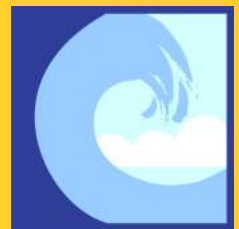


CIMEC

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

ANNUAL PERFORMANCE PROGRESS REPORT 2016 - 2017





CIMEC

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Cooperative Institute for Marine Ecosystems and Climate Annual Performance Progress Report

April 1, 2016 - March 31, 2017

Prepared for



NA15OAR4320071



UC San Diego

UC SANTA CRUZ

UCLA

UC DAVIS

HUMBOLDT
STATE UNIVERSITY

UCSB





Cooperative Institute for Marine Ecosystems and Climate

June 26, 2017

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This report covers the period from April 1, 2016 to March 31, 2017, which was a good year for the Cooperative Institute for Marine Ecosystems and Climate (CIMEC).

During this period CIMEC hosted almost \$20M worth of work for NOAA, approximately the same as last year. A number of new programs started this period, including SIO Prof. Koslow's "Workshop on North American Ichthyoplankton Time Series", HSU Prof. Tissot's "Distribution of Deep-Water Coral and Sponge Habitats off Washington and Oregon and their Functional Links to Demersal Fishes", SIO Prof. Hildebrand's "Bryde's Whales in the Northwestern Gulf of Mexico", SIO Prof. Rudnick's "California Underwater Glider Network (CUGN)" and SIO Resercher Cayan's "Drought Early Warning for the California and Nevada Region".

We are very excited about these projects and their contribution to the NOAA mission, and look forward to closer ties in the future. NOAA has been working hard to refine the CI relationship, and the NOAA Research Council Cooperative Institutes Committee has designated a new role of Technical Program Manager within NOAA for each Cooperative Institute. These are meant to be local laboratory or fisheries science center directors or subject matter experts who will act as primary points of contact for scientific inquiries. For CIMEC, Kristen Koch (Acting SWFSC Director) is filling this role, and we are grateful to have such an experienced and capable person to work with us. Many thanks to her for taking on this role, and to NOAA for their attention to the relationship.

Perhaps partly due to the budget uncertainty, I have not made progress on helping to forge NOAA links for our partners without NOAA funding. I have learned that other CIs struggle with exactly the same problem, and the main approach to this is enhanced communication. Please let me know if there is something that I can try to help with or a connection that we can help make.

Once again, thank you to Rose, Anne and Ryan for keeping things running well, and to all the PIs for their continued excellence and contribution to NOAA's mission.

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INTRODUCTION

The Cooperative Institute for Marine Ecosystems and Climate (CIMEC) research and program activities for the year (2016-2017) of the National Oceanic and Atmospheric Administration (NOAA) grant NA15OAR4320071 are outlined in this report. CIMEC 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 CIMEC researchers and partners at SIO, UC and Cal State, as well as other collaborating organizations associated with CIMEC.

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

During the April 1, 2016 to March 31, 2017 period, the NOAA research entities listed below were engaged with CIMEC in marine, atmospheric, climate, and fisheries research, education and outreach efforts, data collection, and collaborative activities:

- Alaska Fisheries Science Center (AFSC)
- Assessment and Restoration Division (ARD)
- Atlantic Oceanographic & Meteorological Laboratory (AOML)
- Automated Image Analysis Strategic Initiative (AIASI)
- Center for Operational Oceanographic Products and Services (CO-OPS)
- Climate Observations Division (COD)
- Climate Prediction Center (CPC)
- Climate Program Office (CPO)
- Coral Reef Ecosystem Program
- CPO Ocean Observing and Monitoring (OOM)
- Earth System Research Laboratory (ESRL)
- Emergency Response Division (ERD)
- Fisheries Ecology Division (FED)
- Geophysical Fluid Dynamics Laboratory (GFDL)
- Global Monitoring Division (GMD)
- Global Monitoring Division (GMD)
- Integrated Ocean Observing System (IOOS)
- 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 Ocean Service (NOS)
- National Weather Service (NWS)
- Northeast Fisheries Science Center (NEFSC)
- Northwest Fisheries Science Center (NWFSC)
- Ocean Assessment Program (OAP)
- Ocean Exploration Program (OEP)
- Oceanic and Atmospheric Research (OAR)
- Office of Habitat Conservation (OHC)
- Office of Ocean Exploration and Research (OER)
- 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)



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

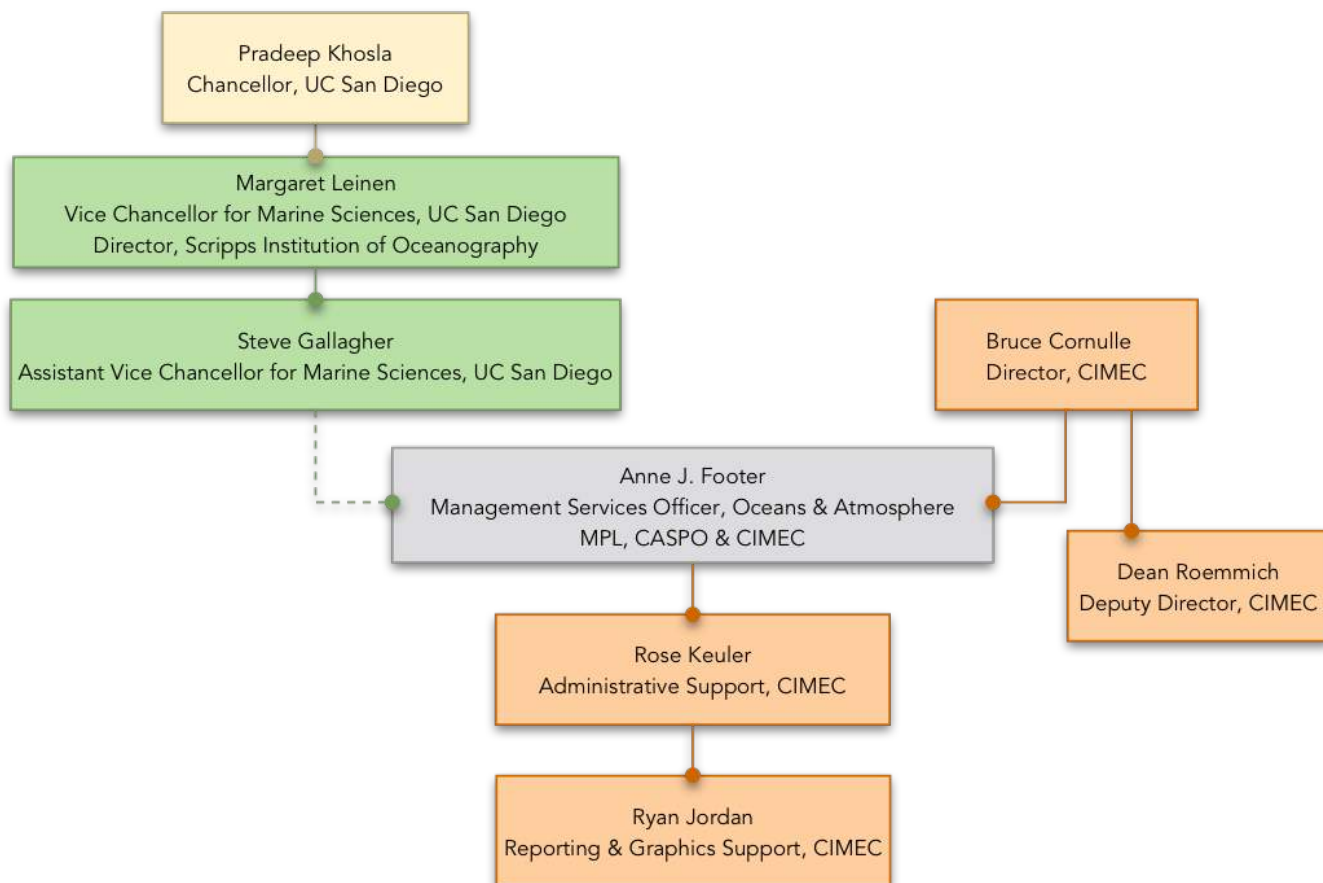
Dr. Roemmich is a professor of oceanography in the Integrative Oceanography Division and Climate, Atmospheric Science, and Physical Oceanography Division at Scripps Institution of Oceanography, University of California, San Diego. He is an expert in the general circulation of the oceans and the role 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, 2016 – March 31, 2017				
Category	Total	B.S./B.A.	M.S.	Ph.D.
Professor	2	0	0	2
Research Scientist	4	0	1	3
Research Specialist	3	0	0	3
Visiting Scientist	1	0	0	1
Project Scientist	9	0	1	8
Programmer Analyst	4	2	2	0
Postdoctoral Fellow	11	0	0	11
Museum Scientist	1	0	1	0
Development Engineer	2	1	1	0
Staff Research Associate/Assistant	17	7	10	0
Laboratory Assistants	6	4	2	0
Marine Technician	4	0	0	0
Assistant to the Director	1	0	1	0
Total (≥ 50% support)	65	14	19	28

Undergraduate Students	30
Graduate Students	17

Employees less than 50% (not including students)	88
--	----

Personnel located at a NOAA Laboratory	48
--	----

Obtained NOAA employment (Since April 1, 2016)		
Name	Division/Laboratory	Date
Andrew Hein	Southwest Fisheries Science Center (SWFSC)	December 2016
Benjamin Martin	Southwest Fisheries Science Center (SWFSC)	December 2016
Sean Rooney	Alaska Fisheries Science Center (AFSC)	December 2016
Molly Gorman	NOAA Fisheries – Northern California Office	March 2017

Sub-Awards	
Postdoctoral Fellow	0
Graduate Student	3
Undergraduate Student	0



CIMEC Fellows Roster

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

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

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

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

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

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

Cherr, Gary - UC Davis

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

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

Gershunov, Alexander - Scripps Institution of Oceanography, UC San Diego

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

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

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

Klimley, Peter - UC Davis

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

Kriegman, David - UC San Diego

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

O'Dowd, Alison - Humboldt State University

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

Palkovacs, Eric - UC Santa Cruz

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

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

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

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

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

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

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

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

Szuwalski, Cody - UC Santa Barbara

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

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

Tissot, Brian - Humboldt State University

Trush, William - Humboldt State University

Ward, Darren - Humboldt State University

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

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



RESEARCH TASKS

Under the Cooperative Institutes' 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:

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 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,



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.

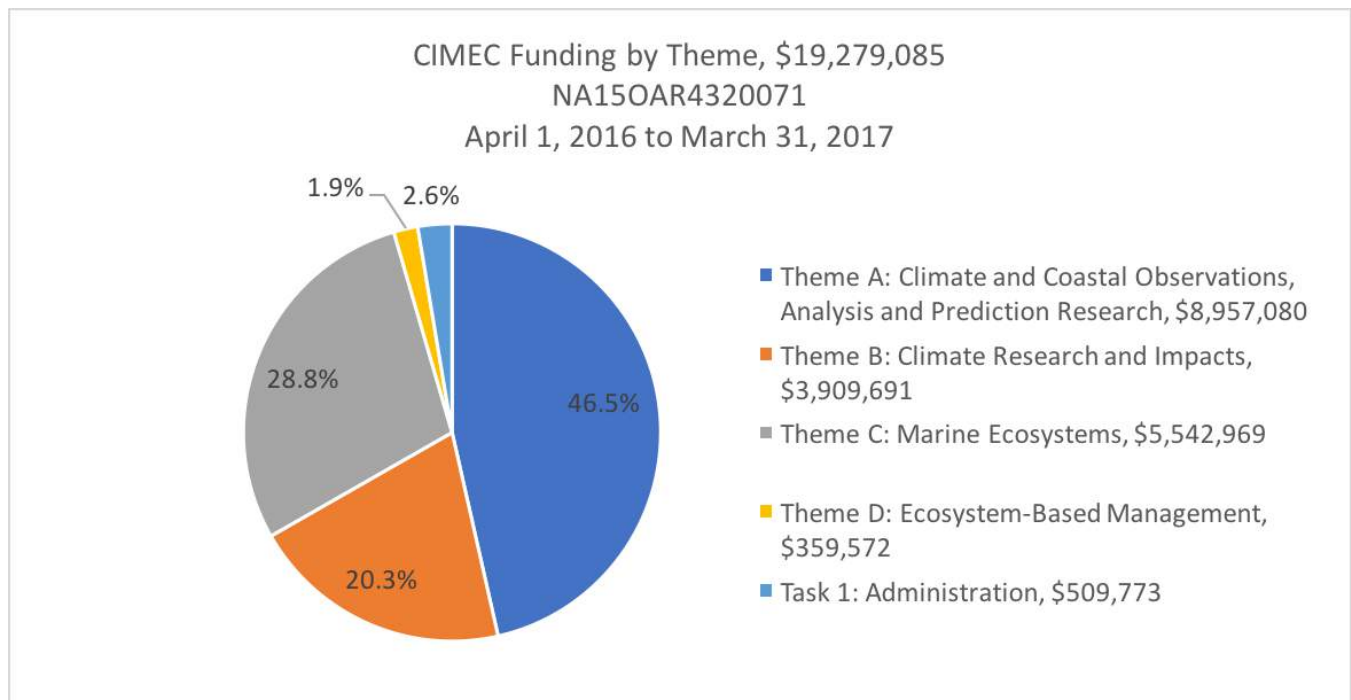
Integration of Marine Protection Areas (MPAs) and Conventional Fishery Management

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.

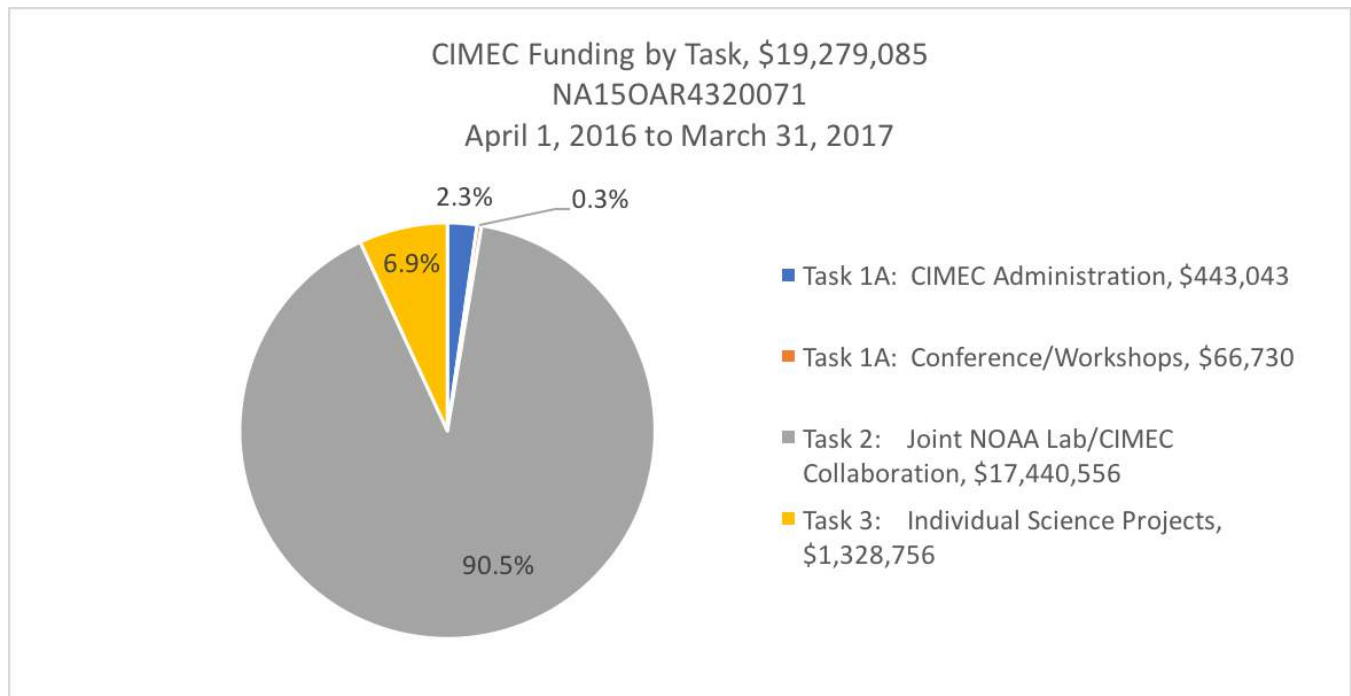


FUNDING SUMMARY

CIMEC Funding by Theme



CIMEC Funding by Task



CIMEC Task 1 Expenditures

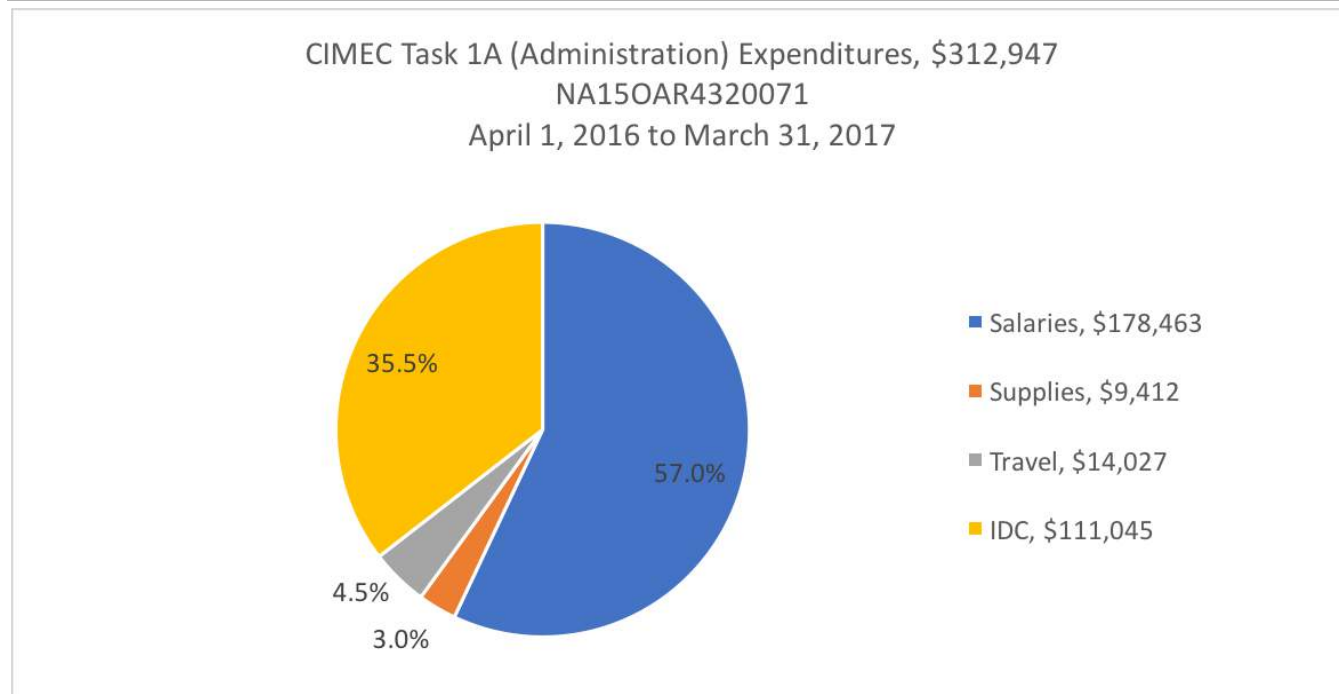


Figure 1: CIMEC Task 1A activities include salary support for the CIMEC Director, the CIMEC Administrative Officer, the CIMEC Administrative Analyst and the CIMEC Administrative IT. Supply activity include communication costs and website maintenance.

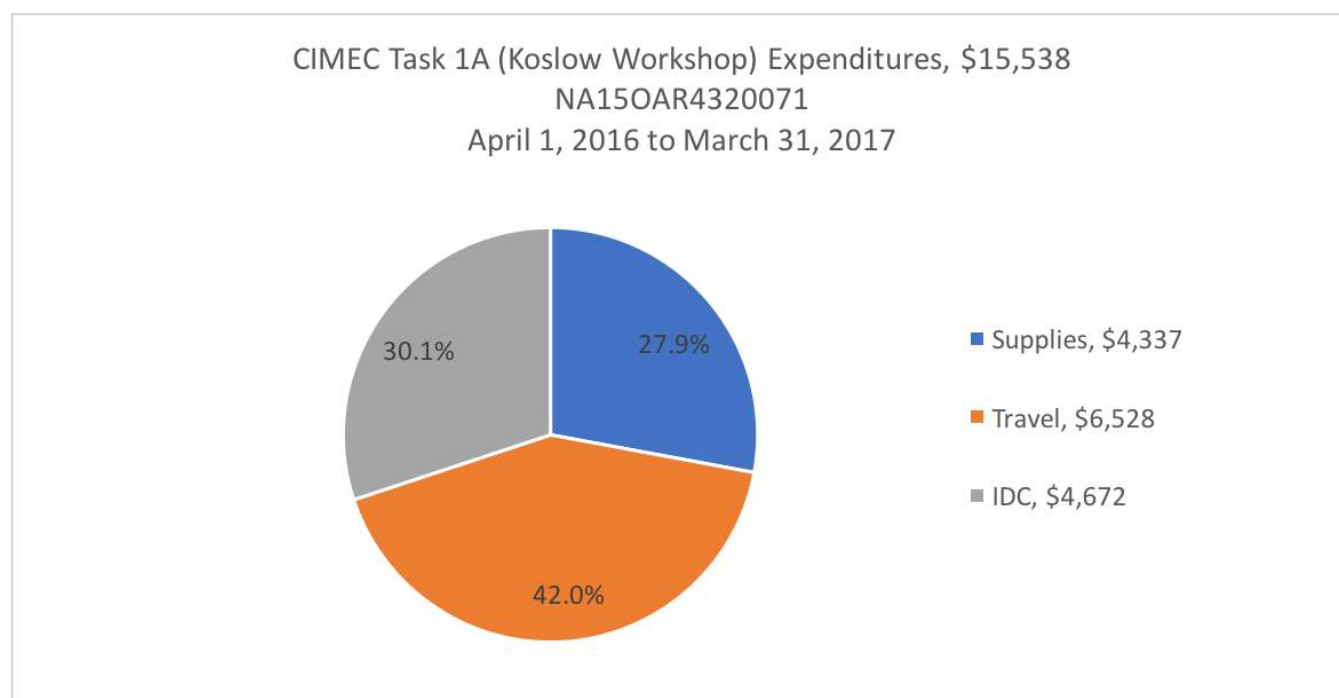


Figure 2: Koslow "Workshop on North American Ichthyoplankton Time Series"



RESEARCH PROJECTS

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

Workshop on North American Ichthyoplankton Time Series

Principal Investigator(s):

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

Other Key Personnel:

Janet Duffy-Anderson, Alaska Fisheries Science Center, Seattle, WA

Ric Brodeur, Northwest Fisheries Science Center, Portland, OR

Sam McClatchie, Southwest Fisheries Science Center, La Jolla, CA

NOAA Primary Contact:

Dr. Michael Ford, NOAA Fisheries

NOAA Task:

Task 1 - Administration

NOAA Theme:

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

Related NOAA Strategic Goal(s):

Goal 1: Health Oceans

Goal 3: Climate Adaption and Mitigation

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$66,730

Amendment(s):

42

Description of Research:

Ichthyoplankton time series are maintained by most of NOAA's Fishery Science Centers as part of their ocean survey and monitoring programs, such as CalCOFI and FOCI. These time series provide quantitative measures of the relative abundance of ichthyoplankton for a wide range of

commercially and ecologically important fish taxa, which may serve as indices for the abundance of their spawning stocks. These time series are routinely used in the management of various commercial species, but they can also serve as indicators of ecosystem status and trends. This project was funded by the NOAA FATE (Fisheries and the Environment) program with the specific objective of holding two workshops to bring together ichthyoplankton time series from around North America (including Mexico and Canada, as well as the US NOAA laboratories), review research progress with them to date, and to examine how they can be assembled and more fully utilized in integrated ecosystem assessments (IEAs) and ecosystem-based fishery management (EBFM).

The first Workshop on North American Ichthyoplankton Time Series was held November 14-16, 2016 at Scripps Institution of Oceanography in La Jolla, California. The second workshop is scheduled to be held September 26-27, 2017 in Woods Hole, Massachusetts. Twenty-nine scientists attended the first workshop, mostly from NOAA laboratories and US academic institutions but also two scientists from Canada and two from Mexico. A similar number and composition is anticipated at the September 2017 workshop. The 2016 workshop focused on reviewing the available ichthyoplankton time series, progress to date in utilizing them, and discussion of analytical methods; the second will focus on progress in the intervening period in analyzing the time series and discussion of methods to utilize them in fisheries and ecosystem management.



Research Objectives:

- survey recent research programs at the NOAA labs utilizing ichthyoplankton time series, focusing on relationships of abundance and diversity with climate
- review methods used to explore ichthyoplankton time series and relationships with climate with a view to establishing a set of questions and research methods that can be examined and applied within and across regions
- develop a framework for moving forward, developing a national/international network with the relevant time series and options for collaboration and funding
- explore how ichthyoplankton may contribute indicators of ecosystem status and be input to stock assessment and fishery management models.

These objectives were to be met through a series of two workshops.

Research Accomplishments:

- The first Workshop on North American Ichthyoplankton Time Series was held November 14-16, 2016 at Scripps Institution of Oceanography in La Jolla, California. Twenty-nine scientists participated and all presented papers.

The second ichthyoplankton workshop will be held September 26-27, 2017 at Woods Hole, MA. Participants have been invited.

Conferences, Meetings & Presentations

- a. PICES annual Symposium, Special 1-day session on “Early life history stages as Indicators and Predictors of Climate Variability and Ecosystem Change”, November 2016, San Diego, CA. Co-convenors included 3 Ichthyoplankton workshop participants: Tony Koslow, Ric Brodeur and Ian Perry.
- b. “The influence of climate on the biodiversity and community structure of fishes in the southern California Current System, 1969 – 2011” presented by J. Anthony Koslow with co-

authors Helena McMonagle and William Watson, PICES annual Symposium, November 2016, San Diego, CA.

- c. “Ichthyoplankton response to environmental change in the NE Pacific Ocean,” presented by Pete Davison and J.A. Koslow, PICES annual Symposium, November 2016, San Diego, CA.
- d. “Ichthyoplankton as an approach to tiered fishery management across large marine ecosystems,” presented by Janet Duffy-Anderson, invited presentation at PICES annual Symposium, November 2016, San Diego, CA.
- e. Patterns of change in California Current fish communities and relationships with ocean forcing,” presented by Tony Koslow at the OMIX Symposium, University of Tokyo, Japan, March 2017. “The influence of Pacific Equatorial Water on fish diversity in the southern California Current System” presented by S. McClatchie with co-authors A.R. Thompson, S.R. Alin, S. Siedlecki, W. Watson and S. Bograd. PICES annual Symposium, November 2016, San Diego, CA.

Education & Outreach

Academic Development

- a. Undergraduate Mentoring

Erica Ferrer, a minority student and undergraduate at University of California, SC was mentored during the summer of 2016 as part of the Scripps Undergraduate Research Fellowship (SURF) program, funded by the NSF’s REU program.

- b. Postdoctoral Mentoring

Dr Pete Davison was mentored by the PI, Tony Koslow from June 2016 – May 2017 at Scripps Institution of Oceanography. Dr Davison was an NRC post-doctoral fellow funded through another FATE project, Janet Duffy-Anderson PI. He analyzed ichthyoplankton time series from the SW, NW and AFSCs from the Gulf of Alaska to southern California. Ric Brodeur and Sam McClatchie were co-PIs.



Networking

- a. Joint symposium between Atmosphere and Ocean Research Institute (AORI), University of Tokyo and Scripps Institution of Oceanography, held at Scripps, September 2016 to foster collaboration between the institutions, followed by an invitation to present a paper at the OMIX symposium in March 2017 in Tokyo. Discussions were held to extend this to a collaboration with Japanese researchers.



Quality Control of CO₂-related Measurements: Work in Support of the NOAA Ocean Acidification Program

Principal Investigator(s):

Prof. Andrew G. Dickson, Marine Physical Laboratory, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Dr. Emily Bockmon, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Libby Jewett, Ocean Acidification Program, NOAA Research

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: Healthy Oceans

Budget Amount:

\$149,909

Amendment(s):

6, 40

Description of Research:

The work done in support of this program has taken a number of forms.

In November 2016, we held a 2-day workshop on the measurement of seawater pH in my laboratory at the Scripps Institution of Oceanography. The workshop was attended by 11 individuals (6 from NOAA laboratories: AOML, PMEL, NWFSC, NEFSC and 5 from NOAA partner laboratories: NANOOS, Seattle; U Puerto Rico; U Delaware; Stonybrook). The workshop introduced the various participants to the various pH scales involved in marine chemistry, as well as to a variety of practical aspects of seawater sampling and subsequent spectrophotometric pH measurement. There was extensive opportunity

for hands-on experience, as well as for group discussions of the various concepts involved. Finally, there were extensive discussions of the likely uncertainty of such measurements as well as of appropriate quality control protocols.

We then planned an interlaboratory CO₂ measurement exercise (a follow-up to an earlier one in 2014 which was subsequently published). The goal was to prepare two test samples: each clearly different from our *normal* CO₂ in seawater reference materials thus allowing a useful assessment of participating laboratories ability to measure samples whose CO₂ composition differs from the available reference materials. These test samples were prepared from coastal California seawater (as our reference materials), but additional alkalinity and CO₂ were added to increase the total alkalinity and total dissolved CO₂ from the usual reference material values. The resulting pH values were around 8 and 7.6 for the two samples. We prepared about 1000 bottles of each sample; and will be able to send out more in the future for labs needing to do further testing of their methodology.

Samples for this exercise were sent out in April 2017. Among the participants were a number of NOAA labs and NOAA collaborating labs whose participation was sponsored by this project. These comprised 16 labs in all: 5 NOAA labs, and 11 others (including labs involved in the *Headlights on High* project). As yet, data have not been returned for all these laboratories, and we are in the process of informing laggards that the absolute deadline will be July 4, 2017.

Starting on that date Dr. Bockmon and Dr. Dickson will review the various data submitted for this exercise (altogether 90 sets of samples were distributed and, as yet, about 70 labs have returned their results). Our goal is first to provide participants with a summary of their results in the context of the assigned values (determined by the Dickson laboratory at Scripps) and in the context



of the entire suite of submitted data. We shall then prepare a scientific manuscript detailing the exercise, and the results obtained, while maintaining the anonymity of the participants with respect to the data submitted.

In particular, we shall discuss the performance of the CO₂ measuring community in the context of the “climate” and “weather” goals of the GOA-ON (Global Ocean Acidification Observing Network).

Ultimately, we are planning to write a second paper that will expressly discuss the likely uncertainties of seawater CO₂ measurements, and offer advice as to how individual laboratories might best work to estimate their own uncertainty on measurements of total alkalinity, total dissolved inorganic carbon, and pH in seawater.

In addition, the Dickson participated in a number of short courses related to ocean acidification, and provided lectures describing the CO₂ system in seawater as well as techniques for measuring the various CO₂ parameters (including a discussion of quality control of such measurements). These courses took place in Mauritius (July 2016), and Mexico (September 2016; December 2016); travel expenses were covered by the course organizers.

Research Objectives:

The aim of these activities is to facilitate evaluation of, and improvement in, the quality of CO₂-related measurements made in support of the NOAA Ocean Acidification Program. The initial requirement is to ensure that the NOAA OAP agrees upon requirements for the uncertainty of measurements of pH, total alkalinity, and total dissolved inorganic carbon that are appropriate to the scientific aims of the program. Next, we shall provide examples of how to estimate the overall uncertainty of each of these measurements, and offer advice to the laboratories as to how to do this for the measurements that they undertake. A key aspect of the effort proposed here is the design and execution of Proficiency Tests (one per year) for these various measurements which will enable the various laboratories (and the NOAA OAP) to

assess if they are meeting the agreed-on quality requirements of the Program. Finally, each year we shall hold a 3-day workshop focused on some aspect related to laboratory CO₂ measurements and their quality control.

Research Accomplishments:

- Held workshop in La Jolla in November 2016 providing participants with an introduction to seawater pH measurements.
- Initiated an interlaboratory proficiency exercise for the measurement of pH, total alkalinity, and total dissolved inorganic carbon in seawater.
- Participated in teaching in various ocean acidification short courses in 2016

Conferences, Meetings & Presentations

- a. Dr. Dickson lectured at an Ocean Acidification Short-Course in Mauritius in Jul 2016
- b. Dr. Dickson lectured at an Ocean Acidification Short-Course in Ensenada, Mexico in Sep 2016
- c. Dr. Dickson lectured at a short-course on CO₂ Measurements in Ensenada, Mexico in Dec 2016
- d. Dr. Dickson & Dr. Bockmon attended the NOAA PI Meeting in Seattle, WA in Jan 2017

Education & Outreach

Academic Development

- a. November 2016: We held a 2-day workshop in my laboratory discussing the measurement of seawater pH and providing hands-on experience measuring seawater pH. The participants were various scientific staff and students from other institutions, although my own graduate students also participated (and assisted).
- b. The various short-courses that Dr. Dickson lectured in (see above) were open to career scientists and graduate students in (a) the Africa region (the Mauritius Workshop) and the Central and South American region (the workshops in Ensenada).

Networking

- a. Dr. Dickson is on the Steering Committee of C-CAN (California Current Acidification Network)



and participated in various telephone meetings of that organization planning future activities and sharing background information.



Drought Early Warning for the California Region

Principal Investigator(s):

Daniel Cayan, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Amanda Sheffield, Scripps Institution of Oceanography, UC San Diego

Julie Kalansky, Scripps Institution of Oceanography, UC San Diego

Kelly Redmond, Desert Research Institute

Tamara Wall, Desert Research Institute

Tim Brown, Desert Research Institute

Nina Oakley, Desert Research Institute

Sam Iacobellis, Scripps Institution of Oceanography, UC San Diego

David Pierce, Scripps Institution of Oceanography, UC San Diego

Michael Dettinger, US Geologic Survey

Alexander Gershunov, Scripps Institution of Oceanography, UC San Diego

Shraddhanand Shukla, UC Santa Barbara

Anthony Westerling, UC Merced

NOAA Primary Contact:

Caitlin Simpson, RISA Program Director, NOAA Research

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: Climate Adaption and Mitigation

Budget Amount:

\$420,000

Amendment(s):

11

Description of Research:

The **California-Nevada Application Program (CNAP)**, in collaboration with the National Integrated Drought Information System (NIDIS), is taking a leading role in California to understand the informational needs of decisions makers and provide better forecasts, risk assessments and drought awareness to reduce the impacts of drought. Throughout the second year of this award, CNAP has continued to work on projects that enhance drought impact monitoring and forecasting as well as stakeholder engagement and communication.

CNAP continued work on forecasting expanding the research findings from last year. First, Dr. Shukla showed that of the models that are included in the North American Multi-Model Ensemble (NMME), CCSM4 forecasted weakest El Niño and in JFM forecasts for each events CCSM4 and CMC1-CanCM3 SST forecast anomalies were the weakest whereas and NASA-GMAO SST anomalies were the strongest. Based on this he concluded that CCSM4 and CMC1-CanCM3 models should be given less weight or removed from the NMME forecast to produced and overall improved forecast. This work is in preparation to be submitted for journal publication.

Other highlights from this year's work include the connection between drought and wildfire. Dr. Westerling and graduate student Joe Crockett have conducted an analysis of the six most severe droughts of the western United States over the last 100 years. The main conclusion was that the droughts in the past 15 years have been more intense relative to the droughts in mid 20th century, mostly because of the effect of warmer temperatures in this latter period. These recent droughts have led to more severe fires and greater tree mortality. This work has been submitted for publication.

The CNAP researchers have continued to organized meetings, webinars and participate in other opportunities to engage with stakeholders in California. Many of these are included in the



highlights below. Over the last two years, CNAP in cooperation with NIDIS has expanded the DEWS network through workshops and webinars led by Drs. Sheffield, Kalansky, and Cayan. This expansion has included record keeping of attendees and inclusion of new stakeholder networks such as tribal groups. And through a series of post-webinar surveys, assessment of the regularity of use of climate information and relevant timely webinar topics that reflect stakeholder needs such as descriptions of atmospheric rivers, streamflow forecasts, snow drought, and wildland fire potential.

Research Objectives:

- Evaluating and understanding seasonal forecast skill, using the North American Multi-Model Ensemble (NMME) in California and the West
- Cultivating relationships with Stakeholders including Stakeholder interface through workshops, webinars and other outreach activities at the state and regional scale.
- Developing baseline information collection through CA-NV DEWS activities to better understand applications and knowledge based shared approaches about drought information, effects, and impacts.

Investigation of the impacts of drought combined with higher temperatures on wildfires

Research Accomplishments:

- Four Drought & Climate Outlooks cohosted with NIDIS
- Launching of Bimonthly Drought & Climate Webinar Series – August 2016 - Present
- In prep publication of NMME forecast skill evaluation
- Submitted publication on wildfire and droughts in the west

Conferences, Meetings & Presentations

- a. Sheffield, Amanda M., D. Cayan, K. Redmond, J. Kalansky, M. Dettinger, T. Wall, T. Brown, Drought Early Warning Systems – Making Drought Science Available, Understandable,

and Useable for Decision Making. Natural Areas Conference, 18-21 October 2016, Davis, CA.

- b. Sheffield, Amanda M., Breaking the Hydro-Illogical Cycle in California. California Adaptation Forum, Long Beach, CA, 6-8 September 2016.
- c. Sheffield, Amanda M., with contributions from other in CNAP, San Diego Climate: Precipitation & Drought. Water Education Foundation San Diego Tour 2016, San Diego, CA, 20 May 2016.
<http://www.watereducation.org/tour/san-diego-tour-2016>
- d. Sheffield, Amanda M., Alicia Marrs, and Justin Huntington, National Integrated Drought Information System (NIDIS) Drought Early Warning Systems (DEWS). Great Basin Climate Forum, Reno, NV, 5 April 2016.
- e. Dr. Sheffield participated in the Western States Water Council Seasonal to Sub-seasonal Forecasting Workshop in San Diego in June 2016 and May 2017.
- f. Dr. Sheffield participated in the CA Dept of Water Resources Drought Response Workshop in Irvine, CA in May 2016.

Education & Outreach

Communication

- a. New CNAP Program Website with climate and drought tools and handouts:
<https://scripps.ucsd.edu/programs/cnap/>
- b. Media Event around the Drought & Water Supply Outlook with San Diego County Water Authority (SDCWA) - In September 2016, Amanda Sheffield participated in a media event with SDCWA that discussed San Diego County Water Supplies in the context of the Seasonal Forecast <http://www.sdcwa.org/san-diego-county-water-supplies-sufficient-meet-demands-2017-and-beyond>
- c. Sheffield, Kalansky, Goodrich, Pierce and Cayan are contributing to the South Coast Climate Science Alliance and are playing lead roles in conducting an assessment of ecosystem vulnerability to climate variability



and climate change in the California South Coast region.

<http://www.climatesciencealliance.org/>

Academic Development

- a. Westerling is Chair and Cayan is Committee Member for UC Merced graduate student Joseph Crockett, who is pursuing a Master's Thesis which compares and analyzes aerially-extensive historical drought episodes in the western U.S. Crockett's Master's Thesis is nearly completed, with a defense scheduled May, 2017.
- b. Cayan is serving on UCSD graduate student (Sociology Dept) Haley McInnis' PhD committee. Ms. McInnis's Thesis topic is titled "Does it hold water?: Determining drought and addressing it as a reoccurring problem through policy in California, 1976 – 2017".
- c. Cayan is serving as mentor for Scripps Institution of Oceanography, UCSD Masters-of-Advanced study student Angela Rabe, whose capstone project investigates the water-energy nexus in San Diego County.

Networking

- a. Co-Hosted with NIDIS, Four Drought & Climate Outlooks:
 - i. Riverside, CA
<https://www.drought.gov/drought/calendar/events/ca-nv-drought-early-warning-system-southern-california-drought-outlook>
 - ii. Seaside, CA
<https://www.drought.gov/drought/calendar/events/north-central-coast-drought-climate-outlook-oct-11>
 - iii. Fresno, CA
<https://www.drought.gov/drought/calendar/events/central-valley-drought-climate-outlook-oct-12>
 - iv. San Diego, CA
<https://www.drought.gov/drought/calendar/events/ca-nv-dews-southern-california-winter-status-update-feb-9>

- b. These meetings focused on past, present and/or expected drought impacts, and offered an opportunity for stakeholders to interact with other decision makers and information providers in the region. The event had three purposes:
 - i. Provide an update on current and forecasted drought & climate conditions
 - ii. Showcase current research and tools available to stakeholders to support drought early warning
 - iii. Gather feedback from stakeholders on current needs for the CA-NV Drought Early Warning System to help inform the development of the CA-NV DEWS Strategic Plan
- c. Co-Hosting with NIDIS Bimonthly Drought & Climate Outlook Webinar: The California-Nevada Drought Early Warning System (CA-NV DEWS) Drought & Climate Outlook Webinars are part of a series of regular drought and climate outlook webinars designed to provide stakeholders and other interested parties in the region with timely information on current drought status and impacts, as well as a preview of current and developing climatic events (i.e. El Niño and La Niña). The webinar takes place on the 4th Monday every two months. Example:
<https://www.drought.gov/drought/calendar/events/california-nevada-drought-climate-outlook-webinar-may-30>



California Cooperative Oceanic Fisheries Investigations: Ocean Observations to Inform Ecosystem-Based Management and Climate Research

Principal Investigator(s):

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

Ralf Goericke, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact(s):

Roger Hewitt, NOAA Fisheries

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: Healthy Oceans

Goal 3: Climate Adaption and Mitigation

Budget Amount:

\$3,171,694

Amendment(s):

18, 46

Description of Research:

The California Cooperative Oceanic Fisheries Investigations (CalCOFI) is the world's longest multi-disciplinary ocean observation program. Its 68-year time series continues to elucidate the effects of interannual and decadal-scale variability on the southern California Current System (CCS) and its living marine resources. Quarterly cruises occur on NOAA fisheries research vessels (winter, spring) and UNOLS research vessels (summer, fall). During each cruise, at 75-113 stations, CTD and plankton nets are deployed for measurement of physical, chemical and biological variables. Between stations, underway measurements are made of temperature, salinity, chlorophyll, pH, pCO₂, currents, acoustic scattering, and fish eggs

and observations of seabirds and marine mammals.

CalCOFI data are increasingly used to obtain insight into impacts of long-term change in the CCS. The program's vitality derives from its continuing evolution to meet the needs of the region's managers and scientists concerned with exploited and protected species, as well as the oceanographic and atmospheric research communities working on the CCS. CalCOFI has leveraged key ancillary programs to meet regional research and management needs: enhanced observations of biogeochemical and lower trophic-level processes through the NSF-funded California Current Ecosystem Long-Term Ecological Research (CCE-LTER) program, nearshore processes with Southern California Coastal Ocean Observing System (SCCOOS) funding, seabirds (Farallon Institute for Advanced Ecosystem Research), marine mammals (Navy-funded), ocean acidification (OA Program, OAR) and genomics (NMFS and OAR). CalCOFI assists other programs, including deployment of surface drifters for the Global Drifter Program (CPO, OAR), and deployment of profiling floats (Navy). CalCOFI data are complemented by mooring, glider and satellite data and are used in physical, biological and biogeochemical oceanographic models. CalCOFI data are increasingly combined with data from around the Pacific to assess basin-scale patterns and processes and contribute to assessment of long-term change of the ocean and its living marine resources.

Research Objectives:

CalCOFI's primary objectives are 1) to continue its 68-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 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. Both of these objectives, in turn, are in support of an ecosystem approach to management of the living marine resources of the southern California Current System.

Our specific plan to achieve these objectives is, in collaboration with NOAA's SWFSC, to conduct quarterly cruises in the CCS, 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 and marine mammal and seabird observers.

Research Accomplishments:

This year's CalCOFI program included the successful completion of five quarterly cruises (1604SH, 1607OS, 1609SR, 1611SR, 1701RL; <http://www.calcofi.org/cruises.html>), observation of the transition from warm (El Niño and warm anomaly) conditions to cooler La Niña conditions and the continued decline of the sardine population and increase in the anchovy population, continuation of underway pH and pCO₂ to monitor ocean acidification, a symposium on the future of CalCOFI, and publications in top scientific journals on a wide range of topics. The SIO R/V New Horizon was decommissioned and the R/V Sally Ride entered the UNOLS fleet at SIO. Fall 2016 CalCOFI (1611SR) was the first science cruise on the R/V Sally Ride and activities were displayed in near-real-time at the Birch Aquarium at Scripps.

Conferences, Meetings & Presentations

- a. Asch RG, Chan K, Sobolewska J. International Symposium on the Drivers of Dynamics of Small Pelagic Fish Resources, Victoria, Canada, 2017.
- b. The Annual Conference and Symposium of CalCOFI was held at NOAA's SWFSC La Jolla Laboratory, December 5-6, 2016. The

symposium title was The Future of CalCOFI. Symposium speakers included Drs. Mark Ohman, Dan Rudnick, Dave Checkley, Sam McClatchie, Steven Bograd, Andrew Thompson, Noelle Bowlin, Manu DiLorenzo, Chuck Greene, Bob Cowen, Tony Koslow and Uwe Send.

- c. Dr. Dave Checkley attended a meeting of the Biology and Ecosystems Panel of the Global Ocean Observing System in Ostende, Belgium, September 19-21, 2016.
- d. Dr. Dave Checkley attended the North Pacific Marine Science Organization annual meeting in San Diego, California, November 2-4, 2016.

Education & Outreach

Communication

- 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).
- b. Dr. Francisco Werner, Director, SWFSC, presented "The Critical Need for Sustained Ocean Observations: CalCOFI and Beyond" lecture at the Birch Aquarium in Scripps, November 4, 2016.
- c. The Birch Aquarium at Scripps featured the fall 2016 CalCOFI cruise, the first science cruise on the R/V Sally Ride, as its first feature in its new Expeditions at Sea Exhibit, with near-real-time communications from the R/V Sally Ride ashore to the Birch Aquarium exhibit.





Figure 3: CTD deployment from R/V Sally Ride on fall, 2016, CalCOFI cruise (1611SR). Photo by James Wilkinson.



Figure 4: CalCOFI Chief Scientist James Wilkinson (right) consulting First Mate Wes Hill (left) and Second Mate Cameron Freels (center) on the bridge of the R/V Sally Ride during the fall, 2016 CalCOFI cruise (1611SR). This was Wilkinson's 104th CalCOFI cruise.



CalWater and West-Coast Atmospheric River Research

Principal Investigator(s):

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

NOAA Primary Contact:

Dr. Robert S. Webb, Climate Program Office, NOAA Research

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: Weather-Ready Nation

Budget Amount:

\$120,000

Amendment(s):

25

Description of Research:

The research objective is to respond to the unique needs of the Western U.S. for information on water and the storms that produce it, many stakeholders have requested additional specialized research and tools be developed. This interest ranges from conditions of too little precipitation and water (drought) to too much (flood). This effort will generate a short concept paper and associated briefing materials describing promising new science directions and collaborations, as well as new tools focused on western U.S. needs. A collaborative approach is envisioned that brings together the expertise and knowledge on drought and flood and their meteorological causes in the region. This collaboration is represented by the leaders of CW3E (Ralph), NIDIS (Pulwarty) and PSD (Webb). Once the concept paper and briefing materials have been generated they will be communicated via meetings with key stakeholders.

Research Objectives:

Increase physical understanding and awareness of weather events that are unique to the Western US and how this impact water supplies and flooding.

Research Accomplishments:

- Western States Water Council and NOAA workshop in Salt Lake City, Utah, October 2016; Ralph presented on requirements, planning and concept development for S2S
- Western States Water Council and NOAA workshop in San Diego, California May 2017; Ralph presented on improving S2S forecasting of ARs
- M. Ralph met with Congressional Staffers and NOAA officials to discuss reconnaissance for atmospheric rivers to understand how better observations off-shore can improve atmospheric river forecasts, Washington D.C., Aug 2016
- Ralph is co-chairing the FIRO steering committee including three meetings, one science workshop and one FIRO workshop.

Conferences, Meetings & Presentations

Please see Research Accomplishments above.



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

Principal Investigator(s):

Dean Roemmich, Scripps Institution of Oceanography, UC San Diego

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

Other Key Personnel:

Michael McClune, Scripps Institution of Oceanography, UC San Diego

Kyle Grindley, Scripps Institution of Oceanography, UC San Diego

Megan Scanderbeg, Scripps Institution of Oceanography, UC San Diego

Lisa Lehmann, Scripps Institution of Oceanography, UC San Diego

Jeffrey Sherman, Scripps Institution of Oceanography, UC San Diego

Russ Davis, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Stephen Piotrowicz, NOAA Research

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: Weather-Ready Nation

Goal 3: Climate Adaption and Mitigation

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$7,428,024

Amendment(s):

7, 31, 58

Description of Research:

Argo is an international collaboration providing a global array of profiling CTD floats for a broad range of research and operational applications (<http://www.argo.ucsd.edu>). The Argo array, now including about 3900 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.

SIO plays 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. SIO produces and deploys one-fourth of the U.S. Core Argo floats, carries out float technology development, participates in delayed-mode quality control, coordinates the U.S. Argo partnership, and provides leadership for international Argo. SIO is producing and deploying over half of U.S. Deep Argo floats in regional pilot arrays. All goals for SIO Argo during the reporting period have been met.



Research Objectives:

- Along with US and international partners, maintain the global Argo array of profiling floats
- Monitor SIO Argo floats for technical performance and problems
- Carry out data communications, decoding, and file formatting for all SIO Iridium Argo floats
- Provide scientific data quality control for SIO floats
- Improve profiling float technologies for Core Argo and Deep Argo floats
- Deploy regional pilot arrays of Deep Argo floats
- Provide leadership for the Argo Data Management Team, Argo Steering Team, and other international Argo activities
- Demonstrate the value of Argo data in basic research

Research Accomplishments:

- 111 Core Argo floats were fabricated, shipped, and deployed by RV Sally Ride, Atlantis, Kaharoa, Revelle, Lasker, Agulhas, Investigator, and Braveheart.
- 19 Deep Argo floats were fabricated, shipped, and deployed in regional pilot arrays by RV Kaharoa, Investigator, and James Cook.
- 4 Deep Argo floats were recovered, re-programmed, and re-deployed by RV Kaharoa
- Improvements in float technology included a transition from primary to hybrid lithium batteries to reduce battery passivation
- Delayed-mode quality control was carried out for all SIO-Argo profiles, approximately 18,000 per year.
- The 18th meeting of the Argo Steering Team was held in Hobart Tasmania in March 2017
- The 17th meeting of the Argo Data Management Team was held in Tianjin China in September 2016

Conferences, Meetings & Presentations

- a. D. Roemmich (AST Co-Chair), M. Scanderbeg, and N. Zilberman attended the 18th meeting of the Argo Steering Team in Hobart Tasmania.
- b. M. Scanderbeg (ADMT Co-Chair) and J. Gilson attended the 17th meeting of the Argo Data Management Team in Tianjin China
- c. D. Roemmich attended three meetings (8/2016, 11/2016, 1/2017) of the National Academy of Sciences Committee on Sustaining Ocean Observations to Understand Future Changes in Earth's Climate
- d. N. Zilberman made a presentation at the National Academy of Sciences Workshop on Sustaining Ocean Observations to Understand Future Changes in Earth's Climate in Washington D.C., November 2016.
- e. N. Zilberman presented on the Deep Argo Program at the Deep Ocean Observing Strategy (DOOS) Workshop at SIO in December 2016
- f. D. Roemmich and N. Zilberman attended the U.S. Argo P.I. Meeting in Silver Spring MD, August 2016

Education & Outreach

Communication

- a. The Argo Steering Team website (<http://www-argo.ucsd.edu>), maintained by M. Scanderbeg (SIO/UCSD) on behalf of the international Argo partnership, provides information on the Argo project, its objectives, status and data system, including how to access Argo data.
- b. The Argonautics Newsletter (<http://www.argo.ucsd.edu/Frnewsletter.html>), edited by M. Scanderbeg (SIO/UCSD) distributed information on Argo status, applications, and progress on key issues.

Academic Development

- a. The Argo Global Marine Atlas project (http://www.argo.ucsd.edu/Marine_Atlas.html), developed by M. Scanderbeg (SIO/UCSD) provides a data display tool to allow students and educators view Argo and other ocean



datasets as maps, vertical sections, time-series plots, and line drawings

- b. The SEREAD Program
(<http://www.argo.ucsd.edu/SEREAD.html>) develops curricular units and conducts teacher training seminars for teaching of weather, climate, sea level, and the ocean's role in climate in Pacific island school systems. D. Roemmich is a member of the SEREAD Steering Committee.

Networking

- a. The Argo Steering Team's Annual Meeting brings together 40 – 50 representatives of the National Argo Programs for discussion and resolution of all issues pertaining to the global Argo array, including the status of Argo, coverage and undersampled regions, modifications to Argo design, technical problems and solution, and future planning. D. Roemmich is Co-Chair of the Argo Steering Team.
- b. The Argo Data Management Team's (ADMT) Annual Meeting brings together Argo's data management experts and representatives of Argo's Data Assembly Centers for discussion of issues pertaining to data flow, quality control, formatting, timeliness and others. M. Scanderbeg is Co-Chair of the ADMT and J. Gilson is one of the team's delayed-mode experts.
- c. Deep Argo event on RV Tangaroa, Wellington New Zealand. The U.S. Embassy in Wellington New Zealand and the New Zealand National Institute of Water and Atmospheric Research co-organized a Deep Argo reception and presentations on board RV Tangaroa in March 2017, attended by D. Roemmich



Figure 5: A Deep Argo float designed and fabricated in the SIO float lab is deployed by N. Zilberman (SIO), P. Sutton (NIWA N.Z.) and crew of the RV Tangaroa. Photo credit: LEARNZ



SIO High Resolution XBT/XCTD Transects

Principal Investigator(s):

Janet Sprintall, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Dean Roemmich, Scripps Institution of Oceanography, UC San Diego

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

Justine Parks, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Kathy Tedesco, Climate Program Office, NOAA Research

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: Weather-Ready Nation

Goal 3: Climate Adaption and Mitigation

Budget Amount:

\$1,845,277

Amendment(s):

5

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 1990s to include basin-spanning temperature transects in all the oceans. Major collaborators in the global HRX network include SIO (Pacific and Indian Ocean), NOAA/AOML (Atlantic), and CSIRO Australia (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. At present, the HRX is the only component of the global observing system to provide long-term near repeat transects of the major boundary currents of the world oceans. All anticipated goals during the reporting period were met.

Research 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.

