Joint Institute for the Study of the Atmosphere and Ocean

JISAO

ANNUAL REPORT

APRIL 2016 - MARCH 2017

Joint Institute for the Study of the Atmosphere and Ocean

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CONTENTS

EXECUTIVE SUMMARY

INTRODUCTION

The Joint Institute for the Study of the Atmosphere and Ocean (JISAO) fosters collaborative research between the University of Washington (UW) and the National Oceanic and Atmospheric Administration (NOAA). JISAO scientists represent a broad range of expertise under seven major themes:

1. Climate research and impacts
2. Environmental chemistry
3. Marine ecosystems
4. Ocean and coastal observations
5. Protection and restoration of marine resources
6. Seafloor processes
7. Tsunami observations and modeling

JISAO scientists focus research on such critical issues as climate change, ocean acidification, tsunami forecasting, and fisheries assessment by:

1. Collecting and analyzing data to better understand physical, biological, and chemical processes of ocean and coastal areas
2. Understanding climate variability and change
3. Improving our understanding of ocean and atmospheric processes associated with climate change and determining adaptation strategies
4. Studying how the ocean absorbs carbon dioxide and the resulting increase in acidity of ocean water
5. Studying hydrothermal vents and volcanoes on the seafloor
6. Studying effects of interactions between human communities and natural ecosystems
7. Developing tools and technology to restore and protect marine habitats
8. Improving prediction and forecasting of tsunami impacts

As a unit within the UW College of the Environment, JISAO works with a number of departments throughout the campus, including Atmospheric Sciences, Oceanography, Fisheries, Earth and Space Sciences, the Applied Physics Laboratory, Civil and Environmental Engineering, Friday Harbor Laboratories, and the Undergraduate Research Program, among others. A large number of JISAO employees work at the NOAA Western Regional Center in Seattle, including the Pacific Marine Environmental Laboratory (PMEL), Alaska Fisheries Science Center (AFSC), and Northwest Fisheries Science Center (NWFSC). The Institute's Education and Outreach (E&O) program makes important contributions in promoting environmental literacy at all levels of society, mentoring the next generation of scientists and reaching out to underrepresented communities with the goal of creating a diverse work force. The history of JISAO's important research and outreach will be recognized in a 40-year anniversary celebration this spring.

Some of JISAO's current research is featured in the Science Highlights section below, followed by a summary of the Education and Outreach program activities of the past year and an update on financial and business operations. Beyond this section are individual progress reports for each new project funded by the NOAA Cooperative Agreement in the past year, as well as appendices with additional information as requested by the NOAA Performance Reporting guidance.

SCIENCE HIGHLIGHTS

CLIMATE RESEARCH AND IMPACTS

Much of the skill in seasonal weather prediction relies on proper specification of the state of El Niño-Southern Oscillation (ENSO) in the tropical Pacific. This has been accomplished in large part during the past couple of decades through the deployment of an array of moored buoys. New methods are becoming available to collect the observations necessary to adequately monitor air-sea exchanges in the tropics. In particular, NOAA and JISAO scientists are leading a new project to determine the feasibility of using autonomous sailing vessels developed by Saildrone, Inc. for this purpose. These small but rugged wind-powered craft are being outfitted with a full suite of sensors to estimate the winds and exchanges of heat and carbon dioxide. This technology promises to provide considerable cost savings that are so important in these times of shrinking budgets, and this project is carrying out the testing required before it becomes operational.

ENVIRONMENTAL CHEMISTRY

The Juneau Icefield is a pristine location, but nevertheless it is subject to the deposition of black carbon (soot). JISAO researcher Sarah Doherty is working with personnel from the University of Alaska to determine how much of this material is being deposited and its effects. It turns out that very small amounts of black carbon can cause significant decreases in the reflectivity of the surface of the snow or ice, hence melt rates increase. A previous major study by Doherty quantified the global impact of black carbon on the climate. The surprising result is that black carbon appears to be the second most important anthropogenic cause of global warming. This recent work featuring data from a remote location should provide additional insights into this under-recognized, but very important constituent of the atmosphere.

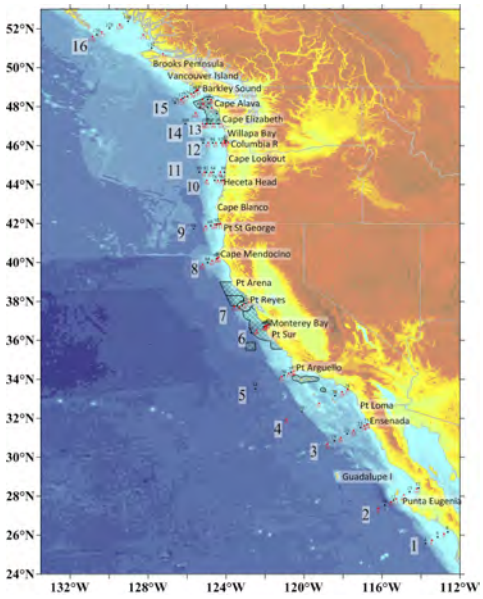
MARINE ECOSYSTEMS

A harmful algal bloom (HAB) of unprecedented geographic scope, duration, and intensity occurred along the West Coast of North America in the summer of 2015. Ryan McCabe of JISAO was the lead author of a journal article on this event (McCabe et al., *Geophysical Research Letters*, 2016) that has gained a great deal of attention from the scientific community, fisheries managers, and health agencies. He and his co-authors showed how warm and nutrient-poor conditions provided a competitive advantage to a particular species that can produce the toxin, *Pseudo-nitzchia australis*. A sort of one-two punch in the winds resulted in a massive bloom followed by the transport of toxic cells onto the coast, including shellfish beds. While this HAB cannot be attributed to climate change, it does illustrate one of the emerging threats of global warming.

OCEAN AND COASTAL OBSERVATIONS

The fifth in a series of West Coast ocean acidification (OA) research cruises was conducted in 2016 from the R/V *Ronald H. Brown*. The Ocean Climate Stations Project (OCS) collects climate quality air-sea interaction observations that can be used as reference time series for assessment studies and process studies. JISAO scientists comprised a major portion of a large team with diverse expertise and interests. There were 16

lines of stations from Vancouver Island south to Baja, California at which water properties were measured and phytoplankton and zooplankton were collected with nets. The chemistry of the ocean is changing, and there is simply no substitute for this kind of effort to document exactly how it is changing and impacting the base of the marine food web.



PROTECTION AND RESTORATION OF MARINE RESOURCES

There are only a few hundred North Pacific right whales in existence. Past whaling decimated their population. What can be done now to avoid them becoming extinct? NOAA and JISAO personnel at the AFSC manage the most complete database on these whales, and are striving to learn more about their behavior and requirements. A key aspect of this work involves fitting individual whales with tags so that they can be tracked via satellite. JISAO scientist Amy Kennedy is one of the world's experts in this kind of work. It is very challenging because these whales are so few in number. But it is also necessary, because this kind of information is essential for establishing critical habitats for North Pacific right whales as part of the Endangered Species Act.

SEAFLOOR PROCESSES

Hydrothermal vents might be expected to be inhospitable places. In actuality, complex biological communities have evolved to take advantage of the chemical energy in the plumes of water emanating from these volcanic springs. David Butterfield of JISAO organized and served as chief scientist on an innovative research expedition to explore new hydrothermal vent fields in the Mariana Back-Arc in the western Pacific Ocean. The ship was the *Falkor* of the Schmidt Ocean Institute, and video and samples were captured from a series of dives with SuBastian, a new and highly capable remotely-operated vehicle (ROV). The cruise included extensive public outreach highlighted by the streaming of dramatic live video from SuBastian.

TSUNAMI OBSERVATIONS AND MODELING

A so-called "megaquake" on the Cascadia Subduction Zone offshore of the Pacific Northwest is inevitable. When it happens, a large tsunami will shortly thereafter deliver walls of water to places such as the Long Beach Peninsula of Washington State. Since there would be insufficient time to get from some low-lying areas to high enough ground, an alternative strategy is to construct some buildings such as schools and hospitals that would serve as refuges from a tsunami. JISAO scientists with the NOAA Center for Tsunami Research (NCTR) partnered with a committee of the American Society of Civil Engineers (ASCE) to address this problem. A large number of high-resolution simulations of tsunamis that could occur along the Pacific Coast were carried out by NCTR; the results showed that surges ranging from 16 to as much as 100 feet high are possible at particular locations. The modeled wave heights and current velocities were used by the ASCE to develop design standards for structures that could withstand tsunamis of these magnitudes.

EDUCATION AND OUTREACH

"This internship was an extraordinary experience for me. I feel significantly more confident in my ability to survive and thrive in a scientific setting." ~ Austin Carter, 2016 JISAO Summer Intern

JISAO's Education and Outreach (E/O) Program continues to make important contributions by advancing environmental literacy at all levels of our society, and educating and mentoring the next generation of scientists who reflect the diversity of our nation and are skilled in science and technology.

Perhaps the most noteworthy project supported by the E/O Program is the success of the JISAO Summer Undergraduate Internship Program. The internship program began with one student in 2008, and has since hosted 57 students from colleges and universities across the United States. Eight of JISAO's former interns have received graduate degrees, including two with Ph.D's. Eleven former interns have completed undergraduate degrees and are currently enrolled in graduate school, including three at the University of Washington.

2016 JISAO Summer Interns (L-R): Grace Stonecipher, Madisyn Frandsen, Sarah Brown, Jeremy Sousa, Iker Madera, Marcos Amezcua, Nicola Paul, Suzanna Officer, Austin Carter, Michael Espriella, Caroline Tribble

JISAO's prominent presence in the local and national environmental science communities is reflected in the growth of the E/O Program and its many successful events and projects as outlined below:

INTERNATIONAL OUTREACH

International workshop in Japan – Edison Gica was the keynote speaker at a workshop at Shirahama Oceanographic Observatory organized by Kyoto University's Disaster Prevention Research Institute. The workshop was an opportunity to discuss field observation and the utilization of observed data. It was attended by local and foreign students, as well as university and local government staff.

Additional Workshops and Talks – JISAO Director Tom Ackerman spoke at the International Radiation Symposium in Auckland, New Zealand, and at university seminars in Melbourne and Sydney, Australia. Additionally, JISAO researchers Kevin Wood, Calvin Mordy, and Muyin Wang presented work during workshops at the University of Maynooth in Ireland, the Hong Kong Observatory in Hong Kong, and the China Meteorological Administration in Beijing.

K-12 EVENTS

Orca Bowl – JISAO scientists were judges and scorekeepers at Washington Sea Grant's 2016 Orca Bowl. Teams of high school students from around Washington State came to the UW campus to challenge their knowledge of the world's oceans. Top prizes included UW Oceanography scholarships and shipboard science experiences.

NOAA Science Camp – Eleven JISAO scientists led sessions for the 2016 NOAA Science Camp at the Pacific Marine Environmental Laboratory (PMEL). 2016 was the 11th year that JISAO funded NOAA Science Camp scholarships for low income and underrepresented students. This year we partnered with the Tukwilla School District's STEAM program and provided enough funding for 25 middle school students to attend the camp.

Students at Sand Point for NOAA Science Camp 2016

Oceanography Internship for High School Students – Samantha Siedlecki mentored a high school student at the UW School of Oceanography's Organic Geochemistry Lab. The 4-week internship required no prior experience from the students – the emphasis of the program is to give student their first experience in an environmental research lab.

Marine biology job shadowing for high school students – Sonya Brown facilitated the event that included hands-on fish and larva sampling and microscope activities done by researchers at the Alaska Fishery Science Center.

Science Day at Seaview Elementary in Edmonds, Washington – Katie Luxa led eight sessions during a full day of marine mammal research aimed at K-3 students. The biannual event has been happening for 20 years, and has always received excellent reviews from the staff, parent volunteers, and student participants.

Ingraham High School class visit to PMEL – Adi Hanein provided an overview of PMEL's research and a tour of its facilities for a group of high school oceanography students. Joe Resing lectured on earth-ocean interaction and underwater volcanoes, and Dave Rivera led the group on a tour of the NOAA dive center.

Heather Tabisola made an alumni visit to her high school in Massachusetts where she spoke with two sections of a marine vertebrates class and worked with a maker class as they constructed a mini-ROV (remotely operated vehicle) and small research platform.

Tour for Kitsap County Homeschool Co-Op – Adi Hanein taught this group about NOAA's research, and arranged a tour of the Weather Forecast Office where students learned about how researchers collect data and create their models. They also received a tour of PMEL engineering, and learned how scientists conduct research out at sea.

Additional Events – Researchers donated their time and expertise for marine research and ocean forecasting talks at Ballard High School (Rolf Sonnerup, Al Hermann), a STEM Career Fair at Sammamish High School (David Butterfield), Science Club at Hazelwood Elementary School (Katie Luxa), Career Day at Aki Kurose Middle School as part of the Kids Envisioning Careers program (Ivonne Ortiz), and Blue Heron Middle School's career day presented by the American Association of University Women (Shaun Bell).

Additional researchers participating in K-12 events include Lucia Upchurch, Wei Chang, William Higley, Nick Bond, Jed Thompson, and Muyin Wang.

ONLINE COMMUNICATION

JISAO's website (*jisao.washington.edu*) provides an effective means to communicate institute activities to constituents with its user-friendly format and organization. Over the years, JISAO has tracked media coverage of all JISAO scientists. Archives of past media coverage, as well as staff profiles, are easily accessible via links on the main page. The following events received notable media coverage in the past year:

- Unmanned vessels deployed for Alaska ocean research – *ABC News*
- Ocean forecast offers season outlook for Pacific Northwest waters – *Science Daily, Science Codex*
- Deep-sea hydrothermal vents more abundant than thought – *Science News*
- A new 'how-to' for tsunami-safe buildings – *Seattle Times, King5 News, Seattle PI*
- Warm Pacific ocean 'blob' facilitated vast toxic algae bloom – *Washington Post, UW Today, Hakai Magazine*
- Breathtaking new video footage of the ocean's uncharted depths – *Gizmodo*
- A century-old Arctic shipwreck could help us predict extreme weather - *FiveThirtyEight*

Research Blog – Kim Martini is an active blogger for *Deep Sea News*. Martini writes about science in a way that is relatable to non-scientists with postings like "Go Go Gadget Jellyfish!" and "Tour the Deep Southern Ocean from the Safety of Your Couch."

A Saildrone for Science – Heather Tabisola organized a Google Hangout video call with students in Alaska to answer questions on how researchers are using the Saildrone equipment for science in Alaska's marine ecosystems.

Live video during ROV dives – Dave Butterfield led a research cruise to the Mariana back arc and broadcast live videos online as ROV dives explored undersea hydrothermal vents.

PUBLIC OUTREACH

Polar Science Weekend – This annual event at Pacific Science Center is three days of hands-on educational activities, live demonstrations, and exhibits presented by scientists who work in polar regions. Cynthia Christman volunteered for the "Polar Detectives" demonstration which taught kids about Arctic seals, the importance of sea ice, and how our actions have global effects. Andy Whitehouse used a display called "Stinky, Slimy Fish Stomachs" to show the work of the Alaska Fisheries Science Center's (AFSC's) Resource Ecology and Ecosystem Modeling Program. The display taught guests about the food habits of fish in Alaska and how researchers use that information to develop models showing how species interact in a food web.

Discover Science Weekend at the Seattle Aquarium – Katie Luxa and Josh Cutler had a table dedicated to marine mammals. In addition to teeth, skulls, furs, baleen, and blubber, they also shared radio tags and some of the other tools they use to conduct their research. Adi Hanein, Nathan Anderson, Muyin Wang, and Heather Tabisola presented an ocean salinity and circulation demonstration along with a buoy model and videos.

Washington State Corrections Center for Women – Rachel White visited the corrections facility and gave a talk titled "Climate Change and Us." This talk was part of the Sustainability in Prisons Project.

Radio and Television – Nick Bond gave a weekly weather outlook on KUOW's "Weekday" program every Friday morning. He's also a frequent guest on other stations such as KCBS Radio in San Francisco where he speaks on subjects such as summer temperature and rain average, pollen allergies, The Blob, and the winter weather outlook. Bond is also a frequent guest on King5 News weather programs.

Public talks – JISAO researchers gave talks at the Rotary Club of Lynnwood (Samantha Siedlecki), the Seattle

Sunset Club (Edward Baker), the Bainbridge Island Science Café (Nick Bond), Weatherfest (Yong Wei, Karin Bumbaco, Nick Bond), the Seattle Mountaineers Club (Nick Bond), the Hood Canal Climate Forum (Nick Bond), the Tulalip Tribe's Climate Core Team Meeting (Nick Bond), a sea glider demonstration (Jim Osse), Horizon House for Senior Living (Edward Baker), Third Place Books (Rachel White), and Science on Tap events at Peddler Brewing Company and Naked City Taproom (Rachel White).

SUMMER INTERN PROGRAM

JISAO welcomed eleven undergraduate students to the JISAO Summer Internship Program in 2016. Students were matched with mentors from JISAO, the UW Department of Atmospheric Sciences, the UW School of Oceanography, the UW School of Aquatic and Fishery Sciences, the NOAA Pacific Hydrographic Branch, the NOAA Marine Mammal Laboratory, and the NOAA Alaska Fisheries Science Center. Student web pages and videos are available on JISAO's website. The interns and their universities are listed below:

Marcos Amezcua – Humboldt State University
Sarah Brown – University of Texas
Austin Carter – University of Michigan
Michael Expriella – University of Southern California
Madisyn Frandsen – Tarelton State University
Iker Madera – Colorado School of Mines
Suzanna Officer – Walla Walla Community College
Nicola Paul – University of Miami
Grace Stonecipher – Yale University
Jeremy Sousa – Lyndon State College
Caroline Tribble – Virginia Polytechnic Institute

For the fourth year in a row, JISAO's summer interns worked together to create a hands-on presentation to teach about marine life and the water cycle for a group of middle school students with autism. The young students spend a week on the UW campus each summer, and have often said that their day with JISAO is one of the most educational.

UNIVERSITY EVENTS

SACNAS (Advancing Hispanics, Chicanos and Native Americans in Science) National Conference in Long Beach, CA – Daniel Hernandez, a former JISAO intern and current graduate student in the UW School of Aquatic and Fishery Sciences represented JISAO and the College of the Environment, and distributed applications for JISAO's internship program.

AISES (American Indian Science and Engineering Society) National Conference in Minneapolis, MN – Jed Thompson, JISAO's Education/Outreach and Communications Specialist, attended the conference and recruited American Indian students who might be interested in applying for JISAO's summer internship program.

Guest Lectures – JISAO researchers gave talks at local colleges and universities including the Seattle Art Institute (Brendan Carter), Seattle University (David Butterfield), the University of Washington (Greg Johnson), UW Tacoma (Nick Bond and Jed Thompson), and Central Washington University (PMEL tour by Heather Tabisola, Dongxiao Zhang, and Adi Hanein).

FINANCIAL MANAGEMENT AND ADMINISTRATION

JISAO bridges two major institutions and can be a management challenge because of its complexity. The UW infrastructure ensures JISAO's ability to manage large financial and human resource portfolios, to meet reporting requirements, to maintain and improve the required compliance systems and procedures, and to provide the best possible overall business management of the Institute's resources. JISAO and local NOAA administrators have formed a strong partnership that works efficiently and contributes to the success of the Institute.

A management team meets once per week for planning purposes and to discuss issues related to budgets/grants, human resources, and general administration. The team includes:

- Thomas Ackerman, Executive Director
- Nicholas Bond, Associate Director (JISAO management representative at NOAA/PMEL)
- Mary Smith, Assistant Director, Finance & Administration
- Fred Averick, Grants and Contracts Manager
- Collen Marquist, Assistant to Executive Director/Administrative Specialist

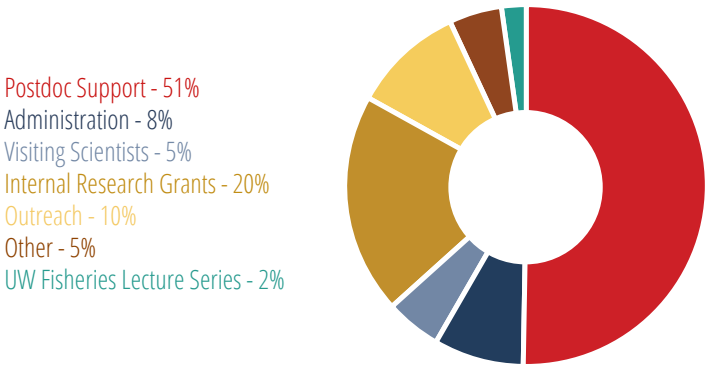
JISAO's Executive Council meets when there are agenda items that require higher-level policy reviews and decisions. Meetings are held either at UW or NOAA once per quarter for JISAO employees. NOAA scientists attend some of these meetings if they are involved with the topic. These meetings focus on items of mutual interest to both organizations, to recognize outstanding scientific, technical, and administrative staff, and to share updated operational information. The JISAO Assistant Director, Finance Manager, and Administrative Specialist hold weekly office hours at NOAA/PMEL to provide both JISAO and NOAA employees with a variety of services related to human resources, financial issues, travel, purchasing, and other administrative matters that arise.

JISAO's Cooperative Agreement is funded through three tasks:

Task I, also supported by the UW, includes:

- Three to six postdoctoral fellows on annual appointments, renewable for a second year – additional postdoctoral funding was provided this year by Chris Sabine, PMEL Director
- Senior visiting scientists on leave from their home institutions
- Honoraria and travel expenses for short-term visitors
- Education and outreach activities
- Small percentage of administrative support

Below is a breakdown of Task I budget:



JISAO provides space, network access, computer, and administrative support for postdoctoral researchers and visitors supported on Task I. JISAO has been able to double the number of research associates in the past year, a result of a judicious plan for Task I spending. The current group includes:

- Hannah Horowitz, PhD, Earth and Planetary Sciences, Harvard, 2017
  Horowitz is working with Cecelia Bitz and Lyatt Jaegle, of the UW Department of Atmospheric Sciences, on the first study to examine climate change impacts on the sea ice source of sea-salt aerosol, and to estimate the direct and indirect climate impacts of potential changes to sea-salt aerosol resulting from changing sea ice and warming ocean temperatures in a future climate scenario. Horowitz will investigate the full range of cascading chemistry-climate effects: from changes to sea-salt aerosol production, to reactive halogens and atmospheric oxidant concentrations, and finally to impacts on the greenhouse gases methane and ozone and the toxic pollutant mercury. The process-level understanding gained from these results will improve future studies of chemistry-climate interactions and climate change impacts and inform parameterizations in simpler, computationally inexpensive models. Jaegle and Bitz submitted a pending NSF proposal focusing on past climate changes, while Horowitz's focuses on future climate change. These two projects have the potential to be complementary and synergistic.
- Cristian Proistosescu, PhD, Earth and Planetary Sciences, Harvard, 2017
  Proistosescu is working on a research project that will investigate the interaction between ocean heat uptake and regional climate feedbacks across a range of temporal and spatial scales, with the aim of exploring the prospects for (and limitations of) what can be learned about Earth's climate sensitivity from the instrumental and paleo records of climate variability and change. Further, his research will build a process-level understanding of how modes of climate variability (such as the PDO, AMOC and ENSO) have consequences for Earth's global energy budget. These are timely and important topics, given the recent evidence that climate sensitivity is variable, and that future warming may be underestimated from modern climate observations. His research interests dovetail perfectly with several ongoing projects to understand the operation of climate feedbacks under climate variability and change, with Gerard Roe, UW Earth and Space Sciences, and Kyle Armour, UW Oceanography.
- Hannah Zanowski, PhD, Atmospheric and Oceanic Sciences, Princeton, 2017
  Zanowski is working with Cecelia Bitz, UW Atmospheric Sciences, and Kyle Armour, UW Oceanography, here on campus, and with Greg Johnson of NOAA Pacific Marine Environmental Laboratory, on a research project that will include both observational analysis of decade-to-decade historical water-mass changes in the Southern Ocean, as well as diagnosis of model output, specifically to study full-depth southern ocean responses to changes in wind and freshwater (buoyancy) forcing when they are applied in the open ocean vs. along the coast. By comparing observations and different climate models (developed at GFDL and NCAR), Zanowski hopes to elucidate key mechanisms for variability in the Southern Ocean limbs of the meridional overturning circulation. This work, incorporating observations and working through the water column, should substantially broaden her research horizons and has the potential to provide substantial insights into Southern Ocean variability that is in tum important to climate.
- Rachel White, Imperial College, London
  Interests: Dynamical climate modeling, atmospheric-ocean coupling, topographic effects on general circulation, jet streams, storm tracks, impacts of tropical deforestation.
- Anne Gothmann, PhD Geosciences, Princeton University
  Interests: The development and application of paleo-proxies in biogenic carbonates. Also, investigating coral proxies for the carbonate system using culture experiments and geochemical measurements of coral skeletons, as well as testing models of biomineralization and exploring the impacts of ocean acidification and global change on calcifying organisms.

Funded by non-Task I funds:

- Mariona Claret, PhD Physical Oceanography, Joint Program University of Las Palmas de Gran Canaria and Institut de Ciències del Mar, ES
  Interests: Changes in ocean circulation with climate variability that have an impact on the oceanic carbon cycle and oxygen availability. Additionally, the physics of smaller scales such as sub-mesoscales, and internal waves, and their interaction with marine biogeochemistry using state-of-the-art ocean models.

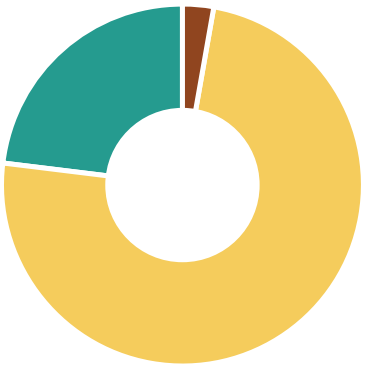
JISAO's education and outreach program activities are supported by a small portion of Task I funds, with additional support provided by other funding sources. Please see the section above for details about this program, which is vital to JISAO's mission.

Additionally, a small portion of Task I supports a fraction of administrative salaries. The administration was downsized a few years ago, and because of streamlining systems and resources, JISAO's business operations are managed effectively with a small team of individuals who each possess unique expertise and skills. Organizationally, each staff member handles a specific operational area, but there is also cross-training, so that staff can have coverage of their positions during times they need to be away from the office.

Task II serves as a vehicle for funding research scientists, (UW professional staff), postdoctoral research associates, and technical staff who work at the local NOAA laboratories in directed, collaborative research efforts between NOAA and university scientists.

Task III supports research related to JISAO's themes on the UW campus, and includes a broad range of departments. Principal Investigators include university academic and research faculty, as well as research scientists. Task III also supports postdoctoral research associates housed at NOAA, and graduate students working in a variety of campus departments.

The JISAO/NOAA Cooperative Agreement funding for the period April 1, 2016 – March 31, 2017 totals $20,143,284; JISAO's funding for non-Cooperative Agreement grants for the same period is an additional $3,100,456. The charts below break down Cooperative Agreement funding by tasks and themes.
Besides providing the ongoing infrastructure and support to successfully manage JISAO, the administration worked on the following initiatives over the past year to improve and strengthen JISAO as an organization:

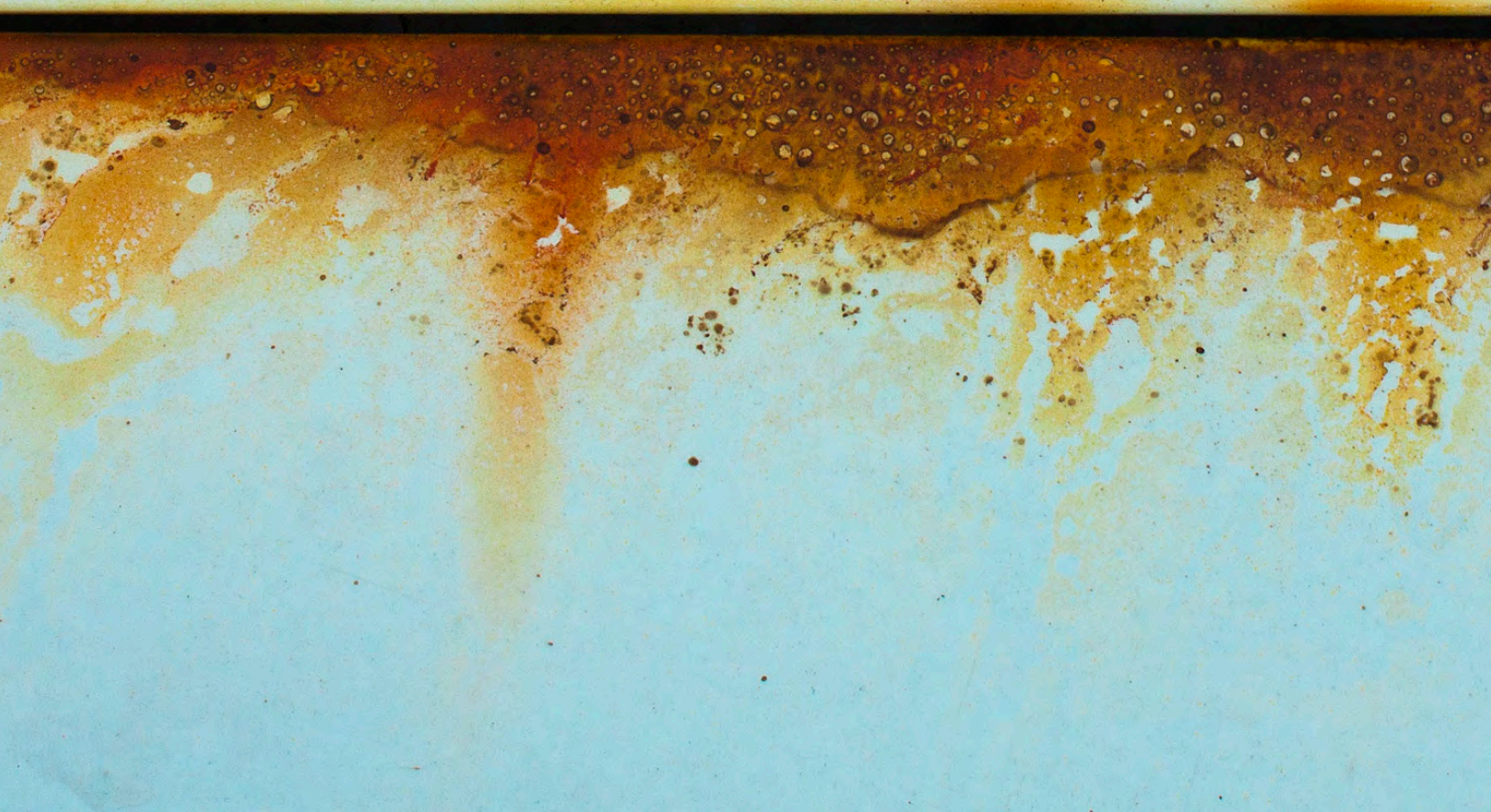


Task I - 3%
Task II - 74%
Task III - 23%

Climate Research and Impacts - 2%
Environmental Chemistry - 17%
Marine Ecosystems - 22%
Ocean and Coastal Observations - 25%
Protection and Restoration of Marine Resources - 11%
Seafloor Processes - 6%
Tsunami Observations and Modeling - 6%
Various - 13%

- JISAO Outreach and Education Program
  1. Strengthened and broadened the success of the E&O program (see section above for details of the year's activities)
- JISAO Staff Recognition Program
  1. Recognized outstanding research, papers, honors, and awards on JISAO website
  2. Presented UW service awards to JISAO employees
  3. Several JISAO scientists and team members in the JISAO administrative group received cash awards for outstanding work over the past year in various capacities
- Communications
  1. Continued joint quarterly meetings with JISAO and NOAA employees
  2. Held the annual all-personnel meeting on UW campus that includes all JISAO employees at UW and those who work at NOAA facilities; NOAA scientists also attended
  3. JISAO assistant director, the finance manager, and the administrative specialist held weekly office hours at NOAA/PMEL, improving communications, services and collaboration between NOAA and UW personnel. Other staff go to NOAA when needed
  4. Website evolution continued with plans to completely re-do current site
  5. Participated on both the NOAA and UW College of the Environment communications teams to regularly share information and best practices
  6. Continued to develop JISAO's marketing and public relations efforts to communicate research and education goals and activities to partnering organizations, as well as local, regional, and national communities
  7. Continued social networking via Facebook, YouTube, and Twitter
  8. Continued to track media coverage and publications of JISAO researchers
  9. Developed additional educational and public outreach materials
- Organization and Infrastructure
  1. Streamlined/consolidated staff assignments, continuing to work with reduced number of FTEs by not filling 2 vacant positions
  2. Continued strengthening overall organizational structure, working directly with JISAO scientific and technical staff to ensure meaningful supervisory and mentoring relationships
  3. Thomas Ackerman, JISAO Executive Director, is a member of the College of the Environment Executive Committee, and served the College in various capacities
  4. JISAO staff worked on university-wide initiatives and on committees addressing financial, human resources, diversity, equity and inclusion, communications, and safety matters

CLIMATE RESEARCH AND IMPACTS



CONTRIBUTION TO NATIONAL CLIMATE ASSESSMENT 4

PI
Sarah Doherty – UW Joint Institute for the Study of the Atmosphere and Ocean

TASK III

NOAA SPONSOR
David Fahey – Earth Systems Research Lab

NOAA GOALS
Climate Adaptation and Mitigation

DESCRIPTION
There are two components to the work under this grant, based on the Revised Statement of Work (submitted November 22, 2016 to NOAA). All work is specified as being conducted by PI Doherty:

1. Assist in the writing and management of a Climate Science Special Report (CSSR) being generated in advance of the 4th National Climate Assessment (NCA4). The periodically produced NCA summarizes the impacts of climate change on the United States, now and in the future (e.g. see the last assessment at *nca2014.globalchange.gov*). A key element of NCA4 is a special, stand-alone report on the state of the science on climate change and its physical impacts. Following the finalization of the CSSR, the author team is to work with the NCA4 authors to ensure consistency across regions and sectors in analyses, interpretation, and explanation. Writing of the CSSR started in March, 2016; expected completion date is mid-2017. Writing of NCA4 started in March, 2017; expected completion is end of 2018. David Fahey at NOAA Earth Systems Research Lab is one of three coordinating lead authors of the CSSR report, as well as lead author on Chapter 2 of the report. Doherty is assisting him in both of these roles.
2. Act as assessment coordinator for the 2018 Ozone Assessment. Fahey is one of four co-chairs of this assessment. Doherty will assist Fahey and the other co-chairs in all aspects of report preparation. She will be the main communication hub between the co-chairs, the Scientific Steering Committee (SSC – 5 members), the author team (12 lead authors plus approximately 35 to 40 authors) and the review editors (12), as well as with the assessment Technical Support Unit at NOAA and the sponsoring office at the United Nations Environment Program (UNEP Ozone Secretariat).

OBJECTIVES
1. Complete the CSSR to the NCA4. In particular, Doherty is one of the authors on Chapter 2 of the report ("Physical Drivers of Climate Change," March 2016 through mid-2017).
2. Assure consistency in quality and messaging across all chapters of the CSSR. Doherty is assisting the coordinating lead author team and the CSSR Technical Support Unit in achieving this goal (March 2016 through mid-2017).
3. Complete Chapter 1 of the NCA4, which will summarize the CSSR (activity starting in March 2017).
4. Assure efficient coordination of and high quality of content in the 2018 Quadrennial Ozone Assessment (activity starting November 2017).

ACCOMPLISHMENTS
1. Produced four iterative drafts of Chapter 2 of the CSSR, and assisted on completion of several other chapters of the report and the Executive Summary. Each successive draft was reviewed, then iterated based on review comments. In particular, the Third Order Draft was reviewed by three external groups: a)

the general public, including scientific colleagues; b) NOAA members at the National Weather Service, the National Marine Fisheries Service, the Office of Ocean and Atmospheric Research, and the Great Lakes Environmental Research Lab; and c) a team at the National Academy of Sciences. Doherty and Fahey collaborated to address and respond to all review comments; a Fourth Order Draft of Chapter 2 of CSSR was submitted to the Technical Support Unit for editorial review and final formatting on April 14, 2017.

2. Participated as a member of the Core Writing Team of the CSSR Executive Summary on identifying and wording key messages of the overall CSSR report, which will feed into the writing of Chapter 1 of NCA4.
3. Attended three lead author meetings as a member of the CSSR team:
   a. April 18-19, 2016: U.S. Global Change Research Program headquarters, Washington, DC.
   b. November 2-4, 2016: National Center for Atmospheric Research, Boulder, CO.
   c. March 21-22, 2017: National Centers for Environmental Information, Asheville, NC.
4. Worked with the coordinating lead authors of the 2018 Quadrennial Ozone Assessment on:
   a. Solicited, consolidated and utilized input from the broader scientific community on the proposed structure, content, and timeline for the 2018 Ozone Assessment and potential authors for different sections of the report.
   b. Selected and invited chapter lead authors and review editors.
   c. Worked with the chapter lead authors and lead authors on identifying and inviting each chapter's author team.
   d. Worked with the lead authors, chapter lead authors, and SSC on draft chapter outlines.
   e. Planned the first Assessment meeting (Royal Society, London UK, May 3-5, 2017).

LIGHTNING STUDIES

PI
Robert H. Holzworth – UW Earth and Space Sciences

OTHER UW PERSONNEL
Todd P. Mitchell – Joint Institute for the Study of the Atmosphere and Ocean

TASK III

NOAA SPONSOR
Steven J. Goodman – NOAA GOES-R Series Program

DESCRIPTION
This project is a study of global lightning activity to help define the parameters needed for the NOAA/GOES-R Global Lightning Mapper (GLM) mission. This year we moved from the pre-launch phase to the on-orbit validation phase of the mission following the successful launch in the fall of 2016. First light for the NOAA-GOES-R-GLM occurred the first week of January, 2017, and the data will be available to the public by mid-June 2017. We are currently in the post-launch validation phase, and all GLM data remain embargoed until May 12, 2017.

OBJECTIVES
1. To increase our abilities to detect lightning globally, combining ground-based VLF (very low frequency) lightning detection networks into one super system.
2. To study the effects of lightning on the upper atmosphere, and analyze lightning activity in the North and South American regions using the energy/stroke to analyze storm dynamics.

ACCOMPLISHMENTS
1. Global Lightning Detection – During this grant year, we have finally succeeded in combining the World Wide Lightning Location Network (WWLLN) lightning location data with the VLF waveforms produced by the Earth Networks sensors to form a new improved global lightning network called the Earth Networks Global Lightning Network (ENGLN).This grant has helped with the analysis of these combined data to validate the new system for direct comparison to the NOAA GOES-R data.

This WWLLN lightning research was presented at the American Geophysical Union (AGU) meeting in San Francisco in December 2016, and the American Meteorological Society meeting in Seattle in January 2017.

2. Detailed analysis of lightning activity in the North and South American regions using the energy/stroke to analyze storm dynamics has been underway. Regional comparisons of average stroke energy as a function of diurnal times and regions has been done. These analyses confirm the earlier work showing that there is a strong gradient in average stroke energy across a land-sea interface such as along the East Coast of the U.S., and along the North Coast of South America. However, our analysis of individual storm dynamics is still underway.

Additionally we have demonstrated the importance of the global lightning data set on the upper atmosphere and ionosphere in presentations at the AGU meeting, and in a publication.

ARCTIC PROJECT

PI
Muyin Wang – UW Joint Institute for the Study of the Atmosphere and Ocean

OTHER UW PERSONNEL
Nicholas A. Bond, Kevin Wood, and Qiong Yang – Joint Institute for the Study of the Atmosphere and Ocean

TASK II

NOAA SPONSOR
James E. Overland – Pacific Marine Environmental Laboratory
Jeremy T. Mathis – Arctic Research Program/Climate Program Office

OTHER NOAA PERSONNEL
Phyllis Stabeno, Sigrid Salo, Sue Moore, and Nancy Soreide – Pacific Marine Environmental Laboratory

DESCRIPTION
There has been a marked acceleration of environmental changes and impacts in the Arctic since 2007. Change is occurring sooner than projected by climate models. The subsequent cascade of ecosystem and human consequences has resulted in enhanced access to commercial shipping, tourism and industrial development (e.g., mining, oil, and gas prospecting), increased biological productivity, and shifts of marine mammal habitat. Impacts are evident on ecosystems-fisheries and marine mammals, coastal communities, industrial development, perception of climate change, and mid-latitude weather connections.

OBJECTIVES
Our goal is to strengthen Arctic science and stewardship, to improve our understanding of changing climate and environmental conditions, to improve our forecast skills, and to better inform policy options and management responses to the unique challenges in the Arctic region.

The NOAA goals associated with our projects are:

Among the six prioritized elements below from NOAA's 2011 "Arctic Vision and Strategy" document, Pacific Marine Environmental Laboratory (PMEL)/Joint Institute for the Study of the Atmosphere and Ocean (JISAO) are leaders in elements 1, 2 and 5:

1. Forecast sea ice on all time scales: from sub-seasonal to seasonal, to multi-decadal.
2. Strengthen foundational science to improve our understanding and to detect Arctic climate and ecosystem changes.
3. Improve weather and water forecasts and warnings.
4. Enhance international and national partnerships.
5. Improve stewardship and management of ocean and coastal resources in the Arctic.
6. Advance resilient and healthy Arctic communities and economies.

PROJECT AREAS
1. Arctic Change Detection – We continue to evaluate and understand recent rapid changes in the Arctic, with special focus on climate impacts of sea ice loss, and evaluation of future climate projections at

pan-Arctic and regional scales. We are increasingly involved with communicating and advising on Arctic synthesis and policy to NOAA's Arctic Priority Objective Team, the Marine Mammal Commission, the U.S. Arctic Research Commission, the International Arctic Science Committee, and the U.S. Climate Variability and Predictability (USCLIVAR) program. This project focuses on:

a. The Arctic Report Card – In 2011, NOAA described the Arctic Report Card as "influential scientific information." The content is organized into five sections: Atmosphere, Sea Ice and Ocean, Marine Ecosystems, Terrestrial Ecosystems, and Hydrology and Terrestrial Cryosphere. An independent peer-reviewed article was completed by the Arctic Monitoring and Assessment Program. JISAO PI Muyin Wang and James E. Overland of PMEL continue to update their part of the Arctic Report Card annually. This has become an internationally collaborated research effort with the NOAA news release at the American Geophysical Union conference in December 2016.

b. The Sea Ice Outlook – The Sea Ice Outlook builds a community consensus of the summer sea ice season. This has evolved as part of the main focus of the Sea Ice Prediction Network project in which Wang and Overland are members of the leadership team. Wang was responsible for organizing bi-monthly webinars in 2016 hosted by the Arctic Research Consortium of the U.S. The Sea Ice Outlook for Walrus is a novel product specifically focused on capturing changes in sea ice coupled with weather/wind predictions at a temporal and spatial scale useful to local hunters in the Bering Strait region.

c. Coupled Climate Models Assessments – We continue our efforts on climate model assessment and evaluations, which now include the National Center for Environmental Prediction Coupled Forecast System version 2 (CFSv2), with a focus on the pan-Arctic, as well as the sub-Arctic seas (e.g., the Chukchi, Beaufort, Bering, and Barents seas) on sea ice, surface air temperature, and other atmospheric forcing fields. The research results have also helped other projects and programs across the agencies, the Inter-Agency Standing Committee working group, the U.S. Geological Survey (via David Douglas), and the Walrus Project.

d. Rapid Changes in the Arctic and Mid-Latitude Weather Connections (linkages) – We continue our research on the rapidity of Arctic changes. There is growing evidence of increased connectivity between Arctic changes and mid-latitude climate and weather.

e. Data Recovery – New versions of Old Weather were developed and deployed online in December 2016. JISAO's Kevin Wood continues his leadership role in this data recovery project. Recovered data are assimilated by sparse-input reanalysis systems such as the NOAA 20th Century Reanalysis, and used to update global gridded data sets widely used for weather and climate research.

2. Pacific Arctic Group Support (Northern Bering/Chukchi seas) – Our main focus is to understand and present the historical climate variability of the region and its relation to biological productivity and potential ecosystem changes. We are doing this via the activities listed below.

   a. The Distributed Biological Observatory promotes long-term north-south biophysical observations in the Pacific Arctic by multiple national and international institutions.

   b. Historical analysis of Pacific-Arctic region climate, developing data rescue and analyses products for the region.

   c. The Bering Climate Website (*beringclimate.noaa.gov*) is maintained and updated annually.

ACCOMPLISHMENTS

1. Arctic Sea Ice – We continue our ongoing research on the past, present, and future climate of the Arctic. This work represents an important foundation for the Arctic Report Card (*arctic.noaa.gov/Report-Card*). This year's edition showed that Arctic mean annual air temperature continues to increase at a rate of warming that is more than twice the rate of the global mean. Persistent warming trend and loss of sea ice are triggering extensive Arctic changes The average annual surface air temperature anomaly over land north of 60° N for October 2015-September 2016 (+2.0° C, relative to a 1981-2010 baseline) was by far highest in the observational record beginning in 1900; this represents a 3.5° C increase since the beginning of the 20th Century

2. Coupled Model Intercomparison Project 5 model assessment over the Arctic on ice and atmosphere – Wang and the team extended their study to finer time scales, with a focus on sea-ice duration, sea-ice freeze-up, and break-up dates in the Pacific Arctic. A manuscript is in revision.
3. Arctic Heat Open Science Project – We carried out an extensive airborne research and engineering R&D campaign in Alaska between June and September 2016, in collaboration with the Innovative Technologies for Arctic Exploration program and the Woods Hole Oceanographic Institution. We deployed six new generation air-launched autonomous floats in the Chukchi and Beaufort seas, and from them collected (so far) ~1,000 ocean profiles. Two floats are still under the sea-ice as of April 12, 2017. We collected flight-level weather and radiometry data over 6,000 miles of survey track. Near real-time data were relayed to the National Weather Service – Alaska Sea Ice Program, and to the NOAA Earth Systems Research Laboratory for ocean reanalysis test assimilation. A paper is being submitted to the Bulletin of the American Meteorological Society, and initial results presented at the American Meteorological Society annual meeting in January (*pmel.noaa.gov/arctic-heat/*).
4. Yang led the investigation of the impacts of model physics and initial sea ice thickness on seasonal forecasts of surface energy budget and air temperature in the Arctic during summer based on CFSv2 simulations. Over the Chukchi/Bering seas, the model physics modification reduced the seasonal forecast bias in surface air temperature by 24%. However, the use of initial Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS) sea ice thickness alone worsened the surface air temperature predictions. The experiment with physics modifications and initial PIOMAS sea ice thickness achieves the best surface air temperature improvement. A manuscript was published in *Monthly Weather Review*.
5. Wood continued his leadership role in the joint imaging programs at the U.S. National Archives, the New Bedford Whaling Museum, and other regional museums and libraries including the Nantucket Historical Association, Providence Public Library, Martha's Vineyard Museum, and Mystic Seaport Museum. New versions of Old Weather were developed and deployed online in December 2016. We have recovered 1.35 million new-to-science weather and ocean observations, and these have been integrated into ICOADS Deck 710.
6. Wang continued to serve as USCLIVAR Predictability, Predictions, and Applications Interface (PPAI) panel member and Arctic Mid-Latitude working group member. She was invited to participate the PPAI panel meeting (Washington DC, July 26-28, 2016), and the Arctic Mid-Latitude workshop (Georgetown University, Washington DC, February 1-3, 2017).
7. Wang is the lead convener for the session on Arctic Mid-Latitude linkage study at the Asia Oceania Geosciences Society meeting, August 1-5, 2016 in Beijing, China. She is also a member of the organizing committee of the 4th Santa Fe Climate Conference (Santa Fe NM, February 6-10, 2017).

