

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

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FINAL REPORT
2016





CIMEC

Cooperative Institute for Marine Ecosystems and Climate

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Cooperative Institute for Marine Ecosystems and Climate Final Performance Progress Report

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Prepared for



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UC San Diego

UC SANTA CRUZ

UCLA

UC DAVIS

HUMBOLDT
STATE UNIVERSITY

UCSB





CIMEC

Cooperative Institute for Marine Ecosystems and Climate

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September 12, 2016

The first five years of the Cooperative Institute for Marine Ecosystems and Climate (CIMEC) began on July 1, 2010, replacing the old Joint Institute for Marine Observations (JIMO) with a new, larger, and more diverse team. In its first 5 years, CIMEC has advanced the science along with supporting key aspects of NOAA's mission and outreach to the public. Our projects are sorted by themes which naturally overlap one another: Climate and Coastal Observations, Analysis and Prediction Research; Climate Research and Impacts; Marine Ecosystems; and Ecosystem-Based Management. Observational programs are important, along with understanding marine ecosystems, education, and technology development.

We are grateful to many individuals and groups in NOAA for their roles in the transition and growth, especially the Cooperative Institutes office, OAR, NMFS, and other line offices. Similarly, Rose Keuler, Anne Footer, and Ryan Jordan have worked tremendously hard to make this new project function well, often under very challenging circumstances.

Many projects continued from JIMO and many new projects were added, broadening the scope of the research. All of the science contributes to inform management and policy at all levels of government and to engage and educate the public. CIMEC continues to contribute to the education of the next generation of scientists through the support of students and postdoctoral scholars. During this period we saw the completion of two new buildings on the UCSD Scripps Institution of Oceanography campus with significant connections to CIMEC: the MESOM building, sponsored by NIST and hosting projects like CalCOFI at the intersection of physical, biogeochemical, and ecological observations and analysis; and the new NOAA SWFSC building just across the street from the MESOM building.

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INTRODUCTION

The Cooperative Institute for Marine Ecosystems and Climate (CI-MEC) research and program activities for the period April 1, 2016 to June 30, 2016 of the National Oceanic and Atmospheric Administration (NOAA) grant NA10OAR4320156 are outlined in this report. In addition to covering the last reporting period, this report also serves as the award's closing 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.

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:

- Alaska Fisheries Science Center (AFSC)
- Antarctic Ecosystem Research Division (AERD)
- Assessment and Monitoring Division (AMD)
- Assessment and Restoration Division (ARD)
- Atlantic Oceanographic and Meteorological Laboratory (AOML)

- Center for Operational Oceanographic Products and Services (CO-OPS)
- Climate Observations Division (COD)
- Climate Program Office (CPO)
- Earth System Research Laboratory (ESRL)
- Emergency Response Division (ERD)
- Fisheries Ecology Division (FED)
- Geophysical and Fluid Dynamics Laboratory (GFDL)
- Global Monitoring Division (GMD)
- Integrated Ocean Observing System (IOOS)
- Marine Ecosystems Division (MED)
- National Centers for Environmental Information (NCEI)
- 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 Marine Mammal Laboratory (MML)
- National Ocean Service (NOS)
- National Weather Service (NWS)
- Northeast Fisheries Science Center (NEFSC)
- Northwest Fisheries Science Center (NWFSC)
- Ocean Acidification 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, (NWS-Los Angeles/Oxnard)
- Weather Forecasting Office, (NWS-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

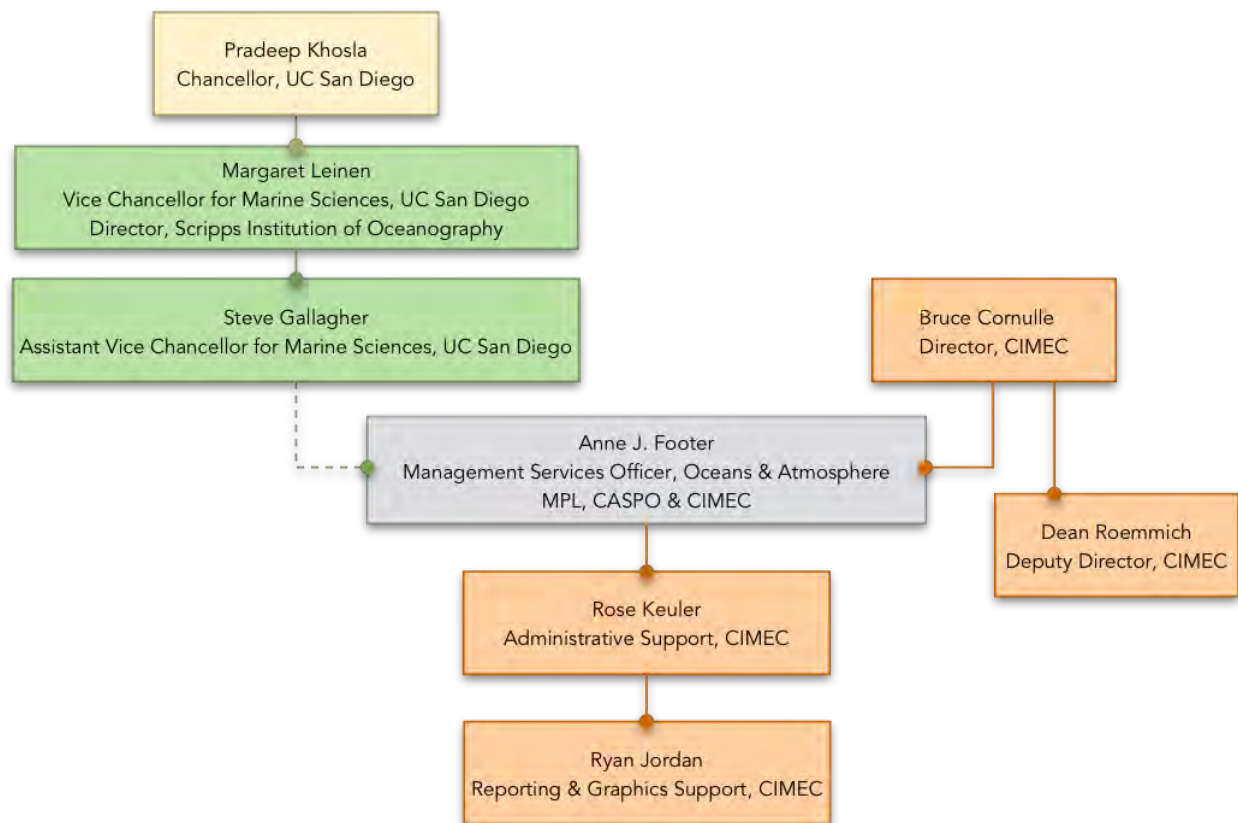
Dr. Roemmich is a professor of oceanography in the Integrative Oceanography Division and Climate, Atmospheric Science, and Physical Oceanography Division at Scripps Institution of Oceanography, University of California, San Diego. He is an expert in the general circulation of the oceans and the role 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 – June 30, 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 – June 30, 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 2015
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 – Department of Oceanography, Humboldt State University

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

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

Bartlett, Douglass – 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 – Department of Ocean Sciences, UC Santa Cruz

Faloon, Ian – Department of Land, Air and Water Resources, UC Davis

Fang, Peng – Scripps Institution of Oceanography, UC San Diego

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

Goldstein, Tracey – Coastal Marine Sciences Institute, UC Davis

Griggs, Gary – Earth & Planetary Sciences and Institute of Marine Sciences, UC Santa Cruz

Hankin, David – Department of Fisheries Biology, Humboldt State University

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 – Computer Science and Engineering, UC San Diego

Levin, Lisa – Scripps Institution of Oceanography, UC San Diego

Mangel, Marc – Baskin School of Engineering, UC Santa Cruz

Marinovic, Baldo – Ecology and Evolutionary Biology and Institute of Marine Sciences, UC Santa Cruz

Mulligan, Timothy – Department of Fisheries Biology, Humboldt State University

Ohman, Mark – Scripps Institution of Oceanography, UC San Diego

Palkovacs, Eric – Ecology & Evolutionary Biology, Institute of Marine Sciences, and NOAA Fisheries @ Long Marine Lab, 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

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



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

Tissot, Brian – Department of Biological Sciences, Humboldt State University

Ward, Darren - Department of Fisheries Biology, Humboldt State University

Whitehead, Andrew – Department of Environmental Toxicology, UC Davis

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.