Research Accomplishments:

- 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 in the Pacific and Indian Oceans.
- Implementation of Iridium communication 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 NCEI 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. Dr. Janet Sprintall attended the International Quality Ocean Database Workshop held in Tokyo Japan from 3-5 October 2016.
- b. Dr. Janet Sprintall attended and presented at the XBT Science Meeting held in Tokyo Japan from 5-7 October 2016.
- c. Dr. Janet Sprintall attended and presented at the Tropical Pacific Observing System (TPOS-2020) workshop in Lima Peru from 25-28 October 2016.
- d. Dr. Janet Sprintall attended and presented at the Ship Observations Team meeting for

SOOPIP held in London UK from 27-31 March 2016

Education & Outreach

Communication

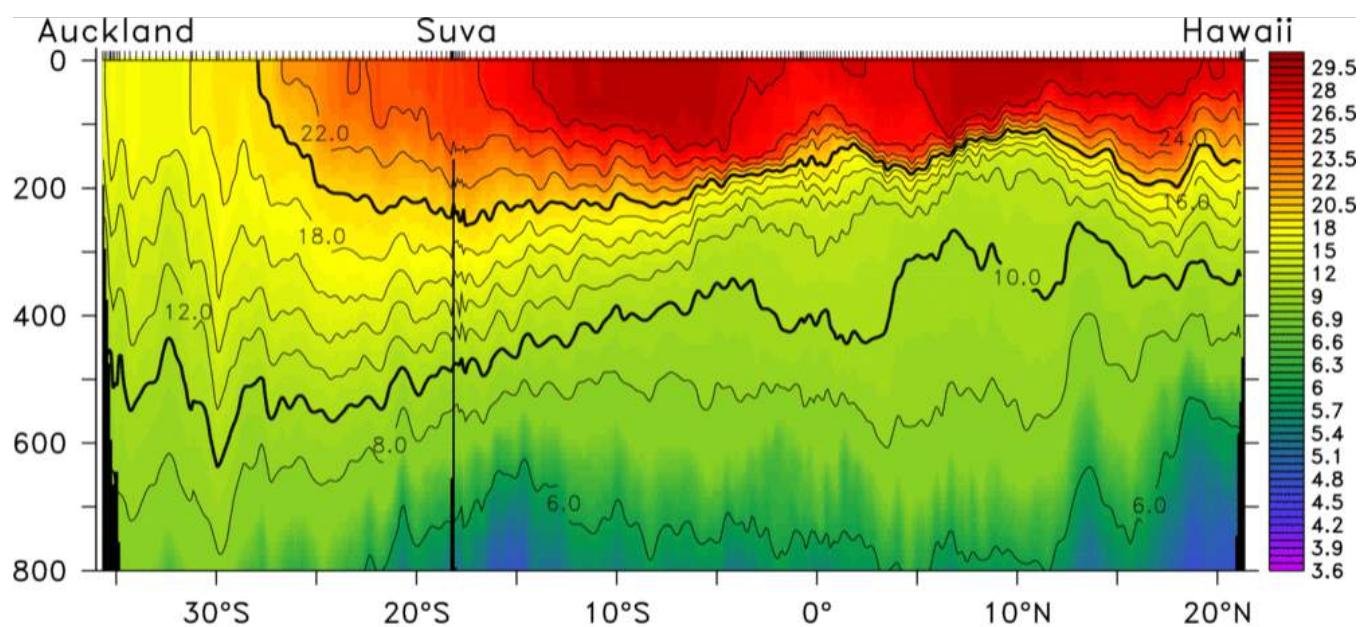
- a. HRX Data Website

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. PI Sprintall co-advises SIO PhD student Manuel Othon Gutierrez Villanueva using HR-XBT data as part of his original research.





PX06/PX09, Cap Pasado, 29 Aug 2016– 8 Sep 2016, Good drops=217

Figure 6: Temperature section with latitude and depth along HRX transect PX06/PX09. Transect PX06 has now been occupied for 30 years, providing high quality temperature and geostrophic transport estimates that have enabled scientific discovery of strongly filamentous jets in the South Pacific and investigations into subtropical gyre responses to wind changes.



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

Russ Davis, Scripps Institution of Oceanography, UC San Diego

Dean Roemmich, Scripps Institution of Oceanography, UC San Diego

Bruce Cornuelle, Scripps Institution of Oceanography, UC San Diego

Daniel Rudnick, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Matthias Lankhorst, Scripps Institution of Oceanography, UC San Diego

Jeffrey T Sherman, Scripps Institution of Oceanography, UC San Diego

Evan Goodwin, Scripps Institution of Oceanography, UC San Diego

Gui Castalao, Scripps Institution of Oceanography, UC San Diego

Kyle Grindley, Scripps Institution of Oceanography, UC San Diego

Ganesh Gopalakrishnan, Scripps Institution of Oceanography, UC San Diego

Nathalie Zilberman, Scripps Institution of Oceanography, UC San Diego

Florent Gasparin, formerly Scripps Institution of Oceanography, UC San Diego, presently Mercator Ocean, Toulouse France

NOAA Primary Contact:

Diane Stanitski, Climate Program Office, NOAA Research

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: Healthy Oceans

Goal 2: Weather-Ready Nation

Goal 3: Climate Adaption and Mitigation

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$2,692,027

Amendment(s):

4, 36

Description of Research:

Motivated by national and international planning efforts, CORC is currently 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 testing 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.

Research Objectives:

1. Develop and demonstrate techniques for sustained observations of eastern and western boundary currents.
2. Combine boundary current and interior-ocean observations from ARGO and altimetry.
3. Design efficient boundary current observing systems delivering data needed for NOAA missions, modeling efforts, and other user applications.

Research Accomplishments:

1. Completed 9.5 years of sampling flow through the Solomon Sea to the equatorial warm pool,

including 88 sections spanning 1½ weak ENSO events and 2 significant ones. 82 of these have been quality controlled.

2. Completed a sequence of data visualizing data processing and quality control programs leading to data sets where data errors are cleaned by interpolation and areas of bad data are marked.
3. Added to the analysis sequence programs to translate the data above into a product containing error correction by algorithmic and subjective procedures. This is designed for users wanting to use the data without assessing errors and repairing them.
4. Three full years of transport through the Solomon Sea in hand now from endpoint moorings/PIES.
5. Analysis of poleward flow anomalies along the southern California Coast.
6. First results about upwelling volume flux into the CORC/CCE mooring box around southern California.
7. A website (spraydata.ucsd.edu) has been established for public access of quality controlled delayed mode data.
8. Updated CCS state estimates, including atmospheric state, eddies, and cross-shelf transports, cross-validated against independent observations (CalCOFI stations and buoy records).
9. Integrated index of CCS upwelling in terms of isopycnal displacements on and between glider/mooring lines (directly from observations and from assimilations)
10. Related indexes of heat and mass transport of the northward-flowing currents, particularly the CUC and warm surface currents during the El Niño events.

Conferences, Meetings & Presentations

- a. U. Send and M. Lankhorst co-organized and attended the international OceanSITES meeting in Southampton/UK, April 2016



- b. U. Send attended the GSOP meeting in Qingdao/China, Sept 2016
- c. U. Send attended the POGO meeting and presented OceanSITES in Plymouth/UK, Jan 2017
- d. D. Roemmich attended three meetings (8/2016, 11/2016, 1/2017) as a member of the National Academy of Sciences Committee on Sustaining Ocean Observations to Understand Future Changes in Earth's Climate
- e. N. Zilberman gave an invited presentation at the National Academy of Sciences Workshop on Sustaining Ocean Observations to Understand Future Changes in Earth's Climate in Washington D.C., November 2016.
- f. D. Rudnick attended the CLIVAR sponsored Forecasting ENSO Impacts on Marine Ecosystems of the US West Coast Workshop held in La Jolla, CA during August 10-11, 2016.
- g. U. Send and D. Rudnick attended the CalCOFI symposium held in La Jolla, CA during December 5-6, 2016.
- h. D. Rudnick, U. Send, D. Roemmich, and M. Lankhorst attended the Deep Ocean Observing System Workshop held in La Jolla, CA during December 7-8, 2016.
- i. D. Rudnick attended the Implementation of Multi-disciplinary Sustained Ocean Observations Workshop held in Miami, FL during February 8-10, 2017.
- j. D. Rudnick chaired the ALPS-II meeting held in La Jolla, CA during February 21-24, 2017.
- k. D. Rudnick attended the international OceanGliders Steering Team meeting held in Paris, France during April 20-21, 2017.

Education & Outreach

Communication

- a. CORC maintains a mooring website mooring.ucsd.edu/corc and data from some CORC moorings are delivered and disseminated via OceanSITES. The Spray Underwater Glider Data Website spraydata.ucsd.edu was established to

provide access to quality controlled delayed mode data.

Academic Development

- a. One graduate student (Caroline Lowcher) is being trained by participating in all aspect of the CORC project. Additional students sometimes participate in CORC field work.
- b. The Argo Global Marine Atlas project (http://www.argo.ucsd.edu/Marine_Atlas.html), developed by M. Scanderbeg (SIO/UCSD) provides a data display tool to allow students and educators view Argo and other ocean datasets as maps, vertical sections, time-series plots, and line drawings.
- c. Undergraduate research assistants were trained in the quality control of CTD data, using state-of-the-art automatic and manual procedures.

K-12 Outreach

- a. High School Lab Tours
PI Daniel Rudnick participated in an afternoon of lab tours on April 27, 2017 for several local high schools whose students were interested in ocean technology.

Networking

- a. U. Send and Ma. Lankhorst partnered with other time series operators at the international OceanSITES meeting in Southampton/UK, April 2016
- b. U. Send interacted with other international research teams at the CLIVAR Open Science Conference and the GSOP meeting in Qingdao/China, Sept 2016
- c. D. Roemmich, D. Rudnick, U. Send, M. Lankhorst participated in the international DOOS workshop in La Jolla, Dec 2016
- d. U. Send attended the POGO meeting of global ocean observation partners in Plymouth/UK, Jan 2016
- e. M. Lankhorst, N. Zilberman, U. Send participated in the OOMD Community Workshop in Silver Spring, May 2017



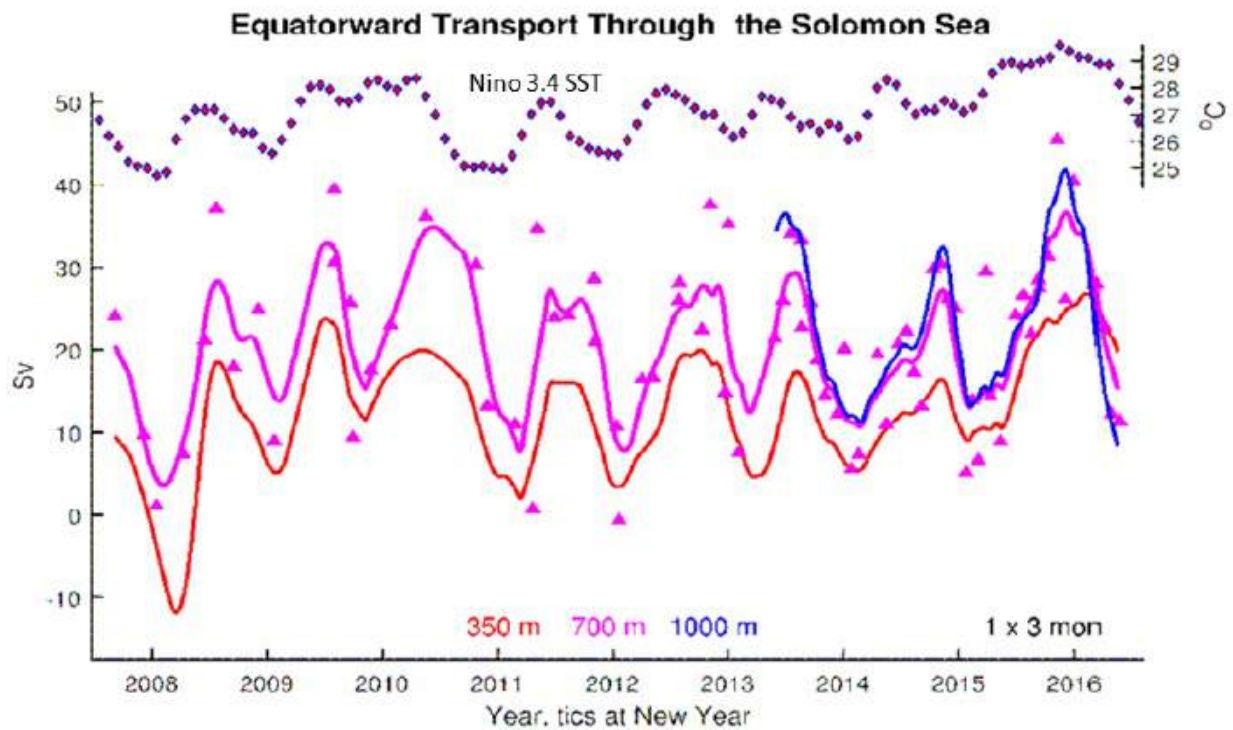


Figure 7: Transport vs depth from the 9-year glider record. Depths 350 and 700 m are well sampled; 1000 m began only in 2013. The annual cycle masks variability, but the El Niños in 2009-10 and 2015-16 were associated with large transport to the equator, particularly below 350 m. Triangles represent the section-average measurement from which the curve is made. This curve apparently under-represents the extremes of variability. It remains to be seen if the equator-ward peaks are significant in the warm pool heat budget or the under-current.

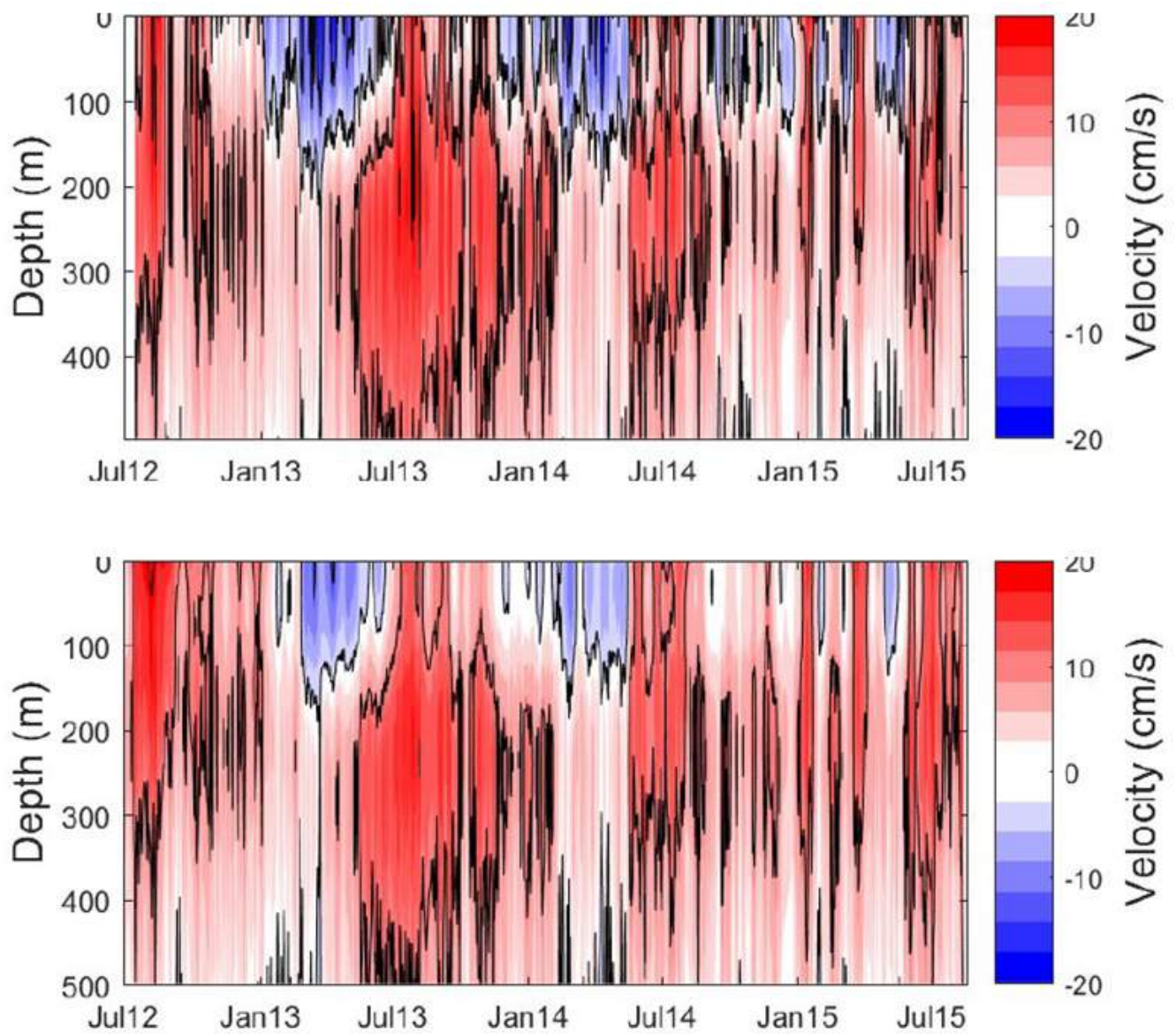


Figure 8: Total transport through the Solomon Sea inferred from endpoint moorings and PIES (top), and from only PIES but with altimetry to provide upper-layer information (bottom). Since two vertical EOFs can explain most of the variance, two suitably chosen measurements are sufficient to describe the time/depth structure of the horizontally integrated flow (transport).

HF Radar National Network Data Management Development

Principal Investigator(s):

Dr. Eric Terrill, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Joseph Chen, Scripps Institution of Oceanography, UC San Diego

Thomas Cook, Scripps Institution of Oceanography, UC San Diego

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

Lisa Hazard, Scripps Institution of Oceanography, UC San Diego

Mark Otero, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Jack Harlan, Integrated Ocean Observing System (IOOS), National Ocean Service

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: Healthy Oceans

Goal 2: Weather-Ready Nation

Goal 3: Climate Adaption and Mitigation

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$905,821

Amendment(s):

9, 45

Description of Research:

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).

Research Objectives:

The U.S. High Frequency Radar Network (HFRNet), a backbone of the Integrated Ocean Observing System (IOOS), supports both operational and research communities by providing high quality, spatially dense, ocean surface current data in near real-time. The rapidly maturing network is created by approximately 130 individual radar stations, regionally operated, which report data to collections sites for subsequent processing, quality control, display, backup, and distribution to operational users including the U.S. Coast Guard, NOAA's National Data Buoy Center, and National Weather Service field offices. This proposal seeks to continue efforts to research, maintain, and improve this data management system established by Scripps approximately 10 years ago in support of U.S. IOOS. The tools necessary to establish a network of data sharing for all HF radar data are essential to meet the NOAA goals of an integrated ocean observing system. This network not only brings together and synthesizes physical data, but also builds relationships throughout the oceanography community. This data system development effort focuses on maintaining the robust portal to node communications with centralized data



repositories that are updated in near real-time, processing and creating national HF radar derived surface current total vector maps, hosting and maintaining data visualization and access, and improving node data processing and accessibility.

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 hosting the Korea Hydrographic and Oceanographic Administration (KHOA) for a three-day workshop. It has been encouraging to see that KHOA continues to invest in HFR based surface current monitoring for both public safety and basic research. We had several detailed discussions over operational maintenance, data processing and validation that should aid in the development of a reliable network and accurate data.

NOAA and KHOA Ministry of Oceans and Fisheries Joint Project Arrangement accomplishments:

- Provide SKOR grid, documentation and well as RTV QC to Sang Ho Lee and Hanseok Ko (cc Jin Kwon)
- Work with KHOA to achieve short term goal of sharing CODAR format totals to SIO for display on GEO
- Provide KHOA (Jin Kwon), Sang Ho Lee and Hanseok Ko with NetCDF RTV documentation, MATLAB code and example NetCDF RTV file so they can begin to build a capability to produce totals in NetCDF with recommended metadata standards

CORDC launched the new HF Radar Diagnostic Operators Interface on January 9, 2017. Operators will be able to enter downtime reasons and estimates for radars. Additionally, the timeseries plots will support the full time of radar operations. We held several webinars reviewing

the changes and modifications to ensure the community was fully informed.

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: 4 on the east coast, 3 on the gulf coast, 3 in Canada, and 1 in Mexico. HFRNet growth chart can be found at: <https://hfrnet.ucsd.edu/diagnostics/networkstats.php>

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

Ridley Island, Canada (VRID) University of Victoria
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=VRID>

Georgina Point, Canada (VGPT) - University of Victoria
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=VGPT>

Rollover Pass, TX (RLVR) - Texas A&M University
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=rlvr>

Surfside, TX (SSDE) - Texas A&M University
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=ssde>

Nantucket, MA (NWTP) - Woods Hole Oceanographic Institution
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=NWTP>

Erendira, Mexico (ERE) - Universidad Autonoma de Baja California
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=ERE&aff=UABC>

Cape May Point, NJ (CLUB) - Rutgers University
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=CLUB>

Padre Island, TX (PINS) - Texas A&M University
<https://hfrnet.ucsd.edu/diagnostics/?p=sta&sta=PINS&t=0#>

Provincetown, MA (PTWN) - Woods Hole Oceanographic Institution
<https://hfrnet.ucsd.edu/diagnostics/?p=sta&sta=PTWN&t=0#>

Haulover Inlet, FL (HAUL) - Florida Atlantic University
<https://hfrnet.ucsd.edu/diagnostics/?p=sta&sta=HAUL&t=0#>



Point Atkinson, West Vancouver (VATK) -
University of Victoria
<https://hfrnet.ucsd.edu/diagnostics/?p=sta&sta=VATK&t=0#>

Decommissioned Sites:

- Belmar, NJ (BELM) Rutgers University
- Squibnocket Farms, MA (SQUB) Rutgers University
- MVCO Meteorological Mast, MA (METS) Rutgers University
- PSUR Naval Post Graduate School

Supported Domains and available data:

- USEGC - US East and Gulf Coast - 2008-03 through present
- USWC - US West Coast - 2008-03 through present
- GAK - Gulf of Alaska - 2009-05 through present (when available)
- PRVI - Puerto Rico and US Virgin Islands - 2010-01 through present

Data Requests:

The Coastal Observing R&D Center has responded to numerous data requests including (but not limited to):

- Coastal Erosion and Dune Dynamics (CEDD) Lab Department of Geography, University of Victoria
- Stennis Space Center, MS
- SRI International
- Naval Surface Warfare Center - Carderock Division, South Florida Ocean Measurement Facility
- CODAR Ocean Sensors

Above and beyond the objectives of the award, 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

Conferences, Meetings & Presentations

- a. Mark Otero attended the Ocean Radar Conference and European Global Ocean Observing System from September 13-15 in La Spezia, Italy (La Spezia) to participate in Global HFR planning and to coordinate with European HF radar operators
- b. Lisa Hazard, Mark Otero, Joseph Chen, Tony de Paolo, Thomas Cook hosted the Korea Hydrographic and Oceanographic Agency (KHOA) at Scripps Institution of Oceanography for a 3-day seminar October 11-13, 2016
- c. Lisa Hazard presented a poster at the AGU Fall Meeting Moscone Convention Center located at 747 Howard Street, San Francisco, CA December 11-13, 2016
- d. Lisa Hazard presented at the Group on Earth Observations (GEO) Meeting for High Frequency Radar Moscone Convention Center located at 747 Howard Street, San Francisco, CA December 11-13, 2016
- e. Lisa Hazard, Mark Otero, Joseph Chen, Thomas Cook participated in the Radiowave Operators Working Group (ROWG) in Galveston, TX March 13-16

Education & Outreach

Communication

- a. HFRNet Website
The Coastal Observing R&D Center maintains and supports the HF radar derived surface current mapping website
<http://www.cordc.ucsd.edu/projects/mapping/> which includes near real-time diagnostics



b. Global HFRNet Website

The Coastal Observing R&D Center maintains and supports the Global HF radar derived surface current mapping website with qty. 9 international partners

<http://cordc.ucsd.edu/projects/mapping/global/>

c. Data Requests

The Coastal Observing R&D Center has responded to numerous data requests including (but not limited to):

- Coastal Erosion and Dune Dynamics (CEDD) Lab Department of Geography, University of Victoria
- Stennis Space Center, MS
- SRI International
- Naval Surface Warfare Center - Carderock Division, South Florida Ocean Measurement Facility

Academic Development

1. Lisa Hazard presented a poster at the AGU Fall Meeting Moscone Convention Center located at 747 Howard Street, San Francisco, CA December 11-13, 2016

Networking

a. LA/LB Area Committee Meeting

Presented at the Los Angeles-Long Beach North/South Area Committee at the Patriot Environmental Services in Wilmington Ca. Co-Chairs, CAPT Jennifer Williams, USCG and LT Christian Corbo, CA Dept of Fish & Wildlife on June 9, 2016

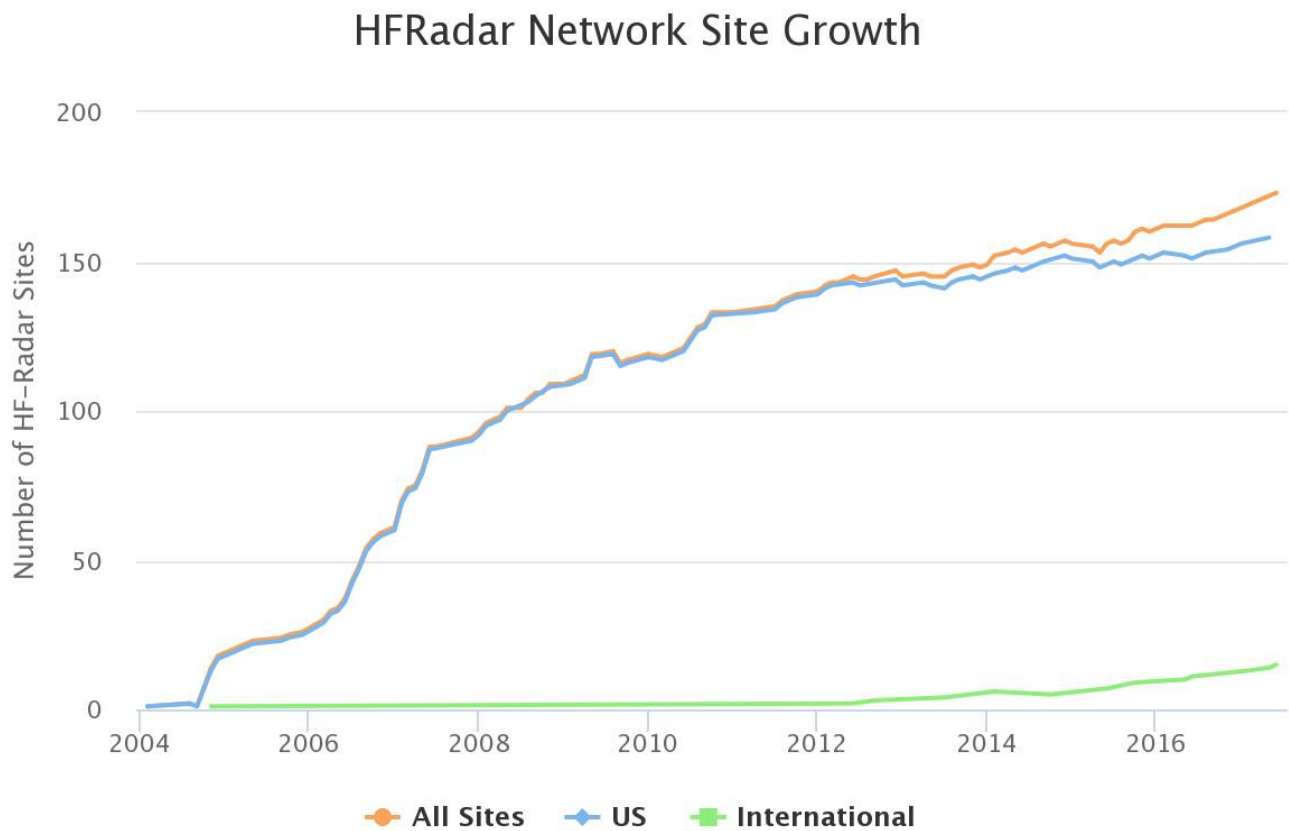
b. CODAR Ocean Sensors Meeting

Tony de Paolo participated in a meeting to review the future use of CODAR radial metrics with CODAR OS staff and Dr. Anthony Kirincich on November 8, 2016.





Figure 9: U.S. National Oceanic and Atmospheric Administration (NOAA) and Korea Hydrographic and Oceanographic Administration's (KHOA) Ministry of Oceans and Fisheries Joint Project Arrangement. From Left to Right: Danielle Williams, Lisa Hazard, Kevin Hong-Bae



Highcharts.com

Figure 10: High Frequency radar site growth time series. Growth has increased from qty. 10 in 2005 to over qty. 173 in 2017.



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

Principal Investigator(s):

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

Other Key Personnel:

Nathaniel Johnson, Princeton University/NOAA GFDL

Jiaxin Black, Scripps Institution of Oceanography, UC San Diego/NOAA GFDL

NOAA Primary Contact:

Dr. Annarita Mariotti, Climate Program Office, NOAA Research

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: Weather-Ready Nation

Budget Amount:

\$192,000

Award:

NA14OAR4310189

Description of Research:

The primary purpose of our project is to develop operational forecast guidance for new week 3-4 forecast products offered by the NOAA Climate Prediction Center (CPC). Through collaboration among SIO, Princeton University/GFDL, and CPC, our work over the past twelve months has advanced our fundamental understanding of teleconnection pattern predictability for lead times of three to four weeks. We also have begun to test hybrid dynamical/statistical methods for developing new subseasonal forecast tools. In addition, we have monitored the performance of

the statistical forecast guidance that we implemented in CPC's Experimental Week 3-4 Outlooks, starting in September 2015. Our primary goals were met, given that we successfully transitioned our forecast guidance into operations, and the guidance has been skillful over the past year.

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

Given the promising results from the Madden-Julian Oscillation (MJO) and El Niño-Southern Oscillation (ENSO) phase model for CPC's Experimental Week 3-4 Outlooks, we have sought ways to enhance week 3-4 forecast guidance by (1) determining other sources of forecast skill aside from the MJO, ENSO, and linear trend, and (2) attempting to incorporate that knowledge into forecast guidance. Over the past year, Dr. Jiaxin Black under the guidance of Dr. Nathaniel Johnson completed a study that analyzed statistical forecasts of the dominant Northern Hemisphere teleconnection pattern indices. The motivation for focusing on teleconnection patterns is their strong modulation of North American temperature and precipitation. Specifically, this work incorporates a partial least-squares regression (PLSR) method to generate 2-week statistical forecasts of the Pacific/North American (PNA) pattern, North Atlantic Oscillation (NAO) and Arctic Oscillation (AO) indices. The candidate predictor fields include tropical outgoing longwave radiation (OLR) and Northern Hemisphere 300 hPa and 50 hPa geopotential height. Overall, we find that the wintertime PLSR forecasts for the 1980-2013 period are skillful at all lead times to five weeks and perform similarly well as the CFSv2 dynamical model forecasts in weeks 3-4 for the 1999-2010 period (Fig. 11).

A potential benefit of the PLSR approach is the ability to isolate a small number of predictor



patterns to shed light on the physical sources of skill for the teleconnection patterns. Indeed, we identify several OLR and 300 hPa geopotential height patterns that are responsible for most of the teleconnection pattern skill (not shown). These results have the promise of providing guidance to forecasters on important precursor tropical convection and atmospheric circulation patterns that lead to skillful teleconnection pattern forecasts in weeks 3-4.

6.2 Development of hybrid dynamical/statistical forecast tools

We have begun to explore subseasonal sources of forecast skill in dynamical models and have explored frameworks for developing hybrid dynamical/statistical forecast tools. We have analyzed hindcasts covering the period of 1980-2016 from the Geophysical Fluid Dynamics Laboratory (GFDL) high-resolution Forecast-oriented Low Ocean Resolution (FLOR) model, which has demonstrated success in the seasonal prediction of surface weather and tropical cyclone/extratropical storm activity. However, few studies have examined the subseasonal forecast skill of FLOR. As an initial effort, we have examined the role of atmospheric initialization in subseasonal forecast skill by comparing two versions of initialization: FLOR-p1, which uses atmospheric initial conditions (AICs) from prior ensemble simulations of the atmospheric component of FLOR that is forced by observed seas surface temperature alone, and FLOR-p2, which uses observed AICs by relaxing surface pressure, horizontal winds and temperature throughout the entire atmosphere to reanalysis data. Therefore, FLOR-p1 primarily captures the forcing from the ocean surface, whereas FLOR-p2 includes the additional contribution from realistic AICs. Our results reveal that the forecast skill of T2m and precipitation increases dramatically for the first two weeks over the majority of North America from FLOR-p1 to FLOR-p2. FLOR-p2 also performs noticeably better at week 3, particularly for temperature, indicating that accurate AICs are important for week 3-4 forecasts over North America. Perhaps not surprisingly, the skill in weeks 3-4 is much higher for temperature than

for precipitation. Overall, these results highlight the importance of AICs for skillful temperature and precipitation forecasts in weeks 3-4.

Currently, we are working on leveraging such promising skill and refining forecasts through statistical post-processing techniques. We are focusing on tests of heteroscedastic extended logistic regression to improve subseasonal probabilistic forecasts for additional thresholds. The intention is that such methods also could be adapted for operational models like the CFSv2. We also are in the process of investigating the sources of predictability.

Research Objectives:

The primary objectives of the project are:

- To transition a statistical forecast model based on the initial state of the Madden-Julian Oscillation (MJO) and El Niño-Southern Oscillation (ENSO) into an operational CPC week 3-4 temperature and precipitation outlook for all seasons
- To develop additional hybrid dynamical/statistical forecast tools for weeks 3-4

Research Accomplishments:

- Successful transition and demonstration of skill of the MJO/ENSO statistical models in CPC's Experimental Week 3-4 temperature and precipitation outlooks
- One paper published and another in press

Conferences, Meetings & Presentations

- a. Dr. Nathaniel Johnson presented project results at the 16th European Meteorological Society Meeting held in Trieste, Italy from September 12 – 16, 2016.
- b. Dr. Jiaxin Black presented project results at the 97th American Meteorological Society Meeting held in Seattle, Washington from January 22-26, 2017.
- c. Dr. Nathaniel Johnson presented a seminar highlighting results from the project at the Taiwan Central Weather Bureau in Taipei, Taiwan on November 15, 2016.



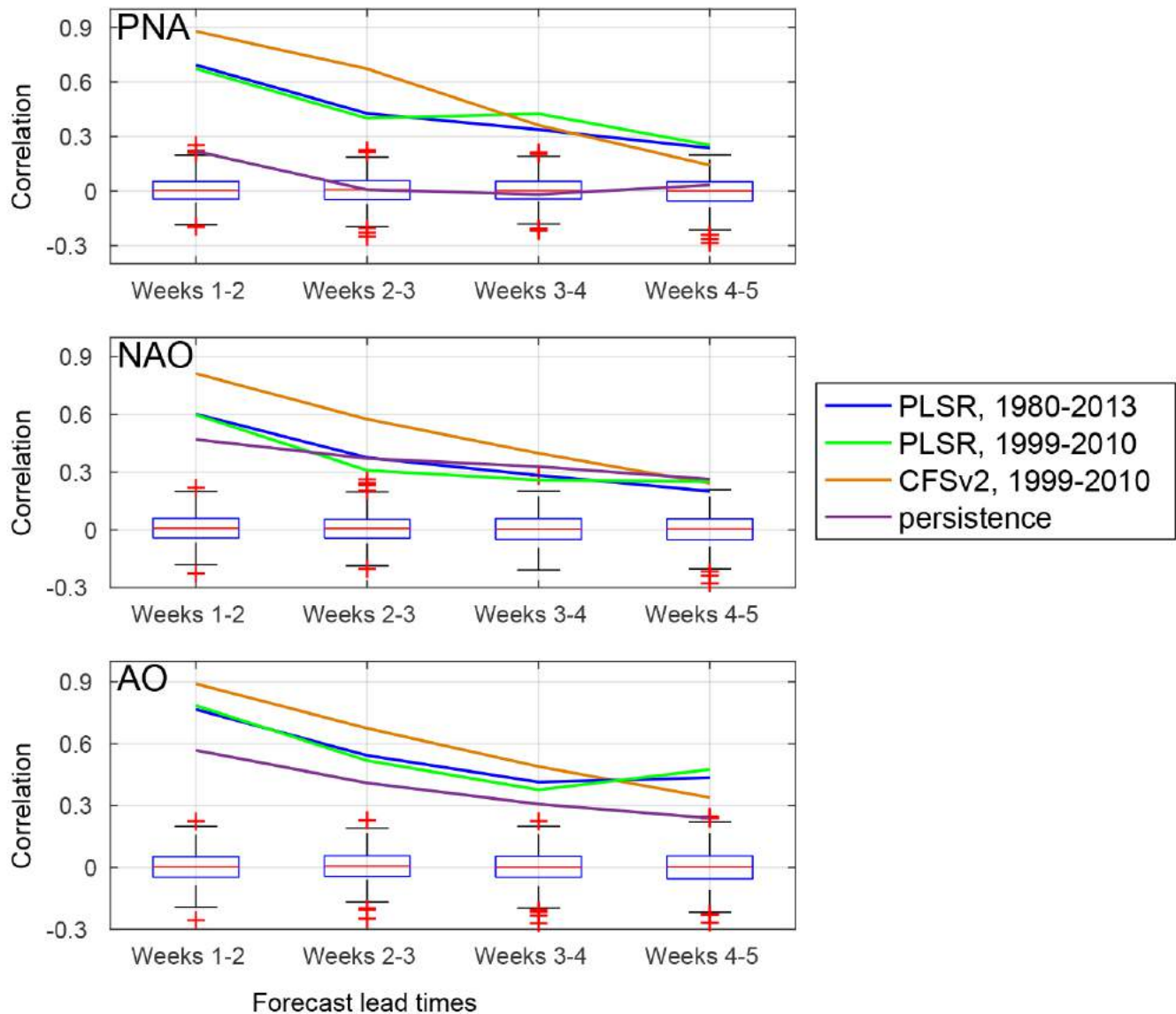


Figure 11: Skillful subseasonal forecasts of atmospheric teleconnection pattern indices. Box plots of the correlation between forecasts derived from partial least squares regression (PLSR) and observed wintertime (DJF) 2-week-averaged Pacific-North American pattern (PNA) (top), North Atlantic Oscillation (NAO) (middle), and Arctic Oscillation (AO) (bottom) index time series at different forecast lead times. The box plots are generated based on reshuffled data using a Monte Carlo approach. The blue (green) lines denote the correlation of PLSR forecasts evaluated from 1980-2013 (1999-2010). The yellow lines denote the correlation of CFSv2 dynamical forecasts evaluated from 1999-2010. The purple solid and black dashed lines denote the correlation from persistence and climatological forecasts, respectively. Adapted from Black et al. (in press).

Western Boundary Current Transport as a Climate Index

Principal Investigator(s):

Nathalie Zilberman, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Dean Roemmich, Scripps Institution of Oceanography, UC San Diego

Sarah Gille, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Jennifer Arrigo, Climate Program Office, NOAA Research

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: Climate Adaption and Mitigation

Budget Amount:

\$231,447

Award:

NA14OAR4310219

Description of Research:

Western Boundary Currents (WBCs) play an essential role in the meridional distribution of heat, mass, and freshwater of the global ocean and constitute the primary pathway for basin-scale heat exchange between the tropics and the mid-latitudes. Because of the narrowness and strong mesoscale variability of WBCs, estimation of WBC velocity and transport places heavy demands on any potential sampling scheme. Our purpose is to develop a new method combining altimetric data with High-resolution expendable bathythermograph (HRX) and Argo profiles and trajectories to improve volume transport estimates in five major WBCs: the East Australian Current (EAC), Kuroshio, Agulhas Current, Gulf Stream, and Brazil Current. The intent of this

research is to improve our knowledge of circulation in WBC regions, to increase our understanding of WBC response to wind forcing, and to quantify WBC transport changes in relation to climate variability.

High-resolution bathythermograph (HRX) profiles to 800-m have been collected along transects crossing the EAC system at 3-month nominal sampling intervals since 1991. EAC transects, with spatial sampling as fine as 10-15 km, were obtained off Brisbane (27°S) and Sydney (34°S), and crossing the related East Auckland Current north of Auckland. We merged HRX profiles collected from 2004 to 2015 off Brisbane with Argo float profiles and 1000 m trajectory-based velocities to expand HRX shear estimates to 2000-m and to estimate absolute geostrophic velocity and transport. The Argo trajectory gridded products currently available end in 2009 (ANDRO) or have a horizontal resolution too coarse to resolve the flow field in space and time along the narrow path of the EAC (G-YoMaHa). For consistency with Argo and HRX profiles used here, and to better capture the signature of the EAC, trajectory-derived velocities were computed using raw trajectory data from all floats available in our study region from 2004 to 2015. To preserve the sharp velocity gradients associated with the along-coast flow and flow reversal in the EAC region, trajectory-based velocities were sorted into 1/6° latitude x 1/2° longitude bins aligned with the 1000-m isobath.

A method was developed for combining altimetric sea surface height from the Archiving, Validation, and Interpretation of Satellite Oceanographic (AVISO) data with HRX and Argo profiles to mitigate temporal aliasing by the HRX transects and to reduce sampling errors in the HRX/Argo datasets.

Our transport estimates were compared against moored observations collected on the continental shelf off Brisbane at approximately 27°S, between April 2012 and August 2013. Additional comparisons were made using velocity and



transport estimates from a moored line deployed at 30°S, south of our study region, between 1992 and 1993 as part of the World Ocean Circulation Experiment.

Research Objectives:

The specific objective of this project is to define a new set of ocean climate indicators to track variability in WBC transport. Our project will support NOAA's long-term climate goal through provision of new information on the ocean heat transport and storage, sea surface temperature, and on surface currents in WBC regions.

Research Accomplishments:

- A method was developed for improving estimates of the volume transport in the EAC region.
- Estimates of the mean volume transport in the EAC System off Brisbane are 19.9 Sv southward for the EAC west of 155.3°E, with a recirculation of 2.7 Sv northward between 155.3°E and 157.5°E.
- Geostrophic transport anomalies in the EAC show variability of ± 1.0 Sv at interannual time scales related to the strengthening and weakening of the wind-stress curl in the Pacific Ocean Interior.

Education & Outreach

Academic Development

- a. Sarah Gille shared the demonstration SOLO float, the Argo program, and physical oceanography in general with broader audiences through Triton Transfer Day (May 2016), a UC San Diego Revelle College forum (May 2016), and with undergraduates enrolled in SIO 119 (January 2017).



California Underwater Glider Network (CUGN)

Principal Investigator(s):

Daniel L. Rudnick, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Jeff Sherman, Scripps Institution of Oceanography, UC San Diego

Gui Castelao, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Diane Stanitski, Climate Program Office, NOAA Research

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

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

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Goal 2: Weather-Ready Nation

Goal 3: Climate Adaption and Mitigation

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$374,150

Amendment(s):

37

Description of Research:

The California Underwater Glider Network (CUGN) is the longest running sustained glider network in the world, to our knowledge. As used off California, the underwater glider Spray profiles to 500 m or the ocean bottom, whichever is shallower. The cycle from the surface to 500 m and back takes about 3 hours to complete, during which time Spray travels 3 km horizontally relative to the water. Spray position is measured by GPS at the beginning and end of each dive, allowing a dead reckoning estimation of depth average water velocity. Spray carries a pumped Sea-Bird

CTD to measure pressure, temperature, and salinity, and a Seapoint fluorometer in the pumped stream. An acoustic Doppler current profiler (ADCP) measures depth dependent water velocity. Data is transferred by the Iridium satellite system once per dive, when commands to the glider can also be sent. A typical deployment lasts about 100 days, allowing a glider to complete two round trips on a 500 km line. Recoveries and deployments are done using a small boat.

The CUGN is operated along the traditional California Cooperative Oceanic Fisheries Investigations (CalCOFI) lines. We began operations in 2005 with line 93.3 because it was the closest line to SIO, making it logistically convenient as we solved engineering problems and developed experience in the field. Line 93.3 was abandoned in 2006 in favor of line 90, which is the most observed line over the history of CalCOFI. Line 90 has been occupied essentially continuously since October 2006. Operations on line 80 began in October 2005, and have been continuous since October 2006. Line 66.7 was begun in April 2007, and has been uninterrupted since April 2008. To date the CUGN has covered 230,000 km over ground and 247,000 km through water in over 10,000 glider-days, while doing 100,000 dives. A reasonable metric of performance is the number of operational glider-days/day, with the goal of having 3 glider-days/day. Since 1 January 2009, coverage has been 97%, which is a fair bulk measure of operational success.

Research Objectives:

Two main objectives, one technical and one scientific, have driven sustained glider observations in the California Current System (CCS). The technical objective has been to demonstrate the utility of gliders in measuring a boundary current system in a logistically convenient location. The scientific objective is to quantify the regional effects of climate variability in a biologically productive eastern boundary



current system. Our approach involves the repeated deployment of Spray underwater gliders on a series of lines off the California coast. With the longest continuously occupied time series 10 years in duration, we believe we have addressed our technical objective. The scientific objective continues to be addressed through observation of the last few years of anomalously warm water in the CCS.

Research Accomplishments:

- The CUGN has been sustained for over a decade, making it the longest-running underwater glider program in the world.
- The anomalies of the last few years in the CCS have been observed, including the warm anomaly of 2014-2015 (also known as “The Blob”) and the El Niño of 2015-2016.
- A website (spraydata.ucsd.edu) has been established for public access of quality controlled delayed mode data.
- A climatology of the CUGN has been published and made publicly available on spraydata.ucsd.edu in the forms of plots and CF-compliant netcdf files.
- The SoCal Temperature Index, based on CUGN data, continues to be used as a metric for climate conditions in the southern CCS.
 - CUGN data continues to be provided to the GTS in real time, and to be used in several models of the CCS.

Conferences, Meetings & Presentations

- a. Daniel Rudnick attended the CLIVAR sponsored Forecasting ENSO Impacts on Marine Ecosystems of the US West Coast Workshop held in La Jolla, CA during August 10-11, 2016.
- b. Daniel Rudnick attended the EGO meeting held in Southampton, UK during September 26-29, 2016.
- c. Daniel Rudnick attended the CalCOFI symposium held in La Jolla, CA during December 5-6, 2016.

- d. Daniel Rudnick attended the Deep Ocean Observing System Workshop held in La Jolla, CA during December 7-8, 2016.
- e. Daniel Rudnick attended the US Underwater Glider Workshop held in Stennis Space Center, MS during January 18-19, 2017.
- f. Daniel Rudnick attended the Implementation of Multi-disciplinary Sustained Ocean Observations Workshop held in Miami, FL during February 8-10, 2017.
- g. Daniel Rudnick chaired the ALPS-II meeting held in La Jolla, CA during February 21-24, 2017.
- h. Daniel Rudnick attended the international OceanGliders Steering Team meeting held in Paris, France during April 20-21, 2017.

Education & Outreach

Communication

- a. Spray Underwater Glider Data Website

The website spraydata.ucsd.edu was established to provide access to quality controlled delayed mode data, and to the CUGN climatology.

Academic Development

- a. Quality Control Training

Undergraduate research assistants were trained in the quality control of CTD data, using state-of-the-art automatic and manual procedures.

K-12 Outreach

- a. High School Lab Tours

PI Daniel Rudnick participated in an afternoon of lab tours on April 27, 2017 for several local high schools whose students were interested in ocean technology.

Networking

- a. Input for State of the California South Coast Report

Products of the CUGN were input for the State of the California South Coast Report prepared by the NGO OceanSpaces. This report is to establish a baseline for Marine Protected Areas in Southern California.



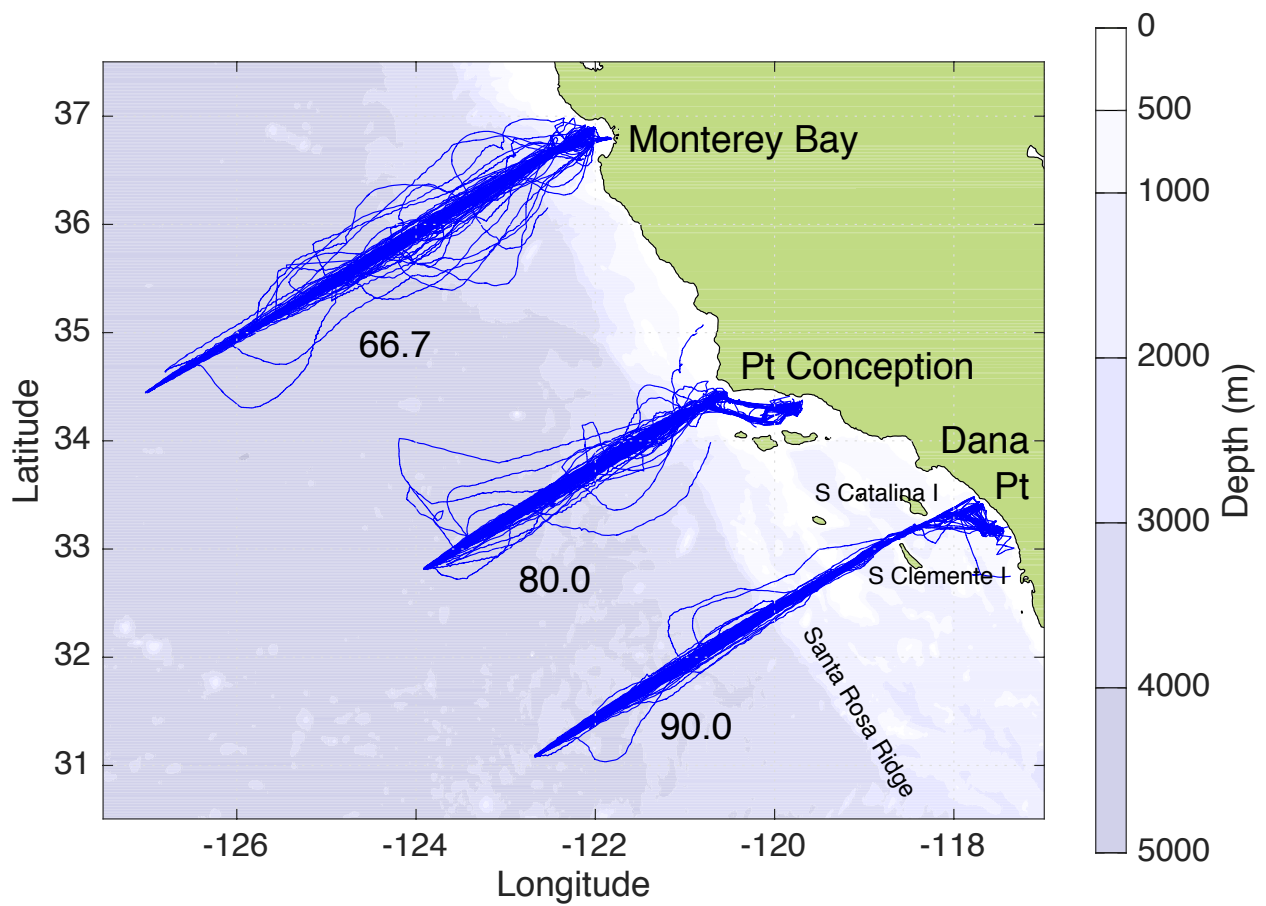


Figure 12: Trajectories of underwater gliders in the California Underwater Glider Network. From north to south are lines with CalCOFI designations 66.7, 80.0, and 90.0. Geographic features are labeled.



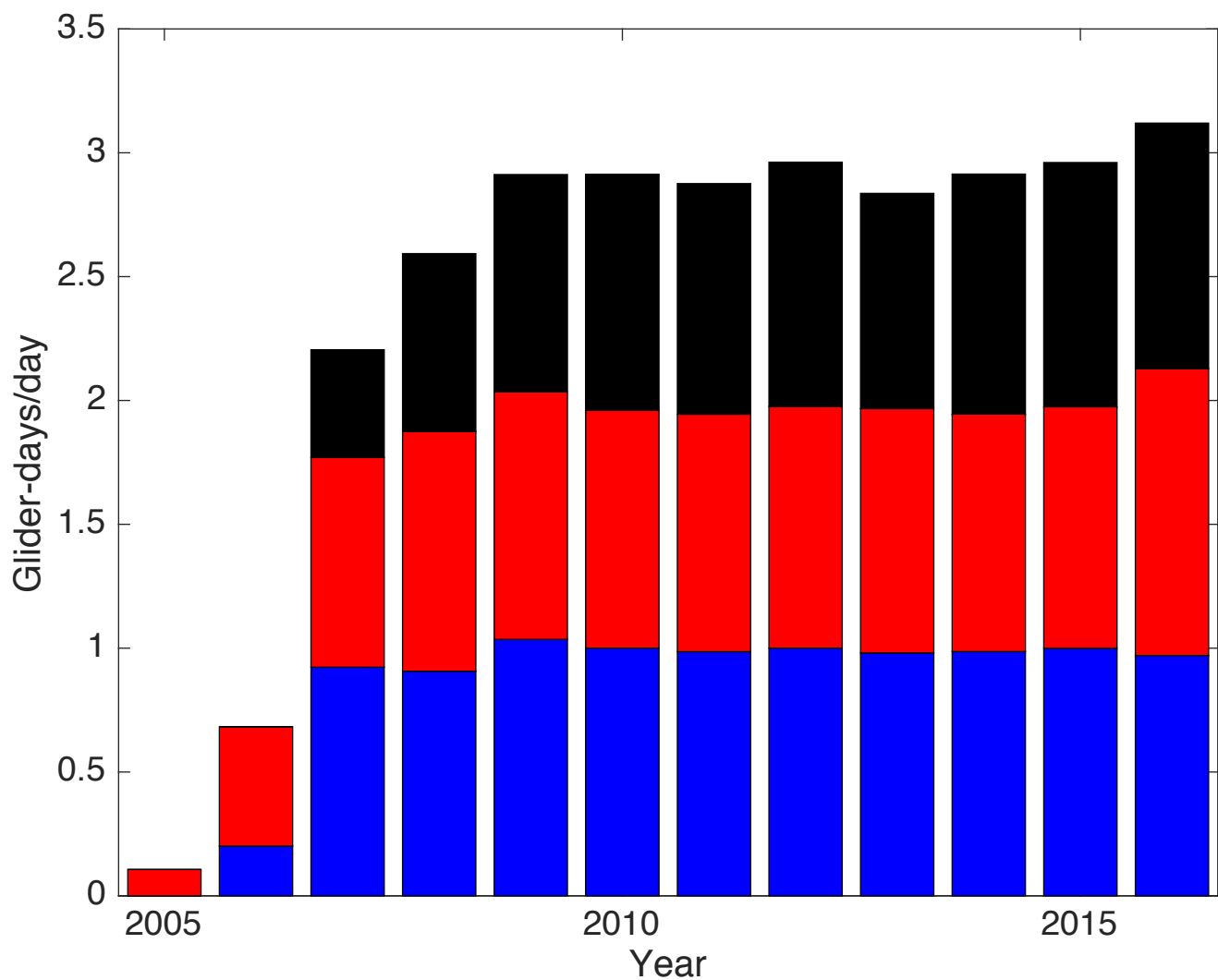


Figure 13: Glider-days/day averaged over calendar years on each of the three CUGN lines 66.7 (black), 80 (red), and 90 (blue). Ideal performance would be a value of 1 glider-days/day on each line for a total of 3 glider-days/day. Lines 66.7 and 90 are supported by OOMD, and line 80 is supported by IOOS. We were fortunate to have even more coverage on line 80 in 2016 as a short mission funded by the NSF California Current Ecosystem LTER.



