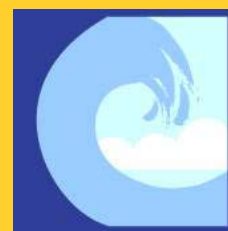


CIMEC

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 2017 - 2018





CIMEC

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Cooperative Institute for Marine Ecosystems and Climate Annual Performance Progress Report

April 1, 2017 – March 31, 2018

Prepared For



NA15OAR4320071



UC San Diego

UC SANTA CRUZ

UCLA

UC DAVIS

HUMBOLDT
STATE UNIVERSITY

UCSB

CAL STATE LA
LOS ANGELES



Cooperative Institute for Marine Ecosystems and Climate

June 27, 2018

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This report covers the period from April 1, 2017 to March 31, 2018, which was an excellent year for the Cooperative Institute for Marine Ecosystems and Climate (CIMEC).

During this period, CIMEC hosted almost \$16M in research programs for NOAA, somewhat less than last year. We are proud of the partnership between universities and NOAA to sustain and continuously evolve and enhance a variety of observation programs, such as Argo, the California Underwater Glider Network, Boundary Current Observing Systems, and the California Cooperative Ocean Fisheries Investigations (CalCOFI) sampling and analysis.

We are very excited about these projects and their contribution to the NOAA mission and look forward to more connections in the future. One area where NOAA is actively seeking new connections is Social Science, both in terms of economic impact of policies and the human response to policies, alters and warnings. One example that is frequently used is that as the Tornado Warning lead time has increased, people have stopped sheltering in place and have started driving to find their families, which has caused some problems. Coming up with ways to inform the public in the proper way about both acute and chronic natural hazards and the uncertainty of forecasts is important to NOAA.

NOAA continues to study their relationships with the Cooperative Institutes (CIs), and the CI Directors have been addressing some of the issues that affect all CIs, such as the interaction between federal and CI employees, NOAA's metrics for evaluating CIs, and the value added and return on investment in CIs. Transitions from research to operations "R2O" remain a priority, but transitions in the opposite direction "O2R" are also encouraged.

CIMEC will be reviewed later this year, and a recompute proposal is expected to be due sometime next year. The review will likely take place at SIO, with representatives from programs and partner institutions coming to the meeting. This will also be a good time to discuss what the renewal for CIMEC will look like and reformulate CIMEC if needed.

Prof. Dean H. Roemmich, the Deputy Director of CIMEC and co-leader of the Argo program, was elected to membership in the National Academy of Engineering for his contribution to development of the Argo Program: "matching the needs for global ocean observations with the new technologies of autonomous profiling floats", and the American Meteorological Society's Sverdrup Gold Medal Award for "major contributions to the measurement and understanding of the ocean's role in climate, and for leading the development and implementation of the Argo profiling array."

Finally, we were shocked and saddened to learn of the sudden passing of Dr. Steve Piotrowicz earlier this year, and the NOAA, Argo, and IOOS communities mourn Steve's passing, especially the OAR Climate Program Office where Steve worked. He was a powerful and effective advocate for many programs, and we have all benefited from his efforts.

Once again, thank you to Rose, Anne and Sienna 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 (2017-2018) 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

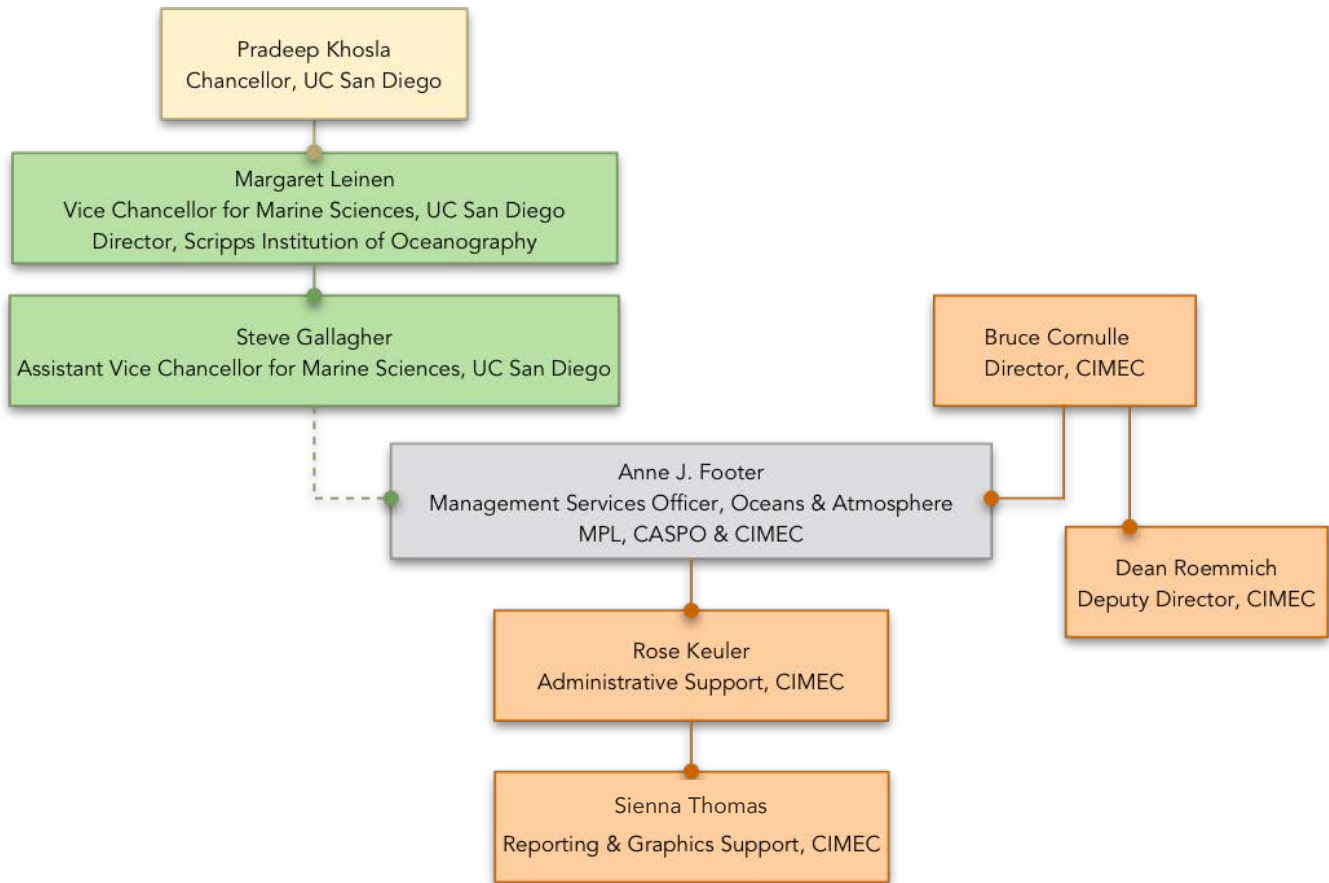
Dr. Roemmich is a professor of oceanography in the Integrative Oceanography Division and Climate, Atmospheric Science, and Physical Oceanography Division at Scripps Institution of Oceanography, University of California, San Diego. He is an expert in the general circulation of the oceans and the role 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, 2017 - March 31, 2018

Category	Total	B.S.	M.S.	Ph.D
Professor	3			3
Associate Professor	1			1
Research Specialist	5		1	4
Researcher	3			3
Project Scientist	8		1	7
Information Systems Analyst	1	1		
Programmer Analyst	3	1	2	
Postdoctoral Fellow	5			5
Assistant to the Director	1		1	
Marine Mechanician	1			
Marine Technician	1	1		
Development Technician	3	2		
Staff Research Assoc/Asst	11	1	8	2
Laboratory Assistants	7	4	2	

Total (≥ 50% support)	53	10	15	25
------------------------------	----	----	----	----

Undergraduate Students	27
Graduate Students	20

Employees less than 50% not including students	98
--	----

Personnel located at a NOAA laboratory	47
--	----

Obtained NOAA employment (Within the last 12 months)

Lyall Bellquist/SWFSC
Michael Jacob/SWFSC
Noah Ben-Aderet/SWFSC

Sub-Awards

Postdoctoral Fellow	2
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

Bartlett, Douglas - 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

Evan, Amato - 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

Johnston, Shaun - 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

Landry, Michael - Scripps Institution of Oceanography, 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

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

Pinkel, Robert - Scripps Institution of Oceanography, UC San Diego

Raimondi, Peter - UC Santa Cruz

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

Rissolo, Dominique - 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:

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, as well as



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.



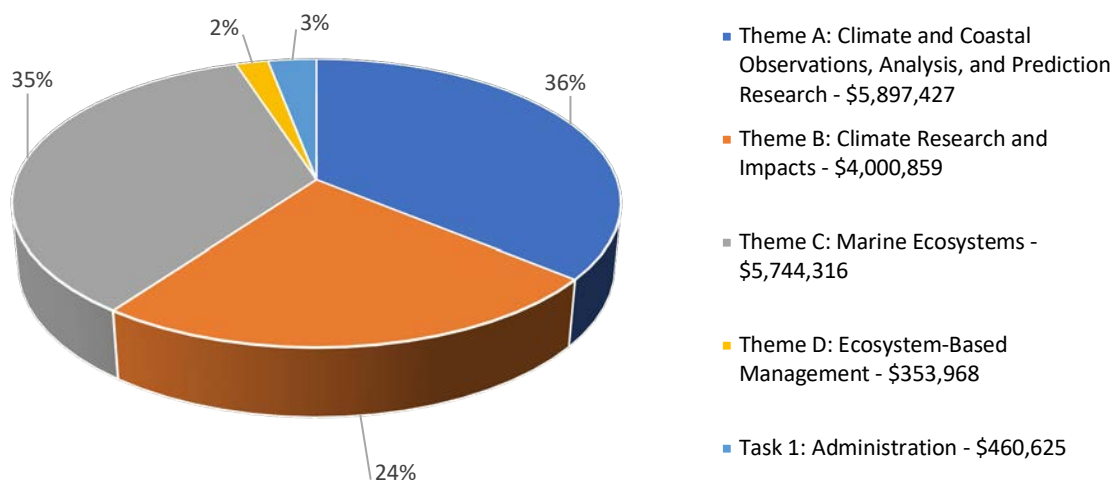
FUNDING SUMMARY

CIMEC Funding by Theme

CIMEC Funding by Theme

\$16,457,195

April 1, 2017 - March 31, 2018

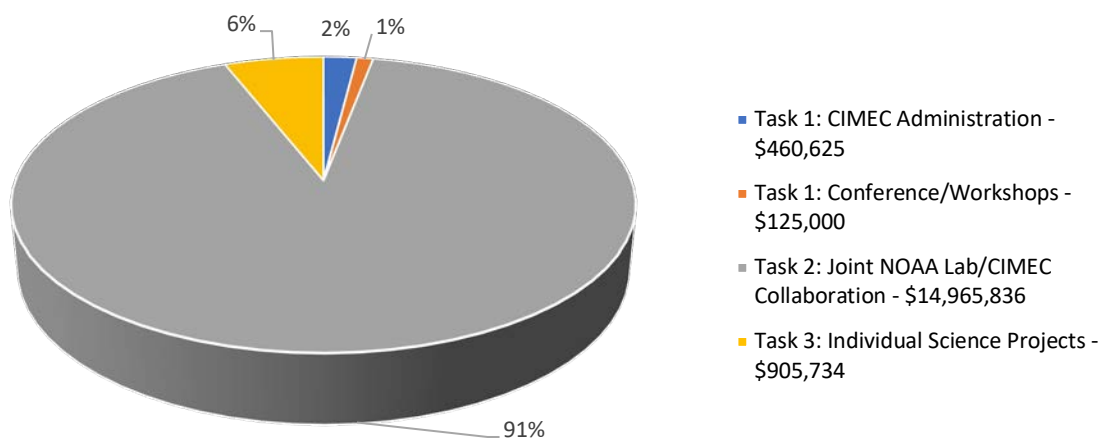


CIMEC Funding by Task

CIMEC Funding by Task

\$16,457,195

April 1, 2017 - March 31, 2018



CIMEC Task 1 Expenditures

CIMEC Task 1: Administration

PI: Bruce Cornuelle

Total Expenditures: \$184,694

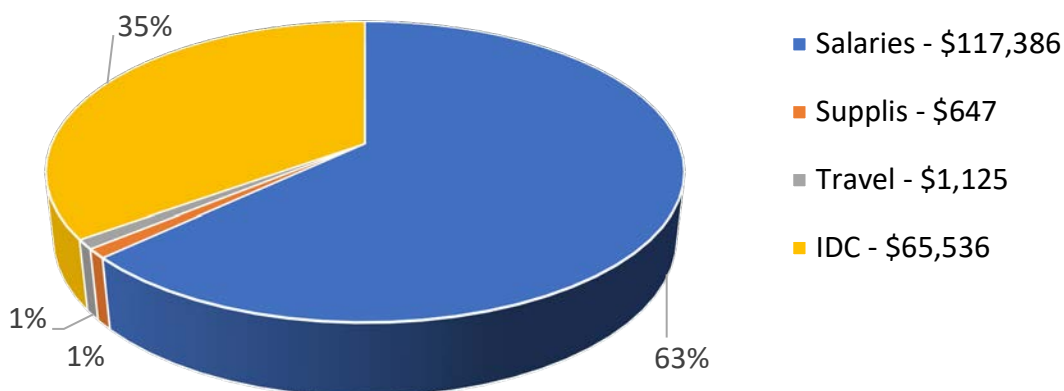


Figure 1: CIMEC Task IA activities include salary support for the CIMEC Director, the CIMEC Administrative Officer, the CIMEC Administrative Analyst and the CIMEC Administrative IT. Supply activity include communication costs and website maintenance. Travel Activity includes travel to Silver Spring, Maryland to attend the CI Directors meeting, Indirect Cost = 55%.

CIMEC Task 1: Workshops, Forums, and Symposiums Expenditures

"Workshop on North American Ichthyoplankton
Times Series"

PI: Anthony Koslow

Total Expenditures: \$15,926

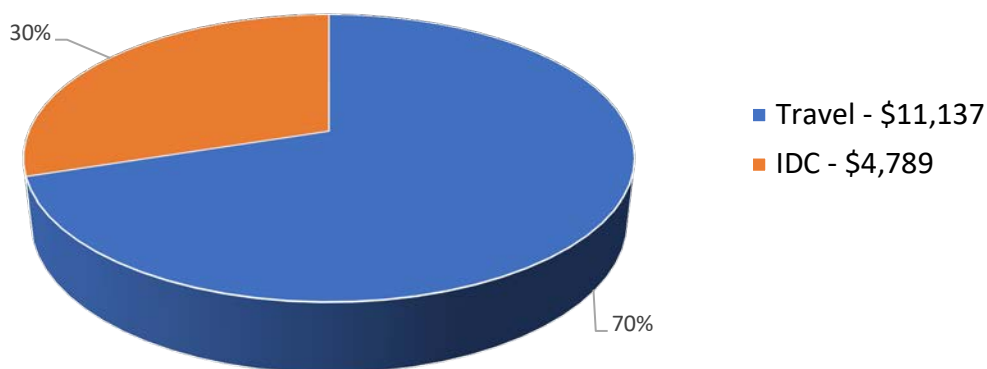


Figure 2: Koslow's "Workshop on North American Ichthyoplankton Time Series" supported costs associated with participant travel.



National Ocean Exploration Forum 2017
"Ocean Exploraton in a Sea of Data"
PI: Dominique Rissolo
Total Expenditures: \$49,144

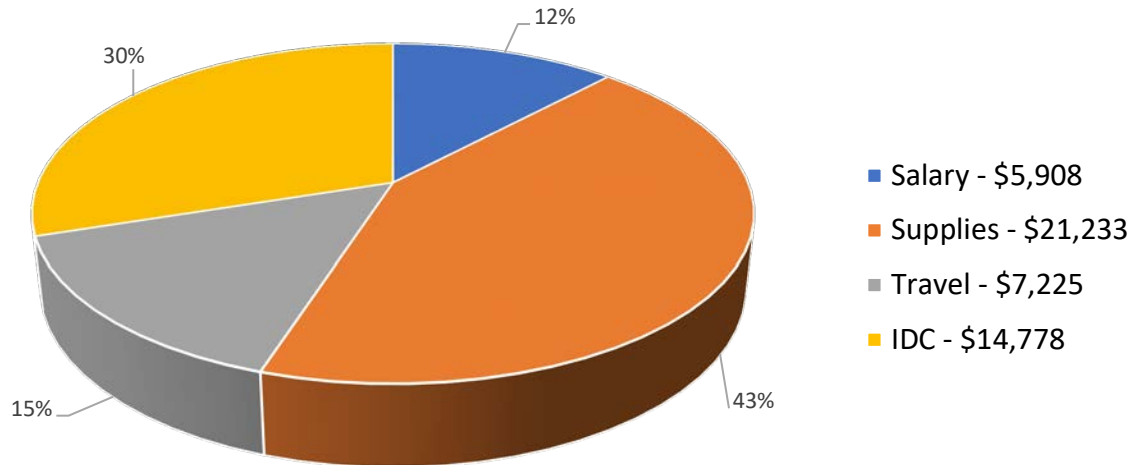


Figure 3: Rissolo's "National Exploration Forum 2017" supported costs associated with participant travel, venue rental, and catering.

**"Symposium: Internal Waves, Ocean Mixing, and the
 Overturning of Circulation of the Ocean"**
PI: Robert Pinkel
Total Expenditures: \$30,724

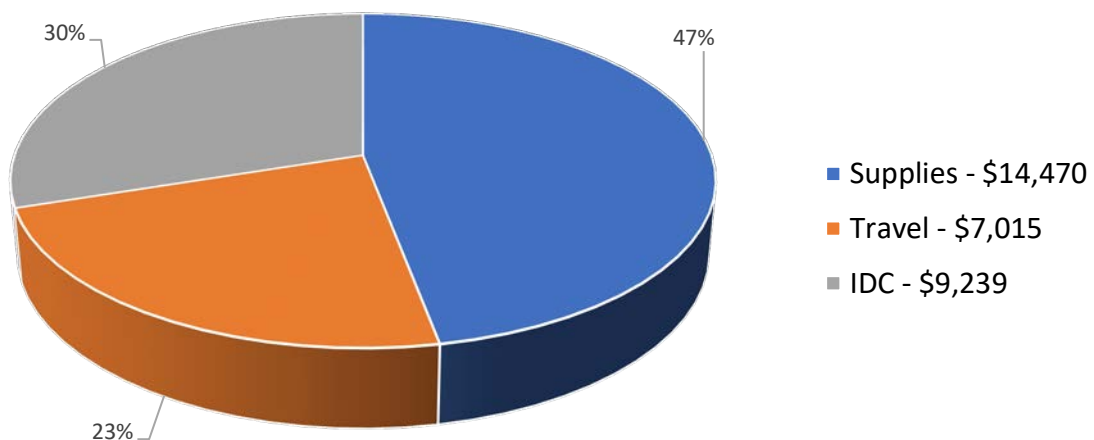


Figure 4: Pinkel's "Symposium: Internal Waves, Ocean Mixing, and the Overturning of Circulation of the Ocean" supported costs associated with participant travel, venue rental, and catering.



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: Climate Adaption and Mitigation

Goal 3: Healthy Oceans

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 was held September 26-27, 2017 in Woods Hole, Massachusetts. Seventeen scientists attended the Woods Hole workshop, mostly from NOAA laboratories and US academic institutions but also two scientists from Canada and two from Mexico, similar in number and composition to the September 2017 workshop. The 2016 workshop focused on reviewing the available ichthyoplankton time series, the progress-to-date in utilizing them, and discussion of analytical methods; the second focused on progress in the intervening period in analyzing the time series and discussion of methods to utilize them in fisheries and ecosystem management.

A follow-up workshop was held in Seattle in December 2017 in conjunction with the FATE annual meeting. A new post-doc, Dr. Jens Nielsen, joined the FATE project to synthesize west coast ichthyoplankton time series, replacing Dr. Pete Davison. This workshop enabled Dr. Koslow to meet with Dr. Nielsen and the NOAA scientists who would be supervising him (Drs. Janet Duffy-Anderson and Lauren Rogers) and collaborating on the project: Alison Deary and Ric Brodeur.

At the Woods Hole workshop, it was decided to continue to meet to discuss further progress in the synthesis and use of ichthyoplankton time series at a special session, "Application of Ichthyoplankton data to Fisheries Management," at the June 2018 Early Life History Symposium/Larval Fish Conference to be held in Victoria, BC (Canada).



Research Objectives:

- Survey recent research programs at the NOAA labs utilizing ichthyoplankton time series, focusing on relationships of abundance and diversity with climate.
- 1. 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
- 2. Develop a framework for moving forward, developing a national/international network with the relevant time series and options for collaboration and funding
- 3. 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:

- Explored how ichthyoplankton may contribute indicators of ecosystem status and be input to stock assessment and fishery management models.
- The second ichthyoplankton workshop was held September 26-27, 2017 at Woods Hole, MA. Seventeen scientists participated and made presentations.

- A follow-up workshop was held in Seattle at the Alaska Fisheries Science Center in conjunction with the annual FATE science meeting.
- A follow-up meeting has been planned for June 2018 as a special session (Application of Ichthyoplankton data to Fisheries Management) of the Early Life History Symposium/Larval Fish Conference in Victoria, BC.

Education & Outreach

Academic Development

a. Undergraduate Mentoring

Michael Andrews, a minority student and undergraduate at California State University Maritime Academy was mentored by Dr Koslow during the summer of 2017 as part of the Scripps Undergraduate Research Fellowship (SURF) program, funded by the NSF's REU program.

b. Postdoctoral Mentoring

Dr. Jens Nielsen has been mentored by scientists at the NOAA Alaska Fisheries Science Center, Dr.'s Lauren Rogers and Janet Duffy-Anderson from December 2017 at Scripps Institution of Oceanography. Dr. Davison is an NRC post-doctoral fellow funded through another FATE project, Janet Duffy-Anderson was the PI on this project. He analyzed ichthyoplankton time series from the SW, NW and AFSCs from the Gulf of Alaska to southern California. Tony Koslow, Ric Brodeur and Sam McClatchie were co-PIs.



Symposium: Internal Waves, Ocean Mixing, and the Overturning Circulation of the Ocean

Principal Investigator(s):

Robert Pinkel, Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Craig McLean, Ocean Acidification Program, NOAA Research

NOAA Task:

Task 1 - Administration

NOAA Theme:

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

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaption and Mitigation

Goal 3: Healthy Oceans

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$50,000

Amendment(s):

75

Description of Research:

In honor of Walter Munk's centennial and the fiftieth anniversary of the Abyssal Recipe, the Scripps Institution of Oceanography, University of California, San Diego requested funding to review the status of the field, acknowledge the many advances, and identify critical gaps in present understanding. A symposium was focused on this review and included veteran researchers from the early days of the GM spectrum as well as the younger scientists and students who lead the field today.

The Munk centennial birthday symposium was held May 15-17, 2017. It consisted of a mix of overview talks and extended discussion sessions, along with poster presentations that enabled the inclusion of late-breaking new results.

Research Objectives:

The objective of the symposium was to identify outstanding issues in ocean mixing and to focus on the next 100 years of research.

Research Accomplishments:

A global convergence of scientists participated in the May 15-17, 2017 Symposium along with students and post-doctoral scholars from the USA.

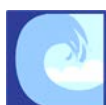
Conferences, Meetings & Presentations

- a. Munk Centennial Symposium, May 15-17, 2017

Education & Outreach

Academic Development

- a. The Munk Centennial Symposium was held May 15-17, 2017. Participating students include: Celia, Ou, Marion Alberty, Maddie Haymann, Dmitri Brazhnikov, Cesar Rocha, Jess Garwood.



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

Sam Iacobellis, Scripps Institution of Oceanography, UC San Diego

David Pierce, Scripps Institution of Oceanography, UC San Diego

Michael Dettinger, US Geologic Survey

Shraddhanand Shukla, UC Santa Barbara

Jordan Goodrich, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Caitlin Simpson, Oceanic and Atmospheric 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: Climate Adaptation and Mitigation

Goal 2: Weather-Ready Nation

Budget Amount:

\$420,000

Amendment(s):

11

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 a regional approach with the goal that lessons learned from the

regional pilots could often be applied in other locations. California was one of the earlier selections as a subject area for a regional DEWS.

Through studying the 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 newly joined California-Nevada 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 which spans CA and NV.

CNAP efforts have supported the multi-prong approach developed by NIDIS to include research pertaining to the drought early warning system, research and outreach involving drought information, engagement with stakeholders, capacity building across institutions and decision makers, research and applications related to seasonal forecasting, regional drought scenario planning, and water supply and drought monitoring. Engagement has included in-person and webinar drought and climate outlooks led by Dr. 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.

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

Research Accomplishments:

- A Sheffield presented or participated at relevant meetings in CA-NV during this award period. This includes: Western States Water Council Seasonal to Sub-Seasonal Forecasting Workshop, US Drought Monitor Forum, Climate Prediction Application Sciences Workshop, American Geophysical Union Fall Meeting, and CA DWR/CW3E Winter Outlook Workshop.
- April 2017 Great Basin Climate Forum
- In prep publication of NMME forecast skill evaluation



- Drought Information Use in the Klamath Basin” – and submitted it to the PNW DEWS coordinator

Conferences, Meetings & Presentations

- a. Presentation of NMME forecasts over CA-NV to regional stakeholders on a Drought & Climate Outlook Webinar (May 2017)
- b. 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.

Education & Outreach

Communication

- a. Dr. Sheffield participated in the Western States Water Council Seasonal to Sub-Seasonal Forecasting Workshop in San Diego in May 2017.

Academic Development

- a. Jordan Goodrich attended a river hydrology meeting in Las Vegas (CO River Hydrology Symposium) hosted by Southern Nevada Water Authority, where other researchers discussed prediction schemes for various basin-scale surface water budget terms.

Networking

- a. California-Nevada Drought Early Warning System Annual Coordination Workshop: NIDIS, the California Nevada Climate Applications Program (CNAP), and the Western Regional Climate Center (WRCC) partnered to coordinate the California-Nevada Drought Early Warning System First Annual Coordination Workshop. This workshop provided a forum to discuss and build upon past drought efforts in the region and increase coordination, collaboration and information sharing across the region as a whole. This two-day event brought together federal, tribal, state, academic, and local partners and stakeholders for an in-depth discussion on drought in California and Nevada, with attention to water, climate, land and emergency management. Specifically, the discussion centered on current and planned DEWS and network activities while exploring new networks and drought resilience activities
(<https://www.drought.gov/drought/calendar/events/california-nevada-drought-early-warning-system-first-annual-coordination-workshop>).





Figure 5: Highlights of the Great Basin Climate Forum



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

Principal Investigator(s):

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

Other Key Personnel:

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

NOAA Primary Contact:

NOAA Contact Name, NOAA Line Office

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

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

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Budget Amount:

\$214,069

Amendment(s):

6, 40, 60

Description of Research:

A key feature of the work carried out during this year was to prepare and distribute test samples for the measurement of seawater CO₂ properties (total alkalinity, total dissolved inorganic carbon, pH). This work for NOAA was done in conjunction with a larger international study (supported by NSF Chemical Oceanography, and by fees charged to the non-NOAA supported participants). Two separate samples were made using techniques related to those that we use in our preparation of CO₂ in seawater reference materials (with the exception that we also added additional CO₂ components so as to distinguish the composition of the test samples as compared with our usual reference materials).

Research Objectives:

A key objective of this work was to allow the NOAA Ocean Acidification Program to understand the likely quality of the CO₂ in seawater measurements being made by the various scientific groups they support.

In addition, Dr. Dickson was extensively involved in planning and working with various capacity-building

workshops aimed at improving the global ocean acidification observing network (GOA-ON).

Research Accomplishments:

- Two separate test samples were prepared a certified using our usual techniques. These samples were distributed to the various interlaboratory study participants.
- The results for measurements on these test samples were solicited from the various participants, in addition to some information as to how the measurements had been made.
- An interim report was made to the NOAA Ocean Acidification Program describing the results of NOAA supported laboratories, in the context of the whole group.
- A manuscript is in preparation (to be submitted summer 2018) describing this study.

Conferences, Meetings & Presentations:

- a. Dr. Dickson presented a poster at the Ocean Sciences Meeting held in Portland, Oregon in February 2018.
- b. He also spoke at, and participated in, the joint OCB / NOAA Ocean Acidification PI meeting (also held in Portland, OR after Ocean Sciences).

Education & Outreach:

Communication

- a. Andrew Dickson is a co-team leader for the Sensors and Equipment team of the new Ocean Acidification Information Exchange and participates where appropriate in threads related to the measurement of seawater CO₂ parameters.

Academic Development

- a. Andrew Dickson was invited to speak on "The Fundamentals: OA Theory and Ocean Carbon Chemistry Measurements at the NOAA OA PI Meeting in Portland, OR (Feb 2018).
- b. Andrew Dickson was invited to speak on "Measurement of Total Alkalinity in Seawaters" at a workshop at the University of Tokyo, Japan (March 2018) and also to provide a Lecture "Introduction to CO₂ Chemistry in Seawater" at the University of the Ryukyus Marine Station in Okinawa, Japan (March 2018).



K-12 Outreach

- a. Andrew Dickson advised two high school students in Southern California, on OA-related projects they were planning.

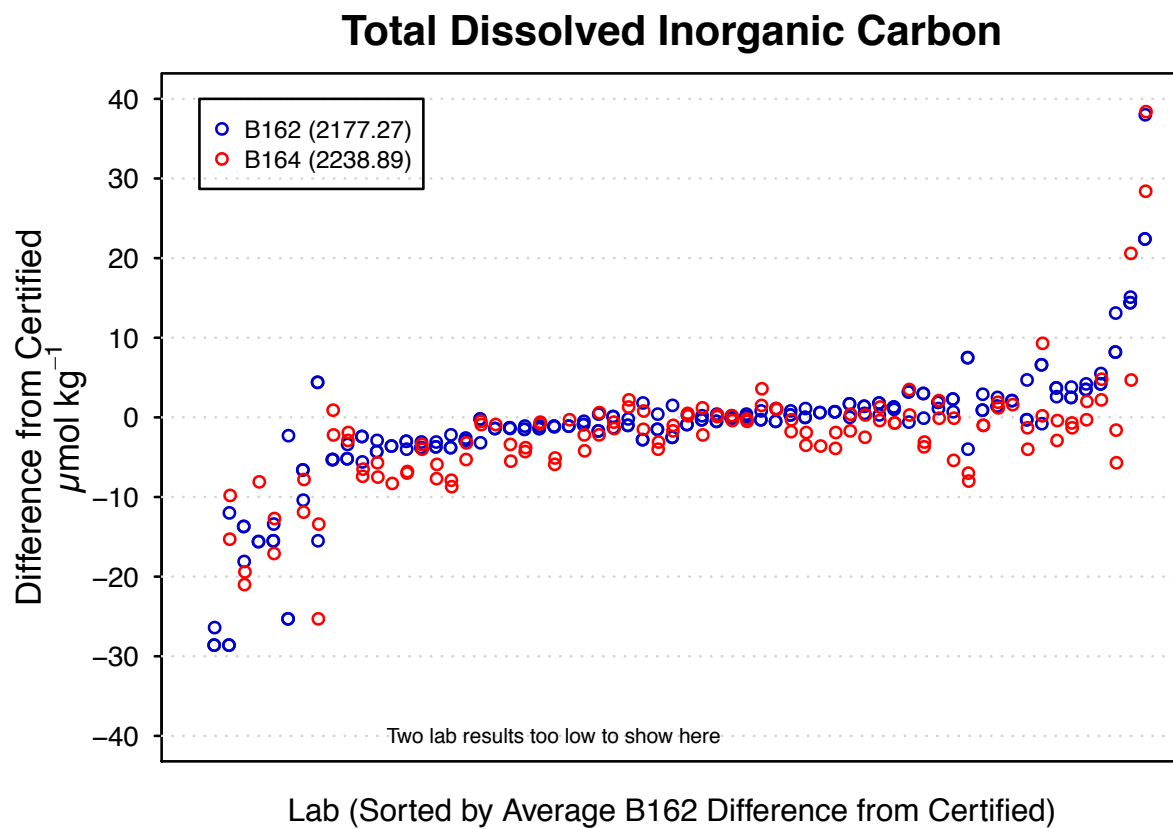


Figure 6: Deviations from SIO Certified Values for measurements of total dissolved inorganic carbon of two test samples (B162 & B164) with different seawater compositions submitted by 65 different laboratories.



CalWater and West-Coast Atmospheric River Research

Principal Investigator(s):

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

NOAA Primary Contact(s):

Robin Webb, Earth Systems Research Lab

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 precipitation and water (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:

Describe promising new science directions and collaborations, as well as new tools focused on western U.S. needs

Research Accomplishments:

- Lead the development of the Southwest Extreme Precipitation Symposium.
- Lead the several Lake Mendocino FIRO steering committee meetings.
- Organized and lead AR Recon, which included a team from NOAA

Conferences, Meetings & Presentations

- a. Dr. Ralph presented at the Southwest Extreme Precipitation Meeting on ARs and research surrounding the topic.
- b. Dr. Ralph presented at the AAAS Annual Meeting in Austin Texas on the Implication of Water Cycle Science and Technology for Resource Management.
- 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.

Education & Outreach

Communication

- a. CW3E keeps an active website of blog posts about presentations.
- b. F. M. Ralph was featured in the Water Zone Podcast on KCAA, San Bernardino
- c. F. M. Ralph was featured in a Weather Channel article on ARs
- d. CW3E became a NOAA Weather-Ready Nation Ambassador
- e. F. M. Ralph Participated in the Western States Water Council Visit at the Bodega Marine Lab





Figure 7: Radiosonde Launch at the Western States Water Council Meeting in Bodega Bay.

The Argo Project: 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

Daniel 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

Sarah Purkey, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Stephen Piotrowicz, Oceanic and Atmospheric 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: Climate Adaptation and Mitigation

Goal 2: Weather-Ready Nation

Goal 4: Resilient Coastal Communities and Economics

Budget Amount:

\$8,288,271

Amendment(s):

7, 31, 58, 63

Description of Research:

Argo is a multi-national 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 3800 active floats, provides near 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 is freely available in near-real time and in delayed-mode for applications requiring highest quality data. Since the beginning of the Argo Program in 1999, over 3000 research publications have used Argo 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 10 Deep Argo floats per year in regional pilot arrays. All goals for SIO Argo during the reporting period have been met.

A focus during the reporting year has been assessment of accuracy and stability of SBE-61 Deep Argo CTDs. While the Deep Argo Program deploys regional pilot arrays, it is essential to ensure that data quality is sufficient for observation of variability in the abyssal ocean. Improvements are being made collaboratively (US Argo and Sea-Bird electronics) in the SBE-61 CTD but the instrument has not yet achieved its ambitious target accuracies in pressure and salinity.

Research Objectives:

- Maintain the global Argo array of profiling floats along with US and international partners,



- 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
- Assess the accuracy and stability of SBE-61 Deep Argo CTD data

Research Accomplishments:

- 96 Core Argo floats were fabricated, shipped, and deployed by RV Palmer, Revelle, Kaharoa, Investigator, Thompson, and Tangaroa.
- 13 Deep Argo floats were fabricated, shipped, and deployed in regional pilot arrays by RV Palmer, Kaharoa, and Investigator.
- Improvements in float technology included (i) harmonizing pumping systems in SOLO-II and Deep SOLO floats and (ii) reducing drag and energy consumption in SOLO-II floats
- Delayed-mode quality control was carried out for all SIO-Argo profiles, approximately 18,000 per year.
- The 19th meeting of the Argo Steering Team was held in Sidney, British Columbia, Canada in March 2018
- The 18th meeting of the Argo Data Management Team was held in Hamburg Germany in November 2017

Honors and Awards

- Dean Roemmich was selected in December, 2017 to receive the National Academy of Science's Alexander Agassiz Medal.
- Dean Roemmich was elected to membership in the National Academy of Engineering in February, 2018.
- Sarah Gille received a 2016 Editors' Citation for Excellence in Refereeing for JGR-Oceans in May, 2017.

Conferences, Meetings & Presentations

- D. Roemmich (AST Co-Chair), M. Scanderbeg, and N. Zilberman attended the 19th meeting of the Argo Steering Team in Sidney, British Columbia, Canada in March, 2018.
- M. Scanderbeg (ADMT Co-Chair), J. Gilson, and N. Zilberman attended the 18th meeting of the Argo Data Management Team in Hamburg Germany, November, 2017.
- D. Roemmich, S. Gille, and N. Zilberman attended Ocean Sciences Meeting in Portland Oregon in February, 2018.
- D. Roemmich, J. Gilson, and N. Zilberman attended the Second Argo Float and Sensor Workshop in Seattle Washington in September, 2017.

Education & Outreach

Communication

- 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.

Academic Development

- 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

K-12 Outreach

- 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.
- 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.
- STEAM Leadership Event
PI Daniel Rudnick participated in an event to encourage high schoolers to pursue careers in marine science and technology. The event took place on the USS Midway in San Diego, CA on June 1, 2017.
- M. Scanderbeg, N. Zilberman, and S. Purkey described the mission of the Argo Program, and presented a Deep Argo float to a broad audience during the Science Exploration Adventure (SEA) Days event, October 21st 2017, at the Birch Aquarium in La Jolla, California.



- e. K-12 outreach presentations in the San Diego community featuring Argo and/or Deep Argo: San Diego French-American School 6th grade (May 11, 2017, Sarah Gille), Triton Day (open day at UCSD for high school seniors, April 14, 2018), Transfer Triton Day (open day at UCSD for prospective transfer students, May 5, 2018).

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.



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

Principal Investigator(s):

Brice X. Semmens, Scripps Institution of Oceanography, UC San Diego

Ralf Goericke, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. 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: Climate Adaption and Mitigation

Goal 3: Healthy Oceans

Budget Amount:

\$4,923,966

Amendment(s):

18, 48, 87

Description of Research:

The California Cooperative Oceanic Fisheries Investigations (CalCOFI) is the world's longest multi-disciplinary ocean observation program. Its 69-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, fish eggs, and observations are made 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. It has 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 is complemented by mooring, glider and satellite data and are used in physical, biological and biogeochemical oceanographic models. CalCOFI data is 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 69-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.
2. To contribute 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.

In order to achieve these objectives, we carry out quarterly cruises in the CCS, analyze the resultant data and samples, make the data and results freely available to users, and present those results in 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. All of these efforts are collaboratively executed by SIO and NOAA's SWFSC.

Research Accomplishments:



This past year, Dr. Brice Semmens took over the position of CalCOFI Director at SIO with the aim of building on his strong existing ties to the fisheries community – the SWFSC in particular. Dr. Semmens has a strong background in quantitative fisheries science and serves as one of the Principle Investigators of the Center for the Advancement of Population Assessment Methodology (CAPAM), a joint program between SWFSC, SIO and IATTC. Students and postdoctoral researchers in his lab maintain a variety of projects aimed at synthesizing CalCOFI data in order to address applied marine resource management problems.

During the grant period, 34 peer-reviewed publications used CalCOFI data as primary fodder for analysis and scientific innovation. These publications have remarkable breadth in inquiry. From assessing the performance of marine protected areas to ocean forecasting and modeling marine mammal and seabird habitat. The diversity of these publications speaks to the unparalleled value of CalCOFI as an ocean ecosystem observing program.

This year's CalCOFI program included the successful completion of four quarterly cruises (1704SH, 1708SR, 1711SR, 1802SH; <http://www.calcofi.org/cruises.html>). Standard CalCOFI observations on the biotic, chemical and physical environment in the California current from this past year captured a rich set of information characterizing the recent changes in ocean conditions. This year we continued to a pilot study on microbial biogeography diversity and gene expression in the Southern California Bight using next generation genetic techniques. This addition to standard CalCOFI sampling protocols is part of a long tradition of using CalCOFI cruises as a test bed for emerging observation tools.

In addition to base monitoring activities, CalCOFI affiliated personnel (Goericke, Semmens, Ohman) participated in the IMECOCAL 20th anniversary meeting in Ensenada, Mexico. This conference spurred renewed efforts to build a collaborative data structure between the two programs, including a new UC Mexus proposal (pending). CalCOFI also successfully coordinated the annual CalCOFI Conference on the SIO campus. The conference theme was "Forage in the California Current Ecosystem." Forage consists of small pelagics (e.g., anchovy, sardine, jack mackerel), mesopelagic fish, and pelagic invertebrates (e.g., krill, squid). Talks addressed topics related to forage predators (including fish, invertebrates, marling mammals and seabirds), current and future forage fisheries (e.g., small pelagic fish and squid), and forcing factors related to stocks fluctuation (both natural and anthropogenic).

