC

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Cooperative Institute for Marine Ecosystems and Climate Performance Progress Report 2015 - 2016

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UC SANTA CRUZ

UCLA

UC DAVIS

HUMBOLDT
STATE UNIVERSITY

UCSB





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June 8, 2016

This report closes out original 5-year CIMEC award under Dave Checkley. The projects are varied and fill critical NOAA needs, evidence of the flexibility that the Cooperative Institutes can provide. It has been exciting and interesting for me to learn about all the different research carried out under CIMEC, and I still have a lot to learn. Many thanks to all the PIs who have contributed their excellent research to this report.

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INTRODUCTION

The Cooperative Institute for Marine Ecosystems and Climate (CI-MEC) research and program activities for the no-cost extension (2015-2016) of the National Oceanic and Atmospheric Administration (NOAA) grant NA10OAR4320156 are outlined in this report. CI-MEC is affiliated with the Scripps Institution of Oceanography (SIO), and is a multi-disciplinary Institution for ocean, climate, earth and environmental research as part of the University of California, San Diego (UC San Diego) campus and greater University of California (UC) system. Included in this report are the individual projects, activities and accomplishments of CI-MEC researchers and partners at SIO, UC and Cal State, as well as other collaborating organizations associated with CI-MEC.

CI-MEC's purpose is to facilitate and enhance research cooperation between NOAA entities and SIO, in particular, and the University of California (UC) and California State Universities (Cal State), in general, pertinent to the mission of NOAA.

During the April 1, 2015 to March 31, 2016 period, the NOAA entities listed below were engaged with SIO as part of CI-MEC in marine, atmospheric and climate research, education and outreach efforts, data collection, and collaborative activities:

- Assessment and Monitoring Division (AMD)
- Atlantic Oceanographic and Meteorological Laboratory (AOML)
- Climate Observations Division (COD)
- Climate Program Office (CPO)
- Earth System Research Laboratory (ESRL)
- Fisheries Ecology Division (FED)
- Global Monitoring Division (GMD)
- Integrated Ocean Observing System (IOOS)
- Marine Ecosystems Division (MED)
- National Data Buoy Center (NDBC)
- National Environmental Satellite, Data and Information Service (NESDIS)
- National Integrated Drought Information System (NIDIS)
- National Marine Fisheries Service (NMFS)
- National Ocean Service (NOS)
- National Weather Service (NWS)
- Northeast Fisheries Science Center (NEFSC)
- Northwest Fisheries Science Center (NWFS)
- Ocean Assessment Program (OAP)
- Ocean Exploration Program (OEP)
- Office of Habitat Conservation (OHC)
- Office of Ocean Exploration & Research (OER)
- Office of Oceanic and Atmospheric Research (OAR)
- Office of Protected Resources (OPR)
- Office of Response and Restoration (OR&R)
- Pacific Islands Fisheries Science Center (PIFSC)
- Pacific Marine Environmental Laboratory (PMEL)
- Protected Resources Division (PRD)
- Southeast Fisheries Science Center (SEFSC)
- Southwest Fisheries Science Center (SWFSC)
- Weather Forecasting Office, Oxnard
- Weather Forecasting Office, San Diego



ORGANIZATION

Mission Statement

The mission of CIMEC is, in collaboration with NOAA, to develop and consolidate leading researching and educational programs across its member institutions in support of NOAA's mission "to understand and predict changes

in the Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social and environmental needs.

Vision Statement

CIMEC shares the fundamental mission and goals of NOAA research and strives to achieve several objectives based on the unique resources and character of the Scripps Institution of Oceanography (SIO) and the other partner institutions in California: (1) to foster collaborative research between NOAA and UC/Cal State scientists; (2) to facilitate participation of UC/Cal State and other academic scientists in NOAA programs; and (3) to use the educational strength of CIMEC both to train students for productive work in environmental activities and to educate the citizenry about the intellectual excitement and importance of studying and managing our environment.

CIMEC builds upon SIO's experience from nearly twenty years of management of the Joint Institute for Marine Observations, and

works closely with NOAA line offices, goal teams and laboratories to assist in transitioning research and development into NOAA data products and services. NOAA leadership and researchers will be strongly represented on CIMEC's Executive Board and Council of Fellows. An annual meeting will be held to communicate progress on CIMEC's projects and to seek input on research directions and priorities from NOAA leadership and scientists and stakeholder groups. CIMEC institutions will work to ensure that wherever possible NOAA's needs are represented in their educational programs, from undergraduate to postdoctoral levels. The education and outreach program will also address ocean-literacy needs at the K-12 levels and in the broader community.



CIMEC Leadership



Bruce Cornuelle, Director

Dr. Cornuelle is a research oceanographer in the Climate, Atmospheric Science, and Physical Oceanography Research Division of Scripps Institution of Oceanography, University of California, San Diego.

Cornuelle received a B.A. in Physics from Pomona College and a Ph.D. in Physical Oceanography from the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program

Cornuelle's work has included at-sea observations, but he is now focused on using numerical models and state estimation for analysis of observations in order to understand ocean circulation in a number of regions, including offshore San Diego, the Gulf of Mexico, and the Pacific Ocean. In addition to ocean dynamics, his research interests include ocean acoustic observations, inverse methods, and state estimation and other forms of data assimilation.

Cornuelle is the recipient of the Medwin Prize in Acoustical Oceanography from the Acoustical Society of America, of which he is also a fellow. He is a member of the American Geophysical Union. Cornuelle is the author or co-author of over 100 scientific publications.



Dean Roemmich, Deputy Director

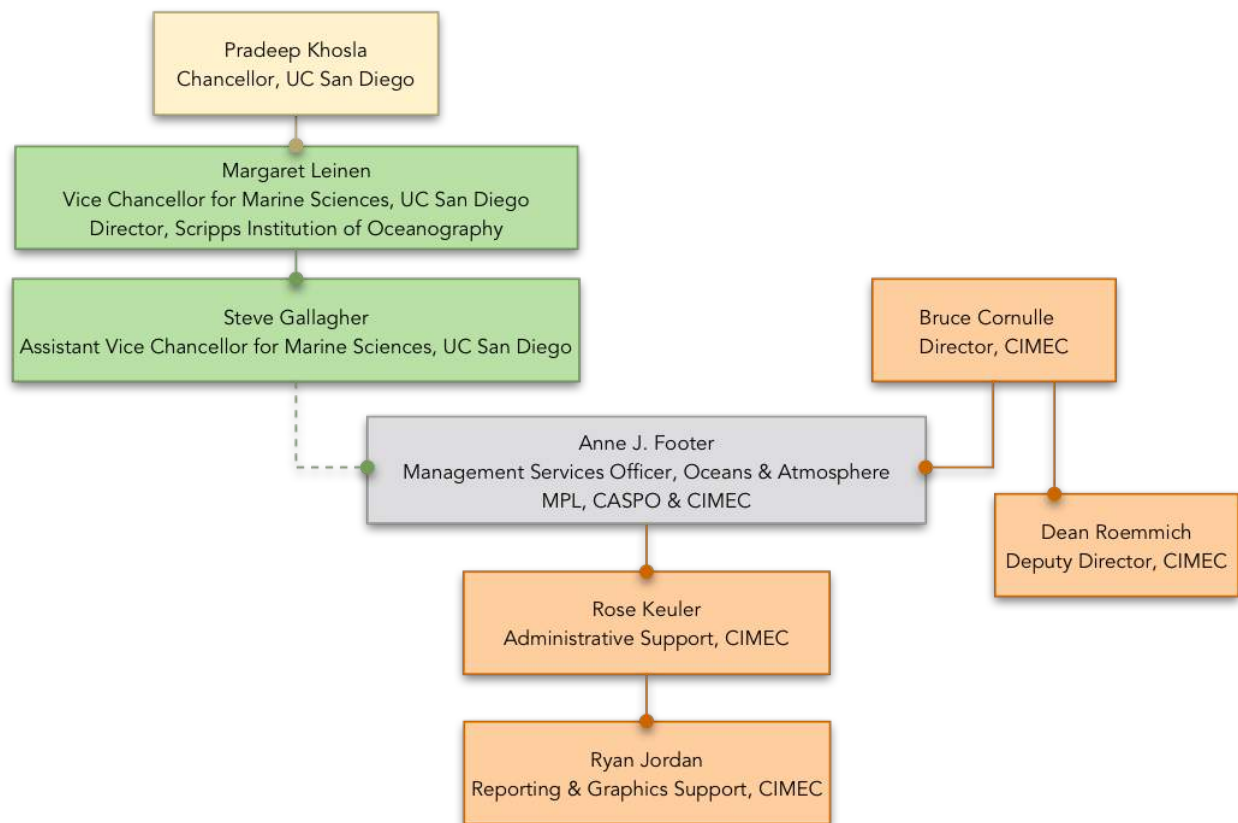
Dr. Roemmich is a professor of oceanography in the Integrative Oceanography Division and Climate, Atmospheric Science, and Physical Oceanography Division at Scripps Institution of Oceanography, University of California, San Diego. He is an expert in the general circulation of the oceans and the role of the ocean in the climate system.

Roemmich teaches courses on observations of large-scale ocean circulation and advises graduate students in the physical oceanography and climate science programs.

Born in Minneapolis, Minn., Roemmich received a bachelor's degree in physics from Swarthmore College and a PhD in oceanography from the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution Joint Program in Oceanography.



CIMEC Organizational Chart



CIMEC Employee Summary

Personnel Supported by NOAA/CIMEC Funding April 1, 2015 – March 31, 2016				
Category	Total	B.S./B.A.	M.S.	Ph.D.
Professor	1	0	0	1
Research Scientist	4	0	0	4
Project Scientist	6	0	1	5
Visiting Scientist	1	0	0	1
Museum Scientist	1	0	1	0
Postdoctoral Fellow	7	0	0	7
Research Specialist	3	0	0	3
Programmer Analyst	5	2	3	0
Staff Research Associate/Assistant	12	3	9	0
Development Engineer	3	2	1	0
Laboratory Assistant	7	4	2	0
Marine Technician	3	3	0	0
Total (≥ 50% support)	53	14	17	21

Undergraduate Students	28
Graduate Students	19

Employees less than 50% (not including students)	92
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Personnel located at a NOAA Laboratory	38 (NOAA Santa Cruz-FED)
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Obtained NOAA employment April 1, 2015 – March 31, 2016			
Name	Degree	Division/Laboratory	Date
Juan Lopez	PhD	Southwest Fisheries Science Center	October 2015
Kate Richerson	PhD	Northwest Fisheries Science Center	January 2016
Lyall Bellquist	PhD	Southwest Fisheries Science Center	September 2016
Noelle Bowlin	PhD	Southwest Fisheries Science Center	January 2016
Rachel Johnson	PhD	Southwest Fisheries Science Center	April 2015

Sub-Awards	
Postdoctoral Fellow	2
Graduate Student	2
Undergraduate Student	0



CIMEC Fellows Roster

Abell, Jeffrey - Humboldt State University

Allen, Andrew - Scripps Institution of Oceanography, UC San Diego

Appelgate, Bruce - Scripps Institution of Oceanography, UC San Diego

Baumann-Pickering, Simone - Scripps Institution of Oceanography, UC San Diego

Bock, Yehuda - Scripps Institution of Oceanography, UC San Diego

Cayan, Dan - Scripps Institution of Oceanography, UC San Diego

Centurioni, Luca - Scripps Institution of Oceanography, UC San Diego

Checkley, David - Scripps Institution of Oceanography, UC San Diego

Cornuelle, Bruce - Scripps Institution of Oceanography, UC San Diego

Dickson, Andrew - Scripps Institution of Oceanography, UC San Diego

Edwards, Chris - UC Santa Cruz

Faloona, Ian - UC Davis

Goericke, Ralph - Scripps Institution of Oceanography, UC San Diego

Goldstein, Tracey - UC Davis

Hildebrand, John - Scripps Institution of Oceanography, UC San Diego

Jacobsen, Mark - Department of Economics, UC San Diego

Keeling, Ralph - Scripps Institution of Oceanography, UC San Diego

Koslow, J. Anthony - Scripps Institution of Oceanography, UC San Diego

Kriegman, David - UC San Diego

Mangel, Marc - UC Santa Cruz

Marinovic, Baldo - UC Santa Cruz

Miller, Arthur - Scripps Institution of Oceanography, UC San Diego

Mulligan, Timothy - Humboldt State University

Palkovacs, Eric - UC Santa Cruz

Ralph, Marty - Scripps Institution of Oceanography, UC San Diego

Ramanathan, Veerabhadran - Scripps Institution of Oceanography, UC San Diego

Roemmich, Dean - Scripps Institution of Oceanography, UC San Diego

Rudnick, Dan - Scripps Institution of Oceanography, UC San Diego

Semmens, Brice - Scripps Institution of Oceanography, UC San Diego

Send, Uwe - Scripps Institution of Oceanography, UC San Diego

Sirovic, Ana - Scripps Institution of Oceanography, UC San Diego

Sprintall, Janet - Scripps Institution of Oceanography, UC San Diego

Subramanian, Aneesh - Scripps Institution of Oceanography, UC San Diego

Sugihara, George - Scripps Institution of Oceanography, UC San Diego

Swift, James - Scripps Institution of Oceanography, UC San Diego

Terrill, Eric - Scripps Institution of Oceanography, UC San Diego

Thode, Aaron - Scripps Institution of Oceanography, UC San Diego

Tissot, Brian - Humboldt State University

Ward, Darren - Humboldt State University

Whitehead, Andrew - UC Davis

Xie, Shang-Ping - Scripps Institution of Oceanography, UC San Diego

Zilberman, Nathalie - Scripps Institution of Oceanography, UC San Diego



RESEARCH TASKS

Under the Cooperative Institute's cooperative agreement, five tasks are outlined by CIMEC and agreed upon by NOAA, allowing CIMEC to group and account for research more easily. The tasks are defined as follows:

Task 1 – Administration

Task 1 funding is for administration of the Institute and includes support for the CIMEC Director's office and minimal support for the staff. It includes costs associated with annual scientific meetings that are deemed important for the CIMEC Director to attend, workshops sponsored by CIMEC, web-site development and maintenance, funding for the Joint Institute Director's and executive board and fellows meetings.

Task 2 – Joint NOAA Laboratory/CIMEC Collaboration

Collaborative proposals have NOAA and participating California University partners working together jointly on research themes. These proposals are divided by theme and include all research associated with funding including the funding of salaries, benefits, travel as well as instrumentation and computer time.

Task 3 – Individual Science Projects

Cooperative research proposals are specific to the CIMEC theme areas, but submitted by individual scientists of CIMEC. The distinction here is that there is a loosely bound tie between individuals working on similar themes or topics. It is also seen that this may

be a mechanism for developing collaborative proposals in the future, as well as encouraging new areas of research to develop. These proposals are divided by theme and include all research associated funding including the funding of salaries, benefits, travel and instrumentation and computer time.

Task 4 – Education and Outreach

In support of NOAA's Mission and Strategic Plan, CIMEC's Task 4 was developed to strengthen and coordinate an education and outreach component to compliment and convey CIMEC research into the academic and public realms.

Task 5 – CIMEC Research Infrastructure Proposals

Because proposals relevant to CIMEC will use a variety of observation platforms in order to carry out the research objectives, an infrastructure task by theme area was defined, which includes proposals for platform and specialized research facilities.



RESEARCH THEMES

Four thematic areas form the basis for research performed in partnership with NOAA. Each of these areas is relevant to the NOAA mission elements, particularly those of environmental assessment and prediction and environmental stewardship.

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

The primary goals for this research theme are to understand the remote forcing functions that control fundamental ocean and atmosphere processes and to utilize this knowledge for prediction. For CIMEC the basis of interest is primarily the Pacific, although other areas may be studied as a model or to put the Pacific information in context (e.g., Indian, Arctic). These thrust areas include the following:

Oceanic roles in climate and global change

The oceans contain 96% of the Earth's free water. They are the source of 86% of all evaporation and the direct recipient of 78% of rainfall. The salinity of the ocean surface layer reflects the global pattern of evaporation minus precipitation, with salinity maxima in regions of excess evaporation and minima in regions of excess rainfall. The meridional transport of water vapor in the atmosphere is equal and opposite to the freshwater transport in the ocean. Long-term trends in salinity show the evaporative regions of the ocean becoming saltier and the high precipitation areas fresher indicating an acceleration of the global hydrological cycle. Slow freshening of the oceans as a whole is a yardstick for the melting of glaciers, ice sheets, and sea ice. Past research in the

hydrological cycle has been focused on the land and atmosphere, while the large role of the oceans has been poorly observed. It is increasingly clear that the complete global hydrological system, including the oceans, must be addressed.

Last, and very importantly among (physical) global change issues, is sea level rise. The present observing system includes satellite and in situ observations of total sea level, plus satellite measurements of changes in ocean mass and in situ observations of the ocean's steric height. While the majority of future sea level rise may come from melting Antarctic and Greenland ice sheets, the steric component of sea level is nonetheless significant, and the increasing heat content of the high latitude oceans is a key factor in understanding and predicting melting and precipitation (ice deposition) rates.

CIMEC projects contribute to datasets in an effort to build the models to address these important issues.

Coastal oceans and climate

The scientific community is faced with challenging issues across our coastal waters:

- How do human activities impact the coastal ocean?
- How do coastal ecosystems respond to climate change?
- How does climate change and sea level rise present itself at local scales?
- What role does the coastal ocean play in the global biogeochemical cycles?
- What processes determine community structure in coastal ecosystems?
- How can we predict and mitigate coastal hazards that impact human populations?

CIMEC has a myriad of tools within its partner institutions, including the long-running



CalCOFI program with its 60-year time series of the California Current, at its disposal to help investigate these questions and find the solutions to the problems some of these questions pose.

Theme B: Climate Research and Impacts

Observations and model simulations are crucial elements needed to guide decisions over the next several decades as global scale changes in climate, sea level and other environmental components such as aerosols and land surface changes continue to produce great impacts across the United States. Regions affected by these changes include the region of the western mountainous states, in particular, California and the adjacent coastal zone. CIMEC research will study climate and its impact on society to serve the nation's needs for climatic information with programs conducting applied climate research to assist decision makers prepare for and adapt to climate changes, both natural and (potentially) anthropogenic.

Theme C: Marine Ecosystems

CIMEC will directly address NOAA's Ecosystem Mission Goal to "protect, restore, and manage the use of coastal and ocean resources through the ecosystem approach to management". Fisheries and protected species and their relation to the environment, including climate change, are broad areas of research and teaching within CIMEC, and will include participation from faculty, graduate students, postdocs, and NOAA colleagues.

Ecosystem characteristics of particular interest are marine population dynamics, biodiversity, and biogeochemistry. The means by which these will be investigated include observing, process studies, and modeling.



Collectively, the results are used to assess and predict ecosystem productivity and health for decision makers. Fishing affects both the target species and their environment. Climate change will affect marine ecosystems through rising sea level, warming, ocean acidification, deoxygenation, and potential changes in productivity and circulation.

Primary regions of interest are the California Current Ecosystem (CCE), the Eastern Tropical Pacific (ETP), and the Southern Ocean (SO). Fisheries management research, such as the long-running 60-year time series of the California Current conducted under the CalCOFI program, provides policymakers and management officers with the information needed to manage the nation's marine resources.

Theme D: Ecosystem-Based Management

Fisheries management has undergone a paradigm shift in recent years from an exclusive focus on individual assessments of commercially exploited stocks to maximize sustainable yield (or comparable metric) to a precautionary, ecosystem-based approach. Ecosystem-based management (EBM) explicitly considers human impacts on key predator, prey and competitor species, on bycatch species and benthic habitat, as well as on directly targeted stocks. NOAA is mandated to manage US fisheries within an EBM framework and is implementing integrated ecosystem assessments (IEA) as a critical science-support tool.

The 60-year California Cooperative Oceanic Fisheries Investigations (CalCOFI) program is one of the longest running ocean observation programs in the world. A joint program of the Scripps Institution of Oceanography, the Southwest Fisheries Science Center (NMFS/NOAA), and the California Department of Fish and Game, CalCOFI is designed to

provide data for stock assessment of key commercial species, as well as physical, chemical, and biological data on the state of the California Current ecosystem (CCE), including quantitative observations on ecologically critical species of krill, fish, seabirds and mammals. CalCOFI observations have provided the basis for much of our current understanding of the impact of climate variability (the El Niño, Pacific Decadal Oscillation, and the North Pacific Gyre Oscillation) on the CCE. In the future, CalCOFI will provide much of the observational 'backbone' for integrated ecosystem assessments (IEAs) and ecosystem-based management (EBM) of the CCE, as well as for modeling and understanding the impacts of long-term climate change.

Integration of Marine Protection Areas (MPAs) and Conventional Fishery Management

More than 15 percent of the coast of California will soon be in MPAs implemented under California's Marine Life Protection Act. Modeling of the effects of these for decision

makers has been done by Partner labs, and will soon be started in a Sea Grant project to develop models to use in the evaluation of ongoing monitoring efforts.

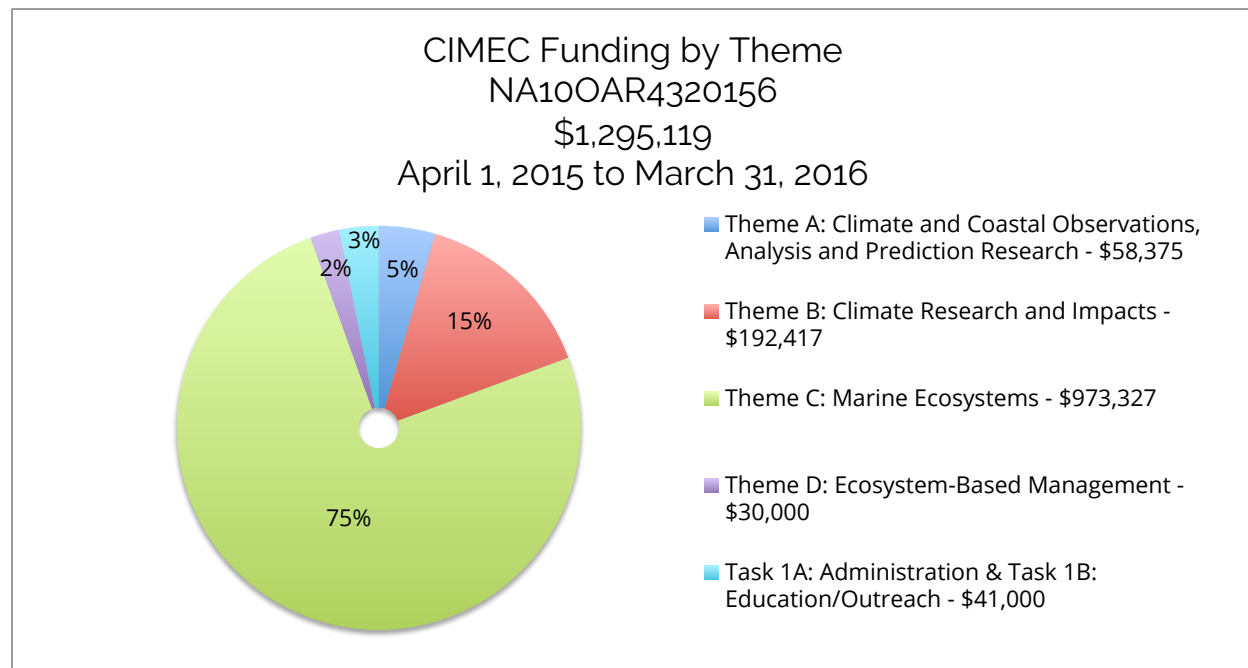
The Center for Stock Assessment Research (CSTAR)

CSTAR was formed in 2001, as a collaboration between the NMFS laboratories in Santa Cruz and Pacific Grove, with the objective of undergraduate, graduate and post-doctoral research and training associated with the problems of assessing the numerical abundance, spatial distribution, size distribution and reproductive status of commercially important fish species and thereby increasing the pool of quantitatively trained biologists available to be hired by NMFS. The program of research and training at CSTAR is science done in the national interest and moves in the direction outlined by the National Research Council in its report "Recruiting Fishery Scientists."

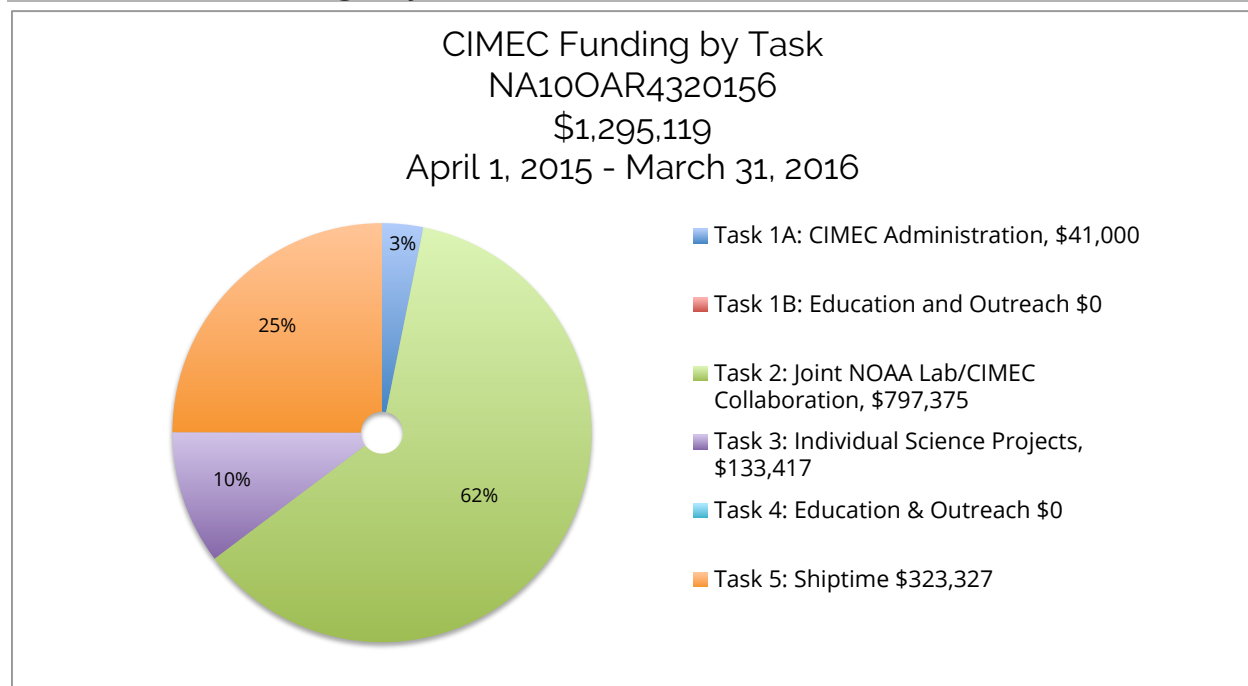


FUNDING SUMMARY

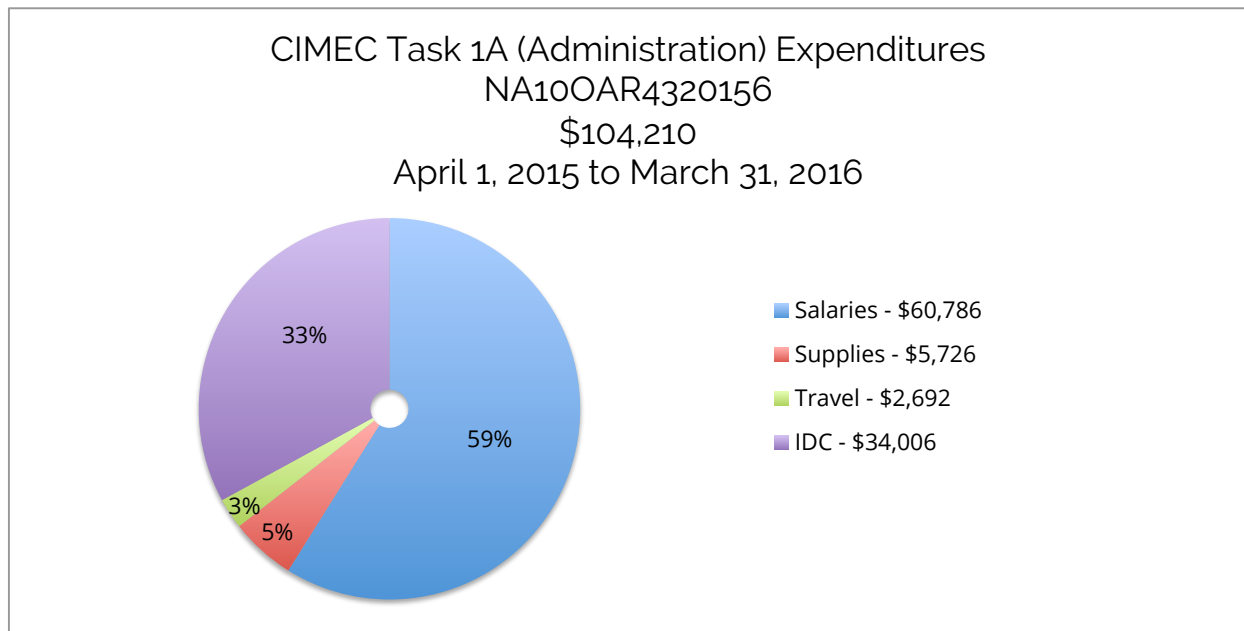
CIMEC Funding by Theme



CIMEC Funding by Task

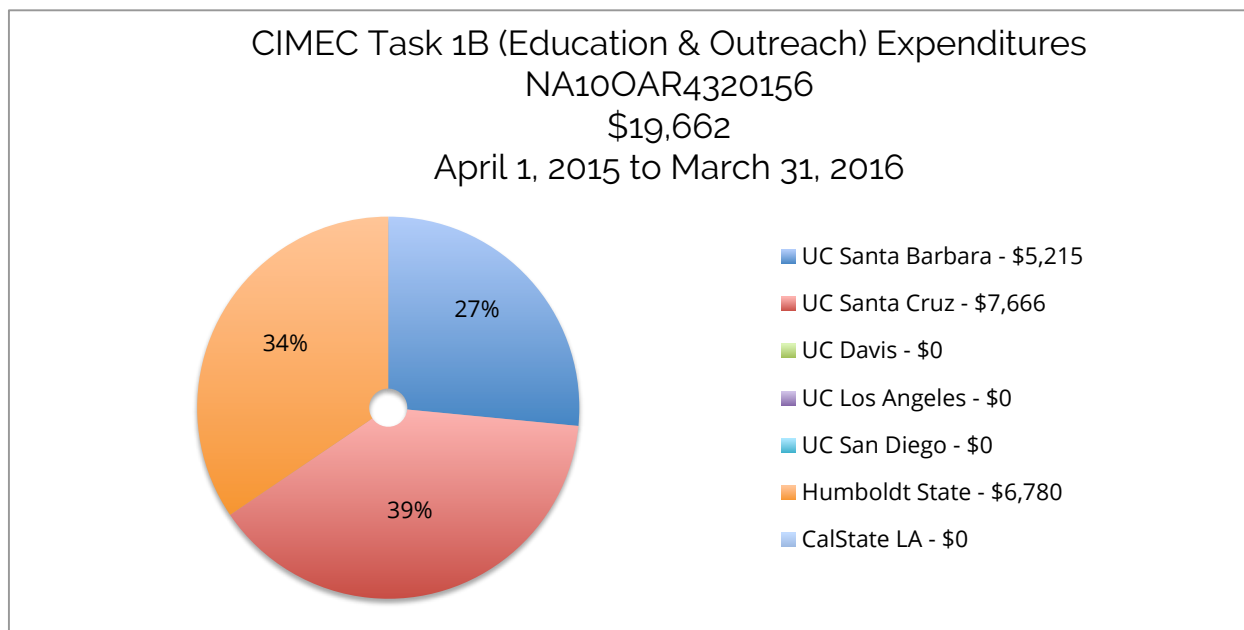


CIMEC Task 1A - Administration Expenses



Note 1: CIMEC Task 1A activities include salary support for the CIMEC Director, the CIMEC Administrative Officer, the CIMEC Administrative Analyst and the CIMEC Administrative IT. Travel activities include an annual trip to the NOAA Cooperative Institute Director's and Administrator's meeting held in Silver Spring, MD. Supply activity includes communication costs and costs specific to administering CIMEC.

CIMEC Task 1B – Education & Outreach Expenses



Note 2: CIMEC Task 1B activities include support for Education and Outreach at each of the 7 CIMEC Partner Institutes. Distribution of funds is pending.



RESEARCH PROJECTS

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Collaborative Scientific and Technical Support to the NOAA Earth System Research Laboratory

Principal Investigator(s):

Yehuda Bock, Scripps Institution of Oceanography, UC San Diego

Peng Fang, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Seth Gutman, Earth Systems Research Laboratory, Global Systems Division (ESRL), retired

NOAA Primary Contact:

Kirk Holub, Earth Systems Research Laboratory, Global Systems Division (ESRL)

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Budget Amount:

\$198,375

Amendment(s):

10, 56, 95, 139

Description of Research:

The main requirements for mapping precipitable water using GPS technology include: (1) maintaining a sufficiently

dense GPS network in which the GPS stations' positions are precisely known; (2) Estimation of GPS satellite orbits and their associated geodetic parameters, such as Earth orientation parameters, in near real time. The Scripps Orbit and Permanent Array Center (SOPAC) is in a unique position to provide necessary support to satisfy ESRL's needs in these aspects. SOPAC routinely processes large amounts of raw GPS data from all over the world including North America. Through analysis of long time span of GPS site position time series, the changes in positions, position velocities, and episodic offsets due to tectonic or hydrological events can be monitored and published for various applications including GPS/Met activity at ESRL.

SOPAC computes precise GPS satellite orbits with short-term predictions in near real time. These precise orbits published on an hourly basis play a critical role in ESRL's near-real-time data processing. Computing the precise satellite orbits in a timely manner is quite challenging. The orbits can only be obtained precisely based on a global reference frame under the condition that various error models can be accounted for. The precise GPS orbits are not estimated alone. They are estimated together with the Earth orientation parameters. This is a very demanding task when the data are available from a non-optimal set of distributed global tracking stations. GPS data processing involves the use of sophisticated software packages and complicated procedures.



As a new direction towards real-time applications, including GPS/met, we will continue to investigate (funded under a separate NASA grant) transition from SIO's network positioning and current orbit determination approach (GAMIT) to one based on precise point positioning (PPP) (e.g., Geng et al., 2013). This would involve the estimation of satellite orbits and clocks from a global distribution of tracking stations, followed by PPP analysis for each NOAA/ESRL GPS Met station. The transition will be implemented once we have validated the PPP approach and ensured that product quality can be maintained and most likely improved. The advantages of the new approach include improved real-time accuracy of satellite orbit and clock estimation and significant improvements in positioning efficiency and robustness. In the interim we will continue to monitor and maintain the Scripps Orbit and Permanent Array Center (SOPAC) orbit facility to insure the reliable estimation of hourly orbits and short-range orbit predictions

Objectives:

1. Continue to provide collaborative scientific and technical support to the National Oceanic Atmospheric Administration (NOAA)/Earth System Research Laboratory (ESRL) GPS Met project. Support shall include maintenance of all existing site positions and velocities, adding new sites as requested, and maintenance of the Scripps Institution of Oceanography SIO5 GPS tracking station at La Jolla, California.
2. Monitor and maintain the Scripps Orbit and Permanent Array Center (SOPAC) orbit facility to insure the reliable estimation of hourly orbits and short-range orbit predictions in our collaboration with NOAA/ESRL. Incorporating latest improved

International GNSS Service (IGS) models for positioning and orbits, including new global reference frame; Global Navigation Satellite Systems (GNSS). As part of this effort, we will compare the quality of SOPAC's ultra-rapid orbit with those available from other centers and how the quality of each impacts GAMIT solutions.

3. Investigate transition from SIO's network positioning and current orbit determination approach (GAMIT) to one based on precise point positioning (PPP). This would involve the estimation of satellite orbits and clocks from a global distribution of tracking stations, followed by PPP analysis for each NOAA/ESRL GPS Met station. The transition will be implemented once we have validated the PPP approach. We will make these solutions available to NOAA for their comparisons with other solutions. This item is funded under a NASA grant.

Accomplishments & Milestones:

Objectives 1 and 2 are accomplished.

Considerable effort and process had been made for Objective 3, which is very resource demanding in terms of code/procedure development and analysis strategy testing.

Education & Outreach

Academic Development

- a. Developed PPP (Precise Point Positioning) based real-time tropospheric delay estimation procedure as a part of hazard early warning system. Provide ongoing scientific and technical consultations to scientists and graduate students from USA as well as worldwide.

K-12 Outreach

- a. North American Monsoon 5-panel video <https://www.youtube.com/watch?v=Dr7rQT33S6w>



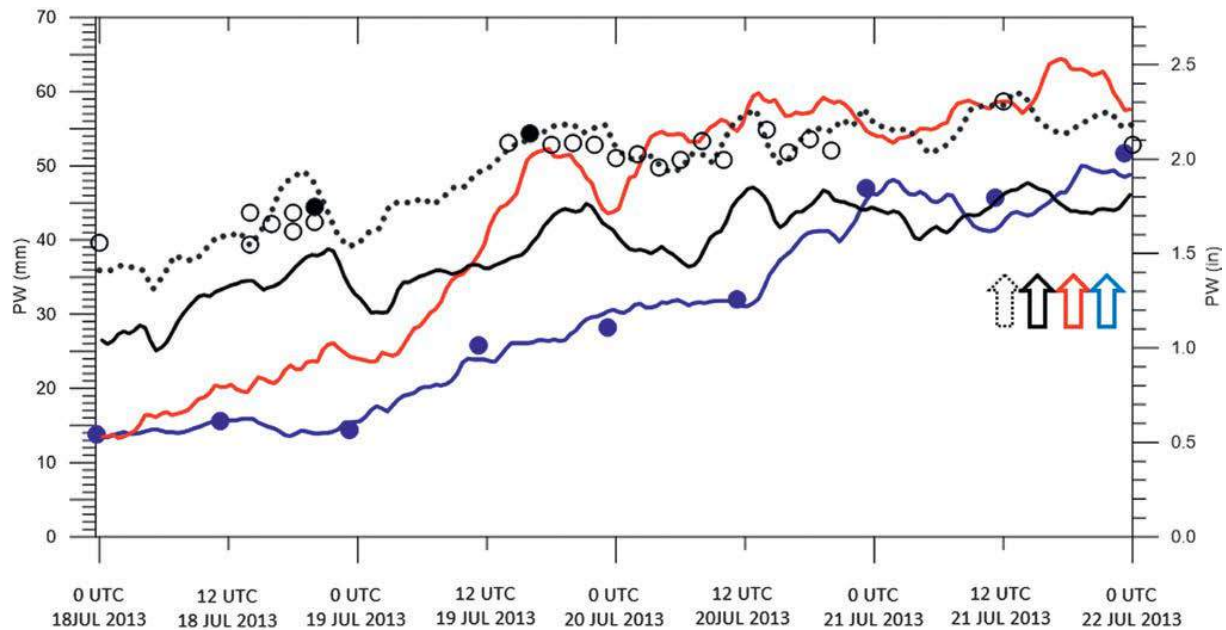


Figure 1: PW measurements during the evolution of the July 2013 monsoon event. Circles represent PW in cm for radiosondes at San Diego (blue) and Yuma, AZ (black). At the U.S. Army Yuma Proving Ground (YPG), radiosondes are launched irregularly in support of the local mission, and many observations only become available to the NWS and WMO retrospectively and with a variable delay. Solid black circles indicate those that were available to forecasters in AWIPS leading up to the flash flood watch and warning. Open circles are additional Yuma soundings provided for retrospective insight into the event. Solid traces show GPS PW measurements at San Diego (blue), Durmid, CA (red), and Glamis, CA about 60 km from Yuma. Dotted black trace is PW from a GPS station in Yuma that was not available to the forecasters at the time of this study, but was post-processed to compare with PW measured by the Yuma radiosondes during the passage of the inverted trough. Arrows indicate the times of passage of the wave at the identified GPS/Met sites.

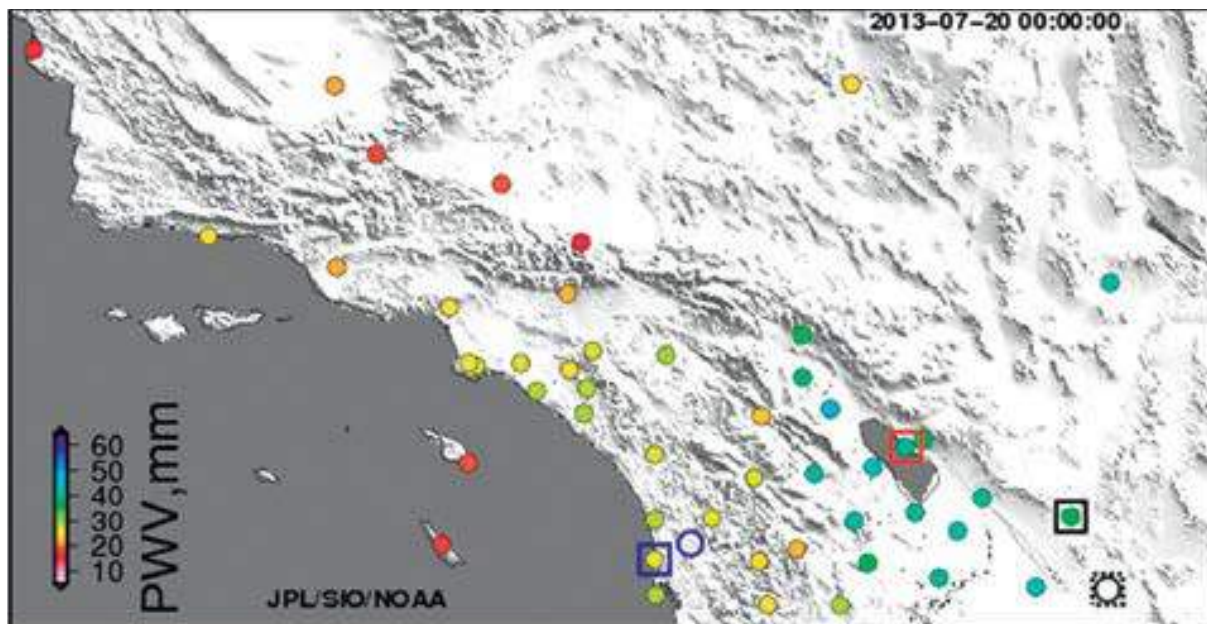


Figure 2: Map locates GPS stations with squares at San Diego (blue), Durmid (red), Glamis (black), and Yuma (dotted black) and radiosondes with circles at San Diego (blue) and Yuma (black). PW in mm at the GPS stations is shown, according to the color scale, at 1700 PDT 19 July (0000 UTC 20 July).



Develop Forecast Methods and an "AR Portal" for Atmospheric River Data Tools

Principal Investigator(s):

Dr. Dan Cayan, Scripps Institution of Oceanography, UC San Diego

Dr. F. Martin Ralph, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Dr. Sam Iacobellis, Scripps Institution of Oceanography, UC San Diego

Dr. Alexander Gershunov, Scripps Institution of Oceanography, UC San Diego

Dr. Jason Cordeira, Plymouth State University

Dr. Jonathon Rutz, University of Utah

NOAA Primary Contact:

Shannon Louie, OAR CIPO

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Budget Amount:

\$510,700

Amendment(s):

Competed NA13OAR4830231

Description of Research:

Many people in the weather and hydrologic prediction communities, as well as engineering, emergency preparedness and response, water supply, flood control, agriculture and others, have been looking for information on atmospheric rivers (ARs). This project addresses many of these needs including, real-time information, short-term

forecasts, medium range forecasts, seasonal outlooks, state-of-the-art, research findings, climate projections and others.

This project has and continues to develop and implement real-time tools for monitoring and prediction of atmospheric rivers, including lead times of hours to days. The potential for seasonal forecasts of AR frequency is also being explored. The developed data and tools are available on an "AR Portal" web site developed by the project and hosted at the Center for Western Weather and Water Extremes at Scripps Institution of Oceanography (arportal.ucsd.edu). These products are available to users from federal, state, local, private and other entities, as well as the public via this AR Portal.