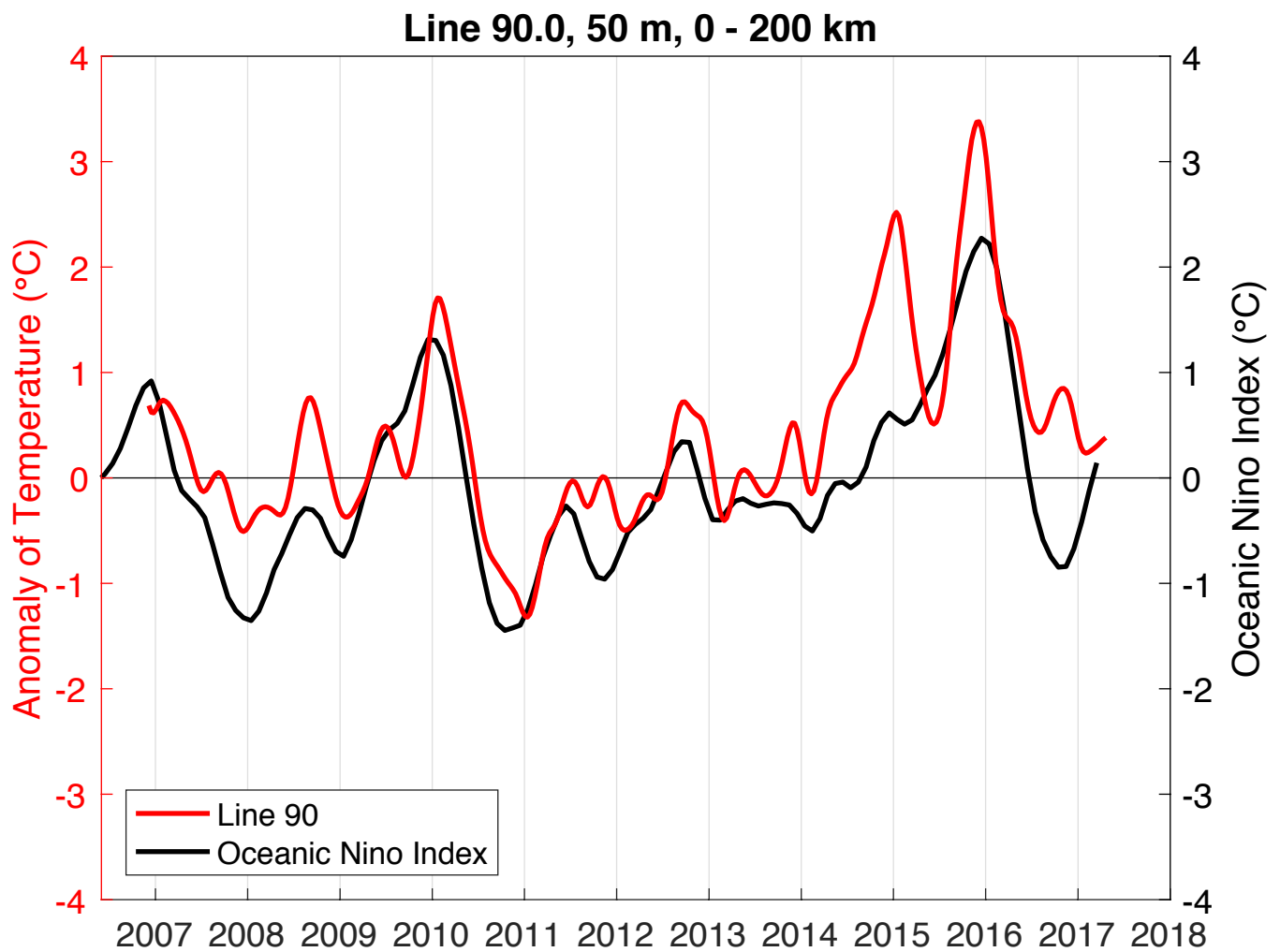


Figure 14: The SoCal Temperature Index, temperature anomaly at 50 m on line 90, averaged over the inshore 200 km, and filtered with a 3-month running mean (red), and the Oceanic Niño Index, Niño 3.4 filtered with a 3-month running mean (black). Note the strong correlation until the anomalous warming of starting near the beginning of 2014, then the strong peak associated with the 2015-2016 El Niño. Conditions at the equator and off California are near neutral.



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 Research

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

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

Related NOAA Strategic Goal(s):

Goal 2: Weather-Ready Nation

Goal 3: Climate Adaption and Mitigation

Budget Amount:

\$811,555

Amendment(s):

10, 35

Description of Research:

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 it 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.

Research Objectives:

1. Obtain decadal-scale time series of meridional transports of the lower limb of the AMOC.
2. Merge observations at 16N with those at other latitudes to study coherence of transports on different time scales.
3. Investigate mechanisms of AMOC variability, including comparison with model simulations.
4. Test utility of satellite methods (altimetry, gravity) in complementing in-situ observations.

Research Accomplishments:

1. Successful mooring service (recovery and re-deployment) in spring 2016
2. Transport time series now extended to 16-year length
3. Validation of reference level calculations with PIES bottom pressure and GRACE bottom pressure



Honors and Awards

- a. Jannes Koelling, NASA Earth and Space Science Fellowship, since Sep 2016

Conferences, Meetings & Presentations

- a. Uwe Send and Matthias Lankhorst co-organized and attended the international OceanSITES meeting in Southampton/UK, April 2016
 - b. Uwe Send presented a poster about the MOVE project at the CLIVAR Open Science Conference and attended the GSOP meeting in Qingdao/China, Sept 2016
 - c. Uwe Send and Matthias Lankhorst presented at the international DOOS meeting in La Jolla, Dec 2016
 - d. Uwe Send attended the POGO meeting and presented OceanSITES in Plymouth/UK, Jan 2017
 - e. Matthias Lankhorst presented a poster at the OOMD Community Workshop in Silver Spring, May 2017
 - f. Jannes Koelling gave a poster and Matthias Lankhorst an oral presentation at the US AMOC Science Team meeting in Santa Fe, May 2017
- Conference and the GSOP meeting in Qingdao/China, Sept 2016
 - c. Uwe Send and Matthias Lankhorst participated in the international DOOS workshop in La Jolla, Dec 2016
 - d. Uwe Send attended the POGO meeting of global ocean observation partners in Plymouth/UK, Jan 2016
 - e. Matthias Lankhorst and Uwe Send participated in the OOMD Community Workshop in Silver Spring, May 2017
 - f. Jannes Koelling, Matthias Lankhorst, and Uwe Send interacted with other AMOC research teams at the US AMOC Science Team meeting in Santa Fe, May 2017

Education & Outreach

Communication

- a. MOVE maintains a website mooring.ucsd.edu/move and data from MOVE are delivered and disseminated via OceanSITES.

Academic Development

- a. One graduate student (Jannes Koelling) is being trained by participating in all aspect of the MOVE project. Additional students sometimes participate in MOVE field work.

Networking

- a. Uwe Send and Matthias Lankhorst partnered with other time series operators at the international OceanSITES meeting in Southampton/UK, April 2016
- b. Uwe Send interacted with other international research teams at the CLIVAR Open Science



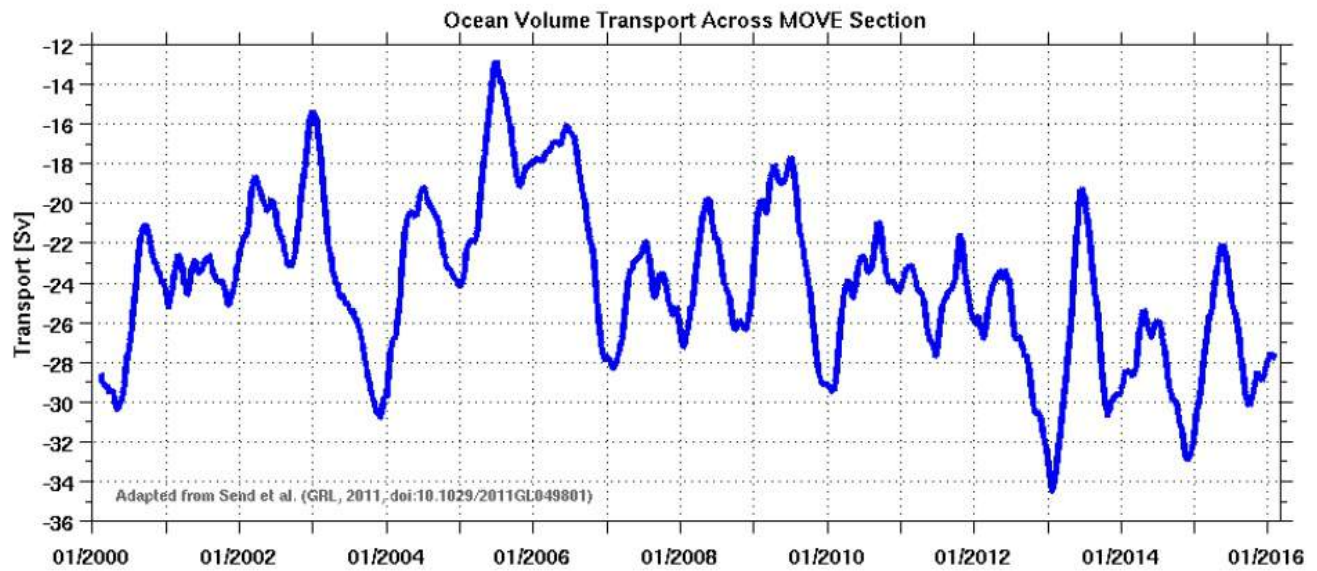


Figure 15: Water volume transport across the MOVE array in the depth layer 1200-5000m. The negative numbers denote the southward flow, which constitutes the lower limb of the AMOC.



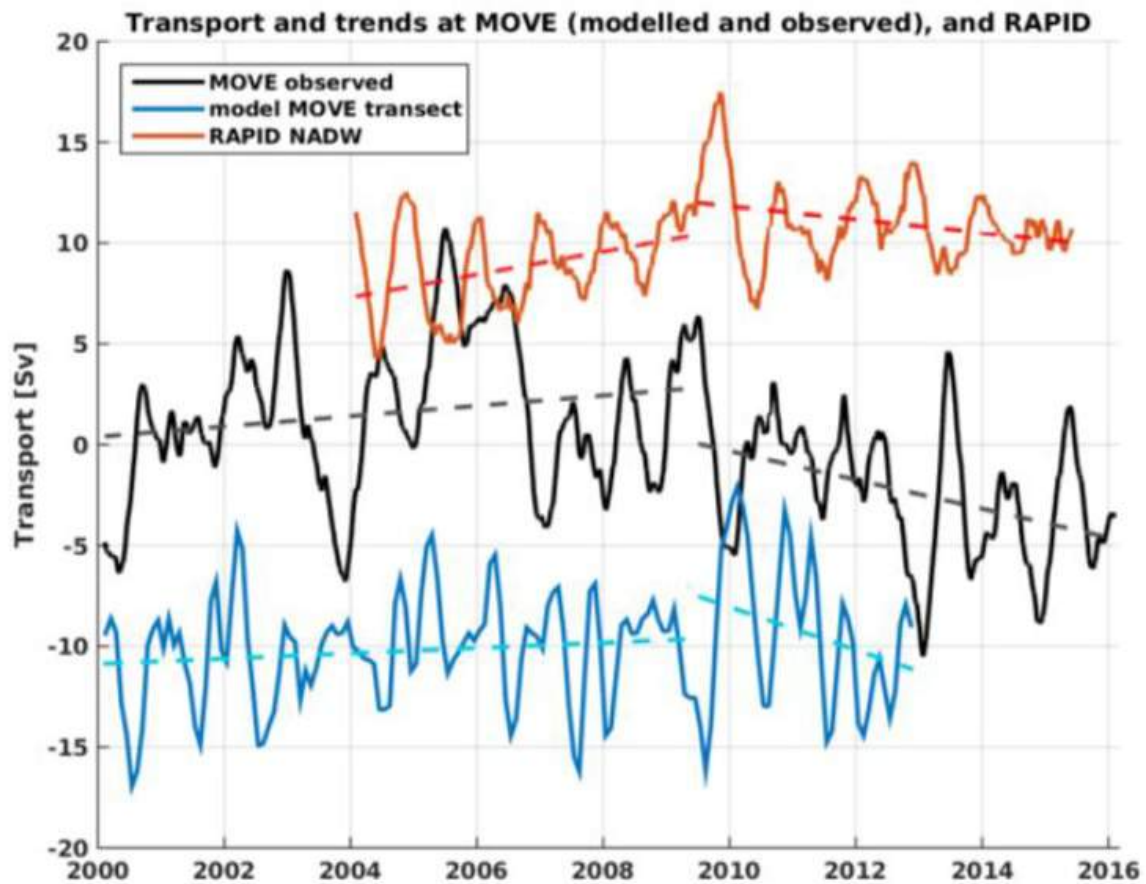


Figure 16: Transport trends in the North Atlantic Deep Water from MOVE in comparison with the RAPID array at 26N and numerical simulations at the MOVE location (courtesy N. Serra and R Kaese, University of Hamburg, Germany). With the right choice of time intervals, long-term trends appear to point in the same direction (dashed lines).

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

Principal Investigator(s):

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

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

Other Key Personnel:

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

Dr. Alicia Karspeck, National Center for Atmospheric Research

Dr. Gokhan Danabasoglu, NCAR

NOAA Primary Contact:

Dr. Sandy Lucas, Climate Program Office, NOAA Research

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

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

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Goal 2: Weather-Ready Nation

Budget Amount:

\$499,080

Award:

NA14OAR310276

Description of Research:

We are analyzing a 30-member ensemble integration of a CESM model (active ocean, atm, land, ice) with CAM5 prognostic aerosols. In situ ocean data from WOD09 is assimilated daily and NCEP radiosonde temp, winds are assimilated at 6 hourly intervals in the atmospheric model. Currently the run is from 1970 to 1980 and still going. No data is assimilated in land or ice. The DART data assimilation software is used. DART is

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

We have analyzed the mean state and the variability in this data assimilated CESM run and compared it to other relevant reanalysis products as well as in-situ observations, in collaboration with Dr. Alicia Karspeck and Dr. Gokhan Danabasoglu at NCAR. The model runs for assimilation are performed by Dr. Alicia Karspeck.

Results from the analysis of model runs show that the data assimilated simulation has a good representation of intraseasonal variability in the Tropics and also a comparable amount of energy in convectively coupled tropical waves as to another reanalysis such as ECMWF. CESM-DART simulations show similar variability frequency-wavenumber space in both equatorial Kelvin waves and the MJO for the zonal winds. Overall CESM-DART has enhanced tropical variability compared to NCEP 20th century reanalysis and suppressed 850 mb wind variability in the Tropics as compared to ERA20C Reanalysis winds. We are currently analyzing the data assimilated tendencies and the ensemble reliability budget for these model simulations to identify robust analysis errors that will inform on the model error terms and ways to reduce the model errors.



Research Objectives:

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

We have progressed in our study of the evaluation of the coupled data assimilated CESM-DART runs for their tropical variability representation and the spatiotemporal structures of bias and variability error development in **CESM forecasts**. We have diagnosed the state estimate of CESM-DART for the period 1970-1981 for the MJO variability and compared this to other reanalysis products (NCEP R1, ECMWF ERA20C and gridded observations as well as in-situ observations where available). We use a recently developed approach to compute a reliability budget in an ensemble data assimilation system to identify model bias, ensemble variability and model error terms. We are trying to ascribe these identified errors to well-known physical processes for the specific climate modes of variability. We will test the sensitivity of the bias development to changes in coupled model configuration. We are currently testing the use of model state variables from the data assimilated CESM model to initialize forecast experiments to further identify robust biases and physical parameterizations that are likely to be responsible for these biases on

subseasonal timescales. We will then pursue methods to propose improved parameterization or model error representation in CESM based on our result.

Research Accomplishments:

- First global climate model with couple data assimilation being analyzed for model biases
- Identified the CESM model mean bias in the Western Pacific region using the reliability budget for ensemble data assimilation system
- Identified ENSO and MJO events in the coupled data-assimilation CESM runs
- Participated in the Coupled Data Assimilation workshop in Toulouse, France.
- Subramanian is working jointly with others from the workshop on a BAMS article summarizing the global coupled data assimilation efforts and paths forward
- Completing a manuscript for submission on the evaluation of the Tropical variability in the assimilated model compared to other reanalysis products.
- Mentored Ph.D. student Jonathan Eliashiv (SIO) in this research

Conferences, Meetings & Presentations

- a. U.S. CLIVAR POS Panel, 17-20, June, Seattle, WA (Miller, Co-Chair)
- b. Joint GODAE OceanView Data Assimilation & Marine Ecosystem (DA/MEAP) Workshop, 11-13 July 2016, UC Santa Cruz (Miller) CESM 2016 Annual meeting, 20-23 July 2016, Breckenridge, CO (Eliashiv)
- c. ENSO-Ecosystem Forecasting Workshop, 10-11 August, SIO, La Jolla, CA (Miller, Co-Organizer, Subramanian, Eliashiv)
- d. CLIVAR Open Science Conference, 15-20 September, Qingdao, China (Miller)
- e. International workshop on coupled data assimilation, 18-21 October, 2016, Toulouse France (Subramanian)
- f. American Meteorological Society Meeting, 23-26 January, Seattle, WA (Miller)



- g. Data Assimilation Workshop, 30 January, 2017, Caltech, Pasadena CA (Miller)

Education & Outreach

Communication

- a. Numerous interviews with TV, radio, and newspapers about the Extreme Pacific Anomalies and El Nino (Miller)
- b. Participant, 2017 Exploring Ocean STEM Careers Night, Birch Aquarium at Scripps (Miller)
- c. Member, Stay Cool for Grandkids, grass roots climate action group in San Diego (Miller)
- d. Home page: <http://meteora.ucsd.edu/~miller/>

Academic Development

- a. Mentored Ph.D. student Jonathan Eliashiv (SIO) in this research

K-12 Outreach

- a. Participant, 2017 Exploring Ocean STEM Careers Night, Birch Aquarium at Scripps (Miller)

Networking

- a. Co-Organized the ENSO-Ecosystem Forecasting Workshop, 10-11 August, SIO, La Jolla, CA, which included multi-disciplinary scientists and program managers from NOAA and NSF (Miller, Co-Organizer, Subramanian, Eliashiv)



The first study assesses the representation of tropical convectively coupled waves and climate variability in CESM-DART. We compare the tropical convectively coupled waves in CESM-DART with those in ECMWF ERA-20C and NCEP R1 Reanalysis fields. Figure 17 shows the two-dimensional power spectra of the 850 hPa zonal winds for the three different products highlighting the different equatorial wave modes. The Kelvin wave mode and the Madden-Julian Oscillation (MJO) are comparable in all three products. The right panels in Figure 17 shows a difference between the two products showing that the CESM-DART simulations have more power in the MJO band as well as in the Kelvin wave mode.

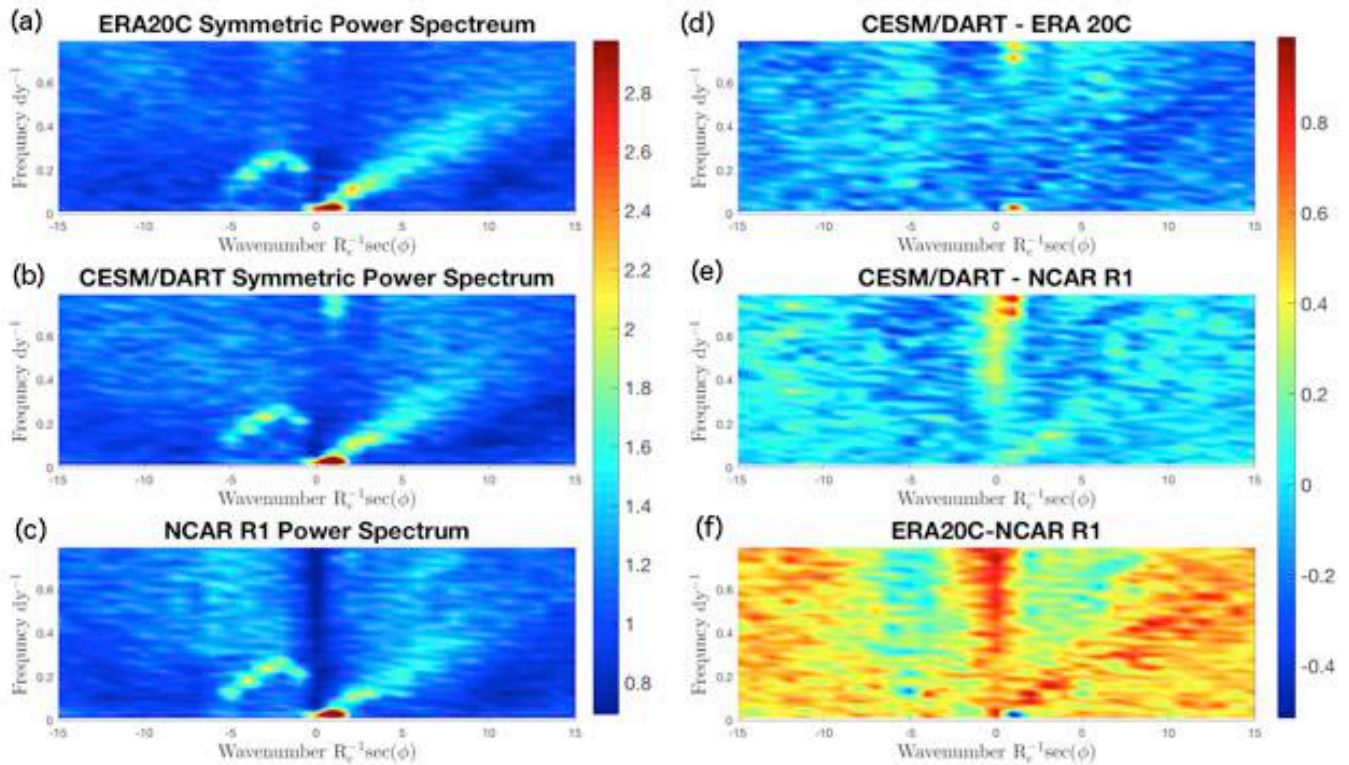


Figure 17: Wavenumber-frequency spectra of the upper tropospheric (200 hPa) zonal wind speeds for (a) ERA-20C, (b) CESM/DART and (c) NCEP R1 reanalysis. The difference in spectra is plotted on the right panel (d) CESM/DART-ERA20C (e) CESM/DART - NCAR R1 (f) ERA20C-NCAR R1. The energy in the Kelvin wave bands are weaker in NCEP reanalysis compared with that of ECMWF or CESM-DART products.

We then computed the MJO index following the Wheeler-Hendon methodology by performing a multivariate EOF analysis of the 850 hPa, 200 hPa zonal winds in the Tropics as well as the velocity potential at 200 hPa. The Madden-Julian Oscillation index for the three reanalysis products being compared are shown in figure 18 for the 1970s decade.

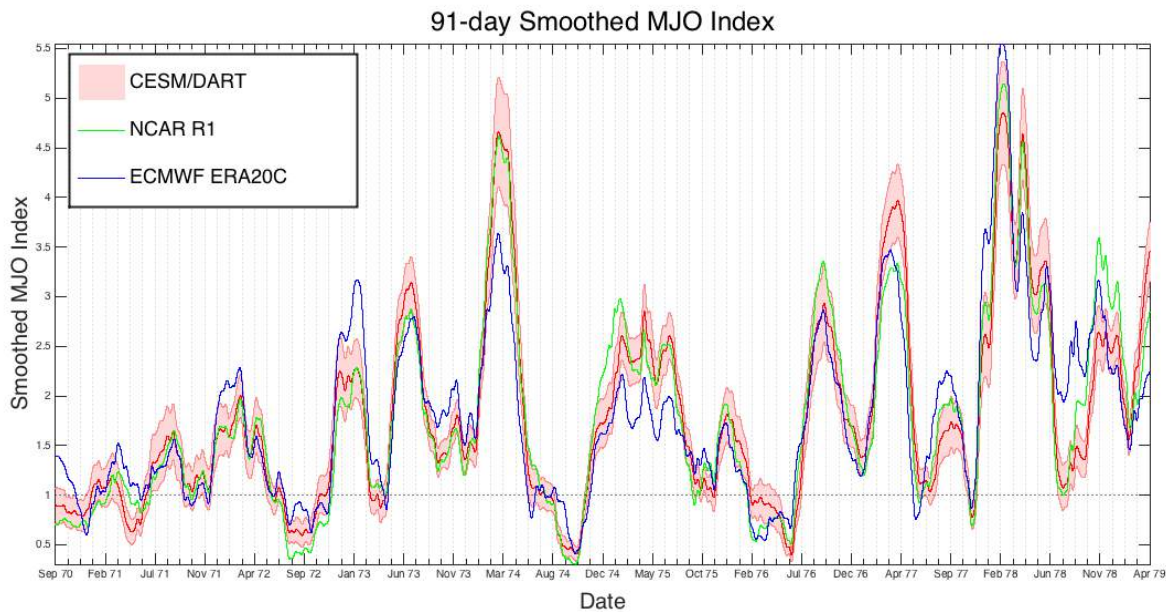


Figure 18: Madden Julian Oscillation index for CESM-DART (red), NCEP/NCAR R1 reanalysis (green) and ECMWF ERA20C (blue) using zonal winds at 200 hPa , 850 hPa and velocity potential at 200 hPa.

We also compare the surface flux fields in the three different reanalysis products to gridded observational products such as OA-Flux (Figure 19). Additionally, we compare each model against observations taken by soundings in the atmospheric column.

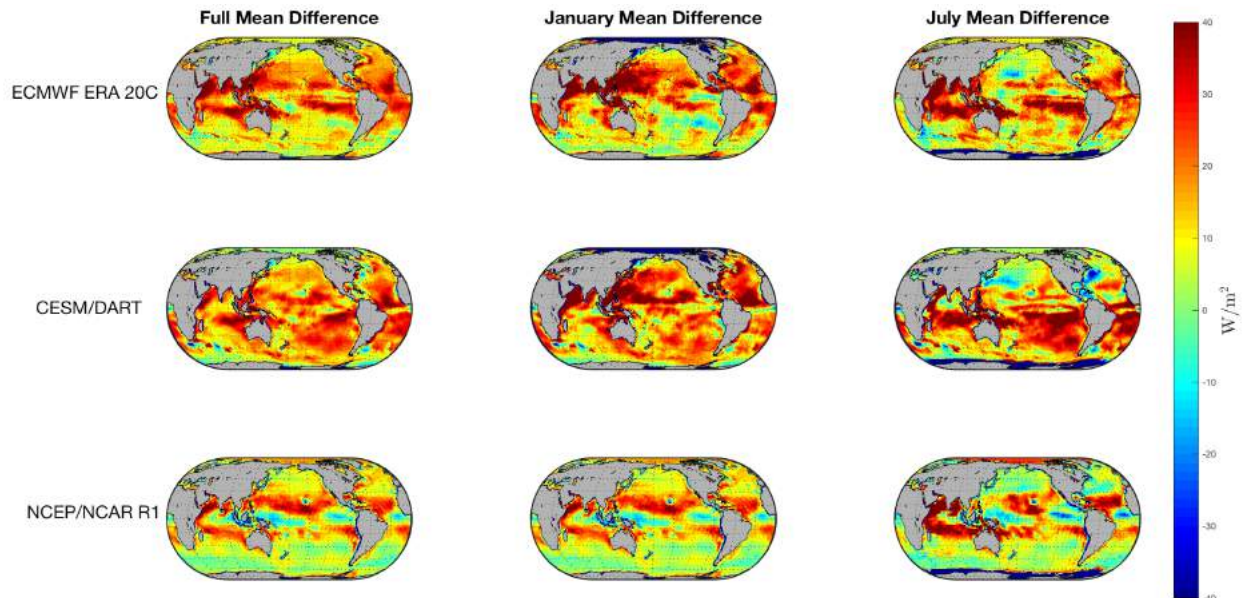


Figure 19: Biases in latent heat flux for ECMWF ERA 20C (top panels), CESM-DART (middle panels) and NCEP/NCAR R1 (bottom panels) for the annual mean (left), January (middle) and July (right) mean fields.

The second study examines the reliability budget of CESM/DART in all the different assimilated variables, and looks for times where error propagates more. The following figure shows the effect of MJO events on the reliability budget for CESM/DART in the equatorial Pacific.

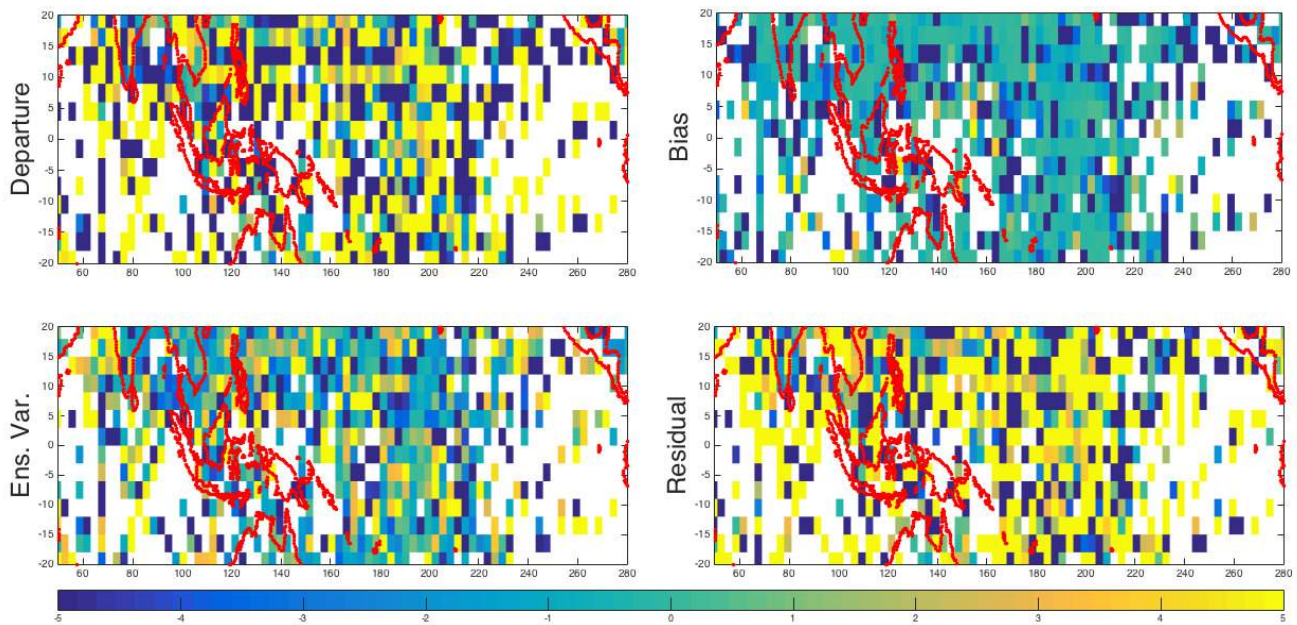


Figure 20: Estimated reliability budget for the zonal 850 hPa winds based on CESM-DART ensemble data assimilated product. the winds is a 6-hour field, based on the CESM-DART data assimilated 6-hr background forecasts for the period Jan 1971 – Dec 1980 (a) Mean-squared departure of the ensemble-mean relative to the observation. (b) squared bias of the ensemble-mean relative to the observation. (c) Mean ensemble variance (d) the residual term within each 2° grid box over the 6-hr data assimilation window. Observations are a combination of aircraft, in-situ and satellite measurements from the National Centers for Environmental Prediction (NCEP) repository.

More research still needs to be done to isolate the physical mechanisms causing changes in the reliability budget for CESM/DART. We plan to submit this manuscript for peer-review in the next six months.



Theme B: Climate Research and Impacts

The Global Drifter Program

Principal Investigator(s):

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

Other Key Personnel:

Dr. Verena Hormann, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Sidney Thurston, Climate Program Office, NOAA Research

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Goal 2: Weather-Ready Nation

Goal 3: Climate Adaption and Mitigation

Budget Amount:

\$5,777,760

Amendment(s):

8, 32

Description of Research:

Provide through the publicly available Global Telecommunication System (GTS) a-real time data stream of drifter's 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.

Research Objectives:

Specific Science Objectives of the GDP

- Provide the Global Telecommunication System (GTS) of the World Weather Watch (WWW) with a stream of near-real time data of SST, SLP, SSS, SLW and Tz for use in climate, NWP and tropical cyclones forecast models. The data latency, i.e. the time between collection and availability on the GTS should be as small as possible. Currently it ranges from ~2 hours with the Argos satellite system to ~10 minutes with if the Iridium telemetry is used.
- Measure the mixed layer currents globally and provide GDP partners at the Atlantic Oceanographic and Meteorological Laboratory (AOML) of NOAA with data to produce maps of the World's ocean circulation that resolve seasonal and inter-annual variations. At present, the quality-



controlled ocean current data are available in delayed mode.

- Provide the scientific oceanographic, climate and meteorological communities and the general public with enhanced, research-quality data sets of ocean currents that incorporate drifter data from individual research programs, including historical data from instruments that differ from the Surface Velocity Program (SVP) Lagrangian drifter design corrected for the wind-induced velocity bias, also known as “slip” ([Niiler; Paduan 1995](#)).
- Support programs of national and international interest, such as the recently launched Aquarius mission to measure SSS from space and NWP efforts worldwide.
- Analyze the GDP drifter data and provide a scientific interpretation of the results. Publish the findings in peer-reviewed, easily accessible journals.

Specific Technical Objectives of the GDP

- Maintain the nominal array resolution of 5°X5°, needed to keep the potential SST satellite bias error smaller than 0.5°C.
- Monitor and evaluate the performances of the GDP array in real time to identify early signs of, and troubleshoot, technical issues.
- Develop and introduce drifter’ construction technological advances in sensors, electronics, power, methods of assembly and packaging for deployment. Special emphasis is given to the implementation of new sensors, air deployable instruments and methods for hurricane research, SSS measurements, and technical solutions to increase the endurance of the drifters.
- Share the technological advances with the drifter manufacturer community (commercial, university and federal agencies) with the goal to maintain a healthy GDP array.

Research Accomplishments:

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 of 84 SVP systems (420 SVP drifters) and 96 SVPB systems (480 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 31, 2016, there were 1,405 GDP drifters actively reporting to the GTS. *This task addresses the program’s priorities of delivering continuous instrumental records for global analyses of sea surface temperature, sea level atmospheric pressure 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 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 again purchased 15 drifters with NASA funds that will be registered under the GDP and the GDP has provided 15 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. An improved designed of the drogue wheel was the focus of this funding cycle. SIO has designed and implemented the new solution that is now being tested on newly fabricated drifters for large scale field testing.

Drifter inspections are routinely performed by the GDP and if non-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. Close attention was paid to the performance of the GPS engine since the Iridium drifters, that are now replacing the Argos drifters, need the GPS for geolocation. Several tests are underway and the firmware of the drifters is being revised as the results become available.

(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;

N/A. To travel to Keesler AFB was not deemed necessary this year.

(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 Geneva, Switzerland, and attended the DBCP 31st scientific and technical workshop, where they delivered a talk, and the plenary session of the DBCP 31 meeting. A list of presentations can be found at (http://www.jcomm.info/index.php?option=com_o&task=viewEventDocs&eventID=1638).

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

Accomplished. Centurioni et al. (2016) Since 1994 the US Global Drifter Program (GDP) and its international partners cooperating within the Data Buoy Cooperation Panel (DBCP) of WMO-UNESCO have been deploying drifters equipped with barometers primarily in the extra-tropical regions of the world's oceans in support of operational weather forecasting. To date, the impact of the drifter data isolated from other sources has never been studied. This essay quantifies and discusses the effect and the impact of in situ sea-level atmospheric pressure (SLP) data from the global drifter array on numerical weather prediction using observing system experiments and forecast sensitivity observation impact studies. The in-situ drifter SLP observations are extremely valuable to anchor the global surface pressure field and significantly contribute to accurate marine weather forecasts, especially in regions where no other in situ observations are available, like, for example, in the Southern Ocean. Furthermore, the forecast sensitivity observation impact analysis indicates that The SLP drifter data is the most valuable per-observation contributor from the Global Observing System (GOS). All these results give



evidence that surface pressure observations of drifting buoys are essential ingredients of the GOS and their quantity, quality and distribution should be preserved as much as possible in order to avoid any analysis and forecast degradations. The barometer upgrade program offered by the GDP, under which GDP funded drifters can be equipped with partner-funded accurate air pressure sensors, is a practical example of how the DBCP collaboration is executed. Interested parties are encouraged to contact the GDP to discuss upgrade opportunities.

Chang et al. (2016). Global data from drifters of the Surface Velocity Program (Niiler, 2001) and tropical cyclones (TCs) from the Joint Typhoon Warning Center and National Hurricane Center were analyzed to demonstrate strong ocean currents and their characteristics under various storm intensities in the Northern Hemisphere (NH) and in the Southern Hemisphere (SH). Mean TC's translation speed (U_h) is faster in the NH ($\sim 4.7 \text{ m s}^{-1}$) than in the SH ($\sim 4.0 \text{ m s}^{-1}$), owing to the fact that TCs are more intense in the NH than in the SH. The rightward (leftward) bias of ocean mixed-layer (OML) velocity occurs in the NH (SH). As a result of this slower U_h and thus a smaller Froude number in the SH, the flow patterns in the SH under the same intensity levels of TCs are more symmetric relative to the TC center and the OML velocities are stronger. This study provides the first characterization of the near-surface OML velocity response to all recorded TCs in the SH from direct velocity measurements.

Lumpkin et al (2016). The Global Ocean Observing System (GOOS) requirements for in situ surface temperature and velocity measurements call for observations at $5^\circ \times 5^\circ$ resolution. A key component of the GOOS that measures these essential climate variables is the global array of surface drifters. In this study, statistical observing system sampling experiments are performed to evaluate how many drifters are required to achieve the GOOS requirements, both with and without the presence of a completed global tropical moored buoy array at 5°S – 5°N . The statistics for these simulations are derived from

the evolution of the actual global drifter array. It is concluded that drifters should be deployed within the near-equatorial band even though that band is also in principle covered by the tropical moored array, as the benefits of not doing so are marginal. It is also concluded that an optimal design half-life for the drifters is ~ 450 days, neglecting external sources of death, such as running aground or being picked up. Finally, it is concluded that comparing the drifter array size to the number of static $5^\circ \times 5^\circ$ open-ocean bins is not an ideal performance indicator for system evaluation; a better performance indicator is the fraction of $5^\circ \times 5^\circ$ open-ocean bins sampled, neglecting bins with high drifter death rates.

Menna et al (2016): Satellite data (images of sea surface temperature and chlorophyll-a), ocean surface wind products, Lagrangian observations (surface drifters) and other ancillary data (upwelling index) are used to describe the upwelling seasons off NW Africa during 2009–2013, with particular focus on the coasts of Senegal and Mauritania. The impact of the upwelling is characterised by a comparative analysis, carried out in terms of wind-induced upwelling and water/ecosystem response to this forcing, of five geographical sectors detected in the study area. The wind forcing analysis shows the most favourable upwelling conditions in the period December–June in the southern sectors (south of 16°N), and from February to October in the northern sectors (north of 18°N). Southern sectors are strongly influenced by wind forcing, whereas to the north the upwelling also occurs during the months with low Ekman transport values. The analysis of the sea surface temperature and chlorophyll-a concentration confirms the existence of an upwelling season during winter–spring in the south, and emphasizes the different behaviours between the northern and southern sectors. Drifter tracks allow the addition of details about the flow of cold water offshore and alongshore. In particular, they describe the westward transport of cold water, by means of energetic filaments rooted at specific locations along the coast, north of Cape Vert and



the south-SW ward transport of the coastal water south of Cape Vert.

Wijesekera et al. (2016): Air-Sea Interactions in the Northern Indian Ocean (ASIRI) is an international research effort (2013-2017) aimed at understanding and quantifying coupled atmosphere-ocean dynamics of the Bay of Bengal (BoB) with relevance to Indian Ocean monsoons. Working collaboratively, more than twenty research institutions are acquiring field observations coupled with operational and high-resolution models to address scientific issues that have stymied the monsoon predictability. ASIRI combines new and mature observational technologies to resolve submesoscale to regional-scale currents and hydrophysical fields. These data reveal BoB's sharp frontal features, submesoscale variability, low-salinity lenses and filaments, shallow mixed layers, with relatively weak turbulent mixing. Observed physical features include energetic high-frequency internal waves in the southern BoB; energetic mesoscale and submesoscale features including an intrathermocline eddy in the central BoB; and a high-resolution view of the exchange along the periphery of Sri Lanka, which includes the 100-km wide East India Coastal Current (EICC) carrying low-salinity water out of the BoB and an adjacent, broad northward flow (~ 300 km wide) that carries high-salinity water into BoB during northeast monsoon. Atmospheric boundary layer (ABL) observations during the decaying phase of the Madden Julian Oscillation (MJO) permit the study of multi-scale atmospheric processes associated with non-MJO phenomena and their impacts on the marine boundary layer. Underway analyses that integrate observations and numerical simulations shed light on how air-sea interactions control the ABL and upper ocean processes.

(D10) R&D activities.

Accomplished. 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. A

pilot array of 27 wave drifters has been deployed in the North Pacific Ocean.

Conferences, Meetings & Presentations

- a. Workshop for drafting the "Vision for WIGOS Surface-based observing components in 2040", (CBS Vision 2040 Surface), Offenbach, Germany, 23-25 August 2016,
- b. PI-2, Second Pacific Islands Training Workshop on Ocean Observations and Data Applications, 24 - 27 May 2016, Noumea Cedex, New Caledonia, http://www.jcomm.info/index.php?option=com_oe&task=viewEventRecord&eventID=1783
- c. Dr. Centurioni Organized and hosted at Scripps the 32nd session of the Data Buoy Cooperation Panel at Scripps in October 2016 and the 36th Argos Joint Tariff Agreement Meeting http://www.jcomm.info/index.php?option=com_oe&task=viewEventRecord&eventID=1792

Education & Outreach

Communication

- a. Interview with Lucy Shouten, Christian Science Monitor, 19 April 2016 <http://www.csmonitor.com/World/Global-News/2016/0419/Debris-linked-to-missing-MH370-flight-but-answers-remain-at-sea>





Figure 21: For more information on the drifters themselves, visit http://gdp.ucsd.edu/ldl_drifter/instruments/svps.html



Measurements of O₂/N₂ and Ar/N₂ ratio by the Scripps O₂ program

Principal Investigator(s):

Ralph Keeling, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. James Butler, Global Monitoring Division, Earth System Research Laboratory, NOAA Research

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Goal 3: Climate Adaption and Mitigation

Budget Amount:

\$873,064

Amendment(s):

3, 39

Description of Research:

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

The primary funded activity involves measurements of atmospheric composition from flasks collected at an array of ten stations extending from the Arctic to the Antarctic along a (mostly) Pacific transect. Flasks are analyzed at the Scripps Institution of Oceanography through a

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

Research Objectives:

The Scripps O₂ program advances NOAA's Strategic Goals of Healthy Oceans and Climate Adaption and Mitigation by:

1. Providing critical estimates of global land and ocean carbon sinks.
2. Resolving signals of ocean processes influencing atmospheric CO₂ and O₂ in relation to the ocean carbon sink, ocean deoxygenation, and changes in ocean ecological processes.
3. Resolving large-scale air-sea heat fluxes through measurements of Ar/N₂ and APO = O₂ + 1.1CO₂.

Research Accomplishments:

An important accomplishment has been maintaining continuity in the time series based on flask sampling at the ten stations. Results for O₂/N₂ are shown in Figure 22. Data from this program have been disseminated on the website: ScrippsO2.ucsd.edu. The data continue to document clearly resolved seasonal cycles and long-term trends on O₂ and CO₂. The trend data



can be used to quantify global land and ocean carbon sinks. Data for Ar/N₂ show a well-resolved seasonal cycle and a small increase over time, both related to air-sea heat exchanges. The data also resolve cycles and long-term trends in the tracer $APO = O_2 + 1.1CO_2$, which can be used to constrain aspects of ocean biogeochemistry and air-sea heat exchange.

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

Several projects using the data from the Scripps O₂ program are in progress at Scripps:

1. The PI has drafted a 51-page technical report on the span sensitivity of the interferometric O₂ analyzer. This report supports a ~2% change in span sensitivity which reduces the amplitude of O₂/N₂ signals, including the long-term rate of O₂/N₂ loss by around 2%. The report includes the following major sections: 1. Overview, 2. Theoretical Span Sensitivity, 3. Parameters for theoretical sensitivity relation, 4. Span check via O₂/CO₂ mixture addition, 5. Span check using gravimetric standards, 6. Scale contraction from incomplete sample/reference replacement, 7. Updating the O₂ database for the revised span sensitivity
2. (2) Laure Resplandy (form postdoc, now Asst Prof. at Princeton U.) has used the long-term trend in APO from 1991 through 2016 to make an estimate of the total uptake of heat by the ocean. The method leverages an understanding that the long-term APO trend will have three primary contributions: Fossil-fuel burning, ocean uptake of anthropogenic CO₂, and additional air-sea exchanges of O₂ and CO₂ not driven directly by the increase in

atmospheric CO₂. The first two are well quantified based on independent estimates, allowing the third to be calculated from the observations by difference. Using both models and hydrographic data, we show that the third contribution is dominated by solubility-driven changes in O₂ and CO₂, and is therefore closely related to the amount of heat taken up by the ocean. This calculation leads an estimates of ocean heat uptake of $\sim 1.3 \times 10^{22} \text{ J /y}$ over the 1991-2016 period. A manuscript is being circulated among coauthors for submission to Science Magazine.

3. (3) Manfredi Manizza (Research Associate) is leading an analysis which challenges ocean models based on the observed ratios of the amplitudes of the APO and Ar/N₂ cycles.
4. (4) Yassir Eddebbar (current grad student) has completed a study detailing the controls on O₂, CO₂, and hence APO exchange associated with El Nino-driven changes in the circulation of the tropical Pacific. This paper shows a complex relationship between heat and APO exchange on this interannual time scale. Yassir has written up this study in a manuscript accepted for publication in Global Biogeochemical Cycles.
5. (5) Yassir Eddebbar is also working on a second study comparing the observed decadal variability in APO with hindcasts from the NCAR community earth system model (CESM). His work particularly focuses on trying to better understand an acceleration of the downward APO trend which started around year 2000, and may have a relation to the global warming "hiatus", which started around the same time.

Conferences, Meetings & Presentations
Presentations by R. Keeling:

- a. 12 April 2016. Presentation at Workshop for Sustained Observations in Boulder Colorado on Sustained Observations. Talk title: "Sustained observations of carbon: the bootlegging of big science"



- b. 7-9 Sept. 2016 Attended ORCAS science team meeting, Boulder Colorado.
- c. 12-13 Sept 2016. Royal Society Meeting, London on Ocean ventilation and deoxygenation in a warming world. Keynote talk title: "Recent oxygen trends in the atmosphere and the oceans: what do we know?"
- d. 3 Oct 2016. Presentation to National Association of Clean Air Agencies (NACAA) via conference call. Title: "Scripps O2 and CO2 programs"
- e. 14 Nov 2016. Department seminar at Boston University Biogeosciences Seminar Series. Talk title: Atmospheric evidence for large-scale shifts in the functioning of the Earth's Biosphere
- f. 17 Nov 2016. General Atomics. Talk title: "Lessons from the Keeling Curve on the state the planet"
- g. 24 Nov 2016. CICESE Oceanography Department Seminar, Ensenada, "Atmospheric evidence of changing global biogeochemistry"
- h. 5 Feb 2017. Fourth Santa Fe Conference on Global & Regional Climate Change. Talk title: "Insights into carbon sinks, land photosynthesis, ocean warming and deoxygenation from long-term measurements of atmospheric CO2 and O2"

significance of the data. (Presentation by R. Keeling)

Academic Development

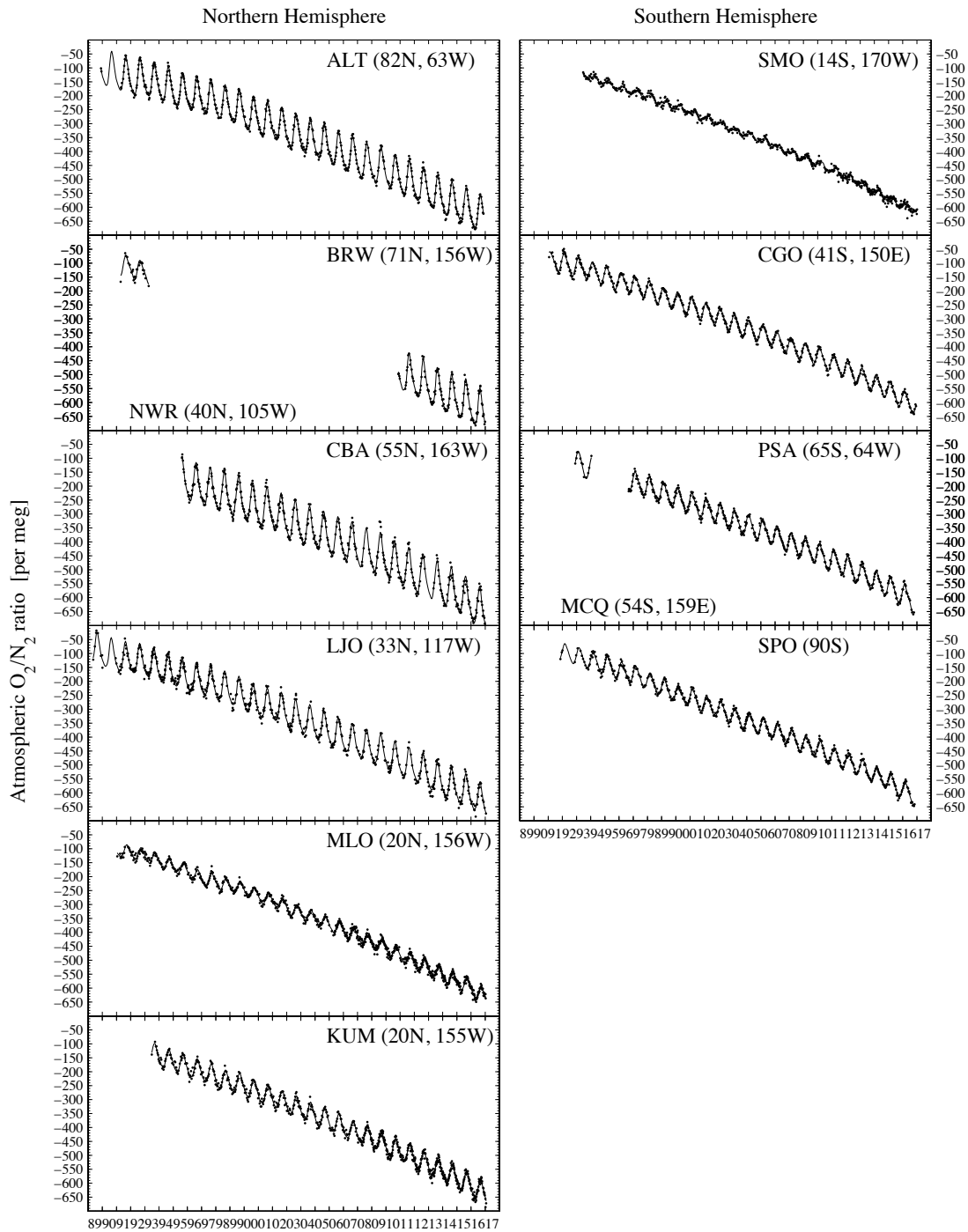
- a. The data from this project has supported the Ph.D. project of current SIO grad student Yassir Eddebbar.
- b. The data has also supported projects by current SIO postdoc Eric Morgan, and former SIO postdoc Laure Resplandy.

Education & Outreach

Communication

- a. 7 Mar 2017: California Naturalist Certification class, Guest Lecture, Carlsbad, California: "Lessons from the Keeling Curve on the state the planet" (Presentation by R. Keeling)
- b. 11 Mar 2017 Oral presentation at KPBS producers club event, Weather on Steroids, La Jolla Historical Society (Presentation by R. Keeling)
- c. The program helps to maintain the ScrippsO2.ucsd.edu website, which serves to disseminate the data and provide content for the general public to understand the





From Archive Dated 25-May-2017 17:56:51
/data/instrument/database_active/figures/traditional_plots/ALLo.eps

Figure 22: Updated time series of O_2/N_2 ratio.



Moored carbon, biogeochemical, and ecosystem observations in the Southern California Current (CCE Moorings)

Principal Investigator(s):

Uwe Send, Scripps Institution of Oceanography, UC San Diego

Mark Ohman, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Matthias Lankhorst, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Diane Stanitski, Climate Program Office, NOAA Research

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Goal 3: Climate Adaption and Mitigation

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$1,077,589

Amendment(s):

12, 29, 49, 57

Description of Research:

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 serving the needs of multiple disciplines and NOAA line offices.

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 (CO₂, wind, temperature, humidity, precipitation, irradiance),
- surface ocean conditions (temperature, salinity, pCO₂, O₂, pH, currents, point and integrated measures of phytoplankton chlorophyll content over the euphotic zone, and nitrate supply), and mixed-layer depth,
- broad-band active-acoustic observations of zooplankton and fish biomass over the upper 300m.

Much of the data is 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.

Research Objectives:

1. Study the time variability of physical conditions and its forcing on time scales from days to years.
2. Observe the impact of physical variability on biogeochemical and ecosystem processes and conditions.



3. Relate environmental habitat conditions to fisheries quantities.

Research Accomplishments:

1. Successful mooring service (recovery and deployment) of CCE2 in May 2016 and CCE1 in October 2016.
2. Upgrade of both moorings with new wide-band autonomous backscatter systems (SIMRAD WBAT).
3. Extension of time series to 7 year record length for some variables.
4. Analysis of anomalies during the 2014-16 warm event and El Nino.

Conferences, Meetings & Presentations

- a. Uwe Send and Matthias Lankhorst co-organized and attended the international OceanSITES meeting in Southampton/UK, April 2016
- b. SungHyun Nam gave a presentation about the CCE project at the CLIVAR Open Science Conference, and Uwe Send attended the GSOP meeting in Qingdao/China, Sept 2016
- c. Uwe Send and Matthias Lankhorst presented at the international DOOS meeting in La Jolla, Dec 2016
- d. Uwe Send attended the POGO meeting and presented OceanSITES in Plymouth/UK, Jan 2017
- e. Matthias Lankhorst and Uwe Send attended the OOMD Community Workshop in Silver Spring, May 2017

Education & Outreach

Communication

- a. The CCE moorings project maintains a website mooring.ucsd.edu/CCE and data from the CCE moorings are delivered and disseminated via OceanSITES.

Academic Development

- a. One graduate student (Laura Lilly) is being trained by participating in some aspects of the CCE project and cruises. Additional students

sometimes participate in CCE mooring field work.

