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EXECUTIVE SUMMARY
INTRODUCTION

The Joint Institute for the Study of the Atmosphere and Ocean (JISAO) is located at the University of Washington (UW), one of the nation's preeminent institutions of higher education and research. It was originally established in 1977 as a NOAA Cooperative Institute to promote interdisciplinary research in atmospheric, oceanic and fishery sciences. The broad range of scientific expertise, represented both at UW and NOAA, is reflected in the research described in this year’s report. JISAO’s interdisciplinary collaborations between UW and NOAA scientists fall 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 maintains strong working partnerships with the laboratories of the NOAA Western Regional Center: Pacific Marine Environmental Laboratory (PMEL), Alaska Fisheries Science Center (AFSC), and Northwest Fisheries Science Center (NWFSC). As part of the UW College of the Environment (CoEnv), JISAO works collaboratively with a number of departments throughout the university campus, including Atmospheric Sciences, Oceanography, Fisheries, and Earth and Space Sciences, among others.

Providing an array of exceptional resources and facilities, JISAO's Education and Outreach Program (E&O) makes important contributions by promoting environmental literacy at all levels of society, mentoring the next generation of scientists and reaching out to include underrepresented communities in these efforts. The Institute's flexible infrastructure facilitates partnerships with a variety of local, regional and national organizations who share the same types of goals in these areas.

The extensive research conducted at JISAO is summarized 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 summaries for each 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.
Executive Summary

SCIENCE HIGHLIGHTS

Climate Research and Impacts

JISAO climate research, in collaboration with NOAA and other partners, spans a wide range of important topics and phenomena ranging from basic physics to applications. Following are a few examples that provide a sampling of the scope and diversity of this work.

Atmospheric carbon dioxide (CO2) concentrations are increasing. What is not as well known is that El Niño Southern Oscillation (ENSO) has dramatic effects on these concentrations, through modulation of a host of mechanisms such as air-sea exchanges and photosynthesis. Andy Chiodi of JISAO and Ed Harrison of NOAA/PMEL have quantified the seasonality of the impacts of El Niño and La Niña on CO2 concentrations. Their findings represent an important source of validation for earth-system climate models; presumably those models that are better at simulating the biogeochemical interactions associated with ENSO are apt to also be better able to project the changes in these properties on longer time scales.

The Arctic has been of long-standing interest to JISAO, and the scope of that research is widening. Nicholas Bond and Kevin Wood, along with James Overland of NOAA/PMEL, carried out a successful field program north of Alaska in fall 2013. This field work featured eight flights with a NOAA P-3 research aircraft, with a focus on air-sea interactions in the marginal ice zone of the Chukchi Sea. Preliminary results suggest that the effects of ice cover on the lower atmosphere are dependent on the large-scale weather conditions. This project will improve our understanding of the regional impacts of the decline of Arctic sea ice, and whether these regional changes are liable to influence the hemispheric circulation.

JISAO is also involved in climate research focusing on its backyard, (i.e., the western U.S.), particularly in relation to water issues. A team with the UW Department of Civil and Environmental Engineering, led by Jessica Lundquist in collaboration with scientists from NOAA’s Earth Systems Research Laboratory (ESRL), has examined the sets of measurements required to adequately monitor and accurately model snowpack and streamflow in mountain watersheds. These results are being used in the design of a hydrometeorological monitoring system for the western U.S. There are a number and variety of stakeholders (Bonneville Power Administration, U.S. Army Corps of Engineers, etc.) interested in this kind of data, and ongoing efforts by Amy Snover of the Climate Impacts Group facilitate the information transfer. A recent focus here has been to provide gridded observations and model projections on a public website (http://warm.atmos.washington.edu/2860/) and to serve as a resource on the use and interpretation of this type of data.
Environmental Chemistry

The Atmospheric Chemistry - Aerosol Program showed that the organic carbon content of sea spray aerosol (produced by breaking waves on the ocean surface) was similar in all regions sampled, regardless of the presence or absence of plankton blooms. Global climate models have generally used chlorophyll $a$, a proxy for plankton biomass, to predict the organic carbon content of sea spray aerosol. This study concludes that this method will lead to inaccurate predictions of the properties of these aerosols, with potential implications for their efficiency as cloud condensation nuclei.

Nitrous oxide (N2O) is found not only in cans of whipped cream and dentists’ offices, but also in the deep ocean, for which it is important in the marine nitrogen cycle. The rates of the key processes in this cycle can be deduced from measurements of its concentrations, in combination with observations of tracers such as chlorofluorocarbons (CFCs) for deducing ventilation and mixing. Bonnie Chang and Rolf Sonnerup of JISAO and John Bullister of NOAA/PMEL have pioneered new techniques for the collection and analysis of these types of measurements.

Marine Ecosystems

Fisheries management is undergoing a transition from harvest quotas being set based on single species stock assessments, to approaches based on integrated ecosystem assessments (IEAs). It is unclear how this is best accomplished, since there are a variety of methods possible for incorporating environmental influences into population estimates and forecasts. Tim Essington of the School of Aquatic and Fishery Sciences (SAFS) and co-investigators, in collaboration with NOAA fishery oceanographers at AFSC and NWFSC, are tackling this problem. Their approach has featured the grouping of individual species with similar life histories at critical stages in their life cycle towards the identification of key environmental drivers. An important result that emerged is that our limited understanding of critical factors during early life stages of many species or groups is liable to compromise the reliability and utility of IEAs.

Ocean acidification is expected to have serious biological effects. For example, ocean acidification may have major consequences for species such as crabs, which support valuable fisheries. Bio-economic models based on a sequence of linked modules are being developed for Eastern Bering Sea Tanner crab and Aleutian Islands Golden king crab. The model for Eastern Bering Sea Tanner crab include interactions between fisheries, namely the bycatch of Tanner...
crab in the harvest of Eastern Bering Sea Snow crab. The bio-economic models will be used to evaluate the impact of trends in ocean pH on maximum sustainable yield, maximum economic yield, and trends in catch and abundance under different management strategies.

JISAO’s marine ecosystem research includes not just consideration of commercially-exploited species, but also other organisms such as marine mammals. Passive acoustic receivers on moorings have been used by Kathleen Stafford, of the UW’s Applied Physics Laboratory (APL), to monitor the presence of Bowhead whales in the vicinity of Barrow, Alaska. This instrumentation has been adapted for year-round deployment. The whale call data is being compared with estimates of zooplankton concentrations from other remote-sensed acoustic measurements; it will be used to see how both the whales and their primary prey relate to variations in the sea ice of the western Beaufort Sea.

Ocean and Coastal Observations

JISAO and NOAA scientists of the Observing System Research Studies group carry out not just basic research, but also develop the information technology required to analyze and manage the vast amounts of observational and model data that are currently being produced. At first blush this sort of work might seem mundane, but that is not the case. The development of the Unified Access Framework (UAF) by this group required extensive research, testing, and close cooperation with potential users. The payoff has been a master catalog of data (>10,000 data sets and growing) accessible to researchers, and an automated system for harvesting real-time ocean observational and numerical model data.
Protection and Restoration of Marine Resources

Plastic debris lasts a long time in the ocean, and represents an important contaminant in a variety of regions. Giora Proskurowski of the UW School of Oceanography has led an effort to determine how plastic particles are distributed in the vertical due to the effects of turbulence. This has provided a means for interpreting the data from surface net tows, which represent the primary source of measurements for estimating total plastic concentrations. The results are sobering, as total amounts appear to be at a far greater depth than would be anticipated based on the buoyancy of the plastic particles themselves.

The DEEPWATER HORIZON disaster of 2010 was the largest oil spill in U.S. history. NOAA’s Office of Response and Restoration (ORR) was charged with developing models for specifying the transport and transformation of oil from this well, with a key uncertainty related to the rates of biodegradation of the various components of this oil. Russell Herwig of SAFS provided the modelers of NOAA/ORR the rate information needed for their models based on an exhaustive review of the literature. This effort made it possible for these models to incorporate different rates of biodegradation for different compounds, providing a more realistic simulation of the fate of the oil, and ultimately its impacts.

Seafloor Processes

The Earth Ocean Interactions (EOI) group (formerly Hydrothermal Vents) studies the fluxes of heat and chemicals at the sea floor, with a focus on submarine volcanoes and vents. This work has featured the development of new measurement capabilities by JISAO scientists David Butterfield and Joseph Resing. Highlights include the recent design and implementation of an incubator that can be mounted on a remotely-operated vehicle (ROV) for measuring microbial growth rates using a technique based on stable isotope analysis of the microbes’ RNA. Another innovation involves the development of an interactive water sampler for monitoring the chemistry and microbiology at submarine vents; this instrument will be deployed at the Axial Seamount off the coast of the Pacific Northwest, and is taking advantage of the communication and power cables installed for the Ocean Observatories Initiative Regional Scale Node (OOI-RSN). These and other state-of-the-art instruments are allowing the EOI group to stay at the forefront of the science being conducted at hydrothermal locations.
**Executive Summary**

**Tsunami Observations and Modeling**

JISAO scientists play key roles in the NOAA Center for Tsunami Research (NCTR). Under the leadership of JISAO’s Don Denbo and Vasily Titov of PMEL, a new forecasting tool, the Short-term Inundation Forecast for Tsunamis (SIFT) was developed and installed at the U.S. Tsunami Warning Centers in Alaska and Hawaii. SIFT represents a quantum leap forward in the capability to provide timely warnings of tsunamis for specific locations. It incorporates open ocean wave height data from the tsunami observing system for estimating the initial properties of the waves at their source, improved handling of the deep-ocean propagation of tsunamis, and seamless coupling of the output from the deep-water model to very high-resolution coastal models. The latter provides reliable simulations of the detailed timing and extent of inundation for site-specific forecasts. A key point is that this process is automated, thereby allowing forecasters to focus on interpretation and communication as events unfold. The development of SIFT and other products has attracted international attention, and NCTR continues to transfer its technology to other countries seeking to improve their tsunami warning capabilities.
EDUCATION AND OUTREACH

“This program was one of the best experiences I’ve ever had. I learned more in these nine weeks than I have in my three years of college. It was great to be involved in cutting edge research with a group of people that are motivated and passionate.”

Laura Migliaccio, 2013 JISAO 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.

Of the many projects supported by the E&O Program, perhaps most noteworthy is the success of the JISAO Research Experience for Undergraduates (REU). The REU program began with one student in 2008, and has since hosted 29 students from colleges and universities across the U.S. Twenty-three of JISAO’s former interns have completed undergraduate degrees, with 13 currently in graduate school at: Fordham University, Pennsylvania State University, San Jose State University, Cambridge University, University of California-Davis, Colorado State University, Virginia Institute of Marine Sciences, City College of New York, Texas A&M University, and four at the University of Washington (two in Atmospheric Sciences, one in Oceanography, and one in the School of Aquatic and Fishery Sciences). In January 2013, Laura Vogel was our first intern to receive a graduate degree, earning an MS in Environmental Engineering from Stanford University.

In past years, JISAO’s REU program has received additional funding support from NOAAs Office of Oceanic and Atmospheric Research (OAR) and the NOAA Center for Atmospheric Research (NCAS) at Howard University. Outstanding interns have returned a second summer to work with mentors who valued the work they performed during their initial internship.

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 on the following pages.

JISAO SUMMER RESEARCH EXPERIENCE FOR UNDERGRADS (REU)

- JISAO welcomed six undergraduate students in summer 2013. Students were matched with mentors in the UW Atmospheric Sciences department, the NOAA Pacific Marine Environmental Laboratory, the U.S. Army Corps of Engineers, the UW Center for Conservation Biology in Friday Harbor, and the Alaska Salmon Research Program near Dillingham, Alaska. Student web pages and videos are displayed on the Internship Opportunities page in the E&O section of JISAO’s website. The interns and their universities are listed below:

1. Daniel Bazemore — University of Northern Colorado
2. Delilah Dougi — Fort Lewis College
3. Daniel Gutierrez — Texas A&M University
4. Makie Matsumoto-Hervol — University of Wisconsin
5. Laura Migliaccio — Clark University
6. Michelle Serino — Millersville University

- Isabel McCoy returned in summer 2013 to continue the research she did as an intern with Andreas Muhlbauer in 2012.

- The 2013 interns created an outreach presentation on marine life in the oceans for a group of middle school students with autism. The event included hands-on activities and a trip to the UW fish collection.

- JISAO’s internship program was named “One of Seattle’s coolest internships” by Seattle Met magazine in their January 2013 issue.

PACIFIC SCIENCE CENTER (PSC) PARTNERSHIP

- **Scientist Spotlights**

  Science Communication Fellows Karin Bumbaco and Drew Hamilton presented hands-on activities related to their work on designated weekends.
Executive Summary

at PSC. Science Communication Fellows are professionals who have been certified by PSC as current science ambassadors and excellent communicators.

- **Paws-On Science: Husky Weekend**
  Seattle families visited PSC for a weekend of activities, games, and demonstrations designed to show the world-class research and achievements of scientists at the UW. JISAO scientists Nick Bond, Karin Bumbaco, and Morgan Ostendorf led activities showing their work on climate change and ocean acidification.

- **Seattle Science Festival Expo Day**
  JISAO was one of more than 150 booths, activities, and demonstrations that celebrated science and technology and showed how integral they are to the region's culture and prosperity. JISAO had an exhibit staffed by researchers Joel Pedro, Morgan Ostendorf, Miriam Doyle, and Albert Hermann.

- **Science Café**
  Science Cafés bring scientists face to face with the public in the comfortable atmosphere of a neighborhood café or pub. Edison Gica was invited to lead a discussion called “Understanding Tsunamis at Eastside Science Cafe.”

**K-12 EVENTS**

- **Orca Bowl**
  JISAO scientists were judges and scorekeepers at Washington Sea Grant's 2013 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**
  1. JISAO scientists led sessions and participated in the 2013 NOAA Science Camp at the Pacific Marine Environmental Laboratory.
  2. 2013 was the eighth year that JISAO funded NOAA Science Camp scholarships for low income and underrepresented students.
  3. JISAO is currently working with Science Camp coordinators to establish a second partnership with a community program working with low-income teens in order to provide them with the opportunity to attend if they have an interest.

- **Science Career Day at Adams Elementary School**
  Karin Bumbaco visited science classrooms and gave brief lessons and hands-on demonstrations of her work with the Office of the Washington State Climatologist.

- **WAC Research Association Science Fair**
  Kevin Wood’s Old Weather project was the subject of Commack High School (NY) students’ science project. They were working on the HMS
PLOVER historical data inter-comparison, and the experiment won first place at the regional science fair in Earth and Environmental Sciences.

- **DO-IT Scholars Program**
  DO-IT works with high school students with disabilities who have the potential to pursue college studies and careers and develop leadership skills, yet face significant challenges because of their disabilities. JISAO provides support for one student to attend the program who wants to pursue education and a career in an area of research supported by NOAA.

- **EcoFOCI Outreach**
  Nancy Kachel presented EcoFOCI educational materials to middle schoolers at Jane Addams K-8 school as part of the school’s 4th Annual Science Day. She also served as a judge for the school’s science fair in May 2013.

**COLLEGE EVENTS**

- **McCall Outdoor Science School (MOSS) at the University of Idaho**
  MOSS focuses on science teaching in an outdoor environment. They host outreach events for K-12 students, and organize events for the general public, including a Visiting Scientist program in which JISAO was involved. Sarah Doherty spoke with MOSS graduate students during the following events:
  1. Science on Tap: Doherty’s talk, “Making Sense of Climate Science,” focused on what controls the earth’s climate, and gave some understanding on what big questions the science community is working on.
  2. Visiting Science Presentation: Doherty met with the MOSS grad students and gave a talk titled “Air pollution, black carbon, and climate,” which discussed how pollution affects both human health and the climate. After the presentation they talked about how the students could use the information in their outreach programs.

- **UW School of Oceanography tOASTER**
  The annual tOASTER (the Oceanography All Student Educational Retreat) took place in April 2014. Adrienne Sutton was a guest scientist and spoke with the students about her ocean acidification research.

- **Northwest Fisheries Science Center (NWFSC) Undergraduate Intern Program**
  A collaboration between UW and NWFSC, the
program provides training to undergraduates interested in fisheries research. Three students participated in 2013.

CONFERENCES AND CAREER FAIRS

• SACNAS (Advancing Hispanics, Chicanos and Native Americans in Science) National Conference in Denver, CO
  1. 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.
  2. One of the students Hernandez recruited from Humboldt State University was selected to be one of JISAO’s 2014 summer interns.

• AISES National Conference
  1. The American Indian Science and Engineering Society (AISES) held their 2013 national conference in San Antonio, TX.
  2. Daniel Hernandez represented JISAO at AISES and spoke with students from tribal colleges about opportunities to apply for JISAO’s summer internship program.

• Sustainability Summit
  The Sustainability Summit event was designed to celebrate the UW’s leadership and accomplishments in environmental stewardship and sustainability. JISAO had a booth on UW’s Red Square staffed by Jed Thompson, Karin Bumbaco, Sarah Doherty, and Todd Mitchell.

WEBSITE COMMUNICATION

• JISAO’s website (jisao.washington.edu) provides 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:
  1. Ice-free Arctic summers: USA Today, NOAA News
  2. Nighttime heat waves in Washington State: Seattle Times, Planetsave
  3. Old Weather Project: Discover Magazine
  5. Ocean acidification in the tropical Pacific: NOAA Research, Think Progress
  6. Arctic research flights: The State, NOAA News
  7. Redwood trees reveal history of rain and fog: Science Codex, UW News

• Research blogs
  1. Morgan Ostendorf maintained a blog on JISAO’s website for the Gulf of Alaska Ecosystem Research program. She traveled on the NOAA ship OSCAR DYSON in April 2013, and gave daily updates and photos of the work being done onboard. The blog can be seen at jisao.washington.edu/education-outreach/events/gulf_of_alaska_blog.
  2. JISAO Postdoc 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 “Was there an epic war or an epic romance between this robot and a squid?” Her blog can be seen at deepseanews.com/author/dr-martini/.

• Live from the North Pole
  Muyin Wang maintains two webcams in the North Pole. Wang updates the animations twice a week so visitors to the page can watch clips of daily weather from the past year. The animations can be viewed at www.arctic.noaa.gov/gallery_np.html.

PUBLIC OUTREACH

• Meet the Scientists: A Discussion on Climate Change
  The Student Association for Green Environments created this free event for the public to hear UW professors and researchers talk about the effects of climate change on the planet. The panel included JISAO Director Tom Ackerman and JISAO Deputy Director Nick Bond.

• Climate Week NYC
  1. Climate Week NYC is an international platform for governments, businesses, and civil society to collaborate on low carbon leadership throughout a week of events, activities, and meetings.
  2. JISAO carbon researcher Sarah Doherty participated in a panel discussion presented
by The Weather Channel. Her talk was live-streamed on the CWNYC website.

- **Seattle Aquarium: Discover Science Weekend**
  1. Families were invited to the aquarium to explore ocean and marine research with local scientists with interactive displays and activities.
  2. Edison Gica and Morgan Ostendorf represented JISAO, along with Albert Hermann, who showed an immersive 3D exploration of ocean models demonstrating how scientists use computer models to investigate properties of coastal oceans.

- **Museum of Flight Climate Day**
  During the “Free First Thursday” in April, the Museum of Flight celebrated NASA Climate Day with activities and presentations exploring climate change. JISAO had an exhibit presented by Drew Hamilton.

- **Old Weather – Arctic**
  1. The Old Weather – Arctic project was started by JISAO’s Kevin Wood in 2012. It engages citizen science volunteers from around the world to transcribe digital scans of logbooks from 19th century mariners sailing in the Arctic. The purpose of the project is to provide previously unavailable historic data to help scientists understand how the Arctic climate has changed over the past 150 years.
  2. Wood leads a small group of volunteers and interns at the U.S. National Archives who are taking digital images of each page of the logbooks. So far they have photographed more than 275,000 pages.
  3. The transcribed data is being added to the International Comprehensive Ocean-Atmosphere Dataset for use in a new generation of climate reanalysis systems.
  4. Coming soon is the National Archives’ companion website which will be the beginning of open access to these documents. The new web pages will provide direct links to all logbooks imaged through the Old Weather project.

- **JISAO on the radio**
  Every Friday morning, Nick Bond gives the weekly weather outlook on KUOW’s “Weekday” program. He’s also a frequent guest on other radio programs where he speaks on subjects such as summer temperature and rain average, pollen allergies, and the winter weather outlook.

- **NOAA Open House**
  Keith Ronnholm guided tours during the NOAA Open House in June 2013. He talked with the groups about NOAA and its collaboration with the University of Washington and JISAO.

- **King5 News**
  Assistant State Climatologist Karin Bumbaco appeared on the King5 weather special “Beyond the Forecast: Power Play,” talking about her seasonal forecast.

- **Sound Waters 2013**
  Nick Bond co-taught a class with JISAO’s Adrienne Sutton and Richard Feely of NOAA/PMEL called “Ocean Acidification, Ecosystems, and Climate.” The fourth annual class was part of the public education efforts by the Island County Beach Watchers. The issues that were addressed involved how climate change affects the Northwest, and how citizens can limit their carbon footprint.

- **Climate Lecture Series**
  Nick Bond annually gives a series of lectures for the Beachwatchers Lecture Series, as well as the Fiero Marine Life Center Lecture Series throughout Washington state.
FINANCIAL MANAGEMENT AND ADMINISTRATION

It is a major challenge to run a complex organization such as JISAO that bridges two major institutions. The UW infrastructure ensures JISAO’s ability to operate as effectively as possible in order to recruit and retain excellent staff, maintain and improve the required compliance systems and procedures, and provide the best possible overall business management of the Institute’s resources. JISAO and local NOAA administrators have formed a strong partnership that works well 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:

1. Thomas Ackerman — Executive Director
2. Nicholas Bond — Deputy Director (JISAO management representative at NOAA/PMEL)
3. Mary Smith — Assistant Director, Finance and Administration
4. Fred Averick — Finance Manager
5. 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 post doctoral funding was provided this year by Chris Sabine, PMEL Director.
- Administrative support
- Visiting scientists on leave from their home institutions
- Education and outreach activities
- School of Aquatic and Fishery Sciences lecture series

Below is a breakdown of Task I spending for the past year:

**Postdoc Support** 73%
**Administration** 6%
**Education and Outreach** 3%
**Visiting Scientists** 3%
**UW Fisheries Lecture Series** 15%

JISAO provides space, network access and computer support, administrative support, and other services for postdoctoral research associates and visitors supported on Task I. Over the past year, Task I funding provided support for the following research associates: Dr. Joel Pedro, University of Tasmania, Australia, Dr. Kim Martini, University of AK-Fairbanks and UW, and Dr. Bonnie Chang, Princeton and UW. The JISAO Research Associate Search Committee is planning to hire three new post docs who will begin work with JISAO and NOAA/PMEL in the coming year.
JISAO’s education and outreach program activities are supported by a small portion of Task I, 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 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 across a broad range of departments on the UW campus. 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 ending on March 31, 2014 totals $11,556,150. JISAO’s funding exclusive of the Cooperative Agreement for the last 12 months amounts to an additional $3,150,397. 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:

1. **JISAO Outreach and Education Program**
   - Strengthened and broadened the success of the E&O program (see section above for details of the year’s activities)

2. **JISAO Staff Recognition Program**
   - Recognized outstanding research, papers, honors, and awards on the JISAO website.
   - Presented UW service awards to JISAO employees.
   - Nominated the Tsunami Research group for an outstanding team award in the College of Environment yearly awards program
   - Provided cash awards for the Tsunami Research group, several JISAO scientists, and the JISAO administrative group for outstanding work over the past year in various capacities.

3. **Communications**
   - Continued joint quarterly meetings with JISAO and NOAA employees
   - Held the annual all-staff meeting on UW campus that includes all JISAO employees at UW and those who work at NOAA facilities; NOAA scientists also attended.
   - Held weekly office hours at NOAA/PMEL, improving communications, services and collaboration between NOAA and UW personnel.
   - Continued website improvements in information presented and user friendliness.
   - Participated on both the NOAA and UW CoEnv communications teams to regularly share information and best practices.
   - 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.
   - Continued social networking via Facebook, YouTube and Twitter
   - Continued to track media coverage and publications of JISAO researchers.
   - Developed additional educational and public outreach materials.

4. **Organization and Infrastructure**
   - Streamlined/consolidated staff assignments, continuing to work with reduced number of FTEs by not filling two vacant positions.
   - Continued strengthening overall organizational
structure, working directly with JISAO scientific and technical staff to ensure meaningful supervisory and mentoring relationships.

- Served on various UW and CoEnv committees.
- Worked on university-wide initiatives and on committees addressing financial, human resources, communications, and safety matters.

### Executive Summary

#### Themes

- Climate Research and Impacts
- Environmental Chemistry
- Marine Ecosystems
- Multiple
- Ocean and Coastal Observations
- Protection and Restoration of Marine Resources
- Seafloor Processes
CLIMATE RESEARCH AND IMPACTS
A QUASI OPERATIONAL PREDICTION SYSTEM FOR THE COASTAL OCEAN OF THE PACIFIC NW

PI
Thomas P. Ackerman — UW JISAO

Other UW Personnel
Samantha Siedlecki, Nicholas Bond, and Albert Hermann — Joint Institute for the Study of the Atmosphere and Ocean
Jan Newton — Applied Physics Laboratory

NOAA Personnel
Isaac Kaplan, Philip Levin, William Peterson, and Greg Williams — Northwest Fisheries Science Center

Task III

NOAA Sponsor
Isaac Kaplan — National Marine Fisheries Service/ Northwest Fisheries Science Center/Conservation Biology Division

NOAA Goal
Climate Adaptation and Mitigation

Description
This is the same project as the one under the Marine Ecosystems section entitled, “Development of a Prediction System for the California Current Integrated Ecosystem Assessment.” Initial funding came separately for the work of Samantha Siedlecki and, therefore, separate budgets were set up. This project fits in the two major themes of Climate Research and Impacts and Marine Ecosystems.
LIFE CYCLE ASSESSMENTS FOR THE IMPROVEMENT OF AQUACULTURE SYSTEMS

PI
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Other UW Personnel
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Task III
NOAA Sponsor
John Colt — Northwest Fisheries Science Center/ National Marine Fisheries Service

NOAA Goal
Healthy Oceans

Description
Assess Alaskan salmon processing waste alternatives: Offal grind and discharge, conventional offal processing, Montlake fresh offal processing, and Montlake stabilized offal processing data, facility and equipment drawings, and related documents provided by NOAA were compiled to conform to LCA data formats. Data were developed to fill gaps, including missing equipment specifications, and distances to landings and to the processing plant (for the representation of feedstock transport). Given the four offal processing data sets, many LCAs were developed and published in an article in Fisheries Research (Cooper et al. 2014). The article examines the gate-to-grave life cycle of salmon processing wastes (offal) management options in Sitka, Alaska using Life Cycle Assessment. The bases for comparison are the management of 1 kg of offal and the management of ~33,000 metric tons of offal generated intermittently throughout the 2010 fishing season in Southeast Alaska. Management options are (a) grind and discharge disposal, (b) two types of fresh processing, and (c) stabilized/ensiled offal processing. It is found that the contributions to eutrophication, acidification, and climate change are consistently reduced by assuming product displacements of meal, oil, and gelatin coproducts as compared to grind and discharge disposal. Further, increasing the allowable storage time by stabilizing the offal feedstock provides additional benefit by reducing the amount of offal ground and discharged.

Assess Alternative Feeds for Aquaculture Systems:
A review of aquaculture feed LCAs revealed misinterpretations based on how growth rate is modeled. A method was developed to correct the treatment of growth rate in LCAs comparing feeds (e.g., fish vs. plant based feeds) coupled with a critique of existing studies within the context of minimizing life cycle environmental, economic, and social impacts.

Objectives
1. Assess Alaskan salmon processing waste alternatives: The objective is to demonstrate the use of LCA in aquaculture for the development of process improvement and dissemination recommendations. The project will assess the “Montlake Processes” described by Nicklason, et al. (Nicklason 2010) as a case study. The Montlake Processes are a modification of current salmon processing intended to reduce life cycle impact through the use of a waste product in the place of virgin resources.
2. Assess alternative feeds for aquaculture systems: The objective is to investigate the integration of LCA into feed optimization for aquaculture systems by developing a framework to facilitate optimal feed selection and management on the basis of minimizing life cycle environmental, economic, and social impacts, with consideration given to feed formulation, species-specific dietary requirements, and the availability of and need for local and global resources.

Accomplishments

1. Many LCAs were developed in support of Objective 1, which both demonstrated the use of LCA in process comparison and provided useful results. The published results provided insight pursuant to discharge regulations in Alaska and the evaluation of “Best Available Technologies” for salmon processing, noting that discharge results in large anoxia areas and serious impacts on benthic animals.

2. Life cycle data were reviewed and a method was developed in support of Objective 2, which identified important data needs and modeling considerations for LCAs comparing aquaculture feeds.
LIGHTNING STUDIES

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Task III

NOAA Sponsor
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NOAA Goal
Climate Adaptation and Mitigation

Description
This is the third year of the project which has two major tasks:

1. To participate in the prelaunch validation for what the GLM on NOAA/GOES-R will be able to detect.
2. To use data assimilative techniques to add lightning location data into the WRF model to develop better prediction capability

Objectives

1. Provide expertise and data on global lightning as part of the NOAA GOES-R prelaunch planning for the GLM (Global Lightning Mapper) instrument.
2. Develop and validate the technology to assimilate lightning into lightning forecasting models.
3. Present our results at appropriate scientific meetings, and to publish our results.

Accomplishments

1. Shared real time WWLLN lightning data with NOAA investigators in the effort to develop prelaunch validation criteria for NOAA/GOES-R/GLM mission. WWLLN has been improving in stroke detection and now produces over 240 million stroke locations annually (up about 5% from 2012-2013) and has experienced no loss of data in the last 10 years of operations. These data are used by many groups looking at NOAA satellite data for lightning related research, and several notable papers have been published in the last year (see Publications in Appendix). Note that this is a small portion of papers using WWLLN lightning data published last year (total is over 20), but these pertain to NOAA related satellite data.

2. Presented papers at scientific meetings (see Publications in Appendix).

3. Progress on assimilation technique – A water vapor nudging technique for assimilating Worldwide Lightning Location Network (WWLLN) data was developed. The technique has been designed with the goal of nudging towards the production of a convective cloud, since a lightning event in the WWLLN data set indicates the presence of a deep tropospheric cloud at the time and location of the observed lightning event. By increasing the water vapor in a column, the lifted condensation level (LCL) decreases and the convective available potential energy (CAPE) increases for parcels lifted in that column. This technique is heavily based on an observation nudging technique described in Stauffer and Seaman (1994), which has already been implemented in the Weather Research and Forecasting (WRF) model.

Over the assimilation period when lightning data is available on the modelled domain, lightning events (specified by a longitude and latitude) are grouped into 5 minute temporal bins. As the model integrates through a particular 5 minute temporal bin, water vapor nudging occurs at each model time step at all model grid points within 3 km of a lightning event where \( p = 200 \text{ hPa} \). Consistent with the 5 minute intervals into which the lightning events are grouped, the water vapor values at grid points meeting the aforementioned criteria are nudged towards saturation using a relaxation timescale of 5 minutes (a nudging coefficient of \( G \approx 3.33 \times 10^{-3} \text{ s}^{-1} \)). No additional nudging occurs when more than one lightning event affects a grid point.
At lightning-affected grid points, the time-dependent equation solved by the model effectively becomes the following for the water vapor mixing ratio at a particular location \( x \) and time \( t \).

\[
\frac{\partial q_{v,\text{model}}}{\partial t} = F(q_{v,\text{model}}, x, t) + Gp^* (q_{v,\text{sat}} - q_{v,\text{model}})
\]

Note that \( q_{v,\text{model}} \) is the water vapor mixing ratio, \( q_{v,\text{sat}} \) is the saturation water vapor mixing ratio, \( F(q_{v,\text{model}}, x, t) \) is the model forcing of the water vapor mixing ratio, and \( G \) is the nudging coefficient.

The equation above is different than that provided in Stauffer and Seaman (1994). While not described fully here, the various modifications to the WRF source code necessary to implement the above technique are now discussed. First, the conversion of the 100% relative humidity observations to saturation water vapor mixing ratio values was rewritten to use the pressure and temperature values at model vertical levels instead of requiring observed values. Second, the vertical dependence of the horizontal radius of influence of observations was removed. Third, the spatial weighting function was simplified from a Cressman function to a boxcar function. Fourth, the temporal weighting function was simplified from a trapezoidal function to a boxcar function. Last, the checks were written that prevented nudging at \( p \leq 200 \) hPa and nudging a grid point more than once per time step.

Thus far, no attempt to nudge quantities resolved by the microphysical scheme has been made. This technique is therefore compatible with the use of any microphysical scheme option in WRF.

**Current Progress and Results**

The assimilation technique described above had a positive impact on deterministic numerical forecasts of the June 29, 2012 derecho (as described at the Sept 2013 GLM GOES-R meeting, and preliminarily discussed in last year’s report). This “progressive” derecho event is an ideal candidate for evaluating the impact of lightning data assimilation since the organization of the mesoscale convective system (MCS) depends on prior convection (Johns 1993) and its development is not subject to strong large scale forcing (Johns and Hirt 1987), errors of which may inhibit attempts to trigger convection by assimilating lightning.

In this case, two 3 km WRF simulations of the event were compared. Both were initialized at 1200 UTC June 29, 2012 using GFS 0.5° data for the initial and boundary conditions and ran for 24 hours. One simulation involved no data assimilation (control), while the other employed the lightning data assimilation technique described above for the first three hours of the simulation (nudged). This lightning data corresponded to the aforementioned early convective activity, the outflows of which later forced the formation of the long-lived MCS. The control simulation failed to produce the early convection, instead producing an MCS with noticeable timing and position errors. The nudged simulation produced the prior convection associated with lightning and improved the short-term forecast of the timing and location of the MCS, compared to the control run. These results were presented in August 2013 at the AMS 15th Conference on Mesoscale Processes in Portland, Oregon.

Since obtaining these results, work has focused on incorporating the assimilation technique into the UW WRF-DART ensemble forecast system, and using the system to model the June 29, 2012 derecho event. Repeating the experiment described above in such an ensemble forecast system that assimilates other, more conventional observations (e.g. METAR observations, radiosondes) using the ensemble Kalman filter will allow for a more realistic evaluation of the impact of the lightning assimilation technique on the forecast. In this experiment, the control ensemble forecast will assimilate only conventional observations using the ensemble Kalman filter. The ensemble forecast will then be repeated, including the lightning assimilation technique described above to form a “hybrid” ensemble forecast of the event. Here the “hybrid” moniker refers to the use of the nudging assimilation technique for lightning data in addition to the ensemble based assimilation of conventional observations.

It is hypothesized that for convective events such as the June 29, 2012 derecho, the “hybrid” ensemble system described above will produce superior forecasts compared to both the deterministic forecast with water vapor nudging and the traditional ensemble Kalman filter forecast system. First, the “hybrid” ensemble system will take advantage of the more complete representation of possible atmospheric
states provided by the ensemble approach, instead of relying on a single deterministic analysis to produce an environment in which water vapor nudging will produce convection consistent with lightning observations. Second, the “hybrid” ensemble system will include the assimilation of the high temporal and spatial resolution data provided by the water vapor nudging technique to supplement the less frequent assimilation cycles of larger scale conventional observations by the ensemble Kalman filter system.

Note. This assimilation work is being done by our graduate student Ken Dixon, who is defending his Master’s thesis this month (May 2014).
MOUNTAIN HYDROMETEOROLOGY FOR WEATHER AND CLIMATE FORECASTING APPLICATIONS

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Task III

NOAA Sponsor
Marty Ralph — OAR/ESRL Physical Sciences Division

NOAA Goal
Climate Adaptation and Mitigation

Description
We have been addressing the following questions, which were developed through discussions with NOAA staff both at ESRL in Colorado, and at the River Forecasting Center in California: 1) What measurements are most critical for accurate modeling of snow accumulation and melt in complex terrain? When such measurements are unavailable, what is the best alternative way to provide model inputs (e.g., satellite, mesoscale model, nearest station(s) plus a lapse rate, or some combination thereof)? 2) How do these different driving datasets impact the performance of a distributed hydrologic model?

Objectives
1. Characterizing snow to address uncertainty in forecasting, flood control, and water management.
2. Evaluating advanced observations of rain and snow, temperature, and soil moisture to provide best possible “forcings” for river prediction, in conjunction with NOAA’s Hydrometeorology Testbed in the North Fork (NF) American River Basin of California.

Accomplishments
1. We deployed and retrieved a network of temperature, relative humidity and stream pressure sensors distributed across the NF American River Basin. We compared ways of estimating annual precipitation and peak snow water equivalent spatially in time to assess the best way to map spatial patterns of snow accumulation across the landscape (Raleigh and Lundquist 2012). This addressed the project objective of characterizing snow.