Objectives:

Main objectives of this research include:

- Develop real-time tools for monitoring and prediction of atmospheric rivers on a variety of timescales.
- Development of "AR Portal" web site to disseminate the developed data and tools.
- Develop local operation of AR Detection Tool (ARDT).
- Explore potential for seasonal forecasts of AR frequency.

Accomplishments & Milestones:

- Several new AR forecast tools have been developed and described in recently submitted journal article.
- AR Portal web site is fully operationally and populated with many observations and forecast tools.
- ARDT is now locally operationally.
- Dropsonde measurements from CalWater 2 campaign processed and



analyzed. Results are basis for soon to be submitted research article.

- Compositing AR statistics produced from application of local ARDT tool to multiple reanalysis products show a distinct signals with respect to opposite phases of selected climate indices (ENSO, PDO, etc) suggesting possibility of longer-range predictability.

Conferences, Meetings & Presentations

- a. NIDIS Southern California Meeting, at Scripps Institution of Oceanography in La Jolla, CA, represented by F. Martin Ralph

Education & Outreach

Communications

- a. AR Portal Website - The AR portal is now operational from the Center for Western Weather and Water Extremes website. The website shows the current AR conditions and forecasted AR conditions. This information has been used by water resource and emergency managers.



Targeted In-Situ Tropical Cyclone Observations from Ocean Sensors

Principal Investigator(s):

Luca Centurioni, Scripps Institution of Oceanography, UC San Diego

Eric Terrill, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

David Léger, Climate Observations Division

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Goal 4: Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation

Budget Amount:

\$717,170

Amendment No.:

Competed NA14OAR4830118

Description of Research:

To improve Tropical Cyclone (TC) forecasts, there is a clear need for 1) positioning ocean sensors directly across the path of the storm to provide accurate and relevant in-situ observations at the air-sea interface and in the ocean and 2) ensuring the data are delivered in real time to forecasters in a format readily available for assimilation (e.g. through the Global Telecommunication System-GTS). Targeting TCs with air-deployed ocean-sensors is an effective answer to the problem. Sensor technology has improved to the point of readiness to address this

problem, but adapting the technology to the complexities of the logistics surrounding operational hurricane monitoring remains. Targeted observations using air-dropped instrumentation allows the observations at the air-sea interface to be made at the right place and time with the scales required to provide direct improvement of the forecast. We developed a modern generation of hurricane instruments for targeted, real-time, ocean-atmosphere data acquisition under TCs in support of HFIP, NHC, NCEP (waves) forecast and coupled-modeling efforts. Archived data will be publicly available to support scientific research on ocean/tropical cyclone interaction. We will modernize and pilot test a family of sensors to observe the upper-ocean and air-sea interface and the data route to make the observations available in real-time to the forecasters and the research community. Floats, drifters and new sensors provide key observations for TC forecast and the need to demonstrate new and improved observing technologies. The lead PI of this proposal is also the PI of the NOAA funded Global Drifter Program, the data of which are fully accessible through the GTS from the Drifter Data Assembly Center located at AOML, Miami, Florida, and from several servers maintained by his group at the Scripps Institution of Oceanography.

Objectives:

The goal of this project is to develop new instruments to provide real-time in-situ observations of TC conditions from drifters, termed Autonomous Drifting Ocean Stations (ADOS), and Miniature Wave Buoys (MWB). The data will be available to the operational modeling centers (e.g. NCEP/EMC), for initialization/assimilation in the operational models for improved storm assessment and forecast guidance. The merit of this project is



to create a new generation of oceanographic instruments that will be more economical to build, easier to store and to refurbish. The smaller size and lighter weight of the proposed drifters, the Mini-ADOS (M-ADOS hereinafter) and the MWB, compared to the current generation of similar instruments, will increase the possibility to store them at multiple locations and will expand the range of aircrafts suitable for deployment, to include the NOAA's P3 and the Global Hawk.

Accomplishments & Milestones:

mADOS

Below we describe the progress on the milestones identified for this phase.

mADOS Host microcontroller

The host microcontroller (uC) is located in the surface float. The host uC manages all slave sub-systems including but not limited to surface sensors (i.e. wind speed and direction, GPS, barometric pressure), temperature and pressure chain (T-Chain) slave electronics, and Iridium SBD communications.

Hardware

Host microcontroller hardware development is complete. Final prototype testing meets or exceeds minimum requirements for project goals.

Discrete circuit components and sensor selection have been approved and finalized. Circuit schematic design and capture has been verified and approved. Printed circuit board (PCB) design and layout has been finalized and approved for production. Fabrication of PCB is complete. Bill of materials has been verified, approved and purchased. Prototype PCB has been assembled with discrete components, and sub-circuits have been checked and verified to function as designed.

Firmware

Host microcontroller prototype firmware for field trials is complete and includes real-time reporting over Iridium SBD and onboard

logging of raw sensor acquisition for refinement of filtering algorithms following field trials.

Firmware has been written to manage onboard sub-circuit hardware (GPS engine, analog-to-digital converter, barometer, etc.) to enable proof-of-concept verification of circuit design. Firmware has been written and tested to sample sensor sub-systems, compress for satellite transmission, and management of Iridium SBD modem for 2-way communications. Firmware has been written for anemometer sensor acquisition and filtering, with Iridium SBD reporting at variable reporting rate using 2-way Iridium communications. Firmware has been tested on land to verify functionality of sensor parameter reporting, and is ready for field-testing.

Data

Data was collected from the surface expression barometer, anemometer and temperature sensors and transmitted via Iridium SBD for payload and firmware validation. SBD payload was routed to the SIO Iridium server and processed in real-time. Data is made available in real-time through web application interfaces.

mADOS TPOD sensor electronics

TPOD sensor electronics are located in each TPOD assembly on the T-Chain. The TPOD sensor electronics manage their discrete sub-systems including the piezoelectric pressure (depth) sensor, temperature probe, and handshaking communication protocol with the host uC.

Hardware

TPOD electronics hardware development is in-progress.

Sensor selection and discrete circuit components have been approved and finalized. Circuit schematic design and capture has been verified and approved. Bill of materials has been generated and approved.



First generation PCB design, layout and fabrication were completed. Following subsystem validation testing, it was determined that method for TPOD communication was unsuccessful. New method of TPOD communication is currently under development, and TPOD electronics for sensor acquisition schematics are complete, PCB layout is under design review.

Second generation TPOD schematic modifications and PCB layout have begun. Modifications are with respect to form factor, ease of manufacturability, and power consumption. Sensor payload remains constant as all sensors meet or exceed functional requirements. Following review and approval of engineering documents, fabrication of second-generation hardware will begin for functional verification of the design.

Firmware

Proof of concept firmware has been written to manage and validate sensor payload. Onboard logging library has been developed to enable raw capture of sensor suite. Validation of hardware sensor selection is complete. Development of T-Pod prototype sensor acquisition firmware is complete. Sensor functionality was verified in the SIO test tank at 25ft depth.

Sufficient hardware has been received to begin field trials. Raw acquisition logs are being captured to enable post-processing filter design. Following filter design approval, the filter will be added to the sampling firmware.

Data

Data was collected from the prototype T-Pods to validate necessary calibration procedures for accurate depth and temperature measurement. Depth measurements were validated using a Seabird SBE-39 Temperature and depth sensor.

mADOS TPOD prototype housing

TPOD Prototype housing is a non-miniaturized, field serviceable TPOD housing for testing and validating TPOD electronics for the mADOS. The housing's design is depth rated for the operational mADOS T-chain depth, and equipped with the same sensors and electronics of the mADOS TPOD.

Hardware

TPOD Prototype housing development is complete.

Functional specifications have been finalized and approved. Conceptual drawings have been finalized and approved. Computer aided design (CAD) drawings have been completed and approved. TPOD prototype housing has been fabricated. TPOD prototype housing was pressure tested for a depth of 200 meters. Prototype housing meets or exceeds all functional requirements.

mADOS Surface Expression Assembly

The mADOS surface expression assembly is the core component of the mADOS system. The surface expression assembly consists of the parachute, parachute release mechanism, bladder, bladder inflation system, anemometer, barometer port, master electronics, and is the T-Chain termination.

Hardware

Surface expression assembly hardware development is complete.

Functional specifications have been finalized and approved. Conceptual drawings have been finalized and approved. Computer aided design (CAD) drawings have been completed and approved. Surface expression assembly and sub-assemblies are currently being fabricated.

Surface assembly and sub-assemblies for testing parachute deployment, bladder deployment firing mechanism, and the bladder have been received. Surface expression sensor package has been fully assembled and tested in a controlled



environment to verify readiness for sea trials with respect to sensor acquisition, raw logging, and transmission via Iridium SBD.

Second generation bladder has been received and validation testing is complete. Bladder passes fitment check with regard fitment to electronics housing. Bladder passes fitment check with regard to stowed form factor. Bladder inflates to full volume without excessive loss of compressed CO₂. Remaining bladders have been ordered from the vendor.

Design and fabricate prototype rotochute assembly

The two new pre-production rotochutes, made out of lighter molded polymer plastic, were received and fully assembled.

In addition, one of the previous pre-production buoy rotor assemblies was modified with a third new housing. A special version of firmware was developed to integrate an Inertial Motion Unit (IMU) and measure three axis accelerations (x",y",z") one three axis rotation rates (roll, pitch yaw).

Design and integrate wave measurements electronics package into A-size MWB package

Previously completed milestone.

Design and fabricate prototype A-size MWB package housing

The three new pre-production A-size MWB housings (see Figure 1) were received and assembled into complete units for additional flight testing. Flight testing was performed on March 3, 2016 (see below).

Field test prototype A-sized MWB system and compare data with standard MWB

All three buoys were flight tested on March 3, 2016. Helicopter drops were performed from

1500', and two at 5000' ASL. Drop one (1500') produced a failure of the bottom plate, jettisoning the battery out the bottom of the buoy. Drop two (5000') produced a failure of the electrical interface between the CPU and the Iridium modem jarring loose, causing communication failure. Drop three (5000') was successful. A standard (spherical) MWB was placed in the water next to the last buoy for a wave measurement comparison.

In addition to the GPS data recorded by the buoy, the IMU data provides insight into the forces upon the buoy.

The GPS data shows the drop altitude of 1558 meters, and a maximum GPS velocity downward of 22.7 m/s. The IMU data shows a maximum G-force at splashdown of 26.7 $m/(s^2) = 2.7G$. Additional, the yaw rate sensor achieved its maximum value for the entire flight indicating a rotation rate above 2000 degrees/s.

Lessons learned from this second flight test are:

Integrate a strengthening rod in to the housing to keep the end cap from breaking on impact

Use additional epoxy, Loctite, etc. to hold the electronics interfaces in place

These modifications are now being made. A third flight test is scheduled for April 27. This test will utilize an airplane (instead of a helicopter), flying at 120 kts., with drops at 500, 1500, and 5000'.

The wave following characteristics of the one surviving A-size buoy were again tested against a standard spherical MWB.





Figure 3: mADOS: Bladder fully inflated. Screen capture from successful bladder inflation test.





Figure 4: New polymer plastic A-size wave buoy



California Cooperative Oceanic Fisheries Investigations (CalCOFI), an Ocean Observation Program for the Southern California Current

Principal Investigator(s):

Dr. David M. Checkley, Jr., Scripps Institution of Oceanography, UC San Diego

Dr. Ralf Goericke, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Ned Cyr, National Marine Fisheries Service

Dr. Francisco Werner, Southwest Fisheries Science Center

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Goal 3: Serve Society's Needs for Weather and Water Information

Goal 4: Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation

Budget Amount:

\$7,241,194

Amendment(s):

7, 28, 58, 90, 119

Description of Research:

In collaboration with NOAA's SWFSC, we conduct quarterly cruises in the California Current System, analyze the resultant data and samples, make the data and results available to users, and present those results

in the peer-reviewed literature and at meetings, including the annual CalCOFI Conference. We also work closely with ancillary programs, including the NSF-sponsored CCE-LTER study, Navy-funded marine mammal and seabird observation program, the NOAA-OAR and Fisheries-funded ocean genomics programs, and the NOAA-OAR-funded ocean acidification program.

Objectives:

CalCOFI's primary objectives are 1) to continue its 67-year time series of comprehensive, high-quality physical, chemical and biological observations of the southern California Current System, with an emphasis on the living marine resources and their ocean environment, and 2) to contribute through its data and analyses to a scientific understanding of the human impacts and influence of climate variability and climate change on the living resources of the California Current in support of an ecosystem approach to management.

Accomplishments & Milestones:

- Four cruises successfully executed: April, July and October-November 2015 and January 2016.
- Hydrographic data analyzed and made available electronically for four quarterly CalCOFI cruises in 2014 and 2015.
- 2014 and 2015 CalCOFI Reports published and distributed electronically.
- Provided SIO contribution to annual State of the California Current Report.
- Publication of papers based on CalCOFI data in peer-reviewed journals.



Conferences, Meetings & Presentations

- a. Outlook: El Niño, Storms and Changing Ocean Conditions, November 19, 2015
- b. Understanding El Niño's Impacts of California's Living Marine Resources Through Ocean Observations, a workshop of California's Ocean Protection Council, September 22, 2015

Education & Outreach

Communications

- a. CalCOFI maintains www.calcofi.org/new.data to share CalCOFI's reported, CTD, underway, and zooplankton data sets in partnership with NOAA NMFS, Scripps' Integrative Oceanography Division (IOD), and California Department of Fish & Game (CDF&G).

Academic Development

- a. The following individuals received PhDs from Scripps/UCSD and were supervised by Scripps faculty during this period and either directly or indirectly benefitted from the use of CalCOFI data:
- b. Bill Jones (Dave Checkley advisor): The Santa Barbara Basin Fish Assemblage in the Last Two Millennia Inferred from Otoliths in Sediment Cores. January 22, 2016.
- c. Noelle Bowlin (Phil Hastings advisor): Ontogenetic changes in the distribution

and abundance of early life history stages of mesopelagic fishes off California. December 8, 2015.

- d. Amanda Netburn (Tony Koslow advisor): Responses of Mesopelagic Fish Assemblages to Environmental Disturbance: Ocean Deoxygenation and Oceanic Fronts. January 25, 2016.
- e. Hao Ye (George Sugihara advisor): Nonlinear Tools for a Nonlinear World: Applications of Empirical Dynamic Modeling to Marine Ecosystems. September 8, 2015.
- f. Ethan Deyle (George Sugihara advisor): Multivariate Empirical Dynamic Approaches to State-Dependence in Ecological Dynamics and Management: A mathy but practical investigation into sidestepping reductionism in the irreducible natural world. September 9, 2015.
- g. Elizabeth Vu (John Hildebrand advisor): Habitat Use of Calling Baleen Whales in the Southern California Current Ecosystem. October 28, 2015.

NOAA Employment

- a. Noelle Bowlin, a PhD, gained employment with Southwest Fisheries Science Center, January 2016



NOAA Ocean Acidification Program Theme 1: OA Monitoring, Small Sample Analysis and QA/QC Analytical Support

Principal Investigator(s):

Andrew G. Dickson, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Elizabeth Jewett, Ocean Acidification Program

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Budget Amount:

\$419,182

Amendment(s):

44, 76, 121

Research Objectives:

The primary goal of the effort proposed here is to work with the NOAA Ocean Acidification Program to assist the various scientific groups supported by the Program to improve the various CO₂-related measurements made in support of ocean acidification research. The CO₂-related measurements that will be addressed here are pH, total alkalinity, and total dissolved inorganic carbon, and the principal focus will be on promoting activities within the various groups that allows them to assess the quality of their measurements in a uniform and correct manner, and enabling them to identify where improvements are necessary. Where practical, we shall offer

technical suggestions for such improvements based on our own knowledge and experience.

The key activities we intend to carry towards achieving this are:

1. Establish agreed requirements for the uncertainty of measurements of pH, total alkalinity, and total dissolved inorganic carbon that will enable the achievement of the various scientific goals of the NOAA Ocean Acidification Program.
2. Provide detailed, worked examples of the estimation of uncertainty of laboratory measurements of pH, total alkalinity, and of total dissolved inorganic carbon.
3. Make stable seawater samples of "known" composition suitable for use in such Proficiency Tests (i.e. with a range of values for the various measurands), and then to organize regular proficiency tests among the various laboratories involved in the NOAA OAP.
4. Conduct workshops that allow the technical personnel within the various groups to improve their knowledge of the individual measurement procedures, as well as of the within-laboratory quality control activities that are required to ensure that such procedures are meeting the desired uncertainty goals.

Research Accomplishments:

In the period since this grant was active (10/01/2015), we have not expended any funds, as we had been using funds from a no-cost extension on an earlier, related, grant from the NOAA Ocean Acidification Program.



Nevertheless we have made some progress in these activities:

1. Dr. Dickson has been working on implementing a full error propagation analysis for seawater carbonate chemistry. This requires both a computational implementation of this, as well as a detailed assessment of the uncertainties of all the parameters used (both those measured directly by a particular investigator, as well as those that are represented as given functions of temperature and salinity such as the various equilibrium constants and the various concentrations that are treated as functions of salinity: e.g. total boron).

The computational framework is relatively straightforward, though cumbersome and a prototype has been implemented in *Mathematica*; a review has been made of the literature for the various equilibrium constants etc. and, based on this, estimates have been made of the likely uncertainty for these various calculated parameters.

The work done so far provides a context for discussions of the necessary target uncertainties for the various measured CO₂ parameters such as pH, total alkalinity, total inorganic carbon as it makes it practical to define these in terms of the likely scientific goals (including estimating carbonate ion concentration, or even aragonite saturation state). Some discussions have already taken place in planning for activities such as GOA-ON (the Global Ocean Acidification Observing Network), but more are needed before this activity can be considered complete.

2. We have almost completed a detailed uncertainty budget for the measurement of total alkalinity using the method and equipment we have designed (and which

is now used in several other labs including NOAA/PMEL). Once this is done, it will be prepared as a manuscript for publication. We are part way through a similar activity for the measurement of “pH” using spectrophotometric measurements and the indicator dye m-cresol purple.

3. Plans are in place to prepare such “test samples” this summer, and a limited amount of work has gone into prototyping a sample that is suitable as a “test sample” for alkalinity. (Earlier work supported by the NOAA Ocean Acidification Program showed we could produce such samples for pH and total dissolved inorganic carbon.)
4. The first such workshop will be held in early Fall 2016, and will focus on pH measurement (both electrometric and spectrophotometric).

Milestones:

Note: none of these milestones has yet been achieved, although progress has been made (see above)

1. Make widely available an uncertainty calculator for the seawater CO₂ system.
2. Publish recommended uncertainty values for the various equilibrium constants etc. as well as recommended “best” values.
3. Publish detailed uncertainty budgets for each of the laboratory measurements: pH, total alkalinity, and total dissolved carbon of seawater.
4. Prepare and distribute “test samples” for the measurement of seawater pH, total alkalinity, and total dissolved inorganic carbon. This will be done in the form of a “proficiency” test for laboratories supported by the NOAA OAP, and others who may be interested in participating.
5. Hold workshops intended to improve the attendees’ understanding of quality



control of seawater CO₂ measurements,
including how to estimate the uncertainty
of a particular laboratory's
implementation of a measurement
technique (rather than simply assuming a
literature value).



Developing a Data-Assimilative Modeling Tool to Estimate Oxygen and pH over the California Current

Principal Investigator(s):

Christopher A. Edwards, UC Santa Cruz

Other Key Personnel:

Paul Mattern, UC Santa Cruz

NOAA Primary Contact:

F. Werner, Southwest Fisheries Science Center

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 3: Serve Society's Needs for Weather and Water Information

Budget Amount:

\$100,001

Amendment(s):

129

Description of Research:

Ocean models are outstanding tools with which to study the ocean and simulate key properties, such as temperature, currents, and chlorophyll biomass. However, by definition ocean models are incomplete representations of nature and thus discrepancies exist between model output and the natural system. One method to reduce such discrepancies is through data assimilation in which model variables are periodically adjusted in rigorous, controlled ways such that model output more closely matches available observations. Applying such data assimilation methods to improve estimates of the physical circulation is now common, but similar developments for

biogeochemical estimates are only recently emerging. This project builds on recent developments in coupled physical/biogeochemical ocean data assimilation to add the capability to estimate oxygen levels and ocean acidification parameters. The anticipated goal of having a data assimilative implementation of the Regional Ocean Modeling System (ROMS) running the NEMURO biogeochemical model that has been modified to include oxygen and carbonate chemistry state variables has been met. The modeling capability is ready for real-world tests as observations of oxygen and pH levels are collected in the California Current System.

Objectives:

The research objectives of this project are to add oxygen dynamics and carbonate chemistry to the data assimilative form of the NEMURO biogeochemical model used within the Regional Ocean Modeling System (ROMS). This effort requires the construction and evaluation of nonlinear, tangent linear and adjoint models that include the new biogeochemical dynamics. These models (particularly the adjoint model) are complex pieces of code that require extensive debugging for functioning within a data assimilative system.

In the present reporting period, we completed the carbonate chemistry component of the research.

Accomplishments & Milestones:

Oxygen and carbonate chemistry dynamics have been successfully added to the nonlinear NEMURO biogeochemical model.

Tangent linear and adjoint versions of oxygen dynamics required for 4DVar assimilation



have been successfully implemented and tested in model twin configurations.

Tangent linear and adjoint versions of carbonate chemistry required for 4DVar assimilation have been successfully implemented and tested in model twin configurations (this reporting period).

Conferences, Meetings & Presentations

- a. Ocean Sciences Meeting, New Orleans, LA, February 2016

Education & Outreach

Communications

- a. At the Ocean Science Meeting in New Orleans, February 2015, we presented new results on biogeochemical data assimilation using the NEMURO model and ROMS within the California Current System.



CalWater and West-Coast Atmospheric River Research

Principal Investigator(s):

Dr. F. Martin Ralph, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

K. A. Prather, Scripps Institution of Oceanography, UCSD

D. Cayan, Scripps Institution of Oceanography, UCSD, USGS

J.R. Spackman, Science and Technology Corporation, NOAA

P. DeMott, Colorado State University

M. Dettinger, USGS

C. Fairall, NOAA

R. Leung, DOE/Pacific Northwest National Lab

D. Rosenfeld, Hebrew Univ. of Jerusalem

S. Rutledge, Colorado State University

D. Waliser, NASA

A. B. White, NOAA

J. Cordeira, Plymouth State University

A. Martin, Scripps Institution of Oceanography, UCSD

J. Helly, San Diego Super Computing Center

NOAA Primary Contact:

Dr. R. Webb, OAR/ESR

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Budget Amount:

\$169,999

Amendment(s):



114

Description of Research:

The variability of precipitation and water supply along the U.S. West Coast create major challenges to the region's economy and environment, as evidenced by flooding and by the recent drought. This variability is strongly influenced by:

- Atmospheric rivers, which deliver much of the precipitation along the U.S. West Coast, especially that associated with major storms, and
- Aerosols—from local sources and transported from remote continents—that modulate clouds and precipitation

A better understanding of these is needed to reduce uncertainties in weather predictions (Wick et al. 2013) and climate projections of droughts and floods, both now and under changing climate conditions. During a workshop in 2008 a vision emerged of bringing the disparate and requisite scientific communities (meteorologists, hydrologists, climate scientists, atmospheric chemists, and oceanographers) together to carry out interdisciplinary research, including new observations over land and offshore of the U.S. West Coast. This built upon separate projects in California between 2003-2008 (SUPRECIP, HMT), and led to coordinated field efforts from 2009-2011 over land. Because the region's precipitation depends heavily upon conditions over the Eastern Pacific, which was out of reach of the earlier campaigns, CalWater has again formed a team to fill this gap. The new program of studies—termed CalWater 2—is motivated by new findings and technologies, and by the need to improve regional climate models and develop tools supporting hydropower and water management. CalWater-2 data

collection will occur off the coast largely between California, Washington and Hawaii. Results will be applicable to the entire west coast of North America, including British Columbia and Alaska. Many policy makers and water managers are looking to this work to provide information for their use in managing today's water and flood risks in the region and in planning for the future. This is especially relevant given the record-setting drought along the U.S. West Coast in 2013-2014.

Objectives:

Task A: Co-chair of the CalWater-2 Core Science Steering Group (SSG).

Task B: Submit a journal article to the Bulletin of the American Meteorological Society (BAMS) summarizing CalWater.

Task C: Analysis of CalWater-2 Early Start G-IV aircraft observations of atmospheric rivers.

These data were collected in February 2014 with F.M. Ralph as Mission Scientist (led the development of the core science goals and flight plans, and led several flights). Analysis will focus on quantifying the magnitude and structure of water vapor transport in ARs.

Task D: Analysis of a strong AR that hit British Columbia in 2010 using data from Canadian scientists on the case study. This includes development of a proposal to pursue an observational and diagnostic study of ARs striking British Columbia.

Accomplishments & Milestones:

A BAMS article will be released in July about CalWater (see reference below).

There was an entire AGU session focused on CalWater and the results from these missions which was lead by F. Martin Ralph.

An additional paper summarizing all the dropsonde data is in prep.

Conferences, Meetings & Presentations

- b. AGU, December 2015 in San Francisco, represented by F. Martin Ralph

Education & Outreach

Academic Development

- a. Graduate student research - CalWater data is being examined by graduate students for research projects and as part of their academic development.



An atmospheric river case study on the Russian River and a vision for Western US observing systems

Principal Investigator(s):

Dr. F. Martin Ralph, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Dr. Daniel Cayan, Scripps Institution of Oceanography, UC San Diego/USGS

NOAA Primary Contact:

Philip Hoffman, OAR

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Budget Amount:

\$100,000

Amendment(s):

94

Description of Research:

This project will document the role of an atmospheric river in creating heavy precipitation during a winter storm that impacted the Russian River of northern California in March 2012, and its role in providing beneficial water supply later in the year's dry season. This event will be compared to a similar March 2007 event. This project also will create and present a vision for Western U.S. observing system enhancements that was created at the request of Western U.S.

Objectives:

Task A: Document the role of an atmospheric river in an extreme event on the Russian River of California in March 2012, and its role in providing beneficial water supply later in the year, and compare this event with one in 2007.

Task B: Submit a formal journal article presenting the Vision of Western Observing Systems that was created for and presented to western Stakeholders

Accomplishments & Milestones:

For Task 2 the following journal article was published.

Ralph, F.M., Dettinger, M., White, A., Reynolds, D., Cayan, D., Schneider, T., Cifelli, R., Redmond, K., Anderson, M., Gherke, F., Jones, J., Mahoney, K., Johnson, L., Gutman, S., Chandrasekar, V., Lundquist, J., Molotch, N., Brekke, L., Pulwarty, R., Horel, J., Schick, L., Edman, A., Mote, P., Abatzoglou, J., Pierce, R. and Wick, G. (2014), A Vision for Future Observations for Western U.S. Extreme Precipitation and Flooding. Journal of Contemporary Water Research & Education, 153: 16–32. doi: 10.1111/j.1936-704X.2014.03176.x

Education & Outreach

Networking

- a. Presentation to State and Federal Decision Makers - F. Martin Ralph presented to legislators on the difficulties of managing a reservoir for both flood control and water supply using the March 2012 atmospheric river case as compared to a December 2012 case.



SIO High Resolution XBT/XCTD Transects

Principal Investigator(s):

Dean Roemmich, Scripps Institution of Oceanography, UC San Diego

Janet Sprintall, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Bruce Cornuelle, Scripps Institution of Oceanography, UC San Diego

Nathalie Zilberman, Scripps Institution of Oceanography, UC San Diego

Lisa Lehmann, Scripps Institution of Oceanography, UC San Diego

Glenn Pezzoli, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Kathy Tedesco, Climate Program Office

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Budget Amount:

\$3,567,771

Amendment(s):

20, 47, 78, 108

Description of Research:

The SIO High Resolution XBT (HRX) Network is a set of basin-spanning shipping routes (<http://www-hrx.ucsd.edu>) along which eddy-

resolving temperature transects are collected four times per year. A scientist or technician (from our program) aboard the ship deploys XBTs at spatial separations of 10 to 50 km. The HRX Network was initiated in 1986 along a commercial shipping route between New Zealand, Fiji, and Hawaii. It was subsequently expanded during the 1990's to include basin-spanning temperature transects in all of the oceans. Major partners in the HRX network include Scripps (Pacific and Indian Ocean), NOAA/AOML (Atlantic), and CSIRO (SW Pacific, Indian). Typically, each transect is repeated on a quarterly basis to resolve variability in temperature, geostrophic circulation and transport on annual and longer periods.

Objectives:

Scientific objectives of the HRX Network are:

Measure the seasonal and interannual fluctuations in the transport of mass, heat, and freshwater across ocean-wide transects spanning the ocean's boundary currents and interior circulations.

Determine the long-term mean, annual cycle and interannual fluctuations of temperature, geostrophic velocity and large-scale ocean circulation in the top 800 m of the ocean.

Obtain long time-series of temperature profiles at precisely repeating locations in order to unambiguously separate temporal from spatial variability.

Determine the space-time statistics of variability of the temperature and geostrophic shear fields.

Provide appropriate *in situ* data (together with Argo profiling floats, tropical moorings, air-sea flux measurements, sea level etc.) for testing ocean and ocean-atmosphere models.

Determine the synergy between HRX transects, satellite altimetry, Argo, and models of the general circulation. What are the



minimal sampling requirements for *in situ* data?

Identify permanent boundary currents and fronts, describe their persistence and recurrence and their relation to large-scale transports.

Estimate the significance of baroclinic eddy heat fluxes.

Accomplishments & Milestones:

Deployment of >4000 XBTs over the review period as part of SIO's HR-XBT basin-wide repeat transects that cross western boundary currents, fronts and eddies

Implementation of Iridium communication during 2015 on all ships participating in the HR-XBT network

Delayed-mode quality control of all XBT profiles and distribution through SIO (<http://www-hrx.ucsd.edu/>) and NODC data archiving web sites.

Contribution of the HR-XBT data to publications (see below and <http://www.aoml.noaa.gov/phod/goos/bib/index.php>)

The use of HR-XBT data in student research is indicative of the increasing value of ocean observations that are sustained over multi-decades.

Conferences, Meetings & Presentations

- a. IUGG Conference, 14 June – 3 July 2015, in Prague Czech Republic, represented by Janet Sprintall

- b. Fourth International IQuOD Workshop/ XBT Science Meeting, 3-5 December 2015, in Hamburg, Germany, represented by Janet Sprintall
- c. AGU Ocean Sciences Conference, 21-26 February 2016, New Orleans LA, represented by Janet Sprintall, Natalia Ribeiro Santos, and Nathalie Zilberman
- d. GOOS Meeting, September 2015, Galway Ireland, represented by Nathalie Zilberman
- e. Ocean Surface Topography Science Team Meeting, October 2015, Reston VA, represented by Nathalie Zilberman

Education & Outreach

Communications

- a. L. Lehmann maintains the High Resolution XBT Network web site: <http://www-hrx.ucsd.edu> to describe the scope and objectives of the Pacific/Indian HRX network; to display data from all cruises; and to provide downloadable datasets on a cruise by cruise basis

Academic Development

- a. Pls Sprintall and Roemmich advise PhD students and post-doctoral fellows using HR-XBT data in their original research.



The Argo Program – Global Observations for Understanding and Prediction of Climate Variability

Principal Investigator(s):

Dean Roemmich, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

John Gilson, Scripps Institution of Oceanography, UC San Diego

Nathalie Zilberman, Scripps Institution of Oceanography, UC San Diego

Dan Rudnick, Scripps Institution of Oceanography, UC San Diego

Sarah Gille, Scripps Institution of Oceanography, UC San Diego

Megan Scanderbeg, Scripps Institution of Oceanography, UC San Diego

Michael McClune, Scripps Institution of Oceanography, UC San Diego

Kyle Grindley, Scripps Institution of Oceanography, UC San Diego

Lisa Lehmann, Scripps Institution of Oceanography, UC San Diego

Glenn Pezzoli, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Stephen Piotrowicz, Climate Program Office

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Budget Amount:

\$10,280,620

Amendment(s):

15, 42, 74, 105

Description of Research:

SIO plays a number of key roles within U.S. and international Argo. The U.S. provides over 50% of the international Argo array, including instrumentation development, float production and deployment, communications and data management, and scientific analyses to demonstrate the value of Argo data. Within the U.S. Argo float Consortium, SIO produces and deploys one-fourth of the conventional U.S. Argo floats (82 SOLO-II floats during the reporting period), carries out float technology development, participates in delayed-mode quality control, coordinates the U.S. Argo partnership, and provides leadership for international Argo through the Argo Steering Team and the Argo Data Management Team. Further, SIO continues the technology improvement of the Deep SOLO float, and during the reporting period produced and deployed 9 Deep SOLO floats in the SW Pacific Deep Argo pilot array.

Objectives:

The objective of the Argo Program, an international collaboration, is to provide a global array of upper-ocean (0-2000 m) profiling CTD floats suitable for a broad range of research and operational applications (<http://www.argo.ucsd.edu>). The Argo array, now including about 3800 active floats, is providing unprecedented real-time views of the evolving physical state of the ocean. These measurements reveal the physical processes that balance the large-scale mass, heat, freshwater and steric sea level budgets of the ocean on basin-to-global scale. Argo is a



major initiative in oceanography, merging research and operational objectives to provide a uniquely valuable global dataset for climate science, ocean state estimation, seasonal-to-decadal forecasting, education and other applications. All Argo data are freely available in near-real time, and in delayed-mode for applications requiring highest quality data.

Accomplishments & Milestones:

- Production, shipping, and deployment of 82 SOLO-II Argo floats.
- Technology improvement in Deep SOLO, production and deployment of 9 Deep SOLO floats
- Data communications, decoding, and file formatting for all Iridium SIO Argo floats
- Array monitoring of all SIO Argo floats (> 500)
- Delayed-mode quality control of all SIO Argo floats (> 500) according to agreed Argo protocols
- Demonstration of the value of Argo data through published research

Honors and Awards

- a. Sarah Gille became a Fellow of the AGU, 2015
- b. Russ Davis received the AGU Ewing Medal, 2015

Conferences, Meetings & Presentations

- a. International Argo Data Management Team Meeting, Bermuda, October 2015, represented by John Gilson, and Megan Scanderbeg
- b. International Argo Steering Team Meeting, Yokohama Japan, March 2016, represented by Dean Roemmich, Megan Scanderbeg, and Nathalie Zilberman
- c. Ocean Surface Topography Science Team Meeting, Reston Virginia, October 2015, represented by Nathalie Zilberman, Dean Roemmich, and Sarah Gille

- d. AGU Ocean Sciences Meeting, New Orleans, Louisiana, February 2016, represented by Nathalie Zilberman, Florent Gasparin, and Sarah Gille
- e. AGU Fall Meeting, San Francisco, California, December 2015, represented by Dean Roemmich and Sarah Gille
- f. International Argo Data Management Team Meeting, Bermuda, October 2015, represented by John Gilson and Megan Scanderbeg

Education & Outreach

Communications

- a. M. Scanderbeg maintains the Argo Science Team web site (<http://www-argo.ucsd.edu>), on behalf of the International Argo partner nations, to provide information on the Argo Program, its objectives, status, and data system, including how to access Argo data.
- b. M. Scanderbeg publishes the Argonautics Newsletter (<http://www.argo.ucsd.edu/Ernewsletter.html>), on behalf of the international Argo partner nations, to distribute information on Argo status, applications, and progress on key issues.
- c. M. Scanderbeg and L. Lehmann developed and continue to improve the Argo Marine Atlas, a data display tool to allow students and educators to view Argo and other ocean datasets as maps, vertical sections, time-series plots, and line drawings. ftp://kakapo.ucsd.edu/pub/argo/Pacific_Marine_Atlas



Academic Development

- a. PIs Roemmich, Rudnick, and Gille teach graduate oceanography courses into which the Argo dataset and its results are integrated, and advise PhD students and post-doctoral fellows using Argo data in their original research.

K-12 Outreach

- a. D. Roemmich advises the SEREAD Program (SOPAC, UNESCO, NOAA, NIWA/NZ, IOC, Education ministries in Cook Is, Samoa, Kiribati) on development of curricular units and for conducting teacher training seminars for teaching of weather, climate, sea level, and the ocean's role in climate in Pacific island school systems . See http://www.argo.ucsd.edu/FrEducational_use.html



Integrated boundary current observations in the global climate system - Consortium on the Ocean's Role in Climate (CORC)

Principal Investigator(s):

Uwe Send, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Russ Davis, Scripps Institution of Oceanography, UC San Diego

Daniel Rudnick, Scripps Institution of Oceanography, UC San Diego

Bruce Cornuelle, Scripps Institution of Oceanography, UC San Diego

Dean Roemmich, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Diane Stanitski, Climate Program Office

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Budget Amount:

\$6,640,175

Amendment(s):

24, 64, 85, 120

Keywords:

Boundary Currents, CORC, California Current, Transports, Observing Systems

Research Objectives:

For over 20 years the Consortium on the Ocean's Role in Climate (CORC) has focused

on implementing new ocean observing technologies and systems. After identifying inadequately measured properties of the ocean circulation that are important to understanding and predicting climate variability, CORC investigators have developed cost-effective technology, methodology and infrastructure to implement observing systems to measure them. These systems have been put into operation to refine and demonstrate their abilities. Examples of past and ongoing projects are the High-Resolution Expendable Bathythermograph network operating from commercial ships, the Surface Velocity Program, the Argo network of profiling floats, the array of California Current glider transects, and moorings to capture high-frequency processes.

Motivated by national and international planning efforts, CORC is now focused on methods to observe boundary currents, both western boundary currents whose powerful circulation signatures affect global climate fluctuations and eastern boundary currents where the circulation affects local weather, ocean acidification, and valuable fisheries. The boundary current data streams are intended primarily for scientists developing societally valuable analyses and prediction products that are influenced by persistent ocean conditions i.e. ocean climate. Examples are developing models to predict seasonal temperature or precipitation anomalies over land, assessing and predicting trends in ocean productivity and fisheries, or planning coastal development in a changing climate.

More specifically, CORC is now developing regional observing systems in the California Current and the Solomon Sea and developing methods to merge these observations with



global ocean climate observations like altimetry, winds, Argo profiles and the Surface Velocity Program. In and inshore of the California Current, changes in processes like alongshore currents from the north and south, upwelling, changes in stratification and mixing, and the frequency and strength of near-surface fronts have been implicated in large changes in the abundance of fish and their prey. CORC data is being used to look for relations between ecosystem properties and coastal circulation. The Western Boundary Current in the Solomon Sea is the main source of the Pacific's Equatorial Undercurrent. This makes it a central part of the shallow overturning circulation that influences central Pacific surface temperatures that drive the El Niño – Southern Oscillation (ENSO) fluctuations with global temperature and precipitation consequences. CORC observing systems are delivering data to test and improve methods of predicting ENSO and its decadal-variability relatives as well as ecosystems and local weather along the California coast. This delivery is done primarily through public web sites where data can be plotted or downloaded. CORC does not intend to operate these observing systems indefinitely and hopes to transition them to a program better suited to sustaining them.

CORC has identified circulation in mid-latitude western boundary currents (WBCs) as another type of inadequately observed components of the ocean climate system and is planning to address them with new methods. We are therefore exploring new ways of observing the transport processes of such WBCs with an eye toward sustaining measurements at a reasonable cost.

Accomplishments:

CORC has supported gliders in the California Current (CC) on line 90 off Dana Point, and line 66.7 off Monterey. Data products have been produced consisting of profiles of

temperature, salinity, density, velocity, chlorophyll fluorescence, and acoustic backscatter on uniform grids for each glider transit along all lines, as well as a glider-based SoCal Niño Index. The gliders have been used to study the Pacific warm anomaly of 2014/15, one glider view is shown in figure 1. The CORC moorings and PIES (inverted echosounders with bottom pressure) are used for several purposes. The mooring/PIES-validated/calibrated altimeter transport index for the California Current (CC) is now updated routinely on our website. The alongshore and cross-shore flow observations are used for analyses of the warm anomaly. We have also detected an apparent correlation between the southward CC index and the northward inshore flow, something we are pursuing further with modellers.

We continued the time series of Solomon Sea (SS) transport (now to 1000m depth) begun in 2007. These observations are the only repeated indicator of the subsurface western boundary current in the tropical South Pacific. The 9 year glider time series show transport variability in the WBC to be well correlated to equatorial SST on ENSO scales. The record includes a single El Niño (2009/10), two La Niñas (2007/08 & 2009/10) and a minor warm event in late 2012. Transport reflects each of these; the mechanism is still unknown. Perhaps more significant is how, since the 2010/11 La Niña, the central Pacific SST has steadily trended up while Solomon Sea transport has gradually declined. The complementary end-point component across the Solomon Sea (moorings and PIES) has provided 2-1/2 years of data now, confirming and resolving very rapid transport changes by 10-15 Sv over 10-20 days. With the longer data set the combination of altimetry and PIES still has good skill at observing the transport and the two leading EOFs. We found that the mean flow determined from absolute dynamic topography versus that from



multiple glider sections is very similar (figure 2).

High Resolution XBT transects, Argo profiles and trajectories, and satellite altimetry have been used for estimation of the East Australia Current (EAC) boundary current and the tight recirculation gyre's transport and variability. Recently recovered (CSIRO) moorings along the same EAC transect have provided independent transport estimates that are consistent with our values during the time period of overlap. ARGO trajectory and profile data have also been used to describe a newly discovered northward current along the western flank of the East Pacific Rise (EPR, the East Pacific Rise Current) between 30°S and 40°S. This local enhancement of the interior flow due to topography cannot be seen in relative geostrophic velocity alone.

CORC is producing sequential short-term state estimates (STSE) of one month duration, now covering from late 2010 to late 2015. Indices are being generated for a new upwelling index (N-S pressure gradient), undercurrent variability/surfacing, and heat content. Isopycnal depth timeseries from the STSE are being compared to CORC mooring observations. With application to the warm anomaly, from the STSE it is clear that the warming in the Southern California Bight has continued winter and summer since 2011. Based on the time series of CUC strength, it appears that the undercurrent is not solely responsible for this change.

Milestones:

- The California Underwater Glider Network has provided fundamental measures of the 2014-2015 Pacific anomalies.
- A California Current index is now routinely generated.
- New results about spin-up of Southern California recirculation cell and cross-shelf upwelling circulation in moored ADCP data have been obtained.



- A nearly 8-year record of glider sections has been assembled and cross-checked to construct time series of volume, heat and freshwater transport in depth and density layers. These time series show a clear correspondence of events in the Nino 3.4 SST and equator ward transport, particularly in the shallow layers; warm SST corresponds to strong transport. The record also shows that transport builds gradually but steadily from cold events to warm ones.
- Potential to derive SS transports and shear from bottom pressure and altimetry alone
- Volume transport estimation for the East Australian Current off Brisbane based on High Resolution XBT, Argo, and Altimetry, and validated by nearby moored observations.
- Discovery of a new current – the East Pacific Rise Current – generated by interaction of the interior South Pacific Gyre with topography.
- Participation in the redesign of the Tropical Pacific Observing System (TPOS 2020).
- Estimation of global ocean heat gain and its spatial patterns based on Argo (2006 – 2014).
- Description of multi-decadal changes in the temperature, salinity, and wind-driven interior circulation of the South Pacific Gyre.
- Continued improved and updated state estimate.

Conferences, Meetings & Presentations

- a. SIO Seminar, September 2015, San Diego, represented by Nathalie Zilberman
- b. ARGO Science Meeting, September 2015, Galway, Ireland
- c. Ocean Sciences Meeting, February 2016, New Orleans, with multiple presentations

and posters, represented by Dean Roemmich, Nathalie Zilberman, Uwe Send, Matthais Lankhorst, Daniel Rudnick, Katherine Zaba, and Bruce Cornuelle

Education & Outreach

Academic Development

- a. 1 postdoc and 2 graduate students were partially supported by CORC.

Networking

- a. Served on the Pacific Island Global Ocean Observing System (PI-GOOS) Advisory Committee to Assist Pacific Island nations in gaining benefit from global ocean observations and products. In association with the South Pacific Regional Environmental Program (SPREP), NOAA, BoM Australia, NIWA New Zealand, Intergovernmental Oceanographic Commission, and South Pacific nations.