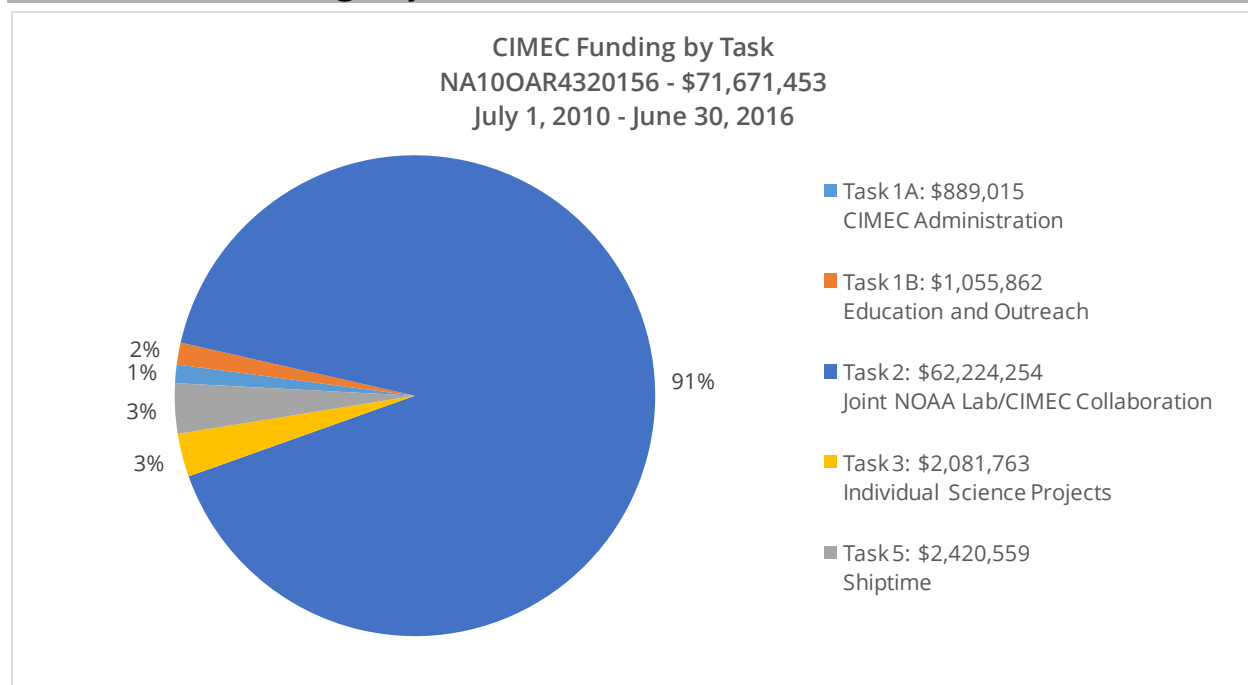
The Center for Stock Assessment Research (CSTAR)

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."

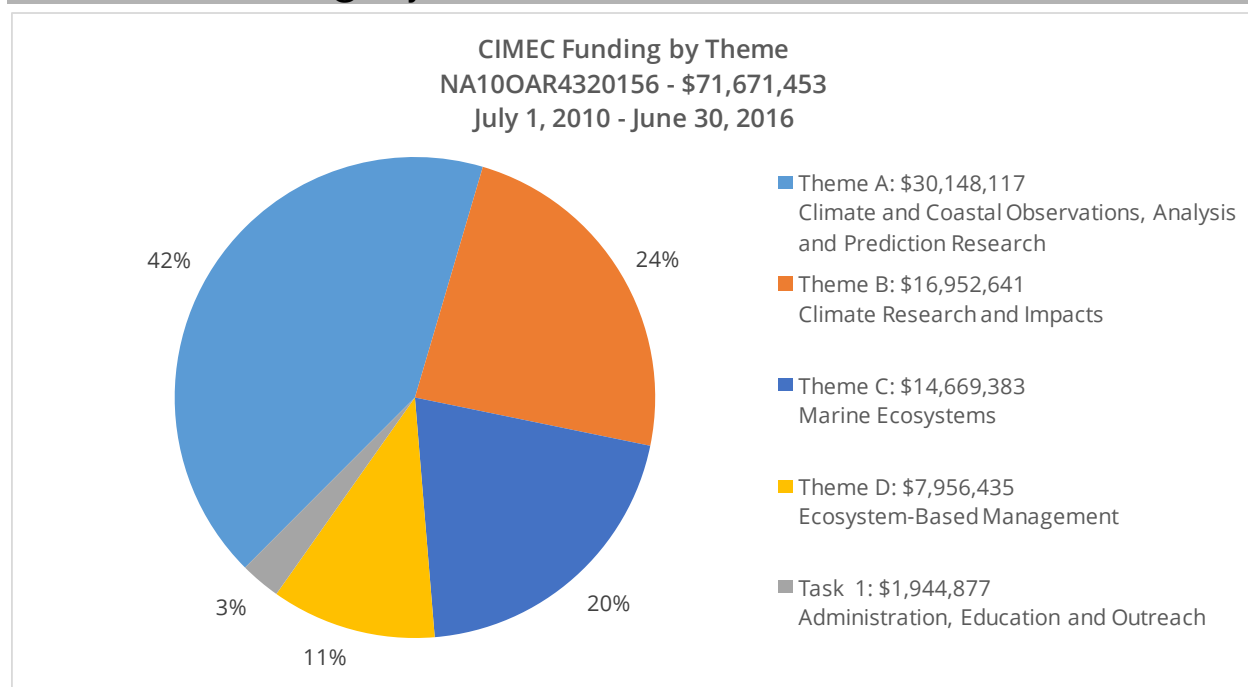


FUNDING SUMMARY

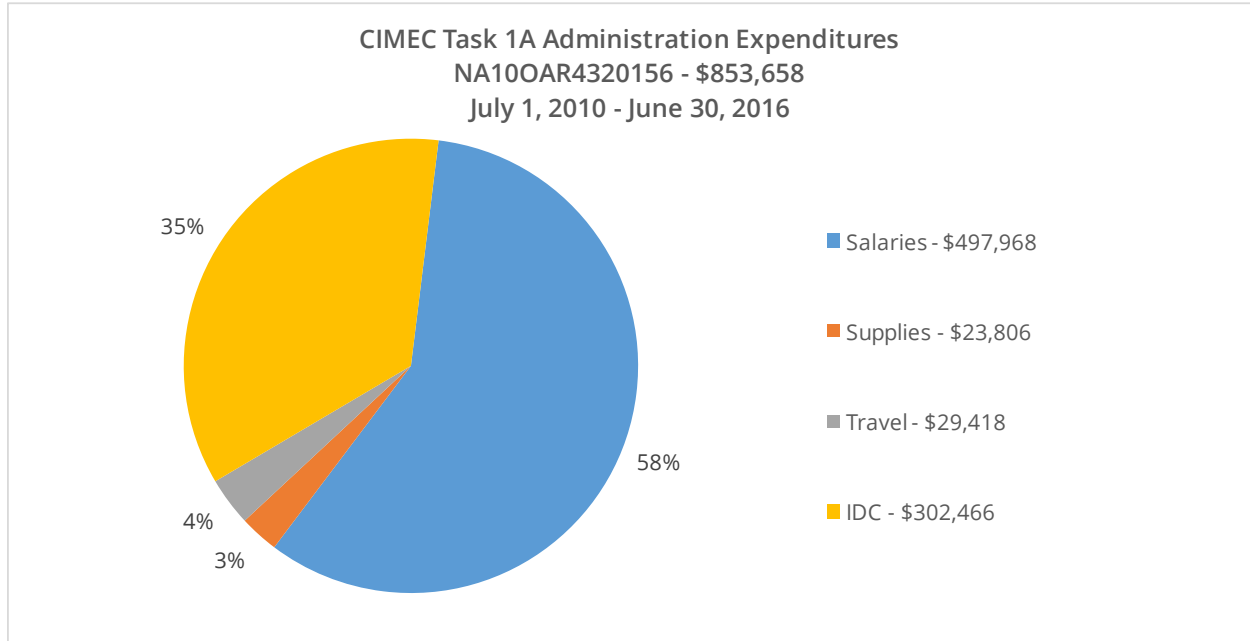
CIMEC Funding by Task



CIMEC Funding by Theme

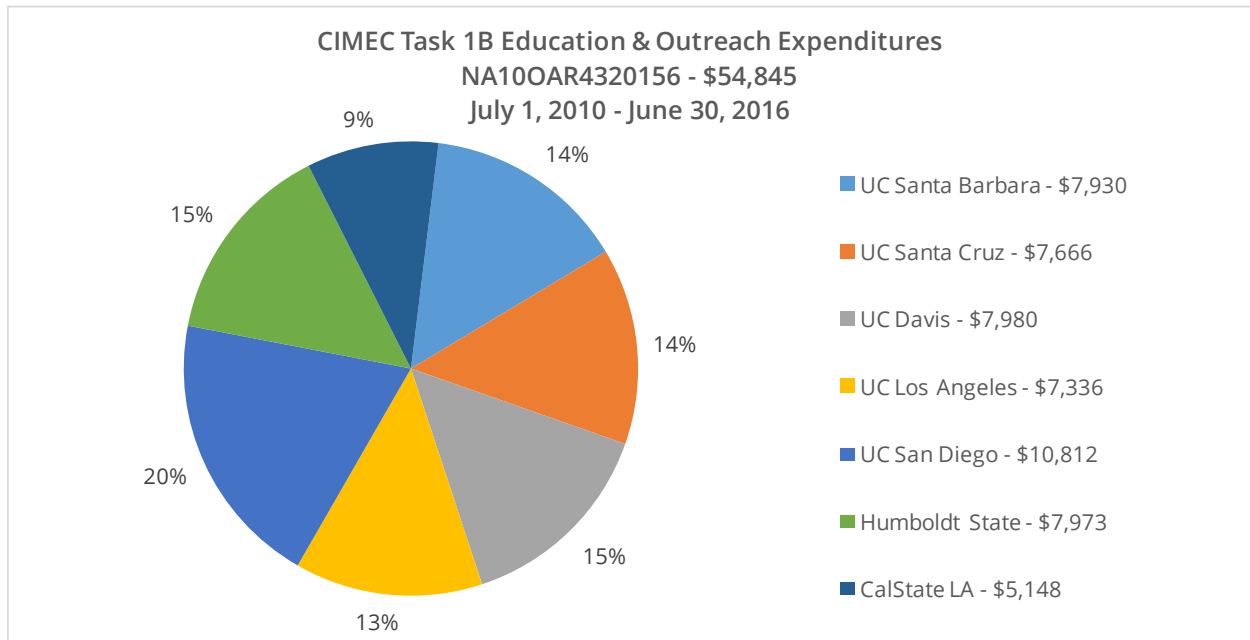


CIMEC Task 1A - Administration Expenses



Note 1: CIMEC Task 1A activities include salary support for CIMEC's Director, Administrative Officer, Administrative Analyst, and Administrative IT. Travel activities include trips to the NOAA Cooperative Institute Director's and Administrator's meeting held in Silver Spring, MD, as well as travel to CIMEC Partner Institutions. Supply activity includes communication costs, meeting costs and other 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>