Cruise specific summaries are provided below:

- **CalCOFI 1802SH**
NOAA RV Bell M Shimada sailed from 10th Ave Marine Terminal San Diego 01 Feb 2018. With only eleven days-at-sea, 40 stations were scheduled. With mostly calm weather and fast transit times, 5 additional stations on Line 77 were added. Forty-five stations were completed before transiting north & offloading in San Francisco.
- **CalCOFI 1711SR**
SIO RV Sally Ride sailed from Nimitz Marine Facilities (MarFac), San Diego at 0800 09 Nov 2017 with 17 scientists, technicians, & volunteers. 74 of 75 scheduled stations were successfully occupied; one station was missed due to naval operations precluding our timely occupation of sta 90.45. A personnel exchange mid-cruise caused a major change in the station order. On Line 80, sta 80.55, we were restricted from station due to a NOAA weather satellite missile launch so we continued west to 80.60. Sta 80.55 was occupied on our southward transit to Line 87. RV Sally Ride returned to San Diego at ~1430 24 Nov 2017 and due to the Thanksgiving holiday, offloading was postponed until 0800 Monday 27 Nov.
- **CalCOFI 1708SR**
SIO RV Sally Ride sailed at 1000PDT 01 Aug 2017 from Nimitz Marine Facilities (MarFac) San Diego. Returning to San Diego 0930PDT 16 Aug 2017. RV Sally Ride was offloaded upon arrival to MarFac. All 73 scheduled stations - 65 standard stations & 8 SCCOOS 20m stations were occupied (see station map). As planned, two stations were dropped - 93.3 120 & 91.7 26.4 - to complete the scheduled stations plus mooring deployment. To maximize ship transit efficiency, saving 10+hrs, RV Sally Ride sailed north after sta 83.3 51.0 to sta 80.0 60.0. With the mooring deployment scheduled for sta 80.0 55.0, this station was scheduled after sta 76.7 49.0 & the pickup of Uwe Send's mooring team at Avila Beach. Eight in-shore stations off Santa Barbara & Ventura were occupied after sta 80.55, as we transited south. In addition to DIC, pH, NCOG sampling, 1708SR included oxygen stable isotope seawater samples collected on 18 stations.
- **CalCOFI 1704SH**
NOAA RV Bell M Shimada sailed from the 10th Ave Marine Terminal on 28 Mar 2017, and returned to the point of departure on 20 Apr 2017. All scheduled stations were successfully occupied - 82 stations on Leg I, 22 on Leg II. Personnel were exchanged at Monterey 15 Apr 2017. Other than rough weather



three days into the cruise slowing station transits, station operations were performed without issues. With fewer analytical personnel aboard, Leg II's CTD-rosette seawater sampling depths were reduced to 12 versus Leg I's 20-24 sampled depths.

Conferences, Meetings & Presentations:

- a. Drs. Brice Semmens, Ralf Georricke, and Mark Ohman attended IMECOCAL 20th anniversary meeting in Ensenada, Mexico, December 12-13 2017.

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).





Figure 8: CalCOFI technicians mount a Pairovet Vertical Net in preparation for deployment at a near-shore station deployment from FSV Bell M Shimada, April 2018. Photo by James Wilkinson.



Figure 9: CalCOFI 1711SR: Catch of the night in our bongo net during the Fall 2017 cruise – a barbeled dragonfish. Sta 86.7 100.0. Photo by James Wilkinson.



SIO High Resolution XBT Transects

Principal Investigator(s):

Janet Sprintall, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Deane 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 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: Climate Adaptation and Mitigation

Goal 2: Weather-Ready Nation

Budget Amount:

\$2,658,771

Amendment(s):

5, 65

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 deploys XBTs at spatial separations of 10 to 50 km from the ship. The HRX Network was initiated over 30 years ago 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, Indian and Southern 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's oceans.

All anticipated goals during the reporting period were met. During this reporting year we deployed ~4500 XBTs along 7 transects in the Pacific, Indian and Southern Ocean. All HR-XBT data were made available without restriction in near real-time through the GTSP and delayed mode versions through NCEI and at the SIO web site (www-hrx.ucsd.edu). This data contributed to the PhD thesis of an SIO graduate student, the analysis effort of an SIO postdoc, as well as the presentation of results by the PIs and others at international conferences and numerous publications in international peer-reviewed journals.

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 is the minimal sampling requirement for *in situ* data?
- Identify permanent boundary currents and fronts and describe their persistence, recurrence, and relation to large-scale transports.
- Estimate the significance of baroclinic eddy heat fluxes.

Research Accomplishments:

- Deployment of >4500 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.

- 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 conference presentations and publications: <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.
- HR-XBT data was assimilated into models such as ECCO and the Southern Ocean State Estimate (SOSE)

Conferences, Meetings & Presentations

- a. Gutierrez-Villanueva, M. O., T.K. Chereskin and J. Sprintall, Eddy Heat and Momentum Fluxes in the Antarctic Circumpolar Current Estimated from Observations in Drake Passage, Conference Proceedings, Ocean Sciences Meeting, Portland, Oregon, February 11-16, 2018.
- b. Sprintall, J. N. Zang and R. Ienny, Transport Variability in the Western Boundary Current of the Arabian Sea, Conference Proceedings, Ocean Sciences Meeting, Portland, Oregon, February 11-16, 2018.
- c. Sprintall, J. et al. Observing low latitude western boundary currents: a pilot study. U.S. CLIVAR meeting: Bridging Sustained Observations and Data Assimilation for TPOS-2020 (Tropical Pacific Observing System), Boulder, CO, April 2018
- d. Verdy, A., B. Cornuelle, M.R. Mazloff, and D.L. Rudnick, Toward evaluating the Tropical Pacific Observing System using ocean state estimation covering 2010—2013, Conference Proceedings, Ocean Sciences Meeting, Portland, Oregon, February 11-16, 2018.
- e. Verdy, A., B. Cornuelle, M.R. Mazloff, and D.L. Rudnick, Toward evaluating the Tropical Pacific Observing System using ocean state estimates covering 2010—2013, U.S. CLIVAR meeting: Bridging Sustained Observations and Data Assimilation for TPOS-2020 (Tropical Pacific Observing System), Boulder, CO, April 2018
- f. Zilberman, N.V., Roemmich D., Gille S., Gilson J., Estimating the velocity and transport of Western Boundary Current systems: A case study of the East Australian Current near Brisbane, Conference Proceedings (Oral presentation), Ocean Sciences Meeting, Portland, Oregon, February 11-16, 2018
- g. Dr. Janet Sprintall co-chaired session PL42: “Multiscale Variability of Boundary Currents and Their Role in Climate and Ecosystems” at the Ocean Sciences Meeting, Portland Oregon, 11-16 February 2018.
- h. Dr. Janet Sprintall attended and presented at the Tropical Pacific Observing System (TPOS-2020) Western Pacific workshop in Qingdao, China in September 2017.

Education & Outreach

Communication

- a. HRX Data Website:
Lisa 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 transect data from all cruises; and to provide downloadable datasets on a cruise-by-cruise basis.
- b. Justine Parks contributed an article on the high resolution XBT network to the 41st Edition "Columbia Compass" for Columbia Ship Management. Justine also contributed outreach articles to shipping companies: Rickmers and Marlow Technical. These articles reach our partners in the shipping industry.

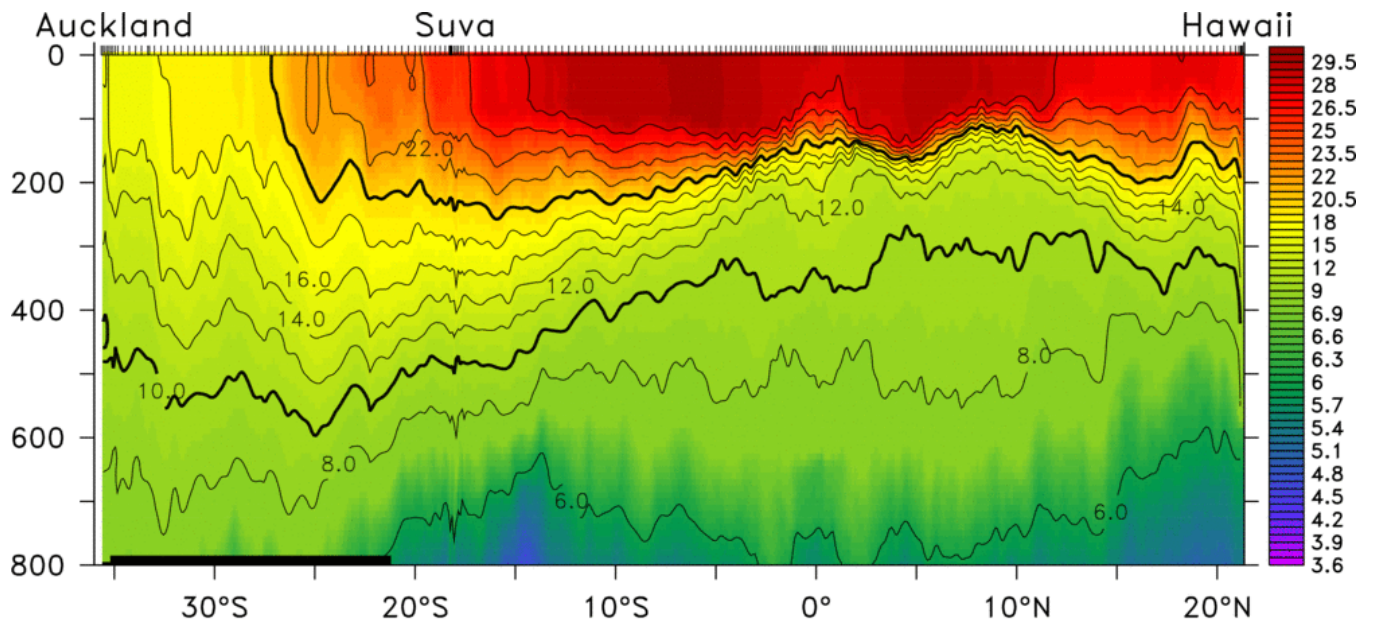
Academic Development

- a. PI Sprintall co-advises SIO PhD student Manuel Othon Gutierrez-Villanueva using HR-XBT data as part of his original research. Gutierrez-Villanueva has presented his thesis work at Ocean Sciences 2018.
- b. PI Sprintall co-mentors SIO postdoc Natalie Freeman using HR-XBT data as part of her analysis to look at the physics and biogeochemical signals in the Southern Ocean.

Networking

- a. Justine Parks contributed an article on the high resolution XBT network to the 41st Edition "Columbia Compass" for Columbia Ship Management. Justine also contributed outreach articles to shipping companies: Rickmers and Marlow Technical. These articles reach our partners in the shipping industry.
- b. Janet Sprintall contributed to the writing of the International CLIVAR Indian Ocean Observing System Decadal Review report, January 2018.
- c. Janet Sprintall contributed to the writing of the TPOS2020 First Report, September 2017.





PX06/PX09, Cap Pasado, 30 Jul 2017– 9 Aug 2017, Good drops=212

Figure 10: 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.



Consortium on the Ocean's Role in Climate (CORC): Integrated Boundary Current Observations in the Global Climate System

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

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

Ben Reineman, 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

John Gilson, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Jim Todd, Ocean Observing and Monitoring Division, Climate Program Office

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

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

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaption and Mitigation

Goal 2: Weather-Ready Nation

Goal 3: Healthy Oceans

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$3,729,053

Amendment(s):

4, 36, 86

Description of Research:

The Consortium on the Ocean's Role in Climate (CORC) implements new ocean observing technologies and systems focused on aspects of ocean circulation that influence global climate or its impact. Cost-effective technologies and methods to observe inadequately measured components are developed, first by implementing small observing systems to test and improve the technique and to show potential utility of the data. When successful, these measurements may become the basis of parts of the global ocean observing system. Examples are the High-Resolution Expendable Bathythermograph network operated from commercial ships, the Surface Velocity Program's surface drifters, the Argo array of profiling floats and the California Underwater Glider Network (CUGN) observing the California Current.

In conjunction with national and international plans, CORC now focuses on sustainable new observations of boundary currents. Powerful Western Boundary Currents (WBCs) have global climate impacts while variability in Eastern Boundary Currents affects local weather, ocean acidification and valuable fisheries. CORC now observes the Pacific's tropical-gyre WBC in the Solomon Sea (SS) and the eastern-boundary California Current (CC). Gliders and moorings measure volume, heat and freshwater transport through the SS, which is a main source to the equatorial warm pool and the trans-Pacific undercurrent that feeds equatorial upwelling – both are key to equatorial air-sea interaction and climate variation. In the CC, an array of four fixed mooring and bottom pressure stations is being used, in conjunction with the CCE project and augmenting the CUGN, to observe along-coast flows and other physical and biogeochemical properties, and to estimate time series of upwelling intensity, which is central to this region's large productivity. Estimates of the broad CC equatorward transport are routinely generated via a mooring-calibrated altimetry approach.



CORCs modelling component is using modern data-assimilation methods to merge CORC observations and regional data from the global ocean observing system to form dynamically-consistent state estimates of the CC System. This technique makes the best use of the data and supports interpretation outside the space-time range of the observations.

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 10 years of sampling flow through the Solomon Sea to the equatorial warm pool with gliders, now achieving 10-15 sections per year to 1000m depth
2. Five full years of transport through the Solomon Sea in hand now from endpoint moorings/PIES.
3. Quantification of the relation between ENSO (via Nino3.4 SST) and various SS transports.
4. Five years of California Current cross-shelf transports in hand now between moorings CORC3 and CCE2.
5. Extension of the cross-shelf transport array northward to near Monterey Bay.
6. A website (spraydata.ucsd.edu) has been established for public access of quality controlled delayed mode data.
7. Improved methods for blending the CORC, Spray Glider, altimeter, and other observations in the California Current system.
8. Favorable cross-validation of the estimates against CalCOFI observations.
9. Updated state estimates for use by others.
10. Study of topographically enhanced northward transport in the South Pacific Ocean.
11. Assessment of the tropical Pacific observing system.

Honors and Awards:

- a. Dean Roemmich was selected in December 2017 to receive the National Academy of Sciences Alexander Agassiz Medal.
- b. Dean Roemmich was elected to membership in the National Academy of Engineering in February 2018.

Conferences, Meetings & Presentations:

- a. D. Roemmich and N. Zilberman attended and presented at the Ocean Sciences meeting in Portland, February 2018
- b. B. Cornuelle and D. Rudnick attended and presented at the Ocean Sciences meeting in Portland, February 2018
- c. U. Send and M. Lankhorst attended and presented at the Ocean Sciences meeting in Portland, February 2018
- d. U. Send, M. Lankhorst, D. Roemmich attended the OOMD Community Workshop. Silver Spring, MD, May 2017
- e. U. Send attended a SPICE workshop in Toulouse/France, May 2017
- f. U. Send attended a NOAA/KIOST Indian Ocean planning meeting in Seoul/Korea, November 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.

Networking

- a. U. Send, M. Lankhorst, D. Roemmich attended the OOMD Community Workshop. Silver Spring, MD, May 2017
- b. U. Send attended a SPICE workshop in Toulouse/France, May 2017
- c. U. Send attended a NOAA/KIOST Indian Ocean planning meeting in Seoul/Korea, November 2017



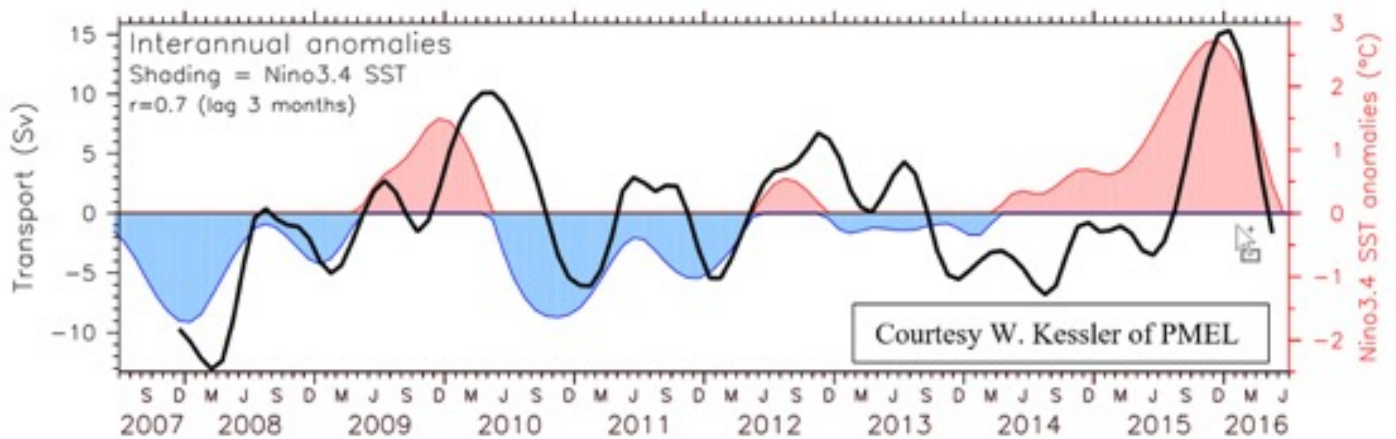


Figure 11: Figure showing the SS transport above 700m (black) and anomalies of Nino3.4 SST. High Nino3.4 and high equatorward transport are apparently related, with transport lagging by 1 to 4 months on semi-annual to ENSO time scales (from collaborator William Kessler of PMEL).

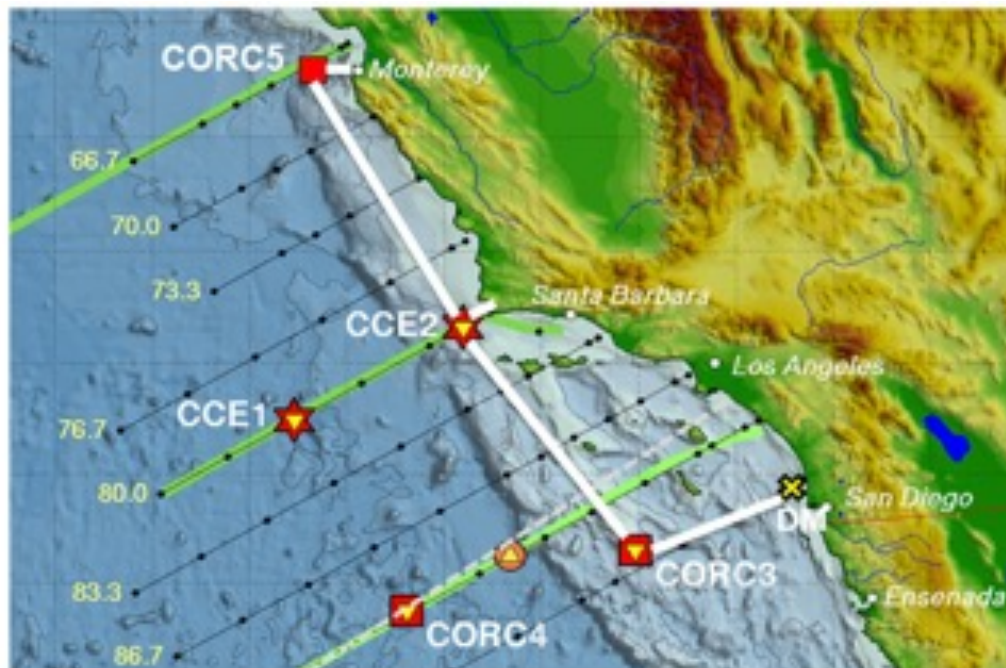


Figure 12: Map of the new control volumes spanned by CORC3, CCE2, and the new CORC5 sites together with sections perpendicular to the coast (white lines). Dynamic height at CORC3, CCE2, and CORC5 is derived from density profiles (moorings, gliders) relative to PIES or satellite altimetry.



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)

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: Climate Adaptation and Mitigation

Goal 2: Weather-Ready Nation

Goal 3: Healthy Oceans

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$1,372,891

Amendment(s):

9, 45, 62

Description of Research:

Local, state, regional, and federal support for the Integrated Ocean Observing System (IOOS) has 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 with this project period to include diagnostic utilities, data summaries, and backend configuration. CORDC programmers modified

the radial database schema to optimize queries and use cases. The schema has been in beta testing on the SIO node to evaluate performance and to provide a framework for downstream development. As in previous years, 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 Advanced Weather Interactive Processing System (AWIPS).

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 154 U.S. radar stations and 14 Canada/Mexico radar stations, regionally operated, which reports data to collection 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. Primary goals during this project period include, but are not limited to:

- Design new database schema (modifications were made to the radial database schema to optimize queries and use cases. The schema has been in beta testing on the SIO node to evaluate performance and to provide a framework for downstream development);
- Design new data acquisition for improved portal to node communications (new data (radial) acquisition code has been designed and is in development. Operational code for radial data storage has been in beta testing for several months. A plan for transitioning from the current operational data acquisition and storage system to the new acquisition system and storage schema has been developed);
- Development of new storage architecture for future added features of radial file versioning and "best processed" data set;
- Publish long term averages and make those available through THREDDS Data Service;



- Support radial access for the OTT modeling effort (buffer depths were increased to provide a deeper archive of radial data per Portal and methods were put in place to allow for more efficient data acquisition re-configuration during prolonged Portal outages);
- Configuration of new node and portal servers.
- Support both U.S. growth and global partnership by expanding the visualization to Croatia and Italy.

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 of the network Implementation of Iridium communication on all ships participating in the HR-XBT network.
- CORDC launched the Operational RTV Long-term Average (LTA) product which currently consists of monthly and annual means with related statistics for all regions and resolutions starting from 2012.
- Details and documentation of processing methods are available at the CORDC HFRNet page:
 - http://cordc.ucsd.edu/projects/mapping/documents/HFRNet_Long_Term_Averages_and_Statistics.pdf

The datasets are available on CORDC's TDS under the 'HF RADAR RTVs' regional links:

 - <http://hfrnet-tds.ucsd.edu/thredds/catalog.html>
- CORDC launched a new SIO THREDDS Data Server (TDS) version 4.6.11 on January, 10, 2018. The site resides on a dedicated server with increased memory to handle more connections. So far, the new version has shown better performance and stability. The new TDS URL is:
 - <http://hfrnet-tds.ucsd.edu/thredds>
- CORDC launched automated notifications regarding connectivity issues affecting participating organization site(s). The monitoring software is called InterMapper and is similar to Nagios or other network monitoring applications. CORDC configures the software to monitor connectivity throughout the network and users can be notified of network outages affecting data acquisition from their site(s).
- 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:
 - Digby Island, Prince Rupert (VDIG), University of Victoria
<https://hfrnet.ucsd.edu/diagnostics/?p=sta&sta=VDIG&t=0>
 - Hillsboro, FL (HILL) Florida Atlantic University
<https://hfrnet.ucsd.edu/diagnostics/?p=sta&sta=HILL&t=0>
 - Rutgers Cape Shore Lab, NJ (CAPE), Rutgers University
<https://hfrnet.ucsd.edu/diagnostics/?p=sta&sta=CAPE&t=0#>
 - Pass Christian Yacht Club, MS (PCYC)
<https://hfrnet.ucsd.edu/diagnostics/?p=sta&sta=PCYC>
 - Silver Slipper Casino, MS (SISL)
<https://hfrnet.ucsd.edu/diagnostics/?p=sta&sta=SISL>
 - Squibnocket Farms, MA (SQUB)
<https://hfrnet.ucsd.edu/diagnostics/?p=sta&sta=SQUB>
 - MVCO Meteorological Mast, MA (METS)
<https://hfrnet.ucsd.edu/diagnostics/?p=sta&sta=METS>
 - Fort Funston, CA (FORT)
<https://hfrnet.ucsd.edu/diagnostics/?p=sta&sta=FORT&t=0#>
- Decommissioned sites:
 - JOUB – Rutgers, Joubin Island
 - PALM – Rutgers, Palmer Station
 - WAUW – Rutgers, Wauwerman's Islands
 - CLUB – Rutgers, Cape May Point, NJ
 - METS – Woods hole
 - MVCO – Meteorological Mast, MA
 - WCDN – U Miami, Crandon, FL
 - WNKL – U Miami, North Key Largo, FL
 - UABC – Universidad Autonoma de Baja California
 - LEND – CODAR, Land's End, CA
- Suspended Sites:
 - ANCH – Anchor Point, AK
 - METL – Metal Magic, AK
 - NANW – Nanwalek, AK
 - OKKO – Steve Okkonen's House, AK
 - OSPY – Osprey Drilling Platform, AK
- Supported Domains and Available Data:
 - USEGC – US East and Gulf Coast, 3/2008 to present
 - USWC – US West coast, 3/2008 to present



- GAK – Gulf of Alaska, 5/2009 to present (when available)
 - PRVI – Puerto Rico and US Virgin Islands, 1/2010 to present
- 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

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

c. Data Requests

- Naval Surface Warfare Center - Carderock Division South Florida Ocean, Measurement Facility
- Engineering Division, NOAA\NOS Center for Operational Oceanographic Products and Services
- Office of Spill Prevention and Response, California Department of Fish and Wildlife

Academic Development

- a. Thomas Cook attended the AGU Ocean Sciences Meeting to participate in the science conference and attend the national high frequency radar meeting in Portland, Oregon, Feb 11 – 16, 2018

Conferences, Meetings & Presentations

- a. Joseph Chen attended the DJANGOCON conference to participate in workshop/training on data visualization for High Frequency Radar network, Spokane, WA, Aug 13-18, 2017
- b. Thomas Cook attended the AGU Ocean Sciences Meeting to participate in the science conference and attend the national high frequency radar meeting in Portland, Oregon, Feb 11 – 16, 2018
- c. Lisa Hazard presented SCCOOS High Frequency Radar efforts at the Joint Strategic Advisory Committee Meeting 11-13, 2016
- d. Lisa Hazard presented California High Frequency Radar efforts at the CA Regional Response Team (RRT) in Long Beach, CA, January 8-10, 2018

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. 10 international partners



HF-Radar Network



Figure 13: Frequency Radar network FY2017 metric statistics – reporting the percentage of time funded radars are operational during a given reporting period.

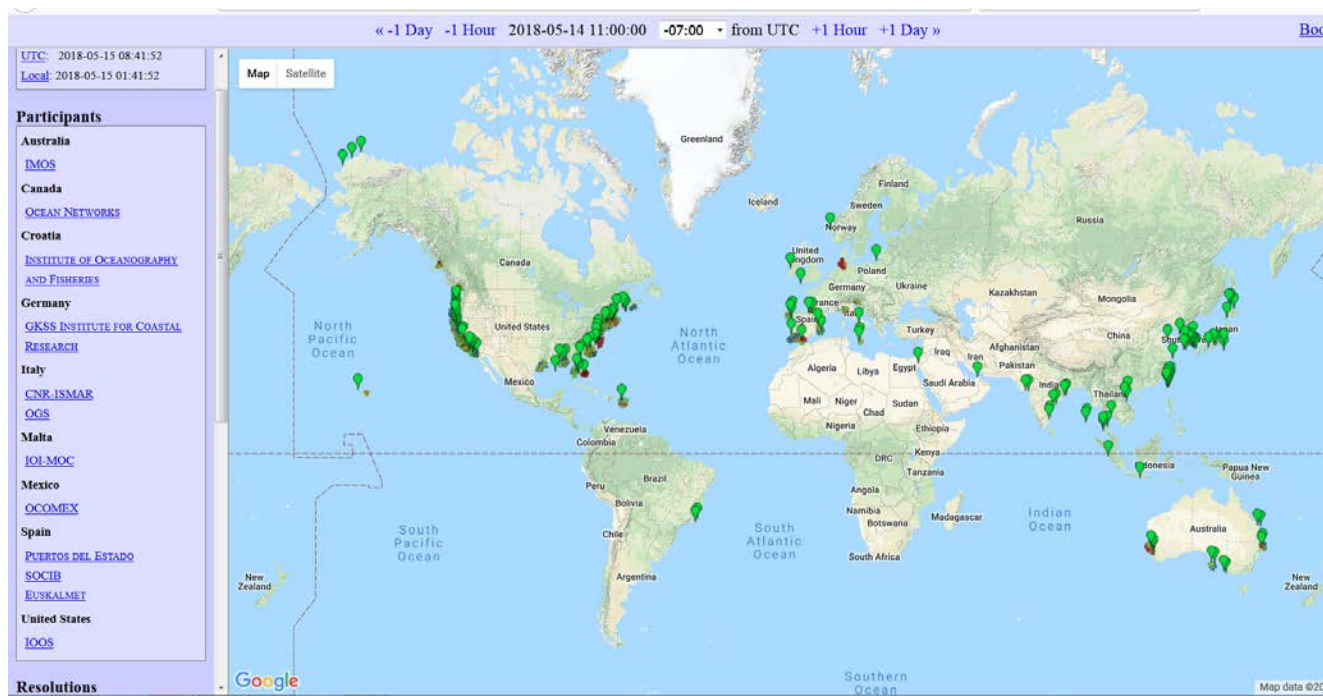


Figure 14: Global High Frequency Radar network depicting global sites near real-time totals from participating countries.



Bridging the Gap to NOAA's Extended Long-Range Prediction Systems Through the Development of New Forecast Products for Weeks 3 & 4 - NA14OAR4310189

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

Michelle L'Heureux, NOAA Climate Prediction Center

Dan Harnos, NOAA Climate Prediction Center

Stephen Baxter, NOAA Climate Prediction Center

Steven Feldstein, Penn State University

NOAA Primary Contact:

Dr. Annarita Mariotti, Climate Program Office (CPO)

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). This guidance is based on a statistical model that generates probabilistic forecasts of temperature and precipitation for lead times of up to four weeks based on the initial states of the Madden-Julian Oscillation (MJO), El Niño-Southern Oscillation (ENSO), and the linear trend. Through collaboration among SIO, Princeton University/GFDL, and CPC, we completed the transition of these operational forecast tools into operations by the end of the project in June 2017. We monitored the performance of our forecast guidance over a two-year test period as part of the implementation of CPC's

Experimental Week 3-4 temperature and precipitation outlooks, and both the temperature and precipitation guidance exhibited promising skill over this period. The MJO/ENSO statistical guidance was officially transitioned into operations for CPC Week 3-4 temperature outlooks on May 19, 2017, and the Week 3-4 precipitation outlook remains experimental. This final step indicated a successful outcome of the project.

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 of the forecast tools from the project into official operations. The project was deemed "a great success" by the NOAA Climate Program Office (<https://cpo.noaa.gov/News/News-Article/ArtMID/6226/ArticleID/1597/New-NOAA-forecast-product-guides-3-to-4-week-temperature-and-precipitation-outlooks>)
- 12 total published articles supported by the grant, including one published during this reporting period

Conferences, Meetings & Presentations

- a. Dr. Nathaniel Johnson presented results on seasonal predictions with weather types at the 2017 AMS 30th Conference on Climate Variability and Change held in Baltimore, MD from July 28-29, 2017.
- b. Dr. Nathaniel Johnson presented results on experimental subseasonal-to-seasonal predictions at the 98th AMS Annual Meeting held in Austin Texas from January 7-11, 2018.

Education & Outreach

Communication

- a. [Climate.gov ENSO Blog](#)

Starting in March 2017, Dr. Nathaniel Johnson has served as one of four primary writers for the NOAA climate.gov ENSO Blog. The ENSO Blog, which has received more than 1.7 million unique page views over the four years of its existence, provides an opportunity to communicate scientific principles related to the El Niño-Southern Oscillation and



climate prediction more generally to a broad audience. Dr. Johnson is responsible for writing four blog posts over the course of a year and contributing to editing the bimonthly posts and moderating the comment section.

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 to 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



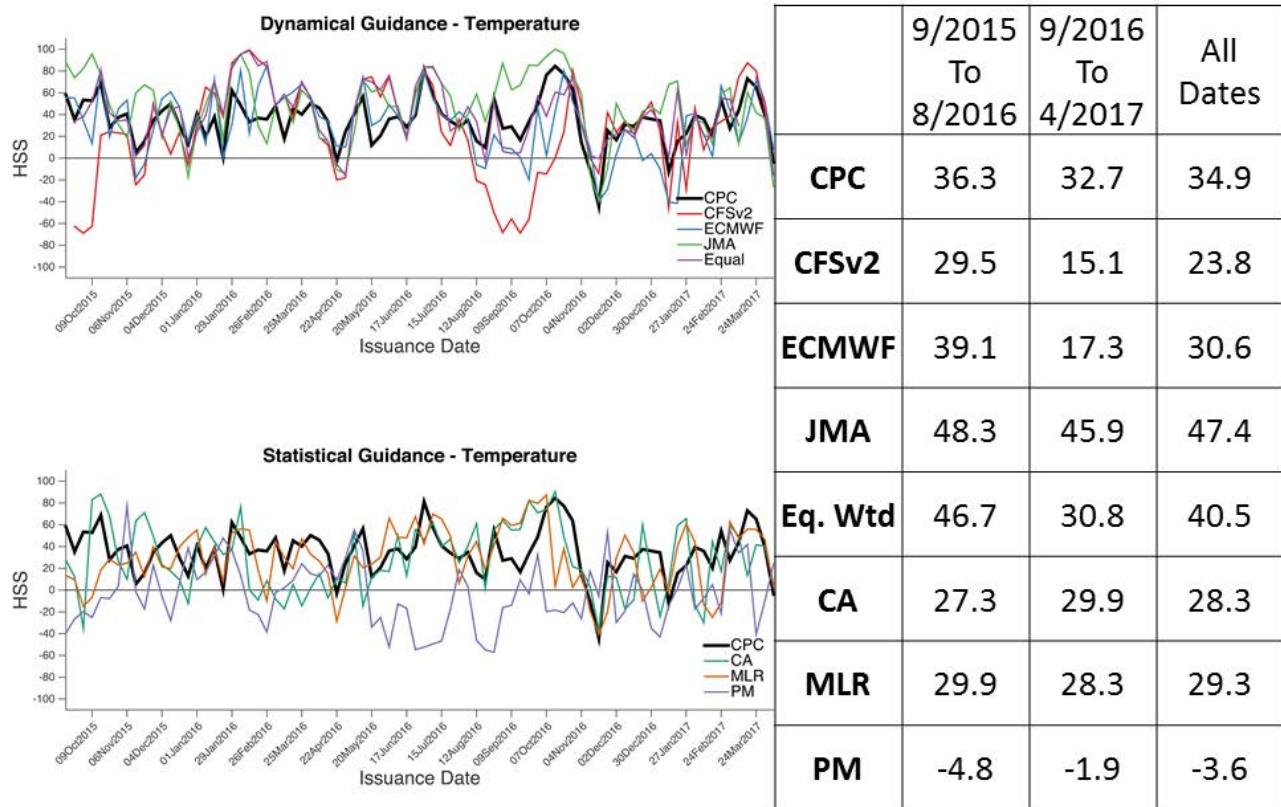


Figure 15: Heidke skill scores (HSS's) of CPC's Experimental Week 3-4 Temperature Outlook for the implementation period beginning in September, 2015. Values greater than 0 indicate skills relative to a random forecast. Top left panel indicates the HSS time series for the dynamical guidance, and the bottom left panel indicates the corresponding time series from the statistical guidance. The table on the right indicates the mean HSS's for the first year, second year, and the full period. "CPC" indicates the official CPC outlook, "CFSv2," "ECMWF," and "JMA" are the dynamical models used, and "Eq.Wtd" indicates the equal-weighted dynamical model ensemble. "CA" indicates the constructed analog statistical guidance, "MLR" is the multiple linear regression model, and "PM" is the MJO/ENSO phase model. The MLR and PM models are the models developed in this project. The table on the right indicates that the MLR model is competitive with all other forms of dynamical and statistical guidance.

Western Boundary Current Transport as a Climate Index - NA14OAR4310219

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:

Emily Osborne, Climate Program Office

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

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

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaptation and Mitigation

Budget Amount:

\$231,447

Award:

NA14OAR4310219

Description of Research:

A new method was developed for improving estimates of the volume transport in Western Boundary Current (WBC) regions sampled by the High-Resolution Expendable Bathythermograph (HR-XBT) network. Transport estimates are based on sustained ocean observations including the HR-XBT network, the Argo array, and altimetric datasets. The robustness of the method is demonstrated using data comparisons of the East Australian Current (EAC) transport at approximately 26.5°S, near the Brisbane end of HR-XBT Line PX30 (Figure 17). The overall good agreement seen between the mean and low-frequency variability of the geostrophic transport across PX30 using the HR-XBT/Argo/altimetry datasets, and from concurrent and nearly co-located moored observations at approximately 27°S, provides evidence of the robustness of the method. Transport estimates of the EAC across PX30 based on HR-XBT/Argo/altimetry show a seasonal cycle with values significantly stronger in summer compared with winter, in agreement with moored observations at 30°S and 34°S as well as historical data (Figure 10).

Research Objectives:

The long-term goal is to define a new set of ocean climate indicators to track the seasonal to decadal variability in WBC transport in the subtropical gyres. The new method developed in this project for improving estimates of the volume transport in WBC regions is a step in that direction.

Research Accomplishments:

A paper describing the method for estimating WBC transport based on the HR-XBT network, the Argo array, and altimetric datasets, was submitted to *J. Tech.* and is now in press (See section 17 Publications).

Honors and Awards

- a. Sarah Gille received a 2016 Editors Citation for Excellence in Refereeing for JGR-Oceans, awarded May, 2017.

Education & Outreach

- a. Nathalie Zilberman attended the Ocean Sciences Meeting held in Portland, Oregon from February 11-16th, 2018.

Education & Outreach

Communication

- a. Nathalie Zilberman, Megan Scanderbeg, and Sarah Purkey described the mission of the Argo Program and presented a Deep Argo float to a broad audience during the SEA Days event, October 21st 2017 at the Birch Aquarium in La Jolla, California.
- b. Sarah Gille and others from SIO presented Argo and Deep Argo to attendees of UCSD's open day events, Triton Day (April 14, 2018) and Transfer Triton Day (May 5, 2018).

Academic Development

a. Undergraduate Teaching:

Students in Sarah Gille's winter quarter 2018 undergraduate course, SIO 119: Physics and Chemistry of the Ocean, had the opportunity to see an Argo float, a CTD, and an XBT, and to learn about the ocean observing systems.



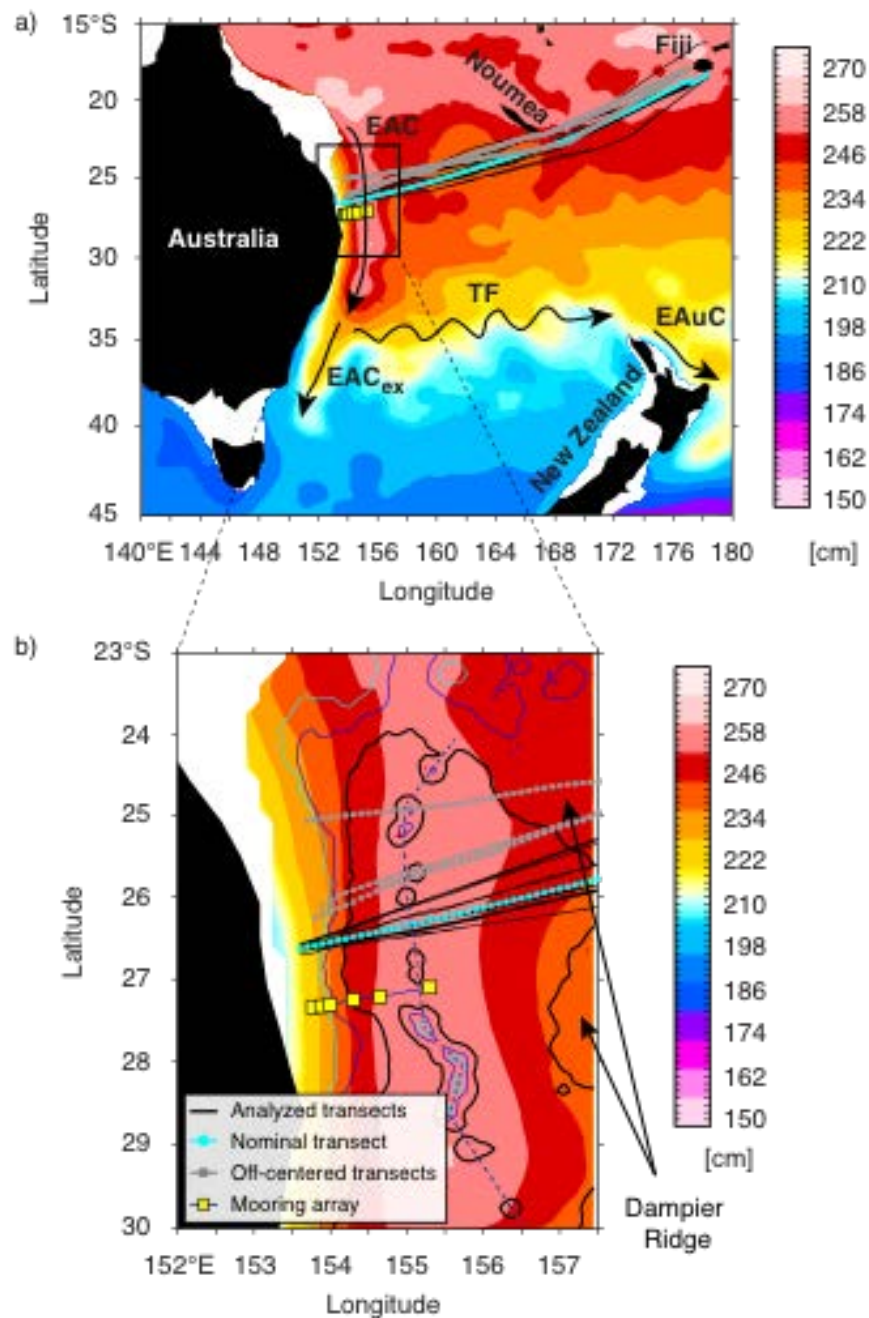


Figure 16: Schematic of the EAC, EAC extension (EAC_{ex}), Tasman Front (TF), and East Auckland Current (EAuC). The underlying color gives the steric height at the sea surface relative to 1975 m averaged between 2004-2015, computed using the gridded Argo climatology data, in (a) the Southwest Pacific and (b) the East Australian Current region near Brisbane. The PX30 transects between 2004-2015 used for analysis are indicated in black. The time-averaged PX30 route, called nominal transect, is shown in round light-blue circles. PX30 routes off-centered from the nominal transect are shown (square gray symbols). Contours in 1b, indicate 1000m (light blue), 2000 m (dark blue), and 4000 m (thick black) depth. Indicated in square yellow symbols are locations of the mooring at nominal latitude of 27°South. The Dampier Ridge is shown with black arrows and the Tasmanid Seamount chain is indicated by the dashed blue line.