ENVIRONMENTAL CHEMISTRY

ATMOSPHERIC CHEMISTRY – AEROSOL PROGRAM

PI
Tim Bates – UW Joint Institute for the Study of the Atmosphere and Ocean

OTHER UW PERSONNEL
James Johnson and Lucia Upchurch – Joint Institute for the Study of the Atmosphere and Ocean

Task II

NOAA SPONSOR
David Fahey – Earth System Research Lab/Chemical Sciences Division

OTHER NOAA PERSONNEL
Patricia Quinn and Derek Coffman – Pacific Marine Environmental Laboratory

NOAA GOALS
Climate Adaptation and Mitigation
Weather-Ready Nation

DESCRIPTION
The Atmospheric Chemistry-Aerosol Program is designed to quantify the spatial and temporal distribution of natural and anthropogenic atmospheric aerosol particles, and to determine the physical, meteorological, and biogeochemical processes controlling their formation, evolution, and properties.

OBJECTIVES
1. Determine the factors controlling the flux of sea spray aerosol to the atmosphere.
2. Develop an unmanned aerial systems (UAS) that can be deployed and recovered on a ship capable of carrying a 15-pound aerosol payload.

ACCOMPLISHMENTS
We participated in the second North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) cruise aboard the R/V *Atlantis* in May 2016. Sea spray aerosol (SSA), consisting of inorganic sea salt and organic matter, is thought to be a major contributor to the cloud condensation nuclei (CCN) population in the marine boundary layer. Our goal was to generate nascent SSA with the PMEL/JISAO Sea Sweep, to measure the physical, chemical, optical, and cloud nucleating properties of these SSA, to compare these measurements to measurements of ambient atmospheric aerosols, and to ultimately assess the contribution of SSA to the CCN population in the marine boundary layer. Sea Sweep was deployed at five stations along the cruise track. Near continuous ambient aerosol and gas sampling was conducted between Sea Sweep stations. Thirty-eight impactor samples were collected during the cruise. Preliminary results show that the CCN activity of SSA was roughly half that of NaCl, as a result of the organic component in the sub 180 nm aerosol.

We participated in a cruise aboard the R/V *Sette* out of Hawaii in June 2016 to test the Latitude Engineering HQ-20 UAS. We demonstrated the UAS's ability to take off using a quad rotor, switch to horizontal fixed wing flight, and return to the ship, switch to quad rotor flight and land back on the deck. We are now pursuing a larger version of this aircraft (HQ-55) for flights with our aerosol payload.

CHLOROFLUOROCARBON TRACER PROGRAM

PI
Rolf Sonnerup – UW Joint Institute for the Study of the Atmosphere and Ocean

OTHER UW PERSONNEL
Bonnie Chang – Joint Institute for the Study of the Atmosphere and Ocean

TASK II

NOAA SPONSOR
John Bullister – Pacific Marine Environmental Laboratory

OTHER NOAA PERSONNEL
David Wisegarver – Pacific Marine Environmental Laboratory

NOAA GOALS
Climate Adaptation and Mitigation

DESCRIPTION
The concentrations of chlorofluorocarbons (CFCs), along with a number of other anthropogenic compounds like CO_2, increased significantly in the global atmosphere during the past century. Oceanic CFC concentrations can be modeled as functions of location and time, and their sea surface histories are well understood. Studies of the entry of CFCs from the atmosphere into the surface ocean, and the subsequent transport of these compounds into the ocean interior provides a unique description of the time-integrated oceanic circulation and uptake of anthropogenic CO_2 and heat. These tracer data can be used to estimate the rates and pathways of ocean circulation and mixing processes, and as a means of testing and evaluating numerical models of ocean circulation. The development and testing of such models is critical for understanding the present state of the ocean-atmosphere system in quantifying the role of the oceans in the uptake of climatically important trace gases such as CO_2, and improving predictions of climate change for the upcoming century. Finally, the tracer data themselves have made important contributions to data-based estimates of oceanic uptake of anthropogenic CO_2, decadal ventilation timescales, changes in ventilation, and ocean biological cycling rates.

Our group has pioneered efficient methods for measuring sulfur hexafluoride (SF_6) in the ocean interior (Bullister and Wisegarver, 2008), and the use of simultaneous determinations of independent transient tracers in the ocean to estimate mixing in the ocean interior and its impacts on transient tracer ages (Sonnerup, 2001, Bullister et al., 2006, Sonnerup et al., 2007; 2008; 2013). The simultaneous use of two transient tracers to account for the effects of mixing provides improved accuracy in estimating ocean CO_2 uptake and ocean acidification from CFCs. In addition, the availability of concurrent CFC and SF_6 measurements now makes it possible to estimate circulation rate changes from transient tracers, and provide carbon remineralization rates in the ocean interior that can be used as benchmarks to evaluate carbon export rates from overlying surface waters. A further refinement to our measurement techniques also allows for precise measurements of dissolved nitrous oxide (N_2O) in seawater. Because N_2O plays an important role in the marine nitrogen cycle, this affords an opportunity to use the tracer and N_2O measurements in combination to estimate key rates of denitrification in the ocean.

PROJECT GOALS
1. To document the transient invasion of CFCs and other tracers (including SF_6) into the thermocline and deep waters of the world ocean, by means of repeat long-line hydrographic sections and at time-series

stations, and to improve methods for using CFC observations to estimate the ventilation rate of water masses in the ocean.

2. To use information on the rates and pathways of the invasion of these compounds in the ocean to improve estimates of the rate of uptake of other gases, including anthropogenic carbon dioxide in the ocean, and the rates of a variety of important biogeochemical processes.
3. To incorporate CFCs and other tracers in large-scale ocean circulation models, and to evaluate the ability of these models to simulate observed tracer distributions in the ocean. Such tests are essential for detecting problems with and improving the models.
4. To develop a method for measuring full sections of N_2O in the oceans. We plan to use these observations, together with the CFCs/SF_6, to quantify removal rates of fixed nitrogen from the oceans.

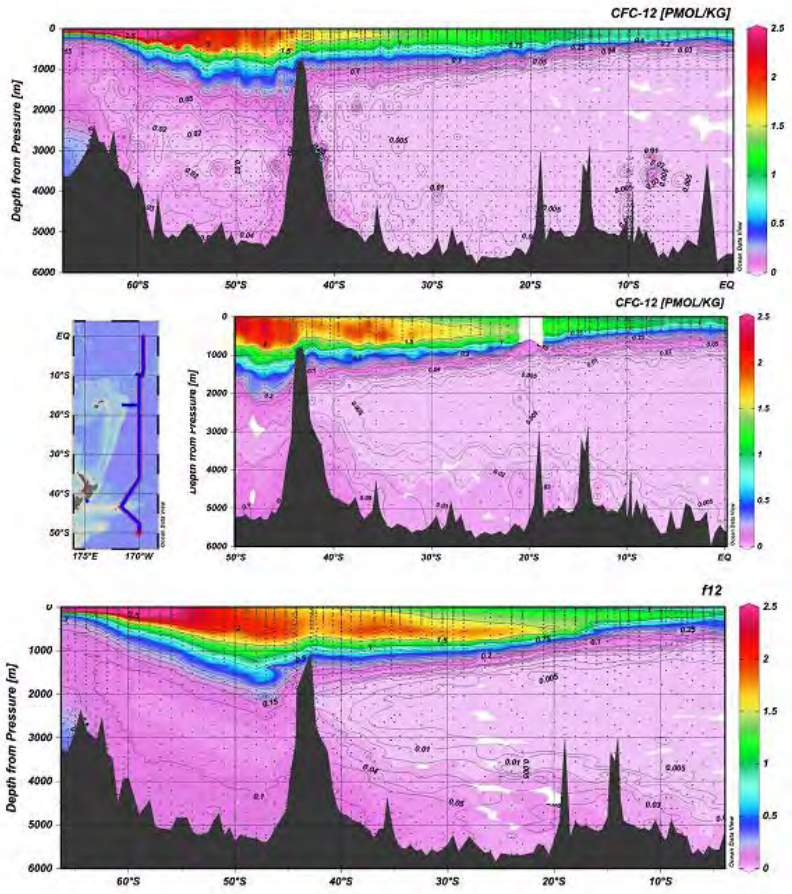


Figure 1. The depth distributions of CFC-12 measured along the P15S line (~170ºW; map insert) in the South Pacific Ocean in (top) 1996, (middle) 2009, and (bottom) 2015.

OBJECTIVES

1. Quantifying oceanographic ventilation processes through collection and analysis of CFC, SF_6, and hydrographic data.
2. Using CFC and SF_6 observations to improve estimates of the uptake of anthropogenic carbon dioxide in the ocean.
3. Using CFC and SF_6 observations to quantify oxygen utilization rates in the ocean interior.
4. Using combined CFC and SF_6 observations as a means of testing and evaluating large-scale numerical models of the ocean.
5. Using CFC and SF_6 observations for quantifying the temporal evolution of tracer ages and correcting for tracer age drift due to mixing processes.
6. Participating on the oceanographic expeditions P18 and P15S as part of the global CLIVAR/GO-SHIP Repeat Hydrography Program.
7. Quantifying regional oceanic denitrification rates via dissolved nutrients, N_2O and CFC/SF_6 observations.
8. Identifying dominant biological metabolic pathways controlling the distribution of marine dissolved N_2O.

ACCOMPLISHMENTS

1. Finalized the chromatographic setup on the seagoing PMEL CFC lab to concurrently analyze four CFCs,

SF_6, and N_2O to good precision on GO-SHIP cruises. Prepared the NOAA CFC lab for a long deployment in the South Pacific Ocean.

2. Completed two long meridional CFC/SF_6/N_2O analyses in the South Pacific Ocean: The P15S line along 170°E in May/June 2016, and the P18 line along 110/103°W in November 2016 through January 2017. JISAO's Bonnie Chang was lead analyst on both of these lines. PI Rolf Sonnerup served as deckhand on P15S, and was "promoted" to chief scientist on the P18 line.
3. Completed a model of the invasion of CFCs into the southwest Pacific Ocean as an invited contribution to Annual Reviews of Marine Science.
4. Drafted a manuscript on ventilation timescales, oxygen, and fixed nitrogen consumption rates in the eastern tropical South Pacific based on a dataset collected in 2013. The manuscript is nearly complete and awaiting co-authors' review.
5. Incorporated additional (new) datasets into a basin-scale preindustrial and contemporary air-sea fluxes in the Pacific Basin based on contemporary 13C measurements and reconstructions from ocean general circulation models (Quay et al., *Global Biogeochemical Cycles*).

RESEARCH HIGHLIGHT

The deep western boundary current (DWBC) flowing northward in the southwest Pacific Basin and through Samoan Passage (SP) is the major source of waters ventilating the entire deep central and North Pacific Ocean basins. In fact, over half of Antarctic Bottom Water (AABW) enters the subtropical oceans via northward transport just east of New Zealand. In 2016, we occupied the P15 section along 170°E in the South Pacific Ocean to document further invasion of the anthropogenic transient into the abyssal Pacific Ocean.

CFCs along P15 have been easily measurable at the sea floor since the 1990s. The CFCs, because of their high signal-to-noise ratio, clearly delineate the pathways of the ventilated component of the deep and bottom waters towards and through the SP at 9°S. The P15S sections repeated in time capture the northward penetration of CFCs from the Southern Ocean to ~ 9ºS in 1996, and to the equator in 2009. The SP CFC signal, only a few hundred meters thick in 1996, was ~800m thick in 2009, and CFCs were detectable over the bottom 1300m in 2015.

We related these CFC observations to the transport of other anthropogenic perturbations, such as CO_2 and heat, in the southwest Pacific DWBC using a 1.5 dimensional DWBC model. The temporal evolution of CFCs at DWBC crossings indicate an anthropogenic pCO_2 increase at the SP of 2.12 ppm in 2009. Using the dissolved inorganic carbon (DIC) and alkalinity measured in the SP during 2009 translates to an anthropogenic DIC increase of ~0.55 mmoles kg^{-1}. These anthropogenic CO_2 levels would not be detectable using current coulometric techniques (precision = ± 2 mmoles kg^{-1}), but are easily detectable using the CFCs. Assuming a mean SP transport from current meters and integrating over time indicates a total of 0.1 Pg anthropogenic carbon has passed through the SP by 2009, 20% of which transited the SP before 1900. Although this is a small number, this anthropogenic carbon transport will increase, and represents CO_2 sequestered on centennial and longer timescales.

MILESTONES

2016 marked the retirement of David Wisegarver, an honest and kindly man whose conscientious and tireless contributions to our program will be sorely missed.

MARINE CARBON PROGRAM

PI
Adrienne Sutton – UW Joint Institute for the Study of the Atmosphere and Ocean

OTHER UW PERSONNEL
Brendan Carter, Julian Herndon, Sylvia Musielewicz, Morgan Langis, John Osborne, Remy Okazaki, Sonya Ruth Newell, Colin Dietrich, Andrew Collins, Sophie Chu, and Samantha Siedlecki – Joint Institute for the Study of the Atmosphere and Ocean

TASK II

NOAA SPONSOR
Richard Feely – Pacific Marine Environmental Laboratory

OTHER NOAA PERSONNEL
Christopher Sabine, Simone Alin, Dana Greeley, Cathy Cosca, Francisco Fuenmayor, Dave Wisegarver, Stacy Jones, and Randy Bott – Pacific Marine Environmental Laboratory

NOAA GOALS
Climate Adaptation and Mitigation
Healthy Oceans
Resilient Coastal Communities and Economies

DESCRIPTION
The Marine Carbon Program provides a mechanism for research collaboration between Pacific Marine Environmental Laboratory (PMEL) scientists, JISAO scientists, and other University of Washington staff with common interests in the marine carbon cycle and its interactions with atmospheric carbon dioxide (CO_2) and climate. The program focuses on multidisciplinary research involving atmosphere-ocean CO_2 exchange fluxes, water column CO_2 distributions and transport, data interpretation and modeling, and ocean acidification. Special emphasis will be placed on the continuing effort to enhance our understanding of the role of the ocean in sequestering the increasing burden of anthropogenic CO_2 in the atmosphere, and the changes that are occurring due to ocean acidification. Project goals include: 1) determining the air-sea exchange of CO_2 from measurements collected on research ships, volunteers observing ships, and

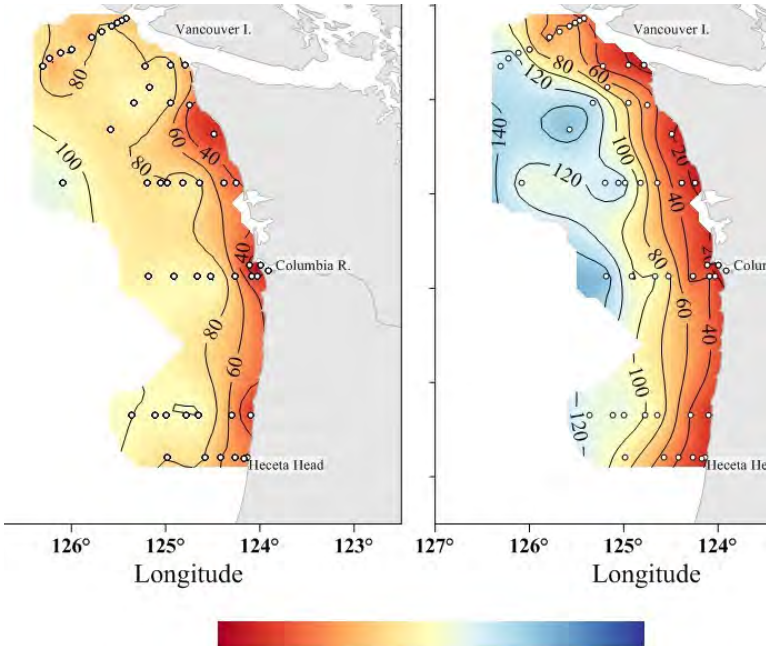


Figure 1. J-SCOPE model comparison for the depth where Ωarag = 1. (left) Model forecast initialized in January and (right) observations from the WCOA 2016 cruise in May of 2016.

moorings; 2) determining the distribution and transport of CO_2 into the ocean interior from measurements collected onboard NOAA and University-National Oceanographic Laboratory System research ships; and, 3) determining the extent of the chemical changes that are occurring in the oceans as a direct result of ocean acidification.

OBJECTIVES

1. Perform a variety of essential functions and provide equipment for analyses on the Pacific Ocean (P18) cruise and the West Coast Ocean Acidification (WCOA) cruise: For the 2016/2017 P18 GO-SHIP Repeat Hydrography cruise, the Carbon Group supplied a chief scientist, carbon analysts, and the data manager. The carbon group also led the WCOA cruise in 2016, providing all three chief scientists, two total titration seawater alkalinity analysts, and one total dissolved inorganic carbon analyst.
2. Service 36 CO_2 and ocean acidification moorings: In order to maintain sustained time series, the moored CO_2 systems and other sensors need to be swapped out with new systems at least once per year. The schedules for servicing are different for each system.
3. Perform required maintenance on underway CO_2 systems: We maintain four underway CO_2 systems that require regular servicing.
4. Collect and analyze discrete samples from the Puget Sound in partnership with the Washington Ocean Acidification Center (WOAC). We have continued working with a number of our colleagues in the Pacific Northwest to collect and analyze discrete carbon samples and deploy autonomous sensors in shellfish hatcheries.

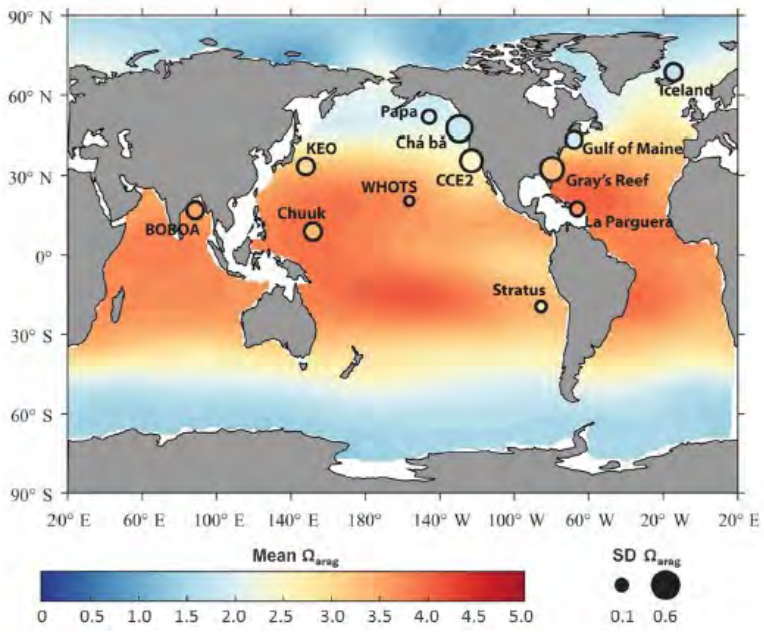


Figure 2. Results from a CO2 and ocean acidification mooring data synthesis: symbol color is annual surface seawater mean aragonite saturation state and symbol size is 1 standard deviation (SD) of the annual mean. From Sutton et al., 2016.

5. Add additional carbon system variables to regional seasonal forecast system (J-SCOPE), utilize that system to provide seasonal ocean acidification (OA) forecasts, and begin development of OA indices for shellfish and crabs in the region.
6. Prepare for the P06 and I07 cruises in May 2017 and early 2018. PMEL and JISAO scientists are serving on these cruises as technicians and analysts.

ACCOMPLISHMENTS

1. Both the P18 and WCOA cruises completed their primary data collection objectives and data quality control (QC) is on schedule: Final dissolved inorganic carbon (DIC) data processing for the 2015 GO-SHIP Repeat Hydrography Section P16N is now complete. Preliminarily-QC'd DIC has been submitted for GO-SHIP Repeat Hydrography Section P18 in 2016/2017. All data have been submitted to the Carbon Dioxide Information Analysis Center.
2. Maintained four underway CO_2 systems.

3. Deployed, maintained, and processed data from 36 moored CO_2 systems.
4. We have continued analyzing discrete samples collected on a number of cruises conducted with our collaborators including samples collected in partnership with WOAC; sampling the Newport Hydrographic Line with Oregon State University and NOAA/National Marine Fisheries Service colleagues based in Oregon; collecting and analyzing samples during mooring maintenance cruises with our colleagues at NOAA's Olympic Coast Marine National Sanctuary; and samples from ocean acidification surveys conducted by scientists at NOAA's Pacific Islands Fisheries Science Center around many of the remote island chains in the Pacific Ocean.

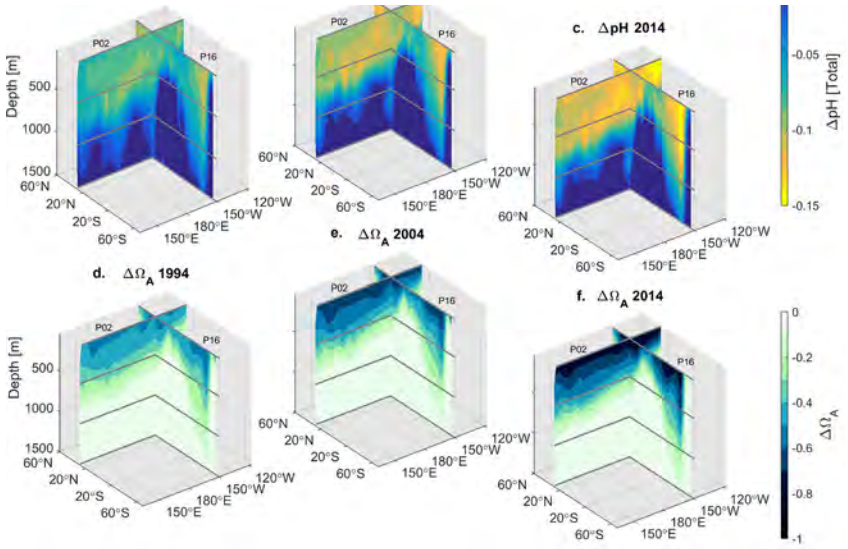
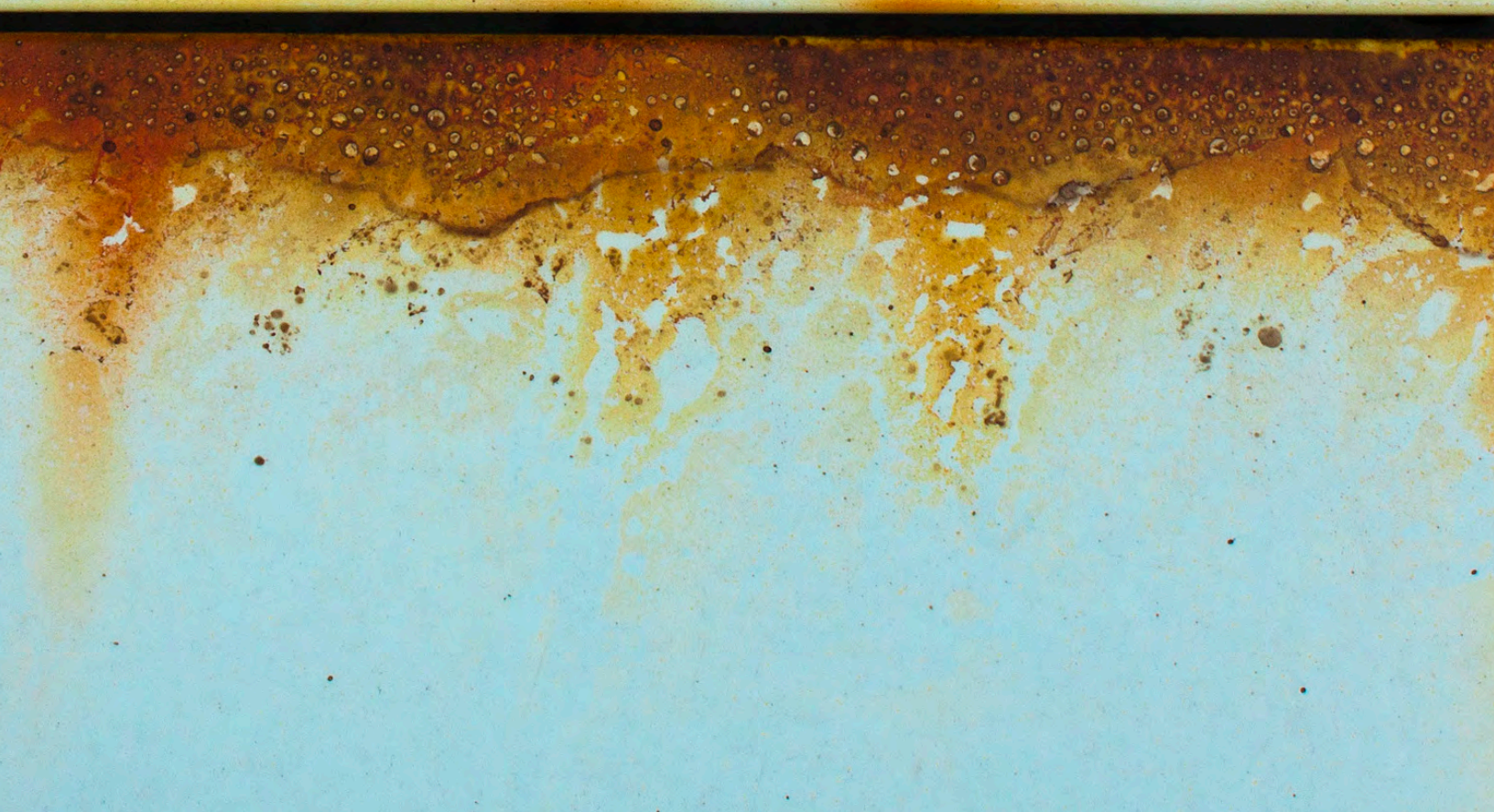


Figure 3. Ocean acidification impacts of cumulative anthropogenic carbon storage along GO-SHIP Repeat Hydrography sections P02 (lower left of each panel to upper right) and P16 (lower right of each panel to upper left) on pH (a. b. and c.) and the saturation state of aragonite (d. e. and f.). From Carter et al., 2017.

5. We have successfully added the carbon system variables to the regional forecast system, J-SCOPE and experimented with past forecasts of 2013, as well as 2016 forecasts. The 2016 results were made available on the web. We have assembled a climatology from 2009-2014 and can now forecast anomalies from those conditions. Some initial results of those anomalies are included below. In addition, we published a paper to Nature's *Scientific Reports* for J-SCOPE including the prior method relying on the algorithm for seasonal forecasts of OA (Siedlecki et al., 2016).
6. Analyzed data from GO-SHIP Repeat Hydrography sections P02 and P16 to quantify anthropogenic contributions to DIC and ocean acidification (Carter et al. 2017, Figure 3).
7. Completed a study of the anthropogenic carbon dioxide distributions along the West Coast of North America (Feely et al., 2016).
8. Completed a study using global circulation model output to determine when total alkalinity measured by repeat hydrography may first reveal a global-scale response of marine calcifiers to ocean acidification (Carter et al., 2016a).
9. Develop algorithms for estimating total alkalinity from salinity in Washington coastal waters (Fassbender et al., 2017).

MARINE ECOSYSTEMS



ALASKA FISHERIES SCIENCE CENTER INTERNSHIP OPPORTUNITIES

PI
Nicholas Bond – UW Joint Institute for the Study of the Atmosphere and Ocean

OTHER UW PERSONNEL
Jed Thompson – Joint Institute for the Study of the Atmosphere and Ocean

TASK II

NOAA SPONSOR
Douglas DeMaster – National Marine Fisheries Service

OTHER NOAA PERSONNEL
Jennifer Ferdinand – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans
Resilient Coastal Communities and Economies

DEFINITION
The education mission of the National Marine Fisheries Service (NMFS) includes providing students with research experiences and materials that support stewardship of living marine resources through science-based conservation and management and the promotion of healthy ecosystems.

Student internships have been a mainstay of the Alaska Fisheries Science Center's (AFSC) education mission to advance and promote environmental literacy and promote a diverse workforce in ocean sciences. The AFSC ran an independent internship program from 2003-2012, and this project partners the AFSC with JISAO to revitalize the AFSC's internship program, and expand on the successful internship program administered by JISAO.

OBJECTIVES
Through this project, three new internship positions were created in JISAO's successful summer internship program for undergraduates. These positions span a range of multi-disciplinary opportunities involving ongoing research programs at AFSC. A special focus of this project is to promote greater diversity in the ocean science workforce.

ACCOMPLISHMENTS
The interns for this project were placed with three different research programs based at AFSC. Sarah Brown of the University of Texas worked with the Polar Ecosystems Program on a project focused on estimating the abundance of polar bears and ice seals in the Alaskan Arctic. Madisyn Frandsen of Tarleton State University studied sudden transitions in marine populations in the Gulf of Alaska. Caroline Tribble of Virginia Polytechnic Institute examined the feeding behavior of beluga whales in Bristol Bay, Alaska. The students produced conference-quality posters that were presented at a forum at the end of the summer session.

CLIMATE IMPACTS ON THE DISPERSAL AND SURVIVORSHIP OF NORTHERN FUR SEAL PUPS

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NOAA GOALS
Healthy Oceans

DESCRIPTION
The main goal of this project is to investigate the influence of North Pacific Ocean climate on foraging, migration, and demography of northern fur seals (NFS; *Callorhinus ursinus*). To address this goal, this project principally uses satellite-telemetered movement and diving data from individual tagged seals, paired with remote or autonomous *in situ* sensing of the surface ocean and atmospheric reanalyses. Where applicable, this study also uses historical on-land observations of NFS and weather records in the Bering Sea and Aleutian Islands. These seals range widely throughout the subarctic during their winter migration, but breed and nurse their young during the summer on a few small islands around the North Pacific rim; the majority of animals do so on three islands in the Bering Sea, which is the primary focus of this project. Multiple studies within this project focus on both the summer and winter phases of the NFS annual cycle. The role of JISAO scientists is to provide analytical support to studies of the summer phase, and to both lead and support studies of the winter phase. Overall, this work seeks to understand how changes in the physical environment at a variety of scales affect behavior and ultimately reproduction of a wide-ranging top predator species; this may aid both the understanding of previous population trends in this species, and the projection of future trends under different climate and ecosystem scenarios. This work also aids NOAA management goals by addressing scientific needs outlined in the 2007 conservation plan for NFS.

OBJECTIVES
JISAO scientists contribute to the following objectives:

1. Linking environmental variables to animal tracks – identifying sources of oceanographic or atmospheric data. Downloading, processing, and interpolating these data to satellite-telemetered animal locations.
2. Basic quantitative ecology – quantifying animal movement, diving character, and habitat use. Statistical testing of bulk environmental properties experienced during migration and differences between subsets of the population.
3. Studies of climate influence on migratory movement – supporting the development and application of statistical methods for movement analyses. Hypothesis formulation, interpretation of results relevant to oceanography and climate, code development, and publishing.

ACCOMPLISHMENTS

1. Summer foraging of nursing adult females and the growth rates of their pups in the Bering Sea during four years of contrasting oceanography, atmospheric conditions, and prey abundance. Findings relevant to this JISAO project include:
   a. For adult female NFS foraging on the Bering Sea shelf, vertical and horizontal localization of foraging shows strong correlation with the abundance, distribution, and age-related behavior of Bering Sea walleye pollock.
   b. JISAO personnel have contributed to the analysis of historical maternal foraging trip duration data from the 1970s and 1980s. Combined with later observations, these data show that trip durations over the shelf negatively correlate with increasing pollock abundance; correspondingly, mid-season pup weights positively correlate with pollock abundance and increasing summer air temperature.
   c. For adult female NFS foraging in the Bering Sea basin, interannual variability appears related to the character of the eddy field. Eddy-rich years correspond to high occupancy of eddy features, reduced range of trips into the basin, and higher pup growth rates for adult females foraging in the basin.
   d. Differences in movement and diving following storms suggests that high winds alter the distribution or aggregation of NFS prey fields, though data are not yet available to determine the precise mechanism by which this occurs.
   e. This study focuses on variables that affect pup mass, which is a known factor in post-weaning survival and recruitment to breeding age; interannual variability in pup mass may therefore affect NFS demography. This study identifies pollock abundance, air temperature, the Bering Sea basin eddy field, and late-season storms as important factors that can affect pup mass during the summer season.
   f. A draft manuscript (J. Sterling et al., in preparation) based on results of this study is expected to be submitted this year.

2. Winter migration of northern fur seal pups.
   a. JISAO personnel have contributed to a study of the habitat use and environmental conditions experienced by pups during their first winter migration at sea in two separate years. Findings relevant to the goals of this JISAO project include:
      i. Most pups experience sea surface temperatures that are at or below their thermal neutral zone for long periods during their first four months at sea.
      ii. There is evidence that thermal conditions can vary significantly for pups leaving from different breeding islands in different years, due to the location of the islands in the Bering Sea shelf or basin domains. This may be a mechanism for differential mortality of pups by island and year.
      iii. Pups leaving from different islands within the Bering Sea migrated through waters exposed to similar levels of surface wind stress or number of windy days. This suggests that interannual atmospheric variability may affect pups from all islands equally. Wind stress affects upper ocean mixing and stratification; studies of adult NFS suggest a correlation between upper ocean stratification and prey depth (accessibility).
      iv. Pup rate of departure from the Bering Sea differed significantly by island and sex, with male pups staying longer and experiencing colder water than females. Rate of departure was significantly enhanced for pups experiencing strong northerly winds in their first 10 days at sea. This suggests a mechanism by which interannual variability in prevailing winds may hasten or delay the departure of newly-weaned pups from the Bering Sea.
      v. A draft manuscript (M.-A. Lea et al, in preparation) describing these and other findings is expected to be submitted for NOAA internal review by the end of May 2017.
   b. Pup movement and initial dispersal: drivers and variability.
      i. When considered relative to the wind direction, pup movements are on average downwind and to the right, as indicated by atmospheric reanalysis products. Deflection to the right is consistent with wind-forced surface currents.

ii. There is evidence for interannual variability in migratory pup movements in the first two months at sea. The majority of satellite-telemetered migratory pup movements were obtained in four winter migrations (1997-98, 2005-06, 2006-07, 2015-16). Pup positions were significantly farther east after two months in 1997-98 and 2015-16 than the remaining years.

iii. Sea level pressure patterns during the first two months at sea show stronger westerlies in the southern Bering Sea and northern North Pacific Ocean in 1997-98 and 2015-16, suggesting that surface winds accounted for the greater eastward displacement.

iv. JISAO scientists are collaborating with Marine Mammal Laboratory statistical ecologists to further investigate correlations between marine winds and NFS migratory movements. This includes supporting the development of a statistical method for analyzing correlations between winds, or other time-varying environmental parameters, and an animal's movement (D. Johnson et al., in preparation). This method will be used to analyze the effects of winds, ocean surface currents, and sea surface temperature on NFS migration, and differences in these effects by age and sex (N. Pelland et al., in preparation). Further analysis will seek to answer whether any effect due to the wind can account for observed differences in pup displacement over the four study years, and whether differences in dispersal are predicted for other years in which pup movements were not observed.

3. Winter migration of juvenile (1- and 2-year-old) NFS. JISAO personnel have also contributed to a study of the habitat use and environmental conditions experienced by juveniles during their winter migration, which serves as a companion study to that of pups described above. Findings relevant to this JISAO project include:
   a. Juveniles also exhibit differences by sex in the rate of exit from the Bering Sea, with juvenile males departing more slowly and experiencing colder sea surface temperatures during the first portion of their migration. Juvenile female habitat use and migratory trajectories show some characteristics similar to adult females; consistent with this, juvenile females also reach warmer southern waters more quickly than female pups.
   b. Juvenile diving depth and movement speed are greater than pups, but nearer to pups than adult females.
   c. Juvenile migratory departure timing is spread over a greater period, implying exposure to a greater range of seasonal environmental conditions than pups or adult females on initial departure. Juveniles also performed pre-migratory foraging trips; trips originating on the Pribilof Islands on the Bering Sea shelf were significantly longer in distance and duration than trips originating on Bogoslof Island (Bering Sea basin). This is consistent with differences in foraging trips of reproductive adult females between these two sites. Adult females, in contrast to juveniles, are constrained to provide for their pups; differences in trip character between sites in both reproductive and non-reproductive individuals suggest a difference in resource availability between the two sites.
   d. A manuscript communicating these and other findings (T. Zeppelin et al., manuscript in preparation) is expected to be submitted for NOAA internal review by the end of May 2017.
4. Results from these studies were included in three presentations at the January 2017 Alaska Marine Science Symposium (see Pelland et al., Sterling and Pelland, and Zeppelin et al. abstracts in (*nprb.org/assets/amss/images/uploads/files/AMSS2017_BookofAbstracts.pdf*).

ECOSYSTEMS AND FISHERIES-OCEANOGRAPHY COORDINATED INVESTIGATIONS (EcoFOCI)

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NOAA GOALS
Healthy Oceans
Resilient Coastal Communities and Economies

DESCRIPTION
EcoFOCI continued to maintain a biophysical mooring array on the eastern Bering Sea shelf, conduct hydrographic surveys, deploy satellite-tracked drifters, and supplement research efforts with new technologies to monitor the large marine ecosystems of Alaska. In 2016, dedicated surveys in the Bering Sea to study the progression of ocean heating and ecosystem response yielded surprising results; that not all warm stanzas in the Bering Sea are the same.

PROJECT OBJECTIVES
1. Monitoring of the oceanographic ecosystem through analysis and processing of data from mooring arrays, satellite-tracked drifters, and shipboard measurements – Biophysical moorings are maintained in the Gulf of Alaska and the Bering and Chukchi seas, providing critical information on the response of the environment to changes in climate. JISAO scientists contribute to: maintaining these moorings; expanding the instruments on moorings to measure ice keel depth, zooplankton abundance, nitrate, and oxygen; and introducing new technology to enable these moorings to report in real time.
2. Disseminating data through websites, presentations, publications, and workshops – JISAO scientists contribute to the maintenance of web pages, author and co-author numerous publications each year, and present their findings at a variety of regional, national, and international meetings.
3. Participating in cruises to examine the variability in physical and chemical oceanic processes that impact the North Pacific, Bering Sea, and U.S. Arctic ecosystems – JISAO scientists take a leading role in these studies. They participate on cruises as chief scientists, and are leaders in the measurements of nutrients, chlorophyll, and oxygen.

4. Projecting impacts of a changing climate – JISAO scientists are involved in an effort to apply simulations of future climate (Intergovernmental Panel on Climate Change 4th Assessment models) to issues related to marine ecosystems. The output from these models is being used to force local dynamical models of the North Pacific Ocean and Bering Sea, and to make projections based on empirical methods.
5. Making data and analysis results available to Fishery Management Councils and other resource managers.

ACCOMPLISHMENTS

1. EcoFOCI continues to maintain observational infrastructure such as the biophysical mooring array on the eastern Bering Sea shelf (mooring stations M2, M4, M5, and M8), conduct hydrographic surveys, and deploy satellite-tracked drifters. 2016 marked the 22nd consecutive year of observations at the M2 mooring. EcoFOCI also continues the use of Argos drifters, research cruises, and most recently, autonomous vehicles to collect data in the large marine ecosystems of Alaska.

Figure 1. EcoFOCI scientists use the UW APL Robertson to field test a towed platform, Acrobat, a lightweight and versatile towed body oceanographic research platform for high-resolution surveys of biological, physical and chemical processes in ecosystems. This equipment was used in the Bering and Chukchi seas in 2016.

2. In 2016, EcoFOCI was present in the Gulf of Alaska, and the Eastern Bering and Chukchi Seas, including the U.S. Arctic. Eighty-six biophysical moorings were deployed and recovered and 484 key-stations were sampled with a CTD (conductivity, temperature and depth) over 11 research cruises totaling 200 days at sea.
3. Disseminating data through websites, presentations, publications, and workshops. In 2016, EcoFOCI Scientists prepared 45 Publications (26 published, 19 in progress). Scientists also participated in a variety of presentations and workshops including the Alaska Marine Science Symposium (January 2017).
4. EcoFOCI scientists attended a Gulf of Alaska Project Integrated Ecosystem Research Program (GOAIERP) synthesis workshop at the University of Washington Friday Harbor Laboratory February 13-17, 2017. Initial findings were reported in a *Deep Sea Research II* special issue in October 2016 which contained seven research articles coauthored by EcoFOCI scientists. The 5-year, multi-institution collaborative project, GOAIERP, concluded in 2014. It was funded by the North Pacific Research Board (NPRB), and examined the physical and biological mechanisms that determine the survival of juvenile groundfishes in the Gulf of Alaska. EcoFOCI scientists played major roles in the effort to determine how physical transport mechanisms influence lower trophic levels, and subsequently the survival and recruitment of five species of groundfish (walleye pollock, Pacific cod, arrowtooth flounder, sablefish, and Pacific Ocean perch).
5. The fourth and final special issue in *Deep Sea Research II* was published in December 2016 (Volume 134): Understanding Ecosystem Processes in the Eastern Bering Sea IV is the fourth and final special

Bering Sea Project issue of *Deep-Sea Research Part II*. It builds upon work presented in the first three special issues, focusing on synthesis of information across broader ranges of disciplines, and presents information on some of the extensive model-based research directions within the project. Since the final full-project meeting in early 2014, Bering Sea Project participants have focused on discussion, collaboration, data analysis, and publications, culminating in nearly 200 peer-reviewed Bering Sea Project papers to date published across a broad spectrum of journals. This growing publication library includes 76 papers in the previous three Bering Sea Project special issues. The Bering Sea Project brought together nearly 100 principal investigators, leading a sprawling team of several hundred postdocs, graduate students, technicians, ship officers, crew, and many others. Over its 7-year course of activity (2007 to 2014, with primary field work taking place from 2008 to 2010), the Bering Sea Project has provided new insights into the functioning of the Eastern Bering Sea ecosystem, particularly in the north-central region where data sets and temporal coverage previously had been sparse.

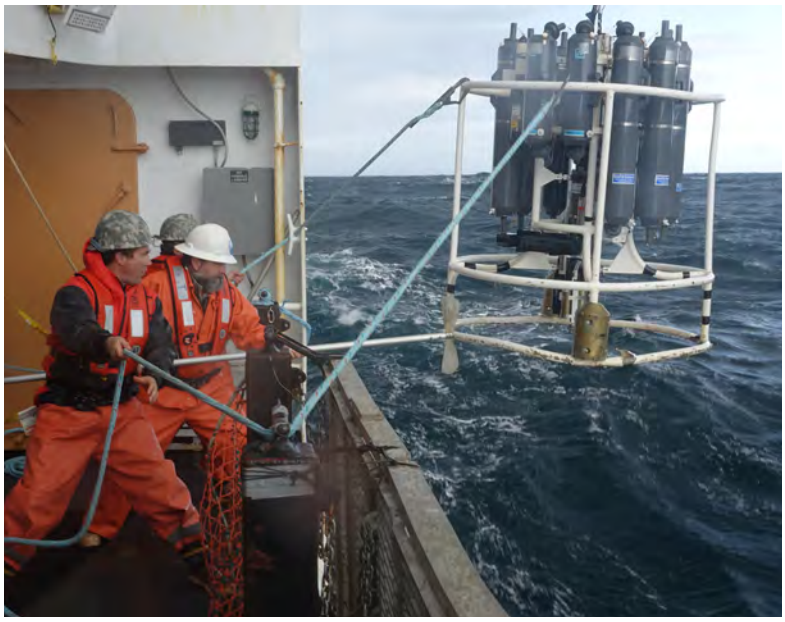

Figure 2. Crew of the NOAA Oscar Dyson retrieve a CTD in the Eastern Bering Sea during an EcoFOCI research cruise in 2016. A CTD is an oceanographic instrument that captures the conductivity, temperature and depth as it is lowered and raised at set locations into the water alongside the vessel. The bottles capture water samples at various depths that are used for further analysis.

6. EcoFOCI scientists attended the first Principal Investigator meeting for NPRB's 5-year Arctic Integrated Ecosystem Research Program (Arctic IERP) in Anchorage, Alaska on June 20-23, 2016. The goals of the meeting were to introduce the funded projects, discuss how these projects are connected, identify any gaps, come to a consensus on the overarching hypothesis for the integrated research, introduce PIs from other Arctic projects that may integrate with the Arctic IERP research, and discuss the framework for integration, data management, and communication/outreach during the project. This Arctic IERP will study the northern Bering and Chukchi seas during spring through fall to better understand how changes in physical environmental drivers influence the structure and function of the biological system and access to subsistence resources. NPRB launched a request for proposals for an integrated Arctic Program near the end of 2015. Decisions were announced in May that four projects with 27 researchers from 11 institutions had been awarded funds totaling $7.75 million. EcoFOCI scientists will lead the Oceanography and Lower Trophic Level Productivity portion of the program.

7. The Synthesis of Arctic Research (SOAR) project is a 6-year Bureau of Ocean Energy Management (BOEM) supported effort to bring together a multidisciplinary group of Arctic scientists and residents to explore and integrate information from completed and ongoing marine research in the Pacific Arctic. The first phase of SOAR culminated in a special issue in Progress in Oceanography dedicated to an ecosystem-based understanding of the "new state" of the Pacific Arctic. Published on July 13, 2015, the special issue includes 17 papers co-authored by more than 100 scientists and local experts on topics

ranging from physics to marine mammals. Authors from JISAO/PMEL contributed to several papers. The synthesis covers three themes, with five papers focusing on observations and models of sea ice loss and effects on primary production; five papers focused on the response of mid-level trophic species to the "new state" of the Arctic; and six papers focused on the responses of upper trophic level species. The second phase of SOAR (also supported by BOEM) is currently in progress, with a second SOAR special issue building upon the new understanding of the current state of the Pacific Arctic marine ecosystem underway and expected for publication in summer 2017. This second SOAR special issue will be published in the journal *Deep-Sea Research Part II*, and is expected to include over a dozen papers, again co-authored by a wide range of specialists and local experts.

Figure 3. How do moorings stay in the same place? Railroad wheels! EcoFOCI maintains a biophysical mooring array in the Bering and Chukchi seas, and each year during deployment, these anchors are used to keep the moorings in place. These are the railroad wheels just after delivery at the NOAA western regional campus.

8. The Arctic Whale Ecology Study (ARCWEST) completed its final field year in 2016. EcoFOCI conducted physical and biological oceanographic sampling and data collection to support the project's objective to further understand the transport and advection of krill and nutrients from the northern Bering Sea through the Bering Strait and to the Barrow Canyon area. Mooring sites from the Chukchi Acoustics, Oceanography, and Zooplankton (CHAOZ) program are also used for ARCWEST. EcoFOCI performed CTD hydrography, and maintained three near-shore biophysical moorings as part of this project (C1, C4, and C5), which recorded a time series of water currents, temperature, salinity, ice draft, chlorophyll fluorescence, and photosynthetically active radiation. The moorings were recovered in 2015. Two of these moorings (C1 and C4) were deployed and remain in the water.

9. The CHAOZ-X BOEM-supported program was an extension of the CHAOZ program focusing on the Hanna Shoal area of the northeast Chukchi Sea, and concludes reporting in 2016. The focus of this study is to determine the circulation of water around the Hanna Shoal area, the source of this water (Chukchi Shelf or Arctic Basin) and its eventual destination, and the abundance of large planktonic prey at the shoal. EcoFOCI performed hydrographic sampling and maintained five moorings as part of this project (C2, C6, C7, C8, and C9) which were recovered in 2015. Two of these moorings (C2 and C9) were deployed and remain in the water.

10. EcoFOCI continues work with projecting impacts of climate change including sea ice predictability in the U.S. Arctic. EcoFOCI scientists are active participants of the Sea Ice Prediction Network leadership team, and helped to organize the 3rd Polar Prediction Workshop held in Lamont-Doherty Earth Observatory, Palisades, New York May 4-6, 2016.