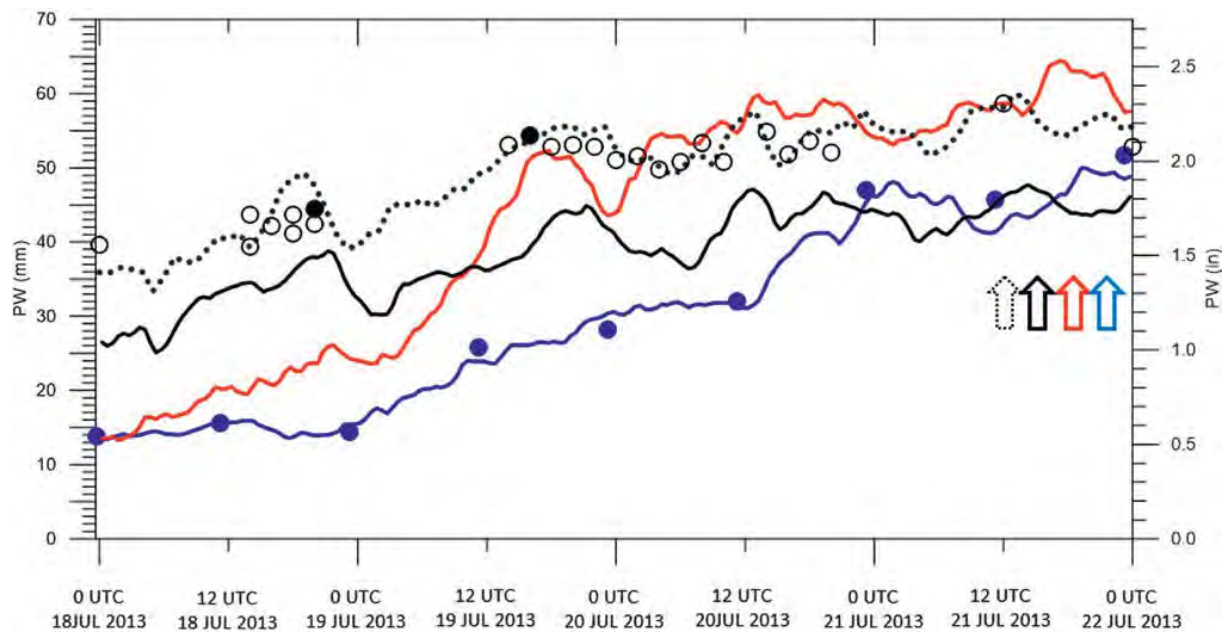


Figure 1: PW measurements during the evolution of the July 2013 monsoon event. Circles represent PW in cm for radiosondes at San Diego (blue) and Yuma, AZ (black). At the U.S. Army Yuma Proving Ground (YPG), radiosondes are launched irregularly in support of the local mission, and many observations only 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.

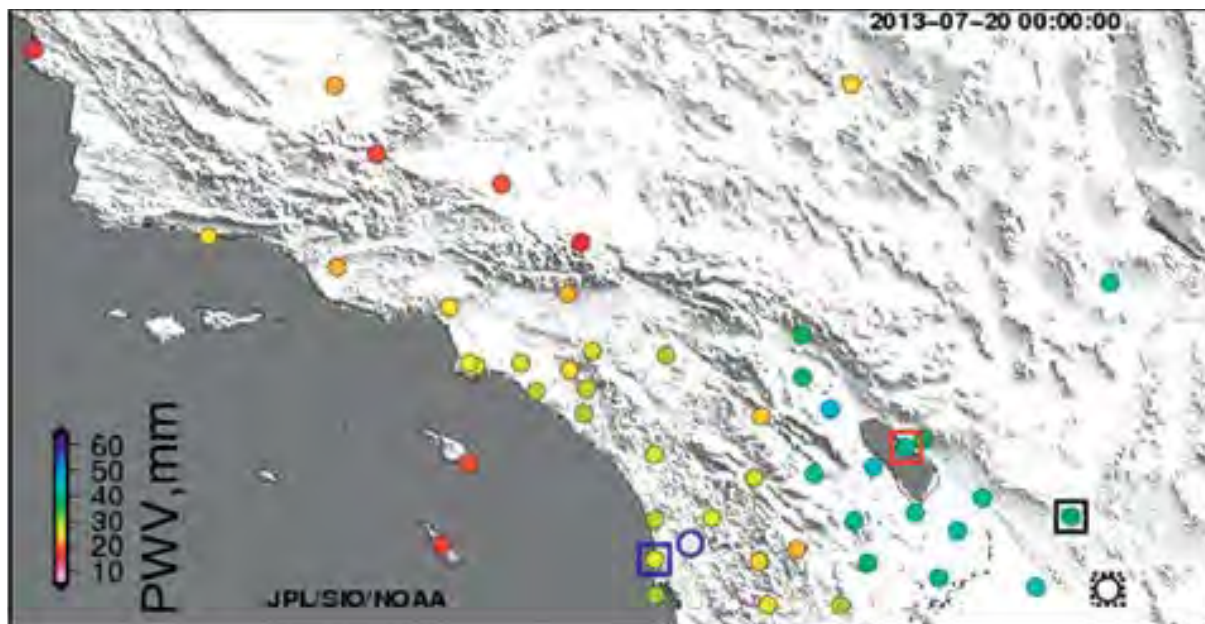


Figure 2: Map locates GPS stations with squares at San Diego (blue), Durmid (red), Glamis (black), and Yuma (dotted black) and radiosondes with circles at San Diego (blue) and Yuma (black). PW in mm at the GPS stations is shown, according to the color scale, at 1700 PDT 19 July (0000 UTC 20 July).



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

- a. 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.



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.

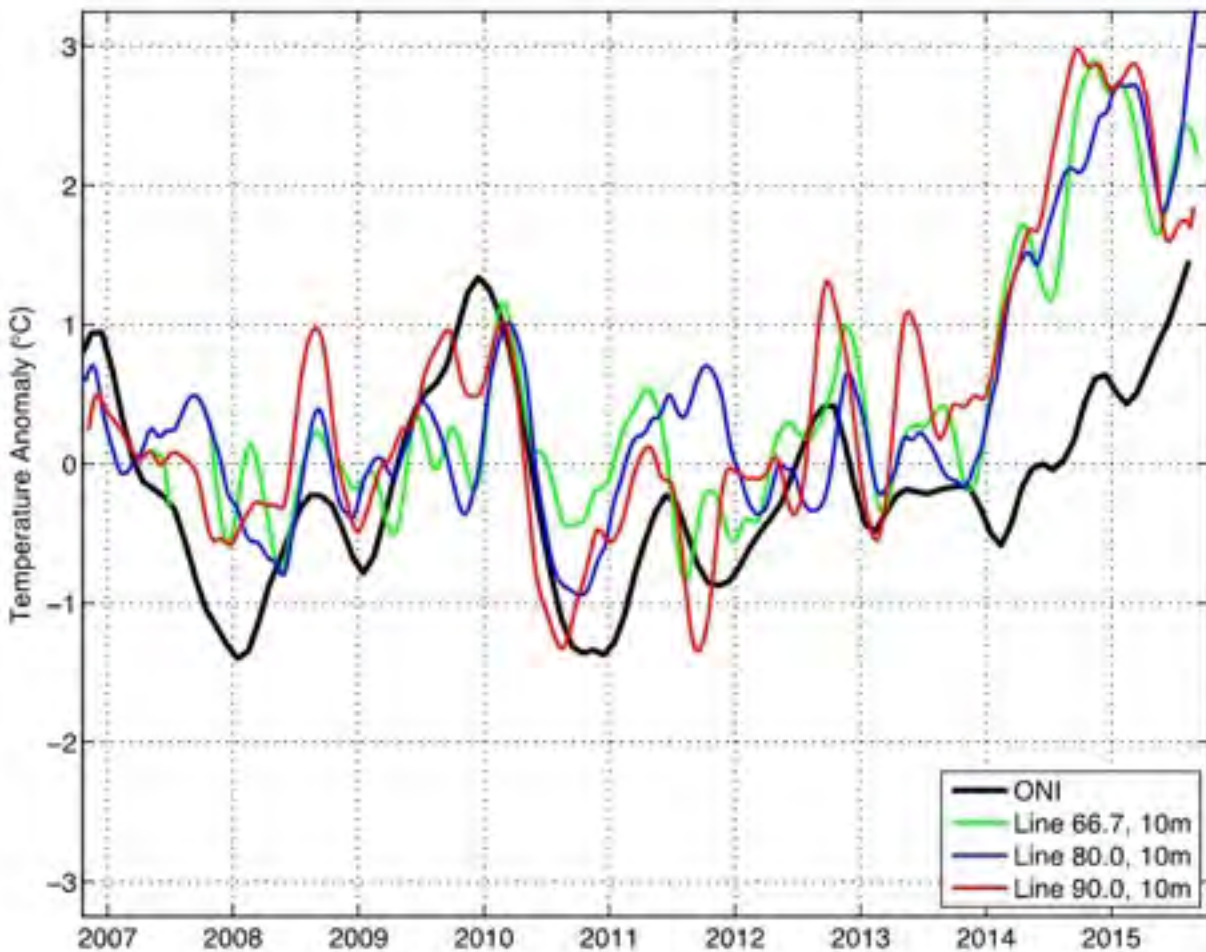


Figure 3: Temperature anomalies at 10 m, averaged over the inshore 200 km of each line, and filtered with a 3-month running mean (colors as in legend). The Oceanic Niño Index is plotted for reference (black). Note the increase in temperature off California concurrent on all lines beginning in January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



