Joint Institute for the Study of the Atmosphere and Ocean

JISAO

ANNUAL REPORT

April 2015 – March 2016

Joint Institute for the Study of the Atmosphere and Ocean

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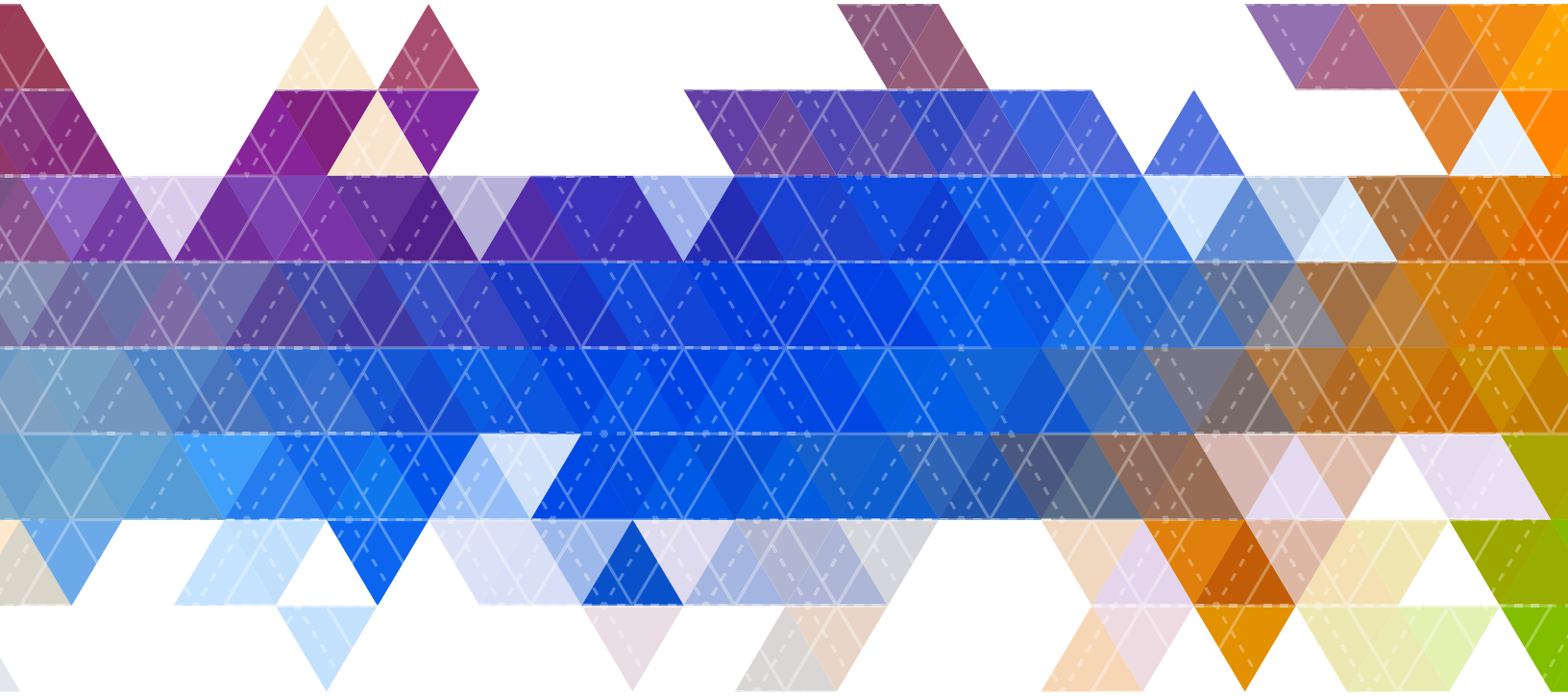


INTRODUCTION

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

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

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

- collecting, and analyzing data to better understand physical, biological, and chemical processes of ocean and coastal areas
- understanding climate variability and change
- improving our understanding of ocean and atmospheric processes associated with climate change and determining adaptation strategies
- studying how the ocean absorbs carbon dioxide and the resulting increase in acidity of ocean water
- studying hydrothermal vents and volcanoes on the seafloor
- studying effects of interactions between human communities and natural ecosystems
- developing tools and technology to restore and protect marine habitats
- improving prediction and forecasting of tsunami impacts

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

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

SCIENCE HIGHLIGHTS

CLIMATE RESEARCH AND IMPACTS

Severe drought developed across much of the Pacific Northwest during 2015, in large part due to a lack of snowpack associated with above normal temperatures. The Office of the Washington State Climatologist (OWSC), which is housed in JISAO, provided key support during this short-term climate event. In particular, the OWSC was a key member of the Water Supply and Availability Committee (WSAC) composed of representatives from municipal, state and federal agencies, and headed by the Washington State Department of Ecology. The principal role of the OWSC was as a source of the latest information on current and forecast conditions in Washington State. The drought and its widespread impacts garnered considerable interest from the media, public and scientific communities. The OWSC fulfilled a large number of requests for interviews, and public and scientific presentations. In particular, the OWSC was able to frame this recent event in the context of the past, present and future climate of the Pacific Northwest. Its activities in this arena are continuing on the state level. On the regional level, the OWSC is part of a team building an early warning system for drought in the Pacific Northwest under the auspices of NOAA's National Integrated Drought Information System (NIDIS).

ENVIRONMENTAL CHEMISTRY

The Chlorofluorocarbon project studies the concentrations of chlorofluorocarbons (CFCs), along with a number of other anthropogenic compounds like CO_2, which have 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 CFCs from the atmosphere into the surface ocean, and the subsequent transport of these compounds into the ocean interior provide a unique description of the time-integrated oceanic circulation and uptake of anthropogenic CO_2 and heat. These tracer data can be used to estimate the rates and pathways of ocean circulation and mixing processes, and as a means of testing and evaluating numerical models of ocean circulation.

MARINE ECOSYSTEMS

To better study the U.S. Arctic marine ecosystems and the rapid changes that are occurring, the Innovative Technology for Arctic Exploration (ITAE) program is developing new sensors and platforms to meet the scientific demand in these regions. ITAE is a collaborative research effort by the University of Washington (JISAO), the University of Alaska Fairbanks (Cooperative Institute for Arctic Research), and NOAA scientists at the Pacific Marine Environmental Laboratory (PMEL). The mission of the ITAE program is to conceptualize and build mission-proof and transfer-effective technologies for the assessment of the Arctic environment and ecosystem. In the

The Saildrone research platform is equipped with technologies to collect oceanographic data. Photo credit: Saildrone Inc.

past year, ITAE and Saildrone, Inc. have completed successful testing of a novel surface vehicle called the Saildrone, resulting in a platform that is ready for ocean research missions around the world. The observations that are becoming available from the Saildrone, and other autonomous vehicles being developed by ITAE, will provide the means to monitor the high-latitude ocean much more completely and cost-effectively than previously possible.

OCEAN AND COASTAL OBSERVATIONS

NOAA's Ocean Climate Stations Project (OCS) collects climate quality air-sea interaction observations that can be used as reference time series for assessment studies and process studies.
OCS currently maintains two reference station moorings in the North Pacific: The Kuroshio Extension Observatory (KEO) and Station Papa. KEO is located in the 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.

PROTECTION AND RESTORATION OF MARINE RESOURCES

The waters of the northeastern Chukchi and western Beaufort Seas represent habitats for bowhead and gray whales, walrus, and other marine mammals. The relative abundance of these species appears to vary substantially, and it has been hypothesized that these variations correspond with ocean properties such as the temperatures and currents. A large and diverse team of JISAO and NOAA (both AFSC and PMEL) personnel has been addressing this issue, with a focus on enhanced monitoring. A key component of this effort consists of passive acoustic instrumentation for cataloging marine mammal presence and behavior. Increasingly, it has been possible to combine this kind of information with oceanographic observations of the physics, chemistry and biology at lower-trophic levels. The ITAE program outlined above promises to revolutionize how this will be accomplished. An important objective of this work is to better understand how the marine mammals endemic to the region are liable to respond to climate change.

Steller sea lions on Ugamak Island rookery.

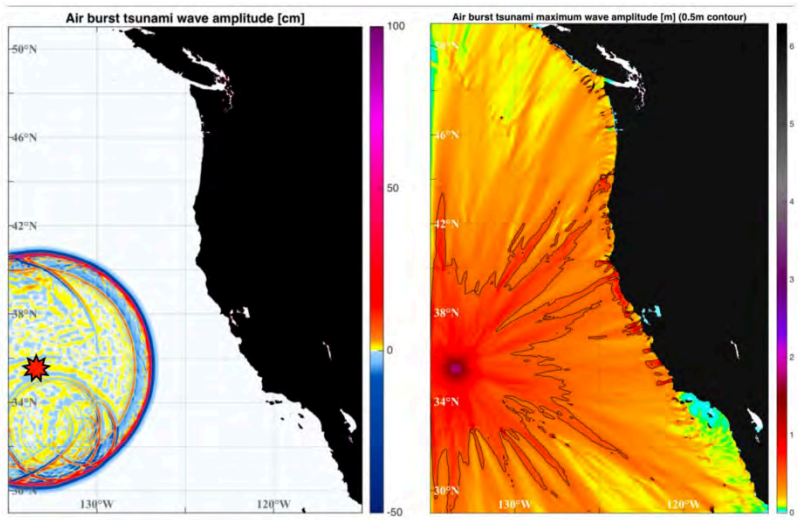
SEAFLOOR PROCESSES

Hydrothermal vents appear to have important impacts on the global carbon cycle in a variety of ways. New JISAO research has highlighted how the high temperatures at hydrothermal vents serve to break down dissolved organic carbon (DOC). This process is particularly important for unreactive carbon that has not been subject to microbial

decomposition or sedimentary degradation. This work has implications for the characteristic residence times of DOC, and ultimately the carbon chemistry of the deep ocean.

TSUNAMI OBSERVATIONS AND MODELING

A Mw 7.8 earthquake occurred near Muisne, Ecuador on 16 April 2016, with a tsunami originating off the coast of Ecuador. This case illustrates the present capabilities of the National Center for Tsunami Research (NCTR), and its team of JISAO and NOAA scientists. Specifically, as part of the array of buoys comprising the DART real-time tsunami monitoring system developed by NCTR, Buoy #32067 transmitted data on water level fluctuations that began about ten minutes after the earthquake. This was crucial and timely information on the threat of tsunamis for coastal communities of the region. The extent of this threat was unclear because the seismic event itself was centered inland, and hence it was not known whether the deformation of the seafloor was sufficient to produce a significant tsunami. The NCTR has been a world leader in the development of real-time tsunami simulation models. Simulations of this particular event, and comparisons of model output with tide gauge measurements in the vicinity, have been used to better understand the nature of tsunamis generated by earthquakes with inland rupture zones.



Wave front from an asteroid exploding at 12km high altitude with 5MT force. The left panel shows ocean surface disturbance induced by the shock wave. The right panel shows maximum tsunami elevation impacting the U.S. West Coast.

EDUCATION AND OUTREACH

"This program gave me the chance to explore atmospheric chemistry and see how I liked it, something I couldn't do in the Midwest. I got to meet some amazing people and I think that the experience I gained, in and out of the lab, will be extremely valuable to me in the future." Claire Buysse, 2015 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 Summer Undergraduate Internship Program. The internship program began with one student in 2008, and has since hosted 46 students from colleges and universities across the United States. Seven of JISAO's former interns have received graduate degrees including PhD's (Cole Perkinson at MIT and Ángel Adames at the University of Washington). Ten former interns have completed undergraduate degrees and are currently in graduate school including three at the University of Washington (one in Atmospheric Sciences, one in Oceanography, and one in the School of Aquatic and Fishery Sciences).

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

CONFERENCES AND CAREER FAIRS

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

AISES (American Indian Science and Engineering Society) National Conference in Phoenix, AZ – Delilah Dougi, a JISAO intern in 2013 and member of the Navajo community, attended the conference and recruited American Indian students who might be interested in applying for JISAO's summer internship program.

Delilah Dougi (right) meeting a prospective student at the 2015 AISES National Conference.

K–12 EVENTS

Orca Bowl – JISAO scientists were judges and scorekeepers at Washington Sea Grant's 2015 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. JISAO also provides travel support to

students traveling to Seattle for the event.

NOAA Science Camp – Seven JISAO scientists led sessions for the 2015 NOAA Science Camp at the Pacific Marine Environmental Laboratory (PMEL). JISAO funded NOAA Science Camp scholarships for low income and underrepresented students. This year we partnered with Dr. Gregory King from the STEAM program in Tukwila School District (noted as the most diverse in the nation), providing enough funding for 25 middle school students to attend the camp.

NOAA Science Camp Junior Leadership Program – JISAO scientist Peggy Sullivan participated in a speed networking event where she was paired with students for five-minute conversations about careers and goals to pursue a future in science.

Youth Climate Summit – Seattle Youth CAN is a partnership between the Woodland Park Zoo and Pacific Science Center. JISAO's Nick Bond and Sarah Doherty were presenters at the program's first Youth Climate Summit. Both also participated in a panel discussion talking with the teens about careers in the sciences. Additionally, students from the Youth CAN program attended the JISAO summer intern's final presentations to learn what it's like to have a research internship.

Woodland Park Zoo – Ivonne Ortiz led a workshop on how to develop hands-on activities to engage the public.

Campus Tours and Talks – Student groups often visit the UW and NOAA campuses for lab tours and to listen to talks with scientists. Rachel White and Lucia Upchurch led many of these tours at UW for schools such as Chestnut Hill Academy, Giddens School, Lake Washington High School.

Career Days – Shaun Bell and Ivonne Ortiz participated in AAUWPT Career Day for middle schoolers in Eastern Jefferson County in Port Townsend, WA. The event provide an opportunity for 8th graders in East Jefferson County public schools to interact with professionals to learn about and become inspired about careers and their educational requirements".

University of Washington Math Day – Nick Bond presented on the use of mathematics in climate science during the University of Washington's Math Day for high school students interested in STEM education.