2. We evaluated low-cost humidity sensors and their utility as key hydrologic forcing for river prediction, and then used them to assess best methods for estimating atmospheric moisture in complex terrain (Feld et al., 2013).

3. We assembled and quality-checked data from a network of 63 temperature sensors over three years, and assessed the best way to patch missing data from temperature networks of different sizes and with different lengths of missing data (Henn et al., 2013).

4. We evaluated the utility of MODIS for detecting fractional snow covered area under different densities of forest cover (Raleigh et al. 2013). These three addressed the project objective of evaluating advanced observations.

5. In work led by Nic Wayand, we assessed the impact of different observational and mesoscale-model-generated input datasets on snow and hydrologic simulations in the Distributed Hydrology Soil Vegetation Model (DHSVM) set up over the NF American River Basin (Wayand et al., 2013). This addressed the project objective of assessing the best forcings for river prediction.

6. Our work was used in developing a vision for hydrometeorological monitoring across the western United States, as detailed in Ralph et al. (2014).
INTernational Arctic Buoy Programme (IABP) – Monitoring the Eurasian Basin of the Arctic Ocean

PI
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NOAA Personnel
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Task III

NOAA Sponsor
Kathleen Crane — NOAA Arctic Research Program

NOAA Goal
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 (NWP) models that are used to forecast weather on synoptic time scales, and into the many long-term atmospheric reanalyses (e.g. NCEP/NCAR Reanalysis) that are used for innumerable climate studies. The impact of these in situ observations was documented in Inoue et al (2009), who show that the standard deviation in gridded sea level pressure (SLP) reanalyses fields over the Arctic Ocean was over 2.6 hPa in areas where there were no buoy observations to constrain the reanalyses, and this uncertainty in the SLP fields spreads to cover the entire Arctic when the observations from buoys are removed from the reanalyses. The buoy observations also help constrain the 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 IABP, and is a critical component of the Arctic Observing Network (AON).

Objectives
Our goal is to 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 to the World Climate Research Programme, the World Weather Watch Programme, and the Arctic Observing Network (AON).

Accomplishments
The IABP is a collaborative effort of 32 different research and operational institutions from many different countries (iabp.apl.washington.edu/Participants.htm). 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 Co-PI Dr. Pablo Clemente-Colón is a member, and operation of the program was delegated to the Coordinator of the IABP, PI Dr. Ignatius Rigor.

The United States contribution to the IABP is coordinated through the United States Interagency Arctic Buoy Program (USIABP), which is managed by Co-PI Lt. Curtis Reinking at the NAVICE and PI Dr. Rigor at the PSC/APL/UW. The USIABP is also a collaborative program that draws operating funds and services from a number of U.S. government organizations and research programs, which include the National Aeronautics and Space Administration, the Coast Guard, the Department of Energy, the National Oceanic and Atmospheric Administration, 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.

1. Arctic Buoy Deployments
   In 2013 we deployed four large (3 AXIB, 1 PAWS) buoys, and 40 smaller meteorological buoys (SVP-B). Two of the AXIB buoys were deployed...
by the CCG Healy, and one was deployed by the U.S. Coast Guard (USCG) during their Arctic Domain Awareness flights during the summer of 2013. The PAWS buoys were deployed by Jamie Morison at the NPEO in April 2013, while the 40 SVP-B were distributed between the ice breakers operating in the Arctic during the summer of 2013 (e.g. Healy, NABOS, Federov). Currently there are 120 buoys reporting in the IABP Arctic Observing Network (Fig. 1).

We are also developing a new collaboration with Alexander Salman, of ES-PAS in Moscow Russia. ES-PAS is the Argos data provider in Russia, and through this connection we have been able to import buoys into Russia at a much reduced tariff rate. So far we have deployed three buoys in April 2013, and plan to deploy eight more buoys around the Russian North Pole (NP) Manned Station.

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 were purchased and deployed using a combination of equipment and logistics coordinated with collaborators of the IABP (Fig. 1).

We have been working with the USCG to deploy buoys during the Arctic Domain Awareness flights. In 2009, we have been able to certify three of our buoys (AXIB, ICEX, and SVP-15BG) for deployment from the USCG C-130s. During the past year we have been working with Environment Canada to also certify these buoys for deployment by Canadian Forces C-130s. This October, we plan to deploy 11 buoys using these new assets.
This grant was a final award in 2010 to support the Climate Impacts Group's projects involving hydrological forecasting and regional climate modeling with the intent to “archive, document, and transition results of prior and ongoing work” and to continue to support stakeholders’ access to this data through various means.

One project in particular, the Pacific Northwest Hydroclimate Scenarios Project, focused on the documentation of gridded climatological observations and predictions (warm.atmos.washington.edu/2860/), providing 1/16 degree gridded (daily) data sets of land surface climate variables (precipitation, temperature, downward solar and longwave radiation, humidity, and wind) for the Pacific Northwest. The project objectives included making the computer codes available and displayed on a publicly-accessible website, as well as providing continuing access and support to the user community.

Accomplishments
Data from the Pacific Northwest Hydroclimate Scenarios Project has been widely used by stakeholders in the PNW region, and this grant continues to support the archiving, updating, and maintenance of the data and the website (warm.atmos.washington.edu/2860/).

Key project stakeholders include the Bonneville Power Administration (BPA), U.S. Army Corps of Engineers (USACE), and Bureau of Reclamation (USBR) – specifically their collaboration to adopt climate change and hydrology datasets for their longer-term planning activities in the Columbia-Snake River Basin.

To support U.S. State Department decision-making with regards to the potential renegotiation of the Columbia River Treaty (CRT) with Canada, the River Management Joint Operating Committee charged the BPA, USBR, and USACE to carry out a series of planning studies for the Columbia River basin to help support the consideration of various alternatives associated with the CRT. The consideration of alternatives encompasses complex tradeoffs between hydropower production (and hydropower revenues), flood control, water supply, navigation, and environmental services, all of which are likely to be substantially affected by climate change (Miles et al. 2000). Through the Pacific Northwest Hydroclimate Scenarios Project, the Climate Impacts Group developed and continues to maintain bias-adjusted streamflow data to support several reservoir operations models, and temperature data to support electrical load forecasting applications. To date, reservoir operations studies by the BPA and USBR have been produced for the Columbia main stem and Snake River basin respectively, and a series of reports describing the study methods and current results have been released to the general public (www.usbr.gov/pn/programs/climatechange/reports/index.html). The River Management Joint Operating Committee (RMJOC) projections have also fed into formal planning exercises such as the WaterSMART Yakima River Basin Study (www.usbr.gov/newsroom/newsrelease/detail.cfm?RecordID=39123).
Although a number of pilot climate change studies have been carried out in the Columbia basin in collaboration with various water management agencies in the past (e.g. NWPCC 2005), the RMJOC study was something of a landmark in that it is the first time that the BPA, USBR, and USACE used climate change information in coordinated inter-agency planning exercises in the Columbia basin. The study was also unique in that this was the first time that these agencies had run their own reservoir operations models to assess climate change impacts in the Columbia basin, an element of the study design which greatly increased the impact of the study conclusions in the agencies involved.

Other initial project stakeholders include Pacific Northwest Hydroclimate Scenarios, Project co-funders and collaborators: WA State Department of Ecology, Northwest Power and Conservation Council, Oregon Department of Water Resources, British Columbia Ministry of the Environment. More recent users of these projections of fundamental underlying hydrologic change include Seattle City Light, Skagit Climate Science Consortium, the Nature Conservancy, and a diverse array of scientists evaluating climate change impacts on various sectors and locations across the Pacific Northwest (see, for example, Beechie et al. 2012, Wenger et al. 2011, McKelvey et al. 2011).

CDEP Transition funds have supported ongoing Climate Impacts Group efforts to ensure data quality (adjusting a subset of the data with improved calibration techniques, ensuring long-term reliability of online data delivery by updating hardware and transferring data, and developing peer-reviewed documentation of the datasets). Specifically, writing, review and final editing were completed on a paper published in the journal *Atmosphere-Ocean*, titled, “An Overview of the Columbia Basin Climate Change Scenarios Project: Approach, Methods, and Summary of Key Results” (Hamlet et al. 2013).

In September 2014, the University of Washington will host the 5th Annual PNW Climate Science Conference (http://pnwclimateconference.org/) for scientists and stakeholders in the region. The Climate Impacts Group is once again providing leadership for the preparations and organization of this important regional two-day meeting where the latest research and data for climate change adaptation will be presented and discussed.
METHODS OF ASSESSING FISHERIES VULNERABILITY TO CLIMATE CHANGE (INTERNATIONAL)

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**NOAA Personnel**  
Penny Dalton — Washington Sea Grant

**Non-UW/Non-NOAA Personnel**  
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Bob Glazer, Florida Fish and Wildlife Conservation Commission

**Task III**

**NOAA Sponsor**  
Roger Griffis — National Marine Fisheries Service

**NOAA Goals**  
Climate Adaptation and Mitigation  
Resilient Coastal Communities and Economies

**Description**  
This project aims to enhance collaborations to link national and international approaches to assessing fisheries vulnerability to a changing climate.

We convened experts and participated in a series of fora and discussions on “Climate Ready” Management of Living Marine Resources at the first National Adaptation Forum (Denver, April 3-4, 2013). The National Adaptation Forum is a conference designed and attended by a diverse group of professionals from the private and public sectors concerned about the need to anticipate and prepare for the potential impacts of climate change on the United States. It represents a collective effort to enhance the resilience of the nation’s communities and economy in the face of a changing climate, through open participation from actors across the country. The 2013 Forum is the initial event in an ongoing series intended to bring together individuals from the wide spectrum of sectors and regions across the country, integrating climate adaptation planning into their day-to-day activities. At the National Adaptation Forum, this funding helped catalyze discussions among experts and practitioners from the public sector (e.g., NOAA, NMFS, Sea Grant, NCAR), academia (e.g., University of Washington), and non-profits (e.g., Nature Conservancy) by supporting travel and/or participation by: Amy Snover (University of Washington), Robert Pomeroy (professor of agricultural and resource economics at the University of Connecticut with a focus on small-scale fisheries management and policy), and Bob Glazer (Associate Research Scientist with the Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute).

Sessions included:

- **Symposia**
  “Climate Ready” Management of Living Marine Resources: Planning and Action to Reduce Risks  
Organizers: Roger Griffis, Malin Pinsky, Laura Petes  
Speakers: Vera Agostini, Robert Pomeroy, Robert Glazer, Suzanne Langridge

- **Implementing the National Fish, Wildlife and Plants Climate Adaptation Strategy**  
Organizer: Roger Griffis  
Speakers: Lynn Helbrecht, John O’Leary, Robert Glazer, Karen DeBord, Noah Matson

“Climate Ready” Management of Living Marine Resources: Assessing Risks and Impacts  
Organizers: Roger Griffis, Malin Pinsky, Laura Petes  
Speakers: Michael Alexander, Amy Snover

- **Working Group Discussion**  
Getting to Climate Savvy Fisheries Management: Fish Managers Guide to Climate Change  
Organizers: Lara Hansen, Roger Griffis

These events enabled presentation and discussion of methods, approaches, and identification of collaborative opportunities with broader international efforts to assess methods and to develop guidance for analyzing fisheries impacts/vulnerability to climate change.
Workshop Documenting Practical Experience and Findings of a Joint Science-Management-Industry Effort to Assess Fisheries’ Vulnerability to Climate Change

The University of Washington’s Climate Impacts Group (CIG) hosted a workshop in May 2011 to assess the vulnerability of four West Coast fisheries to climate change in partnership with West Coast Sea Grant programs and other partner agencies. The fisheries evaluated were Pacific whiting, sablefish, Canary rockfish, and Dungeness crab.

The workshop drew upon the expert knowledge of managers, scientists, industry, NGOs, and tribes associated with these fisheries in order to apply and test frameworks for rapid assessment of climate change vulnerabilities developed by Johnson and Welch (2010) and Chin et al. (2010) [see related references]. The vulnerability assessment frameworks have the advantage of being specific to fisheries and intended for use in data-limited situations.

Through discussion and application of the frameworks, workshop participants helped identify the factors that influence the vulnerability of these fisheries to climate change, and the relative significance of those factors to each other. The results of this effort are being summarized in a paper that covers the following:

2. Stage-setting: information on components of vulnerability (exposure, sensitivity, adaptive capacity), the use of the rapid assessment methodology as an alternate approach to standard vulnerability assessments, and existing methods and application of rapid assessment methodology in practice.
3. An overview of workshop goals and objectives, pre-workshop activities (selection of the fisheries, participants, development of the white papers, adaptation of the Chin et al. and Johnson and Welch methodology, and pre-workshop interviews, plus major findings from those interviews).
4. A summary of the workshop structure and workshop results.
5. Lessons learned in adapting and applying the methodology.
6. Conclusions and examples of how the rapid assessment approach is being utilized in other parts of the U.S. and the Caribbean.

A draft of the paper is expected in summer 2014.

Objectives

1. Review published materials (peer-reviewed literature on fisheries vulnerability assessment, management agency reports) related to methods of assessing fisheries vulnerability to climate change.

2. Work with NOAA Fisheries staff to hold an expert workshop to identify and review methods of assessing fisheries’ vulnerability to climate-related ocean changes, including increasing water temperature, ocean acidification, changing ocean currents, hypoxic zones and sea-level rise.

3. Enable knowledge transfer and shared learning among experts in fisheries science and management, focusing initially on efforts in the United States, Australia and the Philippines, while open for expansion to include other leaders in assessment of fisheries vulnerability to climate change.

Accomplishments

Objective 1: Built a foundation for literature review developed in previous reporting period, which will form the context for the paper under development.

Objective 2: Not met (was contingent on receipt of additional funding).

Objective 3: Knowledge transfer and shared learning enabled among leading experts, and between experts and practitioners in fisheries science, management, and vulnerability assessment at the 2013 National Adaptation Forum.
CALIFORNIA NIDIS PILOT

PI
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Task III

NOAA Sponsor
Robin Webb — Earth System Research Laboratory

NOAA Goal
Climate Adaptation and Mitigation

Description
This work with the California NIDIS Pilot spans the design, development, implementation, and evaluation of drought early information resources and strategies, working closely with both the producers and users of drought information, including agencies, industries, institutions, tribes, and other major stakeholders. The pilot is implemented through four pilot activities, each of which explore important and distinctive phenomena of drought: (1) Southern California, complexities of urban droughts in a well-plumbed system, heavily reliant on imported water; (2) Russian River, hydrologic extremes with droughts draining reservoirs and precipitation events filling reservoirs; (3) Central Valley, remote sensing to assess the extent of fallowed land; and (4) Klamath Basin, integrated hydroclimate information system in a complex water environment.

To date, the California Pilot has held eight meetings across the state, engaged more than 100 stakeholders, and identified drought information uses, needs, partners, and concrete ways that the NIDIS could help decision-makers to reduce drought impacts. Results from the California Pilot will include the following: early warning information capabilities for a range of decisions, user communities, temporal scales and spatial scales; real-time on-the-ground use of NIDIS information, demonstrating ways that early warning capabilities can reduce drought costs and impacts; and products, resources, and lessons that can be transferred to the rest of nation. The results of this work and the overall project, including summaries from stakeholder meetings and the four Pilot Activities, are detailed on the California NIDIS Pilot website: (www.drought.gov/drought/regional-programs/california/california-home)

Objectives
1. Design California NIDIS pilot and implementation strategy.
2. Evaluate California NIDIS pilot and process.
3. Evaluate drought indicators, triggers, and early warning system.

Accomplishments
1. Design of California NIDIS Pilot and Implementation Strategy
   a. Assisted in development of process for elicitation of potential NIDIS Pilot projects. Four pilot activities were selected through group processes and criteria developed during planning meetings.
   b. Communicated with personnel in other NIDIS Pilots and the NIDIS Program Office to obtain insights, experiences, and lessons. Coordinated with other pilot activity leaders to determine objectives and processes for the pilot to ensure that the four pilot activities will generate synergies and opportunities for cross-learning, with lessons and resources that can be transferred to other regions and states.
   c. Provided advice and coordination for the meetings and the selection process. Designed roundtable discussions, including questions to be asked, format for eliciting input, intended outcomes from meetings, and follow-up procedures. Identified participants to be included at meetings and in NIDIS Pilot activities, and communicated with participants. More than 100 stakeholders have been involved in the California NIDIS Pilot, with about half in the Southern California Pilot Activity.
   d. Assisted in development of criteria for NIDIS Pilot and pilot activities. Synthesized stakeholder input and refined list of criteria. Presented revised list of criteria to stakeholders, and incorporated additional information from the meetings.
feedback.

e. Identified critical drought issues for focus of NIDIS Pilot activities. Identified stakeholders to be involved, along with goals, processes, and expected outcomes. Together with pilot activity leaders, determined objectives for pilot, and ways to develop results and resources that would be useful to the rest of the country.

2. Evaluation of California NIDIS Pilot and Process
   a. Conducted both a pilot evaluation and process evaluation. The pilot evaluation focused on the California NIDIS Pilot, its progress, and its results, and the process evaluation focused on the overall process and individual steps for the design, selection, and implementation of the NIDIS Pilot.
   b. Developed protocols to document activities in each stage of implementation. Developed evaluation criteria, metrics, and methods for data collection and analysis. Currently collecting data on the use and potential value of NIDIS Pilot activities and information. A primary finding is that stakeholders can identify specific and needed applications of NIDIS drought early warning information, and the economic and societal benefits of using that information.
   c. Performed first-phase evaluation of NIDIS Pilot. Dimensions include the following: What would make a successful pilot? How do the pilot activities each contribute to that success? How would NIDIS drought information be used and integrated into decision-making? What are the net benefits of the use of that information to reduce drought impacts and costs? What can NIDIS provide decision-makers that wouldn't otherwise be possible? What resources and lessons can be transferred from California to the rest of the county? Stakeholders indicated that NIDIS offers a valuable and needed resource that doesn't otherwise exist, and it could provide a centralized, authoritative, integrated, and usable source of drought information.
   d. Performed first-phase evaluation of NIDIS process. Dimensions included the following: What is a successful process for the NIDIS Pilot activities? What are criteria for evaluation? Were the processes fair, efficient, participatory, and supportive? What do stakeholders think? What recommendations can be provided for future NIDIS Pilot efforts? Stakeholders indicated that the NIDIS Pilot activity processes and meetings have been inclusive and valuable, and cite specific benefits of the meetings and the overall NIDIS process and goals.

3. Evaluation of Drought Indicators, Triggers, and Early Warning System
   a. Compiled and compared the range of drought indicators used by decision-makers (e.g., water managers) in each of the pilots, and links with drought decisions. Nearly half of the agencies rely on the U.S. Drought Monitor for assessing and triggering drought, even though they note its limitations for regional and local drought assessment.
   b. Developed criteria for drought indicator evaluation. For instance, what is a “good” drought indicator and early warning system? In the absence of a gold standard for drought indication, design ways to assess indicator performance. For instance, one set of criteria relate to an indicator providing early warning, without false alarm or false assurance.
   c. Determined possible indicators for integrated NIDIS drought information resources, including indicators for varying types of decisions and early warning time frames, drought supplies, drought demands, temporal and spatial scales, historic analogs, climatologies, and formats. Stakeholders indicated the value of a percentile-based system, which can be used to compare different indicators and varying temporal and spatial scales, and for messaging to the public in a way that is understandable and useful.

Meetings and Presentations


NIDIS Drought Preparedness Workshops for Small Water Systems and Tribes, Sponsored by NIDIS, in collaboration with CNAP, California DWR, and
California Rural Water Association. San Diego, CA, November 24, 2013


Drought Impacts: National RISA and NIDIS Meeting (Steinemann-leader and organizer of meeting). RISA / NIDIS, San Diego, CA, July 1, 2013

NIDIS and Climate-Related Hazards, RISA Annual Meeting (Steinemann-leader and organizer of session). San Diego, CA, January 16, 2013

NIDIS and Extreme Events, RISA Annual Meeting (Steinemann-leader and organizer of session). San Diego, CA, December 4, 2013

Russian River NIDIS Pilot Activity. Santa Rosa, CA, September 20, 2013

e. U.C. Irvine, Presentation of California NIDIS Pilot, Irvine, CA, June 1, 2012.
g. Russian River Pilot Activity, planning meeting, Santa Rosa, CA, March 14, 2012.
i. Southern California Pilot Activity, all-participant meeting, San Diego, CA January 20, 2012.
ARCTIC CLIMATE CHANGE PROGRAM

PI
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Other UW Personnel
Nicholas A. Bond and Kevin Wood — Joint Institute for the Study of Atmosphere and Ocean

NOAA Personnel
Jim Overland, Phyllis Stabeno, Sigrid Salo, Sue Moore and Nancy Soreide — Pacific Marine Environmental Laboratory

Task II

NOAA Sponsor
Janet M. Intrieri — Earth System Research Laboratory

NOAA Goal
Climate Adaptation and Mitigation

Description
The Arctic Climate Change Program has continued to maintain close ties with the EcoFOCI group in ecosystem research. Our main focus of climate research is in the Arctic region, including sub-Arctic seas, such as the Chukchi Sea, the Beaufort Sea and the Bering Sea.

Objectives
1. Build and maintain a suite of Arctic climate observing networks (ocean, sea ice, and atmosphere) in association with national and international partners.
   a. JISAO scientists Nicholas Bond, Kevin Wood, and Muyin Wang along with NOAA/PMEL scientist, James Overland carried out a successful field program north of Alaska in the fall of 2013. This field work featured eight flights with a NOAA WP-3D research aircraft, with a focus on the marginal ice zone in the Chukchi Sea.

2. Provide data and analysis to climate assessment activities, and the international science community.
   a. JISAO scientists take active roles in studies of Arctic climate and climate change based on their collected data from stations and climate models. The research results have been published in peer-reviewed journals, as well as presented in meetings and workshops (Wang, Wood, Bond).

3. Support and enhance NOAA's mission in climate variability and ecosystem impacts in the Pacific sector of the Arctic.
   a. JISAO scientists are involved in an effort to apply simulations of future climate (IPCC AR5) to issues related to Arctic and North Pacific marine ecosystems. The output from these models is being used to force regional ocean models of the North Pacific Ocean and Bering Sea, and to make projections based on empirical methods. This is collaborative work with scientists from EcoFOCI groups (Wang, Cheng, Hermann, and Bond).

4. Participate in public education and outreach, and making data and analysis results available to fishery management councils and other resource managers.
   a. Wang is responsible for updating the Bering Climate Website, which is a collection of physical and biological variables for the Bering Sea studies. This website has been a popular source for ecosystem study communities.

   b. Wang is responsible for creating animations based on polar web cams deployed at the North Pole. This is, in part, in collaboration with the North Pole Environmental Observatory led by Applied Physics Laboratory (APL)/UW. The animations have been a hit on the internet, and were reported by the New York Times twice in the past.

Accomplishments
1. Arctic Sea Ice – Wang, in collaboration with Overland of NOAA/PMEL and others, has led
ongoing research on the past, present, and future climate of the Arctic. This work represents an important foundation for the “Arctic Report Card” (www.arctic.noaa.gov/reportcard/). This year’s edition discussed the occurrence of fewer snow and ice extremes than in 2012, and many regions and components of the Arctic environment were closer to their long-term averages. However the effects of a persistent warming trend that began over 30 years ago remain clearly evident. These changes are apparently having important biological consequences as evidenced by declines in caribou and increases in goose populations. It bears noting that the Arctic report card is becoming an increasingly valuable resource of information for scientists, other users and policy makers for the region. Its effectiveness can be directly linked to the efforts of JISAO web specialist Tracey Nakamura towards the development and maintenance of the web interface.

2. CMIP5 model assessment over the Arctic on ice and atmosphere – A comprehensive assessment of the CMIP5 models resulted in several publications by Wang and Overland from NOAA/PMEL. Wang is a contributing author and Overland (PMEL) is a lead author in the IPCC AR5 report. They updated their analysis based on CMIP5 models, and have published two related journal manuscripts. A third manuscript is in revision, which addresses the potential open water duration of the Alaskan Arctic (the Chukchi Sea and the Beaufort Sea) based on selected CMIP5 models.

3. The connection of Arctic change and mid-latitude climate variability is another research focus. One manuscript has been published (Overland et al. 2012), and the other is submitted (Overland and Wang, 2014).

4. Bond, Wang, and Wood, along with Overland of NOAA/PMEL, carried out a successful field program north of Alaska in fall of 2013. This field work featured eight flights with a NOAA P-3 research aircraft, with a focus on the marginal ice zone in the Chukchi Sea. The analysis of this data is in progress. The primary objectives are to compare the heat fluxes from the open ocean with those in areas covered with newly-formed sea ice, and to determine how these heat fluxes influence the atmospheric boundary layer structure. Preliminary results suggest that the effects of ice cover are dependent on the large-scale weather conditions. The ultimate goal of this project is to improve our understanding of the impacts of the decline of Arctic sea ice from both regional and hemispheric perspectives.

5. Wang and Wood, with Overland and Nancy Soreide of NOAA/PMEL have successfully launched an international collaborative program to recover and digitally transform historical climate and environmental data on a large scale (led by Wood). To date, nearly 400,000 manuscript pages of multivariate weather, sea ice and other types of environmental data have been imaged by project staff and interns at the National Archives and posted for transcription via Old Weather – Arctic (www.oldweather.org). The first phase of Old Weather has already produced transcriptions of 1,090,745 pages of handwritten data that has been transferred to the International Comprehensive Atmosphere Ocean Data Set (ICOADS) where it is available for use by new U.S. and European extended reanalysis projects. More than 200 whaling logbooks provided through partnerships with the Providence Public Library and the New Bedford Whaling Museum are also now available in digital form. New opportunities to amplify scientific output have also arisen, as the project has become more widely known. Other collaborators include Mark Mollan, U.S. National Archives, Philip Brohan, U.K. Met Office Hadley Centre, Gilbert Compo, CIRES and NOAA/ESRL, and Axel Schweiger, UW Applied Physics Laboratory.

6. Wood and Bond (JISAO), Overland, Salo, and Stabeno (NOAA/PMEL), and Jonathan Whitefield (University of Alaska Fairbanks) have produced a decadal climatology for the Synthesis of Arctic Research (SOAR), which is currently in review for the SOAR special issue of Progress in Oceanography.

7. Wood gave a presentation to the JISAO summer interns (Aug. 2013) entitled “Communicating with a Poster” to help them with their final presentations at the end of their internships.
SYNTHESIS OF ARCTIC RESEARCH (SOAR) AND APPLIED PHYSICS LABORATORY COLLABORATIVE PROJECTS

PI
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Other UW Personnel
Bonnie Light, Kristin Laidre, Kate Stafford and Kay Runciman — Applied Physics Laboratory

NOAA Personnel
Jim Overland — Pacific Marine Environmental Laboratory
Catherine Berchok and Megan Ferguson — National Marine Fisheries Service

Non-NOAA and Non-UW Personnel
Craig George, Robert Suydam — North Slope Borough
Matt Druckenmiller — National Snow and Ice Data Center
Chris Clark — Cornell University
David Hannay — JASCO Research
Susannah Blackwell — Greeneridge Associates
Brenda Norcross — University of Alaska, Fairbanks
John Citta — Alaska Department of Fish and Game
Janet Clarke — Science Applications International Corporation

Task III

NOAA Sponsor
Phyllis Stabeno, Pacific Marine Environmental Laboratory

NOAA Goals
Climate Adaptation and Mitigation
Healthy Oceans

Description

The Synthesis of Arctic Research (SOAR) aims to bring together a multidisciplinary group of Arctic scientists and Alaskan coastal community representatives to explore and integrate information from completed and ongoing marine research in the Pacific Arctic Region. The goal of the SOAR project is to increase scientific understanding of the relationships among oceanographic conditions, benthic organisms, lower trophic pelagic species (forage fish and zooplankton), and higher trophic species (seabirds and marine mammals) in the Pacific Arctic, with particular emphasis on the Chukchi Sea Lease Sale Areas. The SOAR project is supported by the Bureau of Ocean Energy Management and NOAA, and led by Dr. Sue Moore, Dr. Phyllis Stabeno, and an 11-member Science Steering Committee.

The major deliverable of SOAR will be a collection of peer-reviewed scientific publications in a special issue or theme section of an appropriate journal. Science themes and questions appropriate for synthesis were developed at a science workshop held in Anchorage, Alaska from March 14-16, 2012. The potential impact of the effects of annual variability of sea ice in the Pacific Arctic and the associated variability in primary production was one of the questions discussed under the theme of Responses to Step Change in Physical Drivers of the Marine Ecosystem. The work proposed here will result in manuscripts on the topic of sea ice variability and primary production in a peer-reviewed journal. APL scientists contribute to various SOAR projects, as outlined below.

Objectives

1. Update estimates of shortwave radiative flux into the arctic from 2008 to present. Rebecca Woodgate and Bonnie Light are part of the SOAR project “Causes of Drastic Climate Change for the Pacific Arctic,” and with the support of scientific programmer Kay Runciman, will use remotely sensed sea ice concentration, adjusted shortwave down welling radiative fluxes, and an albedo model for sea ice to estimate total absorbed shortwave radiative fluxes in the Arctic Ocean.

2. Collaborate with marine mammal expert Kristin Laidre in body condition analyses, ecological interactions of Arctic marine mammals with sea ice habitat, and in general on whale ecology in the Arctic. She is working with other SOAR investigators to help develop and interpret...
quantitative models of bowhead whale body condition relative to changes in remotely sensed sea ice in Alaska.

3. Collaborate on the sound environments bowhead whales encounter in the Chukchi and Beaufort Seas throughout the year. Kate Stafford is working on this objective, contributing relevant data and providing scientific expertise pursuant to the development of a collaborative paper suitable for a peer-reviewed publication on bowhead whale call detections and the overall sound environment of the Chukchi and Beaufort seas for the period September 2009 – 2010. In support of co-authorship on the paper, this effort will include participation in a 3-day working meeting convened by the Bioacoustics Research Program (BRP) at Cornell University in Ithaca, NY. Support to attend the BRP meeting will be provided via Invitational Travel from NOAA’s PMEL.

4. Collaborate with investigators to address the relationship between beluga whales, Arctic cod, and oceanographic conditions in Barrow Canyon and at the shelf break of the western Beaufort Sea. Within this project, Kate Stafford is helping develop a better understanding of how and why beluga whales use Barrow Canyon and the shelf break of the western Beaufort Sea by combining varied data sets including aerial surveys, satellite tracking, and dive data from tagged belugas of the eastern Chukchi Sea, fish trawls, passive acoustic monitoring, and oceanographic conditions.

Accomplishments
1. The analysis of solar shortwave (SW) radiative flux to the Chukchi has yielded some interesting results. Our calculations suggest that roughly half of the incoming SW reaches the ocean, with total energy annually being comparable to the annual Bering Strait heat oceanic heat input but showing different interannual variability. Variability in SW input to the ocean is mostly due to changes in the timing of the spring melt back of ice, but overall the SW flux to the ocean in the Chukchi changes remarkably little from year to year. These results will form part of a manuscript on the heat balance of the Chukchi Sea.

2. A full analysis of bowhead whale body condition from the harvest in Barrow has been completed. A manuscript has been written and submitted for peer review in *Progress in Oceanography*. We are waiting for the peer review comments to return, and expect to revise the paper by summer 2014. The bowhead data were analyzed in two condition models: a girth model and a volume model, and used to examine seasonal and interannual trends in bowhead whale body condition with multiple regression models relative to sea ice breakup and wind-driven upwelling. The authors on the paper are J.C. George, M. Druckenmiller, K. L. Laidre, and R. Suydam and it is titled "Western Arctic bowhead whale body condition and links to summer sea ice and upwelling in the Beaufort Sea".

3. A manuscript has been submitted to *Progress in Oceanography* entitled, “A year in the acoustic life of western Arctic bowhead whales.”

4. The beluga whale project collaborators met in Anchorage in January 2014 to finalize the outline of a manuscript. The passive acoustic monitoring (PAM) data were contributed to this effort and have been plotted out with text provided to the lead author. This manuscript is being led by Dr. Robert Suydam of the North Slope Borough, Alaska.
ENVIRONMENTAL CHEMISTRY
ATMOSPHERIC CHEMISTRY – AEROSOL PROGRAM

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NOAA Personnel
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Task II

NOAA Sponsor
A.R. Ravishankara — Chemical Sciences Division

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
To assess the regional climate and air quality impacts of atmospheric aerosol particles through measurements of their physical chemical, radiative, and cloud nucleating properties.

Accomplishments
1. We continued analysis of data from the Western Atlantic Climate Study (WACS), an ocean-derived aerosol cruise on R/V Brown from Boston to Bermuda in August 2012. The purpose of this study was to measure the flux of ocean-derived aerosol to the atmosphere over biologically productive and non-productive waters. Breaking waves on the ocean surface generate air bubbles that scavenge organic matter from the surrounding sea water. When injected into the atmosphere, these bubbles burst, yielding sea spray aerosols enriched in organic matter relative to the sea water. Downwind of plankton blooms, the organic carbon content of sea spray aerosol is weakly correlated with satellite-derived measurements of chlorophyll a levels, a measure of phytoplankton biomass. This correlation has been used in large-scale models to calculate the organic enrichment in sea spray aerosol. We assessed the relationship between the organic carbon content of sea water and freshly emitted sea spray aerosol in the presence and absence of plankton blooms in the North Atlantic Ocean and the coastal waters of California. The organic carbon content of freshly emitted sea spray aerosol was similar in all regions sampled, despite significant differences in seawater chlorophyll a levels. The proportion of freshly emitted aerosols that served as cloud condensation nuclei at a given supersaturation was also similar across sampling sites. The large reservoir of organic carbon in surface sea water remained relatively constant across the regions sampled, and independent of variations in chlorophyll a concentrations. We suggest that this reservoir is responsible for the organic carbon enrichment of freshly emitted sea spray aerosol, overwhelming any influence of local biological activity as measured by chlorophyll a levels.

2. We conducted aerosol and snow measurements in Vernal, Utah as part of the Uintah Basin Winter Ozone Study (February 2014). The purpose of this study was to advance an understanding of the chemical processes that control winter ozone formation and its sensitivity to VOC and NOx. This includes radical species that initiate the formation of ozone and heterogeneous processes, including snow and aerosol photochemistry that might produce radical precursors. The data will be used to develop mitigation strategies to reduce the high ozone concentrations in the Basin.
Sampling site for the Uintah Basin Wintertime Ozone Study in February 2014. The tall pipe on the middle container is the aerosol sampling mast.

Ocean-derived aerosol generator deployed off the port side of the R/V Brown.
NUTRIENTS

PI

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Other UW Personnel

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NOAA Personnel

Eric Wisegarver — Pacific Marine Environmental Laboratory

NOAA Sponsor

Dennis Moore — Pacific Marine Environmental Laboratory

NOAA Goal

Healthy Oceans

Description

The Repeat Hydrography CO2/Tracer Program is a systematic and global re-occupation of select hydrographic sections to quantify changes in storage and transport of heat, fresh water, carbon dioxide (CO2), chlorofluorocarbon tracers, and related parameters. It builds upon earlier programs (e.g., World Ocean Circulation Experiment (WOCE)/Joint Global Ocean Flux Survey (JGOFS) during the 1990s) that have provided full depth data sets against which to measure future changes, and have shown where atmospheric constituents are entering the oceans. The Repeat Hydrography CO2/Tracer Program will reveal much about internal pathways and changing patterns that will impact the carbon sinks on decadal time scales.

The primary goal is to assess changes in the ocean’s biogeochemical cycle in response to natural and/or man-induced activity. For example, global warming-induced changes in the ocean’s transport of heat and freshwater could affect the circulation by decreasing or shutting down the thermohaline overturning. Because the Argo array has a depth range of 2000 m, repeat hydrographic measurements are the only global measurement programs capable of observing these long-term trends deep in the ocean.

Objectives

The objectives of this project are:

1. To make high-quality measurements of inorganic nutrient (nitrate, nitrite, phosphate and silicate) concentrations in seawater on CLIVAR repeat hydrographic cruises.
2. Perform data quality control.
3. Make this data available to the climate and carbon research community.

The data are used for measuring spatiotemporal trends in biogeochemical properties; model calibration and validation; carbon inventory and transport estimates; and deep and shallow water mass and ventilation studies.

Accomplishments

The team was responsible for nutrient analysis on the Repeat Hydrographic Lines A16N and A16S in the Atlantic Ocean. Wisegarver participated on each cruise, and conducted high precision shipboard analysis of phosphate, nitrate, nitrite and silicic acid on samples collected from the CTD rosette at discrete depths (see sections below). Quality control of the A16N data set was completed, and the final data is available and archived at the CCHDO website: http://ushydro.ucsd.edu/cruise_data_links.htm. Quality control and submission of A16S data will occur in FY15.