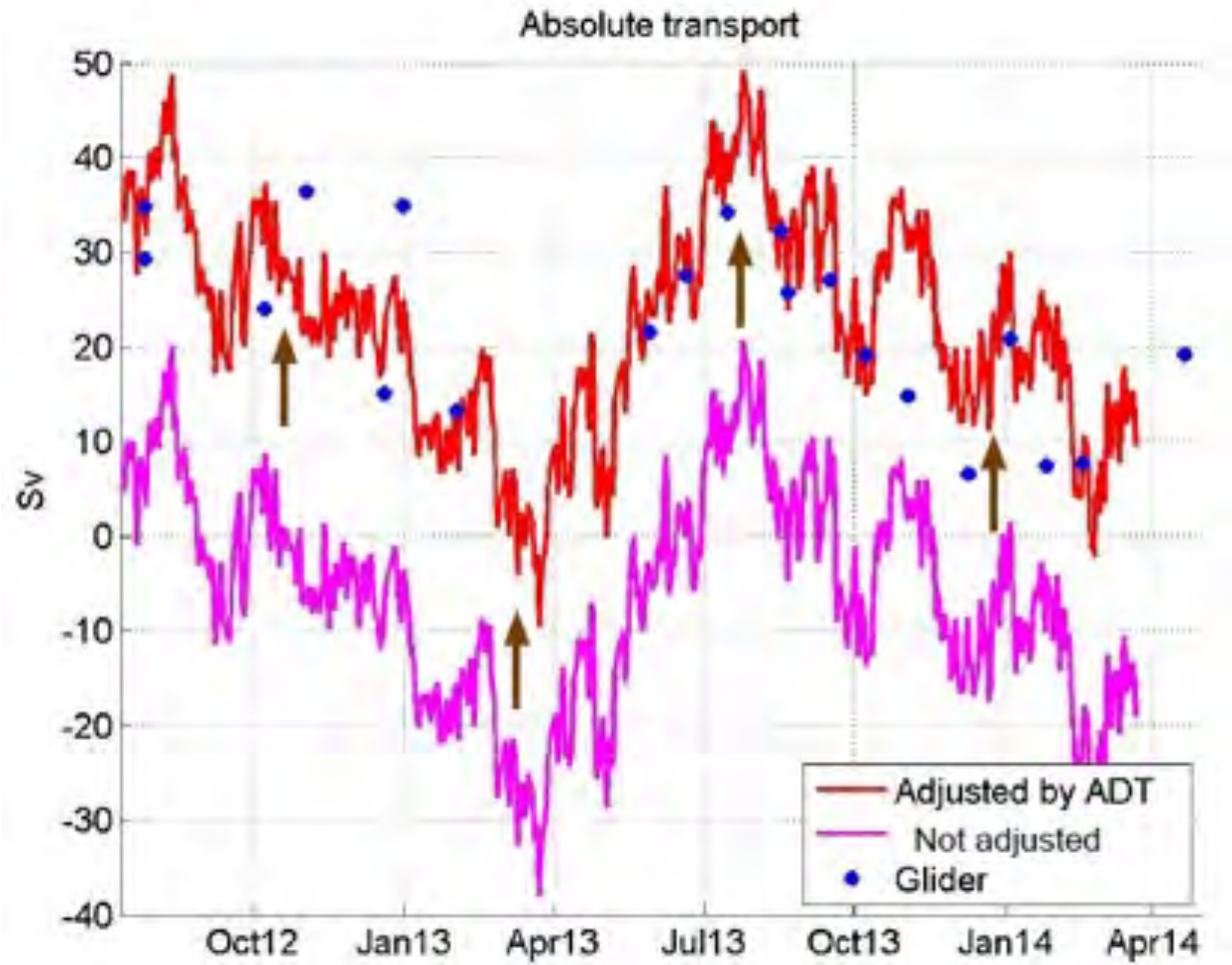


Figure 4: Total Solomon Sea through flow volume transport from mooring-derived dynamic height, referenced to PIES bottom pressure. Pink: without any additional offsets; Red: using a mean offset to reference the mean pressure gradient to the mean surface dynamic topography. The red line is in very good 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 5: Group on Earth Observations Global High Frequency Radar Network Meeting in Crete, Greece.

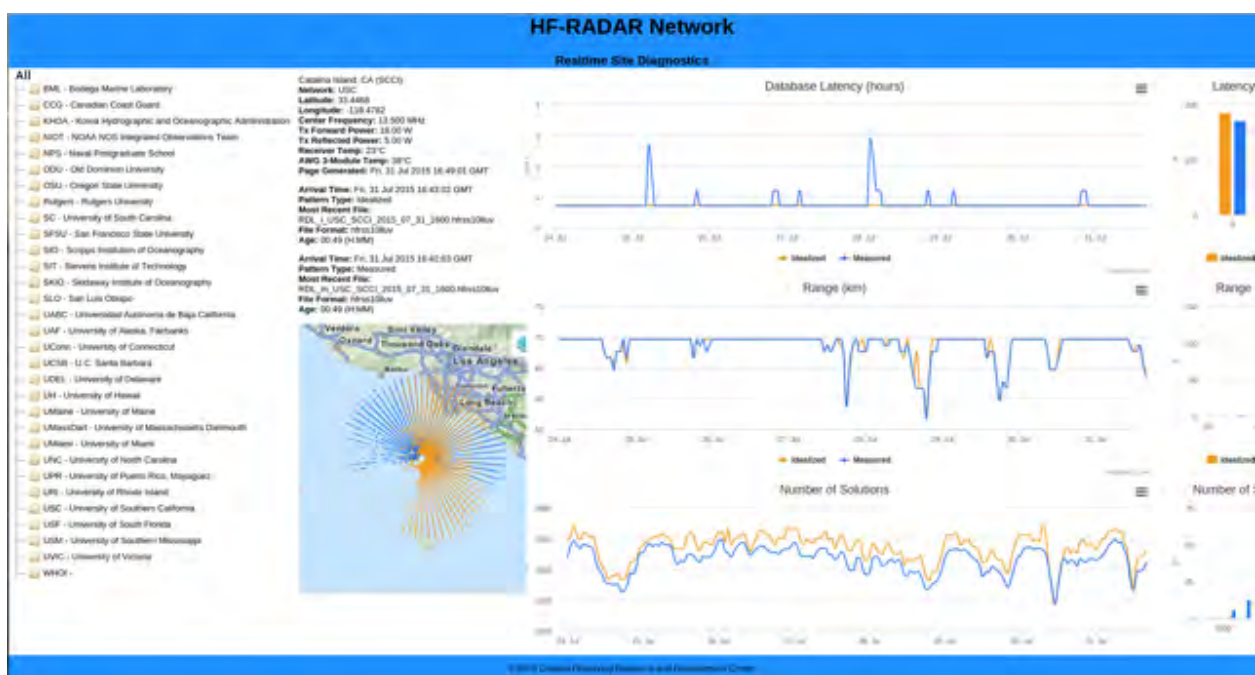


Figure 6: Enhanced HF Radar Network (HFRNet) diagnostics tools for improved performance, interactivity, and capability.



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 tasks 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_oe&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)



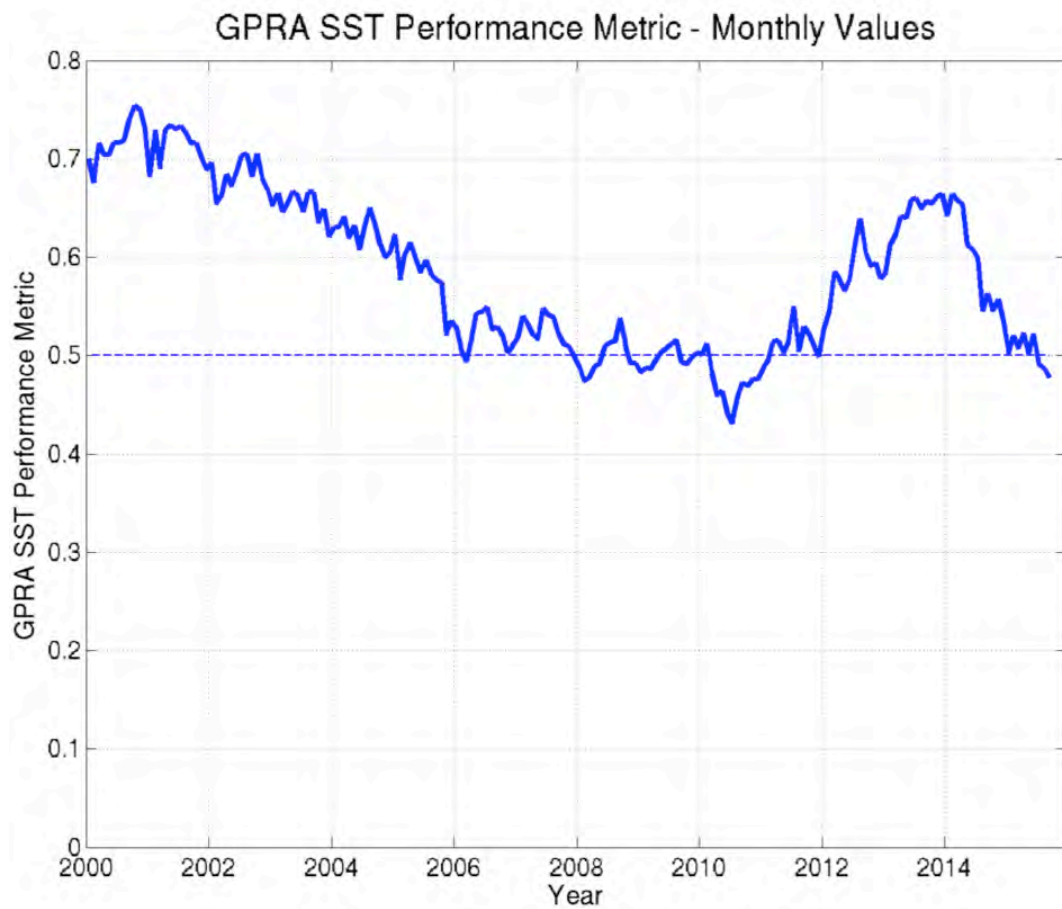


Figure 7: Quarterly SST GPRA Performance Measure and Buoy Need Map by Dr. Huai-min Zhang , NOAA



