

# CIMEC

Cooperative Institute for Marine Ecosystems and Climate

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

## PROGRESS REPORT 2015-2016





# CIMEC

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

Prepared for



NA15OAR4320071



UC San Diego

UC SANTA CRUZ

UCLA

UC DAVIS

HUMBOLDT  
STATE UNIVERSITY

UCSB





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April 11, 2016

The Cooperative Institute for Marine Ecosystems and Climate (CIMEC) began the first year of our 5-year renewal on July 1, 2015. Many thanks to all who contributed to that review, and to all the scientists who make CIMEC exceptional. Dave Checkley deserves special recognition, having just stepped down from leading CIMEC to spend time on research. I am very grateful to him for completing the review and renewal, and for all his tutorials, help, and advice. I am looking forward to working with NOAA, CIMEC, and all other stakeholders to try to emulate Dave's success.

The amount of funding awarded through CIMEC has continued to grow, reaching \$20M this year. Many excellent projects are sustained through CIMEC, and we are very proud of our role in facilitating their relationships with NOAA. In particular, the University of California Santa Barbara obtained funding this year through CIMEC, having been previously unfunded. That leaves only two unfunded partners, UCLA, which has funding from NOAA outside CIMEC, and California State University Los Angeles.

One of my priorities going forward will be to engage with NOAA on behalf of our partners to see what more can be done to match NOAA needs to partner capabilities. I have already started this during my recent visit to NOAA Headquarters for the annual Cooperative Institute (CI) Directors meeting, and I will be reaching out to CIMEC partners to look for synergies.

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# INTRODUCTION

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The Cooperative Institute for Marine Ecosystems and Climate (CIMEC) research and program activities for the year (2015-2016) 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 July 1, 2015 to March 31, 2016 period, the NOAA research entities listed below were engaged with SIO as part of CIMEC in marine, atmospheric and climate research, education and outreach efforts, data collection, and collaborative activities:

- Office of Habitat Conservation (OHC)
  - Office of Oceanic and Atmospheric Research (OAR)
  - Protected Resources Division (PRD)
  - Southwest Fisheries Science Center (SWFSC)
- 
- Climate Observations Division (COD)
  - Climate Program Office (CPO)
  - Earth System Research Laboratory (ESRL)
  - Fisheries Ecology Division (FED)
  - Global Monitoring Division (GMD)
  - National Environmental Satellite, Data and Information Service (NESDIS)
  - National Marine Fisheries Service (NMFS)
  - National Ocean Service (NOS)
  - Ocean Assessment Program (OAP)
  - Ocean Exploration Program (OEP)



# ORGANIZATION

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## 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**

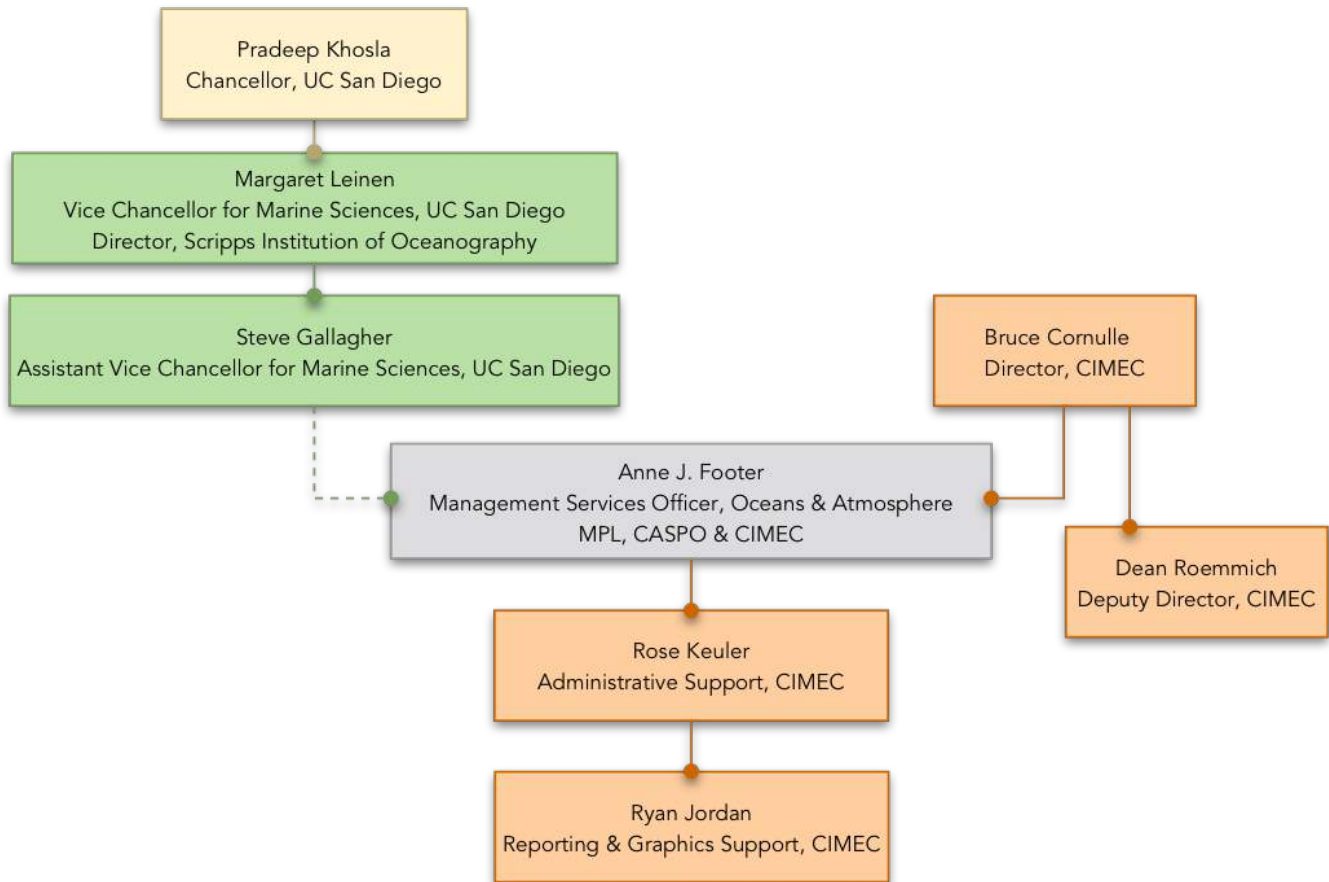
Dr. Roemmich is a professor of oceanography in the Integrative Oceanography Division and Climate, Atmospheric Science, and Physical Oceanography Division at Scripps Institution of Oceanography, University of California, San Diego. He is an expert in the general circulation of the oceans and the role 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 July 1, 2015 – March 31, 2016				
Category	Total	B.S./B.A.	M.S.	Ph.D.
Professor	3	0	0	3
Research Scientist	5	0	0	5
Visiting Scientist	1	0	0	1
Project Scientist	6	0	0	6
Postdoctoral Fellow	7	0	0	7
Programmer Analyst	3	1	2	0
Staff Research Associate/Assistant	12	3	9	0
Marine Technician	1	0	0	0
Laboratory Assistant	12	3	9	0
<b>Total (≥ 50% support)</b>	<b>50</b>	<b>7</b>	<b>20</b>	<b>22</b>

Undergraduate Students	13
Graduate Students	6

Employees less than 50% (not including students)	56
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Personnel located at a NOAA Laboratory	43
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Obtained NOAA employment (Within the last 9 months)			
Name	Position	Division/Laboratory	Date
Lyall Bellquist	Post-Doctoral Researcher	Southwest Fisheries Science Center	August 2015

Sub-Awards	
Postdoctoral Fellow	2
Graduate Student	4
Undergraduate Student	0



## CIMEC Fellows Roster

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

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

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

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

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

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

**Cherr, Gary** - UC Davis

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

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

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

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

**Klimley, Peter** - UC Davis

**Kriegman, David** - UC San Diego

**O'Dowd, Alison** - Humboldt State University

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

**Palkovacs, Eric** - UC Santa Cruz

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

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

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

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

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

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

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

**Szuwalski, Cody** - UC Santa Barbara

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

**Tissot, Brian** - Humboldt State University

**Trush, William** - Humboldt State University

**Ward, Darren** - Humboldt State University



# RESEARCH TASKS

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

as well as encouraging new areas of research to develop. These proposals are divided by theme and include all research associated funding including the funding of salaries, benefits, travel and instrumentation and computer time.

## Task 1 - Administration

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

## Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

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

## Task 3 - Individual Science Projects

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



# RESEARCH THEMES

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

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

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

### Oceanic roles in climate and global change

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

global hydrological system, including the oceans, must be addressed.

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

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

### Coastal oceans and climate

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

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

CIMEC has a myriad of tools within its partner institutions, including the long-running CalCOFI program with its 60-year time series of the California Current, at its disposal to help investigate these questions and find the solutions to the problems some of these questions pose.



## Theme B: Climate Research and Impacts

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

## Theme C: Marine Ecosystems

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

Ecosystem characteristics of particular interest are marine population dynamics, biodiversity, and biogeochemistry. The means by which these will be investigated include observing, process studies, and modeling. Collectively, the results are used to assess and predict ecosystem productivity and health for decision makers. Fishing affects both the target species and their environment. Climate change will affect marine ecosystems through rising sea level, warming, ocean acidification, deoxygenation, and potential changes in productivity and circulation.

Primary regions of interest are the California Current Ecosystem (CCE), the Eastern Tropical

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

## Theme D: Ecosystem-Based Management

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

The 60-year California Cooperative Oceanic Fisheries Investigations (CalCOFI) program is one of the longest running ocean observation programs in the world. A joint program of the Scripps Institution of Oceanography, the Southwest Fisheries Science Center (NMFS/NOAA), and the California Department of Fish and Game, CalCOFI is designed to provide data for stock assessment of key commercial species, as well as physical, chemical, and biological data on the state of the California Current ecosystem (CCE), including quantitative observations on ecologically critical species of krill, fish, seabirds and mammals. CalCOFI observations have provided the basis for much of our current understanding of the impact of climate variability (the El Niño, Pacific Decadal Oscillation, and the North Pacific Gyre Oscillation) on the CCE. In the future, CalCOFI will provide much of the observational 'backbone' for integrated ecosystem assessments (IEAs) and ecosystem-based management (EBM) of the CCE,



as well as for modeling and understanding the impacts of long-term climate change.

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

More than 15 percent of the coast of California will soon be in MPAs implemented under California's Marine Life Protection Act. Modeling of the effects of these for decision makers has been done by Partner labs, and will soon be started in a Sea Grant project to develop models to use in the evaluation of ongoing monitoring efforts.

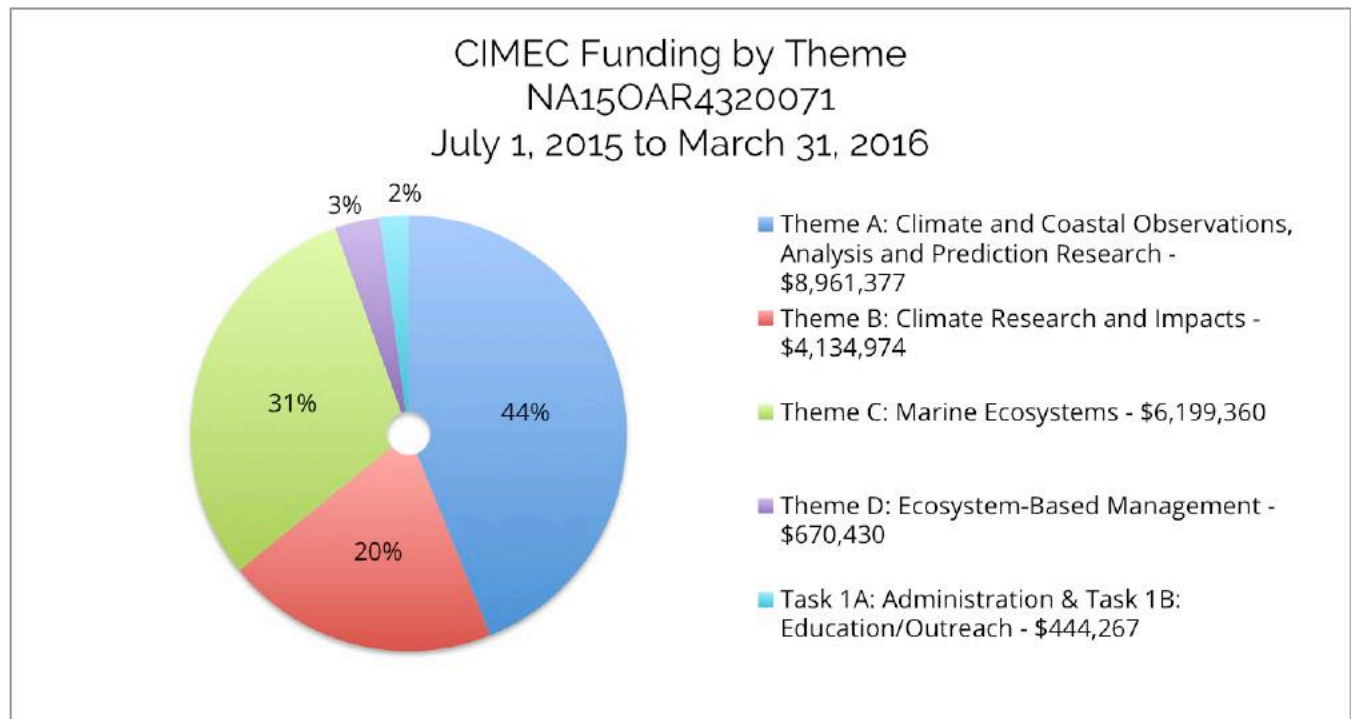
#### **The Center for Stock Assessment Research (CSTAR)**

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

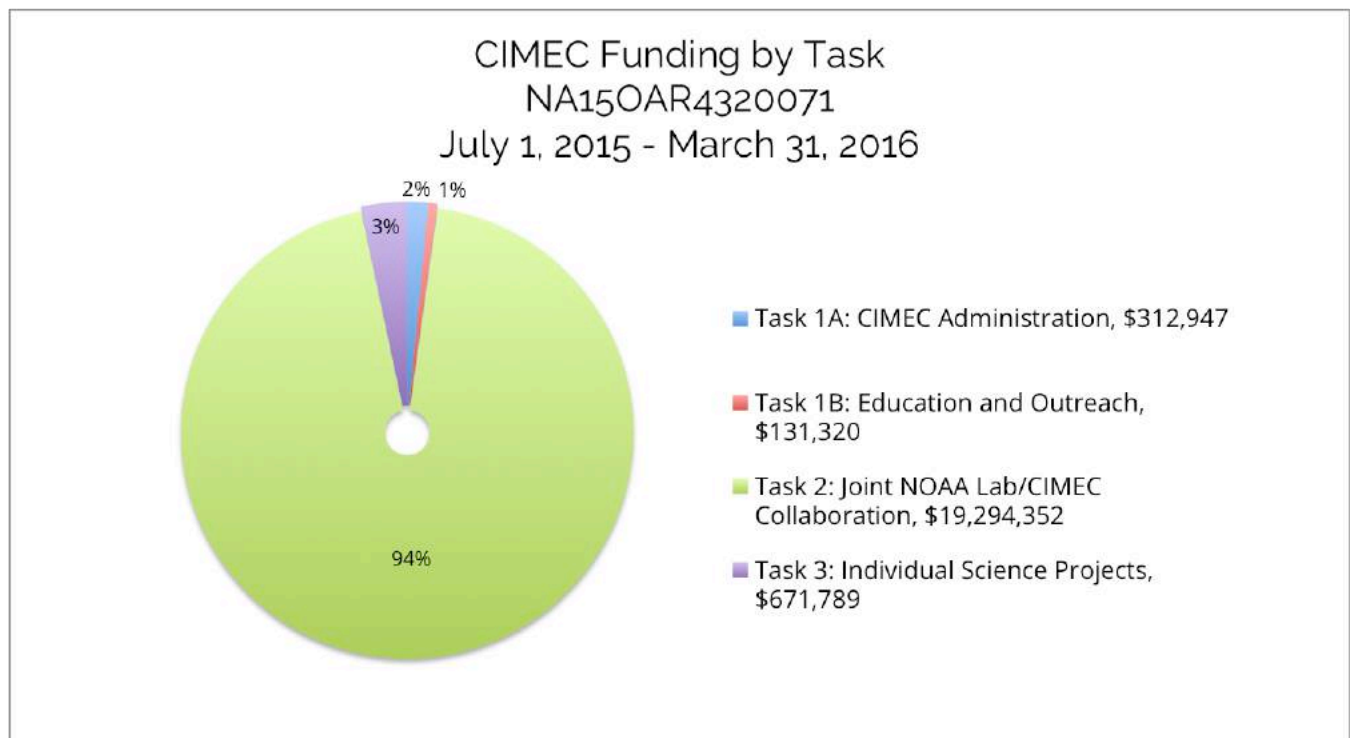


# FUNDING SUMMARY

## CIMEC Funding by Theme

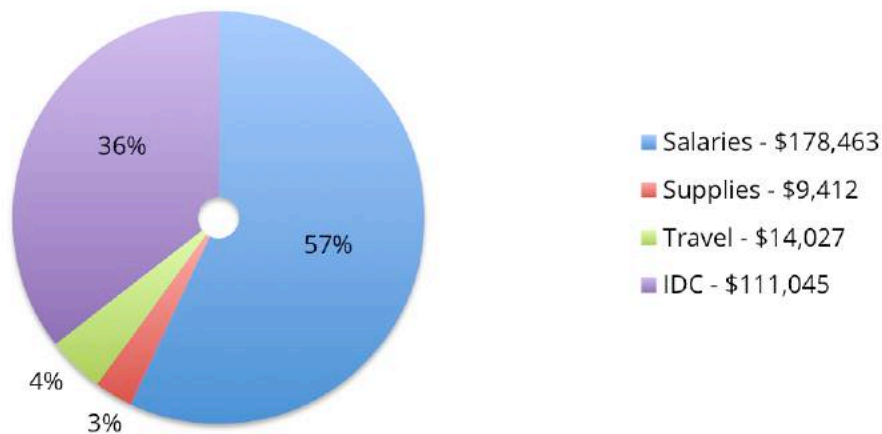


## CIMEC Funding by Task



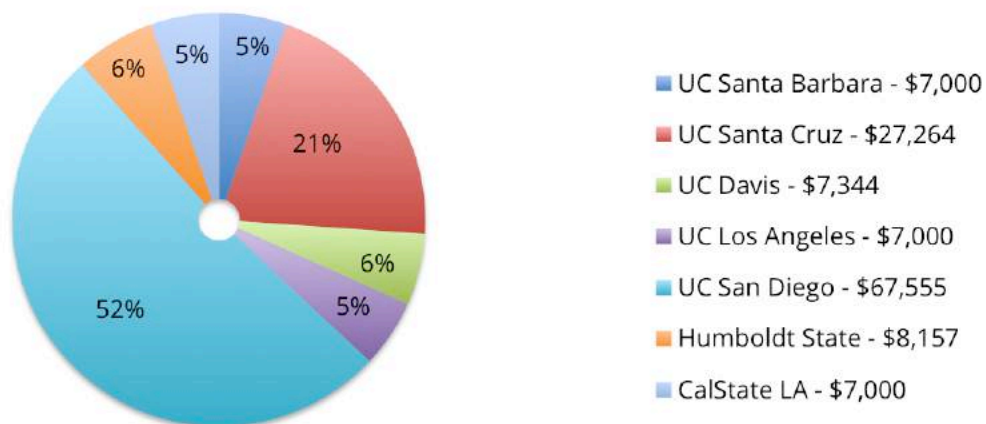
## CIMEC Task 1

### CIMEC Task 1A (Administration) Funding NA15OAR4320071 July 1, 2015 to March 31, 2016



CIMEC Task 1A activities include salary support for the CIMEC Director, the CIMEC Administrative Office, the CIMEC Administrative Analyst and the CIMEC Administrative IT. Travel activities include an annual trip to the NOAA Cooperative Institute Director's and Administrator's meeting held in Silver Spring, MD. Travel also supports Partners to travel to SIO for Executive Board Meetings. Supply activity includes communication costs, meeting venue rental and costs specific to administering CIMEC.

### CIMEC Task 1B (Education & Outreach) Funding NA15OAR4320071 July 1, 2015 to March 31, 2016



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



# RESEARCH HIGHLIGHTS

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

### Quality Control of CO<sub>2</sub>-related Measurements: Work in Support of the NOAA Ocean Acidification Program

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

- Publication in Marine Chemistry describing interlaboratory proficiency at CO<sub>2</sub> measurements in seawater.
- Dickson participated as a lecturer in numerous workshops on ocean acidification, detailing CO<sub>2</sub> chemistry in seawater and discussing measurement techniques and their quality control.

### Drought Early Warning for the California Region

**Daniel Cayan**, Scripps Institution of Oceanography, UC San Diego

- California Climate Likelihood Tool (<http://wrcc.dri.edu/col/index/>)
- Making a publically available website to show the historical context of drought for the various climate divisions throughout the country. [http://cw3e.ucsd.edu/?page\\_id=2956](http://cw3e.ucsd.edu/?page_id=2956)
- Working with KPBS (San Diego's NPR) to track the drought with the "Drought Tracker" (<http://www.kpbs.org/news/drought-tracker/>)

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

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

**Ralf Goericke**, Scripps Institution of Oceanography, UC San Diego

- Observation of 2015-2016 El Niño, including warming, deep salinity maximum, and observations of warm-water taxa.
- Observation of anomalous warming of N Pacific.
- Continued underway pH and pCO<sub>2</sub> measurements.
- Continued observations by ancillary programs (seabirds, marine mammals, NSF-funded CCE-LTER program)
- Two years of NOAA-CalCOFI Ocean Genomics (NCOB) samples analyzed and manuscript in preparation.
- Completion of collaboration with Dr. Ken Buesseler (WHOI) on collection and analysis of water to trace radioactivity from Fukushima accident.
- Publications based on CalCOFI data on California Current System physics, chemistry, biology, ecosystem and fisheries.



## CalWater and West Coast Atmospheric River Research

**Marty Ralph**, Scripps Institution of Oceanography

- Western States Water Council and NOAA workshop in Salt Lake City, Utah, October 2015; Ralph presented on requirements, planning and concept development for S2S
- Western States Water Council Workshop in Las Vegas Nevada, Dec 2015; Workshop focused on Southern Colorado River Basin Stakeholder
- Western States Water Council and NOAA workshop in Washington D.C., Ralph presented on requirements, planning and concept development for S2S

## The Argo Project: Global Observations for Understanding and Prediction of Climate Variability

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

- Two prototype Deep SOLO floats were successfully recovered in the SW Pacific Basin by RV Kaharoa, having completed 110 cycles each to the ocean bottom in 5700 m depth.
- 371 research papers were published in 2015 using Argo data – more than a paper per day! - <http://www.argo.ucsd.edu/Bibliography.html>
- The Argo Program has obtaining more than 1.5 million Temperature/Salinity/Pressure profiles since 2000.
- The Argo Program has sustained its global coverage of more than 3000 active floats since 2007.
- An updated assessment of global ocean heat gain ( $0.7 \text{ W m}^{-2}$  averaged over the area of the Earth) was published by S. Wijffels, D.

Roemmich, D. Monselesan, J. Church and J. Gilson in Nature Climate Change.

## SIO High Resolution XBT Transects

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

- High Resolution XBT data provide the near-surface and subsurface temperature structure and the geostrophic current, 0-800m, flowing across the sampled routes, on a quarterly basis and with spatial resolution as fine as 10-15 km in boundary current regions.
- Many of the HR-XBT transect lines now have 2-3 decades of high-resolution temperature and geostrophic velocity measurements (e.g. PX-06; PX-30)
- Data from Scripps High Resolution XBT transects have been used in 10 PhD dissertations.
- The HR-XBT network is at present the main element of the global observing system to provide systematically repeating observations to resolve the western boundary currents (WBCs). Ongoing effort at SIO to form a climatic index of the time-mean and varying WBC transport from HR-XBT, Argo and altimetry (N. Zilberman).
- The HR-XBT data and other components of the global observing system are included in the ocean state estimate, Estimating the Circulation and Climate of the Ocean (ECCO) framework, based on the MIT GCM and its adjoint model. Ongoing analysis will evaluate the contribution of the different observational types (including the HR-XBT data) to the skill of the state estimate for determining the Pacific ENSO variability (B. Cornuelle). This type of assessment will contribute to the redesign of the ENSO-Observing System (as part of TPOS-2020) for better effectiveness and efficiency.



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

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

- The California Underwater Glider Network has provided fundamental measures of the 2014-2015 Pacific anomalies.
- A California Current index is now routinely generated.
- New results about spin-up of Southern California recirculation cell and cross-shelf upwelling circulation in moored ADCP data have been obtained.
- A nearly 8-year record of glider sections has been assembled and cross-checked to construct time series of volume, heat and freshwater transport in depth and density layers. These time series show a clear correspondence of events in the Nino 3.4 SST and equatorward transport, particularly in the shallow layers; warm SST corresponds to strong transport. The record also shows that transport builds gradually but steadily from cold events to warm ones.
- Potential to derive SS transports and shear from bottom pressure and altimetry alone
- Volume transport estimation for the East Australian Current off Brisbane based on High Resolution XBT, Argo, and Altimetry, and validated by nearby moored observations.
- Discovery of a new current – the East Pacific Rise Current – generated by interaction of the interior South Pacific Gyre with topography.
- Participation in the redesign of the Tropical Pacific Observing System (TPOS 2020).
- Estimation of global ocean heat gain and its spatial patterns based on Argo (2006 – 2014).

- Description of multi-decadal changes in the temperature, salinity, and wind-driven interior circulation of the South Pacific Gyre.
- Continued improved and updated state estimate.

## HF Radar National Network Data Management Development

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

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

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

1. Gaviota, CA (TRL1) University of California, Santa Barbara – Oil Spill Response  
<http://cordc.ucsd.edu/projects/mapping/stats/?sta=TRL1>
2. Pepe'ekeo, HI (PPK) University of Hawaii  
<http://cordc.ucsd.edu/projects/mapping/stats/?sta=PPK>
3. Keaukaha, HI (KKH) University of Hawaii  
<http://cordc.ucsd.edu/projects/mapping/stats/?sta=KKH>
4. Conalep, Mexico (CON) Universidad Autonoma de Baja California  
<http://cordc.ucsd.edu/projects/mapping/stats/?sta=CON>
5. Ponce Yacht and Fishing Club at Ponce, Puerto Rico (PYFC) University of Puerto Rico  
<http://cordc.ucsd.edu/projects/mapping/stats/?sta=PYFC>
6. <http://cordc.ucsd.edu/projects/mapping/stats/?sta=PYFC>



7. Cabo Rojo Lighthouse at Cabo Rojo, Puerto Rico (FARO) University of Puerto Rico
8. <http://cordc.ucsd.edu/projects/mapping/stats/?sta=FARO>
9. Icy Cape, AK (ICYC) University of Alaska Fairbanks  
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=ICYC>
10. Kapolei, HI (KAP) University of Hawaii  
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=KAP&aff=UH>
11. Old Bridge Waterfront Park, NJ (OLDB) Rutgers University  
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=OLDB>
12. Amagansett, New York (AMAG) Rutgers University  
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=AMAG>
13. Punta Tuna Lighthouse, Maunabo, Puerto Rico (MABO) University of Puerto Rico  
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=MABO>

#### Decommissioned Sites:

1. (TRL1) University of California, Santa Barbara – temporary site
2. (PTLY) University of Alaska Fairbanks

#### Supported Domains and available data:

1. USEGC - US East and Gulf Coast - 2008-03 through present
2. USWC - US West Coast - 2008-03 through present
3. AKNS – Alaska North Slope – 2006-11 (when available)
4. GAK - Gulf of Alaska - 2009-05 through present (when available)
5. PRVI - Puerto Rico and US Virgin Islands - 2010-01 through present
6. USHI – US Hawaii – 2010-07

## Meridional Overturning Variability Experiment (MOVE)

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

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



## Theme B: Climate Research and Impacts

### The Global Drifter Program

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

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

### Measurements of $O_2/N_2$ and $Ar/N_2$ ratio by the Scripps $O_2$ program

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

- Measurements have continued which resolve global atmospheric trends in  $O_2$  and  $CO_2$  and can quantify global carbon sinks
- Data from program are increasingly relied on as benchmark for ocean biogeochemical model validation
- The data provide emergent constraints on natural ocean heat transport from southern to northern hemispheres.
- The data provide emergent constraints on natural ocean heat transport from southern to northern hemispheres.

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

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

- Recovery and re-deployment of two equivalent highly instrumented real-time moorings across the California Current ecosystem with physical, chemical, carbon, and ecosystem sensors
- Quantification of upwelling circulation during the 2014/15 warm anomaly
- Confirmation of anomalous poleward advection
- Impacts of the warm anomaly on biogeochemistry and ecosystem
- Early-Start Proposal to Begin Development of an Atmospheric River-Focused CDR (Climate Data Record) in Support of Regional
- Stakeholder Needs and Scientific Interests Including Drought and Flood



## Early-Start Proposal to Begin Development of an Atmospheric River-Focused Climate Data Record in support of Regional Stakeholder Needs and Scientific Interests Including Drought and Flood

**Marty Ralph**, Scripps Institution of Oceanography

- A methodology for AR detection has been implemented and tested
- A catalog of AR from 1949-2014 has been developed
- Verification shows agreement with the GS and SSM/I observation
- Continuing verification and refinement is being performed
- CA Department of Water Resources held a Winter Outlook Workshop at SIO in November 2015, where we (Gershunov) presented experimental results using the new Catalog.

## NOAA Support for the CLIVAR and Caron Hydrographic Data Office at UCSD/SIO 2015

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

- Continued increase of US and non-US CTD profiles, both public and non-public, available for Argo reference data.
- Continued reconciliation of EXPOCODE expedition identifiers among US data centers.
- Continued improvement of the means for large data users (e.g., modelers) to directly download any/all data of interest, for example

all-basin data, or all program (e.g. WOCE) data.

- On-going harmonization of disparate data centers and the data from various large-scale hydrographic surveys has led to a better "capture percentage" of all data (US-HYDRO, GO-SHIP, DIMES). Because the CCHDO carries out data curation for these programs, their data interoperability is improved as the metadata and discovery information. NOAA/NCEI benefits because it obtains all curated data from the CCHDO.
- NOAA funded observations are captured by the CCHDO through the GO-SHIP, Argo and OceanSITES programs and are provided in a uniform format with consistent content. The CCHDO is an IODE Associated Data Unit (ADU), a class of IODE members created specifically to include organizations such as BCO-DMO, CDIAC and the CCHDO, on par with each member nation's national oceanographic data center.
- The CCHDO's involvement in IODE, SOOS, Argo, OceanSITES, GO-SHIP, DIMES and related organizations leads to continued improvement in the areas of NOAA interest funded by the award. For example CCHDO-related data issues raised by the Argo Coriolis team have been resolved.