Sections of nutrients along the A16 cruise track.
**MARINE CARBON PROGRAM**

**PI**  
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Richard Feely, Christopher Sabine, Simone Alin, Jeremy Mathis, Dana Greeley, Cathy Cosca, Dave Wisegarver, Stacy Jones and Randy Bott — Pacific Marine Environmental Laboratory

**Non-UW/Non-NOAA Personnel**  
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**Task II**

**NOAA Sponsor**  
Richard Feely — 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 PMEL scientists, JISAO scientists and other University of Washington staff with common interests in the marine carbon cycle and its interactions with atmospheric CO2 and climate. The program focuses on multidisciplinary research involving atmosphere-ocean CO2 exchange fluxes, water column CO2 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 carbon dioxide in the atmosphere and the changes that are occurring due to ocean acidification. Project goals include: (1) determining the air-sea exchange of CO2 from measurements collected on research ships, volunteer observing ships and moorings; (2) determining the distribution and transport of CO2 into the ocean interior from measurements collected onboard NOAA and University National Oceanographic Laboratory System (UNOLS) 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. Collect dissolved inorganic carbon (DIC) and process data on P16S cruise: PMEL provided equipment and personnel for the P16S cruise which departed New Zealand in March 2014.
2. Service 38 CO2 moorings: In order to maintain sustained time series, the moored CO2 systems 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 CO2 systems: We maintain four underway CO2 systems that require regular servicing.
4. Prepare new underway CO2 system: We have plans to install one new underway system on a ship during the year.
5. Collect and analyze discrete samples from the Prince William Sound, AK. We have continued working with a number of our colleagues around Alaska to collect and analyze discrete carbon samples. This includes a Wave and profiling glider survey in the summer of 2014.

**Accomplishments**

1. Conducted final DIC data processing for two legs of the CLIVAR/CO2 Repeat Hydrography Section S4P in the Pacific and the A20/22 cruise in the Atlantic. All data have been submitted to the Carbon Dioxide Information Analysis Center.
2. Maintained five underway CO2 systems.
3. Deployed and/or maintained 38 moored CO2 systems.
4. We have continued analyzing discrete samples collected on a number of cruises conducted with our collaborators including a 2013 cruise along the West Coast of the U.S.; sampling the Newport
Hydrographic Line with OSU and NOAA/NMFS 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.
CHLOROFLUOROCARBON TRACER PROGRAM

PI
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Other UW Personnel
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NOAA Personnel
David Wisegarver — Pacific Marine Environmental Laboratory

Task II

NOAA Sponsor
John Bullister — Pacific Marine Environmental Laboratory

NOAA Goal
Climate Adaptation and Mitigation

Description
The concentrations of chlorofluorocarbons (CFCs), along with a number of other anthropogenic compounds like CO2, 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 fairly well understood. Studies of the entry of chlorofluorocarbons (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 CO2 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 CO2, 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 CO2, decadal ventilation timescales, changes in ventilation, and ocean biological cycling rates.

Our group has pioneered efficient methods for measuring sulfur hexafluoride (SF6) 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 CO2 uptake and ocean acidification from CFCs. In addition, the availability of concurrent CFC and SF6 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 (N2O) in seawater. Because N2O plays an important role in the marine nitrogen cycle, this affords an opportunity to use the tracer and N2O measurements in combination to estimate key rates of denitrification in the ocean.

Project Goals
1. A key goal of the Chlorofluorocarbon Tracer Program is to document the transient invasion of CFCs and other tracers (including SF6) 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. A second key goal of this program is 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. A third goal is 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. Recently we have developed a method for measuring full sections of N2O in the oceans, and we plan to use these observations together with the CFCs/SF6 to quantify removal rates of fixed nitrogen from the oceans.

**Objectives**

1. Quantification of oceanographic ventilation processes through collection and analysis of CFC, SF6, and hydrographic data.

2. Using CFC and SF6 observations to improve estimates of the uptake of anthropogenic carbon dioxide in the ocean.

3. Using CFC and SF6 observations to quantify oxygen utilization rates in the ocean interior.

4. Using combined CFC and SF6 observations as a means of testing and evaluating large-scale numerical models of the ocean.

5. Using CFC and SF6 observations for quantifying the temporal evolution of tracer ages and correcting for tracer age drift due to mixing processes.

6. Participate on oceanographic expeditions as part of the global CLIVAR/GO-SHIP Repeat Hydrography Program.

7. Quantify regional oceanic denitrification rates via dissolved nutrients, N2O and CFC/SF6 observations.

8. Identify dominant biological metabolic pathways controlling the distribution of marine dissolved N2O.

**Accomplishments**

1. Measured CFC-12, SF6, and N2O on an oceanographic survey to the oxygen-deficient waters of the Eastern Tropical South Pacific Ocean.

2. Measured CFCs, SF6, and N2O on three long cruises in the Atlantic Ocean as part of the CLIVAR/GO-SHIP Repeat Hydrography Program, and provided chief scientist support on one.

3. Processed oceanographic data, and submitted these to national and international data archives.

**Figure 1.** The 1994 to 2007/8 increase in anthropogenic CO2 (in umol kg⁻¹) reconstructed using the 2007/8 CLIVAR P18 tracer data. The first three of these approaches assume that the sea surface has historically been tracking the atmospheric pCO2 change, and use different dating techniques to estimate the size of that pCO2 change for subsurface samples. The top figure uses transit time distributions tuned to the SF6/CFC-11/CFC-12 tracer triplet to estimate the CO2 uptake during this period. The second figure uses pCFC-12 ages, while the third figure uses pSF6 ages. The final two figures represent the 1994-2007/8 DIC change measured by comparing the 1994 and 2007/8 DIC datasets forward, and backward, in time, where water mass and nutrient changes are accommodated using the statistical correlations of DIC with hydrographic and nutrient parameters (Wallace, 1995; Plancherel et al., 2013).
Examined in detail the constraints on transit time distributions in the Southeast Pacific Ocean provided by CFC and SF6 data. The transit time distributions were used to improve estimates of thermocline ventilation and oxygen utilization rates in the South Pacific Ocean (manuscript in preparation for Deep-Sea Research).

5. Inferred the time-integrated transport of anthropogenic CO2 into the abyssal tropical Pacific Ocean through the Samoa Passage using measurements of trace levels of CFCs and carbon tetrachloride.

6. Initiated development of techniques to measure the 15N/14N and 18O/16O of marine N2O, including the specific isotopic ratios of the two (non-equivalent) nitrogen atoms.

7. Collection of marine N2O samples from the tropical Atlantic Ocean for isotopic analysis.

Research Highlight

We evaluated the added utility of SF6 and CFC-constrained transit time distributions (TTDs) in constraining anthropogenic CO2 uptake in the Southeast Pacific Ocean along the 2007/8 CLIVAR P18 section. TTDs tuned to CFCs and SF6, and simple pSF6 ages, yielded dissolved inorganic carbon (DIC) increase estimates that were comparable to those measured. Although the penetration depth of the pCFC-12 derived anthropogenic CO2 changes was similar to that measured, the pCFC-12 ages alone yielded a significant underestimate in shallow waters (Z < 500m). The reason is mixing has biased these shallow samples’ pCFC-12 ages too old, yielding a lower anthropogenic CO2 uptake. Anthropogenic CO2 computed from simple pSF6 ages, however, yield comparable anthropogenic CO2 to the more elaborate TTD approach, and comparable to the 1994-2007/8 increases measured, with the advantage that an historical DIC dataset is not required.
TROPICAL ATMOSPHERE – OCEAN INTERACTION

PI
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Task II

NOAA Sponsor
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NOAA Goal
Climate Adaptation and Mitigation

Description
JISAO research on tropical atmosphere-ocean interaction seeks to improve understanding and prediction of El Niño and the Southern Oscillation (ENSO). The centerpiece of the ENSO observing system is the Tropical Atmosphere Ocean (TAO) mooring array, designed to monitor variability in the tropical upper ocean, and at the surface. Scientists in JISAO and at PMEL maintain the TAO array in collaboration with NOAA’s National Data Buoy Center (NDBC). In combination with the TRITON array maintained by Japanese scientists in the western Pacific, the TAO array is comprised of 70 moorings at 11 different longitudes, spanning the equator from 8°S to 8°N. Data from the array are used for ENSO forecasting and a variety of oceanographic and climate research studies. The array also supports carbon cycle studies in the Pacific by providing access to ship and buoy platforms, and by providing a physical oceanographic and meteorological context in which to interpret biogeochemical measurements. Ships servicing the TAO array provide a platform for the regular launch of Argo floats and drifting buoys. With completion of the transfer of TAO operations and maintenance from PMEL to NDBC, this is the final year in which JISAO and PMEL scientists provided maintenance support for TAO. We will continue to monitor performance of TAO/TRITON, and analyze, display and disseminate the data via the Web.

Complementing the TAO array in the tropical Pacific 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 and together TAO/TRITON, PIRATA and RAMA comprise the Global Tropical Moored Buoy Array. 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 moorings in RAMA, and maintain an array of Subsurface Acoustic Doppler Current Profiler (ADCP) moorings as part of a process study within the context of RAMA.
3. Evaluate dust contamination of PIRATA radiation
measurement in the northeast tropical Atlantic.
4. Improve understanding of the ENSO cycle in the Pacific.
5. Advance understanding of the dynamics of ocean circulation in the Indian Ocean.
6. Improve understanding of Atlantic Niños.

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 http://www.pmel.noaa.gov/tao/. Between April 1, 2013, and March 31, 2014, TAO web pages received more than 13 million hits, delivered more than 560,000 mooring data files via the Web and more than 1.5 million files via FTP to the international community.

2. Since last year’s report, we deployed one new ATLAS Flux mooring in the Indian Ocean: at 2°S, 67°E from the Indian research vessel Sagar Nidhi in July 2013. This mooring represents progress in a developing RAMA, which is now 70% complete. 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. Seven prototype systems have been deployed – three of which were in the past year. Comparisons between ATLAS and T-Flex systems indicate that they report comparable data.

3. Long-term and direct measurements of surface shortwave radiation (SWR) have been recorded by the Prediction and Research moored Array in the Tropical Atlantic (PIRATA) since 1997. Previous studies have shown that African dust, transported westward from the Sahara and Sahel regions, can accumulate on mooring SWR sensors in the high-dust region of the North Atlantic (8°N–25°N, 20°W–50°W), potentially leading to significant negative SWR biases. We have quantified dust-accumulation biases for each PIRATA mooring using direct measurements from the moorings, combined with satellite and reanalysis data sets and statistical models. (Foltz et al., JOAT, 2013). The dust-accumulation biases described will be useful for interpreting SWR data from PIRATA moorings in the high-dust region. The biases are also potentially useful for quantifying dust deposition rates in the tropical North Atlantic, which at present are poorly constrained by satellite data and numerical models.

4. Sea surface temperature (SST) is a critical control on the atmosphere, and numerical models of atmosphere–ocean circulation emphasize its accurate prediction. Yet many models demonstrate large, systematic biases in simulated SST in the equatorial ‘cold tongues’ (expansive regions of net heat uptake from the atmosphere) of the Atlantic and Pacific oceans, particularly with regard to a central but little understood feature of tropical oceans: a strong seasonal cycle. The biases may be related to the inability of models to constrain turbulent mixing realistically, given that turbulent mixing, combined with seasonal variations in atmospheric heating, determines SST. In temperate oceans, the seasonal SST cycle is clearly related to varying solar heating: in the tropics, however, SSTs vary seasonally in the absence of similar variations in solar inputs. Turbulent mixing has long been a likely explanation, but firm, long-term observational evidence has been absent. We showed the existence of a distinctive seasonal cycle of subsurface cooling via mixing in the equatorial Pacific cold tongue, using multi-year measurements of turbulence in the ocean. In boreal spring, SST rises by 2 kelvin when heating of the upper ocean by the atmosphere exceeds cooling by mixing from below. In boreal summer, SST decreases because cooling from below exceeds heating from above. When the effects of lateral advection are considered, the magnitude of summer cooling via mixing (4°C per month) is equivalent to that required to counter the heating terms. These results provide quantitative assessment of how mixing varies on timescales longer than a few weeks, clearly showing its controlling influence on seasonal cooling of SST
5. We examined the ocean mixed layer response to intraseasonal atmospheric forcing using moored time series data in the central equatorial Indian Ocean for October 2004 to March 2005, a period coincident with two active phases of the Madden-Julian Oscillation (MJO). Both MJO events were accompanied by a sea surface temperature decrease that was partially the consequence of reduced net surface heat flux. In addition, during the first event in October–November 2004, advection by an enhanced Wyrtki Jet contributed substantial cooling, while during the second event in December 2004 to January 2005, vertical processes, most likely related to entrainment mixing, were pronounced. Heavy rainfall at the mooring location during the first event may have contributed to the formation of a 30–40m thick barrier layer that limited turbulent vertical transfers between the mixed layer and the thermocline. There was no barrier layer present during the second event, which presumably allowed for much freer vertical turbulent exchanges. Two figures are shown from that paper, one depicting the basis RAMA data at the mooring location (right) and the other showing various terms and diagnostics for the mixed layer heat balance (McPhaden and Foltz, 2013, GRL).

6. Unprecedented warm SST anomalies were observed off the west coast of Australia in February–March 2011. Peak SSTs during a 2-week period were 5°C warmer than normal, causing widespread coral bleaching and fish kills. Understanding the climatic drivers of this extreme event, which we dub “Ningaloo Niño”, is crucial for predicting similar events under the influence of global warming. Here we use observational data and numerical models to demonstrate that the extreme warming was mostly driven by an unseasonable surge of the poleward-flowing Leeuwin Current in austral summer, which transported anomalously warm water southward along the coast. The unusual intensification of the Leeuwin Current was forced remotely by oceanic and atmospheric teleconnections associated with the extraordinary 2010–2011 La Niña. The amplitude of the warming was boosted by both multi-decadal trends in the Pacific toward more La Niña-like conditions and intraseasonal variations in the Indian Ocean (Feng, McPhaden, Xie, and Hafner, Science Reports, 2013).

7. The Atlantic meridional overturning circulation (AMOC) simulated by 10 models from phase 5 of the Coupled Model Intercomparison Project (CMIP5) for the historical (1850–2005) and future climate is examined. The historical simulations of the AMOC mean state are more closely matched to observations than those of phase 3 of the Coupled Model Intercomparison Project (CMIP3). Similarly to CMIP3, all models predict a weakening of the AMOC in the 21st century, though the degree of weakening varies considerably among the models. Under the representative concentration pathway 4.5 (RCP4.5) scenario, the weakening by year 2100 is 5%–40% of the individual model’s historical mean state; under RCP8.5, the weakening increases to 15%–60% over the same period. RCP4.5 leads to the stabilization of the AMOC in the second half of the 21st century and a slower (then weakening rate) but steady recovery thereafter, while RCP8.5 gives rise to a continuous weakening of the AMOC throughout the 21st century. In the CMIP5 historical simulations, all but one model exhibit a weak downward trend [ranging from −0.1 to −1.8 Sverdrup (Sv)/century; 1 Sv = 106 m3/s] over the 20th century. Additionally, the multimodel ensemble–mean AMOC exhibits multidecadal variability with a ~60-yr periodicity and a peak-to-peak amplitude of ~1 Sv; all individual models project consistently onto this multidecadal mode. This multidecadal variability is significantly correlated with similar variations in the net surface shortwave radiative flux in the North Atlantic and with surface freshwater flux variations in the subpolar latitudes. Potential drivers for the 20th century multimodel AMOC variability, including external climate forcing and the North Atlantic Oscillation (NAO), and the implication of these results on the North Atlantic SST variability are discussed. (Cheng, Chiang and Zhang, Journal of Climate, 2013).

8. Previous studies have linked the Indian Ocean Equatorial Undercurrent (EUC) variability to the development of Indian Ocean Dipole (IOD),
with stronger EUC generally corresponding to positive IOD. These studies however were based on analysis of single events due to lack of long-term continuous observation of EUC. Here we use a continuous ADCP measurement of EUC at 80° during 2004-2012, together with Argo float measurements and satellite winds, to investigate the interannual variability of EUC and its connection with IOD, thermocline variability and surface winds. The ADCP records last from October 2004 to August 2012, allowing us to calculate the seasonal cycle and interannual anomalies. We found that the EUC at 80°E is only marginally correlated to the IOD index with 90% significance, but more significantly to the IOD East (IODE) index (above 95% significance level). Further analysis shows that there is a positive feedback between IODE and EUC. The 7-year timeseries of EUC is significantly correlated with the zonal pressure gradient at the thermocline depth range, but not significantly to the equatorial zonal wind. There is however a tendency of anti-correlation between EUC and zonal wind during the IOD events. The atmospheric forcing to sustain the EUC variability comes from the off-equatorial wind stress curl associated with the IODE anomalies. The anomalous Ekman pumping depresses or raises the thermocline, and generates equatorward thermocline currents to feed the EUC, in a similar way that the Pacific STCs feed the Pacific EUC. The interpretation of observational results is assisted by ECCO2 ocean data assimilation to overcome the potential lack of basin scale coverage of Argo floats on the equator (Zhang, McPhaden and Lee, manuscript to be submitted).
MARINE ECOSYSTEMS
POPULATION CONNECTIVITY VIA LARVAL DRIFT OF PRIBILOF ISLANDS BLUE KING CRAB IN THE EASTERN BERING SEA

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NOAA Goals
Healthy Oceans
Climate Adaptation and Mitigation

Description

Blue king crab (BKC, Paralithodes platypus) stocks in the eastern Bering Sea (EBS) have historically supported important commercial fisheries that benefit local coastal communities in Alaska. The two crab stocks managed within the federal Fishery Management Plan (FMP) for Bering Sea and Aleutian Islands (BSAI), King and Tanner Crabs, are located around the Pribilof Islands and St. Matthew Island. While the St. Matthew Island BKC stock has increased in abundance in recent years after collapsing in the 1990s, the Pribilof Islands stock has remained depressed, with mature male biomass declining from 30,000 t in the late 1970s to a low of 412 t in 2011 (Chilton et al., 2011). Although the mechanisms of the collapse are not known, substantial measures implemented to reduce the impacts of fisheries have not resulted in the rebounding of the stock. As such, it is imperative that other factors such as the role of environmental variability on the distribution, abundance, and interaction of this stock with the St. Matthew BKC stock be assessed before considerable restrictions are placed on coastal communities.

Stock structure of BKCs in the EBS is largely unknown. Population trends are very different between the Pribilof Islands regions and the St. Matthew region, however, there are no apparent barriers to adult dispersal between the regions. Yet they are infrequently taken in NMFS trawl surveys between those islands, suggesting limited post-settlement dispersal as adults. General current structure in the EBS suggests that there may be a possible source-sink relationship between planktonic larvae released in the Pribilof Islands region that could settle in the St. Matthew region, but also potential retention in the area around the Pribilof Islands (Parada et al. 2010). Survey data revealed that the distribution of BKC in the EBS averaged over the past decade stretches from southeast of the Pribilof Islands to northwest of St. Matthew Island with obvious clusters of biomass around the Islands (Fig. 1). Additional data based on observed bycatch during groundfish fisheries suggests that the distribution extends even farther to the southeastern portions of the EBS. The mechanisms or proportion of interactions that occur among these regions is unknown and may be driven by spatially variable environmental conditions such as currents or bottom temperature. Historically the EBS had high year to year variability in temperature. Since 2000, it has entered a period of multiyear variability (2001-2005: warm, 2007-2012: cold). The EBS is influenced by many factors such as flow through the Aleutian passes, variable winds and ice. Currents also differ in warm vs. cold years, with stronger westward flow in cold and weaker westward flow in warm years (Stabeno et al. 2012).

In this project we are working on an existing larval drift individual-based model (IBM) to demonstrate connectivity patterns for blue king crab across the EBS. The IBM is forced with annually varying ROMS hydrodynamic model outputs (Shchepetkin and McWilliams, 2005; Haidvogel et al., 2008) for the Bering Sea.
**Objectives**

1. Determine connectivity between larval release and benthic settlement areas for EBS BKC populations by adapting a biophysical IBM.
2. Determine the likelihood of exchange via larval drift among populations of BKC in different regions of the EBS, from near the Alaska Peninsula, the Pribilof Islands, and St. Matthew Island.

**Accomplishments**

We held meetings in July 2013 to define best practices for generating initial conditions for the BKC IBM, to review the life history (Table 1) of BKC, and to discuss the configuration of the biological model and the parameterization of the IBM. We discussed the selection of a suite of hydrodynamic model years to run the simulations. Coordination and logistic aspects were discussed, such as how to access data and hydrodynamic model runs. Several telephone conference meetings were held in 2013 and early 2014 to discuss the status of the model advances.

An extensive and in-depth search of the literature was conducted to collect antecedents on blue crab life history to provide the rationales and support for parameterization of the simulation model. The search was extended to cover technical reports and unpublished material archives from OCSEAP (Outer Continental Shelf Environmental Assessment Program) projects. A conceptual life history model for the BKC IBM was developed (Table 1 and Figure 2).

An additional benefit of the extensive literature review is the support of two undergraduate thesis projects supported by an NPRB grant under the “data rescue” program. These students are helping to re-enter original data from the 1983-84 Pribilof cruises that had been lost as electronic files. Among tasks that will benefit this FATE program is a GIS analysis of sediment types that will focus on shellhash that has been found to be critical for early benthic juvenile settlement and survival. We anticipate that this will help define spatial extent of larval settlement in areas that promote higher survival around both the Pribilof Islands.

In this project we have been working with an existing IBM of larval drift that was designed for snow crab research in the EBS (Parada et al. 2010, Parada et al. in revision). That model was used to demonstrate connectivity patterns of snow crab across the EBS. The IBM was forced by annually varying ROMS hydrodynamic model output (Shchepetkin and McWilliams, 2005; Haidvogel et al., 2008) for the Bering Sea.

We have finished adapting the snow crab IBM for BKC, including life history characteristics and a new IBM code. The BKC IBM will be run for each of the chosen hydrodynamic model years, between March and late fall. Spatial conditions of larval release (initial conditions, IC) have been explored based on BKC mature female distribution, which allowed us to generate spatially-explicit reproductive potential indices (ICs). Our work on initial conditions is completed. ICs were estimated for the entire available time series (1978-2012), but with emphasis on key years (1999 and 2001) and expressed as female reproductive output by factoring in several components. A spatially-explicit approach used the standard NMFS annual survey grid (20 x 20 nmi quadrants) as a template, with special considerations.
for the “corner stations” around St. Matthew and Pribilof Islands (finer grid of 10 x 10 nmi). We consider the following factors affecting female reproductive output over time and space: (a) female abundance; (b) mean carapace width; (c) size-at-maturity; (d) fecundity-at-size. Results shown in Figure 1 for years 1999 and 2001 indicate that reproductive output is restricted to a handful of stations surrounding St. Matthew and Pribilof Islands.

Gravel and shell hash are considered important refuge habitats for early BKC juveniles, especially during the settlement period. Spatial information on empty gastropod and bivalve shell presence and relative abundance and percentage of gravel were synthetized based on AFSC groundfish survey data and from R. McConnaughy’s Eastern Bering Sea (EBS) sediment database (EBSSED). Data was integrated over time and mapped in GIS layers (Fig 3). This information will be used during the post-processing of IBM model output, to refine our simulated settlement results to include juvenile habitat preferendum (HP).

The EBS spatial discretization is in progress, which will use IC and HP information to spatially discretize the EBS into strata for larval release areas and settlement areas, similar to what was done for snow crab, but modified for blue king crab. Blue king crab larvae will be released in March and April around the Pribilof Islands and St. Matthew Island and in other locations where blue king crab have been observed.

The milestones associated to the design of the conceptual IBM for BKC, derivation of parameters, establishment of initial conditions, conversion of the snow crab IBM to BKC, and the tests of model algorithms are completed.

**Delays**

The milestones associated with performing runs of the IBM have been delayed. The hydrodynamic model run necessary to run the IBM was only received in March 2014. The initial conditions for forcing the model are now completed for the whole time series, which is a key factor to run the IBM. Given that all the pieces of information are now available, the final products should be available for the next meeting on July 21, 2013.
### Table 1. Review of the Life history of Blue King crab and Red King crab

<table>
<thead>
<tr>
<th>Red king crab (Paralitodes camtschaticus)</th>
<th>Blue king crab (Paralithodes platypus)</th>
<th>Refs (BKC only)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Larval stages and duration of pelagic larval life</strong></td>
<td>Four zoea and a glaucothoe; 2 months.</td>
<td>In lab experiments larval survival was not affected by temperature or rearing density, but length of larval life did: 109 d @ 3 °C and 70 d @ 6 °C or 9 °C. In Herendeen Bay (June) larvae always above the thermocline (40 m), concentrating shallower at midnight (10-20 m) and deeper at noon (30-40 m). Estimated larval period was less than two months (temperature 4-7 °C in May to 8-10 °C in June).</td>
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<tr>
<td><strong>Settlement period and juvenile habitat</strong></td>
<td>May-July; nearshore high-relief habitat.</td>
<td>In a lab experiment juveniles were reared at temperatures ranging from 1.5 to 12 °C, showing inverse exponential relationship between water temperature and intermolt period up to 8 °C; little sign of cannibalism in culture (unlike RKC). Beach sand, gravel, shells and cobble were offered to glaucothoe anc C1 in a lab experiment. Glaucothoe began to settle immediately after being released; beach sand was rejected and cobble, shell and gravel were chosen equally. C1 preferred cobble and shell over gravel and beach sand. In Russia young individuals occur in areas where communities are dominated by hard bottom epifauna.</td>
</tr>
<tr>
<td><strong>Growth</strong></td>
<td>Mean sizes at 1, 2 and 3 years post-settlement are 9-16 mm CL, 23-42 mm CL, and 47-66 mm CL, depending on location. Females molt annually prior to mating and egg extrusion. Males molt annually until maturity, and then do not molt every year.</td>
<td>Off W Kamchatka males molt in spring, molting completed in summer. In the Sea of Okhotsk large males molt every two years; mass molting was observed at the end of June and July. Growth rate reduce in males parasitized by rhizocephalans.</td>
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<tr>
<td><strong>Size/age/stage at maturity- Females</strong></td>
<td>Mean size of female maturity: 89 mm CL (Bristol Bay) and 102 mm CL (Kodiak).</td>
<td>50% maturity was 96.3 CL mm in the Pribilos, 80.6 mm in St. Mathew.</td>
</tr>
<tr>
<td><strong>Size/age/stage at maturity- Males</strong></td>
<td>For Kodiak, physiological size at maturity is ~80 mm CL, but functional size of maturity is ~130 mm CL based on studies of mating pairs.</td>
<td>90% of males carry spermatophores at 60-69 mm CL in the Pribilofs, and at 50-50 mm CL in St. Mathews. Morphometric maturity was 108 mm in the Pribilofs, 77 mm in St. Mathew.</td>
</tr>
<tr>
<td><strong>Maximum lifespan and size</strong></td>
<td>&gt;20 years, based on a captive specimen in Japan.</td>
<td>Max size smaller at Bering Strait (males: 145 mm, fems: 130 mm, CL), N end of range, compared to EBS.</td>
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<tr>
<td></td>
<td><strong>Red king crab (Paralitodes camtschaticus)</strong></td>
<td><strong>Blue king crab (Paralithodes platypus)</strong></td>
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<tr>
<td><strong>Spawning, brooding and hatching</strong></td>
<td>Egg hatching occurs in spring (March-May) followed immediately by mating, egg extrusion, and fertilization</td>
<td>Mating and egg extrusion occur in late March to early May (late winter according to Stevens, 2006a). Eggs hatch in mid April to mid May of following year. In the laboratory hatching started in mid February, and lasted ca. 1 month for individual spawners.</td>
</tr>
<tr>
<td><strong>Duration of reproductive cycle</strong></td>
<td>Embryos are brooded for 207-305 days, depending on temperature.</td>
<td>Biennial cycle due to slow ovarian growth in large, multiparous females; smaller primiparous females often able to spawn in two consecutive years. Embryo development period has been estimated at 12 months (Jensen and Armstrong, 1989), 14-15 months (Somerton and MacIntosh, 1985) and up to 19 months (Sasakawa, 1973a). In a lab experiment hatching was significantly delayed at colder temperatures with about a 46-day difference from 2.3 °C to 6.1 °C. Long-term laboratory holding may impact hatch timing due to differences in ambient temperature and perhaps other suppressed seasonal effects of the artificial environment.</td>
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<tr>
<td><strong>Mating system</strong></td>
<td>In the laboratory, most small (80-89 mm CL) males failed to induce more than one female to ovulate, whereas large (&gt;120 mm CL) males induced ovulation in all four females tested. Among wild mating pairs most (56-61%) males were oldshell or very oldshellb.</td>
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<tr>
<td><strong>Migrations and aggregations</strong></td>
<td>In Russia the young are non-migratory; adult migrations controlled by depth of the CIL. Female blue king crabs tend to aggregate in shallow water for brooding and hatching from spring to summer and are found deeper (130-180 m) during winter months. Male crabs come into nearshore areas for mating in the spring, but are otherwise found in deeper water (120-250 m).</td>
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DEVELOPMENT OF A PREDICTION SYSTEM FOR THE CALIFORNIA CURRENT INTEGRATED ECOSYSTEM ASSESSMENT

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Task III

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NOAA Goal
Resilient Coastal Communities and Economies

Description
JISAO's Seasonal Coastal Ocean Prediction Experiment (J-SCOPE) represents a collaborative project involving scientists at JISAO and NOAA’s Northwest Fisheries Science Center (NWFSC). Quantitative forecasts have begun to be produced of physical, chemical and biological (through lower-trophic levels) ocean properties on time horizons of ~9 months. These forecasts are tailored towards NOAA and other operational stakeholders. They are based on numerical ocean model simulations using a high-resolution (grid spacing ~1.5 km) version of the Regional Ocean Modeling System (ROMS), with a module that predicts the nutrient, plankton, and oxygen distributions. The initial and boundary conditions for the ROMS simulations are being provided by a global coupled atmosphere-ocean model, the Coupled Forecast System (CFS) that is currently being run operationally by NOAA/National Centers for Environmental Prediction (NCEP)/Climate Prediction Center (CPC) for seasonal weather prediction. The focus is on specific properties crucial to the ecosystem, including coastal upwelling, currents and trajectories of water parcels, mixed layer depths, oxygen concentrations, pH, and plankton community types.

Objectives
The marine ecosystem of the Pacific Northwest Coast is subject to large variations in physical forcing. Skillful predictions on time horizons of 6-9 months would be of substantial benefit to managers and coastal communities and appear to be feasible using existing resources and tools. The present project represents a first step towards achieving these predictions on an operational basis.

Accomplishments
1. J-SCOPE forecasts for 2013 were made once a month with the model system.
2. Climate predictions from the CFS global climate model with respect to the regional ocean forcing have been further evaluated; analysis of the 2013 forecasts of the J-SCOPE indicate that it has positive skill in projecting wind and sub-surface temperature anomalies out at least six months into the future, and at least four months in the future for biogeochemistry (Chl, oxygen, and pH).
3. Collaborations with PMEL and NWFSC resulted in products of forecasted pH and sardine habitat. Observations were compared to the model, and metrics of predictability are beginning to take place. A journal article is in the final stages of preparation.
5. JISAO scientist Nicholas Bond presented a review of the forecast system at a PICES Conference in Hawaii in April 2014. JISAO scientist Al Hermann presented this forecast system at the PCC summer
institute in August 2013 and at Ocean Sciences in Hawaii in February 2014. JISAO scientist Samantha Siedlecki presented the forecast system at CERF in November 2013, AGU in December 2013, and at Ocean Sciences in February 2014.

This is the same project as one under the Climate Research and Impacts section entitled, “A Quasi-Operational Prediction System for the Coastal Ocean of the Pacific NW.” Initial funding came separately for the work of Samantha Siedlecki for that project and, therefore, separate budgets were set up. This project fits in the two major themes of Climate Research and Impacts and Marine Ecosystems.

Figure 1: Panels showing (from left to right) bottom oxygen, chlorophyll-a, SST and the 8-day upwelling index from the April forecast of July 2013.
ECOSYSTEMS AND FISHERIES-OCEANOGRAPHY COORDINATED INVESTIGATIONS (ECOFOCI)

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Task II

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NOAA Goals
Healthy Oceans
Climate Adaptation and Mitigation

Description
Ecosystems and Fisheries-Oceanography Coordinated Investigations (EcoFOCI) is a collaborative research effort among oceanographers, atmospheric scientists, chemists, and fisheries biologists from JISAO, NOAA’s Pacific Marine Environmental Laboratory, and the Alaska Fisheries Science Center. EcoFOCI’s mission is to understand the dynamic relationships among climate, fisheries, and the marine environment to ensure sustainability of Alaskan living marine resources and healthy ecosystems.

Investigations into the ecosystem impacts of fluctuations in temperature and salinity, sea-ice extent, atmospheric forcing, tides, freshwater influx, productivity, and mixed-layer depth are on-going in the Gulf of Alaska, Aleutian Islands, Bering Sea, and Chukchi Sea. The timescales of interest range from short-term episodic and seasonal events to long-term annual and decadal trends. EcoFOCI incorporates field, laboratory, and modeling approaches to determine how varying physical and biological factors influence these large marine ecosystems.

Objectives
1. Monitoring of the oceanographic ecosystem through analysis and processing of data from the North Pacific mooring array, satellite tracked drifters, and shipboard measurements – biophysical moorings are maintained in 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 zooplankton abundance 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 and Bering Sea ecosystems – JISAO scientists take a leading role in studies of North Pacific ecosystems. They participate on cruises as chief scientists, and are leaders in the measurements of nutrients, chlorophyll, and oxygen.

4. Projecting impacts of climate change – JISAO scientists are involved in an effort to apply simulations of future climate (IPCC AR4 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 continued to maintain the biophysical mooring array on the eastern Bering Sea shelf (M2, M4, M5, M8), conduct hydrographic surveys, and deploy satellite-tracked drifters. 2014 will mark the 20th consecutive year of observations at the M2 mooring.

2. EcoFOCI's Arctic Ocean observing system – The Chukchi Acoustics, Oceanography, and Zooplankton (CHAOZ) program incorporates biophysical moorings, hydrographic measurements, and numerical climate models to examine the changing ecosystem of the Chukchi Sea where future offshore oil development activities may occur. EcoFOCI contributes to the evaluation of how annual variability in environmental conditions such as sea ice, oceanic currents, water temperature and salinity, and prey abundance influence whale distribution and relative abundance. The field component of this study is complete, and the analysis and writing phase continues.

3. The Arctic Whale Ecology Study (ARCWEST) completed its first field year in 2013. This program continues much of the work performed by the CHAOZ project, and is also Bureau of Ocean Energy Management (BOEM)-supported. EcoFOCI conducts physical and biological oceanographic sampling 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 Arch area. Mooring sites from the CHAOZ program are also used for ARCWEST. EcoFOCI maintains three nearshore biophysical moorings as part of this project (C1, C4, and C5) and performs hydrographic sampling. Twelve satellite-tracked drifters were deployed in 2013, and several are still transmitting locations. Drifter tracks can be viewed here: [www.ecofoci.noaa.gov/efoci_drifters.shtml](http://www.ecofoci.noaa.gov/efoci_drifters.shtml).

4. CHAOZ-X – This BOEM-supported program is an extension of the CHAOZ program in the Hanna Shoal area of the northeast Chukchi Sea. The first field year for CHAOZ-X was in 2013. 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 maintains five biophysical moorings as part of this project (C2, C6, C7, C8, and C9) and performs hydrographic sampling.

5. Bering Sea Project – The Bering Sea Open Science Meeting was held in Honolulu, Hawai‘i February 22-23, 2014. EcoFOCI scientists presented results and synthesis of the Bering Sea Project studies. JISAO scientists Cheng, Hermann, Kachel, and Mordy presented at the meeting.

6. BEST Synthesis Project – An NSF grant was awarded to JISAO PI Mordy to develop a synthesis of research that resulted from the BEST-BSIERP program (Bering Ecosystem Study - Bering Sea Integrated Ecosystem Research Program). JISAO scientists Kachel, Hermann, and Bond are also contributors. The BEST Synthesis continues to examine the impact of sea ice on the distribution and abundance of zooplankton, and how they are partitioned among top predators. To this end, new and historical data are being used to test a series of hypotheses and answer questions relating to bottom-up and top-down control of large crustacean zooplankton and their impact on the flow of carbon and energy in the ecosystem. From the examination of these hypotheses, new mechanisms will be derived and old ones re-evaluated. Existing numerical models will be used to assess the relative importance of these mechanisms. Existing conceptual models will be tested, and new conceptual models of carbon and energy flow will be developed. This synthesis is a multi-disciplinary (climate to predators) collaboration among academic institutions, government (NOAA), and two countries.