11. EcoFOCI scientists continue to make data and analysis results available to its scientists, collaborators, the larger research community, fishery management councils, and the general public. EcoFOCI scientists along with PMEL IT/development support are active in an on-going effort towards modernizing the EcoFOCI data format and infrastructure. A successful small-scale prototype, accomplished in 2015-16, converted subsets of profile data into a more standard and ISO-compliant NetCDF data format that includes compliant metadata. These updated templates make EcoFOCI data more functional for external data users, and with dominant software tools. The effort will incrementally direct the long-running volumes of data into a more publicly-accessible interface. Work continues in this transition, with enhancement of the initial set of ISO-compliant variables, attributes, and metadata.
12. EcoFOCI scientists also continue to build and enhance a database-driven in-house information portal with access to past instrument, cruise, and station information, and heavily used field-planning tools that have become imperative to the success of our field programs. Additionally, work will continue on streamlining structure and population of our internal data repository and archive to include various phases of data, data processing, and support documents.
13. EcoFOCI worked in partnership with another JISAO program, Innovative Technology for Arctic Exploration in 2016. EcoFOCI scientists provided oceanographic data analysis and expertise for technologies used including the Saildrone, radiometer, ALAMO float, and PRAWLER.
14. EcoFOCI continues the past decade of partnership with the Arctic Climate Change program at PMEL, focusing on atmosphere-oceanography-sea ice relationships in the Arctic region, including the sub-Arctic Chukchi, Beaufort, and Bering seas. In collaboration with Jim Overland of NOAA/PMEL and others, they lead ongoing research on the past, present, and future climate of the Arctic. This work represents an important foundation for the Arctic Report Card.
15. EcoFOCI is again collaborating with the International Pacific Halibut Commission (IPHC) in processing and managing hydrographic profile data acquired during their annual Stock Assessment Survey. The annual survey provides catch information and biological data independent of the commercial fishery, from pre-defined station grids that extend from the Bering Sea and Aleutian Islands, along the Gulf of Alaska shelf and along the U.S. West Coast to northern California. The IPHC-JISAO-EcoFOCI collaboration began in 2009, and comprises an annual influx of ~1,200 profile data files that are processed and analyzed, then made available to the public. These data are a complement to data-collection areas and research of the EcoFOCI program.
16. EcoFOCI continues to work with the main authors of the Ecosystem Considerations Chapter of the Stock Assessment and Fishery Evaluation reports to provide ecosystem indicators for the Bering Sea. The Ecosystem Considerations Report is produced annually to compile and summarize information about the Alaska Marine Ecosystem for the North Pacific Fisheries Management Council, the scientific community, and the public. The report includes ecosystem report cards, ecosystem assessments, contributions with updated status and trend indicators, and ecosystem-based management indicators and information for the Bering Sea, Aleutian Islands, the Gulf of Alaska, and Arctic ecosystems.
17. EcoFOCI scientists also continue a long-time commitment to outreach by participating in NOAA campus tours, NOAA Science Camp, Seattle Aquarium Discover Science Weekend, and Washington Sea Grant's Orca Bowl, among other opportunities.

SHORT-TERM FORECASTING OF PACIFIC HAKE DISTRIBUTION IN THE CALIFORNIA CURRENT ECOSYSTEM

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NOAA GOALS
Healthy Oceans

DESCRIPTION
This project entails the development of a system to provide short-term (weekly to monthly) forecasts of Pacific hake (*Merluccius productus*) distributions based on oceanographic conditions to improve the design of acoustic surveys and to support fisheries management in the California Current Ecosystem (CCE). It features the use of JISAO's Seasonal Coastal Ocean Prediction of the Ecosystem (J-SCOPE). J-SCOPE has been developed for the northern CCE along the West Coast of North America to provide projections of physical, chemical, and biological ocean properties on 6-month time horizons. These forecasts are derived using output from the Climate Forecast System (CFS) model dynamically downscaled with the Regional Ocean Modeling System (ROMS).

OBJECTIVES
1. Model the relationships between hake distributions and oceanographic variables in the CCE by age class (age-1+) and/or life stage (juvenile, subadult, adult);
2. Assess the skill of J-SCOPE to predict ocean variables likely important for hake, such as sea surface temperatures, mid-water temperatures, salinity, poleward flowing subsurface California undercurrent, and upwelling;
3. Force hake distribution models with seasonal lead-time forecasts of oceanographic variables produced by J-SCOPE to provide weekly to monthly forecasts of hake distribution; and
4. Assess skill of hake distribution forecasts by age class and month by comparing data from the hake acoustic survey to J-SCOPE forecasts.

ACCOMPLISHMENTS
A post-doctoral research associate, Michael Malick, was hired under the auspices of this program. He has been involved in the construction and evaluation of general additive models and their extensions – general additive mixed effects models (GAMMs). They are providing a way to account for non-linear relationships and threshold dynamics between response and explanatory covariates. More specifically, variable

coefficient GAMMs are being developed to model hake biomass as a function of environmental and spatial covariates. J-SCOPE ocean forecasts from January 2017 initial conditions have been produced; these results will be used to start making experimental hake forecasts in the spring of 2017.

EVALUATION OF GROUNDFISH ECOLOGICAL RESPONSE TO CURRENT FISHERIES MANAGEMENT SYSTEMS

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NOAA GOALS
Healthy Oceans

DESCRIPTION
The West Coast groundfish fishery has been through substantial changes over the last 25 years, driven by the low productivity of many of the target species (long-lived rockfish) and the overfished designation of several stocks. Rebuilding plans have required steep reductions in exploitation rates to around 1% per year, the closure of much of the productive fishing areas, and most recently a switch to managing the fishery to an Individual Fishing Quota (IFQ) system. IFQs involve allocating individual quota of both target and restricted species, requiring fishermen to keep a positive balance of both types of species in their accounts before fishing is initiated. To date, we have seen a dramatic decline in discard, and a very low ratio of catch to allowable catch, as well as shifts in fishing effort and the timing of the

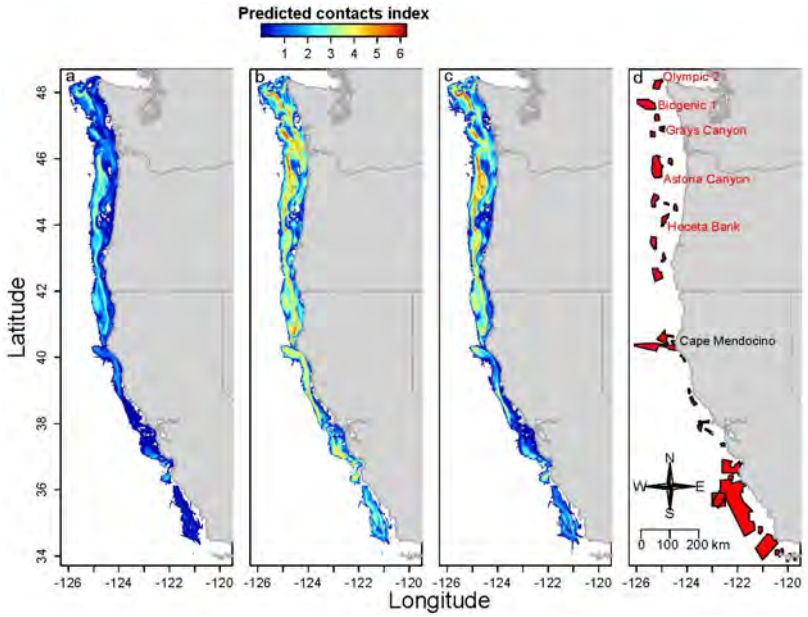

Figure 1. Maps of predicted groundfish bottom-trawl interactions with U.S. West Coast biogenic habitat summarized overall years (2002-2014) for a) stony corals, b) soft corals, and c) sponges, with d) a map of landmarks and areas closed to bottom-trawling highlighted in red (note that this does not show the boundaries of the coast-wide trawl Rockfish Conservation Area, which are dynamic). The index of predicted contacts is plotted on a log + 1 scale to ease visualization of large-scale patterns.

fishery. The postdoctoral scholar has access to fishery, observer, and survey data to compare and contrast characteristics of Pacific Coast groundfish species and communities before and after the implementation of the IFQ program.

OBJECTIVES

Analyze the available biological data (catches, discards, and spatial fishing patterns) to explore the consequences of changes in these data on fisheries management on the U.S. West Coast.

ACCOMPLISHMENTS

A wide array of projects are being explored, have been conducted, or are in preparation, as listed below.

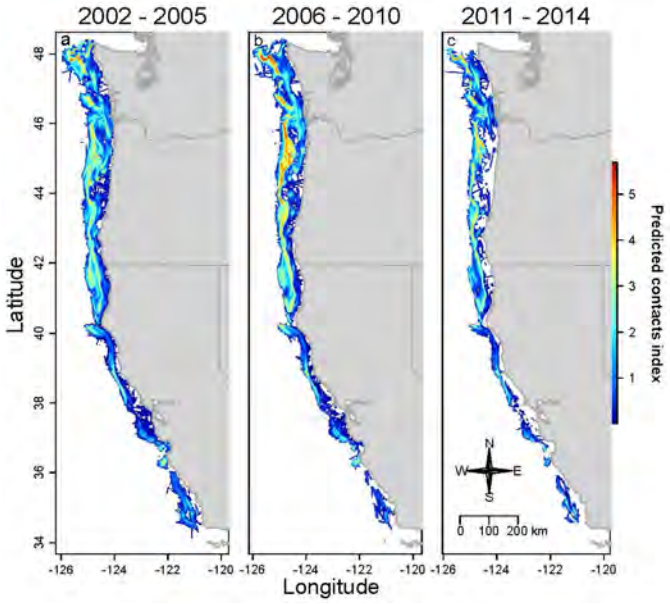

Figure 2. Maps of predicted groundfish bottom-trawl interactions with U.S. West Coast sponges summarized by management period. The index of predicted contacts is plotted on a log + 1 scale to ease visualization of large-scale patterns.

1. We are exploring the plausibility and utility of developing a framework to analyze population cycles in groundfishes from trawl survey data, in application to prioritizing species for incorporation of ecosystem effects in stock assessments.
2. We are planning a review and regional comparison of groundfish associations with biogenic habitats (e.g., corals, sponges) to reveal context-dependencies in the strength of such associations.
3. We are preparing and reviewing four species narratives for inclusion in a paper summarizing the results of the NOAA West Coast climate vulnerability assessments.
4. A web-based survey is being programmed to contrast people's perceptions of natural mortality and how this differs depending on the method used to obtain these estimates.
5. We are developing a modeling framework to assess the theoretical basis for assumptions in ecological risk assessments of fishery interactions with habitats, and tradeoffs between protection of habitat and fishery yield from bottom trawling.
6. Analyses have been conducted on correlations between genotypes, phenotypes, and life history parameters in rockfishes.
7. Analyses have been conducted on drivers of among-vessel variance in bycatch of biogenic habitat (e.g., corals and sponges) in the U.S. West Coast groundfish trawl fishery.
8. We have a manuscript submitted evaluating how environmental variation propagates through food webs in application to Pacific hake and forage fish predator-prey interactions.
9. A synthesis of the magnitude and extent of age truncation in fished populations was completed, and the manuscript is in review.
10. A manuscript in review looks at trends in space and time on the impact of groundfish trawling on biogenic habitat (e.g. corals and sponges) off the U.S. West Coast, and how these have been affected by IFQs, spatial closures, and vessel buybacks.
11. We had a paper published on the utility of incorporating habitat associations among biogenic habitat (e.g., corals and sponges) and fishes (Pacific rockfishes and thornyheads) for estimating trends in population biomass and spatial distribution on the U.S. West Coast. We are currently conducting analyses to reveal what ecological and fishery-dependent factors drive patterns in age truncation of fishes, and to test whether fishing alters recruitment variation.

NORTHWEST FISHERIES SCIENCE CENTER AND UNIVERSITY OF WASHINGTON UNDERGRADUATE INTERN PROGRAM

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Jessica Salvador – Center for Experiential Learning and Diversity
Nirupam Nigam – School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
Kathleen Jewett – Northwest Fisheries Science Center

OTHER NOAA PERSONNEL
Beth Sanderson and Jameal Samhouri – Northwest Fisheries Science Center

NOAA GOALS
Resilient Coastal Communities and Economies

DESCRIPTION
This project is an educational collaboration between Undergraduate Academic Affairs at the University of Washington and the Northwest Fisheries Science Center (NWFSC) to provide education and training to undergraduates interested in fisheries research. This project is designed to engage undergraduates from a range of scientific and other relevant disciplines in internships with scientists and leaders at NWFSC to develop their research interests and skills. These research experiences extend and enhance students' classroom learning at the UW. At the same time, it provides scientists at NWFSC opportunities to prepare promising students for careers in fisheries science research.

OBJECTIVES
Up to two internship positions are anticipated annually under this project for UW students to gain research experience with NWFSC's several research divisions. These academic year internships will also offer a summer quarter option, with varying numbers of hours. One of the internships will also include fieldwork and travel during the summer. Selected interns will commit between 10 and 19.5 hours per week during the academic year, and up to 40 hours per week during summer and interim periods to their research projects. The number of interns engaged in the program will depend upon the time commitment each intern is able to make to the experience. The type of research in the host lab – for instance, some research requires longer blocks of time and occasional field work – determines the total number of students involved each year. In addition to providing internships that give undergraduates experience in fisheries science research, the program also aims to provide other professional development for interns, such as learning how to network with other scientists, and how to present their projects in poster format at NWFSC and/or at the UW undergraduate research symposium. Anticipated outcomes include undergraduate interns moving on to graduate study in biological, marine, fisheries, or related science fields and/or developing career aspirations related to the learning and skills acquired during their internship experiences.

ACCOMPLISHMENTS
This year, one student has participated in the internship program. We are in the process of hiring a second intern who will be engaged in the project throughout the spring and summer terms. The interns participate

in networking activities and poster sessions at NWFSC; one of them presented their research results at the UW Undergraduate Research Symposium. This year's participant is listed below. We anticipate one additional intern to be hired this month.

Nirupam Nigam: Aquatic and Fishery Sciences and Biology

DISTRIBUTION AND APPLICATION OF A NEW GEOSTATISTICAL INDEX STANDARDIZATION AND HABITAT MODELING TOOL FOR STOCK ASSESSMENTS AND ESSENTIAL FISH HABITAT DESIGNATION IN ALASKA AND NORTHWEST ATLANTIC REGIONS

PI
Timothy Essington – UW School of Aquatic and Fishery Sciences

OTHER UW PERSONNEL
Jin Gao – School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
James Thorson – Fishery Resource Analysis and Monitoring

NOAA GOALS
Healthy Oceans

DESCRIPTION
We have successfully recruited and hired Jin Gao, who will be the chief analyst for this project. She has developed a set of analyses that will be used to test the performance of alternative methods for modeling geo-temporal data. She started her position January 1, 2016, so the project activities are in the ramp-up stage. Gao has already written the computer code for the three simpler analysis methods, and is working on finalizing the fourth more complex method, testing it with simulated data and then using actual data.

OBJECTIVES
1. Improve documentation for the SpatialDeltaGLMM package, including better encapsulation of functions for model fitting and visualization, and better examples of scripts.
2. Develop case-study applications of the SpatialDeltaGLMM package for Alaska Fisheries Science Center (AFSC) and Northeast Fisheries Science Center (NEFSC) stocks.
3. Demonstrate improvements resulting from the use of the geostatistical index standardization technique relative to prior methods used regionally and globally.

Recent research has shown the value of using spatial models to generate annual estimates of stock abundance from bottom trawl survey data for West Coast groundfishes. For example, Shelton et al. (2014) showed that spatial variation in density for darkblotched rockfish explained a substantial portion

of variation in catch rates, and Thorson et al. (2015) showed that spatial models improved precision for estimated indices using simulated data relative to a nonspatial model. Spatial models can incorporate measured habitat variables (e.g., bottom substrate type) or infer habitat from biological sampling (e.g., infer rocky substrate from the presence of rock-associated species), and these measured or inferred habitat variables are then incorporated into the stock assessment process when the estimated index of abundance is used in a stock assessment model. Spatial models have subsequently been approved for consideration in stock assessments by the Pacific Fishery Management Council Scientific and Statistical Committee for the 2015 assessment cycle.

However, bottom trawl data are routinely collected in many other National Marine Fisheries Service (NMFS) regions, including long-term data sets available for the Gulf of Alaska, the Bering Sea, and the Northwest Atlantic regions. This project therefore seeks to ease documentation, implementation, and exploration of spatial index standardization tools for NMFS regions outside the California Current. The project will improve documentation and examples for the publicly available R package SpatialDeltaGLMM, and will work with collaborators at the AFSC and NEFSC to explore applications of the tool for stock and habitat assessments in each region. In this way, the project will provide a proof-of-concept for sharing habitat-analysis methods between regions and centers.

ACCOMPLISHMENTS

We have improved documentation and example scripts, and have significantly encapsulated model functions to reduce complexity for first-time users of the geostatistical tool. We have also reposited documented Rmarkdown scripts that contain user-documentation and results on our publicly available website. Example species include Pacific cod in the Gulf of Alaska, walleye pollock in the Eastern Bering Sea, and haddock in the Northwest Atlantic regions. Results in the Bering Sea were already explored and/or used for northern and dusky rockfish assessments in the Gulf of Alaska in 2015 stock assessments.

Results for northern shrimp in the Gulf of Maine are currently being compared against results using a conventional design-based method (Cao et al., 2017). We have also completed a project estimating density-dependent range shift arising from the geostatistical index model with previous analysis for multiple regions worldwide, including in the Northeast Atlantic, Bering Sea, and Gulf of Alaska (Thorson et al., 2016).

Having accomplished the original project objectives, we are currently conducting two additional analyses:

1. We are exploring the performance of the multi-species VAST tool to spatially referenced fishery dependent log book data in the Eastern China Sea. We are comparing the results generated by VAST to reported landings by other surrounding countries that fish the same region. We are also exploring the entire CalCOFI dataset using VAST to identify species associations (cold, warm-water) and distributions over time.
2. In order to compare the predictions of the geostatistical index tool to the fully non-parametric time delay embedding method, we are using Gaussian process model to extend the conventional single time series method to accommodate spatial time series. The data in use is the larval densities in the CalCOFI data set, and we plan to further apply the method to the Eastern Bering Sea bottom trawl survey.

AUTOMATED IMAGE PROCESSING FOR FISHERIES APPLICATIONS

PI
Jenq-Neng Hwang – UW Electrical Engineering

OTHER UW PERSONNEL
Gaoang Wang – UW Electrical Engineering

TASK III

NOAA SPONSOR
Kresimir Williams – Alaska Fisheries Science Center

OTHER NOAA PERSONNEL
Nathan Lauffenburger – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
The research aims at building a fully automatic fish identification and fish length measurement system based on a Cam-trawl dataset. The system contains three parts: fish detection, fish identification, and length measurement. For input video frames, a Gaussian mixture model (GMM) is applied to locate moving objects (fish) underwater. After roughly locating the fish positions, a double local thresholding method is adopted to segment fish bodies from the background. Then we use a bounding box to crop the fish out of the image frame and rotate the body in a major direction using principal component analysis (PCA). After we obtain the fish bounding boxes, we train a species identification classifier based on the shrinking encoding method followed by the bag-of-features (BoF) framework. Since stereo cameras are used, we do the same segmentation for both left and right images, and calculate the real length of the fish by triangulation of the bounding box from both left and right image frames.

OBJECTIVES
1. Fish detection for Cam-trawl video frames for both left and right images.
2. Species identification on cropped and rotated fish bounding box images.

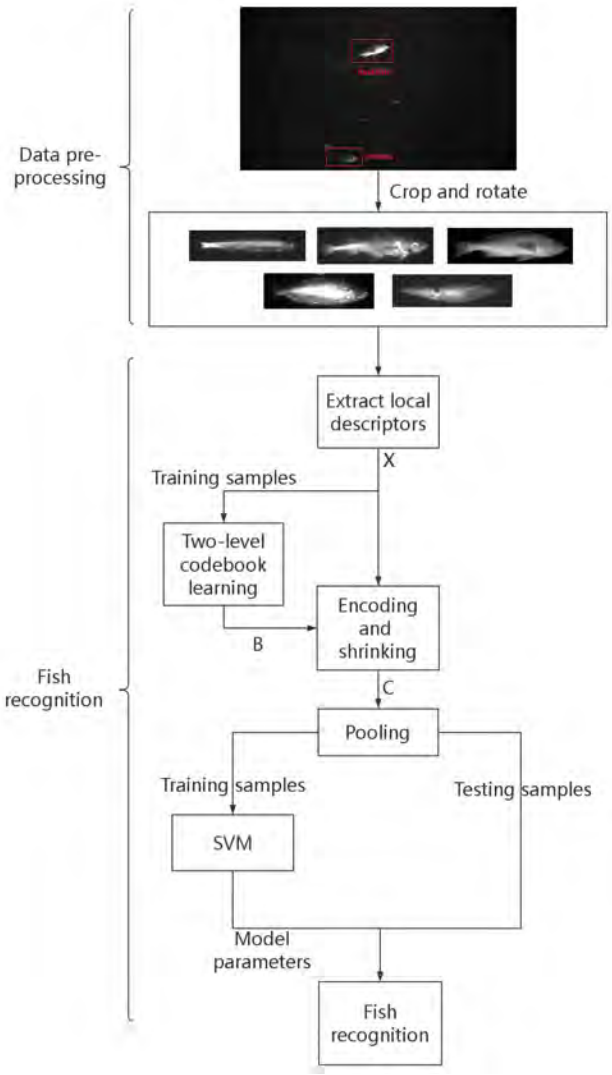


Figure 1. The flowchart of fish detection and species identification.

3. Estimate the fish length by triangulation of the left and right images.

	Eulachon	Pollock	Rockfish	Salmon	Squid
Eulachon	113	3	1	2	0
Pollock	0	416	0	0	0
Rockfish	0	0	215	0	1
Salmon	1	1	1	156	0
Squid	1	5	0	0	110

Figure 2. The confusion matrix of species identification results for five species. The total accuracy is 98.44%.

ACCOMPLISHMENTS

1. We combined GMM for background subtraction and double local thresholding method to make the segmentation more robust.
2. We implemented the species identification algorithm followed by BoF framework, which gives a much higher accuracy on the Cam-trawl dataset.

REASONS WHY OBJECTIVES WERE NOT MET

Sometimes the fish tail is very dark and hard to detect, which makes the bounding box estimation very challenging. As a result, the length measurement is not very reliable. An alternative way to address this issue is that we only measure the fish body length without including the tail. Then we can estimate the total length by the standard ratio of *body length/total length*. In most situation, this estimation works well.

IMPROVING TECHNIQUES FOR ESTIMATING ABUNDANCE AND HABITAT USE IN NEARSHORE MARINE HABITATS USING ENVIRONMENTAL DNA

PI

Ryan Kelly – UW School of Marine and Environmental Affairs

TASK II

NOAA SPONSOR

Linda Park – Northwest Fisheries Science Center

OTHER NOAA PERSONNEL

A. Ole Shelton and Correigh Greene – Northwest Fisheries Science Center

NOAA GOALS

Resilient Coastal Communities and Economies

DESCRIPTION

To date we have completed several components of our first-year proposal. First we successfully hired a postdoctoral researcher – James O'Donnell – to lead the field collections and molecular aspects of our proposal. We collected field water samples (six replicates per site) from 20 site-day combinations from Skagit Bay in late May and June 2016. All water samples were filtered, and to date DNA has been extracted

from 112 water samples (extractions include appropriate controls). We have identified primers that could be used for quantitative polymerase chain reaction (qPCR) and independently confirmed their ability to solely amplify Chinook salmon DNA using 192 qPCR assays.

To test qPCR against field survey methods, we chose samples from 10 sites that span the full range of Chinook salmon abundances observed in the field. Figure 1 shows a preliminary comparison of Chinook salmon DNA concentration derived from qPCR and Chinook salmon captured in beach seines at 10 sites in Skagit Bay. Each point represents the number of Chinook salmon captured in beach seines at each site and the median DNA concentration estimated from three independent water samples. A linear model demonstrates the number of fish (log(x+1)) was a significant predictor of DNA concentration ($p = 0.000762$) and that the intercept cannot be distinguished from 0 ($p = 0.596$). This result shows that our approach to date has been successful, and we are ready to expand our work to additional sites and samples.

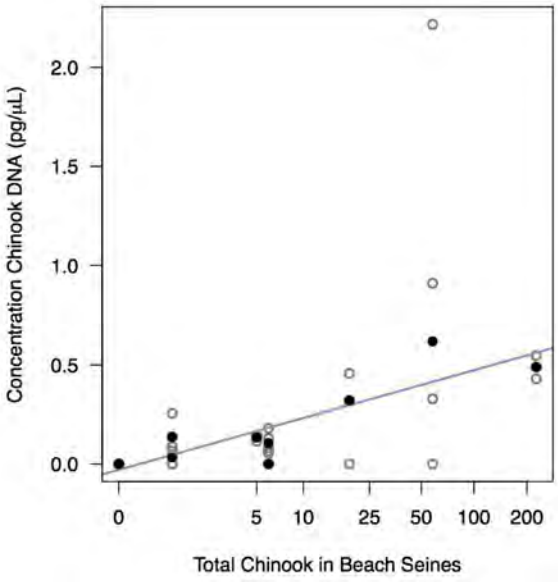


Figure 1. Skagit Chinook salmon eDNA concentration varies as a function of the total chinook caught in beach seines (N=10 sites). Black points indicate site medians, gray points indicate individual replicate samples. Note that the black point indicating zero Chinook salmon and zero DNA represents identical results from two sites.

In addition to these successes using qPCR for Chinook salmon, we have identified candidate primers for using qPCR on surfperch. Beyond single-species primers, we have in hand general metabarcoding primers that can be used for sampling the nearshore fish community in Puget Sound. We have tested eDNA samples from Puget Sound using these primers and successfully detected salmonids and other nearshore fish species under field conditions (O'Donnell et al. 2017; Kelly et al. 2017; Kelly et al. 2016).

We did not collect eDNA using our third sampling method – surface trawls – during the summer of 2016 due to vessel mechanical troubles beyond our control. The surface trawl surveys simply did not occur for almost the entirely of 2016. We intend to reassess the potential for collecting eDNA in concert with surface trawls in 2017.

OBJECTIVES

The work has far-reaching applications, insofar as environmental DNA tools are likely to be broadly useful for surveying field sites for known species (via qPCR) and for a cross-section of species of interest (via amplicons sequencing). In particular, if our project succeeds in quantitatively cross-validating the eDNA methods with the existing effort- and cost-intensive net-based methods of surveying fish species of management interest, we imagine eDNA methods could meaningfully complement, or eventually even replace such net sampling.

The first year has focused on tool development and methods testing, and as indicated in the original proposal, the second year of fieldwork will focus on developing the quantitative relationship between field samples and DNA quantification. Our progress has been right in line with our proposed schedule, and 2017 sampling began in February, which will sample across the entire temporal range of the Chinook outmigration from the Skagit River.

ACCOMPLISHMENTS
In addition to the scientific progress detailed above, our team has engaged in substantial outreach and communications, including the following public presentations:

- O'Donnell – Corvallis, OR, December 2016
- Kelly – Western Society of Naturalists, November 2016
- Kelly – Puget Sound Partnership/Puget Sound Ecosystem Monitoring Program Steering Committee, November 2016
- Kelly – NOAA Science Advisory Board Ecosystem-Based Management Working Group, October 2016
- Kelly – Ecological Society of America, August 2016

LARVAL ROCKFISH DISPERSAL MODELING

PI
Parker MacCready – UW School of Oceanography

OTHER UW PERSONNEL
Bradley Bartos – School of Oceanography

TASK II

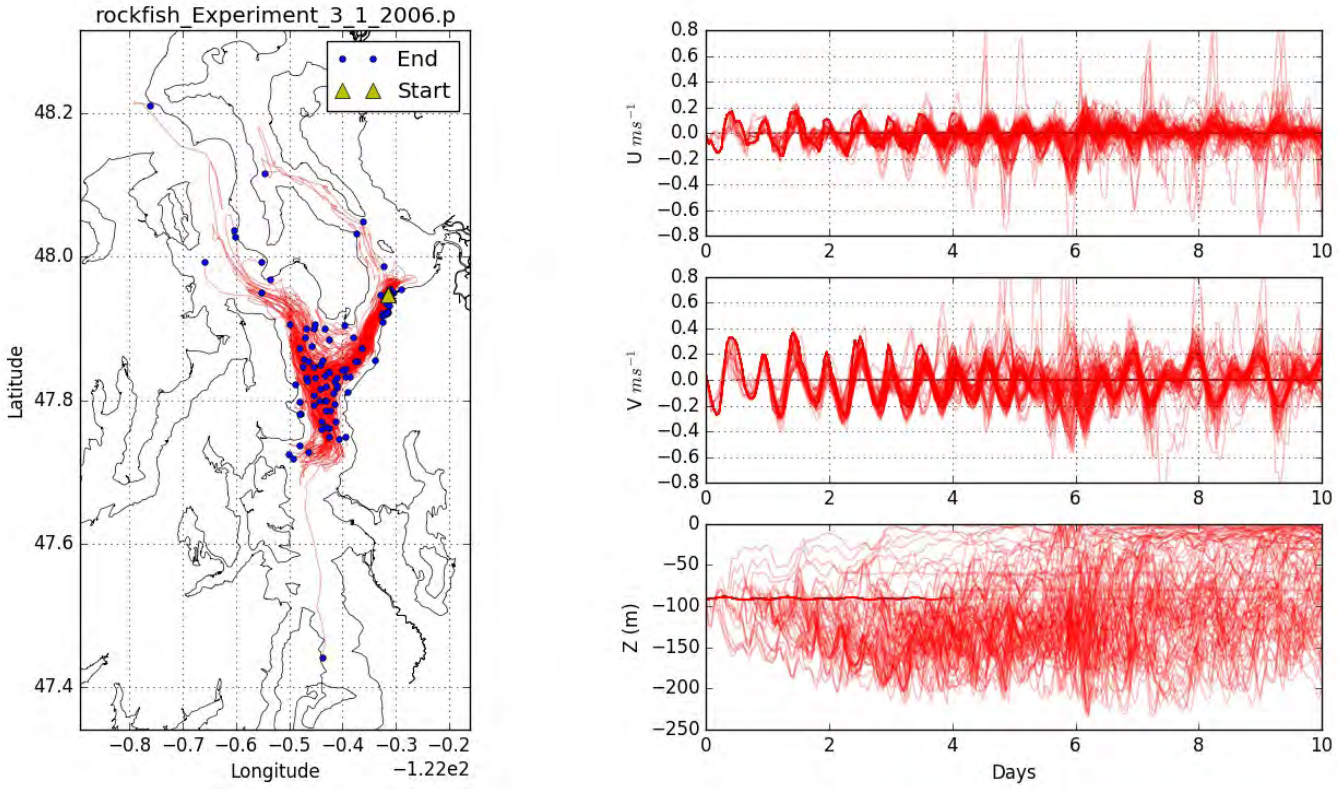
NOAA SPONSOR
Kim Raneses – NOAA Fisheries, West Coast Region

OTHER NOAA PERSONNEL
Dan Tonnes – Northwest Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
The draft ESA-listed rockfish recovery plan identifies the need to assess larval connectivity among the areas of the Puget Sound/Georgia Basin and the outer coast through modeling. More understanding of the larval connectivity of ESA-listed rockfish between the outer coast and the inside waters and among different sub-basins in the Puget Sound will enhance our understanding for causal factors behind recent genetic findings, and enhance our ability to protect and recover these fish.

OBJECTIVES
We are using an existing oceanic circulation model in conjunction with particle tracking software to test the connectivity between: 1) Puget Sound and the outer coast, and 2) Puget Sound basins including Hood Canal, South Sound, Central Sound, the San Juan Islands, and potentially the Strait of Georgia (Canadian waters). We will run the particle-tracking model with various scenarios to investigate differences in dispersal resulting from time of parturition, larval release location/depth, and larval fish behavior such as pelagic larval duration, diel vertical migration, swimming speed, and larval mortality rate.



ACCOMPLISHMENTS

In consultation with NOAA/NMFS researchers (Dan Tonnes, Chris Harvey, and Kelly Andrews) we developed a list of experiments to be conducted using stored hourly model fields from 2005 and 2006 in a realistic hindcast model of Salish Sea circulation.

A UW senior undergraduate, Bradley Bartos, already working with PI Parker MacCready, was recruited to perform the particle tracking experiments for this project. Originally two months of postdoc time were budgeted for this task. However, Bartos already had sufficient experience working with MacCready's particle tracking code, so, after consultation with the NOAA sponsors, he was hired for the job.

Bartos has modified the particle tracking code to work with the input parameters from our NOAA colleagues, and has begun the set of experiments needed to determine plausible rockfish larval dispersal patterns.

Bartos implemented and tested the vertical-dispersion module of the particle tracking code based on published schemes that relate turbulence and vertical displacement. He also modified the code so that it could automatically process the list of start locations and times from the sponsor. Benchmark experiments have been conducted, and these demonstrate that the requested suite of experiments can be performed using MacCready's existing computer resources over about a month.

REASONS WHY OBJECTIVES WERE NOT MET

The experiments will be finished before mid-June when Bartos graduates, and the final report will be written by September 30, 2017 by MacCready as planned. A draft report will be prepared by MacCready by June 30, 2017. This is later than the originally planned date of April 1, 2017. This delay was caused by the timing of when MacCready and Bartos were available to conduct the research. We will be meeting soon with NOAA colleagues to discuss initial results.

MARINE BIOLOGICAL INTERACTIONS IN THE NORTH PACIFIC – FISH INTERACTIONS TASK

PI
Bruce Miller – UW School of Aquatic and Fishery Sciences
Nicholas Bond – UW Joint Institute for the Study of the Atmosphere and Ocean

OTHER UW PERSONNEL
George Andrew Whitehouse, Ivonne Ortiz and Kelly Kearney – Joint Institute for the Study of the Atmosphere and Ocean
Caroline Robinson, Kim Sawyer, Sean Rohan and Richard Hibpshman – School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
Kerim Aydin – Alaska Fisheries Science Center

OTHER NOAA PERSONNEL
Stephani Zador and Troy Buckley – Alaska Fisheries Science Center

NOAA GOALS
Resilient Coastal Communities and Economies
Healthy Oceans

DESCRIPTION
This research project focuses on improving ecosystem-based fishery management through increased understanding of predator/prey relationships, improved predator/prey models, development of ecosystem indicators and ecosystem models synthesizing trophic interactions, population dynamics, fisheries, and climate.

OBJECTIVES
1. To perform investigations of the feeding ecology of North Pacific fishes.
2. To assist in collecting stomach, plankton, or benthic samples in the field.
3. To estimate parameters and testing single-species, multi-species, and ecosystem models.
4. To refine, update, and expand the Ecosystem Considerations report, and develop ecosystem indicators.

ACCOMPLISHMENTS
Feeding ecology and sample collections
1. In collaboration with the Resource Ecology and Ecosystem Modeling (REEM) Program at the Alaska Fisheries Science Center (AFSC), analyzed the stomach contents of 33 species sampled from the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions. The contents of 20,975 stomach samples were analyzed including 2,183 stomach samples analyzed at sea during the AI groundfish survey, and 2,388 stomach samples analyzed at sea during the EBS Continental Slope groundfish survey. This resulted in the addition of 53,037 records to AFSC's Groundfish Trophic Interactions Database. In addition, bill-load samples from 330 seabirds were analyzed for the Alaska Department of Fish and Game. Stomach analysis was conducted by Kim Sawyer, Caroline Robinson, Sean Rohan, and Richard Hibpshman.

2. Additional stomach samples were collected through resource surveys, research surveys, and special studies comparing stomach contents with prey-sampling. Approximately 9,920 stomach samples were collected from the EBS continental shelf, 1,225 stomach samples from the EBS continental slope to supplement the 2,388 stomach samples analyzed at sea and an estimated 1,795 stomach samples were collected from the AI to supplement the 2,183 stomach contents analyzed at sea in that region. Stomach samples were collected by Robinson, Sawyer, Rohan, Hibpshman, and Andy Whitehouse.
3. Rohan started his graduate studies (M. Sc.) at the School of Aquatic and Fishery Sciences, and has been working on consumption of octopus by Pacific cod and limitations of the consumption-based octopus stock assessment in the EBS and AI. Rohan also coauthored a paper with Troy Buckley on octopus predation, and another paper with David T. Drumm of EcoAnalysts, Inc. on a new species of shrimp.
4. Whitehouse and Buckley coauthored a paper on arctic cod diets, now in press.

Multispecies and Ecosystem models

5. Whitehouse, in collaboration with the REEM Program at the AFSC and scientists at the Northeast Fisheries Science Center continued working on the development of an R implementation (Rpath) of the ecosystem modeling program Ecopath with Ecosim (EwE). This work implements the Ecosense routine of Aydin et al. (2007) as an add-on for the Rpath package. The Ecosense routine uses a simplified Bayesian Synthesis approach to incorporate uncertainty in model parameters into simulations facilitating sensitivity analyses of model parameters, food web structure, and the characterization of uncertainty in simulation results, and describes a range of possible simulation outcomes. Rpath with Ecosense is used to conduct a range of mortality-based perturbations on food web models of the eastern Chukchi Sea, EBS, and Gulf of Alaska (GOA) ecosystems to identify key sensitivities in food web structure and to evaluate food web response time to perturbations. This comparative approach helps identify distinguishing features of the simulated ecosystems. Whitehouse and colleagues are preparing a manuscript detailing the simulation results and implementation of Ecosense with Rpath.
6. Ortiz and Aydin worked on several manuscripts related to the Bering10k-ROMS-BESTNPZ-FEAST model which are now finalized and available in print.

Ecosystem Considerations report & ecosystem indicators

7. The Ecosystem Considerations report for the North Pacific Fishery Management Council contains ecosystem assessments for four large marine ecosystems in Alaska (*access.afsc.noaa.gov/reem/ecoweb/index.php*). Whitehouse has updated the indicators i) Time Trends in Non-Target Species Catch for the EBS, GOA, and AI regions; ii) Historical and Current Alaska Salmon Trends for the EBS and GOA, and iii) the Fish Stock Sustainability Index (FSSI) for the EBS, GOA, and AI regions.

Presentations & workshops

8. Whitehouse gave a presentation on "The eastern Chukchi Sea food web: Parameter uncertainty and the response of upper trophic levels to perturbations" at the Pathways to Adaption: Ocean Acidification in the Arctic Meeting, 2016 in Finland.
9. Ortiz presented the talk "Updating the Aleutian Islands Fisheries Ecosystem Plan" at the Aleutian Islands Life Forum, 2016. She also presented a talk on potential contribution and relevance of monitoring endangered and declining species during the workshop on Endangered and Declining Species in the Aleutians: Are the Declines Driven by Changes in the Ecosystem or Human Interaction.
10. Whitehouse attended the National Ecosystem Modeling Workshop organized by NOAA Fisheries, 2017, St. Petersburg, Florida.
11. Robinson, Sawyer, Rohan, and Hibpshman were nominees for the UW Distinguished Staff Award.

INNOVATIVE TECHNOLOGY FOR ARCTIC EXPLORATION/ DEVELOPMENT OF THE OCULUS COASTAL GLIDER

PI
Calvin Mordy – UW Joint Institute for the Study of the Atmosphere and Ocean

OTHER UW PERSONNEL
Thomas Ackerman, Shaun Bell, Geoff Lebon, Kim Martini, Andrew Meyer, Timothy James Osse, Peter Proctor, David Rivera, David Strausz, Margaret Sullivan, and Heather Tabisola – Joint Institute for the Study of the Atmosphere and Ocean

TASK II

NOAA SPONSOR
Chris Sabine – Pacific Marine Environmental Laboratory

OTHER NOAA PERSONNEL
Christian Meinig, Jessica Cross, Edward Cokelet, Nicholas Delich, Daniel Langis, Noah Lawrence-Slavas, Phyllis Stabeno, and Dirk Tagawa – Pacific Marine Environmental Laboratory

NOAA GOALS
Climate Adaptation and Mitigation
Healthy Oceans

DESCRIPTION
The Innovative Technology for Arctic Exploration (ITAE) program is developing new sensors and platforms to meet the scientific demand in harsh and remote arctic regions. ITAE is a collaborative research effort by the University of Washington (JISAO) and NOAA scientists at the Pacific Marine Environmental Laboratory (PMEL). In 2016, ITAE completed several key field missions in the first ecosystem study using Saildrones. Sensing innovations on the Saildrone included a specially developed echo sounder and a modified whale acoustic hydrophone. Collectively, the oceanographic, meteorological, and fisheries mission measurements provided unique and groundbreaking insights which could change the understanding of ecosystems and how to better accomplish tasks related to regional management and conservation.

OBJECTIVES
1. Conceptualize, design, build, and mission test innovative sensors and platforms to meet the demand of research in the Arctic.
2. Monitor the arctic marine ecosystem through analysis and processing of data from innovative technologies – providing critical information on the response of the environment to changes in climate.
3. Publicize data through websites, presentations, publications, and workshops.

ACCOMPLISHMENTS
1. In FY 2016, ITAE collaborated with 18 public and private-sector partners on the development of numerous sensors and platforms to improve measurement capabilities in the expansive and complex Alaskan coastal region.
2. In 2016, ITAE used two Saildrones to measure the environment, fishes, and marine mammals in the Bering Sea simultaneously. Following a successful 2015 ~98-day field test of the Saildrone unmanned surface vehicle (USV); in 2016, ITAE collaborated with Alaska Fisheries Science Center scientists and

Figure 1. D. Rivera (JISAO/PMEL) and M. Strick (JISAO/PMEL) assist the PMEL Engineering Group and Oculus designer, J. Osse for pool testing at The Weyerhauser Aquatics Center in Federal Way, WA. (Photo: H. Tabisola)

deployed two Saildrone USVs in the southeastern Bering Sea on a ~103-day mission (~6000 km) crisscrossing the eastern Bering Sea middle and outer shelf between 54˚N and 59˚N. The goals of this mission were to test new techniques to determine a) the distribution of walleye pollock; b) the presence of the critically endangered North Pacific right whale; and c) the summer foraging behavior of northern fur seals in relation to the prey field. Fifteen engineers and scientists representing six research groups and three non-federal companies worked together. This mission demonstrated the capability of the Saildrone vehicle as an ecosystem research tool that has the potential to contribute to informed management and conservation decisions in the Bering Sea. These new techniques will help provide reconnaissance for ship-based fisheries surveys through collection and transmission of preliminary data by autonomous platforms, and represent a breakthrough in understanding foraging behavior and feeding success of the northern fur seal. The kickoff of this mission was broadcast live on YouTube at *youtube.com/watch?v=EholPRD-UJ4*.

3. An ITAE buoy was deployed near the Ecosystems and Fisheries Oceanography Coordinated Investigations (EcoFOCI) M2 site in May, and recovered in September. Included on the buoy was a new-generation radiometer and a modified Prawler that measures pressure, temperature, salinity, oxygen, chlorophyll fluorescence, and turbidity. The Prawler provided high-resolution sampling during the spring bloom and across the 2-layer interface that develops in that region during summer. The Prawler is a new-generation autonomous platform that harnesses wave energy to ratchet along the mooring line with shore-based command and control.

4. Deployed on EcoFOCI M2 biophysical mooring, the Lab-on-a-Chip was developed by the National Oceanography Centre (NOC), Southampton UK, and was loaned by NOC at no cost for deployment and testing in 2015 and 2016. The sensor operated for the full 90-day deployment, but a fault introduced at the start of the deployment meant that the onboard standard could not be measured. This is highly unfortunate, as the onboard standard is key for accurate nitrate measurements, and distinguishes this technology from the optical measurements from the Submersible Ultraviolet Nitrate Analyzer.

5. Pop-up floats (previously referred to as ExFloat or EXIT float) are designed to be deployed in the fall (ice-free) months and sequentially released during the winter and spring (ice-covered) months. The floats collect data while moored along the bottom, during ascent through the water column, and while positioned directly underneath the ice. Once free from the ice, all data from the floats is telemetered to shore using an on-board iridium modem. In order to reduce production costs for these expendable floats, they have been custom designed in-house. A number of novel cost-saving design features have been integrated to achieve a cost per float of ~$2,000 – such as pressure housings, commercial electronics, and the use of inexpensive burn-wire releases. Despite cost reductions, the floats still provide high-quality data, measuring temperature (±0.01°C accuracy), depth (±0.21m accuracy), and

photosynthetic active radiation (PAR) (±3% accuracy), as well as tilt angle and GPS location.

6. The ALAMO float is an aircraft deployed Argo float built by MRV Systems, LLC. Through a collaboration between ITAE, PMEL Arctic Heat Program, Woods Hole Oceanographic Institution, and MRV Systems, the ALAMO float has been modified for operations under sea ice. This includes an ice-reinforced assembly, new algorithms for sensing and profiling while underneath the ice, and incorporation of additional sensors including conductivity, temperature, and depth (CTD) and PAR. The float can be programmed to rest along the bottom between profiles. The goal is to obtain Eulerian data (profile and under-ice) that can be integrated with data from the EcoFOCI moored observatory in the Chukchi Sea. From deployments in 2016, ITAE scientists detected a previously unseen warm saltier bottom layer in the central Chukchi, and observed the seasonal transition from the summer two-layer system to the arrival of sea-ice.

Figure 2. Field testing the Oculus in Lake Washington. (Photo: H. Tabisola)

7. In 2016, development continued of a variable speed coastal glider called the Oculus. The Oculus is a coastal glider catered to the shallow depths of the Arctic. By using a rapid buoyancy system this glider can change buoyancy states 20 times faster, and achieve speeds three times faster than legacy gliders – allowing for a more efficient and adaptive Arctic survey, but transferable to a variety of markets. It was designed and built in collaboration with the Office of Ocean and Atmospheric Research's Autonomous Marine Sampling Technology Testbed program. The Oculus has been tested through a series of bench testing (PMEL and UW Deepglider Lab), UW Oceanography saltwater tanks, King County Aquatic Centers Olympic dive pool, and open water tests in nearby Lake Washington and Puget Sound. The base sensor package on the Oculus includes CTD, oxygen, chlorophyll fluorescence, turbidity, carbon biomass, and PAR. A Record of Innovation for "Oculus Coastal Glider" was successfully submitted to UW CoMotion, with plans to sell the technology for commercial production in 2017.

8. In collaboration with the Carbon Program at PMEL and Saildrone Inc., a new generation MapCO2 system – the ASVCO2 – was developed and integrated into the Saildrone. The ASVCO2 is being evaluated through sea trials alongside the NOAA ship *Bell M. Shimada* that has a state-of-the-art underway CO2 system.

9. ITAE team members attended several conferences during FY 2016 to present preliminary data. Details of the Saildrone mission and preliminary results were presented at three meetings: MTS/IEES Oceans'16 (Monterrey, CA), the Alaska Marine Science Symposium (January, Anchorage, AK), and at Oceanology International (February, San Diego, CA). A portion of Prawler results were presented in one manuscript (Stabeno et al., 2017).