## Theme C: Marine Ecosystems

### Collaborative Opportunity: Exploring 'omic Technologies to Support Ecosystem Understanding and Fisheries Assessments

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

- Design and implementation of MiSeq technologies
- Implementation of epmotion robotics platform
- Data generated for 16S and 18S DNA for 2014 and 2015 samples (all four cruises)
- Preliminary analyses of data suggest large scale contrast between cyano dominated vs diatom dominated food webs

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

**David Kriegman**, Jacobs School of Engineering, UC  
San Diego

- A new upload function has been implemented to allow users to more conveniently upload archived sets of annotations.
- The page to view image details has been updated to allow for better control of the image settings.
- The vision backend-system has been updated to better handle large set of images uploaded as part of NOAA's analysis.
- An updated sign-up procedure makes signing up to the website more convenient

- Thorough experimentation has been conducted on the appropriate implementation of deep learning methods for computer vision.
- New, "background" deep learning model has been trained on over 2Million annotations harvested from CoralNet.
- Advances of the new method have been demonstrated on a publically available data set and demonstrate very significant improvements in recognition accuracy.

### Collaboration in Freshwater Ecology Research

**Eric Palkovacs**, UC Santa Cruz

- Published the first genetic assessment identifying the natal origins of river herring bycatch and potential impacts on river herring recovery.
- Published a paper illustrating the ecological importance of sex ratio variation in a widespread invasive fish species.

### Investigations in Fisheries Ecology

**Eric Palkovacs**, UC Santa Cruz

- Published a journal article relating trends in hatchery practices to strength of portfolio effects in Central Valley Chinook salmon
- Published a journal article using genetic techniques to learn about the ocean spatial distribution of multiple Chinook salmon stocks
- Published a commentary about climate change and adaptive responses in Pacific salmon
- Published a report on the feasibility of parentage-based genetic tagging (PBT) in management of Pacific salmon
- Submitted a manuscript on methods for integrating high-resolution spatial data from vessel monitoring systems with traditional sources of fisheries management data.



- Published a journal article describing historical fishing mortality rates for Sacramento River winter-run Chinook salmon.
- Published a Technical Memorandum describing the proceedings of a workshop focused on evaluation of the feasibility of developing alternative fishery management strategies for California coastal Chinook salmon.
- Implemented a feasibility study to develop and test a variety of Passive Integrated Transponder (PIT) tag detection systems to assess the feasibility of implementing large scale tagging and detection programs in the Central Valley and Sacramento-San Joaquin Delta for monitoring movement and survival of listed salmonids. Designed and installed prototype detection arrays on the San Joaquin and Mokelumne River for field-testing in spring 2016.
- Published a journal article on methods for measuring relative predation risk on salmonid smolts using Predation Event Recorders (PERs).
- Published a journal article reporting on effectiveness of spatial closures for rockfish recovery.
- Published a Technical Memorandum on the benefits to steelhead of Carmel River Reroute and Dam Removal
- Published a journal article describing the reproductive strategy and annual reproductive cycle of Pacific sanddab in California waters.
- Published a journal article describing the importance of age data in developing accurate stock assessments for West Coast groundfish populations.
- Completed stock assessments of Bocaccio and Chilipepper rockfish, both including updated life history and reproductive ecology data, to support fisheries management.
- Published a journal article on the cooperative fishery research project with the ocean salmon fishing fleet on ocean distribution and migration patterns of Chinook salmon in the California Current.

- Published a journal article outlining the genetic relationships of steelhead and rainbow trout from hatcheries and natural populations in the California Central Valley.

## Collaborative Ocean Observing and Fisheries Oceanography Research off Northern California

**Brian Tissot**, Humboldt State University

- Roxanne Robertson continued to serve as lead technician, where she coordinated and often led hydrographic and biological sampling on 12 cruises along Trinidad head Line (THL).
- Completion of a retrospective analysis of euphausiid abundance and community for the THL time series and presentations of these and complementary results at several conferences and workshops.

## Freshwater Fish Ecology Research Collaboration

**Darren Ward**, Humboldt State University

- Recent project alumni published two peer-reviewed journal articles: recent graduate student Meiling Roddam published an article based on her thesis research on life history of Chinook salmon in the Klamath River in Ecology of Freshwater Fish, recent undergraduate research student Ryan Vazquez published an article based on his independent study project on New Zealand mud snails in Redwood National Park in Biological Invasions.
- Molly Gorman completed stable isotope analysis of otoliths of adult coho salmon that had returned to spawn in the Klamath River. Strontium isotope variation in the juvenile region of these otoliths indicates that nearly half of them had juvenile life histories that involved movement among multiple rearing locations.
- Darren Ward organized and moderated a symposium on life history diversity and plasticity



at the national meeting of the American Fisheries Society in Portland Oregon in August 2015. Graduate students Gabe Scheer, Michelle Krall, and Molly Gorman also presented at the conference.



## Theme D: Ecosystem-based Management

### Tethys Bioacoustics Metadata Workbench Improvements

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

- Improved version 2.3 of Tethys is available online
- Increased use of Tethys by a larger number of users outside of the initial developers and collaborators.
- Several peer-reviewed journal articles that used Tethys-generated output are published and underway.

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

**Dr. Gary N. Cherr**, Bodega Marine Laboratory, UC Davis

- Greatest captive white abalone spawning in the history of the white abalone recovery program.
- Successful distribution of competent larvae to partner institutions.
- Successful distribution of F2 animals to partner institutions.
- Advancements in understanding the effects of photoperiod on reproductive condition.

### Green Sturgeon Habitat Suitability in Response to Drought Related Flow Regimes

**Peter Klimley**, UC Davis

- Baseline model for measured habitat units and multi-dimensional fish movement data complete
- Defined criteria of preferences for substrate, velocity, and depth

### Training the Next Generation of Marine Population Dynamics Scientists

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

- Lab members authored or co-authored 5 peer-reviewed manuscripts, 2 in press, and 1 PhD dissertation
- Lab members authored or co-authored 7 conference presentations
- PI Semmens taught an 'Intro to Field Methods' undergraduate course
- PI Semmens taught a grad. level course in Bayesian modeling with joint attendance by SIO and SWFSC students and scientists
- Lab members helped coordinate and implement a CAPAM Data Weighting workshop
- Lab Members maintained and downloaded set of data from 44 hydrophones that compose the La Jolla Acoustic Array (LJAA)
- PI Semmens co-edited a special issue in Fisheries Research related to growth models in fisheries assessments
- PI Semmens participated in collaborative research into Cowcod with SWFSC scientists
- Lab members coordinated 3 summer outreach student group visits for underserved community high schools
- PI Semmens executed the annual Grouper Moon K-12 education/outreach program for schools throughout the Caribbean and US



## “Fixing” Retrospective Biases in Stock Assessment and Implications for Management Targets

**Cody Szuwalski**, Marine Science Institute, UC Santa Barbara

**Steve Gaines**, Marine Science Institute, UC Santa Barbara

- Built full-feedback simulation framework (see at [www.github.com/szuwalski/General-MSE](http://www.github.com/szuwalski/General-MSE))
- Generated retrospective biases in simulated populations
- ‘Fixed’ retrospective biases through allowing for time varying processes in the stock assessment

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

**William J. Trush**, Humboldt State University

**Alison O’Dowd**, Humboldt State University

- Identification of two basic annual recession hydrographs that can be regionalized using dimensionless daily average flow duration curve.
- The rating curve for an unsubmerged natural riffle has many characteristics of the rating curve for a broad crested weir. The rate of the rate-of-change in stage with streamflow, i.e., the second derivative of a general weir equation, provides an objective methodology for identifying transitions in the type of hydraulic control a given streamflow exerts. The transition from complete section control

to complete channel control is of great ecological interest. Rating curve inflections from historic USGS gaging station rating curves are used to identify hydraulic thresholds, and with field data corroboration, interpreted as ecological streamflow thresholds.



# RESEARCH PROJECTS

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

### Quality Control of CO<sub>2</sub>-related Measurements: Work in Support of the NOAA Ocean Acidification Program

#### Principal Investigator(s):

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

#### NOAA Primary Contact:

**Dr. Libby Jewett**, NOAA Ocean Acidification Program

#### NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

#### NOAA Theme:

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

#### Related NOAA Strategic Goal(s):

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

#### Budget Amount:

\$74,939

#### Amendment No.:

6

#### Keywords:

Ocean Acidification

#### Milestones:

- 2015 Workshop on Quantifying Uncertainty in Seawater CO<sub>2</sub> measurements was held at SIO

#### Research Objectives:

The aim of these activities is to facilitate evaluation of, and improvement in, the quality of CO<sub>2</sub>-related measurements made in support of

the NOAA Ocean Acidification Program. The initial requirement is to ensure that the NOAA OAP agrees upon requirements for the uncertainty of measurements of pH, total alkalinity, and total dissolved inorganic carbon that are appropriate to the scientific aims of the program. Next, we shall provide examples of how to estimate the overall uncertainty of each of these measurements, and offer advice to the laboratories as to how to do this for the measurements that they undertake. A key aspect of the effort proposed here is the design and execution of Proficiency Tests (one per year) for these various measurements which will enable the various laboratories (and the NOAA OAP) to assess if they are meeting the agreed on quality requirements of the Program. Finally, each year we shall hold a 3-day workshop focused on some aspect related to laboratory CO<sub>2</sub> measurements and their quality control.

#### Research Accomplishments:

During this period we have accomplished the following activities:

- (1) Continued to collect and analyze samples from quarterly CalCOFI cruises. Samples are analyzed for total dissolved inorganic carbon, total alkalinity, and salinity. Some additional samples are also analyzed for spectrophotometric pH. Samples were collected on the following cruises: CalCOFI 1507OC (July 2015); CalCOFI 1511OC (November 2015) and CalCOFI 1601RL (January 2016) – the analyses for these are still in process.



- (2) Have performed a complete uncertainty analysis for measurements of total alkalinity and of total inorganic carbon measurements appropriate to the Dickson laboratory at SIO. This work is presently being prepared as a manuscript. Initial work has been started on estimating the uncertainty for spectrophotometric pH measurements in the lab.
- (3) In June 2015, a workshop on Quantifying Uncertainty in Seawater CO<sub>2</sub> measurements was held at SIO for NOAA personnel, and for other individuals associated with the NOAA Ocean Acidification program. Thirteen scientists attended the workshop.

Planning is now in process for another workshop to be held in summer 2016. This will focus on the measurement of pH, including its likely uncertainties, and will provide some hands-on experience.

### Conferences, Meetings & Presentations

- a. Second WESTPAC Training Workshop on Research and Monitoring of the Ecological Impacts of Ocean Acidification on Coral Reef Ecosystems, 26-28 August 2015, Phuket Thailand where Andrew Dickson was an invited lecturer.
- b. IAEA Training Course on Best Practices in Ocean Acidification Research, 19-23 October 2015, Xiamen, China where Andrew Dickson was an invited lecturer.
- c. IAEA Training Course on Best Practices in Ocean Acidification Research, 2-6 November 2015, Cape Town, South Africa where Andrew Dickson was an invited lecturer.
- d. QUASIMEME Workshop on Ocean Acidification, 3-5 February 2015, Southampton, United Kingdom where Andrew Dickson was an invited lecturer



# Drought Early Warning for the California Region

## Principal Investigator(s):

**Daniel Cayan**, Scripps Institution of Oceanography, UC San Diego

## Other Key People

**Anthony LeRoy Westerling**, Sierra Nevada Research Institute, UC Merced

**Shraddhanand Shukla**, Department of Geography, UC Santa Barbara

## NOAA Technical Contact(s):

**Caitlin Simpson**, Climate Program Office

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC Collaboration

## NOAA Theme:

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

## Related NOAA Strategic Goal(s):

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

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

## Budget Amount:

\$420,000

## Amendment No.:

11

## Keywords:

Drought, Wildfire, Stakeholder Engagement, Forecasting

## Milestones:

- NIDIS California DEWS Winter Status Update – Jan. 22 (S. CA), Jan 26 (webinar)
- [http://cnap.ucsd.edu/nidis\\_socal\\_20160122.html](http://cnap.ucsd.edu/nidis_socal_20160122.html)
- [http://cnap.ucsd.edu/nidis\\_webinar\\_20160126.html](http://cnap.ucsd.edu/nidis_webinar_20160126.html)

- California Climate Likelihood Tool (<http://wrcc.dri.edu/col/index/>)
- Making a publically available website to show the historical context of drought for the various climate divisions throughout the country. [http://cw3e.ucsd.edu/?page\\_id=2956](http://cw3e.ucsd.edu/?page_id=2956)
- Working with KPBS (San Diego's NPR) to track the drought with the "Drought Tracker" (<http://www.kpbs.org/news/drought-tracker/>)

## Research Objectives:

The California-Nevada Climate Application Program (CNAP), in collaboration with the National Integrated Drought Information System (NIDIS), is taking a leading role in California to understand the informational needs of decisions makers and provide better forecasts, risk assessments and drought awareness to reduce the impacts of drought. Throughout this year, CNAP has worked on, and will continue to work on projects, that enhance drought impact monitoring and forecasting as well as stakeholder engagement and communication. Through analysis of the NMME, researchers are determining the best models that are part of the ensemble at predicting drought and why. CNAP is using statistical approaches to understand how drought relates to wild fire severity and is also characterizing how drought affects wild fire behavior. In addition CNAP has been engaging with stakeholders on drought monitoring through presentations, drought tracking websites and media interviews. There was a lot of interest in how El Nino would affect the drought.

## Research Accomplishments:

CNAP work on forecasting led to two new important research findings. First, Dr. Shukla showed that of the models that are included in the North American Multi-Model Ensemble (NMME), CCSM4 forecasted weakest El Niño and in JFM forecasts for each events CCSM4 and CMC1-CanCM3 SST forecast anomalies were the weakest whereas and NASA-GMAO SST anomalies were the strongest. Based on this he conclude



that CCSM4 and CMC1-CanCM3 models should be given less weight or removed from the NMME forecast to produced and overall improved forecast. In addition, research by CNAP scientists Cayan, Icoabellis, and Tyree that dry years can be characterized quite effectively using a census of weather types via a cluster analysis of winter 500hPa height anomaly patterns which show dry years in California and Nevada do not arise from one pattern -- multiple patterns are involved. This finding has potential help with the forecasting of dry months supporting a drought early warning system.

CNAP researchers have been investigating the connections between drought and wildfire through two different approaches. Dr. Westerling and a graduate student have looked at a through analysis of the six most severe droughts of the western United States over the last 100 years. The research has shown that the drought in 2014 resulted as a combination of high temperature and low precipitation coordinates, while the drought in 1930's was primarily caused by low precipitation. These two droughts also affected different types of vegetation with the drought in the 1930's affecting in normally wet forested areas, whereas the 2014 drought saw higher severity in drier woodlands, croplands, and bare or sparsely vegetated areas (Figure 1). This work will continue over summer and fall 2016, extending the analysis to look at the effects of the last two major droughts on wildfire activity. In addition work with stakeholders have shown there is a need to identify drought information that is currently used by the fire management community and determine how it is used in decision-making. Also the wildfire community also determined two important areas of research include understanding drought impacts on fire behavior and effect and researching the efficacy

of fuel treatments (all types) in the context of drought.

CNAP team has been heavily involved with stakeholder engagement. Some of which is included below in highlights and communications.

## Conferences, Meetings & Presentations

- a. California Water Action Plan 2.0, January 14, 2016; Sacramento, CA
- b. Nevada Water Resources Association Annual Meeting, March 1-3, 2016, Las Vegas, NV
- c. Southern California Water Commission Urban Drought Workshop, March 30, 2016, Los Angeles, CA
- d. Annual RISA Meeting, February 2016, Tucson, AZ
- e. Great Basin Climate Forum, April 5, 2016, Reno, NV
- f. CDWR Drought Response Workshop, May 16-17, 2016, Irvine, CA

## Education & Outreach

### Communication

- a. NIDIS California DEWS Winter Status Update – Jan. 22 (S. CA), Jan 26 (webinar)  
[http://cnap.ucsd.edu/nidis\\_social\\_20160122.html](http://cnap.ucsd.edu/nidis_social_20160122.html)  
[http://cnap.ucsd.edu/nidis\\_webinar\\_20160126.html](http://cnap.ucsd.edu/nidis_webinar_20160126.html)
- b. Workshop, Wildfire and Drought: Impacts on Wildfire Planning, Behavior, and Effects (Oct)  
<https://www.drought.gov/drought/documents/wildfire-and-drought-impacts-wildfire-planning-behavior-and-effects>
- c. Two page informational handouts on El Nino and Snowpack  
[http://cnap.ucsd.edu/pdffiles/CNAP\\_Snowpack.pdf](http://cnap.ucsd.edu/pdffiles/CNAP_Snowpack.pdf)  
[http://cnap.ucsd.edu/pdffiles/CNAP\\_ElNino\\_Dec2015.pdf](http://cnap.ucsd.edu/pdffiles/CNAP_ElNino_Dec2015.pdf)



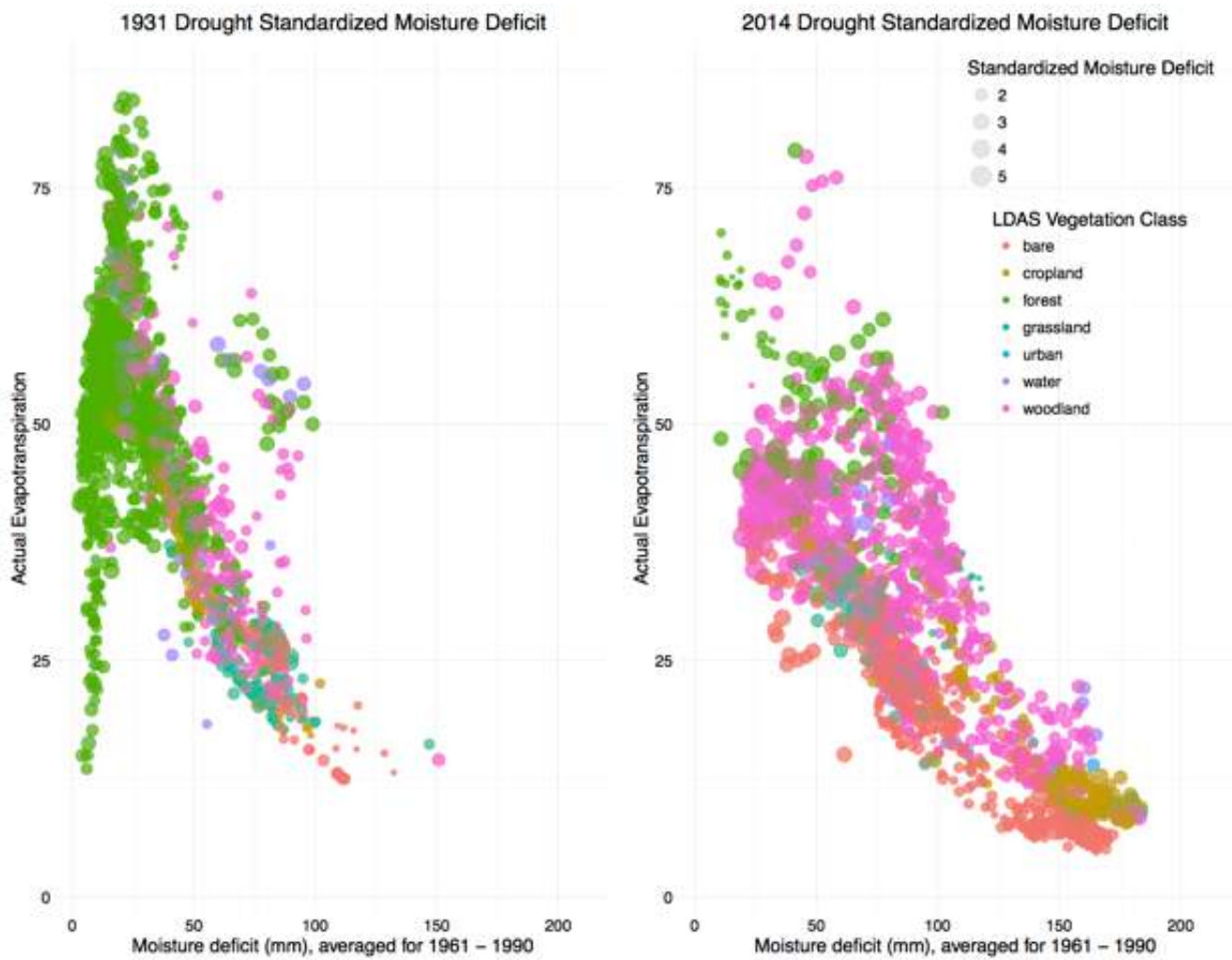


Figure 1: The three year droughts ending in 1931 and 2014 were the largest multiyear droughts in the period studied, but were dissimilar in terms of vegetation affected, severity in the third year of the drought, and climate of affected area. The 1931 drought exhibited lower standardized moisture deficit severity in normally wet forested areas, while the 2014 drought saw higher severity in drier woodlands, croplands, and bare or sparsely vegetated areas.



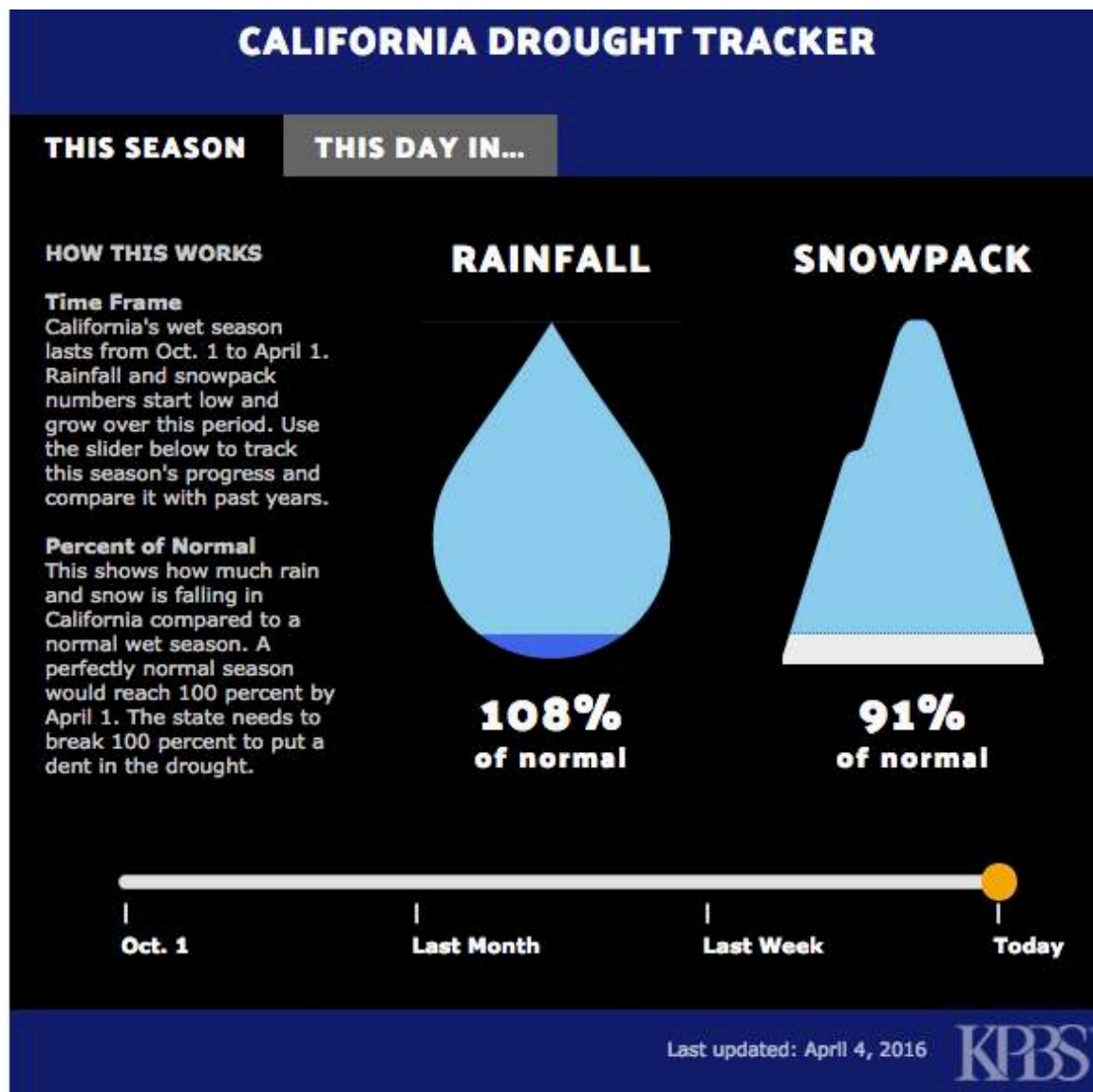


Figure 2: This is the drought tracker that CNAP developed with KBPS that the public used to track how El Nino impacted the drought in California



# California Cooperative Oceanic Fisheries Investigations: Ocean Observations to Inform Ecosystem-Based Management (CalCOFI)

## Principal Investigator(s):

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

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

## NOAA Technical Contact(s):

Dr. Ned Cyr, NOAA Fisheries

Dr. Francisco Werner, 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: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management;

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

## Budget Amount:

\$1,422,423

## Amendment No.:

18

## Keywords:

Ecosystem, Oceanography, Fisheries, Climate, Time Series, California Current, Ecosystem-Based Management

## Milestones:

- Four cruises successfully executed: July and October-November 2015 and January and April 2016.

- Hydrographic data analyzed and made available electronically for four quarterly CalCOFI cruises in 2015.
- 2015 CalCOFI Reports published and distributed electronically.
- Provided SIO contribution to annual State of the California Current Report.
- Publication of papers based on CalCOFI data in peer-reviewed journals.

## Research Objectives:

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

Our specific plan to achieve these objectives is, in collaboration with NOAA's SWFSC, to conduct quarterly cruises in the CCS, analyze the resultant data and samples, make the data and results available to users, and present those results in the peer-reviewed literature and at meetings, including the annual CalCOFI Conference. We also work closely with ancillary programs, including the NSF-sponsored CCE-LTER study and marine mammal and seabird observers.

## Research Accomplishments:

Accomplishments this year by the CalCOFI program include successful completion of four quarterly cruises, observation of anomalous North Pacific warming and the 2015-2016 El Niño, continuation of directed genomics observations, underway pH and pCO<sub>2</sub> measurements. Journal publications were on topics including physics (e.g.,



circulation and upwelling), chemistry (nutrient dynamics), biology (primary production, plankton, forage fish, seabirds and the ecosystem) and modeling. Many are related to fisheries management and climate variability and change.

### **Conferences, Meetings & Presentations**

- a. Outlook: El Niño, Storms and Ocean Conditions, Scripps Institution of Oceanography, La Jolla, CA, November 19, 2015, with Dave Checkley
- b. Changing Ocean Conditions: Understanding El Niño's Impacts on California's Living Marine Resources Through Ocean Observations, Ocean Protection Council Workshop, September 22, 2015, Sacramento, CA, with Dave Checkley, Laura Rogers-Bennett, Emmanis Doval, and Cheryl Peach

### **Education & Outreach**

#### **Networking**

- a. Continuing collaborative relationships with other ocean observation programs on the West Coast with CenCOOS, a close collaborator with SCCOOS.
- b. Provide CalCOFI data to global ocean time series data center with OceanSites, a CalCOFI partnership.
- c. Ongoing partnerships with to maintain ancillary observations of seabirds, marine mammals, and biogeochemistry and lower trophic levels with Farallon Institute, Hildebrand Laboratory at Scripps Institution of Oceanography, and the CCE-LTER Program.
- d. Provide CalCOFI input to integrated ecosystem assessment and ecosystem-based management of the California Current with Pacific Fisheries Environment Lab at SWFSC/NOAA.
- e. Continued ocean acidification monitoring with PMEL/NOAA.
- f. El Niño Workshop for California Ocean Protection Council, Sacramento, CA with the Ocean Protection Council (OPC).

- g. Foster CalCOFI partnerships with North Pacific rim marine research. Member of PICES, participation in Technical Committee on Data Exchange (TCODE) and Advisor Panel for Program in East Asian Marginal Seas (AP-CREAMS).

#### **Fellowships & Internships**

- a. Approximately 6 people per year provided opportunity to experience oceanographic research, volunteering on CalCOFI cruises.





Figure 3: Pelagic red crabs (*Pleuroncodes planipes*) collected offshore of Southern California in a plankton net during the winter, 2016, CalCOFI cruise. Red crabs (also known as tuna crabs) are indicative of the warm water associated with the 2015-2016 El Niño. (Figure courtesy of James Wilkinson, SIO CalCOFI)



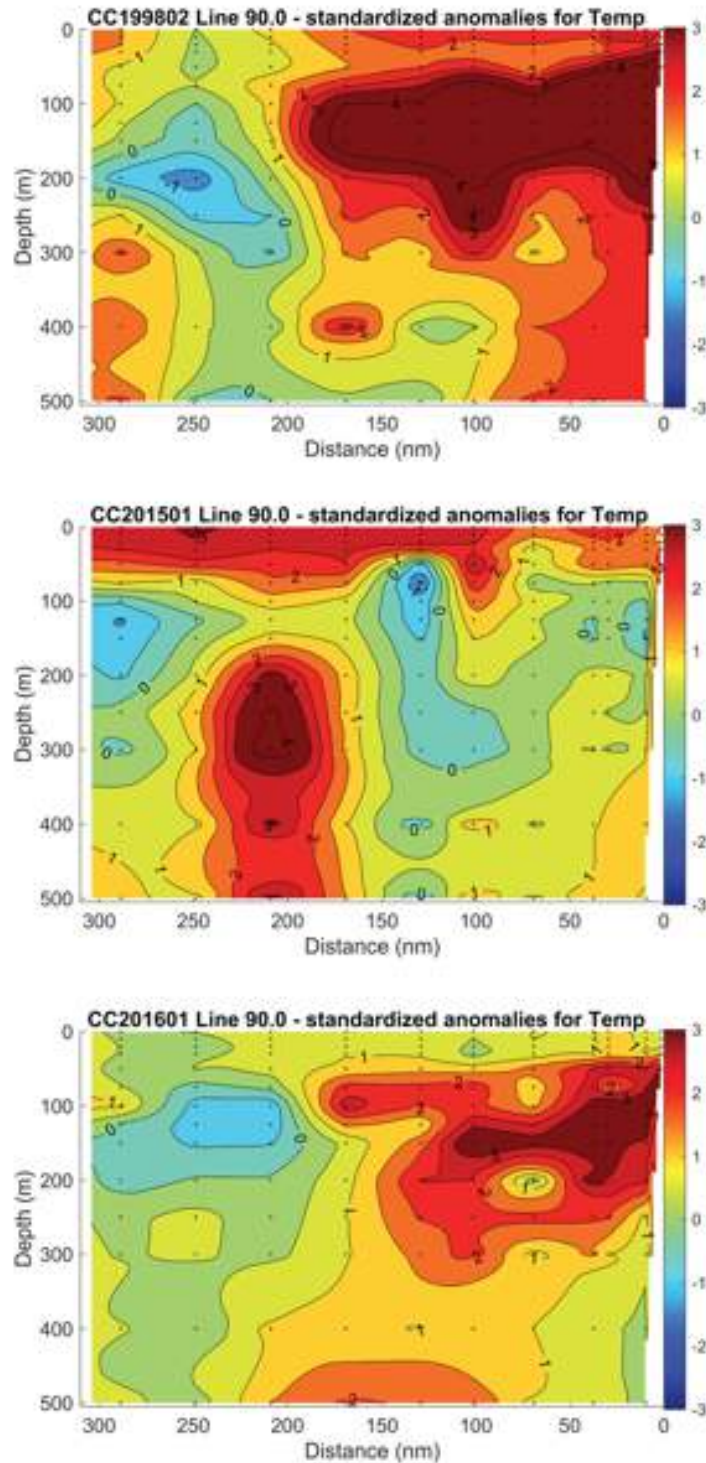


Figure 4: Temperature anomalies along CalCOFI Line 90 during the winters of 1998, 2015 and 2016 illustrate the different responses of the system to forcing by an El Niño (1997-98 and 2015-16) and by the 2014-16 warm anomaly. During El Niño, the strongest relative anomalies (normalized by the StDev of the property) are found at depth, consistent with propagation from the Equator along the coastal boundary. During the warm anomaly, temperatures were elevated only at the surface, consistent with atmospheric forcing. The strong subsurface anomaly 200 nm offshore in 201501 was confined to Line 90, indicating it was a local, not regional, phenomenon. (Figure by Dr. Ralf Goericke)



# CalWater and West Coast Atmospheric River Research

## Principal Investigator(s):

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

## NOAA Technical Contact(s):

Robin Webb, Earth System Research Laboratory

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC Collaboration

## NOAA Theme:

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

## Related NOAA Strategic Goal(s):

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

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

## Budget Amount:

\$120,000

## Amendment No.:

25

## Keywords:

Seasonal to Subseasonal Forecasting (S2S), Forecast Informed Reservoir Operations (FIRO), Stakeholder Engagement

## Milestones:

- FIRO 5 year work plan is completed and resulted from co-chairing FIRO steering committee

## Research Objectives:

The research objective are to respond to the unique needs of the Western U.S. for information on water and the storms that produce it, many stakeholders have requested additional specialized research and tools be developed. This interest ranges from conditions of too little

precipitation and water (drought) to too much (flood). This effort will generate a short concept paper and associated briefing materials describing promising new science directions and collaborations, as well as new tools focused on western U.S. needs. A collaborative approach is envisioned that brings together the expertise and knowledge on drought and flood and their meteorological causes in the region. This collaboration is represented by the leaders of CW3E (Ralph), NIDIS (Pulwarty) and PSD (Webb). Once the concept paper and briefing materials have been generated they will be communicated via meetings with key stakeholders.