Networking

- a. Uwe Send and Matthias Lankhorst partnered with other time series operators at the international OceanSITES meeting in Southampton/UK, April 2016
- b. Uwe Send interacted with other international research teams at the CLIVAR Open Science Conference and the GSOP meeting in Qingdao/China, Sept 2016
- c. Uwe Send and Matthias Lankhorst participated in the international DOOS workshop in La Jolla, Dec 2016
- d. Uwe Send attended the POGO meeting of global ocean observation partners in Plymouth/UK, Jan 2016
- e. Matthias Lankhorst and Uwe Send participated in the OOMD Community Workshop in Silver Spring, May 2017
- f. Jannes Koelling, Matthias Lankhorst, and Uwe Send interacted with other AMOC research teams at the US AMOC Science Team meeting in Santa Fe, May 2017



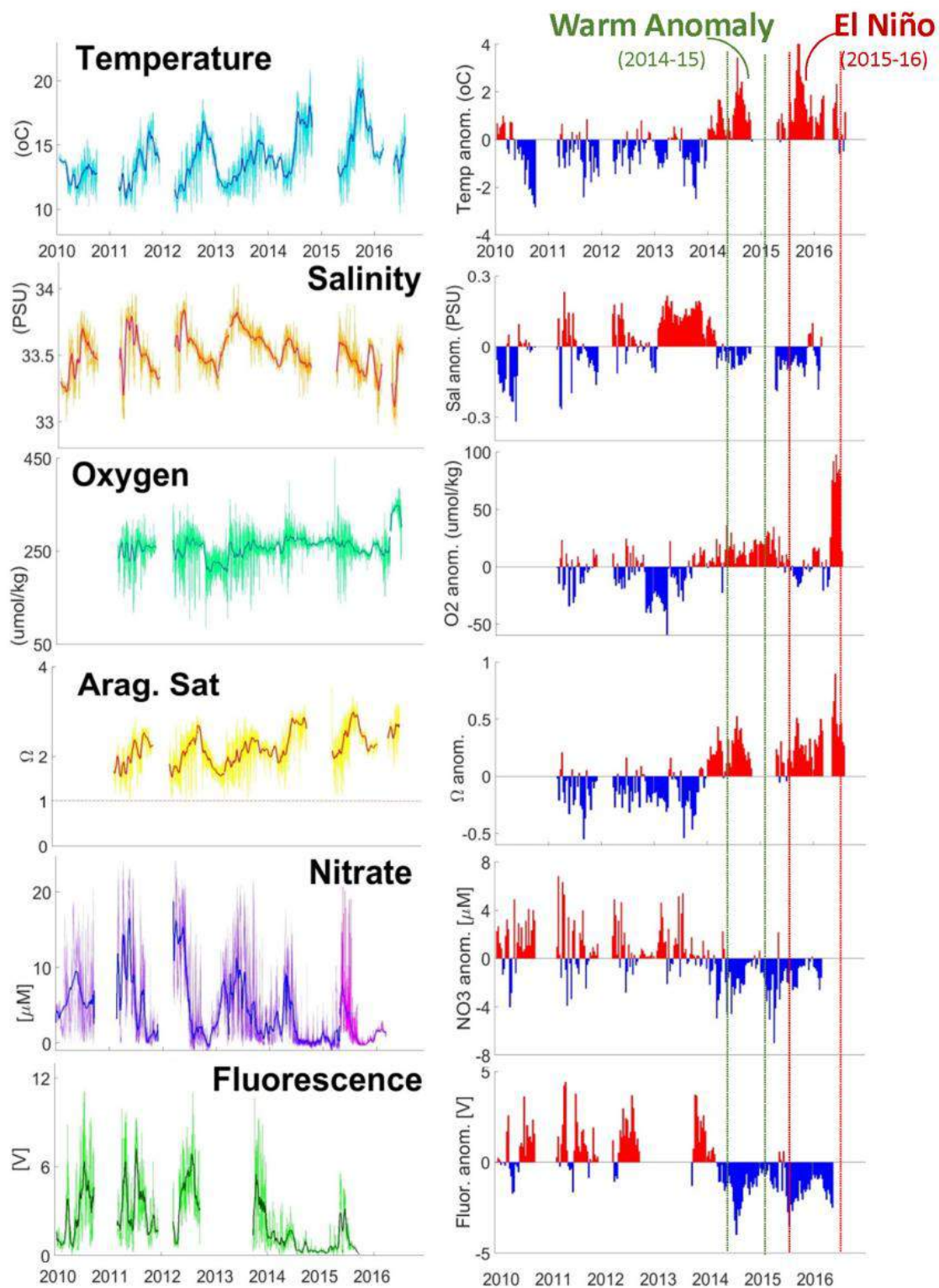


Figure 23: Multi-year record of various quantities at CCE2 at 15m depth (left: absolute values; right: anomalies).



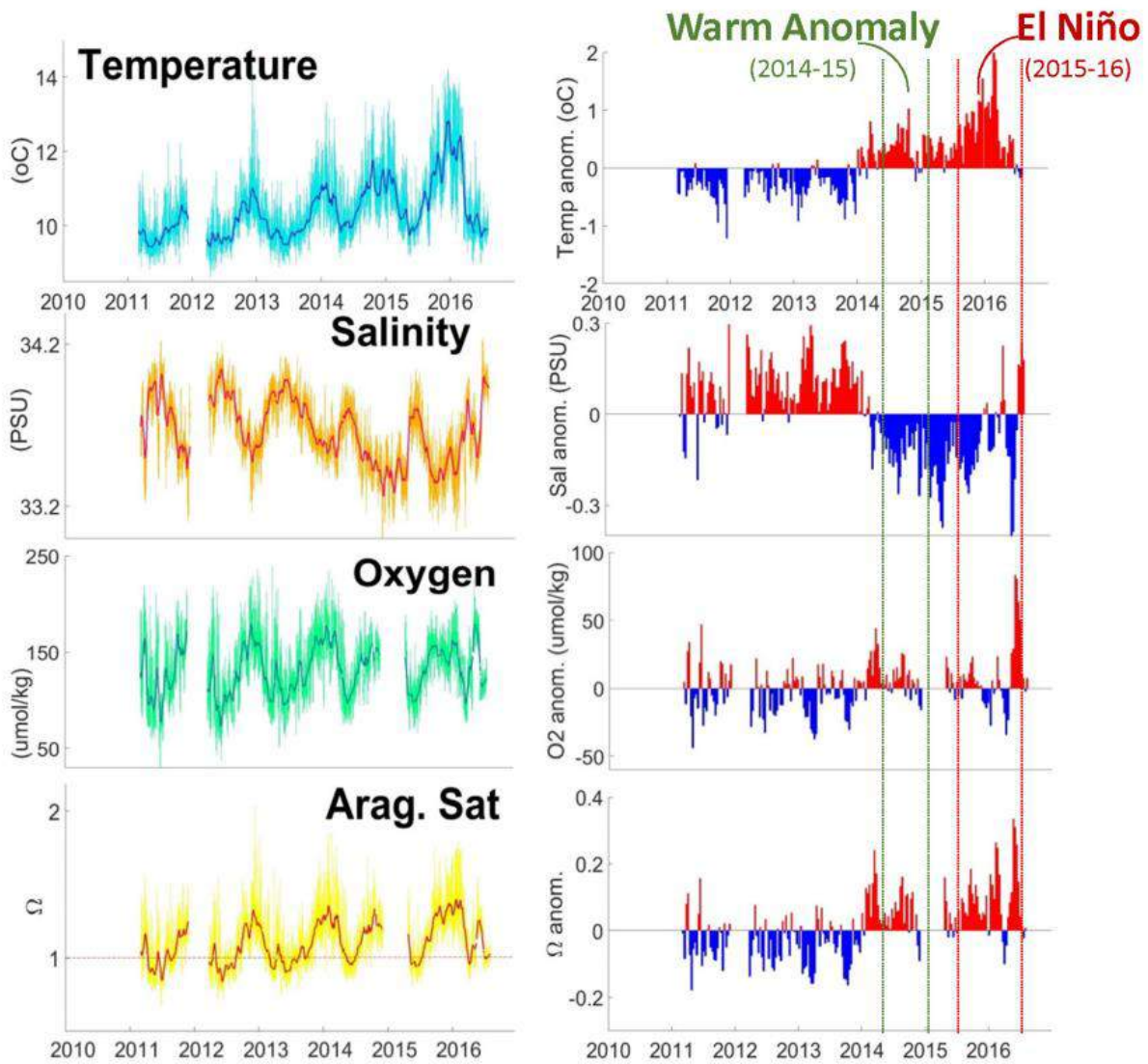


Figure 24: Multi-year record of various quantities at CCE2 at 75m depth (left: absolute values; right: anomalies).

Drought Early Warning for the California and Nevada Region

Principal Investigator(s):

Daniel Cayan, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Amanda Sheffield, Scripps Institution of Oceanography, UC San Diego

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Jordan Goodrich, Scripps Institution of Oceanography, UC San Diego

Sam Iacobellis, Scripps Institution of Oceanography, UC San Diego

Shraddhanand Shukla, UC Santa Barbara

Kelly Redmond, Desert Research Institute

Tamara Wall, Desert Research Institute

Tim Brown, Desert Research Institute

Michael Dettinger, US Geologic Survey

NOAA Primary Contact:

Claudia Nierenberg, Climate Program Office, NOAA Research

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 3: Climate Adaption and Mitigation

Budget Amount:

\$451,895

Amendment(s):

48

Description of Research:

In 2006, Congress passed a law for the development of the National Integrated Drought Information System (NIDIS), in effect a drought early warning system (DEWS) with the goal of mitigating the impacts of drought. Because the

manifestation of drought and the effects of drought vary geographically, NIDIS developed regional approach with the goal that the lessons learned from the regional pilots will be applied in other locations. California was one of the earliest regional DEWS.

Drought in California is complex. After four years of drought throughout California and a water year that delivered a strong geographic polarity in precipitation, the wet season ended with large parts of the drought in Northern California being ameliorated while the drought becoming more severe in Southern California. Through studying physical aspects of drought, including climate indicators and drought-related forecasts, and investigating the complexities of the water networks and stakeholders needs in California, the **California Nevada Applications Program (CNAP)** has taken a leading role in the continued development of the California DEWS. Also, CNAP's climate and decision maker experience, including an ongoing set of stakeholder relationships has assisted in the development of the Nevada DEWS, which is understood to fold into the larger regional DEWS in NV and CA.

CNAP efforts described below have supported the multi-prong approach that NIDIS has develop to include research pertaining to the drought early warning system, drought information research and engagement. This includes research and applications related to seasonal forecasting, regional drought scenario planning, and water supply and drought monitoring including estimations of groundwater pumping in the Central Valley. Engagement has included in-person and webinar drought and climate outlooks led by Amanda Sheffield, timely topical 2-pagers, and other interviews and presentations given by key personnel. The activities have been carried out by key personnel listed above under the direction of CNAP PI Dan Cayan and other senior key personnel.



Dr. Shrad Shukla has been examining the forecast skill of the North American Multi-Model Ensemble (NMME), a

state-of-the-art dynamical forecast system that could help to meet S2S forecasting needs. Sub-seasonal to Seasonal (S2S) forecasts, if they can be demonstrated to be skillful, are needed by California and Nevada stakeholders for making water resource decisions, emergency preparations and public health planning. He has found that the skill over California-Nevada is greatest in short lead time (<2 weeks). And he has found that at the seasonal scale, precipitation forecasts made in early January and February are the most skillful while temperature forecasts in April through June are the most skillful. This information is currently being prepared for publication and has been shared at stakeholder meetings.

CNAP has continued efforts to produce updates on the status of the water supply throughout the region including looking at regional and state precipitation totals, as well as reservoir levels and snowpack. (See an example here: <https://scripps.ucsd.edu/programs/cnap/water-storage-tracking-in-california/>) This drought monitoring effort was invaluable to this year's drought busting.

Dr. Jordan Goodrich is working with USGS colleagues to understand how water use in the California Central Valley is influenced by climate variability, and how climate variability and surface water diversions in the region may relate to ground water usage. Ultimately this work will be used as input to the USGS Central Valley Ground Water Model.

Cayan and Pierce, using a set of downscaled global climate model projections, derived potential scenarios of 20 year California Drought for the 4th California Climate Change Vulnerability and Adaptation Assessment.

In addition to these efforts, CNAP has continued to partner with regional stakeholders on research and activities related to regional drought resiliency efforts. This has included Dr. Kalansky

continued work with Sonoma County Water Agency on the dissemination of the information generated from a workshop on drought mitigation for natural and working lands in the Russian River to help make the area more resilient to future droughts. This effort also considered the amount of precipitation required to end a drought in the Russian River and how best to characterize an end of drought, both in water supply and landscape. Dr. Sheffield has been working with local stakeholders to present drought and climate updates and outlook information throughout the water year to increase the capacity of regional stakeholders for to mitigate the impacts of drought. And Drs. Kalansky and Sheffield have worked with Southern Nevada Water Authority to examine historical trends in regional temperature and precipitation in order to select appropriate global climate models to examine future climate scenarios. This report provides SNWA with a comprehensive look at the climatology and provides information on their susceptibility to conditions that may impact water demand. SNWA anticipates that this climate and drought information will inform their water supply projections and capital projects.

Research Objectives:

- Continued engagement with stakeholders to continue development of the California DEWS and collaboration with the Nevada DEWS
- Continued investigation of NMME forecasts and application to drought indicators
- Stakeholder engagement in the Russian River and Southern Nevada
- Water Supply, Drought Monitoring, and Drought Busting Scenarios
- Near Real Time Ground Water Pumping estimates in the Central Valley

Research Accomplishments:

- Four Drought & Climate Outlooks cohosted with NIDIS
- Launching of Bimonthly Drought & Climate Webinar Series – August 2016 - Present



- Completion of Historical Analysis and Global Climate Model Selection for Southern Nevada with SNWA
- Presentation of NMME forecasts over CA-NV to regional stakeholders in San Diego – February 2017
- Co-host Russian River Workshop on drought mitigation strategies for working and natural lands
- Derivation of potential scenarios of 20 year California Drought for the 4th California Climate Change Vulnerability and Adaptation Assessment.

Conferences, Meetings & Presentations

- a. Sheffield, Amanda M., et al., CA-NV DEWS: Making Drought Science Available, Understandable, and Useable for Decision Making. Climate Prediction Application Sciences Workshop (CPASW), Anchorage, AK, 2-4 May 2017.
- b. Sheffield, Amanda M., Flooding During Drought: Drought Relief in California (Finally). US Drought Monitor Forum, Keystone, SD, 2-4 April 2017.
- c. Sheffield, Amanda M., A. Marrs, T. Wall, D. Cayan, J. Kalansky, K. Redmond, J. Huntington, D. McEvoy, Creating a Regional Drought Early Warning System (DEWS) for California and Nevada: Building Off of Information Gathered and Lessons Learned after 5 Years of Drought. American Geophysical Union Fall Meeting, San Francisco, 12-16 December 2016.
- d. Drs. Cayan, Sheffield, and Kalansky participated in the annual Winter Outlook Workshop hosted by CA Dept of Water Resources and CW3E in November 2016.
- e. Dr. Sheffield participated in the Western States Water Council Seasonal to Sub-seasonal Forecasting Workshop in San Diego in June 2016 and May 2017.
- f. Shukla, Shraddhanand, A. Sheffield, D. Cayan, and J. Kalansky, Seasonal to Sub-Seasonal Skill in NMME Forecasts of Extreme Precipitation and Heat Waves in California and Nevada. AMS Annual Meeting, Seattle, WA.
- g. Kalansky, J.F., Flint, L., Pierce, D., Dettinger M., Cayan D. (2017), Southern California Water: Study Regionally, SoCal Storm Water Forum, hosted by Congresswoman G. Napolitano.
- h. [Kalansky](#), J.F., Cayan, D., Pierce, D., Dettinger, M., Gershunov, S., Iacobellis, S. (2016) California Climate, Past, Present and Future, Association of Environmental Professionals, Sacramento.
- i. Kalansky, J.F (2017), Climate and Drought Outlook (April 2017), NIDIS webinar.
- j. Cayan presented on Possible Climate Change Effects on California Water Resources to Western Water Law Conference, San Diego, February 2017.
- k. Cayan presented on climate variability and changes related to California Drought, Loma Linda University, May 2016.
- l. Cayan presented/participated in “Water in the West”, A Science Policy Roundtable event at The Great Hall, UCSD, 12/8/2017.
- m. Cayan presented a seminar “California’s Sierra Nevada snowpack-odds of normal snowpack will decline” UCLA Department of Civil and Environmental Engineering, March 2017.

Education & Outreach

Communication

- a. New CNAP Program Website with climate and drought tools and handouts:
<https://scripps.ucsd.edu/programs/cnap/>
- b. 2-pager on Seasonal to Sub-Seasonal Forecasting:
Developed with CA Department of Water Resources, the National Weather Service, and the Center for Western Weather and Water Extremes (CW3E)
https://scripps.ucsd.edu/programs/cnap/wp-content/uploads/sites/109/2017/02/CNAP_S2S_TwoPager_FINAL.pdf
- c. Public Policy Institute of California Report- California’s Water: Climate Change and Water



Dan Cayan served as a co-author and regional expert on the above PPIC publication.

<http://www.ppic.org/main/publication.asp?i=1131>

- d. Continued Precipitation Tracking with KPBS
CNAP continued to support a precipitation and snowpack tracker developed with KPBS.
<http://www.kpbs.org/news/drought-tracker/>

Networking

- a. Co-Hosted with NIDIS, Four Drought & Climate Outlooks:
- Riverside, CA
<https://www.drought.gov/drought/calendar/events/ca-nv-drought-early-warning-system-southern-california-drought-outlook>
 - Seaside, CA
<https://www.drought.gov/drought/calendar/events/north-central-coast-drought-climate-outlook-oct-11>
 - Fresno, CA
<https://www.drought.gov/drought/calendar/events/central-valley-drought-climate-outlook-oct-12>
 - San Diego, CA
<https://www.drought.gov/drought/calendar/events/ca-nv-dews-southern-california-winter-status-update-feb-9>

These meetings focused on past, present and/or expected drought impacts, and offered an opportunity for stakeholders to interact with other decision makers and information providers in the region. The event had three purposes:

1. Provide an update on current and forecasted drought & climate conditions
2. Showcase current research and tools available to stakeholders to support drought early warning
3. Gather feedback from stakeholders on current needs for the CA-NV Drought Early Warning System to help inform the development of the CA-NV DEWS Strategic Plan

- b. Co-Hosting with NIDIS Bimonthly Drought & Climate Outlook Webinar:

The California-Nevada Drought Early Warning System (CA-NV DEWS) Drought & Climate Outlook Webinars are part of a series of regular drought and climate outlook webinars designed to provide stakeholders and other interested parties in the region with timely information on current drought status and impacts, as well as a preview of current and developing climatic events (i.e. El Niño and La Niña). The webinar takes place on the 4th Monday every two months. Example:
<https://www.drought.gov/drought/calendar/events/california-nevada-drought-climate-outlook-webinar-may-30>



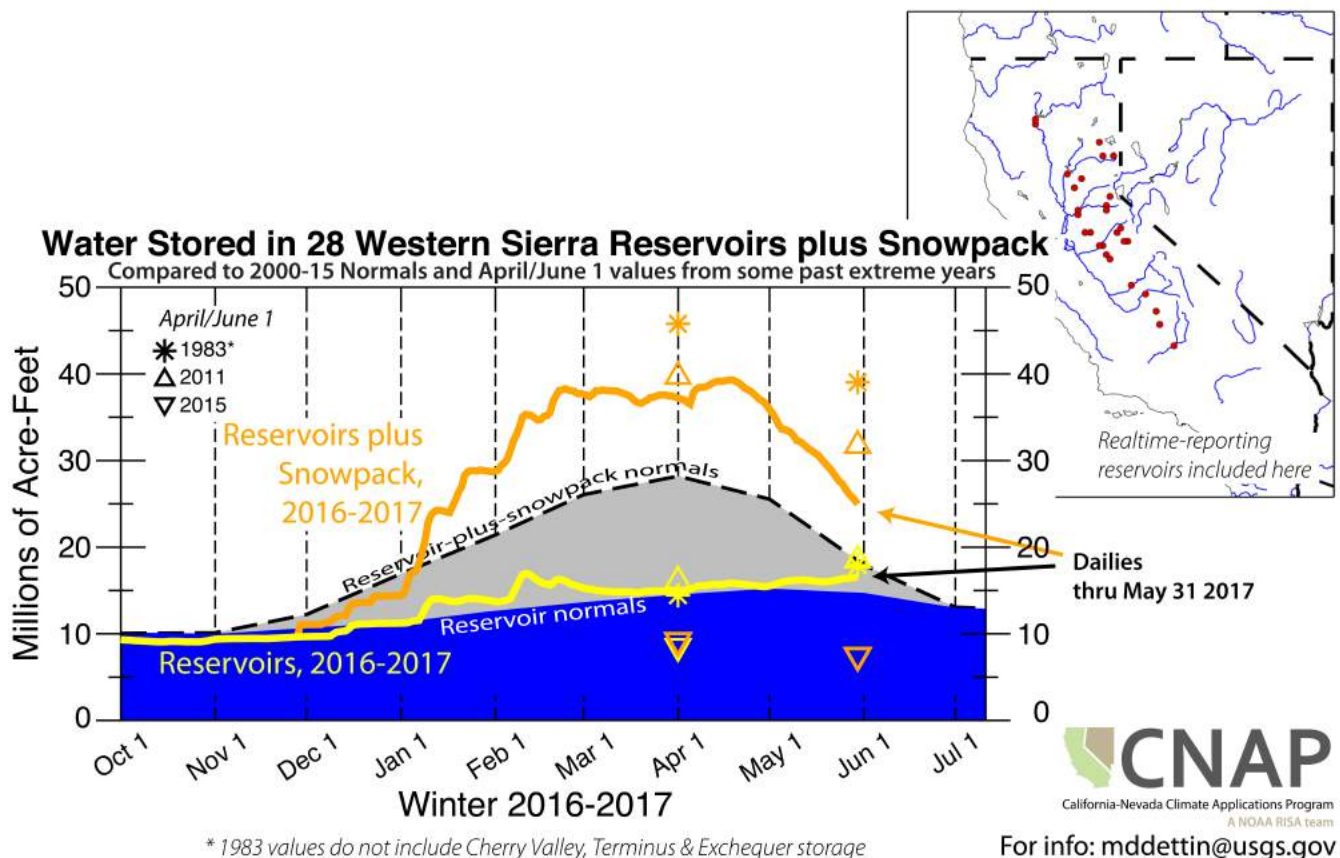
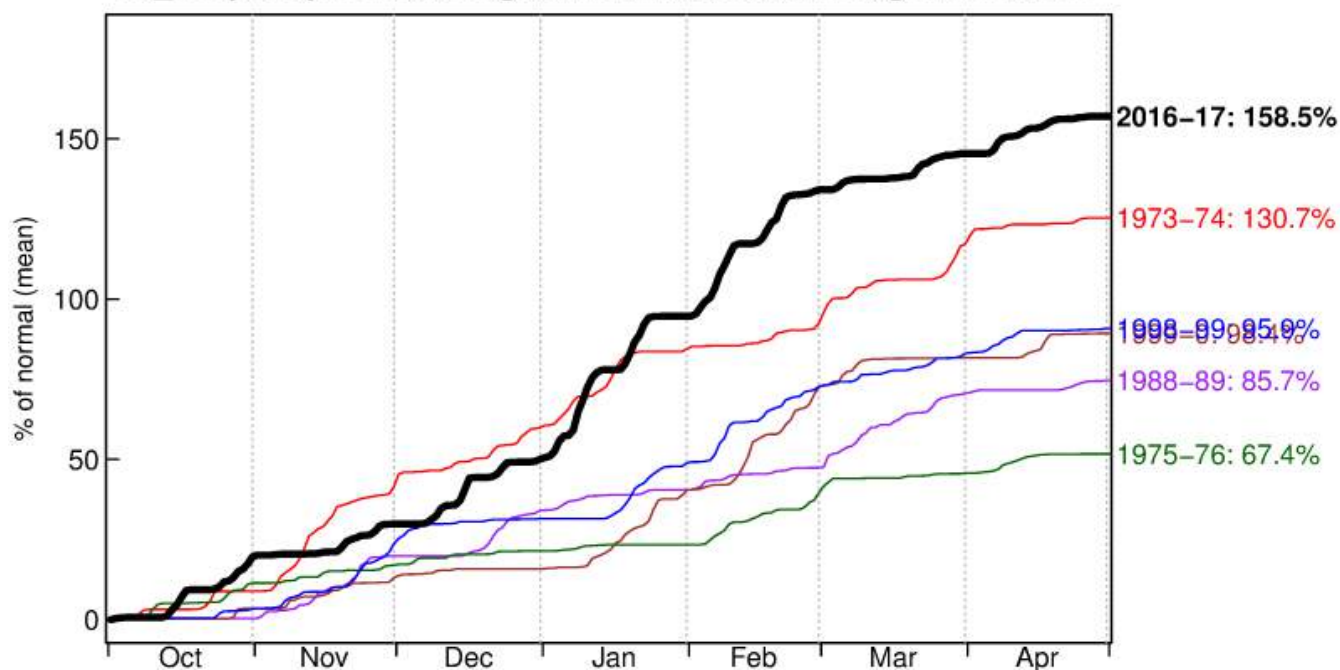


Figure 25: Mike Dettinger tracks water storage in the Sierra Nevada, in real time, by combining daily storage updates from 28 reservoirs (red dots on the map to the right) with snow-pack totals for the Sierra. Understanding the combination of storage in snow-pack and reservoir is important, because snow-pack acts as a natural reservoir in CA that holds water during the cooler months and releases it in the warmer drier months. Monitoring the timing of changes in the snow-pack and reservoir levels provides not only a more holistic water supply understanding, but also provides information on how droughts, storms, management, and climate change impact water availability in CA. During drought years (like 2015, indicated by downward-pointing triangles at April 1), reservoirs and (especially) snowpacks are much reduced, and getting through the summer irrigation seasons is a major challenge. In wet years, like 1983 (starburst), 2011 (upward-pointing arrow), and this year (curves), average storage totals are rapidly exceeded, and management of reservoirs and rivers to avoid flooding becomes the real challenge. In the figure, the blue shaded region is the average reservoir storage of the 28 reservoirs from 2000-2015 and the grey is the average snow-pack over the same time period. The yellow curve is the current reservoir storage and the orange line is the current sum of reservoir plus snow-pack storage.

Source: <https://scripps.ucsd.edu/programs/cnap/water-storage-tracking-in-california/>



all_CA precip vs. 5 strongest La Ninas, data through 2017/06/07



all_CA precip for all years, data through 2017/06/07

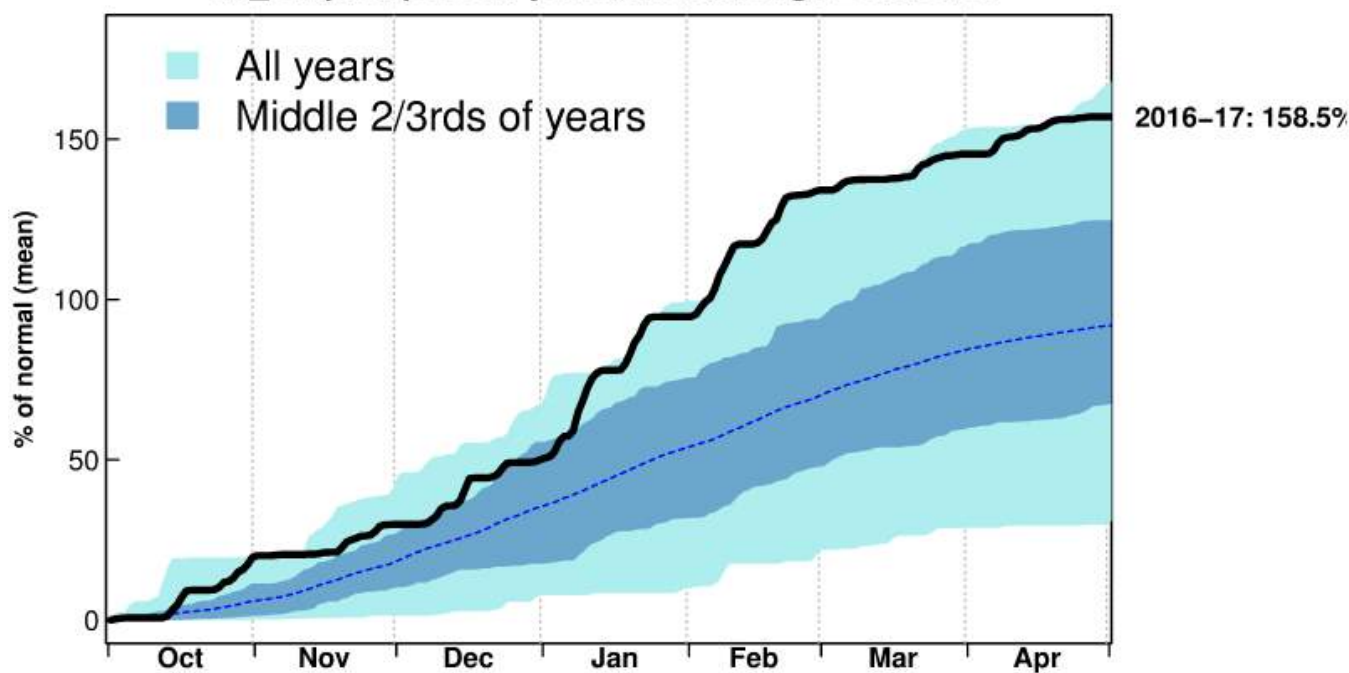


Figure 26: This figure shows the accumulated water year-to-date precipitation for all of California. Water years start on October 1st and extend through the following September 30th and are numbered by the year of the January of the water year. For example, the period October 1, 2015 to September 30, 2016 is water year "2016", since the January in that period is January 2016. Values are shown as a percent of normal (mean) accumulation found on the *last* day of the water year. So, values always start at zero on October 1st and increase gradually over the year (never declining). For example, if the "Current" value is 15% and the "1-day delta" (change) is 1.0%, that means that currently we have accumulated 15% of the total precipitation we usually accumulate over an entire water year, and that yesterday that number was 14%. For a normal year, the "Current" value will end up at 100% at the end of the water year. A dry year will end up below 100%, and a wet year will end above 100%. Source: <http://cirrus.ucsd.edu/~pierce/sdprecip/>



Interplay of marine layer clouds and heat waves along the California coast: Impacts on human health

Principal Investigator(s):

Alexander Gershunov, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Kristen Guirguis, Scripps Institution of Oceanography, UC San Diego

Rupa Basu, California Environmental Protection Agency, Oakland

Rachel Clemesha, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Adrienne Antoine, Climate Program Office, NOAA Research

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 2: Weather-Ready Nation

Goal 3: Climate Adaption and Mitigation

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$278,815

Award:

NA15OAR4310114

Research Objectives:

The health of California residents and visitors is most vulnerable to heat waves along the highly populated and poorly acclimated coast. Heat wave activity is on the rise and is projected to increase in the future, particularly at the coast. The presence or absence of marine layer clouds (MLC) makes an essential difference to whether a heat wave impacts human health along the coast. A persistent MLC cover, most prominent during the peak of summer, contributes to the lack of coastal acclimation to heat. Some inland heat

waves are associated with a stronger and more extensive marine layer, while others are not. The absence of MLC aggravates coastal heat impacts. We aim to quantify and clarify the statistical relationships and physics that control this MLC response and improve the understanding of heat waves and their impacts in California, particularly along the coast. We will define heat waves as health-impactful events a priori by using hospitalizations data alongside temperature. We will adjust these definitions for specific demographic and at-risk groups and translate them into local temperature thresholds. Global climate models will be validated with their ability to simulate regional heat waves and used, in conjunction with improved statistical downscaling to assess the risk of future heat waves in inland and coastal California. Health risks of future heat waves will be assessed and results will be used to improve California's resiliency to current and future heat waves.

Description of Research:

A. Defining Heat Waves

Before we begin analyzing heat extremes, a look at the seasonal cycle in daytime maximum temperature (Tmax) provides insights into the varying summer climates of California and the best method for defining heat waves. As examples here, we highlight two population centers of the Bay Area, San Francisco and Sacramento, using COOP weather stations. We have also analyzed two gridded data sets of Tmax [Maurer et al. 2002 and Livneh et al. 2013] and classified heat waves using the six California heat waves regions defined by Gershunov and Guirguis [2012]. In Sacramento, Tmax peaks in late July/early August at around 34.4°C, an increase of about 9.5°C from May. On the other hand, San Francisco exhibits a much smaller and shifted seasonal cycle only increasing about 5.3 °C from May to the late September peak of 22.4°C.

Heat waves can be defined as temperature Peaks Over a high Threshold (POT), e.g. 95th percentile.



Due to geographic variation in the seasonal cycle of temperature, inland and coastal heat waves tend to occur at different parts of the warm season. For example, if the threshold is applied to raw Tmax, the majority of heat waves occur in July in Sacramento and in September in San Francisco. Thus, in the presence of the seasonal cycle, the POT definition does not always detect coastal and inland expressions of the same heat waves. A solution is to remove the seasonal cycle from local Tmax, and calculate the 95th percentile on the anomalies. We model the seasonal cycle by fitting double (annual and semiannual) harmonics to local daily Tmax. We then subtract the fitted seasonal cycle from daily Tmax. Working with Tmax anomalies increases the power of POT methodology to detect inland and coastal expressions of the same heat waves. Note, there is still a seasonal cycle in the occurrence of heat waves now shifted toward shoulder months due to the seasonal cycle of variance, which is not removed and is weakest in summer. In the following, the heat wave index is defined as Tmax excess over the local May – September 95th percentile of de-seasonalized Tmax anomalies.

B. Extended Principal Component Analysis

Principal component analysis (PCA) and extended PCA (EPCA) were carried out on the heat wave index over California for ~ 1950 to 2015 (range depends on which of three data-sets were used). Since only positive heat wave index values are logically interpreted varimax rotation was used. Extended PCA allows for the analysis of the space-time progression of a variable, by performing standard PCA on an aggregate of lagged variables. That is, the heat wave index matrix of time X space is arranged to have additional space columns which are the original ($t + 0$) data at the following days ($t + 1$, $t + 2$ etc.).

C. GCM Evaluation of Heat Waves

Dettinger et al.

(<http://www.water.ca.gov/climatechange/cctag.cfm>) have screened about 40 global climate models (GCMs) on the basis of their performance, relative to observations, in representing salient historical global and regional climatological patterns and

synoptic or meteorological patterns associated with regional extremes in the Southwest United States. They identified ten GCMs that were superior at representing climatological patterns of temperature, precipitation, and the dominant natural modes of climate variability, such as El Niño and La Niña, and their relations with regional precipitation and temperature, i.e. teleconnections.

We have further screened these ten global climate models (ACCESS1-0, CanESM2, CCSM4, CESM1-BGC, CMCC-CMS, CNRM-CM5, GFDL-CM3, HadGEM2-CC, HadCEM2-ES, MIROC5) on the basis of regional heat waves. We have compared synoptic conditions seen in the models during heat waves in the Southwest US with those seen during historical observed heat waves identified using NCEP Reanalysis. Specifically, we used point correlation analysis between sea level pressure and a regional heat wave index defined as degree days over the 95th percentile for the Southwest region. While the observations clearly show a difference between synoptic conditions yielding daytime heat waves (measured by daily maximum temperatures, Tmax) versus nighttime heatwaves (measured by daily minimum temperatures, Tmin), most models do not capture this difference. The observations show daytime heatwaves as resulting from northeasterly flow from the continental interior while nighttime heatwaves are due to southwesterly flow from the Gulf of Mexico region. This is logical since nighttime events would be more humid owing to the influx of marine moisture from the Gulf. In general, the models simulate nighttime events well. However, most models (seven of ten) do not adequately represent the synoptic conditions associated with daytime heat waves. We found three models (CNRM, CMCC-CMS, and MIROC5) to be superior at representing the observed synoptic conditions associated with heat waves in the Southwest, and these were uniquely able simulate both types of heat waves relatively well.

D. Health

We have obtained the most recent patient discharge (PD) data from Office of Statewide



Health Planning and Development for years spanning 1999-2013 and have begun analysis for San Diego County, California. For three regions of San Diego County (coastal, inland, and desert) we have identified heat waves that were harmful to health using the bootstrapping methodology described in Guirguis et al. 2014. First, we define warm episodes for each region of San Diego County. By our definition, a warm episode is a string of consecutive days where temperatures remained above the 80th percentile. Within these warm episodes temperatures will rise, peak, and then fall back to normal. Differences between episodes are measured by various statistics such as duration, peak maximum temperature, peak minimum temperature, number of days from start to peak, how hot the peak was relative to the rest of the summer so far, etc. The health impact is calculated as cumulative, unscheduled hospitalizations during the warm spell. Each cumulative value is compared to all other time periods in the record spanning the same duration and a significant impact is said to occur if the cumulative count is above the 90th percentile. Relative Risk (incidence in exposed versus incidence in non-exposed) is calculated for all impactful events to estimate the relative health risk during the impactful heat events. For coastal San Diego there were 82 warm episodes and 15 of these were impactful. On average, the impactful events saw an increase in hospitalizations of about 12%. Peak maximum temperatures were about 3 degrees F higher for the impactful events compared with the non-impactful ones. Additionally, the impactful events were more likely to occur in September, possibly due to Santa Ana winds. The peak temperatures for the impactful events were often among the hottest of the contemporaneous summer at the time they occurred, and the average summer temperature at the start date was, on average, slightly cooler. Therefore, these early findings suggest that the most harmful events for coastal San Diego are those that occur late in the summer, where the summer has been a little cooler than average, and which has not yet seen an extremely hot event.

Significant Deviations from Proposed Workplan

Although we have been experimenting with reconstructing CLC at the daily timescale back to 1948, we find this to be a very challenging activity given the poor reconstruction skill and saddle-type distribution of daily CLC. We are trying to get around these challenges by exploring creative ways to parameterize the daily CLC diurnal cycle and achieve a value-added product and possibly a more skillful reconstruction. The same methodology later applied to GCM projections would also result, we hope, in a more meaningful CLC downscaling product. Since even monthly information on past and future CLC is not available, we have also experimented with reconstructions on the monthly timescale that would lead to valuable projections. One question that could be addressed on the monthly timescale concerns possible changes in the seasonality of CLC given the robustly projected poleward extension of the subtropical subsidence zone and other less certain but relevant climatic changes in the coastal zone. Thus, the only significant deviation from our proposed work plan resulting from these challenges, is leading to a delay and possible adjustments in our work plan concerning CLC projections. For this reason, we are planning to request a no-cost extension of our project for an additional year.

Research Accomplishments:

A. Modulation of heat waves by low clouds

Together with our partners and regional decision makers at the National Weather Service (NOAA), Alex Tardy and Ivory Small, we recently submitted our research findings for journal publication: Clemesha, R. E. S., K. Guriguis, A. Gershunov, I. J. Small, and A. Tardy, California heat waves: their spatial evolution, variation, and coastal modulation by low clouds, *Climate Dynamics*. Below we summarize these findings.

California is home to several diverse climate regions and important regional detail of extreme events may be lost if the whole state is considered on average. In this research, we focus on the comparison and interaction of heat wave expressions at the coast and inland, while



considering one of the key modulating factors of summertime coastal climate - coastal low cloudiness (CLC). We examine the California regions of the North Coast, South Coast, Central Valley, and Southern Deserts as defined by (Gershunov and Guirguis, 2012). We focus on the unseasonably warm events, which often cluster in the shoulder seasons, and may also result in significant human health impacts.

The observations indicate that characteristics of extreme heat events are variable throughout California. Heat wave events tend to be shorter, but more anomalously intense along the coast. These features of coastal heat waves may have competing effects on the health of coastal residents. Furthermore, our work examined the spatial and temporal movement of individual heat wave events. This event-centered framework uncovered features of California heat waves, such as their inland progression, that would be lost if examined in an aggregate method. That is, for heat wave events with a strong impact across regions, the coast feels the initial effects first, as well as the end of the extreme weather before inland areas. Thus, the timing of inland heat impacts can be gauged by monitoring the eastward progression of heat waves and the shifting axis of the upper ridge. Conversely, forecasting the beginning of coastal heat waves is a greater operational challenge since the impacts are felt at the coast first.

Our analyses also uncover the progression and variability of coastal low cloudiness during heat wave events. The beginning of coastal heat waves is associated with a loss of CLC, followed by a strong rebound of CLC starting close to the peak in heat wave intensity. While it is clear at the coast during coastal heat wave onset, our work identified some important factors influencing heat and cloudiness at the coast during cases of inland heat waves. The degree to which an inland heat wave is expressed at the coast is associated with the presence of low clouds. This suggests that CLC is an important modulating factor controlling the expression and impacts of extreme heat at the coast. This relationship is

especially true for the South Coast during Central Valley heat waves. In agreement, with our previous findings (Clemesha et al. 2017) that daily CLC variability is positively related to $T_{max} \sim 650 - 800\text{km}$ to the north, there are cases when the South Coast stays persistently cloudy and protected from extreme heat while a heat wave impacts the Central Valley.

We demonstrate that during inland heat waves, the height of the inversion base (ZBASE), which caps the marine boundary layer, is a key factor determining coastal cloudiness, and thus, coastal heat expressions. During inland heat waves the coastal inversion strength (DT), tends to be stronger than during average non-heat wave conditions, but the strength has less influence on CLC during inland heat waves than ZBASE (Figure 27).

Since there are past cases when the inversion is strong but elevated and maintenance of coastal cloudiness buffers the coast from extreme, long term trends in inversion characteristics may cause changes to CLC and thus, coastal heat waves. Although determining the future of ZBASE is more challenging, our results suggest that inversion height is more critical than strength in determining CLC for the coastal terrestrial swath, where large populations reside. Future changes in CLC will have impacts on mean climate and may also change the coastal expression of extreme heat events. We also show that heat wave events typically impact both coastal and inland regions, although there is more propensity towards coastally trapped events than inland trapped events. Through uncovering the evolution and variability of coastal and inland heat waves in the observational record, this work paves the way for validating the ability of global climate models to accurately simulate the evolution of heat waves and to assess the risk of future heat waves in inland and coastal California.

B. Heat waves and health outcomes

On the health side, we are working with the most recent patient discharge (PD) data from Office of Statewide Health Planning and Development for years spanning 1999-2013 focusing our analysis on San Diego County. For three regions of San



Diego County (coastal, inland, and desert) we have identified health-risk temperature thresholds based on unscheduled hospitalizations for heat illness. These results show coastal San Diegans to be more sensitive to heat than inland residents, consistent with expectations due to acclimation to cooler temperatures there. We also found heightened heat sensitivity in zip codes where fewer residents have central air conditioning.

Additionally, we looked at in air conditioning access in the County found notable disparities related to income level, race/ethnicity, and home ownership. We presented these results in a poster and an oral presentation at UCSD's Public Health Research Day in April and are currently writing up the results for publication.

Measuring Impact on Decision-Making

As we have previously mentioned, our collaboration with the National Weather Service meteorologists, particularly with Warnings Coordination Meteorologist, Mr. Alex Tardy, has resulted in a new experimental online heat warnings tool. Recently, the NWS has released this previously experimental tool to the public (<https://www.wrh.noaa.gov/wrh/heatrisk/>). The HeatRisk tool is based on research results, specifically the co-produced research of Guirguis et al. (2014). HeatRisk is already providing public benefit and we expect it to become broadly used, particularly, as we approach the warm season. Our collaboration with the NWS continues and future improvements to HeatRisk are already being discussed with respect to addressing disparities and vulnerable populations.

Deliverables Produced

Together with our partners and regional decision makers at the National Weather Service (NOAA), Alex Tardy and Ivory Small, we submitted our research findings for journal publication: Clemesha, R. E. S., K. Guriguiz, A. Gershunov, I. J. Small, and A. Tardy, California heat waves: their spatial evolution, variation, and coastal modulation by low clouds, *Climate Dynamics*. The findings of this paper are summarized in the "Research Findings" section of this report. -- We

completed a research study focusing on the implications of a changing climate on extreme temperature probabilities in the Southwest US and submitted the results to the journal *Climate Dynamics* in a paper entitled "Heat wave probability in the changing climate of the Southwest US". This paper provides analyses of observed non-Gaussian daily minimum and maximum temperature probability distribution functions (PDFs) in the Southwest US to highlight the importance of variance and warm tail length in determining future heat wave probability. Even if no PDF shape change occurs with climate change, locations with shorter warm tails and/or smaller variance will see a greater increase in heat wave probability, defined as exceedances above the historical 95th percentile threshold, than will long tailed/larger variance distributions. Projections from ten downscaled CMIP5 models show important geospatial differences in the amount of warming expected for a location. However, changes in heat wave probability do not directly follow changes in background warming. Projected changes in heat wave probability are largely explained by a rigid shift of the daily temperature distribution. In some locations where there is more warming, future heat wave probability is buffered somewhat by longer warm tails. In other parts of the Southwest where there is less warming, heat wave probability is relatively enhanced because of shorter tailed PDFs. Effects of PDF shape changes are generally small by comparison to those from a rigid shift, and fall within the range of uncertainty among models in the amount of warming expected by the end of the century.

We kicked off a collaborative effort with local ecologists to conduct a vulnerability assessment for San Diego County with the goal that it will be incorporated into California's Fourth Climate Assessment. Our first workshop took place on September 22, 2016 and we have since had two follow-up workshops and have begun drafting the introductory chapters for the Assessment. Our chapters will focus on the impacts and influences of 1) fog and low clouds and 2) temperature and temperature extremes on biodiversity in San



Diego. For example, fog and low clouds, which we quantify using airport and satellite observations, are an important driver of species demographics along the coast and increases woody species seedling survival.

We have prepared outreach documents for conservation resource managers in the Southwestern US for communication through the Southwest Climate and Environmental Information Collaborative (SCENIC, <http://www.wrcc.dri.edu/csc/scenic/>) in the form of two short reports describing the implications of climate change on (1) heat wave probability in the Southwest US and (2) the thermal tolerance of the California Spotted Owl in the Central Sierras.

Conferences, Meetings & Presentations

- a. "A Heat Warning System to Reduce Heat Illness in San Diego County", American Geophysical Union, December 15, 2016 (presented by Alex Tardy of the National Weather Service with Guirguis and Gershunov as co-authors).
- b. San Diego County: The Ecological Impacts of Climate Change on a Biodiversity Hotspot", California Climate Symposium, January 15, 2017 (presented by Julie Kalanski with Clemesha, Gershunov, and Guirguis as co-authors)
- c. "Interplay of marine layer clouds and heat waves along the California coast", March 3, 2017, Project Stakeholder Research Meeting with National Weather Service, Scripps Institution of Oceanography, San Diego (Clemesha presented)
- d. "Heat Waves, Human Health, & Disparities in San Diego County", April 5, 2017, Public Health Research Day, UCSD Institute of Public Health (Gershunov presented keynote oral presentation and Guirguis presented poster)
- e. 2016 and used by Clemesha et al. 2017 is publicly available.
- b. Guirguis presented research on climate change and health with a focus on vulnerable populations in San Diego County, and served on the discussion panel for the Climate Education Partners health- focused presentation and tour held at 2-11 San Diego on January 9, 2017.
- c. Clemesha organized a meeting with key personnel, including the Warning Coordination Meteorologist, at the San Diego National Weather Service (NWS). Clemesha presented her research on marine layer clouds and heat waves and the group discussed future collaborations including a peer reviewed publication and presenting this work to the broader NWS audience. Clemesha, Gershunov, and Guirguis participated. March 3, 2017
- d. Gershunov presented "Weather extremes in a varying and changing climate" to stakeholders from the water resource, ecology and public health sectors. UCLA, April 13, 2017
- e. Clemesha volunteered at public outreach event, the Balboa Park Earth Fair in San Diego April 23, 2017.
- f. Guirguis met with San Diego Department of Public Health to discuss topics of climate change and health with the goal of identifying future efforts of collaboration. April 25, 2017

Education & Outreach

Communication

- a. <http://tenaya.ucsd.edu/~rclemesha/data.html>
The GOES derived Coastal Low Cloudiness (CLC) record as described by Clemesha et al.



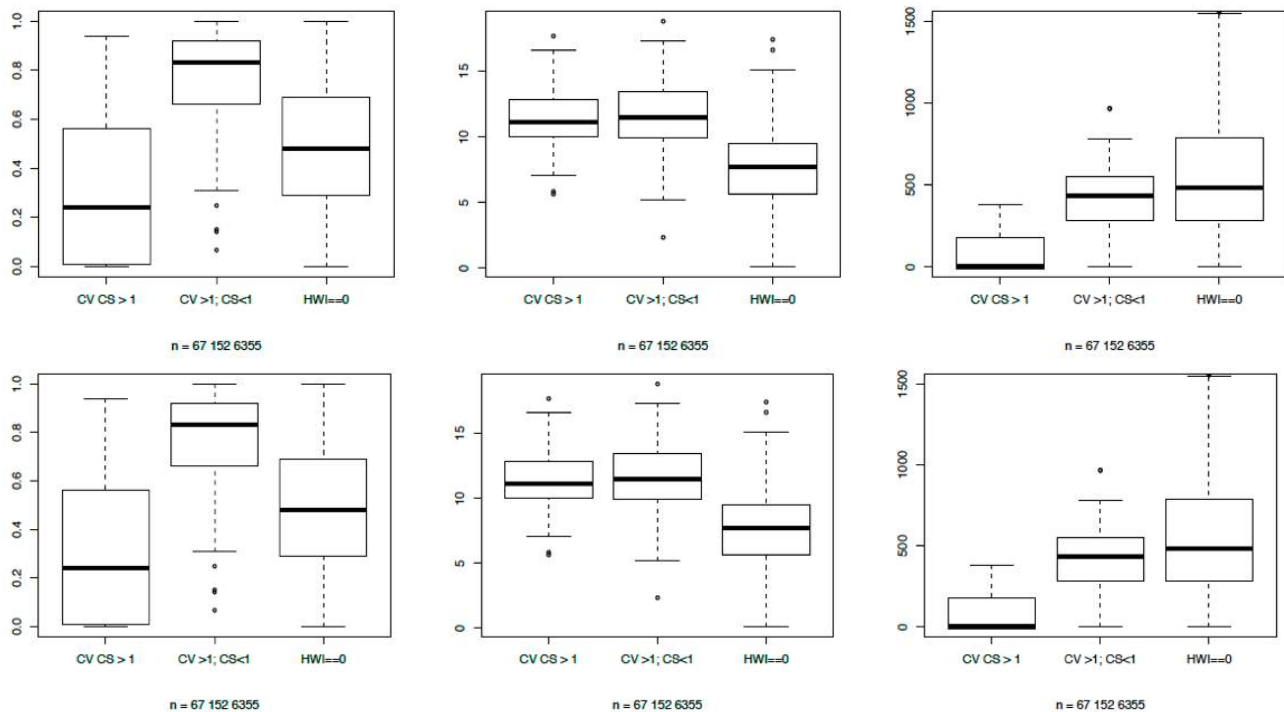


Figure 27: Box plots during three classes, left box: “coastal and inland heat wave” (HWI > 1 at both regions), middle box: “inland only heat wave day” (inland HWI > 1; coastal HWI < 1) and right box: “non-heat wave” (HWI = 0 at both regions). The coastal region is Coastal South (CS). The inland region is (top) Central Valley (CV) and (bottom) Southern Deserts (SD). For (left) CLC, (middle) DT, and (right) ZBASE under 1500 meters above ground level. Median, quartiles, and 1.5 times



Early start to begin development of an atmospheric river-focused CDR in support of regional stakeholder needs and scientific interests

Principal Investigator(s):

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

Other Key Personnel:

Alexander Gershunov, Scripps Institution of Oceanography, US San Diego

Tamara Shulgina, Scripps Institution of Oceanography, US San Diego

NOAA Primary Contact:

Hilawe Semunegus, National Environmental Satellite, Data & Information Service (NESDIS)

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 2: Weather-Ready Nation

Goal 3: Climate Adaption and Mitigation

Budget Amount:

\$60,000

Amendment(s):

14

Description of Research:

A new automated method for detection of Atmospheric Rivers (ARs) making landfall at the west coast of North America has been developed. This method has been applied to 6-hourly IVT and IWV data in the NCEP-NCAR reanalysis to create a catalog of ARs land-falling upon the North American west coast (SIO R1) which currently includes 69 full years (1948-2016) plus the winter of 2017. We have validated SIO-R1 against an established shorter and less extensive catalog (RNW) based on satellite-retrieved IWV data and independent finely resolved daily precipitation record (Livneh et al. 2013). The SIO-R1 catalog yielded stronger seasonality of AR landfalls that

are clearly associated with heavy precipitation over the coastal ranges and to some extent over the inland topography of the mountainous West. The new AR detection methodology was applied for NOAA-CIRES 20th Century reanalysis data, which was used to successfully validate the SIO-R1 with respect to possible discontinuities associated with the start of the satellite era; no broadly systematic discontinuities in the SIO-R1 were detected.

The study of the SIO-R1 record shows the seasonal migration of peak AR activity from the Gulf of Alaska in the late summer – early fall, when AR landfalls are most frequent, to northern California in late fall – early winter. Climatological AR intensity does not closely follow AR frequency; intensity peaks in December in far Northern California where ARs are the prominent cause of flooding (Ralph et al. 2006). We also see infrequent yet sustained AR landfalls over Baja California and Southern California that appear to be largely IVT/wind-driven in winter and IWV/moisture-driven (with apparent tropical storm-related moisture origins) in late summer with a distinctive lull during the May and June peak of coastal low cloudiness in that region (Clemesha et al. 2016). We have examined the updated 70-winter (JFM) record for links between AR-related (as well as the seasonal total) IVT at the North American west coast and Pacific climate variability expressed in sea surface temperatures. Leading patterns that emerged indicate that land-falling AR activity is sensitive to modes of climate variability expressed in SST. These modes include most notably the PDO and associated eastern Pacific SST. They also include the northeastern Pacific warm “blob”, described by Bond et al. (2015), suggesting a consistent role for ARs in the recent California drought. Moreover, a long-term trend expressed broadly in stronger winter AR activity over the U.S. and Canadian west coast (weaker over Mexico) is associated with long-term



warming of the western tropical Pacific; the latter SST trend has previously been identified in multiple observational data sets and explained by anthropogenic forcing (Wang et al. 2015).

Research Objectives:

- Developing a method for AR detection;
- Creating the Reanalysis-based catalog of ARs land-falling upon the North American west coast.
- Validating the catalog against satellite-based AR catalog and historic reanalysis.
- Studying the monthly climatology AR activity and examining the linkage between AR-related (as well as the seasonal total) IVT at the North American west coast and Pacific climate variability expressed in sea surface temperatures.

In particular, we have examined the updated 70-winter (JFM) record for links between AR-related (as well as the seasonal total) IVT at the North American west coast and Pacific climate variability expressed in sea surface temperatures. Leading patterns that emerged indicate that land-falling AR activity is sensitive to modes of climate variability expressed in SST. These modes include most notably the PDO and associated eastern Pacific SST. They also include the northeastern Pacific warm “blob”, described by Bond et al. (2015), suggesting a consistent role for ARs in the recent California drought. Moreover, a long-term trend expressed broadly in stronger winter AR activity over the U.S. and Canadian west coast (weaker over Mexico) is associated with long-term warming of the western tropical Pacific; the latter SST trend has previously been identified in multiple observational data sets and explained by anthropogenic forcing (Wang et al. 2015).