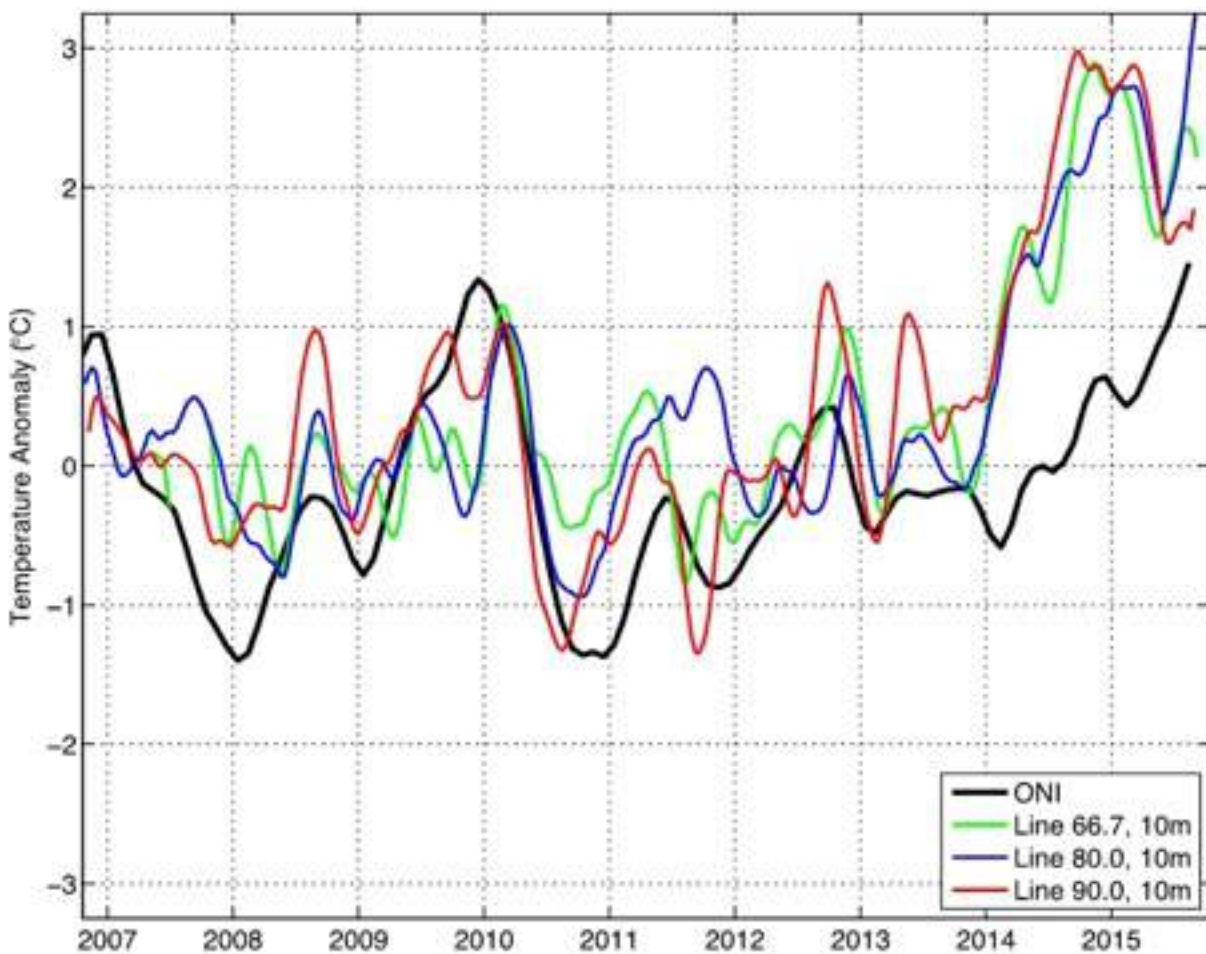


Figure 5: Temperature anomalies at 10 m, averaged over the inshore 200 km of each line, and filtered with a 3-month running mean (colors as in legend). The Oceanic Niño Index is plotted for reference (black). Note the increase in temperature off California concurrent on all lines beginning in January 2014.



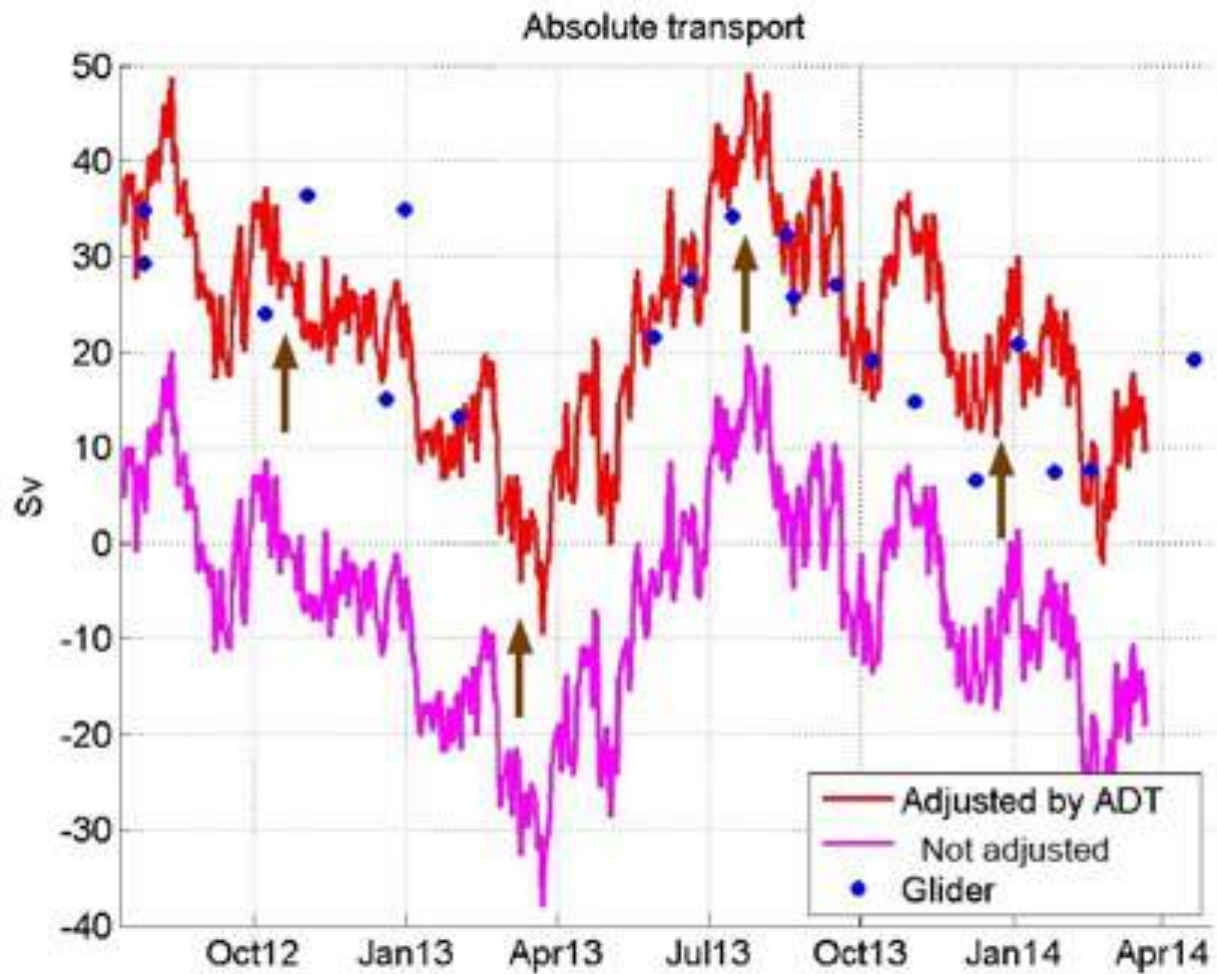


Figure 6: Total Solomon Sea through flow volume transport from mooring-derived dynamic height, referenced to PIES bottom pressure. Pink: without any additional offsets; Red: using a mean offset to reference the mean pressure gradient to the mean surface dynamic topography. The red line is in very good agreement with the individual transport estimates from glider sections (blue dots).



HF Radar National Network Data Management Development

Principal Investigator(s):

Dr. Eric Terrill, Coastal Observing R&D Center, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Lisa Hazard, Scripps Institution of Oceanography, UC San Diego

Tony de Paolo, Scripps Institution of Oceanography, UC San Diego

Mark Otero, Scripps Institution of Oceanography, UC San Diego

Joseph Chen, Scripps Institution of Oceanography, UC San Diego

Tom Cook, Scripps Institution of Oceanography, UC San Diego

Paul Reuter, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Jack Harlan, Ph.D., NOAA Integrated Ocean Observing System (IOOS) Program Office

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Goal 3: Serve Society's Needs for Weather and Water Information

Goal 4: Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation

Budget Amount:

\$2,064,000

Amendment(s):

2, 23, 39, 89, 103, 110

Keywords:

HF radar, National Network, Real-Time, Data Management, Surface Current Mapping, Surface Currents, Portal, Node, National Grid

Research Objectives:

Local, state, regional, and federal support for the Integrated Ocean Observing System (IOOS) have supported the installation, development, and operation of a network of surface current mapping systems for use by a broad range of end users. Central to the operational success of a large scale network is a scalable data management, storage, access, and delivery system. The objectives for this project are to continue development and maintenance of the national network including backend processing and diagnostic enhancements. The surface currents are made available for integration into systems such as the United States Coast Guard (USCG) Search and Rescue Optimal Planning System (SAROPS); NOAA Office of Response and Restoration (ORR) General NOAA Operational Modeling Environment (GNOME); and CA Regional Ocean Modeling System (ROMS).

The architecture of the HF-Radar Network lends itself well to a distributed real-time network and serves as a model for networking sensors on a national level. This proposal concentrates on development activities critical for network growth, sustainability, and



enhancements. Programming staff will finalize backend refactoring to increase code efficiency and decrease processing times, improve and expand diagnostic utilities by integrating operator input, and further validation of Direction of Arrival (DOA) metrics. Additionally, efforts to maintain the total vector currents pathway for data archival with the National Centers for Environmental Information (NECI), initiate radial data archiving, identify new relationships established at the global scale, and participate in the radiowave operators working group (ROWG) workshop and Group on Earth Observations (GEO) to promote national knowledge exchange and cooperation.

Research Accomplishments:

CORDC research and implementation efforts met expectations during this reporting period. Throughout this reporting period, efforts focused on continued operations, maintenance, and expansion; improving national diagnostics; configuring and initializing improved backend processing; implementation of the rowg website; and presenting on DOA metrics. Additionally, CORDC supported global partnership by visualizing surface current measurements of Mexico and Balearic Islands networks.

As the network of HF radar systems grows nationally, programmers continue to update and incorporate new data streams into the mapping system. This reporting period showed a significant increase in the number of sites and their distribution. A total of 11 new sites were added to the network during this period: 1 site on the west coast, 1 in Alaska, 3 in Hawaii, and 5 sites on the east coast.

CORDC staff enabled rapid HF radar response to west coast oil spill in June, 2015. IOOS funded HF Radar derived surface currents have established feeds to NOAA Office of Response and Restoration (ORR), CA State Office of Spill Prevention and Response

(OSPR) and regional models such as Regional Ocean Model System (ROMS) for oil spill response within the California region. These data are used to assist in analyzing and tracking oil spills as they enter the region of coverage. In response to the Refugio oil spill, HF radar operators from University of California, Santa Barbara established a temporary site at Gaviota in order to fill in coverage north of the spill and ran a local trajectory model advecting simulated particles through the current field to visualize the potential path of the slick:

<http://euler.msi.ucsb.edu/realtime/spill/sim/>.

Scripps programmers integrated the new site into the High Frequency Radar Network (HFRNet):

<http://cordc.ucsd.edu/projects/mapping/maps/fullpage.php> for near real-time visualization

and distribution to operational organizations responding to the spill. SCCOOS HF radar visualizations were used by local News Channel 3 in Santa Barbara for use during the weathercast in order to show circulation patterns in the area. These data were used to compare with General NOAA Operation Modeling Environment (GNOME) in forecasting spill affects along the coast.

CORDC programmers maintained a THREDDS server for hosting the near real-time vectors (RTV) and operationally support the following organizations:

- University of Connecticut Short Term Prediction System (STPS)
- Applied Science Associates (ASA) Environmental Data Server (EDS)
- U.S. Coast Guard Search and Rescue Optimal Planning System (SAROPS)
- Office of Response and Restoration (OR&R) Emergency Response Division (ERD) and Assessment and Restoration Division (ARD)
- Official NOAA forecasts for oil spill trajectories General NOAA



Operational Modeling Environment (GNOME)

- Office of Spill Prevention and Response (OSPR), California
Department of Fish and Wildlife

Research Highlights:

- Improved HFRNet diagnostics to use near real-time database and initiated enhancements for user input.
- Supported International radial acquisition and RTV processing within HFRNet for Mexico
- Supported International totals for two regions: Mexico and Balearic Islands
- Supported Refugio Oil Spill in June 2015
- Upgraded National HFR metric
- Maintained THREDDS server for near real-time RTV's

New Codar sites were made available to all Nodes for RTV processing:

Gaviota, CA (TRL1) University of California, Santa Barbara – Oil Spill Response
<http://cordc.ucsd.edu/projects/mapping/stats/?sta=TRL1>

Pepe'ekeo, HI (PPK) University of Hawaii
<http://cordc.ucsd.edu/projects/mapping/stats/?sta=PPK>

Keaukaha, HI (KKH) University of Hawaii
<http://cordc.ucsd.edu/projects/mapping/stats/?sta=KKH>

Conalep, Mexico (CON) Universidad Autonoma de Baja California
<http://cordc.ucsd.edu/projects/mapping/stats/?sta=CON>

Ponce Yacht and Fishing Club at Ponce, Puerto Rico (PYFC) University of Puerto Rico
<http://cordc.ucsd.edu/projects/mapping/stats/?sta=PYFC>

Cabo Rojo Lighthouse at Cabo Rojo, Puerto Rico (FARO) University of Puerto Rico
<http://cordc.ucsd.edu/projects/mapping/stats/?sta=FARO>



Icy Cape, AK (ICYC) University of Alaska Fairbanks
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=ICYC>

Kapolei, HI (KAP) University of Hawaii
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=KAP&aff=UH>

Old Bridge Waterfront Park, NJ (OLDB) Rutgers University
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=OLDB>

Amagansett, New York (AMAG) Rutgers University
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=AMAG>

Punta Tuna Lighthouse, Maunabo, Puerto Rico (MABO) University of Puerto Rico
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=MABO>

Decommissioned Sites:
(TRL1) University of California, Santa Barbara – temporary site

(PTLY) University of Alaska Fairbanks

Supported Domains and available data:
USEGC - US East and Gulf Coast - 2008-03 through present

USWC - US West Coast - 2008-03 through present

AKNS – Alaska North Slope – 2006-11 (when available)

GAK - Gulf of Alaska - 2009-05 through present (when available)

PRVI - Puerto Rico and US Virgin Islands - 2010-01 through present

USHI – US Hawaii – 2010-07

Conferences, Meetings & Presentations

- a. Environmental Protection Agency, Marine Debris Program, Regional Response Team, April 28, 2015 & July 1, 2015 in La Jolla, CA with Lisa Hazard and Mark Otero

- b. Los Angeles Area Committee Meeting, May 14, 2015 in San Pedro, CA with Lisa Hazard
- c. Oceans '15 MTS/IEEE, May 18-21, 2015 in Genoa, Italy, with T. de Paolo
- d. CA Resources Agency Deputy Secretary for Oceans and Coastal Policy, June 4, 2015 in La Jolla, CA with Eric Terrill
- e. USCG Meeting, July 29, 2015 in La Jolla, CA, Eric Terrill and Lisa Hazard
- f. San Diego Area Committee Meeting, August 6, 2015 in San Diego, CA, with Lisa Hazard
- g. GEO Conference, September 20-23, 2015 in Crete, Greece with Eric Terrill and Lisa Hazard
- h. Korea Hydrographic and Oceanographic Administration (KHOA), September 20-24, 2015 in Busan, Korea with M. Otero and J. Chen
- i. '15 MTS/IEEE Conference, October 20-21, 2015 in Washington, DC with Lisa Hazard
- j. Radiowave Operators Working Group (ROWG), November 2-4, 2015 in Woods Hole, MA with Lisa Hazard, Thomas Cook, Mark Otero, Joseph Chen, Heidi Batchelor
- k. Statewide Area Committee Meeting, January 12-14, 2016 in Santa Barbara, CA with Lisa Hazard(remotely)

Education & Outreach

Communications

- a. <http://cordc.ucsd.edu/projects/mapping> provides online access to surface current

mapping sites, radial data, and diagnostics for participating sites.

Academic Development

- a. Partnership with Woods Hole Oceanographic Institution researchers to further examine radial metrics.

K-12 Outreach

- a. Partnered with the Birch Aquarium to supported the surface currents in aquarium display titled "Boundless Energy Exhibit" to educate and bring awareness of ocean energy to general public.

Networking

- a. Presented at Oil Spill Area Committee Meetings in San Diego and Los Angeles to provide updated information regarding HF radar surface current application to oil spill response, with partners from US Coast Guard, Office of Spill Prevention and Response (OSPR), Marine Resources Advisory Committee (MRC), and Chevron.
- b. Meeting with Environmental Protection Agency to discuss HFR use for marine debris applications, with partners from Marine Debris Program and Regional Response Team.
- c. Correspondence NOAA ORR and CA OSPR for data integration from THREDDS versus shape files for Oil Spill Response with partners from NOAA OR&R and Office of Spill Prevention and Response.
- d. GEO to promote HF radar derived surface currents standards and distribution with NOAA and other International partners.





Figure 7: Group on Earth Observations Global High Frequency Radar Network Meeting in Crete, Greece.

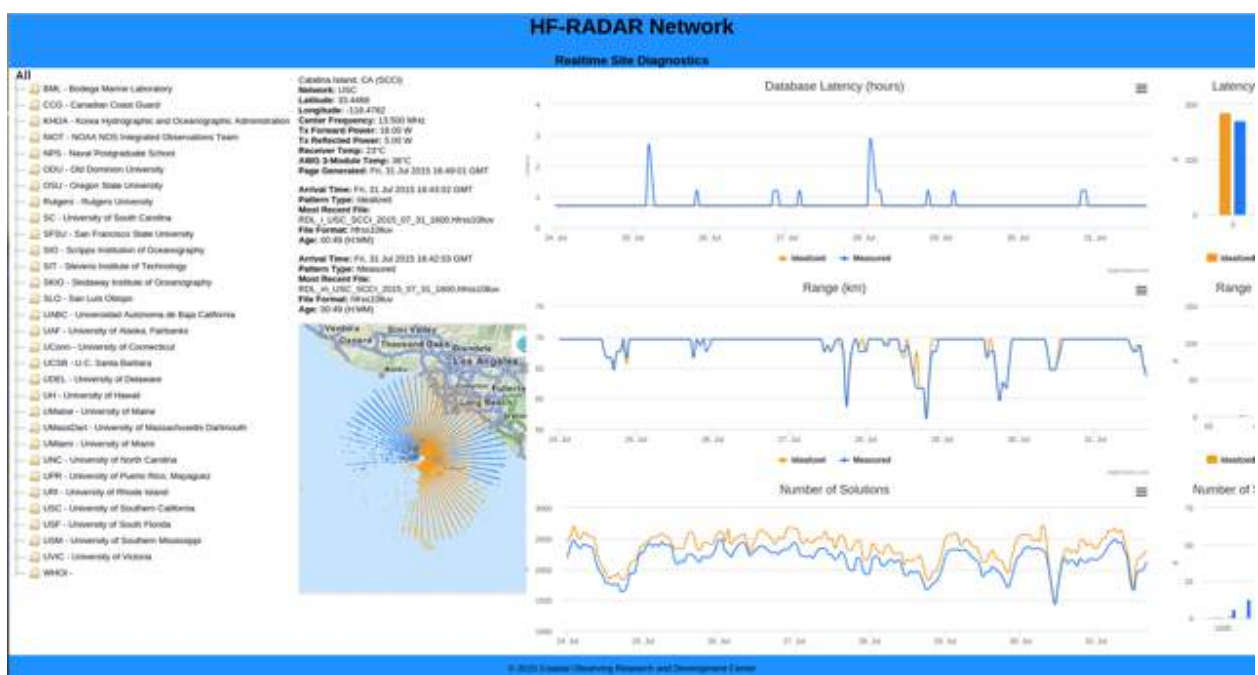


Figure 8: Enhanced HF Radar Network (HFRNet) diagnostics tools for improved performance, interactivity, and capability.



Bridging the gap in NOAA's extended and long range prediction systems through the development of new forecast products for weeks 3 and 4

Principal Investigator(s):

Shang-Ping Xie, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Steven Feldstein, Pennsylvania State University

Michelle L'Heureux, NOAA CPC
and Stephen Baxter, NOAA CPC

NOAA Primary Contact:

A. Mariotti, Climate Program Office

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Goal 3: Serve Society's Needs for Weather and Water Information

Budget Amount:

\$192,000

Amendment(s):

Competed NA14OAR4310189

Research Results and Accomplishments:

Our work over the past twelve months has featured significant progress in transitioning our research into the implementation of the new CPC Experimental Week 3-4 Outlooks, which has been the primary focus of our project. In addition we have advanced our fundamental understanding of predictability

for lead times of three to four weeks and have begun developing potential new forecast tools. We describe our progress below.

1.1 Transitioning forecast guidance for weeks 3 and 4 into operations

One of the primary initial objectives of the project is to transition the statistical model of Johnson et al. (2014) (hereafter referred as the "phase model"), into operational CPC forecast guidance for weeks three and four. The phase model generates probabilistic forecasts for lead times of up to four weeks based on the initial states of the Madden-Julian Oscillation (MJO), El Niño-Southern Oscillation (ENSO), and the linear trend. Subsequent refinement and operational transition efforts with the phase model have been overseen by collaborator Dr. Daniel Harnos in close support with Co-PIs L'Heureux, Baxter, and Johnson. During the past year the phase model has been extended to predict precipitation for all seasons, in addition to temperature. Guidance from the phase model was supplied to CPC forecast staff throughout the dry run period for week 3-4 forecasts, and for the entire period since the experimental week 3-4 product went live in September 2015. The phase model has also entered operations at CPC, and is automatically updated weekly for the forecast team.

Throughout the dry run period CPC forecasters expressed a desire for information about climate variability amplitude to be incorporated into statistical guidance, given the major El Niño event that subsequently developed in 2015. The phase model lacks such information, instead compositing together events based upon the initial climate state rather than permitting any scaling of the response by amplitude. To remedy this, collaborator Harnos developed a



“multiple linear regression” forecast tool for the combined weeks 3 and 4 period to complement the phase model. The multiple linear regression uses predictors incorporating the most recent Real-Time Multivariate MJO values (RMM1 and RMM2), Niño 3.4 anomaly over the preceding two weeks, and linear trend to develop probabilistic guidance for temperature and precipitation for days 15 through 28. The regression tool has been provided informally to CPC forecasters in support of week 3-4 operations, and is currently being transitioned to operations. The retrospective Heidke Skill Score (HSS) values of both statistical tools since CPC began to officially issue week 3-4 forecast are shown in Fig. 1, where positive values indicate improvement relative to random chance. We see that both the phase model and regression have proven to be skillful guidance (i.e. mean positive HSS values) for temperature and precipitation forecasts. Further, mean HSS values from each statistical tool have thus far outperformed certain dynamical model guidance forecasts for both temperature and precipitation. The results of this work are being incorporated into a manuscript that is in preparation.

1.2 Weeks 3-4 forecasts of North American teleconnection pattern indices

Given the promising results from the phase model, we have sought ways to enhance weeks 3-4 forecast guidance by (1) determining other sources of forecast skill aside from the MJO, ENSO, and linear trend, and (2) attempting to incorporate that knowledge into forecast guidance. To that end, Dr. Jiaxin Black has led an effort under the guidance of Co-I Johnson to develop statistical forecasts of the dominant Northern Hemisphere teleconnection pattern indices, given that these teleconnection patterns are strong modulators of North American temperature and precipitation. Specifically, this work incorporates a partial least-squares

regression (PLSR) method to generate 2-week statistical forecasts of the Pacific/North American (PNA) pattern, North Atlantic Oscillation (NAO) and Arctic Oscillation (AO) indices. The candidate predictor fields include tropical outgoing longwave radiation (OLR) and Northern Hemisphere 300 hPa and 50 hPa geopotential height. Overall, we find that the wintertime PLSR forecasts for the 1980-2013 period perform similarly well as the CFSv2 dynamical model forecasts in weeks 3-4 for the 1999-2010 period. Specifically, the correlations between the weeks 3-4 PLSR forecasts and observation for the PNA, NAO and AO are 0.34, 0.28 and 0.41, all of which are significant the 1% level using a Monte-Carlo approach. However, PLSR forecasts generated with data only from the 1999-2010 CFSv2 reforecast period perform substantially worse than the CFSv2 forecasts, which highlights the need for large sample sizes to generate robust PLSR forecasts.

A potential benefit of the PLSR approach is the ability to isolate a small number of predictor patterns to shed light on the physical sources of skill for the teleconnection patterns. Figure 3 illustrates an example of this feature in the form of lagged composites (300 hPa streamfunction and wave activity flux) associated with the first OLR predictor for the PNA. A clear Rossby wave train can be seen, which forms in response to the tropical heating associated, in part, with El Niño episodes (not shown). The energy from this wave source propagates downstream to form the quadrupole centers of action that project onto PNA. Other PLS predictor patterns also are examined in the same fashion, and the results will be incorporated into a manuscript that is currently in preparation and will be submitted in the summer of.

1.3 Dynamics of the midlatitude circulation

Several studies performed by Co-PI Steven Feldstein and his collaborators have investigated the dynamical process through



which tropical convection impacts the midlatitude circulation over a period of 1 to 4 weeks. In addition to gaining further insight into the physics of tropical-extratropical interaction, these studies have the potential to further refine the week 3-4 operational outlooks. In Flournoy et al. (2016), it was shown that MJO tropical convection impacts the surface temperature over Alaska through several processes tied to the excitation of poleward propagating Rossby waves.

To further increase of our understanding of the impact of the MJO on the extratropics, two types of NAO events were examined – one when the MJO is active and the other when the MJO is inactive. This analysis revealed that an active MJO modifies the stratospheric circulation, which then impacts the behavior of the NAO. The MJO-related NAO events persist for about 30 days, whereas when the MJO is inactive the NAO persists for only 10 days. The results of this study highlight the important role that the stratosphere may play for extended-range prediction, and indicate that improvement in the operational week 3 and 4 forecast may be possible if the state of the stratosphere is taken into account. Dai et al. (2016) compare the formation mechanism for the PNA when MJO-like tropical convection is active and when it is inactive. This study reveals that the PNA tends to develop from distinct initial extratropical flow patterns, especially over Eurasia, depending on whether the convection is active or inactive.

Goss and Feldstein (2016) examine the impact of individual centers of MJO convection on the midlatitude circulation both with an idealized model and with ERA-Interim data. They found that individual centers of MJO convection excite teleconnections of opposite sign in midlatitudes. The midlatitude response is dominated by the influence of the MJO convection center with the largest amplitude. These results indicate that possible improvement in operational week 3 and 4

forecast may occur if the relative amplitudes of the MJO centers of convection are taken into account. Lukens et al. (2016) examine the relationship between MJO tropical convection, the Rossby wave source, and the extratropical response with an idealized model. They found that the initial anomalies are excited by advection of the climatological absolute vorticity by the anomalous divergent wind in the subtropics and by the anomalous horizontal divergence with the tropics. The resulting anomaly is then advected eastward by the climatological zonal wind toward the central Pacific, after which amplification and dispersion into the extratropics takes place.

1.4 Examining subseasonal variability of El Niño

During the past twelve months, Co-I Johnson completed a study examining the role of the nonlinearity between deep convection and eastern equatorial Pacific sea surface temperatures (SSTs) on the diversity of El Niño teleconnection patterns (Johnson and Kosaka 2016). This work reveals that the wintertime climate impacts of El Niño over North America vary based on whether the eastern Pacific is convective (EPC) or non-convective (EPN). These results suggest that forecast guidance for weeks 3-4 that incorporates the phase of ENSO may benefit by differentiating the particular type of El Niño.

Highlights:

- Successful transition of MJO/ENSO phase model into the implementation of the CPC Experimental Week 3-4 temperature and precipitation outlooks
- Four papers submitted, in press, or published
- Advances in understanding dynamics of midlatitude dynamics contributing to North American weeks 3-4 predictability
- NOAA MAPP webinar on project delivered by Co-I Johnson and Dr. Harnos in October 2015 and an oral presentation



delivered by Dr. Harnos in AMS Annual Meeting in January 2016

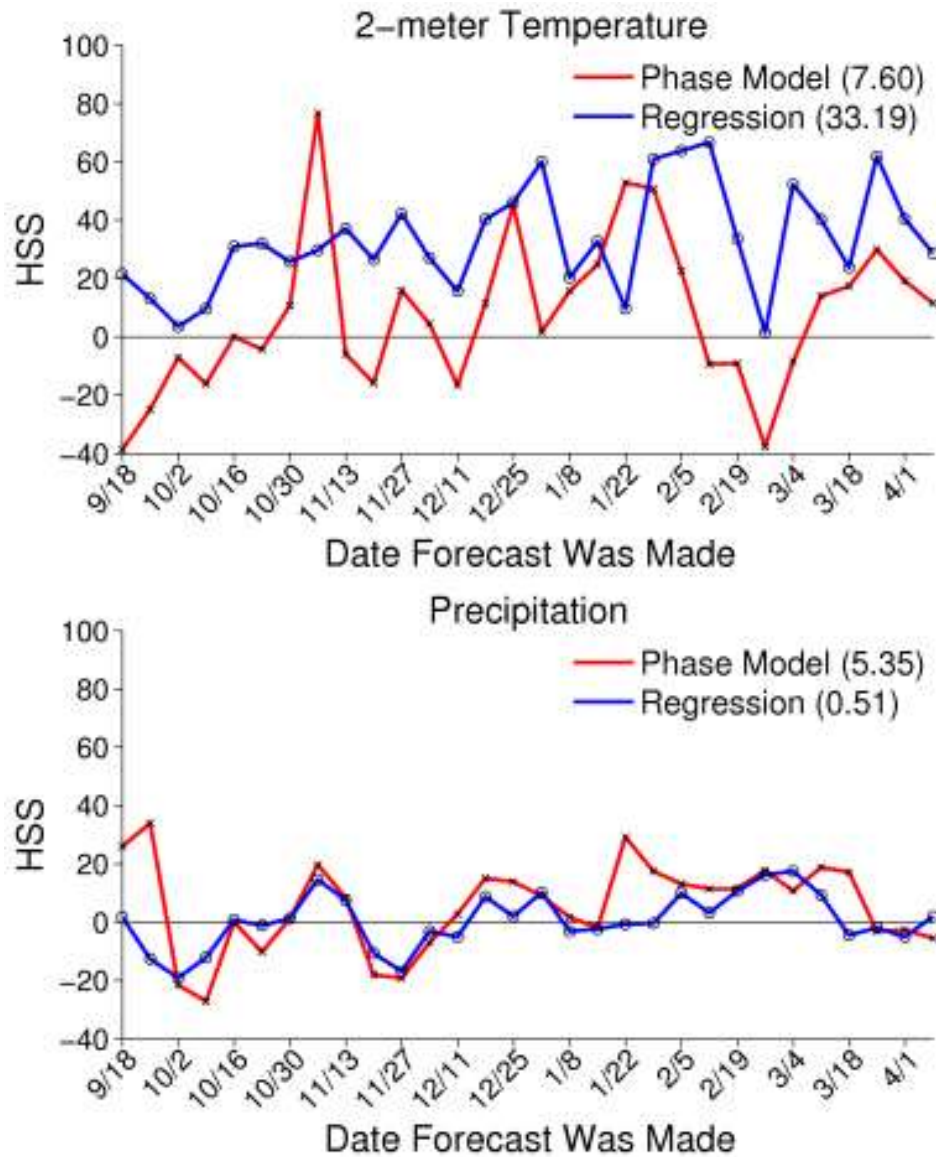


Figure 9: Time series of Heidke Skill Score (HSS) for temperature (top) and precipitation (bottom) forecasts from phase model (red) and multiple linear regression (blue) guidance over the United States since CPC's week 3-4 experimental forecasts began in September 2015. Numbers in parentheses indicate the mean HSS values over the full period. For comparison, mean HSS temperature (precipitation) scores by dynamical guidance over this period are: CFSv2 50.8 (11.0), ECMWF 45.3 (2.9), JMA 28.0 (-0.7).



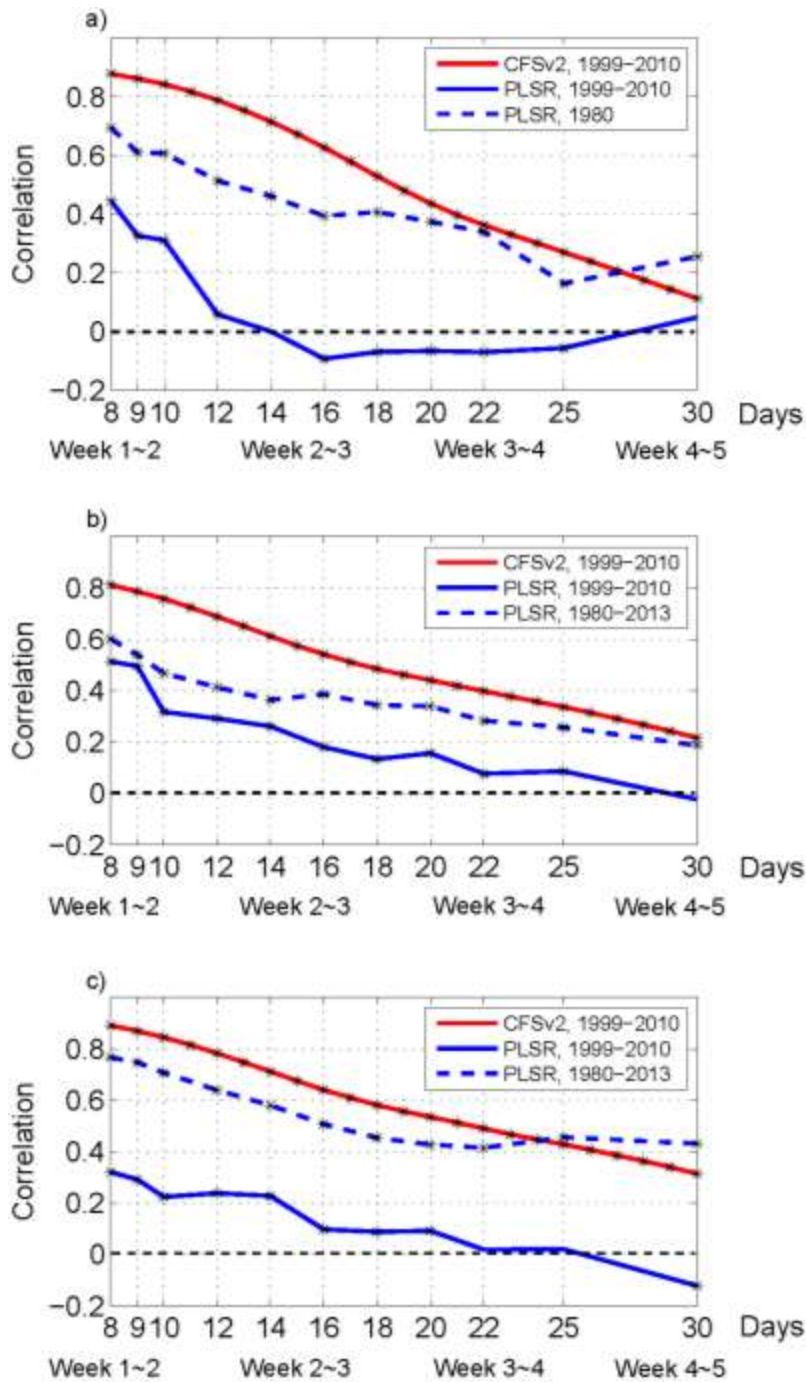


Figure 10: Correlation between hindcasts and observed wintertime (December – February) (a) PNA, (b) NAO, and (c) AO index time series at different 14-day lead windows (x-axis). The solid red and solid blue curves represent the CFSv2 hindcasts and statistical forecasts with PLS regression over the period of 1999-2010. The dashed blue curve represents the statistical forecasts over the period of 1980-2013. The asterisks denote 1% significance using a Monte-Carlo approach.



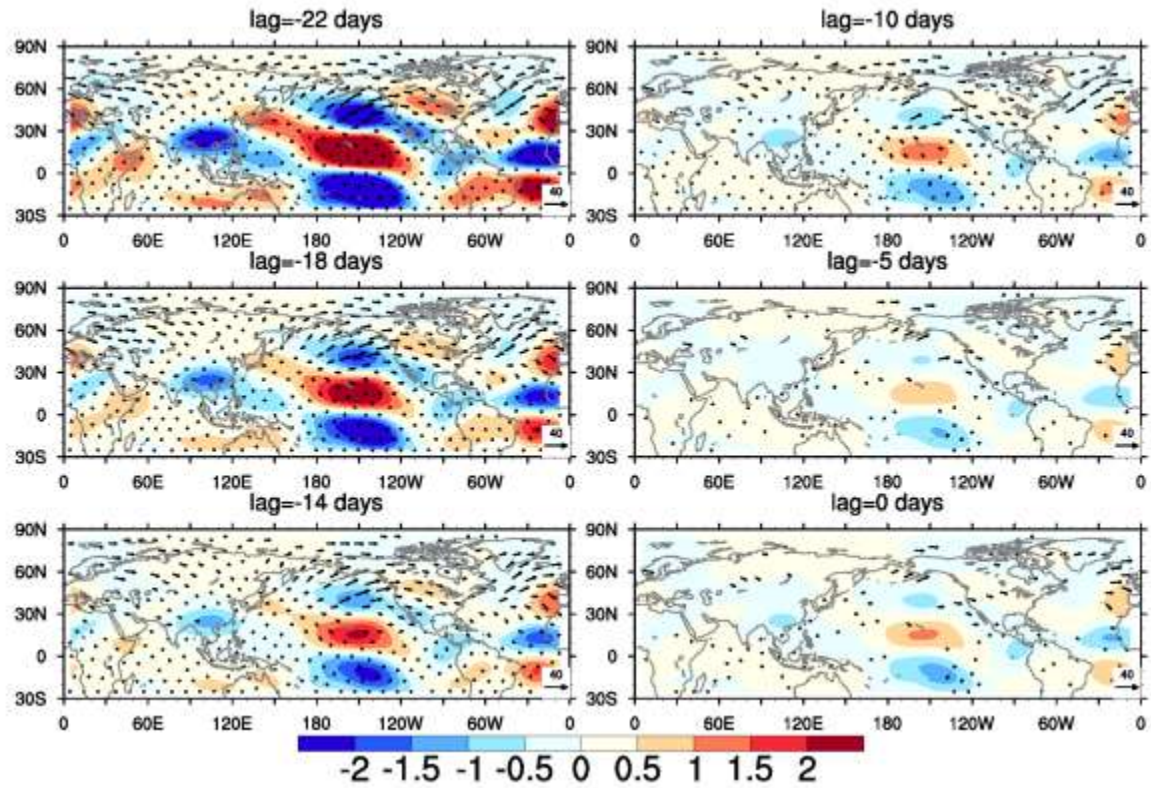


Figure 11: Lagged composite of 300hPa eddy streamfunction anomalies ($m^2 s^{-1}$, shading) and wave activity flux ($m^2 s^{-2}$, vectors) based on the 1st PLS component of OLR for wintertime PNA forecasts. Only composites that are significant at the 1% level are plotted. The streamfunction is scaled by a factor of 10^{-6} . Lag = 0 corresponds to the peak of the basis time series (see text for details), which is also the forecast validation time; lag = -22 days corresponds to the forecast initialization time for weeks 3-4.



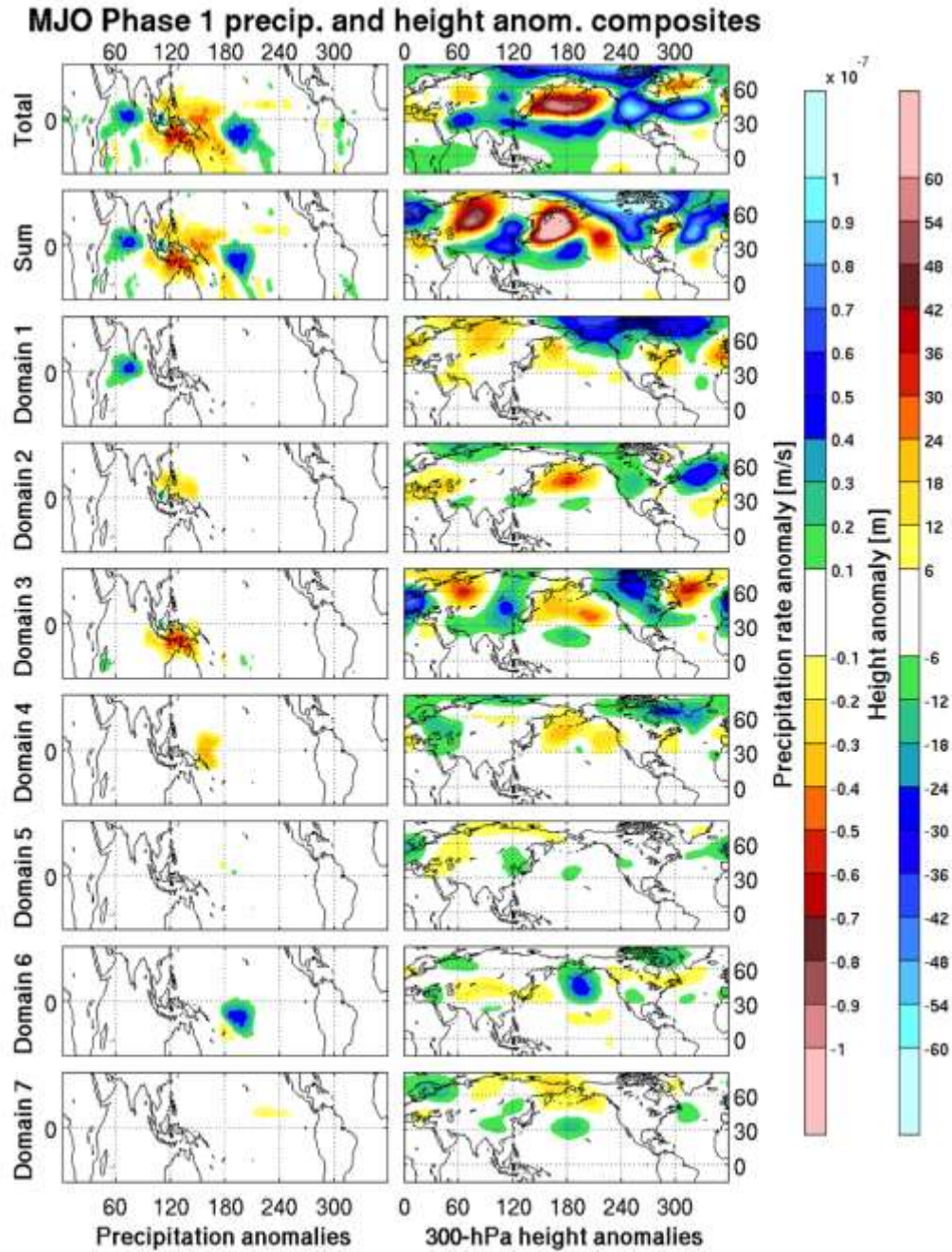


Figure 12: Observed MJO Phase 1 composites based on analog days (left column), and the corresponding day 7-10 300-hPa geopotential height anomaly composites (right column). The first row corresponds to the full convective heating field case. Rows 3-9 correspond to analog days for particular centers of tropical convection. Row 2 corresponds to a sum of rows 3-9.