7. Gulf of Alaska Integrated Ecosystem Research Program – The EcoFOCI program is part of a major multi-institution project in the Gulf of Alaska funded by the North Pacific Research Board (NPRB). EcoFOCI's role in the Gulf of Alaska Integrated Ecosystem Research Program
(GOA IERP http://gulfofalaska.nprb.org/) is 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). JISAO scientists are playing a major role in this effort. The specific objectives are to determine: (1) the timing and magnitude of the different cross-shelf exchange mechanisms, using an extensive suite of oceanographic (i.e., moorings, drifters, cruises) and atmospheric measurements; (2) how these physical mechanisms influence the distribution, timing, and magnitude of phytoplankton productivity; and (3) how both transport and primary productivity control the distribution, productivity, and fate of both zooplankton and ichthyoplankton. New observations will be supported by retrospective studies using previously collected data from these regions, in some cases extending the team’s horizon back as much as 30 years. The field years for this project were 2011 and 2013. The program held a PI meeting in Seattle March 25-28, 2014.

8. Synthesis of Arctic Research (SOAR) – SOAR is a 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. This five-year program began in May 2011, and is led by Phyllis Stabeno (NOAA/PMEL) and Sue Moore (NOAA/ST7). JISAO scientist Guy is program coordinator, and Sullivan and Mordy are also contributors. A special issue in Progress in Oceanography is in progress and we expect to have 12 synthesis articles. More details of the SOAR project, including products and participants, can be found on the website at www.arctic.noaa.gov/soar/.

9. EcoFOCI scientists continued 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 current Bering Sea Report Card and related information can be found here: http://access.afsc.noaa.gov/reem/ecoweb/Index.cfm.

10. Arctic – The Arctic Climate change program
DEFINING ECO-REGIONS AND APPLYING SPATIAL ANALYSES OF SPECIES ABUNDANCE, COMMUNITY DYNAMICS AND STOCK SUBSTRUCTURE TO INCORPORATE HABITAT IN SSMS AND MSMS

PI
Trevor A. Branch — UW School of Aquatic and Fishery Sciences

Other UW Personnel
Matt Baker and Kirstin Holsman — School of Aquatic and Fishery Sciences

Task III

NOAA Sponsor
Anne Hollowed — Alaska Fisheries Science Center

NOAA Goal
Healthy Oceans

Description
This research will provide an analytical method to define boundaries of fish habitats in space and time, and integrate knowledge of habitat associations as a means to measure multispecies interactions in multispecies assessments (MSMs) of Gulf of Alaska (GOA) and Bering Sea (BS) stocks. This research integrates habitat considerations into existing MSM and single species models (SSMs) to improve estimation of fishing mortality targets, given multispecies interactions and stock substructure. Habitat is a continuum defined by multiple variables and defining discrete habitat types is a challenge. Understanding how habitat volume influences species interactions is critical to simulate effects of fishing and climate on species abundance and ecosystem structure, and to better evaluate species and system resilience to exploitation.

Objectives
1. Develop a protocol to incorporate habitat-specific data into stock assessments.
   a. Apply random forest methods to determine threshold responses and assess the importance of physical variables on species distributions.
   b. Quantify multi-species turnover along environmental gradients and partition systems into coherent spatial units as per biological community response to physical habitat.
   c. Evaluate dynamic physical forcing on the stability of eco-region boundaries.

2. Enhance MSMs for BS by distinguishing predation dynamics in distinct habitats.
   a. Incorporate temporal trends in habitat volume into MSMs to evaluate influence on predator-prey interactions. Specifically, MSM predation mortality is a function of temperature, predator biomass, and vulnerable prey biomass (V); analyses weight V as a function of changes in habitat to evaluate effects on predation dynamics.

3. Delineate stock sub-structure via spatial autocorrelation in abundance.
   a. Apply cluster analyses to times series of annual abundance to define spatially explicit sub-stocks and determine how stock substructure alters stock-recruitment models.
   b. Add an index of positive recruitment (biomass-weighted error) based on spatial stock structure to account for distinct temperature regimes for distinct sub-stocks.

4. Develop multi species autoregressive state-space models (MARSS) to distinguish density dependence and inter-species compensation.
   a. Apply multivariate autoregressive state space models to analyze population dynamics as an integrated response to multiple concurrent drivers and feedbacks and partition the effects of density dependence, compensatory, and environmental mechanisms.

Accomplishments
1. Compiled and analyzed data sources from NOAA trawl survey databases, fisheries observer data, stock assessments, and environmental indices.
2. Applied random forest methods to quantify threshold responses in individual species to environmental variables (marginal effect of each individual variable, accounting for the combined effects of all influencing environmental variables) and determined variable importance as a means to classify species by response to environmental forcing.

3. Integrated random forest outputs across multiple species, synthesizing goodness-of-fit and predictor importance metrics to estimate turnover in community composition along environmental gradients as a means to identify distinct ecological regions in the GOA.

4. Applied dynamic factor analysis (linear combinations of hidden random walks) to identify underlying trends in abundance for species in functional guilds, determine factor loadings, and correlate to environmental indices. Contrasted trends in the EBS (distinct trends among functional guilds according to benthic versus pelagic pathways), GOA (distinct trends in functional guilds according to upper and lower trophic levels), and AI systems (evidence for alternating top down and bottom up forcing).

5. Collaborated with NOAA scientists in the Status of Stocks and Multispecies Assessment and Resource Ecology and Ecosystem Modeling divisions to refine multispecies (Walleye pollock, Pacific cod, Pacific halibut, Arrowtooth flounder) stock assessment models to inform predatory and competitive interaction terms based on estimated spatial overlap and random forest outputs on environmental threshold responses. Continued efforts to characterize threshold responses according to age-class within these dominant nodal species based on available data.

6. Developed lag-one MARSS to facilitate analyses of the relative influence of species-specific density dependence, inter-species compensation, climate indices, and fishery extraction in productivity trends.

7. Presented research on spatial distribution and MARSS at the annual conference of the International Council of the Exploration of the Sea (ICES) in Reykjavik Iceland, September 2013.

8. Presented research on community-level responses to environmental thresholds to define biogeographic regions, and on underlying trends in functional guilds extracted via dynamic factor analyses at the annual conference of ICES in Reykjavik Iceland, September 2013.

LINKS BETWEEN THE EARLY LIFE HISTORY DYNAMICS OF FISH SPECIES AND CLIMATE/OCEAN CONDITIONS IN THE GULF OF ALASKA

PI
Miriam Doyle — UW Joint Institute for the Study of the Atmosphere and Ocean

Other UW Personnel
Nicholas Bond and Albert Hermann — Joint Institute for the Study of the Atmosphere and Ocean

NOAA Personnel
Kathryn Mier — Alaska Fisheries Science Center

Task II

NOAA Sponsor
Jeffrey Napp — Alaska Fisheries Science Center

NOAA Goals
Healthy Oceans
Climate Adaptation and Mitigation

Description
This research is being carried out in conjunction with the NOAA Alaska Fisheries Science Center’s (AFSC) Recruitment Processes and EcoFOCI Groups. Early life history aspects of recruitment processes among Gulf of Alaska (GOA) fish species are being investigated. Data are from ongoing (since 1972) collections of ichthyoplankton samples and associated oceanographic and climate measurements in this region. Ichthyoplankton surveys that sample the early ontogeny pelagic phase (eggs/larvae) of fish integrate information on a diverse range of species with variable adult habitats and ecologies. Synthesis of these ichthyoplankton and associated environmental data are being carried out in order to understand species pelagic exposure patterns and response outcome during early ontogeny. The research is contributing to a mechanistic understanding of environmental forcing on early life history aspects of recruitment processes among marine fish species.

Objectives
Project 1 — Gulf of Alaska late spring ichthyoplankton time-series and associated environmental forcing variables. Continue development of this time-series by calculating the late spring indices of species abundance from the designated study area for all available recent years, and provide update for NOAA reports and publications. Match the new extension of the ichthyoplankton time-series with further compilation of time-series of environmental forcing variables.

Project 2 — Participate in the NPRB-sponsored Gulf of Alaska Integrated Ecosystem Research Program (GOAIERP). As part of the Retrospective component of GOAIERP, develop the synthesis of historical GOA ichthyoplankton data into a comprehensive review of the early life history of the GOAIERP focus species; Walleye pollock, Pacific cod, Pacific ocean perch, Sablefish, and Arrowtooth flounder. Collaborate with other GOAIERP Principal Investigators in integrating this early life history synthesis into different components of the project. Represent SFSC’s Recruitment Processes program in cruise planning and ichthyoplankton sample design, field logistics, and data analyses and dissemination for the 2013 field season.

Project 3 — Conceptual framework for evaluating early ontogeny aspects of recruitment dynamics among GOA fish species – Early life history phenologies (timing). Continue synthesis of multispecies patterns in the historical ichthyoplankton data, and species life history and ecological traits, to identify coherent patterns that may help us to identify species’ early life history responses to environmental forcing. Further to Doyle and Mier (2012), investigate the distribution of species along the primary phenology gradient, and relationships between timing of sub-intervals of early life among species and seasonal patterns in the physical and biological environment.

Accomplishments
Project 1 — Late spring larval fish abundance data have been accumulated annually in the Gulf of Alaska
through 2011, and from 2013 are being collected on an alternate year schedule. Species abundance indices have been calculated from the designated study area for all available recent years, extending the time-series from 1981 through 2011. The ichthyoplankton species abundance time-series through 2011 is described and interpreted in the 2013 Ecosystem Considerations report to the North Pacific Fisheries Management Council (Doyle and Mier, 2013). Time-series data pertaining to the GOAIERP focal species are incorporated into the retrospective analysis of ichthyoplankton data for this research (Doyle and Mier, submitted). Time-series of physical variables to match the larval fish abundance time-series continue to be updated in conjunction with scientists from the EcoFOCI research program at NOAA’s Pacific Marine Environmental Laboratory.

Project 2 — Synthesis of historical GOA ichthyoplankton data for the Retrospective component of the NPRB-sponsored GOAIERP program has been completed and incorporated into a paper that provides a comprehensive review of the early life history of the focal species (Doyle and Mier, submitted). The observed patterns are discussed with respect to characterizing species early life history strategies, identifying long term adaptations to the GOA environment, and associated resilience and vulnerability factors that may modulate early life history response to environmental forcing. This synthesis has contributed to the development of Individual Based Models for each species by the Modeling component of GOAIERP, and provides a comparative framework for interpreting the results of the 2010-2013 ichthyoplankton sampling. The early life history pelagic exposure profiles are also being utilized in the construction of a new Conceptual Model for the GOA ecosystem by Doyle and other GOAIERP project principal investigators.

Project 3 — The Conceptual Framework for evaluating early ontogeny aspects of recruitment processes among GOA fish species (Doyle and Mier, 2012) has led to some new research for developing a mechanistic understanding of early life history responses to environmental forcing. Specifically for this year, phenological patterns have been described for species early life history phases (e.g. Fig. 1), and relationships between timing of these phases and annual cycles in the physical and biological environment of the GOA continue to be investigated (Doyle et al., in prep.). This diversity of early life history phenologies represents trade-offs in species adaptations to prevailing environmental conditions in the GOA, especially with respect to synchrony of early ontogeny with suitable conditions (e.g. temperature, transport processes, and prey availability) for successful growth and survival. Vulnerability and resilience factors associated with these different phenologies may modulate species’ responses to environmental variability. Such ecological similarities in early life history patterns have been linked to recruitment synchrony among species (Stachura et al., in press).
**Figure 1.** Early life history phenologies: Seasonal variation by month (no sampling in December) in occurrence and relative abundance of the numerically dominant species of fish larvae in historical ichthyoplankton samples from the western Gulf of Alaska, and their association with different pelagic habitats.

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<tr>
<th>Species</th>
<th>Common Name</th>
<th>Habitat</th>
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**Level of abundance:**
- Lowest
- Moderate
- Highest
- Absent

**Primary larval habitat:**
- Inner Shelf
- Shelf
- Slope and Deeper

* Larvae associated with the neuston
JISAO R/V CENTENNIAL SHIP TIME WITH NWFSC

PI
David Duggins — Friday Harbor Laboratories

Other Personnel
Marc Lammers — Oceanwide Science Institute

Task III

NOAA Sponsor
M. Bradley Hanson — NMFS/Northwest Fisheries Science Center

NOAA Goal
Healthy Oceans

Description
This award was used for ship time in order to recover and redeploy passive acoustic recorder moorings on the Washington coast.

Objectives
Our objective was to obtain Southern resident killer whales (SRKW) acoustic detections to assess seasonal movements and distribution. Acoustic recorders provided a unique, long-term dataset that will be important to inform future consideration of Critical Habitat designation for this U.S. Endangered Species Act listed species.

Accomplishments
The recorders were successfully recovered and redeployed. These efforts will allow us to build a more robust database needed by managers to consider designating SRKW Critical Habitat along the West Coast.
FISH ASSESSMENT IN ACOUSTIC DEAD ZONE

PI
David Duggins — Friday Harbor Laboratories

NOAA Personnel
Kresimir Williams, Chris Rooper, and Alex De Robertis — AFSC RACE Division
Vanessa Tuttle — NWFSC FRAM Division

Task III

NOAA Sponsor
Chris Wilson — AFSC RACE Division

NOAA Goal
Healthy Oceans

Description
A stereo camera system was configured with different underwater lighting setups to assess fish responses to the presence of the camera in the Acoustic Dead zone (0-1.5 m off the sea floor). Deployments consisted of 10 minutes of visual contact of the camera with the sea floor at a velocity of 1-2 knots speed over ground. Six specialized cameras designed to trigger in the presence of fish were also deployed and left on the sea floor for up to 6 hours. Position and acoustic data at 38 and 120 kHz were collected throughout the cruise period.

Objectives
1. Assess fish response to camera system at strobed red LED (660 nm), strobed white LED, and constant white (halogen/led combo) lighting configurations.
2. Test TrigCam device for suitability of detecting fish in the acoustic dead zone (bottom – 2 m off bottom).
3. Develop protocols for effective deployment and retrieval of TrigCams using commercial crab fishing equipment.

Accomplishments
1. Forty-three stereo-camera drops were conducted resulting in 33 usable transects for comparison of lighting effects. Transects conducted with red strobe lights (outside the visible range of rockfish) found significantly higher densities of small rockfish than white strobe lights or constant white lights. For larger species of rockfish there was no significant effect of lighting on fish density. Rockfish behavioral responses measured by the height of fish off the seafloor with distance were also lowest for the red strobe light transects (although not significantly different than white strobe light effects). The height off the seafloor decreased as the drop camera approached for all treatments for both small and large rockfishes. Small rockfishes exhibited stronger responses to light treatments both in terms of density and behavior, while large rockfishes were less sensitive to any of the light treatments.

2. TrigCams were deployed 12 times in open water, with only two of six units functioning properly. Successful tests were conducted at the Friday Harbor Lab docks.

3. TrigCam deployment methods were successfully tested, with deployment and retrieval times of ~10 min in 70 m of water. Gear handling specifics...
determined include optimal boat positioning during approach and retrieval, line handling for retrieval, and float rigging for TrigCam units.

**Reasons Why Objectives Not Met**
Acoustic dead zone assessment was limited by the availability of rockfish school types that are visible in both acoustic data and in the cameras. TrigCam performance was limited by having only two operational units. Despite these limitations, successful information for future work was collected.

![Figure 3. Upper image shows the TrigCam Camera mounted on sacrificial deployment base. Example images from test deployments in Puget Sound.](image)

![Figure 2. density of small rockfish as counted by cameras using red LED strobos (RS), white LED strobos (WS) and continuous white (CW) lighting (LED/Halogen combination).](chart)

p = 0.005
IMPROVING ECOSYSTEM-BASED STOCK ASSESSMENT AND FORECASTING BY USING A HIERARCHICAL APPROACH TO LINK FISH PRODUCTIVITY TO ENVIRONMENTAL DRIVERS

PI
Timothy Essington — UW School of Aquatic and Fishery Sciences

Other UW Personnel
Nathan Mantua, Trevor Branch, Megan Stachura, and Christine Stawitz — School of Aquatic and Fishery Sciences

NOAA Personnel
Paul Spencer — Alaska Fisheries Science Center
Melissa Haltuch — Northwest Fisheries Science Center

Task III

NOAA Sponsor
Anne Hollowed — Alaska Fisheries Science Center

NOAA Goals
Healthy Oceans
Climate Adaptation and Mitigation

Description
A central feature of ecosystem-based fishery management is a broader consideration of environmental influences on stock productivity when assessing populations and setting harvest policies. Insights into environment-stock productivity relationships may be used in short term, tactical advice (e.g. annual catch limits) or in medium to long-term strategic advice that evaluates the long-term effectiveness of proposed harvest strategies in the face of climate change (A’mar et al. 2009). Thus, improved insight into how environmental factors affect stock productivity offers the promise of improved stock assessment and forecasting, especially when it allows for pre-emptive reductions in fishing effort on species likely to be worst affected. The emerging push for including ecosystem-based considerations in fisheries management decisions has therefore resulted in increased demands for information on how ecosystem dynamics affect fished stocks. This project seeks to conduct a synthetic analysis of environmental drivers of fisheries productivity to improve our capability of incorporating these drivers into stock assessments and forecasts.

Research regarding the direct inclusion of environmental information into stock assessments is still developing (Maunder and Watters 2003; Deriso et al. 2008; Schirripa 2009). Moreover, information on environmental links to stock productivity can be used to guide the specification of assessment models. For example, understanding environmentally forced changes in growth over time can be used to specify periods of good and poor growth in assessments. Hollowed et al. (2009) and A’mar et al (2009) demonstrate how long-term climate impacts on fish and fisheries can be predicted from a mechanistic understanding of how fish productivity responds to climate-sensitive environmental variables.

Given the large number of stocks that are presently managed by North Pacific and Pacific Fisheries Management Councils, the challenge of identifying key causative agents underlying production dynamics for each is daunting. This challenge is made even more difficult by the notorious problems that arise when attempting to identify causal relationships from serially autocorrelated time series data (Walters and Collie 1988; Myers 1998). Here we hypothesize that the process of including environmental information in stock assessments and forecasts can be improved by identifying groups of stocks that respond to environmental conditions in the same way. If this hypothesis is true, then the challenge is greatly simplified because instead of linking production to dynamic environmental features for each stock individually, one can predict the average response of groups of stocks that are expected to respond similarly. Therefore, our proposed work seeks to make a significant step forward for stock assessment and forecasting by using advances in numerical statistical methods that permit the estimation of hierarchical ensemble models.
There is considerable support for the notion that groups of stocks may respond to similar sets of environmental conditions. Previous studies revealed that patterns of recruitment variability in marine fishes showed similarities across species (Caddy and Gulland 1983) and these similarities produced recognizable patterns in population variability (Spencer and Collie 1997). In the North Pacific region, the well-known shift in the Pacific Decadal Oscillation transformed the ecosystems of Alaska and Northern California Current by enhancing the productivity of some species and diminishing the productivity of others (Anderson and Piatt 1999; Mantua et al. 1997; Hollowed et al. 2001). Mueter et al. (2007) demonstrated that in the Gulf of Alaska and eastern Bering Sea – Aleutian Islands, gadid and pleuronectid recruitment patterns were inversely related to each other, suggesting that stocks in these groups were responding to a common set of environmental forcing in opposing ways.

We will conduct a Bayesian hierarchical ensemble analysis to evaluate environmental drivers that govern the production dynamics of groundfish stocks in the Aleutian Islands, Gulf of Alaska and Northern California Current. These areas represent distinct ecosystems, and allow contrasts between groups of species that may be influenced by different environmental conditions. The statistical approach is ideally suited to identifying group-level effects of environmental features on populations: these models directly estimate the average effects of environmental drivers for entire groups of stocks (e.g. the average effect of sea surface height (SSH) on recruitment for each group of stocks). These estimation models use information on all stocks simultaneously, resulting in enhanced statistical power and diminished probability of spurious correlations. By proposing a suite of candidate grouping/classification schemes and evaluating model fit for each alternative, we can identify which grouping scheme is best supported by the data. An additional strength of the Bayesian approach is that the resulting output (posterior probability distributions) can be used as an informative prior for data-poor stocks.

**Objectives**

1. Identifying ecologically relevant forcing functions and developing databases that contain time series for each.
2. Collecting recruitment and growth data from target and non-target (likely growth only) fisheries data as time series and developing a database structure to house these data.
3. Identifying candidate grouping structures for species i.e., what attributes of species might predispose them to respond to environmental forcing in similar ways?
4. Running Bayesian hierarchical models under alternative grouping structures to estimate the effects of environmental variables on productivity, and to test which group structure is best supported by the data.

**Accomplishments**

Our work on recruitment dynamics is completed and was published in Fisheries Oceanography. This work (Stachura et al.) was included in the “highlights” list for the March 18, 2014 NOAA Scientific Publications Report. This paper reported on our attempts to test the hypothesis that recruitment synchrony could be explained by shared sensitivity to a common set of environmental drivers. Our conclusions on this hypothesis were mixed. In the eastern Bering Sea and California Current, there was fairly large statistical support for our models in which we group stocks based on prior judgments about key processes dictating recruitment, while there was marginal support in the Gulf of Alaska. In all ecosystems, the ability to link recruitment of groups to specific sets of environmental conditions varied among groups – some groups showed strong associations with environmental conditions, and others showed no association. We suggest that a main limitation was detailed knowledge of early life history processes.

We have nearly finished the analysis of growth rate patterns in Alaska and California Current groundfish, and it is part of Christine Stawitz’ MS thesis. Stawitz, who joined the project in June 2012, has developed a novel method of evaluating trends in fish growth rates from size-at-age data that permits comparison across stocks, and allows for explicit consideration of errors-in-measurement that are common. Importantly, she finds that the most common form of growth rate variability are "annual" growth deviations, whereby there are systematic departures from typical growth rate felt by individuals of all ages in a given year. She has a draft manuscript prepared, and is editing it before submission for publication.
Reasons Objectives Not Met
We are slightly behind our initial timetable because of difficulties in recruiting a graduate student to the position. However, we benefited from adding Megan Stachura to the project in an unofficial capacity, and Stawitz as a funded graduate student. We are on track to complete the final manuscript by June 2014.
FISH PRODUCTIVITY AND FISHING IMPACTS COMPARED ACROSS A RANGE OF MARINE ECOSYSTEMS

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Task III

NOAA Sponsor
Anne Hollowed — National Marine Fisheries Service/Alaska Fisheries Science Center

NOAA Goal
Healthy Oceans

Description
To determine how fishing affects the productivity of fish stocks and ecosystems as a whole by investigating: (a) mean ecosystem trophic level changes according to catch, survey and stock assessment data, and whether the trophic level of catch reflects changes in the ecosystem; (b) shifts in community structure from trawl surveys; and (c) the extent to which environmental changes or fishing impacts drive productivity. This project provides a comparative analysis across ecosystems, with the key tools being databases on catch, trawl surveys and fisheries stock assessments in four U.S. ecosystems: the NE U.S. Continental Shelf, the California Current, the Gulf of Alaska, and the Eastern Bering Sea.

Objectives
1. Compare shifts in mean trophic level in surveys, stock assessments and catch.
2. Evaluate the correlation between species, trophic levels, and functional groups and productivity over time. Analyses will investigate:
   a. Temporal trends and variability in productivity of individual stocks, as well as production for the ecosystem as a whole.
   b. The correlation structure of surplus production, either by species, trophic levels, or functional group (pelagic/demersals).
   c. Variability in productivity within and among species and functional groups for the four focal ecosystems, as well as productivity summed over all stocks within an ecosystem.
3. Assess extent to which environmental changes or impacts of fishing drive productivity. Analyses will evaluate:
   a. Environmental impacts on productivity.
   b. The extent to which productivity has been driven by abundance, environmental regime changes, or random fluctuations.
   c. The extent to which productivity is explained by changes in abundance, environmental regime shifts, or a mixed model for each unit of analysis (e.g. stock, trophic level or functional group).
   d. The correlation in breakpoints across species or groups for significant regime shifts.
   e. Correlations between productivity units of analysis (i.e. determine whether fishing pressure causes productivity to shift from demersal stocks to pelagic stocks or from high trophic levels to low trophic levels).
   f. Evidence for ecosystem-wide changes in productivity (i.e. determine whether productivity is impacted by fishing, and whether surplus production of fisheries responds to increasing fishing pressure).

Accomplishments
1. Compiled and analyzed data sources databases within the California Current (CC) and updated data in the eastern Bering Sea (EBS), Gulf of Alaska (GOA), and Aleutian Islands (AI) related to NOAA trawl survey data and environmental indices.
2. Characterized trends in biomass for individual species and aggregate functional guilds in the CC system.
3. Developed correlation matrices of species abundance trends within functional guilds.
4. Developed maps of integrated abundance and coefficient of variation in abundance of species over time series data in the EBS, GOA, AI, and CC systems to distinguish core habitats and use of marginal habitat in response to species density.

5. Applied random forest methods to quantify threshold responses in individual species to a range of environmental variables (marginal effect of each variable in isolation) and determined variable importance measures as a means to classify species by common response to environmental forcing. Contrasted results for similar species across systems.

6. Collaborated with NOAA scientists developing predictive multispecies (Walleye pollock, Pacific cod, Pacific halibut, Arrowtooth flounder) stock assessment models to inform predatory and competitive interaction terms based on estimated spatial overlap and random forest outputs on environmental threshold responses. Continued efforts to characterize these effects by age within these dominant nodal species.


8. Developed analyses exploring why systems varied in response to outside drivers such that dynamics in the EBS reflected distinctions according to benthic and pelagic pathways, dynamics in the GOA reflected distinctions according to upper and trophic level dynamics and the AI reflected alternating top down and bottom up control.

9. Developed lag-one multispecies autoregressive models to facilitate analyses of the relative influence of species-specific density dependence, inter-species compensation, climate indices, and fishery extraction in productivity trends.


11. Presented research on gradient forest outputs, delineating distinct biogeographic divisions within and underlying trends in functional guilds in the EBS, GOA, AI extracted via dynamic factor analyses at the annual conference of the International Council of the Exploration of the Sea in Reykjavik Iceland, September 2013.


13. Published manuscript in the second special edition of Deep Sea Research II on the delineation of distinct ecological regions to inform spatial management in the EBS.

14. Developed draft manuscripts developed on species distributions, trends in shifts in abundance and the influence of underlying trends driving system dynamics in the EBS, GOA, AI and CC.
FORECASTING WALLEYE POLLOCK RECRUITMENT IN A BAYESIAN FRAMEWORK

PI
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Task III

NOAA Sponsor
Jeffrey Napp — Alaska Fisheries Science Center

NOAA Goal
Healthy Oceans

Description
A two-year project is proposed to design, implement, and evaluate a life-stage recruitment forecast model for Gulf of Alaska walleye pollock (Theragra chalcogramma). The objective of this research is to develop a stage-based mortality model that predicts abundance of age-2 pollock in the Gulf of Alaska, and to quantify uncertainty in forecasts of age-2 pollock abundance. The parameters of the model will be estimated using a Bayesian statistical framework. Posterior distributions for model parameters will be used to determine the probability associated with forecasts of future recruitment. A system of state equations that incorporate explicit descriptions of the progression through egg, early larvae, late larvae, juvenile and age-1 stages will be produced using the EcoFOCI’s conceptual pollock survival or “switch” model. Life-stage equations will be related to biotic and environmental covariates, incorporating errors through a Bayesian formulation. Dynamic features of the life-stage recruitment model will be retained through stage-specific survivorship parameters that link life stages. Observation equations will relate the predicted states to measured quantities in the data set. Posterior predictive distributions will be used to evaluate model fit. Model results, which can be presented as relationships between abundance, spawning success, and climatic conditions, will be explored.

Accomplishments
There is no progress to report, as a candidate has not been identified to complete the project.
NWFSC ACOUSTIC SURVEY SUPPORT

PI
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Task II

NOAA Sponsor
Lawrence C. Hufnagle — Northwest Fisheries Science Center

NOAA Goal
Healthy Oceans

Description
This project will partially support a faculty position at the UW School of Aquatic and Fishery Sciences (SAFS). Activities will include research, supervision of graduate students, and service. Research activities will examine the ecology and acoustic backscatter properties of northwest Pacific fish species, develop analytic and visualization tools to increase the understanding of using sound to census fish populations, and investigate equipment and methods used to acoustically enumerate, size, and map aquatic organism density distributions. Ongoing projects include examining forage fish distributions in the Bering Sea and Gulf of Alaska, the use of multifrequency acoustics to discriminate fish and invertebrate species, and the application of acoustic technologies to ocean observatories and marine renewable energy projects. Supervision of graduate students will include those employed by RACE and REFM divisions at the Alaska Fisheries Science Center (AFSC). Service activities will include fostering collaboration between the SAFS and the AFSC, organizing and administering the SAFS-AFSC summer internship program, acoustic training of students and government scientists, participation in academic committees at the SAFS, and consultation and participation in Midwater Assessment and Conservation Engineering (MACE) research programs and activities.

Accomplishments
There is no progress to report, as the candidate was hired at the end of the reporting period.
The primary goal of this project is to produce an annotated checklist of the marine macroinvertebrates of Alaska. The Alaska Fisheries Science Center (AFSC) has conducted annual bottom-trawl surveys of the Alaska continental shelf and upper slope since 1975. These surveys are the most comprehensive of their kind, conducted across the continental shelf and upper slope, and are well established for the management of commercially significant fishes and crabs. The potential for using these surveys as indices of invertebrate distribution and abundance is also immense. Yet, while invertebrates have generally been identified to the species level during these surveys, the quality of invertebrate identifications, with the exception of commercially important crabs and shrimps, has been suspect and inconsistent through the years, in part because of the lack of a consistent reference to the complex nomenclature and known distribution of invertebrates. With the availability of recent field guides, gaps in our knowledge are increasingly evident.

This project entails the preparation of an annotated checklist of the marine macroinvertebrates of Alaska, and the evaluation of the historical bottom-trawl survey database. Collaborators will participate in surveys for the observation and collection of data and photographs of specimens at sea, examine significant specimens from historical collections in national museums, survey taxonomic and other biological literature, and publish an annotated checklist of the marine macroinvertebrates of Alaska. With these comprehensive data at hand, we will conduct a retrospective analysis of the bottom-trawl survey database to assess levels of confidence for each invertebrate species over survey years.

Objectives
1. Produce a comprehensive annotated checklist of Alaskan invertebrates to be submitted for publication in NOAA Professional Papers, a series available digitally over the internet with a worldwide print distribution.
2. Publish the results of the AFSC survey database assessment in the local Technical Memorandum series, also freely available over the internet.
3. Incorporate synthesized results of this analysis into research publications planned for the primary literature.

Accomplishments
1. The checklist passed through AFSC internal review with only minor suggestions. It was then submitted for publication on August 12, 2013 to NOAA Professional Papers by senior author David T. Drum, and is currently undergoing peer-review. The manuscript, with authorship and title as follows, includes over 3,500 species, listed by higher classification down to species

The external review process has been delayed for several reasons, the primary problem arising from the sheer size of the manuscript. The editors have had exceptional difficulty finding reviewers willing to evaluate it. Several individuals who promised reviews failed to return them as promised, even after repeated reminders. As of March 11, 2014, responses from a couple of referees had still not been received. In addition, two major events created a delay of three to four months: (1) federal offices were closed in October due to the U.S.-Government shutdown; and (2) the editorial offices of the Honolulu Laboratory, NOAA Fisheries, began a move to a new location in November—packing, moving, unpacking, and organizing offices and laboratories continued over the holiday season and the work was only finished in March. The combined effect of these events has put the process severely behind schedule in sending authors decisions about manuscripts (Bruce C. Mundy, Scientific Editor, personal communication, March 11, 2014). In summary, we are confident that the manuscript will be accepted for publication but, at this point in the process, we cannot say when we will have the final decision.

2. In satisfying Objective 2, we have published or submitted for publication two documents that report the results of the AFSC survey database assessment in the local Technical Memorandum series: the first, which focuses on “Species identification confidence in the Gulf of Alaska and Aleutian Islands groundfish surveys (1980–2011),” was published this year; the second, “Species identification confidence in the Bering Sea slope groundfish surveys (1976–2010),” is currently in review.

3. In satisfying Objective 3, four peer-reviewed papers have been published. Two of these are devoted to descriptions of new taxa discovered while carrying out this work: a new species of crustacean of the apseudid genus Fageapseudes; and a new species of sponge of the geodiid genus Geodia. The third publication describes range extensions and provides notes on the biology of three species of decapod crustaceans, while the fourth provides evidence of genetic divergence in sibling species of deep-sea crangonid shrimps of the genus Argis.
ARCHIVAL AND DISSEMINATION OF SPECIMENS AND DATA FOR THE NORTHEAST PACIFIC OCEAN AND BERING SEA FISH EGGS, LARVAE, AND ADULTS COLLECTED DURING NMFS SURVEYS

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**NOAA Goal**
Healthy Oceans

**Description**
The Alaska Fisheries Science Center (AFSC) RACE Division annually collects ichthyoplankton and adult fishes from Alaska. The National Marine Fisheries Service (NMFS) 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 Ground-fish 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 over 107,000 lots of eggs and larvae collected between 1977–2013. This consolidation of material has made the UWFC the largest repository of early life history stages of fishes in North America. Database records for 107,402 cataloged lots of eggs and larvae (totaling 7,799,288 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 juveniles and adult fishes collected since the 1970s through the Center’s activities. Thousands of lots of adult fishes collected from 1995–2013 have already been transferred to UWFC during recent years. Database records for 52,792 cataloged lots of juveniles and adults (totaling 381,545 individual specimens) are now available on-line 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 Resource Assessment and Conservation Engineering Division, AFSC 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, Washington, to allow for easy and frequent access by the AFSC staff.

2. Transfer all available fish eggs and larvae collected by the RACE Division, AFSC, to the University of Washington, School of Aquatic and Fisheries Science, Fish Collection (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 reporting period (February 27, 2013 through September 24, 2013), the task of curating the early life history (ELH) collections fell to incoming graduate student Alicia Godersky. The last two years have been tumultuous, with massive renovation of our building bringing collection access to a halt for several months, and a high rate of turnover in personnel working with the ELH collection. Alicia has spent most of her time conducting an inventory of the odd-year material left over from the prior year’s transfer of material and in teasing out some difficult locality data. She is working to complete the curation of the material received from the AFSC Ichthyoplankton lab in the fall of 2012, which included approximately 75,505 larval individuals in 4,662 vials, along with 1,918 vials of eggs. The inventory and on-line posting of this material is now well underway, and we will be ready to receive the next transfer of material in the fall of 2013. Despite the disruptions, collections staff have maintained their ability to fulfill numerous outstanding data and cataloging requests from AFSC personnel, as well as from many other outside user groups.

2. During this same period (February 27, 2013 through September 24, 2013), 408 lots of adult fishes, including a total of 1,440 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 (thus fulfilling part of deliverable number 3 listed above; see www.UWFishcollection.org). At the same time, tissues for future DNA studies were taken from 252 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 of tissue samples has now reached 5,021, representing 765 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.

3. During the reporting period (September 21, 2013 through February 24, 2014), graduate student Alicia Godersky worked to complete the curation of the material received from the AFSC Ichthyoplankton lab in the fall of 2012, which included approximately 75,505 larval individuals in 4,662 vials, along with 1,918 vials of eggs. She made great progress in recovering from the many disruptions of the prior two years, with massive renovation of our building bringing collection access to a halt for several months, and a high rate of turnover in personnel working with the ELH
collection. Alicia has almost completely reconciled the inventory of the odd-year material left over from the prior year’s transfer which includes some inconsistent locality data that has stymied her two predecessors. The inventory, cataloging, and online posting of this material is now well underway. We received the next transfer of material in the fall of 2013 and will be processing it this spring. The Early Life History collections staff has maintained their ability to fulfill outstanding data and cataloging requests from AFSC personnel, as well as from other outside user groups.