Research Accomplishments:

- The monthly climatology AR activity in terms of AR frequency and intensity has been studied.
- The updated 70-winter (JFM) record for links between AR-related (as well as the seasonal total) IVT at the North American west coast and Pacific climate variability expressed in sea surface temperatures has been examined.

Conferences, Meetings & Presentations

- a. Dr. Alexander Gershunov presented the results on atmospheric river variability at west coast of North America at the International Atmospheric River Conference in August 2016.
- b. Dr. Alexander Gershunov presented the results on atmospheric rivers and historic California floods using the AR catalog at AGU 2016 in December 2016.

Education & Outreach

Networking

- a. F. M. Ralph and A. Gershunov organized and participated in a AR detection meeting at Scripps Institution of Oceanography in May 2012, which brought together 24 researchers from all over the world. Organizations included NCAR, NOAA, LBL, PNNL, NASA-JPL, University of Lisbon, University of Michigan, UCLA, UC Davis, ECMWF, Colorado State, U. Illinois, UC Irvine, University of Washington and University of Aviero
- b. Ralph, Gershunov and Shulgina have all participated in regular scheduled AR detection meetings with Scripps researchers, NASA-JPL and NWS to begin to develop a catalogue of ARs using different detection algorithms.



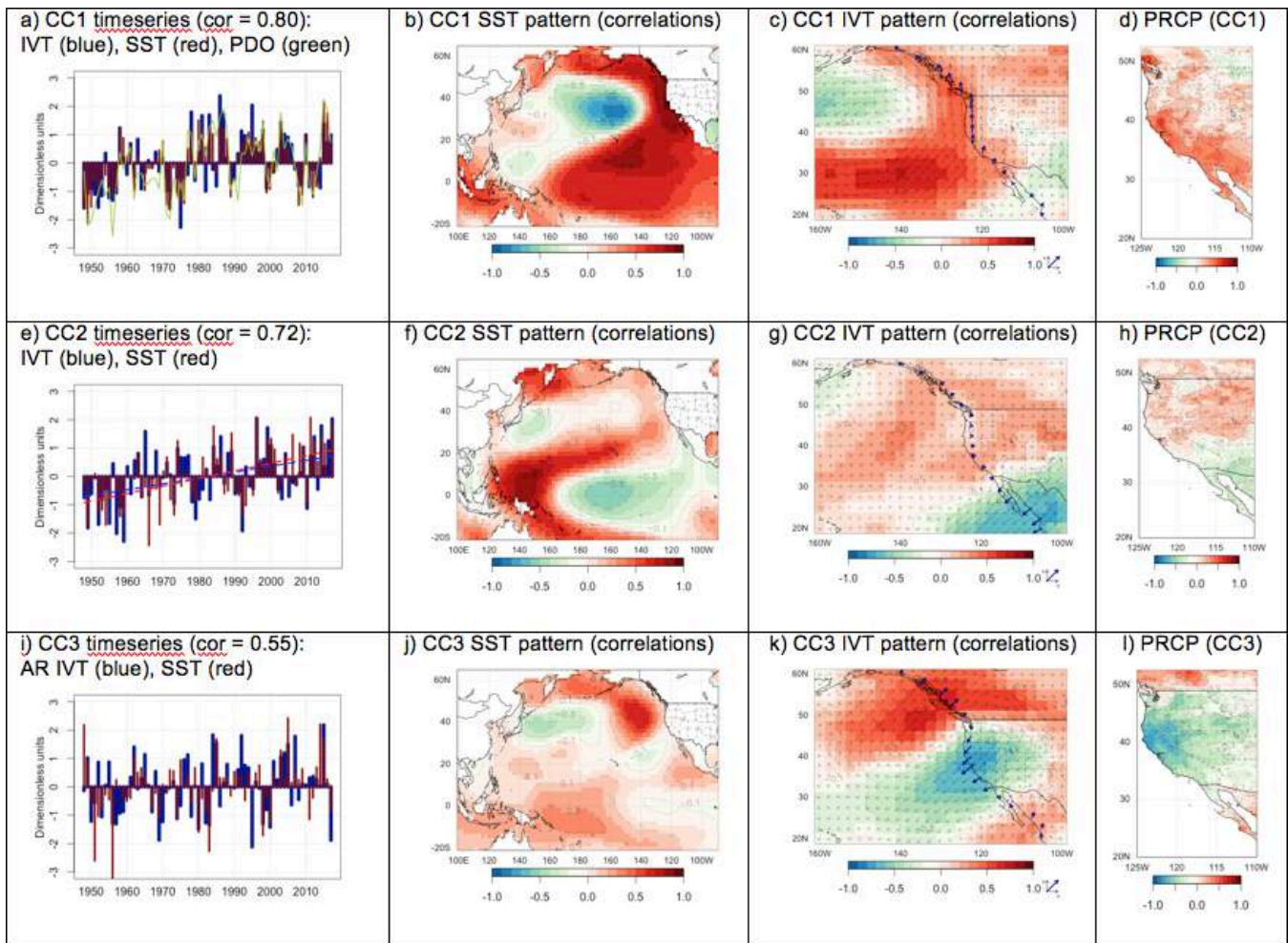


Figure 28: Leading canonical correlates (time series, panel a) and their associated spatial patterns expressed as correlations between the time series and their respective fields of variables: SST (b) during the January – March, JFM, season and seasonally summed AR-associated IVT (c). Correlations between the IVT time series (a, blue bars) and AR-associated precipitation (d). The middle row shows the second leading coupled mode (e-h) while the bottom row shows the third leading mode (i-l). The analysis was done on AR-related vector IVT confined to the coastal zone grid cells and expressed as correlations with the entire domain of AR-related IVT, both u and v components (arrows) and magnitude (colors), while the coastal grids that comprised the analysis domain are marked with thick arrows (c, g, k). AR-associated JRM precipitation (PRCP) correlated with the corresponding modal IVT time series shown in panels (d, h, l). Note that PRCP data span a shorter period (1950-2013) compared to SST and IVT data (1948-2017). The green curve on panel (a) represents the time evolution of the JFM PDO (<http://research.jisao.washington.edu/pdo/PDO.latest.txt>), which is correlated with CC1_{SST} at $r=0.86$. The least squares-fitted trends on panel (e) are significant with p-values < 0.0005.

Coping with Drought in the Russian River Watershed

Principal Investigator(s):

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

Other Key Personnel:

Julie Kalansky, Scripps Institution of Oceanography, UC San Diego

Lorraine Flint, US Geological Survey

Michael Dettinger, US Geological Survey

Alan Flint, US Geological Survey

Jay Jasperse, Sonoma County Water Agency

Don Seymour, Sonoma County Water Agency

Christopher Delaney, Sonoma County Water Agency

John Mendoza, Sonoma County Water Agency

Susan Haydon, Sonoma County Water Agency

NOAA Primary Contact:

Nancy Beller-Sims, Climate Program Office, NOAA Research

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 2: Weather-Ready Nation

Goal 3: Climate Adaption and Mitigation

Budget Amount:

\$298,520

Award:

NA14OAR431024

Description of Research:

Two publications were finalized over the last year. The first of the two focused on the 2012-2015 drought in the Russian River and discuss the area preparedness for future droughts. The paper places the most recent drought in historical context and highlights that during the recent drought there were more extended dry periods during what are typically the wettest months of

the year. This aligns with what is expected from climate change in the region, extended dry periods punctuated by extreme storms. In addition, the paper details the 2012-2015 drought and the role of atmospheric rivers, or absence of them, in the drought (Figure 29), and the management actions to preserve water supply. The paper also documents that after extended dry periods, when atmospheric rivers occur, they produce less run-off and thus less water storage than when the soils are wet. The paper discusses the impacts of the recent drought on the region, with the largest impacts being felt by the ranching community. The paper then summarizes what the region is doing to prepare for and mitigate the impacts from the next drought.

Kalansky, J.F., Ralph, F.M., Jasperse, J., Flint, L.E., Dettinger, M.D., Flint, A (submitted), The 2012-2015 Drought in the Russian River Basin, A Case Study, *Journal of Hydrology; Regional Studies*.

The second publication on the extreme drought scenario is in final draft form. The drought scenarios developed for this paper was based on conversations with stakeholders in the region and their desire to understand how a drought more extreme than the 2012-2015 drought would impact the region. In addition, the scenarios included increased temperature to account for climate change impacts. The modeling efforts of the extreme drought scenarios brought to attention that the landscape and the reservoirs do not necessarily recover at the same point, which has implications for the different water users in the Russian River. The recovery of the Russian River from 2012-2015 drought also highlighted this in that reservoirs in the region reached the target storage curve by the end of 2016, but there were areas in the Russian River that remain under "landscape drought (Figure 30)." When the drought scenarios were run through Sonoma County's reservoir model, the acute drought scenarios lead to a lower storage level for both reservoirs in the Russian River, Lake Mendocino (goes dry) and Lake Sonoma, compared to the



extended drought scenarios, because it a more severe drought over the short term. However, the system in the acute drought recovers very quickly (2 years for Lake Mendocino and 4 years for Lake Sonoma), while the long-term drought depresses the storage in Lake Mendocino and Lake Sonoma for the entirety of the 10-year drought period. The interpretation is that this is due to the longer recovery of the landscape which impacts the water supply. Further understanding the connectivity between landscape drought and water supply drought is of great interest because it motivates the region to work together to improve drought resilience.

Research Objectives:

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

Research Accomplishments:

In June of 2016 we held a workshop for natural and working land managers at Sonoma County Water Agency. The workshop had several of the key stakeholders in the region that are working on these topics including the regional Resource Conservation Districts, Sonoma Land Trust, Mendocino County Farm Bureau, amongst others. During the workshop L. Flint presented on the results of the extreme drought scenarios and many of the stakeholders presented on regional activities to improve drought resilience. The breakout sessions on best practices were extremely informative and highlighted approaches the region needs to do to better prepare natural and working lands for the next drought.

Education & Outreach

Communication

Other outreach events also included the introduction to the concept of landscape drought. At an Earth Day event in San Diego we had a booth and prepared a landscape drought flier to discuss the concept of landscape drought and what people could do in a more urbanized area to prepare for landscape drought. The projected changes of extreme precipitation and evolution of landscape drought from 2012-2015, both results from this project, were presented at Storm Water Conference hosted by Congress Woman Grace Napolitano in Pomona, CA. Using research from task one, M. Dettinger presented on examination of the drought of 2012-2016 and what it implies for the future at a Public Policy Institute of California drought workshop.



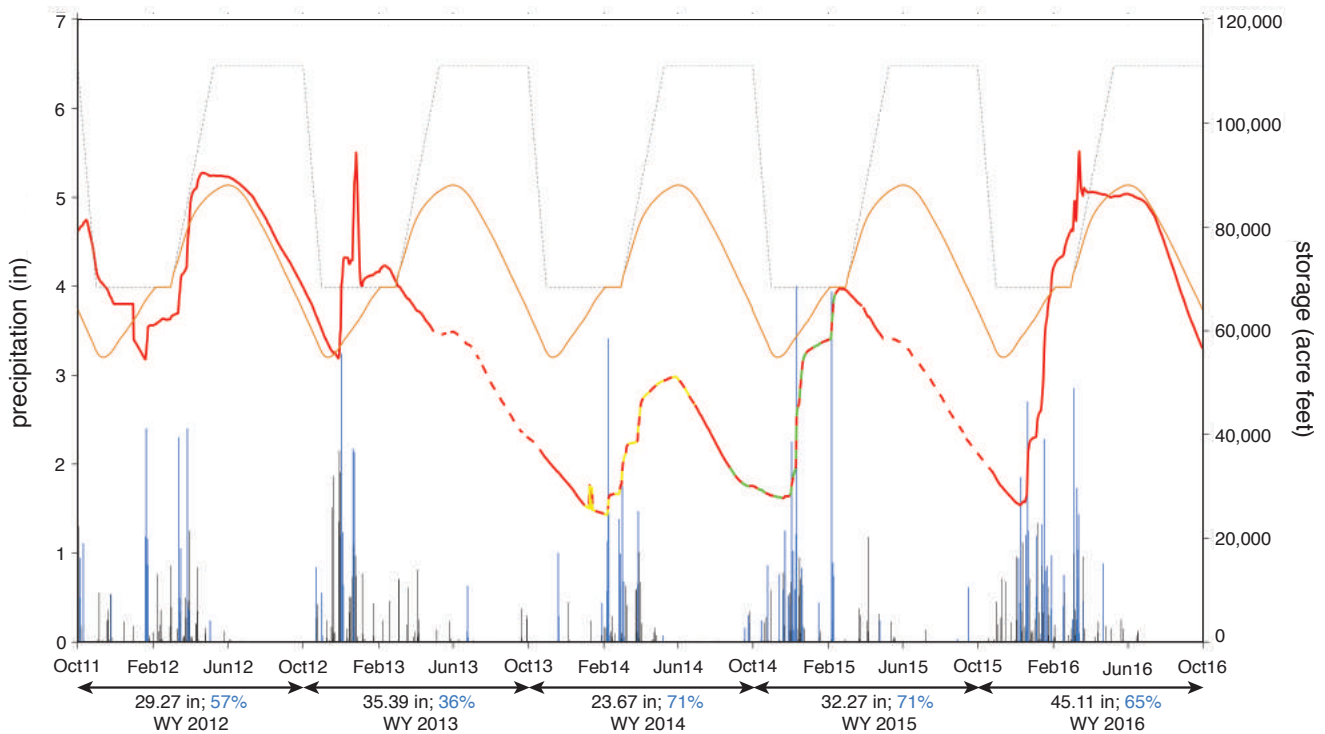


Figure 29: The evolution of the drought is illustrated with precipitation events, highlighting ARs, and Lake Mendocino Storage levels highlighting management actions to conserve water. The bars on the bottom are the mean areal precipitation over the Lake Mendocino watershed with the blue bars indicating precipitation that occurred during AR conditions at the Bodega Bay observing station. The total water year precipitation is indicated below the water year totals with the percentage of precipitation from ARs noted in blue. The red line illustrates the storage in Lake Mendocino with the dashed periods indicating a time when a temporary urgency change petition was in place to reduce the out flow from Lake Mendocino. During the time period of the white dashes the outflow was reduced to 75 cfs, during the yellow dashes the outflow was reduced to 50 cfs and during the green dashes it was reduced to 25 cfs. The dashed grey line is the guide curve and the orange line is the target storage curve identified by SCWA



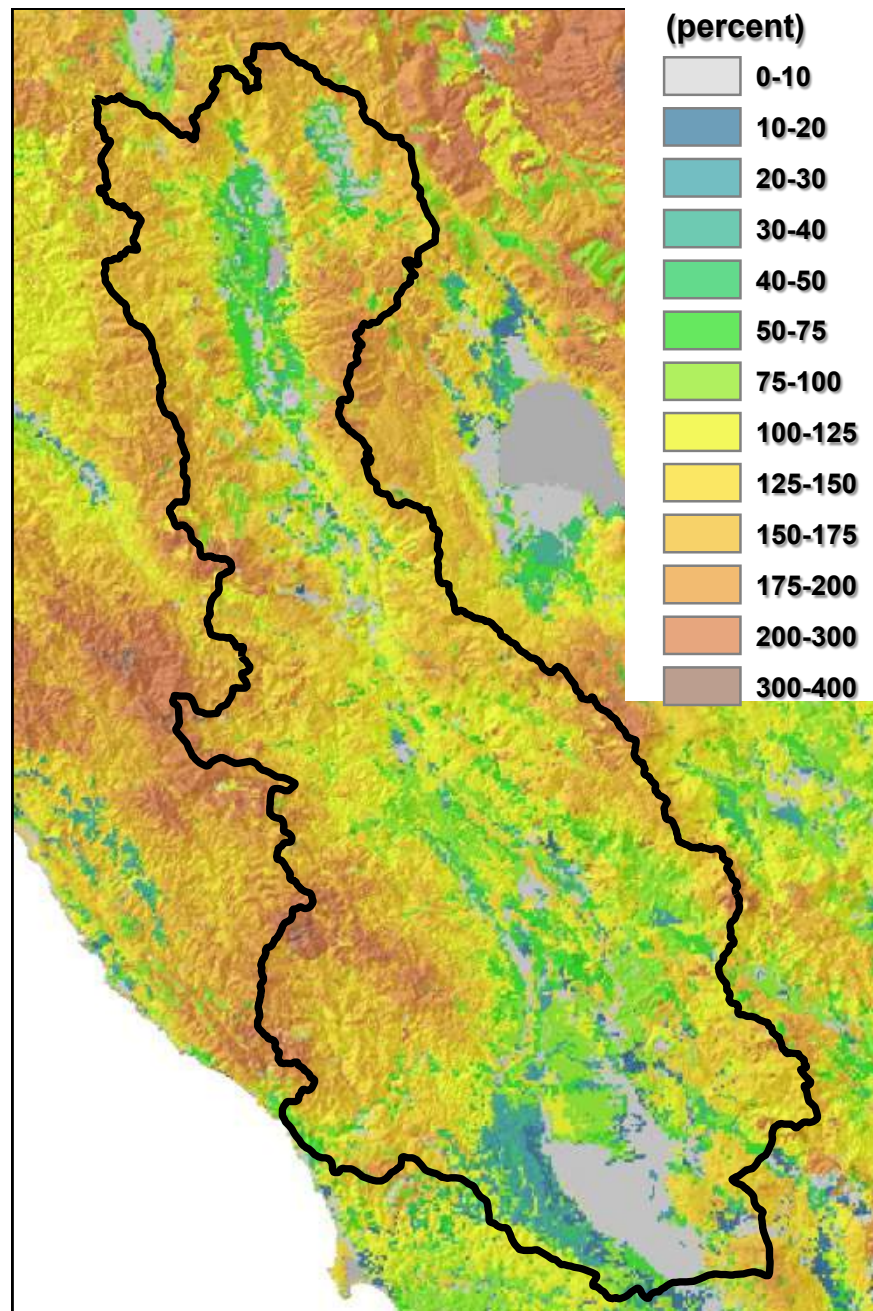


Figure 30: The percent of normal Climatic water deficit in the Russian River (black outline) in May 2016. The warm colors indicate that the climatic water deficit is higher than normal and these areas are in a landscape drought. The areas in the most severe landscape drought in May of 2016 were the lower Russian River, and parts of the Potter Valley watershed



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

Principal Investigator(s):

James Swift, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Bruce Appelgate, Scripps Institution of Oceanography, UC San Diego

Steve Diggs, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. David Legler, Climate Program Office, NOAA Research

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Goal 3: Climate Adaption and Mitigation

Budget Amount:

\$220,946

Amendment(s):

13, 38

Description of Research:

The CLIVAR and Carbon Hydrographic Data Office (CCHDO) brings together, verifies, and corrects content and format errors in the CTD, hydrographic and tracer data used in large-scale ocean carbon, global change, water mass, and circulation studies. The CCHDO is an intermediary between investigators carrying out CTD/hydrographic field work and the research/education community, saving data users a great deal of effort by bringing disparate files, information, and formats to a common standard. (Otherwise each data user would need to do this.) Not only are the data easier to use, their quality and usefulness are enhanced by the CCHDO's careful assembly of documentation with the data,

helping to assure a data service lifetime far into the future. The CCHDO supports CLIVAR and carbon science programs, and is a data component of a global observing system for the physical climate/CO₂ system. The data are used to help quantify the uptake and storage of anthropogenic CO₂ by the ocean, to document long-term trends in ocean warming, and to determine heat and freshwater fluxes. NOAA support supplements existing National Science Foundation support for the CCHDO, and targets work that supports NOAA objectives.

During the reporting period the CCHDO continued to: increase its US and non-US CTD profiles, including both public and non-public data available for Argo reference; increase its data holdings of US, GO-SHIP, and many other cruise data; increase its on-line library of cruise reports; reconcile EXPOCODE expedition identifiers among US data centers; and improve data search capabilities and bulk data download on the CCHDO web site.

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. The CCHDO also coordinates with OceanSITES to update records of moored instruments and repeat hydrography. Problems remain with respect to the CCHDO obtaining full quality BATS hydrographic data [BATS = Bermuda Atlantic Time Series]. At the end of the reporting period, the CCHDO initiated renewed efforts to finally solve this problem (which were working well after the reporting period). The goal remains to find a means to see that BATS hydrographic data are public within 2-3 months of the end of each of their cruises.

The NOAA/NCEI works with several data assembly centers, including the CCHDO, to bring data into



NCEI. The CCHDO continues to improve this relationship with NCEI in the following areas:

- Continued data assembly of cruise hydrographic data and metadata, particularly those from the GO-SHIP program.
- Working with NCEI to improve efficiency of transfer of data and to make CCHDO data more archive ready.
- Working with NCEI to better synchronize data holdings.
- Continued CCHDO participation in discussions towards enhancing integration of the related Data Assembly Centers (specifically CDIAC* and BCO-DMO; [CDIAC = Carbon Dioxide Information and Analysis Center; BCO-DMO = Biological and Chemical Oceanography Data Management Office]), to reduce ambiguity and redundancy in data archiving. For example, this includes continued EXPOCODE reconciliation between the CCHDO, BCO-DMO, and CDIAC. This also reconciles GO-SHIP EXPOCODES since the CCHDO is the data assembly center for GO-SHIP.

[*The CDIAC was the CCHDO's data partner. CDIAC lost support from the Department of Energy, and the subsequent transfer of its ocean carbon data functions to NOAA/NCEI is a work in progress. NCEI's success with this is important to the community because the CCHDO does not at this time have funding (funds for one FTE would be required) or the in-house expertise in QC and adjustment of the ocean carbon data which are crucial to studies of the oceans' role in the global carbon cycle and change. The CCHDO is working with NCEI on this.]

CCHDO holdings are of great value to a wide audience of climate researchers and other users (e.g. modelers). The CCHDO continues to make the data holdings query-able and accessible through modern data management standards and practices (including those that NOAA and the international oceanographic community recommend). The CCHDO uses an easy to maintain, reliable means for locating and downloading data using concatenating cruise

metadata, geographic bounds, and temporal criteria.

Submissions from US data originators (the PIs who are in charge of one or more parameters) has been excellent, with only a few moderately overdue data deliveries. International data originators have also been cooperative and timely regarding data submissions and updates.

Through attendance at meetings (OceanSITES, Argo, DIMES, etc.), and the CDIAC and Dr. Robert Key (Princeton), the CCHDO receives an increasing stream of data from other countries.

Because the CCHDO is widely recognized as the CTD/hydrographic/tracer/carbon data center for international GO-SHIP, data receipts from the GO-SHIP community are straightforward, prompt, and complete.

International coordination continues at reasonable levels, partly due to CCHDO efforts and partly due to the growing success of the international scientific oversight and planning body GO-SHIP, which brings together scientists with interests in physical oceanography, the carbon cycle, marine biogeochemistry and ecosystems, and other users and collectors of hydrographic data to develop a globally coordinated network of sustained hydrographic sections as part of the global ocean/climate observing system. GO-SHIP has become a widely known and appreciated effort within the community. The relationship with GO-SHIP assists the CCHDO in keeping up to date with international cruises of interest to the CCHDO's data users.

The CCHDO continues to enjoy a mutually beneficial relationship with both the Argo and OceanSITES programs. In exchange for the CCHDO providing both programs with specifically formatted CTD data, these NOAA programs in turn assist the CCHDO in the discovery and acquisition of hydrographic data from the PIs involved in those communities. CCHDO data management support of the NSF-funded DIMES project has developed well, especially regarding data access and distribution. The tools, formats



and methods that NSF and NOAA have invested in for the CCHDO have proven to be directly applicable to effective management of data for these types of process studies and field programs.

Since the time of WOCE (World Ocean Circulation Experiment) and the WHPO WOCE Hydrographic Program Office; the CCHDO's predecessor), the CCHDO has provided direct benefits to NOAA and NOAA researchers, including, for example, supplying a full range of data and documentation services for NOAA cruises for the program, providing data to many NOAA scientists who routinely use CCHDO data and documentation, supporting CTD data services for the NOAA-supported Ocean-SITES program, and providing significant "front-end" data services which aid NOAA/NCEI. The CCHDO's present, partial fiscal support from NOAA helps to support the above activities and to provide data from specific cruises that are of special interest to NOAA, to work more closely with NOAA on data assembly as related to NOAA data centers, to broaden and simplify the accessibility of CCHDO data sets to NOAA investigators, and to make holdings query-able and accessible through modern data management standards and practices (including those that NOAA and the international oceanographic community recommend).

The CCHDO maintains files for more than 1300 cruises. The underpinnings of the CCHDO's in-house (staff only) and on-line (public) operations require continual modifications and updates to maintain compliance with security and operational guidelines, always with a focus on ease and power of use combined with underlying simplicity of operations and maintenance. The CCHDO continues to expand automation of routine tasks to speed the work of the data specialists and reduce time, errors, inconsistencies, and omissions.

The CCHDO has (internal) software modules that read and write data in WOCE, WHP-Exchange, netCDF, OceanSITES, MATLAB, and some "in-house" formats used by major data submitters. This software includes some unit conversions,

conversion of depths to pressures, reorder of rows based on pressure, and so forth. A module is in use to read some SeaBird CTD files directly. The new and updated modules resulted in performance enhancements for reading and writing data formats.

The goal and result of CCHDO activities is an ever-growing, publicly-available library of World Ocean CTD, hydrographic, ocean carbon, and tracer data which are correct, up-to-date, properly attributed, well-documented, and with a clear data history. The CCHDO is a stable, mature operation with a consistent goal: supplying a broad community with a dependable data set meeting community needs. The CCHDO's multi-year strategy for utilizing its NSF and NOAA support includes continuing to broaden its reach to more of the data originators who generate the data the community wishes to obtain from the CCHDO in consistent form, and continuing to work with all data providers to assist their transfer of data and documentation to the CCHDO in forms that mutually reduce the workload on them and the CCHDO. At the same time, internal CCHDO operations are continually being examined and improved for greater reliability, accuracy, and efficiency. Thus, an increasing volume of data can be handled from an increasing number of data originators, and supplied to an increasing number of data users, with minimal changes in CCHDO staff or inflation/merit-adjusted agency support.

There are limits to efficiency improvements. Simply put, the data handled by the CCHDO are products of human endeavor and so contain errors and inconsistencies which require evaluation by data specialists. A data specialist working for a reference data center such as the CCHDO cannot blithely quick-correct or simply ignore many of the subtle or confusing issues which arise in handling data. Meeting the responsibility to "get it right" can require serious expertise, attention and time. With the ever-increasing volume of international and quick-release data, the data and documentation backlogs faced by the CCHDO's specialists are increasing. We judge that to work the data stream



in the timely manner expected by the community of CCHDO data users, at a minimum the CCHDO requires funds to hire, train, and support at least one additional data specialist to handle principal matters, and to hire 1-2 more undergraduate student research assistants to carry out more nearly routine data and documentation tasks. This would require approximately \$100k more per year in agency funding, i.e. from NSF and/or NOAA. The interim measure being applied is to prioritize data tasks with US CO2/repeat hydrography first, International GO-SHIP second, and issues for other cruises third. This does, however, create a backlog of not-yet-addressed data tasks. To ensure that users at least have access to them, all new data files not yet groomed by the CCHDO data specialists are immediately placed on-line in a special category labeled "as received" data.

The CCHDO serves all of its information, data and documentation from its long-term web site <http://cchdo.ucsd.edu>. The CCHDO's on-line pages are live-generated from the CCHDO database of cruise information so that the CCHDO's data users are literally as up to date as the CCHDO is itself. Most data files for cruises supported by US funding agencies contain citation information in the files themselves, and the CCHDO web site pages acknowledge support from NSF and NOAA. Data access problems reported by users are addressed immediately. The CCHDO's data holdings are regularly harvested (approximately quarterly) by NOAA/NCEI for new data and updates.

The data files curated and on-line at the CCHDO are in wide use by US and international research communities working to address key questions about the state of the world's oceans and their regional variations. The CCHDO data are used to address sea surface temperature and calculated surface currents, ocean heat content and transport, fluxes of heat, momentum, and freshwater, and ocean carbon content and uptake. Because many of the CCHDO data are considered to be of reference quality, the CCHDO data cover an ever-growing time span, thus

providing a keystone in assessing and understanding the extent and nature of ocean changes.

The CCHDO is using NOAA support to develop two new tools for data users: (1) a tool which will locate the nearest CCHDO CTD/hydrographic profile(s) to a given location (such as the location of an Argo float), and (2) a tool which will deliver in one data file all CCHDO CTD or bottle profiles which meet user-specified criteria (focusing on geographic limits at present).

Research 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>. Direct benefits of this support to NOAA investigators and programs include broadened accessibility of CCHDO data to all users, such as modelers and students; improved access to CTD data reformatted by the CCHDO to a common readability standard from cruises of special interest to Argo; reports of new and updated data to Argo at regular intervals; and estimating the suitability of new CTD data for Argo purposes.

Research Accomplishments:

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. Recent accomplishments include:

- Continued increase of US and non-US CTD profiles, both public and non-public, available for Argo reference data.
- Continued reconciliation of EXPOCODE 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. Dr. James Swift attended a meeting at NOAA Headquarters, 08-10 November 2016, to discuss options for the future of the activities of the Carbon Dioxide Information and

Analysis Center (CDIAC), which is the CCHDO's partner organization, handling ocean carbon data. (No NOAA funds were used, though the discussions were CIMEC related.)

- b. Andrew Barna attended the IQuOD 4th Workshop, 03-07 October 2016, Tokyo, Japan, to discuss data quality control activities and initiatives, with the ultimate goal of bringing all subsurface temperature measurements to a common standard and integrated into a common (value-added) database for public use. (Partial NOAA funding. CIMEC-related)
- c. Andrew Barna attended the December 2016 AGU Fall meeting in San Francisco, CA. (No NOAA funds were used, but CIMEC-related activities were carried out.)
- d. Steve Diggs attended an OceanSITES Steering/Data Meeting, 22-29 April 2016, in Southampton, UK. No NOAA funds were used, but the trip was CIMEC related.)
- e. Steve Diggs attended the IQuOD 4th Workshop, 2016-10-03 to 2016-10-07, Tokyo, Japan, to discuss data quality control activities and initiatives, with the ultimate goal of bringing all subsurface temperature measurements to a common standard and integrated into a common (value-added) database for public use. Worked closely with Tim Boyer of NOAA NCEI. (No NOAA funds were used, but the trip was CIMEC related.)
- f. Steve Diggs attended the December 2016 AGU Fall meeting in San Francisco, CA. (No NOAA funds were used, but CIMEC-related activities were carried out.)
- g. Steve Diggs attended the Argo Data Team Meeting, 24-29 September 2016, in Tianjin, China. (NOAA funded and CIMEC related.)
- h. Steve Diggs attended the Argo Steering Team Meeting, 10-18 March, 2017, in Hobart, Australia. (NOAA funded and CIMEC related.)
- i. Steve Diggs attended the EarthCube All Hands Meeting, 05-08 July 2016, in Denver, CO. (No NOAA funds were used, though some discussions were CIMEC related.)



- j. Steve Diggs attended the ASLO Meeting, 25 February - 03 March, 2017, in Honolulu, HI, to discuss EarthCube matters. (No NOAA funds were used, though some discussions were CIMEC related.)
- k. Steve Diggs attended the Research Data Alliance 7th Plenary, 28 February - 04 March 2016, in Tokyo, Japan. (No NOAA funds were used, though some discussions were CIMEC related.)
- l. Steve Diggs attended the Research Data Alliance IG/WG Chairs Meeting, 04-10 June, 2016, in Nottingham, UK. The trip also included travel to BODC to reconcile data holdings and formats with the GO-SHIP and GEOTRACES team. (No NOAA funds were used, though some RDA discussions were CIMEC related, and the BODC visit was entirely CIMEC related.)
- m. Steve Diggs attended the Earth Science Information Partners (ESIP) Summer Meeting, 17-22 July, 2016, in Durham, NC. (No NOAA funds were used, though some discussions were CIMEC related.)
- n. Steve Diggs attended the Earth Science Information Partners (ESIP) Winter Meeting, 09-13 January, 2017, in Bethesda, MD. Added 1-day to travel to discuss CDIAC data transfer to NCEI and CCHDO responsibilities. (NOAA funds were used for one night lodging and meals. The CDIAC-related visit was CIMEC business. Some ESIP discussions were CIMEC related.)

outreach pages on the US GO-SHIP web site, including a virtual cruise (ship plans, photos, videos, etc.) and an example of a complete cruise from proposal through preliminary data interpretation (see <http://usgoship.ucsd.edu/outreach>). [The former URL <http://ushydro.ucsd.edu> and the newer URL <http://usgoship.ucsd.edu> reach the same pages.] Also, the US GO-SHIP site includes blogs from students and scientists participating at sea.

Academic Development

- a. Undergraduate student training and experience is an integral part of the project. Students work with an experienced physical oceanographer and a technical team to handle data and documentation and present them in easy to use, understandable form. Students also work on web site development, learning from the CCHDO staff, with some taking a lead role on a key web development task (programming and/or design).

Education & Outreach

Communication

- a. The CCHDO maintains a website (<http://cchdo.ucsd.edu>) where the data and accomplishments of the project are maintained for public and scientific view and use. CCHDO data form the core data used in the exercises developed for the textbook "Descriptive Physical Oceanography - An Introduction" by Talley, Emery, Pickard, and Swift (see <http://joa.ucsd.edu/dpo>). The CCHDO contributes to and maintains the



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

Annotations:

- minimalist look
- fast response
- new functions for searches and data tables
- build-your-own multi-cruise downloads
- data accessible via APIs (bypass web site)
- 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 NOAA ® EMBLEM IS A REGISTERED TRADEMARK OF THE U.S. DEPARTMENT OF COMMERCE, USED WITH PERMISSION. THE USE OF THE NOAA RESEARCH PARTNERSHIP BETWEEN THE INSTITUTE AND NOAA, AND DOES NOT CONSTITUTE ENDORSEMENT BY THE DEPARTMENT OF COMMERCE.

J. Swift, SIO, May 2017

Figure 31: October 2016 front page of the CLIVAR and Carbon Hydrographic Data Office (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. The CCHDO brings together, verifies, and corrects content and format errors in U.S. and international hydrographic and tracer data used in large scale ocean carbon, global change, water mass, and circulation research. The CCHDO assembles the data with relevant documentation, and carefully prepares them for dissemination and archive, emphasizing strict adherence to community standard formats in order to make the data easy to use. This web site includes tools to browse through data by various criteria, to search for data graphically or by content attributes, and to submit data, plus project and format information. The CCHDO site contains CTD and/or bottle data from more than 1300 cruises. During FY16 there were 6799 users from 94 countries interacting with the CCHDO web site. Each year data from approximately 30-50 cruises and 3000-5000 pages of new documentation files are added to the site. The CCHDO works closely with the former Carbon Dioxide Information and Analysis Center (CDIAC; now hosted by NCEI) to assure up-to-date holdings of ocean carbon parameters.



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

Principal Investigator(s):

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

NOAA Primary Contact:

Dr. Annarita Mariotti, Climate Program Office, NOAA Research

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 2: Weather-Ready Nation

Budget Amount:

\$189,000

Award:

NA13OAR4310092

Research Objectives:

To assess the ability of state-of-the art climate models to produce realistic interannual variability (IAV) and intraseasonal variability (ISV) in the Intra-Americas Sea (IAS) region and the implications for tropical cyclones (TCs), and how mean state biases in CMIP models develop and how they affect forecast biases in ISV to IAV and related variations in TC activity.

Research Accomplishments:

We studied interannual variability in wind velocity over the IAS and equatorial Atlantic Ocean; the effect of the 2015-16 El Nino on California rainfall; and the sources of uncertainty in the seasonal prediction and long-term projection of ENSO. We developed a dynamical method to remove internal variability from the observed records of global mean surface temperature, and the resultant estimate of anthropogenic warming is larger than in the literature but consistent with the latest observations.

Description of Research:

Teleconnection of the 2015-16 El Nino to California (Siler et al. 2017)

The major El Nino of 2015-16 brought significantly less precipitation to California than previous events of comparable strength, much to the disappointment of residents suffering through the state's fourth consecutive year of severe drought. Here, California's weak precipitation in 2015-16 relative to previous major El Ninos is investigated within a 40-member ensemble of atmosphere-only simulations run with historical sea-surface temperatures (SSTs). The simulations reveal significant differences in both California precipitation and the large-scale atmospheric circulation between 2015-16 and previous strong El Ninos, which are similar to (albeit weaker than) the differences found in observations. Principal component analysis indicates that these ensemble-mean differences were likely related to a pattern of tropical SST variability with a strong signal in the eastern Indian Ocean. This SST pattern was missed by the majority of forecast models, which could partly explain their erroneous predictions of above-average precipitation in California in 2015-16.

Uncertainty in ENSO prediction (Ma et al. 2017)

Ensemble forecast has improved the seasonal prediction of El Niño–Southern Oscillation (ENSO) by considering errors in models and initial conditions. While much attention has been given to the ensemble mean, the inter-member spread within an ensemble limits the reliability of the forecast. temporal co-evolution of inter-member anomalies of sea surface temperature (SST) and low-level winds over the tropical and subtropical Pacific is examined in the North American

Multi-model ensemble (NMME) hindcasts. two types of SST spread growth in the equatorial Pacific are identified. The first features an evident southwestward propagation of SST spread from the subtropical Northeast Pacific (NEP) to the western equatorial Pacific in boreal winter-spring,



indicative of the precursor effect of the North Pacific Meridional Mode (NPM) on ENSO variability. Extratropical atmospheric variability generates inter-member variability in ENSO through wind–evaporation–SST (WES) north of the equator and then Bjerknes feedback on the equator (Figure 32). The second type shows a growth in the equatorial Pacific with a weak contribution from the subtropical Southeast Pacific (SEP) in summer. Thus, the extratropical influence on ENSO evolution is much stronger in the Northern than Southern Hemisphere. The growth of Niño4 SST spread among member hindcasts shows a strong seasonality. In hindcasts initialized in September– March, the Niño4 SST spread grows rapidly in January–April, stabilizes in May–June, and grows again in July–September. The rapid growth of the Niño4 SST spread in January–April is attributed to the arrival of NPM perturbations, while the slowdown in May–June and rapid growth in July– September are due primarily to the seasonality of equatorial ocean–atmosphere interaction.

Uncertainty in ENSO projection (Zheng et al. 2017)

How El Niño–Southern Oscillation (ENSO) will change under global warming affects changes in extreme events around the world. The change of ENSO amplitude is investigated based on the historical simulations and representative concentration pathway (RCP) 8.5 experiments in phase 5 of the Coupled Model Intercomparison Project (CMIP5). The projected change in ENSO amplitude is highly uncertain with large intermodel uncertainty. By using the relative sea surface temperature (SST) as a measure of convective instability, this study finds that the spatial pattern of tropical Pacific surface warming is the major source of intermodel uncertainty in ENSO amplitude change. In models with an enhanced mean warming in the eastern equatorial Pacific, the barrier to deep convection is reduced, and the intensified rainfall anomalies of ENSO amplify the wind response and hence SST variability. In models with a reduced eastern Pacific warming, conversely, ENSO amplitude decreases. Corroborating the mean SST pattern effect, intermodel uncertainty in changes of

ENSO-induced rainfall variability decreases substantially in atmospheric simulations forced by a common ocean warming pattern. Thus, reducing the uncertainty in the Pacific surface warming pattern helps improve the reliability of ENSO projections. To the extent that correcting model biases favors an El Niño–like mean warming pattern, this study suggests an increase in ENSO-related SST variance likely under global warming.

Tropical Pacific effect on global surface temperature (Koasaka and Xie 2016)

Global mean surface temperature (GMST) change over the past 120 years resembles a rising staircase: the overall warming trend was interrupted by the mid-twentieth-century big hiatus and the warming slowdown since about 1998. The Interdecadal Pacific Oscillation has been implicated in modulations of global mean surface temperatures, but which part of the mode drives the variability in warming rates is unclear. Here we present a successful simulation of the global warming staircase since 1900 with a global ocean–atmosphere coupled model where tropical Pacific sea surface temperatures are forced to follow the observed evolution. Without prescribed tropical Pacific variability, the same model, on average, produces a continual warming trend that accelerates after the 1960s. We identify four events where the tropical Pacific decadal cooling markedly slowed down the warming trend. Matching the observed spatial and seasonal fingerprints we identify the tropical Pacific as a key pacemaker of the warming staircase, with radiative forcing driving the overall warming trend. Specifically, tropical Pacific variability amplifies the first warming epoch of the 1910s–1940s and determines the timing when the big hiatus starts and ends. Our method of removing internal variability from the observed record can be used for real-time monitoring of anthropogenic warming.

Unlike the conventional model-based method, this new method of deriving forced GMST change is largely free of the uncertainties in radiative forcing and climate sensitivity. The new method



yields an anthropogenic warming of 1.2 oC from the late 19th century (Figure 33), much higher than the visual estimate of 0.9 oC from raw data at 2013. The higher estimate from our study is now in line with the visual one as GMST has since increased by 0.3-0.4oC, aided in part by the major El Niño event of 2015-2016. The 1.2 oC achieved anthropogenic warming heightens the challenges to meet the 1.5 oC goal of the Paris Agreement.

Variability and change in summer temperature over the western U.S. (Kamae et al. 2017).

Over the past decade, anomalously hot summers and persistent droughts frequented over the western United States (wUS), the condition similar to the 1950s and 1960s. While atmospheric internal variability is important for mid-latitude interannual climate variability, it has been suggested that anthropogenic external forcing and multi-decadal modes of variability in sea surface temperature, namely, the Pacific Decadal Oscillation (PDO) and Atlantic Multidecadal Oscillation (AMO), also affect the occurrence of droughts and hot summers. In this study, 100-member ensemble simulations for 1951–2010 by an atmospheric general circulation model were used to explore relative contributions of anthropogenic warming, atmospheric internal variability, and atmospheric response to PDO and AMO to the decadal anomalies over the wUS. By comparing historical and sensitivity simulations driven by observed sea surface temperature, sea ice, historical forcing agents, and non-warming counterfactual climate forcing, we found that large portions of recent increases in mean temperature and frequency of hot summers (66 and

82 %) over the wUS can be attributed to the anthropogenic global warming. In contrast, multidecadal change in the wUS precipitation is explained by a combination of the negative PDO and the positive AMO after the 2000s. Diagnostics using a linear baroclinic model indicate that AMO- and PDO-related diabatic heating anomalies over the tropics contribute to the anomalous atmospheric circulation associated with the droughts and hot summers over wUS on

multidecadal timescale. Those anomalies are not robust during the periods when PDO and AMO are in phase. The prolonged PDO–AMO antiphase period since the late twentieth century resulted in the substantial component of multidecadal anomalies in temperature and precipitation over the wUS.

Seasonal phase locking of the Atlantic Nino (Richter et al. 2017)

The equatorial Atlantic is marked by significant interannual variability in sea-surface temperature (SST) that is phase-locked to late boreal spring and early summer. The role of the atmosphere in this phase locking is examined using observations, reanalysis data, and model output. The results show that equatorial zonal surface wind anomalies, which are a main driver of warm and cold events, typically start decreasing in June, despite SST and sea-level pressure gradient anomalies being at their peak during this month. This behavior is explained by the seasonal northward migration of the intertropical convergence zone (ITCZ) in early summer. The north-equatorial position of the Atlantic ITCZ contributes to the decay of wind anomalies in three ways: (1) horizontal advection associated with the cross-equatorial winds transports air masses of comparatively low zonal momentum anomalies from the southeast toward the equator. (2) The absence of deep convection leads to changes in vertical momentum transport that reduce the equatorial wind anomalies at the surface, while anomalies aloft remain relatively strong. (3) The cross-equatorial flow is associated with increased total wind speed, which increases surface drag and deposit of momentum into the ocean. Previous studies have shown that convection enhances the surface wind response to SST anomalies. The present study indicates that convection also amplifies the surface zonal wind response to sea-level pressure gradients in the western equatorial Atlantic, where SST anomalies are small. This introduces a new element into coupled air-sea interaction of the tropical Atlantic.



Interannual variability in cross-Central American winds (Yang et al. 2017)

A trans-basin mode (TBM) is identified as the leading mode of interannual surface wind variability over the Intra-American Seas across Central America based on Empirical Orthogonal Function analysis. The TBM is associated with variability in Central American gap winds, most closely with the Papagayo jet but with considerable signals over the Gulfs of Tehuantepec and Panama. Although El Niño-Southern Oscillation (ENSO) is the main large-scale forcing, the TBM features a distinct seasonality due to sea level pressure (SLP) adjustments across the Pacific and Atlantic. During July-September, El Niño causes meridional SLP gradient anomalies across Central America, intensifying anomalous geostrophic winds funneling through Papagayo to form the TBM. During wintertime, ENSO peaks but imparts little anomalous SLP gradient across Central America with a weak projection on the TBM mode because

of the competing effects of the Pacific-North American teleconnection and tropospheric Kelvin waves. Besides ENSO, tropical Atlantic sea surface temperature anomalies make a weak contribution to the TBM in boreal summer by strengthening cross-basin gradient. ENSO and the Atlantic forcings constitute a cross-basin see-saw pattern in SLP, manifested as an anomalous Walker circulation across the tropical Americas. The TBM appears to be part of the low-level branch of the anomalous Walker circulation, which modulates Central American wind jets by orographic effect. Our results highlight the seasonality of gap wind variability, and call for further research into its influence on regional climate.

Honors and Awards

- a. Shang-Ping Xie was elected a Fellow of the AGU in 2016 and AMS in 2017
- b. Shang-Ping Xie received the AMS Sverdrup Gold Medal in 2017



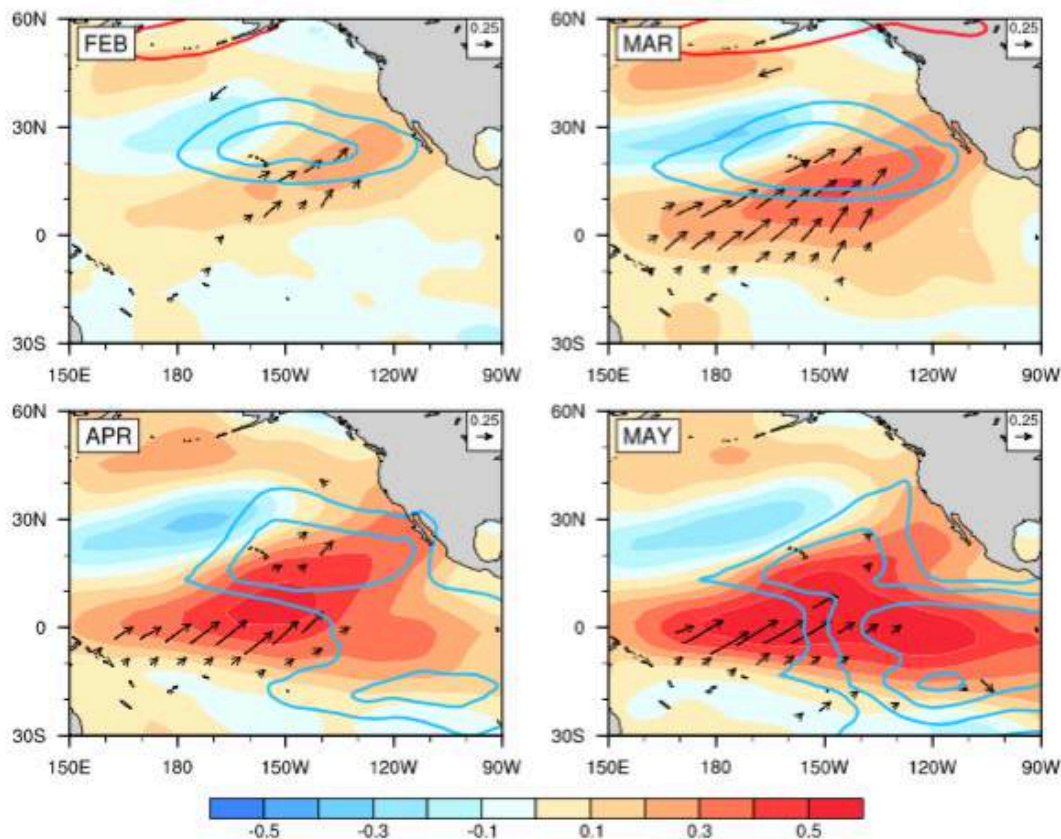


Figure 32: Inter-member spread of seasonal forecast starting in February: SST (color shading in oC), 850-hPa wind vectors (m s-1), and SLP (negative in blue contours with the zero-contour omitted) based on SVD analysis of ensemble seasonal forecast. Ma et al. (2017)

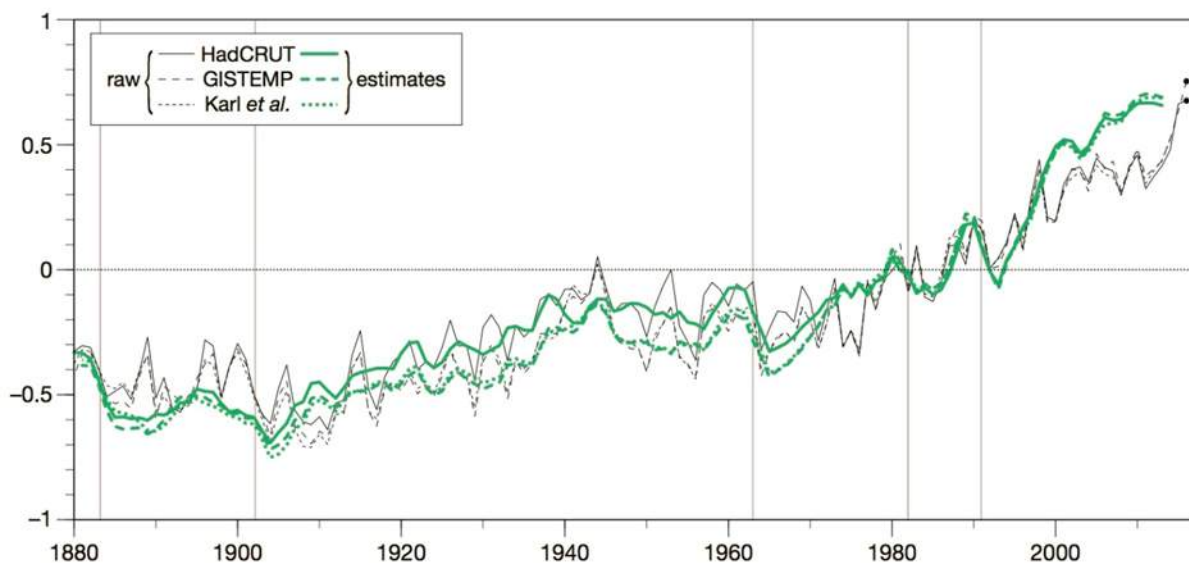


Figure 33: Radiatively forced GMST anomalies ($^{\circ}\text{C}$; green curves) estimated as observations minus “the tropical Pacific effect”. 3-year running average is applied to suppress noise. Black curves show raw annual GMST anomalies. Brown vertical lines indicate major volcanic eruptions in the tropics. Xie and Kosaka (2017)



Theme C: Marine Ecosystems

Collaborative Opportunity: 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:

David Checkley, Scripps Institution of Oceanography, UC San Diego

Kelly Goodwin, NOAA, Atlantic Oceanographic and Meteorological Laboratory

Lisa Zeigler, J. Craig Venter Institute

NOAA Primary Contact:

Margot Bohan, Ocean Exploration and Research, NOAA Reserach

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Budget Amount:

\$394,363

Amendment(s):

2, 30

Description of Research:

The NOAA-California Cooperative Oceanic Fisheries Investigations (CalCOFI) Ocean Genomics (NCOG) Project employs genome-based ocean assessments to complement and augment observations currently collected in the CalCOFI, California Current Ecosystem Long Term Ecological Research (CCE-LTER), and Southern California Coastal Observing System (SCCOOS) programs. Eukaryotic phytoplankton, microbes and viruses comprise the microbial food web and its composition and productivity influence

organisms at higher trophic levels including fisheries. However, current ecosystem and fisheries assessment models are limited to gross biological characterizations, such as total chlorophyll and total zooplankton volume. In comparison, genome-based assessment explicitly details the biological composition of those measurements. Overall aims of the NCOG project include distillation of 'omic data into ecosystem indices to improve NOAA's monitoring, prediction, and forecasting missions.

Research Objectives:

Analyses and Synthesis.

i) Continued analyses of omic data, including **i.a)** regional (offshore vs inshore, north vs south regions of the southern CCE) diversity analyses of microbes, **i.b)** Increased statistical analyses of linkages between microbes and CalCOFI data; in particular specific variables such as mixed layer depth and mixed layer depth anomaly and sea surface height which are key variables that have been invoked as significant drivers in interannual variability related to the location and extent of spawning habitat for small pelagic fishes, **i.c)** refinement and optimization of microbial network analyses, **i.d)** improved annotation and analyses of metazoan (i.e., higher trophic level organisms) data, and **i.e)** investigation of linkages between microbes and zooplankton and fish.

ii) Incorporation of fish (ichthyoplankton) data from Andrew Thompson (Southwest Fisheries)

iii) Development of environmental indices from omics that can be incorporated into ecosystem monitoring and management workflows. Biodiversity as an indicator of ecosystem health does not fully capture the complexity of the system as it can be biased due to various factors such as lack of appropriate time and space scales and specificity. We are investigating associations



between ecosystem perturbations and specific taxa that could be indicative of environmental perturbations.

Implement standards

i) As next generation sequencing technology is maturing it is becoming increasingly clear that quality control standards are necessary to ground truth variation in sequencing runs. Standards, which can be prepared consistently and spiked into runs have emerged as effective methodology. However, there are considerable issues to be resolved regarding effective preparation of such reagents.

Research Accomplishments:

- a. Integrated sustainable 'omic sampling within the CalCOFI program without significantly stressing ongoing CalCOFI activities.
- b. Sequencing and Analyses.
 - 2014-2015 cruise samples: DNA was extracted from 312 samples. DNA was amplified using three primer sets (16S V45, 18s V4, 18S V9), and sequenced on a MiSeq platform. Bioinformatic analysis focused on three major groups: prokaryotes (bacteria/archaeobacteria), phytoplankton (via plastid 16S), and microeukaryotes (e.g., diatoms, dinoflagellates, other protists). Out 33 million total sequences a total of 19.3 million were assembled and assigned to operational taxonomic units (OTUs) which passed quality filtering to include only those consisting of 3 or more sequences which and are represented at more than 1 site – for simplicity, the term OTU can be conceptualized akin to the term “species.”
 - Completion of DNA analysis for 2016 CalCOFI (165 samples) cruises is scheduled for April 2017.
 - Completion of RNA sequencing for 2014-2016 CalCOFI cruises (184 samples) is expected by May 2017.
 - Synergistic samples have been obtained from the following complementary projects: CCE ESP deployments (584

samples), CCE-LTER (130 samples), and MBON (200 samples). These samples are scheduled for sequencing between March and Fall 2017.