Elementary, Middle School, and High School Visits – More than a dozen JISAO researchers visit elementary and middle school classrooms throughout the year to give demonstrations on topics such as tsunami research, career paths, cruise reports, Earth Day, atmospheric science, oceanography, and climate change. Some of the schools visited in the past year include Hazel Wolf, York High School (Flossmore, IL), Homewood-Flossmore High School, Covington Elementary, Chimacum High School, Home Education Exchange, Ballard High School, and Blue Heron Middle School.

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.

PACIFIC SCIENCE CENTER (PSC) PARTNERSHIP

Meet a Scientist – Ivonne Ortiz, a PSC Science Communication Fellow, attended three Meet a Scientist (formerly

Scientist Spotlight) events and presented a hands-on activity geared towards teaching guests about food chains and food webs in the eastern Bering Sea. 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 Karin Bumbaco and Ivonne Ortiz led activities showing their work on climate science and oceanography.

PUBLIC OUTREACH

PopNet Dissemination Workshop and Panel – The Portal to the Public Network (PoPNet) is a diverse community of practitioners dedicated to sharing ideas and strategies for scientist-and-public engagement. Through workshops aimed at organization involved in informal science education, PoPNet has expanded to a range of informal science settings including university outreach groups, zoos, aquariums, and nature centers. Science Communication Fellows, such as Ivonne Ortiz, participate in workshops to showcase their hands-on activities with follow-up Q&A sessions.

WA State Corrections Facilities Talks – Nick Bond visited the Stafford Creek Correctional Center in Aberdeen, WA and spoke to the inmates about the Blob, El Niño, and Climate Change. This talk was part of the Sustainability in Prisons Project.

Nick Bond speaking to the inmates at the Stafford Creek Correctional Center.

Seattle Aquarium: Discover Science Weekend – Heather Tabisola, Nick Bond, Albert Hermann, Colin Dietrich, Lucia Upchurch and Morgan Ostendorf displayed their work for aquarium guests who were invited to explore ocean and marine research with local scientists with interactive displays and activities. Discover Science Weekend engaged a total of 5,218 visitors over the two days.

Seattle Aquarium Lightning Talks – Edison Gica presented his talk titled “Impact of a tsunami similar to Japan’s 2011 event in Washington.”

Mt Baker Ski Area – Nick Bond participated in a speaker series at Mt. Baker Ski Area. His talk was called “The 1.5 Degrees Series and What We Can do to Help” where he spoke on the blob, El Niño, climate change, and the impacts they have for the Pacific Northwest.

Pacific County Marine Science Conference – Nick Bond was one of seven speakers at the conference focusing on scientific topics relevant to the Columbia-Pacific-Willapa region. Nick’s talk was titled “Recent warming of waters of the Pacific Northwest in a climate context: Implication for coastal Washington.”

Old Weather: Whaling – Kevin Wood gave a talk to 50 members of the Seattle Sail and Power Squadron on the new whaling segment of the Old Weather project.

Family Science Night – Nick Bond, Lucia Upchurch, and Collen Marquist had two booths at Lake Forest Park Elementary Family Science Night, in Lake Forest Park, WA. About 75 students came through the event and participated in a hands on activity simulating rainfall in Washington State.

Science Olympiad – Nick Bond was the supervisor of the meteorology component for the Northwest Region's Science Olympiad, held in Federal Way, WA. Science Olympiad is a competition for middle and high school students who participate in challenging and motivating science events.

2015 JISAO Summer Interns (L–R): Isabel, Alissa, Amanda, Haila, Alexis, Jane, Myesa, Eric, Marina, Nevin, and Claire.

USA Science Festival – Rachel Wood was part of a three-person group from UW Atmospheric Sciences who participated in the USA Science Festival in Washington, DC. Their hands-on presentation taught children and adults about the predictability of weather, and sometimes climate.

Friends of Skagit Beaches – Nick Bond gave a talk on the "Recent warming in the NE Pacific or How I learned to stop worrying and love the blob" for the Friends of Skagit Beaches in Anacortes, WA. Friends of Skagit Beaches is a nonprofit organization that protects marine shorelines and nearshore waters through education, citizen science, and stewardship projects.

JISAO on the radio and television – Nick Bond gives the weekly weather outlook on KUOW's "Weekday" program every Friday morning. 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. Bond is also a frequent guest on King 5 News weather programs.

SUMMER INTERNSHIP PROGRAM

JISAO welcomed eleven undergraduate students to the JISAO Summer Internship Program in 2015. Students were matched with mentors and research projects from JISAO, the UW Department of Atmospheric Sciences, the UW School of Oceanography, the UW School of Aquatic and Fishery Sciences, the NOAA Pacific Marine Environmental Laboratory, and the NOAA Alaska Fisheries Science Cennter. Student web pages and videos are available on JISAO's website. The interns and their universities are listed on the following page:

- Claire Buysse – College of Saint Benedict
- Marina Cucuzza – College of the Atlantic
- Amanda Echevarria – University of San Diego
- Isabel Justiniano – Brigham Young University
- Eric Kennedy – Seattle University

- Myesa Legendre-Fixx – University of Washington
- Alexis Lucassen – Gonzaga University
- Alissa Luk – New York University
- Nevin Schaeffer – Whitman College
- Haila Schultz – University of Puget Sound
- Jane Thompson – Williams College

In addition to the research project requirements, the 2015 interns worked together to create 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.

UNIVERSITY EVENTS

Arctic Observing Open Science Meeting – Hosted in Seattle, the 2015 meeting focused on sharing science results to stimulate cross-project and cross-program collaboration. It provided the opportunity for individual scientists to interact with a broader community of researchers including grad students and post-docs.

ENGAGE – Kim Martini was a guest speaker at the University of Washington's ENGAGE seminar series to discuss online science outreach and large scale ocean physics for about 25 students.

Pacific Marine Environmental Laboratory Tours – Nick Bond joins PMEL scientists to lead tours of the laboratory throughout the year. Recent visitors include students from Central Washington University and Pacific Lutheran University.

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:

- Why an 1879 voyage is a time machine for climate change – *The Wall Street Journal, NPR, Reuters*
- US Pacific blue whales rebounding close to historic levels – *NPR, UW News*
- The Gulf of Alaska is unusually warm and weird fish are showing up – *The Washington Post*
- The Day that Changed Tsunami Science – *NBC News, PBS Newshour, Mother Nature Network*
- Warm "Blob" in the Pacific linked to weird weather across the U.S. – *CNN, The Washington Post, Seattle Times, USA Today, Daily Science Journal, NBC News, Discovery News, Seattle PI*
- Study tracks soot pollution in snow – *Popular Science, UW News, Environmental Monitor*

Research Blog – While on the R/V *Falkor* research expedition to the Mariana back-arc, JISAO scientists contributed and updated the daily cruise blog on the Schmidt Ocean Institute website. Scientists included Joe Resing, Dave Butterfield, Ed Baker, and Nathan Buck. They also participated in ship to shore video calls to 16 separate elementary, middle school, high school and community college classrooms on the west coast and in Guam.

Research Blog – Kim Martini is an active blogger for Deep Sea News. Martini writes about science in a way that is relatable to non-scientists with postings like "Go Go Gadget Jellyfish!"

FINANCIAL MANAGEMENT AND ADMINISTRATION

JISAO bridges two major institutions and can be a management challenge because of its complexity. The UW infrastructure ensures JISAO's ability to operate as effectively as possible in order to recruit and retain excellent staff, meet reporting requirements, 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 efficiently and contributes to the success of the Institute.

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

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

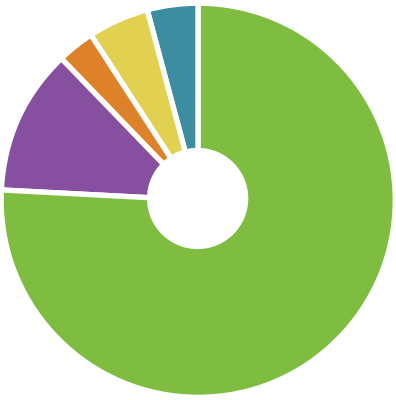
JISAO's Executive Council meets when there are agenda items that require higher-level policy reviews and decisions. Meetings are held either at UW or NOAA once per quarter for JISAO employees. NOAA scientists attend some of these meetings if they are involved with the topic. These meetings focus on items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

JISAO's Cooperative Agreement is funded through three tasks:

Task I, also supported by the UW, includes:

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

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



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

- Bonnie Chang, Princeton and University of Washington, Interests: marine nitrogen cycling and its link to oceanic productivity, nitrogen fixation and denitrification in the major oxygen deficient zones of the world's oceans (eastern tropical North and South Pacific, Arabian Sea), effects of sedimentary nitrogen cycling on the isotopic composition of marine nitrate, origins and air-sea flux of nitrous oxide in the Atlantic and Pacific oceans
- Kim Martini, University of Alaska-Fairbanks and University, Interests: internal waves and turbulence – how internal waves are generated, their path from source to sink, where they dissipate into turbulence and the effects on biology and ecosystems
- Donata Giglio, Scripps Institution of Oceanography, University of California-San Diego, Interests: large-scale ocean circulation and exchanges of heat, freshwater and momentum at the ocean-atmosphere interface
- Sam Potter, Princeton University, Interests: general circulation of the atmosphere, tropical-extratropical interaction, intraseasonal tropical variability, regional climate dynamics
- Adriana Raudzens Bailey, University of Colorado, Interests: atmospheric water cycle, convective mixing and precipitation processes, stable isotopes in water vapor, climate communication
- Rachel White, Imperial College-London, Interests: dynamical climate modeling, atmospheric-ocean coupling, topographic effects on general circulation, jet streams, storm tracks, impacts of tropical deforestation

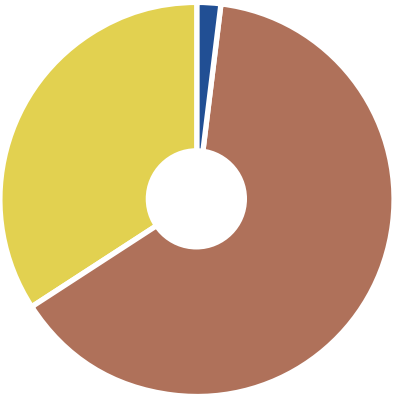
JISAO's education and outreach program activities are supported by a small portion of Task I, with additional support provided by other funding sources. Please see the section above for details about this program, which is vital to JISAO's mission.

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

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

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

The JISAO/NOAA Cooperative Agreement funding for the period April 1, 2015 - March 31, 2016 totals $19,934,566; JISAO's funding for non-Cooperative Agreement grants for the same period is an additional $2,317,804. The charts below break down Cooperative Agreement funding by tasks and themes.



Task I – 2%
Task II – 64%
Task III – 34%

Climate Research & Impacts – 4%
Environmental Chemistry – 15%
Marine Ecosystems – 23%
Ocean & Coastal Observations – 24%
Protection & Restoration of Marine Resources – 11%
Seafloor Processes – 5%
Tsunami Observations & Modeling – 9%
Various – 8%

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:

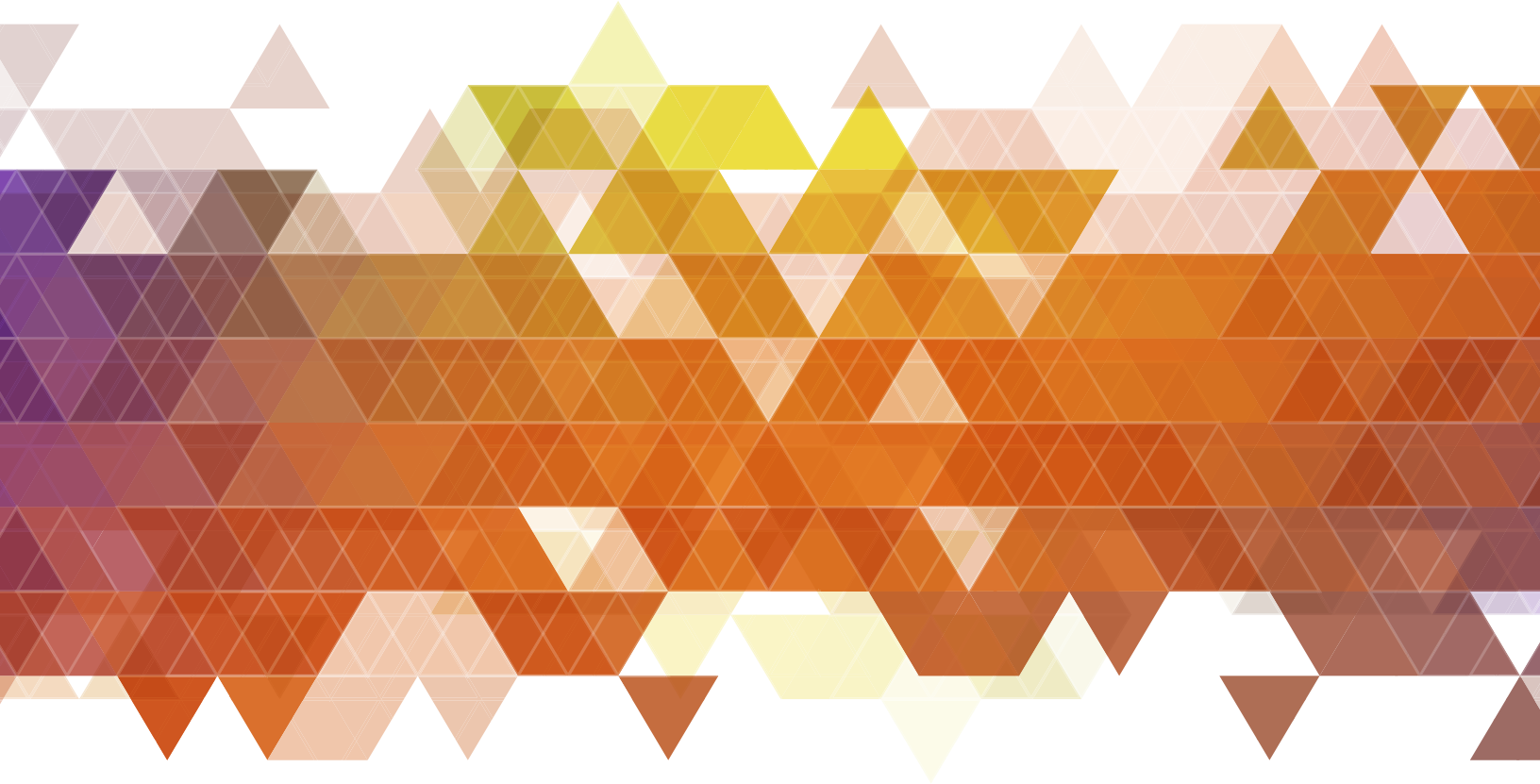
- JISAO Outreach and Education Program
  1. Strengthened and broadened the success of the E&O program (see section above for details of the year's activities)
- JISAO Staff Recognition Program
  1. Recognized outstanding research, papers, honors and awards on JISAO website.
  2. Presented UW service awards to JISAO employees.
  3. Several JISAO scientists and team members in the JISAO administrative group received cash awards for outstanding work over the past year in various capacities.
- Communications
  1. Continued joint quarterly meetings with JISAO and NOAA employees
  2. Held the annual all-personnel meeting on UW campus that includes all JISAO employees at UW and those who work at NOAA facilities; NOAA scientists also attended.
  3. JISAO assistant director, the finance manager and the administrative specialist held weekly office hours at NOAA/PMEL, improving communications, services and collaboration between NOAA and UW personnel. Other staff go to NOAA when needed.
  4. Website evolution continued with improvements in information presented and user friendliness.
  5. Participated on both the NOAA and UW CoEnv communications teams to regularly share information and best practices.