Figure 17: Annual Cycle of the absolute geostrophic transport normal to the PX30 nominal track in the EAC region west of 155.3°E from 2004-2015, computed using merged data. The 2004-2015 mean transport estimate (gray line) is indicated. The standard error of the monthly estimates relative to seasonal means is represented.

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:

Dr. James Todd, Ocean Observing and Monitoring Division

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

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

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaption and Mitigation

Goal 2: Weather-Ready Nation

Goal 3: Healthy Oceans

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$748,300

Amendment(s):

37,79

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. Dissolved oxygen has been added to the data stream during the past year. 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. 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 began in April 2007 and has been uninterrupted since April 2008. To date the CUGN has covered 250,000 km over ground in over 33 glider-years, while doing 110,000 dives. A reasonable metric of performance is the number of operational glider-days/day, with the goal of having 3 glider-days/day (Figure 19). During 2009-2015, coverage was 97%. During the past two calendar years, we have exceeded 3 glider-days/day. There was greater than normal coverage on line 80 in 2016 because of an opportunistic mission funded by the NSF California Current Ecosystem LTER. For the past year, we have experimented with a glider doing an alongshore section between lines 80 and 90, producing slightly more glider-days on line 90.

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, and continued anomalous warmth (figure 20).

- 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:

- Daniel Rudnick attended the international Ocean Gliders Steering Team meeting held in Paris, France during April 20-21, 2017.
- Daniel Rudnick attended the OOMD Community Workshop meeting held in Washington, DC during May 9-11, 2017.
- Daniel Rudnick attended the Ocean Sciences Meeting held in Portland, OR during February 12-16, 2018.

Education & Outreach:

Communication

- 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

- 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

- 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.

- STEAM Leadership Event

PI Daniel Rudnick participated in an event to encourage high schoolers to pursue careers in marine science and technology. The event took place on the USS Midway in San Diego, CA on June 1, 2017.

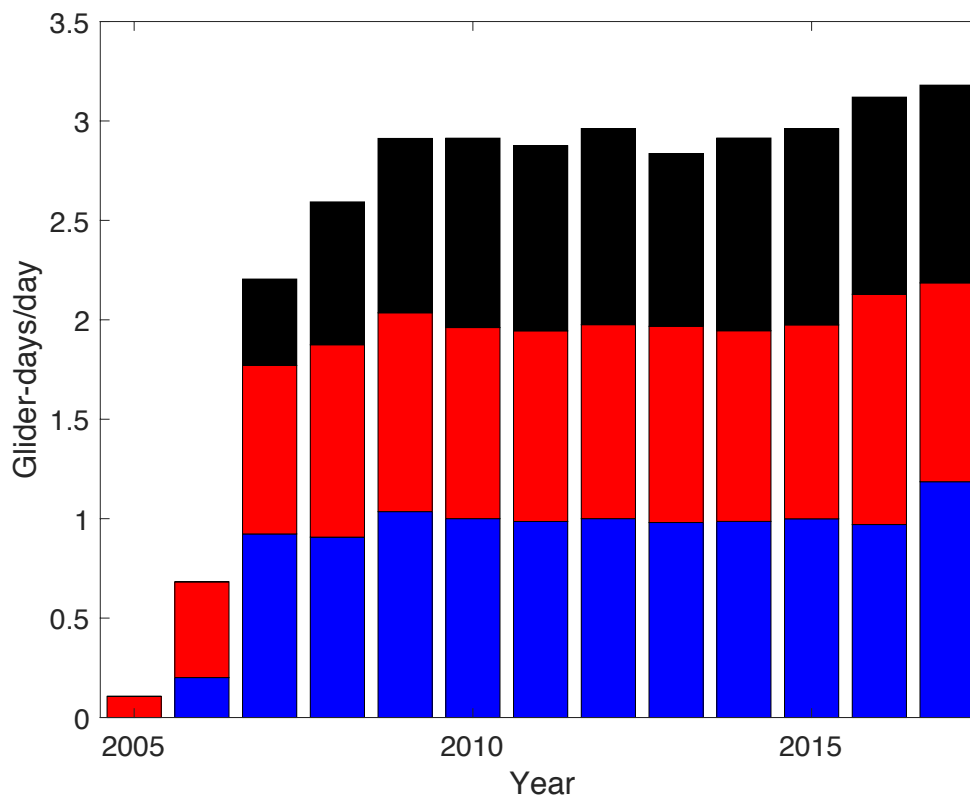


Figure 18: Glider-days/day averaged over calendar years on each of the three CUGN lines 66.7 (black), 80 (red), and 90 (blue). Ideal performance would be a value of 1 glider-days/day on each line for a total of 3 glider-days/day. Lines 66.7 and 90 are supported by OOMD, and line 80 is supported by IOOS. During 2016, there was an extra mission on line 80 funded by other sources, and in 2017, there were a few additional days on line 90.



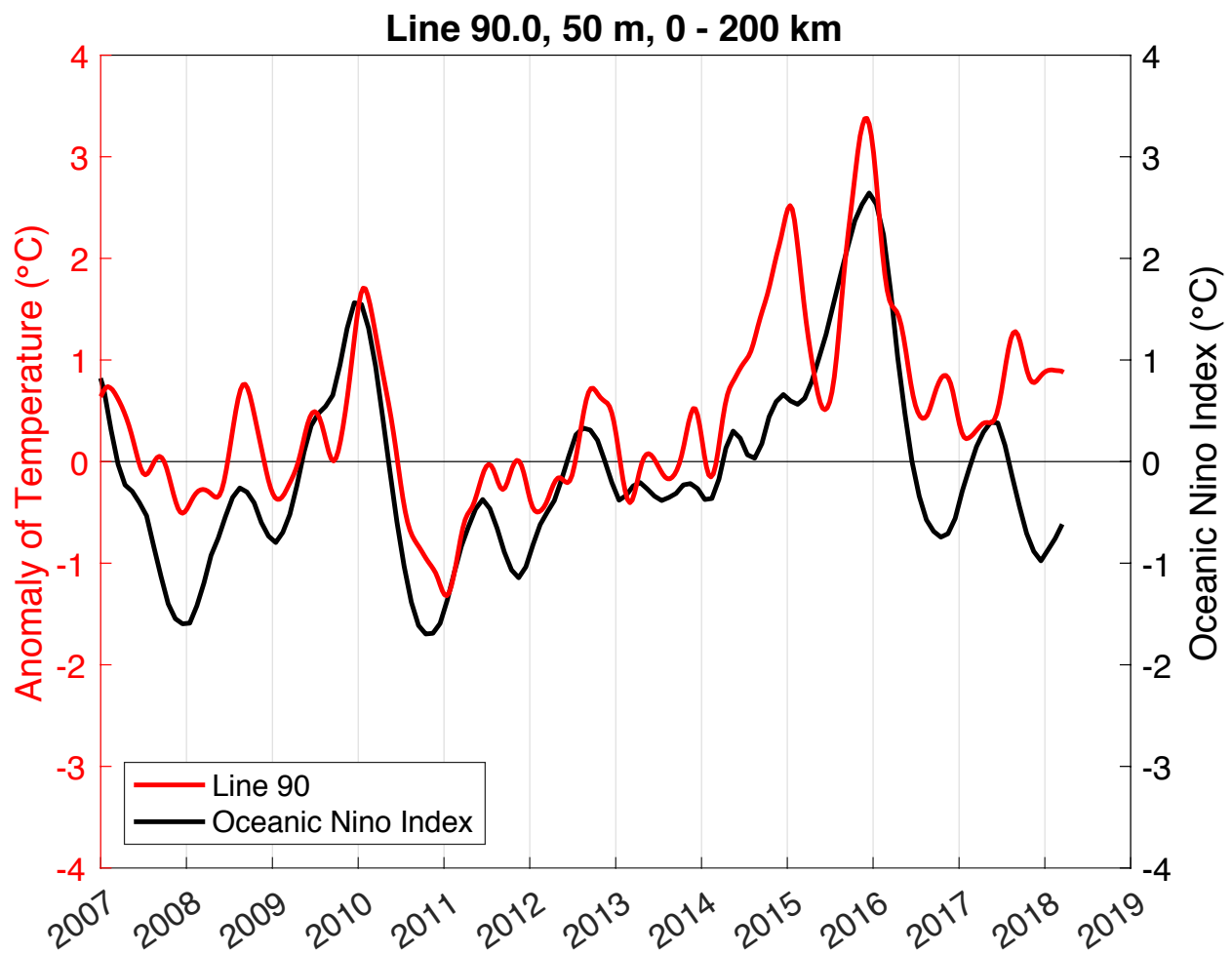


Figure 19: The SoCal Temperature Index, temperature anomaly at 50m on line 90, averaged over the inshore 200km, and filtered with a 3-month running mean (red), and the Oceanic Nino index, Nino 3.4 filtered with a 3-month running mean (black). Note the strong correlation until the anomalous warming of starting near the beginning of 2014, then the strong peak associated with the 2015-2016 El Nino. Conditions at the equator are currently anomalously cool, while California continues to be anomalously warm.



A Nudging and Ensemble Forecasting Approach to Identify and Correct Tropical Pacific Bias-Producing Processes in CESM - NA14OAR310276

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 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: Climate Adaptation and Mitigation

Goal 2: Weather-Ready Nation

Goal 3: Healthy Oceans

Goal 4: Resilient Coastal Communities and Economics

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 with our study of the spatiotemporal structures of bias development in CESM forecasts, launched from numerous initial states during which random ENSO and MJO events occur, to determine the relative importance of poor mean-state representation versus the integrated impacts of the transient flows. We have evaluated 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. The work on the evaluation of tropical variability in CESM-DART runs has been completed and a manuscript describing the results has been submitted to Climate Dynamics Journal for peer-review. As a follow-up study, we used 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. Progress in ensemble data assimilation at operational weather forecasting centers has also led to the development of the EDA reliability diagnostic (Rodwell et al, 2015), which is used to identify biases and model errors in the ensemble forecasting system at ECMWF. Further details of the budget analysis can be seen in Rodwell et al. (2015).

We are performing a similar analysis in the CESM-DART simulations to identify model errors. We are currently working on diagnostics to attribute these identified errors to well-known physical processes for the specific climate modes of variability. We will use model state variables from the data assimilated CESM model to initialize forecast experiments to further identify robust biases and physical parameterizations that are likely to be responsible for these biases. We will then pursue methods to propose improved parameterization or model error representation in CESM based on our result.

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 co-authored a workshop report summarizing the global coupled data assimilation efforts and paths forward currently published by the World Meteorological Organization after peer review (Penny et al., 2017).
- Completed and submitted a manuscript 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:

- RIKEN International School on Data Assimilation, 22-16 January, 2018, Kobe, Japan (Eliashiv)
- American Meteorological Society Meeting, January 7-11, 2018, Austin, TX (Miller)
- AGU Fall Meeting, December 9-15, 2017, New Orleans, LA (Miller)
- COP23, 6-17 November, 2017, Bonn, Germany (Eliashiv)
- WGNE Systematic Error Workshop, 19-23 June 2017, Montreal, Canada (Eliashiv)
- JpGU - AGU Joint Meeting, 20-25 May 2017, Tokyo, Japan (Subramanian).

Education & Outreach:

Communication

- Numerous interviews with TV, radio, and newspapers about the Extreme Pacific Anomalies and El Nino (Miller)
- Participant, 2018 Exploring Ocean STEM Careers Night, Birch Aquarium at Scripps (Miller)
- Member, Stay Cool for Grandkids, grass roots climate action group in San Diego (Miller)
- Home page: <http://meteora.ucsd.edu/~miller/>
- Home page (Dr. Aneesh Subramanian): <http://www.aneeshcs.com>

Academic Development

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

K-12 Outreach

- Participant, 2018 Exploring Ocean STEM Careers Night, Birch Aquarium at Scripps (Miller)

Networking

- Member, *Stay Cool for Grandkids*, climate action group in San Diego (Miller)



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:

Jim Todd, Ocean Observing and Monitoring Division, Climate Program Office

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaption and Mitigation

Goal 2: Weather-Ready Nation

Budget Amount:

\$1,234,245

Amendment(s):

10, 35, 82

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 water column. 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 program from 2000 to 2006 in the tropical 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 Mid-Atlantic

Ridge (yielding dynamic height and bottom pressure differences), plus a small current meter mooring on the slope. Fig. 20 shows the array location. Routine operation is achieved with two-year long deployments, which enables routine delivery of indicators about the state of the AMOC at this latitude. The moorings and PIES are equipped with acoustic modems, allowing data retrieval from research vessels or via gliders. The data collected by MOVE are made freely available through the OceanSITES data portals.

By the end of the present reporting period date, the array had collected nearly 17 years of temperature/salinity data (for relative geostrophic transports), 17 years of current meter data (for boundary slope transports), and 15 years of bottom pressure data (for barotropic transports, a data gap exists from 2005-2007). Due to the built-in redundancy, data were available from early 2000 until late 2016. Interannual and long-term changes in the circulation and its vertical distribution are clearly visible now. Joint analyses with other arrays like RAPID at 26°N, with projects in the Labrador Sea, and also with modeling teams are under way, in order to inter-relate the changes, assess the basin-scale significance of the data and understand the differences (see publications and collaborations sections below).

Fig. 21 shows the NADW transport inferred from MOVE measurements, referenced to the depth (4950m) of the approximate water mass boundary between the southward-flowing NADW and the northward flowing AABW. Long-term variability is evident, with a dominant period of roughly 20 years. Some numerical simulations show similar low-frequency MOC fluctuations. There appears to be a weakening of the southward flow until 2005/6, with a strengthening since then until at least 2013/14; the most recent data are suggestive of a renewed weakening. At first sight these results are in contradiction with data and analyses from the RAPID array, where a weakening of the MOC has been observed since 2004. The present conclusion is that it is not yet certain whether the discrepancies between the two latitudes are due to shortcomings in the observational strategies or due to actual circulation features that lead to convergences/divergences between the two arrays. Resolving these discrepancies remains a research priority for MOVE.

Research Objectives:

4. Obtain decadal-scale time series of meridional transports of the lower limb of the AMOC.



5. Merge observations at 16N with those at other latitudes to study coherence of transports on different time scales.
6. Investigate mechanisms of AMOC variability, including comparison with model simulations.
7. Test utility of satellite methods (altimetry, gravity) in complementing in-situ observations.

Research Accomplishments:

12. Transport time series now extended to 17 years: just prior to this reporting period, field work was carried out to remotely retrieve subsets of the mooring and PIES data. During this reporting period, these raw data were processed and the corresponding AMOC transport time series computed. The new time series is being used for publications (Baringer et al., 2018) and has been presented at scientific conferences (see below).
13. Comparison with observational studies at other latitudes: motivated as a priority item from the US AMOC program, MOVE participated in two studies that compare results between AMOC observations at different latitudes (ELipot et al., 2017; Frajka-Williams et al., 2018).
14. Validation of reference level calculations with PIES bottom pressure and GRACE bottom pressure: comparison with other observational studies showed some discrepancies (Frajka-Williams et al., 2018) that mandated a review of the assumptions in the MOVE methodology. Comparison with independent observational datasets, specifically seafloor pressure observed by PIES instruments and the GRACE satellites, validated the MOVE assumptions and confirmed the MOVE results.

Honors and Awards:

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

Conferences, Meetings & Presentations:

- a. OOMD Community Workshop. Silver Spring, MD, May 2017:
 - Attended by: Uwe Send, Matthias Lankhorst
 - Poster presentation: MOVE – The Meridional Overturning Variability Experiment at 16N
- b. US AMOC Science Team Meeting. Santa Fe, NM, May 2017:
 - Attended by: Uwe Send, Matthias Lankhorst, Jannes Koelling
 - Talk: AMOC Variability at 16N in Comparison with Higher Latitudes

- Poster presentation: Southward NADW transport and property changes at 16N
- c. NOAA Transport Mooring Array Review. Miami, FL, Oct. 2017:
 - Attended by: Uwe Send, Matthias Lankhorst, Jannes Koelling
 - Talk: MOVE: Meridional Overturning Variability Experiment
- d. 2018 Ocean Sciences Meeting. Portland, OR, Feb. 2018:
 - Attended by: Uwe Send, Matthias Lankhorst, Jannes Koelling
 - Talk and poster presentation: Decadal variability in NADW circulation measured by the MOVE array and GRACE satellite data

Education & Outreach:

Communication

- a. MOVE maintains a website at: mooring.ucsd.edu/move. This website contains basic information about the project as well as an overview over results and publications. The target audience is the interested public as well as researchers with an interest in the project.
- b. Data from MOVE are delivered and disseminated via OceanSITES. This is an international program to collect and promote the use of time series data from the open oceans. The target audience consists of external researchers who have an interest in using MOVE data for their own work, as well as data centers assembling climatologies of ocean data.

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.

K-12 Outreach

- a. Matthias Lankhorst acted as a subject-matter expert for three high school senior projects at Jesuit High School, Beaverton, OR. This occurred through informal e-mail communications and was not specific to the MOVE project but covered general oceanographic topics such as large-scale circulation.

Networking

- a. Networking and outreach occurred at all conferences listed in (10) above; attendees for the MOVE project were Uwe Send, Matthias Lankhorst, and Jannes Koelling.



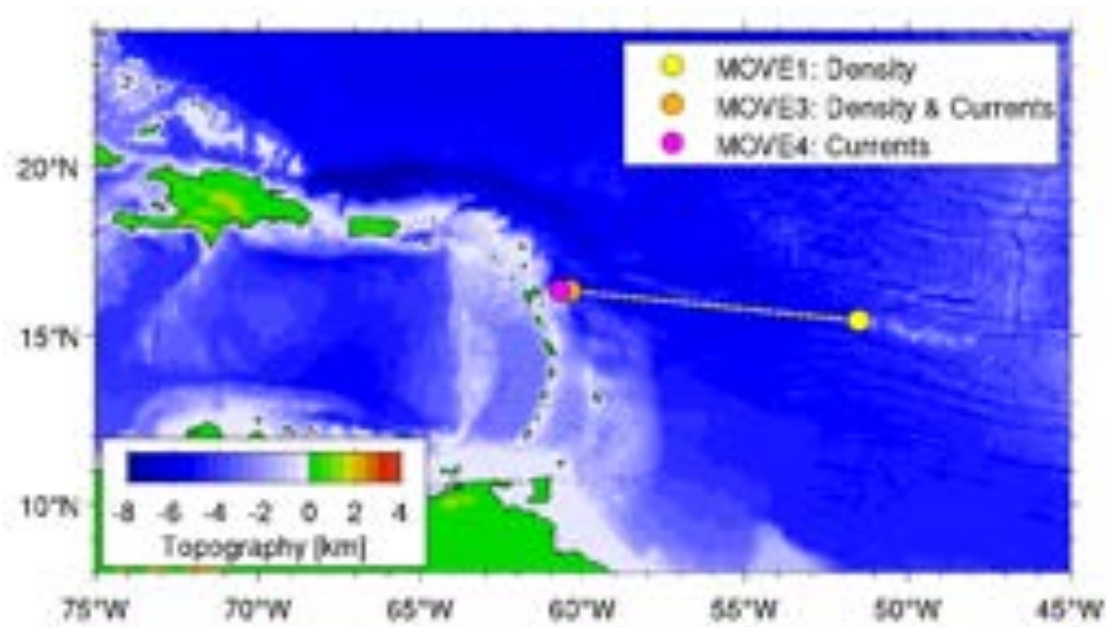


Figure 20: Map of the MOVE array. The goal is to measure the flow at depths of 1200-5000 m across the section shown as yellow dashes. MOVE1, MOVE3, MOVE4 are mooring sites. Additional PIES (pressure-sensing inverted echo sounder) instrumentation is located at MOVE1 and MOVE3.

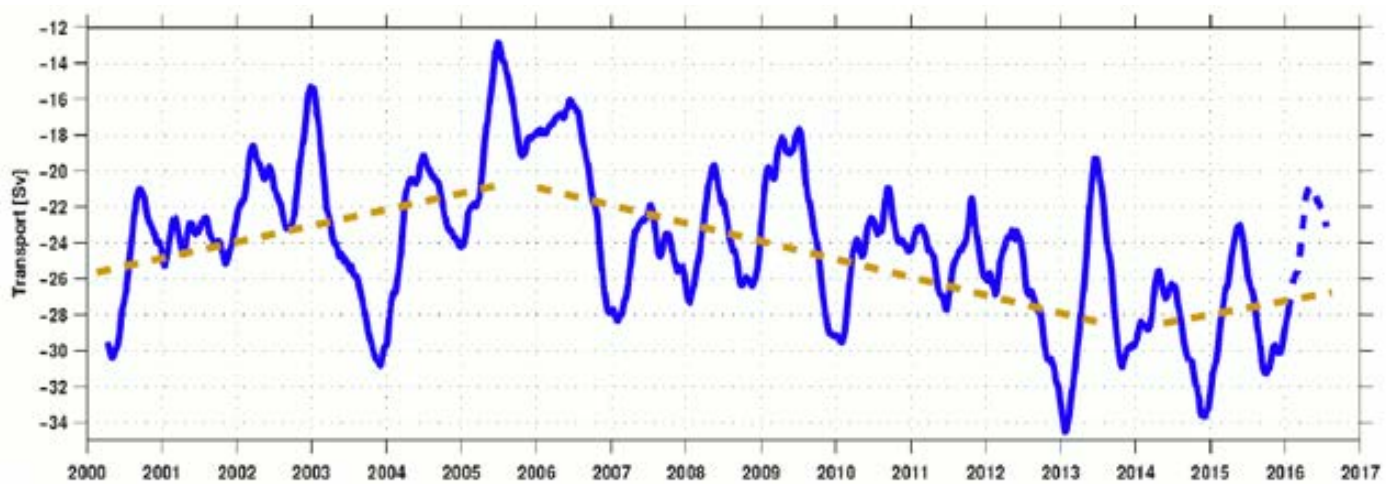


Figure 21: Time series of NADW transport in the depth range 1200-5000 m across the MOVE section (negative southward). The blue dashes denote acoustically retrieved data; more recent data is still being processed. The dashed orange lines indicate decadal-scale variability.

Theme B: Climate Research and Impacts

Constructing Resilient Communities, Landscapes, and Coasts in California and Nevada - NA17OAR4310284

Principal Investigator(s):

Daniel Cayan, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Julie Kalansky, Scripps Institution of Oceanography, UC San Diego

Alexander Gershunov, Scripps Institution of Oceanography, UC San Diego

David Pierce, Scripps Institution of Oceanography, UC San Diego

Jordan Goodrich, Scripps Institution of Oceanography, UC San Diego

Kate Barba, Scripps Institution of Oceanography, UC San Diego

Tamara Wall, Desert Research Institute

Nina Oakley, Desert Research Institute

Kristin VanderMolen, Desert Research Institute

Dan McEvoy, Desert Research Institute

Shraddhanand Shukla, UC Santa Barbara

Tim Brown, Desert Research Institute

Michael Dettinger, US Geologic Survey

LeRoy Westerling, UC Merced

Dennis Lettenmaier, UC Los Angeles

NOAA Primary Contact:

Caitlin Simpson, Oceanic and Atmospheric 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: Climate Adaptation and Mitigation

Goal 2: Weather-Ready Nation

Goal 4: Resilient Coastal Communities and Economics

Budget Amount:

\$600,000

Award:

NA17OAR4310284

Description of Research:

We propose a renewed California Nevada Applications Program (CNAP) under NOAA RISA support. The state of California, as well as cities and counties in Nevada are actively integrating climate information for preparedness and planning but scientific information from these efforts is not necessarily accessible and usable by decision makers. CNAP has shown that it can effectively bridge this climate information accessibility/usability gap through engaging and closely working with stakeholders throughout the region over the last 15 years. Based on the concerns of these stakeholders, CNAP priority areas for the next five years will be climate-driven impacts related to water resources, natural resources, and coastal resources. Under this umbrella, the proposed research program has two related components:

1. core RISA and
2. goals and objectives of the National Integrated Drought Information System (NIDIS)

Both of these components, while separate, support our overall programmatic outcomes and fall within our focus areas. The RISA proposal has an initial focus on wildfire warnings and health impacts; sea level rise and flooding; precipitation events in the Great Basin; and climate information for underserved farmers. The NIDIS portion emphasizes communication and coordination of the CA/NV Drought Early Warning System (CA/NV DEWS) and research projects related to extreme precipitation, seasonal to sub-seasonal forecasting, and incorporation of new evaporative demand data into water management in Southern Nevada as a part of the NIDIS *Coping with Drought* component. These project ideas were developed through discussions with stakeholders and support our programmatic outcomes: *improved understanding and impact on the decision landscape* (near-term); *increased use of climate information* (mid-term); with the ultimate goal of *increased community and ecosystem resilience to climate impacts* (long-term). CNAP will continue to evolve to incorporate more social science research and broaden the evaluation component to better understand the needs and impacts of CNAP work.



Research Objectives:

Our core research areas for the next five years will investigate extreme climate-driven impacts related to water resources, natural resources, and coastal resources. Working within these topics, our program will include activities in three areas:

1. Research including physical, social, and interdisciplinary science¹;
2. Engagement, communication, and outreach with stakeholders; and
3. Mentoring and capacity building through these activities.

The outcomes we seek can be broadly described as:

1. Improved understanding and impact upon decision-making and elevated motivation for stakeholder action to respond to climate-related risks (short-term);
2. Increasing use of climate research to inform decision-making and policy development supporting adaptation strategies (mid-term); and
3. Advanced community and ecosystem resilience in California and Nevada (long-term).

Research Accomplishments:

- Regional reports for the California 4th Climate Change Assessment for San Diego and the Northern Sierras were submitted for review.
- San Diego County Ecosystems: Ecological Impacts of Climate Change on a Biodiversity Hotspot was submitted and is under review. Working with the boundary organization, Science Climate Alliance, we were participated in a climate summit that included over 150 attendees.
- Presented on multiple NIDIS webinars
- Held a meeting with San Diego Public Health Officials and the SD National Weather Service Office to discuss impacts of heat on different areas within the county on people of different demographics.
- Held the CNAP annual meeting, which brought the team together to discuss evaluation, projects, and outcomes.

Conferences, Meetings & Presentations:

- a. Dr. Julie Kalansky presented at the Port of San Diego on sea level Rise and the uncertainty associated with it.
- b. Dr. Dan Cayan presented at an Association of Environmental Planners meeting on sea level rise.

Education & Outreach:

Communication

- a. CNAP Developed a Drought Tracker to track the winter conditions as it was very dry until March on its website.
- b. CNAP contributed to a two-pager for CA Department of Natural Resources and Office of Emergency Management on the causes of high elevation floods and the importance of high elevation monitoring and observations.

K-12 Outreach

- a. CNAP provided data for the San Diego Zoo for a lesson plan for 8th graders to learn about climate and make graphs.

Networking

- a. Presentation to Sierra Club
- b. Julie Kalansky presented in Del Mar at a Sierra Club meeting while the city was going through the approval process of their Sea Level Rise adaptation plan.

¹ In this context, interdisciplinary science refers to researchers from two or more disciplines who combine

and adapt their expertise and methods to better address a problem.



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

Lancelot Braasch, Scripps Institution of Oceanography, UC San Diego

Benjamin Kates, Scripps Institution of Oceanography, UC San Diego

Sjoerd Solleveld, Scripps Institution of Oceanography, UC San Diego

Robert McCool, Stanford University

Lucia Bertero, UC Los Angeles

Matthew Hubbell, Scripps Institution of Oceanography, UC San Diego

Chris Edwards, UC Santa Cruz

NOAA Primary Contact:

Dr. Sidney Thurston, Climate Program Office, Ocean Observing and Monitoring Division

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaption and Mitigation

Goal 2: Weather-Ready Nation

Goal 3: Healthy Oceans

Budget Amount:

\$8,608,648

Amendment(s):

8, 32, 64

Description of Research:

1. Provide through the publicly available Global Telecommunication System (GTS) a-real time data stream of drifters locations, SST, Sea Level Atmospheric Pressure (SLAP), SSS, sea level wind, subsurface temperature and directional wave spectra

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. Newly designed drifters measuring the directional spectra of surface gravity waves were deployed. In collaboration with AOML, we maintained an array in excess 1,250 drifters (average) to measure the circulation of the World's oceans. 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 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 is 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’s 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 drifter’s 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 programs 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 design 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 no-complying items are discovered, these are discussed with the manufacturers as needed.

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

Accomplished.



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

Accomplished. Real time statistics are maintained at the gdp.ucsd.edu website and constitute the main tool for the PI to detect early signs of drifters's 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_oe&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, 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 in 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. Dr. Luca Centurioni attended the NOAA Ocean Observing and Monitoring Division, 10th OOMD Community Workshop, NOAA Science Center, Silver Spring, MD, 9-11 May 2017
- b. Dr. Luca Centurioni attended the 5th DBCP Capacity Building Workshop for the North Pacific Ocean and its Marginal Seas, July 4 – 7, 2017, Tianjin, China. http://www.icomm.info/index.php?option=com_oa&task=viewEventRecord&eventId=1828
- c. Dr. Luca Centurioni attended the Niskine Meeting, Iceland Coast Guard Headquarters, Reykjavik, Iceland, 18 October 2017
- d. Dr Luca Centurioni presented at the Marine Technical Conference (TECO), Joint WMO/IOC Technical Commission For Oceanography And Marine Meteorology, WMO headquarters, Geneva, Switzerland, 23-24 October 2017. <http://meetings.wmo.int/JCOMM-5/layouts/15/WopiFrame.aspx?sourcedoc=/JCOMM-5/TECO/Documents/TECO-programme.pdf&action=default>
- e. Dr. Luca Centurioni attended with the US delegation the Fifth session of the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM-5), <http://meetings.wmo.int/JCOMM-5/SitePages/Session%20Information.aspx>
- f. Dr. Luca Centurioni briefed a UK Royal Navy, Scripps Institution of Oceanography, La Jolla, California, November 7, 2017. Dr. Luca Centurioni briefed Dr. Craig McLean, NOAA's Acting Chief Scientist, Scripps



Institution of Oceanography, La Jolla, California, November 8, 2017.

- g. Dr Luca Centurioni attended the Thirty Third Session of DBCP, 14 - 17 November 2017, Plouzane, France
- h. Dr Verena Hormann attended the Thirty Third Session of DBCP, 14 - 17 November 2017, Plouzane, France
- i. Mr. Lancelot Braasch attended the Thirty Third Session of DBCP, 14 - 17 November 2017, Plouzane, France
- j. Dr. Luca Centurioni briefed a delegation from the Air Force Air Operations Center Brief, Scripps Institution of Oceanography, La Jolla, California, November 29, 2017.
- k. Dr. Luca Centurioni attended the CALYPSO DRI meeting, ProTeQ headquarters, Herndon, Virginia, January 23-24, 2018
- l. Dr Luca Centurioni attended the 2018 Ocean Sciences Meeting, Portland, OR, 12-16 February 2018.
- m. Dr Verena Hormann attended the 2018 Ocean Sciences Meeting, Portland, OR, 12-16 February 2018.
- n. Dr. Luca Centurioni briefed a BKMKG/Indonesia delegation, visit to Scripps Institution of Oceanography, La Jolla, California, March 2, 2018

Education & Outreach:

Communication

- a. The GDP maintains a website at:
http://gdp.ucsd.edu/ldl_drifter/index.html

Academic Development

- a. Dr. Centurioni ran the SIO 219: Observational Oceanography Seminar Fall Quarter, 2017

Topic: The World Ocean Surface Circulation.

Instruments and Methods

The course was focused primarily on the scientific analysis of drifter data:

Description: The overarching goal of the fall quarter Observational Seminar is to familiarize the students with observational and analysis methods to measure the World Ocean Surface Circulation using, for example, Lagrangian (i.e. water following) drifters and other datasets. The course will provide an opportunity to familiarize with effective presentation techniques and ensuing discussion. The course addresses instrument technology and the design of GOOS components, data analysis methods and key results (the core of the program) and a brief description of promising new technologies and sensors that could further the scope of sustained global observations. As in previous years, the first part of the class will consist of student led-presentations based on key papers (optionally, on work in progress) followed by a group discussion led by the presenter(s). Students are encouraged to formally register for the class, and the participation by interested post-docs and faculty is very welcomed.



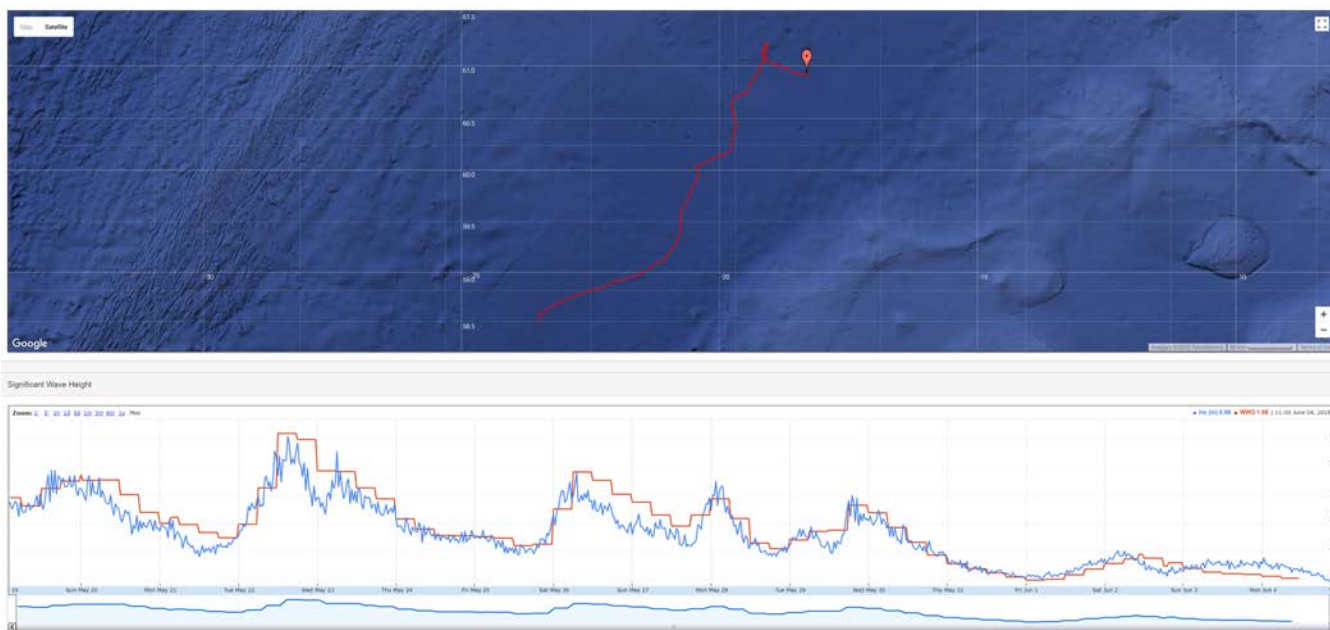


Figure 22: Significant wave height measured with a Directional Wave Spectra Drifter (DWSD) in the Iceland Basin during the NISKINE Pilot cruise, May 2018.



Figure 23: Final stage of fabrication on Minimet drifters at the Lagrangian Drifter Laboratory, Scripps Institution of Oceanography. The Minimet drifters can measure wind velocity, sea surface temperature and atmospheric pressure and are often air-deployed by the 53rd Squadron "Hurricane Hunters" ahead of hurricanes (Photo credit: Mr. Lancelot Braasch)

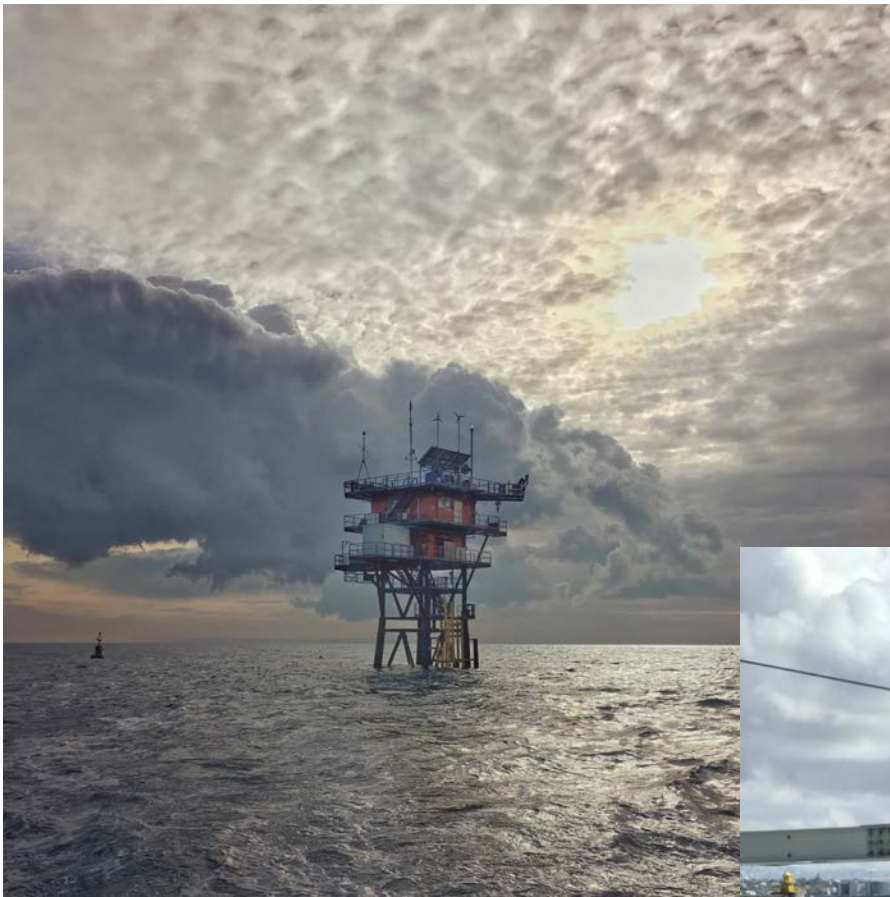


Figure 24: A Directional Wave Spectra Drifter was deployed offshore the Venice Lagoon near the Italian National Research Council (CNR) wave measuring fixed Installation for comparison and validation purposes. (Photo credit: Mr. Lancelot Braasch)



Figure 25: An ADOS drifter is being prepared for deployment from the R/V Armstrong. Reykjavik, Iceland, May 2018. The ADOS instrument can measure wind velocity, sea surface and subsurface temperature to a depth of 200m and atmospheric pressure. The ADOS drifter is often air-deployed by the 53rd Squadron "Hurricane Hunters" ahead of hurricanes. (Photo credit: Mr. Lancelot Braasch).

Development of a Western US Mountain Snowpack Climate Indicator - NA17OAR431016

Principal Investigator(s):

Amato Evan, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

James Todd, Oceanic and Atmospheric Research, Climate Program Office

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaption and Mitigation

Budget Amount:

\$103,419

Award:

NA17OAR431016

Description of Research:

Arguably one of the most important ways in which global climate change impacts society is via impacts on the hydrological cycle. At present, the exact manner by which climate change affects precipitation in the western US is not completely understood, and this is at least in part due to the large influences of natural variability like El Niño, as well as the high degree of complexity in modeling precipitation processes. As such, there is a need for a long-term and high-quality climate indicators that provide near real-time information about the hydrological cycle, and how the hydrological cycle is changing on long time scales. Among the various possible indicators that may fall into such a category, metrics that communicate information on the state of mountain snowpack are of critical importance, especially as snowpack is a hugely important source of freshwater for the western US. Mountain snowpack is a key source of freshwater storage in the Western US, and from one year to the next it is affected by changes in precipitation and temperature. It is likely that climate change is already affecting mountain snowpack in the western US, yet, to-date, there is no clear way to quantify how climate affects mountain snowpack.