10. For a second year, ITAE hosted a special workshop for the NOAA Science Camp Junior Leadership Program at PMEL as a tour of the facility. After a brief walk-around, the students were led to the conference room and given a task. That task was to develop a program or technology (or both) to

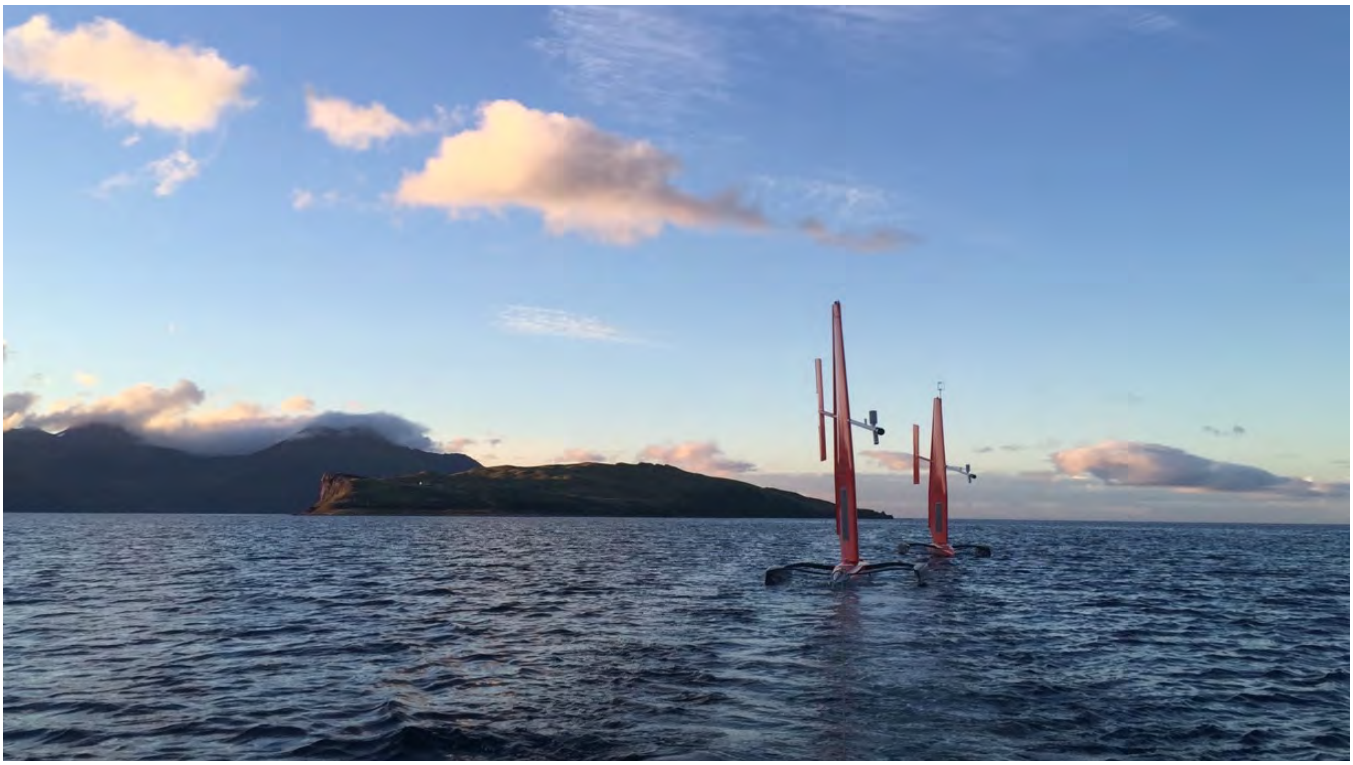


Figure 3. Two Saildrone return to the dock in Dutch Harbor, AK after three months of oceanographic, fish and marine mammal research in the Bering Sea. (Photo: Saildrone Inc.)

investigate the Arctic, and to then present their idea to the group. The students' presentations were judged on four areas: content, communication, engagement, and originality. A bonus was given for utilizing visual components (provided) in their presentation. The idea was to introduce how federal and non-federal scientists at PMEL translate science questions, concepts, and designs into innovative technologies and research missions.

11. The ITAE website *pmel.noaa.gov/itae/* provides near real-time information on the team, technologies, and missions, as well as outreach with features such as "Follow the Saildrone!", which allows the public to join the adventure as Saildrones move about the U.S. Arctic during the summer months.

PARTNERSHIP WITH THE NORTHWEST FISHERIES SCIENCE CENTER AND ALASKA FISHERIES SCIENCE CENTER TO DEVELOP INCREASED CAPACITY IN THE SCHOOL OF AQUATIC AND FISHERY SCIENCES TO ENHANCE TEACHING AND RESEARCH

PI
André E. Punt – UW School of Aquatic and Fishery Sciences

TASK III

NOAA SPONSOR
Mark Strom – Northwest Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
The purpose of this project is to create a partnership with the Northwest Fisheries Science Center (NWFSC) and the Alaska Fisheries Science Center (AFSC) to develop an increased capacity in the UW School of Aquatic and Fishery Sciences (SAFS) to enhance teaching and research in stock assessment and resource management.

OBJECTIVES
1. Faculty support – hire and support two tenure-track faculty members at SAFS.
2. Graduate student support – identify, support, and train graduate students in stock assessment and resource economics for fisheries management.

ACCOMPLISHMENTS
1. SAFS hired Trevor A. Branch as an assistant professor, tenure track as of September 16, 2010. Branch ran the Bevan Series for three years to increase collaboration between SAFS and NOAA. He lectures courses in introductory and advanced R programming, in preparing polished scientific figures from data in R, and in fisheries population dynamics. Since being hired, Branch has published 48 scientific papers, and his lab has published an additional 14 scientific papers. Branch was awarded tenure in 2015, and is now an Associate Professor.

2. Branch is using funds from this award to support Cole Monnahan, a graduate student who is registered in the QERM (Quantitative Ecology and Resource Management) program. Monnahan received his MS in 2013, and is defending his PhD in spring 2017 under Branch. Monnahan received the Sea Grant/National Marine Fisheries Service (NMFS) population dynamics PhD fellowship, which is being used to supplement the NOAA funds in this grant. His MS involved using a spatial model to separate catches of eastern and western North Pacific blue whales, and constructing and fitting a Bayesian population model of northeast Pacific blue whales. Two peer-reviewed papers have been published in *PLoS ONE* and *Marine Mammal Science* from this work. Monnahan has coauthored 11 peer-reviewed papers (several with other graduate students in Branch's group), many involving simulation testing of the Stock Synthesis stock assessment software developed by NWFSC scientists.

3. Monnahan and Branch, together with NWFSC scientist James Thorson, recently published a transformative paper on new algorithms to improve Bayesian convergence time, and explain how the No-U-Turn Sampler (NUTS) algorithm in software package Sampling Through Adaptive Neighborhoods

(STAN) is far more efficient at converging for large complex models (published in *Methods in Ecology and Evolution*). Monnahan has now implemented this method in AD Model Builder and Template Model Builder, and his final PhD chapter will examine the promise the NUTS method has for allowing uncertainty to be estimated within stock assessment models. If the method works as promised, convergence times for U.S. stock assessments will be cut from days to weeks down to minutes to hours.

4. Branch has one graduated MS student (Melissa Muradian) who trained in stock assessment of Prince William Sound Alaska herring, and partial funding from this grant led to a recent stock assessment publication of Prince William Sound herring in PLoS One; and three other PhD students: Merrill Rudd (working on data-poor stock assessment methods), Peter Kuriyama (the effects of catch shares on fishing behavior, and the analysis of hook-and-line surveys for rockfish off California), and John Trochta (modeling herring in Prince William Sound). Rudd is funded from National Science Foundation (NSF) and SAFS funds; Kuriyama from Moore Foundation, Washington Sea Grant, and a NOAA population dynamics fellowship; and Trochta from the Exxon Valdez Oil Spill Trustee Council. Branch has two postdocs: Sean Anderson, who is working with Eric Ward at NWFSC on the influence of catastrophes and black swan events in fisheries; and Lewis Barnett, who is working with Michelle McClure at the NWFSC on the effects of West Coast groundfish fisheries management. In total, 19 scientific papers have been coauthored by graduate students and postdocs in Branch's lab, of which 13 are directly related to stock assessment research topics. The most recent is a paper on black swan events in the *Proceedings of the National Academy of Sciences* by postdoc Anderson, which has direct application to how rare events are modelled in fisheries.

5. SAFS hired Christopher M. Anderson as a tenured Associate Professor of Fisheries Economics, and he began employment January 1, 2012. He teaches a Masters-level course in fishery economics for students in SAFS and the School of Marine and Environmental Affairs; a PhD level-course for students with extensive economics background interested in frontier research in fisheries economics as a part of their dissertation; and a large-lecture 200-level introduction to economics for students primarily interested in the environment and resource use issues. Since being hired, Anderson has published 14 papers, and he serves on the Scientific and Statistical Committee for the North Pacific Fishery Management Council.

6. Anderson has research programs focusing on behavioral responses to catch share management, assessing the economic performance of the harvest, post-harvest, and fishing community sectors of fisheries around the world, and public willingness to pay for ecosystem services. Anderson's lab includes five dissertation-stage economics PhD students. One of them, Jennifer Meredith, has a NMFS Marine Resource Economics Fellowship with mentorship at the AFSC. The five also include a fourth-year Economics PhD student; a third-year Masters SAFS student, and a dissertation-stage co-advised QERM student. Anderson's students have had significant experiences in Bristol Bay, Alaska, and at The World Bank. One economics PhD student, Marie Guldin, is on a long-term contract at the NWFSC; one economics PhD student, Allen Chen, is on a contract at the AFSC; one co-advised economics PhD student, Christopher Martin, is on an NSF-GRIP (Graduate Research Intern Program) fellowship at the NWFSC. In addition, Meredith and Melissa Krigbaum are involved in external contracts with NOAA. Graduates include Andrew Scheld (SAFS PhD), who started as an Assistant Professor of Marine Resource Economics at the Virginia Institute of Marine Science at the College of William and Mary in Fall 2014, Zhi Li (Economics PhD), who started as an Assistant Professor at Xiamen University in Fall 2015, and Thomas Fillebeen (Economics PhD), who turned down an Assistant Professor offer at Texas A&M to work at Amazon in Fall 2016. Anderson's undergraduate thesis advisee, Joshua Kim (Economics 2015) won the Best Thesis award, A&S Dean's Medal in Social Science, and is a PhD student in Stanford's Economics program.

7. Anderson has partnered with NOAA economists Dan Holland (NWFSC) and Alan Haynie (AFSC) to win the bid to host the 2018 conference of the International Institute of Fishery Economics and Trade (a conference last held in North America 20 years ago) at the University of Washington. He is also coordinating a training course to be led by QUEST-supported faculty from around the country at the 2017 ICES Annual Science Conference.

REPORTS

1. Branch, T.A., D.M. Palacios, and C.C. Monnahan. 2016. Overview of the North Pacific blue whale distribution, and the need for an assessment of the western and central Pacific. Scientific Committee of the International Whaling Commission. SC/66b/IA/15.
2. Stewart, I.J. and C.C. Monnahan. 2016. Overview of data sources for the Pacific halibut stock assessment and related analyses. Pages 99-187, IPHC Report of Assessment and Research Activities.
3. Stewart, I.J., C.C. Monnahan, and S. Martell. 2016. Assessment of the Pacific halibut stock at the end of 2015. Pages 188-209. IPHC Report of Assessment and Research Activities.

PRESENTATIONS

1. Branch, T.A. The near extinction and hopeful rebuilding of Antarctic blue whales: the largest animal ever. Seattle Aquarium Lightning Talks. Invited public talk 10/11/2016
2. Branch, T.A. Fishing impacts on marine food webs: multiple working hypotheses University of Minnesota St Paul, Conservation Science. Invited talk 10/14/2016
3. Branch, T.A. A whale tale: the near extinction and partial recovery of Antarctic blue whales. Duke University Marine Laboratory. 07/27/2016
4. Branch, T.A. Opportunistic exploitation: an overlooked path to extinction Duke University Marine Laboratory. Duke University Marine Laboratory. 07/26/2016
5. Branch, T.A. Fishing impacts on food webs: Multiple working hypotheses Duke University Marine Laboratory, Marine Conservation. 07/25/2016
6. Monnahan, C.C. Introducing the no-U-turn MCMC sampler in ADMB and TMB: faster run times for large, complex fisheries models. UW School of Aquatic and Fisheries Science: Fisheries Think Tank. Seattle, WA. 2/7/2017
7. Monnahan, C.C. Faster estimation of Bayesian models in ecology using Hamiltonian Monte Carlo. NOAA Fisheries Sea Grant Fellowship Meeting. Southwest Fisheries Science Center. Santa Cruz, CA. 6/28/2016.
8. Monnahan, C.C. Hamiltonian Monte Carlo in ADMB and TMB: current status and future directions. ADMB/TMB Developers' Workshop. Seattle, WA. 6/23/2016.

ENHANCED NOAA-UW TRAINING AND COLLABORATION THROUGH THE BEVAN SERIES ON SUSTAINABLE FISHERIES

PI
André Punt – UW School of Aquatic and Fishery Sciences

OTHER UW PERSONNEL
Julia Parrish and David McGowan – School of Aquatic and Fishery Sciences

TASK I

NOAA SPONSOR
Mark Strom – Alaska Fisheries Science Center

NOAA GOAL
Healthy Oceans

DESCRIPTION
The purpose of this project is to provide partial support for the Bevan Series on Sustainable Fisheries for winter 2017. Project costs include speaker travel, per diem, accommodations, advertising, and the two associated University of Washington courses (one graduate and one undergraduate).

The Bevan Series on Sustainable Fisheries is a prestigious public seminar series administered by the School of Aquatic and Fishery Sciences (SAFS) and the UW. Ten internationally renowned speakers are invited to speak on a wide range of topics, which for the 2017 series was on the general issue of "How do we use data?" This issue was examined throughout the 2017 series through various talks, including those that highlighted the value of social science data, conventional data for monitoring fisheries, the use of data to support management decision making, and the value and impact of citizen science. In addition, an undergraduate class (21 students) and a graduate class (9 students) read papers selected by the speakers, met the speakers, and discussed the seminars through an online website and in weekly, in-person discussion groups. Each speaker participated for at least two days, allowing ample time for meetings with NOAA researchers and UW academics.

The expenses associated with running the series were also covered during 2016-17 by donations received from the Donald E. Bevan Fund in Fisheries, the School of Aquatic and Fishery Sciences, and the Bering Sea Fisheries Research Foundation.

OBJECTIVES
1. Bring in outstanding researchers from outside Seattle who are at the forefront of marine and freshwater management and fisheries.
2. Increase collaboration between SAFS, other UW departments, NOAA centers, NGOs, and industry.
3. Promote scientific research to the public.

ACCOMPLISHMENTS
1. Ten speakers were invited. There was broad audience support from UW and NOAA personnel.
2. Organized events allowed collaborative discussions in a more informal setting, especially over dinners following the seminar. These events included SAFS Director André Punt, SAFS Associate Director Tim Essington, and Associate Dean of the College of the Environment Julia Parrish, as well as Alaska Fisheries

Science Center and Northwest Fisheries Science Center members. Dinners also included members from other departments at UW, NGOs, fishermen, and a wide cross-section of people from diverse backgrounds.

3. Public participation in the series was excellent. The venue seats 150, and attendance varied between about 100 and 150.
4. Most of the seminars were loaded on to YouTube to provide a broader audience with the opportunity to view the presentations.

WEST COAST GROUNDFISH STOCK ASSESSMENT

PI
André Punt – UW School of Aquatic and Fishery Sciences

OTHER UW PERSONNEL
Lee Cronin-Fine, Lee Qi, and Caitlin Allen Akselrud – School of Aquatic and Fishery Sciences

TASK III

NOAA SPONSOR
Mark Strom – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans
Resilient Coastal Communities and Economies

DESCRIPTION
The purpose of this project is to conduct research on the population dynamics and stock assessments of groundfish species occurring off the coasts of Washington, Oregon, and California (West Coast).

OBJECTIVES
1. Develop quantitative methods for the analysis of the population dynamics of groundfish species which could form the scientific basis for evaluating the consequences of alternative fishery management actions.
2. Collaborate with National Marine Fisheries Service (NMFS) scientists who are conducting quantitative stock assessments of West Coast groundfish species on the implementation of population dynamics and stock assessment methods.
3. Build expertise among scientists conducting management-related research for West Coast groundfish in the application of state-of-the-art methods.
4. Provide support, training, and mentoring for graduate students in the field of quantitative fisheries science.

ACCOMPLISHMENTS
1. André Punt worked with Felipe Carvalho of the University of Hawaii's Joint Institute for Marine and

Atmospheric Research and colleagues from NOAA and the Inter-American-Tropical-Tuna-Commission to develop ways to identify model misspecification in fishery stock assessments. This work resulted in a paper currently in press at *Fisheries Research*. Punt also contributed to producing a Special Issue from the Center for the Advancement of Population Assessment Methodology (CAPAM) Data Weighting Workshop. This Special Issue will be published in the journal *Fisheries Research* 2017.

2. Punt, in collaboration with NOAA Northwest Fisheries Science Center (NWFSC) scientist Jason Cope, identified 13 alternative three-parameter stock-recruitment relationships and examined each in relation to whether they could be parameterized in terms of F_{MSY} and B_{MSY}. The 'best' of these 13 stock-recruitment relationships was linked to the data-poor stock assessment method Simple Stock Synthesis (SSS) so that data-poor stock assessments can be conducted that are comparable to those conducted using Depletion Based Stock Reduction Analysis. Punt and Cope also refined how SSS searches for parameter vectors sampled from the prior distributions. These changes have been added to the software implementing SSS.

3. Punt and School of Aquatic and Fishery Sciences (SAFS) graduate student Kristin Privitera-Johnson (funded by a National Science Foundation fellowship) are working with NWFSC scientists Chantel Wetzel and Owen Hamel to update the meta-analysis used to define "sigma" for data-rich stock assessments. The value for "sigma" is used to calculate the buffer between the overfishing level (OFL) and the acceptable biological catch (ABC) for groundfish and coastal pelagic species. Unlike the previous analysis that focused on biomass estimation, the current analysis is focused on OFL estimation.

4. Punt is conducting a review of methods for handling spatial structure in recruitment in stock assessments, and is conducting simulations to compare some of the alternative methods. This work will form the basis for a keynote address at the 2017 CAPAM workshop on recruitment, and will be written up for publication in the Special Issue of *Fisheries Research* arising from the workshop (Punt will be one of guest editors of that Special Issue).

5. Punt continued to be a member of Pacific Fishery Management Council (PFMC) Scientific and Statistical Committee (and chair of its Coastal Pelagic Species (CPS) Subcommittee) and a member of the North Pacific Fishery Management Crab Plan Team. He has run several workshops and Stock Assessment Review meetings for the PFMC related to assessment and management of CPS.

6. Masters student Lee Qi was partially funded by the grant during the reporting period. She completed her research to explore the advantages and disadvantages of including an index of growth anomalies in stock assessments based on Stock Synthesis. This work was conducted in collaboration with NWFSC scientists James Thorson and Vlada Gertseva, and a paper is currently in review with the *ICES Journal of Marine Science*. She is also involved in two projects in collaboration with NWFSC scientists Melissa Haltuch and Nick Tolimieri, and Southwest Fisheries Science Center scientists Steven Bograd and Michael Jacox investigating the impacts of oceanographic drivers on recruitment mechanisms of sablefish and Petrale sole. The research for sablefish is complete, and a paper is in preparation for publication in *Fisheries Oceanography*. Lee is currently conducting analyses to explore the ability of random effects models to analyze otolith width data to detect climate effects on growth and should defend her thesis in spring 2017.

7. Lee worked with a group of UW graduate students (Christine Stawitz, Margaret Siple, and Stuart Munsch) on a meta-analysis of DNA barcoding papers, examining the prevalence and consequences of seafood mislabeling at a broad scale. This work has been published in *Conservation Letters*, and is still ongoing.

8. Caitlin Allen Akselrud was partially funded by the grant during the reporting period. She worked with Punt and Quantitative Ecology and Resource Management PhD student Lee Cronin-Fine to compare assessment methods based on age-structured, size-structured and age-size-structured models, as applied to Pacific cod in the Eastern Bering Sea. This work is a follow-up to a North Pacific Research Board funded grant to Punt, and a paper is currently in review at *Fisheries Research*. Allen Akselrud should defend her thesis in spring 2017.

9. Allen Akselrud is assisting Melissa Haltuch (NOAA, NWFSC) with the 2017 assessment of U.S. West Coast lingcod. Allen Akselrud's responsibilities include working up commercial age and length composition data, as well as catch per unit effort data for Washington and Oregon, running sensitivity analysis from the Stock Synthesis base model, assisting with document preparation and writing, and presenting the assessment with Haltuch to the Stock Assessment Review Panel in June 2017.
10. The series of regular (generally bi-weekly) UW/NWFSC/AFSC Fisheries Think Tanks continued during the reporting period, coordinated by Cronin-Fine. NMFS scientists and UW faculty and students participated in these workshops, the purpose of which is to increase collaboration among scientists working on West Coast groundfish issues. A list of the Fisheries Think Tanks that took place during the reporting period is given at *puntlab.washington.edu/fisheries-think-tank*. Furthermore, efforts remain ongoing to include presentations from researchers working outside of UW/NWFSC/AFSC to increase the remote audience participation.

MAJOR PRESENTATIONS

1. Allen Akselrud, C., Punt, A.E., and W. Stockhausen. 2016. Age and Size Structured Population Dynamics. NOAA Alaska Fisheries Science Center, Resource Ecology and Fisheries Management Division, Seattle, WA. 3 August, 2016.
2. Lee, Q., Thorson, J.T., Gertseva, V.V. and A.E. Punt. 2016. Incorporating climate-driven growth variability into stock assessment models: a simulation-based decision table approach. World Fisheries Congress, Busan, South Korea, May 2016.
3. Punt, A.E. 2016. An Honest Appraisal of Stock Assessment, NWFSC Monster Jam. Seattle, May 2016.
4. Punt, A.E. 2016. An Honest Appraisal of Stock Assessment, World Fisheries Congress, Busan, South Korea, May 2016.
5. Punt, A.E. 2017. Characterizing Small Pelagic Fishes in Management Simulations: Examples from the US West Coast and South Africa. ICES/PICES International Symposium: Drivers of dynamics of Small Pelagic Fish Resources, Victoria, Canada, March 2017.
6. Punt, A.E. and J.M. Cope. 2016. Extending integrated stock assessment models to use non-depensatory three-parameter stock-recruitment relationships. Groundfish Productivity Workshop of the Pacific Fishery Management Council's Scientific and Statistical Committee. Seattle, December 2016.

DEVELOPMENT AND APPLICATION OF A SIZE-STRUCTURED SPATIOTEMPORAL MODEL FOR INVERTEBRATES: INDIVIDUAL GROWTH, SIZE-TRANSITIONS, AND NATURAL AND FISHING MORTALITY

PI
André Punt – UW School of Aquatic and Fishery Sciences

TASK III

NOAA SPONSOR
James Thorson – Northwest Fisheries Science Center

NOAA GOALS
Climate Adaptation and Mitigation
Healthy Oceans

DESCRIPTION

Ecologists and the public are broadly interested in changes in species abundance and productivity caused by climate and environmental impacts. Climate impacts can now be analyzed using spatiotemporal statistical models, which estimate population abundance at hundreds of sites, changing over time due to human and natural impacts. However, there has been limited research regarding size-based spatiotemporal models, which simultaneously estimate individual growth, birth of juveniles, natural mortality, and human-caused mortality. An existing spatiotemporal model will be modified to be able to represent snow crab, an economically important and charismatic species in the Bering Sea. Snow crab has undergone tremendous changes in abundance and distribution over time, and provides a useful case-study for attributing distribution shift to fishing vs. temperature impacts.

OBJECTIVES

1. An R-package *SpatialVAM* (an existing size-structured spatiotemporal model) will be modified to add a growth-transition matrix, as well as mortality due to human harvest.
2. The model will then estimate 35 years of spatial dynamics for snow crab.

REASONS WHY OBJECTIVES WERE NOT MET

It took longer than expected to identify a postdoctoral fellow with the requisite modelling skills. A search has taken place and a candidate has been identified. We are working with the candidate to hire him to the position.

UNDERSTANDING PARTICIPATION AND EFFORT IN STATE AND FEDERAL FISHERIES ALONG THE WEST COAST

PI
André Punt – UW School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
Daniel Holland – Northwest Fisheries Science Center

NOAA GOALS
Resilient Coastal Communities and Economies

DESCRIPTION
Fishermen and fishing communities along the West Coast of the United States depend on a number of state and federally managed fisheries for income. Many fishermen diversify their income by participating in more than one fishery, and many participate in both state and federally managed fisheries. The goal of this project is to develop a quantitative understanding of how fishing efforts and participation levels in different West Coast fisheries are impacted by economic, biological, and physical conditions in the larger system of fisheries, as well as conditions specific to each individual fishery. We want to understand, and ultimately model how changes in management, such as access rules, affect the flow of effort among these fisheries, and how that affects their sustainability and economic performance, as well as the financial risk individual fishermen and communities face. Understanding the human linkages between fisheries is part of a larger goal to understand and model the overall natural-human system of fisheries. This project will contribute toward a longer term project to integrate our fishery participation models with dynamic bio-physical models. These will be used to explore how shocks to the system, including climate change and ocean acidification will impact this coupled natural-human system, and how those impacts are mediated by management. The initial funding for a post-doctoral researcher will support work primarily on the human dynamics of the system, but also development of a proposal for funding of a larger, multi-disciplinary project.

OBJECTIVES
1. Develop a behavioral analysis that will provide an understanding of the determinants of the levels of effort and movement of fishermen in, out, and between a number of West Coast state and federal fisheries that are regulated primarily with indirect controls (e.g., limited licenses, gear restrictions, and season-time-area closures) as opposed to strict overall or individual catch limits.
2. Provide results that will feed into a proposal for funding of a larger, multi-disciplinary project that incorporates a broader focus to include modeling of these fisheries, providing insights into how they are likely to be impacted by changes in management, and by exogenous factors including climate change.

REASONS WHY OBJECTIVES WERE NOT MET
This project has not started yet. While a postdoctoral fellow has been selected, she is not yet available to work on the project because she was funded to conduct another project through the Northwest Fisheries Science Center.

DEFINING GOOD PRACTICES FOR FISHERY ASSESSMENTS

PI
André Punt – UW School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
Richard Methot – Northwest Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
Fishery stock assessments are a crucial component of an effective scientific approach to fishery management. The quantitative methods by which these assessments are conducted continue to advance. This includes advancements in the software systems used to develop the assessment models, and the assessment models themselves are becoming more powerful and standardized. Despite these advancements, each assessment tends to be treated as an individual scientific endeavor, and the decisions made in developing each assessment are not standardized or systematically documented. The fishery assessment community has recognized this shortcoming and has vigorously participated in workshops held in 2013, 2014, and 2015 to attempt to describe good practices for treatment of key topics in fishery assessments. Despite these efforts, the current state of fishery assessment practices remains undocumented and unguided. The peer review of stock assesments represent a unique source of information about the decisions made in the assembly of each stock assessment. Although all these documents are publically available, the information they contain is not organized in a consistent manner, so the diversity of decisions made in assessments remains unknown. The goal of this research project is to assemble a sufficient sample of such assessments and their peer reviews, and to develop a description of the current state of such decisions, including recommendations on good practices where feasible.

OBJECTIVES
1. Review current literature on recommended practices when conducting fishery assessments.
2. Develop a set of factors by which fish assessments that have used the Stock Synthesis (SS) approach can be quantified.
3. Examine as many SS assessments and their associated peer reviews as feasible to classify decisions that have been made on the factors. Focus on SS assessments conducted for the Pacific, North Pacific, and Gulf of Mexico Fishery Management Councils in the past eight years.
4. Develop a good practices guide to the decision process for these factors.
5. Organize a workshop with invited fishery assessment experts to gain feedback on the proposed guidelines.
6. Develop a publishable manuscript to describe and advocate for these good practices.

REASONS WHY OBJECTIVES WERE NOT MET
It has not proven possible to find a postdoctoral fellow or graduate student with sufficient expertise in stock assessments, particularly SS, to conduct the work.

ALASKA CLIMATE PROJECT: A MULTI-MODEL ASSESSMENT OF CLIMATE CHANGE IMPACTS ON FISH, FOOD-WEBS, AND FISHERIES IN ALASKA

PI
André Punt – UW School of Aquatic and Fishery Sciences

OTHER UW PERSONNEL
Jonathan Reum, School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
Anne Hollowed – Alaska Fisheries Science Center

OTHER NOAA PERSONNEL
Kirstin Holsman – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
Climate change is a global issue affecting marine ecosystems and species that span multiple international boundaries, and is one of the most universal challenges facing fisheries scientists and managers around the world. Yet the effect of warming climate conditions on marine ecosystems and species may be system- and species-dependent, and exhibit considerable variation across space and time. To address this challenge scientists have developed global climate models (GCMs) and earth system models (ESMs) to project future conditions. These models are being tested regionally and discussed globally in an effort to initiate an international collaboration to provide quantitative estimates of the status and trends of commercial fish and fisheries worldwide by 2019. Yet the proliferation of modeling improvements and global projections creates a dilemma for regional ocean modelers and fisheries scientists as the number of possible permutations that could be explored can rapidly become too large to manage. Identifying a reasonable range of representative futures (with sufficient contrast in scenarios) and biological models allows analysts to compare projections and report on the relationship between model complexity, efficiency, and the computational costs of increased ecological realism in models. Given the rapid pace of improvements in global climate models, there is immediate need for modeling tools and frameworks that can downscale output from GCMs for use in regional ocean simulations and fisheries models. Such advancement would ensure that fisheries models and management are keeping pace with rapidly evolving climate change projections. This project will develop, evaluate, and implement a framework to couple the Intergovernmental Panel on Climate Change (IPCC) scenario-driven global climate models to fisheries population models and compare the performance of harvest control rules under future climate scenarios. Results of this work will provide essential information for strategic National Marine Fisheries Service management of fisheries under future climate conditions.

OBJECTIVES
1. How will climate change impact the productivity (in terms of biomass, growth, and recruitment) and survival of key species?
2. Are current fishery management approaches robust to climate-driven changes, or should additional

alternative harvest control rules be used?

3. What is the expected change in future fishable biomass and recommended harvest rates under climate change?

ACCOMPLISHMENTS

1. The Project Team continued to interpret derived model indices in the context of climate change (i.e., comparison with 20th century hindcast simulation) and inter-model spread. Kirstin Holsman of the Alaska Fisheries Science Center (AFSC) developed code to readily access the Regional Ocean Modeling System (ROMS) model outputs, including interactive data visualization tools (e.g., shiny() in R). This data access tool was used to derive common annual indices for use in population and food web models. Holsman used the indices to run retrospective studies of the relationships between environmental drivers and predation, mortality, growth, and recruitment of pollock, cod, and arrowtooth flounder. Fall and spring zooplankton and summer bottom temperature were key predictor variables.

2. Jon Reum of the UW School of Aquatic and Fishery Sciences (SAFS) traveled to Hobart, Australia to work with Julia Blanchard from the University of Tasmania on the climate- and species-specific size spectrum model calibration (i.e., refinement of the multi-species spectrum modeling (MIZER) model). In 2016, code for a multispecies size spectrum model was developed which included several novel extensions over earlier versions (e.g., MIZER) that allow representation of key processes of the engineered barrier systems. These include:

    - Size-structured benthos functional group that is dynamically coupled to pelagic production.
    - Species-specific ontogenetic shifts in pelagic versus benthic habitat preference.
    - Sex-specific fishery selectivities and life history traits.
    - Predation interactions between species calibrated to empirical diet data.

Changes to model code are complete and model calibration and validation is currently underway.

3. Alan Haynie of AFSC and Amanda Faig, a SAFS postdoc, have made extensive progress in identifying frameworks for identifying representative fishing pathways for use in the projections. Haynie led a 1-day ACLIM-focused socioeconomic scenario workshop at AFSC in August.

4. Several lead investigators participated in outreach activities. Haynie, Holsman, Albert Hermann of JISAO and Anne Hollowed of AFSC gave a webinar on the ACLIM project as part of outreach to research partners within NOAA. They also participated in a workshop held in conjunction with the February 2017 North Pacific Fishery Management Council meeting. The focus of the workshop was to solicit input on possible responses to climate change impacts on fish. Hermann described the ACLIM project and presented regional model results to a local high school oceanography class at Ballard High School in Seattle using immersive 3D visualization hardware.

ORAL PRESENTATIONS

1. Alan Haynie et al., Invited. “From BSIERP to ACLIM: How great acronyms and long-term research programs can help us better manage fisheries under a changing climate.” NOAA Resilient Communities Workshop, Silver Spring, MD., May 2016.
2. Jon Reum, “Identifying potential ecosystem effects of ocean acidification using size structured food web models” PICES, La Jolla, CA, November 2016.
3. Albert Hermann, “Statistical downscaling of global projections to the Bering Sea, based on an ensemble of regional model output”, PICES, La Jolla, CA, November, 2016.
4. Albert Hermann, “Statistical downscaling of global projections to the Bering Sea, based on an ensemble of regional model output”, AMSS, Anchorage, AK, January, 2017.

MANAGEMENT SCENARIOS FOR SNOW CRAB UNDER CLIMATE CHANGE

PI
André Punt – UW School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
William Stockhausen – Alaska Fisheries Science Center

NOAA GOALS
Climate Adaptation and Mitigation
Healthy Oceans

DESCRIPTION
Climate change is expected to be the largest and most rapid in the Polar Regions. In the Arctic, the combined forces of climate change and ocean acidification due to increasing atmospheric CO2 will cause changes in the ecosystem. Predicting responses of commercially valuable species in the Arctic to these changes is of great interest to scientists, managers, and fishers alike, and developing climate-ready harvest strategies and control rules is a core goal of the National Marine Fisheries Service Climate Science Strategy. This study will develop a suite of projection models that can be used to project changes in the distribution, growth, molting cycle, and abundance of snow crab in the Arctic (Northern Bering, Chukchi, and Beaufort seas) in response to loss of sea ice, warming ocean conditions, and ocean acidification. Although there is currently no snow crab fishery in the Northern Bering and Chukchi seas, it is essential for managers to collect information towards managing this stock, because there is likely to be demand for such a fishery in the next several decades.

OBJECTIVES
1. Adapt the individual-based modeling platform DisMELS (Dispersal Model for Early Life Stages) to evaluate the ratchet hypothesis that suggests that larval drift and settlement locations govern the movement trajectories of snow crab populations.
2. Conduct projections of DisMELS under various future climate hypotheses and scenarios.

REASONS WHY OBJECTIVES WERE NOT MET
It took longer than expected to identify a postdoc fellow with the requisite modelling skills. A search has taken place and a candidate has been identified. However, she just had a baby, and will not be able to start until September 2017. Once she starts, we expect to see substantial progress.

AN EVALUATION OF MANAGEMENT STRATEGIES FOR IMPLEMENTATION OF ANNUAL CATCH LIMITS FOR ALASKA GROUNDFISH

PI
André Punt – UW School of Aquatic and Fishery Sciences

OTHER UW PERSONNEL
Kotaro Ono – School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
Anne Hollowed – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans
Resilient Coastal Communities and Economies

DESCRIPTION
The National Marine Fisheries Service (NMFS) National Standard 1 guidelines for implementing the Magnuson-Stevens Fishery Conservation and Management Act identified the need to formally incorporate uncertainty into future harvest projections. This project will review the impacts of implementing management strategies that aim to satisfy these guidelines for the eastern Bering Sea Aleutian Islands (BSAI) and Gulf of Alaska (GOA) groundfish fisheries. A multispecies technical interaction model based on a linear programming approach developed at the Alaska Fisheries Science Center will be updated to reflect the constraints resulting from recent amendments to the North Pacific Fishery Management Council (NPFMC) groundfish fishery management plans for the GOA and BSAI. Methods will also be developed to estimate uncertainty buffers for species or species groups within these fisheries using the P* and decision theoretic approaches, and these methods will be linked into the multispecies interaction model. Finally, alternative management strategies will be evaluated and presented to the relevant management bodies.

OBJECTIVE
Develop a multi-species Management Strategy Evaluation (MSE) by constructing an operating model in FORTRAN and linking the operating model to an ADMB-based (Automatic Differentiation Model Builder) assessment model and a technical interactions model developed by NOAA. The technical interactions model will include constraints resulting from recent amendments to the NPFMC groundfish fishery management plans for the GOA and BSAI.

ACCOMPLISHMENTS
1. Kotaro Ono of the School of Aquatic and Fishery Sciences developed a multi-species MSE that includes a technical interaction subroutine (based on a few major BSAI groundfish species and halibut).
2. Ono worked on a collaborative project with members of the International Pacific Halibut Commission, NMFS, and the NPFMC to develop a framework for an abundance-based halibut Prohibited Species Catch (PSC) management approach (i.e. considering the control rule and the population indices to use for informing the control rule). The work was presented at the NPFMC and a few workgroup reports were written.

3. Ono developed a halibut distribution model using data from all three Alaska regions (i.e. Bering Sea, Aleutian Islands, and Gulf of Alaska) to create an index of young halibut abundance. The work was done in collaboration with NOAA employees.
4. Ono worked on a collaborative project with staff from the Institute of Marine Research in Norway, and NMFS to develop a multispecies approach for acoustic dead zone correction and catchability ratio estimate between acoustic and bottom trawl data.
5. Ono worked on a collaborative project with Stan Kotwicki of NOAA to examine the effect of variable sampling efficiency on the reliability of the survey observation error as a measure of uncertainty in abundance indices from scientific surveys.

PRESENTATIONS

1. Playing hide and seek: an insight on early stage halibut distribution in Alaska. WGISDAA Hamburg, Germany. July 2016.
2. BSAI Halibut Abundance-based PSC limits. NPFMC public workshop. Seattle. September 2016.
3. BSAI Halibut Abundance-based PSC limits. NPFMC council meeting. Anchorage. October 2016.

COLLABORATORS

1. Jim Ianelli (NOAA), Dana Hanselman (NOAA), Allan Hicks (IPHC), Carey McGilliard (NOAA), Diana Stram (NPFMC), and Rachel Baker (NOAA) for the abundance-based halibut management work.
2. Jim Ianelli (NOAA) and Carey McGilliard (NOAA) for the work on young halibut distribution and abundance index.
3. Stan Kotwicki (NOAA), Gjert E. Dingsør (IMR, Norway), and Espen Johnsen (IMR, Norway) for the multispecies approach, for acoustic dead zone correction, and catchability ratio estimate between acoustic and bottom trawl data work.
4. Stan Kotwicki (NOAA) for the work on the effect of variable sampling efficiency on the reliability of the observation error as a measure of uncertainty in abundance indices from scientific surveys.

OA PROJECTIONS FOR SNOW, TANNER, AND RED KING CRAB IN ALASKA

PI
André Punt – UW School of Aquatic and Fishery Sciences

TASK III

NOAA SPONSOR
Michael Dalton – Alaska Fisheries Science Center

NOAA GOALS
Climate Adaptation and Mitigation
Healthy Oceans

DESCRIPTION
The increase in atmospheric CO2 concentrations caused primarily by fossil fuel emissions, deforestation, and concrete production, has led to a corresponding increase in the CO2 concentrations in the ocean. This increase is leading to changes in the carbonate chemistry of the oceans and a decrease in pH. As CO2 levels continue to rise over the coming decades, the pH in the ocean will fall even further. This reduction in pH, and increase in p CO2, can have substantial physiological effects on marine organisms, affecting growth, survival, reproduction, and behavior. Calcifying organisms may be particularly affected because the reduction in pH makes it more difficult to excrete and sustain a calcified shell or exoskeleton. There is already some evidence that ocean acidification (OA) is likely to impact crabs. While the focus of the impacts of ocean acidification has been mainly on the biological effects, species such as crabs support valuable fishery resources, and OA may have major consequences for these fisheries and how they are managed. This project forecasts the potential consequences of OA on the future abundance of three vulnerable and commercially important North Pacific crab stocks. The work plan builds on past and ongoing NOAA-supported research in this area. In particular, model input will be taken from physiological research for these species that is being conducted at the Alaska Fisheries Science Center to characterize the susceptibility of juvenile eastern Bering Sea Tanner and Bristol Bay red king crab to OA and temperature changes, and the interaction between changes in pH and temperature.

OBJECTIVES
1. Extend bio-economic models for eastern Bering Sea Tanner and snow crab to allow OA impacts on juvenile survival.
2. Extend an existing bio-economic for Bristol Bay red king crab that already allows for OA impacts on juvenile survival to also account for the impacts of changing temperature on the population dynamics of this stock.

REASONS WHY OBJECTIVES WERE NOT MET
The OA and fishery data needed to conduct the analyses are not yet available.

MANAGEMENT STRATEGY EVALUATION USING THE GENERIC MODELING FOR ALASKA CRAB STOCKS (GMACS)

PI
André Punt – UW School of Aquatic and Fishery Sciences

OTHER UW PERSONNEL
D'Arcy Webber – School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
Anne Hollowed – Alaska Fisheries Science Center

OTHER NOAA PERSONNEL
Jim Ianelli – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans
Resilient Coastal Communities and Economies

DESCRIPTION
The University of Washington School of Aquatic and Fisheries Sciences (SAFS), in partnership with the Alaska Fisheries Science Center (AFSC), have developed a general size-based stock assessment model for the assessment of crab. This general model is the result of a collaborative effort to produce a framework ideally suited to accommodate users/developers working at academic institutions and different agencies. The model is suited for species that molt – i.e., growth occurs as an event rather than a continuous process. The purpose of this project is to further the development of the generalized crab stock assessment modeling framework Gmacs.

OBJECTIVES
1. Further develop software infrastructure to accommodate the many different types of data that currently exist in Alaskan crab fisheries.
2. Develop Gmacs model configurations for simulation testing and construction of an operating model.

ACCOMPLISHMENTS
1. D'Arcy Webber of SAFS is working on Gmacs together with Jim Ianelli of the AFSC, sharing code through GitHub, an open source repository that facilitates code sharing and collaboration.
2. Webber is currently working on further development of the generalized crab stock assessment model, Gmacs. The model is written in the Automatic Differentiation Model Builder (ADMB) programming language. Specifically, time-varying growth and the ability to use custom (user specified) growth matrices, sex-specific recruitment, and sex-specific natural mortality rates. These are all features required for modelling Bristol Bay red king crab.
3. Webber is currently working with Jie Zheng of the Alaska Department of Fish and Game on an assessment of Bristol Bay red king crab. Webber presented an early version of this assessment in Gmacs to the Crab Plan Team in January 2017. A preliminary version of this assessment will be presented to the North Pacific Fishery Management Council Crab Plan Team in May 2017.

4. Webber, working with Zheng and Ianelli, completed the first accepted Gmacs assessment of St. Matthew Island blue king crab in 2016.

PRESENTATIONS

1. Webber, D., Ianelli, J. and A. Punt. 2016. Gmacs & BBRKC. NPFMC Crab PLAN Team, September 2016.
2. Webber, D., Zheng, J. and J. Ianelli. 2016. Gmacs update & Saint Matthew Island Blue King Crab Assessment. NPFMC Crab PLAN Team, May 2016.
3. Webber, D. and J. Ianelli. 2017. Status Report: Gmacs BBRKC. NPFMC Crab Modelling Workshop, January 2017.

ADVANCED COMPUTING FOR ECOSYSTEM MODELING AND MANAGEMENT

PI

Ivonne Ortiz – UW Joint Institute for the Study of the Atmosphere and Ocean
Andre Punt (former PI) – UW School of Aquatic and Fishery Sciences

OTHER UW PERSONNEL

Kelly Kearney and Albert Hermann – Joint Institute for the Study of the Atmosphere and Ocean

TASK II

NOAA SPONSOR

Kerim Aydin – Alaska Fisheries Science Center

OTHER NOAA PERSONNEL

Stephani Zador, Chris Rooper, Bob Lauth, and Stan Kotwicki – Alaska Fisheries Science Center
Tiffany Vance – Integrated Ocean Observing System

NOAA GOALS

Resilient Coastal Communities and Economies
Healthy Oceans

DESCRIPTION

This project focuses on advanced computing solutions for ecosystem modeling and fisheries management. The project combines high performance computing (HPC), cloud solutions, and web tool development for a suite of models using the Regional Ocean Modelling System (ROMS) or Ecopath with Ecosim (EwE) as a framework. For models under the ROMS platform, the Bering10K-ROMS-BESTNPZD and Bering10K-ROMS-BESTNPZD-FEAST models, the project streamlines model update for programmatic use, continues model improvement and development, as well as facilitating use of model output for research. The application of ROMS models output focuses on the use of hindcast results to fill in environmental data, as well as the effect of climate change under different climate scenarios. These collaborative projects include, but are not limited to, essential fish habitat, fish distribution based on thermal envelopes, climate vulnerability assessments, and ecological indicators. Simulation using these models form the base of standardized

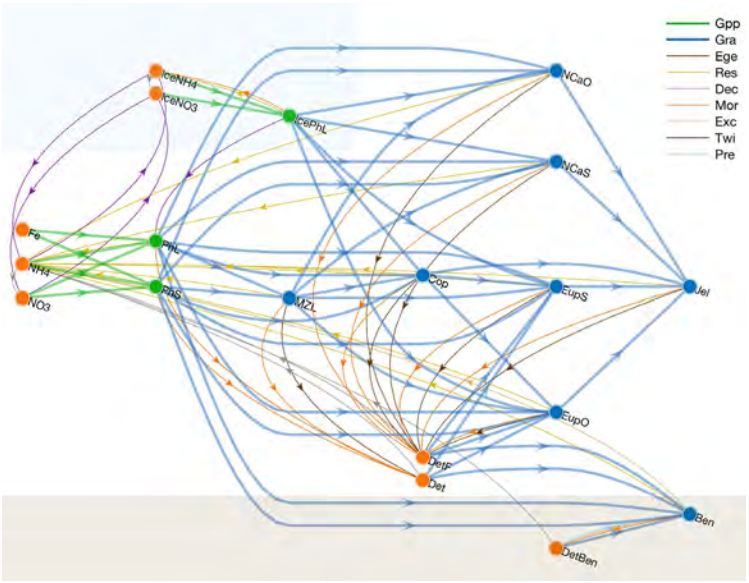
tests that will be used to evaluate alternative HPC platforms within NOAA, and the University of Washington. Finally, the project also includes the development of data visualization tools (such as food web diagrams) as part of the launch of the EwE model written in the programming language R, Rpath. Rpath and associated tools, is a project in collaboration with the Northeast Fisheries Science Center.

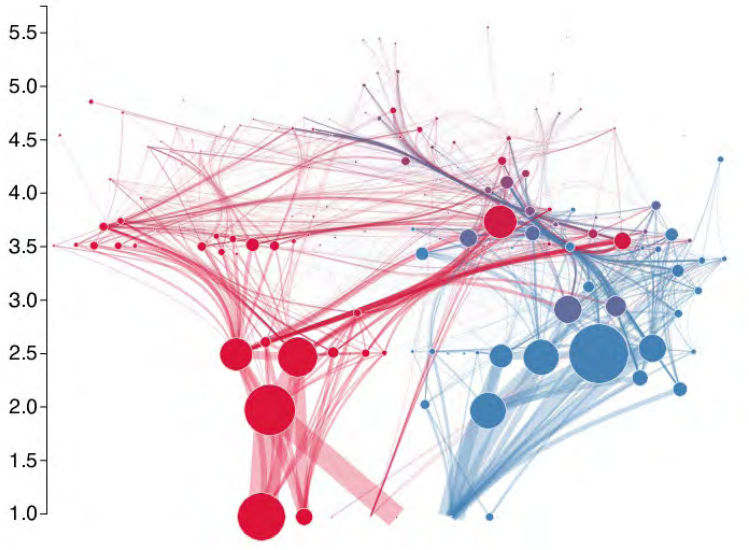
OBJECTIVES

1. Streamlining annual updates and simulation of coupled biophysical models;
2. Improvement of model routines as needed;
3. Facilitation of use of biophysical coupled model output;
4. Evaluation of alternative platforms to conduct HPC; and
5. Advance use of HPC for simulations and analysis of ecosystem models other than biophysical coupled models, as well as advance tool development for analysis of ecosystem model output and food web visualization.