4. During this same period (September 21, 2013 through February 24, 2014), 305 lots of adult fishes, including a total of 918 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 (thus fulfilling part of deliverable number 3 listed above; see www.UWFishcollection.org). At the same time, tissues for future DNA studies were taken from 157 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 tissue samples has now reached 5,268, representing 795 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.
DEVELOPMENT OF A PACKAGE OF FUNCTIONS TO FACILITATE
THE DEVELOPMENT OF CUSTOM STOCK ASSESSMENT MODELS, INCLUDING SIZE-BASED CRAB MODELS

PI
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Other UW Personnel
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Task III

NOAA Sponsor
James Ianelli — Alaska Fisheries Science Center

NOAA Goals
Healthy Oceans
Resilient Coastal Communities and Economies

Description
General stock assessment models have many benefits, but there are cases in which general models do not have the required structure, and inappropriate or suboptimal assumptions have to be made (i.e. shoehorning the stock into the general model) or a custom model developed. There is also a need to develop models for research so that general models can be improved. In these cases, methods that facilitate the development of models can greatly reduce development time, increasing the productivity of researchers. One such approach is the package system used in the R statistical language. Packages consist of functions developed for previous analyses put together in a consistent format so that they can be used by others. These packages are used by other developers to create new functions. There are several packages developed for fisheries stock assessment, including the Fisheries Library in R (FLR), which is used extensively in Europe. A similar package for AD Model Builder (ADMB) would greatly facilitate the development of custom stock assessment models and methodological research. It would also encourage others to produce and make available their own ADMB packages.

Objectives
1. Develop a consistent format for packages in ADMB.
2. Create, test, and provide functions.
3. Provide examples.
4. Develop a generic assessment package for North Pacific crab stocks.

Accomplishments
1. Dr. Athol Whitten began work on this project in January 2013 and continued work throughout 2013. He has created an online codeshare repository (https://github.com/awhitten/cstar) to facilitate the development of an ADMB-compatible function package for fisheries stock assessment. This repository serves as the online home of the project, and is being utilized by Whitten, Punt, Ianelli, and Mark Maunder of the Inter-American Tropical Tuna Commission to collaborate on the project.

2. The function package under development will eventually be made available as a contributed library to the ADMB software suite (following the similar concept of preinstalled packages for R), and will be called Common Stock Assessment Routines (Cstar). The Cstar package is being developed concurrently with a Generalized Model for Alaskan Crab Stocks (Gmacs), intended for use as a modeling framework for future crab stock assessments for use by the North Pacific Fishery Management Council (NPFMC) Crab Plan team. Gmacs will be the first model developed using the Cstar package, and will thus serve as an example for others. Whitten is collaborating with NOAA crab modellers, including Jack Turnock and William Stockhausen, and with intended end-users at the Alaska Department of Fish and Game to ensure Gmacs is designed with end users in mind. Gmacs is being developed as an online and open-source software tool and is publicly available at https://github.com/awhitten/gmacs. A working pilot version of the model was presented at the January 2014 Crab Modeling Workshop in Anchorage. The modeling framework, and a
document describing the underlying mathematics of the model, were reviewed by the NPFMC Crab Plan Team. The team supported continued development of Gmacs and deliberated upon an extended list of next step tasks for Whitten, who has continued to make progress in that regard. The next version of the model will be presented to the Crab Plan Team in May 2014 in Juneau. That version is being used to develop a working assessment model for Bristol Bay Red King Crab, and will serve as the first comprehensive example of use of Gmacs for tactical assessment.

3. Fishing gear selectivity functions are an integral part of modern fisheries stock assessment modeling. As such, selectivity functions have been among the first types of functions to be developed for the Cstar package. These functions are available online, and are being used as part of the Gmacs modeling framework as an example to others. Other generic functions are now included in the Gmacs framework, and the team is expecting that the open-source nature of the project should soon see others contributing functions to this process.
FORECAST EFFECTS OF OCEAN ACIDIFICATION ON ABUNDANCE OF EASTERN BERING SEA TANNER CRAB AND ALEUTIAN ISLANDS GOLDEN KING CRAB

PI
André Punt — UW School of Aquatic and Fishery Sciences

Task III

NOAA Sponsor
Michael Dalton — Alaska Fisheries Science Center

NOAA Goal
Resilient Coastal Communities and Economies

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 pCO2, 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 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 ocean acidification may have major consequences for these fisheries and how they are managed. Bio-economic models based on a sequence of linked models will be developed for Eastern Bering Sea (EBS) Tanner crab and Aleutian Islands golden king crab. The bio-economic models will be used to evaluate the impact of trends in ocean pH on maximum sustainable yield, maximum economic yield, and trends in catch and abundance under different harvest strategies.

Objectives
EBS Tanner Crab
1. Construct a model which relates pre-recruit mortality and the time to grow from one stage to another given changes in ocean pH to forecast how the proportion of EBS Tanner crab eggs which lead to recruits (at 65 mm carapace width [CW]) will change over time.
2. Develop a population dynamics model for adult EBS Tanner crab. This model will have two options, one in which EBS Tanner crab constitute a single homogeneous biological stock throughout its range, and another in which the dynamics (e.g. growth, fecundity), differ east and west of 170E.
3. Develop a bio-economic model which integrates the population dynamics for EBS snow and Tanner crab, allows for bycatch of Tanner crab due to the fishery for EBS snow crab, and permits growth and mortality of pre-recruit stages to depend on pH.

Golden King Crab
1. Develop a model which relates pre-recruit mortality and the time to grow from one stage to another given changes in ocean pH to forecast how the proportion of Aleutian Islands golden king crab eggs which lead to recruits will change over time.
2. Link this model to an economics model and use it to calculate MSY and MEY over time given different rates and trends in future ocean pH.

Accomplishments
A size-structured population dynamics model which includes post-recruit EBS snow and Tanner crab has been developed. This model can be projected forward under sequences of target fishing mortality rates for the directed fisheries for EBS snow and Tanner crab. The model is spatially structured (three spatial cells divided at 1660W and 580N), and the fishing mortality on EBS snow crab leads to fishing mortality on EBS Tanner crab. The values of the parameters of the population models for the two species are based on fitting them to spatial data on catches, catch length-frequency, survey indices of abundance, survey length-frequency data, and bycatch of EBS Tanner crab in the EBS snow crab fishery.
AN EVALUATION OF MANAGEMENT STRATEGIES FOR IMPLEMENTATION OF ANNUAL CATCH LIMITS FOR ALASKA GROUNDFISH

PI
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Carey McGilliard — 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 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 which 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.

Objectives
1. Develop a multiple-species management strategy evaluation (MSE) by creating an operating model in FORTRAN and linking the operating model to an ADMB-based 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.
2. Conduct flatfish assessments for Alaska flatfish species to provide scientific advice to the NPFMC.

Accomplishments
1. McGilliard continued to develop an MSE that explicitly accounts for uncertainty about parameters that are fixed (assumed to be known with no uncertainty) in many assessments due to an inability of the data to adequately inform estimates of those parameters. The operating model for the MSE includes multiple species and links to an ADMB-based age-structured stock assessment model. The MSE is currently configured to model Alaska groundfish species.
2. McGilliard re-configured previous Gulf of Alaska Dover and flathead sole assessments in Stock Synthesis (SS3) by creating SS3 models to match the dynamics of the previous ADMB-based age-structured assessment models as closely as possible. SS3 is a much more flexible assessment framework than the previously-used ADMB-based framework, allowing for exploration of alternative hypotheses about stock dynamics and the potential addition of more sources of fishery-dependent and fishery-independent data. McGilliard presented this work for review to the GOA Plan Team in September 2013 in Seattle.
3. McGilliard conducted stock assessments and wrote Stock Assessment and Fishery Evaluation (SAFE) reports for Gulf of Alaska Dover and flathead sole to provide formal scientific advice to the NPFMC. Both assessments were deemed “benchmark” assessments, indicating that major overhauls and updates of the assessment models were completed. A number of changes
were applied to the Dover sole assessment to appropriately account for missing strata in the survey data. Both assessments were updated to use a “conditional age-at-length” approach, which uses raw age-at-length data directly in the assessments, informing the estimation of growth parameters. Data weights were re-evaluated using an updated approach to account for correlation in residuals. Many sensitivity analyses were included in the two assessments that could not be explored using the previous assessment framework. McGilliard presented this work for review to the GOA Plan Team in November 2013 in Seattle.

4. McGilliard and 20 graduate students and postdoctoral researchers collaborated as a working group to construct a simulation framework using Stock Synthesis as both an operating and assessment model. The framework is complete and is now available for public use as an R package called “ss3sim.” McGilliard is an author of the package. The working group developed three simulation studies using the R package. One study focused on methods for estimating or specifying natural mortality in assessments when it is thought to vary over time (accepted for publication in ICES Journal of Marine Science). A second study investigated impacts of data quality and quantity on the performance of assessment methods (accepted for publication in ICES Journal of Marine Science). A third study investigated the potential for time-varying processes, such as natural mortality and growth, to cause retrospective patterns in assessments. McGilliard moderated meetings of the working group and guided the development of study design, coded sections of the simulation framework in R, and participated in writing and editing the resulting papers and presentations. All studies were presented at the World Conference on Stock Assessment Methods (WCSAM) in July 2013 in Boston.
INCORPORATING CLIMATE DRIVEN GROWTH VARIABILITY INTO STOCK ASSESSMENT MODELS: A SIMULATION-BASED DECISION TABLE APPROACH

PI
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NOAA Personnel
Vladlena Gertseva — Northwest Fisheries Science Center

Task III

NOAA Sponsor
James Thorson — Northwest Fisheries Science Center

NOAA Goal
Resilient Coastal Communities and Economies

Description
Biological characteristics of managed fishes are likely to vary with time due to environmental variability. Growth of splitnose and yelloweye rockfishes has been previously found to be highly correlated with several productivity indicators in the California Current Ecosystem, and time-series of climate-growth indices have been developed for these two species using otolith band reading techniques. These indices, however, have not been used to inform stock assessments due to a lack of guidance for when and how to incorporate indices of time-varying individual growth into an assessment model. A generic decision table approach will be used to evaluate the effects of incorporating climate-driven time-varying growth into stock assessment models. Values in the decision table will represent management outcomes (i.e., lost yield and the probability of overfishing) and will be generated using simulation modeling, while existing data for splitnose and yelloweye rockfishes will be used to estimate the prior probability of time-varying growth. This simulation-based decision table approach will provide guidance on whether and how to include the environmental indices in future splitnose and yelloweye rockfish assessments. It could also be used generically to help evaluate the utility of including environmental data in stock assessment models.

Objectives
1. Use the Stock Synthesis ‘bootstrap’ simulator to generate data that are similar to those for splitnose and yelloweye rockfish, and evaluate both (a) the ability to correctly identify the presence or absence of an environmental effect on individual growth; and (b) the effect of ignoring an environmental index when present, and estimating an environmental index when absent, upon management quantities of interest, (i.e., the probability of overfishing and lost yield).
2. Apply various methods to include an environmental index in Stock Synthesis to data for splitnose and yelloweye rockfish.
3. Synthesize objectives 1 and 2 to construct a decision table to demonstrate the costs and benefits of estimating an environmental index in the splitnose and yelloweye rockfish assessment models.

Reasons objectives were not met
This project has not started yet because we did not have a suitable Masters student. Two Masters students have been recruited for Punt’s lab, and will start in 2014. One of these students will take on this project in summer 2014.
SARDINE RISK ANALYSIS

PI
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Other UW Personnel
Felipe Hutardo — School of Aquatic and Fishery Sciences

NOAA Personnel
Kevin Hill and Patricia Culver — Southwest Fisheries Science Center

Task III

NOAA Sponsor
Kristen Koch — Southwest Fisheries Science Center

NOAA Goals
Healthy Oceans
Resilient Coastal Communities and Economies

Description
Management advice for the Pacific sardine fishery is based on Overfishing Limit (OFL) and Harvest Guideline (HG) control rules. The parameters of these harvest control rules (HCRs) were originally selected as part of Amendment 8 to the Coastal Pelagic Species (CPS) Fishery Management Plan. A key feature of these control rules was that the proxy for Fish Mortality Sustainable Yield (FMSY) depended on the temperature at Scripps Pier. However, recent research based on updated information on recruitment from stock assessments conducted by the National Marine Fisheries Service suggests that the original relationship between temperature and recruitment no longer holds. Research is ongoing to explore alternative relationships for use in management. The Pacific Fishery Management Council (PFMC) held a workshop during February 2013 to examine possibilities to improve on management strategy concepts and elements currently in use for the Pacific sardine fishery in the PFMC process. As part of that workshop, participants designed a risk assessment projection model that can evaluate the current use of selected HCR parameters with regard to risk in jeopardizing long-term stock productivity, for potential Council decision making in 2013. This project involves conducting the additional analyses which arose from the initial calculations.

Objectives
1. Contribute to a draft set of specifications for how alternative HCRs can be compared in terms of performance measures relevant to the Pacific sardine fishery, including those on which Amendment 8 was based. These specifications will be based on those for the operating model used for Amendment 8 and should outline how a potential environmental index could be utilized for decision making.
2. Update the specifications based on the recommendations of the workshop, and provide them to PFMC Scientific and Statistical Committee at its April 2013 meeting.
3. Code the model and provide results for an initial set of candidate HCRs to the April 2013 Council meeting. The candidate HCRs will be selected during the February 2013 workshop and during subsequent meetings of the Council, CPS Advisory Subpanel and CPS Management Team.
4. Present the results to the Council at its June and September 2013 meetings.
5. Draft a manuscript for publication in the peer-reviewed literature outlining the process and calculations.

Accomplishments
Hurtado and Punt participated in the February 2013 CPS workshop. They presented the draft specifications developed before the workshop, which were modified in response to analyses conducted during the workshop. Hurtado updated the specifications in response to these comments. They were presented to the Scientific and Statistical Committee, the Coastal Pelagic Species Advisory Subpanel and the Coastal Pelagic Species Management Team of the PFMC who provided suggestions for additional performance statistics, as well as additional HCR variants. The updated analyses were presented to the Council and its advisory bodies at subsequent meetings. The work is now complete and Hurtado and Punt are currently writing up the results for submission to a peer-reviewed journal.
INVESTIGATING VALUE OF SPATIALLY EXPLICIT MODELS FOR PELAGIC FISH

PI
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Other UW Personnel
Felipe Hurtado — School of Aquatic and Fishery Sciences

Task III

NOAA Sponsor
Richard Methot — Northwest Fisheries Science Center

NOAA Goal
Resilient Coastal Communities and Economies

Description
A feature of Stock Synthesis that is particularly relevant for assessment of Pacific sardine is its capability to sub-divide the stock into interacting geographic regions. However, the quality and quantity of data needed to calibrate the model in this configuration is not well known. The performance of Stock Synthesis (SS) for Pacific sardine is amenable to investigation through simulation studies that generate hypothetical datasets and evaluate the fidelity with which Stock Synthesis (SS) is able to estimate the characteristics of the hypothetical fish stock from which those data were drawn. Management Strategy Evaluation will therefore be used to test the performance of various configurations of SS, including configurations which include spatial structure. The operating model to be used for the evaluation will be more complicated than any potential SS model configuration (fine spatial and temporal strata from Mexico to Canada, and time-dependent movement probabilities by age). A key focus for the evaluation will be the generation of catch length-frequency and conditional age-at-length data for four major fisheries (Mexico, California, the U.S. Pacific Northwest, and Canada), as well as indices of abundance from the Daily Egg Production Method, an aerial survey from Oregon to the Canadian border, and an acoustic-trawl survey which covers the entire U.S. West Coast. Length-frequency data are available for the latter two indexes. An initial set of simulations to evaluate the performance of various configurations of SS has been conducted, and a paper summarizing the results is currently being drafted by Hurtado and Punt.

Objectives
1. Develop a spatially-structured operating model based on the actual situation for Pacific sardine.
2. Use this operating model to represent a range of situations which capture uncertainty in the spatial structure of the Pacific sardine resource.
3. Use the operating model to generate data and apply SS to estimate biomass and fishing mortality.
4. Summarize the results in terms of measures of bias and precision.

Accomplishments
An operating model has been developed which can represent the Pacific sardine population spatially, and generate the types of data available for assessments of Pacific sardine: catch-length frequency and conditional age-at-length data for four major fisheries (Mexico, California, the U.S. Pacific Northwest, and Canada), as well as indices of abundance from the Daily Egg Production Method, an aerial survey from Oregon to the Canadian border, and an acoustic-trawl survey which covers the entire U.S. West Coast. Length-frequency data are available for the latter two indexes. An initial set of simulations to evaluate the performance of various configurations of SS has been conducted, and a paper summarizing the results is currently being drafted by Hurtado and Punt.
PARTNERSHIP WITH THE NORTHWEST FISHERIES SCIENCE CENTER AND ALASKA FISHERY SCIENCE CENTER TO DEVELOP INCREASED CAPACITY IN THE SCHOOL OF AQUATIC AND FISHERY SCIENCES TO ENHANCE TEACHING AND RESEARCH

PI
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NOAA Personnel
Steve Ignell and John Stein — Alaska Fisheries Science Center

Task III

NOAA Sponsor
Guy Fleischer — RACE Division NMFS/AFSC

NOAA Goal
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 in 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. He ran the Bevan Series for three years inter alia to increase collaboration between SAFS and NOAA. He lectures courses in introductory and advanced R programming, in converting data to scientific graphics in R, and in fisheries population dynamics. Since being hired, Branch has published 28 scientific papers, has been awarded the Ecological Society of America’s 2011 Sustainability Science Award, is a Leopold Leadership Fellow in 2013, and received the Outstanding Researcher award in 2013 from the College of the Environment (CoEnv).

2. Branch is using money from the CoEnv award to support Cole Monnahan, a graduate student who is registered in the Quantitative Ecology and Resource Management (QERM) program. Monnahan recently received his MS, and is now pursuing a PhD under Branch. Monnahan received the prestigious Sea Grant/NMFS population dynamics PhD fellowship, which will 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 are currently under review from this work. His MS committee included Brett McClintock from NOAA’s National Marine Mammal Laboratory. In addition, he coauthored two additional peer-reviewed papers (one with another of Branch’s graduate students, Melissa Muradian) involving simulation testing of the SS stock assessment software developed by NWFSC scientists. Monnahan has also completed a summer project on methods to improve convergence time in Bayesian stock assessments with scientists at NWFSC that will form part of his PhD. In addition to Monnahan and Muradian, Branch has two other grant- or fellowship-supported graduate students: Merrill Rudd and Peter Kuriyama, and an additional student, John Trochta, will start in Fall 2014. All are being trained in stock assessment methods.

3. SAFS hired Christopher M. Anderson as a tenured Associate Professor of Fisheries Economics. Anderson 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 200-level introduction to economics for students primarily interested in the environment and resource use issues. Since being hired, Anderson has published six papers, one of which obtained an honorable mention for Best Paper in Marine Resource Economics in 2012.

4. 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: one SAFS student who transferred with him from the University of Rhode Island, and will graduate in June to become an Assistant Professor of Marine Resource Economics at the Virginia Institute of Marine Science at the College of William and Mary; one Economics PhD student who transferred with him; four advanced Economics PhD students; two first-year Economics PhD students, one of whom won an National Science Foundation Postgraduate Fellowship; and a co-advised QERM student. His students have had significant experiences in Bristol Bay, Alaska; NOAA’s NWFSC; and at The World Bank. He has one new SAFS student entering in fall 2014, with a SAFS fellowship.
WEST COAST GROUNDFISH STOCK ASSESSMENT

PI
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Other UW Personnel
Kotaro Ono and Kelli Johnson — School of Aquatic and Fishery Sciences

Task III

NOAA Sponsor
Michelle McClure — Northwest 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 assessment 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 fisheries 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. Punt developed a framework for conducting a management strategy evaluation (MSE) to compare alternative rebuilding revision rules for use by the Pacific Fishery Management Council (PFMC). The results from the MSE will form part of the basis for Amendment 24 to the Groundfish Management Plan. The MSE has been presented to the Groundfish Management Team (GMT) of the PFMC. This framework is currently being applied to three U.S. West Coast groundfish species by Chantel Wetzel (UW PhD student, and Northwest Fisheries Science Center (NWFSC) staff member).

2. The work initiated by Punt during 2013-14 to extend the work of Motoki Wu (UW MS student, previously funded by this project) on evaluating the performance of methods for estimating meta-analysis-based priors for the steepness parameter of the stock-recruitment relationship has been completed. A paper was written with Martin Dorn (NOAA, Alaska Fisheries Science Center [AFSC]) and published in the journal Fisheries Research.

3. The paper evaluating the best ways to select among alternative selectivity patterns when conducting stock assessments, which Punt started writing in collaboration with a UW Postdoc Athol Whitten and a UW PhD student Felipe Hurtado, was completed and is currently in press in the journal Fisheries Research. The paper formed the basis for a keynote address during the March 2013 Center for the Advancement of Population Assessment Methodology selectivity workshop organized by scientists from the Scripps Institution of Oceanography, NOAA Southwest Fisheries Science Center, and the Inter-American Tropical Tuna Commission.

4. Kelli Johnson and Kotaro Ono (UW PhD students) worked on a collaborative project with other UW SAFS students to assess the performance of Stock Synthesis when natural mortality varies with time and various levels of data quality and quantity are available, and to assess the importance of age and length composition data in statistical age structured models. Johnson presented the work on time-
varying natural mortality at the World Conference on Stock Assessment Methods for Sustainable Fisheries in Boston in July 2013. Papers describing this work are currently in press in the ICES Journal of Marine Science. Johnson and Ono were co-authors of an R package to facilitate simulation with Stock Synthesis, which is currently available on CRAN.

5. Johnson is working on methods to improve the estimation of trophic interactions for multi-species stock assessments. Using simulations, she is testing whether functional response parameters can be estimated from abundance time-series to alleviate the dependence of multi-species stock assessments on diet data. Johnson is also working on improving the performance of a multi-species stock assessment framework developed by Doug Kinzey (NOAA, SWFSC) and Punt. The framework allows for uncertainty in the functional response using both integrated analysis and model selection. Additionally, Johnson is using Bayesian state-space models and survey trawl data to assess stock boundaries for the three species included in the multi-species model.

6. Ono is continuing to evaluate the performance of new statistical methods to improve the accuracy of fishery catch per unit effort (CPUE) standardization methods. He is specifically testing the effect of spatial closures on the accuracy of the derived index of abundance, and comparing the performance of a few traditional approaches against a new method based on imputation. His simulations are based on a spatially-explicit model that includes vessel dynamics. The work has been submitted to the Canadian Journal of Fisheries and Aquatic Sciences.

7. The series of regular (generally bi-weekly) UW/NWFSC/AFSC Fisheries Think Tanks continued during the reporting period, coordinated by Johnson. 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 http://fish.washington.edu/news/miniworkshop/index.html. Furthermore, efforts were initiated during 2013-14 to include presentations from researchers working outside of UW/NWFSC/AFSC to increase the remote audience participation.
EVALUATING PREDATOR MOVEMENTS TO DETERMINE THE VULNERABILITY OF SALMON SMOLTS TO PREDATION IN THE SAN JOAQUIN DELTA

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Task III

NOAA Sponsor
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NOAA Goal
Healthy Oceans

Description
Understanding the factors that influence the survival of juvenile salmon migrating from rivers to the ocean is critical for conserving their populations throughout the United States, but especially in areas where their abundance has declined to low levels. Many factors affect salmon survival, including direct and indirect effects of temperature, water quality, barriers, flow conditions, and predation. In the San Joaquin River, tagging studies have revealed a high rate of mortality on salmon smolts (80-99%). Predation is thought to be one of the major sources of mortality in this river because there are many non-native predatory fishes (notably striped bass, largemouth bass, and channel catfish). The purpose of this study is to assess the movement of predators in relation to Endangered Species Act (ESA) listed and economically important salmonid smolts in an area of known high mortality and high predator densities. To accomplish this task, predators will be tagged with acoustic transmitters, allowing them to be detected by an array of stationary receivers throughout the San Joaquin Delta that record the date, time, and unique identity of each fish. Concurrently, in cooperation with a larger research project, the National Marine Fisheries Service (NMFS) will release acoustically tagged Chinook and steelhead smolts into the system. This will allow for the quantification of spatiotemporal overlap of predators and prey that can subsequently be used to advance ecological theory and inform decisions on salmon management and conservation.

Objective
The extent to which predation by non-native fishes affects juvenile Pacific salmon in the Sacramento – San Joaquin system is currently not known. The goal of this project is to use sonic telemetry to determine the movement patterns of several putative predators during periods of juvenile salmon migration. These data will be combined with data from other investigators to provide an overall picture of the movements of different predators and the impact that they may have on salmon populations.

Accomplishments
The budget was active for only a few weeks, but during this period we finalized the study plan and commenced field work. There are no results to report at this time but we anticipate that there will be next year, and the project is on schedule.
SABLEFISH REPRODUCTIVE LIFE HISTORY AND GENETICS

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NOAA Personnel
Walt Dickhoff, Frederick Goetz, Krista Nichols, Adam Luckenbach and José Guzman — Northwest Fisheries Science Center

Task III

NOAA Sponsor
Penny Swanson — Northwest Fisheries Science Center

NOAA Goal
Healthy Oceans

Description
Sablefish (Anoplopoma fimbria) are an important commercial fishery in the North Pacific and currently are the highest valued finfish (per pound) in the Alaska fishery. However, information on their reproductive life history is very limited. While it is generally known that sablefish reproduce in the winter and early spring, the precise timing and duration of reproduction in a given population, and the relationship of timing to latitude, are still unknown. This study aims to assess the reproduction of sablefish populations at two sites in the Pacific (California and Washington) throughout the year by measuring gonadosomatic indices, assessing gonadal stage by histology and by measuring the levels of reproductive hormones. This is being done on samples collected from sablefish taken monthly throughout the year.

While it is believed that different stocks of sablefish exist in the Pacific, the number and arrangement of those stocks is still unclear. Further, comprehensive genetic analyses of sablefish populations across the Pacific have not been conducted. A second part of this study is directed at developing SNP (single nucleotide polymorphism) markers by RAD (restriction site associated DNA) sequencing from samples taken across the entire range of sablefish from California to Alaska and across to the Aleutian Islands and the Bering Sea. SNPs will be used to evaluate population structure using standard population genetic methods and for the evaluation of specific genes that may be under selection. A linkage map will be produced so that SNPs can be more fully evaluated and genome sequencing will be conducted to provide a framework for 1) gene expression studies through the annotation of transcriptomes; 2) association and population genetic studies to examine extant genetic diversity in natural populations of sablefish and identify candidate genome regions under selection; and 3) the development of future genome-wide SNP panels for pedigree tracking as well as genomic prediction.

Objectives
1. The portion of the reproductive life history study that is included in the grant is the analysis of the tissue samples that are being collected in the field. Specifically, blood will be extracted and analyzed for estradiol (females) and 11-ketotestosterone (males); gonad tissue will be fixed and processed for histology and slides containing sections will be viewed under a compound microscope and stages of oogenesis and spermatogenesis described; fecundity will be analyzed in the ovaries of females sampled at the peak of oogenesis. Once collected, data will be analyzed by ANOVA against sampling site and time.

2. Resources (temperature controlled freezing system, liquid nitrogen storage containers, and computer aided analysis system (CASA)) will be acquired and used to establish conditions for the cryopreservation of sablefish sperm.

3. RAD-tag sequencing will be used to generate SNPs from sablefish samples to be taken on NOAA surveys. SNPs will be analyzed to evaluate the genetic relationship of sablefish across their range and to identify possible SNPs under selection (showing unusually high or low patterns of diversity) in these populations.
4. Produce a genetic linkage map for sablefish that provides a framework for detecting signatures of adaptive differences in natural populations of sablefish, and for the sablefish genome sequence that we will obtain under Objective 5.

5. Produce a genome sequence for sablefish, which will be used in the identification and annotation of genes important in many life history traits including development, reproduction, growth, environmental tolerance, as well as for the development of tools for genomic prediction.

Accomplishments

1. The reproductive life history study was initiated in August, 2012, and sampling of sablefish off the Washington (WA) and California (CA) coasts was conducted on a monthly basis and was complete this past Fall, 2013. All meristic data (length, weight, sex, GSI, HIS) have been collected. Histological slides of the gonads and blood steroid levels for the WA samples are now complete and are being processed for the CA samples. Otoliths for both WA and CA samples are being aged. Samples were taken for the analysis of fecundity and methods for assessing fecundity are being developed.

2. Using a Crysalys PTC-9500 user-programmable controlled-rate freezing system and computer aided sperm analysis (CASA) system (microscope, video camera and computer) to quantify changes in sperm motility, experiments were conducted to determine the optimal conditions for storing and activating sablefish sperm. Sperm were activated with ionic (NaCl, KCl, MgSO4 and CaCl2) and non-ionic (urea and glucose) solutions of varying osmolalities. KCl and NaCl activated sperm at the lowest osmolalities, followed by MgSO4, urea, glucose, and CaCl2. Compared to NaCl and KCl, non-ionic solutions required higher osmolalities for activation. The results indicate that the primary stimulus for sablefish sperm activation is increased osmolality and not the presence/absence of a specific ion. The effects of several cryoprotectants including dimethyl sulfoxide, propylene glycol and glycerol at two concentrations (5% and 10%) and three freezing rates (-2.5, -5 and -7.5 °C/min) were tested on the cryopreservation of sperm. There were differences observed in the motility maintained following freezing between all cryoprotectants, but the highest motility after freezing was observed with 10% dimethyl sulfoxide at all freezing rates. The objectives for this part of the project are now complete.

3. Samples were collected in the summer of 2012 by various NOAA surveys conducted in Alaska and off the West Coast of the United States. The Alaska Fisheries Science Center’s Marine Ecology and Stock Assessment (MESA) division collected 1,922 fin clips and otoliths during their annual sablefish longline survey in the Gulf of Alaska. The Resource Assessment and Conservation Engineering Division (RACE) of the Alaska Fisheries Science Center collected 140 samples during their groundfish bottom trawl survey of the Bering Sea slope and 580 finclip and otolith samples were obtained from the Fishery Resource and Monitoring (FRAM) Division’s West Coast Groundfish survey to represent the southern sablefish stock. RAD sequencing libraries have now been made and sequenced by the Illumina HiSeq for 441 individuals selected from the three surveys. From these sequences, at least 10,000 SNPs have been obtained that are currently being analyzed for traditional population genetics, as well as for genes under selection.

4. Single pair crosses have been made for a number of sablefish families that were also used in an experiment in which sablefish larvae were reared at three different temperatures. From the analysis of the family representation in that experiment we know that the effects of temperature have some genetic basis. Therefore, these sequences may be helpful in detecting signatures of selection. DNA from these crosses will be sequenced to provide resources for mapping.
BOWHEAD WHALE FEEDING IN THE WESTERN BEAUFORT SEA: PASSIVE ACOUSTIC SURVEY COMPONENT

PI
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Task III

NOAA Sponsor
Catherine Berchok — National Marine Mammal Laboratory

NOAA Goals
Resilient Coastal Communities and Economies
Healthy Oceans

Description
As part of a larger Minerals Management Funded Study on the feeding behavior of bowhead whales in the vicinity of Barrow, Alaska, an acoustic recording component was incorporated with other sampling regimes undertaken by the National Marine Mammal Laboratory (NMML), the University of Alaska at Fairbanks, and the Woods Hole Oceanographic Institution.

Passive acoustic detection and tracking is a proven tool for assessment of large whales in Alaskan seas (Moore et al. 2006). This may be the best method to effectively monitor seasonal occurrence over large spatial and temporal scales. Specifically, acoustic detection has proven a key addition to the census of bowhead whales during their spring migration past Barrow (Clark and Ellison 2000), and in relation to oil and gas development activities offshore of Prudhoe Bay (Greene et al. 2004). More recently, gray whale calls have been detected year-round near Barrow on long-term recorders deployed in collaboration with the NSF/Shelf-Basin Interaction Study (Stafford et al. in press); this was the first evidence of gray whale occurrence in winter near Barrow. An array of moored passive acoustic receivers east and west of the study area will be able to detect bowhead calls as the whales enter and use the waters of the western Beaufort Sea. Year-round deployment will provide previously unattainable assessment of the seasonal occurrence of bowheads in the study area.

Objectives
1. Attend project meetings. Milestone: Use these meetings as an open forum in which to present proposals for acoustic research.
2. Coordinate analysis of the detection results with other members of the Bowhead Whale Feeding project, particularly Catherine Berchok of NMML, Mark Baumgartner of WHOI, and physical oceanographer Steve Okkonen of the University of Alaska, Fairbanks. Milestone: Documentation of temporal occurrence of bowhead whales in the study area and preparation for further analysis in successive years of this project. Milestone: Integrate oceanographic data when available with passive acoustic detections; determine temporal differences in call type usage.
3. Outreach/communication with other scientists, managers, and members of the North Slope Borough community to keep them updated on project progress and results. Milestone: Presenting material in scheduled meetings and through routine reports as requested.
4. Submission of manuscripts to peer-reviewed journals.

Accomplishments
1. Provided detections to Catherine Berchok and generated ambient noise level data for comparisons among years and locations. Bowhead whale detection data have been provided to Okkonen to be compared with data from Acoustic Doppler Current Profiler data to determine if the diel vertical migration of zooplankton seen in the ADCP data corresponds with bowhead whale detections.
2. Visited Barrow in April 2013 and was filmed for a talk at the local Saturday Academy, and interacted with hunters out on the ice. This entailed bringing a dipping hydrophone out on the ice so local hunters could listen to the ocean.
3. One manuscript was published in Polar Biology, and another was submitted to Progress in Oceanography.
Percentile ambient noise levels in 1 Hz bins (Hanning window, 50% overlap) were calculated for all available data streams using a program custom written by JASCO, Ltd. Time series of absolute ambient noise levels were averaged into decades (10-100 Hz, 100-1000 Hz, 1000-4000 Hz, 10-4000 Hz).

For all sites and all years, ambient noise levels were highest in the late summer and fall corresponding to open water months, and lowest in winter. Long-term 5%, 50%, and 95% noise levels for all available data are shown in Figures 2-5.
Figure 2. Long-term average monthly ambient noise levels (dB re 1 uPa^2/Hz) for M2 (~71.6N 155.6W). Ambient noise levels are highest in the late summer and fall.

Figure 3. Long-term average monthly ambient noise levels (dB re 1 uPa^2/Hz) for M3 (~71.7N 154.5W). Ambient noise levels are highest in the late summer and fall.

Figure 4. Long-term average monthly ambient noise levels (dB re 1 uPa^2/Hz) for M4 (~71.7N 153.2W). Ambient noise levels are highest in the late summer and fall.

Figure 5. Long-term average monthly ambient noise levels (dB re 1 uPa^2/Hz) for M5 (~71.4N 152.5W). Ambient noise levels are highest in the late summer and fall.

PI
Kathleen M. Stafford — UW Applied Physics Laboratory

Task III

NOAA Sponsor
Kathleen Crane — NOAA Arctic Program

NOAA Goals
Resilient Coastal Communities and Economies
Healthy Oceans

Description
As part of the Russian-US Long Term Census of the Arctic (RUSALCA) program, an acoustic recording component was incorporated into oceanographic moorings in the Bering Strait region. Passive acoustic detection and tracking is a proven tool for assessment of large whales in Alaskan seas (Moore et al. 2006). This may be the best method to effectively monitor seasonal occurrence over large spatial and temporal scales. Specifically, acoustic detection has proven a key addition to the census of bowhead whales during their spring migration past Barrow (Clark and Ellison 2000), and in relation to oil and gas development activities offshore of Prudhoe Bay (Greene et al. 2004). More recently, gray whale calls have been detected year-round near Barrow on long-term recorders deployed in collaboration with the NSF/Shelf-Basin Interaction Study (Stafford et al. in press); this was the first evidence of gray whale occurrence in winter near Barrow. An array of moored passive acoustic receivers east and west of the study area will be able to detect bowhead calls as the whales enter and use the waters of the western Beaufort Sea. Year-round deployment will provide previously unattainable assessment of the seasonal occurrence of bowheads in the study area.

Objectives
1. Attend project meetings. Milestone: Use these meetings as an open forum in which to present results from acoustic research.
3. Obtain marine mammal sightings from mooring cruises. Milestone: Work with other researchers in the area to amass all opportunistic sightings form the area.

Accomplishments
1. Attended project meetings in Honolulu, HI in February 2014 to discuss results and synthesis of data from 5 years of RUSALCA moorings.

Figure 1. Location of hydrophone from which acoustic data were analyzed with region for visual sightings outlined in black dashed line.
2. Examined data from one mooring over three years for marine mammal occurrence and presented these results at annual RUSALCA PI meeting and the 2014 Ocean Sciences Meeting in Honolulu, HI in February 2014.

3. Peer-reviewed manuscript based on visual data published in Oceanography. Provided data for manuscript submitted to Progress in Oceanography.

4. Data have been provided to Axiom to upload to the Alaska Ocean Observing System website: www.aoos.org; this is still in progress.
Figure 4. Acoustic detections of humpback whales from hydrophone in Bering Strait shown in Figure 1.

Figure 5. Visual sightings of all subarctic cetaceans overlaid on satellite-derived September sea surface temperature for cruises in the southern Chukchi Sea.