The main goal of this project is to create a climate indicator of Western US mountain snowpack. The purpose of this climate indicator is to communicate how global climate change is affecting water resources in the western US. This indicator is being created via a novel

analysis of snow water equivalent (SWE) measurements from the Natural Resources Conservation Service and National Water and Climate Center Snow Telemetry (SNOTEL) program. The first step in this process, which has been completed, involves fitting annual cycles of measured SWE time series at all SNOTEL stations to gamma distribution probability density functions (PDF). Fitting gamma PDFs to SWE data minimizes the influence of spurious and erroneous SWE measurements on trend analysis and allows one to examine how climate change is affecting the way in which SWE evolves over the course of the season.

To-date, the major discoveries of this work are:

1. Demonstration that gamma distribution PDFs are a good fit to the annual cycle of SWE in the western US;
2. Showing that these PDFs can be used to recreate a climatology of SWE for the region, and
3. A trend analysis of the parameters that describe these SWE PDFs, which provide robust evidence that, over the time period 1982-2017, the winter season is becoming shorter. This shortening of the winter season is manifest as a progressively earlier melting of the mountain snowpack and an effective reduction in the “height” of the mountains, which is to say that, on average, snowpack in western US mountains is becoming characteristic of progressively lower elevations.

Research Objectives:

The overarching objective of this research is to create a climate indicator of western US snowpack. This indicator will be in the form of a metric that describes the length of the mountain winter season, which will be defined as a function of the regionally-averaged SWE PDF.

Research Accomplishments:

The major milestone of this project that has been reached is the creation of a new climatology of mountain snowpack over the western US. This climatology will be permanently archived in an online data repository once the journal article describing the data has been accepted for publication.

Conferences, Meetings & Presentations:

- a. Dr. Amato Evan presented initial results from this new western US snowpack climatology at the CW3E annual meeting at the Scripps Institution of Oceanography in April 2018.



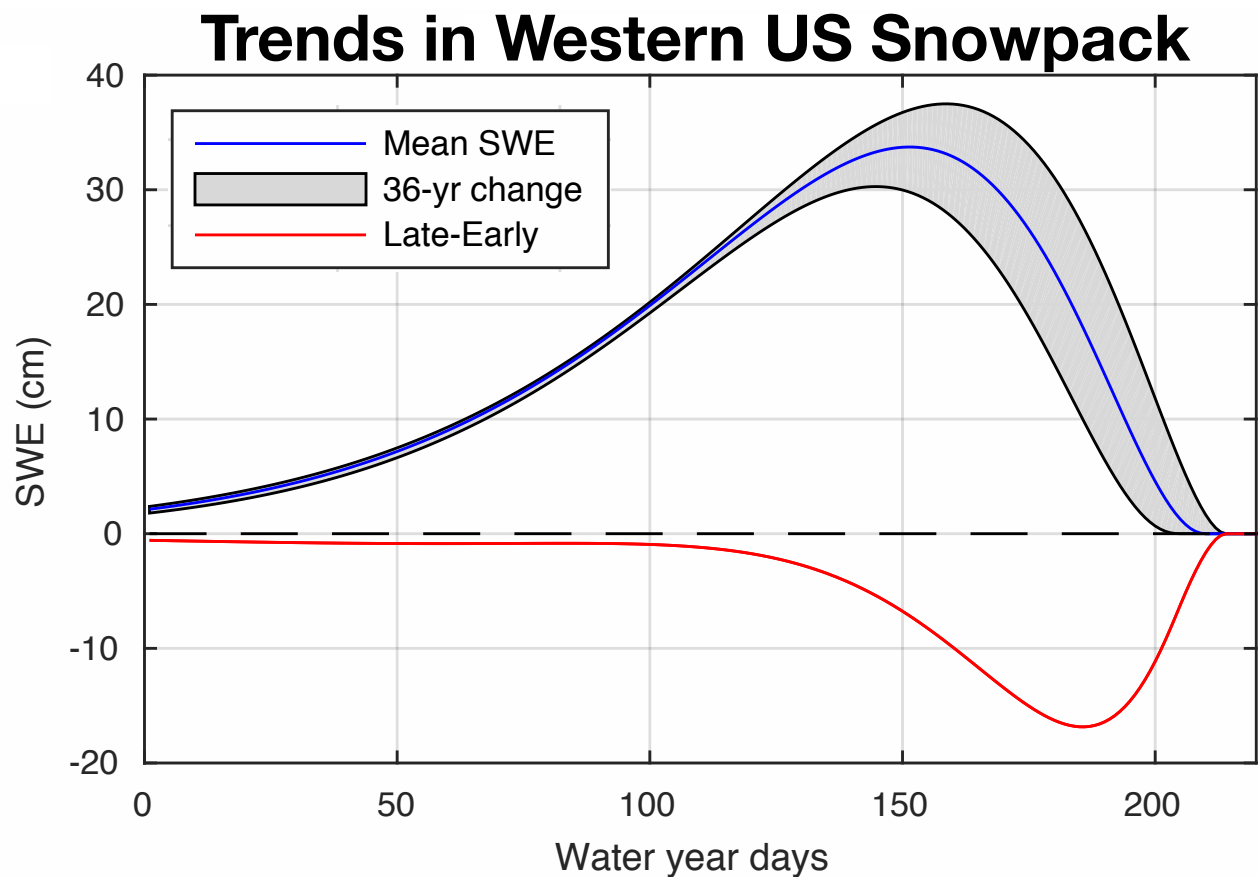


Figure 26: 36-year change in the annual cycle of mountain snowpack (snow water equivalent, SWE). Plotted is the mean SWE (blue), the maximum and minimum SWE over a 36-year time period, based on the linear trends (gray shaded region), and the difference between the maximum and minimum SWE (red), which can also be interpreted as the 36-year linear trend in mountain snowpack. These data are based on observations of SWE that have been fitted to a gamma distribution PDF and then spatially interpolated over the region.



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 Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaption and Mitigation

Goal 3: Healthy Oceans

Budget Amount:

\$1,280,207

Amendment(s):

3, 39, 85

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. Data from this program has been disseminated on the website: ScrippsO2.ucsd.edu. The data continues 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 = O₂ + 1.1CO₂, which can be used to constrain aspects of ocean biogeochemistry and air-sea heat exchange.

The data from this program has been increasingly used by collaborators for improving understanding of ocean and land biogeochemistry and carbon cycling. In the past year, studies have been published that used the seasonal cycles in atmospheric oxygen as a test ocean biogeochemical models, particularly their depiction of biological production and ventilation rates. The O₂ data is 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. Laure Resplandy (former postdoc, now Assistant Professor at Princeton University) 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 $\sim 1.3 \times 10^{22}$ J/y over the 1991-2016 period. A manuscript covering this material is under review at Nature Geosciences.
2. Yassir Eddebbar (former grad student under PI) defended his Ph.D. thesis in Feb 2018. His thesis includes three chapters detailing an analysis of oceanic controls on air-sea O₂ and CO₂ exchanges (and hence also APO exchanges), which directly relate to the measured APO time series. One chapter (published in Biogeochemical Cycles) explores air-sea O₂ and CO₂ exchanges on El Nino times scales. A second chapter explores the impact of volcanic eruptions on air-sea O₂ and CO₂ exchanges via impacts on ocean circulation. A third details the controls on unforced decadal climate variability on O₂ and CO₂ exchanges.
3. The PI is collaborating with Dr. Cindy Nevison (University of Colorado) and Dr. Manfredi Manizza (SIO) on a study to evaluate evidence for long-term changes in the amplitude of the seasonal cycle in APO at the background stations in the Scripps network.
4. Since 2001, the O₂/N₂ measurements at Scripps have been made using two methods, one interferometric, the other based on mass spectrometry. The PI has initiated a study to compare in detail the results from these two methods. The PI presented on this topic at the Greenhouse Gas Measurement Technique (GGMT) meeting in Dubendorf Switzerland in 2017.
5. A 51-page technical report on the span sensitivity of the interferometric O₂ analyzer was detailed in the last annual report. The PI continues to work on aspects of this report relating to the gravimetric calibration, which was previously missing information on the O₂ and Ar impurities in N₂ gas used to prepare the standards. Aliquots of the N₂ material have been sent to NIST to carry out these analyses.

Honors and Awards:

- a. Ralph Keeling received the Scripps Undergraduate Teaching Award, 2016-2017.

Conferences, Meetings & Presentations:

Presentations by R. Keeling:

- a. Ralph Keeling and Eric Morgan (postdoc) attended the 10th International CO₂ conference in Interlaken, Switzerland in 20-25 August 2017.
- b. Ralph Keeling attended the Greenhouse Gas Measurement Technology (GGMT) meeting in Dubendorf, Switzerland in 27-31 August 2018

Education & Outreach:

Communication

- a. Webpage: ScrippsO2.ucsd.edu
This is the primary site for dissemination of the resulting data for O₂/N₂ and CO₂ concentration.
- b. 3 April 2017 photoshoot with the San Diego Union Tribune
- c. 11 May 2017. Invited attendee of TruSalon on Energy and Water Security in San Diego.
- d. 13 Sept 2017. Remote presentation to the CC&E Philanthropy Workshop, "Quantifying greenhouse gas emissions from atmospheric measurements: an important reality check. Part 2: The CO₂ elephant"
- e. 24-27 Sept 2017. Support for NOVA documentary "Decoding the Weather Machine", including early brain storming, being filmed, and providing additional supporting graphical and conceptual materials.
- f. 12-Dec 2017, Advisory Council Meeting for "Keeling Curve Prize", San Francisco, California.

Academic Development

- a. Fall 2017. R. Keeling taught "Physical Basis of Global Warming", 4 unit upper division science course at UCSD.
- b. 4 Feb 2018. R. Keeling gave a guest lecture to Yale Climate Change Seminar at Yale School of Forestry and Environmental Studies, led by Peter Raymond.

K-12 Outreach

- a. 9 May 2017. Presentation to entire body of Bishop's School, La Jolla on Climate Change.
- b. 7 Mar 2018. Presentation for Mr Tennebaum's Advanced Placement Environmental Science class at La Jolla High School, "CO₂ and Climate Change".

Networking

- a. Greenhouse Gas Measurement Technology Meeting, Dubendorf, Switzerland (see above) Participated in discussions outlining coordination of world-wide measurements of O₂/N₂. Assisted in drafting meeting report: 19th WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracers Measurement Techniques



Understanding and Quantifying the Predictability of Marine Ecosystem Drivers in the California Current - NA17OAR4310106

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:

Dr. Antonietta Capotondi, Cooperative Institute for Research in Environmental Science, University of Colorado, NOAA Research

Prof. Emanuele Di Lorenzo, Georgia Institute of Technology

Nathali Cordero-Quiros, Scripps Institution of Oceanography, UC San Diego

Daniela Faggiani Dias, Scripps Institution of Oceanography, UC San Diego

Daling Yi, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Daniel Barrie, Oceanic and Atmospheric Research, Climate Program Office

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$185,315

Award:

NA17OAR4310106

Description of Research:

We use several approaches to making progress in understanding the predictability of ENSO impacts on the physical and biological system in the California Current System. The first approach is to use a regional eddy-resolving ocean model reanalysis of the CCS to identify

and diagnose the precise structures of the atmospheric and oceanic regional forcing functions (RFPs) that drive ecosystem-relevant oceanic processes (SST, upwelling, transport, thermocline depth). The second approach is to use large-scale and long-term reanalysis products to understand how the CCS RFPs are controlled by large-scale dynamics, specifically ENSO, and if these large-scale controls lead to predictability of the ecosystem drivers on seasonal timescales. For example, it is well-known that when El Niño develops in the tropical Pacific during the fall, its teleconnections will impact the CCS in the following winter. However, the precise structures of these teleconnections is strongly dependent on the type/flavor of El Niño, which needs to be assessed. The third approach is to use the North American Multi-Model Ensemble to quantify the predictability and realism of the RFPs associated with ENSO teleconnections. We also use a linear inverse modeling framework to study predictable components and their linear interactions. This will help identify the different temporal and spatial scales that play a role in predictability of variables of interest over the CCS region.

Research Objectives:

Despite the empirical evidence of ENSO influence upon the California Current marine ecosystems, the detailed influence of different ENSO events is unclear, and the degree of predictability of the various ecosystem drivers for specific tropical Pacific conditions has not yet been properly quantified. The goals of this proposal are to:

1. Use high-resolution ocean reanalysis of the CCS to link the physical drivers of the CCS ecosystem (temperature, upwelling velocity, alongshore & cross-shore transport) to local climate forcing functions (e.g. alongshore winds, wind stress curl, heat fluxes, precipitation and river runoff) at seasonal timescale;
2. Use long reanalysis products (e.g. SODA3, 20CRv2c, CERA-20C) in combination with multiple linear regression and Singular Value Decomposition to objectively link the climate forcing functions variations in the CCS region with conditions (e.g. sea surface temperature, thermocline depth, sea surface height, tropical wind stresses) in the tropical Pacific that can optimally force them at seasonal timescales; and



3. Use Linear Inverse Modeling (LIM) and the North American Multi Model Ensemble (NMME) to determine the predictability and uncertainty of the forcing functions along the CCS region, compare the LIM and NMME forecast skills, and explore possible sources of error in the NMME models.

Research Accomplishments:

- Identified optimal forcing drivers of West Coast oceanic conditions due to tropical Pacific SST variations
- Identified time and space scale interactions affecting Pacific SST predictability
- Constructed a composite physical-biological ENSO in the CCS from a numerical simulation
- Capotondi served as Co-Leader of, and Miller, Subramanian and Di Lorenzo participated in, the MAPP Marine Prediction Task Force
- Mentored Ph.D. students Ms. Nathali Cordero-Quiros (SIO), Ms. Daniela Faggiani Dias (SIO), Ms. Daling Yi (Ocean University of China, Qingdao)

Conferences, Meetings & Presentations:

- a. American Meteorological Society Meeting, January 7-11, 2018, Austin, TX (Miller)
- b. AGU Fall Meeting, December 9-15, 2017, New Orleans, LA (Miller)

Education & Outreach:

Communication

- a. Numerous interviews with TV, radio, and newspapers about climate (Miller)
- b. 2018 Exploring Ocean STEM Careers Night, Birch Aquarium at Scripps (Miller)
- c. Member, *Stay Cool for Grandkids*, climate action group in San Diego (Miller)
- d. Home page (Dr. Art Miller): <http://meteora.ucsd.edu/~miller/>
- e. Home page (Dr. Aneesh Subramanian): <http://www.aneeshcs.com>
- f. Home page (Prof. Emanuele Di Lorenzo): <http://ocean.eas.gatech.edu/manu/>

Academic Development

- b. Mentored Ph.D. students Nathali Cordero-Quiros (SIO), Daniela Faggiani Dias (SIO), Daling Yi (Ocean University of China, Qingdao) in this research effort.

K-12 Outreach

- b. 2018 Exploring Ocean STEM Careers Night, Birch Aquarium at Scripps (Miller)

Networking

- d. Member, *Stay Cool for Grandkids*, climate action group in San Diego (Miller)



CCE Moorings: Moored Carbon, Biogeochemical, and Ecosystem Observations in the Southern California Current

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:

Jim Todd, Ocean Observing and Monitoring Division, Climate Program Office

Libby Jewett, Ocean Acidification Program

Dwight Gledhill, Ocean Acidification Program

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaption and Mitigation

Goal 3: Healthy Oceans

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$1,518,815

Amendment(s):

12, 29, 49, 57, 83

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 March 2017 and CCE1 in November 2017.
2. Extension of time series to 8 year record length for some variables.
3. Analysis of upwelling event statistics and their evolution during the 2014-16 warm event and El Nino.
4. Review of the CCE mooring project as part of the NOAA OOMD review of the surface mooring program.

Conferences, Meetings & Presentations:

- a. U. Send, M Ohman, M. Lankhorst, and student C. Lowcher attended and presented at the Ocean Sciences meeting in Portland, February 2018



- b. U. Send and M. Lankhorst attended the OOMD Community Workshop. Silver Spring, MD, May 2017
- c. U. Send attended a NOAA/KIOST Indian Ocean planning meeting in Seoul/Korea, November 2017
- d. U. Send attended an Ocean Acidification PI meeting in Portland, February 2018
- e. U. Send attended a National Coastal Ecosystem Moorings planning workshop in Seattle, March 2018

Education & Outreach:

Communication

- c. 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

- c. Two graduate students (Caroline Lowcher, Laura Lilly) are being trained by participating in some aspects of the CCE project and cruises. Additional students sometimes participate in CCE mooring field work.

Networking

- a. U. Send and M. Lankhorst attended the OOMD Community Workshop. Silver Spring, MD, May 2017
- b. U. Send attended a NOAA/KIOST Indian Ocean planning meeting in Seoul/Korea, November 2017
- c. U. Send attended an Ocean Acidification PI meeting in Portland, February 2018
- d. U. Send attended a National Coastal Ecosystem Moorings planning workshop in Seattle, March 2018

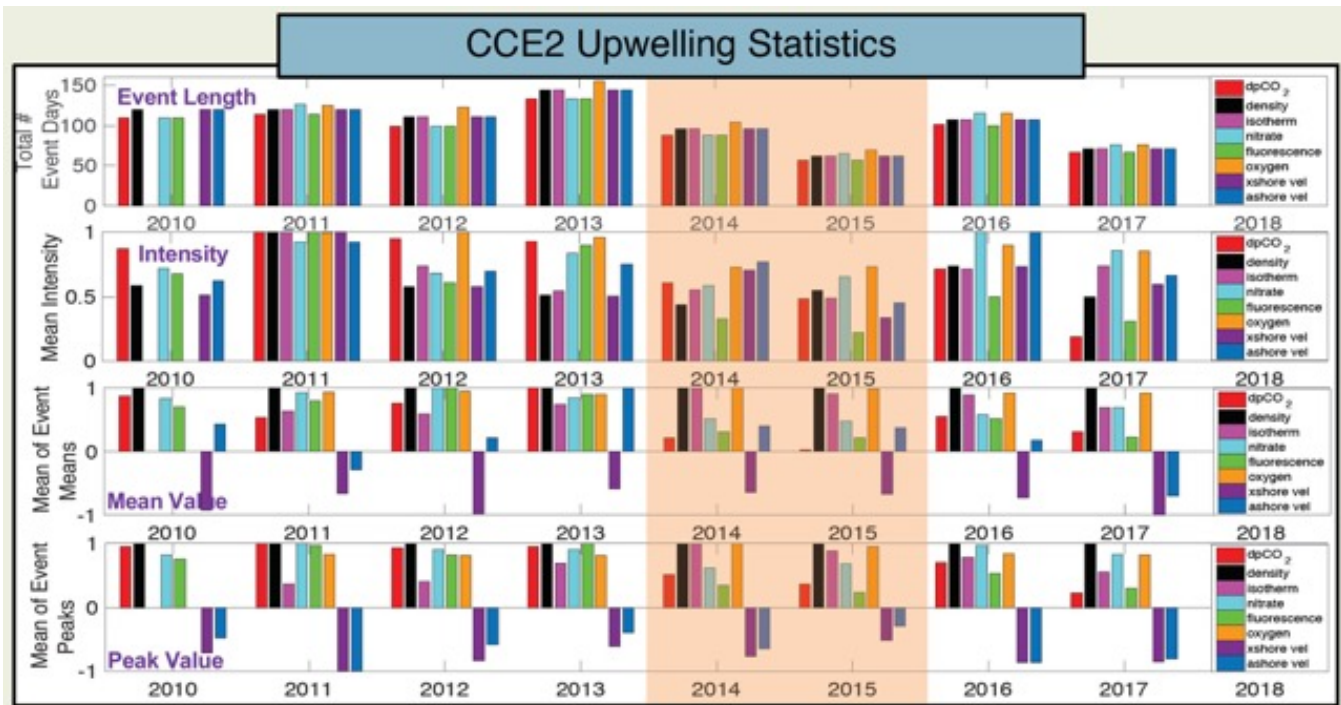


Figure 27: Statistics of various physical and biogeochemical quantities during upwelling events 2010-2017 at mooring CCE2.



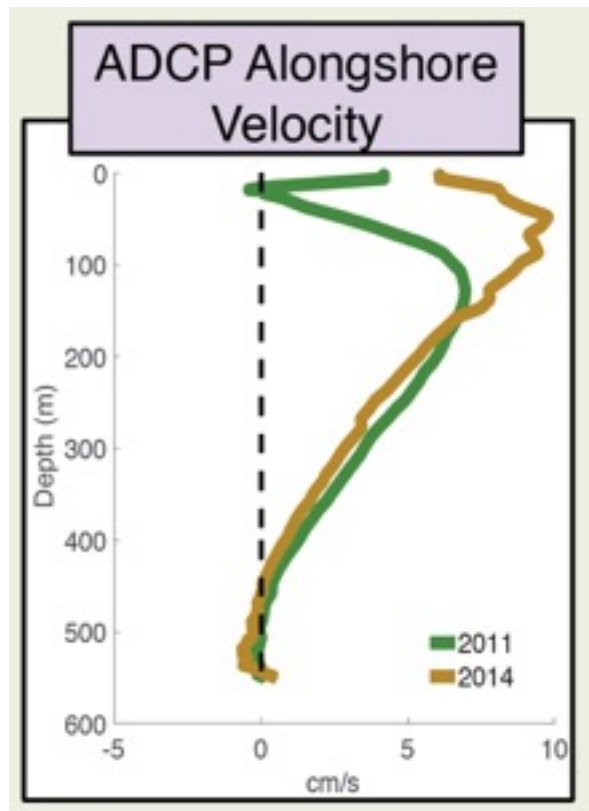


Figure 28: Mean alongshore flow profiles at mooring CCE2 for years 2011 (normal) and 2014 (warm anomaly).

Drought Early Warning for the California and Nevada Region

Principal Investigator(s):

Daniel Cayan, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Julie Kalansky, Scripps Institution of Oceanography, UC San Diego

David Pierce, Scripps Institution of Oceanography, UC San Diego

Jordan Goodrich, Scripps Institution of Oceanography, UC San Diego

Shraddhanand Shukla, UC Santa Barbara

Tamara Wall, Desert Research Institute

Tim Brown, Desert Research Institute

Michael Dettinger, US Geologic Survey

Kate Barba, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Claudia Nierenberg, Climate Program Office

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaptation and Mitigation

Goal 2: Weather-Ready Nation

Budget Amount:

\$451,895

Amendment(s):

48

Description of Research:

CNAP team supported A. Sheffield in the coordination of the CA/NV DEWS in particular through their participation in quarterly calls. D. Cayan and T. Wall have provided guidance throughout the year, particularly on the appropriate invitees for the quarterly calls and individuals to engage with – leveraging their long-standing relationships with stakeholders throughout California. J. Kalansky supported the regional NIDIS workshop in San Diego which focused on the drought monitoring needs. This highlighted how San Diego could potentially be used as an example of other areas throughout Southern California. CNAP participates in and co-hosts with NIDIS

a bimonthly CA-NV DEWS *Drought & Climate Outlook* webinar series 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 such as ENSO, stream forecasts, etc. The CNAP team works with A. Sheffield in brainstorming topics and speakers. D. Cayan provided guidance on the webinars, particularly the updates to ensure they were timely and focused on useful information given the skill of some forecasts beyond two weeks. The webinar takes place on the 4th Monday every two months.

Contributions to this project under this no cost extension are from a NIDIS approved redirection of existing available NIDIS funds. Additional resources here will help ensure more robust collaborations with partners, including the NWS fire weather program and fire agencies, and improved co-production of the project design, goals, and desired outcomes.

Dr. Shukla started examining the skill of NMME's sub-seasonal forecasts (NMME SubX, <http://cola.gmu.edu/kpegion/subx/>) for California and Nevada. This archive of forecasts has only been available for the last few months (it was not available to examine during the first year of the project). The difference between these forecasts and the ones analyzed by Dr. Shukla during the first year is that these sub-seasonal forecasts in operational settings are available at weekly to bi-weekly interval whereas the seasonal forecasts previously analyzed are available once a month. Sub-seasonal forecasts that harness the skill derived from the improved knowledge of initial atmospheric and land surface conditions (and sub-seasonal modes such as MJO) can provide useful and updated early warning information during a given winter season.

We have been working with Southern Nevada Water Authority (SNWA) to develop a report on climate impacts in the region. As water supply in the region is dependent on Lake Mead, the report examines climate impacts on water demand and infrastructure as it relates to water resources in the region. We held a meeting with high-level management within the SNWA to discuss the application of the results. The report was finalized this January and was presented at the AMS meeting. The final report has been shared with NIDIS management.

In addition to the initial goals of characterizing and simulating surface water terms for input to CVHM, work is progressing to test these simulated inputs and compare resulting groundwater usage to the published USGS estimates (figure below), which will feed into an online



tool for stake-holders to visualize current estimates of groundwater status for the Central Valley.

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
- Investigation of surface water inflows, diversions and preparation of model inputs for near real-time ground water pumping estimates in the Central Valley

Research Accomplishments:

- As frequent and heavy rain brought drought relief and challenges to California and Nevada, CNAP with partners created a [two pager](#) recapping the 2017 precipitation water year and related policy decisions.
- With respect to drought monitoring efforts, Dan Cayan, David Pierce and Michael Dettinger produced updates on the CNAP website on the status of water supply throughout California including looking at regional and state precipitation totals, as well as reservoir levels and snowpack. Below is an example from Mike Dettinger which has been shared with regional stakeholders through email, twitter, the [CNAP website](#), and has been integrated into the Drought & Climate Outlook webinar series.

Conferences, Meetings & Presentations: National Integrated Drought Information System (NIDIS) Webinar Presentations

- a. [July 2017](#): Julie Kalansky, Jordan Goodrich, and Dan Cayan
- b. [November 2017](#): Dan McEvoy
- c. [January 2018](#): Julie Kalansky, Shrad Shukla, Tim Brown

Dr. Julie Kalansky, Southwest Tribal Climate Summit, San Diego, California. Kalansky presented on drought in the Southwest, which included research on the impacts of ET versus precipitation as well as highlighting NIDIS tools that includes drought.gov, CNAP page precipitation tracking, and Climate Engine. After the Tribal Climate Summit we had an enhanced registration of tribes on the next webinar.

Dr. Julie Kalansky, AMS, Austin, Texas. Kalansky presented on the work with Southern Nevada Water Authority to address climate impacts on water related infrastructure and water demand.

Education Outreach: Communication

- a. Dettinger: Dale Kasler, Sacramento Bee, Odds of reaching normal precipitation total this year—where Do my numbers come from and what do they mean?, Dec 2017
- b. Dettinger: Jonathan Erdman, [weather.com](#), Reservoir-plus-snowpack storage figure, Jan 2018
- c. CNAP continued to support a [precipitation and snowpack tracker developed with KPBS](#) and participated in 2 radio interviews for the NPR station specifically related to this.



Interplay of Marine Layer Clouds and Heat Waves Along the California Coast: Impacts on Human Health - NA15OAR4310114

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 Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaptation and Mitigation

Goal 2: Weather-Ready Nation

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$278,815

Award:

NA15OAR4310114

Description of Research:

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. 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 coastal and inland 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.

Research Objectives:

The research is designed to improve:

- Understanding and ability to predict and project current and future heat waves in California and particularly their expressions along the coast as they are modulated by coastal marine layer clouds;
- Understanding of heat wave impacts on public health, particularly along the highly populated, poorly acclimated, and demographically-diverse California coast;
- Ability to make decisions and develop policy to protect the health of California communities, particularly at-risk, coastal communities, from the detrimental effects of heat in the current and future climates.

Research Accomplishments:

During this reporting period we had six peer reviewed papers published and have two additional papers in press.:

- 2018a Guirguis, K., Gershunov, A., Cayan, D.R., and Pierce, D., Heat wave probability in the changing climate of the Southwest US, *Climate Dynamics*, 503853. <https://doi.org/10.1007/s00382-017-3850-3> (First published online in 2017)
- 2018. Clemesha, R. E. S., K. Guirguis, A. Gershunov, I. J. Small, and A. Tardy, California heat waves: their spatial evolution, variation, and coastal modulation by low clouds, *Climate Dynamics*, doi: 10.1007/s00382-017-3875-7 <https://link.springer.com/article/10.1007/s00382-017-3875-7> (First published online in 2017)
- 2018b. Guirguis K., R. Basu, W. K. Al-Delaimy, T. Benmarhnia, R.E.S. Clemesha, I. Corcos, J. Guzman-



- Morales, B. Hailey, I. Small, A. Tardy, D. Vashishtha, J.G. Zivin, and A. Gershunov, Heat, disparities, and health outcomes in San Diego County's diverse climate zones, *GeoHealth. In-press*
- 2018. Wu E., R.E.S. Clemesha, and J. Kleissl, Coastal Stratocumulus cloud edge forecasts, *Solar Energy*, 164, 355–369.
doi.org/10.1016/j.solener.2018.02.072
<https://www.sciencedirect.com/science/article/pii/S0038092X18302056>
 - 2017. Sherbakov, T., B.J. Malig, K. Guirguis, A. Gershunov, R. Basu, Ambient Temperature and Added Heat Wave Effects on Hospitalizations in California from 1999–2009. *Environmental Research*, 160, 83–90.
 - 2017. Simonis, A. E., M. A. Roch, B. Baily, J. Barlow, R. E. S. Clemesha, S. Iacobellis, J. A. Hildebrand, and S. Baumann-Pickering, Lunar cycles affect common dolphin (*Delphinus delphis*) foraging in the Southern California Bight, *Marine Ecology Progress Series*, 577, 221–235, doi: 10.3354/meps12247
 - 2018. Baguskas S. A., R. E. S. Clemesha, M. E. Loik, Coastal low cloudiness and fog enhance crop water use efficiency in a California agricultural system, *Agriculture and Forest Meteorology*, 252, 109–120.
doi.org/10.1016/j.agrformet.2018.01.015
<https://www.sciencedirect.com/science/article/pii/S0168192318300157>
 - 2018. Vashishtha, D., W. Sieber, B. Hailey, K. Guirguis, A. Gershunov, W. Al-Delaimy, Outpatient Clinic Visits During Heat Waves: Findings From a Large Family Medicine Clinical Database. *Family Practice*, in Press.

Education & Outreach Communication

- a. Gershunov and Guirguis met with San Diego Health and Human Services (SDHHS) on May 8, 2017 to discuss climate change and health and how we can effectively work together to provide scientific information for decision-making purposes with the goal of mitigating health impacts associated with climate change. This is part of a new strategic effort between SIO and SDHHS on Adaptation Planning: Public Health Impacts on Climate Change.
- b. Gershunov organized and served on a panel discussion on the topic of Health Impacts of Climate Change on May 25, 2017 at the UCSD Great Hall. This public event used art (specifically art created through artist-scientist collaborations) to motivate the discussion and educate the public.
- c. Clemesha and Gershunov presented and interacted with grade students about climate change, clouds,

and waves in the atmosphere at High Tech High School in San Marcos on June 7, 2017.

- d. Gershunov presented “Weather extremes in California’s varying and changing climate” at the California Department of Public Health in Richmond, CA. Oct. 2017
- e. Gershunov and Basu participated in a round-table discussion about heat and health at CA EPA in Oakland, CA Oct. 2017.
- f. Gershunov, Guirguis, and Clemesha presented recent research findings on heat waves, marine layer clouds, and precipitation at the National Weather Service (NWS) San Diego office on Oct. 27, 2017. Attendees included NWS meteorologist, including the new Meteorologist in Charge.
- g. Gershunov presented and served to train County works for the San Diego County Climate Impacts trainings on Jan 10, 2018. Jan 10, 2018 San Diego County Climate Impacts trainings. Calfire, County stakeholders and decision makers were part of the training.
- h. Gershunov presented “Global Climate Change: Evidence and Implication for CA” to students at the School of Medicine at UCSD on Jan 30, 2018.
- i. Gershunov, Clemesha and Guirguis organized and presented at a meeting to discuss the nexus of actionable climate and health research at Scripps Institution of Oceanography in La Jolla, CA on February 5, 2018. Co-I Basu (California Environmental Protection Agency) also attended as well as partners from National Weather Service (NOAA), San Diego, Public Health Services - County of San Diego Health & Human Services Agency, and other County stakeholders. Our stated meeting goals included science updates, stakeholder feedback, and discussion to help steer our science towards being actionable, co-produced, and ultimately relevant for improving health outcomes. To achieve these goals, the meeting was organized roughly into three parts: 1) scientists updated stakeholders on research results, 2) stakeholder partners provided feedback to scientists and highlight their special topics of interest 3) collaborative roundtable discussion of collaborations for the benefit of health outcomes in SD County. As an outcome of this original meeting planning has started to organize a summit on climate and public health for stakeholders and the public. Summit planning was discussed at a meeting (Guirguis was in attendance and Gershunov participated remotely) at San Diego Department of Health and Human Services in April.
- j. Gershunov, Guirguis, and Clemesha presented at the San Diego Climate Summit on March 6, 2018, which



focused on climate change in San Diego and implications for local ecosystems. Attendees included representatives from all levels of government (local, state, federal) as well as tribal representatives and conservation managers.

- k. Guirguis served on a panel discussion on the topic of weather extremes for the inaugural Understanding and Protecting the Planet (UPP) Summit held on May 18, 2018. UPP focuses on communicating environmental change with the goal of creating solutions to improve resilience. The summit was a venue for researchers and community leaders to discuss research priorities and possible collaboration.

K-12 Outreach

- a. Clemesha and Gershunov presented and interacted with grade students about climate change, clouds, and waves in the atmosphere at High Tech High School in San Marcos on June 7, 2017.

Networking

- a. Gershunov, Guirguis, and Clemesha presented at the San Diego Climate Summit on March 6, 2018, which focused on climate change in San Diego and implications for local ecosystems. Attendees included representatives from all levels of government (local, state, federal) as well as tribal representatives and conservation managers.

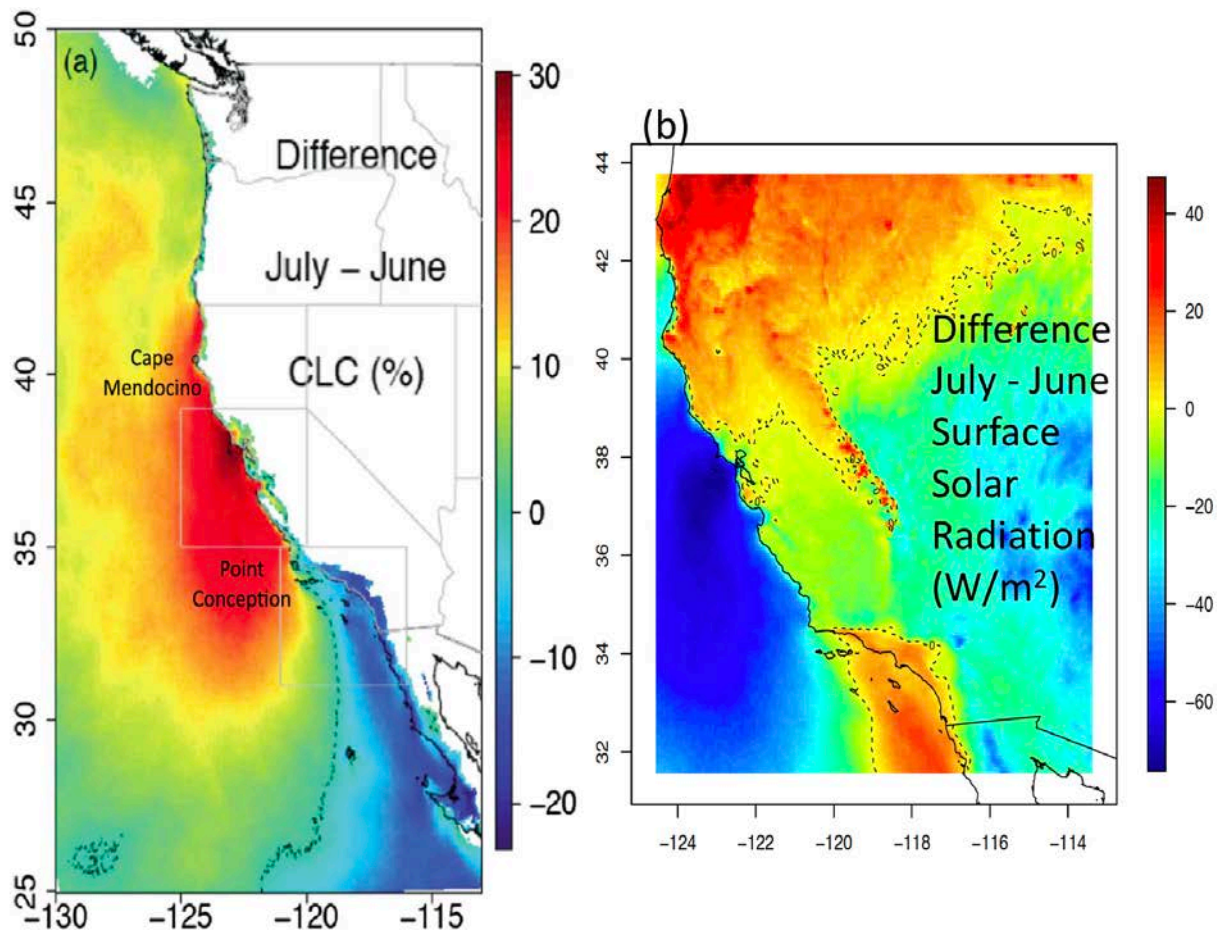


Figure 29: Comparison of (a) coastal low cloudiness (Figure 1a from Clemesha et al. 2016) and (b) Surface Solar Radiation from new LOCA downscaled product of CNRM-CM5 (8 other GCM downscaled products have also been created). Both maps depict the climatology of July minus June.



Variability from Profiling Float Arrays - NA17OAR4310259

Principal Investigator(s):

T. M. Shaun Johnston, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Dan Rudnick, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Sandy Lucas, Climate Program Office

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaption and Mitigation

Budget Amount:

\$414,269

Award:

NA17OAR4310259

Description of Research:

Global models poorly predict the observed diurnal variability in the Maritime Continent and the Maritime Continent's barrier effect on intraseasonal oscillations (ISO). Diurnal sea surface temperature (DSST) both modulates and is modulated by ISO: DSST affects the initiation, propagation, and strength of ISO, while ISO affects diurnal insolation and heat fluxes. The diurnal cycle of mixing raises and lowers the mixed layer (ML) depth. The diurnal wind's propagation across enclosed seas is affected by DSST and geography of islands. Therefore, spatially and temporally extensive measurements of the diurnal cycle in the upper ocean are needed. Fresh water input from June–October into the South China Sea, for example, produces a mixed layer controlled by salinity (S) and a roughly constant temperature (T) layer beneath, which isolates the ML from cooler thermocline waters. Heat fluxes are concentrated into a thin ML and enhance SST variability.

Therefore, accurate SST prediction requires high vertical and temporal resolution observations and modelling of processes affecting not only SST, but also subsurface S and stratification.

This project is a collaboration with ONR's PISTON program during the international Years of the Maritime Continent. In August 2018 during a period of anticipated active ISO, 8 SOLO-II profiling floats will be seeded off the coast of Luzon in the South China Sea by R/V *Revelle*, in a region of varying S, diurnal amplitude, and winds. This float array will yield extensive 3-D coverage of the upper ocean over 30 days via clean, near-surface, high-vertical resolution profiles of T and S from 0–50 m every 25 minutes and produce >10,000 profiles.

Research Objectives:

In the midst of diverse mesoscale conditions during an active ISO, our objectives are to:

- Resolve the diurnal cycle of T and S in the upper ocean from the diurnal warm layer to below the ML base;
- Examine the interplay between diurnal warming/cooling and S-controlled stratification;
- Examine how the diurnal signal varies spatially (i.e., the barrier layer thins and diurnal influence wanes away from coasts); and
- Provide sufficient data across a large footprint with high vertical and temporal resolution to aid state estimates/data assimilation models to further examine the role of S-controlled stratification and the diurnal cycle on ISO propagation and intensity.

Research Accomplishments:

The floats have been fabricated and will be shipped to *Revelle* in June 2018 for cruises in August–September 2018. A PISTON planning meeting was attended in 2017 and a deployment plan was agreed with Jim Moum (OSU), chief scientist on the PISTON cruises.

Conferences, Meetings & Presentations:

- a. Dr.'s T.M.S. Johnston and D.L. Rudnick attended ONR's PISTON planning meeting 30–31 October 2017 at Scripps Institution of Oceanography



Coping with Drought in the Russian River Watershed - NA14OAR4310092

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

Jay Jasperse, Sonoma County Water Agency

NOAA Primary Contact:

Nancy Beller-Sims, Climate Program Office

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaptation and Mitigation

Goal 2: Weather-Ready Nation

Budget Amount:

\$298,520

Award:

NA14OAR4310092

Description of Research:

Over the last year, we worked to publish a paper on the 2012-2015 drought in the Russian River and discuss the area preparedness for future droughts. Although the paper discusses much of the societal impacts, we had difficulty getting the paper published. Reviewers determined that it placed too much focus on the impacts and future preparedness and did not include enough new scientific research. As a result we had to change paths and are now working on a brochure that we can use to discuss drought readiness in the Russian River that can be distributed in the region. We are currently working with Sonoma County Water Agency on the best distribution for the brochure.