ACCOMPLISHMENTS

1. Streamlining and improvement of model routines
   a. The BEST_NPZ code has been debugged and rewritten by JISAO's Kelly Kearney, with several full hindcast simulations available testing different model setups. Diapause dynamics, as well as nutrient distribution throughout the water column have been improved. The code also incorporates updates on the krill dynamics, such as benthic feeding.
   b. The oceanographic component has been improved with updated sea ice modeling and the one month lag on sea ice retreat has been reduced. Likewise, river runoff has been updated and now has a seasonal signal with higher geographical resolution. The code for the river runoff dataset has been streamlined and documented in tech memo currently under review. Updates on the Bering10k-BESTNPZ-FEAST model were postponed until the BEST_NPZ was completed.
   c. Model output from Bering10k-BESTNPZ-FEAST for fish distribution of walleye pollock, Pacific cod, and arrowtooth flounder is being analyzed and included as part of a paper focused on fish movement in





Figures 1 and 2.The two images show pathways in the Bering10k-ROMS-BESTNPZ model and a food web diagram of the eastern Bering Sea shelf and slope ecosystem where benthic pathways are shown in blue and pelagic pathways are shown in red.

the eastern Bering Sea.

d. Al Hermann and Wei Cheng of JISAO conducted six dynamic downscaling simulations using forcing from six CMIP climate models under RCPs 4.0 and 8.5 RCP for CMIP5 models: CCSM4-NCAR (medium ice), GFDL-ESM2M (high ice), and MIROCESM-C (low ice).

2. Use of biophysical model output
   a. Hermann is analyzing covariance between large-scale forcing patterns from the Intergovernmental Panel on Climate Change's (IPCC) global models projections and regional biophysical indices generated from the Bering 10k model, driven by nine separate realizations of that large-scale forcing (the six detailed above and scenario A1 for CMIP3 models CGCM-t47 (low ice), ECHOG (high ice) and MIROCM (medium ice). Ideally, this would enable the direct use of forecast realizations of the IPCC climate models without the need for downscaling simulations. Results from this work are included in a manuscript (in prep), and have been presented at conferences.
   b. Forecasts of sea ice retreat and extent of the cold pool were evaluated to test their performance under varying climate scenarios. For both indices modifications or complements are recommended to increase their information value, which would otherwise decrease under warmer conditions. Results from this analysis are included in a manuscript (in prep).
   c. Hindcasts and forecasts of surface and bottom temperature, surface and bottom current speed and direction, as well as phytoplankton biomass were extracted from regional simulations forced with scenarios from CMIP3 and CMIP5 and regridded to be used in Essential Fish Habitat models. The results will be summarized for near century, midcentury, and end of century predicted habitat for 21 species of commercial groundfish and crab.
   d. Temperature time series from the downscaled climate forecasts and hindcasts were also prepared to evaluate expected shifts in distribution in response to changes to bottom thermal envelopes under high and low biomass conditions in collaboration with Bob Lauth and Stan Kotwicki from the Alaska Fisheries Science Center.

3. Evaluation of multiple HPC platforms
   a. Ortiz got a grant for Azure credits and has been working with Azure architects to evaluate the use of Cloud HPC for simulations of regional downscaling models, and to develop a script to deploy cloud instances. A second grant was submitted to Amazon Web Services (AWS) in collaboration with Tiffany Vance from the Integrated Ocean Observing System and HPC architects from AWS. Nodes from Mox (next-gen Hyak nodes) have been ordered to test the local UW cluster, and NOAA HPC accounts are still pending after nine months.

4. Rpath: tool development for statistical analysis and data visualization
   a. Kelly Kearney has continued updating matlab Ecopath code, and is further developing interactive food web diagrams. Kearney and Aydin attended the Rpath workshop at Woods Hole and gave a presentation on the interactive diagrams at the National Ecosystem Modeling Workshop earlier in March.

ARCHIVAL STORAGE AND DISSEMINATION OF DATA ON NORTHEAST PACIFIC FISH EGGS, LARVAE, AND ADULTS

PI
Luke Tornabene – UW School of Aquatic and Fishery Sciences

OTHER UW PERSONNEL
Katherine P. Maslenikov – School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
James W. Orr – Alaska Fisheries Science Center

OTHER NOAA PERSONNEL
Ann Matarese-Kiernan – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
The Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering (RACE) Division annually collects ichthyoplankton and adult fishes from Alaska. The National Marine Fisheries Service is mandated to transfer important fish collections to the U.S. National Museum or other designated museums for permanent archival storage. The University of Washington Fish Collection (UWFC) has been designated as one of four such institutions in the United States, and is the only one that specializes in fishes from the boreal North Pacific. The facilities and personnel of the UWFC – a fully computerized, well-documented, archival research collection of freshwater and marine fishes of Washington State, the Pacific Northwest, and the Pacific Rim, existing to serve the research and educational needs of students and professionals by providing on-site study facilities; a comprehensive library of books, journals, and reprints; loans and gifts of ichthyological materials; identification services; and an active program of public outreach – are superbly suited to perform the tasks described here. Under the current grant, the RACE Division Groundfish Task, and Recruitment Processes Task each transfers significant numbers of specimens to the UWFC to be archived.

Financial support has been provided to continue a long-standing cooperative relationship with the UWFC as the repository of ichthyoplankton. As a result of previous AFSC support, we have transferred approximately 124,436 lots of eggs and larvae collected between 1977 and 2008. This consolidation of material has made the UWFC the largest repository of early life history stages of fishes in North America. Database records for 8,185,319 individual specimens are now available online from the UWFC website.

At the same time, support has been provided to the UWFC to archive vouchers of juvenile and adult fishes collected during surveys of the Alaskan continental shelf and upper slope. The UWFC has served as the primary repository for tens of thousands of juvenile and adult fishes collected since the 1970s through the center's activities. Thousands of lots of adult fishes collected from 1995 to 2017 have already been transferred to UWFC during recent years. Database records for 56,138 cataloged lots of juveniles and adults (totaling 390,766 individual specimens) are now available online from the UWFC website. These efforts will continue as we also transfer locality data and maintain a full web-based inventory of lots presently housed at UWFC.

OBJECTIVES

To provide for the archival and maintenance of specimens of fish eggs, larvae, and adults collected by the AFSC RACE Division during fisheries resource surveys conducted in the northeast Pacific Ocean and Bering Sea, the following specific tasks will be performed:

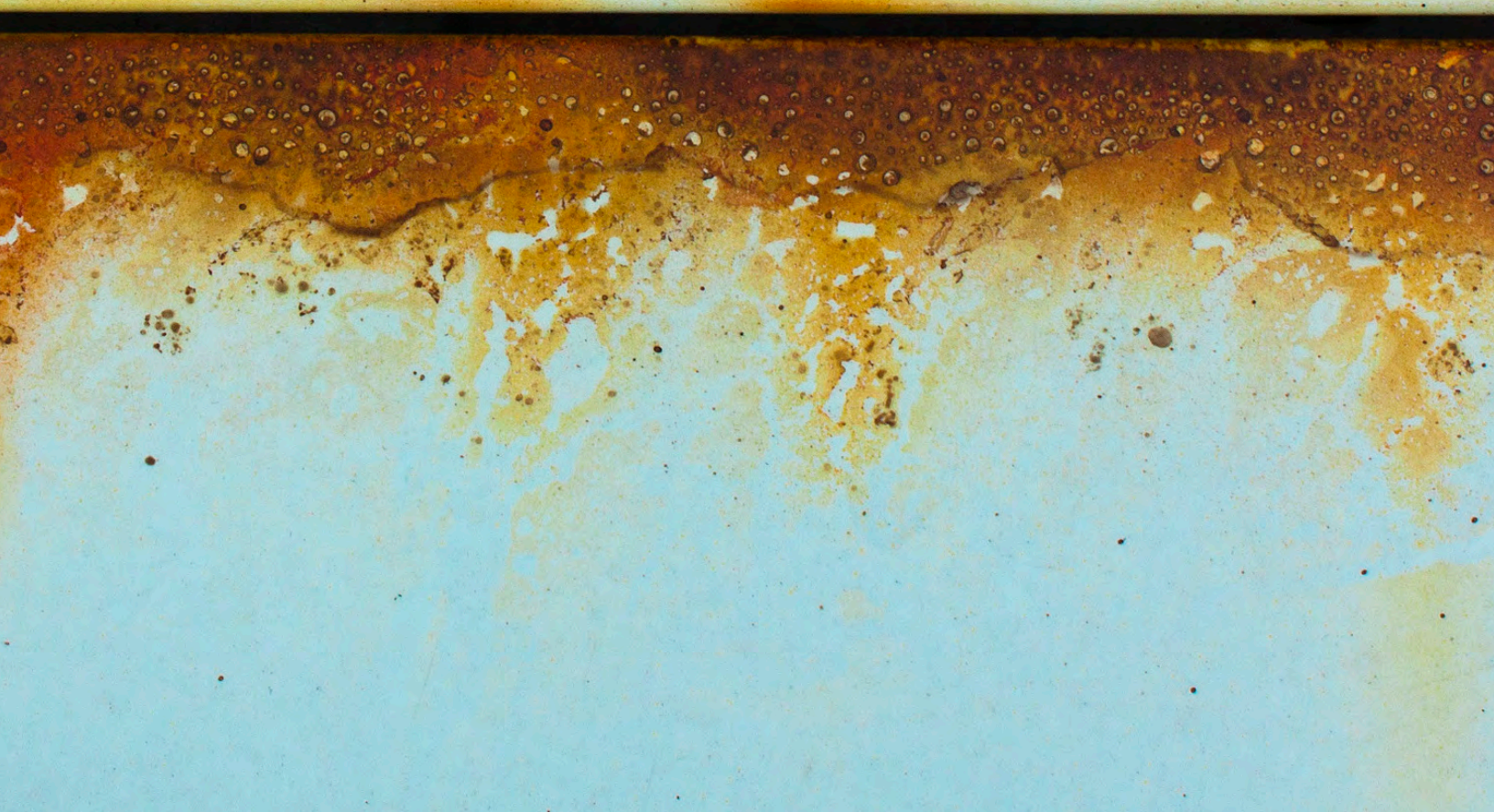
1. Provide location and storage of AFSC specimens within commuting distance of the AFSC at the NOAA Western Regional Center at Sand Point, Seattle to allow for easy and frequent access by the AFSC staff.
2. Transfer all available fish eggs and larvae collected by the AFSC RACE Division to the UWFC during the performance of the base year services of the resulting grant. Additional collections from subsequent years will be made available for transfer if any option is exercised for additional years of service.
3. Transfer up to 1,000 lots per year of adult fishes collected in RACE surveys to the UWFC. UWFC will transport specimens from AFSC to UWFC. Additional collections from subsequent years will be made available for transfer if the options for additional years are exercised.
4. Continue to update the UWFC specimen archival internet database to increase access speed and search efficiency for retrieval of information of AFSC specimens archived at UWFC.
5. Add and catalog lots of fish eggs, larvae, and adult fishes in standard UWFC specimen catalog system and maintain the archived specimens and catalog system database.
6. Provide one to three students or staff per year to participate in AFSC fisheries surveys based on three round-trip fares to Dutch Harbor, Alaska, associated per diem, and any additional labor such as overtime or hardship/weekend pay to participate on a cruise.

ACCOMPLISHMENTS

1. During the current reporting period (September 16, 2016 through March 31, 2017), graduate student Alicia Godersky and staff member Rachel Manning continued to curate the Early Life History (ELH) collection, in particular the fish eggs and larvae from AFSC. They continued to work with the material received in the 2015 transfer, which included larvae and eggs collected in 2008 and a small amount of odd material from the past few years. This material is now cataloged and ready to shelve. Samples collected in the 2009 survey year were transferred during fall quarter. This transfer contained 632,598 specimens in 3,949 lots. These samples are almost finished being labeled and shelved, after which time the data will be uploaded to the collection database and website.
2. In addition to the 2009 survey material, more than 11,000 additional lots of eggs and larvae are being transferred. This additional material is comprised of samples no longer needed in the reference collection at AFSC. This transfer will take a significant amount of time to process, however, good progress has been made in the recent weeks. Godersky defended her Master's thesis in December 2016 and is no longer working at the UW Fish Collection, and Manning has been hired full time to complete the transfer. Both Godersky and Manning collaborated with Jessica Randall, travelling to the AFSC to process the samples in the Fisheries-Oceanography Coordinated Investigations (FOCI) lab so as to clarify any errors and ensure the data in the vials matches the data in the database. Manning will continue to work with Randall until September 2017, by which time the transfer of these additional lots should be complete. We are also exploring the possibility of hiring a part-time undergraduate student to assist with labelling and cataloging of samples at the UWFC from now until September. During this period, the ELH collections staff has maintained their ability to fulfill all data and cataloging requests received from AFSC personnel, as well as those from outside user groups.
3. During this same period (September 16, 2016 through March 31, 2017), 182 lots of adult fishes, including a total of 322 specimens, all obtained from AFSC sources, were identified, curated, and archived (a complete list of species is available on request). The UWFC internet database was updated to reflect these additional cataloged lots. At the same time, tissues for future DNA studies were taken from 27 AFSC lots, transferred to appropriate vials, and placed for long-term storage in our -86º C freezer, thus adding to our

ever-growing collection of genetic resources. The number of lots with tissues samples has now reached 7,036, representing 915 species (a list of species and specimens is available on request). Our internet search interface allows individual searches for records with tissue samples (in addition to skeletal, early life history stages, and adults), using Latinized scientific names as well as common names.

OCEAN AND COASTAL OBSERVATIONS



OCEAN MAPPING METADATA COLLECTION WIZARD

PI
Thomas P. Ackerman – UW Joint Institute for the Study of the Atmosphere and Ocean

OTHER UW PERSONNEL
Iker Madera – Joint Institute for the Study of the Atmosphere and Ocean

TASK II

NOAA PERSONNEL
Peter Holmberg – National Ocean Service, Pacific Hydrographic Branch

NOAA SPONSOR
Ben Evans – National Ocean Service, Office of Coast Survey

NOAA GOALS
Healthy Oceans

DESCRIPTION
NOAA's Office of Coast Survey conducts hydrographic surveys to map depth and bottom characteristics of bodies of water, focusing on shallow features that could be hazardous to vessels. Nautical charts ensure safe navigation of vessels traveling along coastlines, river channels, lakes, and open sea routes. This work supports the continuous flow of maritime commerce through U.S. territorial waters, as well as the preservation of the marine environment.

OBJECTIVES
Grid-based hydrographic data processing requires manual evaluation to choose the best resolution in a dataset, which will be constant to all the grid tiles throughout the surface. CARIS:HIPS & SIPS 10.0 hydrographic data processing software offers a new approach to resolution estimation. It assigns resolution values based on the density distribution of data points (soundings) which are not uniform; tile size varies based on resolution values. It then distributes grouped points (nodes) evenly within a tile. This optimizes the processing time and quality of the final sea floor 2D and 3D surface models. Testing on the functionality of updated algorithms will be performed, focusing on answering the following questions:

1. Do tile resolution values follow density data distribution and bounding parameters?
2. Do nodes contain the amount of soundings set by NOAA's specifications?

ACCOMPLISHMENTS
Through JISAO's summer internship program, undergraduate intern Iker Madera worked under the supervision of Peter Holmberg from NOAA's Pacific Hydrographic Branch at the Western Regional Center. This project consisted of testing an upgraded Beta version of the CARIS: HIPS 10.0 software used to process ocean floor survey data and create 3D surface models. A comparison was conducted between the previous software version and the new capabilities of the upgraded program, ensuring protocols were being followed, and resulting surface models met standards set by the Office of Coast Survey. This internship allowed Madera to learn about the procedures behind hydrographic surveying, computer software testing protocols, and how to apply statistical data analysis concepts to evaluate datasets. He gained invaluable real-world experience of applied science, and was able to work with an excellent group of professionals at NOAA, JISAO, and UW, as well as a group of motivated young scientists who were his peers in the intern group.

POSTDOCTORAL SUPPORT FOR TECHNOLOGICAL SOLUTIONS TO FISHERIES CHALLENGES

PI
Thomas P. Ackerman – UW Joint Institute for the Study of the Atmosphere and Ocean

OTHER UW PERSONNEL
André Punt – School of Aquatic and Fishery Sciences
David Jones – Applied Physical Laboratory

TASK III

NOAA SPONSOR
Elizabeth Clarke – Northwest Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
Estimates of fish population indices from traditional monitoring methods are often very imprecise, extremely personnel intensive to obtain, and they do not provide estimates of absolute abundance. In contrast, in other areas of ocean research, and in robotics and computer vision research in general, huge technological gains are being made, pushed by rapidly increasing processing power and sensor development that could be leveraged for updating population assessment methods. The goal of this postdoc is to move current monitoring practices towards more rigorous, safer, and less personnel-intensive solutions, through activities such as the development and implementation of new sensors and/or software or automation of processes that are currently done by humans. We will hire someone who has a strong foundation in either the fishery sciences or relevant engineering fields, and have a compelling proposal for a project that bridges the gap between current monitoring practices and potential technology. One of the objectives in establishing this position is to increase ties among researchers at the UW School of Aquatic and Fishery Sciences (SAFS), UW Applied Physics Laboratory (APL) and NOAA Fisheries. Therefore, the research project should have the potential to be of interest to researchers at all three institutions.

OBJECTIVES
Hire a postdoctoral fellow to advance the application of new technology to monitor fish populations.

ACCOMPLISHMENTS
A call for proposals was developed and formed the basis for an ad that was distributed widely. Four applications were received and Sarah Webster (APL) and Andre Punt (SAFS) have identified a top candidate, whose name has been provided to JISAO's Tom Ackerman. Ackerman will need to make the final hiring decision as project PI.

OBSERVING SYSTEM RESEARCH STUDIES

PI
Nicholas Bond – UW Joint Institute for the Study of the Atmosphere and Ocean

OTHER UW PERSONNEL
Andrew Chiodi, Kevin O'Brien, Karl Smith, and Steve Hankin – Joint Institute for the Study of the Atmosphere and Ocean

TASK II

NOAA SPONSOR
D.E. Harrison – Pacific Marine Environmental Laboratory

NOAA GOALS
Healthy Oceans

DESCRIPTION
The Observing System Research Studies group performs data and modeling studies to identify climatically significant ocean-atmosphere interaction patterns and their linkages to U.S. and global weather anomalies, with the goals of improving our awareness and understanding of present climate conditions and the effectiveness of the global observing system for climate. This group also develops and makes use of information technology capabilities to manage and analyze large observational and computer-generated datasets.

OBJECTIVES
1. To undertake observing system research studies with an emphasis on evaluating and understanding the activities needed to properly sample climate-relevant variability at the marine surface, in the upper ocean, and more generally for air-sea interaction.
2. To identify useful climate indices and indicators of the state of the climate system, together with estimates of their uncertainty, that help society understand, forecast, and project seasonal and longer term weather and climate anomalies.
3. To undertake other observing system research studies deemed important by the Office of Climate Observations, and develop and maintain information technology solutions that make global oceanographic and climate datasets more accessible to the wider scientific community.

ACCOMPLISHMENTS – INFORMATION TECHNOLOGY
The Observing Systems Research Studies group continues to promote and encourage data integration and interoperability through the embracing of community data and metadata standards. We also strive to provide improved community access to data and data products.

Through projects such as the Observing System Monitoring Center and the Unified Access Framework (UAF), we've promoted the use of data standards to improve data interoperability. We continue to support, through the UAF project, a tool that allows us to crawl remote data catalogs, analyze the information collected, and then create a new, publicly available, catalog that serves data through a wide variety of data-access services. We're currently transforming this tool into a web-accessible tool that will be able to serve a broader community of users, helping other data managers create higher quality data catalogs.

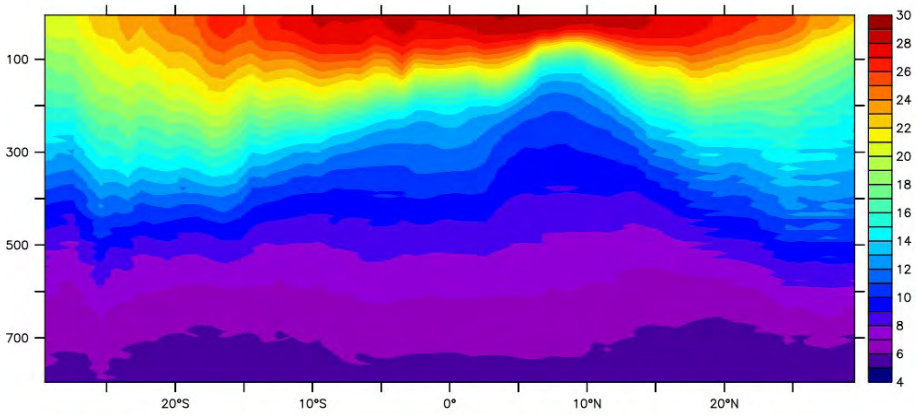


Figure 1. 2015 Tropical Pacific water temperature, averaged over time and longitude. Data pulled from the integrated dataset consisting of data from several distinct platform networks (Argo, Drifting Buoy, Moorings, Gliders, etc.).

We're currently providing data from a wide variety of NOAA and non-NOAA sources to the community, making approximately 11,000 datasets available in this manner. In the past year, we have turned our attention to providing the same level of access to ocean *in situ* observations, as well. By embracing the Climate and Forecast Discrete Sampling Geometry conventions, as well as a data integration framework/tool called ERDDAP (Environmental Research Division's Data Access Program), we are able to provide integrated access to all kinds of ocean observations, both in real time and delayed mode. This past year, we have worked on a pilot project, commissioned and supported by the WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) in providing an integrated platform for the various networks that are a part of the Tropical Pacific Observing System 2020 effort. The goal is to provide ocean data to users in formats that they understand and can access online. This work is being done with the support of the JCOMM Data Integration Task Team, whose co-chair is JISAO's Kevin O'Brien.

The Observing System Research Studies group continues to help scientists visualize and analyze data by assisting them in creating very high quality data products.

PyFerret v7.1.1 – The python version of the popular application Ferret, has been officially released for public use. It's currently being used at NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) in the post-processing workflow integrated with all of their model runs. PyFerret has greatly improved graphics creation and integration of numerical and scientific libraries. The recently added dimensions to the computational facilities of Ferret/PyFerret have allowed scientists to extend their analysis to a total of six dimensions. Typically, the additional dimensions will be used for ensemble and forecast analysis, both of which are becoming increasingly important to large-scale modeling projects. We are working closely with our GFDL colleagues to further integrate PyFerret into the GFDL community, which is quickly embracing python as their analysis tool of choice. The most recent release of PyFerret has the ability create ensemble and forecast aggregations on the fly from model data.

The group continues to play a central role in the data management of the Surface Ocean Carbon Atlas (SOCAT) project, which establishes a high quality, global surface CO_2 dataset. The SOCAT v4 synthesis product was released to the community-at-large in September 2016. SOCAT v4 continued the use of data ingestion and quality control workflow that was pioneered in SOCAT v3. Scientists are able to submit their data and metadata through a data ingestion dashboard, where the data is automatically quality controlled in order to find outliers that would otherwise derail QC work further in the process. This automated framework has significantly improved efficiency. In fact, the Global Carbon Project's Annual Carbon Budget (*globalcarbonproject.org/carbonbudget*) is now exclusively using SOCAT data to calculate the global carbon budget. Data for SOCAT v5 is currently being ingested into the system, and is slated for a June 2017 release.

2016 PRESENTATIONS – INFORMATION TECHNOLOGY

1. "JCOMM Observations Coordination Group Data Integration Perspective", JCOMM Data Management Coordination Group, Oostende, Belgium, 7/2016.
2. "Advancing NetCDF-CF for the Geoscience Community", Earthcube All Hands Meeting, Denver, CO, 7/2016.
3. "Integrating Data and Information Across Observing Systems – an update on JCOMM Observation Coordination Group efforts", Data Buoy Cooperation Panel Annual Meeting, San Diego, CA, 10/2016.
4. "It Takes More than a Data Portal or: Leveraging the Common Framework for Earth-Observation Data to Improve Interoperability", AGU, San Francisco, CA, 12/2016
5. "ERDDAP: Introduction and Usage", Session organizer and chair, NOAA Environmental Data Management Workshop, Bethesda, MD, 1/2017.
6. "ERDDAP: A Framework for Operational Workflows and Interoperable Data Access", AMS, Seattle, 1/2017.
7. "ERDDAP: A Framework for Operational Workflows and Interoperable Data Access", Ocean Data Interoperability Platform 2nd Workshop, Remote participation, 3/2017.
8. "The OpenGTS Pilot Project", US IOOS Data Management and Communications annual meeting, Silver Spring, MD, 3/2017.

ACCOMPLISHMENTS - SCIENTIFIC AND OBSERVING SYSTEM

1. Shown that that the TAO/Triton array fulfills its design objective of providing essential knowledge of the wind and wind stress variability associated with the development of El Niño and La Niña events.
2. Shown that the reanalysis wind products most commonly used in El Niño and La Niña studies would be more useful if they were able to assimilate the available TAO/Triton observations with higher fidelity.
3. Identified the specific aspects of the observed equatorial Pacific wind events that we will need to predict if we want to better forecast the development of El Niño events in years like 2014 and 2015.
4. Confirmed, through examination of the available observations of the coupled tropical Pacific system in 2015 and global weather conditions experienced in the winter of 2015-16, that our previously suggested Outgoing Longwave Radiation (OLR) perspective on El Niño seasonal weather associations holds for the 2015-16 El Niño event. Our OLR El Niño index is directly useful to seasonal winter weather forecasting efforts in the El Niño -affected regions.
5. Showed that using only the OLR events for winter forecasts yields superior retrospective skill than the quasi-linear statistical approach used by many.
6. Characterized the atmospheric circulation conditions associated with the summertime rainfall events over the Pacific Northwest that set the timing of the region's wildland fire season in a way that offers complementary improvement to our existing ability to forecast such events.
7. Began studies of the variability of surface pCO_2 observations in the SOCAT data set, and of Sea Surface Temperature products over the tropical Pacific.
8. Maintained the State of the Ocean website, which is available at *stateoftheocean.osmc.noaa.gov/all/*, and made progress on updating it to include the OLR El Niño index (the back-end calculations and figures needed for adding an OLR El Niño Index page are now regularly produced by our system). When complete, we believe this addition will more conveniently offer the scientific/forecasting community, as well as the interested public, a way to identify, in time to be useful to winter forecasts, the events that are most likely to exhibit the familiar El Niño seasonal weather associations over affected regions.

OCEAN CLIMATE STATIONS

PI
Nicholas Bond – UW Joint Institute for the Study of the Atmosphere and Ocean

OTHER UW PERSONNEL
Jennifer Keene, Nathan Anderson, Patrick Berk, Dongxiao Zhang, Adrienne Sutton, Daniel Dougherty, and Dai McClurg – Joint Institute for the Study of the Atmosphere and Ocean

TASK II

NOAA SPONSOR
Kathy Tedesco – Climate Program Office

OTHER NOAA PERSONNEL
Meghan F. Cronin and Christian Meinig – Pacific Marine Environmental Laboratory

NOAA GOALS
Climate Adaptation and Mitigation

DESCRIPTION
NOAA's Ocean Climate Stations Project (OCS) aims to make climate quality air-sea interaction observations that can be used as reference time series for assessment studies and process studies.

OCS currently maintains two reference station moorings in the North Pacific (Figure 1): The Kuroshio Extension Observatory (KEO) and Station Papa. KEO is located in the North Pacific's western boundary current region, which is characterized by extremely large ocean heat losses to the atmosphere and carbon dioxide uptake by the ocean. Station Papa is where an ocean weather ship was stationed from 1949 to 1981. Ocean measurements at Station Papa extend back almost six decades, making it one of the longest ocean datasets in the world. These moorings are part of the Ocean Sustained Interdisciplinary Time Series Environmental Observatory (OceanSITES) global network of ocean reference stations. Data from OCS moorings provide the foundation blocks for the NOAA Climate Observation Division's program deliverables of global climate analysis products.

Figure 1. Ocean Climate Stations mooring sites. KEO: 32.3°N, 144.6°E; Station Papa: 50°N, 145°W.

OCS surface moorings carry a suite of sensors on the buoy tower and underwater on the buoy bridle. Sensors are also mounted on the mooring line and on the release connecting the mooring line to its anchor. In total, the OCS instruments measure 11 different parameters including winds, air temperature, relative humidity,

barometric pressure, rainfall, downward infrared radiation from the sky, incident light (heat) from the sun, as well as upper ocean temperature, salinity (conductivity), pressure, and currents. Partner instruments on the buoys also measure atmospheric and seawater carbon dioxide, dissolved oxygen, and pH. These are among the Essential Ocean Variables (EOVs) and Essential Climate Variables (ECVs) as defined by the Global Ocean Observing System and Global Climate Observing System programs.

All of these co-located measurements, made over an extended time period, allow researchers to study exchanges of heat, moisture, momentum, and carbon dioxide between the sea and the air. These exchanges (referred to as air-sea fluxes) both depend on, as well as impact the oceanic and atmospheric environments. Interactions between the ocean and atmosphere affect weather, local and global climate patterns, as well as ecosystems and the environment.

Figure 2. Typical OCS surface mooring configuration.

Users of OCS data range from school children to Ph.D. researchers around the world. Purposes for data use include validation of satellite products, validation and improvement of weather and climate models, detection of ocean and atmospheric interactions during typhoons and winter storms, and monitoring longer term changes in the climate system. Data from OCS moorings are also used in the study of ocean acidification resulting from rising levels of carbon dioxide concentrations in the atmosphere, and its impact on ocean ecosystems. Understanding climate processes and biases in models helps scientists to improve the numerical models used to predict weather patterns and potential risks to society. Better forecast models can help reduce vulnerability to weather and climate extremes, predict potential risks to coastlines and coastal infrastructure, and prepare a weather-ready nation.

PMEL OCS stations contribute to the global network of OceanSITES reference stations. These stations provide high quality data that can be used to assess biases and uncertainties in forecasting model and observational product analyses, to detect rapid changes and episodic events, as well as long-term changes in the climate system, and to identify mechanisms and relationships within the climate system.

OBJECTIVES

1. Obtain calibrated surface meteorological and subsurface temperature, salinity, and currents at the OCS stations.
2. Provide access to OCS data and metadata through linked web pages in a standard format to encourage broad use of data.
3. Contribute to the scientific understanding of the global climate system, through analysis of the reference data and analyses of numerical model or satellite products that have been validated against reference data.

For more detail on the OCS project, see *pmel.noaa.gov/OCS*

ACCOMPLISHMENTS

Successful ongoing operation of OCS moorings:
During the summer of 2016, the OCS group successfully performed deployment/recovery operations for all OCS moorings. The KEO mooring was first established in 2004, and has now been deployed for its 13th year. Data from the KEO mooring have become valuable for improving understanding of the effects of tropical cyclones and typhoons.

For Station Papa, 2016 was the 10th year an OCS buoy was deployed at the site. The OCS mooring at Station Papa has become the primary observing platform at a site where weather has been monitored in some form since 1949. It now also serves as the central mooring of an Ocean Observatories Initiative global node established at Station Papa in July 2013.

These moorings deliver continuous instrumental records for global climate analyses. Measurements include upper ocean temperature and surface currents, ocean heat content and transport, air-sea exchanges of heat, momentum and freshwater, and ocean carbon uptake and content. The long-term data sets being established at these sites are valuable for monitoring ocean climate, both in the short term for improving weather forecasts, and long term for understanding and predicting climate variability and change.

Estimate of the diffusivity at base of the mixed layer used to close the carbon budget:
Using data from the OCS KEO and Papa moorings, in combination with data from satellites, Argo floats, and a glider, Cronin, *et al*. (2015) calculated and closed the mixed layer heat budget at both KEO and Station Papa, and also closed the salt budget at Papa. The budget residuals were used to estimate turbulent mixing at the base of the mixed layer, which was then related to a diffusion coefficient.

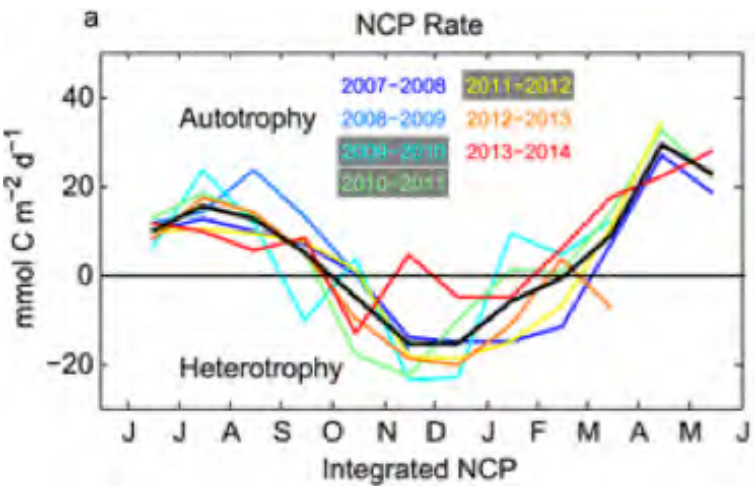


Figure 3. NCP rates from Station Papa, 2007 – 2014. Black line is the mean of all years. From Fassbender, *et al.* (2016a).

These diffusivity time-series at KEO and Papa were then used by Fassbender, *et al*. (2016, 2017) to close the carbon budgets at these sites, with the residual interpreted as the source/sink of carbon associated with the biological activity throughout the year. With the budget framed in terms of Dissolved Inorganic Carbon (DIC) and Total Alkalinity (TA), which was estimated from salinity measurements on the moorings, the residual biological term could be decomposed into a net community production (NCP) term for organic matter, and a calcium carbonate production term for inorganic matter. Data from Papa showed extended net autotrophy from spring through summer, followed by net heterotrophy (i.e. increase in DIC due to respiration) during the fall (Figure 3). KEO showed large net autotrophy and DIC drawdown due to springtime blooms.

These studies used essentially every single observation on both of the KEO and Papa moorings and are providing direct evidence of how western boundary currents regions work to absorb carbon from the atmosphere.

Classic ocean response to winds found to be altered where fronts exist in the ocean:

In regions where strong fronts exist in the ocean, such as the western boundary currents where the OCS KEO mooring is located, Cronin and Tozuka showed that the ocean response to wind does not always match the widely accepted classic theory offered in textbooks and literature.

According to the classic Ekman theory developed in the early 20th century, wind blowing across the sea surface coupled with the rotation of the Earth causes ocean currents that spiral to the right in the Northern Hemisphere, and to the left in the Southern Hemisphere. The spiraling currents result in a net water movement that is offset by 90° from the wind direction.

This classic theory assumes that the near-surface ocean is uniform in density, meaning it has no fronts. In their paper, "Steady state ocean response to wind forcing in extratropical frontal regions," published in Scientific Reports in 2016, Cronin and Tozuka show that the classic Ekman response is actually altered in regions where fronts exist.

Surface geostrophic currents have a vertical shear aligned with density fronts. This oceanic "thermal wind" shear can balance a portion of the surface wind stress. In these regions, surface ocean currents respond to the effective wind stress, which is the portion of the wind stress that is out of balance with the ocean's surface geostrophic shear. This means that the effect of the wind on the ocean currents and water transport, in areas where the water mass is not uniform, is not as simple as the classic theory would indicate.

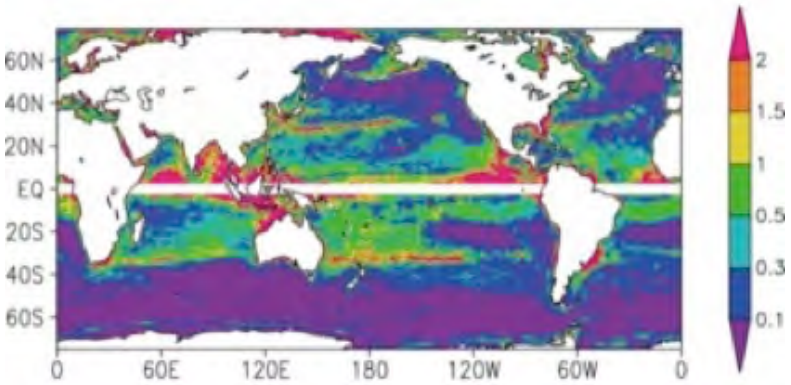


Figure 4. Global map of the ratio of the mean surface geostrophic shear stress magnitude (|τp|) to the mean wind stress magnitude (|τ0). R = |τp|/|τ0|. Where R is greater than 1, frontal effects dominate the classic "Ekman" response to wind forcing. From Cronin and Tozuka (2016).

Using data from the high-resolution Japanese Ocean general circulation model For the Earth Simulator, the authors demonstrate that these frontal effects cannot be ignored in the Tropics or in strong frontal regions in the extra-tropics, such as found in coastal regions and in western boundary currents of all basins. Frontal effects were also shown to dominate the classic Ekman response in regions of both hemispheres where trade winds change to westerlies. Figure 4 shows the regions where the frontal effects were found to be dominant.

These frontal effects on the steady-state surface current response to wind forcing have important implications for vertical motion and for global heat budgets, beyond what has been previously understood using classic theory.

Number of publications that use OCS data for assessments continues to rise:
Researchers from around the world use data from the OCS moorings to study the state of the world's ocean and its regional variations. In FY16, seven papers were published using OCS data for assessments.

Publications by authors other than the project PI are encouraged through making the OCS data freely available to the public. A total of 9,138 data files were downloaded from the OCS website during FY16. OCS data are also served on several other external sites where downloads are not tracked, so the total number of data files downloaded is likely much higher.

Data Downloads	FY11	FY12	FY13	FY14	FY15	FY16
Files downloaded from OCS website	594	666	610	1,900	7,000	9,138

Table 1. Number of data files downloaded from the OCS website each fiscal year since 2011. Usage statistics from other sites that also serve OCS data are not tracked.

It is the consistency and reliability of the OCS data that make them valuable. Data return percentages from the OCS moorings were a combined 90% during FY16, which is considered very good. Due to the harsh conditions of the North Pacific, all OCS moorings carry redundant meteorological sensors and two data acquisition systems for improved data returns. When one sensor or system is damaged or malfunctions, there is a backup that can be used to replace the primary data source. This has helped the project to maintain high data return percentages. The moorings maintained by the OCS project provide information about the state of the ocean and its regional variations through continuous high-quality measurements.

VESSEL CHARTER FOR AN OCEAN ACIDIFICATION MOORING SERVICING CRUISE

PI
Jan Newton and John Mickett – UW Applied Physics Laboratory

TASK III

NOAA SPONSOR
Dwight Gledhill – NOAA Ocean Acidification Program

NOAA GOALS
Climate Adaptation and Mitigation
Healthy Oceans

DESCRIPTION
Since 2010, the University of Washington's Applied Physics Laboratory has partnered with the Pacific Marine Environmental Laboratory's (PMEL) Carbon Group to maintain a long-term Ocean Acidification (OA) mooring system on the Washington Shelf. Maintenance of this mooring system requires semi-annual cruises to swap out the mooring infrastructure and instruments.

Funding was provided to cover vessel costs for the 5-day fall 2016 mooring servicing cruise – specifically for chartering the research vessel Aquila on a 5-day mooring servicing cruise off the Washington Coast that started and ended in Seattle. During this cruise, which spanned October 23-27, we recovered several subsurface moorings used to measure OA properties off the Washington Coast, deployed a new surface mooring (Winter Cha'Ba) that was equipped with a variety of sensors including a PMEL-maintained pCO_2 system and several pH sensors, and collected conductivity, temperature, and depth (CTD) profiles and water samples at 12 different established stations in support of OA research.

OBJECTIVE

As our primary budgets in support of these OA moorings do not include ship time, we required extra funds to cover vessel costs for servicing these moorings. In the past, we have often been generously granted state-paid ship time aboard the R/V *Thompson* to service these moorings during a week-long fall student cruise. However, the R/V *Thompson* was in the yards during the fall of 2016. The primary objective of the cruise was to recover the two moorings that were deployed, and to deploy the new Winter Cha'Ba OA mooring, while also collecting CTD and water samples to augment and verify the mooring observations.

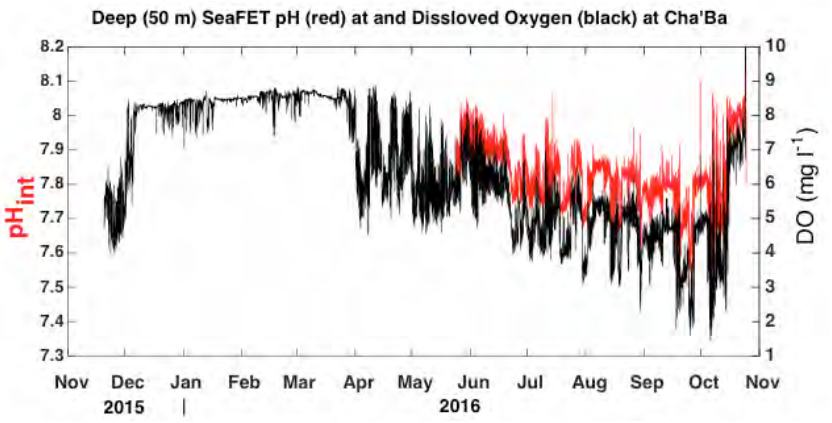


Figure 1. Observations from the OA moorings recovered on this cruise showing dissolved oxygen (black) and pH (red) at 50 m depth at the Cha'Ba mooring site.

ACCOMPLISHMENTS

1. We successfully recovered the two deployed moorings. Together, these moorings provided an exceptional record of deep pH and other properties that can be used in empirical formulas for pH (e.g. dissolved oxygen, salinity, temperature), extending from late May 2016 until recovery on October 24th. Together with previous mooring deployments, these data helped to establish the first records of the seasonal variability of deep (50 m) pH and dissolved oxygen on the Washington Shelf, highlighting the steady drawdown of both during the summer due to local respiration.
2. Despite deteriorating weather, on October 25th, we successfully deployed the new Winter Cha'Ba mooring with all systems working at of the time of deployment.
3. We collected 12 CTD casts at different stations within Puget Sound, collecting water samples to analyze dissolved oxygen, total alkalinity, dissolved inorganic carbon, nutrients and chlorophyll at multiple depths at seven of these stations.

Figure 2. Deploying Winter Cha'Ba from the R/V Aquila.

COORDINATION, DATA MANAGEMENT, AND ENHANCEMENT OF THE INTERNATIONAL ARCTIC BUOY PROGRAMME (AND U.S. INTERAGENCY ARCTIC BUOY PROGRAM)

PI
Ignatius Rigor – UW Polar Science Center/Applied Physics Laboratory

OTHER UW PERSONNEL
Wendy Ermold, Jim Johnson, and Kay Runciman – Polar Science Center/Applied Physics Laboratory

TASK III

NOAA SPONSOR
Debbie Galo – OAR Climate Program Office

NOAA GOALS
Climate Adaptation and Mitigation

DESCRIPTION
Our ability to predict weather and sea ice conditions requires *in situ* observations of surface meteorology and ice motion. These observations are assimilated into Numerical Weather Prediction models that are used to forecast weather on synoptic time scales, and into the many long-term atmospheric reanalyses (e.g., National Centers for Environmental Prediction/National Center for Atmospheric Research Reanalysis) that are used for innumerable climate studies. The impact of these *in situ* observations was documented in Inoue et al. (2009). It showed that the standard deviation in gridded sea level pressure (SLP) reanalyses fields over the Arctic Ocean was more than 2.6 hPa in areas where there were no buoy observations to constrain the reanalyses, and this uncertainty in the SLP field spreads to cover the entire Arctic when the observations from buoys are removed from the reanalyses. The buoy observations also help constrain estimates of wind and heat. *In situ* observations of sea ice motion are also important for estimating the drift of various areas and types of sea ice, and for understanding the dynamics of ridging and rafting of this ice, which changes the thickness distribution of sea ice. Over the Arctic Ocean, this fundamental observing network is maintained by the International Arctic Buoy Programme (IABP), and is a critical component of the Arctic Observing Network (AON). The funds from this particular IABP grant are focused on maintaining a well-spaced AON that may be used as ground truth for satellites, and support ice forecasts by the National Ice Center. We monitor and maintain a network of drifting buoys on the Arctic Ocean to provide meteorological and oceanographic observations for real-time operational requirements and research purposes, including support for the World Climate Research Programme (WCRP), the World Weather Watch (WWW) Programme, and the AON. These observations will also support the WCRP and WWW Polar Prediction Project.

ACCOMPLISHMENTS
The IABP is a collaborative effort of 32 different research and operational institutions from many different countries (*iabp.apl.washington.edu/overview_participants.html*). No single institution or agency can maintain the AON. The IABP is funded and managed by the participants of the program. Management of the IABP is the responsibility of the Executive Committee, of which Pablo Clemente-Colón is a member, and operation of the program was delegated to the coordinator of the IABP, Ignatius Rigor.

The U.S. contribution to the IABP is coordinated through the U.S. Interagency Arctic Buoy Program (USIABP), which is managed by Curtis Reinking at the Naval Ice Center and Rigor at UW's Polar Science Center/Applied Physics Laboratory. The USIABP is also a collaborative program that draws operating funds and services

from a number of U.S. government organizations and research programs, including the National Aeronautics and Space Administration, the Coast Guard, the Department of Energy (DOE), NOAA, the National Science Foundation, the Naval Oceanographic Office, the National Ice Center, and the Office of Naval Research. From these contributions, the USIABP acquires and deploys buoys on the Arctic Ocean, and supports the coordination and data management for the IABP.

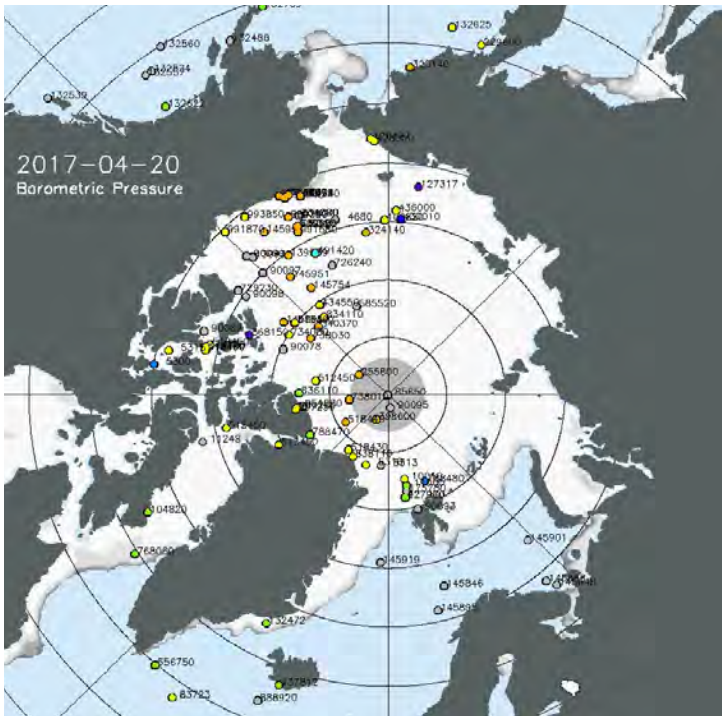


Figure 1. Map of buoys reporting from the Arctic Ocean on April 20, 2017. There are currently 105 buoys reporting in the IABP observing network, and reporting on the WMO/IOC GTS.

1. Arctic Buoy Deployments
   In 2016, we deployed three Airborne Seasonal Ice Buoys (AXIB), 4 Seasonal Ice Beacons (XIB, and 30 Surface Velocity Program (SVP) Barometer buoys. So far this year, we have deployed 1 Ice Mass Balance (IMB), and 6 SVPs and 1 Ice Tracker.

   We currently have 3 AXIBs 2 XIBs and 45 SVPs that we plan to deploy during summer and fall of 2017 from aircraft and ice breakers.

   The USIABP buoys are deployed during various field campaigns. In 2016/2017, these include:
   a. Naval Research Laboratory: 2 SVPs, 2 CALIBs, 1 Ice Tracker north of Barrow, Alaska.
   b. Arctic Submarine Laboratory, Ice Experiment (ICEX) camp: 2 SVPs.
   c. Norseman 2: 3 SVPs.
   d. Coast Guard Arctic Domain Awareness Flights: 3 AXIBs deployed in July and September 2016.
   e. Coast Guard ice breaker CGC Healy: 4 AXIBs, 20 SVPs.