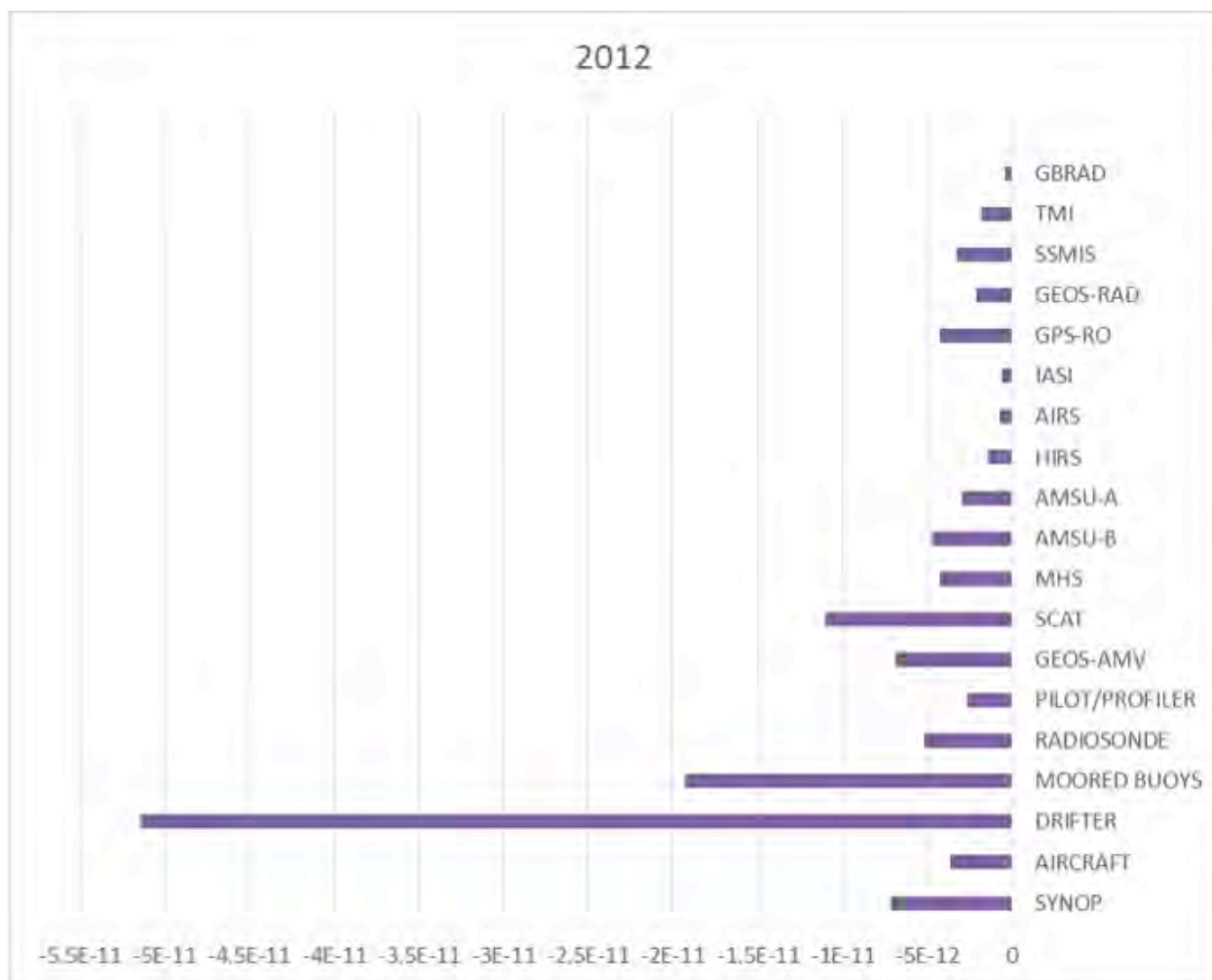


Figure 8: ECMWF operational mean FSOI (i.e. positive impact of the observations on the forecast) for the different observing systems for July-August, 2012. The FSOI values are also normalized by the total forecast error for comparison reason. The observing systems displayed are SYNOP surface observations (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 9: The Mooney & Twin Otter Aircraft with science team and crew on the San Juan Basin Intensive



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

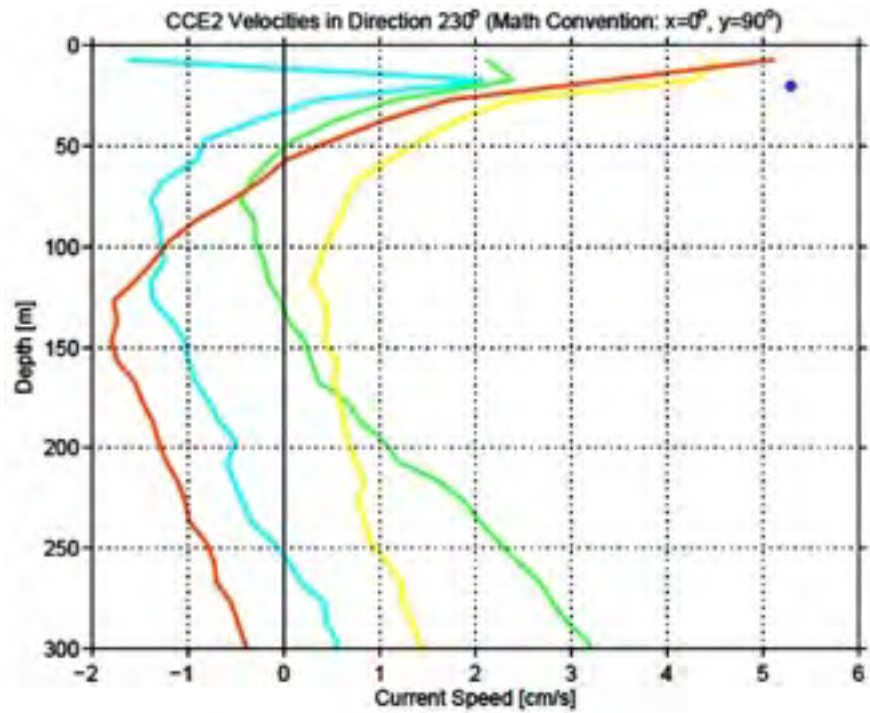
- a. IUGG, July 2015 in Prague with Mark Ohman
- b. Pacific Warm Anomaly Workshop, January 2016 in Seattle with Uwe Send and Mark Ohman
- c. Ocean Sciences Meeting, February 2016 in New Orleans with S. Wilson, Uwe Send, and Mark Ohman

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 10: 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.