Figure 6. Visual sightings of all subarctic cetaceans overlaid on satellite-derived chlorophyll a data for cruises in the southern Chukchi Sea.
OCEAN AND COASTAL OBSERVATIONS
OBSERVING SYSTEM RESEARCH STUDIES

PI
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Other UW Personnel
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Task II

NOAA Sponsor
D.E. Harrison — Pacific Marine Environmental Laboratory

NOAA Goal
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. The Observing System Research Studies group also develops and makes use of information technology capabilities to manage and analyze large observational and computer-generated data sets.

Objectives
1. To undertake observing system research studies with an emphasis on evaluating and better 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. The overarching objective is to identify useful climate indices/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. The project will also undertake other observing system research studies deemed important by the Office of Climate Observations, and work to develop and maintain information technology solutions that make global oceanographic and climate datasets more accessible to the wider scientific community.

Accomplishments
1. Because the El Niño-Southern Oscillation (ENSO) phenomenon is the largest coupled mode of the planet after the seasonal cycle and diurnal cycle, and because of its many associated effects on regional climate and ecosystems around the globe, ENSO has continued to be a focus of group scientific research. Several publications have appeared in, or are in press in the peer-reviewed scientific literature in 2013-2014 based on this research (see list below), which has attracted both national and international attention. Our recently published results show how an outgoing-longwave-radiation (OLR) based index that tracks the spread of deep atmospheric convection conditions over the eastern central tropical Pacific can identify the handful of years with most of the useful associated seasonal weather anomalies over the affected land regions around the globe. We have also identified a separate, but comparably useful index for La Niña, and recent results show that a better winter weather forecast is obtained by ignoring (betting on seeing exactly average conditions) all the other years, and keeping (applying an ENSO-type anomaly forecast) just those years identified as important tropical Pacific events by the OLR-based indices for El Niño and La Niña.

2. Recent work has shown that increases in the easterly trade winds along the equatorial Pacific that take place over timescales of a few days to a couple of weeks (we call these “Easterly Wind Surges”) play an important role in the onset of La Niña waveguide surface cooling, and deserve additional study. The role of Westerly Wind Events in initiating and maintaining El Niño-type warming has long been recognized. This is the first study that shows, in the way we do, that Easterly Wind Surges play a role in initiating La Niña that is akin to the role that Westerly Wind Events play
in initiating El Niño. We expect the initial steps made by this work to be useful in gaining a better understanding of the processes responsible for La Niña, and their predictability.

3. Group work has also: a) re-examined the relationship between extremes in ENSO and changes in atmospheric CO2 concentration to the effect that novel asymmetries between the effects of El Nino and La Nina have been identified that will be useful to the ongoing evaluation of Earth System Model Performance; b) clarified the roles that various types of sub-seasonal wind phenomena in the western tropical Pacific play in initiating El Niño events; and c) used group expertise to help inform fishery-oceanographers about the uncertainties involved in attempting to project future conditions based on trends observed over recent decades.

4. Group work has led to publication of a manuscript that describes how OLR information over the tropical Pacific can be used to sort through the El Niño events identified by the commonly used definitions to separate those that are most likely to have a strong influence on U.S. weather from those that are not. Since the tell-tale OLR behavior typically occurs before winter, considering this OLR behavior may allow more skillful seasonal forecasts to be issued before winter, considering this OLR behavior may allow more skillful seasonal forecasts to be issued before winter, considering this OLR behavior may allow more skillful seasonal forecasts to be issued before winter, considering this OLR behavior may allow more skillful seasonal forecasts to be issued before winter, considering this OLR behavior may allow more skillful seasonal forecasts to be issued before winter, considering this OLR behavior may allow more skillful seasonal forecasts to be issued before winter, considering this OLR behavior may allow more skillful seasonal forecasts to be issued before winter, considering this OLR behavior may allow more skillful seasonal forecasts to be issued before winter, considering this OLR behavior may allow more skillful seasonal forecasts to be issued before winter, considering this OLR behavior may allow more skillful seasonal forecasts to be issued before winter. Since the tell-tale OLR behavior typically occurs before winter, considering this OLR behavior may allow more skillful seasonal forecasts to be issued before winter (see Chiodi and Harrison 2013 and the NOAA press release archive www.noaanews.noaa.gov/stories2013/20130207_pmel_elnino.html for more information).

5. Further work has identified a comparably useful OLR-based index for La Niña and shown that not just in the U.S., but globally as well, most of the useful seasonal weather associations are due to the El Niño and La Niña years distinguished by OLR behavior.

6. We have shown that El Niño and La Niña events have substantially asymmetrical effects on the global carbon cycle. It has long been known that there is a connection between El Niño Southern Oscillation (ENSO) behavior and the atmospheric CO2 variability. Our results reveal that the El Niño effects are about twice as large and persist longer into the calendar year than the La Niña effects. We expect these results will provide useful benchmarks for the ongoing development and evaluation of Earth System Models (see Figure 1 below).

7. Recent results have confirmed, with a near doubling of period, that Westerly Wind Events (WWE) in the western equatorial Pacific (various

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**Figure 1.** El Niño-Southern Oscillation effects on atmospheric CO2. The illustration above summarizes some of the main results of our composite study of the effects of El Niño and La Niña on the concentration of CO2 in the atmosphere. Based on analysis of annually-averaged CO2-change measures, El Niño effects are more than 50% larger than La Niña effects. At seasonally-averaged timescales, it is clear that ENSO effects are seen in winter-to-spring CO2 levels in each phase, but there are also some asymmetries in timing; significant El Niño effects begin later and last about a season longer than the La Niña effects. The composite CO2-change amplitudes revealed here are on the same order of magnitude as the trend due to fossil fuel emissions. We believe these results provide useful benchmarks to test for the successful inclusion of biogeochemical processes in coupled land-ocean-atmosphere models.
tropical weather phenomena that produce average westerly winds of ~7m/s for ~7 days) remain a primary forcing for the cold-tongue warming seen in the developing stages of El Niño events. Our analysis shows, on the other hand, that the Madden-Julian Oscillation (MJO), an atmospheric phenomenon characterized by lower amplitude easterly-westerly oscillations in tropical near-surface winds that occur over timescales of 40-80 days, is not closely connected with such warming unless a WWE occurs during an MJO. Further results show that the presence of an MJO does not significantly affect the likelihood of seeing a WWE. Thus, studying WWEs remains important for better understanding the predictability of warm-ENSO events. Up to now, the published literature is unclear about these relationships.

8. We have revisited the question of whether or not ENSO has a very long-term trend, and whether such a trend can be reliably determined from multi-decadal sub-segments of a geophysical historical record. We use the Darwin sea level pressure record, the longest (135yr) high-quality ENSO-proxy available to do this, and find that the full-record trend in this case is not found to be statistically significant, even by the most lenient statistical test considered. On the other hand, even the strictest test finds many more statistically significant trends at shorter multi-decadal timescales (both positive and negative) than should be expected under the null hypothesis of there being no long-term trend. These results offer a cautionary reminder about the risks of imputing meaning to the trends seen in geophysical time series based on statistical methods alone.

9. Information Technology-Side Accomplishments

The Observing Systems Research Studies group has been actively involved in promoting and encouraging data integration and interoperability through the embracing of community data and metadata standards. We have also been involved in providing improved community access to data and data products.

Data Integration Efforts
Through projects that we lead, including the Observing System Monitoring Center (OSMC), and the Unified Access Framework (UAF), we continue to promote the use of data standards to improve data interoperability. In the past year, we have implemented, through the UAF project, a rubric tool that is part of our previously developed Catalog Cleaner software (see Figure 2). This addition allows us to quantify the quality of data represented in THREDDS catalogs. The information contained in this rubric is designed to assist data providers in improving their data catalogs by providing an easy way to see where their catalogs may not conform to known standards and conventions for data access.

This UAF project, and the associated master catalog of data that we produce, provides access to a multitude of data and makes it available to users, allowing them to use the software tools they are familiar with. We have successfully been able to serve data from a wide variety of NOAA and non-NOAA sources to the community and, in fact, have made available over 11,000 datasets in this manner. In addition, in cooperation with NDBC, we have implemented a metadata harvesting system which, on a nightly basis, makes the metadata derived from the UAF catalog available to the NODC Geoportal, a tool used to assist in data discovery. Up to this point, the primary data focus has largely been numerical model data. However, we have recently provided a means of
interoperable access to the entire collection of real-time ocean observation data. This work, done through the OSMC project, has made available near real time ocean observations that are being sent through the Global Telecommunication System (GTS). Much of the real time ocean data flows through the GTS, and this real time data is of very high value, especially to ocean modelers and forecasters. In the coming year, we will be working to integrate the real time data with delayed mode data that is available from several observing system networks (see figure 3). In addition we will be establishing real time data flow metrics for the climate observations division, which will help understand how well the real time ocean observations are serving the ocean community.

10. Community Access to Data and Data Products
In addition to leading the community in attempts to improve data integration and interoperability, the Observing System Research Studies group continues to help scientists visualize and analyze data.

PyFerret, the python version of the popular application Ferret, has been officially released for public use. In fact, it is currently being widely used at NOAA’s Geophysical Fluid Dynamics Laboratory (GFDL) in the post-processing workflow that is integrated with all of their model runs, including those as part of the Coupled Model Intercomparison Project (CMIP). PyFerret has greatly improved graphics creation and integration of numerical and scientific libraries. Among others GFDL is making very good use of the two additional dimensions that were added in PyFerret/Ferret in the last version. These two additional dimensions will allow 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. In the newest release of PyFerret (v1.02), coinciding with our annual visit to GFDL in support of our ongoing MOU, we have added shapefile outputs for new statistical functions, as well as much improved graphics.

The group continues to play a central role in the data management of the Surface Ocean Carbon Atlas (SOCAT) project. This project, which establishes a high quality, global surface CO2 data set, has laid the foundation for years to come in terms of defining formats for metadata and data, as well as methods for doing first level quality control. SOCAT v2 has been released, and we are in the midst of a complete overhaul to support SOCAT v3. This version will include an automated sanity checker for data entered by scientists, which will continually be refined to ease the QC burden on scientists. This automated data checker will also allow future SOCAT versions to include high quality data with parameters other than just CO2.

This improved automation will allow updates to the global SOCAT data product to be released on a more frequent basis. In parallel, the SOCAT v4 system is also in development, and this version will include a metadata sanity checker. The v3 revamped QC and the v4 automated data submission will be demonstrated at the IMBER Ocean Science Conference meeting in June 2014.

Information Technology-Side Presentations

Figure 3. Potential Observing System metric that shows drifting buoy data that exists in the delayed mode data, but wasn’t transmitted on the GTS.


Current member of UNIDATA’s THREDDS Data Server Steering Team.

OCEAN CLIMATE STATIONS

PI
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Other UW Personnel
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NOAA Personnel
Meghan F. Cronin and Christian Meinig — Pacific Marine Environmental Laboratory

Task II

NOAA Sponsor
Diane Stanitski — NOAA Climate Program Office

NOAA Goal
Climate Adaptation and Mitigation

Description
NOAA's Ocean Climate Stations Project (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 1949-1981. Ocean measurements at Station Papa extend back almost six decades, making it one of the longest ocean data sets 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 NOAA's Climate Observation Division's program deliverables of global climate analysis products.

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 the chain above its anchor. Instruments on the buoy measure winds, air temperature, relative humidity, barometric pressure, rainfall, atmospheric and seawater carbon dioxide, downward infrared radiation from the sky, incident light (heat) from the sun, as well as sea surface temperature, salinity, dissolved oxygen, and pH. Sensors attached to the mooring line measure upper ocean temperature, salinity, and near surface ocean currents. A sensor mounted on the anchor release measures bottom water temperature, salinity and pressure. 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.

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 [www.pmel.noaa.gov/OCS](http://www.pmel.noaa.gov/OCS).

**Accomplishments**

1. JISAO and NOAA scientists participated in two cruises during 2013 in support of the Papa and KEO stations. In June 2013, JISAO employee Jennifer Keene, along with NOAA mooring specialist Michael Craig and UW graduate student Seth Bushinsky deployed a refresh of the Papa mooring at 50°N 145°W while onboard the Canadian Coast Guard Ship R/V JOHN P. TULLY. The prior mooring and all instruments were recovered, and will be refurbished and reused for a June 2014 deployment.

2. In July 2013, JISAO employees Keith Ronnholm and David Rivera successfully recovered the KEO mooring and deployed a replacement mooring. Work was performed from the JAMSTEC research ship KAIYO. The prior KEO mooring and all subsurface sensors were recovered. KEO survived the passage of three typhoons in a one-month period during the fall of 2013, and continues to transmit observations.

3. In November 2013, a JISAO proposal for “Ocean Reference Station Observations Towards Improved Short-Term and Seasonal Hurricane Predictions” was approved and fully funded for two years. This NOAA Sandy Supplemental funding was used in the first half of 2014 to upgrade OCS moorings with dual new generation Flex data loggers to provide both primary and secondary (redundant) data at hourly resolution in near-realtime. Keene was the lead on building and installing the secondary Flex system, modifying buoys, and in troubleshooting significant issues within the software and wiring of the Flex data logger.

Additionally, through the Sandy Supplemental funding, OCS hourly data from the FLEX system (including subsurface data, and all meteorological variables) will be transmitted to the Global Telecommunication System (GTS) directly from PMEL via a National Weather Service (NWS) Gateway. JISAO employee Dan Dougherty wrote the necessary software, and Ronnholm focused on the authorizations to use the NWS Gateway. This in-house capability to directly place buoy data on the GTS is a first for PMEL.

Data from the upgraded KEO mooring, to be deployed in June 2014, will then be used by JISAO PI Nick Bond and operational hurricane forecasters at NCEP to test the value of using near real time upper ocean and surface meteorological observations to validate and/or nudge forecast models of tropical cyclones evolution. This represents an expansion of capability within the OCS project.
4. In November 2013, a completely redesigned and enhanced OCS website was released that integrates the three former OCS public websites (for KEO, stnP and OCS) into a unified OCS website. The website includes technical information and guidance to help users download data, a publication webpage, and a partner page with links to partner’s data (see http://pmel.noaa.gov/OCS). Ronnholm was the primary web designer, with content supplied by Keene. Over the last two years, data was requested from the website by users in government agencies and universities from around the world (US, Japan, Canada, UK, Australia, Spain, China, Taiwan, Russia), and by many anonymous users. Usage descriptions provided by the users included model and satellite data validation, sensor and parameter verification (winds, lidar, flux), research (wave studies, physical-biological coupling, air-sea interactions, wind calculations), and student projects. Ronnholm was presented with a monetary award for his website efforts.

5. In 2013, Keene put in a considerable effort to improve documentation within the OCS group. Data Acquisition and Processing Reports (DAPRs) are being prepared for OCS mooring deployments and the first, for KE-001, is now available. DAPRs contain extensive and detailed information on sensors, instruments, and the data processing procedures that were applied to measurements from that deployment. Keene prepared OCS Technical Notes on RH calibration methods and Flex battery depletion. Keene also updated prior tech notes, and rewrote the Flex software manual. Keene was presented with a monetary award for her documentation efforts.

6. A project begun in 2012, and completed in 2013, consisted of building the software tools to incorporate metadata into deployment files that archive all available data (primary and secondary sensors) in OceanSITES format. The all-inclusive data files are in addition to the “best available” data from each sensor type that is presented on our web site. JISAO employee Daniel Dougherty was the primary developer of this software, and received a monetary award for his efforts. JISAO employees Curran Fey, Sonya Brown, and Dai McClurg contributed to preparing the data.

7. The JISAO team has one peer-reviewed article under review and several more in preparation.

8. NOAA’s Adopt a Drifter program will be supplying 10 drifters to each of the KEO and Papa cruises in June 2014. Ronnholm will be deploying these from the KAIYO, and Keene is coordinating the deployments from the TULLY.

9. Cronin and JISAO team member Ronnholm participated in the Line-P workshop held in Sydney, B.C. in March 2014. The purpose of this
workshop was to help coordinate work on the upcoming Line P cruise in June 2014, and to foster collaboration with Line P and Station P data. Discussions included the coordination of 2014 operations at Papa with the NSF Ocean Observing Initiative (OOI) and their plans to refresh the OOI array of subsurface flanking moorings which were deployed in July 2013. This year, talks previously given at Station P science workshops at PMEL in 2012 and 2013 were incorporated in the Line P workshop program with participation by UW Oceanography and UW Applied Physics Lab researchers. Collaborative projects that have resulted from the OCS mooring deployment at Station P include three UW PhD dissertation projects.
THE EFFECT OF WIND-DRIVEN MIXING ON OBSERVATIONS OF PLASTIC MARINE DEBRIS: MODELING, VERIFICATION AND REANALYSIS

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Task III

NOAA Sponsor
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NOAA Goal
Healthy Oceans

Description
Since the introduction and popularization of “engineered thermoplastics” in the 1950s, plastic has become one of the world’s most important and widespread commodities. The same engineered properties that contribute to the enormous utility of plastic, namely durability and resistance to degradation, also result in long residence times (decades to millennia) when plastic is introduced into the natural environment. The bulk of scientific measurements of plastics in the open-ocean come from surface net tows. However, because the surface ocean is a dynamic environment and plastic fragments act as passive particles, this plastic debris is subject to the physics of mixing within the ocean surface boundary layer. Thus, surface measurements underestimate the total amount of plastic in the upper water column. Previous results by our project team suggest that the surface ocean actually contains between two and 27 times the amount of plastic measured using surface net tows. This project is designed to improve our modeling ability, as well as provide the scientific and citizen scientist communities with easy-to-use numerical tools to report total plastic content given surface plastic and wind observations.

Objectives
We have three major work objectives:
1. To validate the numerical model with additional laboratory data, resulting in an improved model that can be easily adopted by the marine debris community.
2. To apply this improved model to ultimately reanalyze a multi-decadal data set of surface plastic observations.
3. To publish and present the model in an accessible manner so that interested scientists and citizen scientists can apply measurements of surface plastic and wind speed to get total plastic content. In order for model results to be accepted as a useful modification to pure observations by the scientific community, it must be both trusted and viewed as an important contribution. It is

Figure 1. Depth profile of plastic concentration (normalized to surface value). Observations (black dots) were conducted in 2010 using sequential Tucker-trawl net tows. Black line is model prediction from the model presented in Kukulka and Proskurowski et al. (GRL 2012), which is a slight improvement over the model with wave induced turbulence (blue line). Most recent model profile is shown in red, and is much better matched to observations. Most recent model includes breaking waves and Langmuir wave induced turbulence.
our intent to use the reanalysis of a broader subset of the SEA Atlantic dataset to illustrate the importance of including wind speed into plastic content estimates, and to build confidence in the methodology.

**Accomplishments**

1. A graduate student at the University of Delaware has been working on this project for the past 14 months. The student was tasked with incorporating more complexity into the initial 1-dimensional model published in *Geophysical Research Letters* (GRL) 2012. The new model includes breaking and Langmuir wave effects, bringing increased realism to the physics of the modeling effort. A positive result from this effort is that the model profiles of plastic concentration vs. depth are a better match with observations (Figure 1).

2. Ongoing reanalysis of the Atlantic data set using a new, more complex, model (Figure 2).

3. Work toward a comparison of ship-based wind speed observations and satellite derived wind products is underway. European Centre for Medium-Range Weather Forecasting (ECMWF) winds for the Pacific have been matched to SEA gyre data set (341 tows) and the integrated densities computed. A positive result is that the winds from ship-based observations and ECMWF derivations are strongly correlated \( (R=0.67, p =0.0) \) (Figure 3). The difference in wind speed between the ECMWF derived product and the ship-based observation ranges from 0.004 to 7.56 m/s, with a mean difference of 1.39 m/s. This result suggests that ECMWF winds can be used to back correct all legacy data that has reported time and locations matching an ECMWF product. Wind products generated by National Centers for Environmental Prediction (NCEP) are currently being evaluated in a similar fashion.

4. Plastic samples from a series of depth-tow Tucker trawls have been evaluated for physical properties including area, thickness, and length of longest axis. Analyses of polymer composition, and rise velocity are ongoing.

5. Fully documented spreadsheet and Matlab based versions of the model presented in the 2012 GRL paper have been produced for inclusion in a publication expanding on the approach taken in 2011. A draft of this text of a publication of accessible model explanation is in revision. The target journal is Marine Pollution Bulletin.

6. We are still on track to meet all objectives outlined for completion by August 31, 2014.

**Figure 2.** Spatially-averaged plastic concentration as determined from (a) 343 surface net tow measurements, (b) depth-integrated plastic content from model calculations using surface net tow measurements and concurrently measured wind speed, and (c) preliminary results from new more complex model incorporating elements of Langmuir circulation. Figure parts (a) and (b) from Kukulka et al. (2012).

**Figure 3.** Comparison of ECMWF satellite derived wind products and ship-based observations. Comparison matched 341 tows from the NE Pacific 2005-2010 with corresponding time and location ECMWF wind speed product. Mean difference between the satellite derived and measured wind speed was less than 1.4 m/s (~3 knots).
THE ARGO PROJECT: GLOBAL OBSERVATIONS FOR UNDERSTANDING AND PREDICTION OF CLIMATE VARIABILITY

PI
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Other UW Personnel
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Task III

NOAA Sponsor
Steve Piotrowicz — NOAA 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 (UW) 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, 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 (SIO), Woods Hole Oceanographic Institution (WHOI), Pacific Marine Environmental Laboratory (PMEL), 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 and Awards
1. During the past year, the team deployed 109 profiling floats as part of Argo, the largest number of any 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 five winter seasons. A majority of the UW floats were deployed in the subtropical S. 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 15) 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.

3. In addition, floats were deployed in the eastern tropical Pacific, and in the Indian Ocean (Bay of Bengal region).
4. Several papers were published in refereed journals using Argo data, and a graduate student, Alison Gray, will shortly (summer of 2014) finish her PhD dissertation. Gray was recently awarded a NOAA Global Change Postdoctoral Fellowship, which she will use at Princeton University. Her PhD dissertation work was based on the analysis of Argo data.
PROTECTION AND RESTORATION OF MARINE RESOURCES
NORTHWEST FISHERIES SCIENCE CENTER AND UNIVERSITY OF WASHINGTON UNDERGRADUATE INTERNSHIP PROGRAM

PI
Janice DeCosmo — Undergraduate Academic Affairs/Undergraduate Research Program

Other UW Personnel
Tracy Ann Nyerges — Center for Experiential Learning and Diversity
Zack Oyafuso, Susie Dobkins and Jessica Blanchette — Aquatic and Fishery Sciences
Yu-Hsuan Peng and Megan Stephens — Biology
Oleksandr Stefankiv — Environmental and Forest Science
Jeffrey Pham — Microbiology

NOAA Personnel
Beth Sanderson, Linda Rhodes and Rohinee Paranjpye — Northwest Fisheries Science Center

Task II

NOAA Sponsor
Kathleen Jewett — Northwest Fisheries Science Center

NOAA Goal
Resilient Coastal Communities and Economies

Description
This project is an educational collaboration between Undergraduate Academic Affairs at the University of Washington (UW) 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
Between five and 12 internship positions are anticipated annually under this project for UW students to work 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, seven students participated in the internship program, with two new interns starting in Autumn, 2013. All of the interns participated in networking activities and poster sessions at NWFSC; four of them presented their research results at the UW Undergraduate Research Symposium (2013 and 2014). Below is a list of all seven participants and their academic majors:

Jessica Blanchette — Aquatic and Fishery Sciences
Susie E. Dobkins — Aquatic and Fishery Sciences
Zack Suriya Oyafuso — Aquatic and Fishery Sciences
Yu-Hsuan Peng — Biology
Megan H. Stephens — Biology
Oleksandr Stefankiv — Environmental Science and Resource Management
Jeffrey Pham — Microbiology
BIOLOGICAL REMOVAL OF PETROLEUM HYDROCARBONS IN MARINE AND AQUATIC ECOSYSTEMS TO DETERMINE THE FATE OF DEEPWATER HORIZON OIL

PI
Russell P. Herwig — UW School of Aquatic and Fishery Sciences

NOAA Personnel
Christopher Barker, Robert Jones and Bill Lehr — NOS/ORR, Emergency Response Division

Task II

NOAA Sponsor
Alan Mearns — NOS/ORR, Emergency Response Division

NOAA Goal
Healthy Oceans

Description
In April 2010, the Deepwater Horizon began to spill crude oil from a deep-water well blowout in the Gulf of Mexico, resulting in the largest spill in U.S. history. The composition of crude oil changes when it is released into the environment. The chemical, physical, and biological changes are known as weathering. NOAA has developed spill models that describe the fate and transport of spilled oil in marine and aquatic environments. The models lack biodegradation parameters for the different components found in crude oil and other hydrocarbon mixtures. Yet, microorganisms have remarkable properties to degrade crude oil and other petroleum products. Different species of microorganisms, including bacteria, archaea, and yeasts, have the ability to degrade different components of crude oil in the environment, and this property is known as biodegradation or bioremediation. Generally, different fractions of crude oil are degraded by different species of microorganisms. Petroleum has been on earth for millions of years, and it provides carbon for growth and energy for hydrocarbon-degrading microorganisms, including microorganisms in the Gulf of Mexico that were exposed to the spilled oil.

During the funding period from April 1, 2013 – March 31, 2014, a search of the literature was completed related to the microbial biodegradation oil petroleum hydrocarbons in marine and aquatic ecosystems. NOAA was most interested in half-life parameters for the different fractions or components of oil that was spilled into the marine and aquatic environment. The half-life data summarized in our report will be useful for fate and transport models that NOAA’s Office of Response and Recovery (Seattle, WA) is revising. Our search included over 60 years of hydrocarbon biodegradation data, but the emphasis was on oil spills from the EXXON VALDEZ, the DEEPWATER HORIZON, and other recent oil spills. Oil spills from around the world were evaluated. Crude oil is composed of thousands of compounds, and no investigator has the capability to describe the composition and fate of all of the compounds in crude oil. We prepared a spreadsheet that describes the rate of removal of the major components in crude oil in spills from around the world. The components included groups of hydrocarbons that had similar structures, but differed in the length of carbons or number of rings. NOAA received our literature review and biodegradation summary during the 2013 to 2014 project period.

Objectives
A widespread literature review was conducted of papers describing the biodegradation and rates of biodegradation of different fractions found in crude oil spilled in different marine and aquatic ecosystems around the world. When possible, biodegradation rate data were reported as half-lives in our report to NOAA. A half-life is the amount of time required to reduce the parent compound to half the quantity. Half-lives were the unit of measure that NOAA wanted for their fate and transport models. A primary objective was to describe the half-lives for markers found in oil; light alkanes (saturates) C10 to C19 [alkanes with 10 to 19 carbons], pristane, phytane; heavy alkanes (saturates) C20 to C41 [alkanes with 20 to 41 carbons]; two ring aromatics; three ring aromatics; and four ring aromatics. In our report, biodegradation data from spilled components of oil...
are included in a spreadsheet. No biodegradation rate data were found for resins and asphaltenes, although most scientists think that their half-lives are extremely long. Data presented as first-order rates were transformed to half-lives. NOAA was most interested in half-life biodegradation data for the different hydrocarbon compounds and fractions for their rate and transport models.

**Accomplishments**

A thorough literature search was performed of papers published about the biodegradation of crude oil during the past 60 years. A greater emphasis was placed on papers published related to the EXXON VALDEZ, DEEPWATER HORIZON, and other more recent oil spills. In general, a greater number of hydrocarbon compounds were identified and characterized in recent years compared to what was published in the earlier papers. A summary of results was written, and key published tables and figures were included and submitted to NOAA. Papers reviewed in our report were presented as annotated bibliographies. The literature review was organized in chronological order, with older papers described first.

Most petroleum, biodegradation, and bioremediation papers did not calculate removal rates for the different components that were mentioned in spilled oil. If a removal or biodegradation rate was presented, different calculation methods were sometimes used, often making it difficult to draw comparisons between investigations. Biodegradation rate data was not found for all oil fractions, specifically the more recalcitrant fractions, asphaltenes and resins. Rate data is also absent in many studies for alkylation aromatic isomers, the more complex aromatic compounds that have side chains. First-order and half-life rates found were summarized in an MS Excel spreadsheet. Rate data were presented for the fractions described in the previous section. We recommended to NOAA that they use the range of rate data for the different hydrocarbon fractions, rather than using the mean for the data from the different publications. Nevertheless, the incorporation of biodegradation rate data will be a major change to the NOAA models.

**Reasons objectives were not met**

Biodegradation data were described in this review mostly for the simpler saturates and aromatic compounds, because this information can be found in the literature. Few publications described a more complete set of hydrocarbons, including alkylation forms of the hydrocarbons. Biodegradation data has not been published for hundreds of hydrocarbons that have more complex structures, since analytical methods are not readily and widely available.
INTEGRATING SPATIAL HABITAT AND FISHERIES EFFORT DATA TO IMPROVE ABUNDANCE ESTIMATES OF WEST COAST GROUNDFISH

PI
Ray Hilborn — UW School of Aquatic and Fishery Sciences

Other UW Personnel
Kotaro Ono — School of Aquatic and Fishery Sciences

Other NOAA Personnel
Eric Ward, James Thorson, Marlene Bellman and Blake Feist — Northwest Fisheries Science Center

Task III

NOAA Sponsor
Andrew O. Shelton — Northwest Fisheries Science Center

NOAA Goal
Healthy Oceans

Description
To develop statistical approaches that can incorporate habitat and spatial information into a delta general linear mixed model (GLMM) framework for the Shelf-Slope bottom trawl survey of the U.S. West Coast.

Objectives
1. Compare first and second passes of trawl data in the same year to look for short-term changes in species-habitat relationships, and for any modifying effect of fishing effort or catch.
2. Compare base delta-GLMM with a model that includes only habitat as fixed effect covariates and a second model that includes habitat covariates and fishing effort, again as fixed effects. This is a pure spatial model that includes time only as a fixed offset.
3. Work toward the development of a full spatial time-series model. The ultimate goal is to incorporate both habitat information and fishing effort into a single coherent framework.

Accomplishments
1. Developed a Bayesian delta-GLMM model that allows including the spatial correlation and habitat variables into the model.
2. Developed a Bayesian delta-GLMM model that compared the change in biomass between the first and second pass of the survey while taking into account the realized catch data based on trawl logbook.
3. Developed a Bayesian spatio-temporal delta-GLMM model that included both the spatial and temporal correlation structure in the model while accounting for the habitat and fishery catch information.
4. Presented research on the spatio-temporal changes in seasonal dynamics of Dover sole at the Western Groundfish Conference, Canada, February 2014.
5. Presented research on the spatio-temporal changes in seasonal dynamics of Dover sole at Keio University for the Innovation and Challenges for Fisheries Assessment and Management Workshop, Japan, March 2014.
6. Manuscript in review at Canadian Journal of Fisheries and Aquatic Sciences (CJFAS) on the performance comparison of the newly developed Bayesian delta-GLMM model with spatial correlation and habitat variables against two design-based approaches using the example of darkblotched rockfish.
7. Manuscript in preparation to Ecography on the spatio-temporal changes in seasonal dynamics of Dover sole.
FISHERIES ACOUSTIC RESEARCH

PI
John Horne — UW School of Aquatic and Fishery Sciences

NOAA Personnel
Christopher Wilson and Jeff Napp — Alaska Fisheries Science Center

Task III

NOAA Sponsor
Guy Fleischer — Alaska Fisheries Science Center

NOAA Goal
Healthy Oceans

Description
This project partially supports a faculty position at the University of Washington School of Aquatic and Fishery Sciences (SAFS). Activities include research, supervision of graduate students and postdoctoral associates, and service. Research activities examine acoustic reflectivity properties of north Pacific and Bering Sea fish species, and investigate equipment and methods used to acoustically enumerate, size, and map distributions of fish and macrozooplankton. Supervision of graduate students includes those employed by Resource Assessment and Conservation Engineering (RACE) and Resource Ecology and Fisheries Management (REFM) divisions at the Alaska Fisheries Science Center (AFSC). Service activities include fostering collaboration between the SAFS and the AFSC, co-organizing and administering the SAFS-AFSC summer internship program, acoustic training of students and government scientists, and participating in academic committees at the SAFS.

Objectives
1. To support graduate student and postdoctoral associate research programs.
2. To characterize early life stage distributions and dynamics of forage fish species in the NE Pacific.
3. To automate classification of acoustic backscatter using multifrequency data.

Accomplishments
1. A total of seven graduate students (four Masters, three PhDs, and a Postdoctoral Associate) were active during the reporting period. Stan Kotwicki defended his PhD dissertation entitled, “Combining bottom trawl and acoustic data to improve survey derived abundance estimates of semipelagic species,” which examines the influence of selectivity and availability of Walleye pollock (Gadus chalcogrammus) on population abundance estimates from bottom trawl and acoustic-midwater trawl surveys. The first results chapter, “Combining bottom trawl and acoustic data to model acoustic dead zone correction and bottom trawl efficiency parameters for semipelagic species” was published in the Canadian Journal of Fisheries and Aquatic Sciences in 2013. The second results chapter, “Correcting density-dependent effects in abundance estimates from bottom trawl surveys” is scheduled for publication in the International Council for the Exploration of the Sea (ICES) Journal of Marine Science. The third results chapter, “Effect of environmental factors on availability of Walleye pollock to acoustic and bottom trawl sampling” is under review at Fisheries Research. The second results chapter from Kresimir Williams’ PhD dissertation, entitled “Walleye pollock (Theragra chalcogramma) behavior in midwater trawls,” was published in Fisheries Research. Steve Barbeaux, who graduated in 2011, also published the second paper from his PhD dissertation entitled, “A novel approach for estimating location and scale specific fishing exploitation rates of eastern Bering Sea Walleye pollock (Theragra chalcogramma)” in Fisheries Research.

2. Juvenile and small adult fish, typically called forage fish, are an important yet poorly studied part of the NE Pacific ecosystem. This group of species facilitates the transfer of energy up the food chain, but our understanding of their distributions and dynamics is incomplete and hampers efforts to implement ecosystem-based resource management and to track biological responses to climate change in the Bering Sea and Gulf of Alaska. Participation in the North Pacific Research Board’s Bering Sea and Gulf
Protection and Restoration of Marine Resources

Protection and Restoration of Marine Resources

of Alaska Integrated Ecosystem Research Programs has facilitated a series of investigations mapping horizontal and vertical distributions of age-0 Walleye pollock, Pacific cod (*Gadus macrocephalus*), and capelin (*Mallotus villosus*), as well as quantifying the environmental and biological factors that influence their distributions. The first in a series of papers has been published in a special issue of Deep Sea Research II, “Summer distributions of forage fish in the eastern Bering Sea,” with lead author Sandra Parker-Stetter. A review entitled, “A review and ecological synthesis of the first year of life of Walleye pollock (*Gadus chalcogrammus*) in the eastern Bering Sea and comments on implications for recruitment,” summarizes the physical and biological factors that influence growth, survival, and subsequent recruitment has been submitted to Deep Sea Research II by lead author Janet Duffy-Anderson.

3. Work on the probability-based automated classification of multifrequency acoustic data continues. The objective is to quantify uncertainty, reduce subjectivity, and quantify the distributional structure in fisheries acoustic data. Operationally, this translates to developing and implementing a semi-supervised Bayesian Dirichlet Process Mixture Model clustering algorithm that discriminates, categorizes, and ultimately identifies acoustic data acquired during population abundance surveys (Figure 1).

Additional data has been tested in the last year with the goal of finalizing two challenges: the reporting of credible intervals using nested intervals (e.g. 95% credible interval 90% of the time), and determining the number of iterations needed to obtain convergence in a computationally efficient manner. As an illustration of the interest in this topic, a status report of this research was presented to the new ICES working group on target classification.

**Figure 1.** Differences (dB re 1 m⁻¹) in acoustic backscatter measurements using paired frequencies from known fish and invertebrate species aggregations. These points are used as reference data to classify new data as they are acquired during surveys. Separation of point clusters allocated to species along each axis aids classification, overlap in point clusters reduces the probability of membership of any sample to a specific group.
DESIGN AND CONDUCT RESEARCH TO REDUCE SEABIRD BYCATCH IN WEST COAST LONGLINE FISHERIES

PI
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Other UW Personnel
Troy Guy — Washington Sea Grant

NOAA Personnel
Steve Copps — National Marine Fisheries Service, Northwest Region
Jon McVeigh — Northwest Fisheries Science Center, Groundfish Observer Program

Non-UW/Non-NOAA Personnel
Rob Suryan and Amanda Gladics — Oregon State University
Joe Tyburczy — California Sea Grant Extension

Task III

NOAA Sponsor
Tom Good — Northwest Fisheries Science Center

NOAA Goal
Healthy Oceans

Description
Research in the reporting period was focused on collecting and summarizing data on the vessels, gear and fishing practices of the West Coast longline fleet to inform and structure our research. Data were collected via 19 port visits or meetings, through public sources, and via a written survey instrument. These visits also allowed us to make fishermen aware of the availability of free streamer lines through a NMFS-funded program, encourage their voluntary use, alert stakeholders to pending seabird bycatch regulations, and share tools available to prevent seabird mortalities in longline fisheries. Collectively, these activities allowed us to identify industry leaders from Neah Bay, Washington to Monterey, California that hold large amounts of sablefish limited-entry quota, or who are influential in establishing fishing practices for longline vessels found along the coast. Poor catch rates and low prices for sablefish coast wide, and reduced sablefish quotas in the 2013 fishing season led to tremendous uncertainty among Sablefish longline vessel operators in the 2013 fishing season. These circumstances led many longline fishermen to wait until the last weeks of the season to fish, or to abandon fishing for Sablefish altogether. Consequently, host vessels were difficult to recruit to our research program. In some cases, requirements to carry fishery observers precluded vessels from participating in our voluntary research program, as vessels could not accommodate an observer and one of our scientists. Data collection at sea on the performance of streamer lines was limited to two trips aboard one longline fishing vessel based in Eureka, California. Data collection focused on monitoring longline sink rates, measuring bird response to streamer lines, and introducing streamer lines to the vessel owner/operator. Sink rate data were collected from one vessel by a fishery observer and from a volunteer vessel. Several fishery observers, International Pacific Halibut Commission (IPHC) observers and a longline operator were trained to collect sink rate data.