   Further details on our deployment plans may be found at *iabp.apl.washington.edu/overview_deploymentplans.html*.

2. IABP Coordination
   In addition to the buoy purchases and deployment logistics described above, this grant also partially funds the coordination of the entire IABP. All the Arctic buoys are purchased and deployed using a combination of equipment and logistics coordinated with collaborators of the IABP (Figure 1).

3. Arctic Observations Experiment (AOX)
   We are continuing our assessment of the instruments used by the USIABP/IABP to observe Arctic weather and climate at the AOX buoy test site, which we installed in March 2013 at the DOE Atmospheric Radiation Measurement and NOAA Climate Monitoring and Diagnostics laboratory sites in Barrow, Alaska. Preliminary results from our assessments show a warm bias in the air temperatures measured by some buoys. To address this bias, we have been developing a new buoy (electronics) that incorporates better thermistors and ventilated shields. We installed a prototype of this buoy at the test site in March 2016.

PUBLICATIONS
Since the inception of this project over 800 papers have been published using data produced by this grant. During 2016, over 30 papers acknowledge use of our data:

THE ARGO PROJECT: GLOBAL OBSERVATIONS FOR UNDERSTANDING AND PREDICTION OF CLIMATE VARIABILITY

PI
Stephen C. Riser – UW School of Oceanography

OTHER UW PERSONNEL
Dana Swift, Annie Wong, Anil Rupan, Greg Brusseau, Andrew Meyer, and Earle Wilson – School of Oceanography

TASK III

NOAA SPONSOR
Steve Piotrowicz – Climate Program Office

NOAA GOALS
Climate Adaptation and Mitigation
Healthy Oceans

DESCRIPTION
Argo is an international project that has deployed over 3,000 profiling floats in the world ocean since the year 2000. Each of these floats collects temperature and salinity profiles at about 10-day intervals, between the ocean surface and a depth of 2,000 m, and transmits the data to shore stations in real-time while on the sea surface. Over 30 countries are now participating in Argo, with the U.S. providing about half the total number of floats. The University of Washington is one of four U.S. sites that provide Argo floats. In addition to constructing and deploying floats, the UW group carries out delayed-mode adjustment of the salinity data collected by the UW floats, and the project PI, Stephen Riser serves as a member of the U.S. and International Argo Steering Teams.

OBJECTIVES
1. To continue participation in the Argo program. This international program is designed to deploy 3,000 profiling floats in the world ocean (approximately 300 km resolution over the globe) that will collect profiles of temperature and salinity over the upper 1,000 m of the world ocean at approximately 10-day intervals. This is the first subsurface global ocean observing system.
2. The U.S. is committed to providing about half of these floats. For the past several years, the U.S. has been providing over 300 floats per year, split among four institutions: Scripps Institution of Oceanography, Woods Hole Oceanographic Institution, Pacific Marine Environmental Laboratory, and UW.
3. In the past year, funds were received to build and deploy 90 floats. The UW floats were deployed in the Indian Ocean, the Antarctic, the Atlantic, and the Pacific. Most continue to operate as designed for at least four years, many for considerably longer.

4. At the present time, the data are being used to examine the state of the Indian Ocean Dipole, the Pacific Decadal Oscillation in the North Pacific, long-term (decade to century) scale of variability of salinity in the North Pacific, and the circulation and heat and freshwater balances near Antarctica.

ACCOMPLISHMENTS

1. During the past year, the team deployed 101 profiling floats as part of Argo, the largest number of any single float group in the world. Floats were deployed in the Atlantic, Pacific, and Indian Oceans, as well as around Antarctica. Some of the UW floats in the Antarctic have now been operating for four winter seasons. A majority of the UW floats were deployed in the subtropical South Pacific using a charter vessel, the R/V *Kaharoa* from New Zealand, paid for using Argo funds.
2. Some of the floats deployed in the past year (about 28) were deployed in the Southern Ocean, for the third year in a row. These floats used new software that allowed them to operate for extended periods under seasonal Antarctic ice. All of the Antarctic floats used the Iridium communication system, and many carried dissolved oxygen sensors. In some cases the cost of these floats was shared with the National Science Foundation, through the Southern Ocean Carbon and Climate Observations and Modeling program.
3. Seven papers were published in refereed journals using Argo data, and a graduate student, Tyler Hennon (partially supported by this project) received his Ph.D. in June 2016. He is now a postdoc at Scripps Institution of Oceanography.

EVALUATING DEMERSAL FISH IDENTIFICATION AND RESPONSE TO ARTIFICIAL LIGHT AND ACOUSTIC NOISE USING A 360-DEGREE CAMERA AND IMAGING SONARS

PI

Sarah Webster – UW Applied Physics Laboratory

OTHER UW PERSONNEL

Marc Stewart and James Joslin– Applied Physics Laboratory
Brian Polagye – Mechanical Engineering

TASK III

NOAA SPONSOR

M. Elizabeth Clarke – Northwest Fisheries Science Center

NOAA GOALS

Healthy Oceans

DESCRIPTION

We proposed to develop and test a fixed camera platform that includes both a 360-degree camera and imaging sonar in order to 1) improve information gained from fixed camera systems by simultaneously

viewing the entire circumference around camera 2) to determine fish avoidance around the platform to allow determination of absolute abundance.

OBJECTIVES

Most fixed camera platforms in use to assess fish populations have a limited field of view. A 360-degree camera can improve the data collected from fixed platforms by allowing viewing of fish over the entire circumference of the platform simultaneously. This will improve fish counts and estimates of sample volume. Using a 360-degree camera coupled with two different very high frequency sonars will address information gaps that plague remote species identification and enumeration by providing an assessment of fish response to light and acoustic noise. This project will contribute to the future design of sampling equipment and potentially serve as a stationary calibration platform for remote monitoring systems currently in use.

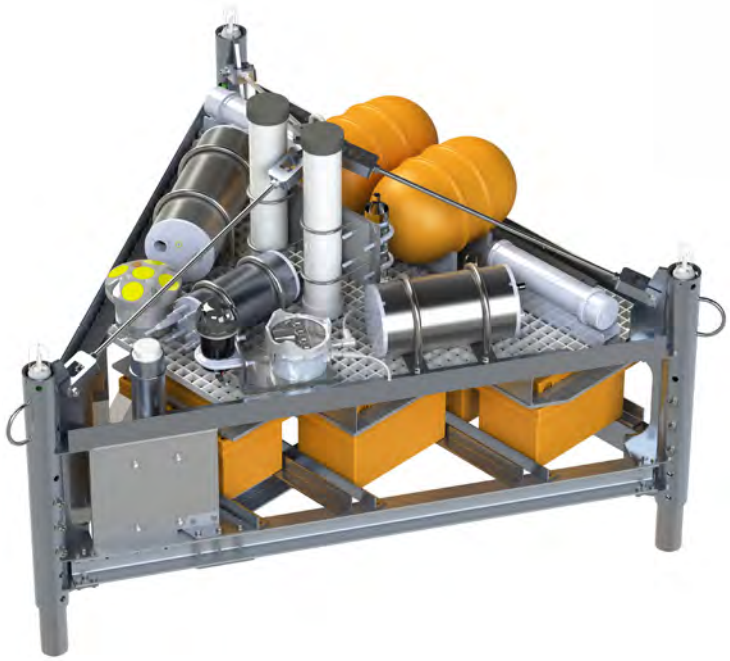


Figure 1. This figure shows a model of the iAMP, which is currently under construction. We are currently designing a special camera mount for the Battelle 360-degree camera.

ACCOMPLISHMENTS

We were able to leverage upgrades to an existing platform, the integrated Adaptable Monitoring Package (iAMP), which is under development at the Applied Physics Laboratory, and already has a camera interface, integrated strobe lights, an integrated M900 BlueView sonar, and command and control software. As such, research has focused on defining the necessary interfaces for the Batelle 360-degree camera, investigating the availability of lower power strobes, and developing a detailed testing plan. Local testing will occur in October 2017. The final testing will be carried out in either November 2017 or January 2018 depending on ship availability. The platform has been selected, and the initial power budget and camera integration plan has been completed. We are in the process of designing a camera mount to provide as much coverage as possible without interference from the iAMP structure, and optimal lighting.

TROPICAL ATMOSPHERE – OCEAN INTERACTION

PI
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OTHER UW PERSONNEL
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TASK II

NOAA SPONSOR
Michael J. McPhaden – Pacific Marine Environmental Laboratory

OTHER NOAA PERSONNEL
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NOAA GOALS
Climate Adaptation and Mitigation

DESCRIPTION
JISAO research on tropical atmosphere-ocean interaction seeks to improve understanding and prediction of phenomena such as the El Niño-Southern Oscillation (ENSO), the seasonal monsoons, the Indian Ocean Dipole, and tropical Atlantic climate variability. Tropical moored arrays are the foundation of observing systems in each of the three tropical oceans. The Tropical Atmosphere Ocean (TAO) in the Pacific was the first to be implemented beginning in 1984. Originally designed, implemented, and maintained by the Pacific Marine Environmental Laboratory (PMEL) and JISAO, the TAO array has been operated since 2005 by NOAA's National Data Buoy Center. Complementing TAO in the western Pacific since 2000 is the Triangle Trans-Ocean Buoy Network (TRITON), maintained by the Japan Agency for Marine-Earth Science and Technology. The Atlantic counterpart to TAO/TRITON is the Prediction and Research Moored Array in the Tropical Atlantic (PIRATA), maintained by PMEL and JISAO scientists in collaboration with NOAA's Atlantic Oceanographic and Meteorological Laboratory and institutions in Brazil and France. This array provides data to advance our understanding and ability to predict intraseasonal-to-decadal variations in the climate of the Atlantic sector. In addition, PMEL and JISAO scientists, along with members of the international community, are engaged in developing an Indian Ocean moored buoy observing system for monsoon research and forecasting. This system is called the Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA). The TAO Project Office at PMEL manages PIRATA and RAMA, which together with TAO/TRITON comprise the Global Tropical Moored Buoy Array (GTMBA). Research related to several aspects of ocean-atmosphere interaction and the role of the ocean in climate is conducted within this programmatic framework.

Our goals for this project are to: 1) ensure high quality and timely access to moored time series data for climate research; 2) contribute to our understanding of the ENSO cycle, the monsoons, and tropical Atlantic climate variability; 3) advance the understanding of decadal variability and trends in the tropics; and 4) establish RAMA in the Indian Ocean for climate studies.

OBJECTIVES
1. Maintain and enhance the TAO, PIRATA and RAMA web pages.

2. Increase the number of ATLAS (autonomous temperature line acquisition system) and acoustic Doppler current profiler moorings in RAMA.
3. Develop new moored observing technologies to enhance and sustain climate quality observations in the tropical oceans.
4. Improve understanding of ENSO variability in the Pacific.
5. Advance understanding of the decadal variability in the Indian and Pacific Oceans.
6. Improve our understanding of tropical Atlantic climate variability.

ACCOMPLISHMENTS

1. Research carried out at JISAO and elsewhere using data from the TAO/TRITON, PIRATA and RAMA arrays depends critically on the collection, quality control, archival, and web-based display and dissemination of mooring data sets. At JISAO, considerable effort is devoted to providing easy access to high quality multi-variate time series through the TAO web page *pmel.noaa.gov/gtmba/*. Between April 1, 2016 and March 31, 2017, GTMBA web pages received more than 26 million hits, delivered more than 375,000 mooring data files via the web, and more than 3.3 million files via file transfer protocol to the international community.

2. Since last year's report, we deployed a new ATLAS mooring in the Indian Ocean near 1.5°N, 67°E in September 2016 from the Indian research vessel, the *Sagar Kanya*. Furthermore, RAMA principal investigators in the U.S., China, India, and Japan have proposed a revised array design referred to as RAMA-2.0 in the context of the 2017-18 Indian Ocean Observing System (IndOOS) review. This design is intended to make the array more robust, more cost-effective, and less dependent on ship time, which is the most limiting resource for sustaining the array. RAMA-2.0 has fewer moorings than the original design, and eliminates moorings in regions prone to heavy fishing vandalism or where it has not been possible to find reliable ship support. It is understood that the RAMA-2.0 proposal needs full vetting as part of the IndOOS review process, but urgent budgetary, ship time, and other pressures require that we adopt it as a working plan for the purposes of developing our FY 2017 budget proposal. These updates represent progress in developing RAMA, which is now 78% complete, with 29 of 37 planned RAMA-2.0 moorings in place.

3. As the ATLAS system ages, several key components have gone out of production and replacements have been difficult to locate. At the same time, new and improved sensors have become commercially available. PMEL has developed a new instrument system, dubbed Tropical Flex, or T-Flex, for use with ATLAS mooring hardware. Side-by-side ATLAS/T-Flex mooring comparisons were conducted from 2011 to 2015. After confirming that T-Flex data are comparable to ATLAS and that T-Flex system performance is comparable to or exceeds ATLAS systems, integration of T-Flex into RAMA and PIRATA began in 2015. Fourteen sites (seven in PIRATA and seven in RAMA) are now occupied with T-Flex systems.

4. Following strong westerly wind bursts in boreal winter and spring of 2014, both the scientific community and the popular press were abuzz with the possibility of a major El Niño developing. However, during the boreal summer of 2014, the Bjerknes feedback failed to kick in, aided and abetted by a strong easterly wind burst. The widely anticipated major 2014–2015 El Niño event failed to materialize and even failed to qualify as an El Niño by conventional definitions. However, the boreal summer easterly wind burst had the effect of not only inhibiting the growth of the El Niño event, but also preventing and then reversing the discharge of the equatorial heat content that typically occurs during the course of an El Niño event. This head start of equatorial heat content helped push the 2015–2016 El Niño event to extreme magnitude (Levine and McPhaden, 2016).

5. Both the Indian and Pacific oceans exhibit prominent decadal time-scale variations in sea surface temperature (SST), linked dynamically via the Walker Circulation in the atmosphere and the Indonesian Throughflow in the ocean. However, the relationship between SST in these two basins underwent a dramatic transformation beginning around 1985. Prior to that, SST variations associated with the Indian Ocean basin mode (IOB) and the interdecadal Pacific oscillation (IPO) were positively correlated, whereas afterward they were much less clearly synchronized. Evidence is presented from both observations and

coupled state-of-the-art climate models that enhanced external forcing, particularly from increased anthropogenic greenhouse gases, was the principal cause of this changed relationship. Using coupled climate model experiments, it is shown that without external forcing, the evolution of the IOB would be strongly forced by variations in the IPO. However, with strong external forcing, the dynamical linkage between the IOB and the IPO weakens so that the negative phase IPO after 2000 is unable to force a negative phase IOB-induced cooling of the Indian Ocean. This changed relationship in the IOB and IPO led to unique SST patterns in the Indo-Pacific region after 2000, which favored exceptionally strong easterly trade winds over the tropical Pacific Ocean, and a pronounced global warming hiatus in the first decade of the 21st century (Dong and McPhaden, 2017).

6. ENSO in the Pacific is asymmetric for warm and cold events with respect to amplitude, spatial patterns, and temporal evolution. Here the symmetry of the Atlantic Niño mode, which many previous studies have argued is governed by atmosphere-ocean dynamics similar to those of ENSO, is investigated using two different ocean reanalysis products. Calculation of Bjerknes feedback terms for the Pacific reveals a pronounced asymmetry between warm and cold events, though unlike most previous studies, the largest asymmetry is found in the relationship between eastern Pacific thermocline depth and sea surface temperature anomalies. For the Atlantic, cold events are effectively mirror images of warm events with Bjerknes feedbacks of similar strength. The analysis supports not only the conclusion that Atlantic Niños are more symmetric than ENSO but also the hypothesis itself that the Bjerknes feedback is operative in the Atlantic given the strength of the relationship between the key variables involved (Luebbecke and McPhaden, 2017)

PROTECTION AND RESTORATION OF MARINE RESOURCES

ECOLOGY OF ARCTIC SEALS

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OTHER UW PERSONNEL
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TASK II

NOAA SPONSOR
Peter Boveng – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
The primary purpose of this project is to gain a better understanding of the factors responsible for the dynamics of seal populations and their roles in Arctic and sub-Arctic marine ecosystems. The proposed work is part of long-term, ecosystem-based analyses to monitor and assess pinniped population status in Alaska, and involves collection of data in the field, as well as data analysis and management in the office. Four main approaches will be used: 1) aerial surveys of seal abundance and distribution, based on photographic and other remote sensing methods; 2) satellite telemetry of seal movements and foraging behavior; 3) assessment of seal health, condition, diet, and stock structure based on measurements and samples obtained during telemetry tagging studies; and 4) retrospective data analysis and modeling of seal demography to investigate the vulnerability or resilience of different seal species to projected warming and loss of sea ice.

OBJECTIVES
1. Aerial Surveys:
   Aerial surveys for harbor seals will be conducted along the coasts and over floating ice in glacial fjords. Surveys for bearded, ringed, spotted, and ribbon seals will be conducted over sea ice, using a system of paired infrared and color cameras; the infrared images are used for detection of seals, and the color photos are used for identification of species. The survey regions will include Southeast Alaska, the Gulf of Alaska, the eastern Bering Sea, and the Chukchi and Beaufort seas.

   These aerial survey projects contribute to long-term databases on marine mammal distribution, abundance or relative abundance, habitat, and behavior using photo-identification, systematic searches, and line- and strip-transect protocols.

   The overarching objectives that aerial surveys can address are as follows:
   a. Document abundance and trends, which are needed for population assessments under the Marine Mammal Protection Act and Endangered Species Act and for inclusion of seals in integrated ecosystems studies and models. For the ice-associated seals, obtaining the first reliable population estimates will provide a reference from which to judge future trends and evaluate population consequences of Arctic warming and ocean acidification; and
   b. Provide the basis for species distribution maps, which are fundamental for investigation of habitat requirements, impacts assessment and disaster planning, and for spatial models of population and ecosystem dynamics.

2. Satellite Telemetry Studies of Seal Movements and Foraging Behavior:
   Satellite telemetry based on the Argos geolocation and data collection system is the primary means of studying movements and foraging behavior of the five species of seals included in this study. In addition to movements and foraging, satellite telemetry is used to monitor haul-out time budgets, which are key elements of abundance estimation; they allow survey counts to be adjusted for seals in the water (i.e., not available for detection) during aerial surveys.

   The overarching objectives that telemetry studies can address are as follows:
   a. Assess patterns of spatial and temporal use by seals;
   b. Investigate the relationships of seal movements and diving behavior to biological and environmental habitat factors;
   c. Estimate proportions of seals hauled out as functions of date, time of day, and other influential covariates; and
   d. Develop and refine telemetry methods for multi-disciplinary studies of marine mammal ecology and oceanography utilizing new animal-borne sensors.

3. Assessment of Seal Health, Condition, Diet, and Stock Structure:
   Samples and measurements collected by PEP during live-animal handling for telemetry studies support collaborative studies on health, condition, diet, contaminants, and genetic structure of seal populations.

   The overarching objectives that health, condition, diet and stock structure studies can address are as follows:
   a. Assess individual-based indicators of population status (i.e., health and condition) for comparison with population-based indicators (i.e., abundance, trends, distribution);
   b. Assess threats such as disease and contaminants, relevant to Endangered Species Act status reviews and listing decisions;
   c. Determine population structure to inform stock assessment, survey design, and threats assessments; and
   d. Quantify individual covariates of potential importance for interpretation of telemetry data.

ACCOMPLISHMENTS

During the 2016-2017 period, the aerial survey component included the following activities:

1. Participated in planning and logistics for harbor seal surveys in June 2017;
2. Processed and analyzed images (e.g., seal detection, enumeration of seals, and species identification) from the extensive aerial surveys of seals in the Chukchi Sea, 2016. This sustained effort led to completion of this important and labor-intensive step in record time;
3. Managed field data forms and geospatial survey data;
4. Produced summary statistics, maps, and other graphics for field operations, community outreach, reports, and presentations (e.g., maps of effort and sightings in the joint U.S.-Russia Chukchi-East Siberian Surveys (ChESS));
5. Assisted with writing reports, peer-reviewed manuscripts, and preparing presentations; and
6. Collaborated with researchers and stakeholders within and outside of NOAA and UW (agency resource managers, Alaska Native organizations, and other entities) to ensure maximum utility and impact of data collected in this project.

During the 2016-2017 period, the satellite-telemetry component included the following activities:

1. Participated in planning, preparation of equipment, and logistics for a major telemetry study involving a harbor seal cruise in the western Aleutians during September 2016.
2. Participated as a key member in the harbor seal capture and tagging operations on western Aleutians cruise aboard the chartered research vessel Norseman;
3. Processed, managed, and analyzed Argos telemetry data;

4. Produced summary statistics, maps, and other graphics;
5. Assisted with writing reports, peer-reviewed manuscripts, and preparing presentations; and
6. Collaborated with researchers and stakeholders within and outside of NOAA and UW (agency resource managers, Alaska Native organizations, and other entities) to ensure maximum utility and impact of data collected in this project.

During the 2016-2017 period, the health, condition, diet, and stock structure component included the following activities:

1. Participated in health, condition, diet, and stock structure studies planning and logistics, including the preparation of equipment for the western Aleutian harbor seal research cruise;
2. Participated in a field study aboard the chartered research vessel Norseman to collect samples from free-ranging seals;
3. Processed and curated biological samples and data in the field.
4. Produced summary statistics, maps, and other graphics;
5. Assisted with writing reports, peer-reviewed manuscripts, and preparing presentations; and
6. Collaborated with researchers and stakeholders within and outside of NOAA and UW (agency resource managers, Alaska Native organizations, and other entities) to ensure maximum utility and impact of data collected in this project.

POPULATION TRENDS, VITAL RATES, AND DIETS OF OTARIID PINNIPEDS IN ALASKA: WHAT CAN THEY TELL US ABOUT THE RELATIVE EFFECTS OF CLIMATE CHANGE AND HUMAN ACTIVITIES

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OTHER UW PERSONNEL
Joshua Cutler and Kathryn Luxa – Joint Institute for the Study of the Atmosphere and Ocean

TASK II

NOAA SPONSOR
Tom Gelatt – Alaska Fisheries Science Center

OTHER NOAA PERSONNEL
Kathryn Chumbley, Lowell Fritz, Jim Thomason, and Tonya Zeppelin – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
The Alaska Ecosystems Program (AEP) of the Marine Mammal Laboratory (MML) conducts research on Steller sea lions and northern fur seals. Research projects are designed to assess the status of these

Figure 1. Flight crew for AEP's Steller sea lion aerial survey in the Aleutian Islands, including Josh Cutler (second from right) and Katie Luxa (third from right).

species under the Endangered Species Act (ESA) and the Marine Mammal Protection Act and to improve knowledge of their ecology and behavior. Steller sea lions and northern fur seals consume a large variety of fish and cephalopod species, but while in Alaskan waters, their primary prey are also targets of commercial fisheries, principally walleye pollock, Atka mackerel, Pacific cod, salmon, rockfish, and Pacific herring. There continues to be considerable controversy about the relative roles of anthropogenic (e.g., competition with fisheries) and environmental variability (e.g., oceanographic and fish community changes related to regime shifts) in their impact on the populations trends of these two apex predators. For instance, National Marine Fisheries Service (NMFS) has been sued by both the fishing industry and environmental groups at different times since 1990 for either implementing or not implementing regulations to minimize the potential competitive interactions between fisheries and western Steller sea lions to allow for the latter's recovery. AEP conducts long-term research on sea lion and fur seal abundance, vital rates (survival, reproduction, and movement) and diet in order to better understand their biology and ecology, and provide information to managers who write documents required by the ESA and other environmental laws governing federal actions (e.g., the National Environmental Policy Act).

OBJECTIVES

1. AEP monitors the abundance, distribution, and age structure of Steller sea lions by conducting aerial surveys annually during the breeding season. AEP uses both manned (NOAA twin Otter) and unmanned (UAS APH-22 hexacopter) aircraft to conduct these photographic surveys. Results are integral to the assessment of population status relative to recovery goals established in the NMFS recovery plans required by the ESA.

2. AEP monitors the abundance of northern fur seals by conducting annual counts of breeding and sub-adult males, and biennial estimates of pup production (using a mark-recapture technique) on the Pribilof Islands; similar male counts and pup production estimates are conducted on Bogoslof Island, but on an opportunistic and less frequent schedule. Abundance monitoring of northern fur seals is a central feature of the research conducted by the U.S. government for over 100 years on the Pribilof Islands.

3. AEP uses sightings and photographs of permanently-marked (hot-branded) or tagged individual animals to determine survival, reproductive, and movement rates of Steller sea lions and northern fur seals in Alaska. Sightings and photographs are collected during vessel and aerial surveys, during land-based field work, or may be sent to AEP by interested members of the public. One of the primary methods used to collect sightings and reproductive behaviors of animals is extended monitoring during the breeding season at rookeries. Rookery monitoring is conducted by trained observers living at field camps on remote, uninhabited islands (for Steller sea lions or fur seals at Bogoslof) or in NMFS staff quarters on the Pribilof Islands. Sightings of marked animals are used to create re-capture histories to estimate age-,

sex-, and rookery-specific survival and reproductive rates, as well as sighting probabilities and movement rates.

4. AEP collects fecal samples (scats) to estimate the diet of Steller sea lions and northern fur seals. Prey species identification is accomplished by matching hard parts recovered from scats to a library of bones and skeletal elements maintained by MML. Other methodologies (e.g., DNA analysis of soft scat material) may also be employed to aid in prey species identification. Understanding the diet of pinnipeds is crucial to evaluating their roles in the ecosystem, and how they might be affected by changes in climate, weather, or human activities.

ACCOMPLISHMENTS

1. JISAO research scientist Joshua Cutler developed software applications to interface with AEP databases without the need for technical expertise. This included applications to collect, validate, manage, and migrate data from the Steller sea lion field camp, Steller sea lion aerial imagery counts, northern fur seal tagging, and northern fur seal resighting trips.
2. Cutler developed and field tested a software application on tablet devices for northern fur seal tag resightings.
3. Cutler contributed to the 2016 Steller sea lion aerial survey in the Aleutian Islands, the 2016 northern fur seal pup count in the Pribilof Islands, and an unmanned aerial survey of northern fur seal pups in the Pribilof Islands.
4. JISAO research scientist Kathryn Luxa organized and supported AEP's three remote Steller sea lion field camps on Marmot and Ugamak islands. Her duties included gear shipping, preparation of field manuals and instructions, personnel training, safety monitoring, and data and photo management.
5. Luxa accomplished several tasks related to Steller sea lion and northern fur seal food habits. First, she completed a physical inventory of all food habits samples – nearly 30,000 vials of prey remains. She also continued to make updates to the food habits databases and developed data processing queries (with Cutler) to streamline data analysis. More recently, she prepared a summary of the northern fur seal diet for a North Pacific Fishery Management Council meeting, and has been collaborating with AEP scientists to examine the Steller sea lion diet in the Aleutian Islands. She is also brushing up on her prey identification skills.
6. Luxa participated in the 2016 Steller sea lion aerial survey in the Aleutian Islands, and tag resighting efforts of northern fur seals in the Pribilof Islands.
7. Both Cutler and Luxa participated in a variety of outreach activities, including NOAA Science Camp and Discover Science Weekend at the Seattle Aquarium, and contributed blog posts to AEP's citizen science program, Steller Watch (hosted by Zooniverse).

ASSESSMENT AND ECOLOGY PROGRAM: UNDERSTANDING CETACEAN DISTRIBUTION IN ALASKAN WATERS IN RELATION TO THE IMPACTS OF CLIMATE CHANGE AND ANTHROPOGENIC ACTIVITIES

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TASK II

NOAA SPONSOR
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OTHER NOAA PERSONNEL
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NOAA GOALS
Healthy Oceans

DESCRIPTION
The National Marine Fisheries Service is charged with managing and protecting marine mammals under the Marine Mammal Protection Act and the Endangered Species Act. The Cetacean Assessment and Ecology Program (CAEP) at the Marine Mammal Laboratory (MML), of the Alaska Fisheries Science Center (AFSC) studies cetaceans in Alaskan waters through a collaborative research effort of biologists, acousticians, and statisticians, as well as biophysical scientists from JISAO, AFSC, the Pacific Marine Environmental Laboratory, and other research organizations. CAEP's mission is to assess cetacean abundance, population trends, and habitat utilization in Alaskan waters, and to facilitate sustainable management of these species and healthy ecosystems.

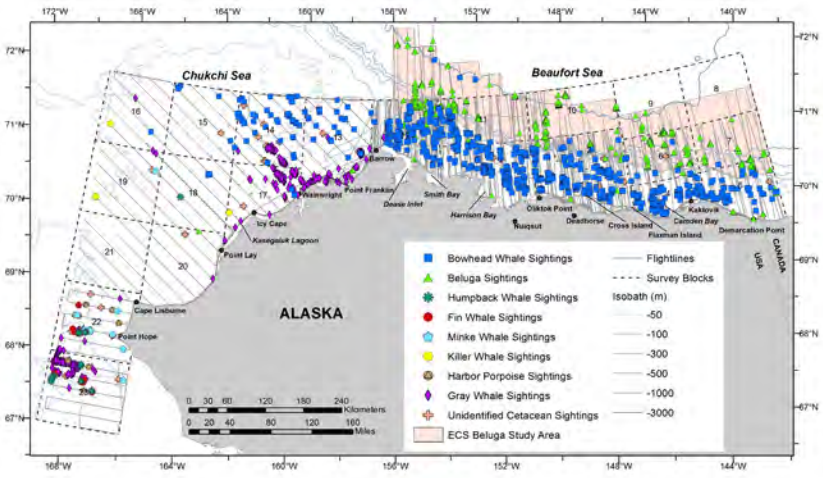

Figure 1. Cetaceans sighted by ASAMM in 2016, transect, search, and circling effort.

The high latitude waters of Alaska are subject to climate change, which may have profound effects on the trophic composition of ecosystems and numerous other anthropogenic impacts, including oil and gas, industrial, shipping, and fishing activities. Monitoring and protecting cetaceans in this changing, high use environment requires long term, ecosystem-based analyses. Research on populations of particular concern, such as Cook Inlet beluga whales and cetaceans in the Chukchi and Beaufort seas, is on going. CAEP incorporates field, analytical, and modeling approaches to monitor cetaceans, and to understand how varying physical and biological factors influence their abundance, distribution, and habitat use.

Figure 2. Bowhead whale cow-calf pair sighted on ASAMM Flight 228, August 25, 2016, in the western Beaufort Sea.

OBJECTIVES

JISAO scientists contribute fully to the following objectives:

1. Assess patterns of spatial and temporal use of Alaskan waters by marine mammals (endangered bowhead, fin, and humpback whales, other cetaceans, ice seals, walruses, and polar bears) through aerial and vessel surveys and acoustic monitoring.
2. Describe the annual migration of bowhead whales across the Alaskan Arctic, significant inter-year differences, and long-term trends in the spatial distribution and timing (duration and start date) of the migration.
3. Document relative abundance and behavior (including calving/pupping, feeding, hauling out) of marine mammals in the Alaskan Arctic.
4. Investigate the movements of individual whales and assess the population structure and origin of whales in the region.
5. Provide an objective wide area context for understanding marine mammal ecology in Alaskan waters, to help inform management decisions and interpret results of other small scale studies.
6. Evaluate the extent to which variability in environmental conditions such as sea ice, oceanic currents, water temperature and salinity, and prey abundance influence cetacean distribution and relative abundance.

ACCOMPLISHMENTS

1. The Aerial Surveys of Arctic Marine Mammals (ASAMM) is a Bureau of Energy Management (BOEM) funded project that describes the annual migration of bowhead whales in the Alaskan Arctic and documents the relative abundance, spatial and temporal distribution, and behavior of marine mammals in the Alaskan Arctic. ASAMM is an ongoing 37 year time series and provides an objective wide area context for understanding marine mammal ecology in the Alaskan Arctic, to help inform management decisions and interpret results of other small scale studies. The extensive annual report for the 2016 season has been drafted, and preliminary results were presented at the Alaska Marine Science Symposium in Anchorage in January 2017. Figure 1 shows cetaceans sighted by ASAMM in 2016. Figure 2 is a bowhead whale cow-calf pair photographed in 2016. Figure 3 is the survey team getting ready for a survey flight. Data analysis, writing for scientific publication, and field preparations for the 2017 field season continue.

Figure 3. ASAMM survey team (left to right: Corey Accardo, Tomo Spaic, Amy Willoughby, Lisa Barry, Stan Churches) getting ready for a survey flight in the northeastern Chukchi Sea.

2. The MML acoustics program deploys numerous passive acoustic recorders throughout the Bering, Chukchi, and Beaufort seas to document the spatial and temporal distribution of marine mammals in the area. These moorings, deployed every summer, collect acoustic data on a duty cycle for a year, and are retrieved and redeployed the following year. Figure 4 shows the location of all passive acoustic recorders deployed by the acoustics group.
3. The Arctic Whale Ecology Study (ARCWEST) is a BOEM-funded, multi-year project to investigate baleen whales in the Chukchi Sea relative to ocean currents and prey resources. Large numbers of baleen whales pass through the Bering Strait during seasonal migrations to feeding grounds further north. Beginning south of the Bering Strait, important baseline data on the occurrence, distribution, and habitat use of baleen whales are being collected using passive acoustic monitoring, visual surveys, and satellite telemetry. Relationships between dominant currents flowing through the Bering Strait and delivering resources to the Barrow Arch area are being determined using biophysical sampling and moorings. The nature of those relationships relative to whale distribution and habitat utilization are also being explored. We have begun processing the data from the moored passive acoustic recorders to obtain the seasonal distribution of marine mammals, as well as environmental and anthropogenic sounds. All sonobuoy data for the ARCWEST project have been processed and uploaded to the Distributed Biological Observatory website. The visual and telemetry field work for this project concluded in 2014, and 2016, respectively. Currently, data from these project components are being processed and synthesized for peer review publication. Preliminary results have been included in the ARCWEST quarterly report submitted to BOEM on October 15, 2016 (*afsc.noaa.gov/nmml/cetacean/arcwest.php*).
4. The Chukchi Acoustics, Oceanography, and Zooplankton Extension Study (CHAOZ-X) is a BOEM-funded, multi-year, multi-disciplinary study to document the temporal and spatial distribution of baleen whales near Hanna Shoal in the northeast Chukchi Sea, and to relate variations to oceanographic conditions, indices of potential prey density, and anthropogenic activities to improve understanding of the mechanisms responsible for observed high levels of biological activity around the shoal. The study took place between years 2013 and 2015. The data are being incorporated into an over-arching final report that will be available in 2017.
5. The acoustics group at MML participated in an educational outreach program called Expanding Your Horizons (EYH) in March. The goal of EYH is to inspire young girls (grades 7 and 8) and spark an interest

in careers in STEM (science, technology, engineering, and mathematics), and to provide them with hands-on experience and an opportunity to interact with females with careers in STEM. This is the Acoustics group's seventh year participating in this program, which is hosted by Highline Community College.

6. Analysis of images and sighting data from the Aerial Calibration Experiments (ACEs) project (field dates: August 26-September 07, 2015), which was designed to test the feasibility and efficacy of using unmanned aircraft to calculate large whale abundance in the arctic, is complete. The survey was designed to: a) conduct a three-way comparison of whale data collected via observers in a manned aircraft, digital photographs from manned aircraft, and digital photos from an unmanned aircraft; and b) to test meteorological sensors recording atmospheric conditions. Of the 65,451 images collected during the ACEs experiment, 16,633 were manually analyzed by trained observers – this equates to 332.5 hours of image analysis. In all, 23 bowhead whales, 22 beluga whales, and 3 gray whales were recorded. Manuscripts detailing the performance of unmanned aerial vehicles vs. manned observation in terms of accuracy, efficiency, logistics, and cost are currently being prepared for peer-reviewed publication.

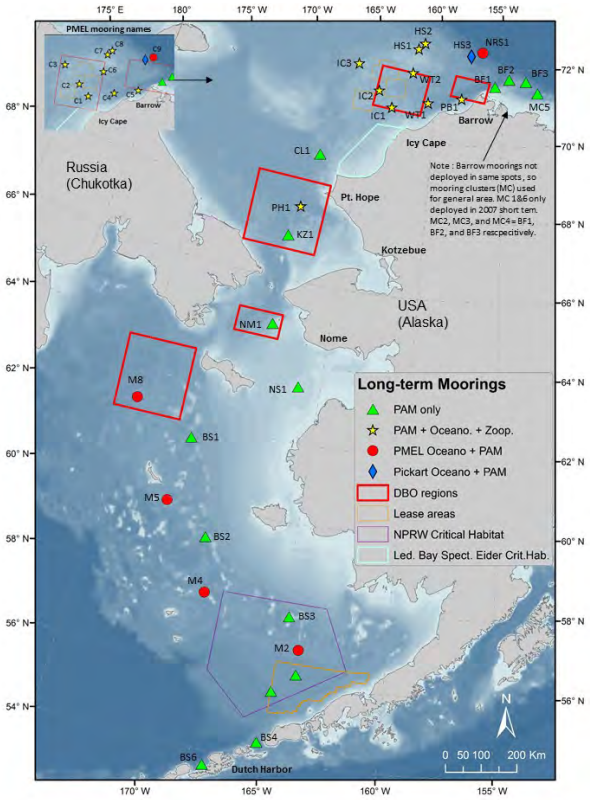

Figure 4. Location of all passive acoustic recorders, oceanographic moorings, and sampling stations for the ARCWEST (yellow area) and CHAOZ-X (red area) studies.

7. The Cook Inlet beluga (CIB) project is NOAA-funded and conducts research on the endangered stock of belugas tracking abundance, distribution, and habitat use. The CIB biennial aerial survey was conducted in June 2016 to assess the beluga population, with blog updates about the survey posted to the AFSC Dispatches from the Field website (*afsc.noaa.gov/Science_blog/BelugaWhale_main.htm*). Video data collected during the survey were quality coded and analyzed for group counts of belugas. Survey data from aerial observer counts and video analysis results were collated, summarized, and provided to MML scientists for statistical analysis for abundance estimation. Various databases were updated with the 2016 aerial survey and analysis results, and updates were made to the beluga opportunistic sightings database. Logistical planning and data management preparations are being made for an upcoming pilot study involving UAV hexacopter work in 2017 for CI belugas. Additionally, CIB staff participated in educational outreach through the 2016 NOAA Science Camp, highlighting marine mammal conservation and survey techniques, and showing students how aerial video of belugas is counted and assessed with specialized computer software.

ASSESSING THE CAPACITY FOR EVOLUTIONARY ADAPTION TO OCEAN ACIDIFICATION IN GEODUCK

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TASK II

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NOAA GOALS
Healthy Oceans

DESCRIPTION
The combination of increasing temperatures and ocean acidification (OA) are expected to have important and broad-ranging effects on the marine environment, and consequently on ecologically and economically important marine species. Puget Sound is one of the first regions likely to experience the effects of OA on important marine species due to the combination of local upwelling events, sea surface temperature anomalies, and the relatively low buffering capacity of local seawater. We propose to examine the effects of OA conditions on the adaptive response of a potentially vulnerable native marine mollusc species with ecological, economic, and social importance in the Pacific Northwest: geoduck clams (*Panopea generosa*). We know that elevated pCO2 – alone, and in combination with other environmental stressors – will result in selection, with survival of larvae based on the possession of beneficial phenotypic traits. However, there are several things we do not know including: a) What underlying factors (e.g., genetic/epigenetic) control these traits? b) What combinations of phenotypic traits will result in survival? and c) How will post-selection populations respond to subsequent environmental stress? This research effort is specifically designed to identify the underlying factors by performing a controlled within-generation selection experiment, and examining alterations in population structure caused by OA.

OBJECTIVE
1. Determine the change in allele frequencies under OA stress at single nucleotide polymorphisms throughout the genome; and
2. Determine the change in frequency of methylation states (epialleles) under OA stress at CpGs throughout the epigenome.

ACCOMPLISHMENTS
The major accomplishments of the current reporting period were analysis of data from larval OA trials, analysis of data from juvenile growth trials, and characterization of epiallele variation upon OA exposure. We initially exposed D-hinge geoduck clam larvae to ambient (~8.0) and low pH (~7.4) for 6 days. We then split the remaining larvae at pH 7.4 into pH 7.4 and 7.0 and measured them again at 10 days. We found that in both portions of the experiment, larval mortality was decreased and shell size increased in the lower pH conditions.

We exposed juvenile geoduck clams to low pH treatments, and found there is a benefit of preconditioning or acclimatization to low pH. We exposed juvenile geoduck to ambient (~8.0), low (~7.4) and lower (~7.0)

pH for 23 days and placed them in an ambient common garden for several months. After exposure to the ambient common garden conditions, juveniles from each initial pH condition were then re-exposed to ambient (~8.0) pH and low pH (~7.4) for another 23 days. The pre-exposed juveniles were more resistant to changes in growth when exposed to low pH for a second time. Our work indicates an exposure memory of the original stressor and that acclimatization to ocean acidification can result in benefits to geoduck growth. This memory may be in the form of DNA methylation.

DNA methylation levels were compared among pH treatments for the juveniles. Reduced representation bisulfite libraries were generated, sequenced, and mapped to the draft geoduck genome generated for this project. The bisulfite treatment converts any non-methylated cytosine into a uracil, while methylated cytosine are not converted. It is therefore possible to obtain base pair resolution information on DNA methylation via next generation sequencing. Methylation analysis (CpG context) identified potential regions of DNA methylation differences between the treatments. These regions will be tested and compared across the additional sampling points.

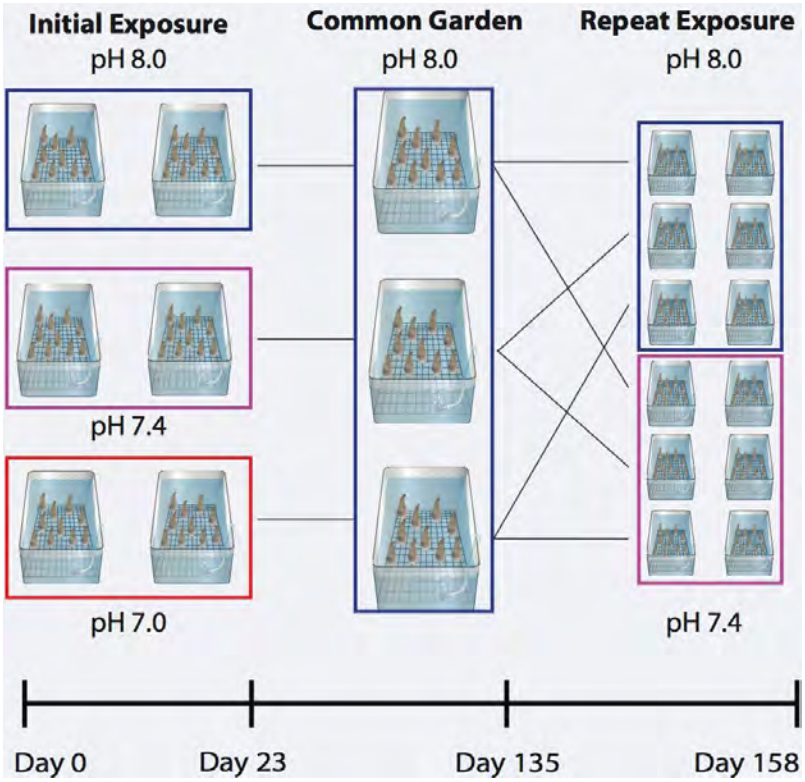

Figure 1. Diagram of juvenile geoduck experimental set-up. Juvenile geoduck seed were obtained at ~3.5 months of age and place in a layer of sand in the bottom of replicate tanks. Samples were collected and growth measures made on Day 0, Day 10, Day 23, Day 51, Day 135, Day 145, and Day 158.

DEVELOPING GENOMIC RESOURCES TO SUPPORT RESTORATION AND PROTECTION OF THE OLYMPIA OYSTER IN PUGET SOUND

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NOAA GOALS
Healthy Oceans

DESCRIPTION
The Olympia oyster (*Ostrea lurida*) is the only native oyster on the West Coast of the United States. In contrast to the invasive Pacific Oyster that represents the majority of the commercial market, the Olympia oyster grows to a smaller size and possesses a unique life history strategy where females brood larvae. Unfortunately, there have been significant declines in Olympia oyster populations, likely due to a number of anthropogenic activities. Over the past few years, there has been significant effort placed in restoring native Olympia oyster populations through reseeding and transplantation. A major milestone in this effort has been the establishment of the Kenneth K. Chew Center for Shellfish Research and Restoration at the NOAA Manchester Field Station. While a core infrastructure for rearing Olympia oysters is now in place, there is a significant gap in our fundamental understanding of the species' resilience in the face of environmental change, ecological interactions, and population structure. This information is critical to: 1) local restoration efforts; and 2) predicting how molluscs will adapt to long-term environmental change. An objective of this proposal is to generate genomic resources for the Olympia oyster that can be used to better understand ecological interactions, while also providing key information to improve conservation of the native Olympia oyster.

OBJECTIVES
1. Produce a draft genome assembly for *Ostrea lurida*.
2. Determine how environmental information is inherited.
3. Develop a web-based platform for discovery and collaboration.

ACCOMPLISHMENTS
Major accomplishments of the current reporting period include additional DNA sequencing using the PacBio technology. This was carried out to fill in gaps in the original draft genome assembled using Illumina sequence data. In addition, an experiment was started in early 2017 where oysters were exposed to ocean acidification conditions at the Kenneth K. Chew Center for Shellfish Research and Restoration at the NOAA Manchester Field Station. Later this year we will assess offspring performance of these oysters to determine to what degree environmental information is inherited. Lastly, we continue to maintain the website: *oystergen.es/olympia*.

STEELHEAD REPRODUCTION AND GENETICS

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NOAA GOALS
Healthy Oceans

DESCRIPTION
Evidence from a number of studies in steelhead (*Oncorhynchus mykiss*), as well as some other salmonids, have demonstrated that fish reared in hatcheries can have substantially reduced reproductive success compared to naturally reared ("wild") counterparts. Further, genetic fitness loss may occur in a single generation (Araki et al. 2007, 2009). A number of factors could be responsible for the decline in fitness, including: inbreeding, hatchery-induced selection (Araki et al. 2008, Christie et al. 2012), and environmentally induced epigenetic changes that are heritable across generations. A combination of these factors are likely involved, but more complex mechanisms involving heritable genetic and epigenetic changes induced by the hatchery-rearing environment have yet to be examined.

The aim of this study is to examine the effects of early rearing environment on genetic variation and epigenetic programming in steelhead, and this work is a continuation of a study started in 2014. This work will take advantage of a long-term project on Methow River steelhead at the Winthrop National Fish Hatchery (WNFH) and the NOAA Manchester Field Station, which has aimed to determine the life history phenotypes and reproductive success of fish produced on rearing regimes designed to generate either yearling or 2-year-old smolts. As part of this study, natural origin and hatchery adults are collected from the Methow River by U.S. Fish and Wildlife Service staff and spawned at the WNFH.

In this study we will conduct a continuation of our genome wide assessment of genetic differences between hatchery and natural origin fish in this system, and determine if early rearing environment and origin of the fish show different epigenetic signatures (e.g. alteration of DNA methylation) that might be heritable. Questions we are asking include: 1) Are there fundamental differences in the epigenome between hatchery and natural origin fish? 2) Are any observed differences in the epigenome persistent across rearing environments? 3) Does environment play a greater role than background genetics on epigenetic signatures? 4) Does variation in the genome between hatchery and natural origin fish, potentially as a byproduct of selection in hatcheries, associate with differences that we see in the epigenome?

OBJECTIVES
1. Characterize epigenetic variation in juveniles reared in experimental 'natural' and 'hatchery' settings.
2. Characterize genomic DNA variation in hatchery and natural origin-adult Methow River steelhead using

Restriction Site Associated DNA Sequencing (RADSeq).