The second publication on the extreme drought scenario was published this past winter. 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 31).” 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.

Flint, L.E., A.L. Flint, J. Mendoza, J. Kalansky, and F.M. Ralph, 2018: Characterizing drought in California: new drought indices and scenario-testing in support of resource management. *Ecological Processes*, 7:1. doi:10.1186/s13717-017-0112-6.

Research Objectives:

The overarching objectives were to understand ARs and their role in the Russian River in causing droughts, the effects of extreme drought in the region, and how prepared the region is for drought. The three specific objectives are listed below.

- Evaluate drought ending atmospheric river (AR) characteristics using historical observations and new AR5 climate projections
- Develop a “drought scenario” for the Russian River by engaging Russian River Stakeholders and by using IPCC model analysis in task one, as well as lesson learned from the “ArkStorm” scenario for California flooding.
- Develop and carry out a process to characterize the drought readiness for the Russian River in close



partnership with Sonoma County Water Agency, using results from task 1 and 2 and past NIDIS workshops.

Research Accomplishments:

Flint, L.E., A.L. Flint, J. Mendoza, J. Kalansky, and F.M. Ralph, 2018: Characterizing drought in California: new drought indices and scenario-testing in support of resource management. *Ecological Processes*, 7:1. doi:10.1186/s13717-017-0112-6.

Education & Outreach:

Communication

- M. Dettinger interview with Stephen Baker, Operation Unite, Past, present, future of California precipitation regime, July 2018
- M. Ralph interview with Jacob Margolis, KPCC, Why Atmospheric Rivers can be a blessing and a curse, March 2018.
- M. Ralph, interview, San Diego Union Tribune, Scientist Foresee Major Changes in Rainfall Patterns Across California, October, 2017.



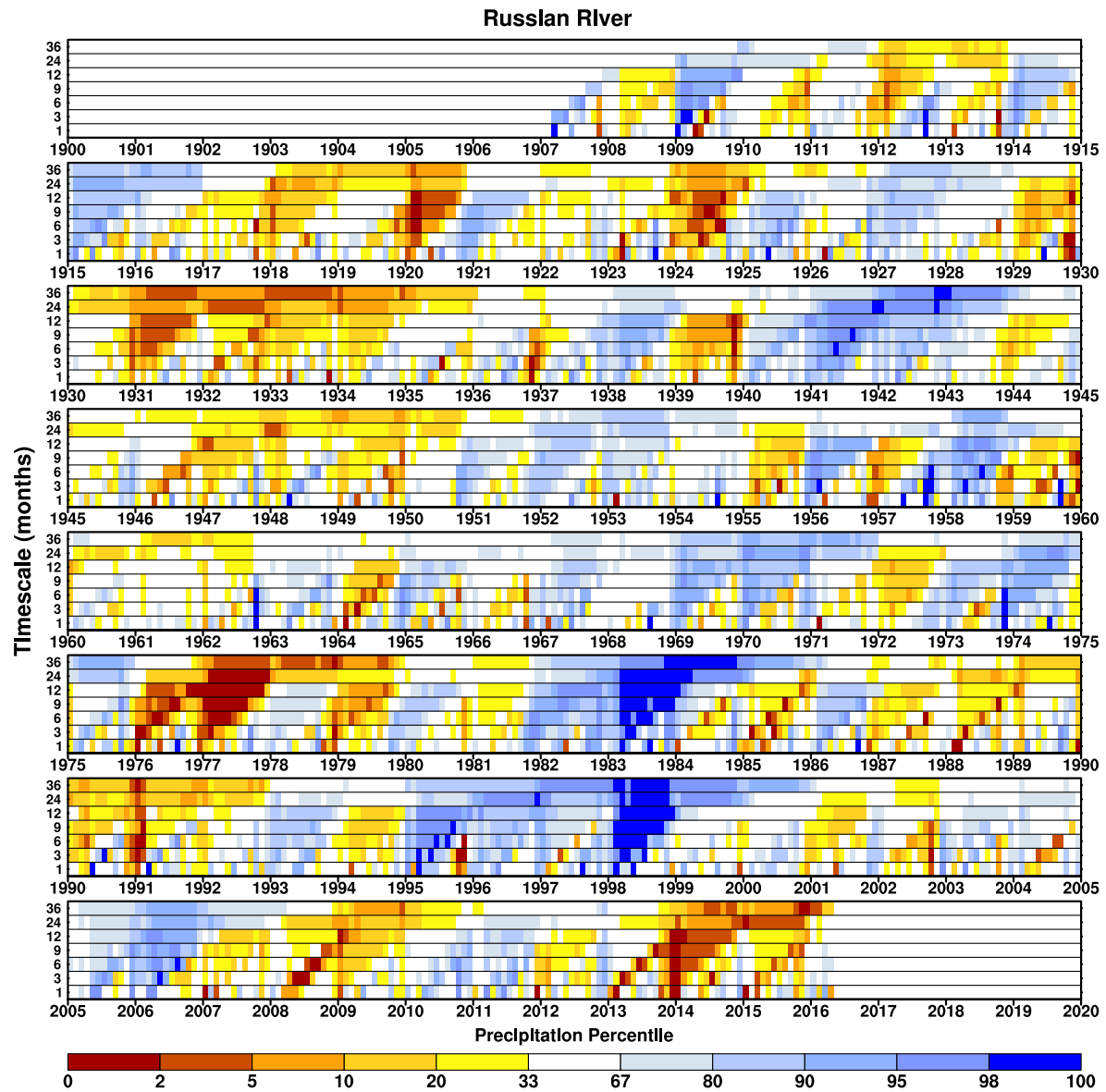


Figure 30: Using the monthly precipitation averages over the Russian River, based on two COOP stations, the precipitation percentiles are shown at different time intervals ranging from 1 month to 36 month, (y-axis) to characterize the severity of the drought on different time scales. Figure after Steinemann et al. (2015).



NOAA Support for the CLIVAR and Carbon Hydrographic Data Office at UCSD/SIO, 2018-2020

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 Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaptation and Mitigation

Goal 3: Healthy Oceans

Budget Amount:

\$329.840

Amendment(s):

13, 38, 61

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 is the data easier to use, its quality and usefulness is 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's 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 EXPCODE 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-supported groups to assemble and incorporate into their holdings select cruise data sets. The principal example relates to Argo. The CCHDO learns of cruises through interactions with regional Argo center staff and through other community contacts. As candidate cruises are identified, the CCHDO works to obtain the CTD data for Argo use. For public data sets (e.g. GO-SHIP) the CCHDO follows its normal data reformatting, verification, and documentation procedures. For non-public data, for example early release CTD data to be used only for Argo reference use, the CCHDO reformats the data to a common readability standard, reports all new and updated data to Argo at regular intervals (normally twice-yearly, ahead of key relevant Argo meetings), and estimates the suitability of each CTD data set for Argo purposes. (The available CCHDO support is not sufficient to fully complete reformatting work on some cruises with more complex or endemic problems. Argo leaders and agency program managers are kept informed of such instances.)

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:

1. Continued data assembly of cruise hydrographic data and metadata, particularly those from the GO-SHIP program.
2. Working with NCEI to improve efficiency of transfer of data and to make CCHDO data more archive ready.
3. Working with NCEI to better synchronize data holdings.



4. CCHDO participation in discussions towards enhancing integration of related Data Assembly Centers, for example to reduce ambiguity and redundancy in data discovery and archiving, improve interoperability, and share best practices.

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).

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 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. 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 1900 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 routine data and documentation tasks. This would require approximately \$100k more per year in agency funding, i.e. from NSF and/or NOAA. (NSF support for the additional data specialist was proposed in February 2018.) 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 online 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 online 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 online 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 is 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 is 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.

Conferences, Meetings & Presentations:

- a. James Swift attended the Ocean Sciences Meeting in Portland, Oregon from February 11-17, 2018. No NOAA funds were used.
- b. James Swift attended the NOAA COD PI meeting in Silver Spring, MD, from May 8-11, 2017. No NOAA funds were used.
- c. Carolina Berys-Gonzalez attended the Ocean Sciences Meeting in Portland, Oregon from February 11-17, 2018. NOAA funds were used.
- d. Andrew Barna attended the Ocean Sciences Meeting in Portland, Oregon from February 10-17, 2018. NOAA funds were used.
- e. Jerry Kappa attended the Ocean Sciences Meeting in Portland, Oregon from February 10-16, 2018. NOAA funds were used.
- f. Steve Diggs attended the Research Data Alliance (RDA/NSF) 9th Plenary in Barcelona, Spain, from April 1-9, 2017. No NOAA funds were used.
- g. Steve Diggs attended the Research Data Alliance (RDA/NSF) US Leadership meeting in Troy, New York, May 15-18, 2017. No NOAA funds were used.
- h. Steve Diggs attended the EarthCube (NSF) All Hands Meeting in Seattle, Washington, June 6-8, 2017. No NOAA funds were used.

- i. Steve Diggs attended the Research Data Alliance (RDA/NSF) WG/IG Chairs meeting in Gothenburg, Sweden, June 10-17, 2017. No NOAA funds were used.
- j. Steve Diggs attended the ESIP Summer Meeting in Bloomington, Indiana, July 24-28, 2017. No NOAA funds were used.
- k. Steve Diggs attended the Research Data Alliance (RDA/NSF) 10th Plenary meeting in Montreal, Canada, September 17-22, 2017. No NOAA funds were used.
- l. Steve Diggs attended the FORCE11 meeting in Berlin, Germany, October 23-27, 2017. No NOAA funds were used.
- m. Steve Diggs attended the SIO-AORI Earth Data and Visualization meeting in Tokyo, Japan, November 1-7, 2017. No NOAA funds were used.
- n. Steve Diggs attended the Argo Data Team meeting in Hamburg, Germany, November 25 - December 1, 2017. NOAA funds were used.
- o. Steve Diggs attended the Fall AGU meeting in New Orleans, Louisiana, December 11-15, 2017. NOAA funds were used.
- p. Steve Diggs attended the ESIP Winter meeting in Bethesda, Maryland, January 7-12, 2018. NOAA funds were used.
- q. Steve Diggs attended the Ocean Sciences Meeting in Portland, Oregon, February 11-16, 2018. No NOAA funds were used.
- r. Steve Diggs attended the Argo Steering Team meeting in Sidney, Canada, March 11-14, 2018. No NOAA funds were used.
- s. Steve Diggs attended the Research Data Alliance (RDA/NSF) 11th Plenary in Berlin, Germany, March 17-24, 2018. No NOAA funds were used.

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 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.

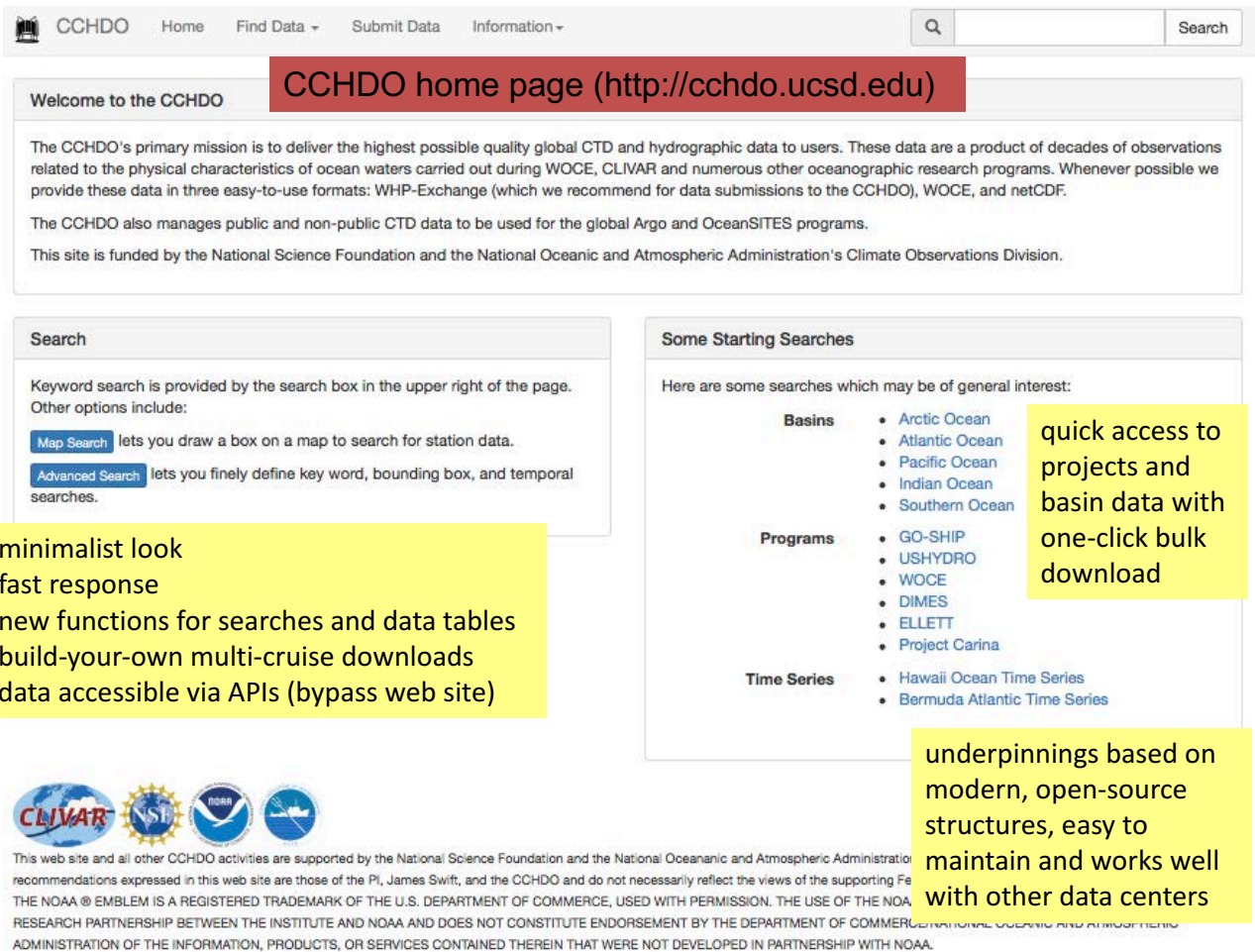
Academic Development

- 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).

K-12 Outreach

- a. The CCHDO Director and Manager participates in area STEM and “career day” events.



J.Swift November 2017

Figure 31: November 2017 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, 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 1900 cruises. Each year there are 4000-7000 users from up to 96 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.



The Role of Ocean Stratification in the Propagation of Intraseasonal Oscillations - NA17OAR4310257

Principal Investigator(s):

Janet Sprintall, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Sandy Lucas, Climate Variability and Predictability Program

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme B: Climate Research and Impacts

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaption and Mitigation

Budget Amount:

\$508,531

Amendment(s):

NA17OAR4310257

Description of Research:

Intraseasonal Madden-Julian Oscillation (MJO) atmospheric forcing exerts a profound influence on the near ocean surface layer of the tropics through the coupled air-sea system that in turn affects the structure, development and propagation of the mesoscale convective systems that are part of the MJO. Models suggest that an accurate depiction of the upper ocean stratification in the Maritime Continent (MC) is necessary to correctly reproduce intraseasonal variability. Nonetheless, the dynamics and time scales of the processes and characteristics at the air-sea interface during MJO events are still not well understood. In particular, little is understood about the role of upper ocean salinity in MJO variability. Since salinity controls stratification throughout much of the MC, it can play a critical role in the complex coupling of the air-sea system during MJO events. In many MC regions, a salt-stratified but isothermal “barrier layer” can exist that traps fluxes of heat, freshwater, and momentum to a thin surface layer. Climatological variations in the thickness of the barrier layer during MJO events are known to drive SST anomalies that influence the coupled air-sea system.

The project objective is to understand the mechanisms responsible for upper ocean stratification variability in the MC, with a particular attention on near surface salinity stratification and how this influences the structure and propagation of MJO convection and winds. High-

resolution ship-board measurements of the upper ocean temperature and salinity will be obtained using a portable underway CTD (uCTD) system as part of the PISTON project to study the boreal summer intraseasonal oscillations, as well as within the Banda Sea in Indonesia. The data will provide distinct case studies of the ocean conditions during MJO events, that will be examined in concert with remotely-sensed and other *in situ* datasets.

During this reporting period (09/01/2017 - 05/31/2018) I have primarily been focused on cruise preparation for participation in the Propagation Of Intra-Seasonal Tropical Oscillations (PISTON) field campaign to be conducted from the *R/V Thompson* 11 August – 9 September 2018 within the seas just west of Luzon island in the Philippines. PISTON will primarily target the Boreal Summer Intraseasonal Oscillation (BSISO) that characterizes the northward and eastward movement of the Asian monsoon during the northern-hemisphere summer. This oscillation impacts weather across the MC and into the southeastern portions of continental Asia and even weather within the United States. PI Sprintall and her Marine Engineer Spencer Kawamoto will participate in the PISTON cruise.

Research Objectives:

Specific science objectives are to:

1. Determine the characteristics and the time and space scales of upper ocean salinity variability of importance to MJO variability;
2. Identify the main forcing mechanisms that control that salinity variability; and
3. Establish connection with the intraseasonal MJO atmospheric phenomena and relationship to the propagation characteristics (speed, intensity, MJO phase, geographical location, et.c) of the MJO across the MC.

Research Accomplishments:

During the reporting period, the PI has attended collaborative organizational meetings with other PISTON PIs at AGU Fall Meeting in December 2017 in New Orleans, LA; the AMS Meeting in January 2018 in Austin TX; and the Ocean Sciences Meeting in February 2018 in Portland OR. The PI has also helped to design the cruise track and hydrographic sampling plans for PISTON with Chief Scientist Jim Moum, OSU, and has worked closely with Dr. Julie Pullen (Stevens Institute) and Dr. Olive Cabrera (University of the Philippines) to co-ordinate US sampling with UP hydrographic sampling proposed as part of PISTON.



The hydrographic work to be undertaken by the PI during PISTON will use a uCTD, a compact system that includes its own spooling system, CTD probe (to provide profiles and temperature, conductivity (salinity) and depth) and a portable winch system that can be mounted on the vessel rail or deployed aft. In survey mode, the uCTD permits a fast temporal and high spatial resolution while underway, thus allowing the vessel to cover large distances at typical ship speeds and obtain a relatively high number of CTD profiles. During the reporting period we have purchased 3 additional CTD probes and batteries for refurbishment of the PIs uCTD system.

The PI has also been working with international colleagues investigating the spatial structure of oceanic intraseasonal variability (ISV) in the Philippine Sea using multi-source observations (moorings, Argo profiles etc.) and numerical simulations. Mesoscale eddies and Rossby waves related to dynamic instability are found to be the major sources of oceanic ISV in the Philippine Sea. The MJO contributes about half of the total observed ISV and acts in forming the ISV features in the Philippine Sea. We are currently writing up this analysis for publication.

Finally, PI Sprintall is also planning to participate in a joint Indonesian-NOAA cruise proposed for January 2018 in the Banda Sea, Indonesia to examine air-sea interaction associated with MJO propagation across the MC. During this reporting period, Sprintall has been working closely with lead PI Chidong Zhang, NOAA/PMEL, assisting with cruise planning and details concerning Indonesian clearances and permitting systems.

Conferences, Meetings & Presentations:

- f. Dr. Janet Sprintall attended the AGU Fall Meeting in December 2017 in New Orleans, LA.
- g. Dr. Janet Sprintall attended the AMS Meeting in January 2018 in Austin TX.
- h. Dr. Janet Sprintall attended the Ocean Sciences Meeting in February 2018 in Portland OR

Education & Outreach:

Communication

- d. Sprintall has contributed material to the official NOAA Years of the Maritime Continent (YMC) website <https://www.pmel.noaa.gov/ymc/>



Intraseasonal to Interannual Variability in the Intra-Americas Sea in Climate Models - NA13OAR4310092

Principal Investigator(s):

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

Other Key Personnel:

Anna Merrifield, Scripps Institution of Oceanography, UC San Diego

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:

\$189,900

Award:

NA13OAR4310092

Description of Research:

We developed a method to separate interannual variability in summer surface temperature over the U.S. into distinct components due to the atmospheric circulation and pre-season soil moisture anomalies.

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. To assess the implications for tropical cyclones (TCs), how mean state biases in CMIP models develop, and how they affect forecast biases in ISV to IAV and related variations in TC activity.

Honors and Awards:

- a. Anna Merrifield received Best Student Presentation Award at the AGU Fall Meeting, 2017.
- b. Shang-Ping Xie received the Distinguished Lecture in atmospheric sciences at the Asia Oceania Geosciences Society, 2017.



Theme C: Marine Ecosystems

National Ocean Exploration Forum 2017 “Ocean Exploration in a Sea of Data

Principal Investigator(s):

Dominique Rissolo, Qualcomm Institute, California Institute for Telecommunications and Information Technology, UC San Diego

Other Key Personnel:

Vicki Ferrini, Lamont-Doherty Earth Observatory, Columbia University

Adrienne Copeland, NOAA Office of Ocean Exploration and Research

NOAA Primary Contact:

David McKinnie, NOAA Office of Ocean Exploration and Research (OER)

NOAA Task:

Task 1 - Administration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$75,000

Amendment(s):

73

Description of Research:

The 2017 National Ocean Exploration Forum: Ocean Exploration in a Sea of Data (NOEF 2017) was the fifth in a series of annual forums focused on establishing a national strategy and program of ocean exploration, as called for in the statute authorizing the National Oceanic and Atmospheric Administration (NOAA)’s ocean exploration program.

The first Forum, Ocean Exploration 2020: A National Forum (OE 2020), held at the Aquarium of the Pacific in Long Beach, California in July 2013, asked participants to describe elements a successful national ocean exploration program should exhibit by the year 2020. National Forum 2014 (NOEF 2014), held in September 2014 at the National Aquarium in Baltimore, Maryland, was much smaller and focused on how to comprehensively address

national ocean exploration needs and how to connect ocean exploration results to NOAA mission priorities, as well as assessing the community’s progress toward the ambitious targets set in OE 2020. The 2015 National Ocean Exploration Forum: Characterizing the Unknown (NOEF 2015), also held at the National Aquarium in Baltimore, Maryland, challenged participants to describe those requirements for first-order exploration that meets multiple requirements and could set a new standard for exploring unknown ocean areas and phenomena. The 2016 National Ocean Exploration Forum: Beyond the Ships (NOEF 2016), held at the Rockefeller University in New York City, highlighted the opportunities and challenges created by new technologies and promoted a shared vision of exploration across new exploration models.

NOEF 2017 took a new approach. Experts in ocean exploration and data science, as well as other fields, attended NOEF 2017 at the University of California, San Diego’s Qualcomm Institute (QI), a division of the California Institute for Telecommunications and Information Technology (Calit2). Expanding the idea of ocean exploration into a truly broad and multidisciplinary concept, this Forum brought together ocean explorers with data scientists, computer scientists, and visualization experts from QI. This synergistic blend of expertise, discipline, perspective, and sensibility allowed participants to experience and understand ocean data in new—and sometimes unexpected—ways.

Forum participants considered how relevant data—whether from satellites, ocean sensors, hydrophones, or deep ocean cores—can be integrated, analyzed, and visualized to gain a novel understanding of the ocean. Taking advantage of QI’s visualization and acoustics laboratories, this Forum demonstrated what can be done with rich terrestrial data sets, what might be done with more limited historical and contemporary data from the deep ocean, and the potential for conducting ocean science differently using these techniques. Graduate students and early career professionals created demonstrations, which included photogrammetric models of deep ocean environments, point-cloud analysis of complex habitats, deep ocean soundscapes, three-dimensional under-ice exploration, and a synthesis of multibeam and backscatter data in a data sparse landscape. The goal of this interdisciplinary Forum was to move the application of ocean exploration data into the future.



Research Objectives:

One of the key recommendations from *Ocean Exploration 2020*, reinforced in Forums since, was the need for better access to data, new techniques for data management, and new tools for visualizing data. A primary objective of NOEF 2017 was to amplify those themes by bringing together data scientists and visualization experts with the ocean explorers to consider how current and emerging data science and visualization techniques can help us understand the deep ocean in new ways. *Ocean Exploration in a Sea of Data* took full advantage of UC San Diego's visualization and acoustics laboratories to demonstrate what *can* be done with rich terrestrial data sets, what *might* be done with historical and contemporary data from the deep ocean and its limitations and challenges, and the *potential* for conducting science differently using these techniques to reach a new understanding of this critical domain.

Research Accomplishments:

On October 21-22, 2017, nearly 125 experts in fields including ocean exploration and data science convened for the fifth National Ocean Exploration Forum in Atkinson Hall, Qualcomm Institute, UC San Diego.

Demonstrations

Forum participants were given a series of demonstrations that presented novel ways of experiencing data to make new discoveries and consider opportunities for making data more accessible and understandable. New data science and visualization techniques challenge the ocean exploration community to think beyond the limitations of traditional approaches and can have a real impact on current data acquisition, data analysis, and data management practices. These techniques also have the potential to bring new life to legacy data and present exciting opportunities for more effective communication of results. The following demos represented active and ongoing research as well experimental collaborations which were initiated for the Forum:

- “Exploring Ocean Data Through Audio Spatialization and Sonification” was held in the QI Audio Spatialization Lab (SpatLab) and presented by QI affiliates, Shahrokh Yadegari and Grady Kestler, and NOAA OER Knauss Fellow and Adrienne Copeland. A combination of physical, biological, geological, and anthropogenic sounds make up marine “soundscapes.” Exploring marine soundscapes can lead to a better understanding of the deep ocean and is an important aspect of characterizing these environments. The SpatLab allowed participants to explore sound in 3D, observing demonstrations of how ocean phenomena can be modeled acoustically and how sound can be used to explore and understand

aspects of the deep ocean in ways otherwise not possible.

- “WAVELab Underwater Photogrammetry: Point-Based Visual Analytics and Habitat Characterization” was held in the Structural and Materials Engineering Building and presented by QI affiliates Falko Kuester (also of the Jacobs School of Engineering) and Dominique Rissolo. Structure-from-Motion (SfM) photogrammetry has become an empowering and widely adopted technique for documenting underwater features or sites in 3D. These techniques render geometrically accurate and photorealistic models that are useful for photo-mapping underwater environments. The resulting 3D data has the potential to serve as a basis for new analytical approaches. The large-scale, immersive visualization system demonstration in the WAVElab (Wide Area Virtual Environment) allowed participants to visualize coral reefs, shipwrecks, and submerged Pleistocene megafauna while exploring the scientific potential of these new analytical tools.
- “SunCAVE: Seabed Mapping: New Perspectives from Immersive Visualization” was presented by Vicki Ferrini of LDEO on the QI SunCAVE. Seabed mapping provides critical baseline information for ocean exploration. As an immersive experience in near 360-degree presentations of video and data, SunCAVE technologies provided participants with a new way to experience deep-ocean bathymetry, seafloor features, and other attributes of the deep ocean. This type of data visualization can inform science, strengthen public interest in ocean exploration, help educators explain the ocean, and engage more of the public in ocean exploration.
- a. “CHEI Lab: Visualizing Antarctic Ice Shelf and Bathymetry with Airborne Radar Data” was presented by Nicholas Frearson of LDEO and Vid Petrovic of QI. Acquiring good bathymetry in remote under-ice environments is critical to understanding these deep-ocean regions and how ice sheets are changing. The Cultural Heritage Engineering Lab allows for 3D displays of high-resolution images, video, and photogrammetric point clouds. The ROSETTA project is mapping the least known ocean floor on our planet, using aircraft as platforms for radar, gravimeters, and other instrumentation. This demonstration integrated aerogeophysical data, allowed for visualization of the data to streamline analysis, and included a fly-through of the ice-penetrating radar data to illustrate how the ice shelf is changing.
- “Being There Without Being There” was presented by John Delaney and Aaron Marburg of the University of Washington, Timothy Crone of LDEO, and Friedrich Knuth of Rutgers University using the



QI Vroom (Virtual Room) display wall. The recent completion of the Cabled Array of sensor networks offers unique opportunities to explore the scientific and educational benefits of real-time access to a highly active portion of the Global Mid-Ocean Ridge System. The Vroom hyperwall and high-definition projections systems demonstrated these capabilities and benefits, highlighting the importance of continuous real-time monitoring to understand change in the deep ocean and the significance of ocean exploration in the time domain.

In the discussion session, participants agreed that the Forum demonstrations highlighted the rapid development of visualization technology, allowing researchers to transform their ability to explore, experiment with, and more deeply understand the complex processes that take place throughout global ocean basins. Participants shared impressions of the demonstrations and discussed how these tools could impact their work, areas of interest, and the ocean exploration community.

Case Studies

In the first case study, professors and students from the Scripps Institution of Oceanography and QI (Stuart Sandin, Falko Kuester, Vid Petrovic, Nicole Pedersen) demonstrated and explained their coral reef point cloud and automated classification scheme. High-resolution photogrammetric images are converted to point clouds; algorithms automate the classification process so that each point contains location and type information as metadata and detailed analysis is possible.

In the second case study, Alice Winter, a user experience researcher at NASA's Jet Propulsion Laboratory, described how OnSight Immersion Environment and other programs are allowing scientists to explore and conduct science on Mars with avatars in a "mixed reality" environment based on live data feeds. OnSight, or similar technologies, could be the next generation of telepresence-enabled deep-ocean exploration, as autonomous vehicles and sensor networks augment and perhaps replace ship-based exploration in the future.

Discussion Groups

The Forum was structured to provide participants, regardless of discipline or experience, with common information and experiences to bring to breakout sessions. The keynotes, panel discussion, case studies, and especially the demonstrations were intended to share new information, provoke thought, spark creativity, and encourage dialogue across ocean exploration and data science and visualization disciplines.

Breakout session participants were asked to rely on this common information, as well as their own expertise and experience, to address several questions that the

organizers intended to help spark discussion about how new techniques in data science and visualization can be applied to ocean exploration to understand the ocean in new ways and to develop recommendations for ocean exploration stakeholders and specific sectors involved in exploring the deep ocean. Each breakout group then provided feedback in plenary.

Conferences, Meetings, & Presentations:

- i. Dominique Rissolo attended the National Geographic Explorers Symposium, Washington, DC (June 2017)
- j. Dominique Rissolo presented at the Conference on Historical and Underwater Archaeology, New Orleans (January 2018)
- k. Dominique Rissolo presented at the AGU Ocean Sciences Meeting, Portland, OR (February 2018)
- l. Dominique Rissolo presented at the MIT MediaLab "Here be Dragons" Oceans Workshop (February 2018)
- m. Dominique Rissolo Presented at the CAA Conference, Tubingen, Germany (March 2018)
- n. Vicki Ferrini presented at the AGU Ocean Sciences Meeting, Portland, OR (February 2018)
- o. Vicki Ferrini presented at the AGU Fall Meeting, New Orleans, LA (December 2017)
- p. David McKinnie presented at the AGU Ocean Sciences Meeting, Portland, OR (February 2018)
- q. Adrienne Copeland presented at the AGU Ocean Sciences Meeting, Portland, OR (February 2018)

Education & Outreach:

Communication

- e. NOEF 2017 Websites
 - <http://noef2017.ucsd.edu/>
 - <https://oceanexplorer.noaa.gov/national-forum/welcome.html>
- f. UC San Diego press release
"Tackling 'Ocean Exploration in a Sea of Data' at the National Ocean Exploration Forum"
- g. *Oceanography*, Vol. 31, No. 1, Supplement, March 2018

Academic Development

- a. NOEF 2017 supported graduate students Grady Kestler and Vid Petrovic at the 2018 Ocean Sciences Meeting in Portland, OR, where they presented on their Forum-related research. They were joined by Forum organizers Dominique Rissolo, Vicki Ferrini, Adrienne Copeland, and David McKinnie.
- b. Integral to NOEF 2017 was a creation of research opportunities for graduate students in the Data Science Program at UC San Diego (Jacobs School of Engineering). The Ocean Exploration Data Capstone Challenge was announced by Jessica Block at the Forum and is ongoing.



K-12 Outreach

- c. NOEF 2017 content was shared with the following groups at UC San Diego:
- Poway High School (April 2017)
 - Rancho Vista High School (April 2017)

Networking

- e. NOEF 2017 co-organizer, Dominique Rissolo, participating in the MIT MediaLab “Here be Dragons” Oceans Workshop (February 2018). MIT MediaLab will be hosting the 2018 NOEF.
- f. NOEF 2017 content was shared with the following groups at UC San Diego:
- Regents Scholars Overnight Stay Program (April 2017)

- Contextual Robotics networking event, demo exhibitor (April 2017)
- Realcomm (June 2017)
- QI Summer Research Communication Seminar (July 2017)
- QI Brazil delegation (July 2017)
- Robotics Frontiers event (September 2017)
- Maritime Alliance, Blue Economy Summit (November 2017)
- Scripps Center for Marine Archaeology (December 2017)
- Aquarium of the Pacific (January 2018)
- South Korea delegation (January 2018)
- Los Alamos National Laboratory (April 2018)





Figure 32: NOEF, Day 1



Figure 33: NOEF, Day 2



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:

Brice Semmens, Scripps Institution of Oceanography, UC San Diego

Kelly Goodwin, NOAA, Atlantic Oceanographic and Meteorological Laboratory

Eric Allen, Scripps Institution of Oceanography, UC San Diego

Lisa Zeigler, J. Craig Venter Institute

Ariel Rabines, 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 3: Healthy Oceans

Budget Amount:

\$588,727

Amendment(s):

2, 30, 81

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.

1. Continued analyses of omic data, including *a)* regional diversity and transcriptional activity analyses of microbes, *b)* Increased statistical analyses of linkages between microbes using Empirical Dynamic Modeling (EDM). We have used oceanographic metadata to subdivide the CalCOFI grid into 4 sub regions, which include Upwelling, Southern California Bight, California Current, and Offshore; in particular specific variables such as dissolve nitrate, chlorophyll concentration, mixed layer depth, nitracline depth, 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, *c)* improved annotation and analyses of metazoan (i.e., higher trophic level organisms) data , and *d)* investigation of linkages between microbes and zooplankton and fish.
2. Incorporation of fish (ichthyoplankton) data from Andrew Thompson (Southwest Fisheries)
3. 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.
4. 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. We are implementing and optimizing standards for quantitative mRNA sequencing as well as PCR based metabarcoding studies.



Research Accomplishments:

- a. Integrated sustainable 'omic sampling within the CalCOFI program without significantly stressing ongoing CalCOFI activities.
- b. Sequencing and Analyses.
 - 2014-2017 cruise samples: DNA was extracted from 660 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). Data from 2014-2016 (478 sample) have been analyzed and a manuscript describing these results is targeted for completion during summer 2018.
 - Completion of DNA analysis for 2017 CalCOFI (165 samples) cruises is scheduled for July 2018.
 - Completion of RNA sequencing for 2014-2016 CalCOFI cruises (184 samples) was completed in Fall 2017. These data have undergone analyses and are currently being incorporated into the manuscript noted above.
 - Synergistic samples have been obtained from the complementary projects seen in Figure 34.
- 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.
 - 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.
- d. Sequence annotation pipelines and databases.
 - 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. Data products
 - 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:
 - Bacteria V45 (16S) - <https://www.arb-silva.de/>
 - 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
 - PhyloDB (metatranscriptomes) <https://scripps.ucsd.edu/labs/aallen/data/>



- 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. L. Zeigler Allen, A. J. Rabines, J. P. McCrow, H. Zheng, K. Goodwin, M. Bohan, A. E. Allen. Exploring the Marine Microbial Food Web and Viral Shunt Using Patterns of Diversity and Gene Expression Within the California Current Long-Term Ecosystem Observatory. *Abstracts of the 119th American Society of Microbiology General Meeting*, Atlanta, GA. May, 2018
- b. Zeigler, L.A., Schwenck, S.M., Zheng, H., Allen, A.E., (2018) Diatom Virus Investigations:

- Connecting Field Dynamics and Physiology [MM31A-02] presented at 2018 Ocean Sciences Meeting, Portland, OR, 12-16 Feb.
- c. Schwenck, S.M., Landry, M.R., Allen, A.E., Zeigler, L.A (2018) A Sequential Look at Viral Mortality in an Upwelling Filament Within the California Current Ecosystem [MM34B-1502] presented at 2018 Ocean Sciences Meeting, Portland, OR, 12-16 Feb.
- d. 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
- e. Allen, L.Z., Rabines, A., McCrow, J.P., Zheng, H., Goodwin, K., Bohan, M.L., Allen, A.E. Exploring ‘omic technologies to support ecosystem understanding and fisheries assessments. California Cooperative Oceanic Fisheries Investigations Annual Conference, Dec 4-6 La Jolla, CA.

Project	16s	18S v4	18S v9	metaT
LTER Process Cruises p1408, p1508, p1604	160 sequenced	160 sequenced	160 sequenced	
2015 ESP	326 sequenced		326 sequenced	
2017 eAUV	67 submitted	67 submitted	67 submitted	
2016 ESP	386 extracted	386 extracted	386 extracted	
LTER p1706	218 extracted	218 extracted	218 extracted	34 in queue
Rock Fish (MBON)	34 extracted	34 extracted	34 extracted	
LTER p1408	64 in queue	64 in queue	64 in queue	64 complete

Figure 34: Synergistic samples were obtained from the complementary projects listed above.



R/V Revelle

Principal Investigator(s):

Bruce Appelgate, Scripps Institution of Oceanography,
UC San Diego

NOAA Primary Contact:

Tom Peltzer, Pacific Marine Environmental Laboratory

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Budget Amount:

\$38,211

Amendment(s):

78

Description of Research:

This award supported ship time and shipboard technical services by the R/V *Roger Revelle* to support a NOAA-sponsored program in the eastern Pacific Ocean titled "NOAA-VENTS-NeMO Research Program on Undersea Hydrothermal Venting Systems." The scientific program was led by Principal Investigator Dr. David Butterfield.

Research Objectives:

Operate the research vessel *Roger Revelle* and provide marine technical support, to execute the scientific program led by Dr. David Butterfield using the Remotely Operated Vehicle Jason as part of the VENTS-NeMO project. This project is involved in maintaining observatory-based time series experiments, discovering new hydrothermal and volcanic features, and responding to volcanic and tectonic events on the Juan de Fuca Ridge and other spreading centers in the Northeast Pacific. The NEMO program's initial priority in the Northeast Pacific is to maintain ongoing measurements at the New Millenium Observatory (NeMO) at Axial Volcano and the Neptune Observatory in the Endeavour Segment of the Juan de Fuca Ridge. At both of these sites long-term (> 10 years) geodetic, chemical, and microbiological observations are underway. Ongoing observatory

research activities include time-series sampling of specific hydrothermal vent sites for chemistry, microbial and vent fauna community structure; instrumental time-series sampling; high-precision depth survey at geodetic benchmarks; water-column plume time-series; and temperature monitoring. In addition to these time-series observations, the VENTS program is interested in discovering new hydrothermal and volcanic features in the Northeast Pacific. Some of these discoveries are expected to be associated with other work in the region while others may be associated with volcanic and tectonic events that are likely to occur in this region over the next 5 to 10 years.

Research Accomplishments:

This project was successfully completed as planned. As a large shared-use facility scheduled within the collaborative framework of the University-National Oceanographic Laboratory System (UNOLS), *Roger Revelle* hosts scientists from across the United States to undertake research in a variety of disciplines. The ship will be operated in a manner that promotes efficiency, capability, and safety in order to maximize Federal investment in this shared-use facility and the programs that are conducted on board. A key element of our approach is preparing the vessel, crew and technicians to rapidly accommodate radically different scientific missions during brief in-port periods involving extensive loading, offloading, laboratory reconfiguration, and installation of project-specific deck equipment. The operating tempo of expeditionary oceanography requires a carefully planned yet flexible approach to vessel maintenance, regulatory compliance, foreign clearance, as well as crewing and working with scientists, which we will execute so that projects can be completed successfully and on schedule.

Education & Outreach:

Communication

a. Axial Seamount Expedition Blog

Informational materials maintained in real-time by the science party.

b. Axial Seamount Resources

Real-time data, volcano status, and volcanic forecasting information available on the web.



Instrumentation to Assess the Untainted Microbiology of the Deep Ocean Water Column - NA17OAR4310276

Principal Investigator(s):

Douglas H. Bartlett, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Matthew Norenberg, Scripps Institution of Oceanography, UC San Diego

Alvaro Munoz Plominsky, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Alan Leonardi, Office of Ocean Exploration and Research

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Budget Amount:

\$544,601

Award:

NA17OAR4310276

Description of Research:

This project is developing an autonomous hadal depth seawater sampling system for the collection of seawater samples without significant temperature or pressure change during recovery. It is needed in order to ascertain how much alteration in abundance, composition, activity and viability of deep-sea microbial communities occurs under routine sampling, e.g., when temperature and pressure are not meticulously controlled. During this initial funding period of ~ 9 months the principal goals were to modify components of an existing hadal depth-rated ocean Lander in the following ways:

1. Construct an insulation box to house two 30-liter Niskin bottles and two pressure-retaining seawater samplers.
2. Construct a set of insulation tubes to house the pressure-retaining seawater samplers within the insulation box.
3. Construct two titanium pressure-retaining seawater samplers.