- c. Established optimized protocols for high-throughput automated DNA and RNA extraction and purification from captured cells and next generation sequencing preparation using robotics (EpMotion)
 - Protocols will be made publicly available online at www.protocols.io. Currently, they have been shared with CalCOFI, NOAA, and SIO collaborators via a shared project drive.
- d. Primer and sequencing methodology optimization.
 - Primer sequences used in amplification reactions and for multiplexing/barcoding up to 384 samples (i.e., combining many samples on a single sequencing run) have been optimized. Primers for 16S rDNA target variable regions 4 and 5; this primer set yields information on heterotrophic and photosynthetic bacteria and eukaryotic phytoplankton (via DNA encoded within the chloroplast organelle). Two sets of primers have been optimized to target two variable regions of the 18S rDNA target – regions 4 and 9. The rationale for targeting two regions is *i.)* v4 yields a longer sequence that is more suitable for species-level phylogenetic assignment and will capture the animal community (e.g, zooplankton and other organisms at higher trophic levels) with greater phylogenetic resolution, and *ii.)* the v9 region yields a shorter sequence with the length conserved among organisms, therefore analyses based on Operational Taxonomic Units (OTUs) are more robust. Also, this region has been used in the recent global study, TARA Oceans; therefore, our goal is to compare and correlate the NCOG CCE diversity to analyses from the global ocean.



- Based on our data we suspected that the use of a previously published custom primer design strategy, from human microbiome studies, necessary for multiplexing (e.g., barcoding) was negatively impacting sequencing run performance. Therefore, we optimized an original strategy for library construction and sequencing which is suitable for maximizing current sequencing technology. Performance has improved significantly.
- e. Sequence annotation pipelines and databases.
- Development of a pipeline, or bioinformatics workflow, was created specifically for large gene-targeted (i.e., amplicon) sequence datasets.
 - i)* Pipeline publicly available at Github, https://github.com/allenlab/rRNA_pipeline.
 - ii)* Databases are available at:
 - *i.a)* Bacteria V45 (16S) - <https://www.arb-silva.de/>
 - *i.b)* Eukaryotes 16S V45, 18S V4, 18S V9 – curated at JCVI in part from various public databases - https://github.com/allenlab/rRNA_pipeline/tree/master/db
 - *i.c)* PhyloDB (metatranscriptomes) <https://scripps.ucsd.edu/labs/aallen/data/>
- f. Data products
- Typical metagenetic studies (i.e., amplicon based) are able to classify organisms but the short length of DNA sequences, large data set sizes, and incomplete reference databases make detailed phylogenetic placement (relationships in term of evolutionary distance) unfeasible for most studies. The work here distinguishes itself by providing robust and precise taxonomic characterization. This ability is

achieved by development and maintenance of robust phylogenies of full length reference sequences (of known organisms from databases) and implementation of phylogenetic placement techniques coupled with custom visualization methodology; developed, in part, through this project (<https://github.com/allenlab/slacTree>).

- i)* constructed pipeline for visualization of large datasets using this method, slacTree, publicly available through Github <https://github.com/allenlab>.
- ii)* constructed pipeline for generating “diversity maps” from NCOG data which illustrate patterns of organismal distribution with the CCE.

Conferences, Meetings & Presentations

- a. Allen, L.Z., Rabines, A., McCrow, J., Goodwin, K., Allen, A.E. Pelagic Microbial Linkages in the Southern California Current Ecosystem. Association for the Sciences of Limnology and Oceanography (ASLO). February 26 - March 3, 2017; Honolulu, Hawaii

Education & Outreach

Communication

- 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>



Passive Acoustic and Ocean Noise Studies in the North Pacific

Principal Investigator(s):

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

Ana Širović, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Anne Simonis, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Erin Oleson, Pacific Islands Fisheries Science Center, NOAA Fisheries

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Budget Amount:

\$197,279

Amendment(s):

51

Description of Research:

Passive acoustic recordings are used to gain insights into the presence and distribution of vocalizing cetaceans in remote areas as well as documenting ambient ocean noise. Pacific Islands Fisheries Science Center (PIFSC) has been carrying out long-term acoustic monitoring in collaboration with Scripps Institution of Oceanography (SIO) since 2006. During this funding period, we have (1) analyzed previously collected data for beaked whale presence, (2) investigated ocean ambient noise in the North Pacific, and (3) made improvements to existing PIFSC equipment and assisted PIFSC with further data collections. This effort is in conjunction with

NOAA's mission to protect marine mammals, as mandated by the Marine Mammal Protection Act.

Partial funding from this award was used to analyze beaked whale presence at five sites in the central Pacific, namely offshore Kona (Hawaii), Pearl and Hermes Reef in the Northwestern Hawaiian Islands, Wake Atoll, and off Tinian and Saipan in the Northern Marianas Islands. In approximately 17 years of recording effort across all sites from 2007 to 2015, acoustic encounters were dominated by Blainville's beaked whales (*Mesoplodon densirostris*) with 2027 days with at least one encounter (1260 hours of encounters). This was followed by Cuvier's beaked whales (*Ziphius cavirostris*) with a total of 1380 days with at least one encounter (425 hours). A signal previously described as "BWC" and possibly originating from ginkgo-toothed beaked whales was detected at all sites but with lower rates of detection on 430 days (83 hours). Pearl and Hermes Reef had the highest percent of days with acoustic encounters overall (Figure 34). Most sites showed some level of seasonality for all species and signal types. For example, at Kona, Blainville's beaked whales were acoustically encountered more often in spring and summer while Cuvier's beaked whales were identified in fall and winter. BWC had a peak occurrence in spring at all sites. We were not able to identify consistent oceanographic drivers within or across sites to explain this varying seasonal occurrence. For the ocean ambient noise task, we partially analyzed with this funding the spectral sound pressure levels over four years of recordings at a station off San Nicolas Island in the Southern California Bight. We identified lower levels in recent years (2014 and 2015) compared to 2009 and 2010. Levels were reduced between 2 to 7 dB in frequencies known for distant shipping (Figure 35). Over the funding period we made relevant progress on reducing noise in the long-line HARPs used by PIFSC and are in the process of finalizing all recorders to be used in the Hawaiian long-line



fishing fleet to study gear interactions of endangered Hawaiian false killer whales. Additionally, we provided upgrades to HARPs currently in use by PIFSC within their passive acoustic monitoring network.

Research Objectives:

Objectives were to (1) analyze previously collected data for beaked whale presence, (2) investigate ocean ambient noise in the North Pacific, and (3) make improvements to existing PIFSC equipment and assist PIFSC with further data collections. No significant changes in objectives, methodology or rationale from previous reports.

Research Accomplishments:

- Report on beaked whale presence off Saipan and Tinian (Dec. 2016)
- Final report (Jun. 2017)

Conferences, Meetings & Presentations

Dr. Simone Baumann-Pickering and Anne Simonis attended the 172nd Meeting of the Acoustical Society of America and presented work funded within this project:

- Simonis AE, Thayre B, Oleson EM, Baumann-Pickering S (2016). Mid-frequency active sonar and beaked whale acoustic activity in the Northern Mariana Islands.
- Baumann-Pickering S, Simonis AE, Trickey JS, Roch MA, Oleson EM (2016). Beaked whale species occurrence in the central Pacific and their relation to oceanographic features.

Education & Outreach

Academic Development

- Graduate student Anne Simonis's thesis work was partially funded through this grant.

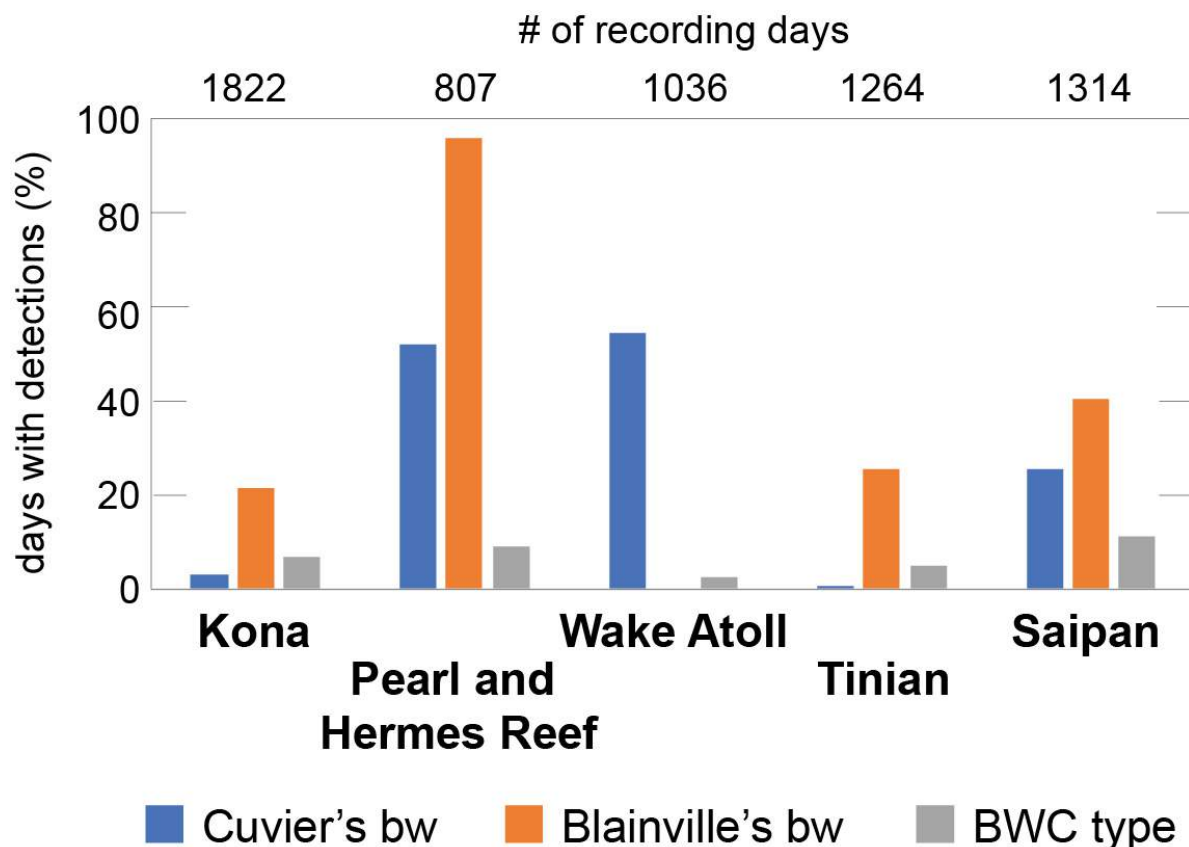


Figure 34: Percentage of days with acoustic detections of Cuvier's (blue) and Blainville's (orange) beaked whales and signal type BWC (grey) at five sites in the central Pacific. Number of recordings are giving at the top.



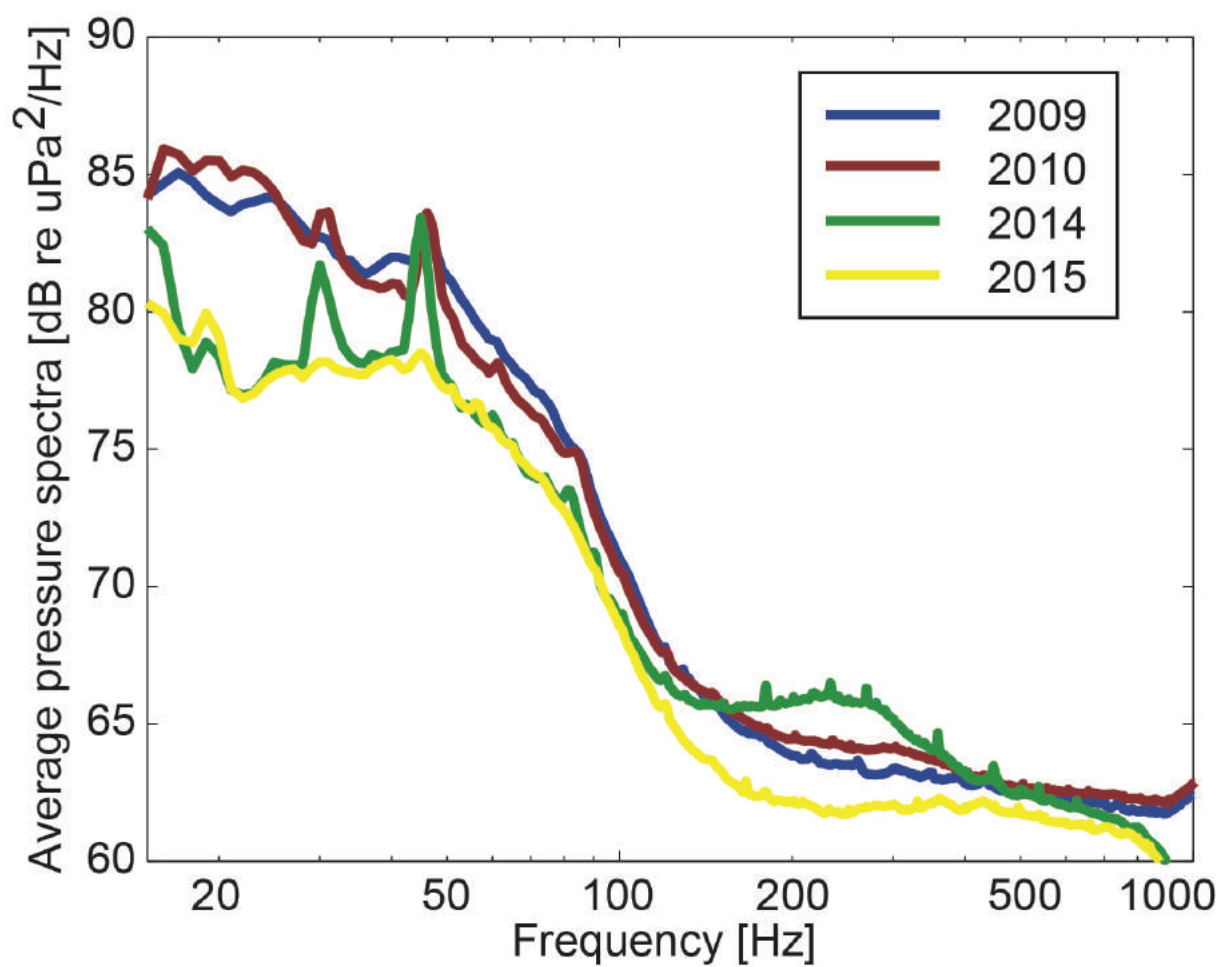


Figure 35: Average pressure spectra (dB re $1 \mu\text{Pa}^2/\text{Hz}$) of ambient sound off San Nicolas Island in the Southern California Bight showing lower sound pressure levels in recent years. Years are color coded.



Development and integration of the CoralNet Automated Image Annotation Tool for NOAA-CREP's Benthic Imagery

Principal Investigator(s):

David Kriegman, Computer Science & Engineering, UC San Diego

Other Key Personnel:

Oscar Beijbom, UC San Diego

NOAA Primary Contact:

Benjamin L. Richards, Pacific Islands Fisheries Science Center, NOAA Fisheries

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Budget Amount:

\$99,436

Amendment(s):

20, 55

Description of Research:

Machine vision researchers at UCSD, working with images and data provided by CREP, have developed computer vision algorithms (CoralNet) that distinguish coral genera and other benthic cover components at rates of accuracy that are similar to coral reef experts. Coralnet.ucsd.edu is a web site where users can upload benthic image data, manually annotate the data through a web browser in a similar fashion as with Coral Point Count, but with advantage that Coralnet uses machine learning and computer vision methods to automatically annotate some point.

The goals for this year's effort were: 1) transition coralnet.ucsd.edu from single desk-side computer to a cloud-based hosting service, 2) develop and deploy on Coralnet deep learning algorithms to allow for increased accuracy and automation levels, and 3) implement recommended changes

to the Coralnet workflow and user interface suggested by NOAA CREP.

To date, 434,466 photos from 516 sources have been uploaded to CoralNet, and over 12M annotations have been made on those photos.

Research Objectives:

The objective of this work was to further develop the capabilities of the CoralNet website to make it the premier tool for automatic analysis of benthic reef images. There were three lines of work:

1. Implement NOAA-recommended changes to CoralNet alpha
2. Transition to a cloud-based hosting service
3. Develop deep learning algorithms to allow for increased accuracy and automation levels

Research Accomplishments:

CoralNet Beta was launched in November 22, 2016, and included the following significant enhancements.

1. Hosting

CoralNet Beta moved from a single desk-side linux machine to being hosted on Amazon Web Services (AWS). This means that the web-server, database and the image data now live in a professionally managed data-center, which guarantees virtually constant uptime and stronger backup and data redundancy plans. Additionally, the backend automatic, deep learning annotation system is significantly faster and dynamically allocates up to 100 hosts depending upon the number of images in the queue.

2. Deep Convolutional Nets for Automatic Annotation

The computer vision back-end system was rebuilt from scratch. The new system relies on deep convolutional neural networks and is deployed using a scalable cluster hosted at AWS. We have also modified some of the processing and interface logic. The resulting improvements include:



- A significant improvement in accuracy.
- Orders of magnitude faster processing.
- Dedicated back-end analytics page.
- We have changed back to letting users directly specify the confidence threshold instead of the previous "alleviate" threshold.
- The back-end does no longer run each 24 hours, but a job is triggered immediately after upload. Users can therefore expect an uploaded image to be automatically annotated within minutes of upload.

3. Labelset Logic

We have made several updates to the way labels are handled in CoralNet.

- While the labels themselves remain global, users can now set the label-codes on a source level. This allows a uniform set of codes for everyone while still sharing the labels themselves.
- Labels can now be edited if (and only if) (1) no-one else is using the label and (2) the labelset-committee hasn't already verified it [see below].
- Source label-sets, including the custom label-codes, can be exported into a simple CSV file format and then re-uploaded to another source.
- We have added a popularity field to encourage emergence of labels used and shared by multiple groups. This is to encourage and facilitate meta-analysis across projects.

4. Labelset Committee

We have created a special group of users called the Labelset Committee (LSC). The long-term goal of the LSC to encourage and shepherd the community towards a unified set of global labels. In practice, the LSC will be responsible for maintaining the global labelset with emphasis on:

- Ensuring consistent label names.

- Ensuring that label descriptions are sufficient.
- Updating species and genera as the scientific literature evolves.
- The labelset committee will therefore have authority to edit any label on the site. Labels inspected, and maintained by the LSC will be designated as "verified", and the user interface will encourage future label-sets to include as many verified labels as possible. As the LSC goes through the existing set of labels and finds duplicates, the most commonly used labels will be chosen as verified.

The Labelset Committee is chaired by Manuel Gonzalez Rivero (U. Queensland) and includes John Burt (NYU), Ben Neal (Colby), John Burns (U. Hawaii), Cori Kane (Humboldt State University, Vincent Moriarty (MCER LTER, IBM).

5. Other improvements to UI and Workflows

5.1. Upload and Image File Names

All image names in a source must now be unique. This is enforced during upload.

We have re-named all images with identical file-names as xxx__dupe-name-01.jpg, xxx__dupe-name-02.jpg, etc. To find and rename these images the way you want, you can go to the Metadata page, use the "Image name contains" search option, and edit the names to your liking.

Image upload, metadata upload, and archived-annotation upload are now three separate steps. CSV file reading is now more flexible; columns can be in any order, and you can omit columns you don't need.

5.2. Auxiliary Metadata fields

Location keys have been renamed to auxiliary metadata fields, and there are now always 5 per source.

5.3. Browsing

Browsing has been split up into three separate pages, now reachable with the menu buttons Images, Metadata, and Patches.



Filtering is now allowed on any metadata field, not just on the auxiliary metadata-fields.

Image delete and export functions now reside in Browse Images.

5.4. Annotation Workflow

From Browse Images, if you do an image search and then use the "Enter Annotation Tool" action at the bottom of the page, the annotation tool's Previous and Next buttons will scroll through only the images you searched for.

Conferences, Meetings & Presentations

- a. Keynote: 'Automated Annotation of Benthic Images of Coral Reefs: From Fluorescence to Deep Networks', David Kriegman, International Workshop on Aqua Vision, Kyoto, September 2016.
- b. Deep Learning in the Shallow Seas: Expert level annotation accuracy using deep convolutional neural networks, Oscar Beijbom, International Coral Reef Symposium, June 2016

Education & Outreach

Communication

- a. CoralNet round-table meeting (users group), June 23, 2017. Held at International Coral Reef Symposium, June 23, 2016.

Networking

- a. D. Kriegman was co-organizer of 3rd Workshop on Automated Analysis of Video Data for Wildlife Surveillance held in conjunction with the IEEE Winter Conference on Applications of Computer Vision, March 2017.



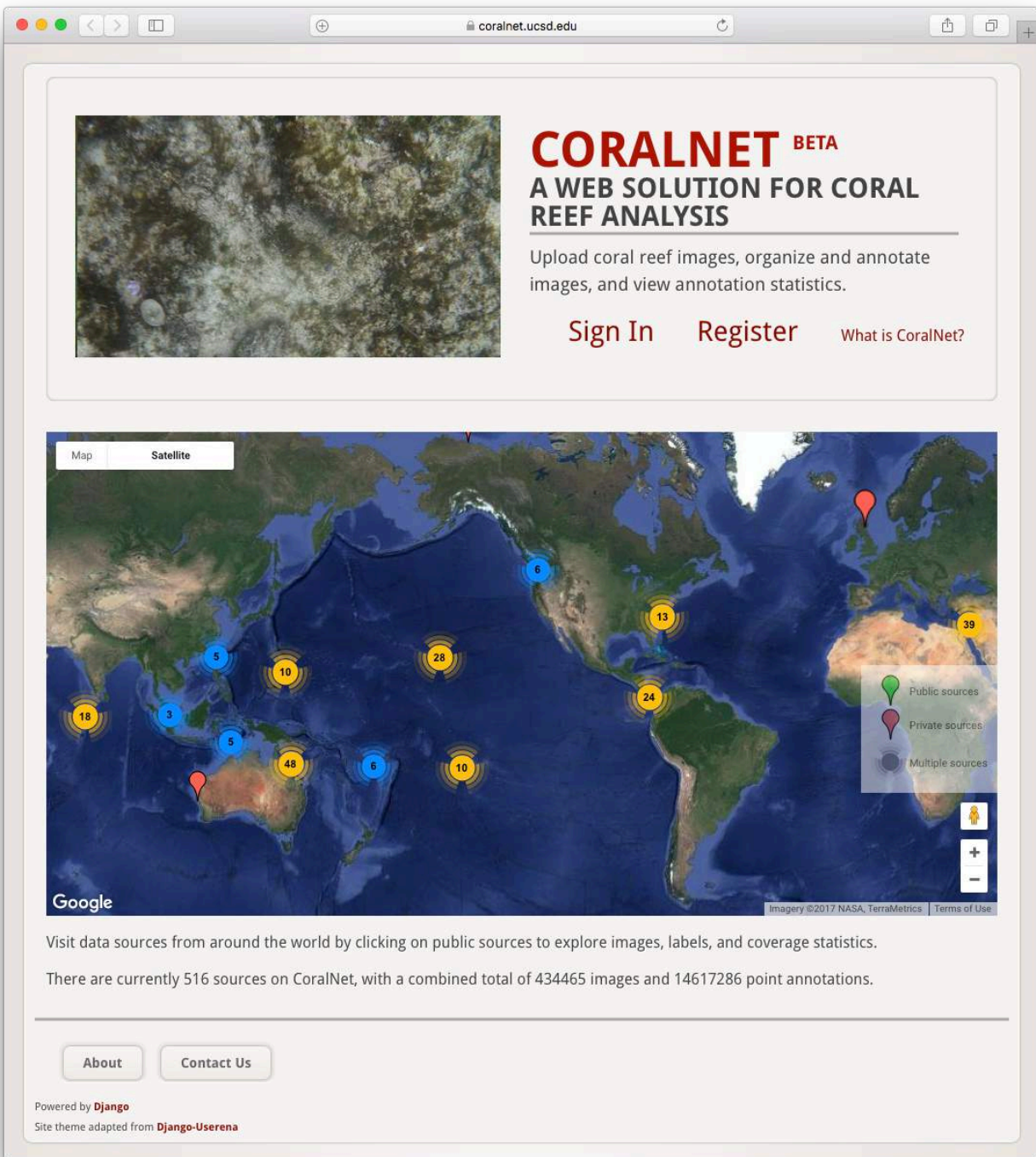


Figure 36: A screen shot of the CoralNet homepage on June 26, 2017. <https://coralnet.ucsd.edu>



Collaboration in Freshwater Ecology Research

Principal Investigator(s):

Eric P. Palkovacs, UC Santa Cruz

Other Key Personnel:

David Fryxell, UC Santa Cruz

Travis Apgar, UC Santa Cruz

Gina Contolini, UC Santa Cruz

Ben Wasserman, UC Santa Cruz

Rebecca Robinson, UC Santa Cruz

Katie Kobayashi, UC Santa Cruz

Megan Sabal, UC Santa Cruz

Liam Zarri, UC Santa Cruz

Nick Macias, UC Santa Cruz

Kerry Reid, UC Santa Cruz

Simone Des Roches, UC Santa Cruz

Krista Oke, UC Santa Cruz

Celia Symons, UC Santa Cruz

Emily Argo, UC Santa Cruz

Maya Friedman, UC Santa Cruz

NOAA Primary Contact:

Steve Miller, Southwest Fisheries Science Center,
NOAA Fisheries

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC
Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Budget Amount:

\$140,696

Amendment(s):

21, 52

Description of Research:

My research program is focused on understanding interactions between ecology and evolution – known as eco-evolutionary dynamics – primarily as these interactions occur in coastal

and freshwater ecosystems. The study of eco-evolutionary dynamics began with the widespread realization that evolution commonly occurs on so-called ecological time scales, enabling dynamic interactions between ecological and evolutionary processes. Human activity is a strong driver of both ecological and evolutionary change. Therefore, my lab studies the impacts of human disturbance on eco-evolutionary dynamics and implications for conservation and resource management.

Research Objectives:

(1) The role of contemporary evolution in shaping ecological dynamics: One of my major goals is to understand the importance of contemporary evolution for shaping aquatic communities and ecosystems. A major assumption across much of ecology is that *species* are the functional building blocks of communities and drivers of ecosystems. In contrast, my studies have shown important community and ecosystem effects of variation within species (among populations), and a recent meta-analysis (currently in review) shows that for many study systems the effects of diversity within species can be as large as the effects of diversity among species. While this past work points to the *potential* importance of contemporary evolution for communities and ecosystems, it is only weakly linked to ecological theory that might help predict *when* such effects might be important. One of my general goals is to link eco-evolutionary dynamics to ecological theory related to the major drivers of community and ecosystem change. One of these major ecological drivers in aquatic ecosystems is the trophic cascade, and one of my major current efforts is to ask whether the contemporary evolution of prey populations in response to predators impacts the strength of trophic cascades. I have funding from NSF to use recently introduced mosquitofish populations in California as a study system to address this question. Another major unanswered question is the extent to which environmental variation influences the



strength of eco-evolutionary effects. No published experiments to date have tested the interaction between environmental variation and contemporary evolution on community or ecosystem responses. My lab is now running these experiments, examining the interacting effects of temperature variation and thermal adaptation in mosquitofish on freshwater pond communities and ecosystems. Such experiments provide important information about the drivers of community and ecosystem change and also provide new insights into how ecosystems will respond to climate change.

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

(3) The integration of eco-evolutionary dynamics into conservation and resource management: I am working on a variety of projects that apply evolutionary principles to

conservation and fisheries management. The largest of these projects involves the application of genetic markers to facilitate the recovery of anadromous river herring populations. This work is in collaboration with scientists at the NMFS Lab and has been funded by grants from the National Fish and Wildlife Foundation, The Nature Conservancy, and the Atlantic States Marine Fisheries Commission. I am also working on the evolutionary effects of dams and culverts on steelhead populations in California and brook trout populations in Quebec. This work is aimed at designing restoration strategies that take into account the effects of human activity on evolution in wild populations. I have initiated collaborations to examine eco-evolutionary dynamics in North American and European lakes where evolution in response to fishing may be having a major impact on the ecology of the lakes. I am leading a recently funded working group to examine the consistency, causes, and consequences of size and age declines in Alaska salmon (National Center for Ecological Analysis and Synthesis). These studies show great promise for moving the study of eco-evolutionary dynamics out of the laboratory and small-scale experiments and into real world managed ecosystems.

(4) Anadromous fish recovery in California: I have several new awards (from CDWF and CA Water Resources Institute) to investigate the role of predators, habitat restoration, and water management on salmon migratory behavior and survival in the Delta. This work combines experiments at a variety of spatial and temporal scales with environmental data to predict the outcomes of various management scenarios on salmon survival.

Research Accomplishments:

- 1) Published 4 peer-reviewed papers, with two in press
- 2) Took 4 new graduate students
- 3) Hired 3 new postdoctoral researchers
- 4) Taught Freshwater Ecology, Freshwater Ecology Lab, and Graduate Seminar Courses



- 5) Received research grants from NSF, CDFW, TNC, NCEAS, CA Water Resources Institute, Pew
- 6) Promotion to Associate Professor with Tenure
- 7) Gave invited symposium talk at the Joint Meeting of Ichthyologists and Herpetologists
- 8) Mentored 5 UCSC undergraduate research projects
- 9) Organized and mentored for the NSF Research Experience for Teachers (RET) Program
- 10) Served as Faculty Sponsor for the American Fisheries Society (AFS) Santa Cruz Subunit
- 11) Peer-reviewer for numerous journals
- 12) Served on NSF full proposal panel

Honors and Awards

- a. Eric Palkovacs earned accelerated promotion to Associate Professor with Tenure (2016)
- b. Eric Palkovacs nominated for Pew Marine Conservation Fellowship (2017)
- c. Travis Apgar awarded Best Student Poster Award at the Cal-Neva AFS Meeting (2017)
- d. David Fryxell awarded UCSC Chancellor's Dissertation Year Fellowship (2017)
- e. David Fryxell awarded Skinner Memorial Award from the American Fisheries Society (2017)
- f. Gina Contolini awarded UCSC Coastal Leadership Award (2016)
- g. Celia Symons awarded UC Presidents Postdoctoral Fellowship (2017)
- h. Simone Des Roches awarded ISEECI Postdoctoral Fellowship (2016)
- i. Emily Argo awarded Knauss Marine Policy Fellowship (2016)
- j. Maya Friedman awarded Best Student Talk at the IEP Bay-Delta Conference (2017)
- k. Liam Zarri awarded Runner-up for Best Student Talk at the Cal-Neva AFS Meeting (2017)
- b. Eric Palkovacs gave promotion seminar for the EEB Department at UCSC (2016)
- c. Travis Apgar gave oral and poster presentations at the Cal-Neva AFS Meeting (2017)
- d. David Fryxell gave poster presentation at the Cal-Neva AFS Meeting (2017)
- e. David Fryxell gave an oral presentation at the Desert Fishes Council Meeting (2016)
- f. Katie Kobayashi presented on Watershed Health and Management at Harbor High School (2017)
- g. Katie Kobayashi attended Alaska Salmon Workshop (2017)
- h. Ben Wasserman gave an oral presentation at the Cal-Neva AFS Meeting (2017)
- i. Ben Wasserman presented at the UCSC-Stanford Species Interactions Workshop (2016)
- j. Ben Wasserman presented at the Cal-Poly Swanton Ranch Research Symposium (2016)
- k. Rebecca Robinson gave an oral presentation at the Cal-Neva AFS Meeting (2017)
- l. Maya Friedman gave an oral presentation at the IEP Bay-Delta Conference (2017)
- m. Liam Zarri gave an oral presentation at the IEP Bay-Delta Conference (2017)
- n. Liam Zarri gave an oral presentation at the Cal-Neva AFS Meeting (2017)
- o. Kerry Reid attended the Genomics Programming Workshop in Leipzig (2017)

Education & Outreach

Communication

a. Social Media

- Eric Palkovacs maintains an active Facebook site (UCSC Freshwater and Coastal Ecology Lab) that describes ongoing events in the lab.
<https://www.facebook.com/FWCEcology/>
- The AFS Santa Cruz Subunit maintains a Facebook page and a Facebook group to communicate ongoing activities and

Conferences, Meetings & Presentations

- a. Eric Palkovacs spoke at the Joint Meeting of Ichthyologists and Herpetologists (2016)



relevant articles.

<https://www.facebook.com/afsscmbas/>

b. Lab Website

Eric Palkovacs maintains a lab website with a description of research projects, lab members, and links to publications.

https://people.ucsc.edu/~epalkova/Palkovacs_Lab/Palkovacs_Lab_Home.html

c. Presentation at the Mid-Atlantic Fishery Management Council Meeting

Eric Palkovacs presented new research on river herring bycatch at the October 2016 Mid-Atlantic Council Fishery Management Council Meeting, where Council members voted on whether to enact new bycatch rules for river herring.

d. Fish Tales Reading Night

Katie Kobayashi and Dave Fryxell helped organize this “Fish Tales” community event, where people got together for food and drinks and to tell their personal stories about fish and fishing. The event was co-hosted by Potluck Magazine and Slow Foods Santa Cruz.

Academic Development

a. AFS Cal-Neva Fisheries Panel Discussion

Katie Kobayashi and Dave Fryxell organized a panel discussion at the annual AFS Cal-Neva meeting focused on exploring diverse perspectives on fisheries management in an era of rapid political and environmental change. The panel included a variety of people who manage and use fisheries resources, including fishermen, scientists, and managers. The panel discussion was attended by students, researchers, and fisheries professionals.

b. Seminar on community-supported fisheries

Katie Kobayashi hosted Alan Lovewell (Founder and CEO of Real Good Fish) for a UCSC seminar on the role of community-supported fisheries in marine conservation. The seminar was attended by UCSC students, researchers, and faculty.

K-12 Outreach

a. Trout in the Classroom

Megan Sabal, Nick Macias, and Katie Kobayashi took trout eggs to local elementary and high schools. They discussed the trout life cycle and the development and hatching of trout eggs. Eggs remain in classrooms for students to observe until hatching, and then the students release the fry into local streams. This project is a collaboration between the AFS Santa Cruz Subunit and California Department of Fish and Wildlife.

b. Arana Creek Watershed Investigation Program

Katie Kobayashi, Nick Macias, and Dave Fryxell are working with teachers and students at Harbor High School (Santa Cruz, CA) on a watershed restoration project at the local Arana Creek. The program was attended by diverse local citizens - parents with kids, students, and seniors.

c. Investigating Seafood Fraud using DNA Barcoding

Hayley Nuetzel, Katie Kobayashi, and Dave Fryxell are taking DNA barcoding into local high schools to explore the issue of fraudulent seafood marketing at local restaurants and grocery stores. They talk about the importance of proper labeling to ensure that consumers are accurately informed about their seafood choices. Students get experience with DNA extractions, PCR, DNA sequencing, and genetic methods for species identification.

d. Lecture on Watershed Health and Management

Katie Kobayashi presented a lecture on watershed health and management to students at Harbor High School (Santa Cruz, CA).

e. Seeing and Saving Desert Fishes

Dave Fryxell designed and implemented a pre-meeting outreach event along the Rio Grande for the Desert Fishes Council with local high school students from historically



underrepresented districts in Albuquerque, NM. Students were taken on a field trip to the Rio Grande to see local fish species and learn about the ecology of threatened desert freshwater ecosystems.

f. WATCH Program

Dave Fryxell, Megan Sabal, and Ben Wasserman participated in the Monterey Bay Aquarium WATCH field research program, which serves high school students from historically under-represented schools. Students participated in a variety of field data collection projects.

g. SIP Program

Dave Fryxell, Travis Apgar, Gina Contolini, and Ben Wasserman served as mentors for summer high school interns through the SIP program. Students participated in data collection and analysis, read scientific literature, attended weekly seminars, and gave oral presentations of their projects at the end of the summer.

h. NSF RET Program

Eric Palkovacs served as mentor for a summer high school teacher (Joseph Centoni, Half Moon Bay High School) through the NSF Research Experience for Teachers (RET) Program. Through a collaboration with Ignited! Education (a local non-profit education outreach organization), the teacher uses his or her research experience to develop interactive lesson plans for use in classes. Joseph Centoni developed lesson plans to use threespine stickleback in local estuaries to teach students about evolutionary biology in his Marine Biology class.

Networking

a. San Lorenzo River Watershed Cleanups

David Fryxell, Liam Zarri, Ben Wasserman, Gina Contolini, and Megan Sabal participated in quarterly projects to remove trash from the San Lorenzo River. This project is a collaboration between the AFS Santa Cruz Subunit and Save Our Shores (Santa Cruz, CA).

b. Loch Lomond Invasive Species Removal

Dave Fryxell, Katie Kobayashi, Ben Wasserman, Megan Sabal, Kerry Reid, and Liam Zarri participated in bi-annual invasive species removals from Loch Lomond reservoir. This project is a collaboration between the AFS Santa Cruz Subunit and the City of Santa Cruz Water Department.

c. Real Good Fish, Community Supported Fishery

Eric Palkovacs is hosting a Real Good Fish pickup location at the UCSC Long Marine Lab.

d. San Lorenzo River Tour

Nick Macias and Travis Apgar took local community members on a tour of the San Lorenzo River watershed. Participants collected aquatic organisms, learned about their life cycles, and the factors that impact the health of local freshwater ecosystems. This project is a collaboration between the AFS Santa Cruz Subunit and the Coastal Watershed Council (Santa Cruz, CA).

e. AFS Santa Cruz Subunit Local Outreach

A variety of networking events were held at local restaurants such as Equinox Winery, East Cliff Brewing Co.





Figure 37: Alewife spawning run in the Coonamasset River, Massachusetts.



Figure 38: Juvenile Chinook salmon from the Mokelumne River, California.

Investigations in Fisheries Ecology

Principal Investigator(s):

Dr. Eric Palkovacs, UC Santa Cruz

Other Key Personnel:

Pete Raimondi, UC Santa Cruz

Anne Criss, UC Santa Cruz

Lyndsey Lefebvre, UC Santa Cruz

Rebecca Miller, UC Santa Cruz

Nick Grunloh, UC Santa Cruz

Kerrie Pipal, 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

Natanael Hamda, UC Santa Cruz

Miles Daniels, UC Santa Cruz

Nicholas Macias, 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

JoAnne Siskidis, UC Santa Cruz

Emerson Kanawi, UC Santa Cruz

Shona Allen, UC Santa Cruz

Youngrog Lee, UC Santa Cruz

Cyril Michel, UC Santa Cruz

Jeremy Notch, UC Santa Cruz

Nicholas Demetras, UC Santa Cruz

Brendan Lehman, 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

Simone Vincenzi, UC Santa Cruz

Diana Baetscher, UC Santa Cruz

Thomas Ng, UC Santa Cruz

Ellen Campbell, UC Santa Cruz

Elena Correa, UC Santa Cruz

Hayley Nuetzel, UC Santa Cruz

Bridgid Moran, UC Santa Cruz

Matthew Campbell, UC Santa Cruz

Joe Bizzaro, UC Santa Cruz

Ethan Mora, UC Santa Cruz

Briana Abrams, UC Santa Cruz

Stephanie Brodie, UC Santa Cruz

Mike Jacox, UC Santa Cruz

Jennifer Patterson-Sevadijan, UC Santa Cruz

Dale Robinson, UC Santa Cruz

Isaac Schroeder, UC Santa Cruz

Heather Welch, UC Santa Cruz

Barbara Muhling, UC Santa Cruz

Desiree Tomassi, UC Santa Cruz

Juan Pablo Zwolinski, UC Santa Cruz

Suzanne Manugian, UC Santa Cruz

Carrie Pomeroy, UC Santa Cruz & CA Sea Grant

Ruthe Smith, UC Santa Cruz

John Richards, UC Santa Cruz & CA Sea Grant
(Emeritus)

Jarrold Santora, UC Santa Cruz

Christopher Edwards, UC Santa Cruz

Ryan Driscoll, UC Santa Cruz

NOAA Primary Contact:

Steve Miller, Southwest Fisheries Science Center,
NOAA Fisheries



NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Goal 3: Climate Adaption and Mitigation

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$1,053,505

Amendment(s):

22, 56

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's Fisheries Ecology Division (FED), Environmental Research Division (ERD) and Fisheries Research Division (FRD); 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.

Research Objectives:

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.

Specific research projects addressed eight objectives:

- a. Habitat Ecology Team - Marine Habitat Studies
- b. Groundfish Analysis - Groundfish Stock Assessment Support
- c. Genetics - Integrated Genetic Monitoring and Evaluation of Salmon and Steelhead in California
- d. Habitat Management - Continued 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
- e. Economics - Spatial Analysis in Fisheries Management
- f. Climate and Ecosystems - Research on Climate Change and Ecosystem Variability in the North Pacific Ocean: The Dynamics of Marine Populations
- g. Landscape Ecology - Landscape Ecology of Pacific Salmonids
- h. Salmon Ocean and Estuarine Ecology - Comparative Studies in Salmon Ecology

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.

Research Accomplishments:

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 39 journal articles (with an additional 32 journal articles in press), two books, 13 reports, two conference proceedings and workshops, and one PhD dissertation. Scientists engaged in more than 35 high profile international and national scientific conferences



and workshops as well as participated in many outreach and communication forums 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 multiple undergraduate and graduate students and post-doctoral scholars through employment and support of thesis and dissertation research.

Honors and Awards

- c. Briana Abrahms, U.S. Presidential Management Fellowship, January 2017
- d. Sara John, National Marine Fisheries Service Team Member of the Year Award 2016
- e. Isaac Schroeder, The National Oceanographic Partnership Program 2016 Excellence in Partnering award for "National Marine Sanctuaries as Sentinel Sites for a Demonstration Marine Biodiversity Observation Network (MBON)"
- f. Jarrod A. Santora, The National Oceanographic Partnership Program 2016 Excellence in Partnering award for "National Marine Sanctuaries as Sentinel Sites for a Demonstration Marine Biodiversity Observation Network (MBON)"

Conferences, Meetings & Presentations

Briana Abrahms:

- Presentation at Gordon Research Conference on Movement Ecology, March 2017, "Classification of common movement syndromes across diverse vertebrate taxa"

Mike Jacox:

- Attended the SWFSC Ecosystem Science Review in La Jolla, CA, Apr. 2016 and gave a talk entitled "Ocean modeling in the California Current System".
- Attended the US Clivar Workshop on Forecasting ENSO Impacts on Marine Ecosystems of the US West Coast in La Jolla, CA, Aug. 2016 and gave a talk entitled "Physical mechanisms driving ecosystem response in the CCS".

- Gave an invited seminar entitled "ENSO and the California Current System: Historical Impacts, Potential Predictability, and the 2015-16 El Niño" at UC Santa, Sep 2016.
- Attended the Forage Summit in Santa Cruz, CA, Jan. 2017, and gave a talk entitled "The future of ocean modeling".
- Attended the CCE LTER Forum in La Jolla, CA, Feb. 2017, and gave a talk entitled "Historical context for the west coast anomalies of 2015-16".
- Gave an invited seminar entitled "ENSO and the California Current System: Historical Impacts, Potential Predictability, and the 2015-16 El Niño" at Scripps Institution of Oceanography, La Jolla, CA, Feb. 2017.

Isaac Schroeder:

- 2016 Ocean Sciences Meeting – AGU in New Orleans, LA. Poster presentation titled "Monitoring biodiversity using ecosystem assessment surveys and regional ocean models within the California current"
- 2016 PICES – North Pacific Marine Science Organization in San Diego CA. Poster presentation titled "Source water variability in the California Current System and implications to rockfish production"
- 2017 Integrated Ecosystem Assessment (IEA) Forage Summit in Santa Cruz, CA. Gave a talk titled "Ocean conditions and influences on bottom-up production"
- Attended the 2016 National Integrated Ecosystem Assessment (IEA) workshop in Boulder, CO.

Liam Zarri:

- 2017 Interagency Ecological Program Annual Workshop in Folsom, CA. "Sacramento River Green Sturgeon: sDPS Population Size and Occupancy Modeling".

Nick Grunloh

- Presentation (with E.J. Dick and Don Pearson) entitled "Improving Catch Estimation Methods in Sparsely Sampled, Mixed Stock Fisheries" to the Pacific Fishery Management Council



historical groundfish catch reconstruction workshop (Portland, OR; November 2016).

- Co-presented (with E.J. Dick) a talk entitled "Reference Point Biases Associated with Beverton-Holt Stock-Recruitment Relationships" to the Pacific Fisheries Management Council Groundfish Productivity workshop (Seattle, WA; December 2016).

Rebecca Miller

- Attended the Monterey Bay Marine GIS User Group Meeting in Moss Landing, CA. The theme was Seafloor Mapping Applications. Presentations included seafloor characterization, underwater mapping technology and GIS tool demonstration. April 2016.
- Presentation entitled "A spatially distinct history of the development of California groundfish fisheries" to the Pacific Fishery Management Council historical groundfish catch reconstruction workshop (Portland, OR; November 2016).

Lyndsey Lefebvre

- Poster entitled "Plasticity in reproductive strategies for rockfish in the Southern California Current" at the 25th annual North Pacific Marine Science Organization (PICES) meeting (San Diego, CA; November 2016).
- Helped to organize and attended the "Maturity Assessment, Reproductive Variability, and Life Strategies" (MARVLS) workshop sponsored by the SWFSC in La Jolla, CA. November 3-5, 2016

Sabrina Beyer

- Presentation entitled "Changing fishing practices through outreach to decrease post-release mortality of overfished rockfish, Western Groundfish Conference (Newport, OR, Feb. 8-12, 2016)
- Presentation entitled "Interannual variability in larval production of rockfishes (*Sebastes* spp.) in the California Current", 25th annual North Pacific Marine Science Organization (PICES) meeting (San Diego, CA; November 2016)

Neosha Kashef

- Presentation entitled "Effects of hypoxia on embryonic development, larval mortality, and critical swimming speed in rockfishes (*Sebastes* spp), Western Groundfish Conference (Newport, OR, Feb. 8-12, 2016)
- Poster entitled "Effects of hypoxia on embryonic development, larval mortality, and critical swimming speed in rockfishes (*Sebastes* spp), Western Society of Naturalists (Monterey, CA, Nov. 10-13, 2016)

David Stafford

- Poster entitled "Effects of hypoxia on intraovarian development of *Sebastes*: from egg to larva, Western Groundfish Conference (Newport, OR, Feb. 8-12, 2016)
- Poster entitled "Effects of hypoxia on intraovarian development of *Sebastes*: from egg to larva, Western Groundfish Conference Western Society of Naturalists (Monterey, CA, Nov. 10-13, 2016)

Cyril Michel

- Presentation entitled "The Black Box for Salmon Survival: Changing Perspectives on Marine Survival and Implications for LifeCycle Models", 34th Salmonid Restoration Conference (Fortuna, CA, April 6-9th, 2016)
- Presentation entitled "Invasive predators and the plight of the California salmon: old problems requiring novel tools", NOAA NMFS PIFSC Inouye Regional Center (IRC), Sept. 9, 2016.
- Presentation entitled "Invasive predators and the plight of the California salmon: old problems requiring novel tools", NMFS California Central Valley Office Fish Monitoring Workshop (Sacramento, CA, Sept. 22, 2016)
- Presentation entitled "Insight into the Diets of the Primary Fish Predators of the California Delta using DNA Barcoding, and Implications for Salmonid Populations", 2016 Bay-Delta Science Conference (Sacramento, CA, Nov. 15-17th, 2016)



Nick Demetras

- Presentation entitled “Development of Predation Event Recorders (PERs) to Quantify Predation of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) in a River Environment”, 2016 Bay-Delta Science Conference (Sacramento, CA, Nov. 15-17th, 2016)

Brendan Lehman

- Poster entitled “The relationship between Chinook Salmon swimming performance and water characteristics in the San Joaquin River, CA”, 34th Salmonid Restoration Conference (Fortuna, CA, April 6-9th, 2016)
- Poster entitled “Quantifying Factors That Influence Salmon Smolt Predation in the San Joaquin River”, 2016 IEP Annual Workshop (Folsom, CA, April 20-22, 2016)
- Presentation entitled “The Relationship Between Chinook Salmon Swim Performance and Water Characteristics in the San Joaquin River, CA”, 2016 IEP Annual Workshop (Folsom, CA, April 20-22, 2016)
- Presentation entitled “Fish Physiology at the Southwest Fisheries Science Center”, NMFS California Central Valley Office Fish Monitoring Workshop (Sacramento, CA, Sept. 22, 2016)
- Poster entitled “Water Quality in the Delta and Chinook Salmon: a hot issue with murky consequences”, 2016 Bay-Delta Science Conference (Sacramento, CA, Nov. 15-17th, 2016)

Megan Sabal

- Poster entitled “Seasonal Movements and Distribution of Central Valley Striped Bass (*Morone saxatilis*)”, 2016 Bay-Delta Science Conference (Sacramento, CA, Nov. 15-17th, 2016)

Suzanne Manugian

- Presentation entitled “Acoustic Detection, Tracking, and Enumeration of Salmon Smolt Predators”, 2016 Bay-Delta Science Conference (Sacramento, CA, Nov. 15-17th, 2016)

Miles Daniels

- Presentation entitled “Coupling Watershed, Reservoir, and River Models for Cold-Water Chinook Salmon Habitat Management”, at the Association for the Sciences of Limnology Oceanography Aquatic Sciences meeting (Honolulu, HI, Feb. 27th – March 3rd, 2017)
- Presentation entitled “Coupling headwaters, reservoirs, and rivers to model water flows and temperatures”, at 2016 Bay-Delta Science Conference (Sacramento, CA, Nov. 15-17th, 2016)
- Poster (helped prepare) entitled “Emigration rate with river flow and temperature of Sacramento River Winter-Run Chinook Salmon”, at 2016 Bay-Delta Science Conference (Sacramento, CA, Nov. 15-17th, 2016)
- Attended the 2016 AGU conference (San Francisco, CA, Dec. 12-16th, 2017)

Peter Dudley

- Presentation entitled “inSALMO in Progress: An IBM for Winter Run chinook on the upper Sacramento” at *Sacramento River Stakeholders Meeting* (August 18, 2016)
- Presentation entitled “inSALMO: An IBM for Winter Run chinook on the upper Sacramento” *Sacramento River Stakeholders Meeting* (April 25, 2017)
- Presentation entitled “inSALMO in Progress: An IBM for Winter Run chinook on the upper Sacramento” at *Upper Sacramento River Meeting* (Aug 25, 2017)
- Attended *Stream Salmonid Simulator (S3) Chinook Salmon Population Dynamics Model Workshop* (October 5-6, 2016)
- Attended *2017 IEP Annual Workshop* (March 1-3, 2017)

Ann-Marie Osterback

- Presentation titled: “Evaluating factors that limit recovery of central California coast steelhead: insights from long-term monitoring in the Scott Creek watershed. Invited Speaker, 2nd Salmonid Restoration Federation



Steelhead Summit, (San Luis Obispo, CA, October 27-28, 2016)

- Attended California Coastal Monitoring Program Workshop, California Department of Fish and Wildlife (Sacramento, CA, May 17-18, 2016)
- Presentation titled: "The effects of early sandbar formation on the ecology and population dynamics of steelhead and coho salmon in the Scott Creek lagoon". 34th Annual Salmonid Restoration Federation Conference (Fortuna, CA. April 6-9, 2016)

Emerson Kanawi

- Poster titled "Changes in the distribution and abundance of juvenile coho salmon in Scott Creek during an extreme drought event", 34th Annual Salmonid Restoration Federation Conference (Fortuna, CA. April 6-9, 2016)
- Poster titled: "Rethinking habitat boundaries: evidence of movement between coastal watersheds by juvenile and adult coho salmon and steelhead", 35th Annual Salmonid Restoration Federation Conference (Davis CA, March 31, 2017)

Alice Thomas-Smyth

- Presentation titled, "Assessing the Accuracy of High Spatial Resolution Effort Data: Comparing VMS and Logbook Data in the California Groundfish Trawl Fishery", International Institute for Fisheries Economics and Trade Forum (7/12/16, Scotland).
- Presentation titled "VMS Tools: Developing tools in ArcGIS for improved access and analysis of fine-scale spatial data", North American Association of Fisheries Economics Forum (3/22/17, La Paz, Mexico)

Hayley Nuetzel

- Poster Presentation titled, "Using SNP-based parentage inference to estimate contribution of coho salmon (*Oncorhynchus kisutch*) from Iron Gate Hatchery to production in the Shasta River.", Coastwide Salmonid Genetics Meeting (June 2016, Astoria OR).

Anthony Clemento

- Presentation titled, "Reintroduction Conjunction: restoring spring-run Chinook salmon in California's Central Valley.", Coastwide Salmonid Genetics Meeting (June 2016, Astoria OR).
- Presentation titled, "Reintroduction Conjunction: restoring spring-run Chinook salmon in California's Central Valley.", San Joaquin River Restoration Program Science Meeting (August 2016, Fresno CA).

Ellen Campbell

- Poster presentation titled, "Intensive monitoring and genetic pedigree reconstruction reveals effects of introduced rainbow trout on population dynamics and life-history traits of endangered marble trout in Slovenia.", Coastwide Salmonid Genetics Meeting (June 2016, Astoria OR).

Cassandra Columbus

- Poster presentation titled, "Identifying stock of origin of coho salmon (*Oncorhynchus kisutch*) sampled at sea.", Coastwide Salmonid Genetics Meeting (June 2016, Astoria OR).

Matthew Campbell

- Presentation titled, "Relationships of early-branching euteleosts based on evidence from ultra-conserved genome elements: Concatenation and the coalescent model produce largely congruent hypotheses.", Coastwide Salmonid Genetics Meeting (June 2016, Astoria OR).

Dale Robinson

- Attended the Jet Propulsion Laboratory's PO.DAAC User Working Group meeting in Pasadena, CA on April 11-14, 2017
- Attended the Ocean Optics meeting in Victoria BC on Oct. 25-28, 2016
- Presented an invited talk titled, "Easy access to satellite environmental data for use with the seascape genetic approach" at the Western Naturalist Society's Seascapes Genetics Symposium in Monterey, CA on Nov. 10, 2016



- Attended the NOAA Data Assimilation Task Team meeting at UCSC in July 11-13, 2016
- Attended and was a session organizer for the Eastern Pacific Ocean Conference at Timberline Lodge OR on Sept. 21-24, 2016

Ryan Driscoll

- Attended the course Age Structured Model in Fisheries Stock Assessment at the University of Washington in Seattle, Washington, March 21-25, 2016.
- Participated in the Winter AMLR data planning meeting at the Southwest Fisheries Science Center in La Jolla, California on December 2, 2016.