3. Characterize DNA methylation of sperm and red blood cells (RBCs) collected from hatchery steelhead produced on rearing regimes designed to generate either yearling or 2-year-old smolts using Reduced Representation Bisulfite Sequencing (RRBS).

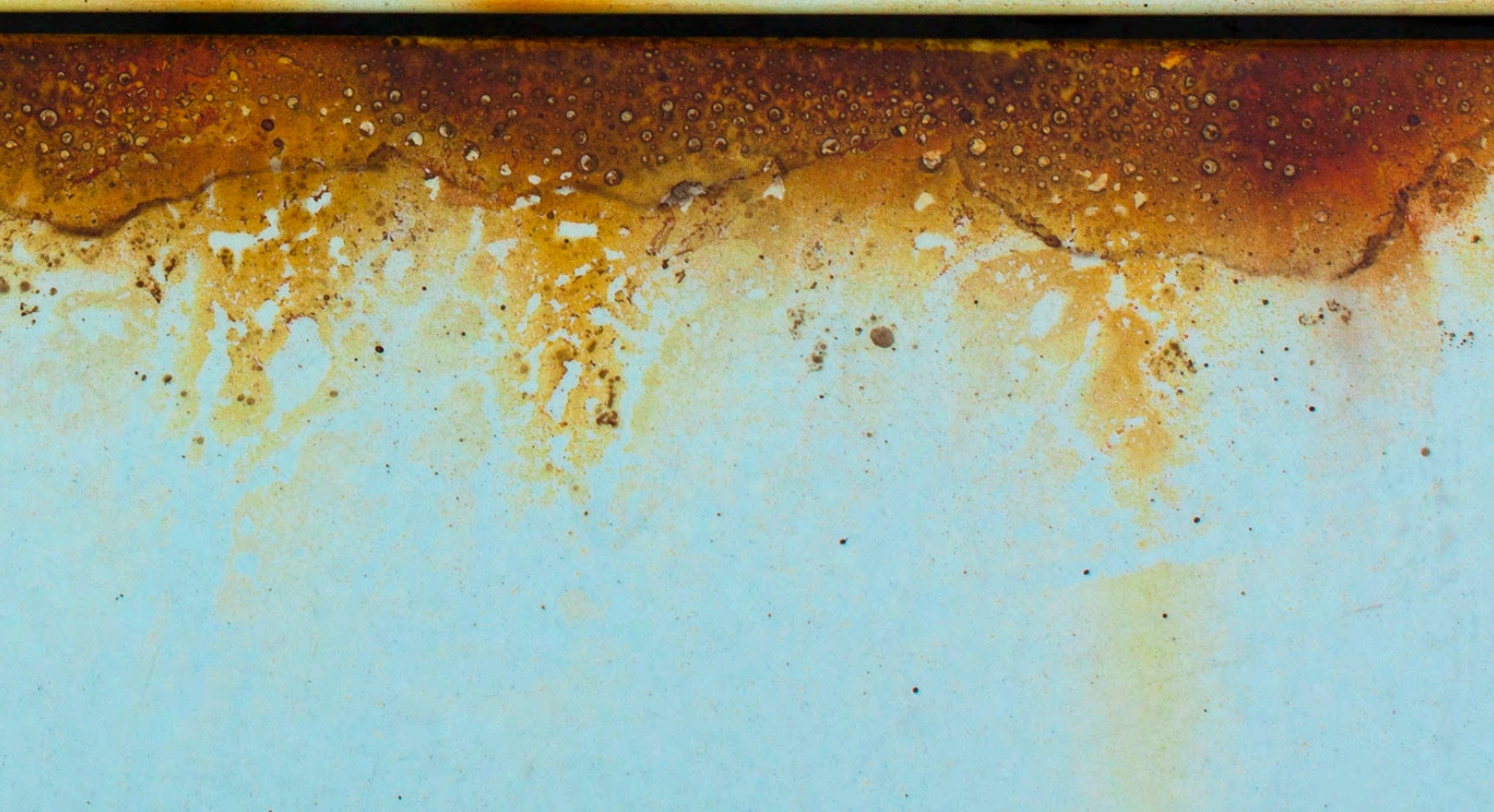
ACCOMPLISHMENTS

1. Characterized genetic and epigenetic variation in the genome of steelhead raised in experimental 'hatchery' and 'natural' environments – Previous results from our study showed significant differences in DNA methylation patterns of both sperm and RBC between hatchery and natural-origin steelhead. We also found a high degree of epigenetic variation among individuals necessitating future studies on how epigenetic and genetic variation interplay to promote such differences, and how much epigenetic variation is inherited (these results were presented at the Coastwide Salmon Genetics Meeting, May 2016). To address this, a second study using controlled genetic backgrounds and simulated 'hatchery' and 'natural' environments was performed to limit the effects of background genetic variation in order to directly address if early rearing environment influences DNA methylation in hatchery steelhead. Steelhead embryos from 20 families were split across hatchery and natural treatments. After 8 months in the treatment environments, fish were tagged and raised to maturity (2 years of age) in a common environment. To date, sperm samples collected from 60 fish (n=30 per treatment) have been analyzed using RRBS. Hierarchical clustering of genome-wide methylation patterns in sperm show strong clustering within family regardless of rearing environment. Initial results do not indicate a strong environmental effect; however additional analyses are required to determine statistical power given the strong heritability of methylation patterns. Our findings emphasize the importance of understanding the effects of kinship among studied individuals in order to properly interpret DNA methylation data.

2. Initiated characterization of genetic variation in the genome of natural and hatchery origin adult steelhead collected in 2016 – Samples were collected from Methow River natural and hatchery origin adult steelhead spawning in spring 2016 (n=175). Genetic analysis for all samples was conducted using RADSeq. We expect this analysis to be completed by summer 2017. These data will be incorporated with the 2014 and 2015 datasets to provide a more complete picture of the genetic variation in this system.

3. Initiated characterization of epigenetic variation in the genome of steelhead raised under rearing regimes designed to generate either yearling or 2-year-old smolts – Sperm and RBCs were collected from returning Methow River hatchery-origin adult steelhead reared either as yearling or 2-year-old smolts (n=20 per group). DNA was isolated, RRBS libraries were prepared, and sequencing is complete as of March 2017. Bioinformatics processing and data analysis is expected to be complete in summer of 2017.

SEAFLOOR PROCESSES



NOAA NeMO TIME-SERIES MAINTENANCE CRUISE

PI
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NOAA GOALS
Healthy Oceans

DESCRIPTION
In 1998, scientists at UW's JISAO and NOAA's Pacific Marine Environmental Laboratory (PMEL) began conducting annual observations and sampling at Axial Seamount as part of the New Millennium Observatory (NeMO) project. The result is a unique, long-term time series of hydrothermal vent temperature, chemistry, and microbiology through three eruptions (1998, 2011, and 2015), along with associated geophysical and geological measurements. After the April 2015 eruption, the National Science Foundation (NSF) provided funding through a RAPID grant to explore and sample the new lava flow with an ROV in August 2015. At that time, a time-series water sampler was installed in a vent and a mooring was installed nearby to monitor the hydrothermal plume at the North Rift Zone eruption site. To recover the time-series sampler and plume mooring in 2016, NOAA and NSF contributed to add one day onto the Ocean Observatories Initiative (OOI) Operations and Maintenance cruise on the RV *Sikuliaq*. There were no other cruises of opportunity in 2016, and there was minimal funding available to continue the NeMO work, so the 2016 observations and sampling were minimal. A more complete time-series sampling program of Axial summit is planned for 2017 on RV *Revelle* with ROV *Jason*.

OBJECTIVES
1. Recover the time-series sampler installed in a hydrothermal vent located on the 2015 lava flow on Axial Seamount's North Rift Zone.
2. Document the site with photography and additional sampling.
3. Recover the plume-monitoring mooring and return the instruments to PMEL.
4. If possible, make observations or collect samples to continue the time-series at Axial Seamount.

ACCOMPLISHMENTS

There was no space available on the *Sikuliaq* for a JISAO or PMEL scientist to participate in the recovery operations, so personnel involved with the OOI maintenance work were instructed on how to recover and handle the samples before the cruise. The sampler was recovered, and two additional vent sites were found and sampled nearby, adding to the data collected in 2015. A time-series of temperature at the North Rift Zone vent site was recorded on a miniature temperature recorder attached to the sampler intake. The level of hydrothermal activity on the 2015 lava flow after 16 months was successfully documented during the *Sikuliaq* cruise. The level of venting and the temperature of the vent sites were significantly decreased in 2016.

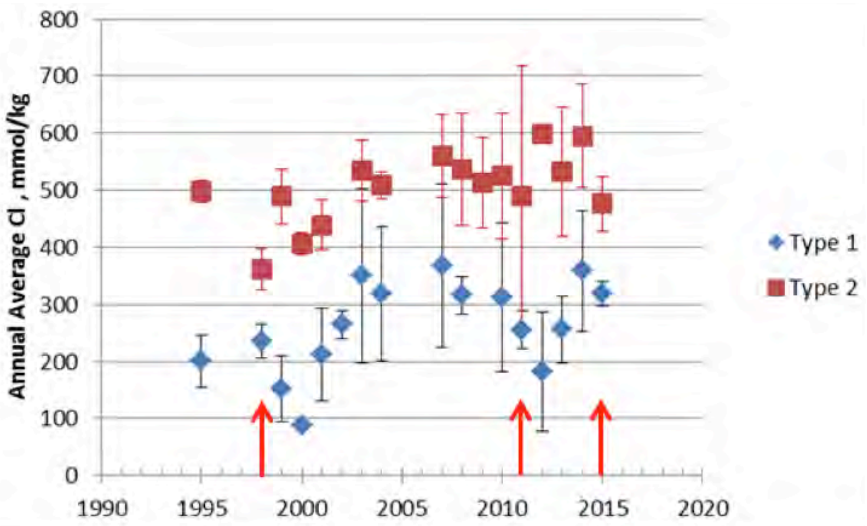

Figure 1. Time-series of high-temperature endmember chloride concentration from NeMO project cruises 1995-2015. Data shown are averages for all vents for each year, broken into two types. Eruption years are indicated by red arrows along the time axis. The composition of hydrothermal vent fluids varies over eruptive cycles, with implications for chemical mass flux and chemosynthetic productivity. (Butterfield et al., in prep).

Butterfield has pursued time-series chemistry and microbiology studies at Axial Seamount since 1998, with funding from NOAA, NSF, and private foundations. Research scientist Kevin Roe has analyzed hundreds of hydrothermal fluid samples for this time-series project. John Lupton and Marvin Lilley have analyzed many gas-tight samples. The Butterfield lab and PMEL have provided time-series sampling instrumentation for the OOI Cabled Array and have provided OOI with chemistry data on recovered samples. With well-documented eruptions in 1998, 2011, and 2015, we are now starting to see some patterns in the evolution of hydrothermal chemistry over eruptive cycles, and we are making connections as to how changing chemistry affects the microbial ecosystem. The most recent papers published focus on the rates of microbially mediated reactions and what chemical factors limit productivity (Stewart et al., 2016, Topcuoglu et al., 2016). Manuscripts describing the time-series chemistry at Axial are in preparation.

REASONS WHY OBJECTIVES WERE NOT MET

The plume-monitoring mooring could not be recovered in 2016 due to complicating factors with the ship's schedule. This was planned as the last operation of the expedition, but the cruise had to be cut short by 18 hours, so the recovery could not be completed. The mooring has remained in place and will collect data until the batteries are drained. The mooring will be recovered by JISAO and PMEL personnel during a scheduled cruise on the RV *Revelle* in July 2017. This should only result in a delay of returned data rather than a loss of data.

EARTH-OCEAN INTERACTION PROGRAM

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NOAA GOALS
Healthy Oceans

DESCRIPTION
Research within the Earth-Ocean Interaction (EOI) group is focused on understanding and quantifying the interaction between the ocean and the solid Earth in the production and maintenance of marine resources and their associated ecosystems. More than 70% of the volcanic activity on Earth occurs below the ocean surface where it produces valuable mineral and biological resources and greatly impacts ocean chemistry and ecology. Along the U.S. coastline, tectonic and sedimentary processes produce methane and hydrocarbon resources that fuel ecosystems while affecting ocean chemistry and biological cycles. The information that we provide to public and private enterprises is gathered through global exploration, including seafloor mapping, mineral and biological resource discovery and characterization, and detailed studies of physical, chemical, and biological processes from the sub-seafloor up into the ocean water column. By addressing global biogeochemical cycles, microbial ecology, technology development, long-term ocean observations, and resource discovery, the EOI group conducts scientific studies that address NOAA strategic goals and are important to society and the broader scientific community.

OBJECTIVES
1. Explore the deep ocean to discover resources produced within neovolcanic areas; locate and characterize hydrothermal ecosystems, mineral deposits, and biological resources; understand the links between these systems and global ocean biology and chemistry.
2. Understand the interplay between biodiversity, the chemical environment of deep ocean habitats, and the structure and function of deep-ocean ecosystems.
3. Assess the impact of hydrothermal and volcanic activity on global ocean chemistry, biological production, and carbon export.
4. Assess the impact of the chemical exchange between solid Earth and the oceans, especially as regards the identification of hydrocarbon resources and areas where chemical exchange between the solid Earth and the ocean impacts ocean chemistry and biological productivity in the oceans.

ACCOMPLISHMENTS

Objective 1: Accomplishments in Exploration and Discovery of Submarine Volcanic Resources

The EOI program explores volcanic areas of the world's oceans to discover locations of hydrothermal activity that produce both mineral and biological resources. In order to address the large issue of how tectonics is linked to seafloor biology, we need improved global and regional knowledge of hydrothermal systems. The submarine volcanic and hydrothermal systems of the Mariana Arc have been studied by EOI since 2003, but there was still very little data from the adjacent Mariana back-arc, so we undertook a two-part exploration to locate new hydrothermal sites in this region. During the 2015 "Hydrothermal Hunt on the Mariana Back-arc" cruise aboard the Schmidt Ocean Institute RV *Falkor* (Cruise # FK151122, Chief Scientist J. Resing), we systematically explored 600 km of the southern Mariana back-arc from 13°N to 18.5°N for the first time, discovering 12 new hydrothermal vent fields, which increased the number of known hydrothermal sites from 6 to 18. In addition, a surprising discovery was made of a lava flow that erupted between early 2013 and late 2015. Results were presented at the 2016 Fall Meeting of the American Geophysical Union (AGU), the Aquatic Science Meeting, the 2016 Goldschmidt conference, and the AGU Chapman Conference on Submarine Volcanism. A cruise report was produced and is available on the EOI website, and data sets are available online (See products below). A paper discussing the regional geophysics is in press (Anderson et al 2017), and another comparing hydrothermal activity among global back-arc spreading centers is in preparation (Baker et al.).

Figure 1. Characteristic fauna of an active, sulfur-rich Mariana arc volcano, Daikoku. The flatfish swimming at left side of image, Symphurus Thermophilus, is the most abundant species in this environment. Many forms of molten and solid sulfur occur at Daikoku and at similar volcanoes on the arc.

In 2016 we conducted part 2 of the Mariana back-arc exploration on RV *Falkor* (Cruise #FK161129, D. Butterfield, chief scientist), using the Schmidt Ocean Institute's new 4500-m rated ROV *SuBastian* to visually explore, sample, and characterize the geology, chemistry, and biology of new vent sites on the seafloor. The overarching goal is to discover what factors control the striking differences observed in the biological communities that live at hydrothermal vents in the Mariana arc and back-arc, and what implications this has for links between the solid-earth, the hydrosphere, and the biosphere on a global scale. To achieve our primary goal, a team of nine scientists focused on surveying four primary back-arc sites, finding hydrothermal activity, and collecting representative vent fauna, hydrothermal fluids for chemistry and microbiology, volcanic rocks and hydrothermal mineral samples. The expedition was successful, and included sampling 2 arc volcanoes and 3 back-arc vent fields in the Alice Springs area (previously sampled by submersibles in 1987 and 1992), and previously unknown vent fields at 17°N and 15.5°N. Underway

cruise data *rvdata.us/catalog/FK161129* and ROV video *youtube.com/user/SchmidtOceanVideos/playlists* are publicly available, and the full cruise report will be available in mid-2017 on the EOI web site.

The 2015 and 2016 *Falkor* expeditions in and near the Mariana Trench Marine National Monument contribute to the overall understanding of deep-sea ecology and reveal amazing new hydrothermal mineral formations and biological communities on the back-arc to the public, government agencies, and scientists. There was keen national/international public interest in the live streaming and outreach of our expeditions, and the people of Guam and the Commonwealth of the Northern Mariana Islands are very curious about what exists in the waters surrounding their islands. The oceans are vital to the health of our planet. With growing industrial interest and planning for deep undersea mining of mineral deposits, understanding the ecosystems at and around hydrothermal vents and how they are affected by disturbance is critical for environmental assessments and minimizing harm to the marine environment. This study contributes to advancing the basic understanding of biodiversity, connectivity, and biogeography at deep-sea vents, and helps with conservation and management of the new Mariana Trench Marine National Monument.

In 2016 we published a paper that reevaluates the global distribution of hydrothermal sites based on results from several ridges using a novel sensor that identifies areas of weaker venting not identified by sensors more commonly used during past exploration cruises (Baker et al., 2016). This paper found that the number of active vent sites on fast- and intermediate-rate spreading ridges (~one half of the global ridge total) may be at least a factor of 3–6 higher than now presumed. Moreover, ~25% of the newly discovered sites are apparently low-temperature discharge, a type difficult to find using conventional exploration techniques. We believe that these are major findings for several reasons: 1) The sensor likely identifies relic hydrothermal sites and mineral deposits not identified by past exploration techniques; 2) Sites like these, and not high–temperature sites, may be the primary source of the hydrothermal Fe that is transported across the ocean basins; 3) The close spacing of vent sites in the study (means of 3-20 km) are, for the first time, consistent with models of hydrothermal fluid circulation in the shallow crust; and 4) The results will aid in the quantification of models of seafloor processes such as dispersal of fauna among seafloor and crustal chemosynthetic habitats. We continue to examine these ideas and their ramifications. We have proposed future work based both on this finding as well our findings on the impact of hydrothermal Fe on oceanic biogeochemistry. These results, along with those discussed in Tagliabue et al. (2016; see below), suggest that exploration for hydrothermal activity near the Southern Ocean will be important to understand how natural processes might impact the oceanic carbon-cycle.

An invited review paper published this year (Baker 2017) in a journal largely dedicated to ore deposits provided an up-to-date view of submarine hydrothermal activity to a community mostly unfamiliar with recent results but highly interested in seafloor resources.

We completed work with French colleagues at the Institut français de recherche pour l'exploitation de la mer (IFREMER) on hydrothermal source discoveries in the Lau basin as reported in Konn et al. (2016). This continues EOI's efforts in the Lau region and begins a longer term collaboration with scientists at IFREMER through their Hydrothermal Exploration and Research for Mineralization in New Environments cruise aboard the RV *Pour Quoi Pas?* from March 15 to April 29, 2017. The groundwork for this collaboration was laid during a visit by Resing (Funded by Royal Society of London; see below) to IFREMER and the University of Brest in September 2016. For this effort, dissolved metal samples will be collected for EOI by scientists participating in the cruise. Work with other international colleagues in Korea and China has led to published discoveries about the tectonic setting of hydrothermal vents in the Indian Ocean (Pak at al., 2017) and on the Mid-Atlantic Ridge (Tao et al., 2016). These efforts allow EOI to study the ocean from a global perspective without the need of U.S. sea-going assets.

Objective 2: Accomplishments in Ecosystem Studies

Since 2013, an interdisciplinary team of microbiologists, chemists, and modelers funded by the Gordon and Betty Moore Foundation has focused attention on the interdependence of chemistry and microbiology

Figure 2. The titanium manipulator arm of the ROV SuBastian holds a sulfur-rich chimney sample from Chamorro, a quiescent arc volcano. 'Hairy snails' attached to the chimney are similar to another 'mature' arc volcano 300 km south of this site.

and the role of viruses in gene transfer and microbial evolution, using Axial Seamount as the field study site. Research scientist Ben Larson has had a significant role in developing models that incorporate real fluid chemistry, thermodynamics, and reaction kinetics to understand reactions and residence time in the sub-seafloor mixing zone where microbes grow. We are in the final stages of running those models and preparing results for publication. We successfully deployed the *in situ* incubator (developed by JISAO scientists David Butterfield, Ben Larson, PMEL engineer Noah Lawrence-Slavas, and microbiology colleagues Julie Huber and Jim Holden), with the novel technique of *in situ* Stable Isotope Probing, whereby $_{13}$C-labeled bicarbonate is incorporated into an actively growing microbial community, preserved *in situ*, followed by sequencing of the isolated, isotopically enriched ribonucleic acid fraction. Two papers (Stewart et al., 2016, Topcuoglu et al., 2016) examine the rates of microbial metabolic reactions and their dependence on dissolved hydrogen gas, which varies with volcanic cycles at Axial Seamount. A paper describing the incubator instrument and first results is in preparation. A paper showing correlations between functional genes (microbial activity) and fluid chemistry across three vent sites and three years has been submitted (Fortunato et al, submitted 2017). Nine scientists working on this Moore-funded project met for a final synthesis meeting in October, 2016, and identified several more collaborative papers that will be developed in the next year, including work on ecosystem models of hydrothermal systems.

Objective 3: Accomplishments on the Impact of Hydrothermal and Volcanic Activity on Oceanic Biogeochemical Cycles

The chemical composition of the oceans is altered by the interaction between the solid Earth and the ocean through hydrothermal activity. Of particular interest is the impact of these processes on the supply of trace metals that act as nutrients in the ocean. Iron often limits primary productivity, and iron supply may control the fixation of CO_2 and its transfer from the atmosphere to the deep ocean and sediments via the export of fixed carbon from the surface ocean. In 2015 we reported on the long range transport and biogeochemical importance of hydrothermal Fe in the ocean. Those findings prompted a variety of questions about what hydrothermal sources might be the most important contributors to oceanic productivity and to the chemistry of the oceans. In 2016 we addressed the question "What are the most important ridge crests sources for providing Fe to the Southern Ocean?" Resing and Alessandro Tagliabue (University of Liverpool) were funded by the Royal Society of London to collaborate on addressing this and other questions about hydrothermal Fe using existing data and a state of the art global biogeochemical model developed in the Tagliabue Lab. Tagliabue and Resing (2016) report that ridges close to the Fe-depleted regions of the Southern Ocean are likely to provide more Fe than do those farther from this region, and thus have a much

greater impact on primary productivity and carbon export from this region. Additionally, the results indicate that ridge crests in the Pacific, because of their greater hydrothermal activity and their depth, are more important for Fe fertilization than those in the Atlantic and Indian oceans.

During 2016-17 we are evaluating the most important hydrothermal sources of Fe to the global ocean in two ways. The first is based on the suggestion in Baker et al. (2016) that low temperature sources are more prevalent than previously thought. If this is so, then they may provide a suitable environment for the stabilization of Fe that is required for its basin-scale transport. The second question is complementary to the first and asks "Is the ambient pool of Fe-stabilizing organic ligands in the deep ocean sufficient to stabilize and transport hydrothermal Fe across the ocean, or do we need a hydrothermal source of these ligands?" These studies are still in their preliminary stages.

On a local scale, we examined the chemical flux from two shallow submarine volcanoes into the surface ocean. Along the coastline of the El Hierro volcano in the Canary Islands, natural oceanic acidification is caused by shallow carbon-dioxide-rich hydrothermal venting with a calculated flux of CO_2 to the ocean that represents about 0.1% of the total emissions from all submarine volcanoes (Santa-Casiano et al., 2016). We also examined the flux of a variety of chemical components from the summit of Ahyi volcano along the Mariana Arc. These estimates are the subject of a manuscript in preparation (Buck et al., 2017). On a regional scale, we continue our effort to determine if hydrothermal effluent from the Mariana Arc reaches beyond the Mariana region, thus impacting mid-depth ocean chemistry in the western Pacific Basin. Student Susanna Michael has analyzed the particle composition of these waters and looks to analyze the dissolved Fe and Mn in mid-2017.

Figure 3. Vent fauna (shrimp, snails, limpets, crabs) on the vertical sides of a massive copper-rich chimney tower in the back-arc site 'Hafa Adai' near 17.0°N. The species here are distinct from those on the arc volcanoes, and appear identical to other back-arc sites in the Mariana region.

In 2016-17 we are initiating a new effort with Tagliabue to examine the impact of the Mid-Atlantic Ridge on Atlantic Ocean chemistry. This effort is in the planning stages with a cruise scheduled for December 2017 to February 2018. We have been invited to participate on the cruise, however, funding constraints make it more likely that samples will be collected for us by other cruise participants.

Objective 4: Accomplishment on the Impact of Chemical Exchange between Solid Earth and the Oceans

In addition to the intense interaction between the solid Earth and the ocean observed at submarine volcanoes, additional interactions occur at the ocean margins. We are interested in these interactions due to the input of trace nutrients and gasses into the coastal ocean.

Ocean margin sediments, especially those below oxygen minimum zones, are important sources of trace

nutrient metals (e.g., Fe and Co) to the ocean. Cyanobacteria (nitrogen fixing organisms) have an absolute requirement for cobalt. For cocolithophores and diatoms, cobalt can partially substitute for zinc when zinc is scarce. Since the majority of Co and Zn in diatoms is allocated to carbonic anhydrase, free Co and Zn are crucial to diatoms' capacity to fix and export carbon. Thus, Co is crucial for global carbon fixation and climate regulation. In Hawco et al. (2016), it is reported that the most important source of Co to the South Pacific is from the margin and margin sediments. Additionally, in Sanial et al. (2017) we demonstrated that elevated ^{228}Ra sourced from coastal sediments was present in surface waters 8500 km away from the coast. These studies confirm that the continental shelf is an important source of sediment-derived trace elements to both coastal and central Pacific Ocean waters. These measurements, combined with Mn and Fe data reported by us previously, enabled the calculation of coastal Mn and Fe fluxes to the ocean, thus providing a quantitative measure of the impact of the solid Earth on ocean chemistry.

Primary productivity in the Gulf of Alaska (GOA) is limited by availability of the micronutrient iron. Because the northern GOA region has been understudied relative to many parts of the world's oceans, our understanding of key processes controlling nutrient supply to surface waters there is limited. In Crusius et al. (2017), we examine the impact of shelf-sediment resuspension and summertime meltwater-input to rivers on Fe distributions and transport to the GOA. In Schroth et al. (2017), we examined the transport of Fe in glacial dust to the open ocean of the GOA. Both efforts looked at Fe transport from coastal sources to the iron-depleted waters of the GOA. This collaborative effort continues into 2017 through the analysis by graduate student Susanna Michael of samples collected across a range of seasons on the GOA shelf.

We continue to work on understanding the sources of iron to the Equatorial Under Current (EUC). The EUC carries nutrient-rich waters eastward to high-nutrient, low-chlorophyll regions in the Eastern Equatorial Pacific, thus potentially impacting one of the more productive regions in the ocean. Although much is still unknown about the sources of trace nutrients to the EUC, exchange between the iron-rich solid Earth and the iron-poor ocean is clearly implicated. We are investigating whether the Solomon Sea, located north and east of Papua, New Guinea is a possible source of iron and other trace metals to the EUC. The Solomon Sea has strong boundary currents that scour the coastal margins. Those sediments, plus input from large rivers, island mining sites, and hydrothermal venting, reach the headwaters of the EUC. Samples were collected for our lab during a study in and around the Solomon Sea conducted by Cathrine Jeandel and colleagues at the Laboratoire d'Etudes en Géophysique et Océanographie Spatiales in Toulouse France. We analyzed these samples for aluminum and manganese. A preliminary examination of the entire data set is reported in Ganachaud et al (2017). Michael has worked on the data throughout 2016-17, and is developing a more extensive manuscript based on her findings.

TSUNAMI OBSERVATIONS AND MODELING

L2-BASED UNIT SOURCE SELECTION AND TIME WINDOW SELECTION FOR THE SIFT APPLICATION

PI
Donald B. Percival – UW Applied Physics Laboratory

TASK III

NOAA SPONSOR
Diego Arcas – Pacific Marine Environmental Laboratory

NOAA GOALS
Weather-Ready Nation

DESCRIPTION
NOAA's Tsunami Warning Centers use data collected in near-real time to detect tsunamis and then to predict their impact at U.S. coastal communities. The data are collected by a network of Deep-ocean Assessment and Reporting of Tsunamis (DART) buoys placed at strategic locations in the open ocean. When a tsunami event occurs, the data are processed by NOAA/PMEL's Short-term Inundation Forecast for Tsunamis (SIFT) application as a first step toward predicting inundation due to the tsunami at various impact sites. The two concurrent tasks described here are both intended to improve the performance of the SIFT application.

The first task considers the selection of unit sources (regressors) to serve as predictors for the tsunami signal in the inversion algorithm embedded within SIFT. Previous work (Percival et al., 2014) considered using the so-called 'elastic net' (Zou and Hastie, 2005) to select regressors. The elastic net is a variation of the popular 'lasso' method (Tibshirani, 1996), which uses the L1 norm to automatically select appropriate regressors from a large collection of potential regressors for a linear regression model. While Percival et al. (2014) demonstrated that the elastic net works well, they also noted that an alternative approach using the L2 norm in conjunction with nonnegativity constraints yielded exactly the same results as the elastic net approach when both approaches were applied to a small set of actual tsunami events.

The L2-based approach has the appeal of being algorithmically much simpler than the L1-based approach, which is important for generating timely results during an ongoing tsunami event. The task at hand is to develop R code for the L2 approach that will serve as the basis for operational code to be incorporated within the SIFT application and to compare the L1- and L2-based approaches on a collection of actual tsunami events.

A second task is to reconsider the automatic selection of data windows for use within SIFT. Previous work focused on searching the data record from a DART buoy for a window isolating the tsunami signal. Percival et al. (2015) provided evidence that estimation of unit source coefficients jointly with coefficients modeling tidal components is superior to various two-stage approaches involving removing the tides and then using the detided data to estimate the unit source coefficients. Optimal use of the joint method requires adapting the data window so that it includes enough data prior to arrival of the tsunami signal to help stabilize estimation of the tidal components, but too much prior data can cause the joint method to deteriorate due to the simplicity of the predictors in the regression model used to locally model the tidal component. The task at hand is to investigate the optimal amount of pre-signal data to use, and to merge this into algorithms isolating the tsunami signal.

OBJECTIVES

1. To investigate the use of the L2 norm for unit source selection.
2. To determine the optimal amount of data prior to the onset of a tsunami event to be used in the joint method.

ACCOMPLISHMENTS

The scientists completed a study to determine how much data prior to the arrival of the tsunami signal should be used with the joint method for estimating source coefficients so that the estimated coefficients are as accurate as possible in a minimum mean square error (MSE) sense.

The study involved randomly selected data recorded under ambient conditions by 11 DART buoys (eight scattered around the Pacific Ocean basin, and three in the Atlantic), with the idea being to get a representative sampling of the full spectrum of tidal conditions encountered in practice. A thousand random selections of data from each buoy were added to a rescaled artificial tsunami signal assumed to come from a unit source for which the buoy is well-positioned to record the event. The rescaling is accomplished by multiplying the artificial signal by a source coefficient (denoted as alpha) picked from a set of values of practical interest (including zero). From three up to seven unit sources were paired with each of the 11 buoys, for a total of 47 pairings of buoys/unit sources and a total of 47,000 simulated tsunami events for each setting of alpha.

The events were then processed using the joint method with constrained least squares (LS) employing differing amounts of data prior to a manually identified start of the signal. For each amount of data, the MSE was computed for the estimated alphas over the thousand simulated tsunami events for that buoy/unit source pair, and for a particular setting of alpha. Different nonzero settings for alpha yielded the fortuitous finding of almost identical MSEs (this is in keeping with the theory for unconstrained LS estimators, and the fact that it does not hold when alpha is set to zero is because, for this setting of alpha, constrained LS estimates differ markedly from unconstrained ones).

When using data just up to the first half wave of the tsunami signal, it is valuable to include 10 to 15 minutes of data prior to the event. When the first full wave becomes available, the need for prior data lessens (none or 5 minutes worth). A concern with these results is the perfect match between the tsunami signal and the component in the regression model used in the joint method used to model the signal.

Following the approach outlined in Percival et al. (2016), mismatches were introduced between the assumed tsunami signal and its representation in the regression model. This exercise demonstrated the need for more prior data to compensate for the unknown tidal component when the signal model is imperfect: about 40 minutes of data prior to the event are on average best to use when either 11 or 21 minutes worth of data after the first quarter wave of the tsunami signal are available. This recommendation merges nicely with operational considerations when using SIFT during a tsunami event. Work on the concurrent task (investigation of the use of the L2 norm) is in progress.

TSUNAMI RESEARCH

PI
Yong Wei – UW Joint Institute for the Study of the Atmosphere and Ocean

OTHER UW PERSONNEL
Diego Arcas (resigned Dec. 1, 2016), Donald Denbo, Edison Gica, Linus Kamb, Jean Newman, Clinton Pells, Michael Spillane (retired May 31, 2016), Lindsey Wright, and Hongqiang Zhou – Joint Institute for the Study of the Atmosphere and Ocean

TASK II

NOAA SPONSOR
Diego Arcas – Pacific Marine Environmental Laboratory

OTHER NOAA PERSONNEL
Marie Eble, Vasily Titov, and Christopher Moore – Pacific Marine Environmental Laboratory

NOAA GOALS
Weather-Ready Nation
Resilient Coastal Communities and Economies

DESCRIPTION
NOAA bears a national responsibility to address issues of public safety and economic costs associated with extreme weather and ocean hazards and, in particular, to "Increase Lead Time and Accuracy for Weather and Water Forecasts." Tsunami waves, having the potential for devastating effects, can in many cases be detected well in advance of coastal impact, and clearly fall within that mandate. Following the horrific Indian Ocean tsunami of December 2004, the U.S. Congress passed the Tsunami Education and Warning Act which identifies four activities – tsunami forecast and warnings, mitigation, research, and international coordination – that can further future preparedness.

Important contributions to each of these activities take place at the NOAA Center for Tsunami Research (NCTR) at the Pacific Marine Environmental Laboratory (PMEL) in Seattle through the collaborative efforts of NOAA and JISAO scientists in the Tsunami Research Program. NCTR is comprised mainly of JISAO scientists. Basic research into tsunami generation and numerical modeling of propagation and inundation provide the basis for forecasting, and the SIFT (Short-term Inundation Forecasting for Tsunamis) tool, developed at NCTR, is employed at NOAA's Tsunami Warning Centers, which have the operational responsibility for disseminating timely warnings. Input to the forecast system is provided by an array of bottom pressure recorders in the Pacific, Atlantic, and Indian oceans which detect and report in real time the passage of a tsunami wave. The instruments, called DART®s (Deep-ocean Assessment and Reporting of Tsunamis – developed at PMEL) are deployed and serviced by the National Data Buoy Center. Array studies, conducted at NCTR, assist in the choice of the optimal locations for the DART® buoys and assessment of the impact of instrument outages.

Other aspects of NOAA's tsunami-related activities include the U.S. National Tsunami Hazard Mitigation Program (NTHMP), a Federal/State collaborative partnership of NOAA, the U.S. Geological Survey, the Federal Emergency Management Agency (FEMA), the National Science Foundation (NSF), and the Emergency Management and Geotechnical agencies of the U.S. coastal states. Modeling efforts at NCTR facilitate risk assessment for exposed communities and existing or planned infrastructure. Public education, both within the U.S. and internationally, training and capacity building for scientific and emergency planning and

response, and the development of partnerships are vital to combating the tsunami threat. NCTR seeks to achieve these goals through presentations and workshops worldwide. In particular, modeling and forecast tools are customized to facilitate this mission and establish warning services for global coastal communities.

OBJECTIVES

1. To provide scientific and operational support for the tsunami forecast system SIFT for use at the U.S. Tsunami Warning Centers (TWC) in Hawaii (Pacific Tsunami Warning Center) and Alaska (National Tsunami Warning Center).
2. To continue development, testing and updating of the SIFT components, specifically, high-resolution forecast models for U.S. coastal communities.
3. To conduct tsunami hazard assessment studies for several coastal locations in collaboration with state and federal partners.
4. To promote accessibility and usability of historical tsunami data.
5. To work with the American Society of Civil Engineers (ASCE) and state stakeholders to develop standard building codes for structures in the tsunami flooding zone.
6. To develop new tools for hazard assessment and forecast.
7. To help develop tsunami forecast and warning capabilities in the Pacific, Indian, and Atlantic oceans in collaboration with international partners using community modeling tools, including training, education, and capacity building.

ACCOMPLISHMENTS

1. Development and improvements to the SIFT software continues. Last year's effort was focused on maintaining the current operational version of SIFT (versions 3.2.x and 3.3.x) and developing and testing the next operational version (version 4.0).
    a. Version 3.2.4nr was released on March 23, 2016 and installed at the TWCs. Several bugs were fixed and the ingest of Neptune Canada data was included.
    b. Version 3.3.1 was released to the TWCs on Oct 17, 2016. Error checking and notifications were added to Neptune data ingest. Data ingest was speeded up by improving the detide/qc calculations.
    c. Version 3.3.2 was released to the TWCs on February 3, 2017. This was primarily a bug fix release. One major fix was to resolve the creation of very large log files caused by Neptune data handling.
    d. The Joint Inversion Method, a new inversion technique, has been implemented from the original R code. This method improves robustness and accuracy by removing the data detide stage and directly determining the M2 tidal coefficients and unit source alphas in a single inversion.
    e. AutoInversion has been developed. AutoInversion runs in the background as a service (doesn't require SIFTView). When a new event is detected, AutoInversion selects the unit sources, determines the time window for the DART data, and computes the inversion. It can automatically adjust the number of unit sources based on the inverted solution, and iterate to a solution.
    f. A new database schema for SIFT tide, DART, and Neptune data was created. The new schema improves the speed and robustness of data handling. This improvement required many changes to how SIFT handles data.
    g. Test versions of SIFT 4.0 were provided to the TWCs for testing. SIFT 4.0 includes:
        I. Adjusting the C grid results using a tidal prediction.
        II. Displaying the tidal adjusted time series at C grid warning points.
        III. Displaying speed for the C grid.
        IV. Running the AutoInversion service to provide automatic inversion results to the user when sufficient data is available.
        V. Auto Inversion uses the Joint Inversion Method and the DART Workbench uses the Joint

Inversion Method as the default method.

VI. Many improvements to the SIFT GUI.

Several new site-specific tsunami forecast models have been developed and are now included in the SIFT system: British Columbia, and Baltra and Ayora Ecuador.

2. The JISAO tsunami group developed high-resolution forecast models for Galapagos, Ecuador in 2016. Three other forecast models are being developed for East of Oahu Island (Hawaii), the Easter Island (Chile), and the Marquesas Islands (French Polynesia).

3. As in previous years, the Tsunami Research Program has continued to lead several Tsunami Hazard Assessment projects for different state and federal agencies.

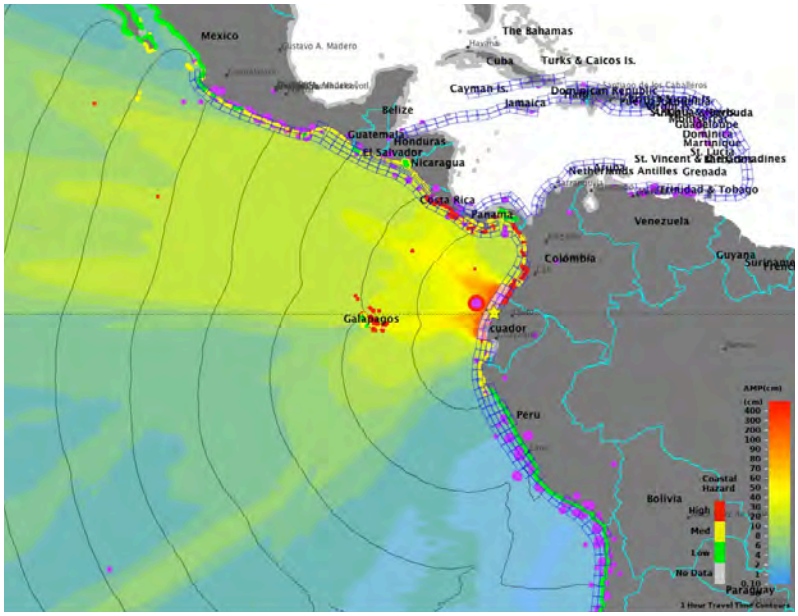


Figure 1. The Tsunami Coastal Assessment Tool (TsuCAT), showing coastal tsunami amplitudes for the 1906 earthquake off the coast of Ecuador.

   a. In collaboration with the Washington State Emergency Management Division (WA EMD), two tsunami hazard assessments in the Puget Sound and Salish Sea area have been developed for the localities of Anacortes and Bellingham. This new hazard assessment evaluates the exposure of both communities to a tsunami generated by a large seismic event along the Cascadia subduction zone. A similar study for communities along the Hood Canal is currently being conducted, and is expected to finish in fiscal year 2017. A proposal to fund the next stage of the project has been submitted to NTHMP for evaluation. In fiscal year 2017, WA EMD is also funding a comparative study to evaluate model accuracies for four tsunami models (MOST, CLIFF, GEOCLAW and HYSEA) through collaboration among UW, NCTR, and the University of Málaga.

   b. NCTR has also been collaborating with FEMA by providing information for a large emergency exercise addressing a Cascadia seismic event (Cascadia Rising) during June 7-10, 2016.

   c. NCTR has completed a Nuclear Regulatory Commission (NRC) document that will regulate tsunami hazard assessment studies for nuclear power plants in the U.S. A final version of the report has been submitted to the NRC (Titov et al., 2016).

4. The Big Earth Data Initiative (BEDI) is designed to promote interoperability of Earth observation data across federal agencies, systems and platforms through the improvement of data management practices and increased discoverability, accessibility, and usability of data collections. As part of BEDI 2016 efforts, and in collaboration with data management staff at NOAA's National Centers for Environmental Information, NCTR is reformatting, documenting, archiving and making discoverable segments of tide gauge marigram records on which are recorded measurements of the 1946, 1952, 1960 and 1964 Pacific Ocean generated tsunamis. These four tsunami events are historically important but data during each event reside only on the marigram records as either a digital or graphical image, or on paper. Conversion of these graphical data to numerical data, and making these digitized tsunami records publicly discoverable will provide new information about these tsunami events, greatly increase the number of observations available for tsunami model validation, and will have a great impact on global oceanic research communities.

5. The online tsunami forecasting capabilities project, Tweb has been focused on implementing

operational uses of Tweb and related systems during the current reporting period. Tweb continues to be used regularly by researchers and by national and international tsunami warning center personnel as a supplementary information source and for tsunami preparedness exercises, including the CaribeWave and LANTEX exercises. NCTR is working on locating an operational platform for Tweb. Development continues on Tview, a revision to the Tweb View-Only interface. When fully operationally deployed at the National Centers for Environmental Prediction, Tview will provide a web portal for the display and dissemination of operational warning and forecast information to Emergency Response Personnel.

6. Continued collaboration between NCTR and UNESCO's International Tsunami Information Center has produced the Tsunami Evacuation Maps, Plans and Procedures (TEMPP) project where modeling expertise helps host countries create inundation and evacuation maps and plans. An initial pilot project in Honduras has produced evacuation maps and plans for two coastal communities: Sambo Creek (Caribbean coast) and Cedeño (Pacific coast). The ComMIT modeling tool, developed at NCTR, was used extensively for this project, and results were presented at the Pacific Tsunami Warning System meeting in Tahiti in March 2017. The next ComMIT training will be held in St. George's, Grenada in June 2017.

   A new tool born of the feedback from the TEMPP project was created at NCTR: the Tsunami Coastal Assessment Tool (TsuCAT). This tool uses the same model and sources as ComMIT, but allows a rapid assessment of coastal impact without running a full inundation model. Not meant to be a replacement for producing an inundation map, it can provide assessment in the crucial minutes between when an earthquake strikes and a forecast is produced (Figure 1). TsuCAT was unveiled during the Pacific Tsunami Warning System meeting, and immediate interest was shown by participants from several South Pacific nations.

7. The collaboration with the University of Málaga has continued over the current reporting period. Installation of the tsunami simulation code HySEA, developed at the University of Málaga at NCTR servers will allow NCTR scientist to use an additional tool for tsunami simulation. The capability of HySEA to model frequency dispersion effects in wave propagation will become fundamental in the computation of tsunamis generated by landslides and other small-scale sources.

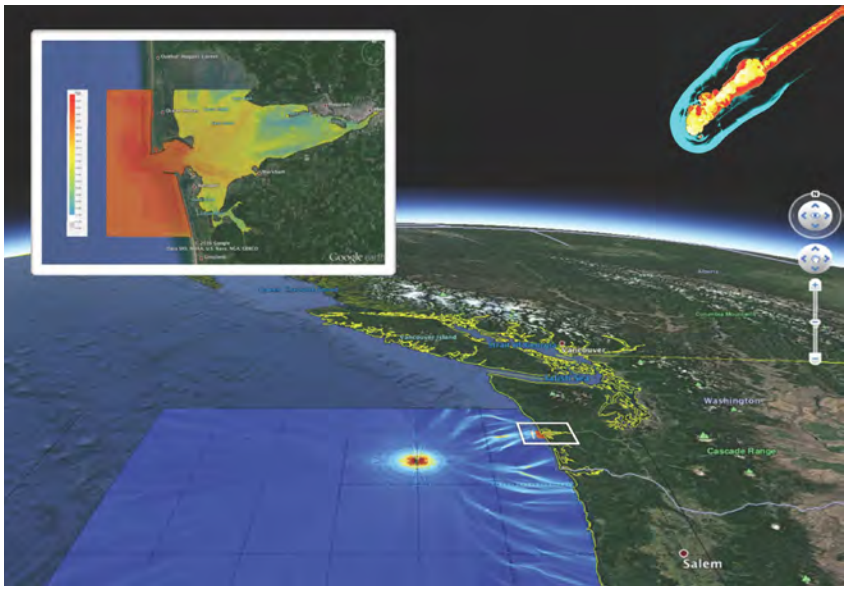


Figure 2. An overview figure for asteroid tsunami modeling. It shows maximum computed offshore and coastal wave amplitudes (inset), generated by an airburst of 140m asteroid at about 10km above ocean surface. The model of the asteroid airburst impact is shown in the upper right corner.

8. NCTR/PMEL and NASA Ames Asteroid Threat Assessment Project co-sponsored an Asteroid Generated Tsunami workshop during August 23-24 at PMEL to address the problem of tsunamis generated by asteroid impact. The workshop resulted in a broad consensus that the asteroid impact tsunami threat is not as great as previously thought, and that airbust events in particular are unlikely to produce significant damage by tsunami (Figure 2).

9. As a result of the collaboration between NCTR and the Scripps Oceanographic Institution to help

identify the connection between tsunami impact along the Ross Sea ice shelf in Antarctica and the occurrence of fracture events in the ice shelf (Figure 3), one research paper has been submitted to JGR-Oceans (Bromisrski et al., 2017). A proposal to NSF (Division of Polar Programs) is being prepared with submission due in May 2017.

10. JISAO has been working closely with ASCE to help develop the ASCE 7-16 tsunami provisions, which provide the first comprehensive tsunami design criteria in the world and represents the state of the art tsunami design knowledge presented in enforceable code language (Naito et al., 2016; Chock et al., 2017). Two related projects are:
    a. JISAO has successfully completed a study, sponsored by FEMA, the Hawaii Emergency Management Agency, the Structure Engineers Association of Hawaii, and the ASCE Hawaii Chapter to benchmark Hawaii tsunami design zone maps per the ASCE 7-16 standard using high-resolution inundation models (Wei et al., 2016).
    b. JISAO is presently conducting a high-resolution site-specific model study, sponsored by the Yorst-Grube-Hall Architecture, to assess the tsunami impact for the proposed Oregon State University (OSU) Marine Science Building at Newport, Oregon (Figure 4). The first phase of this project was completed on February 28, 2017, and the next phase will end on July 31, 2017.