4. Prepare two custom-built rotary actuators to control seawater entry valve opening and closing for each of the pressure-retaining seawater samplers.
5. Design and construct the electronic control circuits to control Niskin bottle endcap closure, pressure-retaining seawater sampler valve opening and closing, and lander ballast release. All of these tasks have been completed and the new lander components will be pressure-tested soon. Later the new lander system will be tested at sea and then used during an expedition to a deep-sea trench. At that time a variety of microbiology and molecular biology experiments will be performed to address the consequences of temperature and pressure changes on trench microbes.

Another goal of this funding period has been to work at optimizing the methods we will employ with the samples collected at sea to measure microbial activity and to collect those microbes which are active at trench temperatures and pressures. We are also making good progress in this goal and will soon be testing a fluorescently activated cell sorter available at a nearby institution to evaluate our ability to identify and collect active microbial cells.

The progress to date has been good, except for two issues. First, our award began 3 months prior to that originally proposed and the postdoc on the award was not able to arrive until 5 months after the project had begun. Second, we have discovered that additional work is needed on our existing subsamplers, which we use to subsample pressure-retained seawater without significant decompression. As a result, we are postponing objective 3 below until we ascertain whether our budget will allow us to both correct our subsampler issue and prepare attachments for our pressure-retaining seawater samplers in insulation tubes to a CTD rosette. This latter system would provide a second system for collecting seawater samples with little temperature/pressure change and would not rely on a coupling to a lander.

Research Objectives:

- PRS fabrication – Completed
- Lander Modification – Completed
- CTD rosette modification – This task has been postponed until a precise accounting of all fabrication costs to date are available.
- Equipment testing – In progress
- Cruise Logistics – In progress



- Microbial activity/FACS sorting optimization (Plominsky) – In progress

Research Accomplishments:

During this initial period of the award, we have assembled both 1) our team and 2) our instrumentation. Pending good results from pressure testing and sea trials we will be ready to transition from engineering to science.

Conferences, Meetings & Presentations:

- a. Dr. Doug Bartlett co-organized a workshop on deep life cultivation in Rotorua, New Zealand from November 5-6, 2017.

- b. Dr. Doug Bartlett presented results on the microbiomes of Pacific Ocean hadal trenches at a deep-sea microbiology symposium at the University of Kyoto, Japan on December 6, 2017.

Education & Outreach:

Academic Development

- a. Antarctic Biology Training Course
In early 2018, Dr. Doug Bartlett served as an instructor for a month-long Antarctic Biology Training Course at McMurdo Station, Antarctica. He provided lectures, and lab and field training in various aspects of polar microbiology to 20 graduate students and postdoctoral researchers.





Figure 35: This photo shows the redesigned Legoo Lander. It now has a thermally jacketed bottom compartment that holds two 30-liter Niskin bottles and two pressure-retaining seawater samplers. All components have been designed for function at hadal depths.

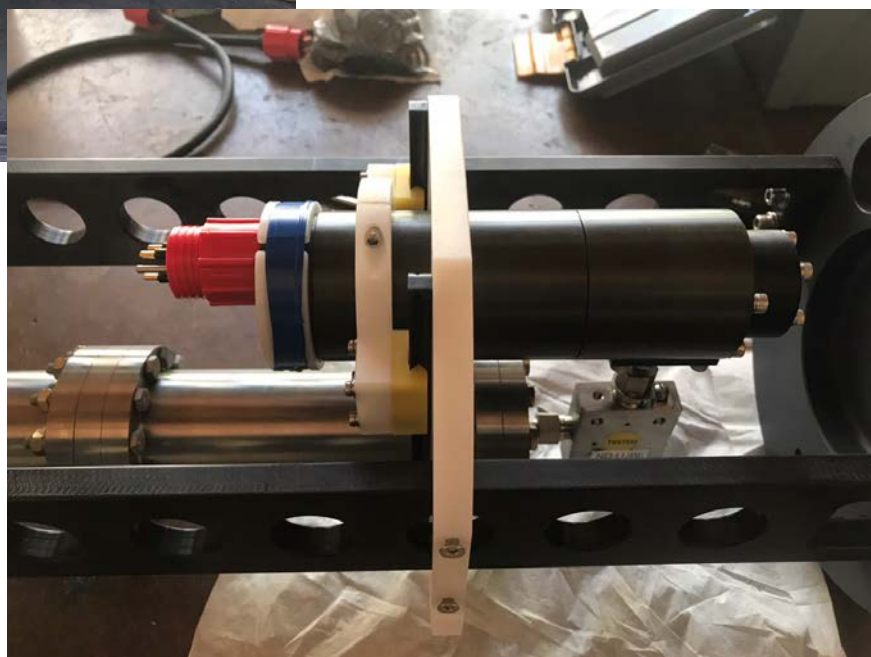


Figure 36: This photo shows a close-up view of a custom-designed rotary actuator (in black hosing) coupled to the seawater entry valve for a pressure-retaining seawater sampler.



Passive Acoustic Studies in the North Pacific

Principal Investigator(s):

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

Other Key Personnel:

Jennifer S. Trickey, Scripps Institution of Oceanography, UC San Diego

Sean M. Wiggins, Scripps Institution of Oceanography, UC San Diego

Ryan Griswold, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Erin Oleson, Pacific Islands Fisheries Science Center

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Budget Amount:

\$124,095

Amendment(s):

70

Description of Research:

Passive acoustics provide 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 at multiple sites in the central and western tropical and sub-tropical Pacific Ocean. Using calibrated High-Frequency Acoustic Recording Packages, or HARP, in collaboration with the Scripps Institution of Oceanography (SIO), continuous high-frequency acoustic monitoring (recording from 10 Hz to 100 kHz) has been underway at various locations since 2006. Analyses of these data sets allow us to gain insights into cetacean presence and uses in the remote areas of the central and western Pacific. Additionally, PIFSC is using several versions of HARP for these studies and need continued support with upgrades and maintenance of this equipment.

Over the course of this past funding period we (1) analyzed previously collected data for beaked whale presence and, (2) made improvements to existing PIFSC equipment and assisted PIFSC with further data collections.

The Pacific Islands region is the habitat for several beaked whale species, among which the most commonly observed are Cuvier's beaked whales (*Ziphius cavirostris*) and Blainville's beaked whales (*Mesoplodon densirostris*). These species are acoustically distinguishable. From previous studies we have learned that geographic variability for Cuvier's beaked whales is surprisingly low while there appears to be a larger variability in signals presumably produced by Blainville's beaked whales. We used a weighted network clustering method that quantified within site variability. We then compared signals across sites. We found that there appears to be a latitudinal relationship with signal peak frequency such that lower frequency signals occur in higher latitudes (Figure 37). This could be related to larger animals who generally produce lower signals to occur in higher latitudes. The latitudinal body size relationship has been shown for numerous species of primarily endo- but also ectotherm animals. Overall, these results can help with the identification of possible population level differences and may be indicators for connectivity between regions.

Research Objectives:

The objective within this funding period was to describe geographic variability of Blainville's beaked whale echolocation clicks and to provide equipment and field work support to PIFSC.

Research Accomplishments:

Geographic differences for Blainville's beaked whales were quantified in the Northern Hemisphere and are being presented at an international workshop. A publication is in preparation.

Conferences, Meetings, & Presentations:

- a. Dr. Bauman-Pickering attended the 8th Detection, Classification, Localization and Density Estimation (DCLDE) Workshop held in Paris, France from June 4-8, 2018.



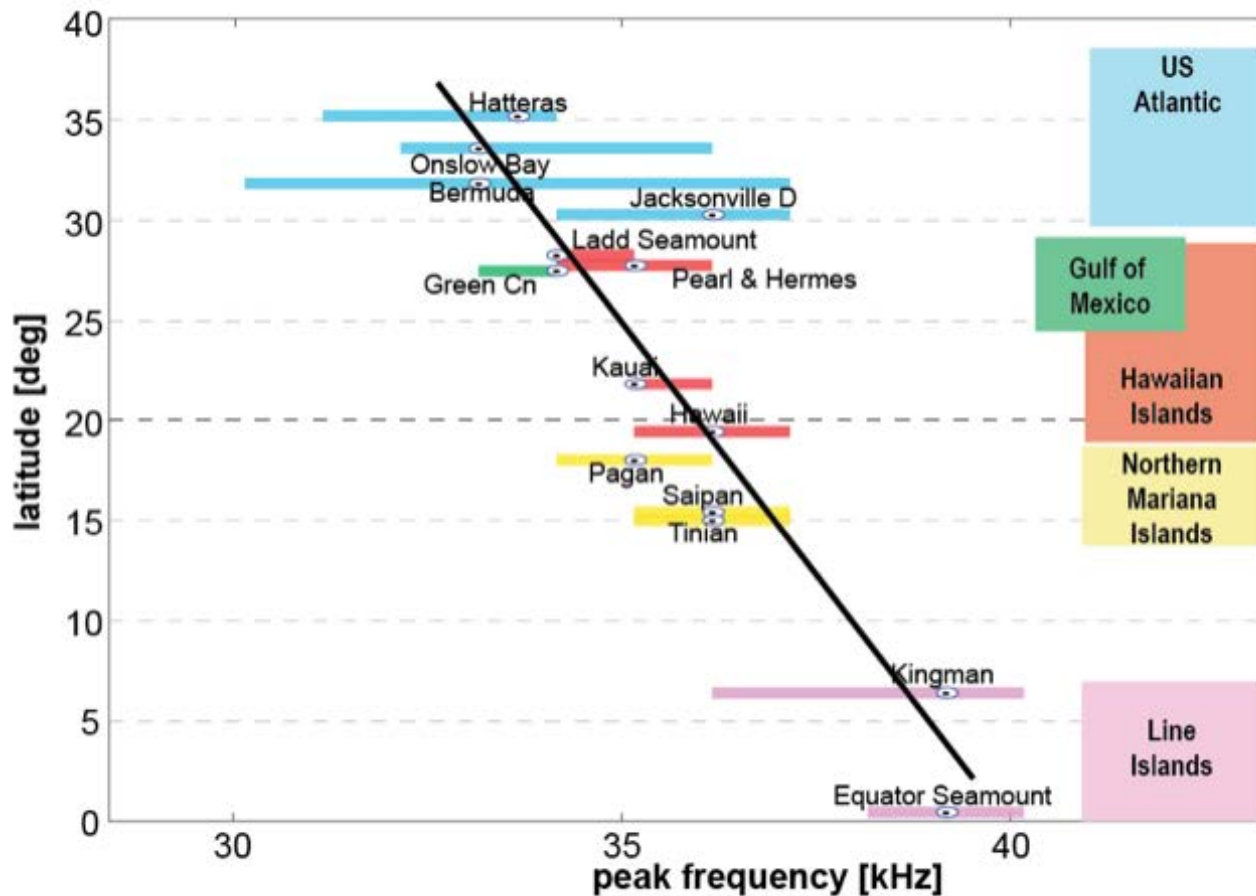


Figure 37: Relationship of geographic location and Blainville's beaked whale echolocation click frequencies. Lower peak frequencies occurred at higher latitude sites. Black line shows linear regression ($y = -5x + 198.5$; $R^2 = 0.82$). Color denotes larger geographic region. Peak frequency values are shown in median and 25th/75th percentiles.



Collaborative Studies of Cetaceans with the Northeast Fisheries Science Center

Principal Investigator(s):

John Hildebrand, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

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

NOAA Primary Contact:

Sofie Van Parijs, Northeast Fisheries Science Center

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Budget Amount:

\$291,546

Amendment(s):

69

Description of Research:

We propose to continue our collaborate with the NOAA Northeast Fisheries Science Center to conduct acoustic studies of cetaceans using High-frequency Acoustic Recording Packages (HARPs). Scripps Institution of Oceanography (SIO) currently has eight HARPs deployed along the Atlantic continental shelf and slope.

Research Objectives:

This proposal is to service the HARP instruments during spring 2017, and to analyze acoustic data for marine

mammal sounds to better understand the distribution of cetacean populations along the Atlantic coast.

Research Accomplishments:

During the spring and summer of 2017, a total of 8 HARPs were serviced.

Conferences, Meetings & Presentations:

- a. John Hildebrand. attended the Acoustical Society of America Meeting held in New Orleans from December 3-8, 2017 and the Acoustical Society of America Meeting held in Minneapolis from May 6-11, 2018.
- b. John Hildebrand attended the Gulf of Mexico Oil Spill and Ecosystem Science Conference in New Orleans, Feb 5-9, 2018.

Education & Outreach:

Communication

- a. Website for outreach is: www.voicesinthesea.org has information on marine mammals and sound.
- b. John Hildebrand made a presentation to the San Diego Chapter of the Explorer's Club regarding whale sounds on Feb 13, 2018.

Academic Development

- a. Summer Intern
Shevonne Sua, an undergraduate at the University of Southern California, is spending a 10-week internship in our lab to learn about underwater and data processing.

K-12 Outreach

- a. Twelve teenagers from Mt. Edgecumbe High School in Sitka Alaska visited SIO during May 14-17, 2018 to present results of their collaborative research with our lab.



Risso's dolphins, photo by Amanda J. Debich



Trophic Interactions and Habitat Requirements of Gulf of Mexico Bryde's Whales

Principal Investigator(s):

John Hildebrand, Scripps Institution of Oceanography,
UC San Diego

NOAA Primary Contact:

Melissa Soldevilla, Southeast Fisheries Science Center

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Budget Amount:

\$24,295

Amendment(s):

71

Description of Research:

Bryde's whales (*Balaenoptera edeni*) are found in tropical and subtropical waters worldwide. Bryde's whales in the Gulf of Mexico (GOM) are only known to occur in a small area in the northeastern Gulf near DeSoto Canyon in waters along the continental shelf break. This population has low genetic diversity and significant divergence from other Bryde's whales so that it may at some point be designated as a separate subspecies. The goal of the proposed research is to monitor Bryde's whale behavior by collecting acoustic tag data in the northwestern GOM.

Research Objectives:

Tags are small sensor packages that can be attached directly to the skin of a whale. The specific objectives of this project are to: (1) collaborate on acoustic tag deployment and data collection on GOM Bryde's whales; (2) provide personnel for cruises directed at Bryde's

whale study; and (3) collaborate on analysis of the data collected.

Research Accomplishments:

- During the first year, software was written to help with acoustic tag data processing.
- Project plans to conduct a cruise in May 2018 were delayed owing to problems with the NOAA Ship Gordon Gunter. I plan to join the upcoming cruise scheduled for November 2018 to initiate this work.

Conferences, Meetings & Presentations:

- a. John Hildebrand attended the Acoustical Society of America Meeting held in New Orleans from December 3-8, 2017, and the Acoustical Society of America Meeting held in Minneapolis from May 6-11, 2018.
- b. John Hildebrand attended the Gulf of Mexico Oil Spill and Ecosystem Science Conference in New Orleans, Feb 5-9, 2018.

Education & Outreach:

Communication

- a. Website for outreach is: www.voicesinthesea.org has information on marine mammals and sound.
- b. John Hildebrand made a presentation to the San Diego Chapter of the Explorer's Club regarding whale sounds on Feb 13, 2018.

Academic Development

- b. Summer Intern
Shevonne Sua, an undergraduate at the University of Southern California, is spending a 10-week internship in our lab to learn about underwater and data processing.

K-12 Outreach

- b. Twelve teenagers from Mt. Edgecumbe High School in Sitka Alaska visited SIO during May 14-17, 2018 to present results of their collaborative research with our lab.



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

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 3: Healthy Oceans

Budget Amount:

\$109,154

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 and manually annotate the data through a web browser in a similar fashion as with Coral

Point Count, but with the advantage that Coralnet uses machine learning and computer vision methods to automatically annotate some point.

To date, 709,227 photos from 833 sources have been uploaded to CoralNet, and over 25M annotations have been made on those photos.

Research Objectives:

While year 3 efforts made significant strides in improving CoralNet by moving it from a desktop server to the cloud (Amazon Web Services) as well as developed and implemented deep learning algorithms for CoralNet, year 4 funding was used to support ongoing operations of Coralnet.

Research Accomplishments:

The Specific Aims/Milestones were:

1. Provide hosting fees for running CoralNet on Amazon Web Services.
2. Provide ongoing support and maintenance of CoralNet software.

Conferences, Meetings & Presentations

- a. Schmidt Ocean Institute Coral Reef Survey Initiative, October 2017.
- b. Distinguished Lecture: "Automated Annotation of Benthic Images of Coral Reefs: From Fluorescence to Deep Networks," Korean Conference on Computer Vision, June 2017.
- c. "Computer Vision for Coral Ecology," Hanyang University, Seoul, Korea, June 2017.



Effects of Nitrogen Sources and Plankton Food-Web Dynamics on Habitat Quality for the Larvae of Bluefin Tuna in the Gulf of Mexico

Principal Investigator(s):

Michael R. Landry, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

John Lamkin, NOAA Southeast Fisheries Science Center, Miami

Trika Gerard, NOAA Southeast Fisheries Science Center, Miami

Michael R. Stukel, Department of Earth, Ocean, and Atmosphere, Florida State University

Angela N. Knapp, Department of Earth, Ocean, and Atmosphere, Florida State University

Karen E. Selph, Department of Oceanography, University of Hawaii at Manoa

Rasmus Swalthrop, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Barbara Muhling, Southwest Fisheries Science Center

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Budget Amount:

\$178,058

Amendment(s):

65

Description of Research:

The overall goal of this research was to enhance stock assessment and effective management of western Atlantic bluefin tuna (ABT) by improved understanding of the environmental factors that impact success of larvae in spawning grounds in the Gulf of Mexico (GoM). Our focus is on elucidating mechanisms that link variability in nitrogen sources and food-web dynamics to habitat quality, feeding, growth and survival of ABT larvae. We aim to evaluate whether/how the preferred prey, growth, and trophic position of ABT larvae are affected by new

production, source nitrogen and lower food-web interactions, and whether/why the boundaries of anticyclonic (retentive) eddies are specific habitats that enhance growth and survival of ABT larvae.

During the present reporting period, we successfully conducted the first of two cruises (May 2017) during the peak GoM spawning season. Sampling surveys used rapid shipboard identification to locate larval patches and were conducted across mesoscale features and adjacent waters, focusing on environmental conditions and larval fish in near-surface waters (0-20 m) where ABT larvae reside. Drogued satellite-tracked drift arrays were then deployed to mark water parcels for repeated sampling and experimental study over time periods of 3-4 days. We completed three experiments on the cruise, each involving daily in situ depth-profile incubations for primary productivity, nitrate uptake, phytoplankton growth rates, and microzooplankton grazing in bottles attached at 6 depths to the drift array. Size-fractionated estimates of biomass and grazing for the mesozooplankton community were also assessed at mid-day and mid-night sampling each day. Our specific component responsibilities were for sampling/analyses of the following: phytoplankton community composition and biomass by microscopy; fluorometry and HPLC pigment analyses; rate estimates of phytoplankton growth and microzooplankton grazing from dilution experiments; biomass and grazing estimates of mesozooplankton from integrated net tows to 100 m; and assessments of food-web source nitrogen and trophic positions of ABT larvae and their selected prey by compound-specific isotopic analyses of amino acids (CSIA-AA). Collaborators Stukel and Knapp conducted complementary studies of nutrient distributions, ¹³C-primary production, new production (¹⁵N nitrate and N₂ fixation) and export fluxes (thorium and sediment traps). Collaborator Selph sampled for community assessments of phytoplankton composition, biomass and size structure by flow cytometry. NOAA collaborators (Lamkin, Girard, and Chief Scientist Estrella Malca) sampled the upper 20-m of the water column at about 4-h intervals throughout each study for ABT larvae and ambient zooplankton prey, from which they will assess larval age and growth rates from otolith analyses and prey preferences from stomach analyses. All cruise goals were met, including acquiring sufficient ABT larval specimens for all required analyses.

Research Objectives:

One of the major study objectives is to assess how variability in nitrogen source to the food web and the



composition of available prey affects feeding, growth and trophic position of ABT larvae. Our contribution to resolving these issues is to apply the technique of compound-specific isotopic analyses of amino acids (CSIA-AA), in which a group of **source** AAs retains $\delta^{15}\text{N}$ values similar to the source of N to the food web, while other **trophic** AAs enrich substantially with each trophic step between phytoplankton and consumers. We will use this approach to evaluate variability in nitrate versus nitrogen fixation as source N and corresponding variability in the trophic position of ABT larvae and their zooplankton prey.

Research Accomplishments:

All cruise experiments were conducted successfully with rigorous and adequate sampling for the planned analyses. Sample and data analyses from Cruise 1 are progressing on all fronts.

A specific accomplishment of the past year has been the refinement and optimization of our CSIA-AA technique, which involves the coupling of High Pressure Liquid Chromatography with offline Elemental Analyzer / Isotope Ratio Mass Spectrometry (HPLC-EA/IRMS), to accommodate the very small sample sizes of individual larval tuna. Various adjustments have been made 1) to improve the performance and reliability of the HPLC and 2) to lower the detection range of the IRMS instrument. Extensive testing has been carried out to quantify methodological precision, accuracy and procedural reproducibility. All errors are substantially smaller than those for the conventional Gas Chromatography method for CSIA-AA. We have also assessed the AA stable isotopes errors associated with different preservation techniques for larval fish. These combined results will be written up as a methods paper to be submitted in 2018. In addition, all samples of ABT larvae selected for CSIA-AA from the 2017 cruise have been processed, purified and are ready for isotopic analysis. This data should be available for interpretation and presentations in the coming year.

Honors and Awards:

- a. Michael Landry was invited to be the Ludwig Lecturer at Old Dominion University in April 2017.

Conferences, Meetings & Presentations:

- a. Michael Landry attended the Ocean Science Meeting in Portland Oregon in February 2018.

Education & Outreach:

Communication

- a. As a means of connecting with a broad public audience, we developed and archived a cruise blog (<http://nfchroniclesnoaa.blogspot.com/>):

“The Nancy Foster Chronicles. A blog about a research survey aboard the NOAA ship *Nancy Foster* searching for bluefin tuna larvae among other fishy creatures”

with photos, videos and various written entries describing the nature of the research, life at sea, interviews with participating researchers and students, and goals and accomplishments of the May 2017 voyage.

Academic Development

- a. Two recently matriculated undergraduate students got their first interdisciplinary research cruise experience as part of the Landry research team. Cameron Quackenbush began graduate studies in physical oceanography at Moss Landing Marine Labs in fall 2017. Jennifer Beatty will begin graduate studies in biological oceanography/marine biology at the University of Southern California in fall 2018.

Networking

- a. On a mid-cruise port stop in Progreso in Yucatán, Mexico (20 May 2017), we held a shipboard Open House event on *R/V Nancy Foster* to explain our scientific research activities in the Gulf of Mexico to groups of local people and students. Over 40 guests participated. These included: Dr. Mario González Espinosa, Director of ECOSUR (a research and higher education center focused on sustainable development in Mexico’s southern border); Dr. Magda Estela Domínguez Machín, Assistant Director of Fisheries Resources in the Atlantic at Instituto Nacional de Pesca y Acuicultura; Dr. Josefina del Carmen Santos Valencia, Chief of CRIP Yucalpetén; Prof. Alvaro Hernández Flores and various doctoral students in Fisheries and Aquaculture Bioeconomics at MARISTA University; Prof. Alfonso Aguilar Perera and Marine Biology students from Universidad Autónoma de Yucatan; and Mr. Manuel Sánchez González, President of the Yucatán Shipowners Union.



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

Doriane Weiler, UC Santa Cruz

Maya Friedman, UC Santa Cruz

NOAA Primary Contact:

Steve Lindley, Southwest Fisheries Science Center

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Budget Amount:

\$219,426

Amendment(s):

21, 52, 67

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 goals is to understand the importance of contemporary evolution for shaping aquatic communities and ecosystems. An 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 shows that for many study systems the effects of diversity within species can be as large as the effects of diversity among species (Des Roches et al. 2018). 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 ecological drivers in aquatic ecosystems is the trophic cascade, and one of my 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 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 to examine 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. This project has yielded many novel results. This year, I began some work on Scott Creek (Santa Cruz County, CA) examining the factors that shape steelhead life



history variation and the consequences for population, community, and ecosystem dynamics. This work is new, but initial sampling last summer yielded some interesting results (see attached photos).

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. Both of these projects have yielded important new results this year.
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 an 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 have produced new results that move 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:

- a. Published 8 peer-reviewed papers, with 2 in press and 2 in review.
- b. Taught Freshwater Ecology, Freshwater Ecology Lab, Undergraduate Research Writing, and Graduate Seminar Courses
- c. Received accelerated merit increase from Associate Professor step 1 to step 3
- d. Gave invited seminar at UC Davis Bodega Marine Lab
- e. Mentored 5 UCSC undergraduate research projects
- f. Graduated one Masters student (Rebecca Robinson)
- g. Organized and mentored for the NSF Research Experience for Teachers (RET) Program
- h. Served as Faculty Sponsor for the American Fisheries Society (AFS) Santa Cruz Subunit
- i. Peer-reviewed for numerous journals
- j. Became Chair of the Genetic Subgroup of the River Herring Technical Expert Working Group
- k. Gave presentations on recent stock structure and bycatch results to the Northeast Interagency River Herring Managers Meeting and the River Herring Stock Status Review Team.
- l. Communicated extensively with the River Herring Stock Status Review Team about how to designate potential Distinct Population Segments for alewife and blueback herring.

Honors and Awards

- a. Eric Palkovacs received accelerated merit increase to Associate Professor, step 3
- b. Gina Contolini received the Conchologists of America Grant
- c. Gina Contolini received the UC Santa Cruz Graduate Student Association Travel Grant



- d. David Fryxell received the American Fisheries Society Skinner Travel Award
- e. David Fryxell received the UC Chancellor's Dissertation Year Fellowship
- f. Megan Sabal received the Best Student Oral Presentation at the Cal-Neva AFS meeting
- g. Megan Sabal received the Delta Science Fellowship
- h. Ben Wasserman received the Mathias Graduate Research Award from the UC Natural Reserve System
- i. Ben Wasserman received the Association for the Study of Limnology and Oceanography Student Travel Award
- j. Doriane Weiler received the NSF Graduate Research Fellowship
- k. Krista Oke was a finalist for the W.D. Hamilton Award, Society for the Study of Evolution
- l. Celia Symons received the Best Poster Award at the UC Santa Cruz Postdoc Symposium
- m. Celia Symons received a job offer as Assistant Professor of Ecology and Evolutionary Biology at UC Irvine

Conferences, Meetings & Presentations

- a. Eric Palkovacs, Invited Seminar, Bodega Marine Lab, UC Davis (2017)
- b. Gina Contolini, Poster Presentation, Western Society of Naturalists, Pasadena, CA (2017)
- c. Gina Contolini, Oral Presentation, Ecological Society of America, Portland, OR (2017)
- d. David Fryxell, Oral Presentation, California Chapter of the Society for Freshwater Science, Davis, CA (2017)
- e. David Fryxell, Oral Presentation, DynaTrait Conference, Hannover, Germany (2017)
- f. David Fryxell, Oral Presentation, American Fisheries Society Annual Meeting, Tampa, FL (2017)
- g. David Fryxell, Oral Presentation, Ecological Society of America, Portland, OR (2017)
- h. Nick Macias, Oral Presentation, Cal-Neva AFS Annual Meeting, Eureka, CA (2018)
- i. Megan Sabal, Oral Presentation, Cal-Neva AFS Annual Meeting, Eureka, CA (2018) *Awarded Best Student Presentation
- j. Megan Sabal, Oral Presentation, American Society of Naturalists Meeting, Pacific Grove, CA (2018)
- k. Liam Zarri, Oral Presentation, Interagency Ecological Program, Sacramento, CA (2017)
- l. Liam Zarri, Oral Presentation, Cal-Neva AFS Annual Meeting, Eureka, CA (2018) *Awarded second place for Best Student Presentation
- m. Krista Oke, Oral Presentation, Society for the Study of Evolution Annual Meeting, Portland, OR (2017)
- n. Krista Oke, Oral Presentation, Alaska Marine Science Symposium, Anchorage, AK (2018)
- o. Krista Oke, Invited Seminar, University of Alaska, Juneau, AK (2018)
- p. Simone Des Roches, Oral Presentation, American Society of Naturalists Meeting, Pacific Grove, CA (2018)
- q. Simone Des Roches, Oral Presentation, Invited Symposium, Canadian Society of Zoologists, Winnipeg, MB, Canada (2017)
- r. Simone Des Roches, Oral Presentation, Canadian Society for Ecology and Evolution, Victoria, BC, Canada (2017)
- s. Simone Des Roches, Invited Seminar, UC Berkeley (2017)
- t. Simone Des Roches, Invited Seminar, UC Santa Cruz (2018)
- u. Simone Des Roches, Poster Presentation, UC Santa Cruz Postdoc Symposium (2018)
- v. Celia Symons, Invited Seminar, UC Berkeley (2017)
- w. Celia Symons, Invited Seminar, UC Irvine (2018)
- x. Celia Symons, Poster Presentation, UC Santa Cruz Postdoc Symposium (2018) *Awarded Best Poster Award
- y. Kerry Reid, Poster Presentation, UC Santa Cruz Postdoc Symposium (2018)
- z. Ben Wasserman, Oral Presentation, American Society of Naturalists Meeting, Pacific Grove, CA (2018)
- aa. Ben Wasserman, Oral Presentation, Ecological Society of America, Portland, OR (2017)
- bb. Travis Apgar, Oral Presentation, Cal-Neva AFS Annual Meeting, Eureka, CA (2018)
- cc. Travis Apgar, Poster Presentation, Cal-Neva AFS Annual Meeting, Eureka, CA (2018)

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 to communicate ongoing activities and 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://palkovacs.eeb.ucsc.edu/>



- c. Presentation to the Northeast Interagency River Herring Managers Meeting
Eric Palkovacs presented new research on river herring stock structure and bycatch to the meeting of river herring managers (February, 2018)
- d. Presentation to the River Herring Stock Status Working Group
Eric Palkovacs presented new research on river herring stock structure and bycatch to the river herring stock status working group (March, 2018)
- e. Designation of River Herring Distinct Population Segments
Eric Palkovacs communicated extensively with the River Herring Stock Status Review Team about how to designate potential Distinct Population Segments for alewife and blueback herring.

Academic Development

- a. Workshop on translating fisheries science into policy:
Eric Palkovacs gave a presentation and facilitated a discussion on how science is used to inform fisheries policy and management. The audience was UC Santa Cruz graduate students and postdoctoral researchers.
- b. Workshop on data visualization:
Simone Des Roches gave a presentation and facilitated a discussion on best practices for data visualization, including tips for making impactful figures and conveying complex concepts with clear graphics. The audience was UC Santa Cruz graduate students and postdoctoral researchers. K-12 Outreach

K-12 Outreach

- a. Trout in the Classroom
Megan Sabal organized and led trout in the classroom. She and her team went to local elementary and high schools to discuss the trout life cycle and the development and hatching of trout eggs. Eggs remained in classrooms for students to observe until hatching, and then the students released the fry into local streams. This project is a collaboration with the California Department of Fish and Wildlife.
- b. WATCH Program
Dave Fryxell, Megan Sabal, and Ben Wasserman, and Simone Des Roches 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.

- c. 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.
- d. NSF RET Program
Eric Palkovacs served as mentor for a summer high school teacher (Cindy Pressley) 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. Cindy Pressley developed lesson plans to teach students about aquatic ecology in her fourth-grade classroom.

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 to raise awareness about the challenges facing coastal watersheds.





Figure 38: The field team prepares to sample steelhead at Scott Creek (Santa Cruz County, CA). The goals of this project are to examine the factors that shape steelhead life history variation and investigate consequences for ecological interactions.



Figure 39: Juvenile steelhead from Scott Creek (Santa Cruz County, CA).

Investigations in Fisheries Ecology

Principal Investigator(s):

Dr. Eric Palkovacs, UC Santa Cruz

Dr. Peter Raimondi, UC Santa Cruz

Other Key Personnel:

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

Rosealea Bond, UC Santa Cruz

Peter Dudley, 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

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

Ilysa Iglesias, UC Santa Cruz

Whitney Friedman, UC Santa Cruz

Anthony Clemento, UC Santa Cruz

Cassie Columbus, 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

Matthew Campbell, UC Santa Cruz

Joe Bizzaro, UC Santa Cruz

Ethan Mora, 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

Carrie Pomeroy, UC Santa Cruz & CA Sea Grant

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

Jarrold Santora, UC Santa Cruz

Christopher Edwards, UC Santa Cruz

Ryan Driscoll, UC Santa Cruz

Elizabeth Becker, UC Santa Cruz

Brennan Helwig, UC Santa Cruz

Alyssa Fitzgerald, UC Santa Cruz

Haley Ohms, UC Santa Cruz

JT Robinson, UC Santa Cruz

Gemma Carroll, UC Santa Cruz

Liam Zarri, UC Santa Cruz

Kimberly Mercado, UC Santa Cruz

Roy Qi, UC Santa Cruz

Eric Medina-Can, UC Santa Cruz

NOAA Primary Contact:

Dr. Steven Lindley, Southwest Fisheries Science Center,

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaptation and Mitigation

Goal 3: Healthy Oceans

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$14,593,073



Amendment(s):

22, 56, 84

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 seven objectives:

1. Groundfish Analysis: Groundfish Ecology Studies and Stock Assessment Support
2. Early Life History: Viability of Early Life Stages of Coho Salmon
3. Habitat Ecology Team: Marine Habitat Studies
4. Landscape/Seascape Ecology: Landscape Ecology of Pacific Salmonids
5. Climate and Ecosystem: Research on Climate Change and Ecosystem Variability in the North Pacific Ocean - the Dynamics of Marine Populations
6. Economics: Economic Analysis of Fisheries and Protected Species Issues on the West Coast
7. 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

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, remote sensing, acoustic technologies, and economic data collection and analysis.

Research Accomplishments:

Accomplishments included final completion of a number of 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 65 journal articles (with an additional 9 journal articles in press), several reports and three conference proceedings/workshops. Scientists engaged in more than 40 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 became a U.S. Presidential Management Fellow in January 2018
- d. Sabrina Beyer, Honorable Mention, National Science Foundation, Graduate Research Fellowship Program 2017
- e. Sabrina Beyer, Best Student Paper, American Fisheries Society California-Nevada Chapter Annual Meeting, San Luis Obispo, CA, March 2018
- f. Mike Jacox was awarded NMFS Team Member of the Year in June 2017
- g. Cyril Michel was awarded the Southwest Fisheries Science Center Staff of the Quarter Award (Q2) 2017
- h. Jarrod Santora was awarded NMFS Team Member of the Year in June 2017
- i. Alice Thomas-Smyth, UCSC Staff Appreciation & Recognition Award, June 2017

Conferences, Meetings & Presentations

Alice Thomas-Smith:

- Presented tool and method development at the Southwest Fisheries Science Center Ignite Talks held jointly in Santa Cruz and La Jolla, California on May 10, 2017.
- Participated in the Office of Science and Technology's Economics and Human Dimensions Program Review 2017 held in Santa Cruz, California from July 24-28, 2017.
- Served as a co-author/presenter on spatial methods in fisheries analysis at the 20th Western Groundfish Conference held in Seaside, California from February 13-16, 2018.



Rebecca Miller:

- Attended the Monterey Bay Marine GIS Users Group Meeting and Python workshop held at the Hopkins Marine Station in Pacific Grove, California on May 25, 2017.
- Attended and participated in the STAR Panel for the Blue/Deacon Rockfish and California Scorpionfish Assessment held in Santa Cruz, California from July 24-28, 2017.
- Attended the statewide California Collaborative Fisheries Research Program (CCFRP) meeting held in Moss Landing, California on November 14, 2017.
- Moderated two sessions (Biology, Assessment) at the Western Groundfish Conference held in Seaside, California from February 13-16, 2018.

Joseph J. Bizzarro:

- Attended and participated in the Board of Directors meeting of the American Elasmobranch Society held in Austin, Texas on July 12 2017.
- Attended the American Elasmobranch Society Conference held in Austin, Texas from July 12-16, 2017, also moderated an Ecology session and presented the results of a recently published book chapter on diet composition and trophic ecology of eastern North Pacific sharks.
- Attended and participated in the BOEM Cross Shelf Habitat Suitability Modeling Workshop held in Santa Barbara, California from December 5-6 2017.
- Attended the Western Groundfish Conference held in Seaside, California from February 13-16, 2018; presented results of a population genetics/life history project on Blue and Deacon Rockfishes.
- Attended the Center for Advancement of Population Assessment Methodology Spatio-Temporal Modeling Workshop held in La Jolla, California from February 26-March 2, 2018.
- Attended the Northeast Pacific Shark Symposium held in Seattle, Washington from March 24-25, 2018; presented results of a recently published manuscript detailing batoid predation on stingrays.

Juan P. Zwolinki:

- Attended the California Cooperative Oceanic Fisheries Investigations Annual Science Conference held in La Jolla, California from December 4-6, 2017 and presented a talk titled "Distribution and abundance of forage fish species in the California Current Ecosystem based on acoustic-trawl surveys."
- Attended the Center for the Advancement of Population Assessment Methodology Workshop on Recruitment: theory, estimation, and application in fishery stock assessment models held in Miami, Florida from October 30-November 3, 2017 and presented a talk titled "Environmental dependence of Pacific sardine recruitment – another spurious

correlation?"

Nicholas Grunloh:

- Presented at the Southwest Fisheries Science Center Ignite Talks held jointly in Santa Cruz and La Jolla, California on May 10, 2017.
- Attended the Western Groundfish Conference held in Seaside, California from February 13-16, 2018.
- Attended the Center for Advancement of Population Assessment Methodology Spatio-Temporal Modeling Workshop held in La Jolla, California from February 26-March 2, 2018.
- Attended and participated in the Pacific Fisheries Management Council Scientific and Statistical Committee's Methodology Review for Improving Catch Estimation Methods in Sparsely Sampled Mixed-Stock Fisheries held in Santa Cruz, California from March 28-29, 2018.

Ryan Driscoll:

- Presented at the Third International Krill Symposium held in St. Andrews, Scotland from June 12-16, 2017.
- Attended the Scientific Committee on Antarctic Research Biology Symposium held in Leuven, Belgium from July 8-15, 2017.

Isaac Schroeder:

- Attended the Ocean Sciences Meeting held in Portland, Oregon from February 11-16, 2018.

Heather Welch:

- Presented a talk at the International Congress for Conservation Biology held in Cartagena, Colombia from July 23-27, 2017.
- Attended the RStudio Conference held in San Diego, California from February 2-3, 2018.
- Attended the Ocean Sciences Meeting held in Portland, Oregon from February 11-16, 2018.

Mike Jacox:

- Presented an invited talk at the Gordon Research Conference on Coastal Ocean Dynamics held in Biddeford, Maine in June 2017.
- Presented a talk and co-chaired a working group meeting at the PICES Annual Meeting held in Vladivostok, Russia in September 2017.
- Attended the Ocean Sciences Meeting held in Portland, Oregon from February 11-16, 2018.

Gemma Carroll:

- Attended the annual Atlantic Deepwater Ecosystem Observing Network meeting held in Durham, New Hampshire from February 5-8, 2018.
- Attended the Ocean Sciences Meeting held in Portland, Oregon from February 11-16, 2018.
- Attended the Pacific Seabird Group meeting held in La Paz, Mexico from February 21-24, 2018.



Briana Abrahms:

- Presented a talk at the Ecological Society of America meeting held in Portland, Oregon from August 6-11, 2017.
- Chaired a session at the Ocean Sciences Meeting held in Portland, Oregon from February 11-16, 2018.

Stephanie Brodie:

- Presented an invited talk at the Australian Society for Fish Biology held in Albany, Australia from July 22-24, 2017.
- Attended the IMBIZO5 workshop on Management Strategy Evaluations held in Woods Hole, Massachusetts from October 1-5, 2017.
- Attended the Ocean Sciences Meeting held in Portland, Oregon from February 11-16, 2018.

Mercedes Pozo Buil:

- Presented a talk at the Ocean Sciences Meeting held in Portland, Oregon from February 11-16, 2018.
- Participated in the Institute for Scientist and Engineer Educators Professional Development Program held in Monterey, California from March 25-28, 2018.

Ilysa Iglesias:

- Participated in a workshop titled “Reproducible science with R, RStudio, and GitHub” held in Moss Landing, California from November 30-December 1, 2017.
- Attended the Western Groundfish Conference held in Seaside, California from February 13-16, 2018.

Sabrina Beyer

- Presented and served as a session moderator Western Groundfish Conference held in Seaside, California from February 13-16, 2018.
- Presented at the California-Nevada Chapter of the American Fisheries Society annual meeting held in San Luis Obispo, California from February 28-March 2, 2018.

Lyndsey Lefebvre:

- Presented a talk titled “Back to basics: Why basic life-history data remains essential in an age of advanced population models” at the Western Groundfish Conference held in Seaside, California from February 13-16, 2018; also served as a session moderator.