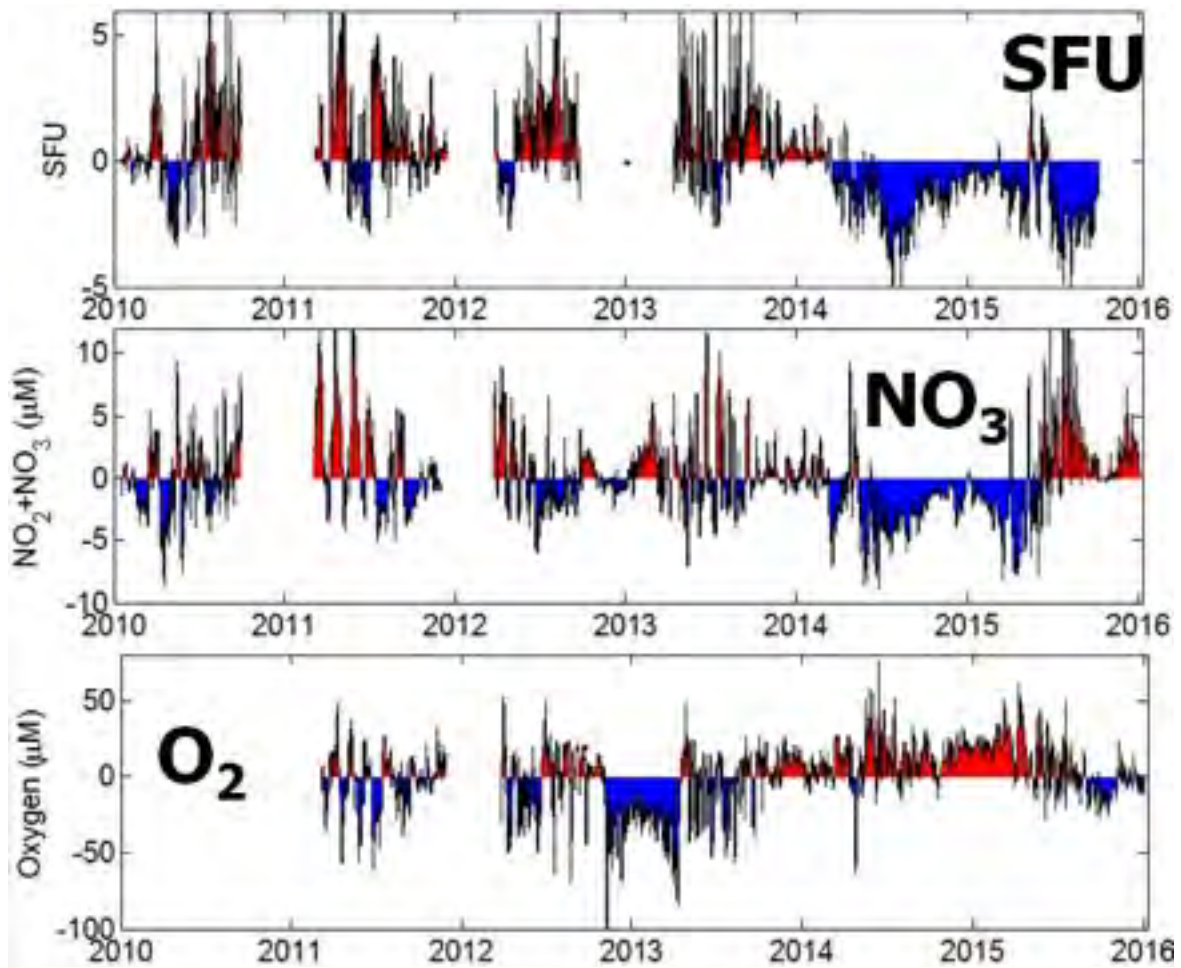


Figure 11: Anomalies (relative to the entire CCE2 mooring data set) of SFU (chlorophyll fluorescence), nitrate, and oxygen concentrations. The very pronounced changes during 2014/15 are clearly visible.



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

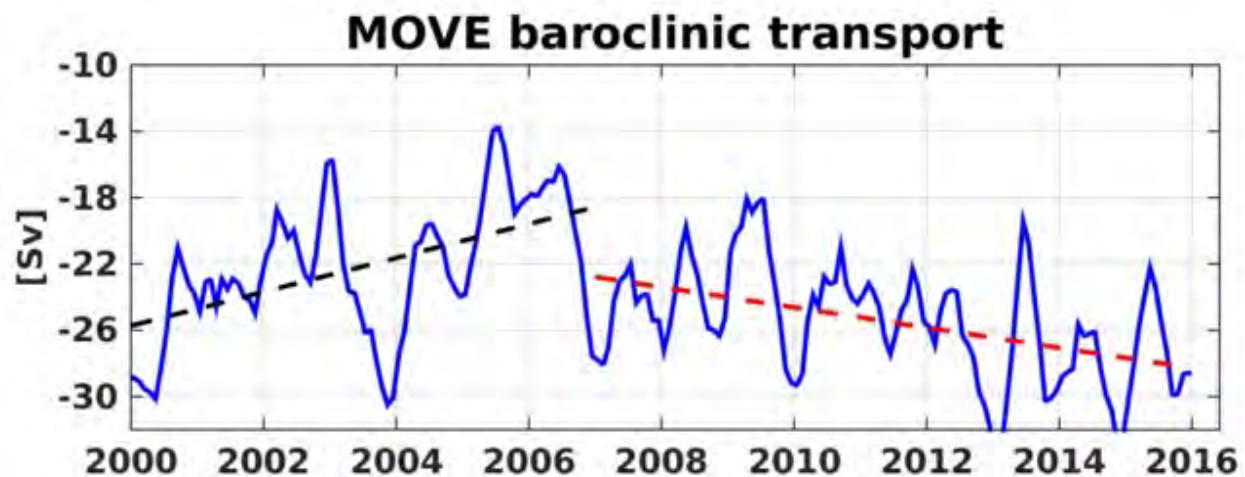


Figure 12: 16 years of quality-controlled baroclinic North Atlantic Deep Water transport (southward therefore negative).



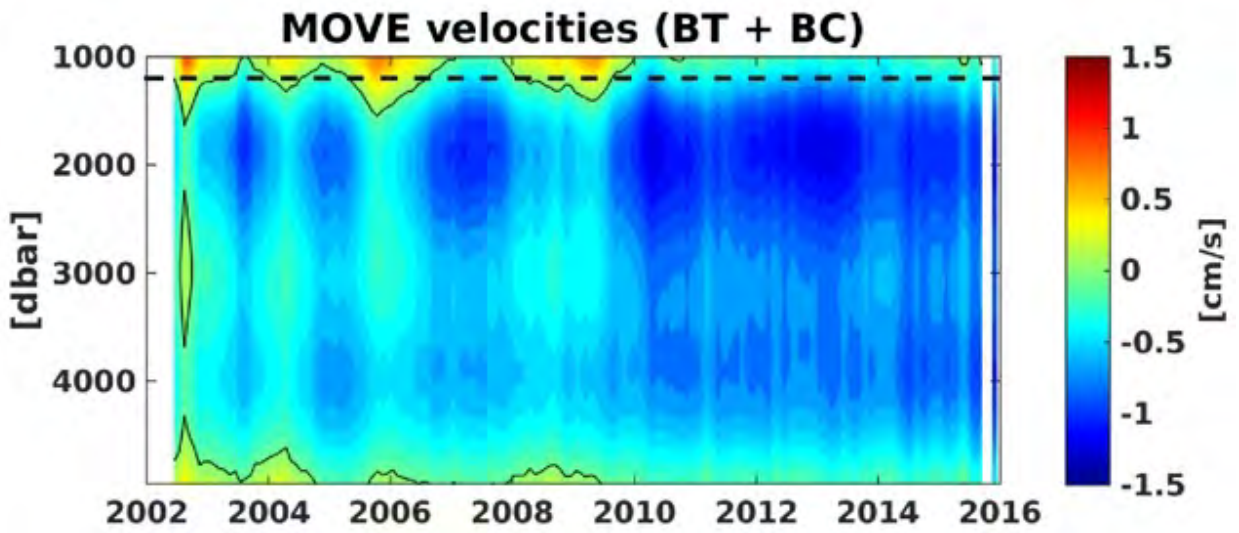


Figure 13: Contour plot of southward NADW flow (blue), showing thickening of the layer since about 2008.



NOAA Support for the CLIVAR and Carbon Hydrographic Data Office at UCSD/SIO, 2010-2016

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

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. THE NOAA EMBLEM IS A REGISTERED TRADEMARK OF THE U.S. DEPARTMENT OF COMMERCE, USED WITH PERMISSION. THE USE OF THE NOAA EMBLEM RECOGNIZES 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 THE DEPARTMENT OF COMMERCE/NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION.

J. Swift, SIO, October 2015

Figure 14: 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.



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 Lony 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.



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 Jarrod 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



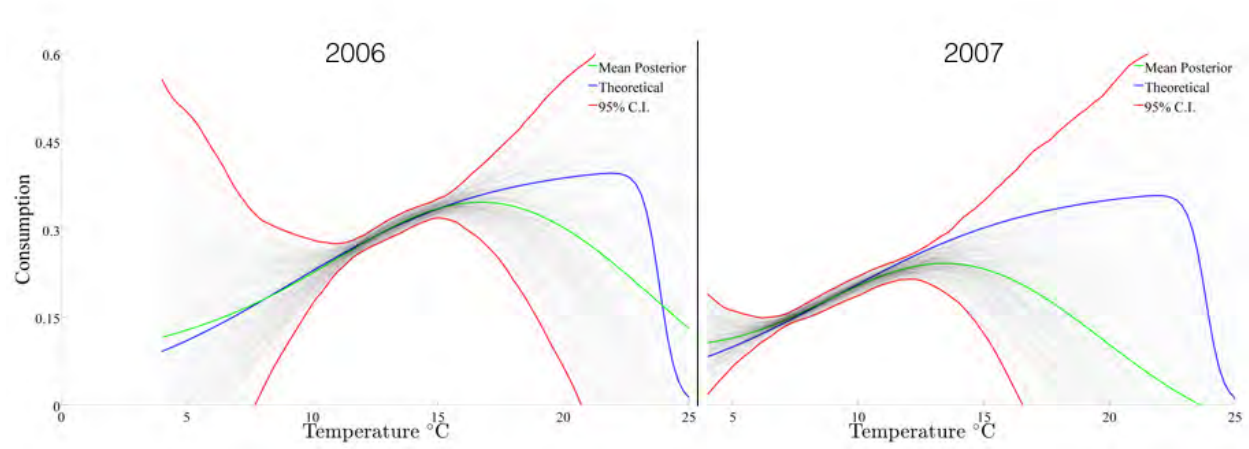


Figure 15: Bayesian computation of the thermal performance curve of steelhead trout