Western Boundary Current Transport as a Climate Index

Principal Investigator(s):

Nathalie Zilberman, Scripps Institution of Oceanography, UC San Diego

Dean Roemmich, Scripps Institution of Oceanography, UC San Diego

Sarah Gille, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

W. Murray, Climate Program Office

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Goal 3: Serve Society's Needs for Weather and Water Information

Budget Amount:

\$146,663

Amendment(s):

Competed NA14OAR4310219

Description of Research:

Western Boundary Currents (WBCs) play an essential role in the meridional distribution of heat, mass, and freshwater of the global ocean and constitute the primary pathway for basin-scale heat exchange between the tropics and the mid-latitudes. Because of the narrowness and strong mesoscale variability of WBCs, estimation of WBC velocity and transport places heavy demands on any potential sampling scheme. Our purpose is to

develop a new method combining altimetric data with High-resolution expendable bathythermograph (HRX) and Argo profiles and trajectories to improve volume transport estimates in five major WBCs: the East Australian Current (EAC), Kuroshio, Agulhas Current, Gulf Stream, and Brazil Current. The intent of this research is to improve our knowledge of circulation in WBC regions, to increase our understanding of WBC response to wind forcing, and to quantify WBC transport changes in relation to climate variability. The specific objective of this project is to define a new set of ocean climate indicators to track variability in WBC transport. Our project will support NOAA's long-term climate goal through provision of new information on the ocean heat transport and storage, sea surface temperature, and on surface currents in WBC regions.

Objectives and Accomplishments:

High-resolution bathythermograph (HRX) profiles to 800-m have been collected along transects crossing the EAC system at 3-month nominal sampling intervals since 1991. EAC transects, with spatial sampling as fine as 10-15 km, were obtained off Brisbane (27°S) and Sydney (34°S), and crossing the related East Auckland Current north of Auckland. We merged HRX profiles collected from 2004 to 2014 off Brisbane with Argo float profiles and 1000 m trajectory-based velocities to expand HRX shear estimates to 2000-m and to estimate absolute geostrophic velocity and transport. The Argo trajectory gridded products currently available end in 2009 (ANDRO) or have a horizontal resolution too coarse to resolve the flow field in space and time along the narrow path of the EAC (G-YoMaHa). For consistency with Argo and HRX profiles used here, and to better capture the signature of the EAC, trajectory-derived velocities were computed using raw trajectory data from all floats available in our study



region from 2004 to 2014. To preserve the sharp velocity gradients associated with the along-coast flow and flow reversal in the EAC region, trajectory-based velocities were sorted

into $1/6^\circ$ latitude \times $1/2^\circ$ longitude bins aligned with the 1000-m isobath. A method was developed for combining altimetric sea surface height from the Archiving, Validation, and Interpretation of Satellite Oceanographic (AVISO) data with HRX and Argo profiles to mitigate temporal aliasing by the HRX transects and to reduce sampling errors in the HRX/Argo datasets.

Our research efforts were focused on interannual variability of the EAC transport, between the sea surface and upper limit of the northward flowing EAC undercurrent (1350 m). Geostrophic transport anomalies in the EAC at 27°S show variability at interannual times scales related to El Niño-Southern Oscillation (ENSO). The ENSO signature seen in EAC transport anomalies is linked to wind-stress curl strengthening in the western Pacific during El Niño events, and wind-stress curl weakening during La Niña.

We shared early results on the EAC through oral presentation at the GO- SHIP/Argo/IOCCP conference in Galway, Ireland, September 2015, and poster presentations at the COD Community Workshop in College Park, MD, June 2015, and at the Ocean Sciences Meeting New Orleans, LA, February 2016.

Honors and Awards

- a. John Doe won the 2015 Hot Dog Eating Contest

Conferences, Meetings & Presentations

- a. International Meeting of Meetings, July 32, 1963, San Diego, CA

Education & Outreach

Academic Development

- a. N. Zilberman and D. Roemmich advised Rachel Flaherman, an undergraduate research student intern at Scripps Institution of Oceanography, who is a physics- major at Swarthmore College. Rachel studied mass conservation in the EAC region (June-August 2015)
- b. S. Gille spoke to UC San Diego first-year honors students about observing climate change in the ocean at the Revelle College Freshman Honors Seminar (December 2015).
- c. S. Gille shared the demonstration SOLO float, the Argo program, and physical oceanography in general with UC San Diego undergraduates on Revelle College Monday (May 2016).

K-12 Outreach

- a. N. Zilberman gave a lecture on Argo floats and climate change to 12th grade classes at Grossmont High School in El Cajon, California (September 2015)
- b. S. Gille and other participants in Argo-related projects shared a demonstration version of a SOLO float and the basics of the Argo program with UC San Diego prospective students and their families on Triton Day and Triton Transfer Day. Triton Day and Triton Transfer day together attract about 25,000 people to campus (April and May 2016).



Modernizing the tropical ocean/atmosphere observing system

Principal Investigator(s):

Dean Roemmich, Scripps Institution of Oceanography, UC San Diego

Daniel Rudnick, Scripps Institution of Oceanography, UC San Diego

Bruce Cornuelle, Scripps Institution of Oceanography, UC San Diego

John Gilson, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

David Legler, Climate Observation Division

NOAA Task:

Task 3 - Individual Science Projects

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Goal 3: Serve Society's Needs for Weather and Water Information

Budget Amount:

\$1,627,790

Amendment(s):

Competed NA13OAR4830216 & NA14OAR4830302

Keywords:

Temperature, Salinity, Steric Sea Level, Ocean Circulation, Climatology, Air-Sea Interaction

Research Objectives:

The project is composed of three distinct but coordinated elements. The overall goal is to demonstrate the scientific potential and cost-effectiveness of modern autonomous

instrumentation (floats and underwater gliders) for modernizing the Tropical Pacific Observing System, and the value of Ocean Data Assimilation Modeling in synthesizing these observations. Objectives and plans for each element are:

Enhanced coverage of Argo profiling floats.

The objective is to provide enhanced spatial resolution of Pacific equatorial variability in relation to El Nino/Southern Oscillation evolution, using Argo profiling floats (Temperature/Salinity/Pressure, 0-2000 m). Production and deployment of 41 SIO SOLO-II Argo floats along the equator between 100°W and 160°E doubled the Argo coverage along the equatorial waveguide.

Underwater glider missions in the eastern equatorial Pacific.

The objective is to make repeated sections with Spray underwater gliders along 95°W between 2°N and 2°S. The glider operations are based in the Galapagos and done in collaboration with INOCAR, the oceanographic institution of the Ecuadoran Navy. The gliders are equipped with sensors to measure pressure, temperature, salinity, and chlorophyll fluorescence, and they calculate a depth-average velocity by dead reckoning.

System evaluation using high resolution ocean state estimation.

The goal of this work is improved estimation of the physical state of the tropical Pacific for resolving intra-seasonal to interannual variability and possibly enabling predictions of ENSO and other air-sea interactions. The benefits of the capabilities enabled by the new observation systems (Argo, gliders, and satellites) are being explored. The synthesis of these observations will be compared to the information available from moorings, which



provide high temporal sampling, but only at a limited number of locations and depths.

Accomplishments:

Enhanced coverage of Argo profiling floats.

The 41 SIO SOLO-II Argo floats were produced and were deployed along the equator between 100°W (23 January, 2014) and 160°E (26 March, 2014). Each float returns a temperature/salinity/pressure profile from the sea surface to 2000 m depth every 7 days and each has completed about 110 cycles since deployment. These floats are providing unprecedented coverage of the equatorial Pacific, including intrapersonal wind-driven Kelvin waves that contributed to the onset of the 2015 El Niño precursor. NOAA models assimilate these data in seasonal prediction (El Niño). All Argo data are publicly available in near real-time via <http://www.argo.net>

Underwater glider missions in the eastern equatorial Pacific.

Two new SIO Spray gliders were constructed, and along with other gliders in the SIO glider pool will support the present mission. Gliders have been deployed in April 2014, August 2014, February, 2015, September 2015, and December 2015. During the 5 missions completed so far, gliders have completed 2212 dives in 550 days, covering 10,433 km over ground and 10,769 km through water. The glider transects along 95°W are coordinated with a separate NSF-funded project obtaining glider transects along 93°W, with a grand total of 2100 glider-days, 37,000 km track length, and 9500 profiles. Data show the sequence of events during this unusual past two years at the equator, including the arrival of a series of Kelvin waves. With profiles separated by about 6 km, our data set includes the most highly resolved sustained, repeated sections ever done across the equator.

System evaluation using high resolution ocean state estimation. The state estimation continues with the 1/3 degree resolution MITgcm model grid spanning the entire

tropical Pacific Ocean and using all observation systems now available: Argo, CTDs, XBTs, gliders, and satellite SST and SSH. The state has been completed from 2010 through 2014 using 4-month assimilation windows with 2 month overlap. The estimates continuing into 2015, and a paper describing the results through 2014 is in preparation.

Highlights:

38 out of the 41 equatorial Argo floats deployed by this project remain active, having completed 110 cycles each between the sea surface and 2000 m since deployment in early 2014.

Repeated Spray glider transects of temperature, salinity, pressure, and chlorophyll fluorescence along 95°W from 2°S to 2°N were obtained for the past two years, including over 2200 dive cycles..

Improved estimates of the spatial statistics of variability in the tropical Pacific, by F. Gasparin based on Argo data, have allowed more accurate mapping of tropical Pacific Ocean variability than was previously possible.

The overlapping 4-month ocean state estimates have been completed from 2010 through 2014, and are continuing into 2015.

Major eastward propagating events (Equatorial Kelvin waves) in the equatorial thermocline (8°C temperature anomalies) were observed in float and glider data throughout 2015.

Milestones:

- 38 active Argo profiling floats have each provided 110 cycles, 0 – 2000 m.
- 24 overlapping 4-month state estimates have been completed and checked.
- 550 days of glider data, including 2200 dives.



Conferences, Meetings & Presentations

- a. Ocean Sciences, February 22-26, 2016
with Daniel Rudnick

Education & Outreach

Communications

- a. Argo Science Team Website, <http://www.argo.ucsd.edu>, with international Argo partnerships to provide information on the Argo project, it's objectives, status and data system, including how to access Argo data.
- b. SIO Argo Website, <http://sio-argo.ucsd.edu>, to provide information on the status and location of SIO Argo floats.
- c. Spray Glider Website, <http://spray.ucsd.edu>, to provide real time status and plots of glider data.
- d. Spray Public Data Access, <http://coastwatch.pfeg.noaa.gov/erddap2/taledap/scrippsGlidern.html>, to provide public access to Spray glider data.



A Nudging and Ensemble Forecasting Approach to Identify and Correct Tropical Pacific Bias-Producing Processes in CESM

Principal Investigator(s):

Dr. Arthur J. Miller, Scripps Institution of Oceanography, UC San Diego

Dr. Aneesh Subramanian, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Mr. Jonathan Eliashiv, Scripps Institution of Oceanography, UC San Diego, Ph.D. student

Dr. Alicia Karspeck, National Center for Atmospheric Research

Dr. Gokhan Danabasoglu, National Center for Atmospheric Research

NOAA Primary Contact:

Sandy Lucas, Climate Program Office

NOAA Task:

Task 3 - Individual Science Projects

NOAA Theme:

Theme A: Climate and Coastal Observations, Analysis and Prediction Research

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Goal 3: Serve Society's Needs for Weather and Water Information

Budget Amount:

\$499,080

Amendment(s):

Competed NA14OAR4310276

Description of Research:

We are now analyzing a 30 member ensemble integration of a CESM model (active ocean, atm, land, ice) with CAM5 prognostic aerosols. In situ ocean data from WOD09 is assimilated daily and NCEP radiosonde temp, winds are

assimilated at 6 hourly intervals in the atmospheric model. Currently the run is from 1970 to 1980 and still going. No data is assimilated in land or ice. The DART data assimilation software is used. DART is an Ensemble Adjustment Kalman Filter with adaptive inflation in ocean/atm. There are no cross-model-component covariance, but data assimilated in one component of the model can pass on information to the other coupled components every time they are coupled. The atmospheric data are assimilated every 6 hourly and the forecasts represent only 6 hours of atmospheric error growth. In the ocean the Priors are 1 day forecasts, so the increments will represent 1 day of error growth in the ocean (but the atmosphere, which forces the surface fluxes has been constrained at 6 hourly intervals).

We have analyzed the mean state and the variability in this data assimilated CESM run, in collaboration with Dr. Alicia Karspeck and Dr. Gokhan Danabasoglu at NCAR. The model runs for assimilation were performed by Dr. Alicia Karspeck.

Results from the analysis of model runs show that the data assimilated simulation has a good representation of intraseasonal variability in the Tropics and also a comparable amount of energy in convectively coupled tropical waves as to other reanalysis such as ECMWF. CESM-DART simulations show similar variability frequency-wavenumber space in both equatorial Kelvin waves and the MJO for the zonal winds. Overall CESM-DART has enhanced tropical variability compared to NCEP 20th century reanalysis and suppressed 850 mb wind variability in the Tropics as compared to ERA20C Reanalysis winds. We are currently



analyzing the data assimilated tendencies and the ensemble reliability budget for these model simulations to identify robust analysis errors that will inform on the model error terms and ways to reduce the model errors

Objectives:

Current short-term tropical climate forecasts (e.g., of the Madden Julian Oscillation (MJO) and of El Niño/Southern Oscillation (ENSO) events) experience both a systematic error (climate drift) that results in sustained biases of the model tropical climatology and an error in representing the space-time scales of the transients (e.g., phase speed errors, etc.). Our objective is to identify the physical mechanisms that lead to the seasonal biases in the tropical Pacific by isolating the parameters and parameterizations that influence the development of biases in short-term climate forecasts. Our overarching scientific objective is to *identify, explain, and correct the climate biases in the Pacific ocean that occur in the Community Earth System Model (CESM)*. We are currently analyzing the output from a coupled data assimilated CESM-DART model to study the analysis tendencies obtained from data assimilation. These tendencies will inform us regarding the biases in the model that are corrected for by the data assimilation method.

We have progressed in our study of the evaluation of the coupled data assimilated CESM-DART runs for their tropical variability representation and the spatiotemporal structures of bias and variability error development in **CESM forecasts**. We use a recently developed approach to compute a reliability budget in an ensemble data assimilation system to identify model bias, ensemble variability and model error terms. We will seek to ascribe these identified error to well-known physical processes for the specific climate modes of variability. We will test the sensitivity of the bias development to changes in coupled model configuration. We

will use model state variables from the data assimilated CESM model to initialize forecast experiments to further identify robust biases and physical parameterizations that are likely to be responsible for these biases. We will then pursue methods to propose improved parameterization or model error representation in CESM based on our result.

Accomplishments & Milestones:

- First global climate model with couple data assimilation being analyzed for model biases
- Identified the CESM model mean bias in the Western Pacific region using the reliability budget for ensemble data assimilation system
- Identified ENSO and MJO events in the coupled data-assimilation CESM runs
- Completing a manuscript for submission on the evaluation of the Tropical variability in the assimilated model compared to other reanalysis products.
- Mentored Climate Sciences Ph.D. student Jonathan Eliashiv (SIO) to participate in this research

Conferences, Meetings & Presentations

- a. CESM 2016 Annual meeting, 20-23 June 2016 in Breckenridge, Colorado with Jonathan Eliashiv
- b. Extreme Pacific Anomalies (Blob) Workshop, 4-5 May, 2015 at SIO in La Jolla with Art Miller
- c. Pacific Anomalies (Blob-2) Workshop 2, 20-21 January, 2016 in Seattle with Art Miller, Aneesh Subramanian
- d. U.S. CLIVAR Summit Meeting, 4-6 August, 2015 in Tucson with Art Miller as the POS Panel Co-chair and Aneesh Subramanian on the PSMIP Panel



Education & Outreach

Communications

- a. Numerous interviews with TV, radio, and newspapers about the Extreme Pacific Anomalies and El Nino (Art Miller)
- b. Participant, Exploring Ocean STEM Careers Night, Birch Aquarium at Scripps (Art Miller)
- c. Member, Stay Cool for Grandkids, grass roots climate action group in San Diego (Art Miller)

- d. Home page:
<http://meteora.ucsd.edu/~miller/>

Academic Development

- a. Graduate Student Jonathan Eliashiv attended CESM 2016 Annual meeting

K-12 Outreach

- a. Interviewed and filmed by middle school students about Climate Change
- b. Participant, Exploring Ocean STEM Careers Night (High school students), Birch Aquarium at Scripps (Art Miller)



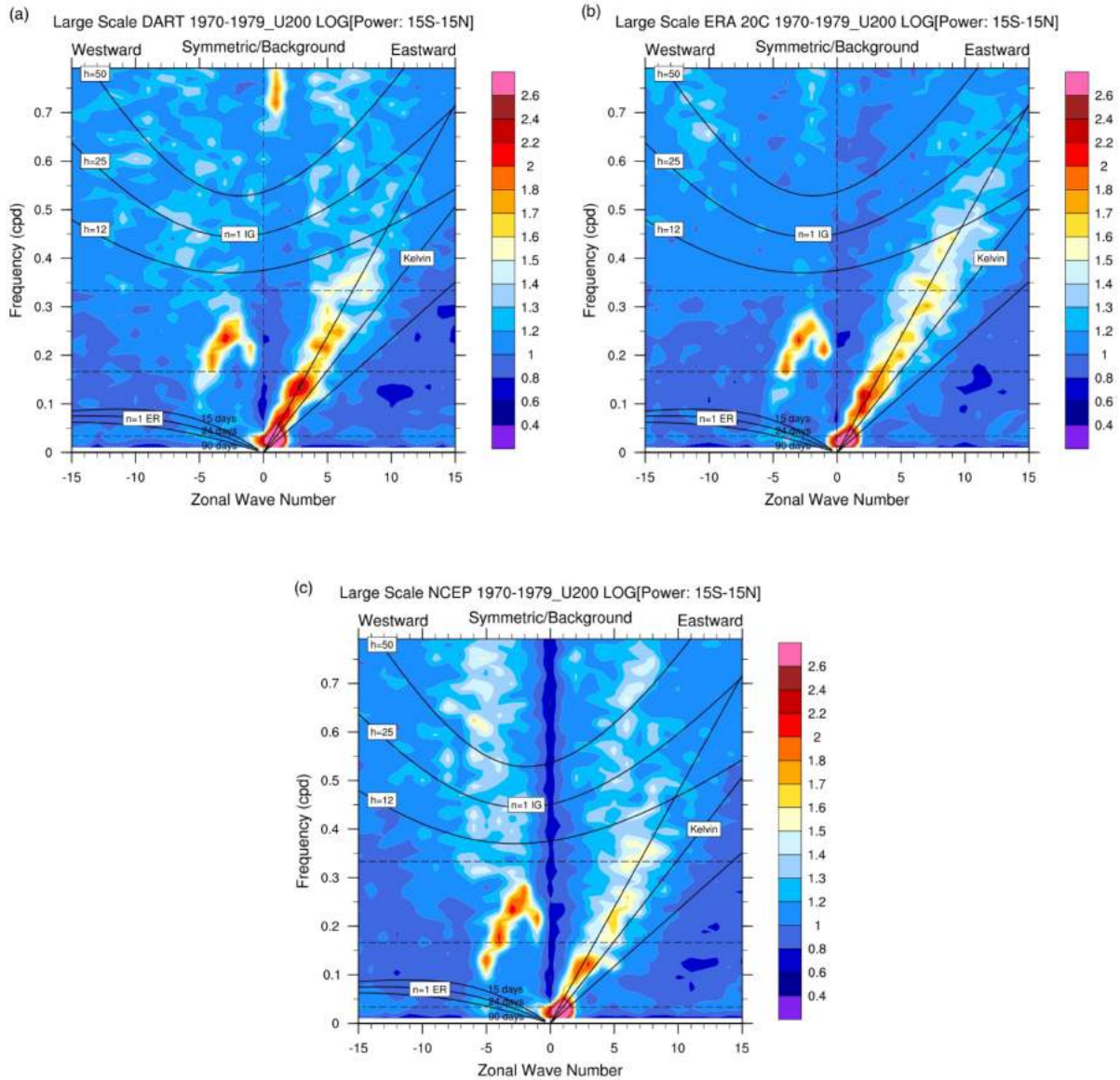


Figure 1: Wavenumber-frequency spectra of the upper tropospheric (200 hPa) zonal wind speeds for (a) CESM-DART, (b) ERA20C and (c) NCEP 20th century reanalysis. The energy in the Kelvin wave bands are weaker in NCEP reanalysis compared with that of ECMWF or CESM-DART products.



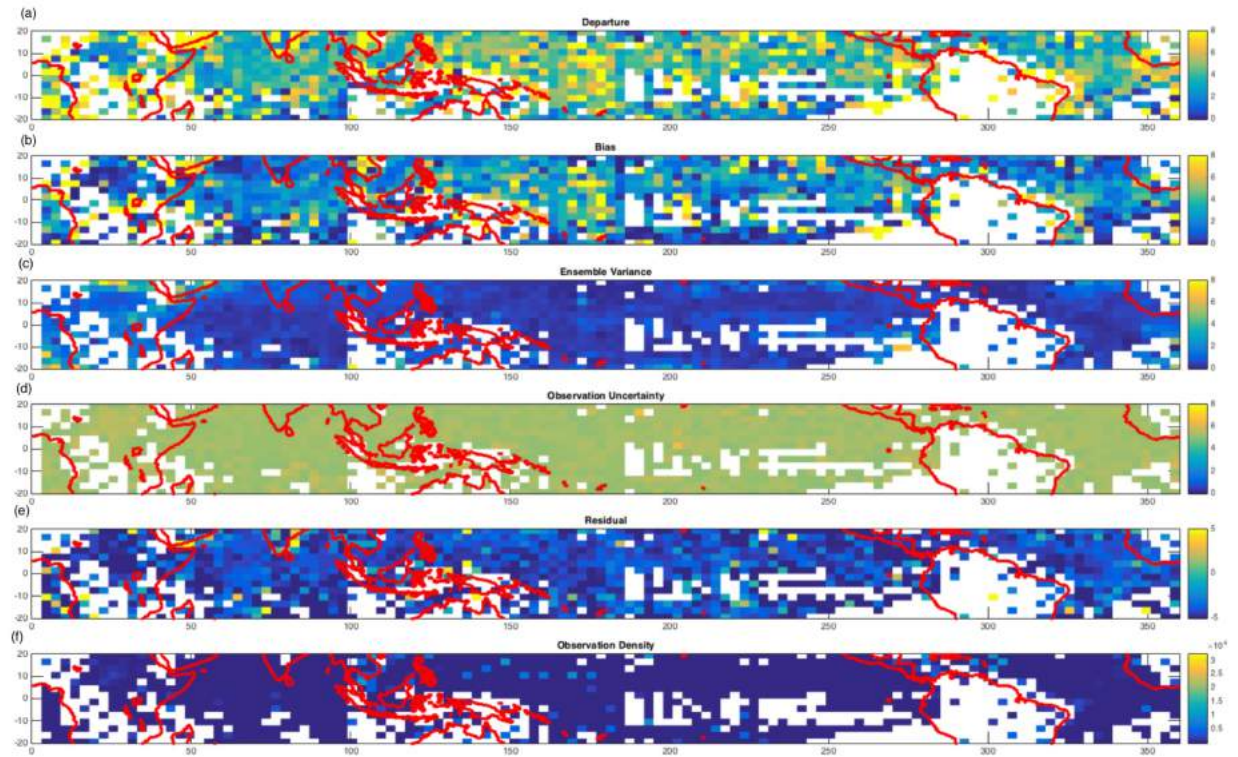


Figure 2: The estimated reliability budget for the upper tropospheric winds in the Tropics, where the winds is a 6-hour field, based on the CESM-DART data assimilated 6-hr background forecasts for the period Jan 1971 – Dec 1980 (a) Mean-squared departure of the ensemble-mean relative to the observation. (b) Squared bias of the ensemble-mean relative to the observation. (c) Mean ensemble variance. (d) Mean of the squared perturbations applied to the observations within the ensemble DA framework. (e) The Residual term (e) The mean number of observations assimilated within each 2° grid box over the 6-hr data assimilation window. Observations are a combination of aircraft, in-situ and satellite measurements from the National Centers for Environmental Prediction (NCEP) repository.



Theme B: Climate Research and Impacts

The Global Drifter Program

Principal Investigator(s):

Dr. Luca Centurioni, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

C. Clark, Climate Program Office

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Goal 3: Serve Society's Needs for Weather and Water Information

Goal 4: Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation

Budget Amount:

\$10,795,285

Amendment(s):

19, 27, 59, 79, 125

Keywords:

Lagrangian Drifters, Ocean Circulation, SST, Air Pressure, GCOS

Research Objectives:

Provide through the publicly available Global Telecommunication System (GTS) a real time data stream of drifters locations, SST, Sea Level Atmospheric Pressure (SLAP), SSS, sea level wind and subsurface temperature. 2) observe 15m depth ocean currents on a global basis with a nominal 5.0° resolution and, jointly with satellite altimeter data, produce circulation data of the world ocean at

0.5° resolution that can be used to trace pollution laden particles or turbulent dispersion of vorticity and thermal energy due to the tropical eddy field; 3) develop and implement drifter's technological advances in sensors, electronics, power, methods of assembly and deployment packaging. 4) provide enhanced research quality data sets of ocean circulation that include drifter data from individual research programs.

All the research objectives were met or exceeded. All drifters' derived data of location, SST and SLAP were posted on the GTS. GTS compatible data of winds, subsurface temperature (Tz) and SSS were also provided basis when these sensors are mounted on the drifters. In collaboration with AOML we maintained an array in excess 1,250 drifters (average) to measure the circulation of the world ocean. In the past two years, these technological advances have introduced new drifter wind sensors integration, drogue-on sensors (strain gauges), improved air pressure ports and improved drogue construction technology; Gridded, global data sets of SST, near surface circulation and dynamic topography, or absolute sea level, are available on line for assimilation into and use in the verification of ocean models, for numerical weather predictions and for SST and SSS satellite products.

Accomplishments:

Since September 2005 the fully implemented global drifter array has consisted of between 1100-1400 drifters. This required global drifter array size is based on the need to return in-situ observations of SST (+/- 0.10C) over the global ocean at a 5° resolution in order to keep the potential SST satellite bias error smaller than 0.5°C. Surface pressure sensors are also supported NOAA and by national



meteorological agencies based on regional needs. The status of the GDP array is updated weekly can be seen at the AOML website: <http://www.aoml.noaa.gov/phod/dac/index.php>. The present drifter array is 15% bigger than its nominal size and stable compared to last year.

36 salinity drifters were deployed in the Bay of Bengal in support of the ONR experiment ASIRI. The experiment is now concluded and data analysis is in process.

Ongoing targeted drifter deployments are underway in the South China Sea and in the Arabian Sea.

Significant outreach and capacity building efforts were made by the PI at DBCP/WMO/UNESCO meetings (23-29 March 2015 Koror, Palau, South Africa; Fouths Capacity Building Workshop of the WMO/IOC Data Buoy Cooperation Panel (DBCP) for the North Pacific Ocean and Its Marginal Seas (NPOMS-4) - Application of Regional Ocean Observations for Increasing Society's Understanding and Forecasting of Typhoons, 3-6 November 2015, Busan, Korea,).

See list of publications for specific research accomplishments

Highlights:

- GDP array completed with 1,424 drifter in the array at the time of writing
- SIO is now posting drifter data to the GTS
- Significant increase in the number of drifters in the Indian Ocean
- Coordinated GDP Activities Between Partners and Support of other science programs
- Enhanced the GDP Array with Matching Contributions
- Monitored and Advised the Drifter Manufacturers to Ensure Drifter are Built According to Specifications
- Updated and Maintain the Enhanced GDP dataset/GDP data distribution



- Maintained Statistics of Drifter Performances
- Reported GDP activities and research at several meetings and conferences
- Scientific Analysis of GDP data

Milestones:

D1: Procuring the Drifters Needed to Maintain the Global Drifter Array at or above of 1,250 Drifters

Accomplished. For this funding cycle the GDP has proposed to build and deploy a total 139 SVP systems (695 SVP drifters) and 50 SVPB systems (250 SVPB drifters). Most of the drifters were either deployed by the Global Drifter Program or delivered to AOML for deployment. A small number of drifters is still in production and is expected to be delivered shortly. Despite this delay, the goal to maintain the array at the 1,250 drifters nominal size was fully achieved and as of October 27, 2015, there were 1,440 GDP drifters actively reporting to the GTS (Figure 1). This task addresses the program's priorities of delivering continuous instrumental records for global analyses of sea surface temperature and surface currents.

D2: coordinate GDP activities between the following entities: US manufacturers of drifters, AOML, SIO engineers, ONR and NASA for joint observational programs and D3 enhance the GDP array by encouraging principal investigators to purchase SVP drifters for their studies

Accomplished. During the reporting period the GDP has assisted the industrial partners upon request with technical matters. We keep providing AOML with technical assistance on a variety of issues related to decoding and archiving drifter data transmitted through the Iridium satellites. The Global Drifter Program at the Scripps Institution of Oceanography is implementing the transition of the GDP array to Iridium using the DoD gateway and is posting the drifter data in real time to the Global Telecommunication System.

Close coordination with scientific program funded by NASA and ONR and in collaboration with the National Sun Yat Sen University and NARA of Sri Lanka gave resulted in extra drifters deployed in support of the GDP.

(D3) enhance the GDP array by encouraging principal investigators to purchase SVP drifters for their studies and make their data available to the international community on the GTS. In exchange, Centurioni will request AOML to/will send to these PIs drifters purchased with this proposal to enhance their Lagrangian array

Besides the synergy promoted by Dr. Centurioni between the GDP and other programs funded by U.S. federal agencies Dr. Peter Gaube of WHOI has purchased 10 drifters with NASA funds that will be registered under the GDP and the GDP has provided 10 extra drifters as part of the matching program.

(D4) monitor and advise the drifter manufacturers to ensure that the specifications required for the GDP drifters are respected;

Accomplished. A thorough evaluation of DoD Iridium gateway implementation was the focus of this funding cycle. The GDP worked closely with OCO, PMEL Pacific Gyre, DBi and AOML implement the transition.

Drifter inspections are routinely performed by the GDP and if no-complying items are discovered, these are discussed with the manufacturers as needed.

(D5) update and maintain the enhanced GDP dataset, corrected for wind slip and drogue losses;

Accomplished.

(D6) maintain real-time statistics of drifter performances.

Accomplished. Real time statistics are maintained at the gdp.ucsd.edu website and constitute the main tool for the PI to detect early signs of drifters' technical issues.

(D7) test the hurricane drifters stored at the Keesler AFB for sensors and hardware functionality and inspect the deployment packages and parachute riggings to ensure they are ready for deployment;

Accomplished. To travel to Keesler AFB was not deemed necessary this year. 10 minimet drifters were deployed ahead of hurricane Danny.

(D8) report GDP's activities, scientific findings and technology advances in the DBCP "Technical Session";

Accomplished. Dr. Luca Centurioni, Dr. Verena Hormann, Mr. Lance Braasch and Mr. Lance Curtiss traveled to Weihai, China, and attended the DBCP 30 scientific and technical workshop, where they delivered a talk, and the plenary session of the DBCP 30 meeting. A list of presentations can be found at http://www.jcomm.info/index.php?option=com_oa&task=viewEventRecord&eventId=1504.

(D9) continue the scientific analysis of the GDP velocity, salinity and hurricane/typhoon datasets.

Accomplished.

Hormann et al (2015). In this study, we evaluate a subset of 83 drifters, which have provided useful salinity measurements in the central SPURS region from a few weeks to more than one year, and we describe an ad-hoc quality control procedure partially based on previously published work and on our new observations. It was found that the sampling algorithm of the drifters introduces a predominantly fresh bias in the noise level of the salinity data, probably caused by the presence of air bubbles within the measuring cell. Since such noise is hard to eliminate with a statistical method, extensive manual data editing was used instead. Such quality control procedure cannot be routinely applied to the real-time data stream of the drifters and a revision of the sampling algorithm of the salinity drifters is needed. Comparisons of the drifter salinity measurements with independent data sets also indicate that the



sensor can provide reliable observations for up to one year.

Centurioni et al (2015). The salinity data from the drifters were used to validate the divergence of the salt transport computed with satellite products, where the satellite salinity was taken from the standard- non SST corrected Aquarius v3.0 dataset. Our results indicate a good agreement between the two independent methods as well as that the effect of the eddy field combined with the SSS variability at the surface is dominant.

The SSS variability within spatial bins comparable to the Aquarius-beam footprints measured by the drifters can be in excess of 0.1 PSU. This suggests that a careful evaluation of the representation error is required when single-point in situ measurements, such as the one collected from Argo floats, are used to validate the spatially averaged Aquarius salinity data

A review article describing the advances in the study of the global ocean's surface circulation in the past 10 years has been published in Maximenko et al. (2013).

Hormann et al. (2014) investigates, the ocean's response to typhoon Fanapi using an extensive air-deployed drifter array. Separation of the observations into near-inertial and sub-inertial motions quantified the importance of strong advection by the sub-inertial circulation for the evolution of the cold wake formed by Typhoon Fanapi. The near-inertial currents generated during the storm showed the expected rightward bias, with peak magnitudes of up to 0.6 m/s and an e-folding time of about 4 days for the strong currents within the cold wake. The shear of the near-inertial currents is crucial for the storm-induced cooling and deepening of the mixed layer and such instabilities were here directly observed across the base of the mixed layer in Typhoon Fanapi's cold wake. During the recovery, the diurnal cycle—a

dominant process for the wake warming—was found to be noticeably reduced when the near-inertial motions were strongest.

Poulain and Centurioni (2015). Velocities of surface drifters are analyzed to study tidal currents throughout the World Ocean. The global drifter dataset spanning the period 1979-2013 is used to describe the geographical structure of the surface tidal currents at global scale with a resolution of 2 degrees. Harmonic analysis is performed with 2 semi-diurnal (M2 and S2) and 2 diurnal (K1 and O1) tidal constituents. For the first time, tidal current characteristics (amplitude of semi-major axis, rotary coefficient, tidal ellipse inclination and Greenwich phase) are mapped over the World Ocean. The M2 currents dominate on all the shallow continental shelves with a maximum of 75 cm/s. They are also substantial (4-5 cm/s) over the main deep topographic features such as the Mid-Atlantic Ridge and Southwest Indian Ridge. The S2 currents have amplitudes typically half the size of the M2 currents, with a maximum of 28 cm/s. The K1 and O1 currents are important in many shallow seas with maximal amplitudes of about 30 cm/s. They are large in the vicinity of the turning latitudes near 30°N/S where they correspond to inertial motions. Maps of rotary coefficients indicate that all tidal motions are essentially anticyclonic, that is clockwise (anticlockwise) in the northern (southern) hemisphere. The rotary coefficient and tidal ellipse inclination of the diurnal tidal currents agree well with the theory of freely and meridionally propagating baroclinic inertia-gravity waves. The Greenwich phase of the M2 constituent has large scale coherent propagation patterns which could be interpreted as the propagation of the barotropic tide.

(D10) R&D activities.

The investigation to assess the causes of shortened drogues lifetimes was launched. The investigation is underway and new



drogue bridles and tether are being tested to identify better drogue construction techniques.

Conferences, Meetings & Presentations

- a. 9th COD Community Workshop, NOAA Center for Weather and Climate Prediction, 15-17 June 2015 in College Park, MD with Dr. Luca Centurioni

Education & Outreach

Communications

- a. Interview with Michael Casey, CBS news, 7/31/2015, MH370 mystery: Could a plane wing drift thousands of miles?
<http://www.cbsnews.com/news/mh370-mystery-plane-wing-drift-thousands-of-miles/>

- b. Interview with Elizabeth Goldbaum of livescience.com. 7/31/2015. Malaysian Airlines Mystery: What Newfound Wing Debris Could Reveal.
<http://www.livescience.com/51741-malaysian-plane-found-wing-ocean.html>
- c. Scientific American. Malaysian Airlines Mystery: Newfound Wing Debris Is from MH370.
<http://www.scientificamerican.com/article/malaysian-airlines-mystery-newfound-wing-debris-is-from-mh370/>
- d. Interview with Maria Egizia Fiaschetti, Corriere della Sera (principal Italian Newspaper), 8/30/2015. Seminare boe nell'oceano porta frutti (in Italian)

Networking

- a. DBCP (see capacity building meetings)



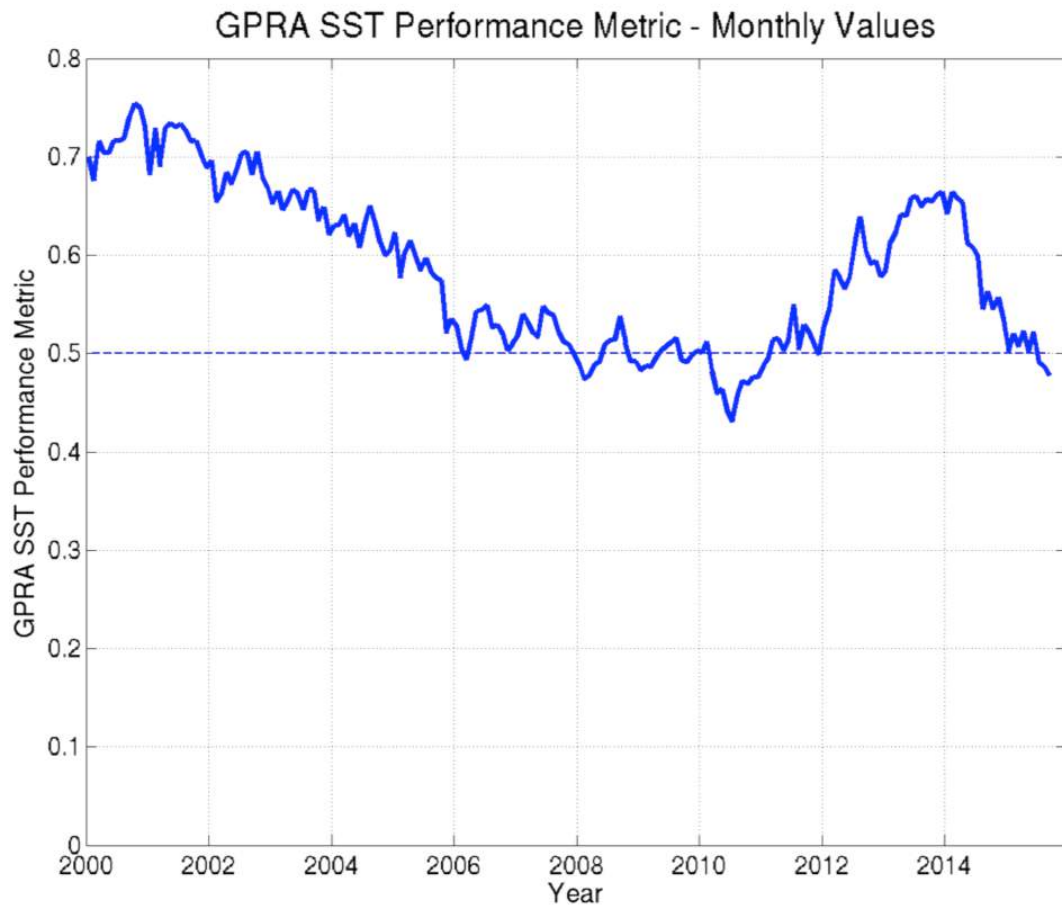


Figure 13: Quarterly SST GPRA Performance Measure and Buoy Need Map by Dr. Huai-min Zhang , NOAA



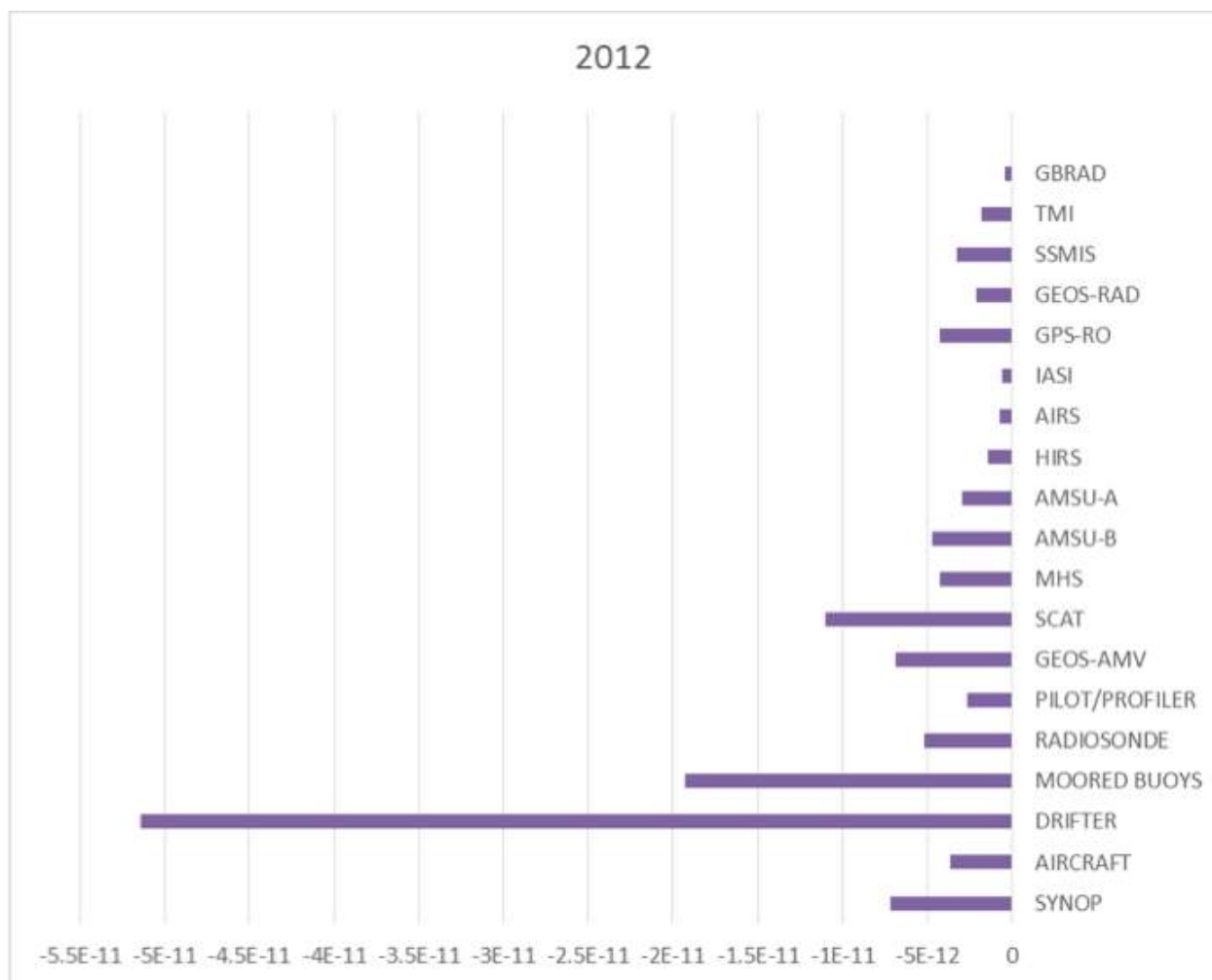


Figure 14: ECMWF operational mean FSOI (i.e. positive impact of the observations on the forecast) for the different observing systems for July-August, 2012. The FSOI values are also normalized by the total forecast error for comparison reason. The observing systems displayed are SYNOP surface observations (surface pressure, moisture and wind), aircraft measurements (wind and temperature), drifters and moored buoys (surface pressure and wind from drifters and moored buoys), radiosondes (wind, temperature, and moisture), pilot/profiler (wind), geostationary atmospheric motion vectors (wind), scatterometer (surface wind), microwave sounder radiances (MHS, AMSU-B and AMSU-A), infrared sounder radiances (HIRS, AIRS and IASI), satellite radio occultation (GPS-RO), geostationary satellite radiances (GEOS-RAD), microwave imager (SSMIS, TMI, AMSR-E), multi-spectral radiometer (MERIS) and radar precipitation (GBRAD). Source: Centurioni et al. BAMS, accepted



Support to Augment an Integrated Study of the San Juan Basin Methane Emissions using Airborne Measurements

Principal Investigator(s):

Ian Faloona, Land, Air, & Water Resources, UC Davis

Other Key Personnel:

Stephen Conley, Land, Air, & Water Resources, UC Davis

Stefan Schwietzke, NOAA Postdoc

Colm Sweeney, NOAA Global Monitoring Division, CIRES CU Boulder

NOAA Primary Contact:

Russ Schnell, NOAA Global Monitoring Division

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Budget Amount:

\$59,000

Amendment(s):

141

Description of Research:

This project was an airborne addendum to a larger proposal entitled, "For Support to Augment An Integrated Study of the San Juan Basin Methane Emissions with an Instrumented Light Aircraft and a Ground-Based Wind Profiling Lidar". The objective was to supplement the multi-agency effort to quantify the emissions of methane, a

c.

powerful greenhouse gas with a large extant uncertainty in overall emissions, from the natural gas collection operations of the San Juan Basin. During April 2015 nearly 80 hours of flight data (wind, methane, ethane, carbon dioxide, water vapor, and temperature) were collected among the oil and gas fields of the Four-Corners region of NW New Mexico/SW Colorado. Approximately 35 point source measurements were made directly of emissions from various locations in the field, as well as long-field surveys. The data has been submitted to the project data archive and is being used by several investigators to understand and quantify the natural gas emissions in the region.