6. Continued to develop JISAO's marketing and public relations efforts to communicate research and education goals and activities to partnering organizations as well as local, regional and national communities.
7. Continued social networking via Facebook, YouTube and Twitter
8. Continued to track media coverage and publications of JISAO researchers.
9. Developed additional educational and public outreach materials.

- Organization and Infrastructure

1. Streamlined/consolidated staff assignments, continuing to work with reduced number of FTEs by not filling two vacant positions.
2. Continued strengthening overall organizational structure, working directly with JISAO scientific and technical staff to ensure meaningful supervisory and mentoring relationships.
3. Thomas Ackerman, JISAO Executive Director, is a member of the CoEnv Executive Committee and served the College in various capacities.
4. JISAO staff worked on university-wide initiatives and on committees addressing financial, human resources, communications and safety matters.

CLIMATE RESEARCH AND IMPACTS



ASSESSING REGIONAL SEA-ICE PREDICTABILITY IN THE U.S. ARCTIC: A MULTI-MODEL APPROACH

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

Other UW Personnel
Albert Hermann – Joint Institute for the Study of the Atmosphere and Ocean

Task III

NOAA Sponsor
Carol Ladd – Pacific Marine Environmental Laboratory

Other NOAA Personnel
Phyllis Stabeno – Pacific Marine Environmental Laboratory

Non-UW/Non-NOAA Personnel
Enrique Curchitser – Institute of Marine and Coastal Sciences, Rutgers University

NOAA Goals
Climate Adaptation and Mitigation

Description
This is the second year of the project. The task for this year is performing initialization runs using the coupled ROMS-CICE model in the pan Arctic domain and analyzing sea ice prognostic predictability from these runs.

Objectives
The research questions to address are: Does the predictability of regional sea-ice depend on the initialization month? Does this dependency vary between ice variables?

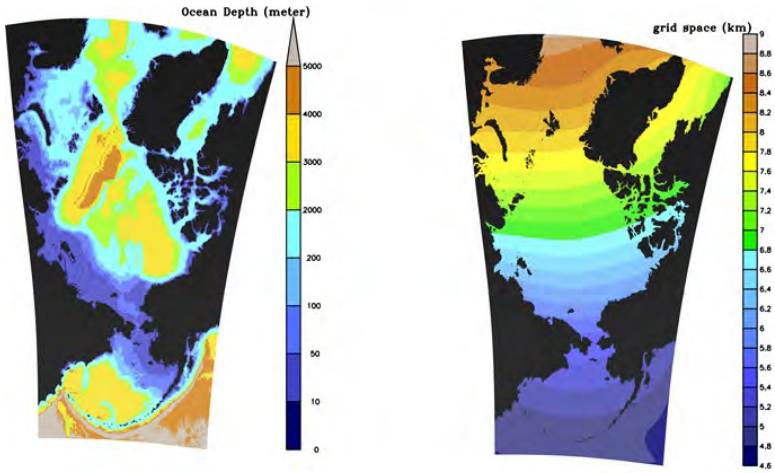


Figure 1. ROMS-CICE bathymetry (left) and horizontal resolution (right) for the pan-Arctic grid. Resolution is enhanced in the oceans surrounding Alaska.

Accomplishments
1. Ice thickness diagnostic predictability was analyzed using the Community Earth System Model (CESM) large ensembles.
2. Up-to-date summary was presented in the Next Generation Global Prediction System workshop in February, 2016 by Jessi Carman; see dtcenter.org/events/workshops16/seaice/ for the workshop link.

3. The coupled ROMS-CICE model was implemented in the pan Arctic domain. Figure 1 shows the model bathymetry and grid spacing. This coupled model was tested in a hind-cast mode by collaborator Enrique Curchitser from Rutgers University. Initialized ensemble integration using this high-resolution regional model is underway. Initial and forcing conditions are derived from the CESM large ensembles.

LIGHTNING STUDIES

PI
Robert H. Holzworth – UW Earth and Space Sciences

Other UW Personnel
Todd Mitchell - Joint Institute for the Study of the Atmosphere and Ocean
J. Michael Wallace - Department of Atmospheric Sciences

Task III

NOAA Sponsor
Steve Goodman - Geostationary Operational Environmental Satellite-R Program

NOAA Goals
Weather-Ready Nation

Description
This project is a study of global lightning activity to help define the parameters needed for the NOAA/GOES-R Global Lightning Mapper (GLM) mission. Presently we are in the pre-launch validation phase, which involves providing global lightning input to the project and developing new science related to global lightning activity.

Accomplishments
1. Global Lightning Detection

   a. We have improved data due to its collection in real time, and the data has been provided to our research colleagues, including other NOAA collaborators in Colorado, Alabama, and Hawaii.

   b. This year we have further expanded the detection efficiency of the network through the addition of new stations, and by improving the signal at several stations. Our expansion using the combined data collected by Earth Networks and World Wide Lightning Location Network (WWLLN) sensors has now demonstrated a 40% increase in data using about 40 Earth Networks sensors. By May 2016, we will be producing WWLLN stroke locations using WWLLN plus more than 100 Earth Networks sensors, when we will expect over 100% increase in the total number of located global strikes with the combined system.

   c. WWLLN based lightning research was presented at the American Geophysical Union meeting in San Francisco in December 2015, and the American Meteorological Society meeting in New Orleans in January 2016.

2. Study of lightning, rain rates, and vertical velocity

   a. We created animations of hourly summertime gridded lightning frequency superimposed on radar reflectivity and NOAA Rapid Refresh assimilated (analyzed) circulation fields over the conterminous United States. All fields were gridded to 1/6° resolution for May through August, 2014.

   b. We analyzed diurnal variations in summertime airmass thunderstorms over the southeastern United States and adjacent coastal waters, including power per stroke at 1/6° resolution for 2012-14.

   c. We also created animations of hourly summertime variations in lightning frequency over mountain areas of

the western United States at 1/6° resolution for May through August, 2014 and 2015. We made animations of the seasonal cycle of monthly climatological lightning frequency for the conterminous U.S., Mexico, and Central America based on data for 2009-15.

d. In addition, we have performed cluster analysis worldwide to group individual lightning flashes into thunderstorms. We have developed composited statistics on lightning flashes within thunderstorms as a function of elapsed time since the first flash in the thunderstorm, discovering that power per flash increases with time over land (i.e., flashes in mature storms are more powerful than those in incipient storms (but in the Intertropical Convergence Zone, power per flash drops to a minimum around the middle of the lifetime of the storm and then rises. Our plans are to extend this analysis, taking into account storm size and shape.

PACIFIC ANOMALIES WORKSHOP SUPPORT

PI
Jan Newton – UW Applied Physics Laboratory

Task III

NOAA Sponsor
Timi S. Vann – National Weather Service

NOAA Goals
Climate Research and Impacts

Description
Unusual ocean weather and climate patterns have been observed throughout 2014 and have continued into 2016 across the North Pacific basin. Because of the impact of this large signal on the ecosystem and society, federal sponsors (NOAA, the U.S. Integrated Ocean Observing System, the NOAA Climate Prediction Center, NOAA Sea Grant) came together to define a two-part workshop series where the first workshop would focus on "what" has happened and the second on "why" these anomalies occurred. The project supported a second workshop held in Seattle at the University of Washington Tower, hosted by the Northwest Association of Networked Ocean Observing Systems on January 20-21, 2016 to improve our understanding of how these significant oceanographic variations arose, their impact on our water, weather, and economic well-being, and ways in which we can potentially improve predictive capabilities.

Objective
In order to achieve the workshop stated outcomes and reach our stakeholders, additional support for the workshop is needed. While some workshop support has been provided, this request is for additional support for travel for speakers and participants at the second workshop.

Workshop Goal
From the Pacific Anomalies Workshop II (PAW2), the desired outcomes are to provide:

1. A workshop document that will succinctly provide a brief synthesis of what we know; what the gaps are (observational, modeling, mechanistic understanding); desired indices; and what we would need in order to have predicted the blob and its effects, or if that is possible.

2. A forum for PIs to discuss plans for scientific publication (group documents, dedicated journal, etc.).

Accomplishments

1. The PAW2 workshop attracted 182 participants from Alaska to California, and also from Canada and Mexico. The workshop was recorded, and video, as well as presentations, are available at: nanoos.org/resources/anomalies_workshop/workshop2.php. The agenda, participants, and other materials can be found at this site. The workshop was highly successful; the workshop was evaluated online, with 100 percent of the 48 survey respondents saying it was worth their time investment, and that they learned new information relevant to their research and work.

2. Student PAW2 associates worked with PI Jan Newton to write the intended workshop report document: a synthesis of what we know; what the gaps are (observational, modeling, mechanistic understandings); desired

indices; and what we would need in order to have predicted the blob and its effects, or if that is possible. The document was delivered to Newton on March 8, 2016, and is under review with the workshop chairs, with a plan to disseminate before June 30, 2016.

3. The workshop participants showed strong support for a dedicated journal for papers on the blob and its ecosystem effects. Meghan Cronin of the Pacific Marine Environmental Laboratory's Ocean Climate Station is in discussion with the American Geophysical Union for a special collection: NE Pacific Marine Heatwaves – Forcing and Impacts. William Sydeman of the Farallon Institute for Advanced Ecosystem Research, and John Largier of the UC Davis Marine Bodega Marine Laboratory are leading the effort to work with the community to get papers in the collection.

AN EXPERIMENTAL DEMONSTRATION AND EVALUATION OF REAL-TIME, OVER-THE-LOOP STREAMFLOW FORECASTING

PI
Bart Nijssen – UW Civil and Environmental Engineering

Other UW Personnel
Elizabeth Clark – Civil and Environmental Engineering

Task III

NOAA Sponsor
Claudia Nierenberg – Climate Program Office

Other NOAA Personnel
Andrew Wood and Pablo Mendoza – National Center for Atmospheric Research

NOAA Goals
Weather-Ready Nation

Description
The Department of Interior Bureau of Reclamation, the U.S. Army Corps of Engineers, the National Center for Atmospheric Research (NCAR), and the University of Washington (UW) are partnering to evaluate: 1) the application of state-of-the-science forecasting methods and datasets in an experimental real-time operational platform serving a selection of watersheds across the contiguous U.S.; and 2) the performance of these methods and datasets in over-the-loop forecasting. Research activities for the reporting period focused on the development of the infrastructure for a real-time streamflow forecast system.

Objectives
1. Create a real-time demonstration and evaluation of advanced streamflow forecasting for a selection of watersheds across the continental United States.
2. Evaluate and feed forward-promising forecasting technologies in forms that are well-suited to meet the water management needs of the water resources community, both in the present, and to enhance resilience under projected climate changed future conditions.
3. Reconcile automated new approaches with the traditional forecaster-centered paradigm for operational prediction.

These objectives are addressed through the following tasks:
1. Configure and calibrate hydrology and routing models for project basins.
2. Establish retrospective and real-time hydrometeorological data system.
3. Meteorological forecast implementation and hydrologic forecasting.
4. Implement streamflow forecast post-processing.

5. Implement automated data assimilation.
6. Establish forecast website and display capability.
7. Forecast system monitoring and maintenance.
8. Hindcasting and verification.
9. Analysis and dissemination of results.
10. Collaboration.

Accomplishments

1. We configured two sets of hydrology and routing models for five sites in the Pacific Northwest: Hungry Horse, Libby, Dworshak, Howard Hanson, and Prineville. The Variable Infiltration Capacity model, routed with RVIC, was configured using an existing set of parameter values that were developed by the PI's group for the Columbia River Basin using the Livneh et al. (2013) meteorological forcing data. The Sacramento/Snow-17 model was calibrated to match no-regulation no-irrigation streamflow for each basin using the ensemble forcings generated for this project. We are currently expanding this domain to include test basins in California and the Upper Colorado River basin.

2. We implemented an automated data feed for the retrieval of raw precipitation, temperature and streamflow observations using ecFlow workflow management software (from the European Center for Medium-Range Weather Forecasting). Retrospective ensemble hydrometeorological data sets for the five basins were generated using automated processes for quality control, data gap filling, and finally the Gridded Meteorological Ensemble Tool (G-MET). Real-time quality control and data gap filling for precipitation and temperature observations has been automated using ecFlow. Real-time gridded ensemble forcings are currently generated outside of ecFlow for specific water supply forecast dates as needed.