Neosha Kashaf:

- Attended and presented posters at the California State University, Monterey Bay Undergraduate Research Opportunity Center Symposium held in Monterey, California on August 11, 2017.
- Attended and presented posters at the Western Society of Naturalists Conference held in Pasadena, California from November 16-19, 2017.

- Attended and presented posters at the Western Groundfish Conference held in Seaside, California from February 13-16, 2018.

David Stafford:

- Attended and presented posters at the California State University, Monterey Bay Undergraduate Research Opportunity Center Symposium held in Monterey, California on August 11, 2017.
- Attended and presented posters at the Western Society of Naturalists Conference held in Pasadena, California from November 16-19, 2017.
- Attended and presented posters at the Western Groundfish Conference held in Seaside, California from February 13-16, 2018.

Miles E. Daniels:

- Presented at the California-Nevada Drought Early Warning System First Annual Coordination Workshop held in Reno, Nevada from June 21-22, 2017.
- Presented a talk discussing decision support tools for salmon health models during the California-Nevada Drought & Climate Outlook Webinar held in Santa Cruz, California on September 25, 2017.
- Presented at the Southwest Fisheries Science Center’s Current Conditions Seminar held jointly in Santa Cruz and La Jolla, California on October 3, 2017.

Dale Robinson:

- Attended the San Francisco Estuary Geospatial Workgroup Meeting held in Tiburon, California on June 15, 2017.
- Attended the NOAA CoastWatch Annual Meeting held in Santa Cruz, California from July 31-August 3, 2017.
- Attended the CeNCOOS Governing Council Meeting held in Petaluma, California from September 7-8, 2017.
- Attended the Ocean Sciences Meeting held in Portland, Oregon from February 11-16, 2018.

Jennifer Sevadjan:

- Attended the NOAA CoastWatch Annual Meeting held in Santa Cruz, California from July 31-August 3, 2017.
- Attended the Ocean Sciences Meeting held in Portland, Oregon from February 11-16, 2018.

Whitney Friedman:

- Organized a talk (presented by Brian Wells) titled “Salmon prey assemblages and oceanographic conditions along the California Current shelf ecosystem” at the CalCOFI conference held in La Jolla, California from December 4-6, 2017.



Natnael Hamda:

- Presented a talk titled “Quantitative classification of animal behaviours from tracking data: machine learning techniques” at The International Society for Ecological Modelling Global Conference 2 held in JeJu, Republic of South Korea from September 17-21, 2017.
- Presented a talk titled “Can Machines Learn Animals Behaviour? A data-driven modelling technique for multivariate time-series clustering and change-point detection” at The Society for Integrative and Comparative Biology annual meeting held in San Francisco, California from January 3-7, 2018.

Brendan Lehman:

- Presented an invited talk titled “Invasive fish species and salmon predation in the Delta” at the Delta Invasive Species Symposium held in Davis, California on August 29, 2017.

Matthew Campbell:

- Presented a talk titled “Adaptation to Residency in Rainbow Trout Above Barriers to Migration: Alternative Molecular Pathways Towards a Predictable Phenotype” at the Western Division American Fisheries Society meeting held in Missoula, Montana from May 22-25, 2017.

Anthony Clemento:

- Presented a talk titled “Utility of genetics in the reintroduction of Chinook salmon to the San Joaquin River” at the California-Nevada Chapter of the American Fisheries Society annual meeting held in San Luis Obispo, California from February 28-March 2, 2018.

Diana Baetscher”

- Attended and presented a talk at the Western Groundfish Conference held in Seaside, California on February 13-16, 2018.
- Attended and presented a talk at the Western Society of Naturalists Conference held in Pasadena, California from November 16-19, 2017.

Anne Criss:

- Attended the GreenMAR workshop (green growth based on marine resources – ecological and socio-economic constraints) held in Oslo, Norway from September 11-14, 2017.
- Presented an invited talk titled “Investigations in Sociological and Ecological Systems: California’s Central Valley – Water and Fisheries Management” to the Interdisciplinary Centre for Conservation Science at Oxford University, Oxford, England on September 18, 2017.

Education & Outreach

Communication

- a. Scientific American Interview
Heather Welch was interviewed for a feature article in Scientific American about challenges and opportunities in the U.S. marine protected areas network.
- b. BBC consultation
Mike Jacox consulted with BBC researchers on the oceanography of Monterey Bay for the Blue Planet II series.
- c. Hakai Magazine Interview
Briana Abrahms was interviewed for an article published in Hakai Magazine on her research on impacts of climate variability on marine megafauna migrations.
- d. Presentation to Recreational Fishing club
Stephanie Brodie was invited to present ecological and fisheries research at a recreational fishing club in Sydney, Australia.
- e. Trout Unlimited
Cyril Michel was invited to present the history of non-native striped bass in Central California coastal lagoons at a Trout Unlimited Steinbeck Chapter meeting (Monterey Bay Area chapter). His presentation was titled “Invasive predators in imperiled watersheds: striped bass on the Central Coast.”
- f. Presentation to Portuguese Institute of the Sea and Atmosphere (IPMA)
Juan P. Zwolinski gave a presentation on the dynamics of the Pacific Sardine in the California Current at IPMA’s headquarters in Lisbon Portugal, on November 2, 2017.
- g. PolarWatch Website
Jennifer Sevadjan maintained the www.polarwatch.noaa.gov website to communicate program news and events.
- h. PolarWatch Data Portal
Jennifer Sevadjan maintained the www.polarwatch.noaa.gov/catalog website as an interface to discover and access ocean satellite data.
- i. CoastWatch Website
Dale Robison maintained the <https://coastwatch.pfeg.noaa.gov/> website to communicate program news and events.
- j. CoastWatch Data Portal
Dale Robinson contributed to the <https://coastwatch.pfeg.noaa.gov/erddap/> website that delivers satellite environmental data to fisheries and ocean scientists.
- k. EcoCast Website



Dale Robinson developed the online presence for the EcoCast project (<https://coastwatch.pfeg.noaa.gov/ecocast/>) which is a real-time data tool to help anglers and resource managers allocate fishing efforts to optimize harvest of target fish while minimizing bycatch of protected species.

- l. Loggerhead Turtle Website
Dale Robinson developed the online presence for the Loggerhead Turtle project (https://coastwatch.pfeg.noaa.gov/el_nino/loggerheads.html) which supports sea turtle conservation and sustainable fisheries using dynamic ocean modeling.
- m. Bureau of Ocean Energy Management website
Rebecca Miller shared spatial maps of historical groundfish catch and economic value to the Databasin Gateway website “California Offshore Wind Energy” at the invitation of Bureau of Ocean Energy Management.
- n. Bodega Bay Marine Laboratory seminar
Rebecca Miller gave a seminar and met with students at the University of California Davis Bodega Marine Laboratory on November 1, 2017. Her talk was titled “A spatiotemporal analysis of landings and ex-vessel value for California marine fishes: 1930-2005.”
- o. Data toolbox
 - Alice Thomas-Smyth developed and shared an ArcGIS independent toolbox (VMS Toolbox) to ease access to high resolution spatial analysis data to all users at the Southwest Fisheries Science Center Fisheries Ecology Division as well as users at other federal organizations (Northwest Fisheries Science Center and Channel Islands National Marine Sanctuary).
 - Alice Thomas-Smyth developed and shared a Python-based self-contained script to improve the spatial representation of bottom-trawling fishing effort in California with users at the Southwest Fisheries Science Center Fisheries Ecology Division as well as others in various agencies.

Academic Development

- a. NOAA Satellite Course
Dale Robinson, Jennifer Sevadjian, Elliott Hazen, Cara Wilson, and Heather Welch developed and ran a hands-on workshop to teach researchers and scientist how to access and use satellite data in their research.
- b. Dale Robinson and Cara Wilson traveled to NOAA line offices in Washington and Alaska to determine potential satellite data users to assess data needs, examine data user issues, and plan for regional workshops (held in January and March 2018).

- c. Data Carpentry Course
Elliott Hazen and Heather Welch helped run a workshop on data analysis and visualization in R.
- d. Graduate Student Supervision
 - Gemma Carroll served as an adjunct supervisor of Lachlan Phillips, Masters of Research, Macquarie University, Australia.
 - Stephanie Brodie served as an adjunct co-supervisor of Honors research students at the University of New South Wales, Australia.
- e. Rockfish Recruitment and Ecosystem Assessment Survey
Rebecca Miller and Lyndsey Lefebvre participated in and educated volunteers during the Rockfish Recruitment and Ecosystem Assessment survey. Volunteers included undergraduate and graduate students from UC Santa Cruz, UC Davis, California Polytechnic University (San Luis Obispo), Stanford, Moss Landing Marine Laboratories, Humboldt State University, and NOAA’s Teacher-at-Sea Program. The sampling, conducted aboard the NOAA Ship *Reuben Lasker* (April 26-June 11, 2017), informs the year-class strength of juvenile rockfish recruitment and the general state of various economically and ecologically important marine forage species.
- f. ArcGIS course
Ilysa Iglesias created and presented a training course for staff (including graduate students from UC Santa Cruz) at the Southwest Fisheries Science Center Fisheries Ecology Division on basic mapping with ArcGIS software, as well as an overview of what mapping resources are available for habitat mapping.
- g. Hands-on training
Ilysa Iglesias provided learning opportunities on rockfish fecundity for UC Santa Cruz and Moss Landing Marine Laboratory undergraduate students during local rockfish research collecting trips in association with the California Collaborative Fisheries Research Program.
- h. R software seminars
Ilysa Iglesias organized and moderated a monthly seminar series on using the R statistical software platform. The seminars were held at the Southwest Fisheries Science Center Fisheries Ecology Division and included staff, students, and participants from other local laboratories and research institutions.
- i. NOAA Hollings Scholar mentorships
 - Sabrina Beyer co-mentored NOAA Hollings Scholar, Timothy Hogan (University of Miami), on a summer 2017 research internship at the Southwest Fisheries Science Center Fisheries Ecology Division and served on his senior thesis committee.
 - Diana Baetscher and Hayley Nuetzel co-mentored NOAA Hollings Scholar, Bailey Carlson, during his summer 2017 research



internship at the Southwest Fisheries Science Center Fisheries Ecology Division.

j. Undergraduate supervision

- Sabrina Beyer supervised and mentored undergraduates, Grace Reed, Jasper Lyons, Pablo Brito Valecillos, Jonathan Lin, Hayley Mapes, Judy Hua (University of California Santa Cruz), and Kirby Bartlett, Kristie Mood and Dana Briggs (California State University Monterey Bay) in internships related to the early life history and reproductive biology of rockfishes.
- Neosha Kashaf and David Stafford mentored 22 undergraduate interns and graduate students from University of California Santa Cruz, Moss Landing Marine Laboratories, California State University Monterey Bay, and San Jose State University while researching the effects of ocean acidification and hypoxia on rockfish reproduction and on behavior and physiology in juvenile rockfishes. The following students were trained in fish husbandry and water quality monitoring and 11 (*) students developed professional posters and presented them at conferences. Jacoby Baker* (CSUMB-MLML), Andrew Cline* (CSUMB), Thomas Dolan* (CSUMB), Steven Eikenbary* (CSUMB), Marisol Figueroa* (CSUMB), Gema Garcia* (UCSC), Nicole Greer (UCSC), Maggie Gusman (CSUMB), Melissa Gutterman (UCSC), Madison Heard* (CSUMB), Lauren Kashiwabara (CSUMB), Peter Lansdale (UCSC), Samuel Le (SJSU), Helaina Lindsay (MLML), Matthew Lindeman* (CSUMB), Caitlyn Maloney (UCSC), Melissa Meredith* (CSUMB), Katie Neylan (UCSC), Melissa Palmisciano* (MLML), Kristin Saksa* (MLML), Jacqueline Toscano (UCSC), and Steven Wertheimer (UCSC).

K-12 Outreach

a. Presentation to high school

Briana Abrahms gave classroom presentations on climate change and wildlife conservation to 10 high school classes in Salinas and Lafayette, California.

b. Middle school outreach

Ilysa Iglesias gave a presentation on the importance of Marine Science to a 6th and 7th grade class at Cesar Chavez Middle School in Watsonville, California.

c. High school internship program

Sabrina Beyer served as a mentor for the University of California Santa Cruz's Science Internship Program by hosting high school student interns Kathleen Cheng, Leah Varghese, and Ruby Rorty for a 9-week internship. This program introduced the students to the scientific method and specifically to

rockfish reproductive biology at the Southwest Fisheries Science Center Fisheries Ecology Division during the summer of 2017. The students submitted a written summary of their summer research to the Siemens High School National Science competition.

d. Outreach talk at The Tatnall School

On 23 January 2018, Ryan Driscoll gave a classroom talk including a question-and-answer session via video chat and conducted an experiment for the class on a March research cruise in Antarctica.

e. Outreach talk at Mar Vista Elementary School

- Diana Baetscher visited two fifth grade classes at Mar Vista Elementary School in Aptos, California with a group of graduate students from UC Santa Cruz in September 2017. Students learned about kelp forest species and habitats and performed "scuba" transects through a pop-up kelp forest to test hypotheses about which species live primarily in the midwater or bottom habitats. The students also tried on scuba gear and learned how scientists use scuba to perform research underwater.
- Diana Baetscher visited two fifth grade classes at Mar Vista Elementary School in Aptos, California with a group of graduate students from UC Santa Cruz in September 2017. Students learned about kelp forest species and habitats and performed "scuba" transects through a pop-up kelp forest to test hypotheses about which species live primarily in the midwater or bottom habitats. The students also tried on scuba gear and learned how scientists use scuba to perform research underwater.
- Hayley Nuetzel led an investigative seafood fraud study at Harbor High School in Santa Cruz, California in May 2017. Students were responsible for collecting samples, extracting DNA, performing PCR and analyzing the resulting sequences to assess mislabeling frequency. The project was featured in an article in the Santa Cruz Sentinel. More information about the study can be found [here](#).

Networking

a. Presentation to California's Drift Gillnet Fishery

Elliott Hazen, Steven Bograd, Stephanie Brodie, and Heather Welch partnered with other researchers at the Southwest Fisheries Science Center and the Pacific Fishery Management Council to introduce a new fisheries management tool to members of California's Drift Gillnet Fishery.

b. Contribution to NOAA Committee

Isaac Schroder provided analysis and figures for presentations given by NOAA's Whale Entanglement Road Map Steering Committee.



- c. Presentation to California Dungeness Crab Task Force
Jarrod Santora provided a presentation on ocean and forage conditions to the California Dungeness Crab Task Force (October 2017).
- d. Contribution to the Australian Integrated Marine Observing Task Team
Stephanie Brodie contributed to the Australian Integrated Marine Observing Task Team that synthesized and conducted a national scale analysis of Australia's acoustic telemetry data.
- e. Data sharing and consultation
 - o Ilysa Iglesias contributed data and provided expertise for a salmon outmigration project to various researchers at Humboldt State University and ICF (environmental consulting firm).
 - o Ilysa Iglesias met with scientists from the Northwest Fisheries Science Center to arrange and establish collection of Myctophid samples. These samples will serve to extend the spatial extent to northern reaches of the California Current.
- f. Survey collaboration
Ilysa Iglesias participated in a specialized research cruise aboard the R/V Shimada; the cruise was a collaborative effort between NOAA's Southwest and Northwest Fisheries Science Centers and surveyed forage organisms.
- g. Coastal Pelagic Species Cooperative Meetings
 - o Juan P. Zwolinski participated in the Southwest Fisheries Science Center and industry planning meeting for an industry-lead inshore survey for Coastal Pelagic Species. Attendees discussed the final plans for using Fishing Vessel *Lisa Marie* to extend the acoustic-trawl sampling conducted by NOAA vessels closer to the shore, where the latter cannot operate. The meeting took place in La Jolla, California on May 4, 2017.
 - o Juan P. Zwolinski provided an overview of the 2017 NOAA and Industry collaborative Summer 2017 Coastal Pelagic Species surveys at the September 6, 2017 meeting in La Jolla, California.
- h. California Current Summer Ecosystem Survey
Juan P. Zwolinski participated in the Southwest Fisheries Science Center's Summer 2017 Acoustic-trawl survey aboard the NOAA Ship *Reuben Lasker*.
- i. Pacific Fisheries Management Council Acoustic-Trawl Methodology Review
A panel conducted the review of the acoustic-trawl methodology currently used to produce biomass estimates for Coastal Pelagic Species off the West Coast of the United States. Juan P. Zwolinski served as a member of the statistical team; the meetings took place in La Jolla, California from January 30-February 2, 2018.
- j. California Current Ecosystem Assessment monthly meeting
Juan P. Zwolinski discussed the results of the U.S. West Coast Coastal Pelagics Species surveys during a webinar held on March 14, 2018.

NOAA Employment

Michael Jacox, a Ph.D., attained a position with the Southwest Fisheries Science Center in November 2017.

Benjamin Martin, a Ph.D., attained a position with the Northwest Fisheries Science Center in January 2018.





Figure 40: Mary Kane (UC Santa Cruz), Rebecca Miller (UC Santa Cruz), Kate Hewitt (UC Davis), Matt McKechnie (CalPoly, San Luis Obispo), Kristen Elsmore (UC Davis), and Thomas Adams (Humboldt State University) sort a fisheries trawl catch of predominantly pyrosomes, blue lanternfish, and California lanternfish near Monterey Bay, CA as part of the annual Rockfish Recruitment and Ecosystem Assessment survey. The sampling, conducted aboard the NOAA Ship *Reuben 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, NOAA Fisheries.





Figure 41: Emily Tucker (UC Santa Cruz) and Alex McHuron (UC Santa Cruz) kayaking on Mille Creek, Tehama County, CA in search of Chinook salmon to seine for a tagging/movement study. Photo credit: Jeremy Notch, UC Santa Cruz/NOAA Fisheries.



Figure 42: Alex McHuron (UC Santa Cruz) with a spring-run Chinook salmon from Butte Creek in the Sutter Bypass, CA. Photo Credit: Jeremy Notch, UC Santa Cruz/NOAA Fisheries.



Submerged Cultural Resource Survey of the Kiska Island National Historic Landmark Maritime Battlefield - NA17OAR0110211

Principal Investigator(s):

Eric Terrill, Scripps Institution of Oceanography, UC San Diego

Andrew Pietruszka, Scripps Institution of Oceanography, UC San Diego

Mark Moline, University of Delaware

Other Key Personnel:

Eric Gallimore, Scripps Institution of Oceanography, UC San Diego

Robert Hess, Scripps Institution of Oceanography, UC San Diego

Andrew Nager, Scripps Institution of Oceanography, UC San Diego

Brian Kim, Scripps Institution of Oceanography, UC San Diego

E. Mike Jilka, Scripps Institution of Oceanography, UC San Diego

Heidi Batchelor, Scripps Institution of Oceanography, UC San Diego

Eric White, University of Delaware

Matt Breece, University of Delaware

NOAA Primary Contact:

Frank Cantelas, Office of Exploration and Research

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$629,535

Amendment(s):

NA17OAR0110211

Description of Research:

This project is an exploratory remote-sensing survey to locate and document WWII era submerged cultural resources in the waters off Kiska Island, Alaska. Kiska remains one of the best preserved historic battlefields from WWII, being one of only two world-wide locations where neither previous nor later settlement obscure military developments. Survey data will provide an inventory of submerged cultural resources associated with the Kiska Island National Historic Landmark as well as baseline environmental/benthic conditions—currents, depth, bottom type, water clarity, existing ecosystems, temperature, salinity, dissolved O₂, and pH—necessary for site management and preservation. Documentation and outreach will promote an increased awareness of maritime cultural heritage and the NOAA mission. Technology, such as photogrammetry fused with sonar data, can allow a distant public access to one of our country's most remote but significant battlefield sites. Technically, this project continues to refine the innovative use of UUVs and other maritime search capabilities for archaeological survey and documentation including field testing experimental UUV mounted magnetometers, sonars, and imagers. Such advances increase efficiency, accuracy, and cost effectiveness across the field of maritime archaeology. Lastly, anticipated sites within the proposed survey areas are associated with the remains of 115 U.S. service members still classified as missing in action and 52 Japanese sailors. Information regarding these sites will aid in the establishment of protected war grave memorials or the recovery and identification of individuals by the U.S. government.

Research Objectives:

Our exploration will provide a comprehensive inventory of submerged cultural resources and baseline environmental characteristics for one of the least studied historical campaigns of WWII. The Kiska Island survey utilizes advanced technology to increase the paces, scope, efficiency, and resolution of archaeological survey. In addition, several experimental sensors, including a UUV mounted magnetometer, will be tested in the field. The proposal is guided by six goals:

1. Provide an inventory of submerged cultural resources associated with the Kiska Island National Historic Landmark and baseline environmental/benthic data for site management and preservation.
2. Interpret documented sites through the lens of battlefield archaeology and contextualized within the greater maritime landscape to elucidate our understanding of the Aleutian Campaign.



3. Research, develop, and refine new maritime search capabilities, concepts of operations, and data exploitation for maritime archaeology to increase efficiency, accuracy, and cost effectiveness.
4. Promote an increased awareness of maritime cultural heritage and the NOAA mission through technology, such as 3D photogrammetric models, that allow a distant public access to one of our country's most remote battlefield sites.
5. Foster a meaningful integration of education and outreach opportunities through this project that bridges both STEM related fields and the social sciences by active participation in the field efforts and generation of learning products from the results by way of print media, video/web/social media production, teaching modules, displays, presentations, models, and professional publications.
6. Document and honor the final resting place of 167 U.S. and Japanese service members who lost their lives in the waters surrounding Kiska Island.

Research Accomplishments:

No specific objectives were established in the federal award for the reporting period; however, work has begun on planning logistics in advance of the field work.

Project dates are confirmed. On site data collection will take place from 7/13/2018 – 7/26/2018 with several days of sailing, mobilization, and demobilization added to each side. The project will utilize the R/V Norseman II owned and operated by Norseman Marine. The dates of service have been confirmed by the R/V Norseman.

All members of the project team have been identified and participated in several preliminary planning meetings outlining project dates, goals, methodologies, and equipment needed.

The project archaeologist, Andrew Pietruszka, has had discussions with the Alaska State Archaeologist and Alaska Maritime NWR of Fish and Wildlife Services to collect information regarding necessary permits required by both state and federal agencies. Efforts are underway

to secure all necessary permits. All agencies we have spoken to are extremely supportive of the project and have ensured there will be no issues obtaining all necessary permits.

Project team members have researched various shipping options for the movement of project gear from San Diego California to Dutch Harbor Alaska where it will be loaded onto the research vessel. Several options have been identified that meet the project's needs. The gear has been shipped from Scripps and is on its way to Alaska.

Team air transportation options to meet the project dates have been identified.

Historical research of the area is ongoing. A MAS student at Scripps University, Tarice Taylor, has taken on the development of a GIS database pertaining to historic, physical, and biological data pertinent to project planning as her capstone project.

No special problems, differences between schedule and accomplished work, have occurred.

Education and Outreach:

Communication

No education & outreach was participated in during the reporting period. The field work and data collection will take place in July and Education and Outreach is planned during and post fieldwork. The research team has met with NOAA officials to map out education and outreach opportunities and have had planning meetings to establish possible outreach venues with partner institutions such as the Birch Aquarium.

Academic Development

Graduate student MAS capstone project:

A MAS student at Scripps Institution of Oceanography, Tarice Taylor, has taken on the development of a GIS database pertaining to historic, physical, and biological data pertinent to project planning as her capstone project.



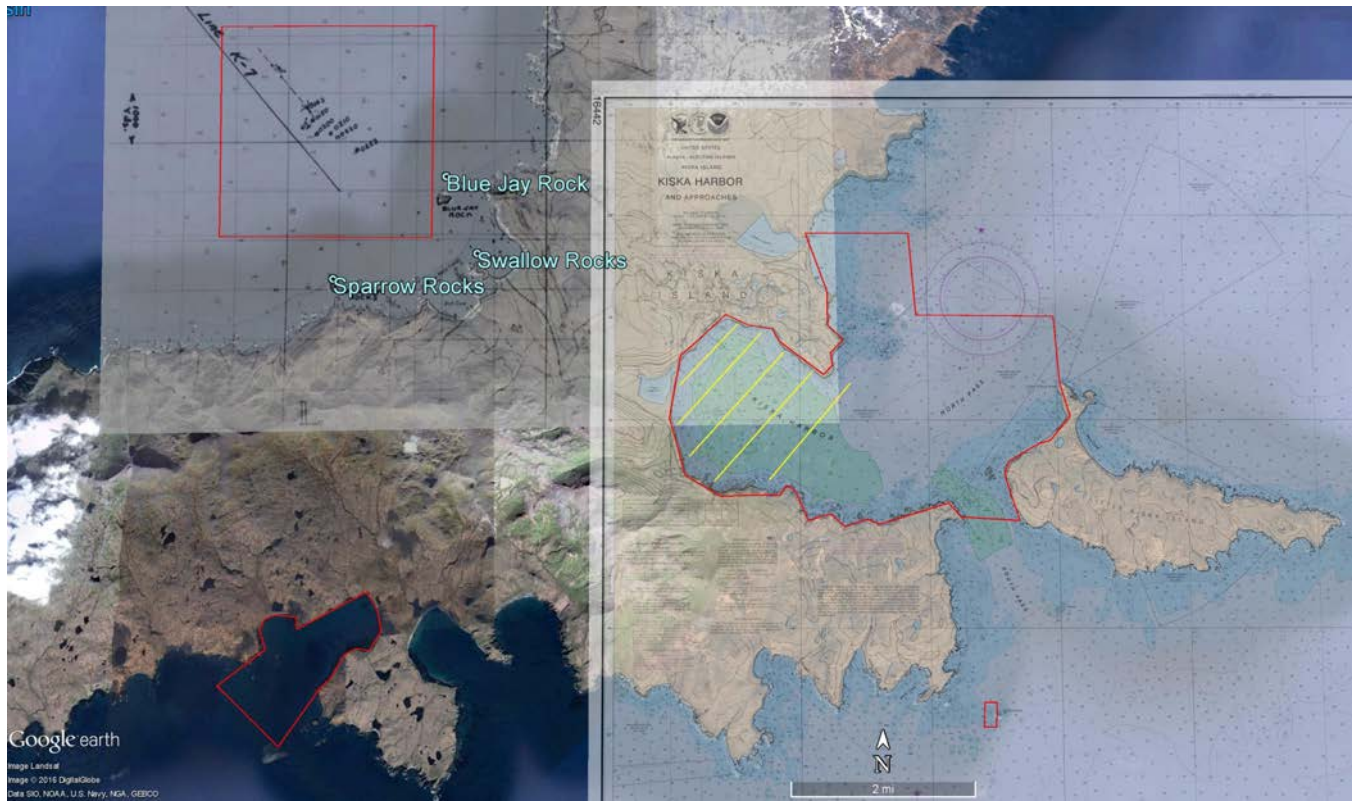


Figure 43: Google Earth image of Kiska Island with historical overlay of the *USS Abner Read* action report, NOAA nautical chart 16442, and four proposed survey areas in red.



Figure 44: R/V Norseman II, survey vessel for the Kiska project.



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 Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$346,137

Amendment(s):

24, 44, 76

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 the 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; extract 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 as we increase our capacity to process these samples in house while developing 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 we 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 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 student.

Conferences, Meetings & Presentations:

- a. Robertson, R.R., E.P. Bjorkstedt. Euphausiid size distribution off northern California in response to the marine heatwave of 2014-2016. Poster presented at Eastern Pacific Ocean Conference at Fallen Leaf Lake, California in September 2017.

Education & Outreach

Communication

a. Guest Lectures:

Roxanne Robertson provided Guest Lectures based on data from the Trinidad Head Line in FISH 478/578 Fisheries Oceanography at Humboldt State University

K-12 Outreach

a. Science Night at Fuente Nueva Charter School

Eric Bjorkstedt used a dice-rolling game to introduce elementary school students and their parents to early life history ecology of rockfish and the use of individual-based models to study survival of larval rockfish kids and parents at Fuente Nueva Charter School's Science Night.



Distribution of Deep-Water Coral and Sponge Habitats Off Washington and Oregon and their Functional Link to Demersal Fishes

Principal Investigator(s):

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

Other Key Personnel:

Sean Rooney, Washington State University Vancouver

Tom Laidig, Southwest Fisheries Science Center, Santa Cruz, CA

Lisa Krigsmann, Southwest Fisheries Science Center, Santa Cruz, CA

M. Elizabeth Clarke, Northwest Fisheries Science Center, Seattle, WA

Jeff Anderson, Nature Imagery

Erica Fruh, NOAA Fisheries, Northwest Fisheries Science Center, Seattle, WA

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

Chris Romsos, Oregon State University, Corvallis, OR

NOAA Primary Contact:

Dr. Elizabeth Clarke, Northwest Fisheries Science Center,

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

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 by comparing them 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 seminars, 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 to 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.

Conferences, Meetings, & Presentations:

- a. Dr. Sean Rooney gave a talk at NOAA's Alaska Fisheries Science Center's Groundfish Seminar Series- 10/3/2017. Rooney, S. Tissot, B. and Rooper, C. Distribution of deep-water corals and sponge habitat off Washington and Oregon and their functional links as fish habitat. (Seattle, WA)
- b. Dr. Sean Rooney gave a talk at the 20th Western Groundfish at Seaside, CA (2/13-16/2018). Rooney, S. Tissot, B. and Rooper, C. Using species distribution models to describe deep-sea coral and sponge habitats on Oregon's continental shelf.



- c. Dr. Brian Tissot provided testimony at the Pacific Fishery Management Council meeting on 4/8/18 in Portland Oregon on the Final Preferred Alternatives EFH and RCA for Amendment 28, including results from this project.

NOAA Employment

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

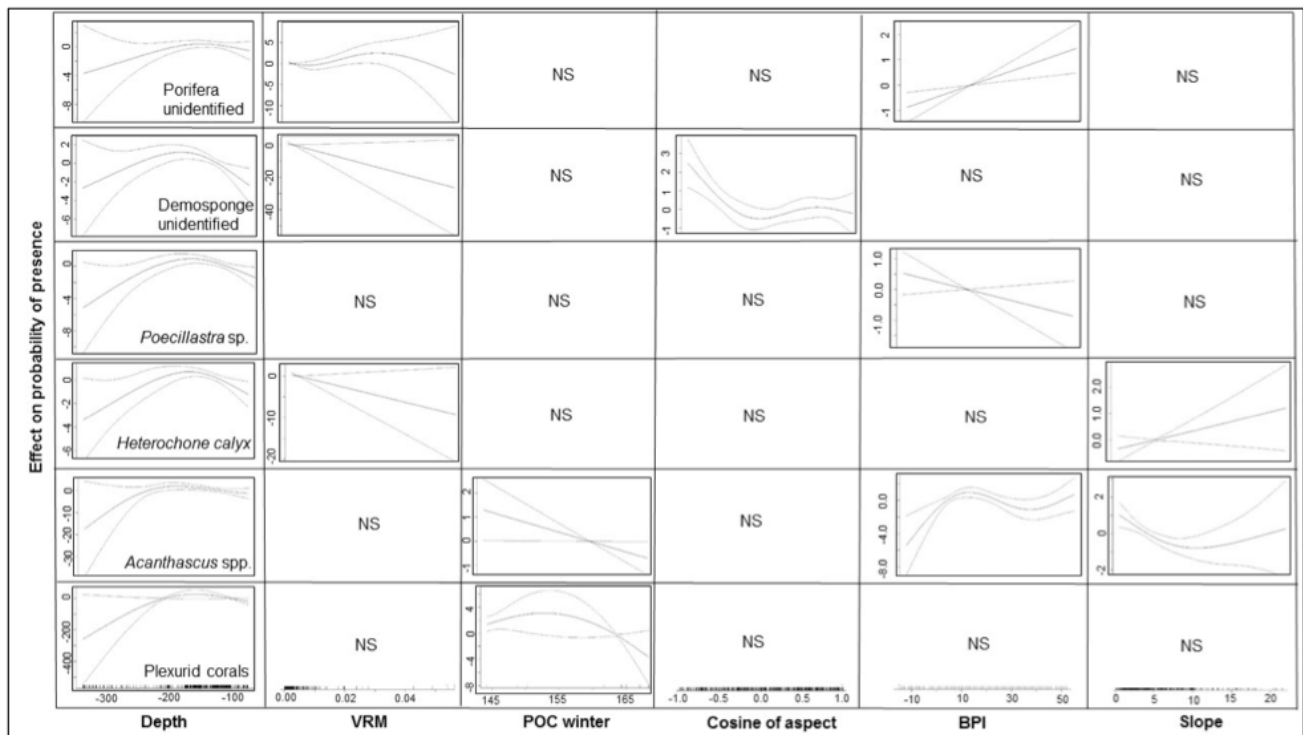


Figure 45: Partial effects of significant univariate variables in the best-fitting generalized additive models for unidentified Porifera, Demosponges, *Poecillastra* sp., *Acanthascus* sp., *Heterochone* calyx, and *Plexaurid* corals predicting the probability of presence. Dashed lines indicate the 95% confidence interval. Tick marks on the x-axis indicate where the samples occurred, and 'NS' indicates the variables were not classified as significant in the models. Variables shown in the columns from left to right are depth, terrain ruggedness measure (VRM), particulate organic carbon (POC) winter (mg m^{-3}), cosine of aspect ($^{\circ}$), bathymetric position index (BPI), and slope ($^{\circ}$).



Freshwater Fish Ecology Research Collaboration

Principal Investigator(s):

Darren Ward, Department of Fisheries Biology,
Humboldt State University

Other Key Personnel:

Gabe Scheer, Humboldt State University

Grace Ghrist, Humboldt State University

Madison Halloran, Humboldt State University

Max Ramos, Humboldt State University

NOAA Primary Contact:

Dr. Steven Lindley, Southwest Fisheries Science Center

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme C: Marine Ecosystems

Related NOAA Strategic Goal(s):

Goal 3: Healthy Oceans

Budget Amount:

\$233,484

Amendment(s):

17, 50, 68

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:

Conduct research projects and mentor graduate students working on research projects relevant to salmon conservation efforts in Northern California and the Klamath River basin.

Research Accomplishments:

- Graduate student Gabe Scheer defended his thesis project titled "A population model for coho salmon (*Onchorhynchus kisutch*) in Freshwater Creek: evaluating the effects of life history variation and habitat restoration" in November 2017.
- Graduate student Grace Ghrist completed model development and analysis of simulated data for her thesis research on juvenile life history and marine survival of coho salmon. Upon completion of field data collection this spring, Grace will complete her data analysis and defend her thesis in Spring 2019.
- New graduate student Madison Halloran started her thesis research in August 2017. Her project will evaluate movement of coho salmon between different watersheds. Madison completed her thesis proposal and is in the process of wrapping up her first year of data collection.
- New graduate student Max Ramos started his thesis research in January 2018. His project will evaluate potential rearing habitats for juvenile coho salmon above the Klamath River dams and characterize the resident fish communities currently occupying those habitats. Max is currently working on his first field season of data collection.

Honors and Awards:

- a. Madison Halloran and Grace Ghrist tied for 3rd place in the student poster competition at the Cal-Neva American Fisheries Society meeting in 2018
- b. Max Ramos received the Sequoia Park Zoo Conservation award for his proposed thesis research
- c. Grace Ghrist received the Richmond Rod and Gun Club student award for her thesis research

Conferences, Meetings & Presentations:

- a. Darren Ward, Grace Ghrist, and Madison Halloran attended the Cal-Neva American Fisheries Society meeting in San Luis Obispo, California February 28-March 2, 2018.
- b. Grace Ghrist attended the Oregon American Fisheries Society meeting in Bend, Oregon March 13-16, 2018.
- c. Darren Ward, Grace Ghrist, Madison Halloran, and Max Ramos attended the Salmonid Restoration



Federation meeting in Fortuna, California April 11-14, 2018.

Education & Outreach:

Academic Development

a. Graduate and undergraduate training in Fisheries Biology

Trained undergraduate and graduate students in Fisheries Biology. Taught the following courses: Fisheries Science Communication (24 students), Biology of Pacific Salmon (16 students). Primary research advisor for 3 current graduate students. Serve on graduate committees for 9 current graduate students.

Networking

b. Klamath River Growth and Learning Tour

Darren Ward participated in a three-day tour of the Klamath River and tributaries upstream of Iron Gate Dam, organized by NOAA biologists and managers.

The tour included opportunities to identify research needs and plan projects that will inform planning and restoration efforts in the upper Klamath Basin.

c. Klamath Estuary Workshop

Darren Ward participated in a two-day tour and workshop to explore opportunities for an integrated

suite of studies of the Klamath River estuary and near shore coastal habitats. Attendees included representatives from Yurok, Hoopa, and Karuk tribal fisheries programs, USGS, National Park Service, and the California Department of Fish and Wildlife.

NOAA Employment:

Molly Gorman attained a masters position with the Sustainable Fisheries in Seattle, WA in November 2017.



Figure 46: Humboldt State University students inspect a beaver dam analog on the Scott River, a Klamath River tributary in Northern California. Beaver dam analogs are human-created habitat structures intended to mimic beaver dams and restore rearing habitat for juvenile salmonids.



Theme D: Ecosystem-based Management

Training the Next Generation of Marine Population Dynamics Scientists

Principal Investigator(s):

Brice X. Semmens, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Josh Stuart, PhD Graduate Student, Scripps Institution of Oceanography, UC San Diego

Lynn Waterhouse, PhD Graduate Student, Scripps Institution of Oceanography, UC San Diego

Brian Stock, PhD Graduate Student, Scripps Institution of Oceanography, UC San Diego

Noah Ben-Aderet, PhD Graduate Student, Scripps Institution of Oceanography, UC San Diego

Kayla Blincow, PhD Graduate Student, Scripps Institution of Oceanography, UC San Diego

Erica Mason, PhD Graduate Student, Scripps Institution of Oceanography, UC San Diego

Peter Kuriyama, PhD Graduate Student, Scripps Institution of Oceanography, UC San Diego

Jordan DiNardo, PhD Graduate Student, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Roger Hewitt, Southwest Fisheries Science Center

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme D: Ecosystem-Based management

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaption and Mitigation

Goal 3: Healthy Oceans

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$588,726

Amendment(s):

16, 53, 80

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, (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.

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 the summer of 2017, the Semmens lab participated in the NSF funded Research Experience for Undergraduate (REU) program at SIO, called SURF (Scripps Undergraduate Research Fellowship, <https://scripps.ucsd.edu/undergrad/surf>). In 2017, the Semmens lab hosted two undergraduate students for the summer. The students both worked on projects related to the Grouper Moon Research project. One student analyzed length data as a means of monitoring recovery of the population and the other conducted a study on egg morphometrics and fertilization rates for Nassau Grouper and Tiger Grouper as part of a larger research project. During the SURF REU program, Semmens lab members, Brian Stock and Lynn Waterhouse, co-taught a short course on R and applied statistics to a dozen of the undergraduate students participating in that program. Additionally, the Semmens lab hosted a paid internship for a high school student through San Diego’s Workforce Partnership’s Life Science Summer Institute (LSSI) program. LSSI provided the salary for the student and PhD student, Lynn Waterhouse, served as the mentor to the student while in the lab. The student worked on digitizing old fisheries files from the Cayman Islands and assisting in the egg morphometric and fertilization project.

In Spring of 2017, Semmens lab PhD candidates, Joshua Stewart, Brian Stock, and Lynn Waterhouse taught an intensive ten day Ecological Data Analysis Workshop for twelve students participating in Proyecto Manta, a manta ray research program in Bahia de Banderas Mexico, from three universities in Mexico (Instituto Tecnológico de Bahía de Banderas; Universidad Autónoma de Baja California Sur; and Universidad de Meláque). The course was provided to the students free of charge. The objectives of the workshop were to expand the pool of

students currently participating in Proyecto Manta capacity building activities, provide a highly applied, targeted crash course in ecological statistics and data analysis, train students in the basics of data visualization and science communication, and expose participants to more advanced field data collection methods and technology. The course materials are all available on a github site (https://github.com/brianstock/StatsClass_public). Over ten days, the students were trained in the R statistical programming language. They practiced analyses ranging from t-tests to generalized linear models and received advice on analyzing their own data from research projects at their home institutions. Lectures provided background on sampling design and selecting appropriate statistical tests, classroom sessions provided hands-on training in R, in-class exercises provided students with practice implementing analyses, and homework assignments reinforced skills learned during classes. An exam administered before the workshop began, and then a final exam demonstrated a mean 588% (min 350% / max 930%) improvement in analytical abilities and statistical knowledge.

PhD student Brian Stock spent two months at the NWFSC and PIFSC via the National Science Foundation Graduate Research Internship Program (GRIP). Brian worked with NMFS researchers on a project aimed at reducing fisheries bycatch of protected, non-target species. Maps of bycatch risk updated in near real-time have recently shown promise as dynamic ocean management tools by providing advice or regulation on where and when to fish. Brian has been collaborating with Eric Ward and Jim Thorson (NWFSC) and Tomo Eguchi (SWFSC) to test different spatiotemporal model frameworks that could be used to generate these bycatch risk predictions. The internship gave Brian a better understanding of the context and limitations of the fisheries observer data through discussions with managers, protected species biologists, and observer program staff for the U.S. West Coast groundfish trawl and Hawaii longline fisheries.