Objectives:

To help "understand climate variability and change to enhance society's ability to plan and respond" by helping to quantify one of the largest sources of methane in the US, which appears to have been largely unaccounted in our official inventories.

Accomplishments & Milestones:

We have analyzed and quality assured the airborne data for point source emission estimates, and submitted the data to the lead scientists. The bulk of our results were presented at a SONGNEX project science meeting in Boulder, October, 2015.

Conferences, Meetings & Presentations

- Thompson Lecture, 8 December 2015, NCAR FL2, with NCAR & NOAA
- SONGNEX Science Meeting, 19 October 2015, NOAA, with NOAA & other agencies





Figure 15: The Mooney & Twin Otter Aircraft with science team and crew on the San Juan Basin Intensive



Measurements of Atmospheric O₂/N₂, Ar/N₂ and CO₂ Abundances in Relation to Carbon Cycling, Ocean Biochemistry, and Global Change

Principal Investigator(s):

Ralph Keeling, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

K. Mooney, Climate Program Office

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Budget Amount:

\$1,683,062

Amendment(s):

16, 40, 71, 124

Description of Research:

This project continues time series of O₂/N₂ and Ar/N₂ ratios at ten background air stations by the Scripps O₂ program. The O₂/N₂ measurements are critical for determining the evolving land and ocean carbon sinks that underpin studies of the global carbon cycle. The Ar/N₂ measurements provide critical insights into changing ocean heat content and its coupling with air-sea O₂ and CO₂ exchange. The program has strong synergies with measurements of CO₂ concentration and CO₂ isotopes by the NOAA-GMD program and the Scripps CO₂ program (also directed under the PI).

Objectives:

The primary funded activity involves measurements of atmospheric composition

from flasks collected at an array of ten stations extending from the Arctic to the Antarctic along a (mostly) Pacific transect. Flasks are analyzed at the Scripps Institution of Oceanography through a combination of interferometric, mass spectrometric, and infrared detection methods. Measurements are also made of air sampled continuously at La Jolla. These flask and continuous measurements are calibrated using an extensive suite of reference gases maintained by the Scripps O₂ program since the mid 1980s. The funded activities further include data reduction and data dissemination activities, including maintaining a dedicated website, ScrippsO2.ucsd.edu. The work also supports continued efforts to improve methods and address the merging of measurements from the Scripps O₂ program with data from other programs, and it supports international intercomparison and intercalibration activities involving O₂/N₂ measurements, as endorsed by the World Meteorological Organization.

Accomplishments & Milestones:

An important accomplishment has been maintaining continuity in the time series based on flask sampling at the ten stations. Data from this program have been disseminated on the website: ScrippsO2.ucsd.edu. The data continue to document clearly resolved seasonal cycles and long-term trends on O₂ and CO₂. The trend data can be used to quantify global land and ocean carbon sinks. Data for Ar/N₂ show a well-resolved seasonal cycle and a small increase overtime which is still too small to be well quantified.

The data from this program have been increasingly used by collaborators for



improving understanding of ocean and land biogeochemistry and carbon cycling. In the past year, studies have been published that used the seasonal cycles in atmospheric oxygen as a test ocean biogeochemical models, particularly their depiction of biological production and ventilation rates. The O₂ data are especially valuable because they provide a well observed large-scale constraint.

Conferences, Meetings & Presentations

- a. ORCAS Planning Meeting, 18-20 August 2015 in Boulder, CO, represented by Keeling and Morgan
- b. GGMT Meeting, 13-17 September 2015 in La Jolla, CA represented by Keeling, Morgan and Resplandy
- c. APO Workshop, 18-20 September 2015 in La Jolla, CA represented by Keeling, Morgan, and Resplandy
- d. Summit on Pathways to Carbon and Climate Neutrality, 26-27 October 2015 in La Jolla, CA represented by Keeling
- e. Network for Detection of Atmospheric Composition Change (NCACC), 15 October 2015 in La Jolla, CA represented by Keeling
- f. Artic Observing Open Science Meeting, 17-19 November 2015 represented by Keeling
- g. Fall AGU Meeting, 14-17 December 2015, represented by Keeling

Education & Outreach

Communications

- a. Lectures by R. Keeling:
 - i. 30 April 2015: Falkoner lecture at U. Albany (Public outreach): "Atmospheric signatures of changing biogeochemistry"
 - ii. 1 May 2015: Research Seminar at U. Albany: "High precision measurements of the composition

of air in a time of rapid climate change

- iii. 6 June 2015: Scripps Day CO₂ group reunion party. Hosting and presenting at symposium: Rising Carbon dioxide, falling oxygen, and other stories from the Scripps CO₂ program.
- iv. 1 Nov 2015: Fireside chat at home of Keith and Lynne Valentine in Del Mar for supporters of Del Mar Sandpiper newspaper: "Thoughts on CO₂ and climate change"
- b. Project Website provides a data portal with an overview of the project <http://scrippsO2.ucsd.edu>

Academic Development

- a. Undergraduate research assistance training: Edward Matios, assisted part-time in the lab from 2014-2016
- b. Graduate student experience: Although not directly funded by this project, graduate students Yassir Eddebbbar, and Mariela Brooks benefited by access to the group resources, including data and expertise.
- c. Postdoc experience: Although not directly funded by this project, postdoc Laure Resplandy benefited by access to the group resources, including data and expertise.
- d. Classroom Teaching: Results from this project help support classroom teaching of R. Keeling in two courses: SIO117: Physical Basis of Global warming, aimed at upper division physical science majors and SIO267: Biogeochemistry, aimed at first year graduate students in marine chemistry and climate.

Networking

- a. The Scripps O₂ (and CO₂) group hosted the 2015 international meeting on Carbon Dioxide, Other Greenhouse Gases, and Related Measurement Techniques (GGMT) meeting 13-17 Sept 2015, La Jolla. This



international meeting is convened very two years, brings together experts from around the world engaged in measuring greenhouse gases and related species, including O_2/N_2 and Ar/N_2 . The 2015 meeting had ~ 150 attendees, and was held at the Seaside Forum at Scripps.

- b. The Scripps O_2 also hosted a workshop on Atmospheric Potential Oxygen to discuss applications and measurement challenges, also at Scripps from 18-20 Sept 2015. This workshop had ~25 attendees.



Moored carbon, biogeochemical, and ecosystem observations in the Southern California Current

Principal Investigator(s):

Uwe Send, Scripps Institution of Oceanography

Mark Ohman, Scripps Institution of Oceanography

NOAA Primary Contact:

Diane Stanitski, Climate Program Office

Libby Jewett, Ocean Acidification Program

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Budget Amount:

\$1,629,792

Amendment(s):

36, 67, 98, 116

Keywords:

California Current, Ecosystems, Ocean Acidification, Ocean Carbon, Time Series, Observing Systems

Research Objectives:

The California Current is a region of large ecological significance and known sensitivity to climate forcing. Climate processes, complex physical systems, carbon and nutrient chemistry, and ecosystem dynamics all interact to create a rich, societally important, and scientifically fascinating ocean environment off the west coast of the US. This project establishes a unique highly multidisciplinary mooring presence in the

southern California Current, to complement the flow and transport monitoring system that has been initiated under CORC, and to start building a comprehensive continuous real-time monitoring system for this region.

Two moorings, called CCE(California Current Ecosystems)-1 and -2 are located in the core of the California Current and in the upwelling regime on the continental slope, respectively, along CalCOFI line 80, and measure

- **atmospheric conditions** ($x(\text{CO}_2)$, wind, temperature, humidity, precipitation, irradiance),
- **surface ocean conditions** (temperature, salinity, $p(\text{CO}_2)$, O_2 , pH, currents, point and integrated measures of phytoplankton chlorophyll content over the euphotic zone, and nitrate supply), and mixed-layer depth,
- **multi-frequency active-acoustic observations** of zooplankton and fish biomass over the upper 300m.

The data will be telemetered in real-time and made available via websites to other researchers and agencies. The moorings observe physical climate changes in the CCE, contribute unique timeseries for the US ocean acidification and carbon observing programs, and add a time dimension to regular ship surveys under CalCOFI, CCE-LTER, and fisheries stock assessment programs.

Accomplishments:

The field work consisted of recovery and redeployment of two nearly identical moorings CCE1 and CCE2 along CalCOFI line 80 in spring and fall 2015, in the offshore and the upwelling regimes off Pt. Conception. This extends our multi-disciplinary data set to 7 years and 6 years at CCE1 and CCE2,



respectively, starting to allow an analysis of anomalies and departures from typical annual evolutions in the quantities observed.

A major focus of the analyses was the 2014/15 Pacific warm anomaly. The CCE moorings provided a unique view into both the physical and biogeochemical changes that happened during this period. The observations of currents at CCE2 suggest, consistent with some wind products, that the upwelling circulation was not weakened in 2014, but that maybe instead warmer water than usual was brought to the surface by the upwelling, see figure 1. This may be related to anomalous along-shore advection in the preceding year which was also observed at that mooring. The moorings further provided a rare view into the changes and their timing of oxygen, chlorophyll, pH, and nitrate nutrients, an example is shown in figure 2. These observations are the topic on ongoing analyses.

Data from both CCE moorings are being displayed in real-time on the website <http://mooring.ucsd.edu/CCE>.

Highlights:

- Recovery and re-deployment of two equivalent highly instrumented real-time

moorings across the California Current ecosystem with physical, chemical, carbon, and ecosystem sensors

- Quantification of upwelling circulation during the 2014/15 warm anomaly
- Confirmation of anomalous poleward advection
- Impacts of the warm anomaly on biogeochemistry and ecosystem

Conferences, Meetings & Presentations

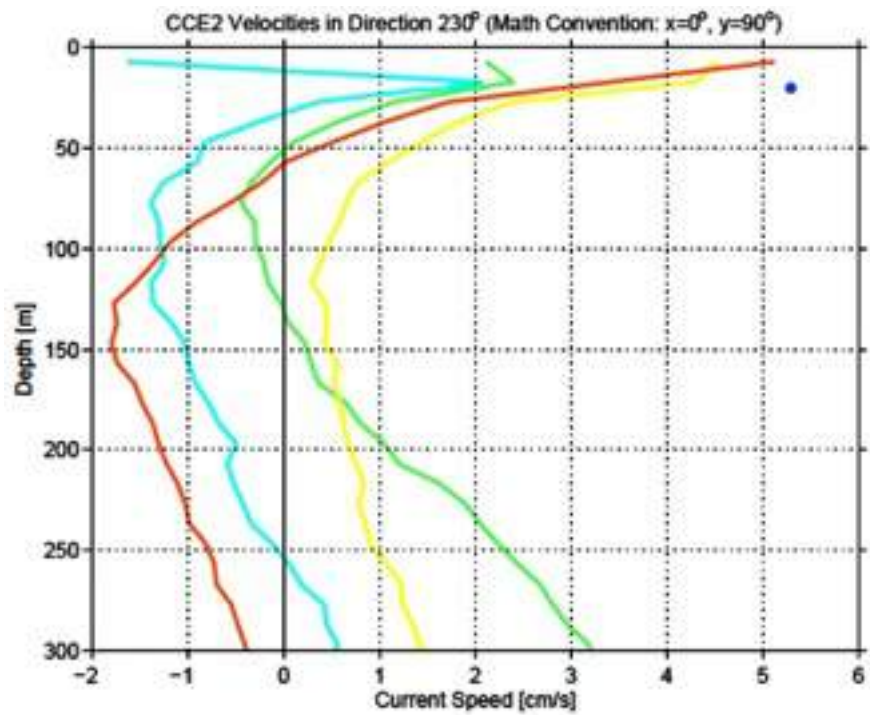
- a. IUGG, July 2015 in Prague with Mark Ohman
- b. Pacific Warm Anomaly Workshop, January 2016 in Seattle with Uwe Send and Mark Ohman
- c. Ocean Sciences Meeting, February 2016 in New Orleans with S. Wilson, Uwe Send, and Mark Ohman

Education & Outreach

Academic Development

- a. the project supports two Ph.D. students who are benefitting from this interdisciplinary training. Several other graduate students have participated in mooring servicing cruises.





01-Jan-2010 to 28-Oct-2010

01-Jan-2011 to 28-Oct-2011

01-Jan-2012 to 27-Oct-2012

01-Jan-2013 to 28-Oct-2013

01-Jan-2014 to 28-Oct-2014

Figure 16: Jan-Oct mean cross-shelf circulation profiles at the CCE2 mooring. The shear between the surface and about 100m depth is taken as a measure for the mean upwelling in that year. There is no absence or significant weakening of upwelling flow visible in 2014.



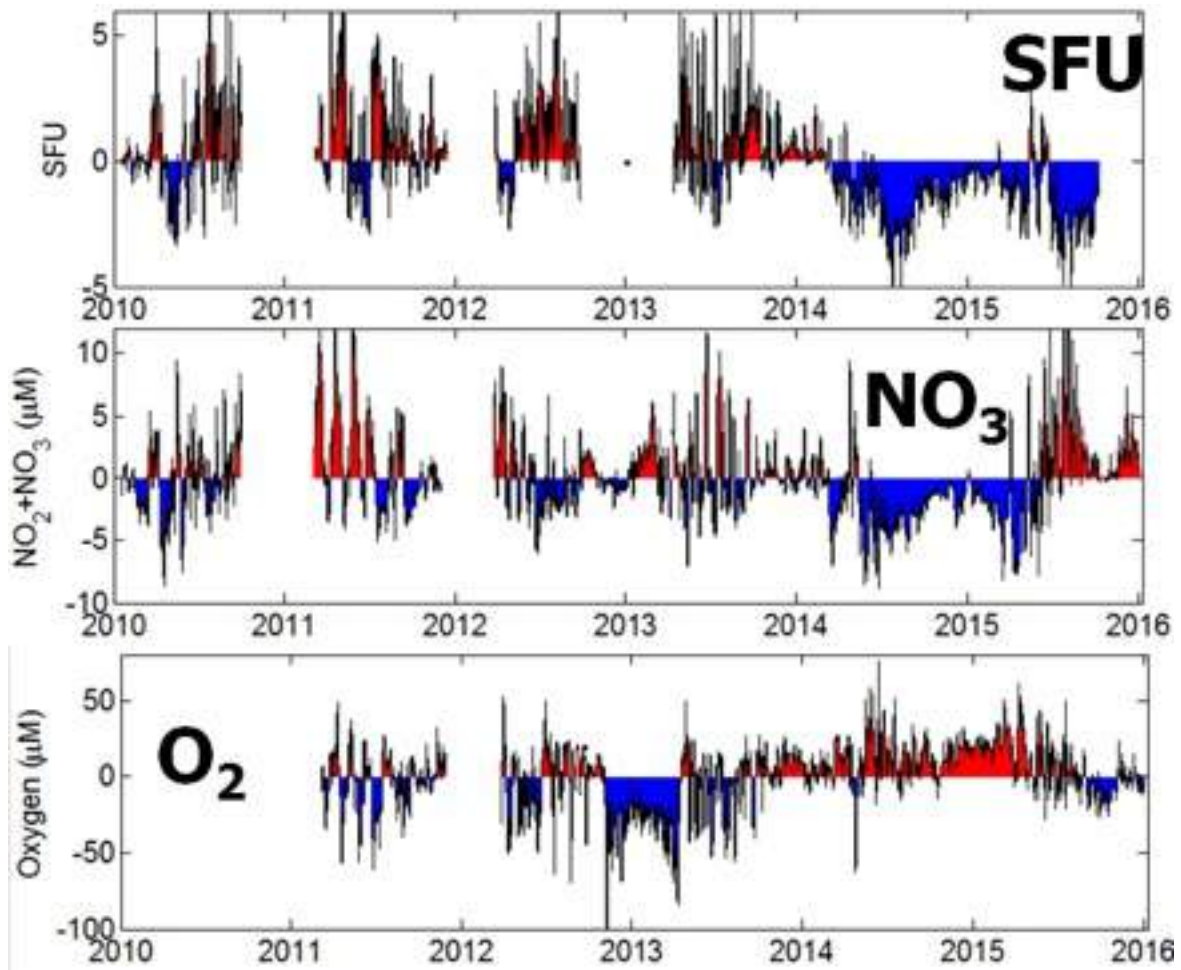


Figure 17: Anomalies (relative to the entire CCE2 mooring data set) of SFU (chlorophyll fluorescence), nitrate, and oxygen concentrations. The very pronounced changes during 2014/15 are clearly visible.



Develop Forecast Methods and an "AR Portal" for Atmospheric River Data Tools

Principal Investigator(s):

Dr. Dan Cayan, Scripps Institution of Oceanography, UC San Diego

Dr. F. Martin Ralph, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Dr. Sam Iacobellis, Scripps Institution of Oceanography, UC San Diego

Dr. Alexander Gershunov, Scripps Institution of Oceanography, UC San Diego

Dr. Jason Cordeira, Plymouth State University

Dr. Jonathon Rutz, University of Utah

NOAA Primary Contact:

Shannon Louie, OAR CIPO

NOAA Task:

Task 3 - Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Goal 3: Serve Society's Needs for Weather and Water Information

Budget Amount:

\$74,961

Amendment(s):

Competed NA14OAR4830271

Description of Research:

Many people in the weather and hydrologic prediction communities, as well as engineering, emergency preparedness and response, water supply, flood control, agriculture and others, have been looking for information on atmospheric rivers (ARs). This project addresses many of these needs

including, real-time information, short-term forecasts, medium range forecasts, seasonal outlooks, state-of-the-art, research findings, climate projections and others.

This project has and continues to develop and implement real-time tools for monitoring and prediction of atmospheric rivers, including lead times of hours to days. The potential for seasonal forecasts of AR frequency is also being explored. The developed data and tools are available on an "AR Portal" web site developed by the project and hosted at the Center for Western Weather and Water Extremes at Scripps Institution of Oceanography (arportal.ucsd.edu). These products are available to users from federal, state, local, private and other entities, as well as the public via this AR Portal.

Objectives:

Main objectives of this research include:

- Develop real-time tools for monitoring and prediction of atmospheric rivers on a variety of timescales.
- Development of "AR Portal" web site to disseminate the developed data and tools.
- Develop local operation of AR Detection Tool (ARDT).
- Explore potential for seasonal forecasts of AR frequency.

Accomplishments & Milestones:

- Several new AR forecast tools have been developed and described in recently submitted journal article.
- AR Portal web site is fully operationally and populated with many observations and forecast tools.
- ARDT is now locally operationally.



- Dropsondes measurements from CalWater 2 campaign processed and analyzed. Results are basis for soon to be submitted research article.
- Composited AR statistics produced from application of local ARDT tool to multiple reanalysis products show a distinct signals with respect to opposite phases of selected climate indices (ENSO, PDO, etc) suggesting possibility of longer-range predictability.

Conferences, Meetings & Presentations

- a. NIDIS Southern California Meeting at Scripps Institution of Oceanography, represented by F. Martin Ralph

Education & Outreach

Communications

- a. AR Portal Website - The AR portal is now operational from the Center for Western Weather and Water Extremes website. The website shows the current AR conditions and forecasted AR conditions. This information has been used by water resource and emergency managers.



Coping with Drought in California's Russian River Watershed

Principal Investigator(s):

Dr. F. Martin Ralph, Scripps Institution of Oceanography

Other Key Personnel:

Michael Dettinger, US Geological Survey

Lorraine Flint, US Geological Survey

Alan Flint, US Geological Survey

Jay Jasperse, Sonoma County Water Agency

Donald Seymour, Sonoma County Water Agency

Christopher Delaney, Sonoma County Water Agency

Daniel Cayan, US Geological Survey & Scripps Institution of Oceanography, UC San Diego

Julie Kalansky, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Nancy Beller-Sims, Climate Program Office

NOAA Task:

Task 3 - Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Budget Amount:

\$298,520

Amendment(s):

Competed NA14OAR4310241

Description of Research:

The project is designed to understand how water extremes in the Russian River Watershed and propose ways in which the region can become more resilient to drought. Through collaboration with Michael Dettinger,

USGS, we have examined how atmospheric rivers will change in the future. Results from this research suggest that atmospheric rivers will become more frequent in the future with the potential to act as drought busters suggesting that drought periods may not be as extensive. Based on stakeholder feedback gathered during the first year of the project we have developed four different drought scenarios to examine the impacts on water supply and the landscape. In this past year we have identified 4 important drought indicators and have synthesized the impacts of the most recent drought on the different sectors.

Objectives:

The project has three main research objectives: 1) evaluate drought ending atmospheric river (AR) characteristics using historical observations and new AR5 climate projections; 2) develop a "drought scenario" for the Russian River by engaging Russian River Stakeholders and using IPCC model analysis in task one; 3) develop and carry out a process to characterize the drought readiness for the Russian River in close partnership with Sonoma County Water Agency.

Accomplishments & Milestones:

Research from task 1 has shown the following:

- In the Russian River, contributions from >90thile wet days "explain" 81% of variance of the fluctuations of total precipitation. Smaller-storm contributions explain only 62% of total-precipitation fluctuations. ARs counts explain 75% of the precipitation variations for 1948-2014.
- The difference in precipitation projections from climate models is



primarily due to the amount of precipitation from the largest (95th percentile) storms. Most climate models project that precipitation from these non-extreme events will decrease, whereas there is large model variability with respect to the extreme events (see figure below).

- Global climate model project ensemble means indicate that AR frequency will increase in the future.

Developments and research from task 2 include the following:

- Four different drought scenarios were established based on the feedback from stakeholders. Stakeholders feedback was the drought scenarios had to be a drought worse than the current California drought and they were interested in droughts that last longer than one to two years, because they had already experienced this.
- The four drought scenarios were all initiated with temperature and precipitation for the time period of October 1, 2011 to June 30, 2015 plus
 - Case 1: July 1, 1976 to December 31, 1985 with temp adjusted to match 2015
 - Case 2: July 1, 1976 to December 31, 1985 with temp adjusted to match 2015 plus an additional 2 °C
 - Case 3: July 1, 1928 to Dec 31, 1937 with temp adjusted to match 2015
 - Case 4: July 1, 1928 to Dec 31, 1937 with temp adjusted to match 2015 plus an additional 2 °C
- The scenarios have been run through the Basin Characterization Model (Flint

et al. 2013) and have also been run through Sonoma County Water Agency's water supply model.

- Early results suggest that the water supply drought ends prior to the landscape drought and the landscape drought persist longer with higher temperatures.

Developments for task 3 include:

- Reservoir levels and ground water have been determined to be good indicators for a water supply drought. Climate water deficit is a good indicator for landscape drought, which affect natural and working land management and lastly tributary flows for fisheries.
- We are planning a workshop for natural and working land managers at Sonoma County Water Agency on June 1, 2016. We will discuss the results of the drought scenarios and have an open dialogue on drought mitigation strategies.
- Sonoma County Water Agency will summarize the drought mitigation approaches and potential future approaches for water utilities in the region.

Conferences, Meetings & Presentations

- a. SARP Project Meeting, July 19, 2015 at Scripps Institution of Oceanography, represented by Michael Dettinger, Lorraine Flint, Alan Flint, Jay Jasperse, Donald Seymour, Christopher Delaney, Daniel Cayan and Julie Kalansky
- b. SARP Project Meeting, March 28, 2016, at SCWA, represented by Michael Dettinger, Lorraine Flint, Alan Flint, Jay Jasperse, Donald Seymour, Christopher Delaney, Daniel Cayan and Julie Kalansky



- c. AMS Meeting, January 14-19, 2016 in New Orleans, represented by Brian Kawzenuk

Education & Outreach

Communications

- a. Sonoma County Adaptation Forum where F. Martin Ralph and Julie Kalansky presented on the project to over 200

community members. F. Martin Ralph presented on the impact and potential future impact of ARs to the region and Julie Kalansky presented on the drought impacts and engaged the attendee on their sectors vulnerabilities to drought.



Meridional Overturning Variability Experiment (MOVE)

Principal Investigator(s):

Uwe Send, Scripps Institution of Oceanography, UC San Diego

Matthias Lankhorst, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Diane Stanitski, Climate Program Office

NOAA Task:

Task 3 - Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Budget Amount:

1,561,817

Amendment(s):

25, 68, 75, 118

Keywords:

Thermohaline Circulation, Overturning Circulation, MOVE, North Atlantic Deep Water, Transports, Observing Systems

Research Objectives:

A present gap in the sustained ocean climate observing system are techniques and programs for monitoring the circulation and mass/heat/freshwater transports of major current systems, sometimes called "transport reference sites". For broad-scale and deep-reaching circulations, an accurate and cost-effective method for this consists of fixed-point installations with moored and bottom-mounted instruments to obtain horizontally integrated measurements throughout the watercolumn. The MOVE project applies this approach to obtain sustained observations of a component of the AMOC (Atlantic

Meridional Overturning Circulation) which is a national ocean observing priority. This effort had been initiated via the German CLIVAR programme from 2000 to 2006 in the subtropical west Atlantic along 16N, in order to observe the transport fluctuations in the North Atlantic Deep Water layer. Since 2006 is has been operated with NOAA funding, now providing the longest record of direct AMOC observations.

Within the current NOAA MOVE project, SIO/CIMEC/NOAA operates the two geostrophic endpoint moorings and bottom pressure recorders (PIES) between the western boundary and the Midatlantic Ridge (yielding dynamic height and bottom pressure differences), plus a small current meter mooring on the slope. This is complemented on the eastern side of the Atlantic with a German-funded and operated mooring (near the Cape Verde islands). Routine operation is now achieved with two-year long deployments, which enables routine delivery of indicators about the state of the thermohaline overturning circulation at this latitude. The moorings and PIES have recently been equipped with acoustic modems, allowing data retrieval from research vessels or via gliders.

Highlights:

- 3 moorings recovered, 3 new moorings deployed, additional data downloaded acoustically, approx 16 years of data in hand now
- The increasing baroclinic transport since 2008 goes along with a thickening of the southward NADW flow

Accomplishments:

In January/February 2016, SIO participated in a new NTAS/MOVE cruise on R/V Endeavor. During this cruise, all moorings recovered and new ones deployed at stations M1, M3 and



M4, and data were downloaded acoustically from some of the PIES at sites M1/M3. This extends the data record in hand for the baroclinic (sheared) flow to approximately 16 years.

The new longer data set shows a continuation of the strengthening trend of the southward NADW (North Atlantic Deep Water) transport which has been present since about 2008 (see figure 1). Referencing the transports to bottom pressure from PIES constrained with GRACE satellite data still preserves this trend. The new results have also revealed a thickening of the layer that is flowing southward (figure 2). Collaboration continues with RAPID researchers, studying the similarities in changes in the water mass structures at RAPID and MOVE, and with modellers in Hamburg about decadal time

scale basin-modes which may explain basin-wide coherences of MOVE transports.

Honors and Awards

- a. John Doe won the 2015 Hot Dog Eating Contest

Conferences, Meetings & Presentations

- a. International AMOC meeting, July 2015 in Bristol, U.K. with M. Lankhorst
- b. OSM 2016, April 2016 in New Orleans with J. Koelling
- c. GSOP-8/CLIVAR HEAT, September 2015 in Exeter, U.K. with Uwe Send

Education & Outreach

Academic Development

- a. One graduate student was supported by MOVE

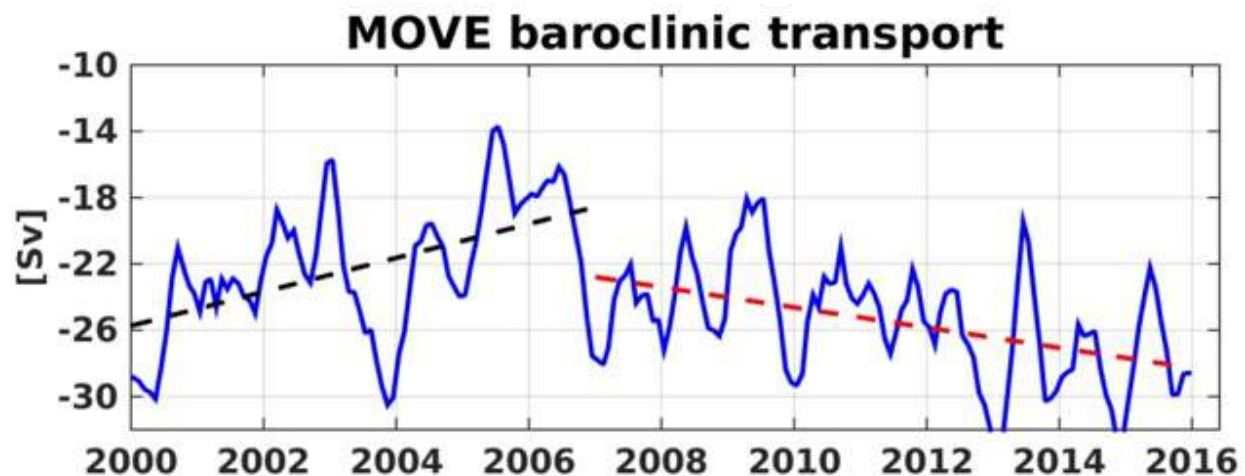


Figure 18: 16 years of quality-controlled baroclinic North Atlantic Deep Water transport (southward therefore negative).



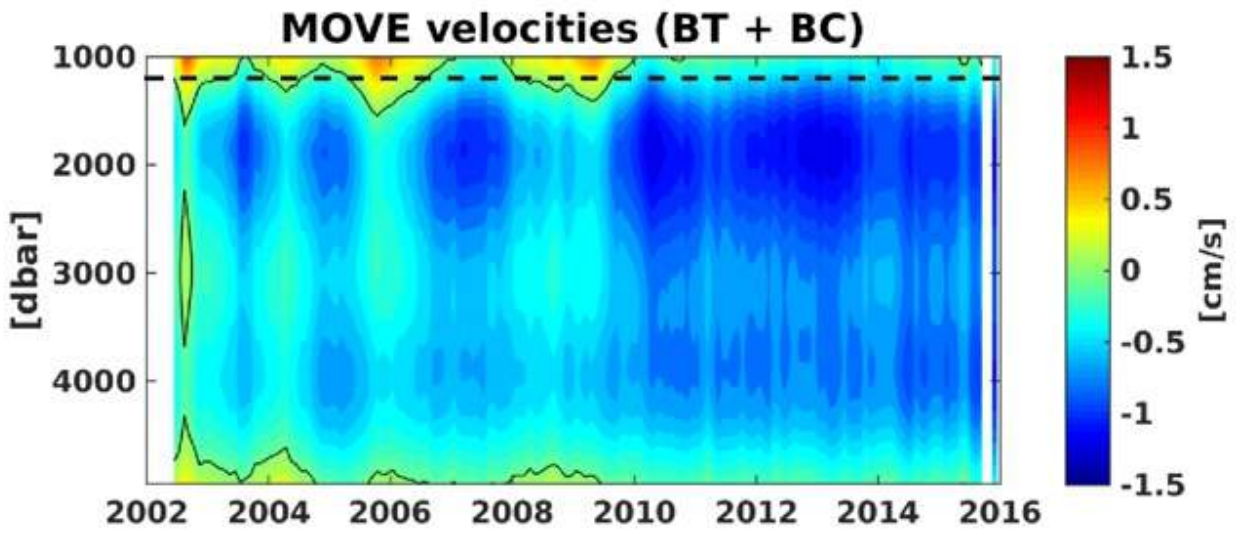


Figure 19: Contour plot of southward NADW flow (blue), showing thickening of the layer since about 2008.



NOAA Support for the CLIVAR and Carbon Hydrographic Data Office at UCSD/SIO, 2016-2018

Principal Investigator(s):

Dr. James H. Swift, Scripps Institution of Oceanography, UC San Diego

Dr. T. Bruce Applegate, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Stephen C. Diggs, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact(s):

Dr. David Legler, Climate Program Office

Dr. Kathy Tedesco, Climate Program Office

NOAA Task:

Task 3 - Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Budget Amount:

\$326,546

Amendment(s):

65, 77, 112

Description of Research:

- a. There is a substantial amount of CTD data of value to the Argo and ocean research/modeling communities. The CCHDO continues to work with NOAA to assemble and incorporate into NOAA-related holdings select cruise data sets. This includes continued addition of HOT and BATS profiles and submitting them to OceanSITES, and new profiles added to the Argo reference CTD data set. The CCHDO Director (Swift) reviews for suitability selected CTD profiles intended for Argo reference use. Steve Diggs

(CCHDO) continues the role of Chair for the SOOS Data Management Subcommittee.

- b. The NOAA/NCEI works with several data assembly centers, including CCHDO, to bring data into NCEI. The CCHDO continues to improve their relationship with NCEI in the following areas:
 - i. Continued data assembly of cruise hydrographic data and metadata, particularly those from the GO-SHIP program.
 1. The CCHDO continues as the official global DAC for GO-SHIP.
 2. The CCHDO continues to coordinate its activities with the JCOMMOPS technical coordinator for the GO-SHIP program, Martin Kramp.
 - ii. Working with NCEI to improve efficiency of transfer of data and to make CCHDO data more "archive ready". The CCHDO and NCEI continue to implement incremental technological enhancements which have improved the efficiency of the data transfer. This has led to an overhaul of the underlying structure for holding and serving data to all customers, including NCEI.
 - iii. Continued CCHDO participation in discussions towards enhancing integration of the related Data Assembly Centers (for example CDIAC and BCO-DMO), to reduce ambiguity and redundancy in data archiving.



c. CCHDO holdings are of great value to a wide audience of climate researchers and other users (e.g. modelers). The CCHDO is making continued progress on changes to make their holdings more query-able and accessible through modern data management standards and practices (including those that NOAA and the international oceanographic community recommend). Data search based on available parameters now available and can be combined with other search features; the CCHDO has enabled bulk download of selected files. A new, easier to maintain and more reliable means for locating and downloading data was developed and is being incrementally put

into place in the period immediately after the reporting period.

d. At a Argo data management meeting (ADMT-16), Steve Diggs (CCHDO) demonstrated progress on issues raised by Argo Coriolis personnel regarding the availability, format consistency and overall quality of CTD profiles provided by the CCHDO for the Argo CTD Reference Database.

The temporary setbacks, which were initially raised in Ottawa at ADMT-15 the previous year, were due in large part to the fact that the CCHDO was in the midst of a long overdue internal redesign and retooling effort. Part of this retooling involved the creation of the CCHDO API.

Issue	Problem caused	How it will be resolved	Deadline
CCHDO automatically assigns WOCE flag "2" (good). This practice was routine during the WOCE program.	Christine is forced to review every new profile CCHDO regardless of QC flag which causes delays in the processing and dissemination of the RefDB.	CCHDO will end this practice. No flags will be assigned to data that have not been quality controlled.	ADMT-16 (Nov 2015)
CCHDO's secure website for Argo proprietary CTD data was not routinely updated with NetCDF formatted file for ingestion by Coriolis.	The most recently acquired ship-based CTD profiles are not available to Coriolis.	CCHDO will provide an API for Coriolis (and others) which will allow downloads of NetCDF CTD files for any time period and users can specify that the transfer include the non-public data submitted only for inclusion in the RefDB.	July 2015
Non GO-SHIP data have not been through QC as CCHDO relies on provider's assessments of profile quality.	Coriolis personnel must QC each profile before inclusion in the RefDB, causing delays in processing.	Volunteer Oceanographers (Swift, Freeland) will review each profile in non GO-SHIP CTD datasets to assess overall profile quality for inclusion in the Argo RefDB.	ADMT-16



Each issue above was addressed and resolved earlier than expected. Coriolis personnel agreed that the overall situation has improved dramatically.

In addition to the issues above, there was an update regarding how many ship-based CTD profiles have been made available to Coriolis for inclusion in the RefDB:

- CCHDO added 15 cruises /1384 profiles (Mar 2015 - Oct 2015)
- NCEI (NODC) added 2529 profiles, 1744 coming from CCHDO (Aug 2014 - Aug 2015)

There were discussions regarding how CCHDO received information about new cruises of interest from regional centers and others which may make it possible to acquire the early-release CTD data that the RefDB relies on. Setbacks and progress with this issue were reviewed.

To summarize, all issues raised at ADMT-15 have been positively resolved ahead of schedule, the semi-retired oceanographer team of Howard Freeland and Jim Swift have performed their CTD data QC duties admirably and have added Breck Owens to their ranks as of ADMT-16

The well-documented CCHDO API v1.0 is in use by both Coriolis and NCEI and quality data are once again moving smoothly throughout the Argo CTD reference data system.

Objectives:

- a. In the CCHDO activities as a CTD/hydrographic/tracer/ocean-carbon data assembly center, the CCHDO will [and does] provide data from specific cruises that are of special interest to NOAA.
- b. The CCHDO will [and does] work with NCEI to improve transfer of data and integration with related data centers.
- c. The CCHDO will (and did) continue to make its holdings more query-able and

accessible through modern data management standards and practices (including those that NOAA and the international oceanographic community recommend). The CCHDO reports new and updated CTD data to Argo for Argo sensor correction. All CCHDO deliverables are expressed as new and revised data and documentation entries on the CCHDO web site <http://cchdo.ucsd.edu>.

Accomplishments & Milestones:

CCHDO activities in support of NOAA interests are more nearly a steady grind, with continual data and documentation updates, posts online, data provided to NCEI, etc., as opposed to a series of milestones.

- Continued increase of US and non-US CTD profiles, both public and non-public, available for Argo reference data.
- Continued reconciliation of EXPCODE expedition identifiers among US data centers.
- Continued improvement of the means for large data users (e.g., modelers) to directly download any/all data of interest, for example all-basin data, or all program (e.g. WOCE) data.
- On-going harmonization of disparate data centers and the data from various large-scale hydrographic surveys has led to a better "capture percentage" of all data (US-HYDRO, GO-SHIP, DIMES). Because the CCHDO carries out data curation for these programs, their data interoperability is improved as the metadata and discovery information. NOAA/NCEI benefits because it obtains all curated data from the CCHDO.
- NOAA funded observations are captured by the CCHDO through the GO-SHIP, Argo and OceanSITES programs and are provided in a uniform format with consistent content. The CCHDO is an IODE Associated Data Unit (ADU), a class



of IODE members created specifically to include organizations such as BCO-DMO, CDIAC and the CCHDO, on par with each member nation's national oceanographic data center.

- The CCHDO's involvement in IODE, SOOS, Argo, OceanSITES, GO-SHIP, DIMES and related organizations leads to continued improvement in the areas of NOAA interest funded by the award. For example CCHDO-related data issues raised by the Argo Coriolis team have been resolved.

Conferences, Meetings & Presentations

- a. Ocean Sciences 2016, 22-26 February 2016 in New Orleans with Swift, Diggs, Berys-Gonzalez, and kappa

- b. Argo/ADMT-16, 2015.11.01 in Hamilton, Bermuda with S. Diggs and A. Barna

Education & Outreach

Communications

- a. All public CCHDO data, documentation, and data information are disseminated via the CCHDO web site <http://cchdo.ucsd.edu>.

Academic Development

- a. Undergraduate research assistants were trained in under-the-hood operations of a data center and website via real-world experience with ongoing CCHDO activities.

CCHDO home page (<http://cchdo.ucsd.edu>)

Welcome to the CCHDO

The CCHDO's primary mission is to deliver the highest possible quality global CTD and hydrographic data to users. These data are a product of decades of observations related to the physical characteristics of ocean waters carried out during WOCE, CLIVAR and numerous other oceanographic research programs. Whenever possible we provide these data in three easy-to-use formats: WHP-Exchange (which we recommend for data submissions to the CCHDO), WOCE, and netCDF.

The CCHDO also manages public and non-public CTD data to be used for the global Argo and OceanSITES programs.

This site is funded by the National Science Foundation and the National Oceanic and Atmospheric Administration's Climate Observations Division.

Search

Keyword search is provided by the search box in the upper right of the page. Other options include:

- Map Search** lets you draw a box on a map to search for station data.
- Advanced Search** lets you finely define key word, bounding box, and temporal searches.

Some Starting Searches

Here are some searches which may be of general interest:

- Basins**
 - Arctic Ocean
 - Atlantic Ocean
 - Pacific Ocean
 - Indian Ocean
 - Southern Ocean
- Programs**
 - GO-SHIP
 - USHYDRO
 - WOCE
 - DIMES
 - ELLETT
 - Project Carina
- Time Series**
 - Hawaii Ocean Time Series
 - Bermuda Atlantic Time Series

quick access to projects and basin data with one-click bulk download

underpinnings based on modern, open-source structures, easy to maintain and works well with other data centers

J. Swift, SIO, October 2015

This web site and all other CCHDO activities are supported by the National Science Foundation and the National Oceanic and Atmospheric Administration. The conclusions or recommendations expressed in this web site are those of the PI, James Swift, and the CCHDO and do not necessarily reflect the views of the NOAA or the U.S. Department of Commerce. THE NOAA ® EMBLEM IS A REGISTERED TRADEMARK OF THE U.S. DEPARTMENT OF COMMERCE, USED WITH PERMISSION. THE USE OF THE NOAA EMBLEM REQUIRES THE COLLABORATIVE RESEARCH PARTNERSHIP BETWEEN THE INSTITUTE AND NOAA AND DOES NOT CONSTITUTE ENDORSEMENT BY THE DEPARTMENT OF COMMERCE/NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION OF THE INFORMATION, PRODUCTS, OR SERVICES CONTAINED THEREIN THAT WERE NOT DEVELOPED BY NOAA.

Figure 20: March 2016 front page of the CCHDO web site <http://cchdo.ucsd.edu>. This 'minimalist' look belies underpinnings of the CCHDO web site and data serving which are powerful, easy-to-support, reliable, and fast.



Intraseasonal to Interannual Variability in the Intra-Americas Sea in Climate Models

Principal Investigator(s):

Shang-Ping Xie, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Anna Merrifield, Scripps Institution of Oceanography, UC San Diego

Xichen Li, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Daniel Barrie, OAR Climate Program Office

NOAA Task:

Task 3 - Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Budget Amount:

\$189,900

Amendment(s):

Competed NA13OAR4310092

Description of Research:

We have studied interannual-decadal variations in the tropics and their impacts on North American summer climate. Our research also includes dynamics of regional climate change.

Objectives:

To understand and predict climate variability and change, with an emphasis on the Intra-Americas Sea

Accomplishments & Milestones:

We published five papers in Nature journals, and have another one in press in J. Climate

Conferences, Meetings & Presentations

- AGU Fall Meeting, 12/2015 in San Francisco with Shang-Ping Xie
- Australian Ocean and Atmospheric Society Meeting, 2/2016 in Melbourne with Shang-Ping Xie
- Ocean Sciences Meeting, 2/2016, New Orleans with Xichen Li

Education & Outreach

Communications

- On 2/17/2016, SP Xie gave a public lecture titled "Hiatus on the Global Warming Staircase" for Florida State University Department of Atmospheric Sciences.
- On 4/7, SP Xie gave a public lecture titled "El Nino, and the rise of the Pacific as a global climate pacemaker" at University of Washington Department of Atmospheric Sciences.
- Featured in a news release on the Scripps website titled "A New Take on the Global Warming Hiatus".



Theme C: Marine Ecosystems

Exploring 'omic Technologies to Support Ecosystem Understanding and Fisheries Assessments

Principal Investigator(s):

Andrew E. Allen, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Dave Checkley, Scripps Institution of Oceanography, UC San Diego

Kelly Goodwin, NOAA Atlantic Oceanographic and Meteorological Laboratory

NOAA Primary Contact:

Margo Bohan, Office of Ocean Exploration (OER)

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Budget Amount:

\$200,000

Amendment(s):

101

Description of Research:

The research team has utilized high throughput sequencing and bioinformatics to implement modern 'omic approaches to traditional ecosystem observation programs. High-throughput DNA and RNA sequencing

will be used to complement and augment oceanographic, biological, and biogeochemical observations currently collected in the California Cooperative Oceanic Fisheries Investigations (CalCOFI), California Current Ecosystem Long Term Ecological Research (CCE-LTER), and Southern California Coastal Observing System (SCCOOS) programs. To date, conserved markers 16S and 18S rDNA genes have been amplified and sequenced from 312 samples spanning seasons, stations and depths during the 2014 and 2015 CalCOFI cruises. Samples for RNAseq data, i.e., community transcriptomics, were also taken and will be processed and sequenced in 2016.