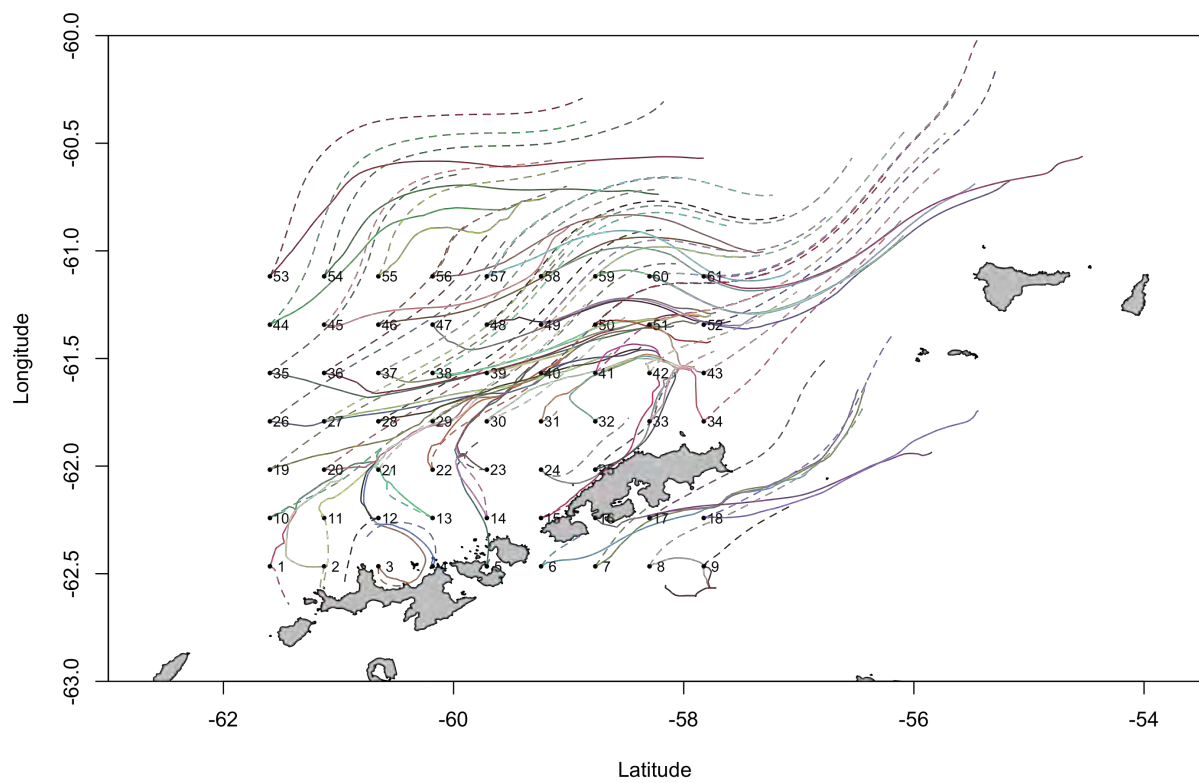


Figure 16: Mean trajectories of simulated active (solid line) and passive (dashed line) krill released at numbered starting points.



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





Figure 18: UCSC and NMFS scientists seining for juvenile Chinook salmon in a Mill Creek irrigation canal." Photo by Alex McHuron





Figure 19: A rotary screw trap used to collect migrating smolts in Mill Creek." Photo by Jeremy Notch





Figure 20: Vanessa Lo (UCSC) holds an ocean sunfish (*Mola mola*) caught during NOAA Fisheries' ocean salmon survey in August 2015." photo credit: Cyril Michel



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

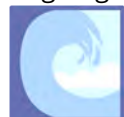
Description of Research:

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.



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)



NOAA Stratus Ocean Reference Station: Mooring, Mapping and in-situ Calibration Operations aboard R/V Melville

Principal Investigator(s):

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

NOAA Primary Contact:

D. Stanitski, Climate Program Office (CPO)

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:

\$664,848

Amendment(s):

51

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

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 21: R/V Melville is the oldest vessel in the academic research fleet, collectively known as the University-National Oceanographic Laboratory System (UNOLS). In April 2016 the vessel was transferred to the Philippines, and commissioned into active service with the Philippine Navy.



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:

\$144,406 (AMD 104)

\$475,481 (AMD 131)

Amendment(s):

104, 131

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>).





Figure 22: 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.



Figure 23: R/V *Roger Revelle* cruises past an iceberg in the Antarctic. Photo by Paul Mauricio



Theme D: Ecosystem-based Management

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.

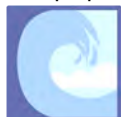
The prototype IBM was developed and reviewed by relevant NOAA Fisheries management and science center staff. This review highlighted the importance of improving our understanding of the at-sea distribution and movement patterns of Chinook salmon (ocean-age 2 and older) and hence their availability as 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 24: Postdoc Charlotte Boyd conducting marine mammal surveys on the 3rd leg of the California Current Cetacean and Ecosystem Assessment Survey (CalCurCEAS) October-November 2015.



CUMULATIVE PROJECT LIST

Task / Theme	Principal Investigator	Project Title	Performance Period	Award Amount	Amendment	Agency Contact
1	David Checkley, Rose Keuler, UC San Diego	CIMEC: Administration	07//01/10 - 06/30/16	\$ 849,423	0, 18, 37, 41,43, 60, 92, 96, 111, 127, 128, 130, 132, 133, 136, 138	P. Hoffman, OAR
1-B	David Checkley, Rose Keuler, UC San Diego	CIMEC Education and Outreach	07/01/14 - 06/30/16	\$ 55,862	130	P. Hoffman, OAR
1	Douglass Bartlett, UC San Diego	Training the Next Generation of Marine Population Dynamics Scientists	07/01/10 - 06/30/15	\$ 1,000,000	5, 31, 45, 91, 100	S. Murawski, NMFS/IOOS R. Hewitt, NMFS/SWFSC
1-B	Daniel Cayan, UC San Diego	Workshop on Vulnerability and Adaptation to Extreme Events in California in the Context of a Changing Climate	11/01/11 - 10/31/12	\$ 20,000	38	A. Parris, CPO
1-D	George Sugihara, UC San Diego	Workshop on Application of Non-Linear Time Series Analysis	04/01/12 - 09/30/12	\$ 19,592	48	R. Hewitt, NMFS/SWFSC
2-A	Eric Terrill, UC San Diego	HF Radar National Network Data Management Development	9/1/2010 - 06/30/16	\$ 2,064,000	2, 23, 39, 89, 103, 110	J. Harlan, NOS
2-A	Andrew Dickson, UC San Diego	Collection and Analysis of Seawater Samples from the California Coast	07/01/10 - 06/30/12	\$ 137,550	8, 30	J. Levy, CPO L. Jewett, CPO
2-A	Andrew Dickson, UC San Diego	Global Carbon Data Management and Synthesis Project	07/01/11 - 06/30/12	\$ 15,000	17	J. Levy, CPO
2-A	Marty Ralph, Daniel Cayan, UC San Diego	An Atmospheric River Case Study on the Russian River and a Vision for Western US Observing Systems	09/01/13 - 08/31/14	\$ 100,000	94	W. Neff, ESRL
2-A	Marty Ralph, UC San Diego	CalWater and Wes-Coast Atmospheric River Research	08/01/14 - 07/31/16	\$ 169,999	114	R. Webb, OAR/ESR/PSD
2-B	Andrew Dickson, UC San Diego	NOAA Ocean Acidification Program Theme 1 CalCOFI OA Monitoring, Small Sample Analysis and QA/QC Analytical Support	7/1/2012 - 06/30/16	\$ 419,182	44, 76, 121	L. Jewett, CPO
2-A	Yehuda Bock, Peng Fang, UC San Diego	Collaborative Scientific and Technical Support to the NOAA Earth System Research Laboratory: January 1, 2011 - June 30, 2011	05/01/11 - 06/30/16	\$ 198,375	10, 56, 95, 139	S. Gutman, ESRL K. Holub, ESRL
2-A	Dean Roemmich, UC San Diego	The Argo Project: Global Observations for Understanding and Prediction of Climate Variability	07/01/11 - 06/30/16	\$ 10,280,620	15, 42, 74, 105	S. Piotrowicz, CPO
2-A	Dean Roemmich, UC San Diego	SIO High Resolution XBT Transects	07/01/11 - 06/30/16	\$ 3,567,771	20, 47, 78, 108	C. Clark, CPO
2-A	Baldo Marinovic, UC Santa Cruz	Shipboard Studies of the California Current System off Central California	10/01/11 - 03/31/14	\$ 143,999	32, 50	S. Miller, NMFS/SWFSC
2-A	Christopher Edwards, UC Santa Cruz	Developing a Data-Assimilative Modeling Tool to Estimate Oxygen and pH over the California Current	10/01/14 - 06/30/16	\$ 100,001	129	F. Werner, NMFS/SWFSC
2-A	Uwe Send, UC San Diego	Integrated Boundary Current Observations in the Global Climate System (CORC)	07/01/11 - 06/30/16	\$ 4,944,175	24, 64, 85	D. Stanitski, CPO
2-A	Uwe Send, UC San Diego	Consortium on the Ocean's Role in Climate (CORC)	07/01/14 - 06/30/16	\$ 1,696,000	120	D. Stanitski, CPO
2-A	David Checkley, UC San Diego	California Cooperative Oceanic Fisheries Investigations: Ocean Observations for Ecosystem-Based Management	07/01/11 - 06/30/16	\$ 6,311,445	28, 58, 90, 119	R. Hewitt, NMFS/SWFSC
2-B	Daniel Cayan, UC San Diego	California NIDIS Pilot	07/01/12 - 06/30/13	\$ 107,291	62	C. McNutt, NIDIS
2-B	Ramanathan/CASPO	Development of Water Vapor Flux Measurements System for Lightweight UAVs	05/01/11 - 04/30/13	\$ 125,000	11	G. Wick, ESRL
2-B	Ralph Keeling, UC San Diego	Measurements of Atmospheric O ₂ /N ₂ , Ar/N ₂ and CO ₂ Abundances in Relation to Carbon Cycling, Ocean Biochemistry, and Global Change	07/01/11 - 04/30/16	\$ 1,683,062	16, 40, 71, 124	K. Mooney, CPO J. Butler, ESRL