Objectives
1. Refine and develop effective and practical tools to reduce seabird bycatch in West Coast longline fishery for sablefish in collaboration with the fishing industry, with a focus on smaller vessels (< 55 feet) and those vessels using combinations of weights and floats on the groundline.
2. Collect data to characterize the fleet (vessel classes, gear, and fishing practices) to structure the research.
3. Based on the fleet characterization, recruit owners/operators of vessels to host research on their vessels in the 2013 and 2014 fishing seasons (April 1 to September 31). Host vessels will be partially compensated to offset increased costs (insurance, food, and possible bait loss) and to provide an incentive.
4. Aboard host vessels, establish the sink profile of longline gears used by the West Coast Sablefish fleet (snap-on, tubs, skate-bottom, auto-bait, weighted, unweighted, with floats, etc.) and evaluate the performance of one vs. two streamer...
lines across these gears. To start, streamer lines will be those designed by Washington Sea Grant (WSG) and currently being made available to the West Coast fleet via Pacific States Marine Fisheries Commission (PSMFC), with funding from NOAA Fisheries.

5. Match the span of the aerial extent of streamer lines to the distance behind the vessel at which birds can access baits—a depth of 2 m for albatrosses by manipulating weights and floats on the gear and streamer line specifications (aerial extent, height of attachment, towed device, and number and type of streamers).

6. In collaboration with the West Coast Groundfish Observer Program, the IPHC, and volunteer vessels, collect data on longline gear sink profiles using time-depth recorders. These data will augment data collected on host research vessels.

7. Based on results, recommend seabird bycatch avoidance requirements for smaller vessels (< 55 ft.) under the adaptive management strategy set forth in the Biological Opinion.

8. Recommend revisions to the pending seabird bycatch avoidance regulations for larger longline vessels (≥ 55 feet), as appropriate.

9. Provide those results and recommendations to NMFS and the Pacific Fishery Management Council for consideration based on results and consultation with the fishing industry and other stakeholders.

**Accomplishments**

**Augmenting Capacity:**
Complementing the capacity augmentation accomplished in the last reporting period through grants from the Packard Foundation ($115,000) to WSG and the National Fish and Wildlife Foundation ($235,000) to Oregon State University, we recruited Joe Tyberczy, California Sea Grant Extension Agent based in Eureka, to the research and outreach effort. Although unsupported by grants at this time, he is providing his time to collect data at sea and assist with outreach efforts in Northern California.

Engaging Fishery Stakeholders:
Engagement with the stakeholders of the West Coast Sablefish longline fishery was extensive in this reporting period. We collected information on the vessels; gear and fishing practices of the West Coast sablefish longline fleet via publicly available fishery permit data, discussions with agency collaborators, and through direct contact with fishing vessel owners and operators. In May and June, 2013, we met with a wide variety of sablefish fishery stakeholders in the course of visits to 13 ports: Westport, Ilwaco, Chinook, Astoria, Warrenton, Hammond, Newport, Reedsport, Charleston, Port Orford, Brookings, Crescent City, and Eureka. Stakeholders included vessel owners, vessel operators, state port biologists, federal fisheries observers and observer program de-briefers, marine suppliers, fish processing managers, and Sea Grant extension agents. These port visits allowed us to identify industry leaders in West Coast ports who are influential in establishing fishing practices for the various size classes of longline vessels found along the coast. More specifically, we identified several Sablefish longline vessels to host our research in the 2013 fishing season.

Building on our 2013 effort to recruit vessels to host our research, in 2014 we hosted five meetings for longline fishermen in five West Coast ports (Westport,
Astoria, Newport, Charleston, and Port Orford) and participated in the annual fisheries meeting of the Makah Tribe in the reporting period. In all these forums, we presented information on seabird bycatch and its prevention in longline fisheries, and renewed effort to recruit vessels to host our research in the 2014 fishing season. Meetings were scheduled for Fort Bragg and Eureka, California in early April 2014. These port-to-port outreach efforts were the cornerstone of a comprehensive outreach effort, which included developing and mailing a four-page flyer and the albatross ID card to all owners of Sablefish limited entry quota; gathering data on fleet characteristics via a revised fleet survey instrument; and launching a website designed to inform West Coast longliners on seabird bycatch. Several longliners were recruited to host research starting April 1, 2014.

Field Work:
Despite difficulties in the fishery in 2013 (see Reasons Objectives Were Not Met), we worked closely with the two largest Sablefish quota holders in the Port of Eureka. One vessel hosted our research for two fishing trips in which we collected data on the sink rates of longline gear using a combination of weights and floats (floating gear) and introduced the vessel to using streamer lines. The other vessel deployed time-depth recorders on similar gear, and started using streamer lines. Data confirmed that floating gear sinks beyond the reach of albatrosses well past the effective span (aerial extent) of streamer lines (Figures 1 and 2).

Following Council action in November 2013, we altered our research approach in three ways:
1. We eliminated the control of no deterrent in our comparison of streamer lines. This change reflects our interest in minimizing albatross mortalities resulting from the research activity and the interest of the Council in finding the best seabird bycatch avoidance options for smaller vessel (as opposed to determining if seabird avoidance methods are necessary).
2. We switched our 2014 research focus to smaller vessels to address the Council’s interest in finding safe and practical options for smaller vessels. Our efforts in 2013 targeted larger vessels knowing that new seabird bycatch requirements were pending. Once in place, manipulating streamer lines performance specification on larger vessels would not be possible without an Exempted Fishing Permit.
3. Given the slowed sink rate of hooks around the floats used in floating gear, our efforts in 2014 will give priority to working with vessels on developing seabird bycatch mitigation options for vessels using floating gear.

**Reasons Objectives Were Not Met**
Poor catch rates and low prices for sablefish coast wide, and reduced sablefish quotas in the 2013 fishing season led to tremendous uncertainty among sablefish longline vessel operators in the 2013 fishing season. These circumstances led many longline fishermen to wait until the last weeks of the season to fish, or to abandon fishing for sablefish altogether, making it difficult for potential host vessels to plan their longline fishing. In some cases, requirements to carry fishery observers precluded vessels from participating.

![Figure 2. Sink profile of floating gear from a 35-foot longline vessel. The sink rate of the longline is variable with weights sinking quickly and within the aerial extent of streamer lines (131 feet). Floats sink much slower and well beyond the protection of streamer lines.](image-url)
in our voluntary research program, due to limited space on the vessel for an observer and our scientists. Consequently, we collected data on only one vessel and that was in the closing days of the fishing season.

In the 2013 fishing season, the Pacific Fishery Management Council had not taken action on the environmental assessment of measures to minimize the take of short-tailed albatross in the Pacific Coast groundfish fisheries. As a result, awareness of the albatross bycatch issue in the West Coast longline fleet was extremely low at the port level, which further compromised our ability to recruit vessels during the 2013 sablefish season. However, the Council did take action in November of 2013. Seabird bycatch avoidance requirements are pending for larger vessels (≥ 55 feet) and scheduled to go into effect sometime during the 2014 season. Council action and our extensive outreach to the fleet are likely to improve prospects for recruiting longline vessels to host our research in 2014.

See the Appendix for publications connected to this project. In February 2014, a flyer was published by Washington Sea Grant and Oregon State University called, “Albatross Protection and West Coast Groundfish Fisheries: What Fishermen Need to Know.” More information can be found on our website at http://seabirdbycatch.washington.edu. A poster was presented at the 18th Western Groundfish Conference in Victoria, British Columbia in February 2014 titled “Reduction of Seabird Bycatch in West Coast Sablefish Fisheries Requires Collaborative Research.” Also at the conference, a presentation was given titled “Overlap of North Pacific Albatrosses with the U.S. West Coast Groundfish and Shrimp Fisheries.”
MARINE BIOLOGICAL INTERACTIONS IN THE NORTH PACIFIC – FISH INTERACTIONS TASK

PI
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Other UW Personnel
Richard Hibpshman, Kirstin Holsman, Sean Rohan, Caroline Robinson and Kimberly Sawyer — School of Aquatic and Fishery Sciences
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Task III

NOAA Sponsor
Kerim Aydin — 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, and development of ecosystem indicators.

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 use groundfish food habits data to develop or improve multispecies models for fisheries management.
4. To refine, update, and expand the Ecosystem Considerations report.
5. To develop ecosystem models of Arctic regions.

Accomplishments
1. Investigations of the Feeding Ecology of North Pacific Fishes – a total of more than 12,350 groundfish stomachs were analyzed in the laboratory, and 5,594 were analyzed at sea.
2. Assistance collecting stomach, plankton, or benthic samples in the field – collection and shipboard analysis of groundfish stomachs during the time period was over 10,000 samples.
3. Multispecies Statistical Model modifications – as part of NOAA's Integrated Ecosystem Assessment (IEA) program, a multispecies statistical model (MSM) was developed for the Bering Sea, connecting the stock assessment models of three groundfish species. Considerable statistical work was performed for the improved, bioenergetic estimation of fish rations based on 30 years of available diet data. Results were used in a series of Management Strategy Evaluations (MSEs) of the Bering Sea that included results of future climate forecasts.
4. Refine, update, and expand the Ecosystem Considerations report – the Ecosystem Considerations report is produced annually for the North Pacific Fishery Management Council (NPFMC) as part of the Stock Assessment and Fishery Evaluation (SAFE) report. The goal of the Ecosystem Considerations report is to provide an overview of marine ecosystems in Alaska through ecosystem assessments and tracking time series of ecosystem indicators. The ecosystems currently under consideration are the Eastern Bering Sea (EBS), the Aleutian Islands (AI), and the Gulf of Alaska. This year, the Ecosystem Considerations chapter includes both new and updated sections.
5. The section describing ecosystem and management indicators includes updates to 52 individual contributions, and presents seven new contributions. In November 2013, the EBS and AI, and Arctic Ecosystem Assessments were updated.
6. The EBS and AI report cards and Ecosystem Assessments were presented to the NPFMC Groundfish Plan Teams in November 2013, and to the NPFMC in December 2013, as part

7. Develop ecosystem models of Arctic regions – an ongoing research project was completed to build and update an ecosystem model for the Chukchi Sea marine ecosystem. The model will be used to 1) characterize the trophic structure of the eastern Chukchi Sea; 2) investigate the potential impacts of introducing commercial fisheries for snow crab (Chionoecetes opilio) and/or Arctic cod (Boreogadus saida); and 3) identify key uncertainties about food web dynamics.
FLOODPLAIN DIVERSITY AND SPAWNING AREA PRODUCTIVITY IN THE YAKIMA RIVER, PART V: LINKING VARIATION IN SPAWNER PHENOTYPE WITH HABITAT CHARACTERISTICS

PI
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Other UW Personnel
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NOAA Personnel
George Pess — Northwest Fisheries Science Center

Other Personnel
Todd Pearsons — Grant County PUD

Task III

NOAA Sponsor
Andrew Dittman — Northwest Fisheries Science Center

NOAA Goal
Healthy Oceans

Description
This study is Phase V of on-going work on floodplain diversity and spawning area productivity in the Yakima River. The initial phases of the proposed work (funded by NOAA) involved collecting and georeferencing spatially continuous data on aquatic habitat and fish assemblages throughout the entire upper Yakima basin (160 km). The goals of the current project are to (1) use these data to develop spatially explicit models that predict habitat selection by hatchery versus wild salmon; and (2) analyze the relationship between individual spawner phenotype (e.g. size) and habitat selection.

Objectives
1. Analyze the relationship between individual phenotype of adult spawners and spawning habitat selection.
2. Conduct multivariate analysis using demographic data from over 15,000 georeferenced spawning salmon in relation to gradients in physical habitat quality.
3. Use these data to refine models for quantifying and predicting differences in habitat selection by hatchery and wild salmon at multiple scales.

Accomplishments
Objective 1: Data entry and analysis for redd surveys were completed and analyzed, and the relationship between individual spawner phenotype and spawning habitat selection was quantified by Darran May. A manuscript has been submitted for review in the journal of Fisheries.

Objectives 2 and 3: Jeremy Cram analyzed data and made significant progress on writing Chapters 2 and 3 of his dissertation (Chapter 1 is published in a peer-reviewed journal; see publications), which identify aquatic habitat predictors of redd and carcass distribution at multiple spatial scales. Jeremy Cram recently accepted a job with Washington Department of Fish and Wildlife and is completing his dissertation as part of this job; he is no longer funded by this grant. Ryan Klett completed his Master’s thesis (see publications) and is revising a journal article from his thesis; he is employed by the Confederated Tribes of The Colville Reservation and is no longer funded by this grant.
SEAFLOOR PROCESSES
ADIOS3: PHYSICAL MECHANISM OF DROPLET FORMATION FOR IMMISCIBLE FLUIDS INJECTED INTO WATER THROUGH A HIGH REYNOLDS NUMBER JET. MODELING DROPLET BREAKUP TO DETERMINE THE FATE OF DEEPWATER HORIZON OIL

**PI**
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**Task III**

**NOAA Sponsor**
William Lehr — Emergency Response Division, National Ocean Service

**NOAA Goals**
Healthy Oceans
Resilient Coastal Communities and Economies

**Description**
The goal of this project is to provide NOAA ERD with better understanding of the physics that determine oil droplet and gas bubble size distributions in underwater blowout conditions. Models derived from carefully controlled laboratory experiments will provide quantitative capabilities to the effort of determining the fate of oil from underwater oil spills.

Air and liquids of different physical properties (density, viscosity and surface tension) have been injected coaxially with a high Reynolds number jet inside a large water tank. Bubble and droplet breakup has been studied and correlated with the velocity field in the jet, measured a priori with Particle Image Velocimetry. The statistics of the turbulent flow, mean velocity, turbulent fluctuations (rms) and shear values across the jet and a function of distance downstream have been measured.

**Objectives**

1. To provide experimental evidence of gas bubble and oil droplet break up in high Reynolds number turbulent flows.
2. To analyze the data to understand the mechanisms that lead to breakup, and determine the daughter size distribution, for different values of the physical properties of the discrete phase (bubbles and droplets) and of the turbulent flow characteristics (turbulent dissipation rate, length scales, mean shear rate, etc.).
3. To create quantitative models to include these mechanisms in large computational codes that simulate the global physics, but contain only a highly parameterized picture of the microphysics that control the break up processes.

**Accomplishments**
The break-up frequency and convective flux of both bubbles and oil droplets have been measured. A model to predict the statistics of the break up process as a function of physico-chemical properties of the fluid and the flow variables have been developed, as shown in figures 1-4.

Two manuscripts have been prepared for archival journal submission, and two presentations have been given at conferences:

Figure 1. Evolution of the Bubble Number Density Flux with distance downstream. The bubble number density increases with Jet Reynolds number, as the more energetic turbulence is more effective at breaking up smaller bubbles. The break-up process is finished at position $z/d_j = 30$.

Figure 2. Cumulative Volume PDF for the bubble diameter, as a function of position downstream. The theoretical model (with no fitting parameters) matches the results, and the evolution with break-up, accurately.

Figure 3. PDF for the non-dimensional bubble diameter, for three different Jet Reynolds numbers. The PDF has a universal shape when the Sauter Mean Diameter (a volume to surface area average) is used to characterize the different sizes resulting from the break-up process at different turbulence intensities.

Figure 4. Empirical fit to the Sauter Mean Diameter of the bubble cloud as a function of turbulent kinetic energy dissipation rate ($\varepsilon$). This value and the non-dimensional PDF, modeled as a Gamma function, provide a complete model for bubble size distribution resulting from turbulent break-up, taking into account the conditions at injection (radial and downstream position and Reynolds number) and the physico-chemical properties (density, surface tension, etc.) of the disperse phase.
EARTH-OCEAN INTERACTION PROGRAM (FORMERLY VENTS HYDROTHERMAL RESEARCH GROUP)

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Task II

NOAA Sponsor
Mark Koehn — Pacific Marine Environmental Laboratory

NOAA Goals
Healthy Oceans

Description

Scientists at the University of Washington and the Pacific Marine Environmental Laboratory share an interest in the interactions between the ocean and solid earth, and how these interactions affect the chemistry of the oceans and impact the living and non-living resources within the ocean.

The primary focus of the Earth Ocean Interactions Research Group (EOI) program is the exchange of heat and chemicals with the Earth’s crust, primarily at sites of submarine volcanism. The ocean is home to more than 80% of Earth’s volcanic activity, including the mid-ocean ridges that girdle the earth and arc and back-arc volcanoes. At these sites, seawater circulates through the hot-ocean crust, producing commercially important mineral and biological resources, and providing pathways for the deep convective overturn of water influencing Earth’s climate. In addition to hydrothermal exchange, EOI also examines impact of the ocean margins and continentally derived dust on ocean chemistry and its relation to ocean productivity and climate.

EOI combines a wide range of scientific expertise and technologies in an interdisciplinary approach to ecosystem studies. Ocean water-column physical and chemical measurements illuminate the sources and distribution of life-limiting ocean nutrients, and are combined with multi-scale seafloor mapping to discover novel and critical benthic habitats. Coordinated chemical/microbiological sampling techniques are used to quantify microbial diversity and the role of microbes in mediating chemical transformations. Benthic biological communities are analyzed and related to their chemical environment and their biogeographical context, while local-to-regional-scale ocean circulation models predict the effects of seafloor topography on the distribution of tracers and the dispersal of larvae. Innovative ocean engineering expertise is directed at developing new deep-sea observing technologies. The synergy of these multiple disciplines produces new approaches to existing NOAA priorities.

Of particular interest to EOI is locating and identifying the chemical character of new volcanic and hydrothermal ecosystems within the world’s oceans. We seek to quantify the impact of submarine volcanism and hydrothermal activity on regional and global-ocean chemical and heat balance. We also contribute to understanding the importance of these sites as habitats for microbes and vent fauna, their distributions in the ocean and their biomedical potential for the development of novel drugs. Hydrothermal areas also provide unique natural laboratories for the study of processes of global importance, such as the impact of increasing global carbon dioxide and ocean acidification on ecosystems, the potential effects of carbon dioxide sequestration in the deep ocean, the potential impact of the mining of mineral deposits generated by submarine hydrothermal activity, and the impact that hydrothermal iron may have on surface ocean productivity. The research performed by the Vents group is interdisciplinary in nature, requiring the
understanding of the geology, geophysics, acoustics, physical oceanography, chemical oceanography, geochemistry, and microbiology of deep sea and hydrothermal ecosystems.

EOI fits within the NOAA Ecosystem Research Program, as part of the Ecosystem Goal Team. JISAO scientists are actively engaged in research that characterizes ecosystems and, in particular, looks at the impact of submarine eruptions and hydrothermal venting on the ocean environment. Active submarine volcanism and hydrothermal ecosystems are important in their own right, but hydrothermal vents also affect marine ecosystems across a wide range of depths, from the deep ocean floor to the surface ocean, and they constitute uniquely valuable natural laboratories. For example, the hydrothermal areas studied by the Vents program provide critical sites (NW Eifuku, Mariana Arc) to study the potential impact of carbon dioxide sequestration in the deep ocean. Many other hydrothermal sites can be used to study local acidification from volcanic carbon dioxide and other acidic compounds as an analog for a future acidified ocean. Finally, sites of hydrothermal activity are soon to be actively mined for their ores, and NOAA has an important stewardship role to document, sample, and understand these ecosystems in light of this anthropogenic impact.

The UW portion of EOI proposes to conduct research on the primary chemical and geochemical aspects of submarine volcanism and hydrothermal venting. This research complements and enhances ongoing research at the University of Washington’s College of the Environment on the geologic, acoustic, physical, geophysical, microbiological and isotopic aspects of this interdisciplinary research.

Objectives
1. To understand the interplay between the chemical environment of deep ocean habitats, biodiversity and the structure and function of deep ocean ecosystems.
2. To assess the impact of the chemical exchange between solid earth and the oceans, especially that associated with submarine volcanic and hydrothermal activity.
3. To understand ocean acidification, especially at sites acidified by volcanic and hydrothermal activity.
4. To explore the deep ocean to locate and characterize neovolcanic areas and their associated hydrothermal ecosystems.

Accomplishments
Objective 1:
Accomplishments in ecosystem studies.

Ocean Observatories. EOI scientists are in the 16th year of continuous monitoring at Axial Seamount with the NeMO observatory, and have now captured a complete volcanic cycle spanning the 1998 and 2011 eruptions at Axial. By providing expertise in hydrothermal systems and access for the OSU pharmacology group to critical sample material, EOI researchers are contributing to frontier research in natural products discovery with importance to society and NOAA strategic goals. The Butterfield lab participated in two remotely operated vehicle (ROV) expeditions (R/V Thompson with Jason and the Schmidt Ocean Institute’s new vessel Falkor with ROV Remotely Operated Platform for Ocean Science [ROPOS]). These cruises are maintaining the longest ongoing time-series for a hydrothermal site, and are conducting new experiments to quantify and model the role of microbes in submarine volcanic systems. A major effort of Butterfield, Larson, and PMEL engineering for 2013/14 has been the development and testing of a new ROV-mounted deep-sea incubator to measure microbial growth rates of hyperthermophiles at controlled temperatures. This new instrument will utilize the technique of in-situ Stable Isotope Probing (SIP), whereby 13C-labeled bicarbonate is incorporated into an actively growing microbial community, followed by sequencing of the isolated, isotopically enriched ribonucleic acid (RNA) fraction. To our knowledge, this will be the first time the SIP technique has been used on the seafloor.

Construction of the Ocean Observatories Initiative Regional Scale Node (OOI-RSN, formerly NEPTUNE) is nearing completion, and will provide real-time cabled communication and power between Axial Seamount and land, with streaming data from multiple sensors. EOI scientists have contributed instruments and scientific expertise to this effort. Our next-generation interactive sampler for time-series chemistry and microbiology will be deployed at Axial Seamount in 2014. Butterfield has deployed and operated an interactive water sampler at a submarine
hydrothermal vent site for NEPTUNE Canada since 2010 (see Figure 1). The latest instrument will be recovered in May 2014, and time-series samples will be analyzed to look for correlations with earthquakes, heat flux, currents, and biological activity. Butterfield is serving on the Ocean Networks Canada Observatory Council to provide scientific advice to the operators of Canada’s cabled observatory.

Ocean Mining. Since 2001, NOAA and the Republic of Korea Ministry of Oceans and Fisheries (MOF) have collaborated under a Joint Project Agreement (JPA) for Science and Technical Cooperation in Integrated Coastal and Ocean Resources Management. As part of this agreement, the NOAA PMEL and JISAO scientists are working with Korean scientists on assessing impacts from proposed Korean Mn-nodule mining in the Eastern Pacific. It is important to evaluate the environmental impacts of this economic activity. In May 2013 and February 2014, Resing participated in “NOAA-Ministry of Oceans and Fisheries (Korea) Joint Project Agreement (JPA) Ocean Research Panel” meetings in Seattle and Honolulu respectively.

Objective 2:
Accomplishment on the impact of chemical exchange between solid earth and the oceans.

Geotraces Pacific Section. In FY2013-2014, we participated on the Geotraces Eastern Pacific Zonal Section from October 25 to December 19, 2013. The program was conducted by the U.S. Geotraces program whose guiding mission is to identify processes and quantify fluxes that control the distributions of key trace elements and isotopes in the ocean, and to establish the sensitivity of these distributions to changing environmental conditions. The cruise track (Figure 2) crossed strong gradients in physical, chemical and biological properties in both surface and subsurface waters. The cruise began at the margin of the Eastern SubTropical South Pacific where cold, freshly upwelled, nutrient-rich waters result in highly productive waters producing a dynamic interplay between margin sediments and ocean chemistry. As the cruise transited west-ward it encountered the oligotrophic waters of the South Pacific Subtropical Gyre, whose chemistry are impacted by the deposition of dust from the Australian continent. Finally, the cruise track crossed the Southern East Pacific Rise (SEPR) where hydrothermal venting impacts the chemistry of the oceans.

Our participation was driven primarily by the opportunity to examine the impact of the SEPR on Ocean chemistry. The net impact of eruptive and hydrothermal emissions from submarine volcanoes has been debated since the discovery of hydrothermal activity at the mid ocean ridges. It has long been thought that hydrothermal Fe and Mn are rapidly removed from solution by particles through scavenging and that they do not readily escape the general area of the ridge crest. However, recent studies indicate that hydrothermal Fe may be stabilized by a variety of processes, including through interactions with organic matter and the formation of organic complexes, small particles, and colloids. In addition, recent data sets suggest that Fe can be transported significant distances from its hydrothermal sources. These studies hint that hydrothermal activity may impact global ocean chemistry and ultimately
oceanic productivity, especially in regions like the southern ocean where abundant macro nutrients exist, but productivity is limited by a deficit in Fe. While at sea JISAO scientists and colleagues from Old Dominion University analyzed samples for dissolved Fe, Mn and Al. Our data unambiguously documented for the first time that Fe, Mn, and Al can be transported > 3000 km from Southern East Pacific Rise (e.g., Mn Figure 2). Previously the EOI program’s John Lupton documented the westward flow of water from the SEPR through the use of 3He, making this the most obvious hydrothermal impact on global ocean chemistry. 3He, which is almost entirely supplied to the oceans from the mantle via submarine hydrothermal and eruptive activity is inert and is only lost through dilution, and therefore it can be carried great distances throughout the ocean. During the Eastern Pacific Zonal Transect (EPZT), we documented that Fe and Mn can be carried along 3He’s pathway more than 3000 km from the SEPR. In addition, we find that at this distance, almost 1% of the hydrothermal Fe still remains in the dissolved form. This is considerably greater than the 0.2% used in models that demonstrated that hydrothermal activity has the capacity to reach the surface waters of southern oceans and thereby impact oceanic productivity.

Trace Metals on the CLIVAR/Repeat Hydrography A16N Expedition. This project examines decadal-scale changes in the distribution dissolved and particulate trace elements in the North Atlantic Ocean. Trace metal distributions in the major ocean basins are controlled interactions between the solid earth and ocean through several mechanisms. One of the most important mechanisms is the transport of dust from land to the ocean. In 2003, the A16N CLIVAR line was first sampled for trace metals and aerosol input, providing high resolution profiling of these elements in the ocean. In 2013, we reoccupied this section and can now resolve how changes in aerosol deposition are linked to observed changes in upper-ocean trace metal distributions.

Atmospheric deposition and partial dissolution of continental mineral dust as a major source of dissolved Fe to surface waters is now well established. It has been demonstrated that the availability of Fe limits the ability of photosynthetic organisms to utilize nutrients, and thus may control their ability to fix CO2. This is especially important for high nutrient low chlorophyll regions of the ocean that are thought to receive extremely low amounts of aerosol deposition and thus have extremely low concentrations of Fe. Understanding the factors that control the magnitude and rate at which CO2 partitions between atmospheric and oceanic reservoirs is critical to understand both the fate of contemporary CO2 emissions, as well as the role that this partitioning has played in glacial-interglacial climate change. Physical processes can redistribute atmospheric CO2 into the ocean while biological ones can transfer carbon from the atmosphere to

Figure 2. Top Panel. Cruise track for the Geotraces Eastern Pacific Zonal Section from Manta Ecuador to Papeete, Tahiti. The cruise took place from October 25 to December 19th, 2013 aboard the University of Washington’s RV THOMAS G. THOMPSON. Bottom panel. The distribution of Mn along the section. A gradual decrease in the concentration of dissolved Mn in the surface ocean is observed from east to west. In the deep waters a large plume of dissolved Mn can be observed emanating from the Southern East Pacific Rise. Enrichments at plume depth can still be observed 3,200 km to the west of the Ridge Crest.
the deep ocean and sediments via surface water productivity and export of phytoplankton during nutrient cycling (the “biological pump”). In the latter case, there is an abundance of evidence that this biological transfer function is moderated by the abundance of biologically-available Fe. Experimental addition of Fe to the surface waters has supported this theory by showing the pronounced effects Fe addition has on biological production in these regions. Clearly, the geochemical effects of dust deposition on the surface of the contemporary ocean must be understood before we can attempt to evaluate the biogeochemical consequences of enhanced dust fluxes during modern and glacial periods. Only when the geochemical systematics of contemporary dust deposition have been thoroughly characterized will it be possible to translate the observed glacial-interglacial fluctuations in atmospheric dust fluxes into possible marine biogeochemical effects. This knowledge is vital if we are to develop realistic models linking atmospheric and oceanic processes that can be used to provide meaningful insights into climate change. Increased focus on the importance of Fe and other biologically-significant trace metals has resulted in an effort to document baseline distributions in a changing climate and environment and understand the biogeochemical processing of these elements. This is highlighted by programs such as the CLIVAR/CO2 Repeat Hydrography program, and the launch of dedicated trace metal sampling efforts like the global GEOTRACES program. We are now moving beyond establishing a baseline and beginning to probe the extent of natural variability by monitoring decadal-scale changes and identifying patterns of dust delivery and trace element biogeochemical cycling in the water column.

In August-September 2013, we participated in the 2013 re-occupation of CLIVAR/CO2 Repeat Hydrography Program section A16N (August 3, 2013 - October 3, 2013 from Reykjavik, Iceland to Natal, Brazil). Along with collaborators at Florida State University, we conducted 64 trace element vertical profiles (with 12 depths in the top ~1100 m) at 64 stations between 63 degrees N and 2 degrees S with approximately 1 degree spacing using GO-FLO bottles on a dedicated trace metal-clean rosette. Subsamples were drawn for temperature, salinity, macronutrient analysis (nitrate, phosphate), and dissolved trace elements in a specially outfitted trace-metal sampling van. Filtered (0.4μm pore size) seawater subsamples were run ship-board for dissolved Fe and dissolved Al by flow injection analysis. Bottles were sampled for particulate matter by pressure filtering seawater through 0.4μm track-etched polycarbonate filters that were rinsed, dried, and stored for shore-based analysis at NOAA/PMEL. In addition, our collaborators collected aerosol samples for chemical analysis and dust solubility studies. Shipboard dissolved Al and Fe data have been compiled and reported to CLIVAR and Carbon Hydrographic Data Office. All particulate matter samples (n=1000) were analyzed post-cruise at NOAA/PMEL for trace element composition by energy-dispersive x-ray fluorescence (ED-XRF). Our high-resolution profiling reveals fine-scale features in the distributions of Fe, Al, and other trace elements which were previously unrecognized (Figure 3). Estimates of the surface-ocean residence time for dissolved and particulate phases of Fe, Al and Mn demonstrate the relative importance of atmospheric deposition, particle scavenging, and biological uptake.

Figure 3. Dissolved Al distributions reveal only small changes between 2003 and 2013. However the surface ocean shows large changes from the equator to 20N further reinforcing our hypothesis about the interannual variability in the Al signal and its application to estimating Fe flux.
for controlling these distributions in different regimes with varying dust inputs and biological activity. As we interpret the results we look to assess whether individual features are in steady-state, and how they may respond to both short-term variability and decadal trends in dust inputs. How are the previously observed features related to variations in dust deposition over the intervening years? We know that dust deposition is quite variable and ask, “In this setting, which of the geochemical tracers best reflects the integrated dust input to the ocean?”

Objective 3: Accomplishments in Ocean Acidification.

The long-term increase in atmospheric carbon dioxide and the consequent increased CO2 content and lowered ocean pH raise serious concerns about the future habitability of the oceans for many species with critical ecological importance to our planet. There is a huge uncertainty in how ocean acidification will affect marine life. Can animals adapt to higher CO2 and lower pH? Which species will survive and which will perish?

In 2013, we proposed to locate and characterize sites of CO2 venting on shallow volcanoes in the northern Mariana arc because the chemical gradients around these sites would provide an opportunity to study communities chronically exposed to low-pH conditions in the natural environment. This concept has been recommended in the Ocean Acidification Research Plan, but very few studies have addressed it. Now, with NOAA ship time, supplementary funding from the NOAA Ocean Exploration and Research program, and the cooperation of the Pacific Island Fisheries Science Center (PIFSC) and other collaborators, we will conduct extensive sampling and surveying by SCUBA divers, combined with in-situ pH sensors, current measurements, and water column profiling to study volcanic ocean acidification in and around Maug caldera. During this May 2014 expedition, we will also explore a suspected underwater volcanic eruption at nearby Ahyi seamount. Volcanic activity began on April 24, 2014, and our goals are to confirm the exact location of the activity and its effects on the ocean. Shallow volcanic eruptions may significantly alter the ecology of the surface ocean, but the impacts are very poorly known.

The initial survey work is a collaboration between JISAO and PMEL scientists and scientists from the PIFSC, Coral Reef Ecosystem Division. During this reporting period, we worked directly with PIFSC to plan for the upcoming field work (see Figure 4). Our scientific equipment was packed and loaded onto the research vessel. Six JISAO scientists will participate on this cruise (Butterfield, Larson, Roe, Buck, Barrett, and Michael). We also attended the NOAA-Ocean Acidification PI meeting in Washington DC to develop working and funding relationship with the Ocean Acidification program.

Atlantic Ocean
In 2013 we completed a study (Barrett et al., 2014) on the impacts of ocean acidification on
the distribution of biogenic particulate calcium (Ca) in the tropical Atlantic Ocean from samples collected in 2003 along CLIVAR’s A16N section (Figure 5). Our observations indicate that there is a deficit in particulate Ca below depths of 400m from 5-30 °N, and that this depth corresponds to corrosive low pH waters (Figure 5) that are undersaturated with respect to aragonite and high magnesium calcite.

In addition, as discussed elsewhere in this report, we participated in the CLIVAR A16N repeat hydrography cruise from August to September 2013. During this cruise we repeated the collection of samples of pCa as discussed in Barrett et al., 2014. These data will allow us to look for shoaling or an increase in the pCa deficit brought about by increased ocean acidification over the last decade. To supplement this study, we filtered large (>10L) seawater samples to collect pteropods that may be present in the surface Atlantic Ocean. Our primary aim is to test the hypothesis that pteropods may be a dominant component of particulate Ca in the Atlantic Ocean due to their large size. In addition, we will examine the impact of this corrosive area on the pteropods that are found.

Objective 4: Accomplishments in Exploration.

Western Pacific. JISAO and NOAA scientists have participated in a multi-year project funded by NOAA Ocean Exploration and the National Science Foundation to study submarine volcanic arcs in the western Pacific. The scientists have conducted more than nine major oceanographic expeditions to study submarine arc volcanoes in this region. Highlights from many of these expeditions can be seen on Ocean Exploration web sites: http://oceanexplorer.noaa.gov/explorations/explorations.html http://laueruptions.blogspot.com/

Lau Basin. The Lau basin has been examined by NOAA and JISAO scientists on six different cruises between 2004 and 2012. No new field work was conducted in 2013, however results of past expeditions are in progress. Three presentations were made at the Fall 2012 meeting of the American Geophysical Union. A manuscript has been submitted by Embley et al, and two others have been edited by all co-authors in 2013 and should be submitted shortly.

Mariana Arc and Back Arc.

Bubble Plume/Volcanic Flux Studies. In 2013, we examined multibeam data from NW Rota-1 submarine volcano, the first site on Earth where underwater explosive eruptions were directly witnessed. These data were used to investigate the dynamics of the eruptive plumes in the water column over the volcano and their effect on the local ocean environment. The primary tool for this study is a new class of multibeam sonar that is capable of imaging CO2 bubbles released during eruption. During an expedition in 2010, we collected an extensive mid-water multibeam sonar dataset. In 2012 we processed and characterized the mid-water multibeam data collected at the volcano in 2010. We extracted key eruption plume information (plume height, intensity, amount and direction of deflection by currents, and how these change with time) and we compared these results with ROV-visual, hydrophone-acoustic, and Acoustic Doppler Current Profiler (ADCP)-current data also collected during the 2010 cruise. Results were presented by Chadwick et al and Merle et al at the 2013 Fall Meeting of the American Geophysical Union.
These mid-water sonars are now available on many research ships, so assessing their full capabilities and scientific usefulness is important. Is this a good way to remotely characterize a volcano’s activity and its impact on the ocean? To complement the sonar approach, we developed a plan to evaluate flux from the volcano using four separate techniques. If the idea is funded it will be pursued in 2014.