Objectives:

Understanding the differential sensitivities of organisms in these habitats to natural climate and anthropogenic stressors will lay the foundation for forecasting future changes in ocean biodiversity. Implementation of high throughput molecular and genomic approaches within the framework of an existing ocean observing network (The Southern California Coastal Ocean Observing System; SCCOOS), and a well-established monitoring program (CalCOFI), and an experimental process-oriented program (The California Current Ecosystem Long Term Ecological Research site (CCE-LTER), will create unique opportunities for science and management. This integrated network will facilitate analyses, with high temporal and spatial resolution and specificity, related to how organisms, including those that directly impact food webs and biogeochemical cycles, respond to environmental perturbations, including global-scale changes. The proposed



research will promote identification of key thresholds and tipping points as well as more subtle shifts resulting from altered species interactions, changes in larval availability, recruitment or recovery potential. Generated data products will provide a currently unavailable Ecosystem Based Management context for valuable biological indicators of ecosystem health and function with connections to fisheries.

Accomplishments & Milestones:

Water samples were filtered onto GFF filters for DNA and 0.2 um sterivex filters for RNA collection at stations across the CalCOFI lines spanning seasons and depths. The average water filtered per sample was 1.3 L for DNA amplicon sequencing and 5.8 L for RNA community transcriptomics. Sequencing has been completed on 312 DNA samples targeting the 16S and 18S rDNA genes. The sequences targeted included, *i*) 16S rDNA Bacteria, *ii*) 16S rDNA Plastid, *iii*) 18S rDNA variable region 4 (V4), *iv*) 18S rDNA variable region 9 (V9).

Conferences, Meetings & Presentations

- a. CalCOFI Annual Conference from December 14-16, 2015 in Monterey Bay, CA, represented by A.E. Allen, K Goodwin, R Goericke, M Bohan, S Dovel, A Rabines, M Roadman, H Zheng, J McCrow, L Zeigler, D Checkley

Education & Outreach

Communications

- a. <http://oceanexplorer.noaa.gov/about/what-we-do/oer-updates/2014/calcofi-111914.html>

- b. <http://oceanexplorer.noaa.gov/about/who-we-are/partnerships.html>
- c. <http://www.calcofi.org/field-work/bottle-sampling/ncog-project.html>

K-12 Outreach

- a. I serve as the Director of the Scientific Advisory Board for the non-profit League of Extraordinary Scientists (LXS) (<https://www.facebook.com/LeagueXS>) (<http://science-ing.org/>). In 2015 my Lab developed a hands-on K-5 marine science outreach program, *WAVES and WATERSHEDS*, centered on the importance of phytoplankton in the global carbon cycle. In the pilot year (2015) PhD students from the Allen Lab visited over 1,400 elementary school children across 44 classrooms in underserved districts in central and southern San Diego. Nearly every PhD student and most post-docs in my lab have participated in delivering LXS presentations (tours). This is the only no-cost K-5 science outreach program in San Diego County, and one of the few K-5 specific programs in the United States. Every LXS tour is designed to encourage kids to explore, discover, share and think like a scientist. Data from evaluations indicates an overwhelming teacher approval of 4.8 out of 5. In the coming year we plan to expand our K-5 program to include polar science and introduce children to microbes and the concept of biogeochemical cycles and the role of the Southern Ocean in climate change.



Evaluation of Exposure to and Infection with Phocine Distemper Virus to the Eastern District Population Segment of Steller Sea Lions

Principal Investigator(s):

Tracey Goldstein, University of California, Davis

Other Key Personnel:

Brett Smith, University of California, Davis

Louise Cosby, Queens University of Belfast, United Kingdom

NOAA Primary Contact:

Lisa Rotterman, National Marine Fisheries Service

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Goal 3: Serve Society's Needs for Weather and Water Information

Budget Amount:

\$45,854

Amendment(s):

84, 115

Description of Research:

Phocine distemper virus (PDV) nucleic acid was detected in live-captured and dead Northern sea otters off the coast of Alaska in 2004, the first confirmation of this virus in a Pacific marine mammal. The emergence of this virus highlighted the need to determine the viral distribution in Arctic and Sub-arctic marine mammals in the Northeast Pacific and examine if it was playing a role in mortality.

Sequence analysis confirmed the viral fragment was identical to that from the 2002 phocine distemper outbreak that caused large-scale mortality in harbor seals in Europe and serological surveys prior to 2000 revealed that marine mammals in Alaska had not been exposed to PDV. Thus we hypothesized that virus was transmitted through the Arctic to the North Pacific after the 2002 epidemic by vector species. A significant reduction in sea ice after 2002 may have altered seal haulout and migration patterns resulting in contact between Atlantic, Arctic, and Pacific Ocean species that was not possible after the 1988 PDV outbreak in Europe.

The purpose of this project was to evaluate the extent of infection and exposure to the potentially deadly virus, phocine distemper, in the Steller sea lion population off Alaska. Additionally, prior to this project, limited testing had been performed on samples from Steller sea lions from the Eastern Distinct Population Segment, a recently delisted population, thus to evaluate how widespread this viral infection is in Steller sea lions across their range, additional testing was needed. The goals of this work were to test for evidence of infection and measure exposure to phocine distemper virus in the samples from the eastern Distinct Population Segment of Steller sea lions, in animals from the western Distinct Population Segment in Russia, and to complete testing of samples collected from the animals from the western Distinct Population Segment in Alaska from 2011 to present to evaluate their current exposure and infection status.

In order to determine the presence of infection and exposure to PDV in Steller sea lions across their range, serum samples (n =



675) were tested for antibodies by serum neutralization and nasal swabs or tissues (n = 965) were tested for viral RNA by PCR, collected between 2001 and 2013. A subset of samples were from animals from the Eastern Distinct Population Segment and included serum samples (n = 99) from 2001 to 2004 and 2009 collected on Benjamin Is, Biali Rocks, Gran Point, Hazy Is, Little Is, Marble Is, Southwest Brothers Is and White Sister Is; and nasal swabs or tissues (n = 63) for PCR from 2001 to 2013 collected from animals on Benjamin Is, Graves Rocks, Gran Point, Sunset Is, Sea Otter Is, Sail Is, Southwest Brothers Is, Sitka and Rogue Reef (OR).

Serologic analyses indicated exposure likely first occurred in 2003 as >50% of Steller sea lions pups tested had antibodies against PDV. The proportion of seropositives appeared to decrease through 2008 and increased again in 2009. PCR supported the serology results as positive tissues and nasal swabs were detected in Steller sea lions in 2004 to 2006 and 2010. The data indicate that exposure to the virus appears to be widespread as animals as far east/southeast as Hazy Island, near Petersburg, in southeast Alaska, and as far west as Iony Island (Sea of Okhotsk) in Russia have antibodies to the virus. The proportion of antibody positives in animals sampled in Southeast Alaska increased in 2003 and 2004, with 79% (15/19) and 55% (11/20) of animals testing positive, and 35% (7/20) were seropositive in 2009, thus PDV results in the EDPS mirrored those from the WDPS. Brain tissues from two dead pups were positive by PCR in 2005 on Marble Is and Benjamin Is. None of the animals tested on Rogue Reef in 2013 were positive by PCR. Findings suggest contact of animals between the Eastern and Western regions is likely facilitating virus transmission, and continued surveillance is warranted to monitor the status of infection of Steller sea lions, especially of the recently delisted population segment in Southeast Alaska.



Objectives:

The purpose of the project is to evaluate the extent of infection and exposure to the potentially deadly virus, phocine distemper, in the Steller sea lion population off Alaska

1. Assess current and past infection in tissues, nasal swabs and blood samples from Steller sea lions by polymerase chain reaction to detect the presence of phocine distemper viral nucleic acid.
2. Assess exposure by measuring antibodies against phocine distemper in serum samples from these same animals.

Accomplishments & Milestones:

- A total of 1,640 samples, including serum samples (n = 675) for antibodies by serum neutralization and nasal swabs or tissues (n = 965) for viral RNA by PCR, were tested from Steller sea lions across their ranged collected between 2001 and 2013.
- Although Nasal swab samples were only available for testing for some years, PCR results supported the serology data confirming that infection did occur first after 2002 and again more recently after 2009.
- Phocine Distemper testing results in animals from the Eastern Distinct Population Segment mirror those from animals from the Western Distinct Population Segment.
- Results suggest that contact of animals between regions is likely facilitating viral transmission.

Education & Outreach

Academic Development

- a. 2014 February 10, Lecture, Climate change and pathogen movement in the arctic, for the Epidemiology Graduate Group Seminar Series at UC Davis/
- b. 2015 April 17, Invited Speaker, Graduate Student Seminar, Emergence of Phocine

Distemper in the North Pacific, Faculty of Veterinary Medicine, University of Calgary

- c. 2015 May 8, Invited Speaker, From seals to primates: Approaches for detecting known and new diseases, Veterinary Medicine Research Symposium for Undergraduates, School of Veterinary Medicine, UC Davis, CA

Networking

- a. Presentation at the Marine Mammal Morbillivirus RAPIDD Meeting where the

purpose was to present on and examine the current knowledge of morbillivirus infections in marine mammals

- b. Presentation at the Eastern DPS Steller sea lion post-delisting meeting where this was the first post-delisting meeting to present and discuss the monitoring of changes in the population that has occurred to date



Collaborative Studies of Cetaceans with the Northeast Fisheries Science Center Using High-Frequency Acoustic Recording Packages

Principal Investigator(s):

John Hildebrand, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Sean Wiggins, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Sofie Van Parijs, Northeast Fisheries Science Center (NEFSC)

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Budget Amount:

\$650,000

Amendment(s):

142

Description of Research:

This collaborative research deployed long-term acoustic recorders along the Atlantic continental shelf and slope to monitor for the full range of cetacean species. Using acoustic data it is possible to sense the presence of marine mammals, and to assess their spatial distribution and relative abundance. Five High-Frequency Acoustic Recording Packages (HARPS) were constructed and deployed. Data from three of these deployments have been recovered and data analysis is underway.



Objectives:

The specific objectives of this project are to: (1) construct HARPs for deployment in the Atlantic; (2) provide personnel, replacement parts, and ship time for HARP deployments and recoveries; (3) provide initial data processing to convert raw acoustic data to wav files and LTSAs; (4) conduct a presence/absence analysis for marine mammal calls across three frequency bands (high 10 – 100 kHz, middle 1 – 10 kHz, and low 10 – 1000 Hz); and (5) write a report summarizing acoustic data collection and HARP data analysis.

Accomplishments & Milestones:

- 1) Five HARPs were constructed.
- 2) These instruments were deployed in the western Atlantic along the continental shelf and slope stretching from Maine to Florida.
- 3) Data from three of these deployed instruments have been recovered and data analysis is underway.

Conferences, Meetings & Presentations

- a. Acoustical Society of America, from May 23-27, 2016 in Salt Lake City, UT, represented by John Hildebrand

Education & Outreach

Communications

- a. Whale Acoustics Laboratory Website - The SIO Whale Acoustics Lab maintains a www site with information on on-going projects, personnel, software and hardware

Academic Development

- a. Kait Frasier (SIO PostDoc) has been assisting with project data analysis and comparison of the Atlantic data collected

with Gulf of Mexico data collected for her PhD thesis.

K-12 Outreach

- a. Underwater sounds for education and outreach are presented in our website www.voicesinthesea.org which is also featured in museum exhibits at the Birch Aquarium and 6 other venues.

Networking

- a. Presentations at the 7th International Workshop on the Detection, Classification,

Localization and Density Estimation using passive acoustics for study of marine mammals. This workshop was held last July in La Jolla and brought together the community of researchers who are using passive acoustic monitoring data to study marine mammals.



The Next Generation of CoralNet: Improving Automated Methods Benthic Image Analysis and Optimizing for NMFS Benthic Imagery

Principal Investigator(s):

David Kriegman, Computer Science & Engineering Department, UC San Diego

Other Key Personnel:

Oscar Beijbom, University of California, San Diego

NOAA Primary Contact:

Steve Miller, National Marine Fisheries Service

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Budget Amount:

\$100,000

Amendment(s):

109

Description of Research:

Research has proceeded along two principal directions. The first direction refers to advances in the coralnet.ucsd.edu graphical user interface. The second refers to advances in the underlying computer vision technology used to automate the annotation work.

In the first direction we first created a new upload function has been implemented to allow users to more conveniently upload archived sets of annotations. This was initiated by CRED partners so that their archived annotations, performed in CPCe,

could more conveniently be uploaded to the system. Further, the page to view image details have been updated to allow for better control of the image settings. This included settings the annotation area, the number of random points for that particular image, and the random point scattering scheme. Further still, the vision backend-system has been updated to better handle large set of images uploaded as part of NOAA's analysis. This was critical in order to handle uploads of >30k images, which is an order of magnitude larger than the site previously could handle. The new system is able to process large sources in smaller portions, thus enabling it to also attend to other, smaller sources, intermittently. Finally an updated sign-up procedure makes signing up to the website more convenient. This was mostly a UI improvement but it was critical as the old system was confusing to many users.

The second direction chiefly concerned development of deep learning methods for automated analysis. Towards this end, experimentation has been conducted on the appropriate implementation of deep learning methods for computer vision. These experiments include, for example, appropriate receptive field / image resolution to provide to the network, analysis of the number of point annotations and images required to achieve appropriate accuracy, and finally a detailed comparison of human versus automated accuracies. Further, a new, "background" deep learning model has been trained on over 2 Million annotations harvested from CoralNet. As our experiments indicate, and as shown in Figure 1 of this report, the new background model significantly improves recognition accuracies, in particular in the



low-data scenario. Advances of the new method have been demonstrated on a publically available data-set and demonstrates very significant improvements in recognition accuracy; in some cases even surpassing manual annotation accuracy.

Researchers at NOAA CRED have been using CoralNet, and Brett Schumacher from NOAA reported on its effectiveness in a public talk entitled “CoralNet: A User Experience” at the 2nd Workshop on Automated Analysis of Video Data for Wildlife Surveillance on 3/10/16 as part of the IEEE Winter Conference on Applications of Computer Vision.

Objectives:

The National Coral Reef Monitoring Plan reef benthic cover data are derived from the analysis of benthic images collected during Rapid Ecological Benthic and Fish Surveys, as well as images collected during the Climate Station Monitoring Surveys. As such, the need for this project is best exemplified by the considerable resources that are already being directed towards manual annotation of benthic photoquadrats. Our team has been developing computer vision and machine learning methods for automatically and semi-automatically annotating benthic reef images.

1. Improve the core classification algorithms.
2. Improve the CoralNet web site software, including updating the system software, porting to Amazon Web Services, improving image uploader, modify the logic

of the label set, and improve the user interface.

3. The project serves as a pilot-study for NOAA divisions and jurisdictional partners to transition from manual to automated image annotation. In turn, an objective was to work with and train CRED scientists on how to use the current version CoralNet and evaluate the results.

Accomplishments & Milestones:

1. General framework for deep learning for analysis of benthic survey images established.
2. UI improvement as requested by NOAA CREP partners implemented.
3. Programmer hired to migrate site to Amazon cloud storage.
4. NOAA CREP is actively using CoralNet, and we've been responding to their needs.

Conferences, Meetings & Presentations

- a. International Coral Reef Symposium, June 2016 in Honolulu, HI with Oscar Beijbom

Education & Outreach

Networking

- a. D. Kriegman was co-organizer of 2nd Workshop on Automated Analysis of Video Data for Wildlife Surveillance held in conjunction with the IEEE Winter Conference on Applications of Computer Vision, March 2016



CSTAR – The Center for Stock Assessment Research

Principal Investigator(s):

Marc Mangel, UC Santa Cruz

Other Key Personnel:

Ryan Driscoll, UC Santa Cruz

Nick Grunloh, UC Santa Cruz

Who-Seung Lee, UC Santa Cruz

Juan Lopez, UC Santa Cruz

Kate Richerson, UC Santa Cruz

Jarrold Santora, UC Santa Cruz

Simone Vincenzi, UC Santa Cruz

NOAA Primary Contact:

Dr. John Field, Southwest Fisheries Science Center

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Goal 3: Serve Society's Needs for Weather and Water Information

Budget Amount:

\$1,236,321

Amendment(s):

1, 35, 54, 87

Description of Research:

CSTAR was formed in 2001 with the goal of undergraduate, graduate, post-graduate, and researcher training in the science associated with the problems of assessing the numerical abundance, spatial distribution, size distribution and reproductive status of commercially important fish species. A broad and deep understanding of population

processes is critical to the development and management of sustainable fisheries.

Finding means to conserve fish populations and to achieve sustainable fisheries requires understanding the effects of fishing on behavior, life history and population biology of exploited fishes. At CSTAR, work focuses on using mathematical, statistical, and computer models to solve important environmental and ecological problems. The work is grounded in data, and also seeks to expand the base of basic knowledge that supports rigorous application of science to real-world problems. Furthermore, research on marine fisheries conducted at CSTAR allows testing theoretical predictions via natural and human experiments on a scale that is appropriate for understanding the dynamics of ecosystems. Such large-scale experiments are rarely available to the scientific community.

Objectives:

CSTAR continues its work of training students and post-docs in quantitative population biology relevant to the mission of NOAA Fisheries and placing them in positions in NOAA Fisheries and beyond. During the review period, CSTAR Representation in the Fisheries Ecology Division Teams are:

- Groundfish Analysis (CSTAR Alumni EJ Dick, Melissa Monk; CSTAR Assistant Specialist Nick Grunloh)
- Salmon Assessment (CSTAR Alum Will Satterthwaite)
- Landscape Ecology (CSTAR student Juan Lopez, CSTAR Assistant Researcher Jarrold Santora)
- Fisheries Economics (CSTAR post-doc Kate Richerson)
- Early Life History (CSTAR Alum Steve Munch, CSTAR Post-doc Juan Lopez)



- Molecular Ecology (CSTAR Alum and Visiting EU Marie Curie Fellow Simone Vincenzi)
- and a bit further afield
- US AMLR (CSTAR Students Ryan Driscoll, Kate Richerson)

Accomplishments & Milestones:

- Completion of the PhD in Statistics and Applied Mathematics of Juan Lopez who then started a post-doc with Dr. Steve Munch at the SWFSC
- Completion of the PhD in Ecology and Evolutionary Biology of Kate Richerson, who then started a post-doc with
- Dan Holland (NWFSC) and Andre Punt (University of Washington) after spending 3 months working with the Economics Team at the Santa Cruz Laboratory
- Ryan Driscoll participated in the US Antarctic Marine Living Resources Antarctic research cruise as a member of the zooplankton survey group.

Conferences, Meetings & Presentations

- Marine Mammal Society Meeting, December 2015 in San Francisco, CA represented by Jarrod Santora
- Alaska Marine Science Symposium, January 2016 in Anchorage, AK represented by Jarrod Santora
- Marine Biodiversity Observation Network, March 2015 at SEFSC in Miami, FL represented by Jarrod Santora
- Marine Biodiversity Observation Network, October 2015 at MBARI in Moss Landing, CA represented by Jarrod Santora
- Western Groundfish Conference, February 2016 in Newport, OR represented by Nick Grunloh
- MPE 2013+ Workshop on Management of Natural Resources, June 2015 at Howard University, represented by Juan Lopez

- American Society of Naturalists, January 2016 in Asilomar, represented by Who-Seung Lee

Education & Outreach

Academic Development

- Ryan Driscoll attended the Workshop/Seminar "Age Structured Stock Assessment" -University of Washington with Ray Hilborn. The seminar involved a weeklong workshop at the University of Washington on developing stock assessments using SS3. Subsequent to the workshop the seminar involves weekly online lectures given by Ray Hilborn and other fisheries scientist at UW. Participants included students from a variety of universities and representatives from several countries and fishery institutions.

K-12 Outreach

- Jarrod Santora provided school project data on bird and mammal distributions from current Antarctic field research survey for Monterey Academy of Ocean Sciences (MAOS, Monterey High School, Monterey, CA). Field work will be used as an educational focus for MAOS students. May and October 2015. This is a "Broader Impact" from funded NSF project.

Networking

- Juan Lopez Arriaza collaborated with the Monterey Peninsula Water Management District for his work on the Carmel River Steelhead.
- Collaborator: Kevan Urquhart, Senior Fisheries Biologist, Monterey Peninsula Water Management

NOAA Employment

- Kate Richerson, a PhD gained employment with Northwest Fisheries Science Center, January 2016
- Juan Lopez, a PhD, gained employment with Southwest Fisheries Science Center, October 2015



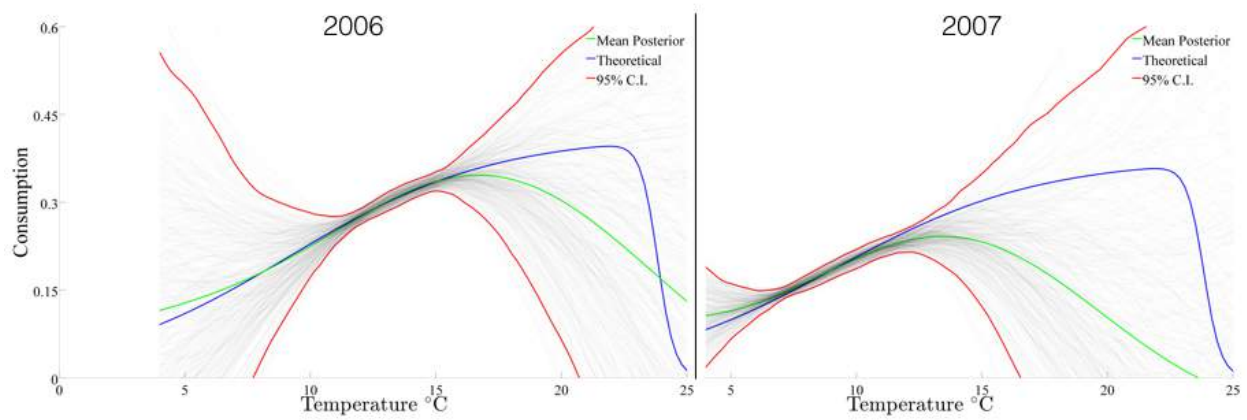


Figure 21: Bayesian computation of the thermal performance curve of steelhead trout

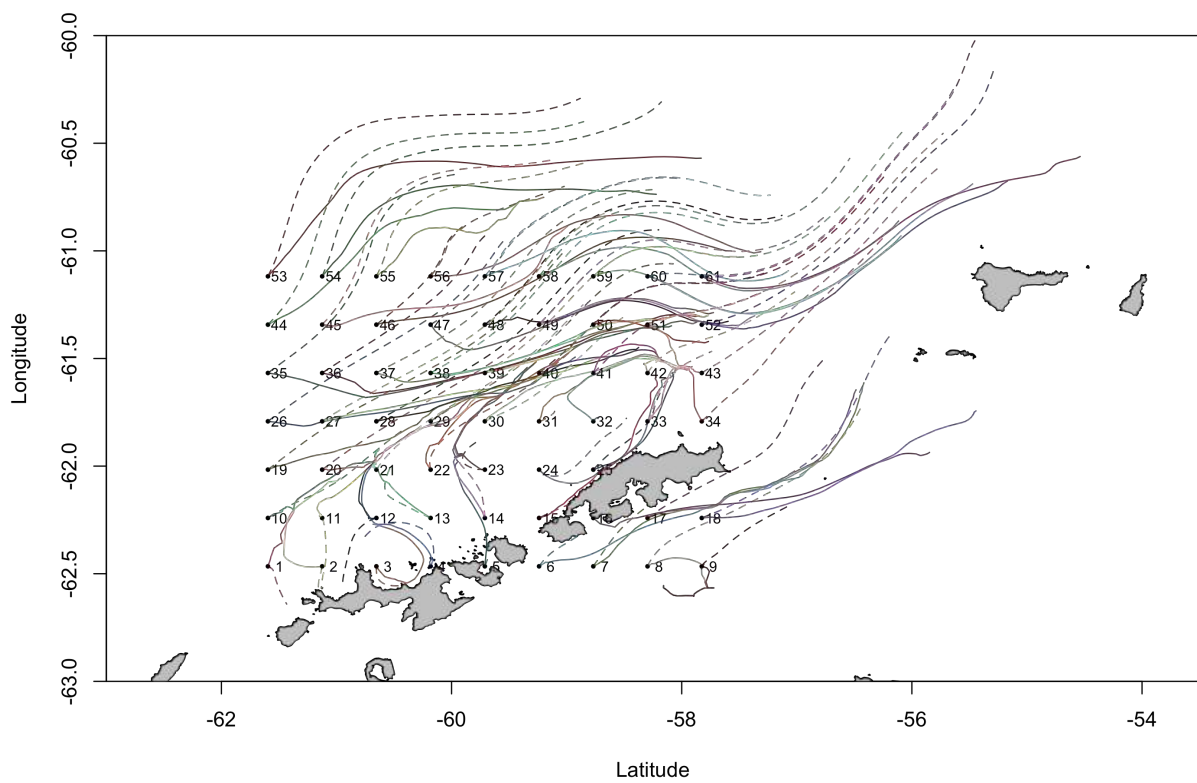


Figure 22: Mean trajectories of simulated active (solid line) and passive (dashed line) krill released at numbered starting points.



Freshwater Ecology Research Collaboration

Principal Investigator(s):

Eric Palkovacs, UC Santa Cruz

Other Key Personnel:

Dave Fryxell, UC Santa Cruz

Ben Wasserman, UC Santa Cruz

Travis Apgar, UC Santa Cruz

Gina Contolini, UC Santa Cruz

NOAA Primary Contact:

Steve Lindley, Southwest Fisheries Science Center

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Budget Amount:

\$245,271

Amendment(s):

9, 21, 52, 88, 117

Description of Research:

My research program is focused on understanding interactions between ecology and evolution – known as eco-evolutionary dynamics – primarily as these interactions occur in coastal freshwater ecosystems. The study of eco-evolutionary dynamics began with the widespread realization that evolution commonly occurs on so-called ecological time scales, enabling dynamic interactions between ecological and evolutionary processes. Human activity is a strong driver of both ecological and evolutionary change. Therefore, I am interested in the impacts of human disturbance on eco-evolutionary

dynamics and implications for conservation and resource management.

Objectives:

1. **The role of contemporary evolution in shaping ecological dynamics:** One of my major goals is to understand the importance of contemporary evolution for shaping aquatic communities and ecosystems. A major assumption across much of ecology is that *species* are the functional building blocks of communities and drivers of ecosystems. In contrast, my studies have shown important community and ecosystem effects of variation within species (among populations), and a recent meta-analysis (currently in review) shows that for many study systems the effects of diversity within species can be as large as the effects of diversity among species. While this past work points to the *potential* importance of contemporary evolution for communities and ecosystems, it is only weakly linked to ecological theory that might help predict *when* such effects might be important. One of my general goals is to link eco-evolutionary dynamics to ecological theory related to the major drivers of community and ecosystem change. One of these major ecological drivers in aquatic ecosystems is the trophic cascade, and one of my major current efforts is to ask whether the contemporary evolution of prey populations in response to predators impacts the strength of trophic cascades. I have recently received funding from NSF to use recently introduced mosquitofish populations in California as a study system to address this question. Another major unanswered question is the extent to which environmental variation influences the strength of eco-evolutionary effects. No published experiments to date have tested the



interaction between environmental variation and contemporary evolution on community or ecosystem responses. My lab is now running these experiments, examining the interacting effects of temperature variation and thermal adaptation in mosquitofish on freshwater pond communities and ecosystems. Such experiments provide important information about the drivers of community and ecosystem change and also provide new insights into how ecosystems will respond to climate change.

2. **The role of eco-evolutionary feedbacks in shaping the trajectory of evolution:** Organisms that cause major changes to the ecosystem (e.g., keystone species, ecosystem engineers, foundation species) may, in turn, shape natural selection and evolution via eco-evolutionary feedbacks. Theory, laboratory experiments, and some observational studies point to the importance of feedbacks for shaping evolution, but testing the strength of feedbacks in nature requires large scale experiments. My lab is currently running such experiments in two study systems – lakes with alewife populations in Connecticut and estuaries with stickleback populations in California. My prior studies on alewife populations suggest that key feeding traits evolve as a result of eco-evolutionary feedbacks. I am further testing this hypothesis using whole lake experiments facilitated by efforts to restore anadromous alewife to lakes with landlocked populations. I currently have an NSF RAPID grant and another NSF proposal in review to fund this work. In addition, I have begun work in California estuaries examining whether feedbacks may contribute to the loss of lateral plates in threespine stickleback populations as they adapt to freshwater conditions. The UCSC Hellman Fellows Program has

funded pilot work in the stickleback system that will provide data to facilitate future proposals.

3. **The integration of eco-evolutionary dynamics into conservation and resource management:** I am working on a variety of projects that apply evolutionary principles to conservation and fisheries management. The largest of these projects involves the application of genetic markers to facilitate the recovery of anadromous river herring populations. This work is in collaboration with scientists at the NMFS Lab and has been funded by grants from the National Fish and Wildlife Foundation, The Nature Conservancy, and the Atlantic States Marine Fisheries Commission. I am also working on the evolutionary effects of dams and culverts on steelhead populations in California and brook trout populations in Quebec. This work is aimed at designing restoration strategies that take into account the effects of human activity on evolution in wild populations. I have initiated collaborations to examine eco-evolutionary dynamics in North American and European lakes where evolution in response to fishing may be having a major impact on the ecology of the lakes. I have proposals in review to examine effects of hatchery adaptation on the recovery of salmon in California. Many of these studies are just beginning, but these study systems show great promise for moving the study of eco-evolutionary dynamics out of the laboratory and small-scale experiments and into real world managed ecosystems.

Accomplishments & Milestones:

- Published the first genetic assessment identifying the natal origins of river herring bycatch and potential impacts on river herring recovery.



- Published a paper illustrating the ecological importance of sex ratio variation in a widespread invasive fish species.
- Received funding for a project using river restoration to test the ecological and evolutionary consequences of secondary contact between anadromous and landlocked alewife populations and consequences for anadromous alewife recovery (NSF, ASMFC, TNC).
- Received research funding to investigate how predation and habitat alteration interact to impact juvenile salmon survival in the SF Bay Delta (CDFW).
- Received research funding to investigate the role of evolution in mediating the strength of trophic cascades in freshwater ecosystems (NSF).

Honors and Awards

- a. Dave Fryxell received the American Society of Naturalists Student Research Award and the Society for Freshwater Science Student Research Award on 3/24/16.

Conferences, Meetings & Presentations

- a. Gordon Research Conference on Predator-Prey Interactions, January 2016 in Ventura, CA, represented by Eric Palkovacs and Dave Fryxell
- b. Cal-Neva/Western Division American Fisheries Society Conference, March 2016 in Reno, NV, represented by Dave Fryxell, Ben Wasserman, Travis Apgar, and Gina Contolini
- c. Western Society of Naturalists Meeting, November 2015 in Sacramento, CA, represented by Ben Wasserman

Education & Outreach

Communications

- a. Public lecture at the Seymour Marine Discovery Center - Described "evolution in the anthropocene: how human activity is changing the shape of life"
- b. Invited lecture at the University of Michigan - Described "evolution as an agent of ecosystem change: the alewife as a case study"
- c. Invited lecture at UC Berkeley - Described "the importance of intraspecific biodiversity for aquatic communities and ecosystems"
- d. Newspaper Column, Capitola-Soquel Times (Oct 1, 2016) - This column describes strategies to manage evolving fisheries.
- e. Newspaper Column, Aptos Times (Sept 1, 2016) - This column describes the causes and consequences of evolution driven by fisheries harvest.
- f. Interviewed for BBC Radio Documentary (aired on February 4, 2016) - *Unnatural Selection* hosted by Dr. Adam Hart

Academic Development

- a. Gordon Research Conference on Predator-Prey Interactions: Eric Palkovacs gave an oral presentation and Dave Fryxell gave a poster presentation
- b. Cal-Neva / Western Division American Fisheries Society Conference: Dave Fryxell, Ben Wasserman, Travis Apgar, Gina Contolini gave oral presentations.
- c. Western Society of Naturalists Meeting: Ben Wasserman gave an oral presentation
- d. Eric Palkovacs gave an invited lecture at the University of Michigan titled, "Evolution as an agent of ecosystem change: the alewife as a case study"
- e. Eric Palkovacs gave an invited lecture at UC Berkeley titled "The importance of intraspecific biodiversity for aquatic communities and ecosystems"



K-12 Outreach

- a. NSF Research Experience for Teachers Program (RET): This program was initiated with the first participating high school teacher working on research in the Palkovacs Lab
- b. Summer Internship Program (SIP): Six high school students from the Santa Cruz/Monterey area were engaged in

summer research projects in the Palkovacs Lab.

Networking

1. Institute for the Study of Ecological and Evolutionary Climate Impacts (ISEECI) Population Ecology and Evolution Working Group: Setting objectives for climate change research across the UC Natural Reserve System.



Figure 23: Scientists sorting through a large catch of pelagic red crabs (*Pleuroncodes planipes*) off San Nicolas Island while aboard the R/V Ocean Starr during the 2015 midwater trawl survey



Investigations in Fisheries Ecology

Principal Investigator(s):

Eric Palkovacs, UC, Santa Cruz

Other Key Personnel:

Anne Criss, UC, Santa Cruz

Lyndsey Lefebvre, UC, Santa Cruz

Kerri Pipal, UC, Santa Cruz

Andrew Pike, UC, Santa Cruz

Maya Friedman, UC, Santa Cruz

Sara John, UC, Santa Cruz

Flora Cordoleani, UC, Santa Cruz

Lea Bond, UC, Santa Cruz

Colin Nicol, UC, Santa Cruz

Peter Dudley, UC, Santa Cruz

Emily Tucker, UC, Santa Cruz

Vamsi Sridharan, UC, Santa Cruz

Alina Montgomery, UC, Santa Cruz

Ben Martin, UC, Santa Cruz

Natnael Hamda, UC, Santa Cruz

Miles Daniels, UC, Santa Cruz

Alice Thomas-Smyth, UC, Santa Cruz

David Stafford, UC, Santa Cruz

Neosha Kashef, UC, Santa Cruz

Jeff Perez, UC, Santa Cruz

Ann-Marie Osterback, UC, Santa Cruz

Cynthia Kern, UC, Santa Cruz

Sabrina Beyer, UC, Santa Cruz

Vanessa Lo, UC, Santa Cruz

JoAnne Siskidis, UC, Santa Cruz

Who Seung Lee, UC, Santa Cruz

Cyril Michel, UC, Santa Cruz

Jeremy Notch, UC, Santa Cruz

Nicholas Demetras, UC, Santa Cruz

Brendan Lehman, UC, Santa Cruz

Megan Sabal, UC, Santa Cruz

Alex McHuron, UC, Santa Cruz

Ily Iglesias, UC, Santa Cruz

Whitney Friedman, UC, Santa Cruz

Anthony Clemento, UC, Santa Cruz

Martha Arciniega, UC, Santa Cruz

Cassie Columbus, UC, Santa Cruz

Diana Baetscher, UC, Santa Cruz

Thomas Ng, UC, Santa Cruz

Joe Bizarro, UC, Santa Cruz

Ethan Mora, UC, Santa Cruz

Michael Beakes, UC, Santa Cruz

Ellen Campbell, UC, Santa Cruz

Elena Correa, UC, Santa Cruz

Raziel Davison, UC, Santa Cruz

Mark Henderson, UC, Santa Cruz

Emerson Kanawai, UC, Santa Cruz

Shona Allen, UC, Santa Cruz

Brigid Moran, UC, Santa Cruz

Hayley Nuetzel, UC, Santa Cruz

Michael Mohr, NOAA Fisheries

John Field, NOAA Fisheries

Don Pearson, NOAA Fisheries

Keith Sakuma, NOAA Fisheries

Xi He, NOAA Fisheries

EJ Dick, NOAA Fisheries

Melissa Monk, NOAA Fisheries

Michael O'Farrell, NOAA Fisheries

Will Satterthwaite, NOAA Fisheries

Nate Mantua, NOAA Fisheries

Heidi Fish, NOAA Fisheries

Tommy Williams, NOAA Fisheries

Brian Spence, NOAA Fisheries

David Boughton, NOAA Fisheries

Dave Rundio, NOAA Fisheries

Brian Wells, NOAA Fisheries

Eric Danner, NOAA Fisheries

Lee Harrison, NOAA Fisheries

Cameron Speir, NOAA Fisheries

Aaron Mamula, NOAA Fisheries



Rosemary Kosaka, NOAA Fisheries
Sue Sogard, NOAA Fisheries
Erick Strum, NOAA Fisheries
Stephan Munch, NOAA Fisheries
Joseph Kiernan, NOAA Fisheries
Jeff Harding, NOAA Fisheries
Arnold Ammann, NOAA Fisheries
Carlos Garza, NOAA Fisheries
Libby Gilbert-Horvath, NOAA Fisheries
Devon Pearse, NOAA Fisheries
Eric Anderson, NOAA Fisheries
Mary Yoklavich, NOAA Fisheries
Tom Laidig, NOAA Fisheries
Diana Watters, NOAA Fisheries
Rachel Johnson, NOAA Fisheries

NOAA Primary Contact:

Steven Lindley, NOAA Fisheries , SWFSC

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC
Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use
of Coastal and Ocean Resources Through
Ecosystem-based Management

Budget Amount:

\$14,870,425

Amendment(s):

6, 22, 63, 72, 97, 99, 122

Description of Research:

This cooperative research program encompasses a large number of individual studies conducted by scientists from the University of California Santa Cruz (UCSC), the National Marine Fisheries Service, Southwest Fisheries Science Center, Fisheries Ecology Division (FED) and Environmental Research Division (ERD), and many collaborators at

other institutions and agencies. The overall objectives are to conduct research needed to support (1) management and recovery planning for Pacific salmonids and sturgeon listed under the Endangered Species Act; (2) stock and ecosystems assessments and harvest management for West Coast groundfish and Pacific salmon fisheries; and (3) economic assessment of fisheries and fishing communities in California.

Project scientists met research goals, which addressed a wide range of topics on biology, analytical methods, and economics related to the management of groundfish, salmon, and the California Current ecosystem.

Accomplishments included final completion of a number of major projects resulting in publication of papers and reports; completion of several large field and laboratory data collection efforts, data analyses, and modeling projects; and initiation of a number of new studies through hiring of research staff, developing research plans and protocols, and beginning data collection or model development. Results were published in 41 journal articles and 2 reports, 1 book review, 1 workshop summary/proceedings, 1 PhD dissertation, and an additional 3 articles were in press or submitted. Many project scientists engaged in more than 10 high profile conferences, workshops, and symposia, as well as participated in multiple outreach events and working groups to present research, network and collaborate with other scientists, contribute to training and professional development within the field, and provide information to the public. Academic development was provided to undergraduate and graduate students and post-doctoral scholars through employment and support of thesis and dissertation research.

Objectives:

Specific research projects addressed 10 objectives:



1. habitat management – research on advanced sampling technologies to estimate the distributions, abundances, and habitats of fish and zooplankton in the north pacific ocean and the California delta
2. climate and ecosystems – research on climate change and ecosystem variability in the North Pacific Ocean: the dynamics of marine populations
3. landscape ecology – landscape ecology of Pacific salmonids
4. habitat ecology – marine habitat studies
5. salmon ocean and estuarine ecology – comparative studies in salmon ecology
6. groundfish analysis – groundfish stock assessment support
7. early life history: climate change effects on early life states of marine and anadromous fishes
8. assessment of black abalone populations
9. economics – application of economic models to fisheries, protected species and ecosystem management issues
10. genetics – integrated genetic monitoring and evaluation of salmon and steelhead in California

Project scientists used a wide range of methods to address these research questions, including field sampling, laboratory experiments, physical and biological modeling, spatial analysis and modeling using GIS and remote sensing, and economic data collection and analysis.

Accomplishments & Milestones:

- Published a journal article relating trends in hatchery practices to strength of portfolio effects in Central Valley Chinook salmon
- Published a journal article using genetic techniques to learn about the ocean spatial distribution of multiple Chinook salmon stocks

- Published a commentary about climate change and adaptive responses in Pacific salmon
- Published a report on the feasibility of parentage-based genetic tagging (PBT) in management of Pacific salmon
- Submitted a manuscript on methods for integrating high resolution spatial data from vessel monitoring systems with traditional sources of fisheries management data.
- Published a journal article describing historical fishing mortality rates for Sacramento River winter-run Chinook salmon.
- Published a Technical Memorandum describing the proceedings of a workshop focused on evaluation of the feasibility of developing alternative fishery management strategies for California coastal Chinook salmon.
- Implemented a feasibility study to develop and test a variety of Passive Integrated Transponder (PIT) tag detection systems to assess the feasibility of implementing large scale tagging and detection programs in the Central Valley and Sacramento-San Joaquin Delta for monitoring movement and survival of listed salmonids. Designed and installed prototype detection arrays on the San Joaquin and Mokelumne River for field testing in spring 2016.
- Published a journal article on methods for measuring relative predation risk on salmonid smolts using Predation Event Recorders (PERs).
- Published a journal article reporting on effectiveness of spatial closures for rockfish recovery.



- Published a Technical Memorandum on the benefits to steelhead of Carmel River Reroute and Dam Removal
- Published a journal article describing the reproductive strategy and annual reproductive cycle of Pacific sanddab in California waters.
- Published a journal article describing the importance of age data in developing accurate stock assessments for West Coast groundfish populations.
- Completed stock assessments of Bocaccio and Chilipepper rockfish, both including updated life history and reproductive ecology data, to support fisheries management.
- Published a journal article on the cooperative fishery research project with the ocean salmon fishing fleet on ocean distribution and migration patterns of Chinook salmon in the California Current.
- Published a journal article outlining the genetic relationships of steelhead and rainbow trout from hatcheries and natural populations in the California Central Valley.
- Developed a generalized salmon cohort reconstruction model.
- Designed and built a Habitat Use Database for Pacific Coast Groundfish.
- Completed the annual summer salmon survey in the coastal ocean between San Francisco and central Oregon: an 18-day research cruise where a team of 12 scientists collected approximately 600 juvenile and subadult salmonids, along with biological and physical ecosystem data.
- Completed a 21-day research cruise aboard the R/V Ocean Starr to collect juvenile salmon and associated biological and oceanographic samples. The cruise encountered “unusual” conditions related to the large persistent pool of warm water in the northeastern Pacific (e.g. uncommon southern species such as sunfish and barracuda in our trawl catch), and relatively few juvenile salmon.
- Developed a Winter-run Chinook salmon individual based model that is being used to evaluate the impacts of varying stream flow, stream temperature, and physical habitat conditions related to spawning, incubation, and fry life stages.
- Developed continuous maps of river channel bathymetry and sediment grain-size for 50 km of the Merced River, using remote sensing techniques. Started constructing hydrodynamic models for ~250 km of the Merced and Tuolumne Rivers.
- Developed a continuous map of river channel bathymetry and fish distribution along the lower San Joaquin River using boat-based acoustic survey technologies developed by the AST team at the SWFSC - La Jolla lab
- Completed the field component of a San Joaquin River salmonid smolt predation study geared towards bridging the gap between low smolt survival estimates seen in the San Joaquin River and the likely cause of mortality: predation. Novel techniques were employed, including predator density maps using acoustic survey technologies, spatial and temporally explicit measures of relative predation risk using Predation Event Recorders, and DNA barcoding techniques to identify salmonid DNA in the diets of predator species.
- Completed a Center for Independent Experts Review of the Central Valley Winter-run Chinook Life Cycle Model.