## Research Accomplishments:

Ralph is co-chairing the FIRO steering committee and has lead two meetings since the summer of 2015 and is organizing a third meeting and a workshop. In addition, Ralph has presented at several meetings, workshops on seasonal to subseasonal (S2S) requirements, planning and concept development. These meetings are highlighted below.

## Conferences, Meetings & Presentations

- a. Western States Water Council and NOAA workshop, October 2015, Salt Lake City, UT
- b. Western States Water Council Workshop, December 2015, Las Vegas NV
- c. Western States Water Council and NOAA workshop, March 21-25, 2016, Washington D.C.

## Education & Outreach

### Communication

- a. With the Western States Water Council and NOAA, the requirements, planning and concept development for S2S methods were determined.

### Networking

- a. Several FIRO Steering Committee Meetings



# The Argo Project: Global Observations for Understanding and Prediction of Climate Variability

## Principal Investigator(s):

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

## Other Key Personnel

**John Gilson**, Scripps Institution of Oceanography, UC San Diego

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

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

**Sarah Gille**, Scripps Institution of Oceanography, UC San Diego

## NOAA Technical Contact:

Stephen Piotrowicz, Climate Program Office

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC Collaboration

## NOAA Theme:

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

## Related NOAA Strategic Goal(s):

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

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

## Budget Amount:

\$2,666,000

## Amendment No.:

7

## Keywords:

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

## Milestones:

- Production and deployment of 59 SOLO-II Argo floats.

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

## Research Objectives:

Argo is an international collaboration providing a global array of profiling CTD floats for a broad range of operational and scientific applications (<http://www.argo.ucsd.edu>). The Argo array, now including about 3800 active floats, is providing unprecedented real-time views of the evolving physical state of the ocean. These measurements reveal the physical processes that balance the large-scale mass, heat, and freshwater budgets of the ocean on basin-to-global scale. Argo is a major initiative in oceanography, merging research and operational objectives to provide a uniquely valuable global dataset for climate science, ocean state estimation, seasonal-to-decadal forecasting, education and other applications. All Argo data are freely available in near-real time.

SIO plays a number of key roles within U.S. and international Argo. The U.S. provides over 50% of the international Argo array, including instrumentation development, float production and deployment, communications and data management, and scientific analyses to demonstrate the value of Argo data. SIO produces and deploys one-fourth of the U.S. floats, carries out float technology development, participates in delayed-mode quality control, coordinates the U.S. Argo partnership, and provides leadership for international Argo through the Argo Steering Team.



## Research Accomplishments:

During the 9 months covered by this report (07/2015 – 03/2016), 59 SIO SOLO-II Argo floats were built, shipped, and deployed, and an additional 34 have been built and shipped. Deployments included 51 floats by RV Kaharoa in the S/W Pacific and 6 floats by RV Braveheart in the Southeast Pacific and the South Atlantic. In addition to these upper-ocean Core Argo floats, 9 Deep SOLO floats were produced. Of these, 7 were deployed by RV Kaharoa and 2 have been shipped to Australia for deployment by RV Investigator.

The total number of active Argo floats, Core plus Deep Argo, produced in our lab is now 549. For all active floats, profile and engineering data are regularly monitored to identify any technical problems with the instrument or sensor. The status of all SIO Argo floats can be monitored at <http://sio-argo.ucsd.edu/index.html>. Technology development continues to focus on further improvements in reliability and capability of profiling floats. Deployments of the new generation SOLO-II float have been successful, with a high percentage of floats deployed since 2011 remaining active. The SOLO-II design provides greater buoyancy adjustment, more robust operation, and increased lifetime relative to all existing Argo floats.

During this reporting period the design and development of Deep SOLO floats, capable of about 150 cycles to full ocean depth (6000 m), was continued. Two prototype Deep SOLO floats were recovered in the Southwest Pacific in September 2015 after 110 cycles each in water depth of about 5700m. After recovery of these instruments, the regional pilot array of 7 Deep SOLOs was deployed.

Scientific quality control of all SIO Argo profile data has been carried out by J. Gilson and S. Escher according to protocols established by the international Argo Data Management Team. All eligible delayed-mode profiles (i.e. > 12 months old) have been reviewed. SIO Argo data are freely available from either of the two Argo Global Data Assembly Centers.

D. Roemmich has been Chairman of the international Argo Steering Team since its inception in 1998. The AST, which is responsible for coordinating the international Argo partnership, was hosted by Argo Japan at JAMSTEC in Yokohama Japan for its March 2016 meeting. The meeting report for AST-16 is available from [http://www.argo.ucsd.edu/FrMeeting\\_reports.htm](http://www.argo.ucsd.edu/FrMeeting_reports.htm)

I. M. Scanderbeg provides support for a wide variety of AST functions, including Steering Team and Data Management Team meeting planning, reporting, and inter-sessional activities, and is responsible for designing and updating of the Argo web site, <http://www.argo.ucsd.edu>.

A report of the international Deep Argo Implementation Workshop was released by meeting organizers N. Zilberman and G Maze (<http://www.argo.ucsd.edu/DAIW1report.pdf>). A consensus design for a global Deep Argo array of 1200 floats was included in the report.

## Honors and Awards

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

## Conferences, Meetings & Presentations

- a. International Argo Data Management Team Meeting, Bermuda, October 2015, with John Gilson and Megan Scanderbeg.
- b. International Argo Steering Team Meeting, Yokohama Japan, March 2016, with Dean Roemmich, Megan Scanderbeg, and Nathalie Zilberman.
- c. Ocean Surface Topography Science Team Meeting, Reston, Virginia, October 2015, with Nathalie Zilberman, Dean Roemmich, and Sarah Gille.
- d. AGU Ocean Sciences Meeting, New Orleans, Louisiana, February 2016, with Nathalie Zilberman, Florent Gasparin, and Sarah Gille.
- e. AGU Fall Meeting, San Francisco, California, December 2015, with Dean Roemmich and Sarah Gille.



## Education & Outreach

### Communications

- a. In conjunction with the International Argo partnership, maintain the Argo Science Team web site, <http://www-argo.ucsd.edu>, which provides information on the Argo project, it's objectives, status and data system, including how to access Argo data.
- b. In conjunction with the International Argo partnership, produce the Argonautics Newsletter, <http://www.argo.ucsd.edu/Fnewsletter.html>, to distribute information on Argo status, applications, and progress on key issues.
- c. In a partnership with PI-GOOS and SEREAD, maintain the Argo Marine Atlas Project,

<http://www.argo.ucsd.edu/Fnewsletter.html>,

to develop 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.

### K-12 Outreach

- a. Maintain the SEREAD Program, to develop curricular units and conduct teacher-training seminars for teaching of weather, climate, sea level, and the ocean's role in climate in the Pacific Island School Systems with SOPCA, UNESCO, NOAA, NIWA/NZ, IOC, Education ministries in the Cook Islands, Samoa, Kiribati, Tonga and Mauritius.



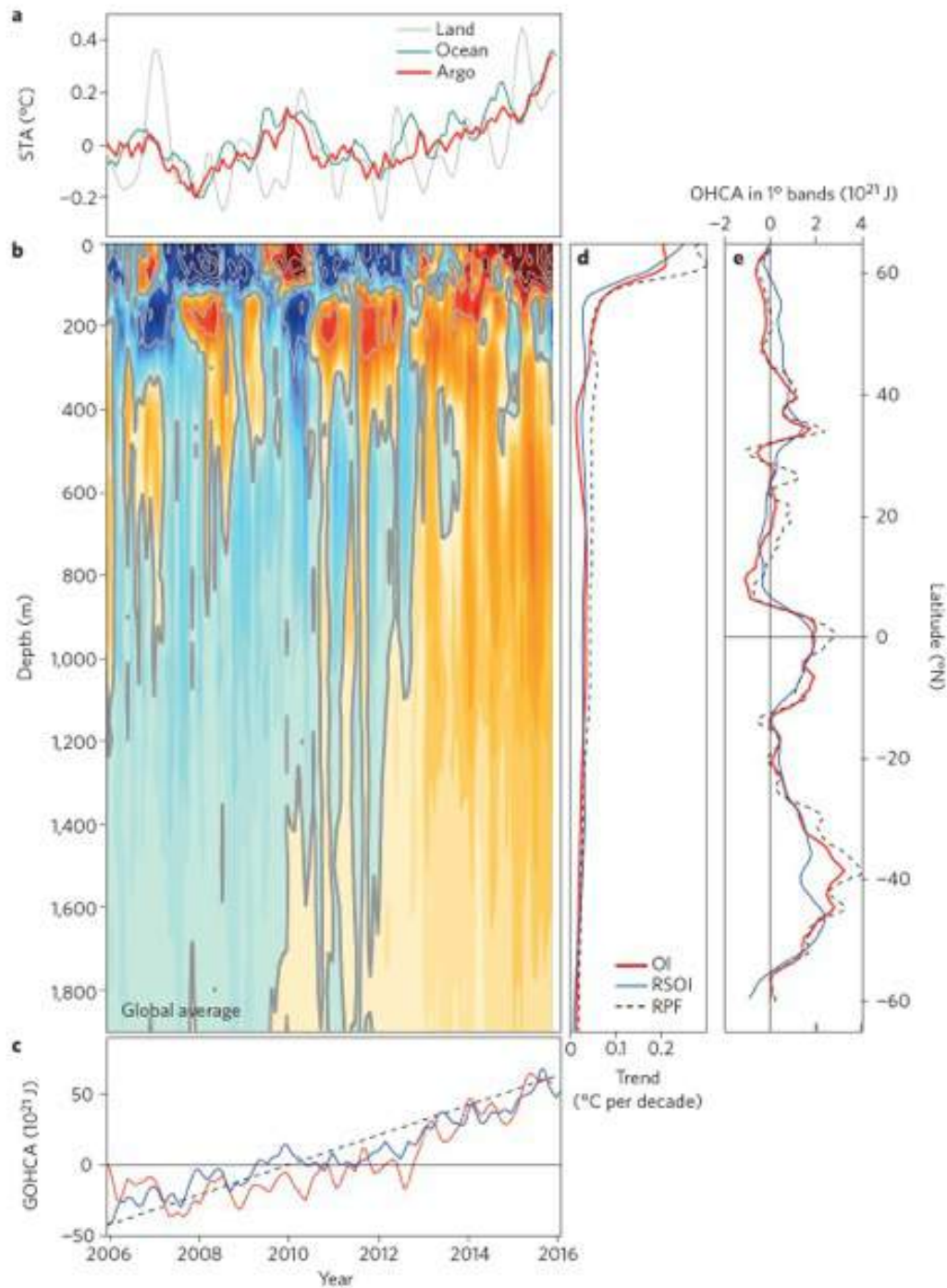


Figure 5: Ocean warming rates and distributions. **a**, Globally averaged surface temperature anomaly (STA, °C), from 5 m Argo OI temperature (red), NOAA (National Oceanic and Atmospheric Administration) global ocean (turquoise) and a 6-month running mean of NOAA global land averages (grey). **b**, Global average ocean temperature anomalies from the Argo OI. **c**, Global ocean 0–2,000 m heat content anomaly as a function of time. **d**, Global average 2006–November 2015 potential temperature trend (°C per decade). **e**, Zonally integrated heat content trends in  $1^\circ$  latitude bands from the three mapping methods. For line plots **c**, **d** and **e**, the sources are: OI (red), RSOI (blue) and RPF (black-dashed). Figure from Wijffels et al (Nature Climate Change, 2016)



# SIO High Resolution XBT/XCTD Transects

## Principal Investigator(s):

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

## Other Key Personnel

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

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

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

## NOAA Technical Contact:

Kathy Tedesco, Climate Program Office

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC Collaboration

## NOAA Theme:

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

## NOAA Strategic Goal(s):

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

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

## Budget Amount:

\$1,845,277

## Amendment(s):

5

## Keywords:

Global Ocean Observations, Ocean Temperature

## Milestones:

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

- Implementation of Iridium communication during 2015 on all ships participating in the HR-XBT network
- Delayed-mode quality control of all XBT profiles and distribution through SIO and NODC data archiving web sites.
- Contribution of the HR-XBT data to publications (see below and <http://www.aoml.noaa.gov/phod/goos/bib/index.php>)
- The use of HR-XBT data in student research is indicative of the increasing value of ocean observations that are sustained over multi-decades.

## Research Objectives:

The SIO High Resolution XBT 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. The HRX Network was initiated in 1986 along a commercial shipping route between New Zealand, Fiji, and Hawaii. It was subsequently expanded during the 1990's to include basin-spanning temperature transects in all of the oceans. Major partners in the HRX network include Scripps (Pacific and Indian Ocean), NOAA/AOML (Atlantic), and CSIRO (SW Pacific, Indian). Typically, each transect is repeated on a quarterly basis to resolve variability in temperature, geostrophic circulation and transport on annual and longer periods. Scientific objectives of the HRX Network are:

- Measure the seasonal and interannual fluctuations in the transport of mass, heat, and freshwater across ocean-wide transects spanning the ocean's boundary currents and interior circulations.
- Determine the long-term mean, annual cycle and interannual fluctuations of temperature, geostrophic velocity and large-scale ocean circulation in the top 800 m of the ocean.



- Obtain long time-series of temperature profiles at precisely repeating locations in order to unambiguously separate temporal from spatial variability.
- Determine the space-time statistics of variability of the temperature and geostrophic shear fields.
- Provide appropriate *in situ* data (together with Argo profiling floats, tropical moorings, air-sea flux measurements, sea level etc.) for testing ocean and ocean-atmosphere models.
- Determine the synergy between HRX transects, satellite altimetry, Argo, and models of the general circulation. What are the minimal sampling requirements for *in situ* data?
- Identify permanent boundary currents and fronts, describe their persistence and recurrence and their relation to large-scale transports.
- Estimate the significance of baroclinic eddy heat fluxes.

### Research Accomplishments:

HRX transects, quarterly in most cases, have been maintained along routes that include:

- PX37/40 (North Pacific – Los Angeles to Hawaii to Yokohama)
- PX38 (North Pacific – Hawaii to Alaska)
- PX05 (Western Pacific – Brisbane to Yokohama)
- PX44 (Western Pacific – Taiwan to Naha to Guam)
- PX06/31 (Central Pacific – Auckland to Fiji to San Francisco)
- PX30 (South Pacific – Brisbane to Fiji, joint with CSIRO Australia)
- IX21 (South Indian –Durban to Mauritius)

Logistical assistance or XBT probes are provided collaboratively for:

- PX34 (South Pacific – Wellington to Sydney, CSIRO Australia)

- IX28 (Southern Ocean – Hobart to Antarctica, CSIRO Australia)
- AX22 (Southern Ocean - Drake Passage)

During each cruise, XBT temperature profiles (0-800 m) were collected at spatial intervals from 10 km near ocean boundaries and the equator, to 50 km in interior regions – resolving boundary currents and interior eddies for calculation of ocean-wide integrals of geostrophic transport.

HRX data are transmitted on the GTS immediately after collection for real-time applications. Scientific quality of the HR-XBT data is undertaken by Data Manager Lisa Lehmann. The Data Manager creates software for data collection and quality control and is responsible for delayed-mode quality control of all data. A web site for the project, with downloadable quality controlled data, is maintained at <http://www-hrx.ucsd.edu> where data are freely available in transect mode. The delayed mode data set is also archived and distributed by the National Oceanographic Data Center (NODC). Due to the rapidly evolving nature of the present-day commercial shipping industry, a strong focus of the work has been to maintain sampling along routes as ships and shipping companies change.

Scientific analysis of the HRX dataset is progressing both on a stand-alone basis and in the context of ocean data assimilation (ODA) modeling. The HRX Network is observing the volume transport and variability of all the world's subtropical western boundary currents: with a total of 10 repeating transects across the Gulf Stream, Kuroshio, Agulhas, Brazil Current, and East Australian Current. Other boundary current sampling includes the California Current and the Antarctic Circumpolar Current. Absolute geostrophic transports for the upper 800 m are estimated using Argo profile and trajectory data in conjunction with HRX transects.

### Conferences, Meetings & Presentations

- IUGG Conference, 14 June – 3 July 2015, Prague, Czech Republic, with Janet Sprintall



- b. Fourth International IQuOD Workshop & XBT Science Meeting, 3-5 December 2015, Hamburg, Germany, with Janet Sprintall
- c. AGU Ocean Sciences Conference, 21-26 February 2016, New Orleans, Louisiana, with Janet Sprintall, Natalia Ribeiro Santos(Brazil), and Nathalie Zilberman
- d. GOOS Meeting, September 2015, Galway, Ireland, with Nathalie Zilberman
- e. Ocean Surface Topography Science Team Meeting, October 2015, Reston, Virginia, with Nathalie Zilberman

by Sprintall. With participation from the UCSD Undergraduate Work/Study Program in Marseille, France and the Federal University of Rio Grande (FURG) in Brazil.

## Education & Outreach

### Communications

- a. High Resolution XBT Network web site: <http://www-hrx.ucsd.edu>, to describe scope and objectives of the Pacific/Indian HRX network; display data from all cruises; provide downloadable datasets on a cruise by cruise basis. Partnered with CSIRO Australia, NIWA New Zealand, and Tohoku University in Japan.

### Academic Development

- a. Provide data set for Ph.D. theses for 10 Scripps Institution of Oceanography graduate students. Partnership with NSF and NASA.

### Networking

- a. Dean Roemmich served on the Pacific Island Global Ocean Observing System (PI-GOOS) Advisory Committee to assist Pacific Island Nations in gaining benefit from global ocean observations and products. Partnered with the South Pacific Regional Environmental Program (SPERP), NOAA, BoM Australia, NIWA New Zealand, Intergovernmental Oceanographic Commission, and other South Pacific Nations.

### Fellowships & Internships

- a. UCSD undergraduates Clifford Hoang, and visiting international student interns Natalia Ribeiro Santos and Remi Lenny, used HR-XBT data in their projects while supervised at SIO



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

## Principal Investigator(s):

**Uwe Send**, Scripps Oceanography

## Other Key Personnel

**Russ Davis**, Scripps Oceanography

**Daniel Rudnick**, Scripps Oceanography

**Bruce Cornuelle**, Scripps Oceanography

**Dean Roemmich**, Scripps Oceanography

## NOAA Technical Contact:

**Diane Stanitski**, Climate Program Office

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC  
Collaboration

## NOAA Theme:

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

## NOAA Strategic Goal(s):

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

## Budget Amount:

\$1,555,000

## Amendment(s):

4

## Keywords:

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

## Research Objectives:

For over 20 years the Consortium on the Ocean's  
Role in Climate (CORC) has focused on  
implementing new ocean observing technologies  
and systems. After identifying inadequately  
measured properties of the ocean circulation that  
are important to understanding and predicting  
climate variability, CORC investigators have

developed cost-effective technology, methodology  
and infrastructure to implement observing  
systems to measure them. These systems have  
been put into operation to refine and  
demonstrate their abilities. Examples of past and  
ongoing projects are the High-Resolution  
Expendable Bathythermograph network  
operating from commercial ships, the Surface  
Velocity Program, the Argo network of profiling  
floats, the array of California Current glider  
transects, and moorings to capture high-  
frequency processes.

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

More specifically, CORC is now developing  
regional observing systems in the California  
Current and the Solomon Sea and developing  
methods to merge these observations with global  
ocean climate observations like altimetry, winds,  
Argo profiles and the Surface Velocity Program. In  
and inshore of the California Current, changes in  
processes like alongshore currents from the north  
and south, upwelling, changes in stratification and  
mixing, and the frequency and strength of near-  
surface fronts have been implicated in large  
changes in the abundance of fish and their prey.



CORC data is being used to look for relations between ecosystem properties and coastal circulation. The Western Boundary Current in the Solomon Sea is the main source of the Pacific's Equatorial Undercurrent. This makes it a central part of the shallow overturning circulation that influences central Pacific surface temperatures that drive the El Niño – Southern Oscillation (ENSO) fluctuations with global temperature and precipitation consequences. CORC observing systems are delivering data to test and improve methods of predicting ENSO and its decadal-variability relatives as well as ecosystems and local weather along the California coast. This delivery is done primarily through public web sites where data can be plotted or downloaded. CORC does not intend to operate these observing systems indefinitely and hopes to transition them to a program better suited to sustaining them.

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

### Milestones:

- The California Underwater Glider Network has provided fundamental measures of the 2014-2015 Pacific anomalies.
- A California Current index is now routinely generated.
- New results about spin-up of Southern California recirculation cell and cross-shelf upwelling circulation in moored ADCP data have been obtained.
- A nearly 8-year record of glider sections has been assembled and cross-checked to construct time series of volume, heat and freshwater transport in depth and density layers. These time series show a clear correspondence of events in the Nino 3.4 SST and equatorward transport, particularly in the shallow layers; warm SST corresponds to

strong transport. The record also shows that transport builds gradually but steadily from cold events to warm ones.

- Potential to derive SS transports and shear from bottom pressure and altimetry alone
- Volume transport estimation for the East Australian Current off Brisbane based on High Resolution XBT, Argo, and Altimetry, and validated by nearby moored observations.
- Discovery of a new current – the East Pacific Rise Current – generated by interaction of the interior South Pacific Gyre with topography.
- Participation in the redesign of the Tropical Pacific Observing System (TPOS 2020).
- Estimation of global ocean heat gain and its spatial patterns based on Argo (2006 – 2014).
- Description of multi-decadal changes in the temperature, salinity, and wind-driven interior circulation of the South Pacific Gyre.
- Continued improved and updated state estimate.

### Research Accomplishments:

CORC has supported gliders in the California Current (CC) on line 90 off Dana Point, and line 66.7 off Monterey. Data products have been produced consisting of profiles of temperature, salinity, density, velocity, chlorophyll fluorescence, and acoustic backscatter on uniform grids for each glider transit along all lines, as well as a glider-based SoCal Niño Index. The gliders have been used to study the Pacific warm anomaly of 2014/15, one glider view is shown in figure 1. The CORC moorings and PIES (inverted echosounders with bottom pressure) are used for several purposes. The mooring/PIES-validated/calibrated altimeter transport index for the California Current (CC) is now updated routinely on our website. The alongshore and cross-shore flow observations are used for analyses of the warm anomaly. We have also detected an apparent correlation between the southward CC index and the northward inshore flow, something we are pursuing further with modellers.



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

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

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

### Conferences, Meetings & Presentations

- a. SIO seminar, Sep 2015, San Diego, with N. Zilberman
- b. ARGO Science Meeting, September 2015, Galway, Ireland
- c. Ocean-Sciences Meeting, February, 2016, New Orleans, Louisiana, with D. Roemmich, N. Zilberman, U. Send, M. Lankhorst, D. Rudnick, K. Zaba, and B. Cornuelle.

### Education & Outreach

#### Academic Development

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

#### Networking

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



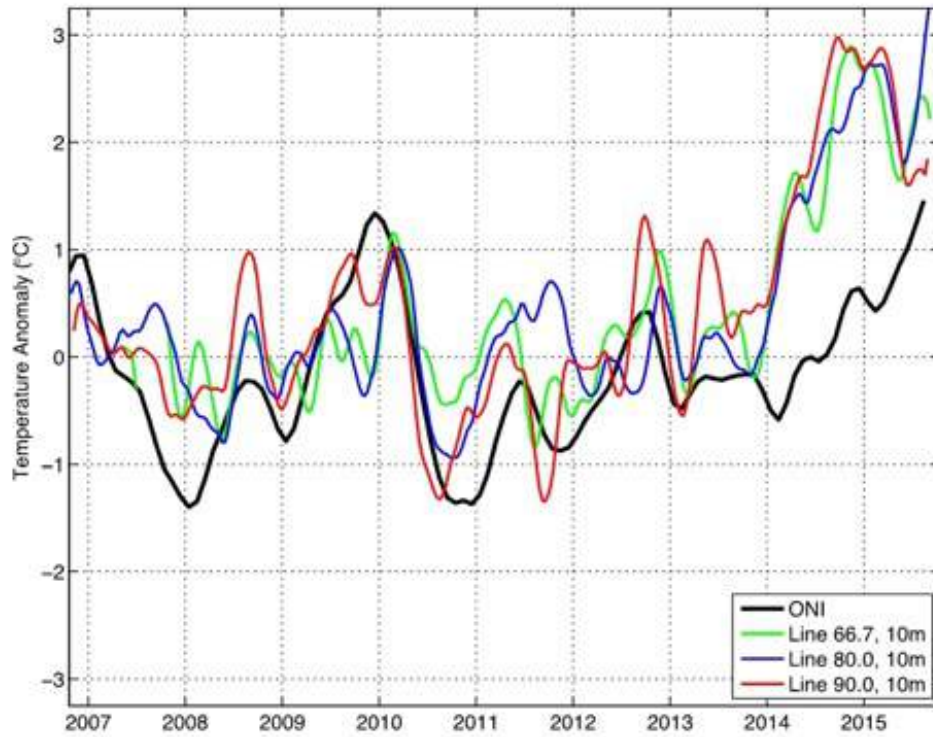


Figure 6 Temperature anomalies at 10 m, averaged over the inshore 200 km of each line, and filtered with a 3-month running mean (colors as in legend). The Oceanic Niño Index is plotted for reference (black). Note the increase in temperature off California concurrent on all lines beginning in January 2014.

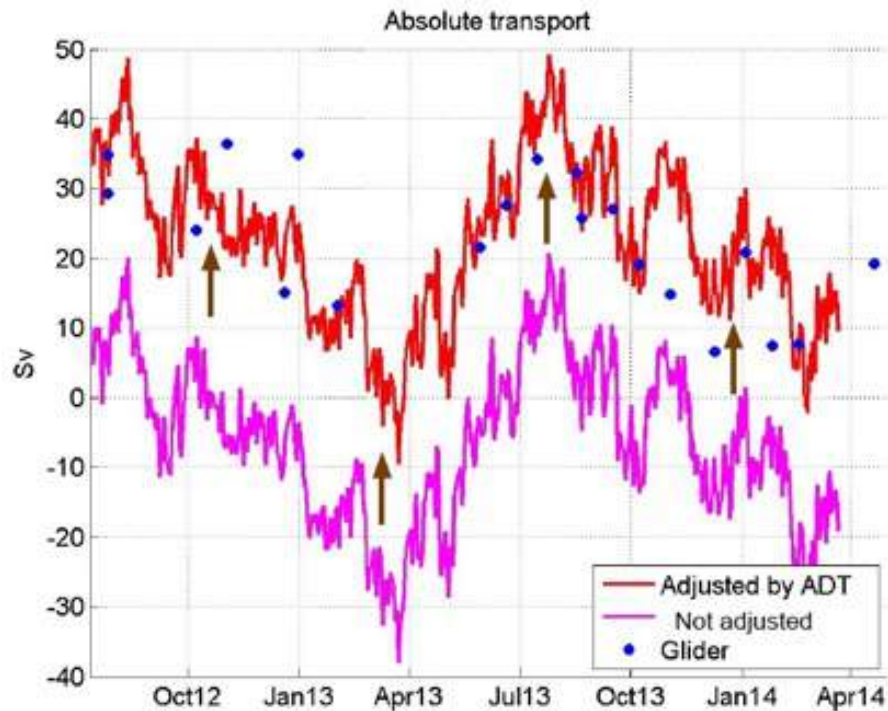


Figure 7: Total Solomon Sea throughflow volume transport from mooring-derived dynamic height, referenced to PIES bottom pressure. Pink: without any additional offsets; Red: using a mean offset to reference the mean pressure gradient to the mean surface dynamic topography. The red line is in very good agreement with the individual transport estimates from glider sections (blue dots.)