3. Seasonal water supply predictions for the five test basins were issued on March 16. These predictions were based on statistical methods that include the initial hydrologic conditions from the Sacramento/Snow-17 model (from objective 1). Efforts to implement short- to medium-range hydrologic forecasts are ongoing.

4. The objective of implementing streamflow forecast post-processing has not been met yet.

5. The objective of implementing automated data assimilation has not been met yet.

6. An initial web design was developed and is available at ral.ucar.edu/staff/wood/seasonal/. This site includes information on how the current year's forecast compares to observations and hindcasts from previous years. It also compares a

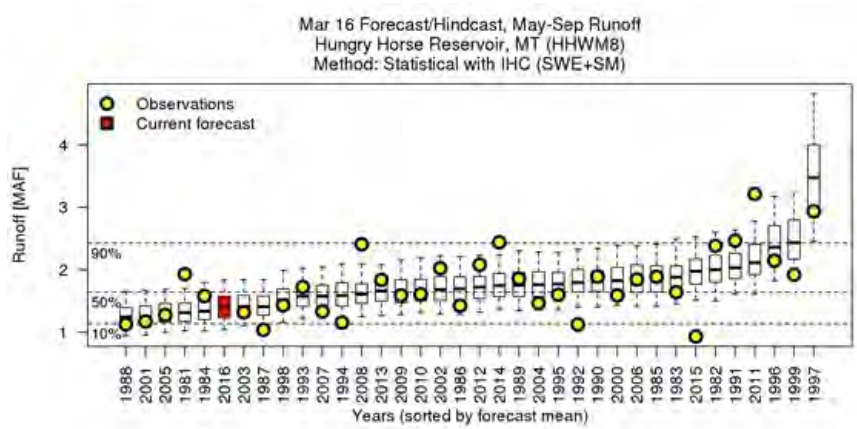


Figure 1. The 2016 forecast (red) and 1981–2015 hindcasts, issued on March 16, of May–September runoff at Hungry Horse Reservoir, MT. The forecast and hindcasts were based on statistical relationship with simulated initial surface water equivalent (SWE) and soil moisture (SM). The horizontal lines show the 10th, 50th, and 90th climatological runoff volume percentiles. Yellow circles show the observed runoff for hindcast years. For 29 of the 35 years, observed runoff falls within the forecast range for this method. Years are sorted by the mean predicted runoff volume, and there is no clear relationship between flow magnitude and the performance of this forecast method.

variety of forecast skill for a range of forecast methods.

7. Forecast system monitoring and maintenance has been greatly facilitated by the use of ecFlow, which includes error-reporting capabilities. All code developed for this project has been written in open source programming languages, primarily R and python. We perform vigorous code reviews and track system development and modifications using version control with GitHub. The GitHub repository is currently private, but we have structured the project such that the code will be made available publically and should be system-transferrable. This task is ongoing.
8. Hindcasts of April to July seasonal water supply were generated for each of the five test basins for the years 1981 to 2014. The hindcasts were used to compare methods of seasonal forecasting based on varying combinations of land and climate measures for monthly initialization times from October 1 to Apr. 1.
9. Preliminary results are available on at ral.ucar.edu/staff/wood/seasonal/. Results have been presented at the Western Snow Conference (April 18-21, 2016).
10. UW and NCAR have collaborated actively on all aspects of this project with regular (weekly to bi-weekly) Skype sessions, code review over GitHub, and almost daily messaging over Slack. Basin selection has taken into account feedback from contacts at the U.S. Bureau of Reclamation, the U.S. Army Corps of Engineers, Tacoma Power, Idaho Power, the Bonneville Power Administration, and the Tennessee Valley Authority. Communication with these agencies is ongoing.

BELUGA WHALES IN THE WESTERN BEAUFORT SEA AND MARINE MAMMAL ACOUSTIC ECOLOGY IN THE PACIFIC ARCTIC

PI
Kathleen M. Stafford – UW Applied Physics Laboratory

Task III

NOAA Sponsor
Phyllis Stabeno – Pacific Marine Environmental Laboratory

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

Description
Two synthetic manuscripts will be produced for inclusion in a special issue of *Deep-Sea Research II* to be edited by Sue Moore, Lisa Guy, and Phyllis Stabeno of NOAA's Pacific Marine Environmental Laboratory.

The purpose of the first manuscript will be to examine passive acoustic data from identified core-use areas of bowhead and beluga whales. We will use as baseline ambient noise levels those determined in Clark et al. (2015). We will then go into existing passive acoustic data sets at locations and seasons when bowheads and belugas are in core-use areas and provide finer scale information on changes in ambient noise levels over short time periods with/without anthropogenic sources including seismic air gun surveys and ship passages and with/without natural sources of noise such as wind (speed and direction), ice noise if appropriate, and other marine mammals. These data will provide estimates of changes in the acoustic environment of Arctic marine mammals due to different sources of noise.

The second manuscript will synthesize existing acoustic, telemetry, and aerial survey data for beluga whales in the western Beaufort Sea from ~150W to 160W. Acoustic data from 2008 to 2012 will be used to examine the timing of beluga arrivals and attempt to put that into the context of the migratory differences between the Beaufort Sea and Eastern Chukchi Sea populations. Aerial survey data will show areas of importance to animals from 1987 to 2012.

Major activities
Work with co-authors to develop two manuscripts for SOAR Phase II – one on Beluga whales in the Beaufort Sea, and another on the acoustic ecology of bowhead and beluga whales in the Pacific Arctic.

Objectives
Produce two manuscripts.

Accomplishments

1. A manuscript entitled "Beluga whales in the Alaskan Beaufort Sea: a synthesis of available information on timing, distribution, habitat use and environmental drivers" was submitted to *Deep-Sea Research II* in April 2016.

2. A manuscript entitled "Acoustic ecology of beluga and bowhead whales at hotspots in the Pacific Arctic" is currently in draft form to be submitted before May 15, 2016.

ARCTIC PROJECT

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

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

Task II

NOAA Sponsor
Jeremy T. Mathis – Arctic Research Program/Climate Program Office

Other NOAA Personnel
James E. Overland, Phyllis Stabeno, Sigrid Salo, Sue Moore, and Nancy Soreide – Pacific Marine Environmental Laboratory

NOAA Goals
Climate Adaptation and Mitigation

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

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

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

1. Forecast sea ice on all time scales.
2. Strengthen foundational science to understand and detect Arctic climate and ecosystem changes.
3. Improve weather and water forecasts and warnings.
4. Enhance international and national partnerships.
5. Improve stewardship and management of ocean and coastal resources in the Arctic.
6. Advance resilient and healthy Arctic communities and economies.

Project Areas

1. Arctic Change Detection – We continue to evaluate and understand recent rapid climate changes in the Arctic, with special focus on climate impacts of sea ice loss, and evaluation of future climate projections at pan-Arctic and regional scales. We are increasingly involved with communicating and advising on Arctic synthesis and policy to NOAA's Arctic Priority Objective Team, the Marine Mammal Commission, the U.S. Arctic Research Commission, the International Arctic Science Committee (IASC), and the U.S. Climate Variability and Predictability (CLIVAR) program. This project focuses on:

   a. The Arctic Report Card – In 2011, NOAA described the Arctic Report Card as "influential scientific information." The content is organized into five sections: Atmosphere, Sea Ice & Ocean, Marine Ecosystems, Terrestrial Ecosystems, and Hydrology and Terrestrial Cryosphere. An independent peer-reviewed article was completed by the Arctic Monitoring and Assessment Program. Muyin Wang of JISAO and James Overland of PMEL continue to update their part of the Arctic Report Card annually. This has become an internationally collaborated research effort with the NOAA news release at the American Geophysical Union (AGU) conference in December 2015.

   b. The Sea Ice Outlook – The Sea Ice Outlook builds a community consensus of the summer sea ice season. This has evolved as part of the main focus of the Sea Ice Prediction Network (SiPN) project in which Wang and Overland are members of the leadership team. Wang is responsible for organizing bi-monthly webinars in 2015/2016 hosted by SiPN. The Sea Ice Outlook for Walrus is a novel product specifically focused on capturing changes in sea ice coupled with weather/wind predictions at a temporal and spatial scale useful to local hunters in the Bering Strait region.

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

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

   e. Historical Arctic Climate and Data Rescue –Kevin Wood of JISAO's activities continue efforts at the U.S. National Archives and elsewhere to recover historical climate and ecosystem data, and sparse-input reanalysis.

   f. We also maintain and update the Arctic Theme Page, including the Arctic Change Detection website (arctic.noaa.gov/detect/) which provides up to date information on selected Arctic indices.

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

   a. Synthesis of available data and observations to understand marine ecosystem variability via the Bureau of Ocean Energy Management-supported Synthesis of Arctic Research project.

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

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

d. Russian-U.S. Long-term Census of the Arctic Support – Wood continues to oversee the marine technical aspects, and coordinating ship movements and documentation with Russian and U.S. authorities.

e. The Bering Climate Website (beringclimate.noaa.gov) is maintained and updated annually by Wang and Nancy Soreide of PMEL.

Accomplishments

1. Arctic Sea Ice – Wang, in collaboration with Overland 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 (arctic.noaa.gov/reportcard/). This year's edition showed that Arctic mean annual air temperature continues to increase at a rate of warming that is more than twice the rate of the global mean. In winter 2016 (January-March), Arctic warming reached a new record high with both months setting new records (5.8°C and 4.6°C, respectively for January and February). This warming trend continued into March, with nearly a new record (3.34°C) due to warm air advection from the south. Wang wrote an essay published at the PMEL Arctic Theme Page (arctic.noaa.gov/essay_wang.html). Later, CLIVAR published a shorter version of this essay in their News & Publications. It bears noting that the Arctic Report Card is becoming an increasingly valuable resource of information for the region for scientists, policy makers, and other users.

2. Coupled Model Intercomparison Project 5 assessment over the Arctic on ice and atmosphere – After publishing the results on pan-Arctic model sea ice assessment, Wang is extending her study to finer time scales, with a focus on ice freeze-up and break-up dates in the Chukchi Sea. A manuscript is under preparation.

3. We had two successful field seasons in 2013 and 2014 with NOAA P-3 flights. Wood has designed a research program using NOAA Twin Otter aircraft to continuously monitor water mass transformation and transport in the Chukchi Sea, and to provide near real-time ocean data for operational and research uses, in collaboration with Innovative Technology for Arctic Exploration and the Woods Hole Oceanographic Institution. Field activities will take place in the summer of 2016 and the spring/summer of 2017.

4. Wang and Qiong Yang of JISAO gave a poster presentation at the AGU Fall 2015 meeting held in San Francisco, and the Alaska Marine Science Symposium in Anchorage in January 2016.

5. Wood continues his leadership role in the joint imaging programs at the U.S. National Archives, the New Bedford Whaling Museum, and other regional museums and libraries including the Nantucket Historical Association, Providence Public Library, Martha's Vineyard Museum and Mystic Seaport Museum. The project has now identified and imaged close to one million pages of ship logbooks. These pages contain valuable weather, sea ice, and other environmental observations about the Arctic's past. Old Weather citizen-scientists have already transcribed three million new-to-science weather records, and these are now flowing into global databases where they are being used to fuel sparse-input reanalysis and reanalysis-driven sea-ice modeling experiments. As of yet, we have found no indications of a large sea ice reduction in the Pacific Arctic comparable to the present. Highlighting the multidisciplinary nature of the project, the first peer-reviewed scientific paper published using our recovered data dealt with aurora observations and space weather phenomena. Visit the Old Weather Blog (blog.oldweather.org/) for more information on this project.

IMPROVING CFS SEA ICE PREDICTABILITY THROUGH UNDERSTANDING THE ROLE OF ATMOSPHERIC FORCING AND ICE THICKNESS CONTRIBUTIONS

PI

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

Other UW Personnel

Qiong Yang – Joint Institute for the Study of the Atmosphere and Ocean
Jinlun Zhang – Applied Physics Laboratory

Task III

NOAA Sponsor

James Overland – Pacific Marine Environmental Laboratory

Other NOAA Personnel

Wanqiu Wang – National Centers for Environmental Prediction
Jessie Carman – Office of Weather and Air Quality

NOAA Goals

Weather-Ready Nation
Healthy Oceans

Description

Over the past decade, summer Arctic sea ice extent was reduced by 40%, whereas sea ice volume was reduced by 75% (Overland and Wang, 2013). Such continuing rapid changes in the Arctic and potential need for improved services provide a strong incentive to increase resources to evaluate and provide credible, reliable sea ice forecast information. Improved prediction of regional Arctic sea ice concentration, motion, and thickness are required for decisions on operations of infrastructure, safe shipping, and marine resource management.

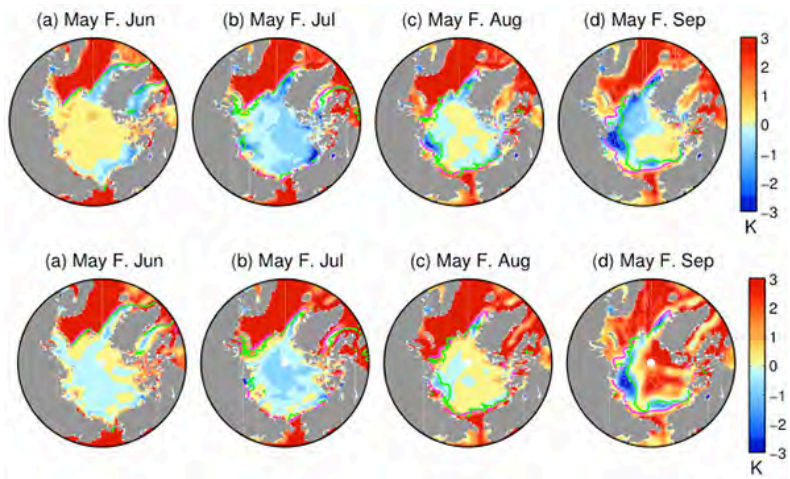


Figure 1. Systematic forecast errors (too warm) are found in the Atlantic Arctic side, and north of Bering Strait when compared with reanalysis products. In the central Arctic, cold bias is obvious. The top one is relative to ERA–interim, and the bottom panels are relative to NCEP/NCAR–R1. These temperature biases result in too much ice cover in the central Arctic.