Conferences, Meetings & Presentations

- a. American Fisheries Society - Cal-Neva, April 2015, Santa Cruz, CA, represented by Rachel Johnson, Flora Cordoleani, Andrew Pike, Eric Danner, Cyril Michel, Jeremy Notch, Nick Demetras, Sean Hayes, Ann Marie Osterback, Colin Nicol
- b. NPAFC Salmon and Climate Change, May 2015, Osaka, Japan, represented by Steve Lindley, David Huff, Sean Hayes
- c. 2015 Biennial Forum of the North American Association of Fisheries Economists, May 2015, Ketchikan, Alaska, represented by Rosemary Kosaka, Alice Thomas-Smyth
- d. American Fisheries Society Annual Meeting, August 2015/Portland, OR, represented by Joe Bizzarro, Alice Thomas-Smyth, Neosha Kashef, David Stafford, Sabrina Beyer, Rebecca Miller, Lyndsey Lefebvre, Anne Criss, David Stafford, Neosha Kashef, Kerrie Pipal, Vamsi Sridharan, Flora Cordoleani, Colleen Petrik, Mary Yoklavich, Elizabeth Gilbert-Horvath
- e. Western Society of Naturalists Meeting, November 2015/Sacramento, CA, represented by Neosha Kashef, Evan Mattiasen, David Stafford
- f. Center for Independent Experts Review of the Central Valley Life Cycle Model, November 2015/Santa Cruz, CA, represented by Anne Criss, Flora Cordoleani, Andrew Pike, Sara John, Kerrie Pipal, Michael Beakes, Steve Lindley, Will Satterthwaite, Michael O'Farrell
- g. Western Groundfish Conference, February 2016/Newport, OR, represented by Joe Bizzarro, Sabrina Beyer, Neosha Kashef, Morgan Arrington, David Stafford, Lyndsey Lefebvre, Rebecca Miller, Nikolas Grunloh, Mary Yoklavich, EJ Dick, Melissa Monk

- h. Ocean Sciences Conference, February 2016/New Orleans, LA, represented by Ben Martin, Eric Danner
- i. Cal-Neva / Western Division American Fisheries Society Conference, March 2016/Reno, NV, represented by Diana Baetscher, Flora Cordoleani, Raz Davison
- j. Pacific Coast Steelhead Management Meeting, March 2016/Asilomar/Pacific Grove, CA, represented by Kerrie Pipal, Rachel Johnson

Education & Outreach

Communications

- a. UC Davis, Guest Lecture - Staff presented a guest lecture and led discussion of ecosystem-based fisheries management for graduate course in conservation biology at UC Davis. The audience included UC Davis faculty and students.
- b. Moss Landing Marine Laboratory Guest Lectures - Staff presented a guest lecture on aspects of fisheries management and ESA-listed salmon populations. The audience included Moss Landing Marine Laboratory faculty and students. Staff gave a lecture on reproductive ecology of rockfish and the role of maternal effects to Moss Landing Marine Laboratory faculty and students.
- c. Presentation at the 2016 CDFW Salmon Informational Meeting - Staff gave a presentation on salmon abundance forecasts and a preliminary outlook for 2016 ocean salmon fisheries to CDFW, fishing groups and the general public.
- d. Media Interviews
 - Sean Hayes and Eric Danner were interviewed by Bob Service, staff writer for Science, about the current drought conditions in California, and how the science center is modeling the impacts on salmon.



- Eric Danner and Nate Mantua did an interview about the drought and winter run Chinook salmon with Anne Casselman from Scientific American magazine.
- e. Webinar on the development of the California's Central Valley Chinook Life Cycle Model - Flora Cordoleani and Colleen Petrik gave updates on the development of the spring-run and fall-run Central Valley Chinook life cycle models as part of a webinar hosted by FED. Approximately 80-100 people attended the webinar.
- f. Presentation to NOAA/NOS staff - Eric Danner presented the talk "Salmon, Water Management, and Drought in California's Central Valley" for the NOAA/NOS Science Seminar Series.

Academic Development

- a. Academic development was provided to undergraduate and graduate students and post-doctoral scholars through employment and support of thesis and dissertation research. Additionally scientists gave several guest lectures and supervised students in field work activities. Examples include
- b. Guest Lectures
 - a. Staff gave multiple guest lectures and seminars to academic institutions. Examples include,
 - b. Devon Pearse gave a seminar presentation to the UC Davis Genetics Graduate Group entitled "Genomic Adaptation, Parallel Evolution, and Conservation of Steelhead/Rainbow Trout."
 - c. Eric Danner presented a talk on a variety of research at FED to the Integrated Marine Biochemistry and Ecosystem Research (IMBER) symposium at UC Santa Cruz.

- c. Field work
 - i. Many graduate students gained on the ground experience by regularly participating in core field work central to the NOAA Fisheries' mission.
 - ii. An example of this work includes the Upper Tuolumne River Genetics Study. Graduate students Jeremy Notch (UCSC) and Ben Burford (Stanford) along with NOAA scientists (Devon Pearse, Sean Hayes) and UCSC scientists (Alex McHuron, Cyril Michel) successfully collected approximately 200 samples of *O. mykiss* from sites in the Upper Tuolumne River as part of a NOAA Fisheries West Coast Regional Office-supported genetic characterization above Don Pedro Reservoir.
- b. Other projects where graduate students gained on the ground experience included
 - i. Salmon Acoustic Tagging and Telemetry Studies – Designed to track salmon movement through California's Central Valley.
 - ii. Juvenile Rockfish Recruitment Study
 - iii. Juvenile Salmon Study
 - iv. Salmon Predator Studies in California's Central Valley

K-12 Outreach

- a. Scientists gave multiple presentations on their work to high schools and elementary schools in the Santa Cruz/Monterey area.

Networking

- a. Staff participated in many formal and informal interagency working groups. The following are examples of the outreach and networking activities.
- b. Eric Danner attended the NASA Biodiversity and Ecological Forecasting



Meeting in Washington, DC, and presented the talk "From the Watershed to the Ocean: Using NASA Data and Models to Understand and Predict Variations in Central California Salmon."

- c. Ann-Marie Osterback and Joe Kiernan held a conference call with a representative of the County of Santa Cruz to discuss potential locations for new PIT tag antenna arrays in the Soquel Creek and San Lorenzo River watersheds.
- d. Carlos Garza and Anthony Clemento attended the first annual San Joaquin River Restoration Project Science Conference. Garza gave a talk entitled "Genetic considerations in donor stock selection for SJRRP broodstock."

- e. Melissa Monk, E.J. Dick and John Field attended the Pacific Fisheries Management Council's (PFMC) Nearshore Assessment Workshop in Portland, OR. Melissa and E.J. gave presentations on data availability and index methodology for the 2015 China rockfish assessment. Attendees included state data stewards, stock assessment team members, PFMC Scientific and Statistical Committee members and industry representatives.

NOAA Employment

Rachel Johnson, a PhD, gained employment with Southwest Fisheries Science Center, Fisheries Ecology Division in April 2015



Figure 24: Jeremy Notch (UCSC) inserting an acoustic tag into a juvenile Chinook salmon smolt on Mill Creek, spring of 2015. Photo by Alex McHuron





Figure 25: UCSC and NMFS scientists seining for juvenile Chinook salmon in a Mill Creek irrigation canal." Photo by Alex McHuron





Figure 26: A rotary screw trap used to collect migrating smolts in Mill Creek." Photo by Jeremy Notch





Figure 27: Vanessa Lo (UCSC) holds an ocean sunfish (*Mola mola*) caught during NOAA Fisheries' ocean salmon survey in August 2015." photo credit: Cyril Michel



Collaborative Acoustic Studies in the Central and Western Pacific Ocean

Principal Investigator(s):

Dr. Ana Širović, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Dr. Simone Baumann-Pickering, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Erin Oleson, Pacific Islands Fisheries Science Center (PIFSC)

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Budget Amount:

\$432,231

Amendment(s):

86, 113

Description of Research:

Trends in low frequency ocean ambient noise were analyzed for three sites (Kona, Palmyra Atoll, and Saipan) over a total of eight instrument-years of data. All sites exhibited low to medium levels of noise from shipping, with the lowest levels at Palmyra Atoll. Most sites also had a seasonally variable contribution to the soundscape by various baleen whales. In Kona, for example, it was possible to identify changes in humpback whale song over the years from their spectral features (Figure 1). Saipan showed the least amount of baleen whale contributions to the soundscape and had the highest noise levels in shipping frequency bands.

To evaluate propagation ranges of baleen whale calls at two sites in the western Pacific (Tinian and Saipan), blue whale, fin whale, minke whale, and humpback whale calling sequences were sampled and their received levels were measured. In general, fin whale received levels were the highest, however that was expected given high source levels of their calls and favorable propagation characteristics at lower frequencies. Based on the measured received levels and our propagation models, there may be a spatial separation between different species of baleen whales that occur in the vicinity of Saipan. Thus, at Saipan, minke whales appeared to be closest to the deployment location, mostly at ranges 10-30 km. Calling fin whales occurred from as close as 10 or 20 km to potentially even beyond our modeled detection range (100 km). The one blue whale call sequence we measured was likely from a relatively distant whale (farther than 60 km). Calling humpback whales were most likely found within ranges of 20-60 km, although farther detection was also possible. At Tinian, there was a lot less variation in range distributions in the measured examples of blue, fin and humpback whales, with all three species likely calling at a distance of more than 20 km, but most closer than 100 km.

One year of acoustic data (July 2013-June 2014) collected at a site off Tinian was analyzed for the occurrence of odontocete signals (Figure 2). Sperm whales were acoustically encountered throughout the year with most detections in March. Short finned pilot whales were also encountered regularly, except from mid-December to late March when few encounters occurred. False killer whales occurred with some regularity throughout the year but overall, they were less frequent than sperm whales or short



finned pilot whales. They appeared to have a diel pattern of increased daytime foraging activity. Risso's dolphins were detected between mid-December and mid-January, with one day of encounters in February and April. They showed a distinct nighttime foraging preference. Pygmy or dwarf killer whales (*Kogia* spp.) were detected frequently during very short encounters (likely due to their small detection range) with peak occurrence in December. Killer whales passed through the detection range of the recorder on three occasions: in October, November, and April. Blainville's beaked whales were detected frequently with peaks in presence in September-October, December-January, and April-May. A beaked whale signal of unknown origin (BWC) occurred in low numbers throughout the recording period. A large number of acoustic detections were from unidentified odontocetes.

Objectives:

The goal of this project was to collaborate with PIFSC on three tasks: (1) investigations of low frequency noise and baleen whale calls; (2) investigations of high frequency cetacean signals; and (3) provide technical support for continued data collection.

Interannual comparison of noise levels were made at three sites with long term data in the

central and western Pacific Ocean to assess overall trends in ambient noise, and we investigated the relationships between ambient noise and changes in local and basin-wide shipping traffic. Also, propagation models to evaluate ranges over which baleen whales are detected in Northern Mariana Islands were developed. In addition, we analyzed one year of data to determine the presence of beaked whale signals in the waters off Saipan.

Accomplishments & Milestones:

- Eight years of data from three sites were analyzed for patterns in ocean ambient noise.
- Acoustic propagation models were developed for low frequency (baleen whale) sounds at two locations in the Northern Marianas Islands.
- Acoustic monitoring of 7 species of odontocetes and two unidentified signal types during one year of acoustic data, showing clear diel behavior for some species and possible seasonal trends.

Conferences, Meetings & Presentations

- a. Oceanoise 2015, May 11-15, 2015 in Vilanova i la Geltru, Spain, represented by Ana Širović



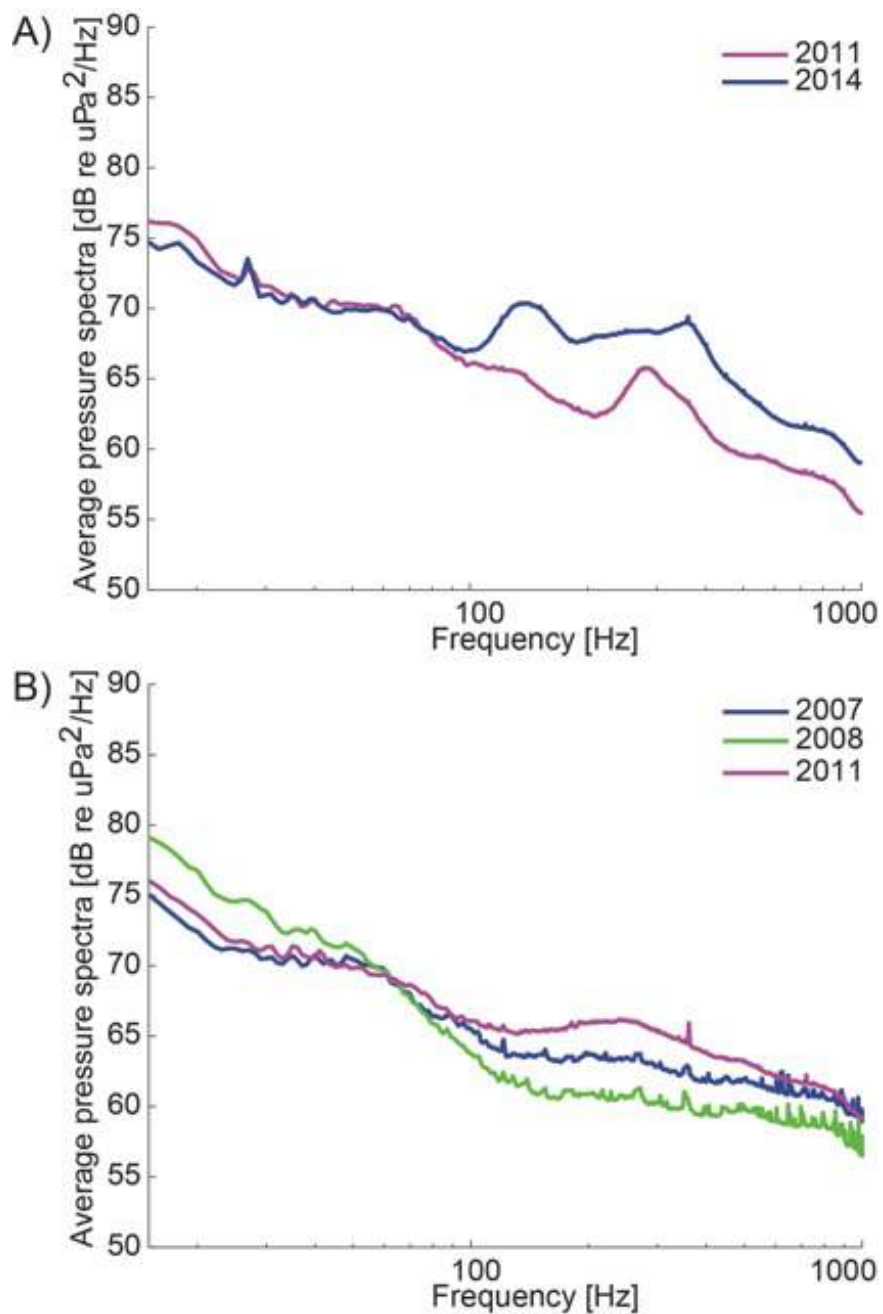


Figure 28: Average monthly sound pressure spectrum levels from 15 to 1000Hz at Kona, Hawaii for (a) March and (b) September. Color denotes different year of data. Note presence of humpback whale “bumps” from 100-500 Hz in March data and their absence in September.



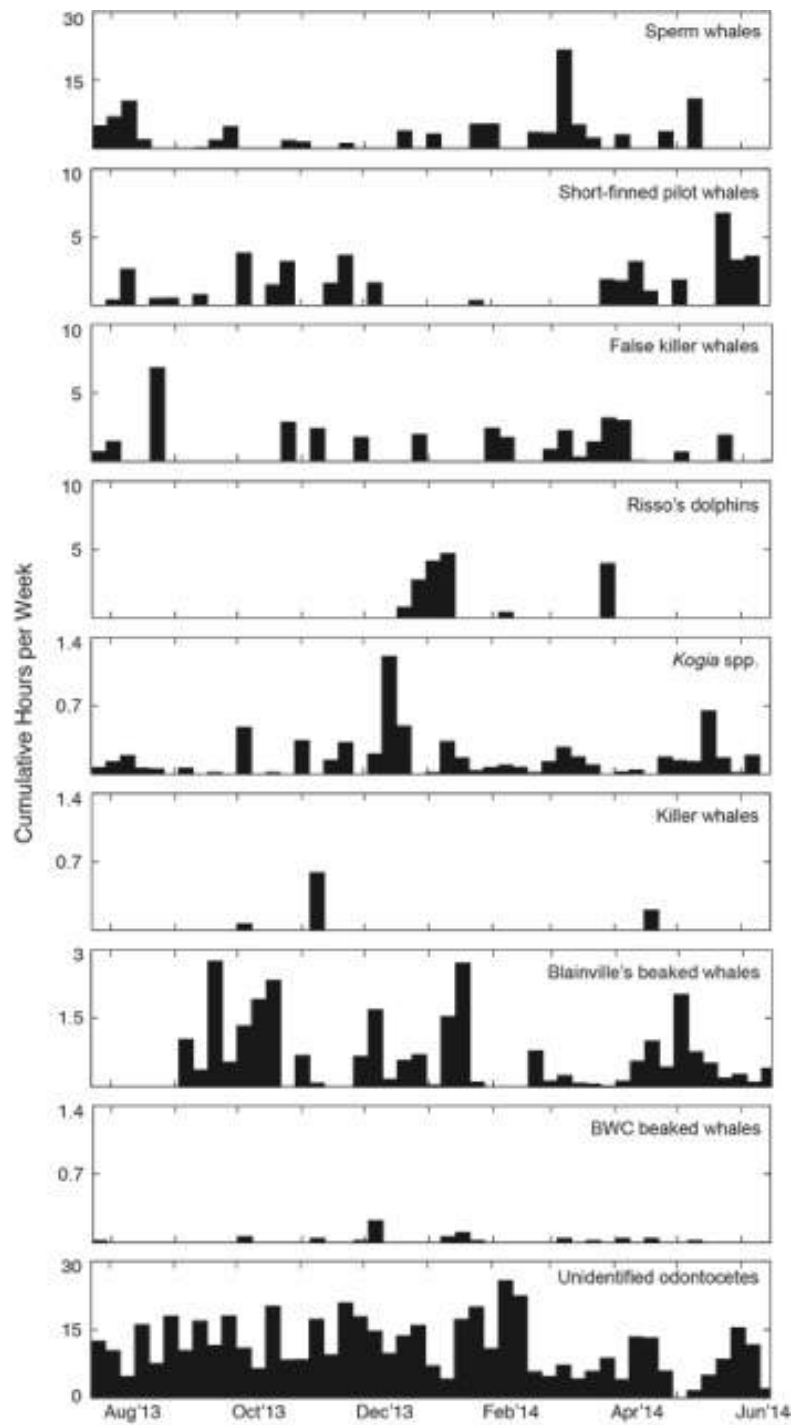


Figure 29: Cumulative hours of acoustic detections of odontocete species per week at site Tinian over one year of acoustic recording effort.



Collaborative Ocean Observing and Fisheries Oceanography Research off Northern California

Principal Investigator(s):

Dr. Brian N. Tissot, Marine Laboratory, Humboldt State University

Other Key Personnel:

Dr. Christine Cass, Department of Oceanography, Humboldt State University

Dr. Jeff Abell, Department of Oceanography, Humboldt State University

Roxanne Robertson, Marine Laboratory, Humboldt State University

NOAA Primary Contact:

Dr. Eric Bjorkstedt, NMFS (SWFSC/FED)

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Goal 3: Serve Society's Needs for Weather and Water Information

Budget Amount:

\$151,563

Amendment(s):

126

Keywords:

Ocean Observing, Zooplankton, Trinidad Head Line, Ecosystem Indicators

Description of Research:

The goals of this project are (1) to facilitate ongoing ocean observation cruises along the

Trinidad Head Line, to prepare hydrographic and biological data to support coastal observation networks and development of ecosystem indicators, and (2) to support focused research in fisheries oceanography and recruitment dynamics off northern California. The primary strategy for achieving these goals is to support a research technician tasked with the day-to-day operations associated with planning, executing, and demobilizing from observation cruises and assisting with coordination of post-cruise laboratory analysis and data synthesis. This work is based out of Humboldt State University, and represents a collaborative effort between HSU and the Fisheries Ecology Division of NMFS' Southwest Fisheries Science Center.

Objectives:

1. Analysis of euphausiid abundance, stage- and size-structure from the bongo samples, as well as the extraction of key meroplanktonic taxa (fishes, decapod crustaceans, and cephalopods) for identification and enumeration, and extend our nascent analysis of energetic content in key zooplankton taxa.
2. Collaborate with Bill Peterson (NWFSC, Newport, Oregon) on analysis of copepod abundance and community structure but will increase our capacity to process these samples in house as we develop experience through training and consultation with expert zooplankton taxonomists;
3. Transfer of historical CTD data sets to the ERDDAP server maintained by the Environmental Research Division of the SWFSC, and implement routine updates to these data sets with the goal of having CTD data available within a week of each



cruise and core zooplankton, chlorophyll, and nutrient data available within approximately two months.

4. Incorporate additional sampling to support harmful algal bloom (HAB) monitoring and research in collaboration with UCSC and CeNCOOS.

Accomplishments & Milestones:

We have conducted hydrographic and biological sampling on 12 successful cruises along the Trinidad Head Line (THL), processed hydrographic data, coordinated laboratory efforts to catch up on analysis of archived specimens (technical support for plankton sorting augmented by funding from the Ocean Protection Council), and ensured timely calibration and maintenance of instrumentation. This year saw completion of a retrospective analysis of euphausiid abundance and community for the THL time series, and presentation of these and complementary results at several conferences and workshops. Results from this work included documenting effects of the “warm blob” waters in late 2014 and the subsequent El Niño on zooplankton communities. CIMEC-funded staff have also supported operations of a SeaGlider along a transect that spans much of the THL and extends well offshore through collaboration with CeNCOOS, NANOOS, and OSU. In response to the massive harmful algal blooms in 2014 and

2015 we have partnered with UCSC to provide monthly samples from along the THL. These samples will support ongoing HAB research at UCSC, e.g., development of HAB forecasts in collaboration with CeNCOOS.

Conferences, Meetings & Presentations

- a. Eastern Pacific Ocean Conference, September 2015 at Stanford Sierra Camp in Fallen Leaf Lake, CA, represented by Roxanne Robertson and Eric Bjorkstedt
- b. Pacific Anomalies Workshop, January 2016 in Seattle, WA, represented by Eric Bjorkstedt and Roxanne Robertson
- c. CalCOFI, December 2015 in Moss Landing, CA, represented by Eric Bjorkstedt

Education & Outreach

K-12 Outreach

- a. Science Night Booth-Presentation at Fuente Nueva Charter School - Dr. Eric Bjorkstedt and Roxanne Robertson participated in the charter school's K-5 science night to introduce basic fisheries oceanography principles to students. Informal demonstrations and lectures were given on zooplankton taxa and sampling methods, the role of plankton in marine food webs, and how environmental conditions can impact zooplankton community structure.



Deep-Sea Coral Survey Off Northern California

Principal Investigator(s):

Dr. Brian N. Tissot, Marine Laboratory,
Humboldt State University

Other Key Personnel:

Tom Laidig, NOAA Fisheries, Southwest
Fisheries Science Center

Lisa Krigsman, NOAA Fisheries, Southwest
Fisheries Science Center

M. Elizabeth Clarke, NOAA Fisheries,
Northwest Fisheries Science Center

Jeff Anderson, Nature Imagery

Erica Fruh, NOAA Fisheries, Northwest
Fisheries Science Center

Jeremey Taylor, University of Hawaii & NOAA
Fisheries, Pacific Islands Fisheries Science
Center

Chris Romsos, Oregon State University

NOAA Primary Contact:

Mary Yoklavich, NOAA Fisheries, Southwest
Fisheries Science Center

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC
Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use
of Coastal and Ocean Resources Through
Ecosystem-based Management

Goal 2: Understand Climate Variability and
Change to Enhance Society's Ability to Plan
and Respond

Goal 3: Serve Society's Needs for Weather and
Water Information

Budget Amount:

\$71,077

Amendment(s):

106



Description of Research:

The overall goals of this study were to assess the abundance, distribution, and habitats of corals and sponges, as well as associated fishes off Northern California, and to provide this information to the Pacific Fishery Management Council's

review of Pacific Groundfish Essential Fish Habitat (EFH). In particular, these data will be useful to interpret the results of recent predictive models of coral habitat suitability that have been developed to locate marine protected areas (MPAs) off Northern California. The primary strategy for achieving these goals was to charter the CSU research vessel Pt. Sur in support of a cruise to conduct visual surveys in the study area. This work represents a collaborative effort between HSU and the Fisheries Ecology Division of NMFS' Southwest Fisheries Science Center.

Objectives:

1. Collect baseline data on the distribution, abundance, size, and condition, of deep sea coral and sponge communities in approximately 500 - 1200 m depth off northern California;
2. Document environmental conditions of DSC&S habitats, including depth, seafloor substratum types, and seawater temperature, salinity, and dissolved oxygen to help understand factors that influence DSC&S distribution; and
3. Conduct a geophysical survey using the ship's echosounder to improve our understanding of topographic features associated with coral and sponge communities;

Accomplishments & Milestones:

With perfect sea conditions and fair skies in an area of the coast that is otherwise

notorious for foul weather and high swells, the researchers recorded close to 100,000 images of corals, sponges, fishes and other marine life with digital, paired still cameras during daytime operations. Nearly 48,000 corals from at least 23 taxa were observed, including black corals, bamboo corals, and gorgonians, some of which may be hundreds if not thousands of years old. Sponges occurred on most of the dives, with a total of 5,200 individuals represented by 13 taxa. Relatively few fishes (mostly thornyheads) and marine debris were observed. The ship's echosounder was used to map the seafloor and sub-bottom geologic features each night, and water conductivity, temperature, dissolved oxygen, and density were measured at each station. These data will help us

characterize seafloor habitat types associated with the corals.

Education & Outreach

Communications

- a. All data from this project has been submitted to NOAA's Deep Sea Coral Research and Technology Program to be made available through the National Database of Deep Sea Corals and Sponges:
<https://deepseacoraldata.noaa.gov/>

Networking

- a. Presentation to the NOAA Deepsea Coral Coordination Group. Mary Yoklavich presented an invited seminar on results of this study to a national group of researchers and resource managers, via a webinar series in January 2016.



Freshwater Fish Ecology

Principal Investigator(s):

Darren M. Ward, Humboldt State University

NOAA Primary Contact:

Tommy Williams, Southwest Fisheries Science Center

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Budget Amount:

\$298,082

Amendment(s):

3, 29, 49, 81, 107

Description of Research:

This project provides support for the Department of Fisheries Biology at Humboldt State University (HSU) to maintain a long-term collaboration between HSU and NOAA/NMFS addressing salmon conservation and restoration in Northern California and the Klamath River basin. This objective is implemented through partial funding for a faculty position held by Dr. Darren Ward at HSU to develop research projects focusing on evaluation of restoration effectiveness and assessment of issues related to restoration of salmon production in the Klamath River. Project funding allows this position to continue as a 50% research and 50% teaching appointment, as compared to typical 100% teaching appointments at HSU, to allow research efforts that complement NMFS efforts and fill needs for management and conservation planning. The project has resulted in the successful completion of research projects and collaborations involving California Department of Fish and Wildlife, the

Karuk Tribe, and the Hoopa Tribe. Ongoing projects include investigations of the causes and consequences of life-history diversity in coastal coho salmon, evaluation of habitat restoration activities in the Klamath River basin, and estimation of the effects of introduced brown trout on native salmonids in the Trinity River.

Objectives:

Recruit and obtain funding to support graduate students conducting research projects that address NOAA/NMFS research needs for salmon restoration efforts. Mentor students through the research process and thesis-writing.

Accomplishments & Milestones:

- Michelle Krall (expected completion Spring 2016) collected data to evaluate growth and abundance of juvenile coho salmon occupying habitat enhancement sites in Klamath River tributaries. Her analysis has helped to identify site features associated with increased juvenile coho salmon survival. She has completed field work and analysis and is currently finalizing revisions to her thesis.
- Molly Gorman (expected completion Spring 2016) compared the fate of juvenile coho salmon that rear in natal habitats in Klamath River tributaries with those that emigrate from the tributaries into the main stem Klamath River. Molly was awarded a 2015 California Sea Grant award to incorporate stable isotope analysis of coho salmon otoliths into her project. She has completed field work and analysis and is currently drafting her thesis.
- Gabe Scheer (expected completion Fall 2016) has constructed a life-history based population model for coastal coho salmon populations in order to predict the relative efficacy of different conservation



approaches at increasing abundance and reducing extinction risk. He has completed coding of the model and most simulation work. He is currently drafting his thesis.

- Justin Alvarez (expected completion Fall 2016) is measuring predation on native salmon by non-native brown trout in the upper Trinity River. Justin recently started his second year of electrofishing surveys of the upper Trinity River. His sampling efforts have produced the first large-scale population estimate of brown trout in this important salmon habitat. Stomach sampling has revealed extensive predation by brown trout on both wild and hatchery produced salmon.

Conferences, Meetings & Presentations

- a. American Fisheries Society National Meeting, August 2015 in Portland, OR, represented by Darren Ward, Michelle Krall, Molly Gorman, and Gabe Scheer
- b. Western Division American Fisheries Society Meeting, March 2016 in Reno, NV, represented by Molly Gorman.

Education & Outreach

Communications

- a. EcoNews Report for the Northcoast Environmental Center: Darren Ward gave

an hour-long interview on December 12, 2015 with Jennifer Kalt covering salmon restoration and research, invasive New Zealand mud snails, and mercury contamination in fish. Broadcast on regional NPR affiliates.

Academic Development

- a. Courses at Humboldt State University: Darren Ward trained undergraduate and graduate students in Fisheries Biology, teaching the following courses: Fish Conservation and Management (31 students), Fisheries Science Communication (28 students), Biology of Pacific Salmon (25 students). Primary research advisor for 4 current graduate students. Serve on graduate committees for 7 current graduate students.

K-12 Outreach

- a. McKinleyville Elementary school science night: Introduce elementary school students to fish biology and fisheries science at public Science Night, using hands on displays and specimens.





Figure 30: Humboldt State University undergraduate fisheries students in Darren Ward's Biology of Pacific Salmon class seining juvenile salmonid rearing habitat in the Mad River estuary.





Figure 31: Humboldt State University Fisheries Biology student Leon Davis III discussing fish anatomy with students at the 2015 McKinleyville Union School District Science Night.



Molecular mechanisms of response to persistent oil spill pollutants

Principal Investigator(s):

Andrew Whitehead, University of California Davis

Other Key Personnel:

Diane Nacci, US EPA

Christoph Aeppli, Bigelow Marine Laboratory

NOAA Primary Contact:

Dr. Rob Ricker, Office of Response and Restoration

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Budget Amount:

\$68,668

Amendment(s):

102

Description of Research:

Heterocyclic compounds, which contain nitrogen, sulfur, and oxygen (NSO's) constituents, are prominent and persistent in a variety of petroleum products, including crude oils and bunker fuels. They are poorly understood in terms of toxicity, yet they persist in the environment. Recent studies from the Deepwater Horizon oil spill have shown increasing oxygen content in hydrocarbon residues, a recalcitrant nature of these oxyhydrocarbons in the environment, and increased mobility of these weathered oil constituents, which facilitates greater penetration into sediments and potentially more widespread exposures to biota.

Various weathering processes lead to increased production of oxygenated hydrocarbons, including heterocyclics, and multiple authorities have speculated that these compounds may contribute significantly to residual toxicity of oil contamination. Yet the scientific studies are lacking to back up this speculation. The research supported by this grant is based on toxicity studies to characterize the toxic contributions of various oxygenated and heterocyclic compounds previously documented in the unresolved complex mixture (UCM), which is distinctive in crude oils and some refined fuel oils. The UCM usually constitutes a significant fraction of the total mass of the oil mixture. The work incorporates a number of toxicity test endpoints including developmental toxicity. The work also includes careful chemical characterization of each oil fraction. We have generated evidence that the polar fraction surprisingly contributes to the developmental toxicity of crude oil.

Objectives:

Our specific aim is to identify polar fractions of weathered oil that cause developmental toxicity in our fish model, and the molecular mechanisms that contribute to such toxicity.

Accomplishments & Milestones:

The aromatic and polar fractions produced toxic effects.

The polar fraction, which makes up less than 10% of whole oil, showed dramatic decreases in heart rate, increases in developmental abnormalities, and 100% mortality in the highest treatment groups.

The saturate fraction, which comprises ~65% of whole oil, did not appear to be toxic.

However, because the concentrations and bioavailability of these compound classes in



the exposure media (WAF) has not been measured yet, their true potency is not yet known.

Conferences, Meetings & Presentations

- a. Society of Environmental Toxicology and Chemistry, November 2015 in Vancouver, BC, represented by Andrew Whitehead and Rachel Struch
- b. Gulf of Mexico Oil Spill and Ecosystem Science Conference, February 2016 in Tampa, FL, represented by Rachel Struch
- c. Northern California Chapter of the Society of Environmental Toxicology and Chemistry, April 2015 in Sacramento, CA, represented by Andrew Whitehead and Rachel Struch

- d. Western Society of Naturalists conference, November 2015 in Seattle, WA, represented by Andrew Whitehead and Rachel Struch

Education & Outreach

Academic Development

- a. Graduate student Rachel Struch received training in chemical fractionation techniques at Bigelow Marine Laboratory (Maine).
- b. Graduate student Rachel Struch received training in developmental landmarking and phenotyping at the US EPA Atlantic Ecology Division research laboratory (Rhode Island)



R/V New Horizon Shiptime

Principal Investigator(s):

Dr. Bruce Appelgate, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Roger Hewitt, Southwest Fisheries Science Center (SWFSC)

NOAA Task:

Task 5 - CIMEC Research Infrastructure Proposals

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Goal 3: Serve Society's Needs for Weather and Water Information

Goal 4: Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation

Budget Amount:

\$323,327

Amendment(s):

137

Description of Research:

This project provides ship time aboard the oceanographic research vessel New Horizon in support of other NOAA projects.

Objectives:

Provide capable oceanographic research vessel suitable for the research requirements specified by the NOAA projects being supported.

Accomplishments & Milestones:

All oceanographic ship days requested were provided.

Education & Outreach

Communications

- a. As ship operators, we expect that the scientific objectives and results of the work performed is reported by the scientific personnel who conduct the research. Aspects of projects conducted aboard Scripps-operated research vessels are communicated on our web site (<https://scripps.ucsd.edu/ships>).



R/V Roger Revelle Shiptime

Principal Investigator(s):

Dr. Bruce Appelgate, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Roger Hewitt, Southwest Fisheries Science Center (SWFSC)

NOAA Task:

Task 5 - CIMEC Research Infrastructure Proposals

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Goal 3: Serve Society's Needs for Weather and Water Information

Goal 4: Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation

Budget Amount:

\$475,481

Amendment(s):

131

Description of Research:

This project provides ship time aboard the oceanographic research vessel Roger Revelle in support of other NOAA projects.

Objectives:

Provide capable oceanographic research vessel suitable for the research requirements specified by the NOAA projects being supported.

Accomplishments & Milestones:

All oceanographic ship days requested were provided.

Education & Outreach

Communications

- a. As ship operators, we expect that the scientific objectives and results of the work performed is reported by the scientific personnel who conduct the research. Aspects of projects conducted aboard Scripps-operated research vessels are communicated on our web site (<https://scripps.ucsd.edu/ships>).





Figure 32: R/V *Roger Revelle* is a highly capable Global Class research vessel that operates worldwide. Operated by Scripps Institution of Oceanography as a shared-use facility within the University-National Oceanographic Laboratory System (UNOLS), Roger Revelle is available to all scientists supported by any US federal, state, and other agencies.



Theme D: Ecosystem-based Management

Training the Next Generation of Marine Population Dynamics Scientists

Principal Investigator(s):

Brice Semmens, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Lynn Waterhouse, Scripps Institution of Oceanography, UC San Diego

Brian Stock, Scripps Institution of Oceanography, UC San Diego

Josh Stewart, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Lyall Bellquist, Southwest Fisheries Science Center (SWFSC)

NOAA Task:

Task 1 - Administration

NOAA Theme:

Theme D: Ecosystem-based Management

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Goal 3: Serve Society's Needs for Weather and Water Information

Goal 4: Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation

Budget Amount:

\$1,000,000

Amendment(s):

5, 31, 45, 91, 100

Description of Research:

In order to support the increased demand for resource assessments and ecosystem-based management, National Oceanographic and Atmospheric Administration (NOAA) requires scientists trained in the development, application, and synthesis of quantitative tools and techniques. NOAA also would be well served by the development of new and/or improved analytic assessment methods that capitalize on existing and emerging survey methods. Towards these objectives, members of the Semmens lab carried out (1) training in quantitative resource assessment and population dynamics, (2) graduate student and PI research into resource assessment tools and techniques, and (3) STEM (science, technology, engineering and mathematics) training for K-12 students, and (4) research into cooperative fisheries science for recreational fisheries. The proposed research and training activities will foster a broad base of highly skilled quantitative fisheries scientists and generate a set of tools to facilitate accurate and informative marine resource assessments in an ecosystem context.

Since April 2015, PI Semmens continued his collaboration with other scientists through the Center for the Advancement of Population Assessment Methodology (CAPAM). Other CAPAM principal investigators include Mark Maunder (Inter-American Tropical Tuna Commission, IATTC) and Paul R. Crone (Southwest Fisheries Science Center, SWFSC). This past year, CAPAM hosted its 3rd workshop focused on data weighting in assessments, held at the SWFSC. As in years past, the workshop spawned a special issue in Fisheries Research, edited by the CAPAM PIs.



This issue is currently in development. The special issue from the prior workshop (growth models in assessment) is now in press, and includes 19 peer-reviewed articles; CAPAM PIs or personnel were authors or co-authors on 6 of these articles. To date, CAPAM personnel have authored over 30 publications directly related to stock assessment methods.

In October of 2015, CAPAM hosted a 1-day Stock Synthesis short course at SWFSC as part of the CAPAM 5-day data weighting workshop. This spring quarter, PI Semmens is teaching a graduate level course on Bayesian population analysis (including mark-re-capture analysis), and a undergraduate course in lab and field techniques. The graduate course in Bayesian statistics was jointly advertised at SIO and SWFSC, and is being attended by 5 SWFSC staff scientists. Outside of formal teaching activities, the Semmens Lab jointly coordinates a quantitative seminar series with the SWFSC that meets periodically, and coordinates an R users group weekly meeting held on the SIO campus.

Semmens Lab members continue to maintain 44 hydrophones deployed as part of the La Jolla Acoustic Array (LJAA). Over the past year, serviced all acoustic receivers (Vemco VR2W) and conducted annual data downloading. The LJAA allows precise monitoring of spatial movement patterns of tagged fish inside and outside of local Marine Protected Areas (MPAs). Information yielded by telemetry research aids assessments of established MPAs and also guides future MPA planning and design. Additionally, acoustic telemetry can yield biological information, such as spawn timing, diurnal patterns in movement and site fidelity, which are important for marine species management.

Semmens Lab members continue to build successful cooperative fisheries research program. PI Semmens, and SWFSC scientists Wegner and Bellquist (current NRC postdoc, former Semmens Lab PhD) began

collaborative research into the spatial ecology of juvenile Cowcod (*Sebastes levis*) of the California coast, using acoustic and Floy tagging methods. Cowcod are currently overfished, and listed as a Species of Concern by the SWFSC. This research, funded through the National Research Coop competition, aims to gain an improved understanding of critical habitat for the species in relation to existing Cowcod Conservation areas along the California coast. Two products from Bellquist's dissertation (defended this past year) related to a novel database of "trophy" recreational catch in California have successfully navigated peer-review. A synthesis of half of century of demersal "trophy" records was published as a Feature Article in Marine Ecology Progress Series, while a similar paper related to pelagic and coastal pelagic species is in press at Transactions of the American Fishery Society. Finally, in December 2015, UC President Janet Napolitano appointed PI Semmens as the UC representative to California's Ocean Resources Enhancement and Hatchery Program.

As part of efforts to broaden the scope of training in fisheries-focused STEM (science, technology, engineering and math) fields, lab members coordinate a series of K-12 education and outreach programs. Each year PI Semmens leads the Grouper Moon education program, targeting K-12 students throughout the Caribbean and US with a combination of experiential learning curricula, and a Web-based "virtual field" component. This last year more than 200 students from 14 different schools participated in the program. Back in San Diego, PI Semmens and lab members coordinated 3 separate 1-day short courses in quantitative fisheries science targeting underrepresented K-12 students from local schools.

In addition to the above research/education areas, PI Semmens oversees 4 PhD students (Lynn Waterhouse, Brian Stock, Josh Stewart,



Noah Ben-Aderet), 1 MS students, 1 staff member and 3 undergraduate volunteers. Students are working on diverse issues in fisheries resource management, including the spatial ecology and population structure of oceanic manta, mark-re-capture studies on locally important recreational marine fish species, the development of novel quantitative tools for abundance and animal movement estimation, stable isotope analysis, and the development of stock assessment methods for data-limited fisheries.

Objectives:

The goal of this project was to facilitate the initiation of a research program for new faculty member Brice Semmens. Brice Semmens was hired during a search for a marine population dynamics scientist with the ability to train future practitioners in the science of population assessment and development of enhanced assessment methods that incorporate environmental variability, food web linkages and spatial heterogeneity. The intent of the appointment was to build upon a long record of accomplishment and collaboration between Scripps Institution of Oceanography and NOAA Fisheries Service. Thus, the objective of these funds included: build a working laboratory suitable for both research and training, initiate field studies, and jumpstart the overall research program on population assessment and dynamics, and characterization of community interactions.

Accomplishments & Milestones:

- Lab members authored or co-authored 5 peer-reviewed manuscripts, 2 in press, and 1 PhD dissertation
- Lab members authored or co-authored 7 conference presentations
- PI Semmens taught an 'Intro to Field Methods' undergraduate course

- PI Semmens taught a grad. level course in Bayesian modeling with joint attendance by SIO and SWFSC students and scientists
- Lab members implemented a CAPAM Data Weighting workshop
- Lab Members attained and downloaded set of data from 44 hydrophones that compose the La Jolla Acoustic Array (LJAA)
- Collaborative research into Cowcod with SWFSC
- Lab members 3 summer outreach student group visits for underserved community high schools in collaboration with TRITON Stem Academy/WildCoast/and Outdoor Outreach
- PI Semmens executed the annual Grouper Moon K-12 education/outreach program for schools throughout the Caribbean and US

Honors and Awards

- a. Semmens elected member of the Gulf and Caribbean Fisheries Research Institute (GCFI) Board of Directors, 2015-2016
- b. Semmens received California Ocean Resources Enhancement and Hatchery Program (ORHEP) appointment, December 2015
- c. Josh Stewart received Switzer Environmental Fellowship, 2015-2016
- d. Rachel Babbe Bellas received UCSD Staff Equal Opportunity Award, March 2015
- e. Josh Stewart received Nacncy Foster Scholarship ONMS, 2015-2018

Conferences, Meetings & Presentations

- a. AFS Annual Meeting, August 16-20, 2015 in Portland, OR, represented by Brice Semmens, Brian Stock and Lynn Waterhouse
- b. JSM Annual Meeting, August 8-13, 2015 in Seattle, WA, represented by Lynn Waterhouse



- c. ICES Annual Science Conference, September 21-25, 2015 in Copenhagen, Denmark, represented by Lynn Waterhouse
- d. Student Conference on Conservation Science (SCCS), October 7-9, 2015 in New York, NY, represented by Lynn Waterhouse
- e. NMFS/Seagrant Annual Population Dynamics Fellowship Meeting, June 9-11, 2015 in Miami, FL, represented by Lynn Waterhouse(sent poster)
- f. Fish 558 Workshop – Decision Analysis in Natural Resource Management, <http://depts.washington.edu/fish558> , taught by Andre Punt, Fall 2015, in Friday Harbor, WA (& online via GoToMeeting), represented by Brian Stock, Josh Stewart, Eiren Jacobsen, and Lynn Waterhouse
- g. Brian Stock presented a public talk on December 10, 2015 at Ocean Enterprises in San Diego, CA
- h. Brian Stock presented at the 100th ESA Annual Convention, August 2015 in Baltimore, MD
- i. Brice Semmens and Brian Stock both presented at the 145th American Fisheries Society Annual Meeting, August 2015 in Portland, OR
- j. Brian Stock presented at the NOAA National Protected Species Toolbox Mini-Symposium, November 18-19, 2015 in Silver Spring, MD
- k. Brice Semmens and Brian Stock both presented at the 68th Annual Gulf and Caribbean Fisheries Institute, November 2015, in Panama City, Panama
- l. Lyall Belquist presented his PhD Dissertation at Scripps Institution of Oceanography on June 9, 2015
- m. Joshua Stewart presented at the International Conference on Conservation Biology, August 2-7, 2015 in Montpellier, France

- n. Joshua Stewart presented at the Fisheries Society of the British Isles Annual Conference, July 25-31, 2015, in Plymouth, UK

Education & Outreach

Communications

- a. PI Semmens gave a QUEST Webinar in March 2016, entitled “Behavior, Hyperstability, and Population Declines in an Aggregating Marine Fish” to reach a broad national audience, and discuss research into mechanistic underpinnings of hyperstability in fisheries, with SIO and NOAA< QUEST.
- b. Graduate student Joshua Stewart gave presentation to Upward Bound students on marine biology, research and graduate school to expose underrepresented high school students to STEM fields and higher education.