In addition to the above research/education areas, PI Semmens oversaw 5 PhD students (Lynn Waterhouse, Brian Stock, Josh Stewart, Kayla Blincow, Erica Mason), 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-recapture 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, Jannot, Feist).



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 10 peer-reviewed manuscripts
- Lab members authored or co-authored 12 conference presentations
- PI Semmens taught undergraduate courses in lab and field techniques
- PI Semmens taught a graduate level course in Bayesian modeling with joint attendance by SIO and SWFSC students and scientists
- 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
- Lab members taught a short course in R and applied statistics to undergraduate students through the REU SURF program at Scripps
- Lab member Erica Mason led the California Collaborative Fisheries Research Program (CCFRP) in Southern California
- Lab member Lynn Waterhouse co-organized a symposium with professors from Oregon State University at the 2017 American Fisheries Society Meeting in Tampa, FL on the Biology and management of aggregating species in freshwater and marine systems
- Lab members funded, organized, and taught a short-course on R, applied statistics, and mobulid research to undergraduate and graduate students in March/April of 2017 in Mexico.

Honors and Awards:

- a. PI Brice Semmens was co-awarded the American Fisheries Society Conservation Achievement Award for the Grouper Moon Project, a long term research

and conservation program PI Semmens runs in the Cayman Islands.

- b. Josh Stewart, NOAA Dr. Nancy Foster Scholarship Program Award (awarded 2015, provides funding for 2015-2018 academic years)
- c. Lynn Waterhouse, PEO Scholar Award for 2017-2018 Academic year
- d. Josh Stewart, Brian Stock and Lynn Waterhouse each awarded the SIO Center for Marine Biology and Conservation (CMBC) Student Travel Award for the short course they taught in Mexico in March/April of 2017.
- 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. Kayla Blincow, Mia J. Tegner Memorial Fellowship 2018

Conferences, Meetings & Presentations:

- a. Dr. Brice Semmens, Brian Stock, and Lynn Waterhouse attended the 70th Annual Gulf and Caribbean Fisheries Research Institute, Merida, Mexico, November 2017. Lynn Waterhouse and Brian Stock gave talks. Additionally, undergraduate students, Kayla Martinez-Soto and India Dove, who worked in the lab through the Scripps Undergraduate Research Fellowship program in the summer of 2017 participated in the conference and each presented a poster.
- b. Lynn Waterhouse presented a talk and Brian Stock presented a poster at the American Fisheries Society meeting in Tampa, FL in August 2017.
- c. Lynn Waterhouse attended the The Ocean Conference for implementation of Sustainable Development Goal 14 (SDG 14) at the United Nations in New York City, NY in June 2017.
- d. Brian Stock and Peter Kuriyama presented at the CAPAM technical mini-workshop on the development of spatio-temporal models of fishery catch-per-unit-effort data to derive indices of relative abundance in La Jolla, CA in February/March of 2018. All members of the Semmens lab attended this workshop.
- e. Josh Stewart presented at the American Elasmobranch Society meeting in Austin, TX in July 2017
- f. Kayla Blincow presented at Western Society of Naturalists meeting in Pasadena, CA in November 2017.
- g. Kayla Blincow attended the Recruitment Workshop hosted by the Center for the Advancement of



- Population Assessment Methodology (CAPAM) in Miami, FL in October 2017.
- h. Noah Ben-Aderet presented at the World Recreational Fisheries Conference in Victoria, British Columbia, in July 2017.
 - i. Brian Stock presented at the ICES Annual Science Conference in Fort Lauderdale, FL, in Sept 2017.
 - j. Brian Stock gave the Claremont Colleges Applied Math Seminar on Sept 11, 2017: “What spatial statistical model is best for predicting fisheries by catch risk?”
 - k. Brian Stock presented at the UC San Diego FISP Symposium on Oct 31, 2017: “Mapping fine-scale processes in the ocean with a novel plankton imaging system”
 - l. Brian Stock gave the Fisheries Think Tank talk at the University of Washington on Oct 17, 2017: “What spatial statistical model is best for predicting fisheries by catch risk?”
 - m. Brian Stock participated in a PIFSC working group on spatiotemporal models for reducing bycatch risk from April 16-20, 2017 (led by T Todd Jones, S Martin, and D Kobayashi). He gave two presentations: “What spatial statistical model is best for predicting fisheries bycatch risk?” and “Using random forests for spatial modeling”.
 - n. Brian Stock and Lynn Waterhouse attended a 3-day workshop on Template Model Builder (TMB) at the SWFSC from Oct 10-12, 2017.
 - o. Jordan DiNardo attended a 5-day workshop on Ecological Niche Modeling using R at the Scottish Centre for Ecology and the Natural Environment (SCENE), University of Glasgow from October 16-20, 2017.

Education & Outreach

Communication

- a. Birch Aquarium, SIO
Lynn Waterhouse and Brian Stock both participated in Birch Aquarium’s Exploring Ocean STEM Careers day, April 2017. Lynn Waterhouse volunteers as a communication diver during the Kelp Tank shows at Birch Aquarium. She communicates with the audience on kelp forest ecology, aquarium facts, fisheries conservation and what it is like to be a marine scientist and scuba diver.
- b. NOAA Office of National Marine Sanctuaries
Josh Stewart gave two webinars on manta and devil ray research and conservation for the NOAA Office of National Marine Sanctuaries and the Flower Garden Banks National Marine Sanctuary.
- 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.

- d. WILDCOAST MPA Ambassador Kayak Film
Graduate student Kayla Blincow partnered with the non-profit WILDCOAST to create a training film for kayak tour outfitters operating in the Matlahuayl State Marine Reserve with the goal of reducing the amount of misinformation disseminated on tours.

Academic Development

- a. Undergraduate Education
 - Dr. Brice Semmens taught the SIO Undergraduate course SIO136: Marine Biology Lab and Field Techniques in Fall of 2017. Lynn Waterhouse served as the teaching assistant for this course.
 - Dr. Semmens and lab members participated as mentors in the National Science Foundation (NSF) Research Experience for Undergraduate (REU) Scripps Undergraduate Research Fellowship (SURF) program for 2 students. SURF is a 10-week summer Research Experience for Undergraduates (REU) designed to engage students in diverse and exciting Earth, ocean and atmospheric sciences research at a world-renowned institution. In particular, the SURF program seeks to increase the diversity of students successfully prepared to pursue Earth and ocean sciences career pathways, and to recruit individuals from institutions with limited undergraduate research opportunities. SURF is supported with funding from the National Science Foundation, Division of Ocean Sciences.
 - As part of the SURF summer program graduate students, Brian Stock and Lynn Waterhouse taught a short course on R and applied statistics.
- b. Graduate Educations
Dr. Semmens taught the graduate course SIO296: Introduction to Bayesian population analysis.
- c. SIO R-Users Group
Graduate students Kayla Blincow, 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. SIO Women and Minorities in Science (WMIS) group
Graduate student Lynn Waterhouse is the co-organizer of WMIS at SIO. In collaboration with SIO faculty Dr. Jane Willenbring, Lynn organized a series of talks on “Growing Up in Science.” Growing up in science is a conversation series that is not about science, but about becoming and being a scientist. At each event, one faculty member shares their life story, with a focus on struggles, failures, doubts, detours, and weaknesses.



- e. 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.
- f. Undergraduate Research Mentoring
- g. Graduate students Brian Stock and Lynn Waterhouse mentored 2 student research projects during summer 2017:
 - India Dove, “Length analysis of a Nassau grouper spawning aggregation,” March-June 2016
 - Kayla Martinez-Soto, “Fertilization rates and egg morphometrics for Nassau grouper and Tiger grouper”
- h. Undergraduate academic development
Graduate student Brian Stock gave a presentation and led a discussion on “Careers in Oceanography” at Harvey Mudd College on Sept 11 2017.
- i. Scripps Student Symposium
Graduate student Brian Stock served on the organizing committee, maintained the website/database, and produced the Book of Abstracts. The symposium is a student-led, one day conference of 30 presentations highlighting the diverse research conducted by SIO graduate students: <https://scripps.ucsd.edu/news/scripps-students-lead-fourth-annual-symposium>.

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 introduces 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. San Diego Workforce Partnership Life Science Summer Institute
Lynn Waterhouse and Brian Stock mentored a summer internship for a high school student through the San Diego Workforce Partnership Life Science Summer Institute (LSSI). LSSI provided the funding

for the paid internship. The high school student worked on digitizing old fisheries documents from the Cayman Islands and assisted with a project on egg morphometrics and fertilization rates.

- d. Birch Aquarium: Beach Science Program
In fall 2015, Birch Aquarium started to deliver, multi-day science program to sixth grade students in underserved communities. This incredible learning experience includes a full day of science investigation at the beach, steps away from the renowned Scripps Institution of Oceanography. Lynn Waterhouse volunteers with this program to educate the sixth-grade students on her path to graduate school and what a quantitative fisheries scientist does.

Networking

- a. American Fisheries Society- Estuaries Section
Lynn Waterhouse became president of the AFS Estuaries Section 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-organized a fundraising event, “Monsters of Habitat Science.” At the 2018 meeting in Atlantic City the Section is co-organizing a fundraising event, “Monsters of Climate Change Science.”
- b. American Institute of Fishery Research Biologists (AIFRB)
Lynn Waterhouse served as a review for AIFRB’s W. F. Thompson Best Student Paper Award. The W. F. Thompson Best Student Paper Award is given by the AIFRB annually to recognize excellence in research as well as to encourage student professionalism in fisheries and aquatic sciences and publication of research results. All scientists are eligible as long as the senior author conducted the research while a student of fish or some aspect of aquatic science and conservation. The award includes a check for up to \$1,000.00.

NOAA Employment:

Noah Ben-Aderet attained a Post-Doctoral position with the Southwest Fisheries Science Center in November, 2017.





Figure 47: QUEST Supported graduate students organize and teach ecological data analysis workshop in Mexico. Group photo of participants and organizers (Josh Stewart, Brian Stock, Lynn Waterhouse).



Figure 48: Graduate student, Brian Stock, learning about the Hawaii longline fleet that targets bigeye tuna and swordfish.



Modeling White Abalone (*Haliotis Sorensen*) Habitat Under Current and Future Ocean Conditions

Principal Investigator(s):

Brice X. Semmens, Scripps Institution of Oceanography, UC San Diego

Other Key Personnel:

Ed Parnell, Scripps Institution of Oceanography, UC San Diego

Octavio Aburto Oropeza, Scripps Institution of Oceanography, UC San Diego

Kevin Stierhoff, Southwest Fisheries Science Center (NOAA)

Melissa Neuman, West Coast Regional Office (NOAA)

David Witting, West Coast Regional Office (NOAA)

Scott Mau, Southwest Fisheries Science Center (NOAA)

Erica Mason, Scripps Institution of Oceanography, UC San Diego

Jordan DiNardo, Scripps Institution of Oceanography, UC San Diego

NOAA Primary Contact:

Dr. Roger Hewitt, Southwest Fisheries Science Center

NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

NOAA Theme:

Theme D: Ecosystem-Based management

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaption and Mitigation

Goal 3: Healthy Oceans

Budget Amount:

\$92,323

Amendment(s):

59

Description of Research:

We are developing habitat models at varying spatial scales for white abalone that will inform future outplanting efforts in Southern California. White abalone were once the target of an intense commercial fishery in Southern California during the 1970s. By the early 1980s the fishery reduced numbers to dangerously low levels and the fishery was closed in 1997. White abalone was listed as endangered under the Endangered Species Act

(ESA) in 2001 and was identified as a “Species in the Spotlight” by NOAA Fisheries in 2016 due to their high risk of extinction. As part of efforts to rebuild the stock, NOAA Fisheries is currently developing a conservation hatchery program for the species, which relies heavily on outplanting activities. Our modeling work will support the recovery of the white abalone population by identifying suitable outplanting habitat and gain a better understanding on the interplay between quality habitat and climate change. To address the lack of historical fishery-independent data, Jordan interviewed former abalone fishermen in Southern California and the Channel Islands in order to gain baseline ecological knowledge on the white abalone population during the fishery before catastrophic declines in the 1980s.

Research Objectives:

1. Identification, acquisition, and integration of data

We will assemble and integrate existing white abalone monitoring and fishery data into a user-friendly database. To the extent possible, habitat data will be identified and integrated into the database. Data sources will include remotely operated vehicles (ROVs), scuba surveys conducted by the Southwest Fisheries Science Center (SWFSC), State Governments (e.g., California Department of Fish and Wildlife (CDFW)), local organizations (e.g. Bodega Marine Laboratory), and citizen scientists, as well as reported commercial and recreational fishery statistics. As part of this effort, we will identify and integrate available benthic habitat maps including kelp spatiotemporal distributional data. We will also conduct a literature search to identify potential indicators of white abalone habitat quality. If deemed relevant, we will also conduct interviews with white abalone experts and fishers to glean additional abundance and habitat association data (especially historically).

2. Habitat modeling and climate change impact predictions

We will identify a suitable habitat in the Southern California Bight to inform future outplanting efforts of white abalone. Given that this population exists at such low numbers and data is limited to presence-only (lacking or unreliable absence data), maximum entropy (Maxent) models are strong candidates for modeling habitat suitability (Phillips et al 2006). Using data assembled in Objective 1, we will develop a Maxent model to inform white abalone outplanting efforts. To the extent possible, we will evaluate the effects of climate change on the designated suitable habitats to predict long-term suitability.



Research Accomplishments:

- Identification, acquisition, and integration of white abalone fishery-dependent and -independent data from 1951 through 1993 and 1993 through 2017, respectively, as well as environmental data (abiotic and biotic) throughout the Southern California bight.
 - Identification of white abalone suitable habitat at a finescale (10 m) using fishery-independent presence-only data and maxent modeling approach.
 - Identification of white abalone suitable habitat at a region-wide scale (CDFG Fishing Blocks (about 17km)) using a presence-absence (fishery-dependent data) and presence-only (fishery-independent data) modeling approach.
- Investigation of the effects of climate change on quality of habitat at the region-wide scale throughout the Southern California bight.

Conferences, Meetings & Presentations:

- a. Graduate student Jordan DiNardo attended a 5-day workshop on Ecological Niche Modeling using R at the Scottish Centre for Ecology and the Natural Environment (SCENE), University of Glasgow from October 16-20, 2017.



Using Combined Video, Acoustic, and Accelerometer Measurements to Determine the Conceptual Viability of a "Smart" Hook - NA14NMF47203289

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

NOAA Primary Contact:

Derek Orner, NOAA Federal

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme D: Ecosystem-Based management

Related NOAA Strategic Goal(s):

Goal 3: 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. 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 if a particular species is present on a given hook and if multiple hooks can 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 was the difficulty of obtaining large sample sizes from pelagic deployments. Attempts to gain additional demersal samples during Summer 2017 were unsuccessful. We have concluded that controlled trials of bycatch species on longlines would provide a more effective means of testing the concept than continued opportunistic deployments.

Research Objectives:

- Expand "TadPro" to include acceleration: The TadPro design would be expanded to incorporate datalogging of accelerometer measurements and ten units would be built.
- 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.
- Extend TadPro lifetime: To 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:

- 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.
- 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



Utilizing Historic Annual Hydrographs to Identify Instream Flow Needs for Southern Steelhead Populations

Principal Investigator(s):

Dr. William 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, National Marine Fisheries Service

NOAA Task:

Task 3 – Individual Science Projects

NOAA Theme:

Theme D: Ecosystem-Based management

Related NOAA Strategic Goal(s):

Goal 1: Climate Adaption and Mitigation

Goal 4: Resilient Coastal Communities and Economies

Budget Amount:

\$81,999

Amendment(s):

26

Description of Research:

Our CIMEC project had its origin on the Santa Ynez River. The National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) had been evaluating how water storage activities in the Santa Ynez River affected migratory instream flow needs (IFNs) of the endangered SoCal steelhead. NMFS contracted with the HSU River Institute to provide additional analyses. O'Dowd et al. (2014) submitted a final report to NMFS (June 30, 2014) titled Annual Hydrograph Assessment for Steelhead Migration in the Santa Ynez River. The HSU River Institute's goal was to evaluate how changes to the Santa Ynez River's annual hydrographs affected successful adult and juvenile steelhead migration within the Santa Ynez River and recommend remedial measures. During the time of this Project, Southern California was experiencing drought. This forced non-traditional approaches to evaluating steelhead passage and migration when there was little to

no water. The primary Project objective was to establish unimpaired baseline conditions for steelhead migration and passage even though historical data was sparse, primarily California Department of Fish and Game (CDFG) reports/memos and United States Geological Survey (USGS) stream gaging records. However, the techniques developed and employed also were useful for evaluating and recommending instream flows. This evolved into another key project objective: develop an instream flow protocol that could be regionalized for all Coastal California streams.

Research Objectives:

Three CIMEC Project objectives are:

1. Quantify how the hydraulic performance of Coastal California streams sustains ecological processes and Southern California steelhead (*Oncorhynchus mykiss*) life history needs,
2. Demonstrate how to evaluate ecological risk from diversions and climate change by evaluating individual annual hydrographs, and
3. Propose a top-down environmentally protective diversion criterion applicable across geographic/hydrologic regions that will meet SWRCB water rights permitting requirements.

All three were achieved by employing old hydrologic and geomorphic tools in new ways. Foremost were the riffle crest (RC), the riffle crest thalweg (RCT), and individual historical/contemporary annual hydrographs. Strategic hydraulically, riffle crest cross-sections (or 'RCs') and their thalwegs (i.e., the 'riffle crest thalwegs', or 'RCTs') are located at the highest channelbed thalweg elevation between an upstream pool and downstream riffle. Simple geometric relationships of the stream channel's family of RCT-Q rating curves estimated streamflow thresholds at each hydraulic control. Instream flow needs for fluvial ecosystems and anadromous salmonid life history needs ('IFNs' collectively) depend directly on the unregulated magnitude, duration, frequency, timing, and rate of streamflows exerting all three hydraulic controls. A diversion policy that assures hydraulic performance should insure environmental protectiveness.

Research Accomplishments:

- Preliminary results indicate a 5% decrease in RCT depth of an unimpaired, ambient streamflow minimally impacts a stream channel's hydraulic performance in Coastal California streams. Ecological



processes are sustained and anadromous salmonid habitat availability incurs minor loss. Thus, an allowable decrease of 5% RCT depth can serve as a regional SWRCB flow criterion for unregulated Coastal California streams. Power function exponents of a stream channel's family of RCT-Q rating curves set the maximum allowable diversion rate. In alluvial gravelbed channels, maximum allowable diversion rates vary 7.5% to 10%. In steep boulder-dominated channels, maximum allowable rates vary 12% to 14%. Importantly, hydraulic streamflow thresholds for pre-disturbance stream and river ecosystems can be estimated using our report's protocols (Figure 49). These thresholds will serve as necessary baselines for evaluating future risks to IFNs from streamflow/groundwater diversion and climate change.

- Another primary task throughout 2017-2018 was preparation of a final project report that would provide further guidance to state and federal resource agencies, especially the SWRCB on how to recommend scientifically-defensible, protective instream flow criteria for unregulated Coastal California streams.

Conferences, Meetings & Presentations:

- b. Dr. William Trush presented a 1-day workshop on Instream Flow Criteria for the Salmonid Restoration Federation on 11 April 2018 to state and federal resource agencies.

Education & Outreach:

Communication

- h. Invited Speaker Event for SoCal CalTrout Chapter.
On June 29 2017, William Trush was an invited speaker to CalTrout's 2017 spring-summer lecture program in Ventura, CA titled: "The Role of the Annual Hydrograph in Recovering SoCal Steelhead Populations."
- i. Featured in "A River's Last Chance."
'Scientist' speaking role in Pacific River's "*A River's Last Chance*." The movie debuted at the Portland EcoFilms Festival on September 28th, 2017, and since has been shown in many venues from Southern California north to Eureka, CA and in several film festivals nationally and inter-nationally.

Academic Development

- d. Seminar Series (2-units) for Fall Semester 2017 in HSU Department of Environmental Science and Management for graduate and undergraduate students River Ecosystem Management in California.

Networking

- d. Presentation to North Coast Regional Water Quality Control Board, Santa Rosa
Met with staff scientists to explain the Riffle Crest approach for water rights permitting. F. Martin Ralph presented to legislators, water managers and the public at a Sonoma County Water Agency meeting to inform the public and policy community on the difficulties of managing a reservoir for both flood control and water supply.
- e. Presentation to The Nature Conservancy, San Francisco
Day meeting with staff of Nature Conservancy, CalTrout, and Trout Unlimited on developing alternative instream flow strategies for Coastal California streams.



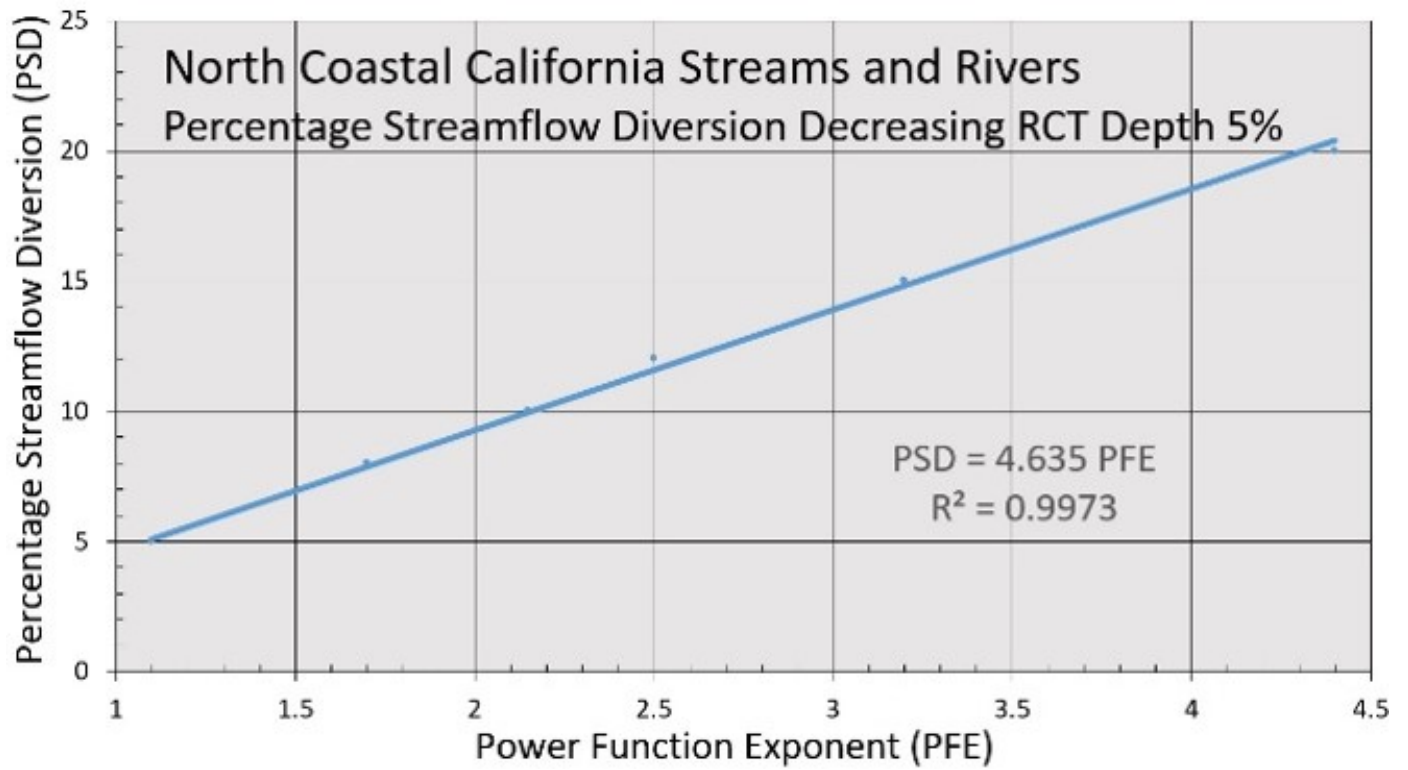


Figure 49: Equation for determining the percentage streamflow diversion (PSD) that decreases RCT depth by 5% as a function of the riffle crest's power function exponent of the RCT-Q Rating Curve (PFE).

PARTNERS & COLLABORATORS

Interagency

CA State Water Resources Control Board	NOAA National Integrated Drought Information System (NIDIS)
California Department of Fish and Wildlife (CDFG)	NOAA National Marine Fisheries Service (NMFS)
Environmental Protection Agency (EPA)	NOAA National Ocean Service (NOS)
NASA Jet Propulsion Laboratory	NOAA National Weather Service (NWS)
National Aeronautics and Space Administration (NASA)	NOAA Ocean Observations and Monitoring Division
National Institute of Standards and Technology	NOAA Office of Ocean Exploration and Research (OER)
National Oceanic and Atmospheric Administration (NOAA)	NOAA Office of Response and Restoration (OR&R)
National Science Foundation (NSF)	NOAA Olympic Coast National Marine Sanctuary
NOAA Atlantic Oceanographic & Meteorological Laboratory (AOML)	NOAA Pacific Marine Environmental Laboratory (PMEL)
NOAA Automated Image Analysis Strategic Initiative (AIASI)	NOAA PIFSC Coral Reef Ecosystem Program
NOAA Climate Prediction Center (CPC)	North Coast Regional Water Quality Control Board
NOAA Climate Program Office (CPO)	NSF National Center for Atmospheric Research (NCAR)
NOAA Earth System Research Laboratory (ESRL)	NSF Office of Polar Programs (OPP)
NOAA Emergency Response Division (ERD)	U.S. Army Corps of Engineers (USACE)
NOAA ESRL Global Monitoring Division (GMD)	U.S. Bureau of Ocean Energy Management (BOEM)
NOAA Fisheries - Alaska Fisheries Science Center (AFSC)	U.S. Bureau of Reclamation (USBR)
NOAA Fisheries - Northeast Fisheries Science Center (NEFSC)	U.S. Coast Guard (USCG)
NOAA Fisheries - Northwest Fisheries Science Center (NWFSC)	U.S. Fish and Wildlife Service (USFWS)
NOAA Fisheries - Pacific Islands Fisheries Science Center (PIFSC)	U.S. Geological Survey (USGS)
NOAA Fisheries - Southeast Fisheries Science Center (SEFSC)	U.S. National Science Foundation (Chemical Oceanography)
NOAA Fisheries - Southwest Fisheries Science Center (SWFSC)	U.S. Navy (USN)
NOAA Geophysical Fluid Dynamics Laboratory (GFDL)	USN Naval Research Laboratory Monterey (NRL-MRY)
NOAA Integrated Ocean Observing System (IOOS)	USN Office of Naval Research (ONR)
NOAA National Centers for Environmental Information (NCEI)	
NOAA National Data Buoy Center (NDBC)	



Partnerships

Atlantic States Marine Fisheries Commission	Investigaciones Mexicanas de la Corriente de California (IMECOCAL)
Benioff Ocean Initiative	IOS (Canada)
BSH (Germany)	J. Craig Venter Institute
California State University, Monterey Bay	Jacobs School of Engineering, UC San Diego
California Current Ecosystem Long Term Ecosystem Research (CCE-LTER)	JAMSTEC (Japan)
California Department of Fish and Wildlife (CDFW)	KMA (Korea)
California Department of Water Resources (CDWR)	Lamont-Doherty Earth Observatory, Columbia University
California Polytechnic State University - San Luis Obispo (CalPoly)	Macquarie University, Australia
California Salmon Council	Manta Trust
California State University, Long Beach (CSULB)	Misool Eco-Resort Conservation Center
CalTrout	Monterey Bay Aquarium Research Institute (MBARI)
Commonwealth Scientific and Industrial Research Organization (CSIRO) (Australia)	Moss Landing Marine Laboratories
Cooperative Institute for Marine Resources Studies, Oregon State University (CIMRS/OSU)	MOU with the Icelandic Coast Guard
Cooperative Institute for Research in Environment Sciences, CU Boulder	MOU with the University of Tuscia, Italy
Cultural Heritage Engineering Initiative, UC San Diego	National Oceanography Centre Southampton (U.K.)
Desert Research Institute (DRI)	NIWA (New Zealand)
Duke University	North Carolina State University
Eastern Research Group (ERG)	Office of Spill Prevention and Response (OSPR), California Department of Fish and Wildlife
Environment and Climate Change, Canada	Oregon State University
Florida State University	Oregon State University (OSU), College of Oceanic and Atmospheric Sciences
Georgia Institute of Technology	Penn State University
Hoopla Tribal Fisheries	Princeton University
Hopkins Marine Station	QEDA Consulting
Hubbs-SeaWorld Research Institute (HSWRI)	Qualcomm Institute, UC San Diego
Humboldt State University	Reef Environmental Education Foundation (REEF)
IFREMER (France)	Rosenstiel Schools of Marine and Atmospheric Science
INCOIS (India)	Rutgers University, Coastal Ocean Observation Lab (COOL)
Institut de recherche pour le developpement, The French Research Institute for Development (New Caledonia)	San Francisco State University (SFSU)
Inter-American Tropical Tuna Association (IATTC)	Schmidt Ocean Institute
	Scott River Watershed Council



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 Second Institute of Oceanography (China)
 Sonic Art Research
 Sonoma County Water Agency (SCWA)
 Southern California Coastal Ocean Observing System (SCCOOS)
 Southern Nevada Water Authority (SNWA)
 Sportfishing Association of California (SAC)
 Stanford University
 Sunshine Coast Univeristy, Australia
 Texas A&M University (TAMU)
 The BentProp Project
 The Biological and Chemical Oceanography Data Management Office (BCO-DMO), Woods Hole, MA
 The Nature Conservancy
 Trout Unlimited
 U.K. Met Office
 Univeristy of Delaware, School of Marine Science and Policy
 Universidad Autonomo de Baja California Sur (UABS)
 University of California Los Angeles (UCLA)

University of California Merced
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PUBLICATIONS

Publication Summary

		07/01/2016 – 03/31/2017	04/01/2017 – 03/31/2018
CIMEC Lead Author	Peer Reviewed	10	74
	Non-Peer Reviewed	0	58
NOAA Lead Author	Peer Reviewed	5	14
	Non-Peer Reviewed	0	8
Other Lead Author	Peer Reviewed	13	79
	Non-Peer Reviewed	1	13
Total Publications		29	246

Journal Articles

- Abrahms, B., DiPietro, D., Graffis, A., and Hollander, A. 2017. Managing biodiversity under climate change: challenges, frameworks, and tools for adaptation. *Biodiversity and Conservation*, 26(10): 2277-2293.
- Abrahms, B., Hazen, E.L., Bograd, S.J., Brashares, J.S., Robinson, P.W., Scales, K.L., D. Crocker and Costa, D.P. 2018. Climate mediates the success of migration strategies in a marine predator. *Ecology Letters* 21: 63-71
- Abrahms, B., Seidel, D.P., Dougherty, E., Hazen, E.L., Bograd, S.J., Wilson, A.M., McNutt, J.W., Costa, D.P., Blake, S., Brashares, J.S. and Getz, W.M. 2017. Suite of simple metrics reveals common movement syndromes across vertebrate taxa. *Movement Ecology*, 5(12):1-11.
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- Ainley DG, Santora JA, Capitolo PJ, Field JC, Beck JN, Carles RD, Donnelly-Greenan E, McChesney GJ, Elliott M, Bradley RW, Lindquist K, Nelson P, Roletto, Warzybok P, Hester M, Jahncke J (2018) Ecosystem-based management affecting Brandt's Cormorant resources and population in the central California Current region. *Biological Conservation*, 271, 407-418
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- Baetscher, DS, AJ Clemento, TC Ng, EC Anderson and JC Garza. 2017. Microhaplotypes provide increased power from short-read DNA sequences for relationship inference in fish and wildlife. *Molecular Ecology Resources* 2018(18):296-305.
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doi.org/10.1016/j.agrformet.2018.01.015
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- Baringer, M. O., D. A. Smeed, J. Willis, M. Lankhorst, W. R. Hobbs, S. Dong, G. McCarthy, D. Rayner, W. E. Johns, G. Goni, C. S. Meinen, and U. Send: Meridional overturning and oceanic heat transport circulation observations in the



North Atlantic Ocean. Submitted to Bulletin of the American Meteorological Society as a chapter of “State of the Climate 2016”, 2017.

- Bautista-Romero, J. J., R. Funes-Rodríguez, S. P. Jiménez-Rosenberg, and D. B. Lluch-Cota. 2018. Preferential distribution of fish larvae in the California Current System: Time, space, and temperature. *Fisheries Oceanography*, 27(3): 259-273
- Becker, E. A., K. A. Forney, B. J. Thayre, A. J. Debich, G. S. Campbell, K. Whitaker, A. B. Douglas, A. Gilles, R. Hoopes and J. A. Hildebrand. 2017. Habitat-Based Density Models for Three Cetacean Species off Southern California Illustrate Pronounced Seasonal Differences. *Frontiers in Marine Science* 4(121).
- Bizzarro, J.J., Carlisle, A.B., Smith, W.D., and Cortés, E. 2017. Trophic ecology of Northeast Pacific sharks, pp. 111–148. In: *Advances in Marine Biology* Vol. 77. Northeast Pacific shark biology, research, and conservation (Larson, S, and Lowry, D., eds.). Elsevier. Amsterdam, Netherlands.
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ACRONYMS

ABL	Atmospheric Boundary Layer
ABT	Atlantic Bluefin Tuna
ADCP	Acoustic Doppler Current Profiler
ADMT	Argo Data Management Team
AMLR	Antarctic Marine Living Resources Program
AOML	NOAA/Atlantic Oceanographic and Meteorological Lab
APO	Asian-Pacific Oscillation
AR	Atmospheric River
ASIRI	Air-Sea Interactions in the Northern Indian Ocean
AWIPS	Advanced Weather Interactive Processing Systems
BAS	Birch Aquarium at Scripps
BML	Bodega Marine Laboratory, UC Davis
BSISO	Boreal Summer Intraseasonal Oscillation
CA COSEE	California Center for Ocean Science Excellence in Education
Cal State	California State University system
CalCOFI	The California Cooperative Oceanic Fisheries Investigations
CalIT	California Institute of Technology
Caltrans	California Department of Transportation
CAP	California Applications Program
CAPAM	Center for the Advancement of Population Assessment Methodology
CBNMS	Cordell Banks National Marine Sanctuary
CCE-LTER	Claifornia Current Ecosystem Long-Term Ecological Research
CCHDO	CLIVAR and Carbon Hydrographic Data Office
CCMA	Center for Coastal Monitoring and Assessment
CCS	California Current System
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
CESM	Community Earth System Model
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
CNAP	California Nevada Applications Program
CNES	Centre National d'Etudes Spatiales
COML	Census of Marine Life
COP	NOAA/NOS/Center for Sponsored Coastal Ocean Research/Coastal Ocean Program
CORDC	Coastal Observing Research and Development Center
CPC	NOAA - Climate Prediction Center
CPO	NOAA/Climate Programs Office (formerly, Office of Global Programs (OGP))
CREP	Coral Reef Ecosystem Program
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)
CUGN	California Underwater Glider Network
CVHM	Central Valley Hydrologic Model
DBCP	Data Buoy Cooperation Panel, WMO-IOC
DEWS	Drought Early Warning System
DoD	Department of Defence
DOE	U.S. Department of Energy
DSC	Deep Sea Corals
DSST	Diurnal Sea Surface Temperature
DWR	California Department of Water Resources
EBFM	Ecosystem-Based Fishery Management
ECCO	SIO's Estimating the Circulation and Climate of Oceans Consortium
ECMWF	European Centre for Medium-Range Weather Forecasts
EICC	East India Coastal Current
ENSO	El Niño and Southern Oscillation
EPA	Environmental Protection Agency
ERD	Environmental Research Division
ESRL	NOAA/Earth System Research Laboratory



FATE	Fisheries and the Environment
FED	Fisheries Ecology Division
FKNMS	NOAA/Florida Keys National Marine Sanctuary
FOCI	Fisheries-Oceanography Coordinated Investigations
FRD	Fisheries Research Division
GACC	Geographic Area Coordination Centers
GDP	Global Drifter Program
GEOSS	Global Earth Observation System of Systems
GEWEX	Global Energy and Water-cycle Experiment
GGMT	Greenhouse Gas Measurement Technique
GIS	Geographic Information Systems
GMD	NOAA/ESRL/Global Monitoring Division
GNOME	NOAA - Operational Modeling Environment
GO-SHIP	Global Ocean Ship-Based Hydrographic Investigations Program
GODAE	Global Ocean Data Assimilation Experiment
GoM	Gulf of Mexico
GOOS	Global Ocean Observing System
GPS	Global Positioning System
GRIP	Graduate Research Internship Program
GSD	NOAA/ESRL/Global Systems Division
GTS	GNU Triangulated Surface
GTS	Global Telecommunication System
HARP	High-Frequency Acoustic Recording Packages
HFRNet	High Frequency Radar Network
HPLC	High-Pressure Liquid Chromatography
HRC	Hydrologic Research Center, San Diego, CA
HRX	Repeat high resolution expendable Bathythermograph
HSU	Humboldt State University
IATTC	Inter-American Tropical Tuna Commission
IAV	Interannual Variability
ICARTT	International Consortium for Atmospheric Research on Transport and Transformation
IEA	Integrated ecosystem assessments
IOC	Intergovernmental Oceanographic Commission
IOOS	Integrated and Sustained Ocean Observations
IRD	Institut de Recherche pour le Développement
IRI	International Research Institute for Climate Prediction
ISO	Intraseasonal Oscillations
ISV	Intraseasonal Variability
JCOMM	Joint WMO-IOC 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
LDEO	Lamont-Doherty Earth Observatory
LJAA	La Jolla Acoustic Array
LSSI	Life Science Summer Institute
MBARI	Monterey Bay Aquarium Research Institute
MC	Maritime Continent
MIT	Massachusetts Institute of Technology, Harvard
MJO	Madden-Julian Oscillation
MLC	Marine Layer Clouds
MPI	Max Planck Institute, Germany
MPL	Marine Physical Laboratory, SIO, UCSD
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCCOS	National Centers for Coastal Ocean Science
NCEI	National Centers for Environmental Information
NCEP	NOAA/National Centers for Environmental Predictions
NCOG	NOAA CalCOFI Genomics Project
NDBC	NOAA/NWS/National Data Buoy Center
NEFSC	NOAA/Northeast Fisheries Science Center
NeMO	New Millenium Observatory
NESDIS	NOAA/National Environmental Satellite, Data, and Information Services
NGI	Northern Gulf Institute
NGS	NOAA/National Geodetic Survey
NIDIS	National Integrated Drought Information System
NIST	National Institute of Standards and Technology
NIWA	National Institute of Water and Atmospheric Research, New Zealand
NMFS	NOAA/National Marine Fisheries Service
NMME	North American Multi-Model Ensemble
NMSP	National Marine Sanctuary Program
NOEF	National Ocean Exploration Forum
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
OCNMS	Olympic Coast National Marine Sanctuary
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
ORR	NOAA - Office of Response and Restoration
OTU	Operational Taxonomic Unites
PDF	Probability Density Functions
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
PSD	NOAA - Physical Sciences Department
QI	Qualcomm Institute
R/V	Research Vessel
RCT	Riffle Crest Thalweg
RISA	Regional Integrated Sciences and Assessments
ROWG	Radio Operators Working Group
SAROPS	Search and Rescue Optimal Planning System
SAS	Simplified Arakawa-Schubert cumulus convection scheme
SCCOOS	Southern California Coastal Ocean Observing System
SCCWRP	Southern California Coastal Water Research Project
SDG&E	San Diego Gas & Electric
SEFSC	NOAA/Southeast Fisheries Science Center, Panama City, FL
SfM	Structure from Motion
SIO	Scripps Institution of Oceanography, UCSD
SLAP	Sea Level Atmospheric Pressure
SNOTEL	Snow Telemetry
SNWA	Sothern Nevada Water Authority
SOPAC	Scripps Orbit and Permanent Array Center
SSS	Sea Level Wind, Subsurface Temperature, and Directional Wave Spectra
SST	Sea Surface temperature
STEM	Science, Technology, Engineering, and Mathematics
SURF	Scripps Intitution Undergraduate Research Fellowship
SVP	Surface Velocity Program
SWE	Snow Water Equivalent
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
UPP	Understanding and Protecting the Planet
USARP	U.S. Antarctic Research Program
USC	University of Southern California
USFS	U.S. Fire Service
USGS	U.S. Geological Survey
UUV	Unmanned Underwater Vehicle
UW	University of Washington, Seattle
VAdm	Vice Admiral
VOS	Voluntary Observing Ship
WAVE	Wide Area Virtual Environment
WBC	Western Boundary Current
WECC	Western Electricity Coordinating Council
WHOI	Woods Hole Oceanographic Institution
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WRCC	Western Regional Climate Center
WWW	World Weather Watch
XBT	Expendable Bathythermograph
XCTD	Expendable Conductivity Temperature and Depth

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