Colin Nichol

- Poster presentation: 'The confounding factor of 'ghost' PIT tags: A case study from Scott Creek, CA' (poster with co-authors Lea Bond, Joe Kiernan, Tommy Williams, and Brian Spence)

Juan Zwolinski

- Attended to PICES Symposium on small pelagic fishes, March 6-11, 2017, Victoria, BC, Canada, and presented the talk *Use of environmental indices to predict the recruitment of Pacific sardine*
- Participated in the 2017 PFMC Pacific Sardine Stock Assessment Review, February 21-24, La Jolla, as a member of the Pacific sardine stock assessment team
- Attended Trilateral Sardine Forum, December 8-9 2016, San Diego, and presented the talk: *Status of the northern stock of Pacific Sardine*.
- Attended ICES Annual Science Conference, September 19-23 2016, Riga, Latvia, and gave the talk *Four years on: Insights on forecasting a fish stock decline*.
- Attended NOAA 2016 Ocean Satellite course, University of Washington, Seattle, WA, August 26, 2016.
- Participated in the 2016 PFMC workshop to develop methods for conducting assessments of short-lived CPS, May 2-5, La Jolla

Education & Outreach

Communication

a. Mike Jacox:

- US Clivar Webinar "Dominant physical mechanisms driving ecosystem response to ENSO in the California Current System", Feb 2017
- Interviews with CNBC, BBC, Southern California Public Radio, Good Times Santa Cruz, and Earth Magazine on ocean dynamics and recent conditions off the US west coast.

b. Heather Welch:

- Presented a beta version of a dynamic ocean management tool (EcoCast) designed to allow fishers to maximize target catch and minimize bycatch in real-time.

c. Sabrina Beyer:

- Developed a website describing outreach efforts to encourage release of rockfish by recreational fishermen using descender devices to reduce mortality from barotrauma: <https://barotrauma.ucsc.edu>

d. Isaac Schroeder:

- A member of the National and California Current IEA web-page development group. Provided content for the California Current IEA web-page.
- Help maintain the "State of the California Current: Live supplement" web-page of California Cooperative Oceanic Fisheries Investigations (CalCOFI). I provide analysis and updated figures.

e. Joe Bizzarro:

- Revised Habitat Use Database for 117 species of US Pacific Groundfishes, for use by fishery scientists, managers, and interested public.
- Provided open access to R code and User Guide for calculation of the Major Prey Index, to fill a data gap in EFH for US Pacific Coast groundfishes; this was published in a recent special issue of



Environmental Biology of Fishes on feeding ecology.

- Provided standardized diet composition data for juvenile and adult life stages of 18 species of groundfishes to NOAA's Integrated Ecosystem Assessment Team for use in ongoing modeling efforts.

f. Miles Daniels

- CVTEMP Website (<http://oceanview.pfeg.noaa.gov/CVTEMP/>) displays model predictions of water temperature in the Sacramento River Watershed and associated predictions of winter-run salmon health related to temperature-dependent egg survival.

g. Dale Robinson

- Developed the web presence for the Loggerhead Turtle Bycatch Reduction project in conjunction with NOAA Fisheries and the University of Maryland.
- Presented an invited talk titled, "Choosing, acquiring and using satellite data for ecological projects", at the California Academy of Sciences in San Francisco on Feb. 14, 2017.
- Taught the NOAA Satellite in Seattle, WA on Aug. 30-Sept. 1, 2016

h. Juan Zwolinski

- Presented the status of the sardine stock in 2015 assessed by the acoustic-trawl survey to the Pacific Fisheries Management Council Meeting, in April 2016.

Academic Development

- a. Mike Jacox served as Instructor a 4-day Inquiry Institute, developed by the UC Santa Cruz Institute for Scientist and Engineer Educators (ISEE) Inquiry Institute. The institute was the main instructional component of a year-long program that culminates with participants teaching inquiry activities for undergraduates in ~25 venues throughout the US. Participants include ~80 graduate students, postdocs, and professionals.

- b. Joe Bizzarro serves as a member of the graduate thesis committee for Moss Landing Marine Laboratories MS student, Amber Reichert, who is conducting a spatial study on catsharks that incorporates NMFS-SWFSC-FED Habitat Team survey data.

K-12 Outreach

- a. Briana Abrahms delivered an outreach talk to Grade 9-12 high school in Berkeley, CA, titled "Climate change and biodiversity".
- b. Isaac Schroeder co-taught oceanography merit badge to boy scouts troop 2 in Monterey, CA.
- c. Hayley Nuetzel developed and led an outreach program with local high schools (Harbor and Watsonville) to demonstrate how molecular genetic methods are used in the detection of Seafood Fraud. Reported in the Santa Cruz Sentinel.
- d. Neosha Kashef and Sabrina Beyer gave presentations at the California Pacific Collegiate School's Women in Science & Engineering Jr. Club 'lunch with a scientist' program in May 2016. Neosha presented research on the effects of hypoxia and ocean acidification on swimming ability in rockfishes. Sabrina presented research on barotrauma and the use of recompression devices.

Networking

- a. Briana Abrahms gave a public seminar at UC-Berkeley titled "Old dogs, new tricks: using novel behavioral data to refine conservation strategies for an endangered carnivore".
- b. Isaac Schroeder provided data, figures and expertise to the National Marine Sanctuary Condition Reports for Monterey and Channel Islands sanctuaries, and provided text and figures for the 2016 "State of the California Current" annual report for Pacific Fishery Management Council (PFMC).
- c. John Richards attended the annual meeting of the Pacific Coast Congress of Harbor Masters and Port Managers to identify information needs and opportunities and to reach out to port managers for possible engagement in



the “Ports Project” (assessing interdependencies between ports and commercial fisheries).

- d. Carrie Pomeroy and John Richards met with Ventura Port District personnel to introduce the Ports Project and secure permission to conduct a case study (interviews, archival data collection, observation) of the port as part of the project.
- e. Carrie Pomeroy engaged USC, Oregon and Washington Sea Grant; personnel from several CA ports, NOAA personnel, and others to review the survey of port manager drafted (as a deliverable) for the Ports Project.

NOAA Employment

- Andrew Hein, a Ph.D., attained a position with the Southwest Fisheries Science Center in December 2016
- Benjamin Martin, a Ph.D., attained a position with the Southwest Fisheries Science Center in December 2016



Figure 39: Lea Bond (UCSC), August Delforge (CSUMB), Lee Harrison (NMFS/SWFSC), Josh Logan (USGS), Colin Nicol (UCSC) and Kelsey Thompson (CSUMB) completed topographic surveys of the Carmel River, aimed at documenting steelhead habitat changes following the removal of San Clemente Dam. The photo below shows Lea Bond surveying a large pool where a sediment wave can be seen moving through the river channel. (photo credit: Palkovacs Lab, UC Santa Cruz)





Figure 40: Researchers from NMFS's Southwest Fisheries Science Center and CIMEC collect juvenile steelhead in Big Creek (Monterey County) as part of a long-term research project examining the population dynamics of steelhead along the Big Sur Coast. *Photo by T. Williams, NMFS-SWFSC*



Figure 41: CIMEC researcher Rosealea Bond surveys channel topography on the Carmel River as part of a project investigating the physical and ecological responses to dam removal. *Photo by L. Harrison, NMFS-SWFSC.*





Figure 42: LTJG Cherisa Friedlander (NOAA Corps), Ryan Howard (UCSC), Thomas Adams (Humboldt State University), Nick Grunloh (UCSC), Rebecca Miller (UCSC), and LTJG Ryan Belcher (NOAA Corps) sort a fisheries trawl catch of predominantly anchovies and pelagic red crabs near San Nicolas Island, CA, for the Rockfish Recruitment and Ecosystem Assessment survey. The sampling conducted aboard the NOAA R/V Ruben Lasker informs the year-class strength of juvenile rockfish recruitment and the general state of various economically and ecologically important marine species. *Photo Credit: Keith Sakuma*



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:

Steve Miller, Southwest Fisheries Science Center,
NOAA Fisheries

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC
Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Goal 4: Resilient Coastal Communities and
Economies

Budget Amount:

\$236,552

Amendment(s):

24, 44

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.

Research 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.

Research Accomplishments:

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. Supported deployment of NC State’s SeaGlider along transect perpendicular to the Trinidad Head Line. This glider will provide seasonal short-term data to support graduate (PhD) research.

Conferences, Meetings & Presentations

- a. Robertson RR, Bjorkstedt EP. Poster. Changes in euphausiid community structure and size distribution off northern California during the 2014-2016 marine heatwave. Eastern Pacific Ocean Conference, Mt. Hood, OR. September 21-24, 2016.
- b. Bjorkstedt EP, Robertson RR, Damm E, Peterson WT. Poster. Comparing connections of coastal copepod, krill, and ‘chthyoplankton communities to crazy contra-cooling conditions in the California Current. Eastern Pacific Ocean Conference, Mt. Hood, OR. September 21-24, 2016.
- c. Bjorkstedt EP, Robertson RR, Peterson WT. Zooplankton indicators of ecosystem productivity in the northern California Current: seasonal patterns and responses to recent climate forcing. CalCOFI Annual Meeting, La Jolla, CA. December 5-7, 2016

Education & Outreach

Communication

- a. Presentation at Lost Coast Interpretative Association
Brian Tissot presented to the public at an open meeting in Garberville, CA where he provided updated information on ocean conditions on the Trinidad Line included productivity and harmful algal blooms
- b. Presentation to the Trinidad Rancheria Tribal Council
Brian Tissot presented to the tribal council at a meeting in Trinidad, CA where he provided information on the Trinidad Line included productivity and harmful algal blooms
- c. Radio Show
Eric Bjorkstedt was a guest on “Thursday Night Talk” a call-in radio show on KHSU (public radio) for a show on climate and coastal ocean, which included discussion of research along the Trinidad Head Line. March 30, 2017.

K-12 Outreach

- a. Science Night at Fuente Nueva Charter School
Eric Bjorkstedt presented rockfish modeling concepts to kids and parents at Fuente Nueva Charter School’s Science Night.

Networking

1. Presentation at the Humboldt Bay Initiative Symposium
Eric Bjorkstedt presented to regional scientists and the public at a bi-annual meeting of the HBI in Eureka, CA where he provided updated information on ocean conditions on the Trinidad Line included productivity and harmful algal blooms
2. Presentation at Multi-Agency Rocky Intertidal Network(MARINe) Annual Meeting
Eric Bjorkstedt presented to west coast scientists and students at the meeting of the HBI in Trinidad, CA where he provided updated information on ocean conditions on the Trinidad Line included productivity and links to intertidal ecosystems



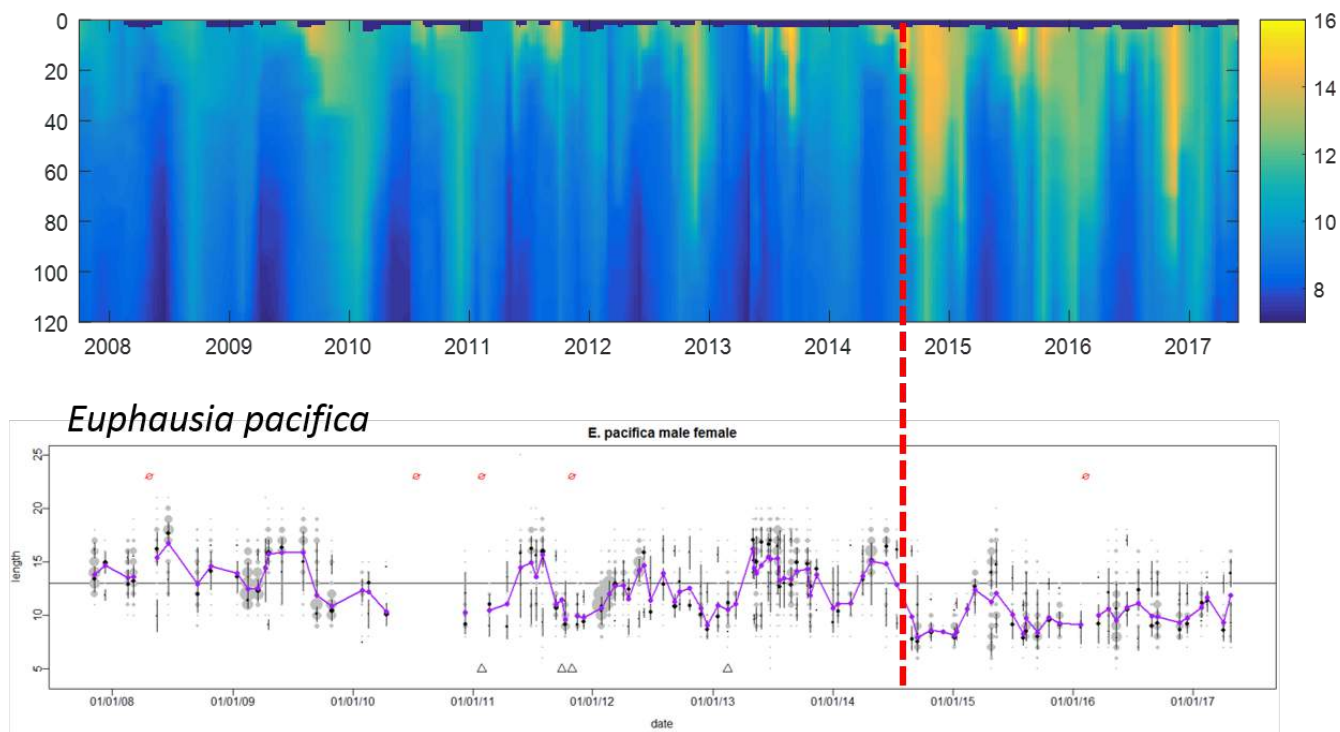


Figure 43: Top Panel: Water column temperature at station TH03 along the Trinidad Head Line. Bottom Panel. Distributions of rostral lengths for adult *Euphausia pacifica* along the Trinidad Head Line. Grey symbols scale with abundance. Purple line tracks mean length. Black dots and lines indicate means and standard deviations of multi-modal distributions. Red dashed line highlights rapid shift to shorter length of adult *E. pacifica* with the arrival of 'warm blob' waters.

Distribution of deep-water coral and sponge habitats off Washington and Oregon and their functional links to demersal fishes

Principal Investigator(s):

Brian Tissot, Director, Marine Laboratory,
Humboldt State University

Other Key Personnel:

Sean Rooney, Washington State University
Vancouver

Chris Rooper, NOAA AFSC

NOAA Primary Contact:

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

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC
Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Goal 4: Resilient Coastal Communities and
Economies

Budget Amount:

\$37,821

Amendment(s):

54

Description of Research:

We utilized pre-existing data from ROV video surveys on Heceta Bank, OR and the Olympic Coast National Marine Sanctuary (OCNMS), WA to synthesize information on the spatial ecology of deep-sea corals and sponges (DSC) and to compare how and under what conditions DSC habitats are utilized by managed fishes. We also developed a series of predictive habitat-suitability models for DSC on Heceta Bank, by integrating observations of DSC with environmental information derived from multibeam bathymetry, satellite imagery, and oceanographic models. The model outputs were used to generate maps of

high probability DSC habitats be compared to existing spatial management restrictions to identify areas needing additional protection. All data collected will be made available as soon as possible to other researchers and managers via web-based archives, online seminar and technical reports.

Research Objectives:

1. Conduct a quantitative analysis of data from ROV surveys collected on Heceta Bank and the OCNMS to evaluate the distribution of DSC habitats and associated fishes and to characterize how these habitats are utilized by these fishes both within and between these deep rocky banks.
2. Develop habitat suitability models for DSC on Heceta Bank, utilizing existing DSC presence observations and environmental variables derived from multibeam bathymetry and other sources, and compare the outputs to existing management closures.

Research Accomplishments:

All objectives have been completed. Data have been analyzed and models were developed. All information was summarized in two chapters of S. Rooney's PhD dissertation which has been published. Sean Rooney was hired by NOAA shortly after his PhD defense and now works at the AFSC in Kodiak, AK.

Education & Outreach

Academic Development

a. PhD Dissertation Defense

Sean Rooney presented his deep-sea coral and sponge research at a public talk at Washington State University Vancouver. Nov. 18, 2016.



NOAA Employment

Sean Rooney attained a Post-Doctoral Researcher position with the Alaska Fisheries Science Center, Kodiak in Dec 2016

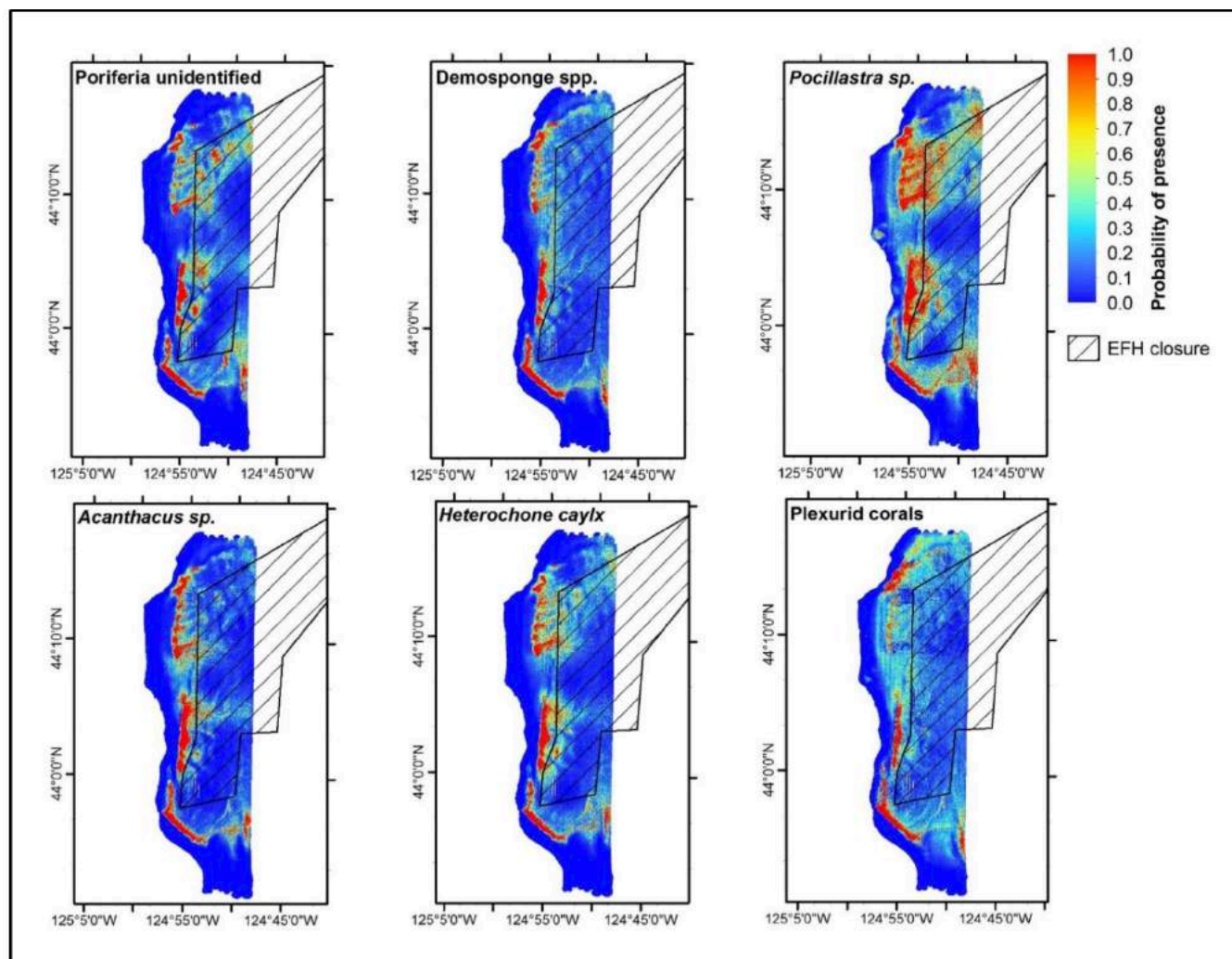


Figure 44: Predictions of the best-fitting MaxEnt models for unidentified Porifera, Demosponges, Poecillastra sp., Acanthascus sp., H. calyx, and Plexaurid corals predicting the probability of presence on Heceta Bank, OR. The striped lines denote the extent of Heceta Bank Essential Fish Habitat closure to bottom trawling.



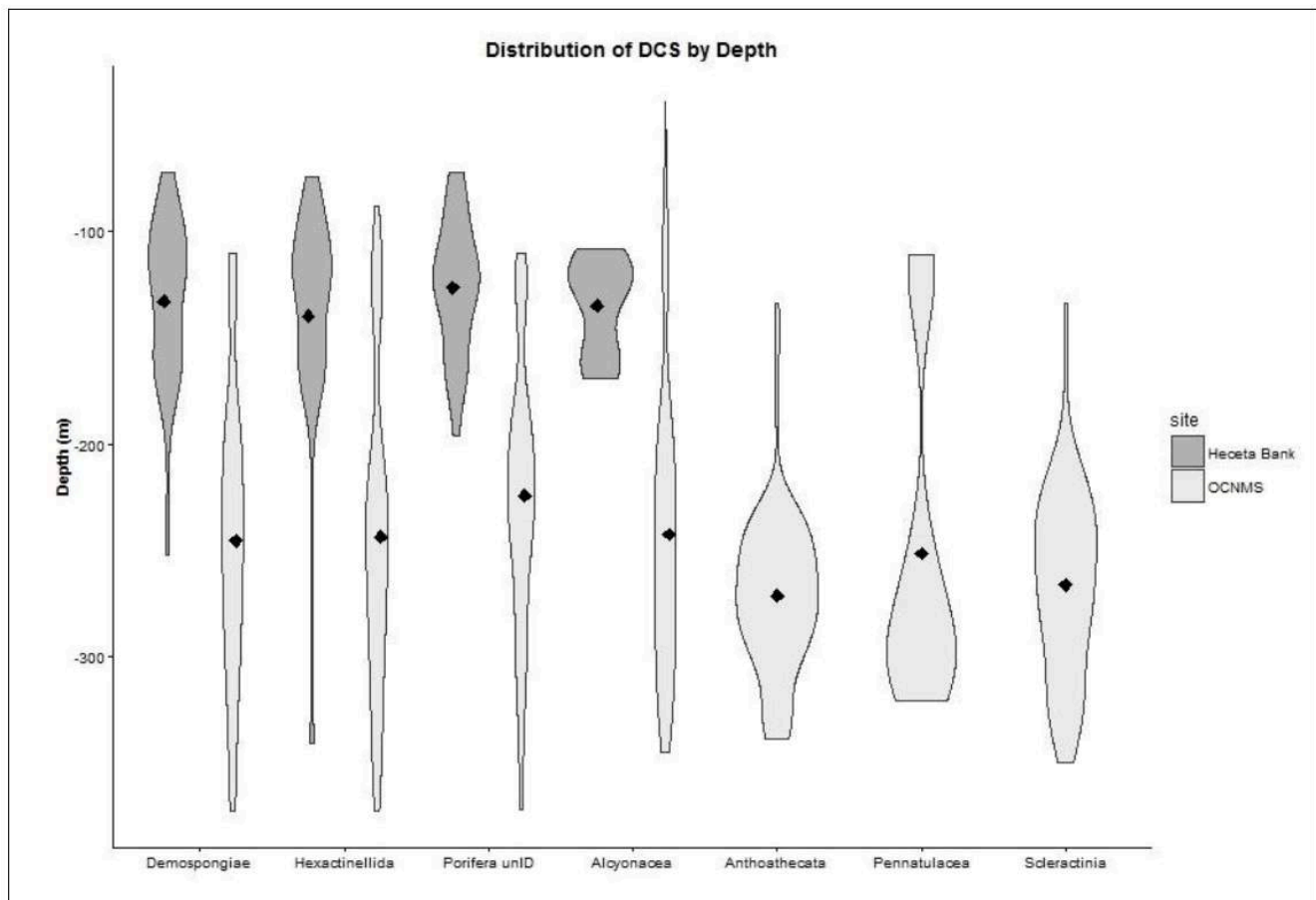


Figure 45: Depth distributions of major deep-sea coral and sponge taxa at Heceta Bank and the Olympic Coast National Marine Sanctuary (OCNMS). Mean depth (\diamond). Width of each distribution polygon at any given depth is proportional to the percentage of observations at that depth (m).

Freshwater Fish Ecology Research Collaboration

Principal Investigator(s):

Darren Ward, Department of Fisheries Biology,
Humboldt State University

NOAA Primary Contact:

Steve Miller, Southwest Fisheries Science Center,
NOAA Fisheries

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC
Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Budget Amount:

\$166,088

Amendment(s):

17, 50

Description of Research:

This project supports a long-term collaboration between the Department of Fisheries Biology at Humboldt State University (HSU) and NOAA Fisheries (SWFSC and West Coast Region Northern California Office), with a focus on salmon conservation in Northern California and the Klamath River basin. The collaboration is implemented through partial funding for a faculty position held by Dr. Darren Ward at HSU to develop research projects focusing on evaluation of restoration effectiveness, population monitoring techniques, and issues related to restoration of salmon production in the Klamath River. Project funding allows this position to continue as a 50% research and 50% teaching appointment, as compared to typical 100% teaching appointments at HSU, to allow research efforts that complement NOAA Fisheries efforts and fill needs for management and conservation planning. Recent funding also directly supports graduate training and population assessment for listed species.

Research Objectives:

1. Conduct research projects and mentor graduate students working on research projects relevant to salmon conservation efforts in Northern California and the Klamath River basin.
2. Estimate abundance and life history diversity for listed coho salmon populations in tributaries of Humboldt Bay, California.

Research Accomplishments:

- Graduate student Michelle Krall completed her Masters research evaluating constructed off-channel ponds on the main stem Klamath River and tributaries as summer rearing habitat for juvenile coho salmon. Michelle defended her thesis titled "The influence of habitat characteristics on abundance and growth of juvenile coho salmon in constructed habitats in the middle Klamath River basin" in May 2016.
- Graduate student Molly Gorman completed her Masters research comparing the fate of Klamath River coho salmon that rear in natal streams that provide suitable seasonal habitat to those that move to non-natal streams when seasonal conditions in their natal streams become unsuitable. Molly defended her thesis titled "Juvenile survival and adult return as a function of freshwater rearing life history for coho salmon in the Klamath River basin" in November 2016.
- Graduate student Justin Alvarez completed his Masters research using field data and a bioenergetics simulation to estimate consumption of hatchery and wild salmon in the Trinity River (Klamath River tributary). Justin defended his thesis titled "Abundance, growth, and predation by non-native brown trout in the Trinity River, CA" in April 2017.
- Graduate student Gabe Scheer completed his thesis research formulating and



parameterizing a population model for coastal coho salmon populations to evaluate extinction risk and restoration scenarios. Gabe will defend his thesis in summer 2017.

- New graduate student Grace Ghrist started work on her project to link juvenile life history and marine survival of coho salmon from Humboldt Bay tributaries.

Honors and Awards

- a. Darren Ward was awarded tenure at Humboldt State University in August 2016.

Conferences, Meetings & Presentations

- a. -Darren Ward and project graduate students Justin Alvarez, Molly Gorman, Michelle Krall, and Gabe Scheer attended the Salmonid Restoration Federation annual meeting held in Fortuna, California from April 6-9, 2016. Justin Alvarez and Gabe Scheer presented research results.

Education & Outreach

Academic Development

- a. Graduate and undergraduate training in Fisheries Biology
Train undergraduate and graduate students in Fisheries Biology. Teach the following courses: Fisheries Science Communication (28 students), Biology of Pacific Salmon (25 students). Primary research advisor for 4 current graduate students. Serve on graduate committees for 8 current graduate students.

K-12 Outreach

- a. Fish Biology and Fisheries Science Workshops
Darren Ward worked with Humboldt County Office of Education's gifted and Talented Education (GATE) to present two hour-long workshops on fish habitat, ecology and morphology for fifth-grade students in an

effort to introduce elementary students to fish biology and fisheries science.

Networking

- a. Presentation to California Department of Fish and Wildlife Arcata Office

Darren Ward presented results of New Zealand mud snail research to biologists from California Department of Fish and Wildlife to guide efforts to identify sites vulnerable to mud snail invasion.

NOAA Employment

Molly Gorman attained a position with the West Coast Region Northern California Office in March 2017.





Figure 46: Humboldt State University undergraduate students participating in the CIMEC-supported coho salmon sampling effort at Freshwater Creek, a tributary of Humboldt Bay, California. The project entails individually marking thousands of juvenile coho salmon in order to characterize variation in seasonal survival and life history in response to annual flow regime.

Theme D: Ecosystem-based Management

Advancements to Passive Acoustic Studies in the Central and Western Pacific Ocean

Principal Investigator(s):

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

Other Key Personnel:

Marie Roch, Department of Computer Science, San Diego State University

NOAA Primary Contact:

Erin Oleson, Pacific Islands Fisheries Science Center, NOAA Fisheries

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme D: Ecosystem-Based management

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Budget Amount:

\$195,000

Amendment(s):

15

Research Objectives:

The central and western Pacific is an expansive region that can be challenging and expensive for conducting visual marine mammal surveys. Passive acoustics provide an alternative method to gain insights into the presence and distribution of vocalizing cetaceans in remote areas. Pacific Islands Fisheries Science Center (PIFSC) has been carrying out long-term acoustic monitoring in collaboration with Scripps Institution of Oceanography (SIO) since 2006. We are proposing advancements both in data analysis as well as instrumentation for passive acoustic monitoring.

Specifically, we propose to (1) analyze previously collected data for beaked whale presence and investigate species classification, and (2) build a

new instrument, make improvements to existing PIFSC equipment, and assist PIFSC with further data collections. This effort is in conjunction with NOAA's mission to protect marine mammals, as mandated by the Marine Mammal Protection Act.

Research Accomplishments:

Passive acoustic data collected at two sites in the Northern Mariana Islands region, site names Saipan and Tinian, were analyzed for beaked whale signals. In recordings from Saipan during the time period of July 2013 through May 2015, signals from Blainville's beaked whales (*Mesoplodon densirostris*), Cuvier's beaked whales (*Ziphius cavirostris*), and a signal of unknown origin, described as BWC and possibly belonging to ginkgo-toothed beaked whales (*M. ginkgodens*) were detected. The three signal types occurred regularly throughout the monitoring period, although acoustic encounters with the BWC type was generally at lower numbers. Beaked whale acoustic encounters at Tinian were dominated by Blainville's beaked whales, with only a single detection of the BWC signal at this site and no detections of Cuvier's beaked whales.

Acoustic data collected at a site off Kona, Hawaii, was searched for repetitive patterns in echolocation signals of dolphin species to possibly determine species-specificity. Two patterns were determined that have not yet been described but regularly occurred with stable spectral and temporal parameters. Further investigation will be required to find these patterns in additional available long-term passive acoustic data and towed array data to determine if these patterns are indeed species-specific.

A new high-frequency acoustic recording package has been built and delivered. Improvements have been made to existing PIFSC equipment and this effort as well as fieldwork assistance is being continued.



Research Highlights

- Passive acoustic data has been analyzed for beaked whale presence in data from two sites at the Northern Mariana Islands.
- Two delphinid echolocation signal types have been defined from around the Hawaiian Islands and origin is being explored.
- A new high-frequency acoustic recording package was built and delivered and improvements were made to existing PIFSC equipment

Education & Outreach

Fellowship Programs/Internships

- Assist graduate student Anne Simonis in defining echolocation click types in acoustic data from Hawaiian Islands

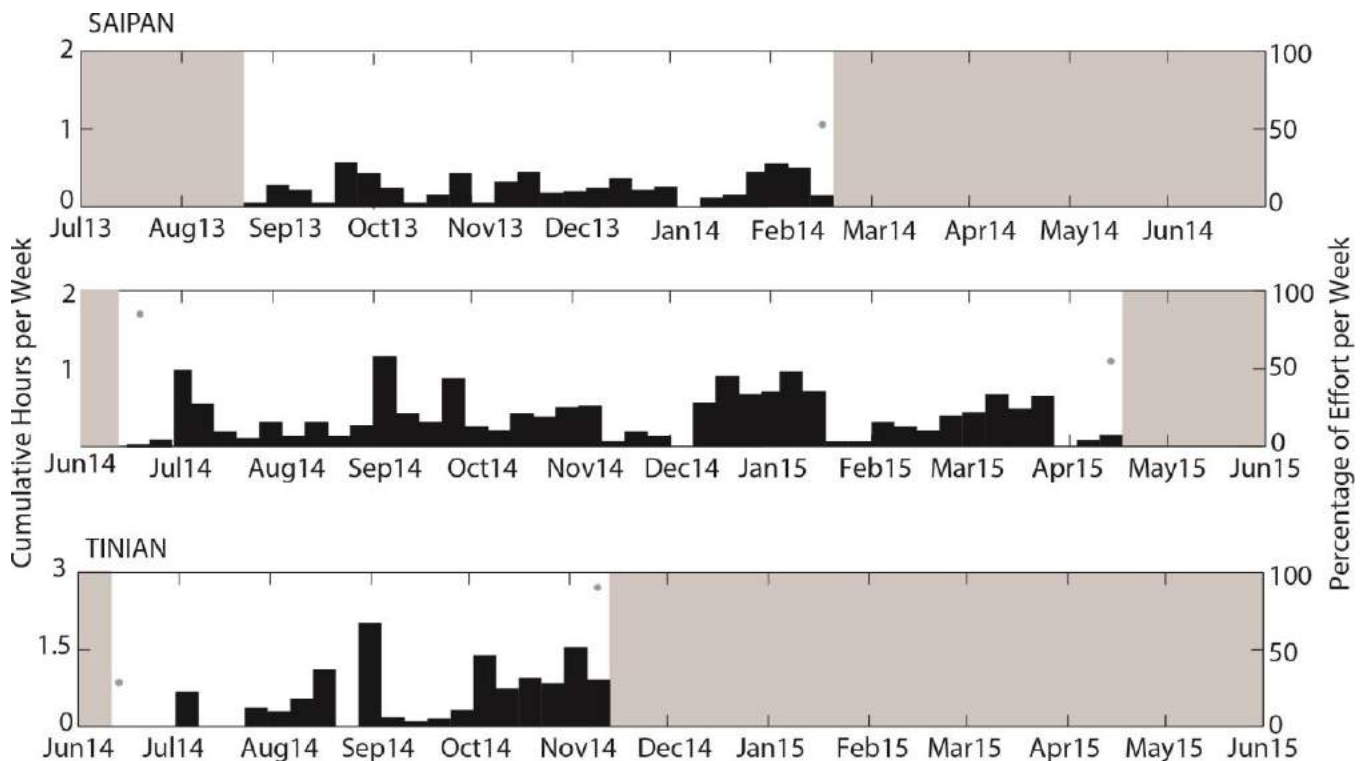


Figure 47: Weekly occurrence of Blainville's beaked whales at Saipan in 2013–2015 (upper and middle panel) and at Tinian in 2014–2015 (bottom panel). Periods with no data are shown as gray boxes. Gray dots indicate less than a full week of available data.



Captive Broodstock Development in the Endangered White Abalone, *Haliotis sorenseni*

Principal Investigator(s):

Gary Cherr, University of California, Davis,
Bodega Marine Laboratory

Other Key Personnel:

Kristin Aquilino, University of California, Davis,
Bodega Marine Laboratory

NOAA Primary Contact:

Melissa Neuman, West Coast Regional Office,
NOAA Fisheries

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC
Collaboration

NOAA Theme:

Theme D: Ecosystem-Based management

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Budget Amount:

\$84,999

Amendment(s):

23

Description of Research:

Our objective is to establish a successful captive propagation program as an integral part of the recovery of white abalone (*Haliotis sorenseni*), the first marine invertebrate designated by the federal government as an endangered species (Federal Register 65 FR 2616 and 66 FR 29046). White abalone was designated as one of eight "Species in the Spotlight" by NOAA Fisheries in 2015. These species are among those most at risk of extinction in the near future. NOAA's 2008 recovery plan for the white abalone dictates that captive propagation efforts continue to expand and improve and eventually produce offspring for outplanting to the wild. With numbers of white abalone in the wild continuing to decline and an aging captive population, it is urgent and imperative that we increase the numbers of white abalone broodstock through captive propagation.

Products from the proposed work include maintaining the white abalone captive propagation and culture facilities at University of California, Davis's Bodega Marine Laboratory (BML), successful reproductive conditioning and spawning of existing captive broodstock, culture of the resulting offspring, and a fuller understanding of the environmental parameters that control reproduction in the endangered white abalone, including diet and photoperiod.

We have met the goals of white abalone recovery through captive breeding by continuing to increase our captive population of white abalone, enhancing the genetic diversity of our white abalone broodstock, and strengthening collaborations with our partners, including NOAA, CDFW, Aquarium of the Pacific, Cabrillo Marine Aquarium, Santa Barbara Museum of Natural History Sea Center, UC Santa Barbara, and The Cultured Abalone Farm.

Research Objectives:

The major research objective for this project is to create a large, sustainable, and genetically diverse captive population of white abalone to be used for outplanting.

Research Accomplishments:

In September, BML received permission from NOAA to collect new wild broodstock for the white abalone recovery program. To date, seven new wild white abalone have been collected. One of these animals collected in late January 2017 spawned 700,000 eggs during the March 2017 spawning attempt at BML, marking the first time in 14 years new genes have been introduced into the captive white abalone progeny.

Captive breeding success remains high, with approximately 9,000-year-old white abalone resulting from the 2016 spawning attempts. The spawning attempt at BML in 2017 was equally as successful as our 2016 attempt, demonstrating



that we can maintain high levels of reproduction among our captive broodstock.

Honors and Awards

- a. Dr. Kristin Aquilino received the Species in the Spotlight Hero Award from NOAA for her work trying to save the endangered white abalone. The award was presented to her in Silver Spring, MD on May 1, 2017 by Sam Rauch, Acting Assistant Administrator for NOAA Fisheries.
- b. Dr. Aquilino and her work with white abalone have also been featured by the following:
 - NPR Science Correspondent Joe Palca's Friends of Joe's Big Idea (http://www.npr.org/2016/11/11/496536328/fojbi-friday-meet-kristin-aquilino-snatching-white-abalone-back-from-the-brink?utm_medium=twitter&utm_campaign=storiesfromnpr&utm_source=dlvr.it)
 - Women in Aquaculture (<https://www.facebook.com/womeninaquaculture/posts/380546448963449:0>)
 - The Council on International Educational Exchange Alumni of the Month (<http://alumni-news.ciee.org/2017/04/from-costa-rica-to-california-one-study-abroad-alums-quest-to-save-an-endangered-species.html>)
 - Jenn Halweil's "Beyond the Boundary" (<https://www.instagram.com/p/BTE5MSijD09/?taken-by=beyond.the.boundary.science&hl=en>)

Conferences, Meetings & Presentations

- a. Dr. Kristin Aquilino attended the 49th Western Society of Malacologists and 82nd American Musicological Society Annual Meeting, Ensenada, Baja California, Mexico on June 12-16, 2016 and presented a talk titled, "Mood lighting and spa treatments: Captive propagation of the endangered white abalone."
- b. Dr. Kristin Aquilino attended the 1st Bi-National Abalone Workshop, Ensenada, Baja California, Mexico on June 17, 2016 and presented a talk titled, "Enhancing captive

reproduction of the endangered white abalone."

- c. Dr. Kristin Aquilino presented at the NOAA Aquaculture retreat held in Silver Spring, MD and presented a talk titled, "The Role of Aquaculture in Saving the White Abalone" on April 26, 2017
- d. Dr. Kristin Aquilino delivered a talk titled, "Playing Matchmaker for a NOAA Spotlight Species: Saving the Endangered White Abalone," at the NOAA Brown Bag Lunch Seminar Series in Silver Spring, MD on May 1, 2017

Education & Outreach

Communication

- a. White Abalone website: Dr. Kristin Aquilino and Dr. Gary Cherr worked with other white abalone recovery partners at UC Davis to develop a web site for UC Davis's white abalone recovery program. The website will go live this summer, and will be a place for people to learn general information about the history of white abalone and the work we are doing to save them.
- b. Science Uncorked seminar series: The general-audience, science outreach seminar series that Dr. Kristin Aquilino co-hosts at a wine bar in Bodega Bay, CA that featured talks about white abalone recovery, including a talk by Ashley Vater in September 2016 titled, "Virus-killing bacteria and research-based biology courses - exploring new ideas with abalone" and a talk by Ben Walker in February 2017 titled, "Guiding our captive white abalone into the big, scary ocean: Restoring an endangered species."
- c. Social media: We have worked to broaden our social media outreach through Facebook (@WhiteAbalone), Twitter (@WhiteAbalone), and Instagram (@white_abalone). Posts to the white abalone Facebook page, an effective social media platform, have been viewed 33,000 times (www.facebook.com/whiteabalone). Our top nine Facebook posts reached an average of about 2,000 viewers per post. Our most



popular post reached 7,200 viewers and received 2,400 interactive responses.

- d. Medium blog post: In January 2017, Dr. Kristin Aquilino authored a blog post on Medium titled, "Top 5 New Year's Resolutions for 2017 (If You're a White Abalone)," which highlighted recovery program efforts (<https://medium.com/@KristinAquilino/top-5-new-years-resolutions-for-2017-if-you-re-a-white-abalone-d0e3698208dc>).
- e. Uplight Blog post: The white abalone captive breeding program was featured in Kelsey Simpkins' "Uplight Blog" on September 25, 2016 (<https://uplightblog.wordpress.com/2016/09/25/science-weekly-saving-white-abalone/>).
- f. KQED story: San Francisco public radio (KQED) featured a story on BML's newly collected wild white abalone in March 2017. This story, titled "Delicious and nearly extinct, can white abalone be saved?" was also picked up by the PBS Newshour (<https://ww2.kqed.org/science/2017/03/17/delicious-and-nearly-extinct-can-white-abalone-be-saved/>).
- g. Ecology Hour on KZYX: Dr. Kristin Aquilino and Melissa Neuman (NOAA Fisheries) participated in a program on white abalone for Northern California radio's KZYX Ecology Hour on September 13, 2016.
- h. Newspaper stories: The white abalone captive breeding program was featured in the following newspapers stories:
 - "White abalone were nearly eaten out of existence in the 1970s. Now, a breeding program aims to revive them," Aaron Orlowski, OC Register, May 29, 2016 (<http://www.ocregister.com/2016/05/29/white-abalone-were-nearly-eaten-out-of-existence-in-the-1970s-now-a-breeding-program-aims-to-revive-them/>).
 - "The decline and hopeful resurgence of Southern California's abalone population," Sandy Mazza, Daily Breeze, August 28, 2016
*<http://www.dailybreeze.com/environmen-t-and-nature/20160828/the-decline-and-hopeful-resurgence-of-southern-californias-abalone-population>).
- i. UC Davis press: The program was featured in a number of UCD press pieces, including:
 - A 360° video of the White Abalone Culture Facility at BML (<https://youtu.be/B-FiDUIY6aQ>) by UC Davis multimedia specialist Joe Proudman was released in November 2016. Joe also photographed the white abalone facilities in May 2017.
 - A piece about UC President Janet Napolitano visiting BML (<https://www.universityofcalifornia.edu/news/uc-president-tours-bodega-marine-lab-and-reserve>).
 - A piece about the collection of new wild white abalone by Kat Kerlin titled "Only the lonely: Captive white abalone get a while new addition" was published on UC Davis' One Health Blog in November 2016 (<https://www.ucdavis.edu/one-health/captive-white-abalone-get-a-new-addition>).
- j. NOAA press: NOAA fisheries published an online piece titled, "Collection of white abalone boosts recovery efforts" in November 2016 (http://www.westcoast.fisheries.noaa.gov/stories/2016/10_11102016_breeding_white_abalone.html).
- k. Scientia story: The popular press magazine, Sientia, published a story on white abalone in May 2017 titled "Bringing white abalone back from the brink" (<http://www.scientia.global/dr-kristin-m-aquilino-professor-gary-cherr-bringing-white-abalone-back-brink/>).
- l. Other press collaboration: We have collaborated with professional photographers and journalists to create photographic media for outreach purposes. Bio Geographic Magazine journalist Gloria Dickie, and freelance photographer Michael Ready, documented the white abalone broodstock spawning event conducted at BML on March



1, 2017. A reporter from CBC was present at a white abalone spawning attempt in March.

Academic Development

- a. Dr. Kristin Aquilino attended a Science Communication Workshop at Bodega Marine Lab in November and December 2016. The workshop was led by UC Davis Professor and AAAS Public Engagement Fellow Dr. Tessa Hill, and covered science-policy integration, honing messages for media, interview skills, public speaking, and social media.

K-12 Outreach

- a. Visit to Pacific Grove High School: Dr. Kristin Aquilino spoke to students at Pacific Grove High School about the white abalone recovery program in November 2016.
- b. Video-Chat with Illinois kindergarteners: In May 2017, Dr. Kristin Aquilino hosted a video chat with approximately 50 kindergarteners from Elmhurst Community School district 205 in Elmhurst, IL, explaining her white abalone recovery work and showing off abalone and other marine critters.
- c. REACH Charter School visit: In May 2017, Dr. Kristin Aquilino hosted 23 2nd- and 3rd-grade students from REACH Charter School in Santa Rosa, CA at UC Davis Bodega Marine Laboratory for a tour of the White Abalone Culture Facility and activities related to white abalone recovery.

Networking

- a. Collaborative white Abalone spawning attempt: Dr. Kristin Aquilino coordinated a collaborative white abalone spawning effort between partners at Aquarium of the Pacific, Cabrillo Marine Aquarium, and the Santa Barbara Museum of Natural History Sea Center in March 2017. Other participating partners were the California Science Center, Get Inspired!, and the Southwest Fisheries Science Center. The main purpose of this event was to produce more white abalone offspring; however, it also served to bring partners together to exchange information and ideas.

- b. Bodega Marine Lab 50th Anniversary Events: In September 2017, UC Davis BML celebrated its 50th anniversary with two events, both of which featured white abalone displays. The first event was for donors to the lab and public figures, including US Congressman Mike Thompson and CA Representative Jim Wood, who both visited the white abalone display. The second event hosted thousands of UC Davis alumni from the past five decades.
- c. Presentation at Hopkins Marine Station: Dr. Kristin Aquilino presented at Drs. Giulio De Leo and Fio Micheli's labs to make them aware of the different aspects of the white abalone recovery program and discuss potential areas for collaboration.





Figure 48: Dr. Kristin Aquilino holds a newly collected white abalone at Aquarium of the Pacific as it is prepared for transport to UC Davis Bodega Marine Laboratory. This was the first new white abalone collected in 12 years. Aquilino is surrounded by partners from Aquarium of the Pacific, NOAA Fisheries, and Bodega Marine Laboratory.



Figure 49: A newly collected wild white abalone spawns eggs during a spawning attempt at UC Davis Bodega Marine Laboratory in March 2017. Photo by Michael Ready.



Collaborative Studies Monitoring for Brydes Whales in the Northwestern Gulf of Mexico

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. Melissa Soldevilla, Southeast Fisheries Science Center, NOAA Fisheries

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme D: Ecosystem-Based management

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Budget Amount:

\$72,886

Amendment(s):

47

Description of Research:

This collaborative research deployed long-term acoustic recorders in the Northwestern Gulf of Mexico to monitor for Brydes Whales. 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 deployed to test for Brydes Whales in areas where there were found in the past, but have not been detected recently. Data from these deployments have been recovered and data analysis will be undertaken in the near future.

Research Objectives:

The specific objectives of this project are to:

(1) prepare five acoustic recording packages for use in the Gulf of Mexico; (2) provide personnel, replacement parts, and ship time for HARP deployments and recoveries; and (3) provide initial data processing to convert raw acoustic data to wav files and LTSAs.

Research Accomplishments:

- 1) Five HARPs were prepared.
- 2) These instruments were deployed in the Northwestern Gulf of Mexico.
- 3) Data from these instruments has been recovered and data analysis is underway.

Conferences, Meetings & Presentations

- a. John Hildebrand attended the Acoustical Society of America conference held November 2016 in Honolulu, HI.

Education & Outreach

Communication

- 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. Rebecca Cohen (SIO Graduate student) has been assisting with project data processing.

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. Project team has been attending Acoustical Society and other meetings related to marine mammal acoustics.



Green Sturgeon Habitat Suitability in Response to Drought Related Flow Regimes

Principal Investigator(s):

Peter Klimley, Ph.D., Department of Wildlife, Fish, and Conservation Biology, UC Davis, California

Other Key Personnel:

Michael Thomas, Department of Wildlife, Fish, and Conservation Biology, UC Davis, California

Richard McDonald, M.Sci., Geomorphology and Sediment Transport Laboratory, United States Geological Survey, Golden, Colorado

NOAA Primary Contact:

Joseph Heublein, Central Valley Office, NOAA Fisheries

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme D: Ecosystem-Based management

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Goal 3: Climate Adaption and Mitigation

Budget Amount:

\$42,614

Amendment(s):

28

Description of Research:

The Biotelemetry Laboratory of the University of California, Davis and Geomorphology and Sediment Transport Laboratory have put together a series of habitat suitability models. These are based upon 2-dimensional tracking of green sturgeon. This is an effort to better understand the relationship between the potential population decline, habitat suitability, and knowledge of the remaining post-dam era habitat available to green sturgeon. Records of the movements of green

sturgeon were collected in 2011 and 2012 using a refined acoustic telemetry system (Vemco Ltd., Vemco Positioning System [VPS]) capable of estimating a sturgeon's position within 2 – 4 meters. Hydraulic models, used for predicting habitat suitability, were implemented with The Flow and Sediment Transport with Morphologic Evolution of Channels (FaSTMECH) model within the iRIC modeling interface (www.i-ric.org). Model inputs included topography, water surface elevation, bathymetry, and velocity profiles. Habitat suitability curves were then derived from the baseline hydraulic model and fish positions using depth, velocity, and substrate as predictors for estimating the Wetted Usable Area (WUA), a metric of optimal habitat within each of the studied reaches. We investigate, through modeling, the effect that reduced river discharges has on optimal spawning habitat for Green Sturgeon over a six year period, the first of which had normal rain conditions and the following years drought conditions. With annual rainfall and snow pack falling well below average, discharge operations below Shasta Dam have deviated from normal operations. We summarize drought related discharge, during the spawning season, for the years of 2011-2016. These discharges were run as inputs for the hydraulic modeling and WUA was calculated for each of the three drought years within the three study sites. A comparison of WUA between drought years and those years previously modelled has been made to investigate either the expansion or more likely the contraction of available optimal habitat within each of the three study sites.

Research Objectives:

We summarized drought related discharge, during the spawning season, for the years of 2011-2016. These discharges were run as inputs for the hydraulic model, and WUA was calculated



for a six-year period, including the drought years of 2013, 2014, and 2015. A comparison of WUA between drought years and 2011, when flows were above average, were made to investigate either the expansion or more likely the contraction of available optimal habitat within each of the three study sites.

Research Accomplishments:

To date we have finalized the baseline model that was in progress at the time of this contract being issued. Now that the baseline model is complete and quantitative values of preference have been assigned to abiotic factors, we have conducted model simulations for drought years. The habitat suitability model has been run for six years from 2011-2016.

Conferences, Meetings & Presentations

- a. Peter Klimley, Ph.D., presented results of study at FISHFIT Annual Conference in Belgrade, Serbia, on 22 April 2016

Education & Outreach

Academic Development

- a. Katerina Totic presented presentation, describing use of model to determine Wetted Useable Area for green sturgeon, by Peter Klimley at FISHFIT Sturgeon Workshop in Belgrade, Serbia, on 6 April 2016.

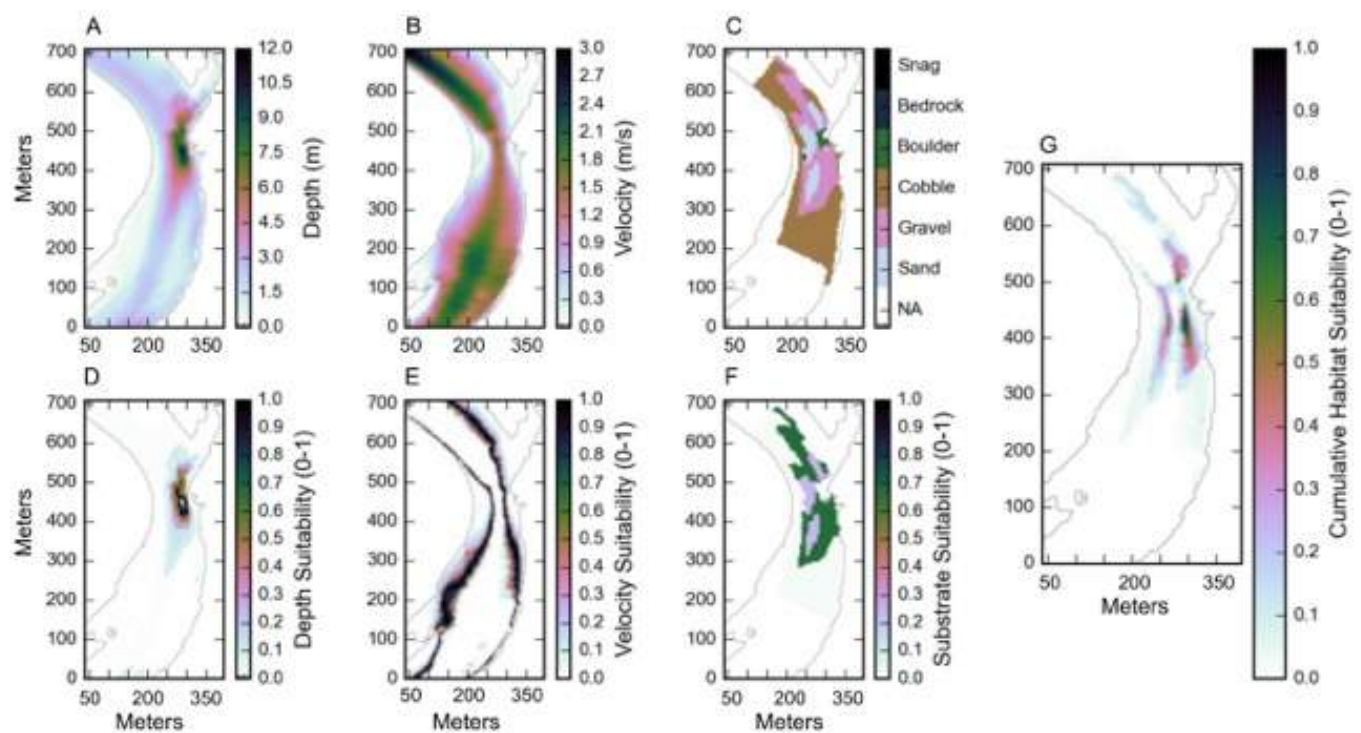


Figure 50: A frame of the animation of habitat suitability at the Site A reach in 2012. Plots A-C display the simulated depth, simulated velocity, and measured substrate based on a discharge. Plots D-F display the habitat suitability indices for each of the three habitat parameters at this discharge level on a scale of 0 – 1 (1 = highest suitability). Plot G depicts the cumulative habitat suitability index calculated as the geometric mean of the suitability indices of the three habitat parameters.