Academic Development

- a. Graduate student Brian Stock started his second year of PhD coursework and passed his first year Marine Biology examination. The goal of second-year coursework is to establish a strong educational foundation in the marine sciences during the beginning of a marine biology PhD
- b. Graduate students Lynn Waterhouse, Lyall Bellquist, Noah Ben-Aderet and Brian Stock attended CAPAM’s data weighing workshop to introduce students to modern statistical models used in fisheries stock assessment and natural resource modeling, providing instruction, demonstration, and exercises in Growth: theory, estimation, and application.
- c. Graduate students Lynn Waterhouse, Joshua Stewart, and Brian Stock attended Andre Punt’s workshop and online course in population modeling (Sept 2015) to build experience in Decision Analysis in Natural Resource Management



- d. Graduate student Lyall defended his PhD on June 9th

K-12 Outreach

- a. PI Semmens lead the annual Grouper Moon K-12 education program, reaching more than 200 students in 14 schools throughout the Caribbean and US.
- b. Staff Member Rachel Labbe Bellas and Brice Semmens hosted 3 student groups for a quantitative ecology interactive afternoon session during summer 2015
- c. Graduate students Lynn Waterhouse and Brian Stock participate as volunteer diver/educators at the Birch Aquarium
- d. Graduate student Josh Stewart mentored an Independent study highschool student working with Manta Ray mobuild tissue.

Networking

- a. PI Semmens is the UC representative to California's Ocean Resources Enhancement and Hatchery Program
- b. Graduate student Lynn Waterhouse continued to be a SIO representative for the Graduate Student Association (GSA)
- c. Graduate student Lynn Waterhouse maintains role as secretary for the Estuaries Section of American Fisheries Society (AFS)
- d. PI Semmens serves on the board of the Gulf and Caribbean Fisheries Research Institute (GCFI)

NOAA Employment

Lyall Bellquist, a PhD, gained employment with Southwest Fisheries Science Center in September 2015.



Figure 33: Semmens Lab Members and REEF team perform a live streaming to elementary schools .





Figure 34: Semmens Lab Members and REEF team provide teacher training to Science teachers from Little Cayman, Cayman Islands.



Tethys Bioacoustics Metadata Workbench Improvements

Principal Investigator(s):

Simone Baumann-Pickering, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Ana Širović, Scripps Institution of Oceanography, UC San Diego

Marie Roch, Department of Computer Science, San Diego State University

NOAA Primary Contact:

Jeremy Rusin, NOAA Fisheries, Southwest Fisheries Science Center (SWFSC)

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme D: Ecosystem-based Management

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Budget Amount:

\$30,000

Amendment(s):

140

Description of Research:

Version 2.3 Tethys schemata and implementation have been released on the project web site (<http://tethys.sdsu.edu>). Major improvements made in the last year came from the output of the final Tethys workshop and include significant enhancements to the import facilities permitting more sophisticated data import (nested queries), the incorporation of the ability to represent quality assurance processes within the schemata, a National Center for Environmental Information trial

with NOAA Northeast and Alaska Fisheries Science Centers to use Tethys deployment metadata in archiving Fisheries Science Center acoustic data, and experiments demonstrating the ability of the system to represent metadata in other domains.

The Tethys metadata system is beginning to gain traction with users outside of the principal investigators. Peter Wrege and Sara Keen (Cornell University Bioacoustics Research Program) are using the system for forest elephants (*Loxondonta cyclotis*) and Cornell plans on developing front-end graphical user interfaces for the system. Jasco Ltd. announced at the 2015 International Workshop on Detection, Classification, Localization and Density Estimation of Marine Mammals that they planned on building a Tethys interface into their visualization system.

The strength of this system is the type of questions that one can ask when one has an analytical engine that can automate the integration of acoustic metadata with environmental information. The system has permitted to reveal spatial and temporal patterns in habitat use for fin and blue whales. The ability to track details of equipment such as calibration curves proved useful in a study that examined performance degradation of species identification algorithms in the face of equipment and site differences and proposed techniques to mitigate for this. It helped to integrate system internal acoustic metadata and external oceanographic satellite data to show influence of changes in oceanography at a remote equatorial Pacific seamount on toothed whale occurrence. Other studies that will use this system for analyzing marine mammals with respect to oceanographic conditions and anthropogenic sources (e.g. sonar, habitat



models) are underway and are expected to produce additional Tethys-enabled publications.

Objectives:

Tethys is a passive acoustic monitoring metadata database system designed to organize and store acoustic metadata. Within this effort we collaborated with the NOAA Southwest Fisheries Science Center (SWFSC), NOAA Pacific Islands Fisheries Science Center (PIFSC), and NOAA Alaska Fisheries Science Center (AFSC) to improve the Tethys bioacoustics metadata workbench working towards priorities established in a December 2014 Tethys workshop of all stakeholders. It was understood that funding in this agreement provided funding towards these goals rather than completion of them.

Accomplishments & Milestones:

- Improved version 2.3 of Tethys is available online
- Increased use of Tethys by a larger number of users outside of the initial developers and collaborators.
- Several peer-reviewed journal articles that used Tethys-generated output are published and underway.

Education & Outreach

Communications

- a. Tethys Website - <http://tethys.sdsu.edu> - website for download and documentation of the database software



Frontiers of Marine Resources Course

Principal Investigator(s):

Mark Jacobsen, Department of Economics,
UC San Diego

NOAA Primary Contact:

Dr. Dale Squires, Southwest Fisheries Science
Center (SWFSC)

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC
Collaboration

NOAA Theme:

Theme D: Ecosystem-based Management

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use
of Coastal and Ocean Resources Through
Ecosystem-based Management

Goal 3: Serve Society's Needs for Weather and
Water Information

Budget Amount:

\$11,273

Amendment(s):

83

Description of Research:

We followed up on our earlier short course in marine economics by inviting a series of lecturers at the frontier of resource economics. Ram Fishman (George Washington University) presented work at the intersection of development and climate economics: "When Water Runs Out: Scarcity, Adaptation and Migration in Gujarat." Jean-Daniel Saphores (UC Irvine) led an engaging discussion on the Salton Sea and the extreme difficulties it presents in management and economic valuation.

Finally, Edward Allison (University of Washington) presented his work on fisheries and nutrition. His talk explored analysis of fisheries governance and food security, identified gaps in empirical research on the

efficacy of competing regulatory objectives, and proposed a role for natural resource economics in the inherently interdisciplinary realm of fisheries governance and nutrition.

All three speakers also met individually with our PhD students in natural resources: this provides a valuable opportunity for students to gain perspectives from outside the department and broaden their research agendas as they enter the dissertation phase.

Objectives:

We seek to increase the educational opportunities available for economics graduate students with an interest in marine resources and climate. Our aim is to expose the students to ideas and methods that they would not receive in their regular economics classes.

Accomplishments & Milestones:

- Sponsored three additional visitors to the economics department, focusing on marine policy and climate
- Department-wide presentations and individual meetings with PhD students working on natural and marine resources

Education & Outreach

Academic Development

All events below feature visiting speakers who also met individually with economics PhD students interested in marine and resource economics.

- a. Ram Fishman (George Washington University): "When Water Runs Out: Scarcity, Adaptation and Migration in Gujarat"
- b. Jean-Daniel Saphores (UC Irvine): "A Spatial Hedonic Analysis of a Large, Failing Desert Lake: The Case of the Salton Sea"
- c. Edward Allison (University of Washington): "Governing Fisheries and Aquaculture for Food Security"



Center for the Advancement of Population Assessment Methodologies (CAPAM)

Principal Investigator(s):

Brice Semmens, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Lynn Waterhouse, Scripps Institution of Oceanography, UC San Diego

Juan Valero, Center for the Advancement of Population Assessment Methodology

Mark Maunder, IATTC

Paul Crone, NOAA Fisheries, SWFSC

Brian Stock, Scripps Institution of Oceanography, UC San Diego

Lyll Bellquist, Scripps Institution of Oceanography, UC San Diego

Josh Stewart, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Roger Hewitt, NOAA Fisheries, SWFSC

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme D: Ecosystem-based Management

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Goal 2: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Goal 3: Serve Society's Needs for Weather and Water Information

Goal 4: Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation

Budget Amount:

\$262,100

Amendment(s):

66

Description of Research:

Research will be carried out through collaboration among CAPAM research candidates (e.g., postdoctoral researchers), SIO faculty (Dr. Semmens), SWFSC/IATTC staff (Drs. Crone and Maunder), and visiting scientists. Visiting scientists will be involved on a systematic basis to provide expertise for more complex problems associated with topics of interest. The candidates will also work alongside analysts (collaborators) on formal species-specific assessments to ensure the integration of practical aspects of stock assessment modeling in their independent research projects, and to provide them with invaluable training/mentorship for working in permanent stock assessment positions in the near future. Workshops will be held to disseminate the research efforts of CAPAM candidates, staff, and visiting scientists, as well as receive input from interested parties and outside experts. An advisory committee will act in the role of a 'review' panel by ensuring the research is timely, sound, and relevant to the needs of stock assessment practitioners (committee membership: R. Methot, A. Punt, J. Ianelli, R. Deriso, and S. Cadrin). Links will be made with developers of general stock assessment programs (e.g., *Stock Synthesis*) so that results generated through CAPAM can be formally implemented as default options in the respective modeling programs. Finally, support of a core group of researchers devoted to stock assessment-related analysis at SIO, SWFSC and IATTC will attract interest from other working groups attempting to achieve similar goals, which will broaden the scope, enhance this effort, and



provide a potential source of collaborative funding/research in the future. During the first two years of CAPAM activities, research will be focused on developing a stock assessment *Good Practices* guide, and on research related to selectivity parameterization in stock assessments. To that end, the specific aim is to fund a highly skilled postdoctoral fellow over a two-year period to work closely with the PI and project collaborators in developing the *Good Practices* guide, and carry out cutting edge research in stock assessment methodologies.

Objectives:

The goals of the Center for the Advancement of Population Assessment Methodology (CAPAM) are to improve quantitative methods generally used in stock assessment modeling efforts, provide guidance regarding good practices in stock assessment methods, and afford the educational opportunities necessary to train the next generation of highly skilled stock assessment scientists. Specifically, emphasis will be on assumptions used in contemporary stock assessment models, e.g., selectivity/catchability, growth, natural mortality, stock-recruitment relationship, covariates, spatial structure, data/likelihoods weighting, multi-species and ecosystem considerations, and diagnostics.

Accomplishments & Milestones:

- Published 19 additional peer reviewed articles, 2 reports, and 2 workshop series proceeding
- CAPAM continued work on the contract to conduct a white seabass stock assessment. CAPAM research scientist, Dr. Juan Valero will mentor Scripps Institution of Oceanography (SIO) graduate student Lynn Waterhouse throughout stock assessment process.
- CAPAM researchers taught 5 courses on stock assessment methods and modeling techniques. Additionally, Brice Semmens taught a graduate level Introduction to

Bayesian Population Analysis course and an undergraduate Statistical Methods in Marine Biology course; both of which were held at UCSD.

- CAPAM's research scientist Juan Valero is working with graduate students and post-docs from the University of Washington, Simon Fraser University and University of British Columbia in collaboration with scientists from the NWFSC in Seattle. The goal of this collaborative work is to provide education and mentoring opportunities for upper level graduate students interested in learning quantitative stock assessment methods. Three presentations resulting from this work were presented at the CAPAM's Stock Assessment workshop and the three papers were submitted to the Fisheries Research Special Issue on Stock Assessment.
- Chris Francis, recently retired from New Zealand's National Institute of Water and Atmospheric Research, spent six-weeks from February to March 14, 2014 at the SWFSC and conducted research on data weighting in stock assessments.

Honors and Awards Conferences, Meetings & Presentations

- AFS Annual Meeting, August 16 to 20, 2015 in Portland, OR, represented by Lynn Waterhouse, and Brian Stock
- JSM Annual Meeting, August 8-13, 2015, in Seattle, WA, represented by Brice Semmens, Brian Stock, and Lynn Waterhouse
- ICES Annual Science Conference, September 21-25, 2015, in Copenhagen, Denmark represented by Lynn Waterhouse
- Student Conference on Conservation Science (SCCS), October 7-9, 2015, in New



York, NY, represented by Lynn Waterhouse

- e. NMFS/Seagrass Annual Population Dynamics Fellowship Meeting, June 9-11, 2015, in Miami, FL, represented by Lynn Waterhouse (did not attend but sent poster)
- f. Fish 558 Workshop -Decision Analysis in Natural Resource Management, Taught by Andre Punt, Fall 2015, Friday Harbor, WA and then online via GoToMeeting, represented by Brian Stock, Josh Stewart, Eiren Jacobsen, Lynn Waterhouse

Education & Outreach

Communications

- a. Lewis Barnett contributed to an article with a focus for a general audience about the Data Weighting Workshop published online.
https://www.nwfsc.noaa.gov/news/feature/s/data_source_workshop/index.cfm
- b. Monster of Stock Assessment Workshop at AFS Annual Meeting in Portland, OR on August 16, 2015 where Lynn help co-organize an event sponsored by the AFS Marine Fisheries Section and AFS Estuaries section entitled "Monsters of Stock Assessment". The event was a fundraiser for the 2 sections for future student travel awards. The event raised \$1,500 for the two sections. The event featured 10 talks from professors in the field of quantitative fisheries science with participants from AFS, NOAA (Patrick Lynch and Lee Benaka), and AIFRB

Academic Development

- a. Grad Students attend CAPAM'S Data Weighting Workshop - Good Practices in Stock Assessment Modeling - The five-day meeting was part of a broader program under CAPAM that focuses on developing guidance for Good Practices in Stock Assessment Modeling. The data weighting workshop was the third in a series

organized by CAPAM as part of its Good Practices in Stock Assessment Modeling Program for improving fishery stock assessments. CAPAM is a collaborative effort between the Southwest Fisheries Science Center (SWFSC), the Inter-American Tropical Tuna Commission (IATTC), and Scripps Institution of Oceanography (SIO) for purposes of conducting both research and education activities to address modern stock assessment modeling issues. The workshop was sponsored by NOAA, CAPAM, and International Seafood Sustainability Foundation (ISSF).

- b. Graduate Student and Postdoctoral Research Mentoring - Graduate student and post-doctoral research associated with CAPAM programs has progressed substantially, in large part due to active support, guidance, and mentoring from CAPAM personnel. Below we highlight recent research activities in this regard.
- c. *White Seabass Assessment Project* - A collaborative project is underway with the Pflieger Institute of Environmental Research (PIER) and California Department of Fish and Wildlife (CDFW) in order to assess the stock of white seabass (*Atractoscion nobilis*) in California. CAPAM took on this project in order to provide SIO graduate students with "real world" stock assessment experience, and to participate in a marine resource assessment associated with a stock actively managed by the state of California (currently ongoing and expected to be completed by Summer 2016.). CAPAM research scientist Dr. Juan Valero will be working with SIO graduate student Lynn Waterhouse on this stock assessment.

K-12 Outreach

- a. K-12 web-based outreach in the Caribbean - With support from Scripps Institution of Oceanography, the Reef Environmental Education Foundation, and



the Cayman Islands Department of the Environment, Dr. Brice Semmens and Grad Students Brian Stock and Lynn Waterhouse coordinated and led a K-12 web-based outreach program associated with Nassau Grouper Research in the Caribbean – Use field based live streaming and in-person classroom visits to educate K-12 students throughout the Caribbean regarding the importance of large marine predators and spawning aggregations.

Networking

- a. Special Session at the International Marine Conservation Congress - Working

with Scripps Institution of Oceanography, the Reef Environmental Education Foundation, and Oregon State University, Dr. Brice Semmens co-coordinated a special session at the International Marine Conservation Congress in Scotland entitled “End-to-end marine conservation: Case studies in successfully translating science into management action through communication and outreach” in order to bring together scientists from the U.K., Europe, and the U.S. to share case studies in marine conservation science and communication.



Figure 35: CAPAM Staff conducted the first modern Stock Assessment for [white seabass](#) (*Atractoscion nobilis*) in California. The white seabass is a nearshore finfish species found in the coastal waters of California (US) and Baja California, and to a much lesser extent, along the coast of Oregon and Washington. The species supports important California recreational and commercial fisheries, which are managed through State regulations. The work was conducted in collaboration with Staff from [Pfleger Institute of Environmental Research](#) (PIER) and California Department of Fish and Wildlife (CDFW). CAPAM Staff used the fisheries stock assessment modeling platform [Stock Synthesis](#) (SS) to assess the California population of white seabass. This project is led by [Dr. Juan Valero](#) and Lynn Waterhouse. The stock assessment was funded by [Pfleger Institute of Environmental Research](#) (PIER) with contributions from the George T. Pfleger Foundation and the Offield Family Foundation.



Identifying critical habitat for highly mobile marine vertebrates under the Endangered Species Act

Principal Investigator(s):

Dr Brice Semmens, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Dr Charlotte Boyd, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Roger Hewitt, NOAA Fisheries, SWFSC

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme D: Ecosystem-based Management

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Budget Amount:

\$80,089

Amendment(s):

123, 135

Description of Research:

The Southern Resident killer whale (*Orcinus orca*) was listed as endangered under the United States Endangered Species Act (ESA) in 2005. Priority management needs include an improved understanding of the coastal distribution of Southern Resident killer whales and factors limiting their recovery, including prey availability. The main objective of Phase I of this research (i.e. the phase completed within this reporting period) was to develop a prototype spatially-explicit individual based model (IBM) of Southern Resident killer whale movement and foraging patterns to explore the effects of variation in prey availability on the population dynamics of killer whales, and assess the possible effects of increases in the

abundance of specific salmon stocks on their recovery potential.

The prototype IBM was developed and reviewed by relevant NOAA Fisheries management and science center staff. This review highlighted the importance of improving our understanding of the at-sea distribution and movement patterns of Chinook salmon (ocean-age 2 and older) and hence their availability as prey for Southern Residents. Key insights from Phase I include the possible significance of large Chinook salmon (e.g. ocean-age 2 and older) that inhabit coastal waters in the years prior to their return to freshwater and salmon run duration as factors influencing prey availability to killer whales.

We are currently seeking funding to support Phase II of this research, based on recommendations by NOAA Fisheries management and science center staff. The main objectives for Phase II are to model the at-sea distribution and movement patterns of Chinook salmon stocks), develop a second-generation IBM and evaluate it against observed data, and use the second-generation IBM to assess the possible effects of increases in the availability of specific salmon stocks on the recovery potential of Southern Resident killer whales.

Objectives:

The research goal was to improve understanding of the coastal distribution, critical habitat and prey resources of endangered Southern Resident killer whales (*Orcinus orca*) in the Northeastern Pacific.

Accomplishments & Milestones:

The prototype IBM was developed and reviewed by relevant NOAA Fisheries management and science center staff at a meeting in Seattle in June 2015. This review



highlighted the importance of improving our understanding of the at-sea distribution and movement patterns of Chinook salmon (ocean-age 2 and older) and hence their availability as prey for Southern Residents.

Education & Outreach

Communications

- a. Charlotte Boyd gave a presentation titled “An individual-based model to support critical habitat identification” as part of the NOAA-SWFSC/NWFSC Review of Science on Marine Mammals & Turtles Theme III: Science to support recovery of Southern Resident killer whales in La Jolla, CA, in July 2015.

Academic Development

- a. Independent Marine Mammal Observations
 - i. Charlotte Boyd participated in NOAA-SWFSC’s Eastern North

Pacific Gray Whale Calf Production Survey, Piedras Blancas Light Station, CA, USA in May 2015.

- ii. Charlotte Boyd participated in the third leg of NOAA- AFSC/SWFSC’s Collaborative Large Whale Survey in Alaskan waters in August 2015.

Networking

- a. Dr Charlotte Boyd participated as an invited expert in the IUCN Cetacean Specialist Group meeting to review IUCN Red List status assessments for several genera of small cetaceans. La Jolla, CA, May 2015.
- b. Dr Charlotte Boyd participated as an invited expert in NOAA’s Protected Species Climate Vulnerability Assessment Workshop in Silver Spring, MD, in July 2015.



Figure 36: Postdoc Charlotte Boyd conducting marine mammal surveys on the 3rd leg of the California Current Cetacean and Ecosystem Assessment Survey (CalCurCEAS) October-November 2015.



Using Combined Video/Acoustic Recordings of Marine Mammal/Fishing Gear Interactions to Evaluate Utility of Passive Acoustic Monitoring

Principal Investigator(s):

Aaron Thode, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Jan Straley, U of Alaska Southeast

Lauren Wild, Sitka Sound Science Center

Victoria O'Connell, Sitka Sound Science Center

Linda Behnken, Sitka Longline Fishermen's Association

Dan Falvey, Sitka Longline Fishermen's Association

Jit Sarkar, Scripps Institution of Oceanography, UC San Diego

Ali Bayless, NOAA PIFSC

Sean Martin, Hawaii Longline Association

NOAA Primary Contact:

Derek Orner, Bycatch Reduction Engineering Program

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme D: Ecosystem-based Management

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Budget Amount:

\$202,476

Amendment(s):

Competed NA12NMF472053

Description of Research:

Motivation

A prominent issue in reducing bycatch is minimizing or preferably eliminating marine mammal interactions with longline gear, particularly for species which remove the catch or bait off gear, a behavior known as depredation. Depredation is the active intentional removal of prey, in contrast to a whale inadvertently stumbling into a net or line. Sperm whales (*Physeter macrocephalus*), killer whales (*Orcinus orca*), and false killer whales (*Pseudorca crassidens*) are among the cetacean species actively engaging in depredation. These whales risk entanglement for presumably easier or more efficient feeding. Fishermen experiencing depredation take longer to catch their quota or have economic loss. Exploring ways to reduce depredation is hampered by lack of knowledge about the basic behavior itself, and the lack of an inexpensive way of quantifying depredation activity on deployments where human observers are impractical and expensive. Passive acoustic monitoring may be a useful cost-effective tool for detecting the presence of certain species around fishing gear, and thereby gaining insight into gear depredation rates and behavior as a function of time and location.

A fundamental assumption behind using passive acoustic monitoring, however, is that animals are acoustically active when interacting with the gear, an assumption that may not be true during daylight conditions, since many odontocetes have good visual acuity. The one published study on false killer whale acoustics around longline gear found no correlation between depredation activity and passive acoustic detections of false killer whales. A preliminary analysis of killer whale interactions with vessels in the Bering Sea



found uncertain correlations between acoustic and depredation activities. Essentially, relatively few (9) click trains or buzzes were detected on a longline with 100% depredation (2600 hooks) deployed during daylight hours, and thus killer whales may use vision, along with echolocation, to interact with gear, at least during the daytime.

Our proposed solution is to simultaneously deploy cameras and acoustic recorders from fishing gear, in order to determine whether visually-documented interactions are accompanied by distinctive acoustic cues, such as echolocation sounds by the species of interest.

Project Summary

The key to reducing depredation with viable and realistic solutions is to fully understand how the whales are removing the bait or catch (and knowing if it is catch or bait, currently uncertain for false killer whales). Previous audio/video work by SEASWAP has found that sperm whales use echolocation to acquire black cod from longlines, even under good visual conditions. We propose to expand this work to address whether sperm whale, killer and false killer whales, consistently use sound to interact with longlines, and whether these sounds can be distinguished from natural acoustic behaviors. Two existing autonomous acoustic recorders previously developed with NOAA and fishing industry support are being expanded to incorporate a camera module that would capture up to 3 frames/sec using a trigger signal generated by the autonomous recorder. The modified system would first be deployed to study killer whale and sperm whale interactions in Alaskan waters, where encounters with marine mammals are predictable and highly probable, and then incorporated with other acoustic field efforts studying endangered false killer whales in Hawaiian waters. Our project includes logistic support for Alaskan fishermen to attend a depredation "summit" in Hawaii. The goal is

to swap ideas for attaching and camouflaging the camera system with minimum inconvenience to fishermen.

The key goals of the project were met during this reporting period: false killer whale depredation was recorded on camera and audio off Hawaii; the animals were confirmed to use acoustics during daylight hours while depredating, and scientific conferences and a peer-reviewed paper were presented and submitted for publication.

Objectives:

The overriding objective is to simultaneously deploy cameras and acoustic recorders from demersal and pelagic longline fishing gear in the Gulf of Alaska and HI, to determine whether visually-documented interactions of killer and false killer whales are accompanied by distinctive acoustic cues, such as echolocation sounds by the species of interest.

Original sub-objectives include the following:

1. Expanding two existing autonomous acoustic recorders to incorporate a long-endurance natural-lighting camera capability (between 24 hours to 7 day coverage, depending on picture frame acquisition rate);
2. Testing the system on sperm and killer whales in Alaska and false killer whales in Ha`waii.
3. Using visually-documented encounters to determine the probability that killer and false killer whales generate sounds during fishing gear interaction during daylight hours, as a function of gear depth.
4. Exploiting opportunistic visual records of other bycatch events to determine whether acoustic cues are generated by entanglement with the fishing gear.

Sub-objective (1) was revised midway through the project to use GoPro cameras as the



hardware solution for a combined acoustic/visual recording system.

Accomplishments & Milestones:

During the reporting period in question,

1. Footage of false killer whales off Hawaii was analyzed visually and acoustically.
2. A peer-reviewed manuscript was written, documenting the sounds made during depredation, and estimating their detection range using passive acoustics. The paper also noted that the “line pluck” associated with depredation was detectable by an accelerometer.
3. The research was presented at the Biennial Marine Mammal Conference in December 2015.

4. The manuscript was submitted for publication in early 2016.

Conferences, Meetings & Presentations

- a. 21st Biennial Conference for Marine Mammology, 2015 in San Francisco, California, from 13-18 December, 2015, represented by Aaron Thode, Jan Straley, and Victoria O’Connell
- b. COLTO Depredation Workshop, from March 15-18, 2016 in Punta Arenas, Chile, represented by Jan straley

Education & Outreach

Communications

- a. Results presented on SEASWAP and SSSC webpages, for public awareness.



Figure 37: Image still from false killer whale depredation video, 15:49:47 on Jan. 27, 2015, using Camera 1.



Using Combined Video, Acoustic, and Accelerometer Measurements to Determine the Conceptual Viability of a "Smart" Hook

Principal Investigator(s):

Aaron Thode, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Jan Straley, U of Alaska Southeast

Lauren Wild, Sitka Sound Science Center

Victoria O'Connell, Sitka Sound Science Center

Linda Behnken, Sitka Longline Fishermen's Association

Dan Falvey, Sitka Longline Fishermen's Association

Jit Sarkar, Scripps Institution of Oceanography, UC San Diego

Ali Bayless, NOAA PIFSC

Sean Martin, Hawaii Longline Association

NOAA Primary Contact:

Derek Orner, Bycatch Reduction Engineering Program

NOAA Task:

Task 3 - Individual Science Projects

NOAA Theme:

Theme D: Ecosystem-based Management

Related NOAA Strategic Goal(s):

Goal 1: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Budget Amount:

\$190,000

Amendment(s):

Competed NA14NMF4720328

Description of Research:

Motivation

Pelagic longline operations face bycatch issues with sharks, sea turtles, and marine mammals (such as false killer whales (*Pseudorca crassidens*)), while demersal longline operations face bycatch issues with rockfish and skates, and interactions with sperm whales (*Physeter macrocephalus*) and killer whales (*Orcinus orca*). Time-area closures and dehooking equipment are strategies being used to reduce sea turtle mortality and whale bycatch in pelagic longline fisheries. Another specific regulatory action recently adopted to reduce false killer whale bycatch in Hawaiian waters is the implementation of "weak hooks": hooks constructed to yield when enough force is implemented

Given recent rapid decreases in the cost and size of consumer electronics, one might ask whether the concept of a "smart" hook is viable: a sensor that measures not only the magnitude, but other features of the acceleration time series of an animal's struggle with the line, such as the duration and persistence of tugs on a line, and rhythms of struggling and other temporal patterns in the tugging during both the initial hook ("first strike") and the subsequent haul. Additional cues to species identification could be obtained from sounds generated by both an animal's struggles and (in the case of marine mammals) vocalizations from the animal itself. If some combination of accelerometer and acoustic measurement pattern could be found to flag the presence of a bycatch or endangered species, then the hook could release via a variety of simple methods, such as a burn wire or relay. Multiple hooks might be monitored by such a system by looking at the spectral content of the accelerometer



data: the more distant the hook, the less bandwidth a single tug should display. The concept, in principle, could be applied to a large range of bycatch species on longlines, or other fishing techniques that catch individual fish on individual hooks.

While these questions could in principle be addressed without underwater video, relying instead on visual observers or video recordings of items hauled onto a vessel's deck, the use of a combined video/acoustic/accelerometer system provides some significant logistical advantages, such as eliminating the need for intrusive or inconvenient video recording during an in-progress haul, and also enabling a larger sample size, in that animals that spin off, escape, or otherwise release before reaching the surface could be documented and analyzed.

Under this project 12 autonomous recorder systems, consisting of GoPro cameras, hydrophones, and accelerometers—dubbed ‘TadPros’, are being deployed off Hawaii and Alaska to test the viability of the “smart hook” concept, using a variety of target and bycatch species as a demonstration fishery. The work described below is being conducted under SEASWAP (<http://seaswap.info>; <http://wp.me/P4j34t-2d>), a twelve-year collaboration between the local fishing community of Sitka, the Alaska Longline Fishermen’s Association (ALFA), the non-profit Sitka Sound Science Center (SSSC), and the Scripps Institution of Oceanography (SIO). The fishing community participates as equal partners in the research effort; for example, our fishermen colleagues have designed and built most of the deployment hardware for the TadPro.

Results

Accelerometers were incorporated into cameras. Over the reporting period 20 longline deployments were conducted off Alaska, with four to six

camera/audio/accelerometer packages attached. Six sets focused on sablefish, 14 focused on halibut. Preliminary video review found up to 140 camera interactions that yielded possible camera/accelerometer motion. Detailed analysis is ongoing.

Data from 14 pelagic sets collected Jan. 2015 were analyzed, identifying two mahi-mahi interactions and two false killer whale reactions. One false killer whale interaction showed three incidents of potential line acceleration caused by “line plucking”. These data were presented at a scientific conference in Dec. 2015 and submitted for peer-reviewed publication before March 2016.

Objectives:

The primary motivation for this work is to see whether, in principle, a “smart hook” could be developed that could be used to identify and release bycatch or endangered species through acceleration (or combined acoustic/acceleration) time series analysis alone. This project has three objectives to achieve by Sept. 30, 2015:

- A. Expand “TadPro” to include acceleration: The TadPro design would be expanded to incorporate datalogging of accelerometer measurements, and ten units would be built.
- B. Species Identification with “A/A”: Fifteen deployments of longline gear (with multiple TadPros attached per deployment) would be used to record acoustic, video, and accelerometer data streams of various hooked animals to determine whether accelerometer and/or acoustic (A/A) time series data are sufficient to distinguish between various caught species.
- C. Extend TadPro lifetime: examine whether accelerometer measurements can be used as a trigger for recording audio and video, thus extending the practical deployment lifetime of the “TadPro”.



Accomplishments & Milestones:

During the reporting period in question:

1. TadPro design incorporated accelerometer (Objective A), sampling data at 32 Hz;
2. Between April and August 2015, 20 demersal longline sets were deployed and reviewed, with 4 to 6 cameras per set. Six sets focused on sablefish, 14 on Halibut. Video review identified 140 potential incidents where fish were interacting with nearby hooks and camera was being moved/shifted. (Objective B)
3. 14 sets from pelagic longline deployments (conducted 1/15) were analyzed for acceleration and depredation. Two false killer whale depredation encounters yielded evidence of line plucks detected by accelerometer.

4. Peer-reviewed paper submitted on line acceleration caused by false killer whale depredation.

Conferences, Meetings & Presentations

- c. 21st Biennial Conference for Marine Mammology, 2015 in San Francisco, California, from 13-18 December, 2015, represented by Aaron Thode, Jan Straley, and Victoria O'Connell
- d. COLTO Depredation Workshop, from March 15-18, 2016 in Punta Arenas, Chile, represented by Jan straley

Education & Outreach

Communications

- b. Results presented on SEASWAP and SSSC webpages, for public awareness.



PARTNERS & COLLABORATORS

Interagency

National Aeronautics and Space
Administration (NASA)

National Oceanic and Atmospheric
Administration (NOAA)

National Science Foundation (NSF)

United States Bureau of Ocean Energy
Management (BOEM)

United States Coast Guard (USCG)

United States Department of Energy (DOE)

United States Environmental Protection
Agency (EPA)

United States Fish and Wildlife Service (FWS)

United States Forest Service (USFS)

United States Geological Survey (USGS)

United States Navy (USN)

Office of Naval Research

Partnerships

Alaska Department of Fish and Game

Alaska Department of Fish and Game, Steller
Sea Lion Program

Alaska Longline Fisherman's Association
(ALFA)

Atlantic States Marine Fisheries Commission

Bigelow Laboratory for Ocean Sciences

BSH (Germany)

California Department of Fish and Wildlife
(CDFW)

California Department of Water Resources
(CDWR)

California Fisheries Cooperative Institute
(CalCOFI)

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Luis Obispo (CalPoly)

California State University Monterey Bay
(CSUMB)

California State University, Long Beach
(CSULB)

Canada Department of Fisheries and Oceans

Center for Stock Assessment Research
(CSTAR)

Colorado State University

Columbia River Inter-Tribal Fish Commission

CSIRO (Australia)

East Bay Municipal Utility District (EBMUD)

Georgia Tech

Hebrew Univ. of Jerusalem

Hoopa Tribal Fisheries

Hoopa Valley Tribal Fisheries Department

Hubbs-SeaWorld Research Institute (HSWRI)

Humboldt State University

Idaho Department of Fish and Game

IfM-Geomar, Kiel, Germany

IFREMER (France)

INCOIS (India)

INOCAR (Ecuadoran Navy)

Instituto Nacional de Investigacion y
Desarrollo Pesquero (INIDEP)



Inter-American Tropical Tuna Commission (IATTC)
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 IOS (Canada)
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 Karuk Tribal Fisheries
 KMA (Korea)
 KORDI (Korea)
 Linneaus University (LU)
 Los Alamos National Labs
 Manta Trust
 MetStat
 Mid Klamath Watershed Council
 Misool Eco-Resort Conservation Center
 Monterey Bay Aquarium Research Institute (MBARI)
 Monterey Peninsula Water Management District (MPWMD)
 Moss Landing Marine Lab
 NASA's Jet Propulsion Laboratory
 National Oceanographic Centre (U.K.)
 Nature Imagery
 NCAR (NSF)
 NIWA (New Zealand)
 Northwest Indian Fisheries Commission
 NSF Polar Programs
 Office of Spill Prevention and Response (OSPR), California Department of Fish and Wildlife
 Orange County Sanitation District (OCSD)
 Oregon Department of Fish and Wildlife

Oregon State University (OSU)
 Pacific Fishery Management Council
 Pfleger Institute of Environmental Research (PIER)
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 Sonoma County Water Agency
 Sportfishing Association of California (SAC)
 Texas A&M University (TAMU)
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 United States Navy - NAVFAC EXWC (CODE EV)
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 United States Navy - Naval Research Laboratory, Monterey (NLR-Monterey)



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University of California, Santa Barbara (UCSB)

University of California, Santa Barbara (UCSB), Institute for Computational Earth System Science (ICESS)

University of California, Santa Cruz (UCSC)

University of Hawaii

University of Maine (UMA)

University of Miami (UM)

University of Michigan

University of Southern California (USC)

University of Southern Mississippi (USM)

University of Washington (UW)

University of Wyoming

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Washington Department of Fish and Wildlife

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Andrew Thorpe, NASA Jet Propulsion Laboratory

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 Breck Owens, Woods Hole Oceanographic
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 Brendan Lehman, UC Santa Cruz
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 Brian Beckman, NOAA Fisheries
 Brian Burke, NOAA Fisheries
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PUBLICATIONS

Publication Summary

	CIMEC Lead Author		NOAA Lead Author		Other Lead Author		Totals
	Peer Reviewed	Non-Peer Reviewed	Peer Reviewed	Non-Peer Reviewed	Peer Reviewed	Non-Peer Reviewed	
2010 - 2011	22	19	24	14	11	7	97
2011 - 2012	30	9	6	8	38	14	105
2012 - 2013	76	29	38	10	40	13	206
2013 - 2014	89	23	15	5	69	10	211
2014 - 2015	60	12	42	20	45	7	186
2015 - 2016	63	41	29	7	60	17	217

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ACRONYMS

AMLR	Antarctic Marine Living Resources Program
AOML	NOAA/Atlantic Oceanographic and Meteorological Lab
BAS	Birch Aquarium at Scripps
BML	Bodega Marine Laboratory, UC Davis
CA COSEE	California Center for Ocean Science Excellence in Education
CalIT	California Institute of Technology
Cal State	California State University system
Caltrans	California Department of Transportation
CAP	California Applications Program
CBNMS	Cordell Banks National Marine Sanctuary
CCMA	Center for Coastal Monitoring and Assessment
CDFG	California Department of Fish and Game
CEC	California Energy Commission
CEFA	Climate, Ecosystem and Fire Applications
CeNCOOS	Central and Northern California Ocean Observing System
CEOP	Coordinated Enhanced Observing Period
ChESS	Biogeography of Deep-Water Chemosynthetic Ecosystems / Census of Marine Life
CICAR	Cooperative Institute for Climate Applications and Research, Palisades, New York
CICOR	Cooperative Institute for Climate and Ocean Research, Woods Hole, Massachusetts
CICS	Cooperative Institute for Climate Science, Princeton, New Jersey
CIFAR	Cooperative Institute for Arctic Research, Fairbanks, Alaska
CILER	Cooperative Institute for Limnology and Ecosystems Research, Ann Arbor, Michigan
CIMAS	Cooperative Institute for Marine and Atmospheric Studies, Miami, Florida
CIMMS	Cooperative Institute for Mesoscale Meteorological Studies, Norman, Oklahoma
CIMRS	Cooperative Institute for Marine Resource Studies
CIMSS	Cooperative Institute for Meteorological Satellite Studies,



	University of Wisconsin, Madison
CIOSS	Cooperative Institute for Oceanographic Satellite Studies
CIRA	Cooperative Institute for Research in the Atmosphere
CIRES	Cooperative Institute for Research in Environmental Sciences
CLIMAS	Climate Assessment for the Southwest
CLSA	California Land Surveyors Association
CMER	Cooperative Marine Education and Research
CNES	Centre National d'Etudes Spatiales
COML	Census of Marine Life
COP	NOAA/NOS/Center for Sponsored Coastal Ocean Research/Coastal Ocean Program
CPO	NOAA/Climate Programs Office (formerly, Office of Global Programs (OGP))
CRIP	Centro Regional de Investigacion Pesquera, Instituto Nacional de la Pesca, Ensenada/La Paz, Mexico
CRTN	California Real Time Network
CSIRO	Commonwealth Scientific and Industrial Research Organisation--Australia
CSRC	California Spatial Reference Center
CTD	Conductivity Temperature and Depth (as in, Underway CTD)
DBCP	Data Buoy Cooperation Panel, WMO-IOC
DOE	U.S. Department of Energy
DWR	California Department of Water Resources
ECCO	SIO's Estimating the Circulation and Climate of Oceans Consortium
ENSO	El Niño and Southern Oscillation
ESRL	NOAA/Earth System Research Laboratory
FKNMS	NOAA/Florida Keys National Marine Sanctuary
GACC	Geographic Area Coordination Centers
GEOSS	Global Earth Observation System of Systems
GEWEX	Global Energy and Water-cycle Experiment
GIS	Geographic Information Systems
GMD	NOAA/ESRL/Global Monitoring Division
GODAE	Global Ocean Data Assimilation Experiment



GPS	Global Positioning System
GSD	NOAA/ESRL/Global Systems Division
GTS	GNU Triangulated Surface
HRC	Hydrologic Research Center, San Diego, CA
HRX	Repeat high resolution expendable Bathythermograph
ICARTT	International Consortium for Atmospheric Research on Transport and Transformation
IOC	Intergovernmental Oceanographic Commission
IOOS	Integrated and Sustained Ocean Observations
IRD	Institut de Recherche pour le Développement
IRI	International Research Institute for Climate Prediction
JCOMM	Joint WMO-10C Technical Commission for Oceanography and Marine Meteorology
JIMAR	Joint Institute for Marine and Atmospheric Research
JIMO	Joint Institute for Marine Observations
JISAO	Joint Institute for the Study of Atmosphere and Ocean
JPL	Jet Propulsion Laboratory, NASA
MBARI	Monterey Bay Aquarium Research Institute
MIT	Massachusetts Institute of Technology, Harvard
MPI	Max Planck Institute, Germany
MPL	Marine Physical Laboratory, SIO, UCSD
NASA	National Aeronautics and Space Administration
NDBC	NOAA/NWS/National Data Buoy Center
NCAR	National Center for Atmospheric Research
NCCOS	National Centers for Coastal Ocean Science
NCEP	NOAA/National Centers for Environmental Predictions
NEFSC	NOAA/Northeast Fisheries Science Center
NESDIS	NOAA/National Environmental Satellite, Data, and Information Services
NGI	Northern Gulf Institute
NGS	NOAA/National Geodetic Survey
NIWA	National Institute of Water and Atmospheric Research, New Zealand



NMFS	NOAA/National Marine Fisheries Service
NMSP	National Marine Sanctuary Program
NOS	NOAA/National Ocean Service
NSF	National Science Foundation
NWFSC	NOAA/Northwest Fisheries Science Center, NMFS
NWS	NOAA/National Weather Service
OAP	NOAA/Ocean Assessment Program
OAR	NOAA/Ocean and Atmospheric Research
OE	NOAA/Office of Ocean Exploration
OGCM	Oceanic General Circulation Model
OGP	See CPO
ONR	Office of Naval Research
ORA	NOAA/Office of Research and Applications
PDO	Pacific Decadal Oscillation
PFEG	NOAA/NMFS/Pacific Fisheries Environmental Group
PIFSC	NOAA/NMFS/Pacific Islands Fisheries Science Center
PMEL	NOAA/Pacific Marine Environment Lab
R/V	Research Vessel
ROWG	Radio Operators Working Group
SAS	Simplified Arakawa-Schubert cumulus convection scheme
SCCWRP	Southern California Coastal Water Research Project
SDG&E	San Diego Gas & Electric
SEFSC	NOAA/Southeast Fisheries Science Center, Panama City, FL
SIO	Scripps Institution of Oceanography, UCSD
SOPAC	Scripps Orbit and Permanent Array Center
SST	Sea surface temperature
SVP	Surface Velocity Program
SWFSC	NOAA/Southwest Fisheries Science Center, NMFS
UC	University of California
UCD	University of California, Davis
UCLA	University of California, Los Angeles
UCSB	University of California, Santa Barbara



UCSC	University of California, Santa Cruz
UCSD	University of California, San Diego
UNAM	Universidad Nacional Autonoma de Mexico
USARP	U.S. Antarctic Research Program
USC	University of Southern California
USFS	U.S. Fire Service
USGS	U.S. Geological Survey
UW	University of Washington, Seattle
VAdm	Vice Admiral
VOS	Voluntary Observing Ship
WECC	Western Electricity Coordinating Council
WHOI	Woods Hole Oceanographic Institution
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
XBT	Expendable Bathythermograph
XCTD	Expendable Conductivity Temperature and Depth

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