# HF Radar National Network Data Management Development

## Principal Investigator(s):

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

## Other Key Personnel:

**Mark Otero**, Scripps Institution of Oceanography, UC San Diego

**Joseph Chen**, 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

**Tom Cook**, Scripps Institution of Oceanography, UC San Diego

**Paul Reuter**, Scripps Institution of Oceanography, UC San Diego

## NOAA Primary Contact:

**Jack Harlan**, Integrated Ocean Observing System (IOOS) Program Office

**Richard Crout**, National Weather Service, National Data Buoy Center

## NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

## NOAA Theme:

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

## Related NOAA Strategic Goal(s):

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

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

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

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

## Budget Amount:

\$440,000

## Amendment No.:

9

## Keywords:

HF Radar, National Network, Real-time, Data Management, Surface Current Mapping, Surface Currents, Portal, Node, National Grid

## Milestones:

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

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

14. Gaviota, CA (TRL1) University of California, Santa Barbara – Oil Spill Response  
<http://cordc.ucsd.edu/projects/mapping/stats/?sta=TRL1>
15. Pepe'ekeo, HI (PPK) University of Hawaii  
<http://cordc.ucsd.edu/projects/mapping/stats/?sta=PPK>
16. Keaukaha, HI (KKH) University of Hawaii  
<http://cordc.ucsd.edu/projects/mapping/stats/?sta=KKH>
17. Conalep, Mexico (CON) Universidad Autonoma de Baja California



<http://cordc.ucsd.edu/projects/mapping/stats/?sta=CON>

18. Ponce Yacht and Fishing Club at Ponce, Puerto Rico (PYFC) University of Puerto Rico
19. <http://cordc.ucsd.edu/projects/mapping/stats/?sta=PYFC>
20. Cabo Rojo Lighthouse at Cabo Rojo, Puerto Rico (FARO) University of Puerto Rico
21. <http://cordc.ucsd.edu/projects/mapping/stats/?sta=FARO>
22. Icy Cape, AK (ICYC) University of Alaska Fairbanks  
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=ICYC>
23. Kapolei, HI (KAP) University of Hawaii  
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=KAP&aff=UH>
24. Old Bridge Waterfront Park, NJ (OLDB) Rutgers University  
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=OLDB>
25. Amagansett, New York (AMAG) Rutgers University  
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=AMAG>
26. Punta Tuna Lighthouse, Maunabo, Puerto Rico (MABO) University of Puerto Rico  
<http://hfrnet.ucsd.edu/diagnostics/stats/?sta=MABO>

#### Decommissioned Sites:

3. (TRL1) University of California, Santa Barbara – temporary site
4. (PTLY) University of Alaska Fairbanks

#### Supported Domains and available data:

7. USEGC - US East and Gulf Coast - 2008-03 through present
8. USWC - US West Coast - 2008-03 through present
9. AKNS – Alaska North Slope – 2006-11 (when available)
10. GAK - Gulf of Alaska - 2009-05 through present (when available)
11. PRVI - Puerto Rico and US Virgin Islands - 2010-01 through present



USHI – US Hawaii – 2010-07

### **Research Objectives:**

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

The architecture of the HF-Radar Network lends itself well to a distributed real-time network and serves as a model for networking sensors on a national level. This proposal concentrates on development activities critical for network growth, sustainability, and enhancements. Programming staff will finalize backend refactoring to increase code efficiency and decrease processing times, improve and expand diagnostic utilities by integrating operator input, and further validation of Direction of Arrival (DOA) metrics. Additionally, efforts to maintain the total vector currents pathway for data archival with the National Centers for Environmental Information (NECI), initiate radial data archiving, identify new relationships established at the global scale, and participate in the radiowave operators working group (ROWG) workshop and Group on Earth Observations (GEO) to promote national knowledge exchange and cooperation.

### **Research Accomplishments:**

CORDC research and implementation efforts met expectations during this reporting period. Throughout this reporting period, efforts focused

on continued operations, maintenance, and expansion; improving national diagnostics; configuring and initializing improved backend processing; implementation of the rowg website; and presenting on DOA metrics. Additionally, CORDC supported global partnership by visualizing surface current measurements of Mexico and Balearic Islands networks.

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

CORDC staff enabled rapid HF radar response to west coast oil spill in June, 2015. IOOS funded HF Radar derived surface currents have established feeds to NOAA Office of Response and Restoration (ORR), CA State Office of Spill Prevention and Response (OSPR) and regional models such as Regional Ocean Model System (ROMS) for oil spill response within the California region. These data are used to assist in analyzing and tracking oil spills as they enter the region of coverage. In response to the Refugio oil spill, HF radar operators from University of California, Santa Barbara established a temporary site at Gaviota in order to fill in coverage north of the spill and ran a local trajectory model advecting simulated particles through the current field to visualize the potential path of the slick:

<http://euler.msi.ucsb.edu/realtime/spill/sim/>. Scripps programmers integrated the new site into the High Frequency Radar Network (HFRNet): <http://cordc.ucsd.edu/projects/mapping/maps/fullpage.php> for near real-time visualization and distribution to operational organizations responding to the spill. SCCOOS HF radar visualizations were used by local News Channel 3 in Santa Barbara for use during the weathercast in order to show circulation patterns in the area. These data were used to compare with General NOAA Operation Modeling Environment

(GNOME) in forecasting spill affects along the coast.

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

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

## Conferences, Meetings & Presentations

- c. Environmental Protection Agency Marine Debris Program Regional Response Team, April 28, 2015 & July 1, 2015, La Jolla, CA, with L. Hazard, M. Otero
- d. Los Angeles Area Committee Meeting, May 14, 2015, San Pedro, CA, with L. Hazard
- e. Oceans '15 MTS/IEEE, May 18-21, 2015, Genoa, Italy, with T. DePaolo
- f. CA Resources Agency Deputy Secretary for Oceans and Coastal Policy, June 4, 2015, La Jolla, CA, with E. Terrill
- g. USCG Meeting, July 29, 2015, La Jolla, CA, with E. Terrill, L. Hazard
- h. San Diego Area Committee Meeting, August 6, 2015, San Diego, CA, with L. Hazard
- i. GEO Conference, September 20-23, 2015, Crete, Greece with E. Terrill, L. Hazard
- j. Korea Hydrographic and Oceanographic Administration (KHOA), September 20-24, 2015, Busan, Korea with M. Otero, J. Chen



- k. '15 MTS/IEEE Conference, October 20-21, 2015, Washington, DC, with L. Hazard
- l. Radiowave Operators Working Group (ROWG), November 2-4, 2015, Woods Hole, MA, with L. Hazard, T. Cook, M. Otero, J. Chen, H. Batchelor
- m. Statewide Area Committee Meeting, January 12-14, 2016/Santa Barbara, CA, with L. Hazard (remotely)

## Education & Outreach

### Communications

- b. <http://cordc.ucsd.edu/projects/mapping/>  
Provide online access to surface current mapping sites, radial data, and diagnostics for participating sites

### Academic Development

- b. Partnered with WHOI researchers to further examine radial metrics.

### K-12 Outreach

- a. Supported surface currents in Birch Aquarium Exhibit, Boundless Energy, to educate and bring awareness of ocean energy to general public.

### Networking

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





Figure 8: Group on Earth Observations Global High Frequency Radar Network Meeting in Crete, Greece.

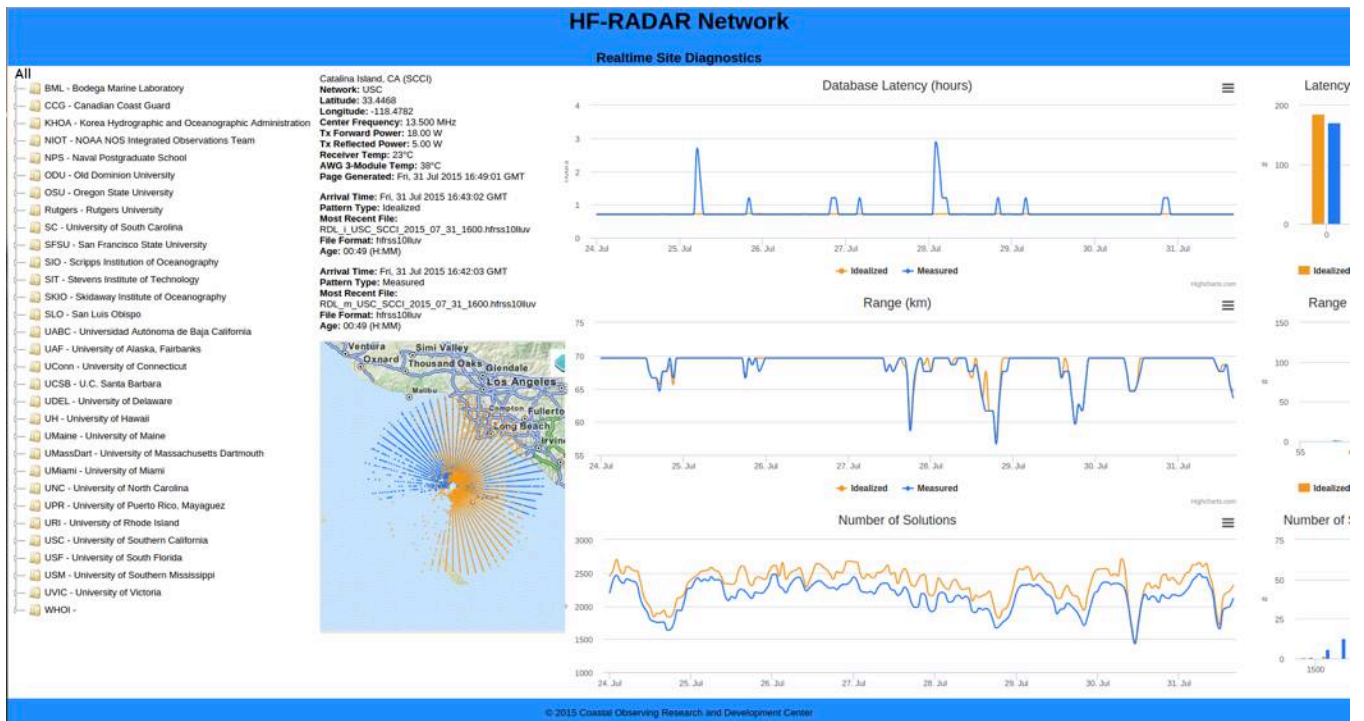


Figure 9: Enhanced HF Radar Network (HFRNet) diagnostics tools for improved performance, interactivity, and capability.



# Meridional Overturning Variability Experiment (MOVE)

## Principal Investigator(s):

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

## Other Key Personnel:

Matthias Lankhorst, Scripps Institution of  
Oceanography, UC San Diego

## NOAA Primary Contact:

First Last Name, Southwest Fisheries Science  
Center

## NOAA Task:

Task 3 - Individual Science Projects

## NOAA Theme:

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

## Related NOAA Strategic Goal(s):

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

## Budget Amount:

\$417,738

## Amendment No.:

10

## Keywords:

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

## Milestones:

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

## Research Objectives:

A present gap in the sustained ocean climate  
observing system are techniques and programs  
for monitoring the circulation and

mass/heat/freshwater transports of major current  
systems, sometimes called "transport reference  
sites". For broad-scale and deep-reaching  
circulations, an accurate and cost-effective  
method for this consists of fixed-point  
installations with moored and bottom-mounted  
instruments to obtain horizontally integrated  
measurements throughout the watercolumn. The  
MOVE project applies this approach to obtain  
sustained observations of a component of the  
AMOC (Atlantic Meridional Overturning  
Circulation) which is a national ocean observing  
priority. This effort had been initiated via the  
German CLIVAR programme from 2000 to 2006 in  
the subtropical west Atlantic along 16N, in order  
to observe the transport fluctuations in the North  
Atlantic Deep Water layer. Since 2006 it has been  
operated with NOAA funding, now providing the  
longest record of direct AMOC observations.

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

## Research Accomplishments:

In January/February 2016, SIO participated in a  
new NTAS/MOVE cruise on R/V Endeavor. During  
this cruise, all moorings recovered and new ones  
deployed at stations M1, M3 and M4, and data  
were downloaded acoustically from some of the  
PIES at sites M1/M3. This extends the data record



in hand for the baroclinic (sheared) flow to approximately 16 years.

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

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

### Conferences, Meetings & Presentations

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

### Education & Outreach

#### Academic Development

- One graduate student was supported by MOVE

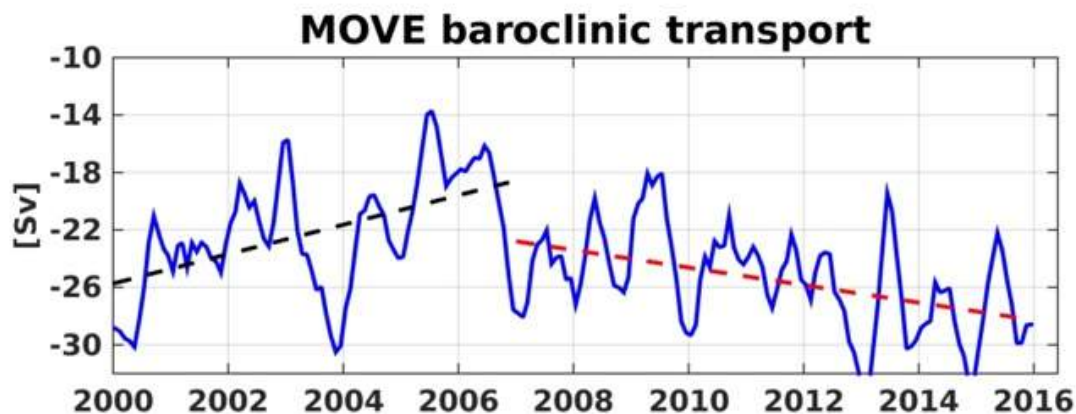


Figure 10: 16 years of quality-controlled baroclinic North Atlantic Deep Water transport (southward therefore negative).

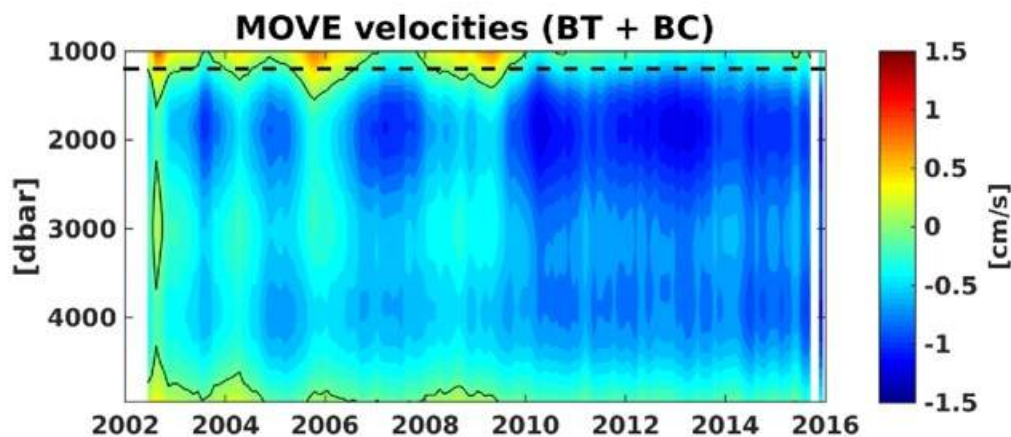


Figure 11: Contour plot of southward NADW flow (blue), showing thickening of the layer since about 2008.



## Theme B: Climate Research and Impacts

### The Global Drifter Program

#### Principal Investigator(s):

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

#### NOAA Primary Contact:

Sidney Thurston, Climate Program Office

#### NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

#### NOAA Theme:

Theme B: Climate Research and Impacts

#### Related NOAA Strategic Goal(s):

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

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

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

#### Budget Amount:

\$2,848,683

#### Amendment No.:

8

#### Keywords:

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

#### Milestones:

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

- **Accomplished.** For this funding cycle the GDP has proposed to build and deploy a total 139 SVP systems (695 SVP drifters) and 50 SVPB systems (250 SVPB drifters). Most of the drifters were either deployed by the Global Drifter Program or delivered to AOML for deployment. A small number of drifters is still in production and is expected to be delivered

shortly. Despite this delay, the goal to maintain the array at the 1,250 drifters nominal size was fully achieved and as of October 27, 2015, there were 1,440 GDP drifters actively reporting to the GTS (Figure 1). This task addresses the program's priorities of delivering continuous instrumental records for global analyses of sea surface temperature and surface currents.

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

- **Accomplished.** During the reporting period the GDP has assisted the industrial partners upon request with technical matters. We keep providing AOML with technical assistance on a variety of issues related to decoding and archiving drifter data transmitted through the Iridium satellites. The Global Drifter Program at the Scripps Institution of Oceanography is implementing the transition of the GDP array to Iridium using the DoD gateway and is posting the drifter data in real time to the Global Telecommunication System.
- Close coordination with scientific program funded by NASA and ONR and in collaboration with the National Sun Yat Sen University and NARA of Sri Lanka gave resulted in extra drifters deployed in support of the GDP.

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

- Besides the synergy promoted by Dr. Centurioni between the GDP and other



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

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

- **Accomplished.** A thorough evaluation of DoD Iridium gateway implementation was the focus of this funding cycle. The GDP worked closely with OCO, PMEL Pacific Gyre, DBi and AOML implement the transition.
- Drifter inspections are routinely performed by the GDP and if non-complying items are discovered, these are discussed with the manufacturers as needed.

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

- **Accomplished.**

D6: maintain real-time statistics of drifter performances.

- **Accomplished.** Real time statistics are maintained at the [gdp.ucsd.edu](http://gdp.ucsd.edu) website and constitute the main tool for the PI to detect early signs of drifters' technical issues.

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

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

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

- **Accomplished.** Dr. Luca Centurioni, Dr. Verena Hormann, Mr. Lance Braasch and Mr. Lance Curtiss traveled to Weihai, China, and attended the DBCP 30 scientific and technical workshop, where they delivered a talk, and

the plenary session of the DBCP 30 meeting. A list of presentations can be found at ([http://www.jcomm.info/index.php?option=com\\_oe&task=viewEventRecord&eventId=1504](http://www.jcomm.info/index.php?option=com_oe&task=viewEventRecord&eventId=1504)).

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

- **Accomplished.**
- Hormann et al (2015). In this study, we evaluate a subset of 83 drifters, which have provided useful salinity measurements in the central SPURS region from a few weeks to more than one year, and we describe an *ad-hoc* quality control procedure partially based on previously published work and on our new observations. It was found that the sampling algorithm of the drifters introduces a predominantly fresh bias in the noise level of the salinity data, probably caused by the presence of air bubbles within the measuring cell. Since such noise is hard to eliminate with a statistical method, extensive manual data editing was used instead. Such quality control procedure cannot be routinely applied to the real-time data stream of the drifters and a revision of the sampling algorithm of the salinity drifters is needed. Comparisons of the drifter salinity measurements with independent data sets also indicate that the sensor can provide reliable observations for up to one year.
- Centurioni et al (2015). The salinity data from the drifters were used to validate the divergence of the salt transport computed with satellite products, where the satellite salinity was taken from the standard- non SST corrected Aquarius v3.0 dataset. Our results indicate a good agreement between the two independent methods as well as that the effect of the eddy field combined with the SSS variability at the surface is dominant.
- The SSS variability within spatial bins comparable to the Aquarius-beam footprints measured by the drifters can be in excess of 0.1 PSU. This suggests that a careful evaluation of the representation error is required when single-point in situ



measurements, such as the one collected from Argo floats, are used to validate the spatially averaged Aquarius salinity data

- A review article describing the advances in the study of the global ocean's surface circulation in the past 10 years has been published in Maximenko et al. (2013).
- Hormann et al. (2014) investigates, the ocean's response to typhoon Fanapi using an extensive air-deployed drifter array. Separation of the observations into near-inertial and sub-inertial motions quantified the importance of strong advection by the sub-inertial circulation for the evolution of the cold wake formed by Typhoon Fanapi. The near-inertial currents generated during the storm showed the expected rightward bias, with peak magnitudes of up to 0.6 m/s and an e-folding time of about 4 days for the strong currents within the cold wake. The shear of the near-inertial currents is crucial for the storm-induced cooling and deepening of the mixed layer and such instabilities were here directly observed across the base of the mixed layer in Typhoon Fanapi's cold wake. During the recovery, the diurnal cycle—a dominant process for the wake warming—was found to be noticeably reduced when the near-inertial motions were strongest.
- Poulain and Centurioni (2015). Velocities of surface drifters are analyzed to study tidal currents throughout the World Ocean. The global drifter dataset spanning the period 1979-2013 is used to describe the geographical structure of the surface tidal currents at global scale with a resolution of 2 degrees. Harmonic analysis is performed with 2 semi-diurnal (M2 and S2) and 2 diurnal (K1 and O1) tidal constituents. For the first time, tidal current characteristics (amplitude of semi-major axis, rotary coefficient, tidal ellipse inclination and Greenwich phase) are mapped over the World Ocean. The M2 currents dominate on all the shallow continental shelves with a maximum of 75 cm/s. They are also substantial (4-5 cm/s) over the main deep topographic features such as the Mid-Atlantic

Ridge and Southwest Indian Ridge. The S2 currents have amplitudes typically half the size of the M2 currents, with a maximum of 28 cm/s. The K1 and O1 currents are important in many shallow seas with maximal amplitudes of about 30 cm/s. They are large in the vicinity of the turning latitudes near 30°N/S where they correspond to inertial motions. Maps of rotary coefficients indicate that all tidal motions are essentially anticyclonic, that is clockwise (anticlockwise) in the northern (southern) hemisphere. The rotary coefficient and tidal ellipse inclination of the diurnal tidal currents agree well with the theory of freely and meridionally propagating baroclinic inertia-gravity waves. The Greenwich phase of the M2 constituent has large scale coherent propagation patterns which could be interpreted as the propagation of the barotropic tide.

#### D10: R&D activities.

- The investigation to assess the causes of shortened drogues lifetimes was launched. The investigation is underway and new drogue bridles and tether are being tested to identify better drogue construction techniques.

#### **Research Objectives:**

Provide through the publicly available Global Telecommunication System (GTS) a-real time data stream of drifters locations, SST, Sea Level Atmospheric Pressure (SLAP), SSS, sea level wind and subsurface temperature . 2) observe 15m depth ocean currents on a global basis with a nominal 5.0° resolution and, jointly with satellite altimeter data, produce circulation data of the world ocean at 0.5° resolution that can be used to trace pollution laden particles or turbulent dispersion of vorticity and thermal energy due to the tropical eddy field; 3) develop and implement drifter's technological advances in sensors, electronics, power, methods of assembly and deployment packaging. 4) provide enhanced research quality data sets of ocean circulation that include drifter data from individual research programs.



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

### Research Accomplishments:

Since September 2005 the fully implemented global drifter array has consisted of between 1100-1400 drifters. This required global drifter array size is based on the need to return in-situ observations of SST ( $\pm 0.10^\circ\text{C}$ ) over the global ocean at a  $5^\circ$  resolution in order to keep the potential SST satellite bias error smaller than  $0.5^\circ\text{C}$ . Surface pressure sensors are also supported NOAA and by national meteorological agencies based on regional needs. The status of the GDP array is updated weekly can be seen at the AOML website:

<http://www.aoml.noaa.gov/phod/dac/index.php>.

The present drifter array is 15% bigger than its nominal size and stable compared to last year.

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

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

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

See list of publications for specific research accomplishments

### Meetings & Presentations

- a. 9<sup>th</sup> COD Community Workshop, NOAA Center for Weather and Climate Protection, College Park, MD, 15-17 June 2015. (Centurioni)

### Education & Outreach

#### Communications

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



## Satellite SST bias constrained by in situ SST data from drifters

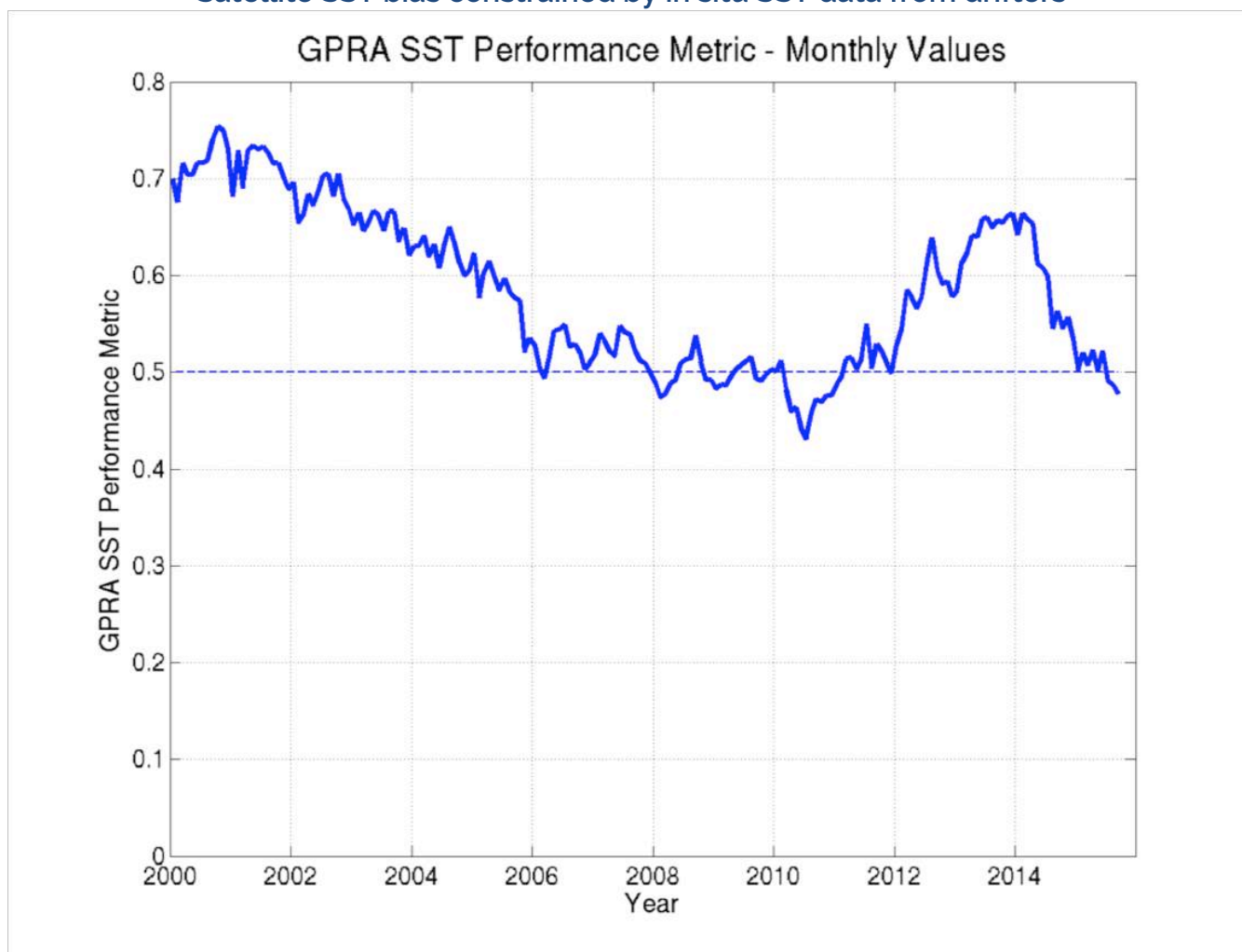


Figure 12: Quarterly SST GPRA Performance Measure and Buoy Need Map by Dr. Huai-min Zhang , NOAA



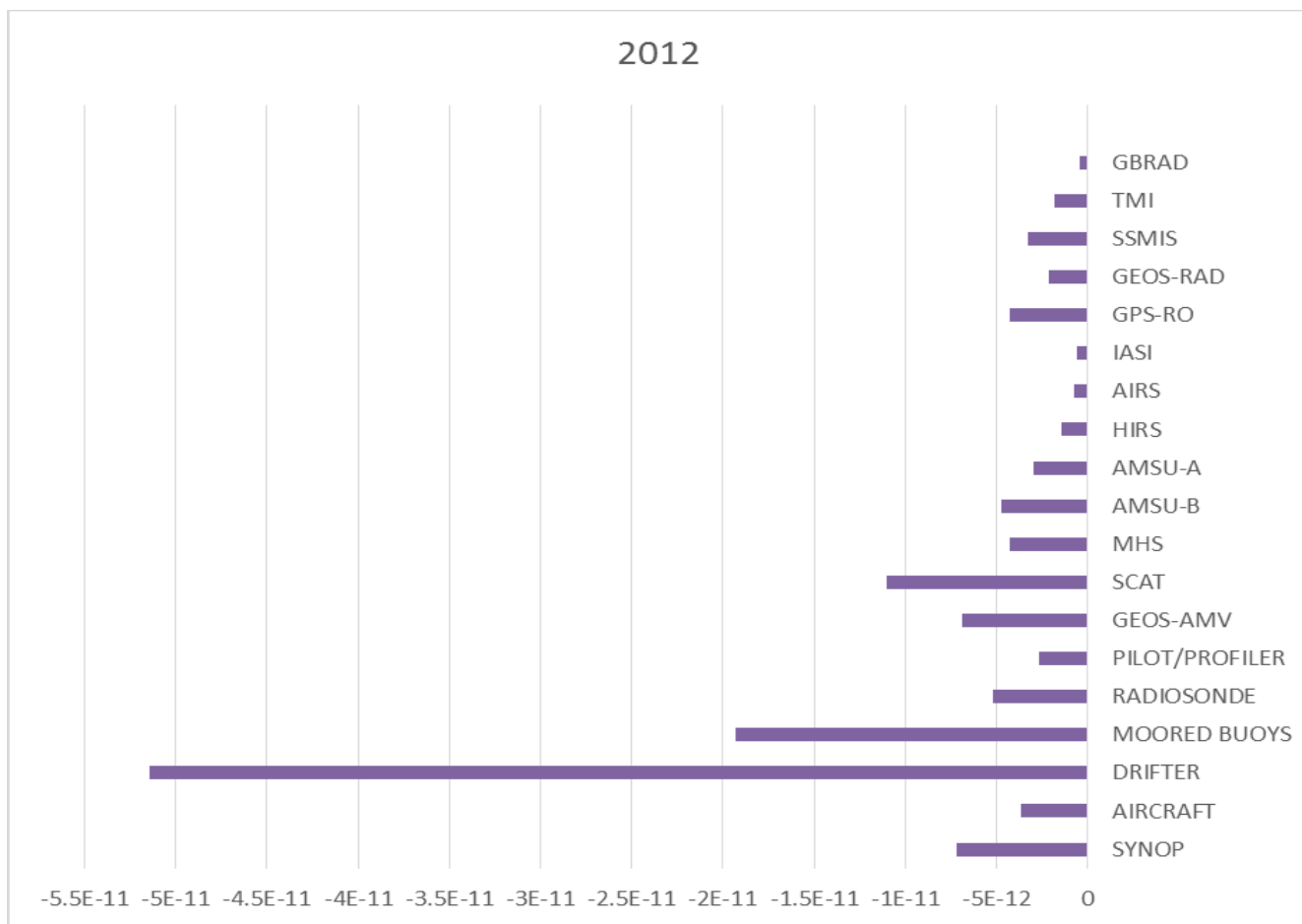


Figure 13: ECMWF operational mean FSOI (i.e. positive impact of the observations on the forecast) for the different observing systems for July-August, 2012. The FSOI values are also normalized by the total forecast error for comparison reason. The observing systems displayed are SYNOP surface observations (surface pressure, moisture and wind), aircraft measurements (wind and temperature), drifters and moored buoys (surface pressure and wind from drifters and moored buoys), radiosondes (wind, temperature, and moisture), pilot/profiler (wind), geostationary atmospheric motion vectors (wind), scatterometer (surface wind), microwave sounder radiances (MHS, AMSU-B and AMSU-A), infrared sounder radiances (HIRS, AIRS and IASI), satellite radio occultation (GPS-RO), geostationary satellite radiances (GEOS-RAD), microwave imager (SSMIS, TMI, AMSR-E), multi-spectral radiometer (MERIS) and radar precipitation (GBRAD). Source: Centurioni et al. BAMS, accepted



# Measurements of O<sub>2</sub>/N<sub>2</sub> and Ar/N<sub>2</sub> ratio by the Scripps O<sub>2</sub> program

## Principal Investigator(s):

**Dr. Ralph Keeling, Jr.**, Scripps Institution of Oceanography, UC San Diego

## NOAA Technical Contact(s):

**Dr. Jim Butler**, NOAA/ESRL

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC Collaboration

## NOAA Theme:

Theme B: Climate Research and Impacts

## Related NOAA Strategic Goal(s):

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

## Budget Amount:

\$453,239

## Amendment No.:

3

## Keywords:

Oxygen, Climate Change, Carbon Cycle, Carbon Sinks

## Milestones:

- Measurements have continued which resolve global atmospheric trends in O<sub>2</sub> and CO<sub>2</sub> and can quantify global carbon sinks
- Data from program are increasingly relied on as benchmark for ocean biogeochemical model validation
- The data provide emergent constraints on natural ocean heat transport from southern to northern hemispheres.