Task / Theme	Principal Investigator	Project Title	Performance Period	Award Amount	Amendment	Agency Contact
2-B	Luca Centurioni, Bruce Cornuelle, UC San Diego	The Global Drifter Program	07/01/11 - 06/30/16	\$ 10,795,285	19, 27, 59, 79, 125	C. Clark, CPO
2-B	Uwe Send, UC San Diego	Moored Climate, Carbon, Biogeochemical, and Ecosystem Observations in the Southern California Current (CCE)	07/01/11 - 06/30/16	\$ 1,629,792	36, 67, 98, 116	D. Stanitsk, CPO L. Jewett, CPO
2-B	Ian Faloona, UC Davis	Support to Augment an Integrated Study of the San Juan Basin Methane Emissions Using Airborne Measurements	04/01/15 - 06/30/16	\$ 59,000	141	R. Schnell, GMD
2-C	Andrew Allen, UC San Diego	Collaborative Opportunity: exploring 'omic Technologies to Support Ecosystem Understanding and Fisheries Assessments	05/01/14 - 06/30/16	\$ 200,000	101	K. Goodwin, OAR
2-C	Marc Mangel, UC Santa Cruz	CSTAR: Stock Assessment and Training Research	10/01/10 - 09/30/14	\$ 1,236,321	1, 35, 54, 87	S. Miller, NMFS/SWFSC
2-C	David Hankin, HSU	Freshwater Fish Ecology	10/01/10 - 09/30/15	\$ 298,082	3, 29, 49, 81, 107	S. Miller, NMFS/SWFSC
2-C	Jeffrey Abell, HSU	Ocean Observing and Fisheries Oceanography Research of the Coastal Ocean off Northern California	10/01/11 - 09/30/14	\$ 78,315	34	S. Miller, NMFS/SWFSC
2-C	Brian Tissot, HSU	Deep-Sea Coral Survey off Northern California	08/01/14 - 6/30/16	\$ 71,077	106	S. Miller, NMFS/SWFSC
2-C	Brian Tissot, HSU	Collaborative Ocean Observing and Fisheries Oceanography Research off Northern California	08/01/14 - 06/30/16	\$ 151,563	126	S. Miller, NMFS/SWFSC
2-C	Baldo Marinovic, UC Santa Cruz	Shipboard Studies of the California Current System off Central California	10/01/10 - 03/31/14	\$ 168,901	4	S. Miller, NMFS/SWFSC
2-C	Gary Griggs, UC Santa Cruz	Investigations in Fisheries Ecology	10/01/10 - 06/30/16	\$ 8,375,174	6, 97, 99, 22	S. Miller, NMFS/SWFSC
2-C	Gary Griggs, UC Santa Cruz	Collaboration in Freshwater Ecology	10/01/10 - 09/30/12	\$ 48,466	9	S. Miller, NMFS/SWFSC
2-C	Gary Griggs, UC Santa Cruz	Freshwater Ecology Research Collaboration	10/01/10 - 06/30/16	\$ 196,805	21, 52, 88, 117	S. Miller, NMFS/SWFSC
2-C	John Hildebrand, UC San Diego	Collaborative Studies of Cetaceans with the Southeast Fisheries Science Center	06/01/11 - 06/30/14	\$ 425,935	13, 55, 82	L. Garrison, NMFS/SEFSC
2-C	John Hildebrand, UC San Diego	Collaborative Studies of Cetacans with the Northeast Fisheries Science Center Using High-Frequency Acoustic Recording Packages	07/01/15 - 06/30/16	\$ 650,000	142	S Van Parjis, NMFS/NEFSC
2-C	John Hildebrand, UC San Diego	SOAR Acoustic Ecology Project	04/01/12 - 02/28/15	\$ 22,880	73	L. Guy, PMEL
2-C	John Hildebrand, UC San Diego	Collaborative Studies of Cetaceans Using Passive Acoustic Monitoring with the Pacific Islands Fisheries Science Center	07/01/12 - 06/30/13	\$ 70,000	46	E. Oleson, NMFS/PIFSC
2-C	John Hildebrand, UC San Diego	Measurements of North Atlantic Ambient Noise	04/01/12 - 03/31/15	\$ 80,000	53	J. Gedamke, MED
2-C	Ana Sirovic, Simone Baumann-Pickering, UC San Diego	Acoustic Studies in the Central and Western Pacific	07/01/13 - 06/30/16	\$ 432,231	86, 113	E. Oleson, NMFS/PIFSC
2-C	Tracey Goldstein, UC Davis	Evaluation of Exposure to and Infection with Phocine Distemper Virus to the Eastern District Population Segment of Steller Sea Lions (Eumetipias Jubatus) and Continued Monitoring of the Western Distinct Population Segment	07/01/13 - 06/30/16	\$ 45,854	84, 115	K. Rivera, NMFS-AKR
2-C	Andrew Whitehead, UC Davis	Molecular Mechanisms of Response to Persistent Oil Spill Pollutants	02/01/14 - 06/30/16	\$ 68,668	102	R. Ricker, ARD
2-C	David Kriegman, UC San Diego	The Next Generation of CoralNet: Improving Automated Methods Benthic Image Analysis and Optimizing for NMFS Benthic Imagery	07/01/14 - 06/30/16	\$ 100,000	109	S. Miller, NMFS/SWFSC
2-D	Darren Ward, HSU	Studies in Anadromous Fisheries	10/01/11 - 09/30/13	\$ 29,973	33	S. Miller, NMFS/SWFSC



Task / Theme	Principal Investigator	Project Title	Performance Period	Award Amount	Amendment	Agency Contact
2-D	Gary Griggs, Eric Palkovacs, UC Santa Cruz	Investigations in Fisheries Ecology	10/01/11 - 06/30/14	\$ 6,495,251	22, 63, 72	S. Miller, NMFS/SWFSC
2-D	David Checkley, UC San Diego	California Cooperative Oceanic Fisheries Investigations: Ocean Observations for Ecosystem-Based Management	07/01/10 - 06/30/16	\$ 929,749	7, 119	R. Hewitt, NMFS/SWFSC
2-D	Simone Baumann-Pickering, UC San Diego	Tethys Bioacoustics Metadata Workbench Improvements	05/01/15 - 06/30/16	\$ 30,000	140	J. Rusin, NMFS/SWFSC
2-D	Brice Semmens, UC San Diego	Developing the Center for the Advancement of Population Assessment Methodologies (CAPAM)	07/01/12 - 06/30/16	\$ 262,100	66	J. McDaniel, NMFS/SWFSC
2-D	John Hildebrand, UC San Diego	Collaborative Studies of Cetaceans with the Pacific Islands Region	07/01/11 - 12/31/12	\$ 118,000	14	E. Oleson, NMFS/PIFSC
2-D	Brice Semmens, UC San Diego	Identifying Critical Habitat for Highly-Mobile Marine Vertebrates Under the Endangered Species Act	08/01/14 - 06/30/16	\$ 80,089	123, 135	R. Hewitt, NMFS/SWFSC
2-D	Mark Jacobsen, UC San Diego	Frontiers of Marine Resources Economics	07/01/13 - 06/30/16	\$ 11,273	83	D. Squires, SWFSC
3-B	Uwe Send, UC San Diego	Meridional Overturning Variability Experiment (MOVE)	07/01/11 - 06/30/16	\$ 1,561,817	25, 68, 75, 118	D. Stanitski, CPO
3-B	Bruce Appelgate, UC San Diego	NOAA Support for the CLIVAR and Carbon Hydrographic Data Office at UCSD/SIO 2012	07/01/12 - 06/30/16	\$ 326,546	65, 77, 112	D. Legler, CPO
3-C	Timothy Mulligan, HSU	Ocean Observing Systems	08/01/12 - 07/31/14	\$ 190,400	57	S. Miller, NMFS/SWFSC
3-D	Lisa Levin, UC San Diego	AAAS Symposium Support: Deep-Ocean Industrialization	07/01/13 - 06/30/14	\$ 3,000	93	D. Squires, SWFSC
5-B	Bruce Appelgate, UC San Diego	NOAA Stratus Ocean Reference Station: Mooring, Mapping and in-situ Calibration Operations aboard R/V Melville	05/01/12 - 04/30/16	\$ 664,848	51	D. Stanitski, CPO
5-C	Bruce Appelgate, UC San Diego	R/V Roger Revelle Shiptime	09/01/14 - 06/30/16	\$ 619,887	104, 131	T. Peltzer, PMEL R. Hewitt, NMFS/SWFSC
5-C	Bruce Appelgate, UC San Diego	R/V New Horizon Shiptime	04/01/15 - 06/30/16	\$ 323,327	137	R. Hewitt, NMFS/SWFSC
5-C	Bruce Appelgate, UC San Diego	Operation of R/V Roger Revelle, Exploring One of Earth's Most Volcanically Active Plate Boundaries: The NE Lau Basin Between Arc and Back-Arc	09/01/12 - 08/31/13	\$ 812,497	61	D. Simon, PMEL
			TOTAL FUNDING	\$ 71,671,453		



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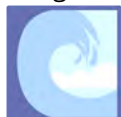


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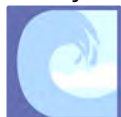
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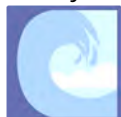
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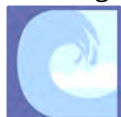
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PUBLICATIONS

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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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.

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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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