Objectives

We seek to improve sea ice predictions in the Arctic by re-initializing the National Centers for Environmental Prediction (NCEP) Coupled Climate Forecast System version 2 (CFSv2) with more realistic ice thickness

distribution provided by the Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS). We will evaluate the contributions from atmospheric forcing and internal sea ice dynamics separately. The outcome will provide model system improvements and quantification of uncertainties of predictions of near future atmospheric, oceanic, and sea ice conditions.

Accomplishments

1. Muyin Wang and Qiong Yang of JISAO have continued their efforts of downloading the operational forecast products generated from NCEP CFSv2 (monthly, daily, and 6-hourly) twice a month since March 1, 2014. In addition, they have obtained the retrospective experimental runs by CFSv2 with improved sea ice thickness, initial condition, and physical processes (cloud parameterization).

2. M. Wang and Yang have evaluated the atmospheric forcing from the CFSv2 real-time operational forecasts against multiple reanalysis such as ERA-Interim, CFSR, MERRA-2 and NCEP/NCAR-R1. Yang gave a poster presentation at the American Geophysical Union (AGU) 2015 fall meeting held in San Francisco, and M. Wang gave a poster presentation at the 2016 Alaska Marine Science Symposium in Anchorage. Analysis is ongoing, and a manuscript is under preparation.

3. M. Wang and Yang have also investigated the impacts of clouds on the September Arctic sea ice predictions based on the CFSv2 retrospective experiments initialized with PIOMAS ice thickness. The initial results will be presented at the Sea Ice Prediction Network (SiPN) polar prediction workshop to be held in May in Palisades, New York, and a manuscript is under preparation.

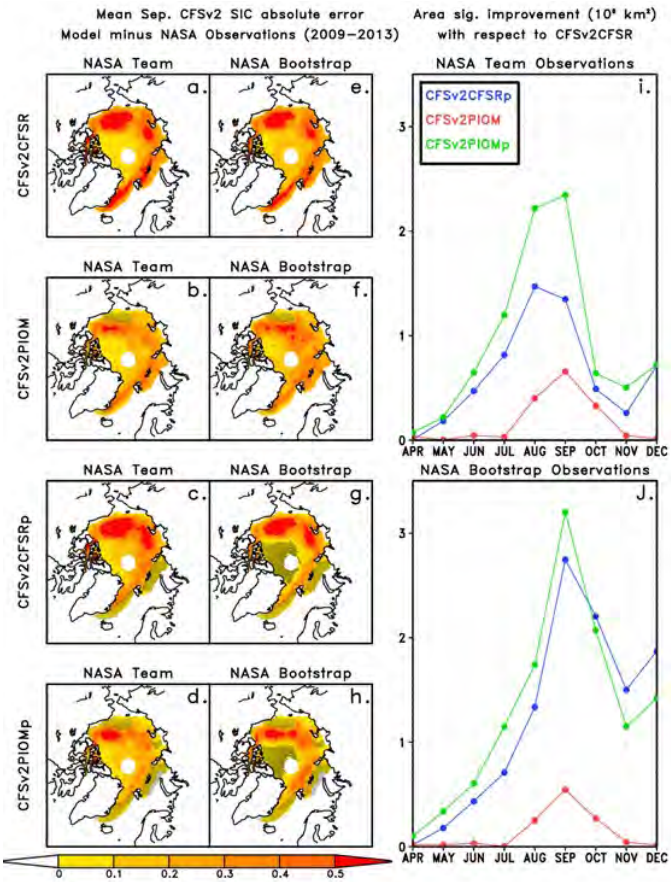


Figure 2. Mean September absolute error between modeled mean sea ice concentration and NASA observations (a–h, label on left minus label above). Shading denotes region where the decrease in the absolute error relative to CFSv2CFSR's absolute error is significant at the 99% confidence interval based on a single tailed t test. Only the region where the mean sea ice concentration in CFSv2CFSR over the hindcast period is greater than or equal to 0.15 is considered. The area of the region (units: 106 km2) with significant reduction in absolute error relative to CFSv2CFSR for each month is plotted in panel i for NASA Team as the observed truth and panel j for NASA Bootstrap as the observed truth.

4. Jinlun Zhang of UW's Applied Physics Laboratory conducted PIOMAS runs starting from January 1, 2015 to present month. The data for the ice thickness distribution profile from PIOMAS was collected from the 8th day to the 12th day of each month from March to October 2015 (5 days per month for 8 months). The files have been transported to Wanqui Wang at NCEP. We will continue this effort until October 2016.

5. W. Wang tested the CFSv2 with ice thickness distribution files provided by Zhang from March to October 2015, with 20 ensemble members each month. The results show improvement with PIOMAS ice thickness

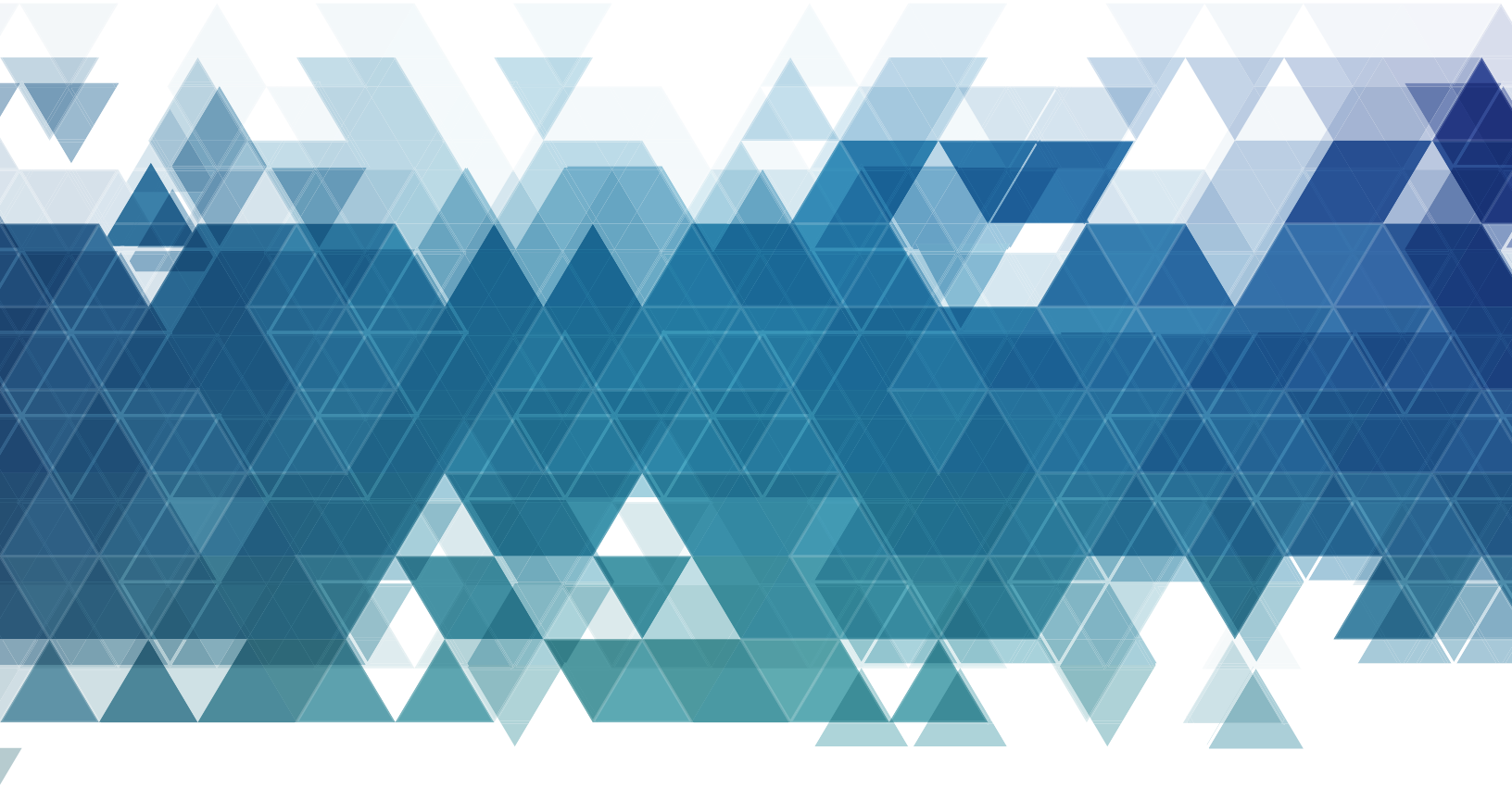
initializations. We started carrying out the same experiments again starting from March 8, 2016, and will continue producing forecasts each month through October.

6. Two meeting presentations are:

   a. Wang, W., X. Wu, T. Collow, and A. Kumar, 2015: Requirements for an improved seasonal sea ice prediction in the NCEP Climate Forecast System. NOAA's 40th Climate Diagnostics and Prediction Workshop in Denver, Colorado, on October26-29, 2015.

   b. Collow, T., W. Wang, and A. Kumar, 2015: Prediction of Arctic sea ice melt data as an alternative parameter for local sea ice forecasting. NOAA's 40th Climate Diagnostics and Prediction Workshop in Denver, Colorado, on October 26-29, 2015.

ENVIRONMENTAL CHEMISTRY



ATMOSPHERIC CHEMISTRY—AEROSOL PROGRAM

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

Other UW Personnel
David Covert – Department of Atmospheric Sciences
James Johnson and Lucia Upchurch – Joint Institute for the Study of the Atmosphere and Ocean

Task II

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

Other NOAA Personnel
Patricia Quinn and Derek Coffman – Pacific Marine Environmental Laboratory

NOAA Goals
Climate Adaptation and Mitigation
Weather-Ready Nation

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

Objectives
1. Determine the factors controlling the flux of sea spray aerosol to the atmosphere.
2. Assess the transport of black carbon in the Arctic using unmanned aerial systems (UAS).

Accomplishments
1. We participated in the first North Atlantic Aerosols and Marine Ecosystems Study cruise aboard the R/V *Atlantis* in November 2015. Sea spray aerosol (SSA), consisting of inorganic sea salt and organic matter, is thought to be a major contributor to the cloud condensation nuclei (CCN) population in the marine boundary layer. Our goal was to generate nascent SSA with the Pacific Marine Environmental Laboratory (PMEL)/Joint Institute for the Study of the Atmosphere and Ocean (JISAO) Sea Sweep, to measure the physical, chemical, optical and cloud nucleating properties of these SSA, to compare these measurements to measurements of ambient atmospheric aerosols, and to ultimately assess the contribution of SSA to the CCN population in the marine boundary layer. Sea Sweep was deployed seven times during the cruise. Near continuous ambient aerosol and gas sampling was conducted between Sea Sweep samples. Thirty-two impactor samples were collected during the cruise. Preliminary results show that the Sea Sweep SSA had the same CCN activity as NaCl, and that any organics that may be present are not affecting CCN activity.
2. Atmospheric aerosol vertical distributions were measured above Svalbard, Norway in April 2015 to investigate the processes controlling aerosol concentrations and radiative effects. The aerosol payload was flown in a

NOAA/PMEL MANTA Unmanned Aerial System on nine flights totaling 19 flight hours. Measurements were made of particle number concentration and aerosol light absorption at three wavelengths, similar to those conducted in April 2011 (Bates et al., Atmos. Meas. Tech., 6, 2115-2120, 2013). A filter sample was collected on each flight for analyses of trace elements. Additional measurements in the aerosol payload in 2015 included aerosol size distributions obtained using a Printed Optical Particle Spectrometer and aerosol optical depth obtained using a four wavelength miniature Scanning Aerosol Sun Photometer. The data show most of the column aerosol mass and resulting optical depth in the boundary layer but frequent aerosol layers aloft with high particle number concentration (2000 cm-3) and enhanced aerosol light absorption (1 Mm-1). Transport of these aerosol layers was assessed using FLEXPART particle dispersion models. The data contribute to an assessment of sources of black carbon to the Arctic and potential climate impacts.

NUTRIENTS

PI
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NOAA Goals
Healthy Oceans

Description
The Repeat Hydrography CO_2/Tracer Program is a systematic and global reoccupation of select hydrographic sections to quantify changes in storage and transport of heat, fresh water, carbon dioxide (CO_2), chlorofluorocarbon tracers, nutrients and related parameters. It builds upon earlier programs (e.g., World Ocean Circulation Experiment/Joint Global Ocean Flux Survey 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 CO_2/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, changes in the ocean's transport of heat and freshwater could affect the circulation by altering thermohaline overturning. Because the Argo array has a depth range of 2000 m, and cannot fully resolve the chemical signatures of the water column, repeat hydrographic measurements are the only global measurement program capable of observing these long-term trends deep in the ocean.

Objectives
1. To make high-quality measurements of inorganic nutrient (nitrate, nitrite, phosphate and silicate) concentrations in seawater on Climate Variability and Predictability program (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 processing nutrient data that was collected in 2015 during the Repeat Hydrographic Line P16N in the Pacific Ocean. On P16N, high precision shipboard analysis was carried out to determine the concentration of phosphate, nitrate, nitrite and silicic acid on samples collected at discrete depths during conductivity, temperature and depth (CTD) casts. Quality control of the P16N data set was completed, and the final data is now archived and available at the CLIVAR & Carbon Hydrographic Data Office website (cchdo.ucsd.edu).