## Research Objectives:

This project continues time series of O<sub>2</sub>/N<sub>2</sub> and Ar/N<sub>2</sub> ratios at ten background air stations by the Scripps O<sub>2</sub> program. The O<sub>2</sub>/N<sub>2</sub> measurements are critical for determining the evolving land and ocean carbon sinks that underpin studies of the

global carbon cycle. The Ar/N<sub>2</sub> measurements provide critical insights into changing ocean heat content and its coupling with air-sea O<sub>2</sub> and CO<sub>2</sub> exchange. The program has strong synergies with measurements of CO<sub>2</sub> concentration and CO<sub>2</sub> isotopes by the NOAA-GMD program and the Scripps CO<sub>2</sub> 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 O<sub>2</sub> program since the mid 1980s. The funded activities further include data reduction and data dissemination activities, including maintaining a dedicated website, [ScrippsO2.ucsd.edu](http://ScrippsO2.ucsd.edu). The work also supports continued efforts to improve methods and address the merging of measurements from the Scripps O<sub>2</sub> program with data from other programs, and it supports international intercomparison and intercalibration activities involving O<sub>2</sub>/N<sub>2</sub> measurements, as endorsed by the World Meteorological Organization.

## Research Accomplishments:

An important accomplishment has been maintaining continuity in the time series based on flask sampling at the ten stations. Results for O<sub>2</sub>/N<sub>2</sub> are shown in Figure 1. Data from this program have been disseminated on the website: [ScrippsO2.ucsd.edu](http://ScrippsO2.ucsd.edu). The data continue to document clearly resolved seasonal cycles and long-term trends on O<sub>2</sub> and CO<sub>2</sub>. The trend data can be used to quantify global land and ocean carbon sinks. Data for Ar/N<sub>2</sub> show a well-



resolved seasonal cycle and a small increase overtime, which is still too small to be well quantified.

The data from this program have been increasingly used by collaborators for improving understanding of ocean and land biogeochemistry and carbon cycling. In the past year, studies have been published that used the seasonal cycles in atmospheric oxygen as a test ocean biogeochemical models, particularly their depiction of biological production and ventilation rates. The O<sub>2</sub> data are especially valuable because they provide a well-observed large-scale constraint.

Several projects using the data from the Scripps O<sub>2</sub> program are in progress at Scripps:

(1) Laure Resplandy (postdoc) has used the O<sub>2</sub>/N<sub>2</sub> and CO<sub>2</sub> data to support an analysis showing that these data provide a constraint on the natural transport of heat by the ocean from the southern to the northern hemispheres. The constraint relates to the observed deficit in "atmospheric potential oxygen" (APO) in the northern hemisphere. The analysis supports an estimate of the ocean heat transport from the southern to northern hemispheres that is on the high end of previous estimates. Further work by Laure shows helps to quantify the natural transport of CO<sub>2</sub> by the ocean from north to south, and her estimates weaken the need for a large northern terrestrial sink in order to explain the north-south CO<sub>2</sub> patterns in the atmosphere. The heat transport study was published in *Climate Dynamics* in early 2016.

(2) Manfredi Manizza (Research Associate) is leading an analysis that challenges ocean models based on the observed ratios of the amplitudes of the APO and Ar/N<sub>2</sub> cycles.

(5) Yassir Eddebbbar (current grad student) is comparing the observed decadal variability in APO with hindcasts from the NCAR community earth system model (CESM). His work particularly focuses on trying to better understand an acceleration of the downward APO trend that

started around year 2000, and may have a relation to the global warming "hiatus", which started around the same time.

Scripps hosted two notable conferences related to this project in Sept 2015, including the bi-annual GGMT meeting on greenhouse gases and a workshop on APO. Both meetings drew an international audience and advanced the goals of this project in data intercomparison and intercalibration

## Conferences, Meetings & Presentations

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

## Education & Outreach

### Communications

- a. 6 June 2015: Scripps Day CO<sub>2</sub> group reunion party. Hosting and presenting at symposium: Rising Carbon dioxide, falling oxygen, and other stories from the Scripps CO<sub>2</sub> program.
- b. 1 Nov 2015: Fireside chat at home of Keith and Lynne Valentine in Del Mar for supporters of Del Mar Sandpiper newspaper: "Thoughts on CO<sub>2</sub> and climate change"

### K-12 Outreach

- b. 22 Mar 2016: Keynote Speaker at San Diego Unified STEAM Leadership Event SCRIPPS FORUM, to an audience of ~250 10<sup>th</sup> and 11<sup>th</sup> graders from San Diego high schools.



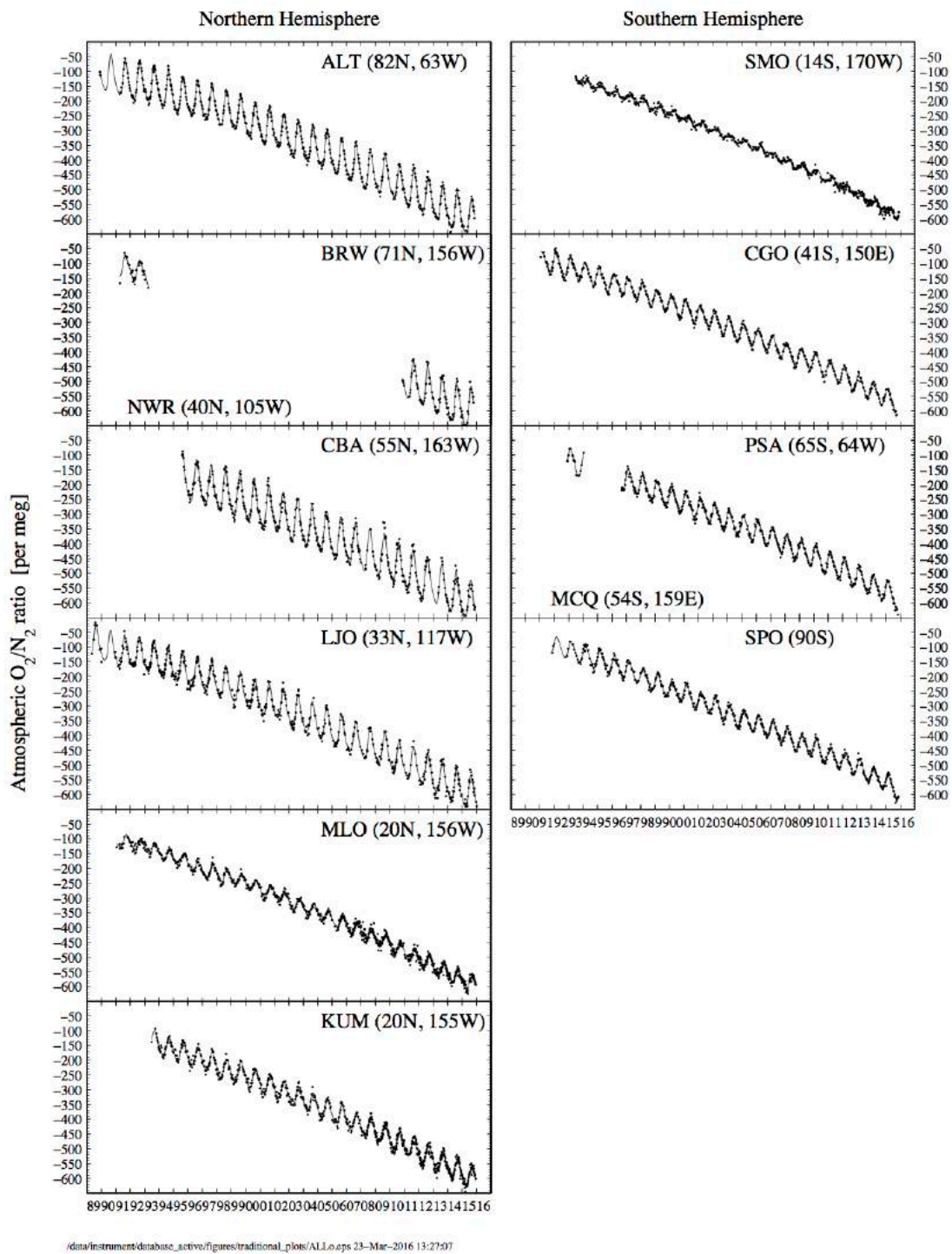


Figure 14: Time series for atmospheric  $O_2/N_2$  ratio at the ten stations in the Scripps  $O_2$  flask network.



# 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

## Other Key Personnel:

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

## NOAA Technical Contact(s):

**Diane Stanitski**, Climate Program Office

**Libby Jewett**, Ocean Acidification Program

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC  
Collaboration

## NOAA Theme:

Theme B: Climate Research and Impacts

## Related NOAA Strategic Goal(s):

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

## Budget Amount:

\$661,000

## Amendment No.:

12 & 29

## Keywords:

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

## Research Objectives:

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

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

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

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

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

## Research Accomplishments:

The fieldwork consisted of recovery and redeployment of two nearly identical moorings CCE1 and CCE2 along CalCOFI line 80 in spring and fall 2015, in the offshore and the upwelling regimes off Pt. Conception. This extends our multi-disciplinary data set to 7 years and 6 years at CCE1 and CCE2, respectively, starting to allow an analysis of anomalies and departures from typical annual evolutions in the quantities observed.



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

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

### Milestones:

1. Recovery and re-deployment of two equivalent highly instrumented real-time moorings across the California Current ecosystem with physical, chemical, carbon, and ecosystem sensors
2. Quantification of upwelling circulation during the 2014/15 warm anomaly
3. Confirmation of anomalous poleward advection
4. Impacts of the warm anomaly on biogeochemistry and ecosystem

### Conferences, Meetings & Presentations

- a. 26<sup>th</sup> IUGG General Assembly, July 2015, Prague, Czech Republic
- b. Pacific Warm Anomaly Workshop, January 2016, Seattle, Washington
- c. Ocean Sciences Meeting, February 2016, New Orleans, Louisiana

## Education & Outreach

### Academic Development

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

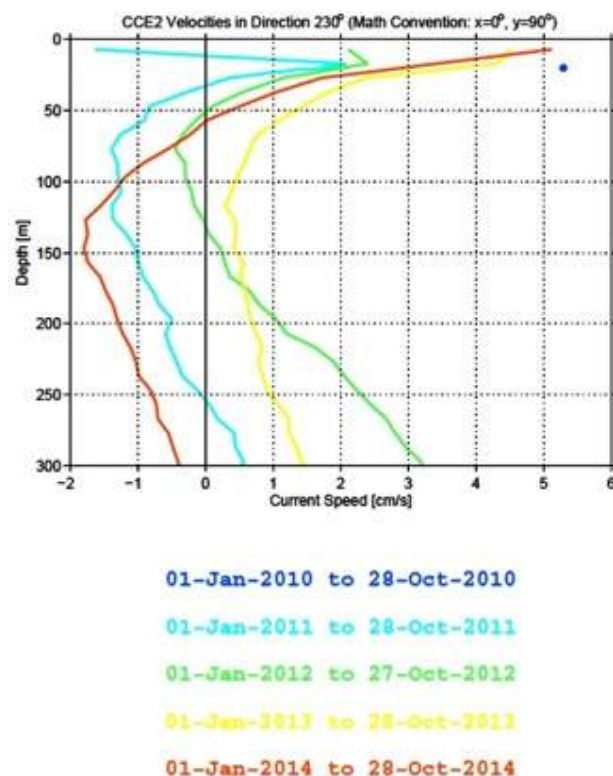


Figure 15: Jan-Oct mean cross-shelf circulation profiles at the CCE2 mooring. The shear between the surface and about 100m depth is taken as a measure for the mean upwelling in that year. There is no absence or significant weakening of upwelling flow visible in 2014.



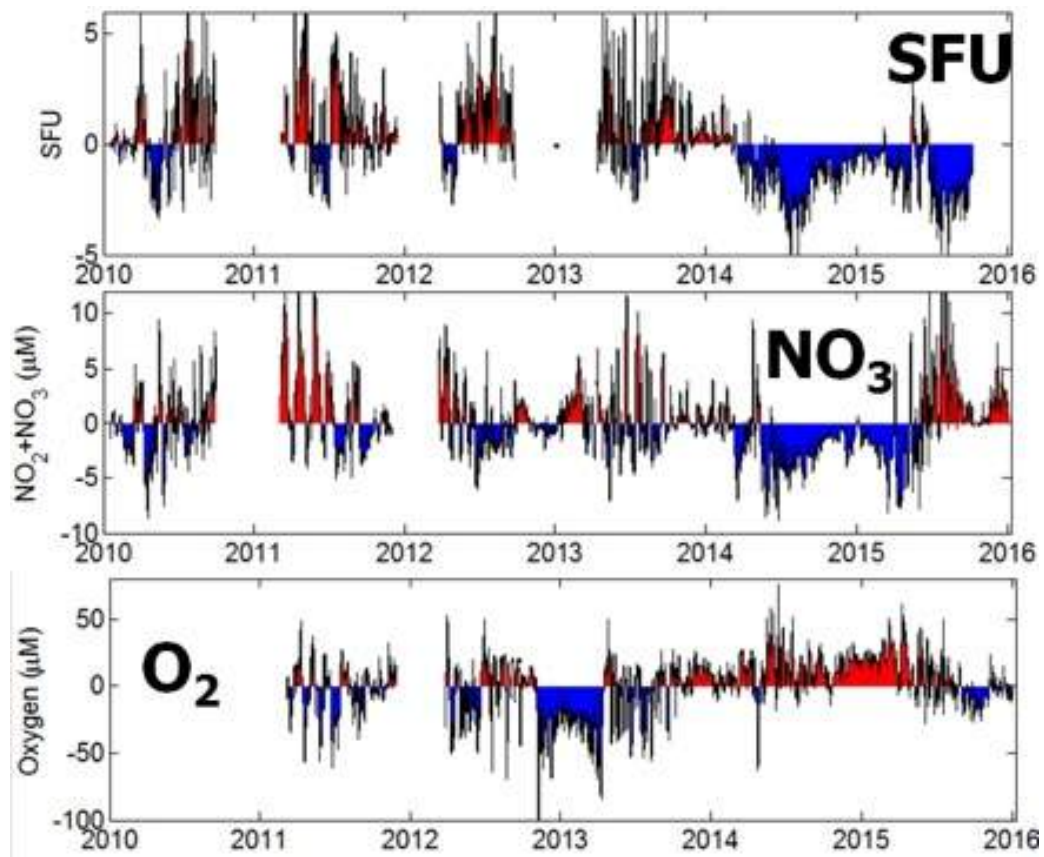


Figure 16: Anomalies (relative to the entire CCE2 mooring data set) of SFU (chlorophyll fluorescence), nitrate, and oxygen concentrations. The very pronounced changes during 2014/15 are clearly visible.



# Early-Start Proposal to Begin Development of an Atmospheric River-Focused CDR (Climate Data Record) in Support of Regional Stakeholder Needs and Scientific Interests Including Drought and Flood

## Principal Investigator(s):

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

## Other Key Personnel:

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

**Tamara Shulgina**, Scripps Institution of Oceanography, UC San Diego

## NOAA Primary Contact:

**Hilawe Seamunegus**, Climatic Science & Development Branch, NESDIS

## NOAA Task:

Task 3 - Individual Science Projects

## NOAA Theme:

Theme B: Climate Research and Impacts

## Related NOAA Strategic Goal(s):

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

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

## Budget Amount:

\$60,000

## Amendment No.:

14

## Keywords:

Catalog, Atmospheric Rivers (ARs), Land-falling ARs

## Milestones:

1. CA Department of Water Resources held a Winter Outlook Workshop at SIO in November 2015, where we (Gershunov) presented experimental results using the new Catalog.

2. A catalog of AR from 1949-2014 has been developed

## Research Objectives:

A new automated method for detection of Atmospheric Rivers (ARs) making landfall at the west coast of North America has been developed. This method has been applied to the NCEP-NCAR reanalysis to create a new Catalog of land-falling ARs at 6-hourly temporal and 2.5 degree spatial resolution going back to 1948. Integrated water Vapor Transport (IVT) is the key parameter determining AR-related precipitation over topography. Thus, the new method for detecting ARs has been developed based on their signature in integrated vapor transport (IVT). We have validated the Catalog by comparison with the SSM/I IWV-based AR catalog (RNW catalog, Ralph et al. 2004, Neiman et al. 2008) and are authenticating it further with independent precipitation data (Livneh et al. 2013).

We are now testing the Catalog by using it to describe the climatology of land-falling ARs, their impact on precipitation over western North America, and their variability with respect to regional climate modes known to be important for this region (ENSO, PDO, etc.) and affecting the region at this time. The new AR detection methodology was applied for NOAA-CIRES 20th Century reanalysis data as well. The result shows good agreement with R1-based AR catalog and can be used for examining AR contribution to historical floods.

## Research Accomplishments:

*The milestone for the first quarter of the project was the establishment of criteria for AR-CDR. We now have a validated catalog – an experimental CDR – that we are testing and analyzing now, in the second*



quarter. The following are the components of our first quarter progress.

### 1A. Methodology of AR detection

Experimentation with IVT and IWV information from NCEP-NCAR Reanalysis, informed by published results and prior knowledge, led to the following algorithm for detecting ARs making landfall at the North American West Coast. The IVT threshold used in detection scheme is 250 kg/m/s. The IWV threshold is a supplemental criterion of AR event identification (15 mm).

Only AR conditions that occurred consecutively during 18 hours (three timesteps) at least were considered as potential ARs. From one time step to the next, maximum movement of two grid points (5° north/south) of the central land-falling location is allowed. To indicate independent AR events making landfall at the same or overlap region, two AR events are considered distinct only if they are separated by more than three consecutive time steps.

Variables characterizing the AR event and its landfall are recorded: count of each AR, time of landfall (year/month/day/hour), latitude-longitude coordinates of AR landfall by grid, IVT value at AR landfall grids, IWV value at AR landfall grids, U/V-wind components at 850 Mb at AR landfall grids.. Six-hourly data on IVT and IWV over the North American West Coast [20.0N – 60.0N, 160W - 100W] are generated and stored as supplementary materials for further research.

The NCEP/NCAR reanalysis data were used as the main resource of atmospheric data for ARs detection. 6-hourly gridded (2.5\*2.5) data on relative humidity, wind speed in the 1000 – 300 hPa atmospheric layer and IWV were used for calculations. The catalog of land-falling ARs (20° – 60°N) was generated for water years (October 1 – September 30) 1949 – 2014.

### 1B. Catalog

The catalog provides 6-hourly information on landfall location (latitude and longitude), IVT and IWV content, zonal and meridional wind components (at 850 mb). AR geometry (footprint)

can be indicated from obtained 6-hourly IVT fields. The general statistics of AR activity at the North American West Coast (20.0N – 60.0N) registers 3567 ARs during water years 1949 – 2014. 2456 of these ARs made landfall at the U.S. west coast (32.5N – 52.5). Moreover, 179 cases recorded two geographically independent AR events making landfall at the same time. 395 cases indicate two consecutive ARs land-falling in the same stretch of coast (at least two latitude grid-points were intersected) with a reprieve of two days at most. The frequency of detected AR events by month and land-falling latitude is shown in Figure 1. The core of AR activity migrates from British Columbia-Washington in the fall to the Oregon-California coast in winter. Spring and summer are relative lulls in AR activity.

### 1C. Catalog verification

To validate our AR catalog we compared it with the existing RNW catalog generated based on SSM/I observations. RNW provides information on ARs making landfall at the West Coast from California to British Columbia during 16 water years from 1998 to 2013 (Ralph et al. 2004, Neiman et al., 2008). ARs impacting the north (Oregon, Washington, and British Columbia, i.e. 42.5-52.5N) or south (California, i.e. 30-40N) coast regions for both the morning ascending SSM/I passes and the afternoon descending satellite passes are presented in the RNW catalog. For verification purposes we extracted subsets of ARs that made landfall on the same days and stretches of coast in both catalogs and those that only registered in one catalog but not the other: False alarm, if an AR registered in our Catalog but not in the RNW, and Miss-hit if visa versa.

### Conferences, Meetings & Presentations

- a. Dr. Gershunov presented experimental results using the new Catalog to CA Department of Water Resources Winter Outlook Workshop, Scripps Institution of Oceanography, UC San Diego, November 2015



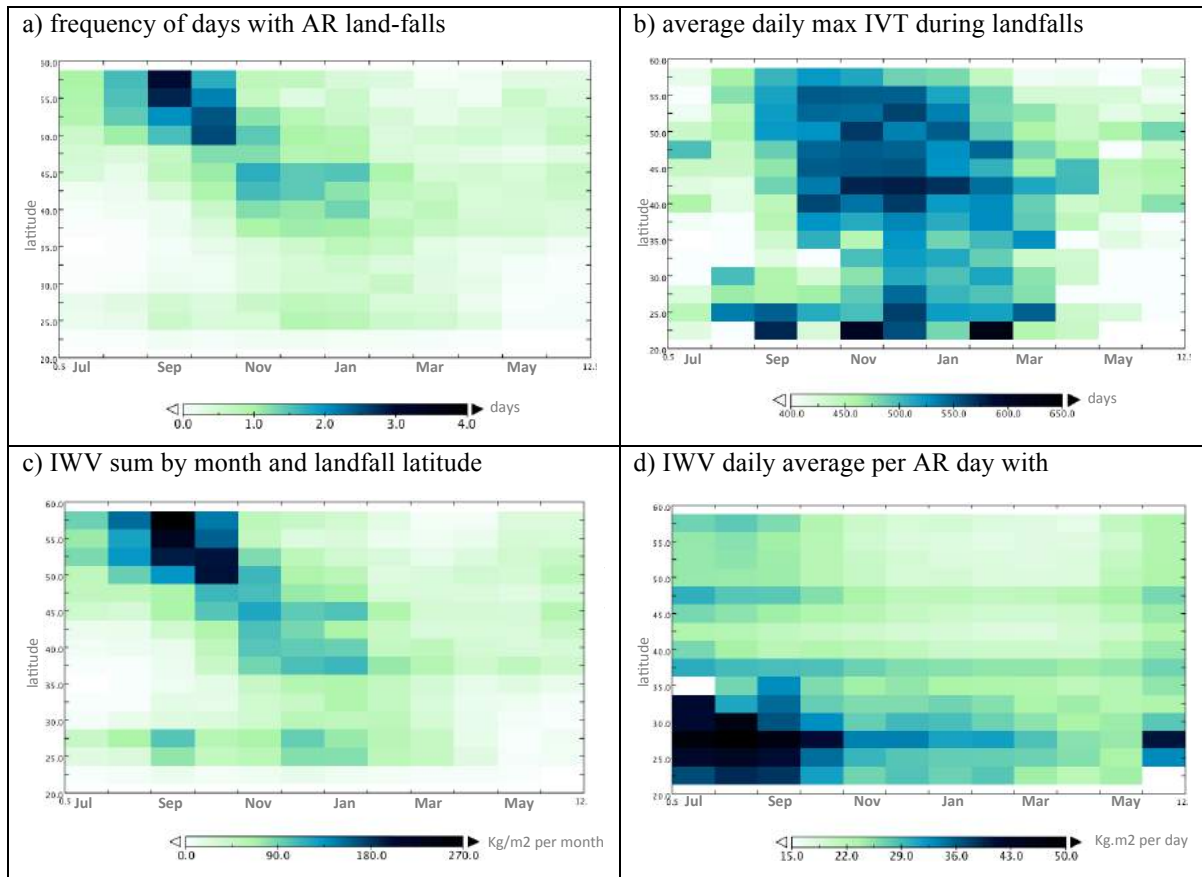


Figure 17: Total number of days (a), average daily maximum IVT (b), total monthly IWV (c) and average daily IWV (d) on days with land-falling ARs by month and central land-falling latitude.



# NOAA Support for the CLIVAR and Caron Hydrographic Data Office at UCSD/SIO 2015

## Principal Investigator(s):

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

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

## NOAA Technical Contact:

**Dr. David Legler**, NOAA Climate Program Office

## NOAA Task:

Task 3: Individual Science Project

## NOAA Theme:

Theme B: Climate Research and Impacts

## Related NOAA Strategic Goal(s):

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

## Budget Amount:

\$112,052

## Amendment No.:

13

## Keywords:

CTD Data, Hydrographic Data, Ocean Carbon Data, Data Assembly Center

## Milestones:

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

## 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>.

## Research Accomplishments:

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

The NOAA/NCEI works with several data assembly centers, including CCHDO, to bring data into NCEI. The CCHDO continues to improve their relationship with NCEI in the following areas:

1. Continued data assembly of cruise hydrographic data and metadata, particularly those from the GO-SHIP program.
  - a. The CCHDO continues as the official global DAC for GO-SHIP.
  - b. The CCHDO continues to coordinate its activities with the JCOMMOPS technical coordinator for the GO-SHIP program, Martin Kramp.
2. Working with NCEI to improve efficiency of transfer of data and to make CCHDO data more "archive ready". The CCHDO and NCEI continue to implement incremental



technological enhancements which have improved the efficiency of the data transfer. This has led to an overhaul of the underlying structure for holding and serving data to all customers, including NCEI.

3. Continued CCHDO participation in discussions towards enhancing integration of the related Data Assembly Centers (for example CDIAC and BCO-DMO), to reduce ambiguity and redundancy in data archiving.

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

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

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



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

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

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

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

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

To summarize, all issues raised at ADMT-15 have been positively resolved ahead of schedule, the semi-retired oceanographer team of Howard Freeland and Jim Swift have performed their CTD

data QC duties admirably and have added Breck Owens to their ranks as of ADMT-16.

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

### Conferences, Meetings & Presentations

- a. Ocean Sciences 2016, 22-26 February 2016, New Orleans, Louisiana, with Swift, Diggs, Berys-Gonzalez, and Kappa
- b. Argo/ADMT-16, November 1, 2015, Hamilton, Bermuda with S. Diggs, and A. Bama

### Education & Outreach


#### Communications

- d. Disseminate all public CCHDO data, documentation, and data information via the CCHDO web site <http://cchdo.ucsd.edu>.

#### Academic Development

- b. Train undergraduate research assistants in under-the-hood operations of a data center and web site via real-world experience with ongoing CCHDO activities.




[CCHDO](#)
[Home](#)
[Find Data](#)
[Submit Data](#)
[Information](#)

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

Welcome to the CCHDO

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

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

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

### Search

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

[Map Search](#) lets you draw a box on a map to search for station data.

[Advanced Search](#) lets you finely define key word, bounding box, and temporal searches.





### Some Starting Searches

Here are some searches which may be of general interest:

<b>Basins</b>	<ul style="list-style-type: none"> <li>Arctic Ocean</li> <li>Atlantic Ocean</li> <li>Pacific Ocean</li> <li>Indian Ocean</li> <li>Southern Ocean</li> </ul>
<b>Programs</b>	<ul style="list-style-type: none"> <li>GO-SHIP</li> <li>USHYDRO</li> <li>WOCE</li> <li>DIMES</li> <li>ELLETT</li> <li>Project Carina</li> </ul>
<b>Time Series</b>	<ul style="list-style-type: none"> <li>Hawaii Ocean Time Series</li> <li>Bermuda Atlantic Time Series</li> </ul>

- minimalist look
- fast response
- new functions for searches and data tables
- build-your-own multi-cruise downloads
- data accessible via APIs (bypass web site)

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

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

J. Swift, SIO, October 2015

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

Figure 18: March 2016 front page of the CCHDO web site <http://cchdo.ucsd.edu>. This 'minimalist' look belies underpinnings of the CCHDO web site and data serving which are powerful, easy-to-support, reliable, and fast.



## Theme C: Marine Ecosystems

### Collaborative Opportunity: Exploring 'omic Technologies to Support Ecosystem Understanding and Fisheries Assessments

#### Principal Investigator(s):

**Andrew Allen**, Scripps Institution of Oceanography, UC San Diego & J. Craig Venter Institute

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

#### NOAA Primary Contact:

**Margot Bohan**, Office of Ocean Exploration

#### NOAA Task:

Task 2 - Joint NOAA Laboratory/CIMEC Collaboration

#### NOAA Theme:

Theme C: Marine Ecosystems

#### Related NOAA Strategic Goal(s):

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

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

#### Budget Amount:

\$200,000

#### Amendment No.:

2

#### Keywords:

omics, phytoplankton networks

#### Milestones:

- Design and implementation of MiSeq technologies
- Implementation of epmotion robotics platform
- Data generated for 16S and 18S DNA for 2014 and 2015 samples (all four cruises)

- Preliminary analyses of data suggest large scale contrast between cyano dominated vs diatom dominated food webs

#### Research Objectives:

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

The program objective is to assay the diversity and distribution of microbes and other planktonic organisms. Ability to link analyses of microbial community structure and diversity directly to measurements of ecosystem productivity will enable evaluation of microbial population and community dynamics in the context of other indicators of ecosystem productivity.

To overcome sample throughput bottlenecks, DNA and RNA purification and MiSeq amplicon and HiSeq metatranscriptomics library construction protocols will be used for high throughput epmotion robotics will be optimized for filters and contents of net tows. A BioCell robotics platform at JCVI will be used for high throughput PCR MiSeq amplicon library generation. Amplicon targets include the



hypervariableV4 and V5 regions of the 16S rDNA gene for bacteria, archaea, and the chloroplast of eukaryotic phytoplankton; the hypervariable V4 and V9 region of the 18S rDNA gene for microbial eukaryotes, and regions of DNA polymerase and Reverse Transcriptase for DNA and RNA viruses.

### **Research Accomplishments:**

We have established new in silico databases that required substantial manual curation in order to achieve meaningful functional and taxonomic assignment.