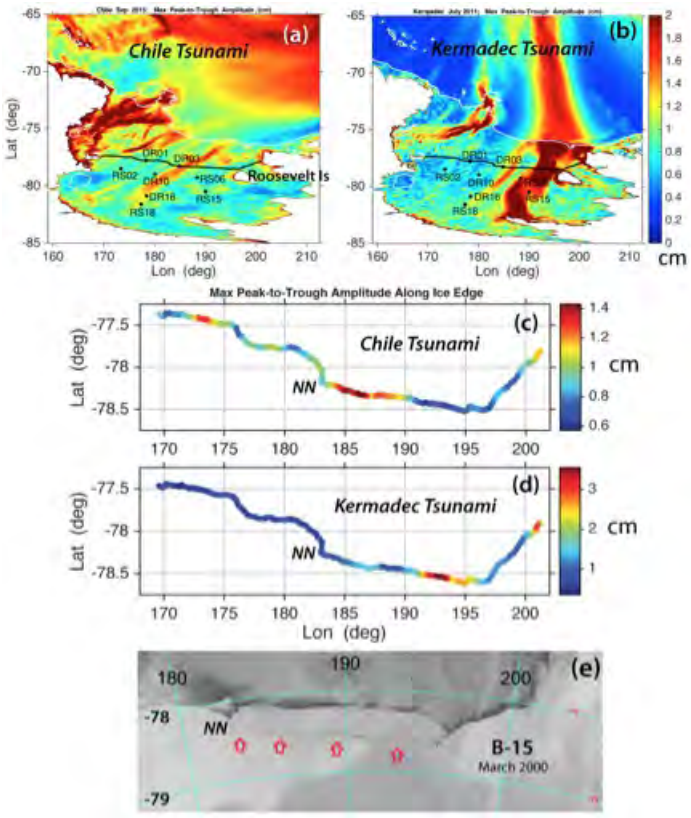


Figure 3. Bathymetry-enhanced very long period and infragravity wave amplitudes in the Ross Sea from the 2015 Chile (a) and 2011 Kermadec (b) tsunamis. Maximum tsunami wave amplitudes along the ice edge for the 2015 Chile (c) and 2011 Kermadec (d) tsunamis. (e) Ice shelf fracture event of the B-15 iceberg in March 2000.

11. Four tsunami events have occurred during the present reporting period: April 16, 2016 in Ecuador; September 1, 2016 in New Zealand; November 13, 2016 in New Zealand; and December 8, 2016 in the Solomon Islands. NCTR has continued to analyze and validate NCTR's forecast tools and methodology with both events. Comparative experimental forecasts are published online (Titov et al., 2016; Tang et al., 2016).

12. One additional training workshop using the ComMIT software, in addition to the ones already mentioned for the TEMPP project, was conducted during the current reporting period at PMEL with participants primarily from Washington State. The next ComMIT workshop is planned to take place on the island of Grenada most likely in the month of June 2017.

13. BEDI is designed to promote interoperability of Earth observation data across federal agencies, systems, and platforms through the improvement of data management practices and increased discoverability, accessibility, and usability of data collections. As part of BEDI 2016 efforts, and in collaboration with data management staff at NOAA's National Centers for Environmental Information, NCTR is reformatting, documenting, archiving, and making discoverable, segments of tide gauge marigram records on which

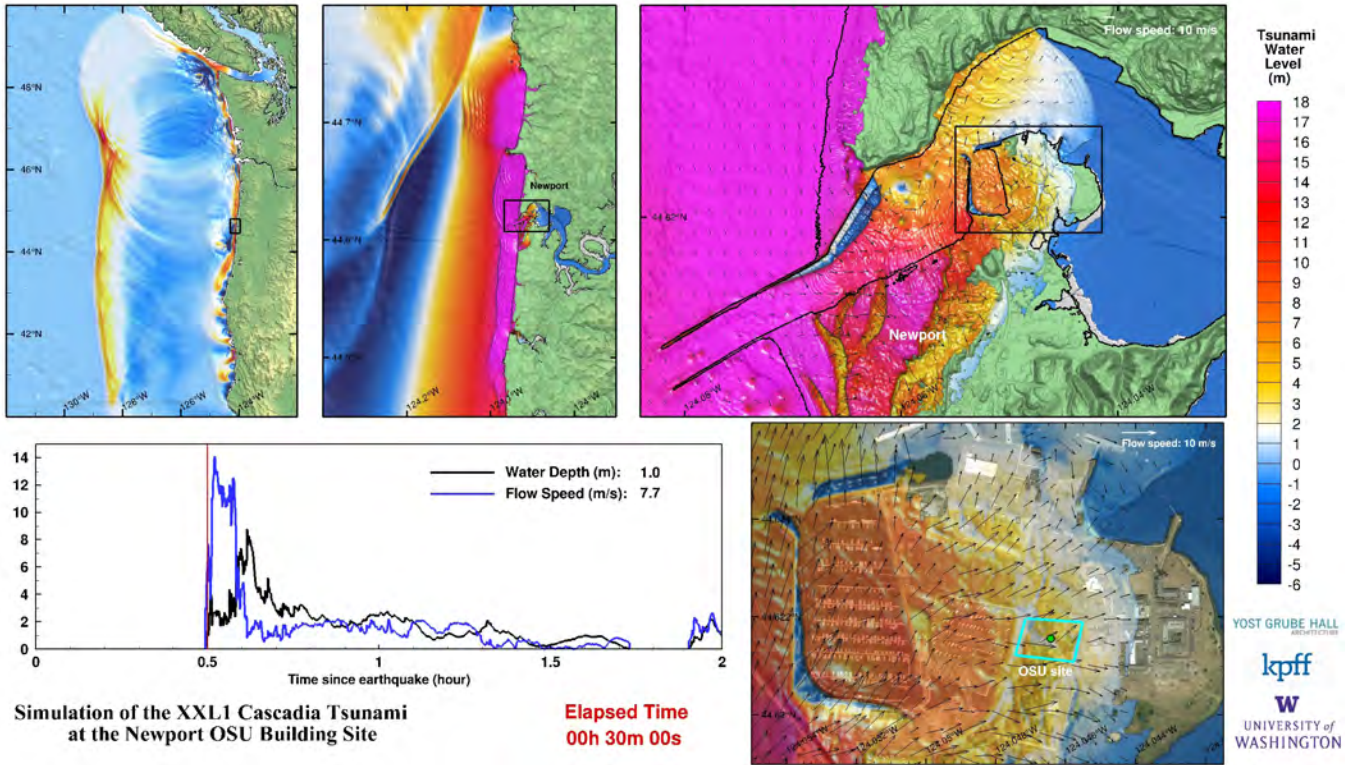
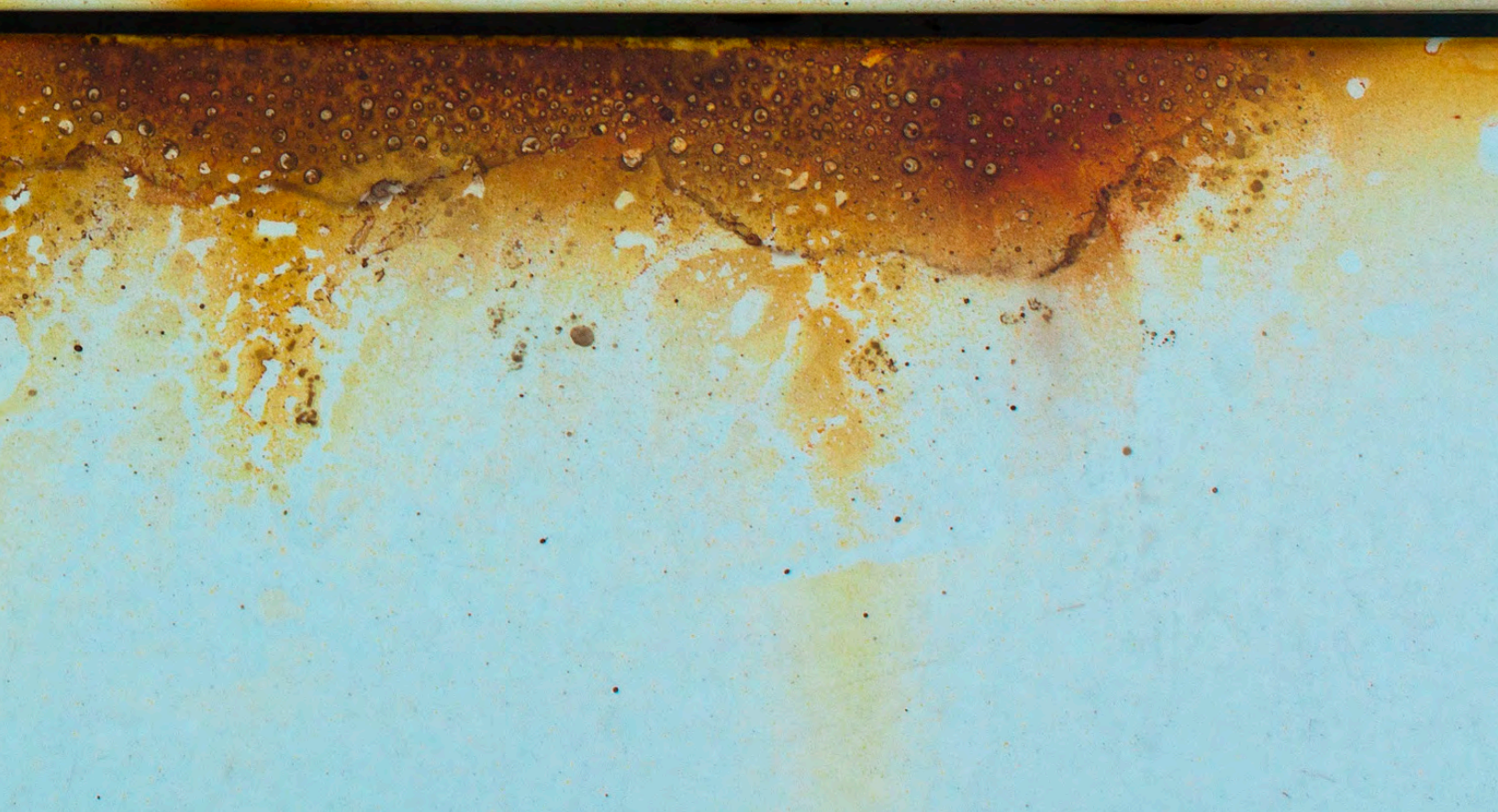


Figure 4. A snapshot of the tsunami propagation and inundation at the proposed Oregon State University Marine Science building site resulted from the XXL1 Cascadia earthquake scenario: a) tsunami propagation offshore; 2) tsunami propagation nearshore; 3) tsunami inundation in Yaquina Bay and the building site, where the arrows indicate the direction of flow velocities; 4) time series of tsunami water level and flow velocity at the center location of the building site; 5) tsunami inundation at the building site at the time of 30 min after the earthquake, where the arrows also indicate the direction of flow velocities.

are recorded measurements of the 1946, 1952, 1960 and 1964 Pacific Ocean generated tsunamis. These four tsunami events are historically important, but data during each event reside only on the marigram records as either a digital or graphical image, or on paper. Conversion of these graphical data to numerical data and making these digitized tsunami records publicly discoverable will provide new information about these tsunami events, greatly increase the number of observations available for tsunami model validation, and will have a great impact on global oceanic research communities.

14. Over the reporting period, NCTR has actively collaborated with national and international experts in submitting NSF proposals and publishing peer-review journal articles:
    a. JISAO, NCTR, Oregon State University, and the University of Southern California submitted a collaborative NSF proposal in January, 2017 on physical and numerical modeling of the fundamental mechanics of tsunami hazards in complex coastal environments.
    b. JISAO and UCLA submitted a collaborative NSF proposal in March 2017 on the application of array back-projections and rapid tsunami observations to tsunami predictions and early warnings.
    c. NCTR has kept publishing high-quality peer-review journal articles with collaborators from different disciplines over the reporting period (Atwater et al., 2017; Bromisrski et al., 2017; Savastano et al., 2017; Naito et al., 2017; Titov et al., 2016).

APPENDICES



APPENDIX 1

JISAO SENIOR FELLOWS AND COUNCIL MEMBERS

University of Washington:

*Ackerman, Thomas, Professor, Atmospheric Sciences, Executive Director, JISAO

Armstrong, David, Professor, Aquatic and Fishery Sciences

Baker, Edward T., Senior Research Scientist, Affiliate Professor, Oceanography

Bates, Timothy S., Senior Research Scientist, Affiliate Associate Professor, Oceanography

Battisti, David S., Professor, Atmospheric Sciences, Tamaki Endowed Chair

*Bitz, Cecilia, Professor, Atmospheric Sciences, Program on Climate Change, Future of Ice Initiative

Bretherton, Christopher, Professor, Atmospheric Sciences/Applied Mathematics

Charlson, Robert J., Professor Emeritus, Atmospheric Sciences

Covert, David S., Research Professor Emeritus, Atmospheric Sciences

Emerson, Steven R., Professor Emeritus, Oceanography

Eriksen, Charles C., Professor, Oceanography

Friedman, Carolyn, Professor, Aquatic & Fishery Sciences

Fu, Qiang, Professor, Atmospheric Sciences

Gammon, Richard H., Professor Emeritus, Chemistry, Professor, Oceanography

Hartmann, Dennis L., Professor, Atmospheric Sciences

Hilborn, Ray, Professor, Aquatic & Fishery Sciences

*Horne, John, Professor, Aquatic & Fishery Sciences, Quantitative Ecology & Resource Management, Center for Quantitative Science

Jaeglé, Lyatt, Professor, Atmospheric Sciences

Jaffe, Dan, Professor, Interdisciplinary Arts & Sciences and Atmospheric Sciences

McDuff, Russell, Professor Emeritus, Oceanography

Murray, James W., Professor Emeritus, Oceanography

Punt, Andre E., Professor and Director, Aquatic and Fishery Sciences, Quantitative Ecology & Resource Management

Quay, Paul D., Professor, Oceanography

Rhines, Peter B., Professor, Oceanography and Atmospheric Sciences

Ruesink, Jennifer, Professor, Biology

Thompson, LuAnne, Professor, Oceanography, Director, Program on Climate Change

Wallace, John M., Professor Emeritus, Atmospheric Sciences

NOAA Pacific Marine Environmental Laboratory:

Bullister, John, Oceanographer, Ocean Climate Research Division, Affiliate Associate Professor, Oceanography

*Cronin, Meghan, Oceanographer, Ocean Climate Research Division, Affiliate Professor, Oceanography

Feely, Richard A., Supervisory Oceanographer, Ocean Climate Research Division, Affiliate Professor, Oceanography

Harrison, D.E., Oceanographer, Ocean Climate Research Division, Affiliate Professor, Oceanography

Johnson, Gregory C., Oceanographer, Ocean Climate Research Division, Affiliate Professor, Oceanography

Kessler, William S., Oceanographer, Ocean Climate Research Division, Affiliate Professor, Oceanography

McPhaden, Michael J., Senior Research Scientist, Ocean Climate Research Division, Affiliate Professor, Oceanography

Overland, James E., Division Leader, Coastal and Arctic Research Division, Affiliate Professor, Atmospheric Sciences

Quinn, Patricia K., Research Chemist, Ocean Climate Research Division

Sabine, Christopher, Director, Pacific Marine Environmental Lab, Affiliate Professor, Oceanography

Stabeno, Phyllis, Supervisory Oceanographer, Ocean Climate Research Division

Titov, Vasily, Oceanographer, NOAA Center for Tsunami Research, Affiliate Assistant Professor, Earth and Space Sciences

*Zhang, Chidong, Division Leader, Ocean Climate Research Division, Affiliate Professor, Atmospheric Sciences

*2016-2017 Council Members

APPENDIX 2

NOAA COOPERATIVE AGREEMENT AWARDS FUNDED IN 2016-2017

PI	Task	Title	Award
Ackerman, Thomas	I	JISAO Task I	$603,351
Punt, Andre	I	Bevan Lecture Series	$15,000
Ackerman, Thomas	II	Research Services	$1,944,846
Bates, Timothy	II	Atmospheric Chemistry - Aerosol Program	$374,518
Bond, Nicholas	II	Alaska Fisheries Science Center Internship Opportunities	$28,073
Bond, Nicholas	II	Climate impacts on the dispersal and survivorship of northern fur seal pups	$97,668
Bond, Nicholas	II	Hake Project	$93,685
Bond, Nicholas	II	Ecosystems and Fisheries-Oceanography Coordinated Investigations (EcoFOCI)	$969,469
Bond, Nicholas	II	Observing System Research Studies	$508,372
Bond, Nicholas	II	Ecology of Seals in the Arctic	$355,306
Bond, Nicholas	II	Population trends, vital rates, and diets of otariid pinnipeds in Alaska: What can they tell us about the relative effects of climate change and human activities	$216,823
Bond, Nicholas	II	Assessment and Ecology Program: Understanding Cetacean Distribution in Alaskan Waters in Relation to the Impacts of Climate Change and Anthropogenic Activities	$1,248,919
Bond, Nicholas Zhang, Dongxiao	II	Ocean Climate Stations	$629,086
Branch, Trevor	II	Evaluation of groundfish ecological response to current fisheries management systems	$49,543
Butterfield, David	II	NOAA NeMO/VENTS Maintenance Cruise	$58,281
Butterfield, David Lilley, Marvin Resing, Joseph Baker, Edward	II	Earth-Ocean Interaction Prograam (Vents Hydrothermal Research Group)	$698,617
DeCosmo, Janice	II	Northwest Fisheries Science Center and University of Washington Undergraduate Intern Program	$7,963
Essington, Timothy	II	Distribution & application of a new geostatistical index standardization & habitat modeling tool for stock assessments & essential fish habitat designation in AK & NW Atlantic regions	$7,733
Kelly, Ryan	II	Improving techniques for estimating abundance and habitat use in nearshore marine habitats using environmental DNA	$98,933

PI	Task	Title	Award
Miller, Bruce	II	Marine Biological Interactions in the North Pacific - Fish Interactions Task	$507,858
Mordy, Calvin	II	Innovation Technology in the Arctic	$563,605
Mordy, Calvin	II	Development of the Oculus Coastal Glider	$252,001
Punt, Andre	II	Partnership with the Northwest Fisheries Science Center and Alaska Fishery Science Center to Develop Increased Capacity in the School of Aquatic & Fishery Sciences to Enhance Teaching and Research	$200,000
Punt, Andre	II	Understanding Participation and Effort in State and Federal Fisheries Along the West Coast	$12,124
Punt, Andre	II	Defining good practices for fishery assessments	$122,646
Punt, Andre	II	Alaska CLIMate Project: A multi-model assessment of climate change impacts on fish, food-webs, and fisheries in Alaska	$231,162
Punt, Andre	II	Management scenarios for snow crab under climate change	$90,000
Punt, Andre	II	An Evaluation of Management Strategies for Implementation of Annual Catch Limits for Alaska Groundfish	$90,000
Punt, Andre	II	Management strategy evaluation using the Generic Modeling for Alaska Crab stocks (GMACS)	$89,999
Punt, Andre	II	Advanced computing for Ecosystem Modeling and Management	$379,442
Roberts, Steven	II	Assessing the Capacity for Evolutionary Adaptation to Ocean Acidification in Geoduck	$90,066
Roberts, Steven	II	Developing genomic resources to support restoration and protection of the Olympia Oyster in Puget Sound	$237,483
Sonnerup, Rolf	II	Chlorofluorocarbon Tracer Program	$218,707
Sutton, Adrienne	II	Marine Carbon Program	$1,521,855
Tornabene, Luke	II	Archival Storage and Dissemination of Data on Northeast Pacific Fish Eggs, Larvae, and Adults	$103,974
Wang, Muyin	II	Arctic Project	$238,000
Wei, Yong	II	Tsunami Program	$1,155,480
Young, Graham	II	Steelhead Reproduction and Epigenetics	$98,448
Zhang, Dongxiao	II	Tropical Atmosphere-Ocean Interaction	$1,374,713

PI	Task	Title	Award
Ackerman, Thomas	III	Postdoctoral Support for Technological Solutions to Fisheries Challenges	$155,189
Doherty, Sarah	III	Contribution to National Climate Assessment 4	$58,227
Holzworth, Robert	III	Lightning Studies	$164,277
Hwang, Jenq-Neng	III	Automated Image Processing for Fisheries Applications II	$68,440
MacCready, Parker	III	Larval Rockfish Dispersal Modeling	$29,038
Percival, Donald	III	L2-Based Unit Source Selection and Time Window for the SIFT Application	$30,000
Punt, Andre	III	West Coast Groundfish Stock Assessment	$145,490
Punt, Andre	III	Development and application of a size-structured spatiotemporal model for invertebrates: individual growth, size-transitions, and natural and fishing mortality	$89,460
Punt, Andre	III	OA Projections for Snow, Tanner, and Red King Crab in Alaska	$48,496
Rigor, Ignatius	III	Coordination And Data Collection Of The U.S. Interagency Arctic Buoy Program (US-IABP) And US Interagency Program For Antarctic Buoys (US-IPAB)	$115,100
Riser, Stephen	III	The Argo Project: Global Observations for Understanding and Prediction of Climate Variability	$3,519,625
Webster, Sarah	III	Task III - Evaluating Demersal Fish Identification and Response to Artificial Light and Acoustic Noise Using a 360-Degree Camera and Imaging Sonars	$136,193
Total			**$20,143,284**

APPENDIX 3

NON-COOPERATIVE AGREEMENT AWARDS FUNDED IN 2016-2017

PI Name	Sponsor Name	Full Title	2016-17 $
Cheng, Wei	NOAA	Collaborative Research: Understanding the freshwater budget of the Atlantic Ocean: Controls, Responses, and the Role of the AM OC	$272,324
Serra, Yolande	DOE	Shallow-to-Deep Convective Transition in the Amazon	$405,118
Chiodi, Andrew	USFS	Climate research for wildland fire management	$55,127
Sonnerup, Rolf	NSF	Evaluating the Accuracy of Biogeochemical Cycling Rates from Transient Tracers	$196,156
McCabe, Ryan	NOAA	MERHAB: An early warning system for Pseudo-nitzschia HABs on Pacific Northwest outer-coast beaches	$190,639
McCabe, Ryan	NOAA	Operational Ecological Forecasting of Harmful Algal Blooms in the Pacific Northwest using an Environmental Sample Processor	$19,308
Resing, Joseph	NSF	Collaborative Research: US GEOTRACES Pacific Section: Shipboard Al, Mn, and Fe in support of the Eastern Pacific Zonal Transect	$39,866
Zhang, Dongxiao	NASA	Tropical Indo-Pacific Thermocline Circulation and its Role on Modes of Climate Variability	$87,125
Bond, Nicholas	NPRB	Climate Model Projections of Extreme Physical Conditions in Alaskan Waters	$163,494
McDonald, Patrick	NPRB	Evaluating the effects of climate, predators and prey, and management actions on data-poor species: application of qualitative network models to blue king crab	$104,354
Ackerman, Tom	TOLEDO	Validation and Application of MISR Cloud Retrievals	$331,914
Wood, Kevin	MET	Citizen-Science OCR: testing & implementation	$66,595
Butterfield, David	CFOL	Ocean Observatories Initiative: Regional Scale Nodes	$22,908
Marchand, Roger	JPL	CloudSat Global Summary and Geometric profile (GeoProf) Datasets	$100,685
Kennedy, Amy	OWL RIDGE NRC	Passive Acoustical Monitoring – Quintillion Cable-Laying Project	$94,996
Ackerman, Tom	JPL	Validation and Application of MISR Cloud Retrievals	$215,000

PI Name	Sponsor Name	Full Title	2016-17 $
Bond, Nicholas	UCAR	EarthCube IA: Collaborative Proposal: Advancing netCDF-CF for the Geoscience Community	$79,933
Wei, Yong	KPFF CON ENGRS	Site-specific modeling of tsunami design guide for the OSU Marine Science Institute building	$57,828
Bond, Nicholas	NPRB	Understanding and predicting patterns in northeast Pacific groundfish species movement and spatial distribution in response to anomalously warm ocean conditions	$192,368
Siedlecki, Samantha	AOOS	Alaska Marine Highway System Ferry C02 System Installation: Part II: MAP C02 Instrument Installation and Validation Onboard the M/V Columbia	$3,417
McCabe, Ryan	NPRB	Arctic Integrated Ecosystem Survey (IES) Phase II: Oceanography and Lower Trophic Level Productivity	$173,425
Bond, Nicholas	WA STATE DOE	Washington State Drought Contingency Task Force	$34,577
Wood, Kevin	MET	Historical Data Recovery for the Western Tropical Pacific: 1850 – 1939 (Part 2)	$35,684
Bond, Nicholas	NFWF	Occurrence and Range of Right Whales in the Bering Sea	$114,285
Mordy, Calvin	NPRB	Connectivity in the Gulf of Alaska: a synthesis based on the Gulf of Alaska Integrated Ecosystem Research Program	$43,330
TOTAL			**$3,100,456**

APPENDIX 4

GRADUATE STUDENTS

Student Name	Academic Unit	Degree	Degree Advisor
ALLEN AKSELRUD, CAITLIN	School of Aquatic and Fishery Sciences	Ph.D.	Andre Punt
ANDERSON, JESSICA E	School of Oceanography	Ph.D.	Stephen Riser
CAMPBELL, ETHAN	School of Oceanography	Ph.D.	Curtis Deutsch, Stephen Riser
CLARK, ELIZABETH A	Computer Science & Engineering	Ph.D.	Bart Nijssen
CRONIN FINE, LEE	Quantitative Ecology & Resource Managment	Ph.D.	Andre Punt
GODERSKY, ALICIA J.	School of Aquatic and Fishery Sciences	M.S.	Theodore Pietsch
HENNON, TYLER DOUGLAS	School of Oceanography	Ph.D.	Stephen Riser
HURTADO FERRO, FELIPE	School of Aquatic and Fishery Sciences	Ph.D.	Andre Punt
LEE, QI	School of Aquatic and Fishery Sciences	M.S.	Andre Punt
LOGAN, PAIGE D	School of Oceanography	Ph.D.	Gregory Johnson
ROHAN, SEAN K.	School of Aquatic and Fishery Sciences	Ph.D.	Kerim Aydin
SCANNELL, HILLARY A	School of Oceanography	Ph.D.	Michael McPhaden
WANG, GAOANG	Electrical Enginnering	Ph.D.	Jenq-Neng Hwang
WEBSTER, MELINDA A.	School of Oceanography	Ph.D.	Ignatius Rigor
WILSON, EARLE	School of Oceanography	M.S.	Steve Riser

APPENDIX 5

POSTDOCTORAL RESEARCH ASSOCIATES

Barnett, Lewis
Blyde, Charlotte
Chang, Bonnie**
Chu, Sophie N.
Faig, Amanda D.
Gao, Jin
Gavery, MacKenzie R.
Gothmann, Anne M.
Hovel, Rachel A.**
McGowan, David W.**
O'Donnell, James L.
Ono, Kotaro
Putnam, Hollie M.
Raudzens Bailey, Adriana
Webber, D'Arcy N.
White, Rachel H
Xu, Haikun**
Zanowksi, Hannah Marie

**Received less than 50% support from JISAO

APPENDIX 6

PERSONNEL COUNT

Category	Number	B.S.	M.S.	Ph.D.
Faculty	1			1
Research Scientist	76	16	31	29
Visiting Scientist	0			
Postdoctoral Fellow**	14			14
Research Support Staff	23	19	4	
Administrative	0			
Total (> or = 50%)	114			
Undergarduate Students	13			
Graduate Students	15			
Employees receiving less than 50% NOAA support	42			
Located at Lab	89 (PMEL), 18 (AFSC), 2 (NWFSC)			
Obtained NOAA employment within the last year	1			

**an additional 4 PostDocs received less than 50% support

APPENDIX 7

PUBLICATIONS COUNT*

JISAO LEAD AUTHOR	2015 – 2016	2016 – 2017
Peer-reviewed	50	30
Non-peer reviewed	2	2
Total	52	32

NOAA LEAD AUTHOR	2015-2016	2016-2017
Peer-reviewed	21	25
Non-peer-reviewed	2	1
Total	23	26

OTHER LEAD AUTHOR	2015-2016	2015-2016
Peer-reviewed	45	89
Non-peer-reviewed	0	0
Total	45	89

Total peer-reviewed	116	144
Total non-peer-reviewed	4	3
Grand Total	120	147

*In previous years, publications in non-published status (such as In Press, Accepted and In Revision) were included. To avoid duplication over reporting years, only published papers are counted and reported.

APPENDIX 8

PUBLICATIONS: APRIL 1, 2016 - MARCH 31, 2017

Not Previously Reported as Published:

1. Barrett PM, Resing JA, Buck NJ, Landing WM, Morton PL, Shelley RU. Changes in the distribution of Al and particulate Fe along A16N in the eastern North Atlantic Ocean between 2003 and 2013: Implications for changes in dust deposition. Marine Chemistry. 2015;177, Part 1:57-68. doi: 10.1016/j.marchem.2015.02.009.
2. Clement Kinney J, Maslowski W, Aksenov Y, de Cuevas B, Jakacki J, Nguyen A, Osinski R, Steele M, Woodgate RA, Zhang J. On the Flow Through Bering Strait: A Synthesis of Model Results and Observations. In: Grebmeier JM, Maslowski W, editors. The Pacific Arctic Region: Ecosystem Status and Trends in a Rapidly Changing Environment. Dordrecht: Springer Netherlands; 2014. p. 167-98.
3. Cooper DW, Duffy-Anderson JT, Stockhausen WT, Cheng W. Modeled connectivity between northern rock sole (Lepidopsetta polyxystra) spawning and nursery areas in the eastern Bering Sea. Journal of Sea Research. 2013;84:2-12. doi: 10.1016/j.seares.2012.07.001.
4. Evans W, Mathis JT, Winsor P, Statscewich H, Whitledge TE. A regression modeling approach for studying carbonate system variability in the northern Gulf of Alaska. Journal of Geophysical Research: Oceans. 2013;118(1):476-89. doi: 10.1029/2012JC008246.
5. Jech J, Horne J, Chu D, Demer D, Francis D, Gorska N, Jones B, Lavery A, Stanton T, Macaulay G, Reeder D, Sawada K. Comparisons among ten models of acoustic backscattering used in aquatic ecosystem research. The Journal of the Acoustical Society of America. 2015;138(6):3742-64. doi: 10.1121/1.4937607.
6. Logerwell E, Busby M, Carothers C, Cotton S, Duffy-Anderson J, Farley E, Goddard P, Heintz R, Holladay B, Horne J, Johnson S, Lauth B, Moulton L, Neff D, Norcross B, Parker-Stetter S, Seigle J, Sformo T. Fish communities across a spectrum of habitats in the western Beaufort Sea and Chukchi Sea. Progress in Oceanography. 2015;136:115-32. doi: 10.1016/j.pocean.2015.05.013.
7. Thorson JT, Clarke ME, Stewart IJ, Punt AE. The implications of spatially varying catchability on bottom trawl surveys of fish abundance: a proposed solution involving underwater vehicles. Canadian Journal of Fisheries and Aquatic Sciences. 2012;70(2):294-306. doi: 10.1139/cjfas-2012-0330.

Published:

1. Aguilar-Islas AM, Séguret MJM, Rember R, Buck KN, Proctor P, Mordy CW, Kachel NB. Temporal variability of reactive iron over the Gulf of Alaska shelf. Deep Sea Research Part II: Topical Studies in Oceanography. 2016;132:90-106. doi: 10.1016/j.dsr2.2015.05.004.
2. Babbin AR, Peters BD, Mordy CW, Widner B, Casciotti KL, Ward BB. Multiple metabolisms constrain the anaerobic nitrite budget in the Eastern Tropical South Pacific. Global Biogeochemical Cycles. 2017;31(2):258-71. doi: 10.1002/2016GB005407.
3. Baker ET, Resing JA, Haymon RM, Tunnicliffe V, Lavelle JW, Martinez F, Ferrini V, Walker SL, Nakamura K. How many vent fields? New estimates of vent field populations on ocean ridges from precise mapping of hydrothermal discharge locations. Earth and Planetary Science Letters. 2016;449:186-96. doi: 10.1016/j.epsl.2016.05.031.
4. Bakker DCE, Pfeil B, Landa CS, Metzl N, O'Brien KM, Olsen A, Smith K, Cosca C, Harasawa S, Jones SD, Nakaoka SI, Nojiri Y, Schuster U, Steinhoff T, Sweeney C, Takahashi T, Tilbrook B, Wada C, Wanninkhof R, Alin SR, Balestrini CF, Barbero L, Bates NR, Bianchi AA, Bonou F, Boutin J, Bozec Y, Burger EF, Cai WJ, Castle RD, Chen L, Chierici M, Currie K, Evans W, Featherstone C, Feely RA, Fransson A, Goyet C, Greenwood N, Gregor L, Hankin S, Hardman-Mountford NJ, Harlay J, Hauck J, Hoppema M,

Humphreys MP, Hunt CW, Huss B, Ibánhez JSP, Johannessen T, Keeling R, Kitidis V, Körtzinger A, Kozyr A, Krasakopoulou E, Kuwata A, Landschützer P, Lauvset SK, Lefèvre N, Lo Monaco C, Manke A, Mathis JT, Merlivat L, Millero FJ, Monteiro PMS, Munro DR, Murata A, Newberger T, Omar AM, Ono T, Paterson K, Pearce D, Pierrot D, Robbins LL, Saito S, Salisbury J, Schlitzer R, Schneider B, Schweitzer R, Sieger R, Skjelvan I, Sullivan KF, Sutherland SC, Sutton AJ, Tadokoro K, Telszewski M, Tuma M, van Heuven SMAC, Vandemark D, Ward B, Watson AJ, Xu S. A multi-decade record of high-quality fCO2 data in version 3 of the Surface Ocean CO2 Atlas (SOCAT). Earth Syst Sci Data. 2016;8(2):383-413. doi: 10.5194/essd-8-383-2016.

5. Branch TA, Kleiber D. Should we call them fishers or fishermen? Fish and Fisheries. 2017;18(1):114-27. doi: 10.1111/faf.12130.
6. Branch TA, Linnell AE. What makes some fisheries references highly cited? Fish and Fisheries. 2016;17(4):1094-133. doi: 10.1111/faf.12160.
7. Breyta R, McKenney D, Tesfaye T, K. O, Kurath G. Increasing virulence, but not infectivity, associated with serially emergent virus strains of a fish rhabdovirus. Virus Evol. 2016;2(1). doi: 10.1093/ve/vev018.
8. Buckley TW, Ortiz I, Kotwicki S, Aydin K. Summer diet composition of walleye pollock and predator–prey relationships with copepods and euphausiids in the eastern Bering Sea, 1987–2011. Deep Sea Research Part II: Topical Studies in Oceanography. 2016;134:302-11. doi: 10.1016/j.dsr2.2015.10.009.
9. Cao J, Thorson JT, Richards RA, Chen Y. Spatio-temporal index standardization improves the stock assessment of northern shrimp in the Gulf of Maine. Canadian Journal of Fisheries and Aquatic Sciences. 2017. doi: 10.1139/cjfas-2016-0137.
10. Carter BR, Feely RA, Mecking S, Cross JN, Macdonald AM, Siedlecki SA, Talley LD, Sabine CL, Millero FJ, Swift JH, Dickson AG, Rodgers KB. Two decades of Pacific anthropogenic carbon storage and ocean acidification along Global Ocean Ship-based Hydrographic Investigations Program sections P16 and P02. Global Biogeochemical Cycles. 2017;31(2):306-27. doi: 10.1002/2016GB005485.
11. Carter BR, Frölicher TL, Dunne JP, Rodgers KB, Slater RD, Sarmiento JL. When can ocean acidification impacts be detected from decadal alkalinity measurements? Global Biogeochemical Cycles. 2016;30(4):595-612. doi: 10.1002/2015GB005308.
12. Carter BR, Williams NL, Gray AR, Feely RA. Locally interpolated alkalinity regression for global alkalinity estimation. Limnology and Oceanography: Methods. 2016;14(4):268-77. doi: 10.1002/lom3.10087.
13. Cheng W, Blanchard-Wrigglesworth E, Bitz CM, Ladd C, Stabeno PJ. Diagnostic sea ice predictability in the pan-Arctic and U.S. Arctic regional seas. Geophysical Research Letters. 2016;43(22):11,688-11,96. doi: 10.1002/2016GL070735.
14. Cheng W, Curchitser E, Stock C, Hermann A, Cokelet E, Mordy C, Stabeno P, Hervieux G, Castruccio F. What processes contribute to the spring and fall bloom co-variability on the Eastern Bering Sea shelf? Deep Sea Research Part II: Topical Studies in Oceanography. 2016;134:128-40. doi: 10.1016/j.dsr2.2015.07.009.
15. Chevallier M, Smith GC, Dupont F, Lemieux J-F, Forget G, Fujii Y, Hernandez F, Msadek R, Peterson KA, Storto A, Toyoda T, Valdivieso M, Vernieres G, Zuo H, Balmaseda M, Chang Y-S, Ferry N, Garric G, Haines K, Keeley S, Kovach RM, Kuragano T, Masina S, Tang Y, Tsujino H, Wang X. Intercomparison of the Arctic sea ice cover in global ocean–sea ice reanalyses from the ORA-IP project. Climate Dynamics. 2016:1-30. doi: 10.1007/s00382-016-2985-y.
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17. Chiodi A, Harrison D. Observed El Niño SSTA Development and the Effects of Easterly and Westerly Wind Events in 2014/15. J Climate. 2017;30(4):1505-19. doi: 10.1175/jcli-d-16-0385.1.
18. Chiodi A, Harrison D. Simulating ENSO SSTAs from TAO/TRITON Winds: The Impacts of 20 Years of Buoy Observations in the Pacific Waveguide and Comparison with Reanalysis Products. J Climate. 2017;30(4):1041-59. doi: 10.1175/jcli-d-15-0865.1.
19. Clardy TR, Hilton EJ. Osteology of the prickleback genus Xiphister (Cottiformes: Zoarcoidei: Stichaeidae).

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20. Cronin MF, Bond NA, Farrar JT, Ichikawa H, Jayne SR, Kawai Y, Konda M, Qiu B, Rainville L, Tomita H. Corrigendum to "Formation and erosion of the seasonal thermocline in the Kuroshio Extension Recirculation gyre" [Deep-Sea Res. II 85 (2013) 62–74]. Deep Sea Research Part II: Topical Studies in Oceanography. 2016;132:263-4. doi: 10.1016/j.dsr2.2016.08.001.
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24. Desch SJ, Smith N, Groppi C, Vargas P, Jackson R, Kalyaan A, Nguyen P, Probst L, Rubin ME, Singleton H, Spacek A, Truitt A, Zaw PP, Hartnett HE. Arctic ice management. Earth's Future. 2017;5(1):107-27. doi: 10.1002/2016EF000410.
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27. Doherty SJ, Hegg DA, Johnson JE, Quinn PK, Schwarz JP, Dang C, Warren SG. Causes of variability in light absorption by particles in snow at sites in Idaho and Utah. Journal of Geophysical Research: Atmospheres. 2016;121(9):4751-68. doi: 10.1002/2015JD024375.
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30. Duffy-Anderson JT, Barbeaux SJ, Farley E, Heintz R, Horne JK, Parker-Stetter SL, Petrik C, Siddon EC, Smart TI. The critical first year of life of walleye pollock (Gadus chalcogrammus) in the eastern Bering Sea: Implications for recruitment and future research. Deep Sea Research Part II: Topical Studies in Oceanography. 2016;134:283-301. doi: 10.1016/j.dsr2.2015.02.001.
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38. Gao RS, Telg H, McLaughlin RJ, Ciciora SJ, Watts LA, Richardson MS, Schwarz JP, Perring AE, Thornberry TD, Rollins AW, Markovic MZ, Bates TS, Johnson JE, Fahey DW. A light-weight, high-sensitivity particle spectrometer for PM2.5 aerosol measurements. Aerosol Science and Technology. 2016;50(1):88-99. doi: 10.1080/02786826.2015.1131809.
39. Gardner JR, Orr JW, Stevenson DE, Spies I, Somerton DA. Reproductive Parasitism between Distant Phyla: Molecular Identification of Snailfish (Liparidae) Egg Masses in the Gill Cavities of King Crabs (Lithodidae). Copeia. 2016;104(3):645-57. doi: 10.1643/CI-15-374.
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APPENDIX 9

ACRONYMS

Acronym	Definition
20CR	NOAA 20th Century Reanalysis
AABW	Antarctic Bottom Water
ABC	acceptable biological catch
ACEs	Aerial Calibration Experiments
ADMB	Automatic Differentiation Model Builder
AEP	Alaska Ecosystems Program
AFSC	Alaska Fisheries Science Center
AGU	American Geophysical Union
AIS	Aleutian Islands
AON	Arctic Observing Network
AOX	Arctic Observations Experiment
ARCWEST	Arctic Whale Ecology Study
ASAMM	Aerial Surveys of Arctic Marine Mammals
ASCE	American Society of Civil Engineers
ATLAS	autonomous temperature line acquisition system
AWS	Amazon Web Services
AXIB	Airborne Seasonal Ice Buoys
BEDI	Big Earth Data Initiative
BOEM	Bureau of Ocean Energy Management
BoF	bag-of-features (BoF) framework
BSAI	Bering Sea Aleutian Islands
CAEP	Cetacean Assessment and Ecology Program
CAPAM	Center for the Advancement of Population Assessment Methodology
CCE	California Current Ecosystem
CCN	cloud condensation nuclei
CFCs	chlorofluorocarbons
CFS	Climate Forecast System
CFSv2	Coupled Forecast System version 2
CHAOZ	Chukchi Acoustics, Oceanography, and Zooplankton
CHAOZ-X	Chukchi Acoustics, Oceanography, and Zooplankton Extension Study
ChESS	Chukchi-East Siberian Surveys
CIB	Cook Inlet beluga project
CO2	carbon dioxide
CPS	Coastal Pelagic Species

Acronym	Definition
CSSR	Climate Science Special Report
CTD	conductivity, temperature and depth
DART	Deep-ocean Assessment and Reporting of Tsunamis
DIC	dissolved inorganic carbon
DisMELS	Dispersal Model for Early Life Stages
DOE	Department of Energy
DWBC	deep western boundary current
EBS	eastern Bering Sea
eDNA	environmental DNA
ELH	Early Life History
ENGLN	Earth Networks Global Lightning Network
ENSO	El Niño-Southern Oscillation
EOI	Earth-Ocean Interaction
ERDDAP	Environmental Research Division's Data Access Program
ESA	Endangered Species Act
ESM	Earth system model
EUC	Equatorial Under Current
EwE	Ecopath with Ecosim
EYH	Expanding Your Horizons
FEMA	Federal Emergency Management Agency
FOCI	Fisheries-Oceanography Coordinated Investigations
FRAM	Fishery Resource Analysis and Monitoring
GAMMs	general additive mixed effects models
GCM	global climate model
GFDL	Geophysical Fluid Dynamics Laboratory
GLM	Global Lightning Mapper
Gmacs	generalized modeling for Alaska crab stocks
GMM	Gaussian mixture model
GOA	Gulf of Alaska
GOAIERP	Gulf of Alaska Project Integrated Ecosystem Research Program
GTMBA	Global Tropical Moored Buoy Array
HAB	harmful algal bloom
HPC	high performance computing
IABP	International Arctic Buoy Programme
iAMP	integrated Adaptable Monitoring Package
IATTC	Inter-American-Tropical-Tuna-Commission
ICOADS	International Comprehensive Ocean-Atmosphere Data Set
IERP	Integrated Ecosystem Research Program
IFREMER	The Institut français de recherche pour l'exploitation de la mer

Acronym	Definition
IFQ	Individual Fishing Quota
IMB	Ice Mass Balance
IOOS	Indian Ocean Observing System
IOB	Indian Ocean basin mode
IPCC	Intergovernmental Panel on Climate Change
IPHC	International Pacific Halibut Commission
IPO	interdecadal Pacific oscillation
ITAE	Innovative Technology for Arctic Exploration
JISAO	Joint Institute for the Study of the Atmosphere and Ocean
JCOMM	WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology
J-SCOPE	JISAO's Seasonal Coastal Ocean Prediction of the Ecosystem
KEO	Kuroshio Extension Observatory
LS	least squares
MIZER	multi-species spectrum modeling
MML	Marine Mammal Laboratory
MSE	Management Strategy Evaluation
MSE	mean square error
N2O	nitrous oxide
NAAMES	North Atlantic Aerosols and Marine Ecosystems Study
NCA	National Climate Assessment
NCTR	NOAA Center for Tsunami Research
NEFSC	Northeast Fisheries Science Center
NeMO	New Millennium Observatory
NFS	northern fur seals
NGO	non-governmental organization
NMFS	National Marine Fisheries Service
NOC	National Oceanography Centre
NPFMC	North Pacific Fishery Management Council
NPRB	North Pacific Research Board
NRC	Nuclear Regulatory Commission
NSF	National Science Foundation
NWFSC	Northwest Fisheries Science Center
NUTS	No-U-Turn Sampler
OA	ocean acidification
OceanSITES	Ocean Sustained Interdisciplinary Time Series Environmental Observatory
OCS	Ocean Climate Stations Project
OFL	overfishing level
OLR	Outgoing Longwave Radiation
OOI	Ocean Observatories Initiative

Acronym	Definition
PAR	photosynthetic active radiation
PCA	principal component analysis
PIOMAS	Pan-Arctic Ice Ocean Modeling and Assimilation System
PIRATA	Prediction and Research Moored Array in the Tropical Atlantic
PMEL	Pacific Marine Environmental Laboratory
PFMC	Pacific Fishery Management Council
PPAI	Predictability, Predictions, and Applications Interface
PSC	Prohibited Species Catch
QC	quality control
qPCR	quantitative polymerase chain reaction
RACE	Resource Assessment and Conservation Engineering
RADSeq	Restriction Site Associated DNA Sequencing
RAMA	Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction
RBC	red blood cells
REEM	Resource Ecology and Ecosystem Modeling
ROMS	Regional Ocean Modeling System
ROV	remotely operated vehicle
RRBS	Reduced Representation Bisulfite Sequencing
SAFS	School of Aquatic and Fishery Sciences
SF6	sulfur hexafluoride
SIFT	Short-term Inundation Forecast for Tsunamis
SLP	sea level pressure
SOAR	Synthesis of Arctic Research
SOCAT	Surface Ocean Carbon Atlas
SP	Samoan Passage
SS	Stock Synthesis
SSA	sea spray aerosol
SSC	Scientific Steering Committee
SSS	Simple Stock Synthesis
SST	sea surface temperature
STAN	Sampling Through Adaptive Neighborhoods
STEM	science, technology, engineering, and mathematics
SVP	Surface Velocity Program Barometer buoys
TAO	Tropical Atmosphere Ocean
TEMPP	Tsunami Evacuation Maps, Plans and Procedures (TEMPP
TRITON	Triangle Trans-Ocean Buoy Network
TsuCAT	Tsunami Coastal Assessment Tool
TWC	Tsunami Warning Center
UAF	Unified Access Framework

Acronym	Definition
UAS	unmanned aerial systems
USCLIVAR	U.S. Climate Variability and Predictability
USIABP	U.S. Interagency Arctic Buoy Program
USV	unmanned surface vehicle
UWFC	University of Washington Fish Collection
VLF	very low frequency
WA EMD	Washington State Emergency Management Division
WCOA	West Coast Ocean Acidification
WCRP	World Climate Research Programme
WNFH	Winthrop National Fish Hatchery
WOAC	Washington Ocean Acidification Center
WWLLN	World Wide Lightning Location Network
WWW	World Weather Watch
XIB	Seasonal Ice Beacons