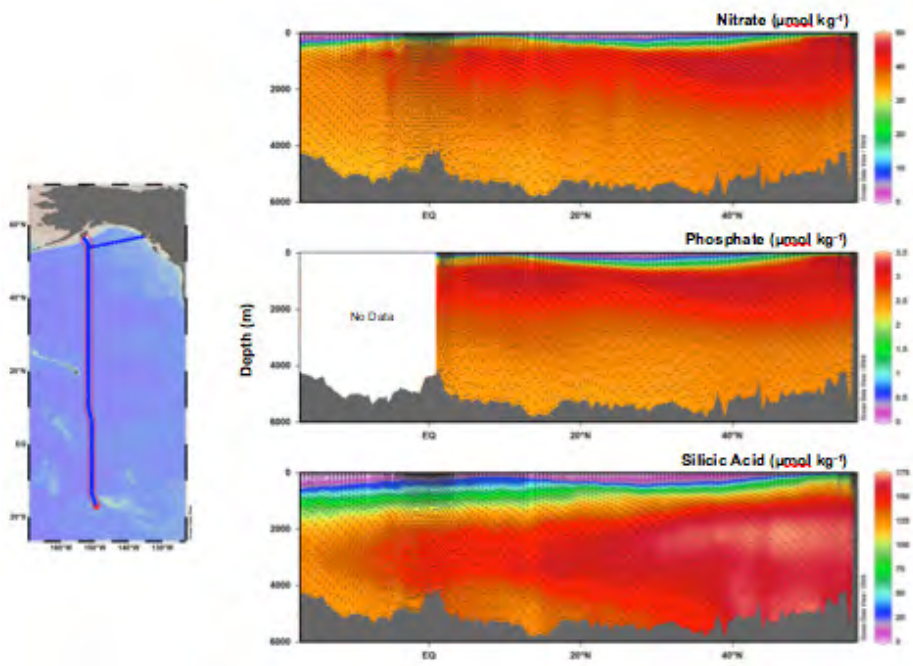

Figure 1. Sections of nitrate, phosphate and silicic acid along the P16N cruise track shown in the map (not including the eastward leg to Baranof Island in SE Alaska).

CHLOROFLUOROCARBON TRACER PROGRAM

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NOAA Goals
Climate Adaptation and Mitigation

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

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

Project Goals

1. A key goal of the Chlorofluorocarbon Tracer Program is to document the transient invasion of CFCs and other tracers (including SF_6) into the thermocline and deep waters of the world ocean, by means of repeat long-line hydrographic sections and at time-series stations, and to improve methods for using CFC observations to estimate the ventilation rate of water masses in the ocean.
2. 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 N_2O in the oceans and we plan to use these observations, together with the CFCs/SF_6, to quantify removal rates of fixed nitrogen from the oceans.

Objectives

1. Quantification of oceanographic ventilation processes through collection and analysis of CFC, SF_6, and hydrographic data.
2. Using CFC and SF_6 observations to improve estimates of the uptake of anthropogenic carbon dioxide in the ocean.
3. Using CFC and SF_6 observations to quantify oxygen utilization rates in the ocean interior.
4. Using combined CFC and SF_6 observations as a means of testing and evaluating large-scale numerical models of the ocean.
5. Using CFC and SF_6 observations for quantifying the temporal evolution of tracer ages and correcting for tracer age drift due to mixing processes.
6. Participate on the oceanographic expeditions P16N and P15S as part of the global CLIVAR/GO-SHIP Repeat Hydrography Program.
7. Quantify regional oceanic denitrification rates via dissolved nutrients, N_2O and CFC/SF_6 observations.
8. Identify dominant biological metabolic pathways controlling the distribution of marine dissolved N_2O.

Accomplishments

1. Finalized oceanographic CFCs, SF_6, and N_2O data from three long cruises in the Atlantic Ocean, and submitted these data to national and international data archives as part of the CLIVAR/GO-SHIP Repeat Hydrography Program.
2. Completed manuscript on transit time distributions in the Southeast Pacific Ocean provided by CFC and SF_6 data. The transit time distributions were used to improve estimates of thermocline ventilation, ventilation changes, and oxygen utilization rates in the South Pacific Ocean (*Journal of Geophysical Research*).
3. Contributed to analysis and evaluation of decadal changes in ventilation based on changes in tracer distributions (Shao et al., submitted to *Journal of Geophysical Research*).

4. Evaluated basin-scale preindustrial and contemporary air-sea fluxes in the Pacific basin based on contemporary 13C measurements and reconstructions from ocean general circulation models (Quay et al., submitted to *Global Biogeochemical Cycles*).
5. Installed a CFC/SF_6/N_2O analysis system in a new seagoing laboratory van and shipped to Australia for three oceanographic expeditions.

TURNING THE HEADLIGHTS ON 'HIGH': IMPROVING AN OCEAN ACIDIFICATION OBSERVATION SYSTEM IN SUPPORT OF PACIFIC COAST SHELLFISH GROWERS

PI

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NOAA Goals

Climate Adaptation and Mitigation
Healthy Oceans
Resilient Coastal Communities and Economies

Description

Working across four Integrated Ocean Observing System (IOOS) Regional Associations in partnership with the shellfish industry and other groups affected by ocean acidification (OA), our project is divided into four tasks that expand both technical capacity and the development of new technology with respect to OA observing needs for shellfish growers and other related impacted and potentially vulnerable U.S. industries, governments (tribal, state, local) and other stakeholders. This project includes development of observing technology, expert oversight intelligence, data dissemination, and outreach and is being executed by

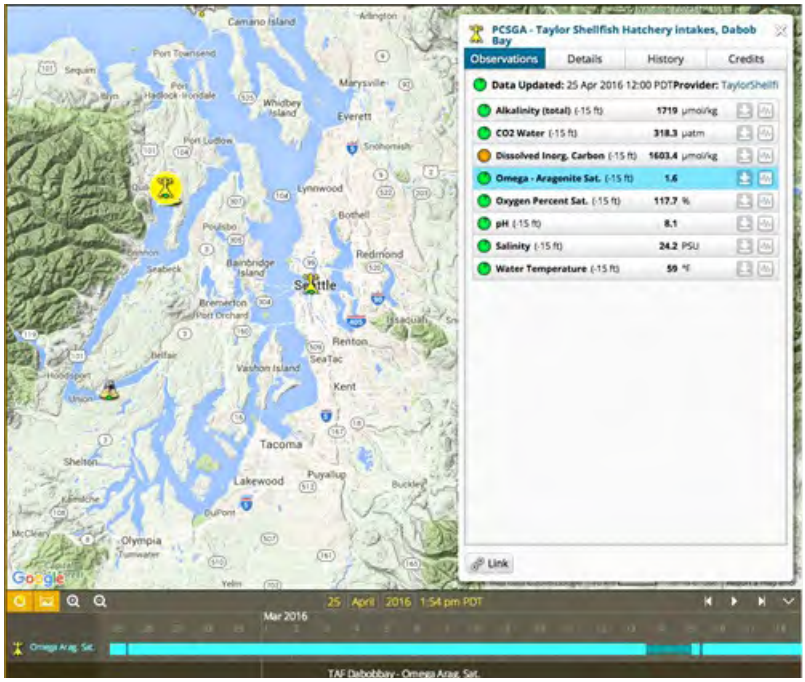

Figure 1. Plot of data from Taylor Shellfish Hatchery pCO2–TCO2 instrument data from IPACOA web site.

a team that includes a sensor technology industry and academic and government scientists.

The JISAO part of this effort includes two sub-tasks of Task II (Utilize regional partnerships of users and local experts to implement and provide Quality Assurance/ Quality Control (QA/QC) tests of the new OA sensors). The first is providing local expertise to keep the Taylor Shellfish Hatchery (TSH) monitoring system, located in Dabob Bay on Hood Canal, Washington, in good operating condition.

The second is to provide QA/QC tests of the new OA sensors. This comes in the form of running validation samples for all five of the shellfish hatchery or growing facilities, from southern California to Seward, Alaska. This is necessary for both existing and new procedures to define if the sensors deliver "weather" or "climate" quality data and to establish the best procedures available. This will facilitate continued evaluation and improvement of the equipment under development.

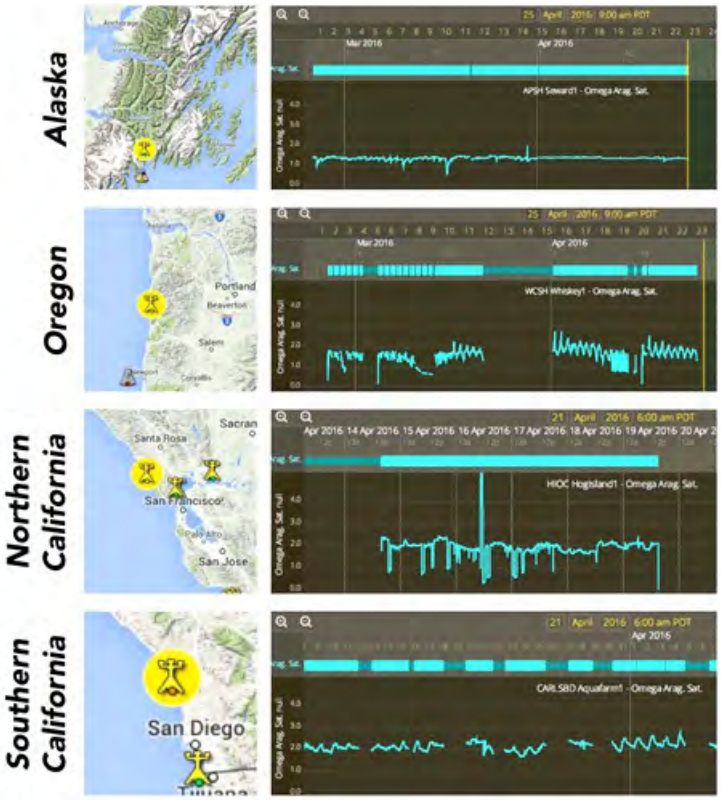

Figure 2. Plots of recent aragonite saturation state data from other shellfish facilities involved in this project.

Objectives

1. Provide technical support and liquid standards to TSH, Hood Canal, Washington (years 1–3).
2. Assist with troubleshooting analytical system as needed for TSH (years 1–3).
3. Develop a QA/QC plan for validation samples from the five shellfish facilities along the U.S. West Coast, including Alaska (years 1–2).
4. Provide sampling kits for all shellfish facilities (years 1–3).
5. Analyze returned QA/QC validation samples from the shellfish facilities (years 2–3).
6. Work with other PIs to evaluate sensor performance in context of validation sample results (years 2–3).

Accomplishments

1. We have regularly provided liquid standards to TSH, and have provided technical assistance as needed to keep the analytical systems in great working order since the beginning of this project.
2. We are working with other PIs to refine a QA/QC plan for collecting, analyzing, and interpreting validation samples from all five shellfish facilities.
3. Sampling kits have been provided for all shellfish facilities.

4. We are awaiting samples to run from the shellfish facilities.
5. Through the above actions we are working with other project PIs at a variety of institutions, from Alaska to California, to come up with sensor performance guidelines and best practices recommendations for these sensors once they are commercialized.
6. We are also working with other PIs to improve outreach portals (e.g., ipacoa.org/Explorer, see Figures 1–2) for better accessibility to target audiences.

MARINE CARBON PROGRAM

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NOAA Goals

Climate Adaptation and Mitigation
Healthy Oceans
Resilient Coastal Communities and Economies

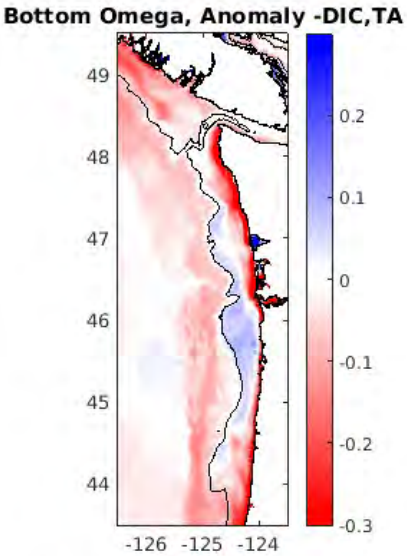

Figure 1. J–SCOPE model bottom Ωarag anomaly for August of 2013 forecasted from April conditions with full carbon variables (DIC and TA).

Description

The Marine Carbon Program provides a mechanism for research collaboration between Pacific Marine Environmental Laboratory (PMEL) scientists, JISAO scientists, and other University of Washington staff with common interests in the marine carbon cycle and its interactions with atmospheric carbon dioxide (CO_2) and climate. The program focuses on multidisciplinary research involving atmosphere-ocean CO_2 exchange fluxes, water column CO_2 distributions and transport, data interpretation and modeling, and ocean acidification. Special emphasis will be placed on the continuing effort to enhance our understanding of the role of the ocean in sequestering the increasing burden of anthropogenic CO_2 in the atmosphere, and the changes that are occurring due to ocean acidification. Project goals include: 1) determining the air-sea exchange of CO_2 from measurements collected on research ships, volunteers observing ships, and moorings; 2) determining the distribution and transport of CO_2 into the ocean interior from measurements collected onboard NOAA and University-National Oceanographic Laboratory System research ships; and, 3) determining the extent of the chemical changes that are occurring in the oceans as a direct result of ocean acidification.

Objectives

1. Collect dissolved inorganic carbon (DIC) and process data on the P16N GO-SHIP cruise: PMEL provided

equipment and personnel for the P16N cruise which departed in April 2015.

2. Service 38 CO_2 and ocean acidification moorings: In order to maintain sustained time series, the moored CO_2 systems and other sensors need to be swapped out with new systems at least once per year. The schedules for servicing are different for each system.

3. Perform required maintenance on underway CO_2 systems: We maintain four underway CO_2 systems that require regular servicing.