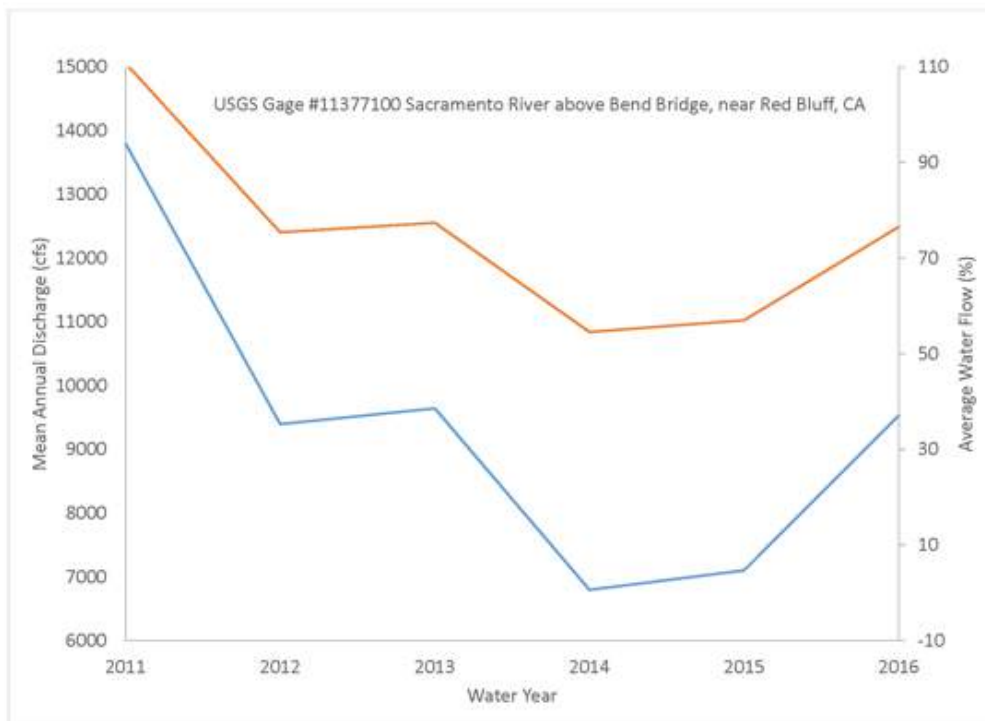


Figure 51: Mean annual discharge (cfs) and percent average yearly water flow as a function of water year based on measurements from USGS Gage #11377100 on Sacramento River above Bend Bridge near Red Bluff.

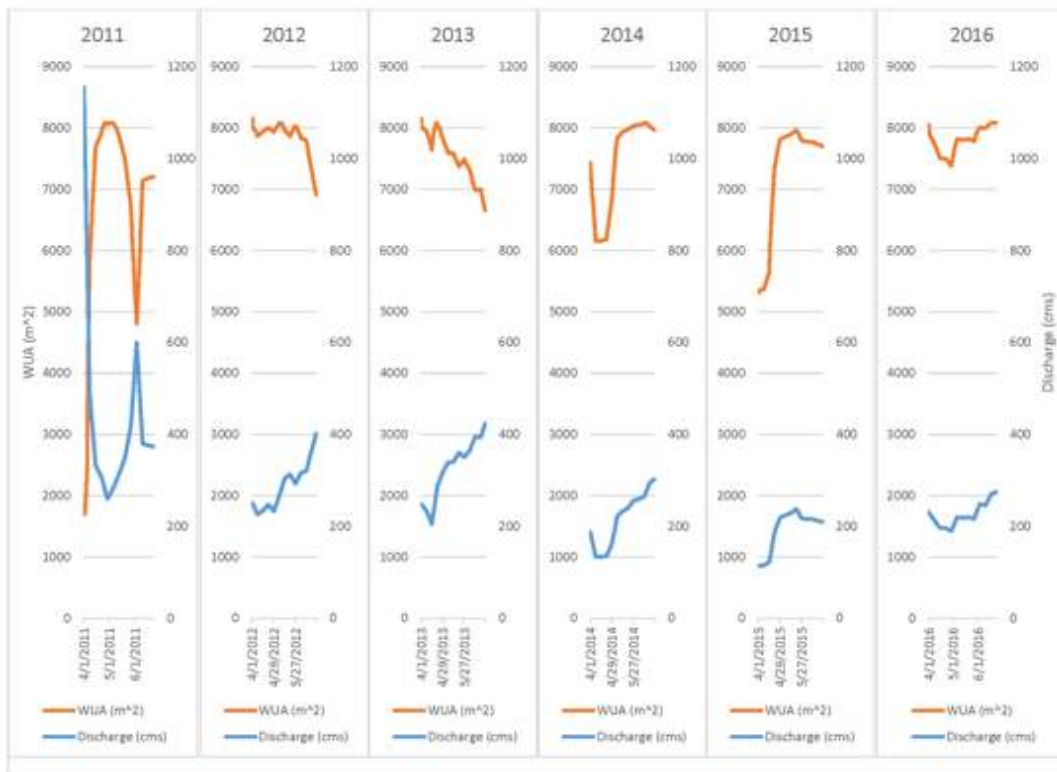


Figure 52: Mean annual discharge (cfs) and percent average yearly water flow as a function of water year based on measurements from USGS Gage #11377100 on Sacramento River above Bend Bridge near Red Bluff.





Figure 53: Weighted usable area (WUA) and discharge (m^3/s) over the observed dates at Paynes, a sturgeon spawning site, during a six-year period from 2011 to 2016. The WUA (m^2) is the sum through the entire modeled reach of the habitat suitability value (0 - 1) at each node in the computational grid, multiplied by the contributing area of that node.



Training the Next Generation of Marine Population Dynamics Scientists

Principal Investigator(s):

Brice Semmens, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Josh Stuart, PhD Graduate Student, SIO

Lynn Waterhouse, PhD Graduate Student, SIO

Brian Stock, PhD Graduate Student, SIO

Noah Ben-Aderet, PhD Graduate Student, SIO

Kayla Blincow, PhD Graduate Student, SIO

NOAA Primary Contact:

Dr. Roger Hewitt, Southwest Fisheries Science Center, NOAA Fisheries

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme D: Ecosystem-Based management

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Goal 3: Climate Adaption and Mitigation

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$394,363

Amendment(s):

16, 53

Description of Research:

In order to support the increased demand for resource assessments and ecosystem-based management, National Oceanographic and Atmospheric Administration (NOAA) requires scientists trained in the development, application, and synthesis of quantitative tools and techniques. NOAA also would be well served by the development of new and/or improved analytic assessment methods that capitalize on existing and emerging survey methods. Towards these

objectives, members of the Semmens Lab carried out (1) training in quantitative resource assessment and population dynamics, (2) graduate student and PI research into resource assessment tools and techniques, and (3) STEM (science, technology, engineering and mathematics) training for K-12 students, and (4) research into cooperative fisheries science for recreational fisheries. The proposed research and training activities will foster a broad base of highly skilled quantitative fisheries scientists and generate a set of tools to facilitate accurate and informative marine resource assessments in an ecosystem context.

During the project performance period, PI Semmens continued his collaboration with other scientists through the Center for the Advancement of Population Assessment Methodology (CAPAM). Other CAPAM principal investigators include Mark Maunder (Inter-American Tropical Tuna Commission, IATTC) and Paul R. Crone (Southwest Fisheries Science Center, SWFSC). This past year, CAPAM PIs and collaborators prepared for upcoming conferences on fisheries recruitment (SEFSC) and spatio-temporal modeling (SWFSC). CAPAM PIs also co-edited a special issue of *Fisheries Research* pertaining to issues addressed in the data-weighting workshop held in 2015. To date, CAPAM personnel have authored over 50 publications directly related to stock assessment methods. Finally, graduate student Lynn Waterhouse, in collaboration with CAPAM personnel, completed the White Seabass stock assessment, and hosted the 2-day assessment review panel on SIO campus.

Semmens Lab members continued to maintain 44 hydrophones deployed as part of the La Jolla Acoustic Array (LJAA). Over the past year, lab members serviced all acoustic receivers (Vemco VR2W) and conducted annual data downloading. The LJAA allows precise monitoring of spatial movement patterns of tagged fish inside and



outside of local Marine Protected Areas (MPAs). Information yielded by telemetry research aids assessments of established MPAs and also guides future MPA planning and design. Additionally, acoustic telemetry can yield biological information, such as spawn timing, and diurnal patterns in movement and site fidelity, which are important for marine species management. This array has supported the research projects of 5 SIO PhD students and postdoctoral researchers to date.

Semmens Lab members continued to build a successful cooperative fisheries research program during the project performance period. PI Semmens, and SWFSC scientists Wegner and Bellquist (former Semmens Lab PhD) carried out collaborative research into the spatial ecology of juvenile Cowcod (*Sebastes levis*) of the California coast, using acoustic and Floy tagging methods. Cowcod are currently overfished, and listed as a Species of Concern by the NOAA. This research, funded through the National Research Coop competition, aims to gain an improved understanding of critical habitat for the species in relation to existing Cowcod Conservation areas along the California coast. PhD student Noah Ben-Aderet concluded collaborative fisheries into Yellowtail (*Seriola lalandi*) movement and behavior using the LJAA. PI Semmens also continued to serve as the UC representative to California's Ocean Resources Enhancement and Hatchery Program.

As part of efforts to broaden the scope of training in fisheries-focused STEM (science, technology, engineering and math) fields, lab members coordinate a series of K-12 education and outreach programs. Each year, PI Semmens leads the Grouper Moon education program, targeting K-12 students throughout the Caribbean and US with a combination of experiential learning curricula, and a web-based "virtual field" component. More than 200 students from 14 different schools participated in the program this year. In San Diego, PI Semmens and lab members coordinated a 1-week STEM short-course in quantitative fisheries science targeting

underrepresented K-12 students from local schools (MARES: Math and Research in Ecology at Scripps).

In addition to the above research/education areas, PI Semmens oversaw 5 PhD students (Lynn Waterhouse, Brian Stock, Josh Stewart, Noah Ben-Aderet, Kayla Blincow), 1 MAS student, 1 MS student and 3 undergraduate volunteers. Students are working on diverse issues in fisheries resource management, including the spatial ecology and population structure of oceanic manta, mark-re-capture studies on locally important recreational marine fish species, the development of novel quantitative tools for abundance and animal movement estimation, stable isotope analysis, and the development of stock assessment methods for data-limited fisheries. Much of this research involves direct collaboration with scientists at the SWFSC (e.g. Wegner, Crone, Eguchi) and the NWFSC (e.g. Ward, Thorson, Scheuerell). During the project performance period, one PhD student successfully defended their PhD (Noah Ben-Aderet), and is currently working as Knauss Marine Policy Fellow.

Research Objectives:

The objective of this project is to support training in marine resource assessment and quantitative population dynamics through ongoing education opportunities, graduate student mentoring, and formal course offerings at Scripps Institution of Oceanography (SIO). Continuing education opportunities in resource assessment are principally organized through the Center for the Advancement of Population Assessment Methodologies (CAPAM), a collaborative program between the Semmens Lab at SIO, the Inter-American Tropical Tuna Commission (IATTC), and the Southwest Fisheries Science Center (SWFSC). Coursework, graduate student mentoring, and research are facilitated jointly through SIO and CAPAM.



Research Accomplishments:

- Lab members authored or co-authored 12 peer-reviewed manuscripts and 1 PhD dissertation
- Lab members authored or co-authored 9 conference presentations
- PI Semmens taught undergraduate courses in statistics and lab and field techniques
- PI Semmens taught a graduate level course in Bayesian modeling with joint attendance by SIO and SWFSC students and scientists
- CAPAM PIs co-edited a species issue of *Fisheries Research*
- Graduate student Lynn Waterhouse, in collaboration with CAPAM personnel, concluded the White Seabass Stock Assessment for the state of California
- Lab members carried out collaborative research related to Cowcod with SWFSC
- Lab members supervised various undergraduate and K-12 students in fisheries research projects
- PI Semmens executed the annual Grouper Moon K-12 education/outreach program for schools throughout the Caribbean and US
- PI Semmens developed and executed the MARES K-12 under-privileged/under-served summer short course in San Diego

Honors and Awards

- a. Brian Stock, UCSD Frontiers of Innovation Scholars Program Award
- b. Brian Stock, NSF Graduate Research Internship Program Award
- c. Lynn Waterhouse, PEO Scholar Award for 2017-2018 Academic year
- d. Lynn Waterhouse, SCRFA Student Travel Award for 2016 GCFI in Cayman Islands
- e. Lynn Waterhouse, WDHOF Graduate Student Research Award (Rachel Morrison Memorial Award) 2017

- f. Lynn Waterhouse, UCSD GSA Travel Award for 2017 AFS in Tampa
- g. Lynn Waterhouse, UCSD Diversity Award as part of SIO Diversity Hire Collective 2017
- h. Dr. Brice Semmens, Appointed as the UC representative, Association of Public & Land-Grant Universities, Board on Natural Resources
- i. Dr. Brice Semmens was invited to give the Keynote speech at the 69th Annual Gulf and Caribbean Fisheries Research Institute, Grand Cayman, Cayman Islands, Nov 2016.

Conferences, Meetings & Presentations

- a. Josh Stewart attended the NOAA Protected Species Assessment Workshop at the NWFSC in Seattle, January 2017.
- b. Dr. Brice Semmens, Brian Stock, and Lynn Waterhouse attended the 69th Annual Gulf and Caribbean Fisheries Research Institute, Grand Cayman, Cayman Islands, Nov 2016. Dr. Semmens gave the keynote speech.
- c. Brian Stock attended the 3rd annual Scripps Student Symposium, La Jolla, CA, Sept 2016.
- d. Dr. Brice Semmens presented at 13th International Coral Reef Symposium, Honolulu, Hawaii, June 2016.
- e. Lynn Waterhouse attended the 2016 Student Conference on Conservation Science – New York (SCCS-NY) in October 2016.
- f. Lynn Waterhouse attended the 2016 Sea Grant/NOAA Fisheries Fellowships in Marine Resource Economics and Population and Ecosystem Dynamics Fellows Meeting, Santa Cruz, CA in June 2016.
- g. Lynn Waterhouse presented and organized the 2016 White Seabass Stock Assessment Review Workshop, La Jolla, CA. California White Seabass Stock Assessment in 2016 at SIO in May 2016.



Education & Outreach

Communication

a. Birch Aquarium, SIO

Josh Stewart gave a public presentation on morbid ray research and management, January 2017. Brian Stock gave a public talk entitled "How can we tell what animals eat?", September 2016. Lynn Waterhouse and Brian Stock both participated in Birch Aquarium's Exploring Ocean STEM Careers day, April 2017.

b. National Geographic

Josh Stewart collaborated with National Geographic to share videos and articles about recent research on manta rays using animal-mounted cameras (Cittercams). The videos and articles reached a combined audience of over 2 million people through social media postings.

c. MixSIAR GitHub website

Graduate student Brian Stock maintains a website (<https://github.com/brianstock/MixSIAR>) offering open-source software for scientists using Bayesian mixing models. This includes an extensive FAQ/Issues forum where users can troubleshoot their problems.

Academic Development

a. Undergraduate Education

- Graduate students Josh Stewart, Brian Stock, and Lynn Waterhouse planned and hosted a 10-day capacity building workshop for undergraduate students in Puerto Vallarta, Mexico. The workshop covered introductory and intermediate statistics and analysis methods for ecological data. 12 students participated and demonstrated a mean ~600% improvement in analytical abilities based on an aptitude test administered before and after the workshop. Dr. Brice Semmens taught the SIO Undergraduate courses SIO136: Marine Biology Lab and Field Techniques, and SIO187: Introduction to Statistics for Marine Biology.

- Dr. Semmens participated as a mentor in the Summer Training Academy for Research Success (STARS) program. STARS is designed to provide under-represented, Ph.D.-bound students with research experience. The program has been highly successful in recruiting talented underrepresented minority students to UCSD graduate programs. STARS is an eight-week summer program.
- Dr. Semmens participated as a mentor for "The Ocean as a Bridge to Enhance Participation in the Sciences", a summer research/training program sponsored by UCOP to link UC campuses with undergraduates from Historically Black Universities and Colleges (HBCUs).

b. Graduate Education

- Dr. Semmens taught the graduate course SIO296: Introduction to Bayesian population analysis.

c. SIO R-Users group

- Graduate students Lynn Waterhouse and Brian Stock help run the weekly R-Users group at SIO, which supports other graduate students who need help with the R programming language.

d. Ecology & Data Analysis Workshop

- Graduate students Josh Stewart, Lynn Waterhouse, and Brian Stock funded, developed, and put on a 10-day workshop in statistics and R programming for Mexican college students in Yelapa, Mexico, March 23 - April 2, 2016.

e. Undergraduate Research Mentoring

- Graduate students Brian Stock and Lynn Waterhouse mentored 3 student research projects during summer 2016:
 - Lauren Arnold, "Plankton associated with a spawn cloud of Nassau grouper eggs," June-Aug 2016
 - Brian Cohn, "Tag counts on a Nassau grouper spawning aggregation," June-Aug 2016



- India Dove, "Length analysis of a Nassau grouper spawning aggregation," March-June 2016
- Graduate student Noah Ben-Aderet mentored 2 students research projects during summer 2016
 - Erin Johnston, "Otolith aging and diet studies based on gut content analysis", March – August 2016
 - Richard Cravey, "Yellowtail diet and growth rate studies", June-August 2016
- Graduate student Joshua Stuart mentored 1 student research project during summer 2016
 - Taylor Smith, "Annotation of video from "critter-cam" deployments on oceanic manta rays", June-August 2016

K-12 Outreach

- a. Grouper Moon K-12 Education
Dr. Semmens led the annual Grouper Moon K-12 education program, reaching more than 500 students in 20 schools throughout the Caribbean and US. The curricula introduce students to the concepts of reef ecology and resilience, and the importance of sustainable fisheries; importantly, the curricula has a technology component that includes an underwater audio/video communication system to live-stream research into classrooms.
- b. Job Shadowing for High School Students
Job shadow day, Brian Stock, May 19 2017 (Andrew Dafnis from High Tech High, San Marcos, CA)
- c. Mission Bay High School- IB Environmental Science Class
Lynn Waterhouse helped out in a Mission Bay High School class in Fall of 2016. She was helping the IB Environmental Science class to learn about experimental design and data

analysis as part of their project requirement to pass the IB exam and receive college credit.

- d. Math and Research in Ecology at Scripps: MARES

Dr. Semmens developed and taught a summer short course (Math and Research in Ecology at Scripps: MARES) to introduce under-served high school students to marine quantitative ecology and to encourage them to pursue science and math fields. MARES aims to make math and science relevant to students (beyond tests and worksheets) by conveying the importance of applying and communicating quantitative tools and their products. In addition to "hands-on" field-based data collection, scientists at SWFSC hosted a tour of the Center's aquaculture facilities. This past year, 15 students participated in the program.

Networking

- a. White Seabass Stock Assessment Review Panel

The Stock Assessment of White Seabass Review Panel (in May 2016) was open to the public and had attendees from California Department of Fish and Wildlife, California Sea Grant, and Commercial and Recreational fishers. Lynn Waterhouse organized and presented at this review session. She was the co-author of the Stock Assessment Review of White Seabass.

- b. American Fisheries Society- Estuaries Section

Lynn Waterhouse was president-elect of the AFS Estuaries Section and will become president at the 2017 meeting in August. She maintains the Facebook and Twitter presence for the group. The section has about 250 members across the United States. At the 2017 meeting in Tampa the Section is co-organizing a fundraising event, "Monsters of Habitat Science".



Fixing retrospective biases in stock assessment and implications for management targets

Principal Investigator(s):

Cody Szuwalski, University of California, Santa Barbara

Other Key Personnel:

Jim Ianelli, Alaska Fishery Science Center

Andre Punt, University of Washington

Steve Gaines, University of California, Santa Barbara

NOAA Primary Contact:

Patrick Lynch, Office of Science and Technology, NOAA Fisheries

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme D: Ecosystem-Based management

Related NOAA Strategic Goal(s):

Goal 3: Climate Adaption and Mitigation

Budget Amount:

\$65,818

Amendment(s):

27

Description of Research:

Stock assessments are used to estimate the biomass of exploited species; estimates of biomass are used to set allowable catches for our nation's marine resources. Retrospective biases are systematic inconsistencies among a series of estimates of biomass based on increasing periods of data and can result in unknowingly over-harvesting (or under-harvesting) a population. There are several methods of 'fixing' retrospective biases in stock assessment, but it is unclear how well they work. The goal of this project is to simulate populations of exploited fish from which data can be drawn for assessment, generate retrospective biases in these simulated populations, then attempt to fix the retrospective biases by allowing population processes to vary

over time in the stock assessments. Then we will evaluate the impact of different methods on management targets and performance.

Originally, an R packaged based on Stock Synthesis (a stock assessment software) called ss3sim was to be used to implement the study. However, it lacks the full-feedback structure that is useful in evaluating management strategies, so a package called "General Management Strategy Evaluation (GeMS)" was created by the authors to complete this study. It consists of a two-box, age- and length-structured operating model in which all population and management processes can vary over time. This simulation platform is sufficiently generalized that it can be used to answer many different questions that require full-feedback simulation to model the management process and will be an asset moving forward. A manuscript describing the analysis is currently in review at ICES.

Research Objectives:

1. Build a full-feedback simulation framework that is generalized enough to model many different species
2. Generate retrospective biases in simulated populations
3. "Fix" retrospective biases using time-varying processes
4. Write manuscript describing the analysis and the impact of fixing retrospective biases with time varying processes on management targets and performance

Research Accomplishments:

We have completed all objectives above and are now undertaking revisions on the manuscript submitted at ICES.



Conferences, Meetings & Presentations

- a. Dr. Szuwalski spoke about the project in Sao Paulo, Brazil at the 2015 PICES meeting. He will also present on the project as an invited speaker at the Wakefield Symposium in Anchorage, AK in May 2017.

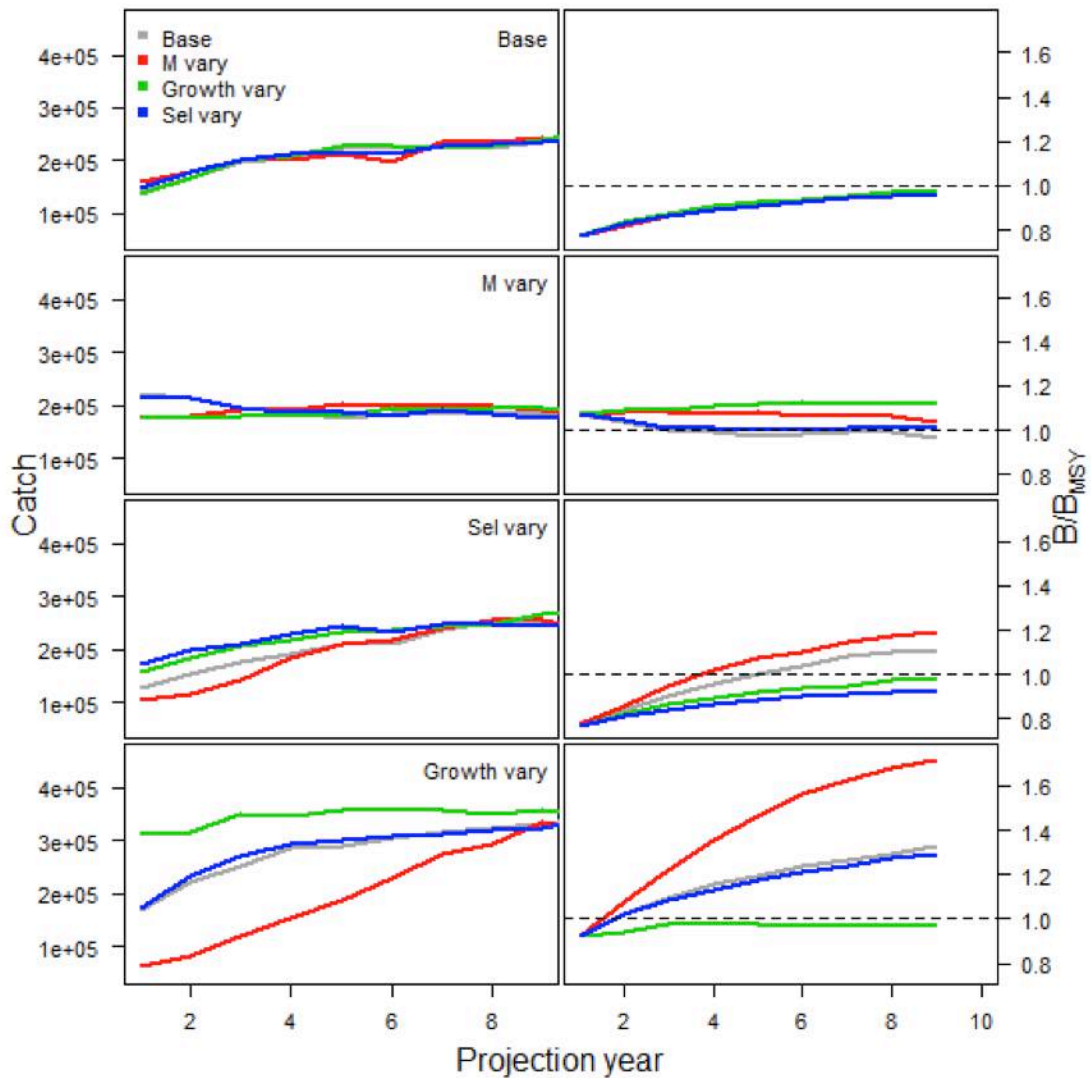


Figure 54: Median catch for each assessment method (line) by scenario (panel) and median true 'status' as calculated by the true current biomass divided by the true target biomass. The dashed line in right column indicates the target spawning biomass.



Utilizing Annual Hydrographs to Identify Instream Flow Needs for Southern California Steelhead (*Oncorhynchus mykiss*) and Evaluate Climate Change Effects

Principal Investigator(s):

Dr. William J. Trush, Adjunct Professor in Department of Environmental Science and Management and Co-Director HSU River Institute, Humboldt State University, Arcata, CA

Other Key Personnel:

Dr. Alison O'Dowd, Department of Environmental Science and Management and Co-Director HSU River Institute. Humboldt State University, Arcata, CA

NOAA Primary Contact:

Anthony Spina, NOAA Fisheries

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme D: Ecosystem-Based management

Related NOAA Strategic Goal(s):

Goal 3: Climate Adaption and Mitigation

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$81,999

Amendment(s):

26

Description of Research:

This HSU River Institute project constructs an objective, practical pathway for helping NOAA and state resource agencies to protect, restore, and manage coastal resources through an ecosystem-based management strategy. By restoring (or partially restoring) annual hydrographs, key ecological processes can be restored to help recover SoCal river ecosystems' capacity for self-renewal, or health. Much of river ecosystem management is concerned with risk. Even SoCal steelhead have been managing risk by evolving diverse life history strategies in response to the

unpredictable annual hydrographs of a Mediterranean climate. Our analytical framework incorporates risk into river ecosystem management and steelhead population recovery. Subtle changes in Southern California runoff attributable to the beginning of significant climate change are being assessed quantitatively as risk. Regionalizing a quantitative assessment of river ecosystems' instream flow needs for Coastal California will improve their standing in water right deliberations and SWRCB permitting.

Research Objectives:

One key objective has been establishing a quantitative relationship between riffle crest thalweg (RCT) depth and streamflow (Q) using power functions transformed from USGS gage rating curves. RCT-Q rating curves for natural riffles have similar characteristics as those of broad crested and triangular weir rating equations. Power function exponents computed from USGS gaging stations ranged from 1.50 to 3.5 (Figure 55), whereas exponents for weir equations range from 1.5 to 2.5. Knowledge and/or predictive capacity for estimating RCT depths can define upstream adult spawning and downstream smolt migration windows from historic annual hydrographs. For example, good downstream smolt migration streamflows have a threshold depth of RCT = 0.40 ft. However, RCT-Q rating curves are offering considerably more ecological insight than simple measures of riffle depth. The rate of the rate-of-change in stage with streamflow, i.e., the second derivative of a general weir equation or RCT-Q rating curve, provides objective identification of the hydraulic control a given streamflow exerts. The transition from complete section control to complete active channel control largely determines key ecological processes including productive riffle habitat for benthic macroinvertebrates, amphibian tadpole rearing success, steelhead smolt outmigration



through pools and runs, and over-summer Pacific lamprey rearing habitat availability. Streamflow thresholds for these key ecological processes can be quantified regionally without engaging traditional time-intensive, costly instream flow methodologies.

Preliminary results indicate that a 5% decrease in RCT depth at any given ambient, unimpaired streamflow will not jeopardize key ecological processes nor incur significant habitat loss, i.e., minimally impact overall hydraulic performance. A maximum allowable 5% RCT depth change attributable to surface and groundwater diversions is being explored as an instream flow threshold that can be applied to unregulated Coastal California streams. The exponent of the RCT-Q rating curve determines the maximum allowable percentage of stream divertable causing no greater than a 5% decrease in RCT depth (Figure 56).

Research Accomplishments:

These two key milestones have been attained: (1) Quantitatively connecting the performance of a stream's or river's hydraulic controls to sustaining key ecological processes using RCT-Q rating curves under historical hydrological conditions and (2)

Regionalizing a Coastal California protocol adaptable to SWRCB water right permitting that protects against cumulative withdrawals by many small individual water users without requiring extensive site-specific studies.

Honors and Awards

- a. Dr. William Trush was awarded the 'Golden Pipe' achievement award at the 2017 Salmonid Restoration Federation Conference for innovative research establishing instream flow needs for Coastal California streams and rivers.

Conferences, Meetings & Presentations

- a. Dr. William Trush attended the Salmonid Restoration Conference in Davis California

Education & Outreach

Communication

- a. Speaking Event for SoCal CalTrout Chapter
On June 29 2017, William Trush scheduled to speak on "The Role of the Annual Hydrograph in Recovering SoCal Steelhead Populations" in Ventura.

Academic Development

- a. Seminar on River Ecosystem Hydrographs and Environmental Risk William Trush in HSU Department of Environmental Science and Management. Instructed (as volunteer) ENV 480 Fall 2016 Semester for graduate and undergraduate students on river ecology and management.

K-12 Outreach

- a. Advanced Placement (AP) Arcata High School Environmental Science Class William Trush guest speaker on stream ecology and climate change impacts for juniors/seniors.

Networking

- a. Presentation to the North Coast Regional Water Quality Control Board William Trush reviewed instream flow methods and proposed a new methodology using RCT depths.



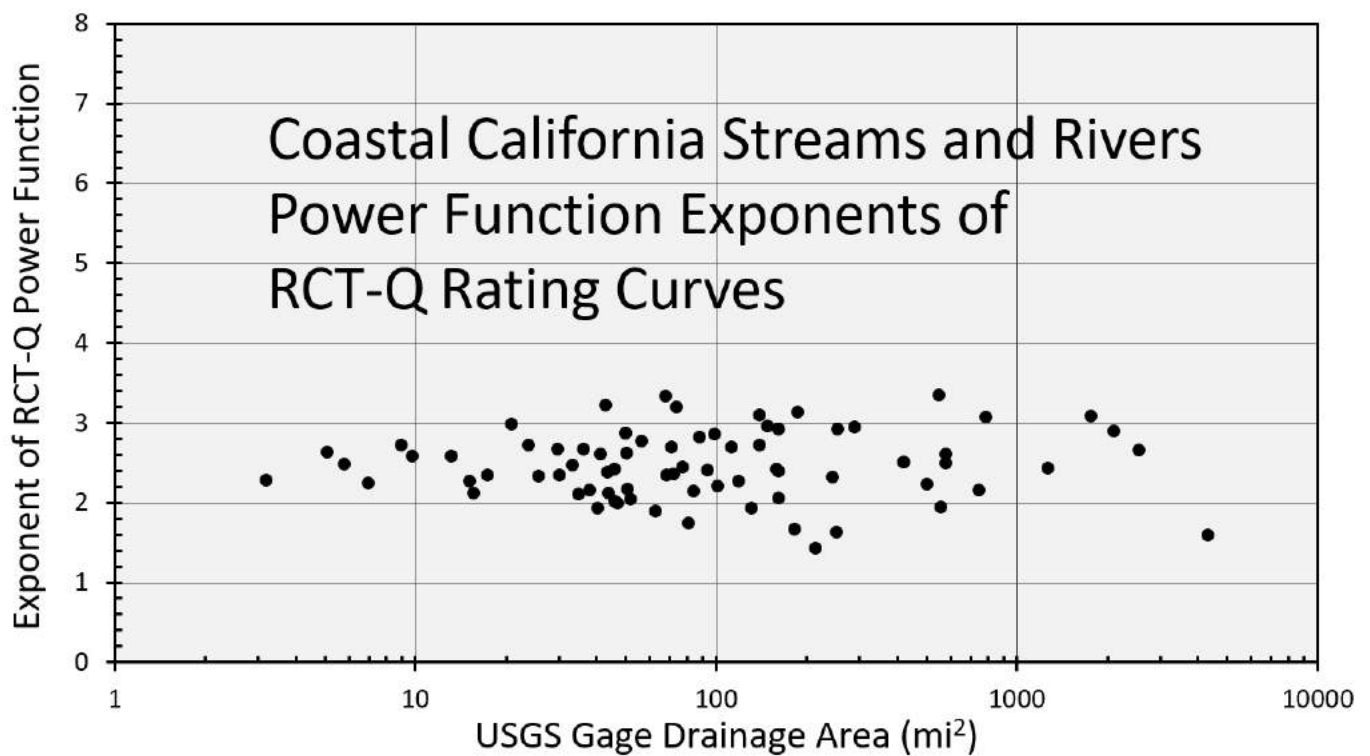


Figure 55: Coastal California RCT-Q rating curve exponents spanning a 3 mi² to 6,000 mi² range in USGS gage drainage area.

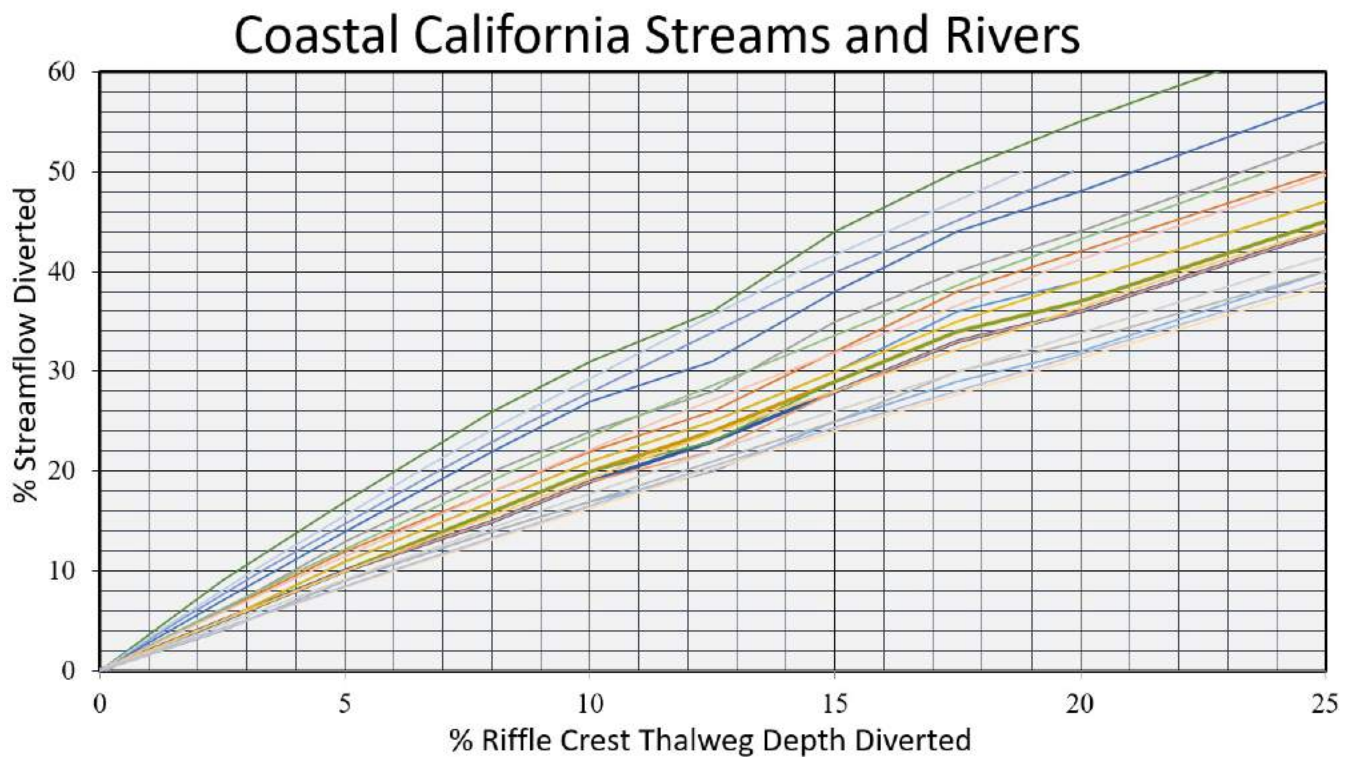


Figure 56: Preliminary percentage streamflow diversion (PSD) decreasing RCT depths by 5% at selected Coastal California USGS gaging stations as a function of the RCT-Q rating curve power function (PFE).



Using Combined Video, Acoustic, and Accelerometer Measurements to Determine the Conceptual Viability of a "Smart" Hook

Principal Investigator(s):

Aaron Thode, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Janice Straley, University of Alaska Southeast

Victoria O'Connell, Sitka Sound Science Center

Dan Falvey, Alaska Longline Fishermen's Association

Linda Behnken, Alaska Longline Fishermen's Association

NOAA Primary Contact:

Derek Orner, NOAA Fisheries

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme D: Ecosystem-Based management

Related NOAA Strategic Goal(s):

Goal 1: Healthy Oceans

Budget Amount:

\$439,974

Award:

NA14NMF47203289

Description of Research:

Ten "TadPro" acoustic/video recorders have been expanded to incorporate datalogging of the acceleration of longline mainlines and branchlines. Our fishermen colleagues have deployed these instruments off the Alaskan coast on demersal longline gear and in offshore Hawaiian waters using pelagic longline gear. The demonstration species addressed in this work are target species like sablefish, grenadier, and halibut; various kinds of bycatch species like rockfish and potentially sharks and skates; and (opportunistically) false killer whale depredation. Longline interactions by all these species were

confirmed by video, and temporal features of both acoustic and accelerometer measurements would be made to determine whether a combination of acoustic/accelerometer measurements can be used to flag whether a particular species is present on a given hook, and whether multiple hooks could be monitored by a single sensor package.

The project has recorded accelerometer measurements for two false killer whale depredation events on Hawaiian pelagic longlines, and a couple of halibut and black cod captures on demersal longlines. One peer-reviewed publication has been produced that discusses the line acceleration associated with depredation, along with acoustic signals detected during depredation. Overall the most significant challenge to the project has been the difficulty of obtaining large sample sizes from pelagic deployments.

Research Objectives:

- a. Expand "TadPro" to include acceleration: The TadPro design would be expanded to incorporate datalogging of accelerometer measurements, and ten units would be built.
- b. Species Identification with "A/A": Fifteen deployments of longline gear (with multiple TadPros attached per deployment) would be used to record acoustic, video, and accelerometer data streams of various hooked animals to determine whether accelerometer and/or acoustic (A/A) time series data are sufficient to distinguish between various caught species.
- c. Extend TadPro lifetime: examine whether accelerometer measurements can be used as a trigger for recording audio and video, thus extending the practical deployment lifetime of the "TadPro".



Research Accomplishments:

1. Acoustic and accelerometer measurements of false killer whale depredation published.

The paper "Source levels of false killer whale (*Pseudorca crassiden*) clicks and whistles during depredation of a pelagic longline" has been published.

2. Acoustic and accelerometer data from 2015 pelagic cruise have been bulk processed, with 2016 pelagic analysis in progress.

Both PI Thode and his student Ludovic Tenorio have created MATLAB software that automatically bulk processes the Tadpro acoustic and accelerometer data (mainline) from the pelagic deployments. Fifty TadPro deployments from 14 pelagic sets in 2015 have been analyzed. Marine mammal depredation audio was captured on eight cameras from two sets: four cameras on Set 4

and three cameras on Set 14. Both sets also captured video of false killer whale depredation. The data from Set 14 suggest that at least five individuals or groups worked their way down the line past two cameras, with fewer individuals present at Set 4. Minke whale calls were detected on two sets, one camera each, suggesting that the animal transited perpendicular to the line.

3. Final accelerometer-only packages designed.

After several false starts, a final accelerometer package has been developed that can be placed directly on a branchline (vs a mainline). The instrument is compact, robust, high-resolution, and long endurance. It uses a combination of off-the-shelf "SlamStick-C" and in-house components.

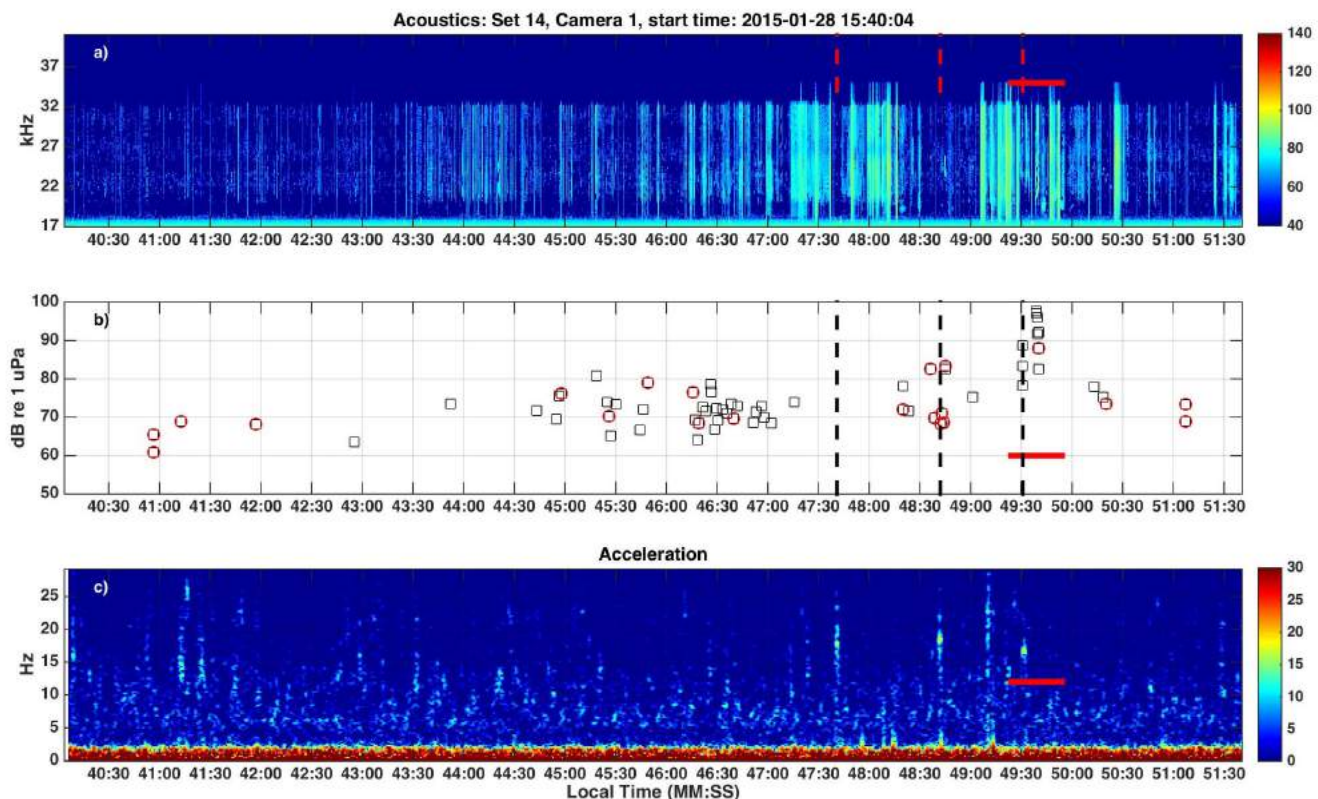


Figure 57: Acoustic (top) and acceleration (bottom) of hook depredation caught on camera in 2015, Set 14, Camera 1. This data set was the topic of the published paper. Bright vertical lines on top plot are echolocation clicks. Red line in bottom plot indicates acceleration signal associated with depredation.



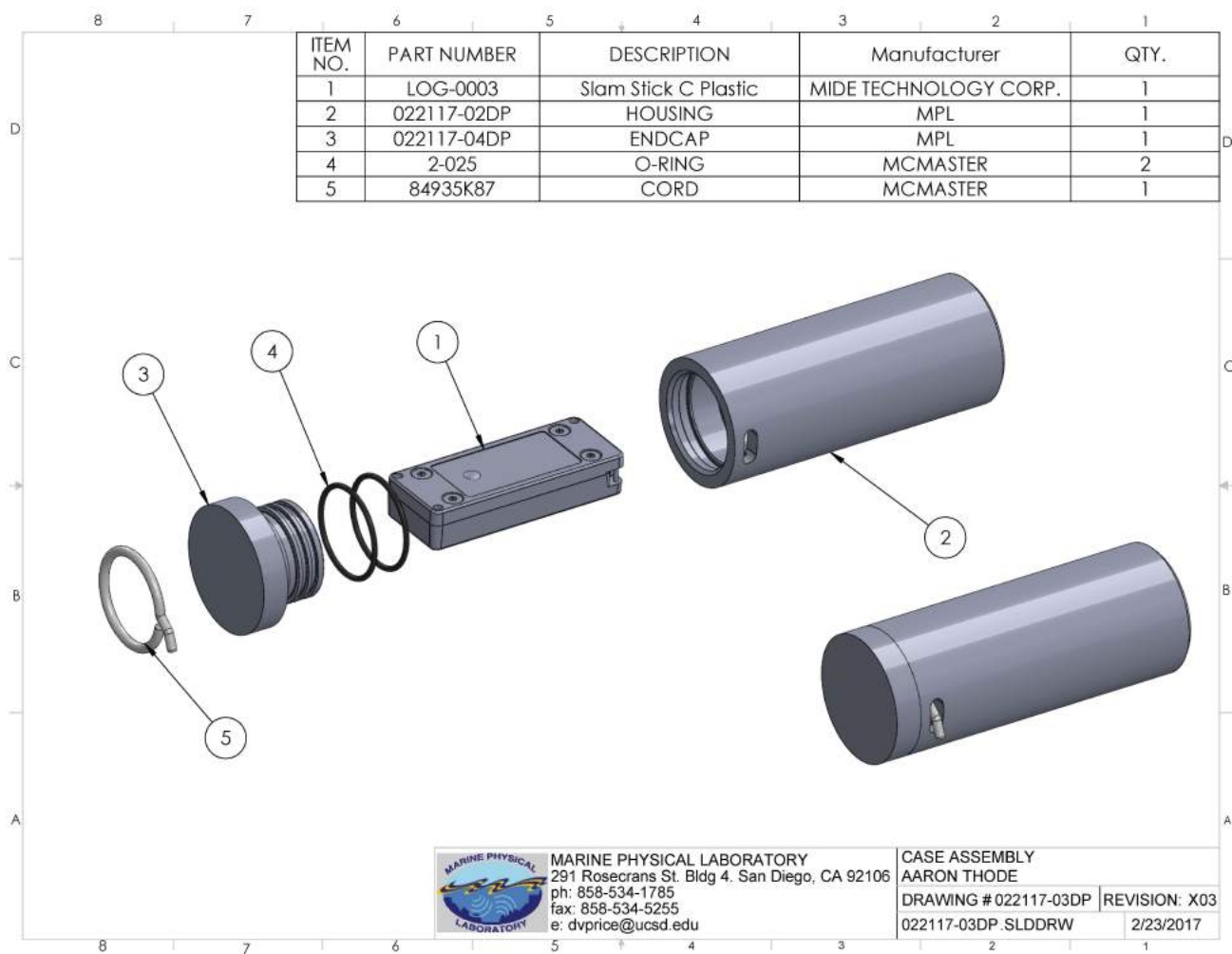


Figure 58: Diagram of pressure case and accelerometer logging device. Instrument is 4.25" long and 1.75" in diameter, and weighs only a couple of ounces submerged.

PARTNERS & COLLABORATORS

Interagency

Centers for Disease Control and Prevention (CDC)

National Aeronautics and Space Administration (NASA)

National Oceanic and Atmospheric Administration (NOAA)

National Science Foundation (NSF)

NOAA Assessment and Restoration Division (ARD)

NOAA Atlantic Oceanographic & Meteorological Laboratory (AOML)

NOAA Automated Image Analysis Strategic Initiative (AIASI)

NOAA Center for Operational Oceanographic Products and Services (CO-OPS)

NOAA Climate Observations Division (COD)

NOAA Climate Prediction Center (CPC)

NOAA Climate Program Office (CPO)

NOAA CPO Ocean Observing and Monitoring (OOM)

NOAA Earth System Research Laboratory (ESRL)

NOAA Emergency Response Division (ERD)

NOAA ESRL Global Monitoring Division (GMD)

NOAA Fisheries Ecology Division (FED)

NOAA Alaska Fisheries Science Center (AFSC)

NOAA Northeast Fisheries Science Center (NEFSC)

NOAA Northwest Fisheries Science Center (NWFS)

NOAA Pacific Islands Fisheries Science Center (PIFSC)

NOAA Southeast Fisheries Science Center (SEFSC)

NOAA Southwest Fisheries Science Center (SWFSC)

NOAA Geophysical Fluid Dynamics Laboratory (GFDL)

NOAA Global Monitoring Division (GMD)

NOAA Integrated Ocean Observing System (IOOS)

NOAA National Centers for Environmental Information (NCEI)

NOAA National Data Buoy Center (NDBC)

NOAA National Environmental Satellite, Data and Information Service (NESDIS)

NOAA National Integrated Drought Information System (NIDIS)

NOAA National Marine Fisheries Service (NMFS)

NOAA National Ocean Service (NOS)

NOAA National Weather Service (NWS)

NOAA Ocean Assessment Program (OAP)

NOAA Ocean Exploration Program (OEP)

NOAA Oceanic and Atmospheric Research (OAR)

NOAA Office of Habitat Conservation (OHC)

NOAA Office of Ocean Exploration and Research (OER)

NOAA Office of Response and Restoration (OR&R)

NOAA Pacific Marine Environmental Laboratory (PMEL)

NOAA PIFSC Coral Reef Ecosystem Program

NOAA Protected Resources Division (PRD)

NSF National Center for Atmospheric Research (NCAR)

NSF Ocean Sciences (OCE)

NSF Office of Polar Programs (OPP)

U.S. Air Force (USAF)

U.S. Army Corps of Engineers (USACE)

U.S. Bureau of Ocean Energy Management (BOEM)

U.S. Bureau of Reclamation (USBR)



U.S. Coast Guard (USCG)
U.S. Fish and Wildlife Service (USFWS)
U.S. Forest Service (USFS)
U.S. Geological Survey (USGS)
U.S. Navy (USN)
U.S. Weather Bureau (at Cold Bay Alaska)
USAF 53rd Weather Reconnaissance Squadron
"Hurricane Hunters"
USN Living Marine Resources Program (LMR)
USN Naval Research Laboratory Monterey (NRL-
MRY)
USN Office of Naval Research (ONR)



Partnerships

Alaska Longline Fishermen's Association	IFREMER (France)
Aquarium of the Pacific (AOP)	INCOIS (India)
Atlantic States Marine Fisheries Commission	Institute for Computational Earth System Science (ICESS), UCSB
BSH (Germany)	Inter-American Tropical Tuna Association (IATTC)
Cabrillo Marine Aquarium (CMA)	Investigaciones Mexicanas de la Corriente de California (IMECOCAL)
California Cooperative Oceanic Fisheries Investigations (CalCOFI)	IOS (Canada)
California Current Ecosystem Long Term Ecosystem Research (CCE-LTER)	J. Craig Venter Institute
California Department of Fish and Wildlife (CDFW)	JAMSTEC (Japan)
California Department of Water Resources (CDWR)	Japan Agency for Marine-Earth Science and Technology
California Energy Commission	Karuk Tribal Natural Resources
California Environmental Protection Agency	KMA (Korea)
California Polytechnic State University - San Luis Obispo (CalPoly)	Manta Trust
California Resources Agency via the 4th California Climate Change Assessment	Mid Klamath Watershed Council
California Salmon Council	Misool Eco-Resort Conservation Center
California State University, Long Beach (CSULB)	Monterey Bay Aquarium Research Institute (MBARI)
Carbon Dioxide Information and Analysis Center	National Oceanic and Atmospheric Administration (SWFSC, NEFSC, SEFSC, AFSC, PIFSC)
Center for Western Weather and Water Extremes (CW3E)	National Oceanography Centre Southampton (U.K.)
Cooperative Institute for Marine Resources Studies, Oregon State University (CIMRS/OSU)	NIWA (New Zealand)
CSIRO (Australia)	NOC /Southampton
Desert Research Institute (DRI)	North Carolina State University
Eastern Research Group (ERG)	Ocean Univeristy of China
Environment Canada	Office of Spill Prevention and Response (OSPR), California Department of Fish and Wildlife
Farallon Institute	Oregon State University
Hawai'i Longline Association	Oregon State University (OSU), College of Oceanic and Atmospheric Sciences
Hoopa Tribal Fisheries	Partnership with W. Kessler (PMEL) and IRD/New Caledonia for Solomon Sea field work
Hubbs-SeaWorld Research Institute (HSWRI)	
IfM-Geomar (Germany)	



Penn State University	University of Tokyo, Japan
Point Blue	University of Tsukuba, Japan
Princeton University	University of Washington
QEDA Consulting	US GO-SHIP
Reef Environmental Education Foundation (REEF)	Woods Hole Oceanographic Institution
Rosenstiel Schools of Marine and Atmospheric Science	ZMAW/Hamburg
Rutgers University, Coastal Ocean Observation Lab (COOL)	
San Diego Foundation	
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Sportfishing Association of California (SAC)	
Texas A&M University (TAMU)	
U.K. Met Office	
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PUBLICATIONS

Publication Summary

		07/01/2015 – 03/31/2016	04/01/2016 – 03/31/2017
CIMEC Lead Author	Peer Reviewed	15	72
	Non-Peer Reviewed	31	21
NOAA Lead Author	Peer Reviewed	23	38
	Non-Peer Reviewed	11	12
Other Lead Author	Peer Reviewed	58	81
	Non-Peer Reviewed	12	7
Total Publications		150	231

Journal Articles

- Abadía-Cardoso A, Pearse DE, Jacobson S, Marshall J, Dalrymple D, Kawasaki F, Ruiz-Campos G, Garza JC (2016) Population genetic structure and ancestry of steelhead/rainbow trout (*Oncorhynchus mykiss*) at the extreme southern edge of their range in North America. *Conservation Genetics* 17: 675–689.
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- Bizzarro, J.J., Yoklavich, M.M., and Wakefield, W.W. 2017. Diet composition and foraging ecology of U.S. Pacific Coast groundfishes with applications for fisheries management. *Environmental Biology of Fishes*. 100: 375–393.
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- Chao Y, Farrara JD, Zhang H, Armenta KJ, Centurioni L, et al. 2017. Development, implementation, and validation of a California coastal ocean modeling, data assimilation, and forecasting system. *Deep Sea Research Part II: Topical Studies in Oceanography*
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- Davison, R. J. and W. H. Satterthwaite. Use of age- and stage-structured matrix models to predict life history schedules for semelparous populations. *Natural Resource Modeling* 29:538-558. (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

Credits

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