Planning Future Exploration. During 2013, we undertook planning for four additional cruises to the Mariana arc in the next two years. Two cruises will take place in 2014. The first is to the Maug volcano on the Mariana arc, as discussed above. The second is to multiple submarine volcanoes on the Mariana Arc in late 2014. It is a joint project between Western Washington University through NSF and NOAA’s Ocean Exploration Program.

Planning was also undertaken for two cruises to the Mariana Back arc in 2015. The first will explore the Mariana Back arc for hydrothermal activity using water column techniques. The second will visit the hydrothermal areas identified by the first leg with an ROV. Ship time for these is funded by the Schmidt Ocean Institute, while exploration and science will be funded by NOAA-Ocean Exploration.
TSUNAMI OBSERVATIONS AND MODELING
TSUNAMI RESEARCH

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Task II

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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 which 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 the JISAO/UW scientists in the Tsunami Research Program. NCTR is comprised mainly of JISAO/UW scientists. Basic research into tsunami generation, and numerical modeling of propagation and inundation provide the basis for forecasting, and the Short-term Inundation Forecasting for Tsunamis (SIFT) 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 Ocean, which detect and report in real time the passage of a tsunami wave. The instruments developed at PMEL, called DART’s (Deep-ocean Assessment and Reporting of Tsunamis) 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, a federal/state collaborative partnership of NOAA, the U.S. Geological Survey, the Federal Emergency Management Agency, the National Science Foundation, and the Emergency Management and Geotechnical agencies of 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 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 develop new tools for hazard assessment and forecast, including landslide-generated tsunami modeling.

5. 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. Version 3.1.0 of the tsunami forecasting software SIFT has been enhanced with new experimental features. Some of the most significant improvements include:
   a. Automated inversion capability. This feature completely automates the generation of a tsunami source based on DART® data and allows for the complete automation of the forecast process.
   b. Improved Travel Time algorithm. The algorithm that computes tsunami arrival time has been enhanced to avoid discontinuities in isochrones.
   c. Optimization of the propagation database forecast in deep water. This improvement allows a faster solution of the ocean-wide forecast.
   d. Access to the data generated by the Inundation Forecast Models has been streamlined and improved.
   e. Some cosmetic changes to the SIFT interface have been introduced.

2. The Tsunami Research Program has continued to lead a number of Tsunami Hazard Assessment projects for different state and federal agencies. Collaborative work with Washington State Emergency Management Division (WA EMD) has led to the development of tsunami hazard assessment maps for the San Juan Islands based on a Cascadia subduction zone seismic scenario and will be used for WA EMD to develop tsunami evacuation maps. As a follow up on previous work for WA EMD, the hazard maps developed for Grays Harbor and Willapa Bay in previous years have been updated using corrected and updated bathymetric and topographic data from the National Geophysical Data Center. A joint proposal with WA EMD has been submitted to the National Hazard Mitigation Program to fund the development of hazard maps for the Puget Sound area, at high resolution, from a Cascadia seismic event.

   A new hazard assessment methodology developed at NCTR is also being employed in the generation of hazard assessment maps of the community of Pago Pago in American Samoa, through a project funded by the National Ocean Service.

   A preliminary report has been submitted to the U.S. Nuclear Regulatory Commission (NRC) on best modeling practices for tsunami hazard assessment. The report is meant to serve as the basis for a Nuclear Regulatory document to be produced by the NRC. Two workshops have been conducted at the NRC facilities in Washington, DC to introduce NRC staff to Transcribe Weather Enroute Broadcast (Tweb) software as a means of obtaining real-time forecasts for nuclear power
plant sites.

3. Software improvement and feature enhancement on Tweb has allowed this software to reach a number of milestones over the last year. Among the major milestones were:
   a. Tweb was used as one of the tsunami event information dissemination tools during the national AlaskaSHIELD event to mark the 50th anniversary of the 1964 Alaska earthquake.
   b. During the April 1, 2014 Iquique, Chile tsunami event, Tweb was used by the National Tsunami Warning Center (NTWC) to give tsunami risk information to the U.S. Navy in Hawaii.
   c. Tweb was presented to international collaborators, and has received an enthusiastic reception as a new method to access tsunami modeling and forecast results.

Wider use of this application by TWC evaluators and modelers has resulted in new feature requests that are being implemented. Among the new capabilities added is the capacity for communities to retrieve authoritative event information from Tweb, and to use this to run local high-resolution inundation models. These model results can then be uploaded to Tweb, where it is viewable by all Tweb users.

4. A test-bed has been established at NCTR with the purpose of testing the accuracy and stability of different tsunami models. NCTR scientists have been trained by Pacific Tsunami Warning

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**Figure 2.** Forecast of the tsunami triggered by the 2014 Mw 8.2 Iquique, Chile event at Crescent City, CA. The image shows an inundation forecast generated with the tsunami forecasting software T-web for the community of Crescent City, CA and its neighboring areas. The full forecasting capabilities of SIFT are now available online to selected agencies via Tweb.
Center (PTWC) staff to use the tsunami propagation model RIFT (Real-time Inundation Forecasting of Tsunamis), in use at PTWC, and benchmarking work has started. Benchmarking of the tsunami code used by the NTWC is scheduled to take place in the summer/fall of 2014.

Updates to the community specific tsunami forecasts developed in previous years for both Tsunami Warning Centers have continued through the period 2013 – 2014.

5. NCTR’s partnership with the University of Málaga, Spain has continued during the current reporting period. Previous projects have resulted in the acceleration of the MOST (Method of Splitting Tsunami) tsunami propagation code by a factor of approximately 30, using a Graphics Processing Unit (GPU) implementation of the code. The same type of implementation is currently being investigated with the inundation version of the MOST code.

6. Real tsunami events have continued to occur during the current reporting period, providing multiple opportunities to test the forecasting system with real scenarios. Tsunami research group scientists have responded to all of these events in real time and have had their experimental forecasts available for assistance to the Warning Centers within a few hours of the event, and have published results on NCTR’s webpage for the general public, within 24 hours. The most significant of these events was the Mw 8.2 Iquique (Chile) event.

7. Four additional training workshops, using the Community Modeling Interface for Tsunami (ComMIT) were conducted during the current reporting period in Tonga, the Cook Islands and Washington D.C. A new workshop is scheduled to take place in the island of Fiji in the summer of 2014.

Figure 3. Distribution of the maximum wave elevation (left) and current speed (right) of a tsunami originating along the Cascadia Subduction Zone from a Mw 9.3 seismic event in the San Juan Islands.
AUTOMATIC UNIT SOURCE SELECTION AND JOINT DETIDING AND INVERSION FOR THE SIFT APPLICATION

PI
Donald B. Percival — UW Applied Physics Laboratory

Task III

NOAA Sponsor
Vasily Titov — Pacific Marine Environmental Laboratory

NOAA Goal
Weather-Ready Nation

Description
NOAA has deployed a series of Deep-ocean Assessment and Reporting of Tsunamis (DART®) buoys (primarily in the Pacific Ocean) that can directly record the passage of a tsunami over a pressure detector mounted on the bottom of the ocean. These buoys are strategically placed in the ocean off of coastlines where earthquake-generating tsunamis have occurred historically, or are predicted to be likely to occur. Data collected in near-real time by DART buoys that are off-shore from an earthquake reflect the start of a tsunami and can be used to predict the impact of the tsunami along U.S. coastal communities away from the earthquake site. While very large tsunami-generating events will lead to an order to immediately evacuate, there is a need to assess the impact of moderate-sized events and to judiciously issue evacuation orders, with the realization that false alarms carry a cost to society. Since it is not possible to predict the impact of a tsunami perfectly, it is necessary to use statistical methods to evaluate the possible impact of a tsunami. The most relevant statistical measure is a confidence interval (CI) that quantifies how large a tsunami event is likely to be when it reaches a coastal community. Such a CI necessarily depends upon the uncertainty in the estimated tsunami source amplitudes, which are intermediate measures of interest.

Objectives
1. To estimate tsunami source amplitudes.
2. To produce CIs for the true unknown amplitudes.
3. The estimation of the amplitudes must not only be reliable, but also use methods that allow them to be computed as rapidly as possible.
4. The estimated amplitudes are to be based upon fitting data collected in near-real-time by the DART® buoys to a database of pre-computed models for what these buoys would observe from a magnitude 7.5 reverse thrust earthquake located within a unit source.

Accomplishments
1. The scientists completed a paper summarizing their study of an elastic net-based method for automatic selection of unit sources to be used in estimating tsunami source amplitudes (the elastic net is a variation on the lasso method, which is a penalized least squares procedure that is popular in the statistical community, with the penalty acting here to automatically select unit sources). The paper, currently (April 2014) in press at the Journal of the American Statistical Association, is entitled ‘Automated Tsunami Source Modeling Using the Sweeping Window Positive Elastic Net,’ and is authored by D.M. Percival, D.B. Percival, D.W. Denbo, E. Gica, P.Y. Huang, H.O. Mofjeld and M.C. Spillane. Efforts are under way to incorporate this new methodology into the operational Short-term Inundation Forecasting for Tsunamis (SIFT) system used by the Tsunami Warning Centers.

2. The scientists completed a study on methods for detiding data collected by DART buoys for use within NOAA’s SIFT tool. Removal of tides from DART® buoy data is needed, since the inversion algorithm that is used to estimate tsunami source amplitudes assumes that tidal components have been removed. Using data from 11 representative buoys that were located in the Pacific and Atlantic Oceans, and to which representative artificial tsunamis (based upon 42 unit source models) were added, the scientists evaluated detiding methods based on harmonic analysis (including the so-called Foreman method), Kalman filtering/smoothing and empirical orthogonal functions, in addition to methods that perform joint detiding and inversion using local polynomials.
and local harmonic analysis. This comprehensive study indicates that joint detiding and inversion estimation, while computationally simpler than other methods, is the best way of handling the detiding problem. A paper that summarizes this study is currently (April 2014) under review at the journal Pure and Applied Geophysics, and is entitled 'Detiding DART® Buoy Data for Real-time Extraction of Source Coefficients for Operational Tsunami Forecasting.' It is authored by D.B. Percival, D.W. Denbo, M.C. Eble, E. Gica, P.Y. Huang, H.O. Mofjeld, M.C. Spillane, V.V. Titov and E.I. Tolkova.
## 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 Principal Research Scientist, Affiliate Professor, Oceanography  
Bates, Timothy S. — Senior Principal Research Scientist, Affiliate Associate Professor, Oceanography  
Battisti, David S. — Professor, Atmospheric Sciences  
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, Oceanography  
Eriksen, Charles C. — Professor, Oceanography  
Friedman, Carolynm — Professor, Aquatic & Fishery Sciences  
Fu, Qiang, Professor — Atmospheric Sciences  
Gammon, Richard H. — Professor Emeritus, Oceanography and Chemistry  
Hartmann, Dennis L. — Professor, Atmospheric Sciences*  
Hilborn, Ray — Professor, Aquatic & Fishery Sciences  
Horne, John — Professor, Aquatic & Fishery Sciences*  
Jaeglé, Lyatt, Professor — Atmospheric Sciences  
Jaffe, Dan — Professor, Science and Technology, UW Bothell  
Lettenmaier, Dennis P. — Professor, Civil and Environmental Engineering  
McDuff, Russell — Professor, Oceanography  
Miles, Edward L. — Professor Emeritus, Marine and Environmental Affairs, Climate Impacts Group  
Murray, James W. — Professor, Oceanography  
Punt, Andre E. — Professor and Director, Aquatic and Fishery Sciences  
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**  
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  
Moore, Dennis W. — Leader, 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, Project Leader for NOAA Center for Tsunami Research, Affiliate Assistant Professor, Earth and Space Sciences  

*2013-2014 Council Members
APPENDIX 2

JISAO Professional Awards, Events, and Visitors

Awards
Trevor Branch
- College of the Environment Outstanding Researcher Award, University of Washington, 2013 for “research or scholarship contributed within the past two years that has been, or has the potential to be, widely recognized by peers and whose achievements have had, or may have, a substantial impact on the profession, on research or the performance of others, or on society as a whole”.
- Leopold Leadership Fellow, 2013, Leopold Leadership Program, Stanford Woods Institute for the Environment, acknowledging a fellow who exhibits “the skills, approaches, and theoretical frameworks for translating their knowledge to action, and for catalyzing change to address the world’s most pressing sustainability challenges.”

Jeremy Cram
- Best Student Presentation award at the 2010 Water Center Annual Review of Research. Additional PhD research funds for the project were awarded through a competitive proposal submitted to the U.S. Geological Survey State Partnership Program (Christian Torgersen, PI).

Jessica Lundquist
- Journal of Hydrometeorology Editor’s Award, 2014
- Chair’s Award for Excellence in Mentoring Doctoral Students, Civil and Environmental Engineering, University of Washington, 2013.

Mark Raleigh (graduate student of Jessica Lundquist)
- U.S. Society on Dams-Grand Scholarship, 2012
- Hydro Research Foundation Fellowship, 2012-2013
- Ronald E. Nece Fellowship, 2012
- College of Engineering Dean’s Award, 2013

Award Nominations
JISAO Tsunami Research Group
- UW College of the Environment Award Nomination for Outstanding Researchers (team), for the entire tsunami project, but particularly for the development, installation and implementation of the SIFT system at the Tsunami Warning Centers

Monetary Awards
Jennifer Keene
- JISAO/UW Award for “excellent documentation” for the OCS project.

Keith Ronnholm
- JISAO/UW Award for work on the redesign of the OCS web site, greatly enhancing the content, both in text and images. The new web site combines the content of three prior web sites, which streamlined access to information about OCS moorings and data.

JISAO Tsunami Research Group
- JISAO/UW Award for the SIFT Software for Tsunami forecasting operations at the Tsunami Warning Centers. The researchers are: Diego Arcas (PI), Donald Denbo, Edison Gica, Linus Kamb, Jean Newman, Clinton Pells, Michael Spillane, Liujuan Tang, Yong Wei, Lindsey Wright, and Hongqiang Zhou.

JISAO Administrative Staff:
- JISAO/UW Award for planning and implementation of the NOAA Five-Year Science and Administrative Reviews.

Events and Visitors
Alexander Marshak

Armin Sorooshian
- University of Arizona, Department of Chemical and Environmental Engineering, Assistant Professor, www.chee.arizona.edu/armin-sorooshian, Speaker for the Atmospheric Sciences Colloquium April 19, 2013: “Aerosol Interactions with Water Vapor and Clouds: Insights from Recent Field Measurements in Continental and Marine Atmospheres”
Kristen Davis
- University of California, Irvine, Department of Civil and Environmental Engineering, Assistant Professor http://davis.eng.uci.edu/, Gordon Research Conference on Coastal Ocean Circulation in Biddeford, Maine from June 9 through 14, 2013

Chris Measures
- University of Hawaii at Manoa, Department of Oceanography, Professor www.soest.hawaii.edu/oceanography/faculty/measures.html, Collaborator with Dr. Joseph Resing on A16N CLIVAR research cruise van set up from June 1 through 8, 2013 at NOAA Pacific Marine Environmental Lab, Seattle, WA

Mariko Hatta
- University of Hawaii at Manoa, Department of Oceanography, Postdoctoral Researcher http://oregonstate.edu/cla/shpr/kathleen-dean-moore, Collaborator with Dr. Joseph Resing on A16N CLIVAR research cruise van set up from June 1 through 8, 2013 at NOAA Pacific Marine Environmental Lab, Seattle, WA

Jocelyn Lin
- Salmon Management Analyst, Wild Salmon Center, Portland, Oregon http://bootcamp.nkn.uidaho.edu/jocelyn_lin, GOAIERP Modelers meeting from July 9 through 11, 2013 at NOAA Pacific Marine Environmental Lab

Colleen Wall
- Oregon State University Earth, Ocean and Atmospheric Sciences, graduate student http://oregonstate.edu/marinesciences/collen-wall, Ocean acidification cruise support meeting with Jeremy Mathis, NOAA Pacific Environmental Laboratory on July 30, 2013

David Crisp
- California Institute of Technology Jet Propulsion Laboratory Senior Research Scientist, and Orbiting Carbon Observatory Mission Principal Investigator http://science.jpl.nasa.gov/people/DCrisp/, JPL Satellite Meeting with Tom Ackerman and Roger Marchand on October 17, 2013

Rebecca Goldburg

Christopher Clark
- Cornell University Lab of Ornithology, Senior Scientist http://vivo.cornell.edu/display/individual5549, Synthesis of Arctic Research Science Steering Committee meeting in Anchorage, AK from January 19 through 22, 2014

Paul Markowski

Andrew Rosenberg
- Union of Concerned Scientists, Director of Center for Science and Democracy, www.ucsusa.org/about/staff/staff/andrew-rosenberg.html, Speaker at the IGERT Program on Ocean Change 2014 Winter Seminar, February 12, 2014: “Science, Democracy and the Changing Ocean”

Visiting Scientists
Alexander Marshak

Nannan Wang
- Ocean University of China, PhC, NOAA Pacific Marine Environmental Laboratory Center for Tsunami Research from Sep 2013 through Oct 2014. Research Topic: Developing a global database using NOAA’s MOST model, and applying global database to assess the potential tsunami hazards for China coasts
## APPENDIX 3

### NOAA Cooperative Agreement — Newly Funded Projects, 2013-2014

<table>
<thead>
<tr>
<th>Task</th>
<th>Principal Investigator</th>
<th>Department</th>
<th>Title</th>
<th>Award Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Ackerman, Thomas</td>
<td>JISAO</td>
<td>JISAO Task I</td>
<td>$300,100</td>
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<tr>
<td>I</td>
<td>Branch, Trevor</td>
<td>SAFS</td>
<td>Bevan Lecture Series</td>
<td>$10,000</td>
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<tr>
<td>II</td>
<td>Ackerman, Thomas</td>
<td>JISAO</td>
<td>Joint Institute for the Study of the Atmosphere and Ocean Task II</td>
<td>$5,944,577</td>
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<td>II</td>
<td>Bond, Nicholas</td>
<td>JISAO</td>
<td>Linkage of Arctic Sea Ice Loss, Increased Ocean Heat Storage, and Regional and Far-field Winds</td>
<td>$95,736</td>
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<td>II</td>
<td>Doyle, Miriam</td>
<td>JISAO</td>
<td>Links between the early life history dynamics of fish, climate and ocean conditions in the large marine ecosystems of Alaska</td>
<td>$68,841</td>
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<td>II</td>
<td>Horne, John</td>
<td>SAFS</td>
<td>NWFSC Acoustic Survey Support</td>
<td>$160,000</td>
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<td>II</td>
<td>Punt, Andre</td>
<td>SAFS</td>
<td>An Evaluation of Management Strategies for Implementation of Annual Catch Limits for Alaska Groundfish</td>
<td>$45,000</td>
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<td>III</td>
<td>Armstrong, David</td>
<td>SAFS</td>
<td>Population connectivity via larval drift of Pribilof Islands blue king crab in the Eastern Bering Sea</td>
<td>$87,497</td>
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<td>III</td>
<td>Duggins, David</td>
<td>Fri Harb</td>
<td>JISAO R/V Centennial ship time with NWFSC</td>
<td>$12,150</td>
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<td>III</td>
<td>Duggins, David</td>
<td>Fri Harb</td>
<td>Fish Assessment in Acoustic Dead Zone</td>
<td>$16,800</td>
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<tr>
<td>III</td>
<td>Hilborn, Ray</td>
<td>SAFS</td>
<td>Integrating spatial habitat and fisheries effort data to improve abundance estimates of west coast groundfish</td>
<td>$51,769</td>
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<td>III</td>
<td>Holworth, Robert</td>
<td>ESS</td>
<td>Lightning Studies</td>
<td>$210,182</td>
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<td>III</td>
<td>Horne, John</td>
<td>SAFS</td>
<td>Fisheries Acoustics Research</td>
<td>$39,999</td>
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<td>III</td>
<td>Miller, Bruce</td>
<td>SAFS</td>
<td>Marine Biological Interactions in the North Pacific – Fish Interactions Task</td>
<td>$794,490</td>
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<td>III</td>
<td>Pietsch, Theodore</td>
<td>SAFS</td>
<td>Archival and Dissemination of Specimens and Data for the Northeast Pacific Ocean, Bering Sea, and Artic Ocean Fish Eggs, Larvae, and Adults Collected During NOAA Fisheries Surveys and research</td>
<td>$78,714</td>
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<td>III</td>
<td>Punt, Andre</td>
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<td>Sardine Risk Analysis</td>
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<td>III</td>
<td>Punt, Andre</td>
<td>SAFS</td>
<td>Forecast Effects of Ocean Acidification on Abundance of Aleutian Islands Golden King Crab</td>
<td>$46,200</td>
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<td>III</td>
<td>Punt, Andre</td>
<td>SAFS</td>
<td>Incorporating Climate Driven Growth Variability into Stock Assessment Models: a Simulation-based Decision Table Approach</td>
<td>$112,584</td>
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<td>III</td>
<td>Punt, Andre</td>
<td>SAFS</td>
<td>Investigating value of spatially explicit models for pelagic fish</td>
<td>$132,330</td>
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<td>III</td>
<td>Punt, Andre</td>
<td>SAFS</td>
<td>Partnership With The NWFSC And AFSC To Develop Increased capacity In The School Of Aquatic And Fishery Sciences To Enhance Teaching And Research</td>
<td>$200,000</td>
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<td>III</td>
<td>Punt, Andre</td>
<td>SAFS</td>
<td>West Coast Groundfish Stock Assessment</td>
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<td>III</td>
<td>Rigor, Ignatius</td>
<td>APL</td>
<td>International Arctic Buoy Programme (IABP) – Monitoring the Eurasian Basin of the Arctic Ocean</td>
<td>$100,000</td>
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<td>III</td>
<td>Riser, Steven</td>
<td>Oceanography</td>
<td>Argo: Global Observations for Understanding and Prediction of Climate Variability</td>
<td>$2,667,000</td>
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<td>III</td>
<td>Roberts, Steven</td>
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<td>Sablefish Reproductive Life History and Genetics</td>
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<td>III</td>
<td>Stafford, Kate</td>
<td>APL</td>
<td>Analysis of Bering Strait passive acoustic monitoring data from 2009-2012 and visual survey data from 2004-2012</td>
<td>$93,000</td>
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**TOTAL**  | $11,556,150
## APPENDIX 4

### Non-NOAA Cooperative Agreement Projections — Funded, 2013-2014

<table>
<thead>
<tr>
<th>Project Title</th>
<th>Principal Investigator</th>
<th>Lead NOAA Collaborator</th>
<th>Award Amount</th>
<th>Awarding Agency</th>
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</thead>
<tbody>
<tr>
<td>The Interaction Among Mesoscale Dynamics, Microphysical Properties and Radiative Effects of Mid-Latitude Cirrus Clouds</td>
<td>Ackerman, Thomas</td>
<td>N/A</td>
<td>$182,216</td>
<td>NSF</td>
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<tr>
<td>Validation and Application of MISR Cloud Retrievals</td>
<td>Ackerman, Thomas</td>
<td>N/A</td>
<td>$120,000</td>
<td>JPL</td>
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<tr>
<td>Structure of Cross-shelf Circulation in a Buoyancy-Influenced, Wind-Driven Eastern Boundary Current System</td>
<td>Ackerman, Thomas</td>
<td>N/A</td>
<td>$265,362</td>
<td>NSF</td>
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<tr>
<td>Coastal Carbon Synthesis for the Continental Shelf of the North American Pacific Coast (NAPC): Preliminary Results</td>
<td>Ackerman, Thomas</td>
<td>N/A</td>
<td>$12,000</td>
<td>WHOI</td>
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<tr>
<td>Tsunami Hazard Modeling for U.S. Coastlines</td>
<td>Arcas, Diego</td>
<td>Titov, Vasily</td>
<td>$161,572</td>
<td>DOI</td>
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<tr>
<td>PNWTOX - The Columbia River plume and HABs in the Pacific Northwest: bioreactor, barrier, or conduit?</td>
<td>Banas, Neil</td>
<td>N/A</td>
<td>$15,363</td>
<td>NOAA</td>
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<tr>
<td>Novel Blending of Numerical/Statistical Models and Satellite Data to Improve Coastal Ocean Water Quality Predictions</td>
<td>Banas, Neil</td>
<td>N/A</td>
<td>$62,389</td>
<td>UC Santa Cruz</td>
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<tr>
<td>UW Contribution to the West Coast Component of the US IOOS Coastal Modeling Testbed</td>
<td>Banas, Neil</td>
<td>N/A</td>
<td>$97,884</td>
<td>SURA</td>
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<tr>
<td>Interaction of Air, Sea Ice, and Ocean Around Antarctica</td>
<td>Bond, Nicholas</td>
<td>N/A</td>
<td>$9,386</td>
<td>NSF</td>
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<tr>
<td>Deep Sea Hydrothermal Vent Site Prep Initiative</td>
<td>Butterfield, David</td>
<td>N/A</td>
<td>$27,071</td>
<td>ONR</td>
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<tr>
<td>Functional Dynamics, Interactions and Biogeochemical Impact of Chemolithoautotrophic Subseafloor Microbial Ecosystems at Axial Seamount, a Mid-Ocean Ridge Cabled Observatory</td>
<td>Butterfield, David</td>
<td>N/A</td>
<td>$286,310</td>
<td>MBL</td>
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<td>Cross-isobath Exchange in Bering Canyon: Episodic and Seasonal Variability</td>
<td>Cheng, Wei</td>
<td>Ladd, Carol</td>
<td>$118,996</td>
<td>NPRB</td>
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<tr>
<td>Shipboard Measurements of Aerosol Chemical, Physical, Optical and Cloud Nucleating Properties During the DYNAMO Field Campaign</td>
<td>Covert, David</td>
<td>Quinn, Patricia</td>
<td>$180,790</td>
<td>ONR</td>
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<tr>
<td>Exploring Temporal and Spatial Variability in Gulf of Alaska Groundfish Dynamics with Integrated Biophysical Models</td>
<td>Hermann, Albert</td>
<td>Stockhausen, William</td>
<td>$131,870</td>
<td>NPRB</td>
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<tr>
<td>Using CERES and MODIS Data to Improve Energy Balance Snowmelt Modeling</td>
<td>Hinkelman, Laura</td>
<td>N/A</td>
<td>$205,000</td>
<td>NASA</td>
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<td>A Public-Private-Academic Partnership to Advance Solar Power Forecasting</td>
<td>Hinkelman, Laura</td>
<td>N/A</td>
<td>$28,190</td>
<td>UCAR</td>
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<td>Evaluation of MERRA Cloud and Radiative Variables using Integrated Calipso-CloudSat Data Products</td>
<td>Hinkelman, Laura</td>
<td>N/A</td>
<td>$205,359</td>
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<td>Development of an Adaptive Vertical Grid Scheme for Large Scale Models</td>
<td>Marchand, Roger</td>
<td>N/A</td>
<td>$109,286</td>
<td>NOAA</td>
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<td>CloudSat Global Summary and Geometric Profile (GeoProf) Datasets</td>
<td>Marchand, Roger</td>
<td>N/A</td>
<td>$24,749</td>
<td>JPL</td>
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<td>Project Title</td>
<td>Principal Investigator</td>
<td>Lead NOAA Collaborator</td>
<td>Award Amount</td>
<td>Awarding Agency</td>
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<tr>
<td>The Role of Cross-shelf and Along-shelf Transports as Controlling Mechanisms for Nutrients, Plankton and Larval Fish in the Coastal Gulf of Alaska</td>
<td>Mordy, Calvin</td>
<td>Stabeno, Phyllis</td>
<td>$2,044</td>
<td>NPRB</td>
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<tr>
<td>Observational and Modeling Studies of Cirrus and Boundary Layer Clouds Using A-Train Data</td>
<td>Muehlbauer, Andreas</td>
<td>N/A</td>
<td>$17,414</td>
<td>UTAH</td>
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<tr>
<td>Collaborative Research: Trace Metal Deposition And Cycling In The North Atlantic On The 2013 CLIVAR/Repeat Hydrography A16N Expedition</td>
<td>Resing, Joseph</td>
<td>N/A</td>
<td>$187,986</td>
<td>NSF</td>
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<td>2013 CLIVAR Repeat Hydrography Cruise A16N</td>
<td>Sonnerup, Rolf</td>
<td>Bullister, John</td>
<td>$38,454</td>
<td>NSF</td>
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<tr>
<td>Large-scale Environmental Data Recovery and Analysis for the North Pacific–Arctic Region</td>
<td>Wang, Muyin</td>
<td>N/A</td>
<td>$660,706</td>
<td>NPRB</td>
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<td><strong>TOTAL</strong></td>
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<td><strong>$3,150,397</strong></td>
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## APPENDIX 5

### Graduate Students

<table>
<thead>
<tr>
<th>Student Name</th>
<th>Academic Unit</th>
<th>Degree</th>
<th>Degree Advisor</th>
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<tbody>
<tr>
<td>Babej, Alaric J.</td>
<td>Mechanical Engineering</td>
<td>M.S.</td>
<td>Joyce Cooper</td>
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<tr>
<td>Bateson, Colin Padriac</td>
<td>Mechanical Engineering</td>
<td>Ph.D.</td>
<td>Alberto Aliseda</td>
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<tr>
<td>Dilmen, Derya Itir</td>
<td>Earth And Space Sciences</td>
<td>Ph.D.</td>
<td>Vasily Titov, Joanne Bourgeois</td>
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<tr>
<td>Dixon, Kenneth</td>
<td>Atmospheric Sciences</td>
<td>M.S.</td>
<td>Cliff Mass</td>
</tr>
<tr>
<td>Godersky, Alicia J.</td>
<td>School of Aquatic and Fishery Sciences</td>
<td>M.S.</td>
<td>Theodore Pietsch</td>
</tr>
<tr>
<td>Gray, Alison R.</td>
<td>School of Oceanography</td>
<td>Ph.D.</td>
<td>Clifford Mass</td>
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<tr>
<td>Harbitz, Caroline R.</td>
<td>School of Oceanography</td>
<td>Ph.D.</td>
<td>Stephen Riser, Peter Rhines</td>
</tr>
<tr>
<td>Hennon, Tyler D.</td>
<td>School of Oceanography</td>
<td>Ph.D.</td>
<td>Stephen Riser, Matthew Alford</td>
</tr>
<tr>
<td>Hurtado, Ferro Felipe</td>
<td>School of Aquatic and Fishery Sciences</td>
<td>Ph.D.</td>
<td>Andre Punt</td>
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<tr>
<td>Immerman, Douglas A.</td>
<td>School of Aquatic and Fishery Sciences</td>
<td>M.S.</td>
<td>Steven Roberts</td>
</tr>
<tr>
<td>Jasonowicz, Andrew J.</td>
<td>School of Aquatic and Fishery Sciences</td>
<td>M.S.</td>
<td>Steven Roberts</td>
</tr>
<tr>
<td>Li, Zhi</td>
<td>Department of Economics</td>
<td>Ph.D.</td>
<td>Christopher Anderson</td>
</tr>
<tr>
<td>Monnahan, Cole C.</td>
<td>Quantitative Ecology &amp; Resource Mgmt</td>
<td>M.S.</td>
<td>Trevor Branch</td>
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<tr>
<td>Ono, Kotaro</td>
<td>School of Aquatic and Fishery Sciences</td>
<td>Ph.D.</td>
<td>Ray Hilborn</td>
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<tr>
<td>Purkey, Sarah Michelle</td>
<td>School of Oceanography</td>
<td>Ph.D.</td>
<td>Gregory Johnson</td>
</tr>
<tr>
<td>Stawitz, Christine C.</td>
<td>Quantitative Ecology and Resource Management</td>
<td>M.S.</td>
<td>Timothy Essington</td>
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<tr>
<td>Stingle, Kelli F.</td>
<td>School of Aquatic and Fishery Sciences</td>
<td>Ph.D.</td>
<td>Andre Punt</td>
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<tr>
<td>Wenegrat, Jacob O.</td>
<td>School of Oceanography</td>
<td>M.S.</td>
<td>Mike McPhaden</td>
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<td>Williams, Nancy L.</td>
<td>School of Oceanography</td>
<td>M.S.</td>
<td>Richard Feely, Chris Sabine</td>
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APPENDIX 6
Personnel Count

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<th>B.S.</th>
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<tr>
<td>Personnel &gt; 50%</td>
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<tr>
<td>Faculty</td>
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<td>2</td>
<td></td>
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<tr>
<td>Research Scientist</td>
<td>58</td>
<td>9</td>
<td>23</td>
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<tr>
<td>Visiting Scientist</td>
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<tr>
<td>Postdoctoral Fellow*</td>
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<td>Research Support Staff</td>
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<td>Administrative</td>
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<td><strong>Total Personnel &gt; 50%</strong></td>
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<tr>
<td>Employees &lt; 50% NOAA support</td>
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<td>17</td>
<td>21</td>
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<td>Undergraduate Students</td>
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<td>Graduate Students</td>
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<td>Employees located at NOAA Labs</td>
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<td>Employees employed by NOAA in past year</td>
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</table>

*An additional four PostDocs received less than 50% support*
APPENDIX 7

Postdoctoral Research Associates

Baker, Matthew R.*
Chang, Bonnie
Drumm, David T.
Hagerman, Shannon M.*
Hristova, Hristina*
Johnstone, James A.*
Martini, Kim I.
McGilliard, Carey
Pedro, Joel B.
Uslu, Burak
Whitten, Athol
Zhou, Hongqiang

*Received less than 50% JISAO support
## APPENDIX 8

### Publications Count, 2012-2014

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<th>2012-2013</th>
<th>2013-2014</th>
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<tr>
<td><strong>JISAO Lead Author</strong></td>
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<tr>
<td>Peer-reviewed</td>
<td>85</td>
<td>73</td>
</tr>
<tr>
<td>Non-peer-reviewed</td>
<td>3</td>
<td>6</td>
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<tr>
<td>Total</td>
<td>88</td>
<td>79</td>
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<tr>
<td><strong>NOAA Lead Author</strong></td>
<td></td>
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<tr>
<td>Peer-reviewed</td>
<td>34</td>
<td>23</td>
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<tr>
<td>Non-peer-reviewed</td>
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<td>0</td>
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<tr>
<td>Total</td>
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<td>23</td>
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<tr>
<td><strong>Other Lead Author</strong></td>
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<tr>
<td>Peer-reviewed</td>
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<td>66</td>
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<tr>
<td>Non-peer-reviewed</td>
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<tr>
<td>Total</td>
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<td>66</td>
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<tr>
<td><strong>Total Peer-reviewed</strong></td>
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<td><strong>Total Non-peer-reviewed</strong></td>
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<td><strong>Grand Total</strong></td>
<td>240</td>
<td>168</td>
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APPENDIX 9

Publications April 1, 2013 – March 31, 2014

Not Previously Reported


Published


parameters, 40 pp, Pacific Fishery Management Council, Portland, OR.


79. Lehnert, H., R. P. Stone, and D. Drumm (2014), Geodia starki sp. nov. (Porifera, Demospongiae, Astrophorida) from the Aleutian Islands, Alaska, USA, Journal of the Marine Biological Association of the United Kingdom, 94(02), 261-265, doi:10.1017/S002531541300101X.


96. Muhlbauer, A., I. L. McCoy, and R. Wood


111. Pietsch, T. W., J. H. Caruso, C. R. Fisher, S. W. Ross, and M. G. Saunders (2014), In-situ image of *Sladenia shaefersi* in the northern Gulf of Mexico, individual in the foreground approximately 570 mm SL, specimen behind, about 615 mm SL, ROV Little Hercules, aboard NOAA ship Okeanos Explorer, depth 1165 m, April 2012 (frame-grab from video), *Copeia*, 1.


118. Riedel, T. P., et al. (2013), Chlorine activation within urban or power plant plumes: vertically resolved ClNO2 and Cl2 measurements from a tall tower in a polluted continental setting, Journal of Geophysical Research: Atmospheres, n/a-n/a, doi:10.1002/jgrd.50637.


146. Wagner, N. L., et al. (2013), N2O5 uptake coefficients and nocturnal NO2 removal
Appendices


In Press


158. Denton, J. S. S. (In Press), Seven-locus molecular phylogeny of Myctophiformes (Teleostei; Scopelomorpha) highlights the utility of the order for studies of deep-sea evolution, *Molecular Phylogenetics and Evolution* (0), doi:http://dx.doi.org/10.1016/j.ympev.2014.02.009.