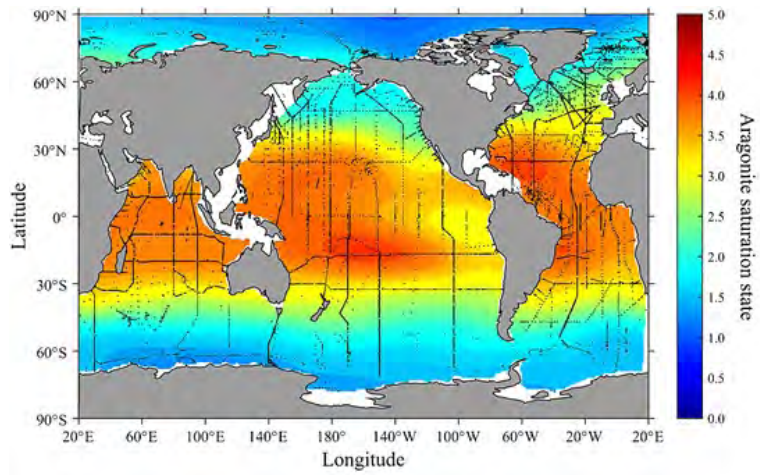

Figure 2. A surface ocean aragonite mineral saturation climatology from Jiang et al., 2015.

4. Collect and analyze discrete samples from the Puget Sound in partnership with the Washington Ocean Acidification Center (WOAC). We have continued working with a number of our colleagues in the Pacific Northwest to collect and analyze discrete carbon samples and deploy autonomous sensors in shellfish hatcheries.

5. Add additional carbon system variables to regional seasonal forecast system (J-SCOPE), utilize that system to provide seasonal OA forecasts, and begin development of OA indices for shellfish and crabs in the region.

6. Prepare for the West Coast Ocean Acidification (WCOA) cruise in May 2016 and the P18 Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP) cruise in November 2016, for which PMEL and JISAO scientists are serving in roles as chief scientists, technicians, and analysts.

Accomplishments

1. Conducted final DIC data processing for GO-SHIP Repeat Hydrography Section P16N in the Pacific. All data have been submitted to the Carbon Dioxide Information Analysis Center.

2. Maintained five underway CO_2 systems.

3. Deployed and/or maintained 38 moored CO_2 systems.

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

5. We have successfully added the carbon system variables to the regional forecast system, J-SCOPE and experimented with past forecasts of 2013, as well as new 2016 forecasts. We expect to make those available on the web by June. We have assembled a climatology from 2009-2014 and can now forecast anomalies from those conditions. Some initial results of those anomalies are included below. In addition, we submitted a paper to *Nature's Scientific Reports* for J-SCOPE including the prior method relying on the algorithm for seasonal forecasts of OA; that is in its second round of revisions (see "Publications" for citation).

6. WCOA and P18 are moving ahead on schedule.

TROPICAL ATMOSPHERE–OCEAN INTERACTION

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NOAA Goals
Climate Adaptation and Mitigation

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

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

Objectives

1. Maintain and enhance the TAO, PIRATA and RAMA web pages.
2. Increase the number of ATLAS (autonomous temperature line acquisition system) and acoustic Doppler current profiler moorings in RAMA.
3. Develop new moored observing technologies to enhance and sustain climate quality observations in the tropical oceans.
4. Improve understanding of ENSO and decadal time scale variability in the Pacific.
5. Advance understanding of the dynamics of ocean circulation in the Indian Ocean.
6. Improve our understanding of ocean surface boundary layer dynamics.

Accomplishments

1. Research carried out at JISAO and elsewhere using data from the TAO/TRITON, PIRATA and RAMA arrays depends critically on the collection, quality control, archival, and web-based display and dissemination of mooring data sets. At JISAO, considerable effort is devoted to providing easy access to high quality multi-variate time series through the TAO web page (pmel.noaa.gov/tao/). Between April 1, 2015, and March 31, 2016, TAO web pages received more than 18 million hits, delivered more than 375,000 mooring data files via the web, and more than 3 million files via file transfer protocol (FTP) to the international community.

2. Since last year's report, we deployed a new ATLAS mooring in the Indian Ocean near 4°S, 57°E in November 2015 from a contracted merchant vessel, the *Tethys Supporter*. These moorings represent progress in a developing RAMA, which is now 76 % complete, with 35 of 46 planned moorings in place.

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

4. The ENSO is the dominant climate phenomenon affecting extreme weather conditions worldwide. Its response to greenhouse warming has challenged scientists for decades, despite model agreement on projected changes in mean state. Recent studies have provided new insights into the elusive links between changes in ENSO and in the mean state of the Pacific climate. The projected slow-down in Walker circulation is expected to weaken equatorial Pacific Ocean currents, boosting the occurrences of eastward-propagating warm surface anomalies that characterize observed extreme El Niño events. Accelerated equatorial Pacific warming, particularly in the east, is expected to induce extreme rainfall in the eastern equatorial Pacific and extreme equatorward swings of the Pacific convergence zones, both of which are features of extreme El Niño. The frequency of extreme La Niña is also expected to increase in response to more extreme El Niños, an accelerated maritime continent warming and surface-intensified ocean warming. ENSO-related catastrophic weather events are thus likely to occur more frequently with unabated greenhouse-gas emissions. But model biases and recent observed strengthening of the Walker circulation highlight the need for further testing as new models, observations and insights become available. (Cai et al, 2015, *Nature Climate Change*).

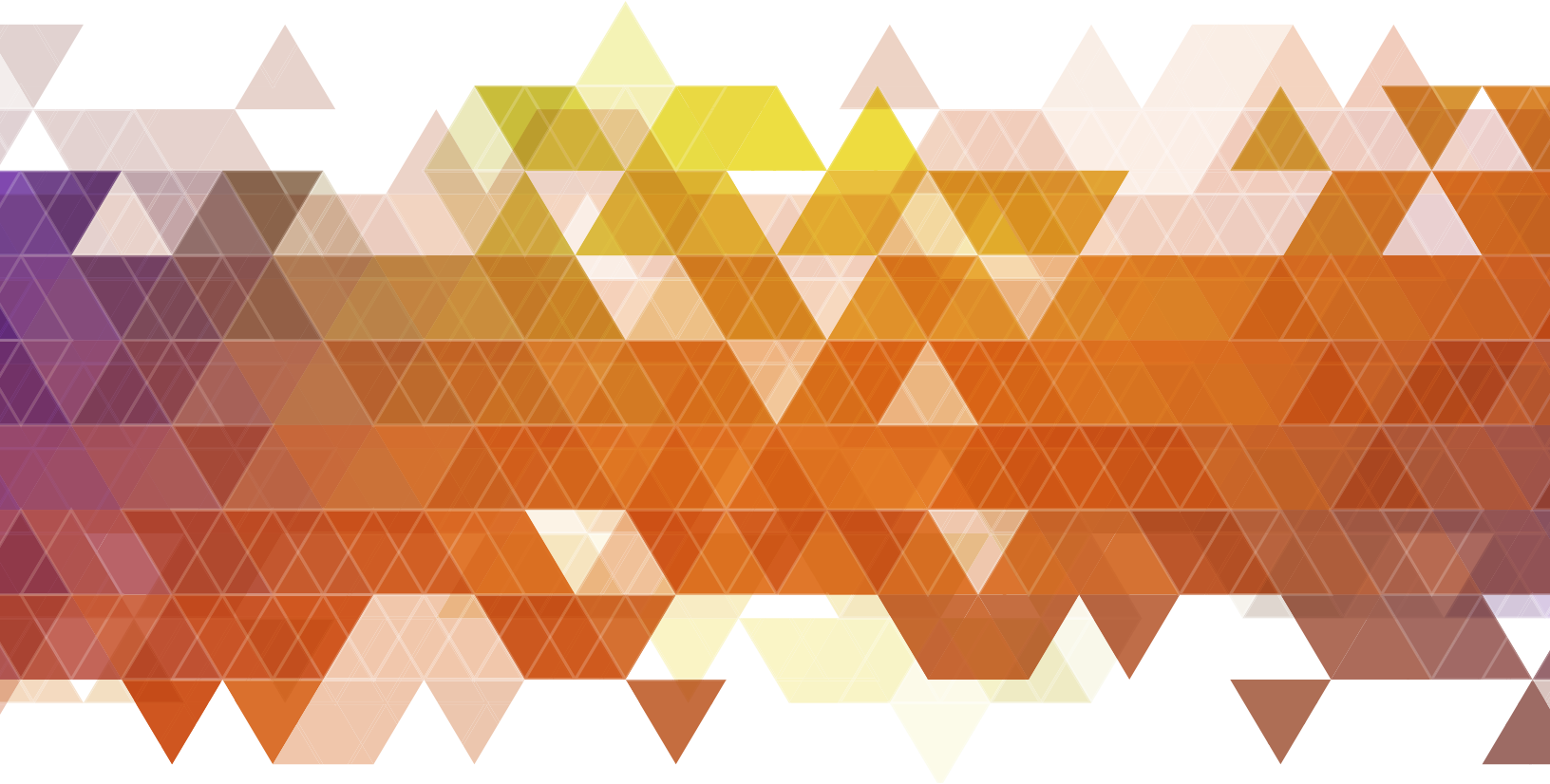
5. Equatorial Pacific changes during the transition from a non-hiatus period (pre-1999) to the present global warming hiatus period (post-1999) were identified using a combination of reanalysis and observed data sets. Results show increased surface wind forcing has excited significant changes in wind-driven circulation. Over the last two decades, the core of the Equatorial Undercurrent (EUC) intensified at a rate of 6.9 cm s-1 decade-1. Similarly, equatorial upwelling associated with the shallow meridional overturning circulation increased at a

rate of 2.0 x 10-4 cm s-1 decade-1in the central Pacific. Further, a seasonal dependence is identified in the sea surface temperature trends and in subsurface dynamics. Seasonal variations are evident in reversals of equatorial surface flow trends, changes in subsurface circulation, and seasonal deepening/shoaling of the thermocline. Anomalous westward surface flow drives cold-water zonal advection from November to February, leading to surface cooling from December through May. Conversely, eastward surface current anomalies in June–July drive warm-water zonal advection producing surface warming from July to November. An improved dynamical understanding of how the tropical Pacific Ocean responds during transitions into hiatus events, including its seasonal structure, may help to improve future predictability of decadal climate variations. (Amaya, Xie, Miller, McPhaden, 2015, *Journal of Geophysical Research*).

6. We investigated the structure and dynamics of the EUC of the Indian Ocean by analyzing *in situ* observations and reanalysis data and performing ocean model experiments using an ocean general circulation model and a linear continuously stratified ocean model. The results show that the EUC regularly occurs in each boreal winter and spring, particularly during February and April, consistent with existing studies. The EUC generally has a core depth near the 20°C isotherm and can be present across the equatorial basin. The EUC reappears during summer through fall of most years, with core depth located at different longitudes and depths. In the western basin, the EUC results primarily from equatorial Kelvin and Rossby waves directly forced by equatorial easterly winds. In the central and eastern basin, however, reflected Rossby waves from the eastern boundary play a crucial role. While the first two baroclinic modes make the largest contribution, intermediate modes 3 through 8 are also important. The summer through fall EUC tends to occur in the western basin but exhibits obvious interannual variability in the eastern basin. During positive IOD years, the eastern basin EUC results largely from Rossby waves reflected from the eastern boundary, with directly forced Kelvin and Rossby waves also having significant contributions. However, the eastern basin EUC disappears during negative IOD and normal years because westerly wind anomalies force a westward pressure gradient force and thus westward subsurface current, which cancels the eastward subsurface flow induced by eastern boundary-reflected Rossby waves. Interannual variability of zonal equatorial wind that drives the EUC variability is dominated by the zonal sea surface temperature gradients associated with IOD and is much less influenced by equatorial wind associated with Indian monsoon rainfall strength (Chen, Han, Li, Wang, McPhaden, 2015, *Journal of Physical Oceanography*).

7. Ocean currents in the surface boundary layer are sensitive to a variety of parameters not included in classic Ekman theory, including the vertical structure of eddy viscosity, finite boundary layer depth, baroclinic pressure gradients, and surface waves. These parameters can modify the horizontal and vertical flow in the near-surface ocean, making them of first-order significance to a wide range of phenomena of broad practical and scientific import. In this work, an approximate Green's function solution is found for a model of the frictional ocean surface boundary layer, termed the generalized Ekman (or turbulent thermal wind) balance. The solution admits consideration of general, more physically realistic forms of parameters than previously possible, offering improved physical insight into the underlying dynamics. Closed form solutions are given for the wind-driven flow in the presence of Coriolis-Stokes shear, a result of the surface wave field, and thermal wind shear, arising from a baroclinic pressure gradient, revealing the common underlying physical mechanisms through which they modify currents in the ocean boundary layer. These dynamics are further illustrated by a case study of an idealized two-dimensional front. The solutions, and estimates of the global distribution of the relative influence of surface waves and baroclinic pressure gradients on near-surface ocean currents, emphasize the broad importance of considering ocean sources of shear and physically realistic parameters in the Ekman problem (Wenegrat and McPhaden, 2016, *Journal of Physical Oceanography*).

MARINE ECOSYSTEMS



AFSC INTERNSHIP OPPORTUNITIES

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NOAA Goals
Healthy Oceans
Resilient Coastal Communities and Economies

Objectives
Through this project, three new internship positions have been created in JISAO's successful summer internship program for undergraduates. These positions span a range of multi-disciplinary opportunities involving ongoing research programs at NOAA/Alaska Fisheries Science Center (AFSC). A special focus of this project is to promote greater diversity in the ocean science workforce.

Accomplishments
The interns for this project have been selected and matched with NOAA/AFSC scientists that will serve as their primary mentors. Mentors for the 2016 program include Manolo Castellote, Ivonne Ortiz, and Erin Richmond. The interns will be in Seattle from June 20 – August 19, 2016. Final arrangements are being completed.

INCORPORATING RECRUITMENT–ENVIRONMENT LINKAGES INTO STOCK ASSESSMENT MODELS FOR ALASKAN GROUNDFISH WITH APPLICATION TO POPULATION PROJECTIONS IN A CHANGING CLIMATE

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Task II

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NOAA Goals
Healthy Oceans

Description
This project is using simulations to develop stock assessment models that incorporate hypothesized relationships between recruitment and environmental indices, and we will evaluate the accuracy of model selection tools to distinguish among these relationships. Results from the simulation study will inform best practices for including recruitment-environment linkages in a suite of stock assessment-based forecasts for Gulf of Alaska flatfish, including Pacific halibut.