### **Conferences, Meetings & Presentations**

- a. NOAA CalCOFI Genomics Project (NCOG):  
Influence of Nutrients and Temperature on Pelagic Ecosystem Microbial Networks in the Southern California Current Ecosystem, December 14-16, 2015, Monterey Bay, California, with A.E. Allen, K. Goodwin, R. Goericke, M. Bohan, S. Dovel, A. Rabines, M. Roadman, H. Zheng, J. McCrow, L. Zeigler, D. Checkley

### **Education & Outreach**

#### **Communications**

Project and partnership announcement to the NOAA and CalCOFI community with SIO, NOAA, and JCVI

- a. - <http://oceanexplorer.noaa.gov/about/what-we-do/oer-updates/2014/calcofi-111914.html>
- b. <http://oceanexplorer.noaa.gov/about/who-we-are/partnerships.html>
- c. <http://www.calcofi.org/field-work/bottle-sampling/ncog-project.html>



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

## Principal Investigator(s):

**David Kriegman**, Jacobs School of Engineering,  
UC San Diego

## NOAA Technical Contact:

**Steven Miller**, NOAA Fisheries Ecology Division

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC  
Collaboration

## NOAA Theme:

Theme C: Marine Ecosystems

## Related NOAA Strategic Goal(s):

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

## Budget Amount:

\$70,281

## Amendment No.:

20

## Keywords:

Benthic Surveys

## Milestones:

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

## Research Objectives:

The National Coral Reef Monitoring Plan reef benthic cover data are derived from the analysis of benthic images collected during Rapid Ecological Benthic and Fish Surveys, as well as images collected during the Climate Station

Monitoring Surveys. As such, the need for this project is best exemplified by the considerable resources that are already being directed towards manual annotation of benthic photoquadrats. Our team has been developing computer vision and machine learning methods for automatically and semi-automatically annotating benthic reef images.

1. Improve the core classification algorithms.
2. Improve the CoralNet web site software, including updating the system software, porting to Amazon Web Services, improving image uploader, modify the logic of the label set, and improve the user interface.
3. The project serves as a pilot-study for NOAA divisions and jurisdictional partners to transition from manual to automated image annotation. In turn, an objective was to work with and train CRED scientists on how to use the current version CoralNet and evaluate the results.

## Research Accomplishments:

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

In the first direction we first created a new upload function has been implemented to allow users to more conveniently upload archived sets of annotations. This was initiated by CRED partners so that their archived annotations, performed in CPCe, could more conveniently be uploaded to the system. Further, the page to view image details have been updated to allow for better control of the image settings. This included settings the annotation area, the number of random points for that particular image, and the random point scattering scheme. Further still, the



vision backend-system has been updated to better handle large set of images uploaded as part of NOAA's analysis. This was critical in order to handle uploads of >30k images, which is an order of magnitude larger than the site previously could handle. The new system is able to process large sources in smaller portions, thus enabling it to also attend to other, smaller sources, intermittently. Finally an updated sign-up procedure makes signing up to the website more convenient. This was mostly a UI improvement but it was critical as the old system was confusing to many users.

The second direction chiefly concerned development of deep learning methods for automated analysis. Towards this end, experimentation has been conducted on the appropriate implementation of deep learning methods for computer vision. These experiment include, for example, appropriate receptive field / image resolution to provide to the network, analysis of the number of point annotations and images required to achieve appropriate accuracy, and finally a detailed comparison of human versus automated accuracies. Further, a new,

"background" deep learning model has been trained on over 2Million annotations harvested from CoralNet. As our experiments indicate, and as shown in Figure 1 of this report, the new background model significantly improves recognition accuracies, in particular in the low-data scenario. Advances of the new method have been demonstrated on a publically available data-set and demonstrates very significant improvements in recognition accuracy; in some cases even surpassing manual annotation accuracy.

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

## Conferences, Meetings & Presentations

- a. International Coral Reef Symposium, June 2016, Honolulu, Hawaii, with Oscar Beijborn

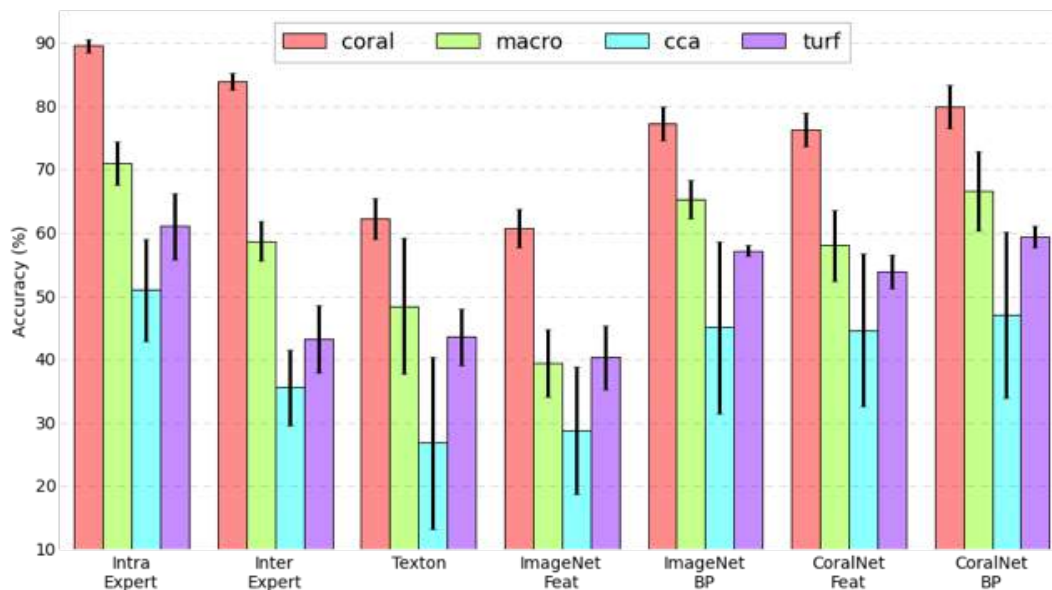


Figure 19: Classification accuracies of benthic functional groups. Intra and Inter Expert refers to self and between accuracy of human experts. Texton refers to the previous state-of-the-art. {ImageNet, CoralNet} {feat, BP}, refer to the developed methods where the first member indicates the dataset (ImageNet or CoralNet) used for pre-training and the second the level of back-propagation. Feat here refers to solely adjusting the classifier, and BP refers to deep back-propagation of gradients. The rightmost method is most effective and the one proposed for use in CoralNet.



# Collaboration in Freshwater Ecology Research

## Principal Investigator(s):

**Dr. Eric Palkovacs**, UC Santa Cruz

## NOAA Technical Contact:

**Dr. Steven Lindley**, SWFSC - Fisheries Ecology Division

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC Collaboration

## NOAA Theme:

Theme C: Marine Ecosystems

## Related NOAA Strategic Goal(s):

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

## Budget Amount:

\$61,386

## Amendment No.:

21

## Keywords:

Anadromous Fish, Climate Change, Endangered Species Act, Fisheries Management, Freshwater Ecology, Genetics, Invasive Species

## Milestones:

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

## Research Objectives:

My primary objectives since arriving at UCSC have been to (1) establish my lab group and build my research program focused on the eco-evolutionary dynamics of aquatic ecosystems, (2) develop my undergraduate courses in freshwater ecology and mentor successful graduate students and postdocs, and (3) provide service to the department and the university, the scientific and resource management communities, and the general public. I describe my accomplishments in these areas below.

My research program is focused on understanding interactions between ecology and evolution – known as eco-evolutionary dynamics – primarily as these interactions occur in aquatic ecosystems. Human activity is a strong driver of both ecological and evolutionary change. Therefore, I am interested in the impacts of human disturbance on eco-evolutionary dynamics and implications for conservation and resource management. 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. Research activity on eco-evolutionary dynamics has expanded dramatically over the past decade. For example, an ISI Web of Science keyword search for “eco-evo\*” shows an increase from 1 publication in 2005 to 110 publications in 2014 (I have authored three papers ranking in the top 20 most highly cited papers in this search).

## Research Accomplishments:

(1) The role of contemporary evolution in shaping ecological dynamics: One of my major goals is to understand the importance of contemporary evolution for shaping aquatic communities and ecosystems. A major assumption across much of ecology is that *species* are the functional building blocks of communities and drivers of ecosystems. In contrast, my studies have shown important community and ecosystem effects of variation



within species (among populations), and a recent meta-analysis (currently in review) shows that for many study systems the effects of diversity within species can be as large as the effects of diversity among species. While this past work points to the *potential* importance of contemporary evolution for communities and ecosystems, it is only weakly linked to ecological theory that might help predict *when* such effects might be important. One of my general goals is to link eco-evolutionary dynamics to ecological theory related to the major drivers of community and ecosystem change. One of these major ecological drivers in aquatic ecosystems is the trophic cascade, and one of my major current efforts is to ask whether the contemporary evolution of prey populations in response to predators impacts the strength of trophic cascades. I have recently received funding from NSF to use recently introduced mosquitofish populations in California as a study system to address this question. Another major unanswered question is the extent to which environmental variation influences the strength of eco-evolutionary effects. No published experiments to date have tested the interaction between environmental variation and contemporary evolution on community or ecosystem responses. My lab is now running these experiments, examining the interacting effects of temperature variation and thermal adaptation in mosquitofish on freshwater pond communities and ecosystems. Such experiments provide important information about the drivers of community and ecosystem change and also provide new insights into how ecosystems will respond to climate change.

(2) The role of eco-evolutionary feedbacks in shaping the trajectory of evolution: Organisms that cause major changes to the ecosystem (e.g., keystone species, ecosystem engineers, foundation species) may, in turn, shape natural selection and evolution via eco-evolutionary feedbacks. Theory, laboratory experiments, and some observational studies point to the importance of feedbacks for shaping evolution, but testing the strength of feedbacks in nature requires large scale experiments. My lab is

currently running such experiments in two study systems – lakes with alewife populations in Connecticut and estuaries with stickleback populations in California. My prior studies on alewife populations suggest that key feeding traits evolve as a result of eco-evolutionary feedbacks. I am further testing this hypothesis using whole lake experiments facilitated by efforts to restore anadromous alewife to lakes with landlocked populations. I currently have an NSF RAPID grant and another NSF proposal in review to fund this work. In addition, I have begun work in California estuaries examining whether feedbacks may contribute to the loss of lateral plates in threespine stickleback populations as they adapt to freshwater conditions. The UCSC Hellman Fellows Program has funded pilot work in the stickleback system that will provide data to facilitate future proposals.

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



laboratory and small-scale experiments and into real world managed ecosystems.

### **Conferences, Meetings & Presentations**

- a. Gordon Research Conference on Predator-Prey Interactions, January 2016, Ventura, California, with Eric Palkovacs and Dave Fryxell
- b. Cal-Neva / Western Division American Fisheries Society Conference, March 2016, Reno, Nevada, with Dave Fryxell, Ben Wasserman, Travis Apgar, Gina Contolini, and Katie McElroy
- c. Western Society of Naturalists Meeting, November 2015, Sacramento, California, with ben Wasserman

### **Education & Outreach**

#### **Communications**

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

#### **Academic Development**

- a. Support graduate education and research with 3 Ph.D. and 2 Masters students in the Palkovacs Lab at UC Santa Cruz.

- b. Support research and professional development for 1 postdoctoral scholar in Palkovacs Lab at UC Santa Cruz.

#### **K-12 Outreach**

- a. Research Experience for Teachers Program funded by NSF for high school teachers to participate in summer research and curriculum development. In cooperation with UC Santa Cruz, high schools in the Santa Cruz and Monterey areas, and Industry Initiatives for Science and Math Education.
- b. Summer Internship Program (SIP) for high school students in the Santa Cruz and Monterey areas.

#### **Networking**

- a. A Population Ecology and Evolution Working Group with the Institute for the Study of Ecological and Evolutionary Climate Impacts (ISEECI) 2015, that works on setting objectives for climate change research across the UC Natural Reserve System

#### **Fellowships & Internships**

- a. Undergraduate internships provide training and experience at UC Santa Cruz.





Figure 20: River herring captured in marine bycatch off the coast of Southern New England. New research shows that bycatch is impacting the most depleted river herring genetic stocks and likely hindering population recovery.



Figure 21: Female (top) and male (bottom) western mosquitofish differ in ecologically important traits such as body size and feeding rates. New research shows that these trait differences can impact aquatic ecosystems when sex ratios become skewed toward one sex or the other.



# Investigations in Fisheries Ecology

## Principal Investigator(s):

**Dr. Eric Palkovacs**, UC Santa Cruz

## NOAA Technical Contact:

**Dr. Steven Lindley**, SWFSC, Fisheries Ecology Division

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC Collaboration

## NOAA Theme:

Theme C: Marine Ecosystems

## Related NOAA Strategic Goal(s):

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

## Budget Amount:

\$5,664,236

## Amendment No.:

22

## Keywords:

Climate Change, Economics, Endangered Species Act, Fisheries Management, Freshwater Ecology, Genetics, Groundfish, Habitat, Marine Ecology, Salmon

## Milestones:

- Developed a generalized salmon cohort reconstruction model.
- Designed and built a Habitat Use Database for Pacific Coast Groundfish.
- Completed the annual summer salmon survey in the coastal ocean between San Francisco and central Oregon: an 18-day research cruise where a team of 12 scientists collected approximately 600 juvenile and subadult salmonids, along with biological and physical ecosystem data.
- Completed a 21-day research cruise aboard the R/V Ocean Starr to collect juvenile salmon and associated biological and oceanographic samples. The cruise encountered “unusual”

conditions related to the large persistent pool of warm water in the northeastern Pacific (e.g. uncommon southern species such as sunfish and barracuda in our trawl catch), and relatively few juvenile salmon.

- Developed a Winter-run Chinook salmon individual based model that is being used to evaluate the impacts of varying stream flow, stream temperature, and physical habitat conditions related to spawning, incubation, and fry life stages.
- Developed continuous maps of river channel bathymetry and sediment grain-size for 50 km of the Merced River, using remote sensing techniques. Started constructing hydrodynamic models for ~250 km of the Merced and Tuolumne Rivers.
- Developed a continuous map of river channel bathymetry and fish distribution along the lower San Joaquin River using boat-based acoustic survey technologies developed by the AST team at the SWFSC - La Jolla lab
- Completed the field component of a San Joaquin River salmonid smolt predation study geared towards bridging the gap between low smolt survival estimates seen in the San Joaquin River and the likely cause of mortality: predation. Novel techniques were employed, including predator density maps using acoustic survey technologies, spatial and temporally explicit measures of relative predation risk using Predation Event Recorders, and DNA barcoding techniques to identify salmonid DNA in the diets of predator species.
- Completed a Center for Independent Experts Review of the Central Valley Winter-run Chinook Life Cycle Model.

## Research Objectives:

This cooperative research program encompasses a large number of individual studies conducted by scientists from the University of California Santa Cruz (UCSC), the National Marine Fisheries



Service, Southwest Fisheries Science Center, Fisheries Ecology Division (FED) and Environmental Research Division (ERD), and many collaborators at other institutions and agencies. The overall objectives are to conduct research needed to support (1) management and recovery planning for Pacific salmonids and sturgeon listed under the Endangered Species Act; (2) stock and ecosystems assessments and harvest management for West Coast groundfish and Pacific salmon fisheries; and (3) economic assessment of fisheries and fishing communities in California.

Specific research projects addressed 10 objectives:

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

Project scientists used a wide range of methods to address these research questions, including field sampling, laboratory experiments, physical and

biological modeling, spatial analysis and modeling using GIS and remote sensing, and economic data collection and analysis.

### Research Accomplishments:

Project scientists met research milestones for the projects above, which addressed a wide range of topics on biology, analytical methods, and economics related to the management of groundfish, salmon, and the California Current ecosystem. Accomplishments included final completion of a number of major projects resulting in publication of papers and reports; completion of several large field and laboratory data collection efforts, data analyses, and modeling projects; and initiation of a number of new studies through hiring of research staff, developing research plans and protocols, and beginning data collection or model development. Results were published in 16 journal articles and 2 reports, 1 book review, 1 workshop summary/proceedings, 1 PhD dissertation, and an additional 3 articles were in press or submitted. Many project scientists engaged in more than 7 high profile conferences, workshops, and symposia, as well as participated in multiple outreach events and working groups to present research, network and collaborate with other scientists, contribute to training and professional development within the field, and provide information to the public. Academic development was provided to undergraduate and graduate students and post-doctoral scholars through employment and support of thesis and dissertation research.

### Meetings & Presentations

- a. Western Groundfish Conference, February 2016, Newport Orgean, with Joe Bizzarro, Sabrina Beyer, Neosha Kashef, Morgan Arrington, David Stafford, Lyndsey Lefebvre, Rebecca Miller, Nikolas Grunloh, Mary Yoklavich, EJ Dick, Melissa Monk
- b. American Fisheries Society Annual Meeting, August 2015, Portland Orgean, with Joe Bizzarro, Alice Thomas-Smyth, Neosha Kashef, David Stafford, Sabrina Beyer, Rebecca Miller, Lyndsey Lefebvre, Anne Criss, David Stafford,



Neosha Kashef, Kerrie Pipal, Vamsi Sridharan, Flora Cordoleani, Colleen Petrik, Mary Yoklavich, Elizabeth Gilbert-Horvath

- c. Cal-Neva / Western Division American Fisheries Society Conference, March 2016, Reno, Nevada, with Diana Baetscher, Flora Cordoleani, Raz Davison
- d. Center for Independent Experts Review of the Central Valley Life Cycle Model, November 2015, Santa Cruz, California, with Anne Criss, Flora Cordoleani, Andrew Pike, Sara John, Kerrie Pipal, Michael Beakes, Steve Lindley, Will Satterthwaite, Michael O'Farrell
- e. Western Society of Naturalists Meeting, November 2015, Sacramento, California, with Neosha Kashef, Evan Mattiasen, David Stafford
- f. Ocean Sciences Conference, February 2016, New Orleans, Louisiana, with Ben Martin and Eric Daner
- g. Pacific Coast Steelhead Management Meeting, March 2016, Asilomar/Pacific Grove, California, with Kerrie Pipal and Rachel Johnson

## Education & Outreach

### Communications

- a. Presented guest lecture at UC Davis for faculty and students and led discussion of ecosystem-based fisheries management for graduate course in conservation biology at UC Davis.
- b. Presented guest Lecture at Moss Landing Marine Laboratory for faculty and students on aspects of fisheries management and ESA listed salmon populations.
- c. Presented salmon abundance forecasts and a preliminary outlook for 2016 ocean salmon fisheries at the 2016 CDFW Salmon Informational Meeting for the general public, fishing groups and CDFW.
- d. Presented a lecture on reproductive ecology of rockfish and the role of maternal effects for faculty and students at Moss Landing Marine Lab.

### Academic Development

- c. Support graduate education and research at UC Santa Cruz, Humboldt State University, Moss Landing Marine Labs and UC Santa Barbara.
- d. Support professional development of postdoctoral scholars at UC Santa Cruz and UC Berkeley.
- e. Support professional development of graduate students at Moss Landing Marine Labs and UC Santa Barbara.

### K-12 Outreach

- c. Presentations and field trips for elementary and high school students and teachers in the Santa Cruz and Monterey areas.

### Networking

- h. Staff participated in many formal and informal interagency working groups with USBR, NASA, USFWS, USGS, California Department of Water Resources, California Department of Fish and Wildlife, Washington Department of Fish and Wildlife, Oregon Department of Fish and Wildlife, University of Washington, University of California, Santa Cruz, University of California, Davis, University of California, Santa Barbara, University of California, Berkeley, Humboldt State University, University of Wyoming, Department of Fisheries and Oceans, Canada, Center for Stock Assessment Research (CSTAR), California State Water Board

### Fellowships & Internships

- b. Undergraduate internships provide training and experience at UC Santa Cruz.





Figure 22: Scientists sample steelhead in the study reach immediately below San Clemente Dam on the Carmel River as part of ongoing research to examine the impacts on the fish and fish habitat resulting from the dam removal. When the 106 foot high dam was constructed in 1921, it had a reservoir storage capacity of approximately 1,425 acre-feet. The reservoir had been filled by more than 2.5 million cubic yards of sediment, leaving a reservoir storage capacity of approximately 70 acre-feet as of 2008. The Carmel River Reroute and San Clemente Dam Project is the largest dam removal project ever to occur in California and one of the largest to occur on the West Coast.  
 Photo Credit: Tommy Williams, NOAA Fisheries - SWFSC



# Collaborative Ocean Observing and Fisheries Oceanography Research off Northern California

## Principal Investigator(s):

**Brian Tissot**, Humboldt State University

## NOAA Technical Contact:

**Steven Miller**, NOAA Fisheries Ecology Division, SWFSC

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC Collaboration

## NOAA Theme:

Theme C: Marine Ecosystems

## Related NOAA Strategic Goal(s):

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

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

## Budget Amount:

\$136,724

## Amendment No.:

24

## Keywords:

Ocean Observing, Zooplankton, Trinidad Head Line, Ecosystem Indicators

## Milestones:

- Roxanne Robertson continued to serve as lead technician, where she coordinated and often led hydrographic and biological sampling on 12 cruises along Trinidad head Line (THL).
- Completion of a retrospective analysis of euphausiid abundance and community for the THL time series and presentations of these and complementary results at several conferences and workshops.

## Research Objectives:

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

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

## Research Accomplishments:

Roxanne Robertson continued to serve as lead technician and to be a tremendous asset to the program. She has coordinated and in many cases led hydrographic and biological sampling on 12 successful cruises along the Trinidad Head Line (THL), processed hydrographic data, coordinated laboratory efforts to catch up on analysis of archived specimens (technical support for plankton sorting augmented by funding from the Ocean Protection Council), and ensured timely calibration and maintenance of instrumentation. This year saw completion of a retrospective analysis of euphausiid abundance and community for the THL time series, and presentation of these and complementary results at several conferences and workshops. Results from this work included documenting effects of the "warm blob" waters in late 2014 and the subsequent El Niño on zooplankton communities. CIMEC-funded staff have also supported operations of a SeaGlider along a transect that spans much of the THL and extends well offshore through collaboration with CeNCOOS, NANOOS, and OSU.



## Conferences, Meetings & Presentations

- a. Eastern Pacific Ocean Conference, 9/20-23/2015, Stanford Sierra Camp, Fallen Leaf Lake, California, with Roxanne Robertson and Eric Bjorkstedt
- b. Pacific Anomalies Workshop II, January 2016, Seattle Washington with Roxanne Robertson and Eric Bjorkstedt
- c. CalCOFI, December 2015, Moss Landing, California, with Eric Gjorkstedt



# Freshwater Fish Ecology Research Collaboration

## Principal Investigator(s):

**Darren Ward**, Humboldt State University

## NOAA Technical Contact:

**Steven Miller**, NOAA Fisheries Ecology Division

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC Collaboration

## NOAA Theme:

Theme C: Marine Ecosystems

## Related NOAA Strategic Goal(s):

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

## Budget Amount:

\$66,733

## Amendment No.:

17

## Keywords:

Klamath River, Salmon Conservation, Coho Salmon, Restoration Evaluation

## Milestones:

- Funding proposals drafted and submitted for over \$2.5 million in research funds (two projects still under consideration).
- Michelle Krall's thesis defense date set for April 2016.
- New research collaboration initiated with the Scott River Watershed Council to evaluate beaver dam analogs as a habitat restoration technique.

## Research Objectives and Specific Plans to Achieve Them:

This project provides support for the Department of Fisheries Biology at Humboldt State University (HSU) to maintain a long-term collaboration between HSU and NOAA/NMFS addressing salmon conservation and restoration in Northern California and the Klamath River basin. This objective is implemented through partial funding

for a faculty position held by Dr. Darren Ward at HSU to develop research projects focusing on evaluation of restoration effectiveness and assessment of issues related to restoration of salmon production in the Klamath River. Project funding allows this position to continue as a 50% research and 50% teaching appointment, as compared to typical 100% teaching appointments at HSU, to allow research efforts that complement NMFS efforts and fill needs for management and conservation planning.

## Research Accomplishments:

Research activities for this project are primarily carried out through increased time investment in mentoring graduate students and developing funding proposals. Over the course of the research collaboration, four Master's students have completed research theses under Dr. Ward's direction. These projects have all focused on salmon conservation efforts, particularly improving population monitoring programs and evaluating habitat restoration efforts. Four additional students are currently at work on related projects.

- Michelle Krall (expected completion Spring 2016) collected data to evaluate growth and abundance of juvenile coho salmon occupying habitat enhancement sites in Klamath River tributaries. Her analysis has helped to identify site features associated with increased juvenile coho salmon survival. She has completed fieldwork and analysis and is currently finalizing revisions to her thesis.
- Molly Gorman (expected completion Spring 2016) compared the fate of juvenile coho salmon that rear in natal habitats in Klamath River tributaries with those that emigrate from the tributaries into the main stem Klamath River. Molly was awarded a 2015 California Sea Grant award to incorporate stable isotope analysis of coho salmon otoliths into her project. She has completed



fieldwork and analysis and is currently drafting her thesis.

- Gabe Scheer (expected completion Fall 2016) has constructed a life history based population model for coastal coho salmon populations in order to predict the relative efficacy of different conservation approaches at increasing abundance and reducing extinction risk. He has completed coding of the model and most simulation work. He is currently drafting his thesis.
- Justin Alvarez (expected completion Fall 2016) is measuring predation on native salmon by non-native brown trout in the upper Trinity River. Justin recently started his second year of electrofishing surveys of the upper Trinity River. His sampling efforts have produced the first large-scale population estimate of brown trout in this important salmon habitat. Stomach sampling has revealed extensive predation by brown trout on both wild and hatchery produced salmon.

During the 9 months covered by this report (07/2015 – 03/2016), 59 SIO SOLO-II Argo floats were built, shipped, and deployed, and an additional

## Meetings & Presentations

- e. American Fisheries Society National Meeting, August 2015, Portland, Oregon, with Darren Ward, Michelle Krall, Molly Gorman and Gabe Scheer
- f. Western Division American Fisheries Society Meeting, March 2015, Reno, Nevada with Molly Gorman

## Education & Outreach

### Academic Development

- f. Train undergraduate and graduate students in Fisheries Biology at Humboldt State University. Teach the following courses: Fish Conservation and Management (31 students), Fisheries Science Communication (28 students), Biology of Pacific Salmon (25 students). Primary research advisor for 4

current graduate students. Serve on graduate committees for 7 current graduate students

### K-12 Outreach

- d. Introduce elementary school students to fish biology and fisheries science at public Science Night at McKinleyville Union School District.





Figure 23 : Humboldt State University Fisheries Biology student Leon Davis III discussing fish anatomy with students at the 2015 McKinleyville Union School District Science Night.



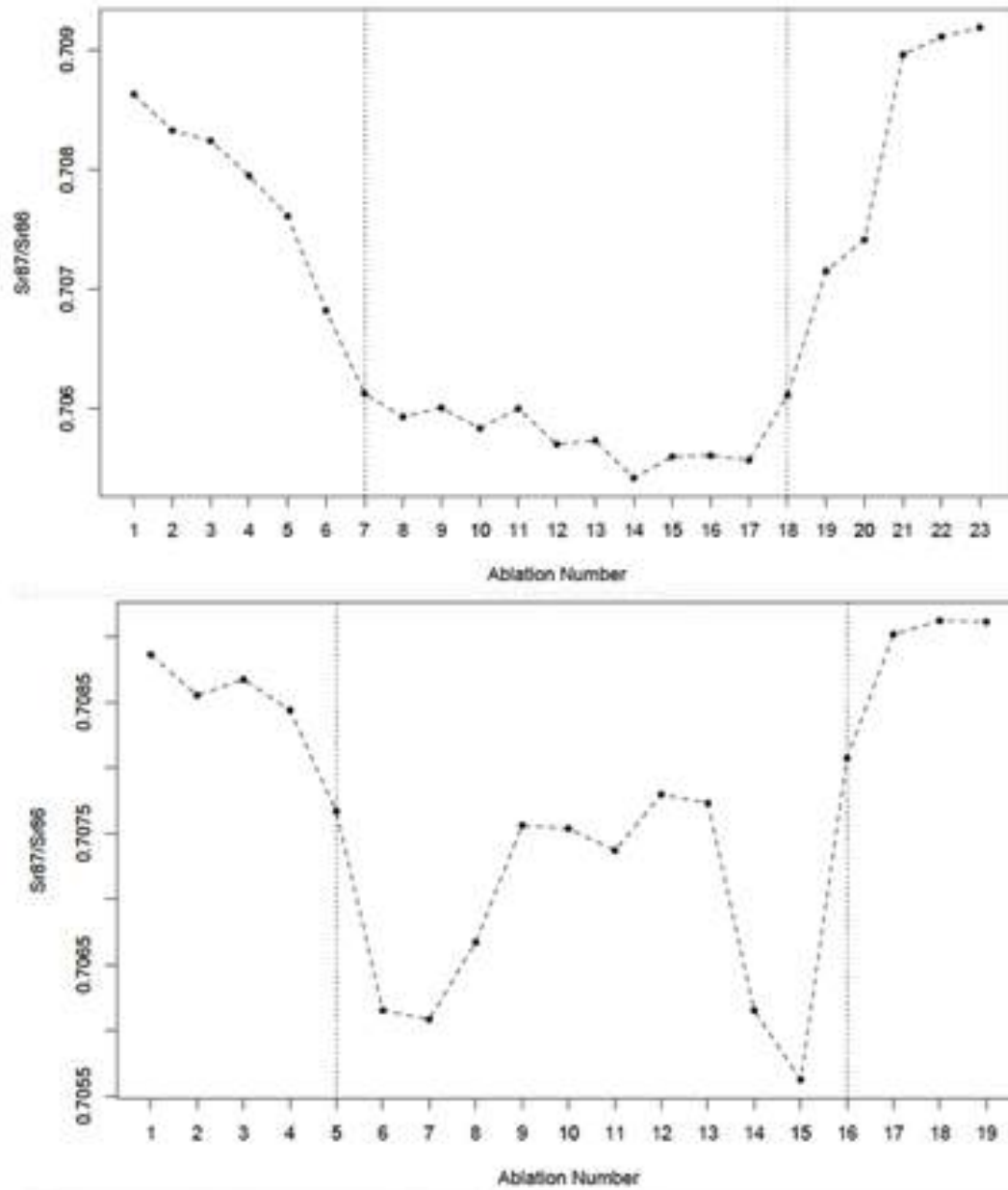


Figure 24: Example laser ablation transects of coho salmon otoliths from the Klamath River. The juvenile rearing period is enclosed between the vertical dashed lines. The top figure shows an individual with a consistent isotope signature through the juvenile period, consistent with rearing at the natal site. The bottom figure shows repeated shifts in the isotope signature through the juvenile period, consistent with a non-natal rearing life history.



## Theme D: Ecosystem-based Management

### Tethys Bioacoustics Metadata Workbench Improvements

#### Principal Investigator(s):

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

#### NOAA Technical Contact:

**Jeremy Rusin**, NOAA 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: Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

#### Budget Amount:

\$195,000

#### Amendment No.:

15

#### Keywords:

Cetaceans, Protected Species

#### Milestones:

- Improvements to Tethys towards goals defined by 2014 Tethys workshop.

#### Research Objectives and Specific Plans to Achieve Them:

Tethys is a passive acoustic monitoring metadata database system designed to organize and store acoustic metadata. Within this effort we collaborated with the NOAA Southwest Fisheries Science Center (SWFSC), NOAA Pacific Islands Fisheries Science Center (PIFSC), and NOAA Alaska Fisheries Science Center (AFSC) to improve the Tethys bioacoustics metadata workbench working towards priorities established in a December 2014 Tethys workshop of all stakeholders. It was understood that funding in this agreement

provided funding towards these goals rather than completion of them.

#### Research Accomplishments:

Version 2.3 Tethys schemata and implementation have been released on the project web site (<http://tethys.sdsu.edu>). Major improvements made in the last year came from the output of the final Tethys workshop and include significant enhancements to the import facilities permitting more sophisticated data import (nested queries), the incorporation of the ability to represent quality assurance processes within the schemata, a National Center for Environmental Information trial with NOAA Northeast and Alaska Fisheries Science Centers to use Tethys deployment metadata in archiving Fisheries Science Center acoustic data, and experiments demonstrating the ability of the system to represent metadata in other domains.

The Tethys metadata system is beginning to gain traction with users outside of the principal investigators. Peter Wrege and Sara Keen (Cornell University Bioacoustics Research Program) are using the system for forest elephants (*Loxodonta cyclotis*) and Cornell plans on developing front-end graphical user interfaces for the system. Jasco Ltd. announced at the 2015 International Workshop on Detection, Classification, Localization and Density Estimation of Marine Mammals that they planned on building a Tethys interface into their visualization system.

The strength of this system is the type of questions that one can ask when one has an analytical engine that can automate the integration of acoustic metadata with environmental information. The system has permitted to reveal spatial and temporal patterns in habitat use for fin and blue whales. The ability to track details of equipment such as calibration curves proved useful in a study that examined performance degradation of species identification



algorithms in the face of equipment and site differences and proposed techniques to mitigate for this. It helped to integrate system internal acoustic metadata and external oceanographic satellite data to show influence of changes in oceanography at a remote equatorial Pacific seamount on toothed whale occurrence. Other studies that will use this system for analyzing marine mammals with respect to oceanographic conditions and anthropogenic sources (e.g. sonar, habitat models) are underway and are expected to produce additional Tethys-enabled publications.



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

## Principal Investigator(s):

**Dr. Gary N. Cherr**, Bodega Marine Laboratory, UC Davis

## NOAA Technical Contact:

**Melissa Neuman**, National Marine Fisheries Service, West Coast Region

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC Collaboration

## NOAA Theme:

Theme D: Ecosystem-based Management

## Related NOAA Strategic Goal(s):

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

## Budget Amount:

\$84,999

## Amendment No.:

23

## Keywords:

Endangered Species, Abalone, *Haliotis sorenseni*, Captive Breeding

## Milestones:

- Greatest captive white abalone spawning in the history of the white abalone recovery program.
- Successful distribution of competent larvae to partner institutions.
- Successful distribution of F2 animals to partner institutions.
- Advancements in understanding the effects of photoperiod on reproductive condition.

## Research Objectives and Specific Plans to Achieve Them:

Our objective is to establish a successful captive propagation program as an integral part of the recovery of white abalone (*Haliotis sorenseni*), the

first marine invertebrate designated by the federal government as an endangered species (Federal Register 65 FR 2616 and 66 FR 29046). White abalone was recently designated as one of eight “Species in the Spotlight” by NOAA Fisheries (NOAA Fisheries 2015). These species are among those most at risk of extinction in the near future. The recovery plan for the white abalone dictates that captive propagation efforts continue to expand and improve and eventually produce offspring for outplanting to the wild (NMFS 2008). With numbers of white abalone in the wild continuing to decline (Steirhoff et al. 2012) and an aging captive population, it is urgent and imperative that we increase the numbers of white abalone broodstock through captive propagation. Products from the proposed work include maintaining the white abalone captive propagation and culture facilities at University of California, Davis’s Bodega Marine Laboratory (BML), successful reproductive conditioning and spawning of existing captive broodstock, culture of the resulting offspring, and a fuller understanding of the environmental parameters that control reproduction in the endangered white abalone, including diet and photoperiod

## Research Accomplishments:

In November 2015, we transferred captive-bred animals to partner facilities for the first time, sending 50 animals each to Aquarium of the Pacific, CMA, Santa Barbara Museum of Natural History Sea Center, and SWFSC. We are tracking growth and reproductive condition of these animals across facilities.

In March 2016, we had the most successful white abalone spawning in the history of the recovery program. In a spawning attempt with all of 14 BML’s large broodstock, six females and two males from the 2001 cohort spawned. Not only was this a large proportion of animals successfully spawning, but they produced the greatest number of gametes ever released during a



captive white abalone spawning attempt for the recovery program, with the females producing around 24 million eggs. The nearly 3 million competent larvae surpassed BML's settlement capacity, and we successfully shipped extra larvae to our partners at the Southwest Fisheries Science Center (SWFSC) and Cabrillo Marine Aquarium (CMA) for settlement.

We are mid-way through an experiment examining the effects of photoperiod on reproductive condition, and preliminary results indicate that photoperiod influences reproductive maturity in white abalone. This is the first experiment in to our knowledge to show that photoperiod can influence reproductive condition in abalone. This has great promise for being able to have more control over reproduction and potentially enhance annual gamete output.

We are collaborating with John Hyde at SWFSC to use genetic techniques to identify the parentage of the primary broodstock from the 2001 and 2003 cohorts, and we now have a better idea of which animals are most closely related so we can optimize genetic diversity when creating F2 crosses.

### Conferences, Meetings & Presentations

- a. Western Society of Naturalists, November 5-8, 2015, Sacramento, CA
- b. NMFS Abalone Workshop, January 20-21, 2016, Long Beach, CA

### Education & Outreach:

#### Communication

In a partnership with the California Department of Fish and Wildlife the following list supports an increased awareness about the status of wild white abalone and recovery efforts the following:

1. Video: *Delicacy of the Deep: Saving White Abalone* <https://youtu.be/kXGv5pwZ29o>
2. BML Newsletter article [http://bml.ucdavis.edu/wp-content/pdf/newsletter/BML\\_Newsletter\\_Winter\\_2015.pdf](http://bml.ucdavis.edu/wp-content/pdf/newsletter/BML_Newsletter_Winter_2015.pdf)

er\_2015.pdf

3. SF Chronicle article <http://www.sfchronicle.com/bayarea/article/Keepling-endangered-abalone-alive-1-fertilized-6869129.php>
4. NBC Bay Area News <http://www.nbcbayarea.com/news/local/Chemicals-Induce-Abalone-to-Become-Broadcast-Spawners-in-Bodega-Bay-372014442.html>

#### Networking

In cooperation with NOAA, strengthen partnerships with abalone aquaculture facilities like The Cultured Abalone Farm, and The Abalone Farm.

#### K-12 Outreach

With STEM Café at Piner High School in Santa Rosa and Bodega Marine Laboratory's ISOpods, develop inquiry-based outreach activities for middle and high school students to demonstrate concepts related to white abalone population declines and recovery.

#### Fellowship Programs/Internships

With Santa Rosa Junior College, provide opportunities for college students to gain laboratory experience through volunteering



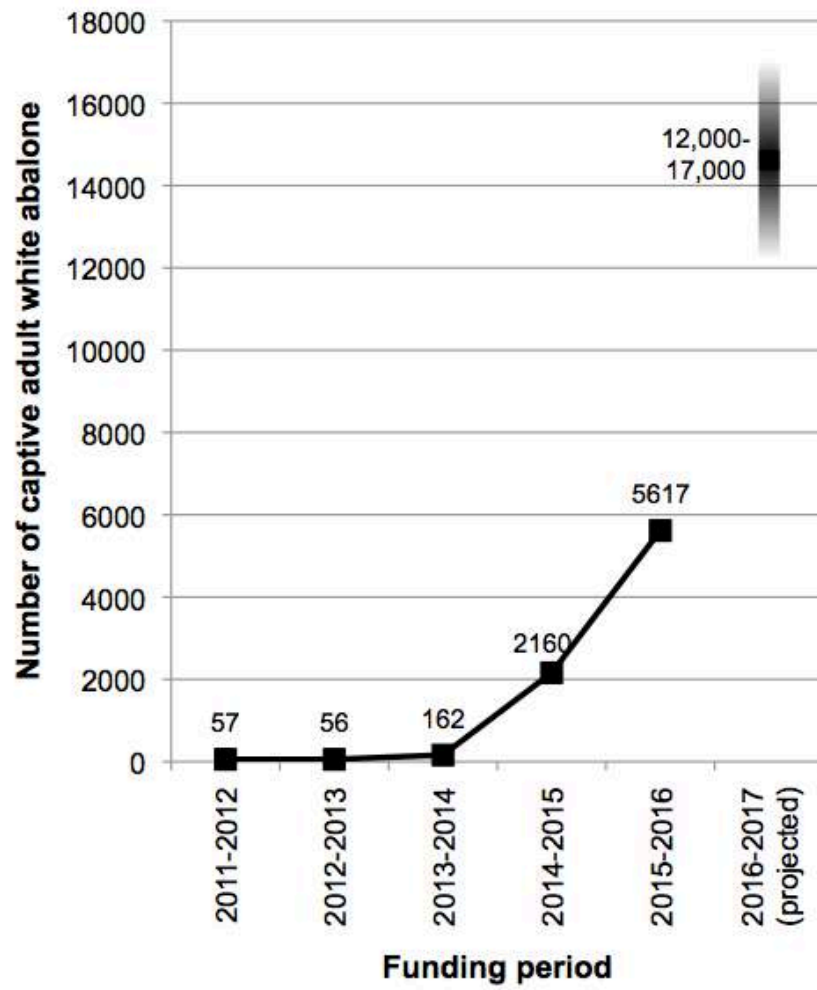


Figure 25: Increase in captive white abalone propagation since BML was issued the white abalone permit.

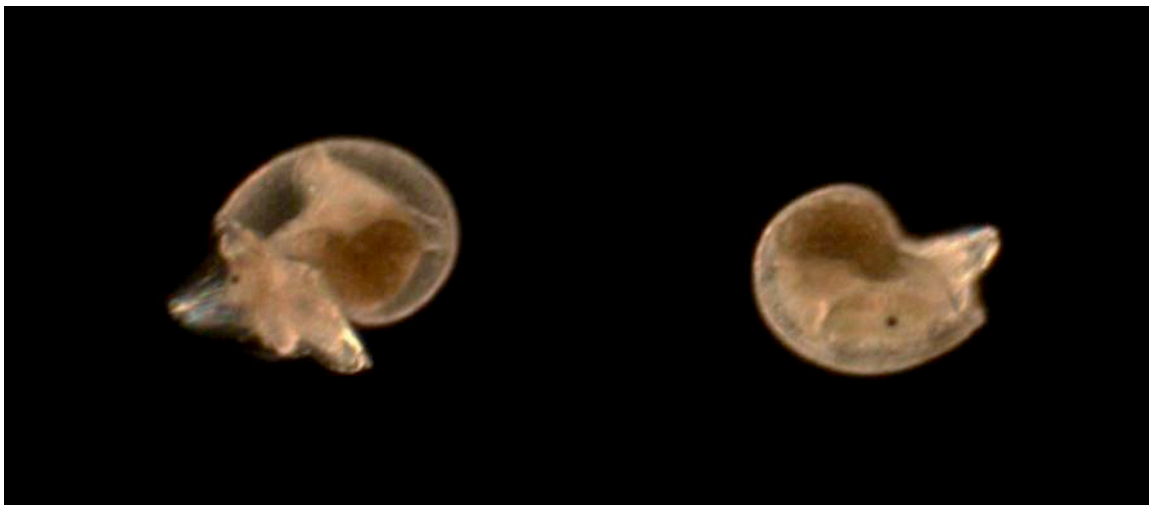


Figure 26: Larval white abalone from the March 2016 spawning





Figure 27: Kristin Aquilino examines a tile containing newly-settled white abalone in BML's White Abalone Culture Facility

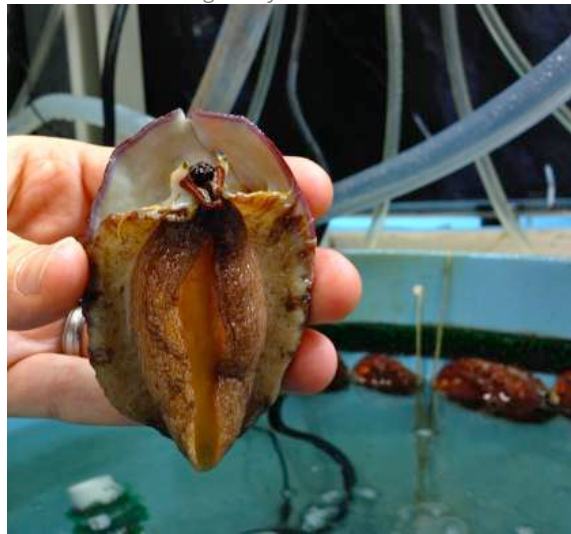


Figure 28: A 2.5-year-old captive-bred white abalone



Figure 29: Size variation in 1-year-old white abalone from the 2015 spawning at BML.



# Green Sturgeon Habitat Suitability in Response to Drought Related Flow Regimes

## Principal Investigator(s):

**Peter Klimley**, UC Davis

## NOAA Technical Contact:

**Joseph Heublein**, NMFS/WCR

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC Collaboration

## NOAA Theme:

Theme D: Ecosystem-based Management

## Related NOAA Strategic Goal(s):

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

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

## Budget Amount:

\$42,614

## Amendment No.:

28

## Keywords:

Habitat, Drought, Flow, Green Sturgeon

## Milestones:

- Baseline Model Complete

## Research Objectives and Specific Plans to Achieve Them:

Our intent is to summarize drought related discharge, during the spawning season, for the years of 2013, 2014, and 2015. These discharges will be run as inputs for the hydraulic modeling and WUA will be calculated for each of the three drought years within the three study sites. A comparison of WUA between drought years and those years previously modeled will be made to investigate either the expansion or more likely the

contraction of available optimal habitat within each of the three study sites.

## Research Accomplishments:

To date we have finalized the baseline model that was in progress at the time of this contract being issued. Now that the baseline model is completed and quantitative values of preference have been assigned to abiotic factors, we can begin the evaluation of model simulations for drought years. We are just getting to the compiling of flows to run in the habitat suitability model for the years of 2013, 2014, and 2015.

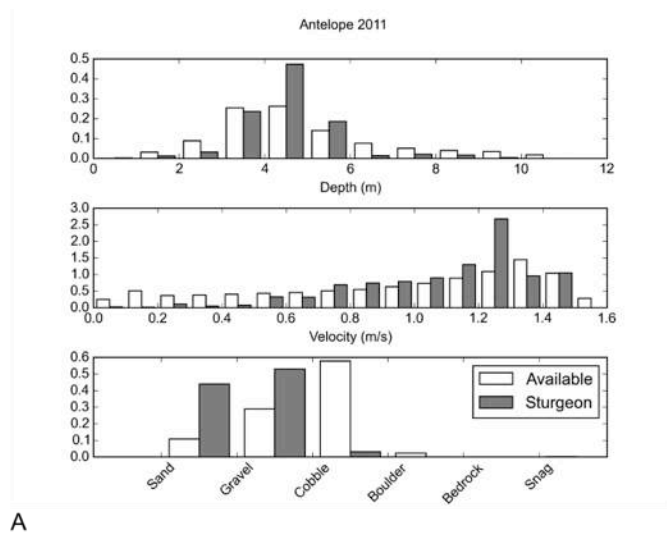
Version 2.3 Tethys schemata and implementation have been released on the project web site (<http://tethys.sdsu.edu>). Major improvements made in the last year

## Education & Outreach

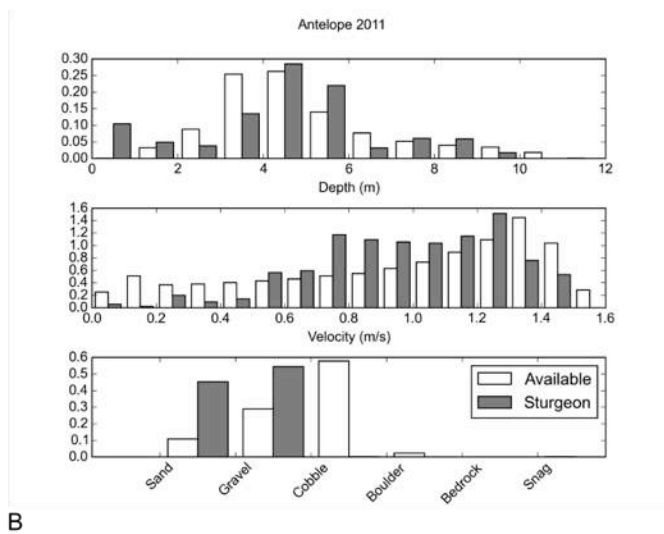
### Networking

- a. Work with Rich McDonald, a Hydrologist with the USGS to combine biological expertise with hydraulic modeling expertise

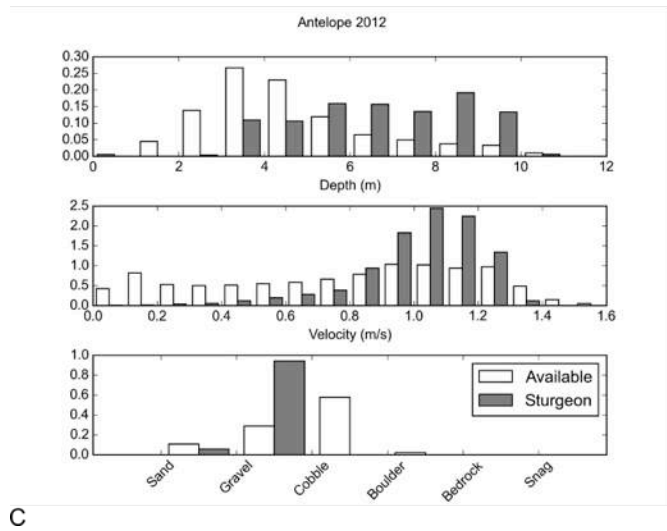




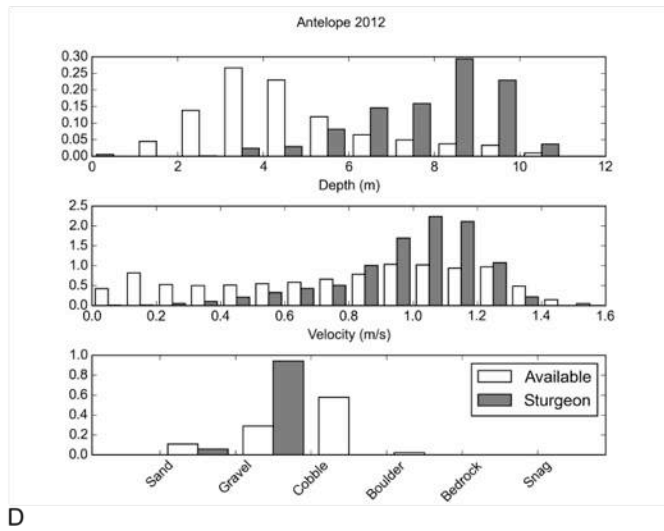
A



B



C



D

Figure 30



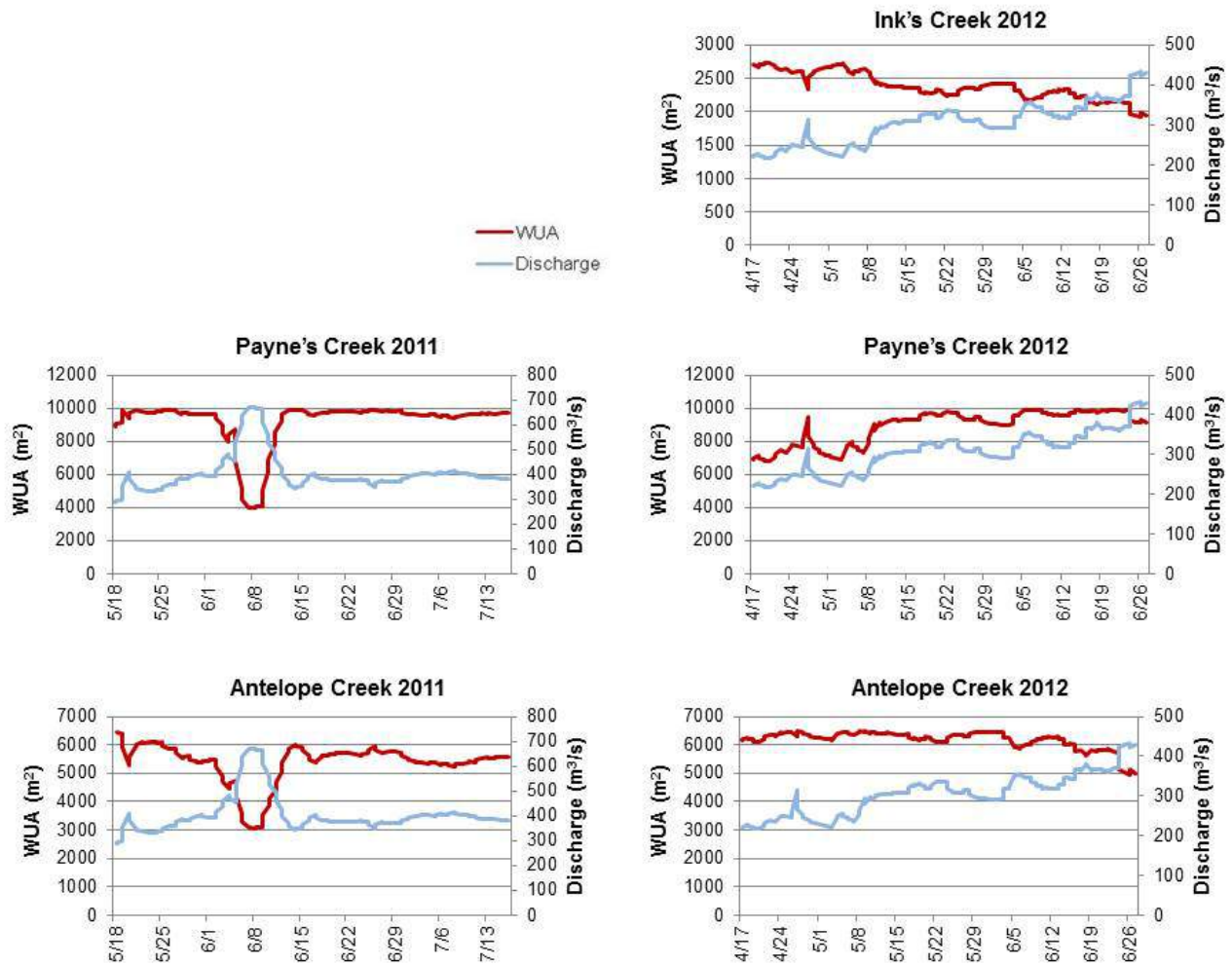


Figure 31



# Training the Next Generation of Marine Population Dynamics Scientists

## Principal Investigator(s):

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

## NOAA Primary Contact:

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

## Budget Amount:

\$200,000

## Amendment No.:

16

## Keywords:

Marine Population Dynamics, Quantitative Ecology, Mark-Recapture Analysis

## Milestones:

- Lab members authored or co-authored 5 peer-reviewed manuscripts, 2 in press, and 1 PhD dissertation
- Lab members authored or co-authored 7 conference presentations
- PI Semmens taught an 'Intro to Field Methods' undergraduate course
- PI Semmens taught a grad. level course in Bayesian modeling with joint attendance by SIO and SWFSC students and scientists
- Lab members helped coordinate and implement a CAPAM Data Weighting workshop

- Lab Members maintained and downloaded set of data from 44 hydrophones that compose the La Jolla Acoustic Array (LJAA)
- PI Semmens co-edited a special issue in Fisheries Research related to growth models in fisheries assessments
- PI Semmens participated in collaborative research into Cowcod with SWFSC scientists
- Lab members coordinated 3 summer outreach student group visits for underserved community high schools
- PI Semmens executed the annual Grouper Moon K-12 education/outreach program for schools throughout the Caribbean and US

## Research Objectives and Specific Plans to Achieve Them:

In order to support the increased demand for resource assessments and ecosystem-based management, National Oceanographic and Atmospheric Administration (NOAA) requires scientists trained in the development, application, and synthesis of quantitative tools and techniques. NOAA also would be well served by the development of new and/or improved analytic assessment methods that capitalize on existing and emerging survey methods. Towards these objectives, members of the Semmens lab carried out (1) training in quantitative resource assessment and population dynamics, (2) graduate student and PI research into resource assessment tools and techniques, and (3) STEM (science, technology, engineering and mathematics) training for K-12 students, and (4) research into cooperative fisheries science for recreational fisheries. The proposed research and training activities will foster a broad base of highly skilled quantitative fisheries scientists and generate a set of tools to facilitate accurate and informative marine resource assessments in an ecosystem context.



## Research Accomplishments:

Since April 2015, PI Semmens continued his collaboration with other scientists through the Center for the Advancement of Population Assessment Methodology (CAPAM). Other CAPAM principal investigators include Mark Maunder (Inter-American Tropical Tuna Commission, IATTC) and Paul R. Crone (Southwest Fisheries Science Center, SWFSC). This past year, CAPAM hosted its 3rd workshop focused on data weighting in assessments, held at the SWFSC. As in years past, the workshop spawned a special issue in Fisheries Research, edited by the CAPAM PIs. This issue is currently in development. The special issue from the prior workshop (growth models in assessment) is now in press, and includes 19 peer-reviewed articles; CAPAM PIs or personnel were authors or co-authors on 6 of these articles. To date, CAPAM personnel have authored over 30 publications directly related to stock assessment methods.

In October of 2015, CAPAM hosted a 1-day Stock Synthesis short course at SWFSC as part of the CAPAM 5-day data weighting workshop. This spring quarter, PI Semmens is teaching a graduate level course on Bayesian population analysis (including mark-re-capture analysis), and an undergraduate course in lab and field techniques. The graduate course in Bayesian statistics was jointly advertised at SIO and SWFSC, and is being attended by 5 SWFSC staff scientists. Outside of formal teaching activities, the Semmens Lab jointly coordinates a quantitative seminar series with the SWFSC that meets periodically, and coordinates an R users group weekly meeting held on the SIO campus. In March of 2016, PI Semmens gave a nationally Webcast seminar summarizing research into hyperstability in aggregating fishes as part of NOAA's QUEST program.

Semmens Lab members continue 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, diurnal patterns in movement and site fidelity, and demographic rates, all of which are important for marine resource management.

Semmens Lab members continue to build a successful cooperative fisheries research program (e.g. research directly involving members of the fishing community). PI Semmens, and SWFSC scientists Wegner and Bellquist (current NRC postdoc, former Semmens Lab PhD) began collaborative research into the spatial ecology of juvenile Cowcod (*Sebastes levis*) of the California coast, using acoustic and Floy tagging methods. Cowcod are currently overfished, and listed as a Species of Concern by the SWFSC. This research, funded through the National Research Coop competition, aims to gain an improved understanding of critical habitat for the species in relation to existing Cowcod Conservation areas along the California coast. Two products from Bellquist's dissertation (defended this past year) related to a novel database of "trophy" recreational catch in California have successfully navigated peer-review. A synthesis of half of century of demersal "trophy" records was published as a Feature Article in Marine Ecology Progress Series, while a similar paper related to pelagic and coastal pelagic species is in press at Transactions of the American Fishery Society. Finally, in December 2015, UC President Janet Napolitano appointed PI Semmens as the UC representative to California's Ocean Resources Enhancement and Hatchery Program.

As part of efforts to broaden the scope of training in fisheries-focused STEM (science, technology, engineering and math) fields, lab members coordinate a series of K-12 education and outreach programs. Each year PI Semmens leads the Grouper Moon education program, targeting K-12 students throughout the Caribbean and US



with a combination of experiential learning curricula, and a Web-based “virtual field” component. This last year more than 200 students from 14 different schools participated in the program. Back in San Diego, PI Semmens and lab members coordinated 3 separate 1-day short courses in quantitative fisheries science targeting underrepresented K-12 students from local schools.

In addition to the above research/education areas, PI Semmens oversees 4 PhD students (Lynn Waterhouse, Brian Stock, Josh Stewart, Noah Ben-Aderet), 1 MS students, 1 staff member and 4 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.

### Honors and Awards

- c. NSF Graduate Research Fellowship, Josh Stewart, 2012-2015
- d. NMFS/Sea Grant Population Dynamics Fellowship, Lynn Waterhouse, 2013-2016
- e. NSF Graduate Research Fellowship, Brian Stock, 2014-2018
- f. Nancy Foster Scholarship ONMS, Josh Stewart, 2015-2018
- g. UCSD Staff Equal Opportunity Award, Rachel Labbe Bellas, March 2015
- h. Switzer Environmental Fellowship, Josh Stewart, 2015-2016
- i. California Ocean Resources Enhancement and Hatchery program (ORHEP) appointment, Brice Semmens, December 2015
- j. Elected member of the Gulf and Caribbean Fisheries Research Institute (GCFI) Board of Directors, Brice Semmens, 2015-2016
- a. AFS Annual Meeting, August 16-20, 2015, Portland, OR with Brice Semmens, Brian Stock, Lynn Waterhouse
- b. JSM Annual Meeting, August 8-13, 2015, Seattle, WA with Lynn Waterhouse
- c. ICES Annual Science Conference, September 21-25, 2015, Copenhagen, Denmark, with Lynn Waterhouse
- d. Student Conference on Conservation Science (SCCS), October 7-9, 2015, New York, NY with Lynn Waterhouse
- e. NMFS/Seagrant Annual Population Dynamics Fellowship Meeting, June 9-11, 2015, Miami, FL with Lynn Waterhouse (did not attend, but sent poster)
- f. Fish 558 Workshop -Decision Analysis in Natural Resource Management, <http://depts.washington.edu/fish558/> Taught by Andre Punt, Fall 2015, Friday Harbor, WA and then online (gotomeeting), with Brian Stock, Josh Stewart, Eiren Jacobsen, Lynn Waterhouse
- g. Public talk at Ocean Enterprises, December 10, 2015, San Diego, CA with Brian Stock presenting
- h. 100th ESA Annual Convention, August 2015, Baltimore, MD with Brian Stock presenting.
- i. 145th American Fisheries Society Annual Meeting, August 2015, Portland, OR with both Brian Stock and Brice Semmens presenting.
- j. NOAA National Protected Species Toolbox Mini-Symposium, November 18-19 2015, Silver Spring, MD with Brian Stock presenting.
- k. 68th Annual Gulf and Caribbean Fisheries Institute, November 2015, Panama City, Panama with Brian Stock and Brice Semmens presenting.
- l. PhD Dissertation at Scripps Institution of Oceanography on June 9th 2015 by Lyall Bellquist.
- m. International Conference on Conservation Biology, August 2-7 2015, Montpellier, France with Joshua Stewart presenting.

### Conferences, Meetings & Presentations



- n. Fisheries Society of the British Isles Annual Conference, July 25-31 2015, Plymouth, UK with Joshua Stewart presenting.

## Education & Outreach

### Communications

- e. Working with NOAA and Scripps Oceanography, PI Semmens gave a QUEST Webinar in March 2016, entitled "Behavior, Hyperstability, and Population Declines in an Aggregating Marine Fish" to reach a broad national audience, and discuss research into mechanistic underpinnings of hyperstability in fisheries.
- f. Scripps Oceanography graduate student, Joshua Stewart, gave a presentation to Upward Bound students on marine biology, research and graduate school to expose underrepresented high school students to STEM fields and higher education.

### Academic Development

- a. Graduate student Brian Stock started his second year of PhD coursework and passed his first year Marine Biology examination. The goal of second-year coursework is to establish a strong educational foundation in the marine sciences during the beginning of a marine biology PhD.
- b. Graduate student Brian Stock trained as Scripps Oceanography motorboat operator. Motorboat operator training and certification is required for students to safely and effectively use small boats during fieldwork.
- c. Graduate students Lynn Waterhouse, Lyall Bellquist, Noah Ben-Aderet and Brian Stock attended CAPAM's data weighing workshop. Introduce students to modern statistical models used in fisheries stock assessment and natural resource modeling, providing instruction, demonstration, and exercises in Growth: theory, estimation, and application. Partners with CAPAM, SIO, SWFSC, and IATTC.
- d. Graduate students Lynn Waterhouse, Joshua Stewart, and Brian Stock attended Andre Punt's UW workshop and online course in population modeling (Sept 2015) to build

experience in Decision Analysis in Natural Resource Management

- e. Scripps Oceanography Graduate student Lyall Bellquist defended his PhD on June 9<sup>th</sup>, 2015.

### K-12 Outreach

- a. With partnerships from Scripps Oceanography, Cayman Islands Department of Environment and the Reef Environmental Education Foundation, PI Semmens lead the annual Grouper Moon K-12 education program, reaching more than 200 students in 14 schools throughout the Caribbean and US. Use field-based live streaming and in-person classroom visits to educate K-12 students throughout the Caribbean regarding the importance of large marine predators and spawning aggregations.
- b. With partnerships from Scripps Oceanography, The Birch Aquarium, and Wildcoast, Staff Member Rachel Labbe Bellas and Brice Semmens hosted 3 student groups for a quantitative ecology interactive afternoon session during summer 2015 to build a student interest in quantitative ecology, especially with teens from underserved communities.
- c. Graduate students Lynn Waterhouse and Brian Stock participate as volunteer diver/educators at the Birch Aquarium to help communicate ocean science and research to youth.
- d. Graduate student Josh Stewart mentored an high school student working with Manta Ray mobuild tissue to provide science and research supervision for an independent study

### Networking

- a. PI Semmens is the UC representative to California's Ocean Resources Enhancement and Hatchery Program to provide guidance to the state of California regarding marine resources enhancement programs.
- b. Graduate student Lynn Waterhouse continued to be a SIO representative for the Graduate Student Association (GSA) to



advocate the rights and interests of graduate students at UCSD

- c. Graduate student Lynn Waterhouse maintains role as secretary for the Estuaries Section of American Fisheries Society (AFS). The Estuaries Section is dedicated to protecting, maintaining and enhancing the viability of the fisheries and other aquatic living resources dependent upon healthy estuaries.
- d. PI Semmens serves on the board of the Gulf and Caribbean Fisheries Research Institute (GCFI). GCFI coordinates an annual meeting of fisheries scientists, managers and practitioners on the Caribbean and Gulf of Mexico.

#### **Fellowships & Internships**

- a. SIO peer mentor program 2015-2016, Daniel Metz (first year PhD student) by Graduate Students Brian Stock and Lynn Waterhouse.
- b. SIO MAS program, 2015-2016, Gwendal Le Fol, "An analysis of finfish bycatch in the California large mesh drift gillnet fishery" with Graduate Students Brian Stock and Lynn Waterhouse.
- c. SURF REU program, June-Aug 2015, Bethany Fowler, "Passive Acoustic Monitoring of Grouper in the Cayman Islands" with Graduate Students Brian Stock and Lynn Waterhouse.
- d. SURF REU program, June-Aug 2015, Jarvon Stout, "Fingerprinting Fish: Computer-aided Pattern Matching of the Nassau Grouper (*Epinephelus striatus*)" with Graduate Students Brian Stock and Lynn Waterhouse.
- e. STARS program, June-Aug 2015, Patricia Villalobos, "Length distribution analysis of a Nassau Grouper (*Epinephelus striatus*) spawning aggregation in the Cayman Islands" with Graduate Students Brian Stock and Lynn Waterhouse.

#### **NOAA Employment**

Lyall Bellquist attained a Post-Doctoral Researcher position with the Southwest Fisheries Science Center (NRC Fellowship) in August 2015





Figure 32: high school students participate in a crab mark re-capture exercise as part of a 1-day quantitative fisheries training course targeted at under-served students in the San Diego area.



Figure 33: high school students learn about common intertidal organisms as part of a 1-day quantitative fisheries training course targeted at under-served students in the San Diego area.



# "Fixing" Retrospective Biases in Stock Assessment and Implications for Management Targets

## Principal Investigator(s):

**Cody Szuwalski**, Marine Science Institute, UC Santa Barbara

**Steve Gaines**, Marine Science Institute, UC Santa Barbara

## NOAA Technical Contact:

**Patrick Lynch**, NMFS Office of Science and Technology

## NOAA Task:

Task 2: Joint NOAA Laboratory/CIMEC Collaboration

## NOAA Theme:

Theme D: Ecosystem-based Management

## Related NOAA Strategic Goal(s):

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

## Budget Amount:

\$65,818

## Amendment No.:

27

## Keywords:

Stock Assessment, Fishery Management, Retrospective Biases, Simulation Study

## Milestones:

- Built GeMS

## Research Objectives and Specific Plans to Achieve Them:

Stock assessments are used to estimate the biomass of exploited species; estimates of biomass are used to set allowable catches for our nation's marine resources. Retrospective biases are systematic inconsistencies among a series of estimates of biomass based on increasing periods of data and can result in unknowingly

overharvesting a population. There are several methods of 'fixing' retrospective biases in stock assessment, but it is unclear how well they work. The goal of this project is to simulate populations of exploited fish from which data can be drawn for assessment, generate retrospective biases in these simulated populations, then attempt to fix the retrospective biases by allowing population processes to vary over time in the stock assessments.

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

## Research Accomplishments:

GeMS has three main parts: an operating model, an estimation model, and a harvest control rule model. Each can be customized to the user's specifications. Currently the estimation model can either be a production model coded in R or an age- and length-structured assessment coded in Auto-differentiating Model Builder similar to those implemented in Stock Synthesis. GeMS has been used to successfully generate retrospective biases in estimates of biomass and these biases have been 'fixed' by allowing population processes in the age- and length-structured assessments to vary over time.



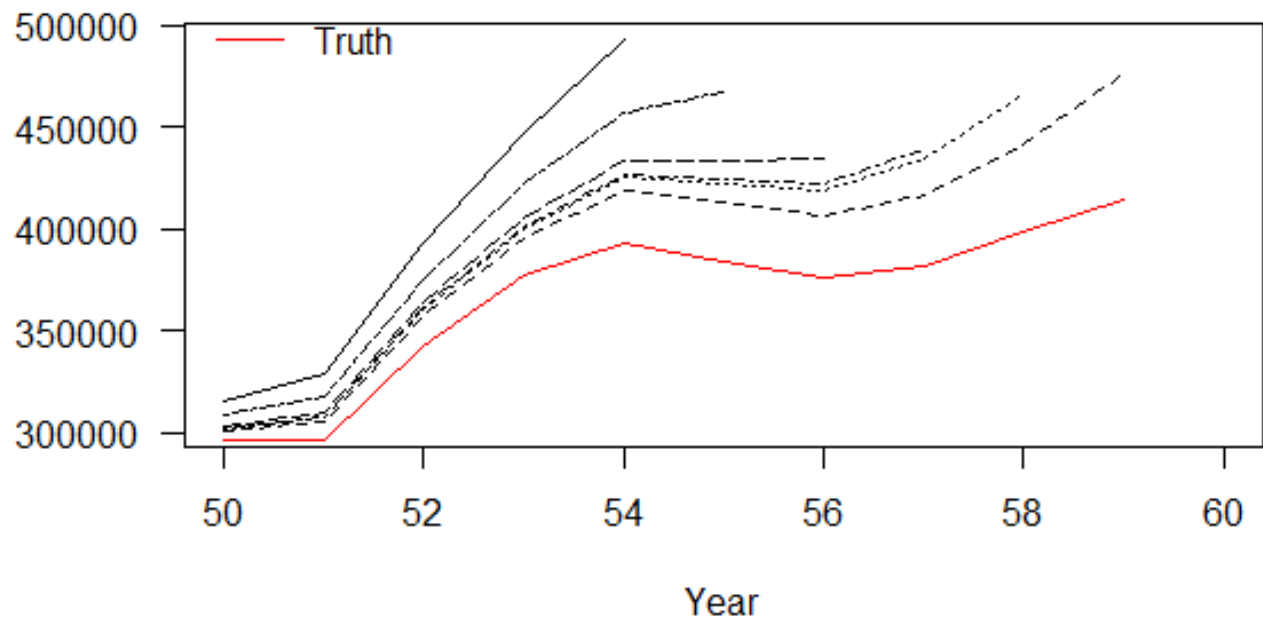


Figure 34: A retrospective in estimated biomass bias was produced when natural mortality varied over time within the simulated population, but natural mortality was not allowed to vary within the assessment. Red line represents the true underlying spawning biomass, each black line represents the estimated biomass with one fewer year of data.

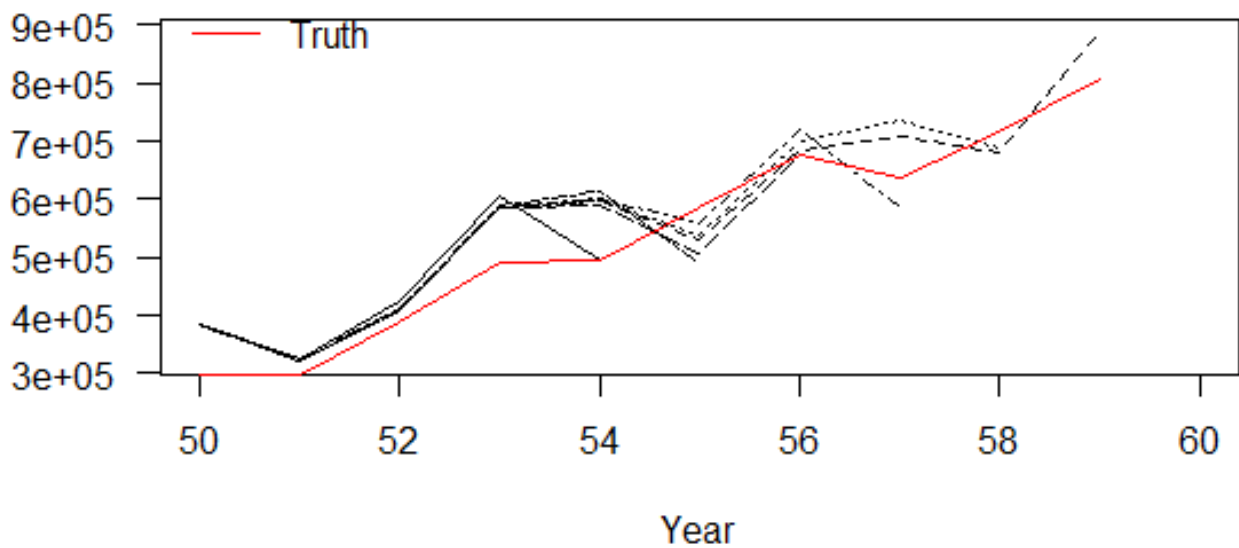


Figure 35: Estimates of biomass from a stock assessment model that allows natural mortality to vary over time applied to the same data in which the retrospective bias was produced in figure 1. This shows that allowing time varying processes can eliminate retrospective biases.



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

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## NOAA Task:

Task 3: Individual Science Projects

## NOAA Theme:

Theme D: Ecosystem-based Management

## Related NOAA Strategic Goal(s):

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

## Budget Amount:

\$81,999

## Amendment No.:

26

## Keywords:

Steelhead, River Ecosystems, Annual Hydrograph, Recovery, Smolt

## Milestones:

1. Develop a methodology relating stream channel hydraulic controls to anadromous salmonid habitat that allows assigning a diversion protocol without requiring site-specific studies. This opens-up the pathway toward SWRCB regionalizing water right permitting in Coastal California streams.

## Research Objectives and Specific Plans to Achieve Them:

Southern California steelhead (*Oncorhynchus mykiss*) adapted multiple life history strategies to thrive in an arid environment. But these strategies will remain relevant only if key components of the region's annual Mediterranean hydrographs, upon which they evolved, continue and/or are

recovered. Our research objectives are to first understand how steelhead life history tactics relied on components of unimpaired annual hydrographs, and second to identify/quantify which high priority hydrograph components need recovering given future water demand and climate change by using an ecosystem-based management strategy.

'Achievement' is having our research findings and recommendations from the second objective used by state and federal resource agencies in FERC re-licensing procedures and water rights adjudications/permitting. This will require establishing streamflow thresholds and developing a diversion rate protocol that can be applied regionally and customized for specific points of diversion.

## Research Accomplishments:

We've begun our investigation focusing on the critical role of one hydrograph component: the annual decline of spring into summer baseflows called the recession hydrograph. Higher priority river basins investigated, including the Santa Ynez River, Santa Clara River, Ventura River, and the Arroyo Grande, have several long-term continuous tributary and mainstem USGS gaging stations with relatively unimpaired streamflows. Inventorying all hydrologic records, including non-traditional sources, has been underway, followed by compartmentalizing annual hydrograph into component parts.

Preliminary analyses identified two types of recession hydrographs: (1) headwater recession hydrographs where baseflows follow a negatively exponential decline to extremely low streamflows, or no surface streamflow, by late-summer and (2) valley-bottom recession hydrographs that receive ecologically significant groundwater recharge throughout most summers. In many larger Southern California river basins, such as the Santa



Ynez and Santa Clara, both recession hydrograph types accommodated distinctive steelhead life history strategies. Perhaps more endangered than the steelhead themselves, are unimpaired valley-bottom recession hydrographs in larger Southern California river basins. We hypothesize why healthy steelhead populations and recession hydrographs were so tightly intertwined.

Steelhead smolts migrating downstream in springtime need continued growth to improve their chances of returning as spawning adults. Productive mainstem habitat, such as highly productive benthic macroinvertebrate populations in riffles, were sustained by higher streamflows early in the recession hydrograph under active channel hydraulic control. Unimpaired recession hydrographs could nurture highly significant growth in migrating smolts. The X-axis in Figure 1 is the exceedence probability of each water year's total annual rainfall and the Y-axis is the date when the WY recession hydrograph drops below the threshold streamflow (65 cfs) for productive mainstem riffle habitat. Unimpaired annual recession hydrographs sustained productive steelhead smolt habitat into early-June for approximately 30% of the WYs and into early-May for 50% of the WYs (Figure 1).

Compiling relatively unimpaired recession hydrographs from the USGS gaging records is an important step though not an endpoint. Hydrographs portray the magnitude, duration, frequency, and timing of streamflows, something traditional daily average flow duration curves cannot. The application of exceedence probabilities to water years as the independent variable is a form of risk analysis (i.e., in Figure 1, the chance of having productive riffles last into June during smolt migration was approximately 30% in the Arroyo Seco River). By replacing a recession hydrograph's Y-axis with dependent variables more relevant to fish and/or the river ecosystem than daily average streamflow (Q), the magnitude, duration, frequency, and timing of key ecological processes can be characterized under

unimpaired conditions. The endpoint, therefore, is quantification of key ecological processes provided by the unimpaired annual hydrograph. Forecasts of hydrological change, whether induced by greater diversions, climate change, or both, can be objectively evaluated for potential impacts to steelhead population recovery and future river ecosystem health.

## Conferences, Meetings & Presentations

- a. Salmonid Restoration in Working Watersheds, Salmonid Restoration Federation, April 6-9, 2016, with William Trush

## Education & Outreach

### Academic Development

- a. Challenge Environmental Resource Engineering and Environmental Science and Management students to think past concepts and devise quantitative management solutions by setting-up a field laboratory with Humboldt State University, HSU River Institute, and Green Diamond Timber Company.

### Networking

- a. Two-day field workshop at University of California's Angelo Coast Range Reserve with Humboldt State University, UC Berkeley, SWRCB and CDFW



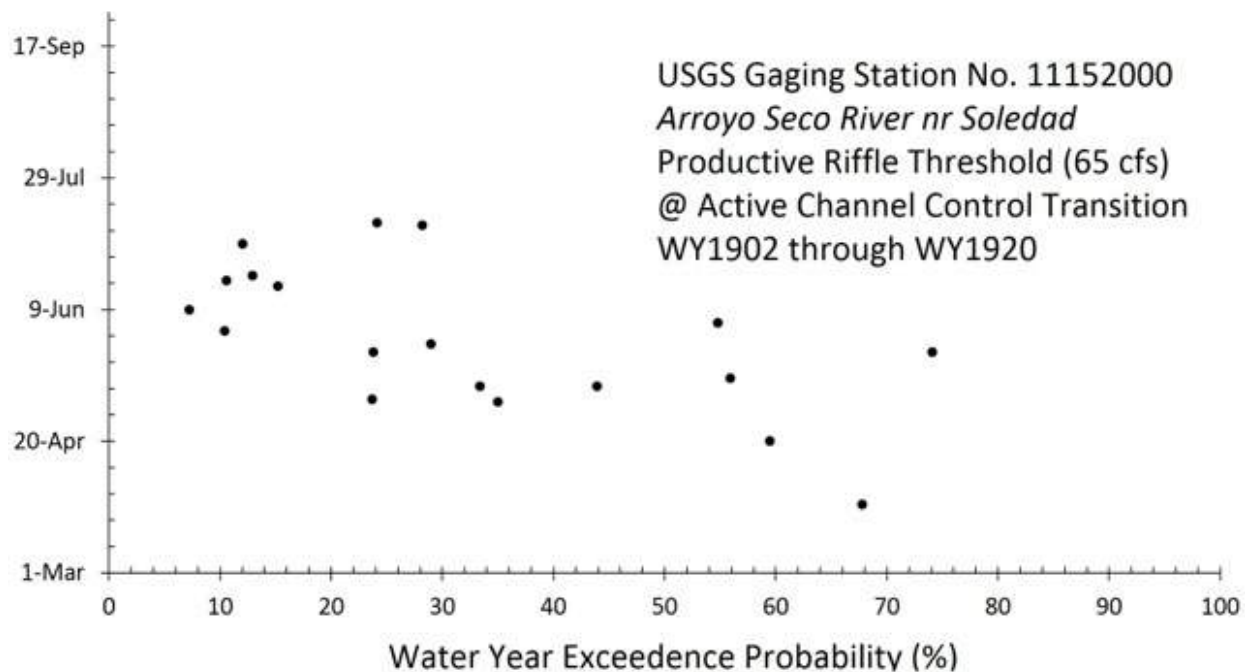


Figure 36: Final date for a streamflow threshold sustaining productive mainstem riffle habitat during spring recession in the Arroyo Seco River estimated from monitored daily average streamflows in WY1902 through WY1920 at USGS Gaging Sta.No.11152000 Arroyo Seco River nr Soledad.



Figure 37: Environmental Resource Engineering and Environmental Science and Management students at Humboldt State University utilize these life-sized Chinook salmon models to measure migration depth criteria in developing a regional diversion protocol for small Coastal California tributaries (Photo Credit: Lindsey Holm).





Figure 38: Humboldt State University students in Environmental Resource Engineering and Environmental Science and Management departments measure migration depth criteria utilizing life-sized Chinook salmon models in developing a regional diversion protocol for small Coastal California tributaries (Photo Credit: Lindsey Holm).



# PARTNERS & COLLABORATORS

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National Science Foundation (NSF)

Naval Research Laboratory, Monterey (NRL-MRY)

NOAA Alaska Fisheries Science Center (AFSC)

NOAA Assessment and Restoration Division (ARD)

NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML)

NOAA Center for Operational Oceanographic Products and Services

NOAA Climate Program Office (CPO)

NOAA Earth System Research Laboratory (ESRL)

NOAA Emergency Response Division (ERD)

NOAA Fisheries Ecology Division (FED)

NOAA Global Monitoring Division (GMD)

NOAA Integrated Ocean Observing System (IOOS)

NOAA National Centers for Environmental Information (NCEI)

NOAA National Data Buoy Center (NDBC)

NOAA National Marine Fisheries Service (NMFS)

NOAA National Ocean Service (NOS)

NOAA National Weather Service (NWS)

NOAA Northwest Fisheries Science Center (NWFSC)

NOAA Ocean Acidification Program (OAP)

NOAA Oceanic & Atmospheric Research (OAR)

NOAA Office of Exploration and Research

NOAA Office of Response and Restoration (OR&R)

NOAA Pacific Islands Fisheries Science Center (PIFSC)

NOAA Pacific Marine Environmental Laboratory (PMEL)

NOAA Southern California Coastal Ocean Observing System (SCCOOS)

NOAA Southwest Fisheries Science Center (SWFSC)

NSF US Antarctic Research Program (USARP)

Office of Naval Research (ONR)

ONR Marine Mammals and Biology (MMB)

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

U.S. Bureau of Reclamation (USBR)

U.S. Coast Guard (USCG)

U.S. Environmental Protection Agency (EPA)

U.S. Fish and Wildlife Service (USFWS)

U.S. Forest Service (USFS)

U.S. Geological Survey (USGS)

U.S. Navy (USN)

U.S. Navy Living Marine Resources Program (LMR)

USGS Geomorphology and Sediment Transport Lab

USGS Pacific Coastal and Marine Science Center (PCMSC)



## Partnerships

Aquarium of the Pacific	Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP)
Atlantic States Marine Fisheries Commission	Hubbs-SeaWorld Research Institute (HSWRI)
Biological and Chemical Oceanography Data Management Office (BCO-DMO)	Humboldt State University (HSU)
Birch Aquarium at Scripps Institution of Oceanography	Indian National Centre for Ocean Information Services (INCOIS)
Bodega Marine Laboratory	Institute for Computational Earth System Science (ICESS)
Cabrillo Marine Aquarium	Institute of Ocean Sciences (IOS - Canada)
California Current Ecosystem – Long-Term Ecosystem Research (CCE-LTER)	Institute Search Le Developpement, Noumea
California Department of Fish and Wildlife (CDFW)	Inter-American Tropical Tuna Association (IATTC)
California Department of Water Resources (CDWR)	J. Craig Venter Institute
California Polytechnic State University San Luis Obispo (CalPoly)	Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
California State University Monterey Bay (CSUMB)	JCOMM Observations Coordination Group (OCG)
California State University, Long Beach (CSULB)	JCOMM Ship Observations Team (SOT)
Canada Department of Fisheries and Oceans	JCOMM Tropical Pacific Observing System (TPOS-2020)
Carbon Dioxide Information and Analysis Center (CDIAC)	Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM)
Center for Stock Assessment Research (CSTAR)	Korea Meteorological Administration (KMA)
Commonwealth Scientific and Industrial Research Organization (CSIRO - Australia)	Linnaeus University (LU)
East Bay Municipal Utility District (EBMUD)	Manta Trust
Environment Canada – Weather Service	Max Planck Institute for Biogeochemistry, Germany
Farallon Institute	McKinleyville Union School District
Farallon Institute of Advanced Ecosystem Research	Met Office (United Kingdom)
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French Research Institute for Exploitation of the Sea (IFREMER)	Monterey Bay Aquarium Research Institute (MBARI)
GEOMAR, Germany	Monterey Peninsula Water Management District (MPWMD)
Georgia Tech	National Center for Atmospheric Research



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SHOA-Chile

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The Abalone Farm

The Cultured Abalone Farm

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Trinity College Dublin

U.S. Argo Float Consortium

U.S. Repeat Hydrography Program

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# PUBLICATIONS

## Publication Summary

		7/1/15 - 3/31/16
CIMEC Lead Author	Peer Reviewed	15
	Non-Peer Reviewed	31
NOAA Lead Author	Peer Reviewed	23
	Non-Peer Reviewed	11
Other Lead Author	Peer Reviewed	58
	Non-Peer Reviewed	12
Total Publications		150

## Journal Articles

- Abadia-Cardoso, Alicia, John Carlos Garza, Richard L. Mayden, and Francisco Javier Garcia de Leon. 2015. Genetic structure of Pacific trout at the extreme southern end of their native range. *PLoS ONE* 10(10):e0141775 (20 p.).
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# ACRONYMS

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AMLR	Antarctic Marine Living Resources Program
AOML	NOAA/Atlantic Oceanographic and Meteorological Lab
BAS	Birch Aquarium at Scripps
BML	Bodega Marine Laboratory, UC Davis
CA COSEE	California Center for Ocean Science Excellence in Education
CalIT	California Institute of Technology
Cal State	California State University system
Caltrans	California Department of Transportation
CAP	California Applications Program
CBNMS	Cordell Banks National Marine Sanctuary
CCMA	Center for Coastal Monitoring and Assessment
CDFG	California Department of Fish and Game
CEC	California Energy Commission
CEFA	Climate, Ecosystem and Fire Applications
CeNCOOS	Central and Northern California Ocean Observing System
CEOP	Coordinated Enhanced Observing Period
ChESS	Biogeography of Deep-Water Chemosynthetic Ecosystems / Census of Marine Life
CICAR	Cooperative Institute for Climate Applications and Research, Palisades, New York
CICOR	Cooperative Institute for Climate and Ocean Research, Woods Hole, Massachusetts
CICS	Cooperative Institute for Climate Science, Princeton, New Jersey
CIFAR	Cooperative Institute for Arctic Research, Fairbanks, Alaska
CILER	Cooperative Institute for Limnology and Ecosystems Research, Ann Arbor, Michigan
CIMAS	Cooperative Institute for Marine and Atmospheric Studies, Miami, Florida
CIMMS	Cooperative Institute for Mesoscale Meteorological Studies, Norman, Oklahoma
CIMRS	Cooperative Institute for Marine Resource Studies



CIMSS	Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin, Madison
CIOSS	Cooperative Institute for Oceanographic Satellite Studies
CIRA	Cooperative Institute for Research in the Atmosphere
CIRES	Cooperative Institute for Research in Environmental Sciences
CLIMAS	Climate Assessment for the Southwest
CLSA	California Land Surveyors Association
CMER	Cooperative Marine Education and Research
CNES	Centre National d'Etudes Spatiales
COML	Census of Marine Life
COP	NOAA/NOS/Center for Sponsored Coastal Ocean Research/Coastal Ocean Program
CPO	NOAA/Climate Programs Office (formerly, Office of Global Programs (OGP))
CRIP	Centro Regional de Investigacion Pesquera, Instituto Nacional de la Pesca, Ensenada/La Paz, Mexico
CRTN	California Real Time Network
CSIRO	Commonwealth Scientific and Industrial Research Organisation-- Australia
CSRC	California Spatial Reference Center
CTD	Conductivity Temperature and Depth (as in, Underway CTD)
DBCP	Data Buoy Cooperation Panel, WMO-IOC
DOE	U.S. Department of Energy
DWR	California Department of Water Resources
ECCO	SIO's Estimating the Circulation and Climate of Oceans Consortium
ENSO	El Niño and Southern Oscillation
ESRL	NOAA/Earth System Research Laboratory
FKNMS	NOAA/Florida Keys National Marine Sanctuary
GACC	Geographic Area Coordination Centers
GEOSS	Global Earth Observation System of Systems
GEWEX	Global Energy and Water-cycle Experiment
GIS	Geographic Information Systems
GMD	NOAA/ESRL/Global Monitoring Division
GODAE	Global Ocean Data Assimilation Experiment



GPS	Global Positioning System
GSD	NOAA/ESRL/Global Systems Division
GTS	GNU Triangulated Surface
HRC	Hydrologic Research Center, San Diego, CA
HRX	Repeat high resolution expendable Bathythermograph
ICARTT	International Consortium for Atmospheric Research on Transport and Transformation
IOC	Intergovernmental Oceanographic Commission
IOOS	Integrated and Sustained Ocean Observations
IRD	Institut de Recherche pour le Développement
IRI	International Research Institute for Climate Prediction
JCOMM	Joint WMO-10C Technical Commission for Oceanography and Marine Meteorology
JIMAR	Joint Institute for Marine and Atmospheric Research
JIMO	Joint Institute for Marine Observations
JISAO	Joint Institute for the Study of Atmosphere and Ocean
JPL	Jet Propulsion Laboratory, NASA
MBARI	Monterey Bay Aquarium Research Institute
MIT	Massachusetts Institute of Technology, Harvard
MPI	Max Planck Institute, Germany
MPL	Marine Physical Laboratory, SIO, UCSD
NASA	National Aeronautics and Space Administration
NDBC	NOAA/NWS/National Data Buoy Center
NCAR	National Center for Atmospheric Research
NCCOS	National Centers for Coastal Ocean Science
NCEP	NOAA/National Centers for Environmental Predictions
NEFSC	NOAA/Northeast Fisheries Science Center
NESDIS	NOAA/National Environmental Satellite, Data, and Information Services
NGI	Northern Gulf Institute
NGS	NOAA/National Geodetic Survey
NIWA	National Institute of Water and Atmospheric Research, New Zealand
NMFS	NOAA/National Marine Fisheries Service



NMSP	National Marine Sanctuary Program
NOS	NOAA/National Ocean Service
NSF	National Science Foundation
NWFSC	NOAA/Northwest Fisheries Science Center, NMFS
NWS	NOAA/National Weather Service
OAP	NOAA/Ocean Assessment Program
OAR	NOAA/Ocean and Atmospheric Research
OE	NOAA/Office of Ocean Exploration
OGCM	Oceanic General Circulation Model
OGP	See CPO
ONR	Office of Naval Research
ORA	NOAA/Office of Research and Applications
PDO	Pacific Decadal Oscillation
PFEG	NOAA/NMFS/Pacific Fisheries Environmental Group
PIFSC	NOAA/NMFS/Pacific Islands Fisheries Science Center
PMEL	NOAA/Pacific Marine Environment Lab
R/V	Research Vessel
ROWG	Radio Operators Working Group
SAS	Simplified Arakawa-Schubert cumulus convection scheme
SCCWRP	Southern California Coastal Water Research Project
SDG&E	San Diego Gas & Electric
SEFSC	NOAA/Southeast Fisheries Science Center, Panama City, FL
SIO	Scripps Institution of Oceanography, UCSD
SOPAC	Scripps Orbit and Permanent Array Center
SST	Sea surface temperature
SVP	Surface Velocity Program
SWFSC	NOAA/Southwest Fisheries Science Center, NMFS
UC	University of California
UCD	University of California, Davis
UCLA	University of California, Los Angeles
UCSB	University of California, Santa Barbara
UCSC	University of California, Santa Cruz
UCSD	University of California, San Diego



UNAM	Universidad Nacional Autonoma de Mexico
USARP	U.S. Antarctic Research Program
USC	University of Southern California
USFS	U.S. Fire Service
USGS	U.S. Geological Survey
UW	University of Washington, Seattle
VAdm	Vice Admiral
VOS	Voluntary Observing Ship
WECC	Western Electricity Coordinating Council
WHOI	Woods Hole Oceanographic Institution
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
XBT	Expendable Bathythermograph
XCTD	Expendable Conductivity Temperature and Depth

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