Objectives
1. Improving forecasts of fish population dynamics given hypotheses about future climate change and fishing by identifying robust tools for model selection.
2. Evaluating the potential for alternative harvest policies to meet management objectives over a range of future climate scenarios using forecasting models that incorporate both correctly and incorrectly specified linkages between population dynamics and environmental conditions.

Accomplishments
The work being carried out under the auspices of this project is in its early stages. The operating model (OM) for stock assessment that will be used to represent the true state of fish populations is in the process of being developed by Carey McGilliard of the Alaska Fisheries Science Center, and a collaborator Gavin Fay from the University of Massachusetts. Preliminary simulations have been carried out with observational errors. The activities during the upcoming year will focus on using the OM being developed to explore the effects of various future climate scenarios on the population dynamics of the groundfish species of interest.

ECOSYSTEMS AND FISHERIES–OCEANOGRAPHY COORDINATED INVESTIGATIONS (EcoFOCI)

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NOAA Goals

Healthy Oceans
Climate Adaptation and Mitigation

Description

The dynamic relationships of marine ecosystems and the impact of change on these ecosystems in important economic and cultural regions are being studied by the Ecosystems and Fisheries-Oceanography Coordinated Investigations team (EcoFOCI). EcoFOCI is a collaborative research effort by JISAO, NOAA scientists at the Pacific Marine Environmental Laboratory (PMEL), and the Alaska Fisheries Science Center (AFSC), which focuses on the unique and economically important high-latitude ecosystems of Alaska. The mission of the EcoFOCI Program is to understand the dynamic relationships between climate, fisheries, and the marine environment to ensure sustainability of Alaskan living marine resources and healthy ecosystems.

Ongoing investigations delve into ecosystem impacts of fluctuations in temperature, salinity, sea-ice extent and duration, atmospheric forcing, freshwater runoff, productivity, and mixed-layer depth in the Gulf of Alaska, the Aleutian Islands, and the Bering and Chukchi Seas. The timescales of interest range from short-term episodic and seasonal events to long-term annual and decadal trends. EcoFOCI incorporates field observation, 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 mooring arrays,

satellite tracked drifters, and shipboard measurements – Biophysical moorings are maintained in the Gulf of Alaska and the Bering and Chukchi seas, providing critical information on the response of the environment to changes in climate. JISAO scientists contribute to: maintaining these moorings; expanding the instruments on moorings to measure ice keel depth, zooplankton abundance, nitrate, and oxygen; and introducing new technology to enable these moorings to report in real time.

2. Disseminating data through websites, presentations, publications, and workshops – JISAO scientists contribute to the maintenance of web pages, author and co-author numerous publications each year, and present their findings at variety of regional, national, and international meetings.

3. Participating in cruises to examine the variability in physical and chemical oceanic processes that impact the North Pacific, Bering Sea, and U.S. Arctic ecosystems – JISAO scientists take a leading role in these studies. They participate on cruises as chief scientists, and are leaders in the measurements of nutrients, chlorophyll, and oxygen.

4. Projecting impacts of climate change – JISAO scientists are involved in an effort to apply simulations of future climate (Intergovernmental Panel on Climate Change 4th Assessment models) to issues related to marine ecosystems. The output from these models is being used to force local dynamical models of the North Pacific Ocean and Bering Sea, and to make projections based on empirical methods.

5. Making data and analysis results available to Fishery Management Councils and other resource managers.

Accomplishments

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

2. In 2015, EcoFOCI was present in the Gulf of Alaska, and the Eastern Bering and Chukchi Seas, including the U.S. Arctic. Fifty-five biophysical moorings were deployed and recovered, 16 Argos drifters were deployed, and 472 key-stations were sampled with a CTD (conductivity, temperature and depth) over 10 research cruises totaling 140 days at sea. EcoFOCI scientists also co-led the first research cruise to the Arctic on the NOAA Ship *Ronald H. Brown*.

3. Disseminating data through websites, presentations, publications and workshops. In 2015, EcoFOCI scientists prepared 62 Publications (21 published, 41 in progress), including special issues for *SOAR* and the Bering Sea Integrated Ecosystem Research Program Projects. Scientists also participated in a variety of presentations and workshops including the Marine Technology Society/Institute of Electrical and Electronics Engineers Oceans '15 Conference (October 2015), Alaska Marine Science Symposium (January 2016), American Geophysical Union Ocean Sciences Meeting (February 2016), and the Distributed Biological Laboratory Workshop (March 2016).

4. In July of 2015, members of EcoFOCI (both federal and contract) were awarded a NOAA Group Gold Medal for Scientific and Engineering Achievement, one of the highest honors researchers at NOAA can receive. The award recognized the group for leading and conducting a comprehensive, integrated ecosystem research program that reveals how climate cycles affect the nation's largest fishery.

5. The Gulf of Alaska Project Integrated Ecosystem Research Program (GOAIERP) concluded in 2014. The 5-year, multi-institution collaborative project, funded by the North Pacific Research Board (NPRB), examined the physical and biological mechanisms that determine the survival of juvenile groundfishes in the Gulf of Alaska.

EcoFOCI scientists played major roles in the effort to determine how physical transport mechanisms influence lower trophic levels, and subsequently the survival and recruitment of five species of groundfish (walleye pollock, Pacific cod, arrowtooth flounder, sablefish, and Pacific Ocean perch). Participating EcoFOCI scientists attended a GOAIERP synthesis workshop at the University of Washington Friday Harbor Laboratory March 1-5, 2016. Initial findings will be reported in a *Deep Sea Research II* special issue expected in 2017.

6. The Bering Ecosystem Study and Bering Sea Integrated Ecosystem Research Program, 2007 through 2012, was a multi-institution collaborative project, funded by the National Science Foundation and the NPRB, respectively, to understand the impacts of climate change and dynamic sea ice cover on the eastern Bering Sea ecosystem. The fourth and final special issue in *Deep Sea Research II* is in progress.

7. The Synthesis of Arctic Research (SOAR) was a 5-year Bureau of Energy Management (BOEM) supported effort, now concluding in 2017, 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. A special issue in *Progress in Oceanography* dedicated to an ecosystem-based understanding of the "new state" of the Pacific Arctic was published on July 13, 2015. The special issue is comprised of 17 papers by more than 100 scientists and local experts, on topics ranging from physics to marine mammals. Authors from JISAO/PMEL contributed to several papers. The synthesis covers three themes, with five papers focusing on observations and models of sea ice loss and effects on primary production; five papers focused on the response of mid-level trophic species to the "new state" of the Arctic; and six papers focused on the responses of upper trophic level species. A second SOAR special issue building upon this new understanding of the current state of the Pacific Arctic marine ecosystem is now underway and expected for Winter 2017.

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

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

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

11. EcoFOCI scientists continue to make data and analysis results available to its scientists, the research community, Fishery Management Councils, and the public. Currently, EcoFOCI scientists, along with the PMEL data and systems support group, are initiating the first steps towards modernizing the EcoFOCI data infrastructure. If successful, the test will be a prototype for converting a large volume of long-running EcoFOCI time series and profile data into a more standard and accessible resource for the research community and the

public. The project began in Summer 2015 and will conclude in June of 2016. EcoFOCI scientists also continue to build a database-driven in-house go-to resource in support of the extensive field program.

12. EcoFOCI worked in partnership with another JISAO program, Innovative Technology for Arctic Exploration in 2015. EcoFOCI scientists provided oceanographic data analysis and expertise for technologies used including the Saildrone, Ecosystem Wave Glider, and a Radiation Mooring.

13. EcoFOCI continues the past decade of partnership with the Arctic Climate Change program at PMEL focusing on climate-oceanography relationships in the Arctic region, including the sub-Arctic Chukchi, Beaufort, and Bering Seas. JISAO Scientist Muyin Wang, in collaboration with Jim 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.

14. EcoFOCI is again collaborating with the International Pacific Halibut Commission (IPHC) in processing and managing hydrographic profile data acquired during their annual Stock Assessment Survey. The annual survey provides catch information and biological data independent of the commercial fishery, from pre-defined station grids that extend from the Bering Sea and Aleutian Islands, along the Gulf of Alaska shelf and along the U.S. West Coast to Northern California. The IPHC-JISAO-EcoFOCI collaboration began in 2009, and comprises an annual influx of ~1200 profile data files that are processed and analyzed, then made available to the public. These data are a compliment to data-collection areas and research of the EcoFOCI program.

15. EcoFOCI continues to work with the main authors of the Ecosystem Considerations Chapter of the Stock Assessment and Fishery Evaluation reports to provide ecosystem indicators for the Bering Sea. The Ecosystem Considerations Report is produced annually to compile and summarize information about the Alaska Marine Ecosystem for the North Pacific Fisheries Management Council, the scientific community, and the public. The report includes ecosystem report cards, ecosystem assessments, contributions with updated status and trend indicators, and ecosystem-based management indicators and information for the Bering Sea, Aleutian Islands, the Gulf of Alaska, and Arctic ecosystems.

16. EcoFOCI scientists also continue a long-time commitment to outreach by participating in NOAA campus tours, NOAA Science Camp, Seattle Aquarium Discover Science Weekend, University of Washington Paws-on-Science Weekend, and Washington Sea Grant's Orca Bowl, among other opportunities.

NOAA SUPPORT FOR DO-IT SCHOLARS PROGRAM

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Task III

NOAA Sponsor
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NOAA Goals
Healthy Oceans

Description
DO-IT (Disabilities, Opportunities, Internetworking, and Technology) serves to increase the participation of individuals with disabilities in challenging academic programs and careers, particularly those in science, technology, engineering and mathematics (STEM). The DO-IT Scholars Program 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. During a 10-day, live-in summer program at the University of Washington (UW) in Seattle, DO-IT Scholars participate in academic lectures and STEM labs; live in residence halls; and practice skills that will help them become successful in college and careers. During the year that follows, each scholar completes a project, engages with staff in a presentation or meeting at his/her school, and participates in online and/or on-site activities.

Objectives
The ultimate goal of the DO-IT Scholars Program is to increase the success of students with disabilities in challenging postsecondary academic programs and careers. The objective of the funded project is to support one student with a disability interested in pursuing postsecondary education and a career in one of the areas of focus of NOAA through the first year of the DO-IT Scholars Program.

Accomplishments
1. Scholar identified, computer delivered, and training completed.
2. Online and on-site interaction with peers, near-peers, mentors and staff.
3. Participation in 10-day Phase I Summer Study.
4. Funded scholar is a junior in high school and a member of the National Honor Society.
5. Evidence of impact of DO-IT Scholars participation: Pre/post surveys of DO-IT Scholar participants, participant evaluations of Summer Study activities and internships, progress of participants in longitudinal transition study, and other evaluation data (uw.edu/doit/Stem/tracking4.html) suggest positive impact with respect to preparing participants for college and career success.

Specific activities for 2014 – 2016 include:

June 2014
DO-IT Advisory Board selected one additional DO-IT Scholar to be supported with NOAA funds. Scholar was notified and details for involvement shared. Scholars received program DVDs and materials. Computer was set up in scholars' homes. Scholars were "introduced" to mentors, peers, and near-peers online.

July 2014
Scholars engaged in 10-day residential Phase I Summer Study at UW. They gained internet, college preparation, career planning, self-determination, and leadership knowledge and skills. Scholars chose year-long projects.

August 2014 – May 2015
Scholars participated in DO-IT's online e-mentoring community; they received mentoring, near-peer, and peer support; weekly electronic lessons; and access to useful college preparation, academic, and career information online. Scholars participated in DO-IT conferences and other online and on-site activities. Scholars completed year-long projects. Scholars helped DO-IT recruit DO-IT Pals and Scholars from their schools. DO-IT staff members participated with scholars in presentations and meetings at their schools.

May 2015 – March 2016
During this time period the scholar supported through this funding continues to engage in DO-IT. He attended a 1-week Summer Study Phase II session on the UW campus, during which he presented his year-long project.

Following his second Summer Study he will engage in the e-mentoring community and learn about on-site activities and events in which he can participate. The third summer he will work as an intern in the Summer Study. After that, he can continue engaging as an ambassador in the e-mentoring community, gaining and offering resources and support.

USING ACOUSTICS TO IMPROVE SPECIES IDENTIFICATION OF MARINE ORGANISMS IN THE NORTH PACIFIC

PI
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Task III

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NOAA Goals
Healthy Oceans

Description
Acoustic methods are widely used for remote sensing of marine zooplankton and fishes. Large-scale acoustic-trawl (AT) surveys have been conducted annually for over three decades in the north Pacific by NOAA researchers as part of the stock assessment process. The frequency response of organisms measured at multiple narrowband frequencies with center frequencies between 10 and 200 kHz has been used to improve interpretation of backscatter during these AT surveys. However, this approach currently does not reliably distinguish different species of fishes with swimbladders. Additional information derived from newly developed broadband acoustic instruments (see Accomplishments section) may aid in the size and species classification of backscatter when the multi-frequency approach fails. Thus, the broadband approach enables frequency-dependent quantification of the backscatter over a wider uninterrupted frequency range, resonance classification (i.e. sizing of swim bladders), and high spatial resolution via pulse compression to provide more information for classification of acoustic targets.

Accomplishments
The post-doctoral research associate funded by the project, Chris Bassett, commenced work in June 2015, starting with travel to Alaska to board the NOAA ship R/V *Oscar Dyson* to conduct the Alaska Fisheries Science Center biennial Gulf of Alaska acoustic-trawl survey. As part of this survey, a field study to evaluate the utility of broadband (frequency sweep range 10-100 kHz) acoustic measurements for species identification was conducted.

To make broadband measurements on the NOAA ship, a prototype constant-beamwidth transducer built for the University of New Hampshire was installed on the centerboard looking downward (similar to the existing Simrad transducers) in April 2015 when the vessel was in port in Kodiak, Alaska (Figure 1). The broadband field work focused on target backscatter that is difficult to classify using traditional multi-frequency techniques. Examples of this include characterizing the broadband signature from aggregations of important forage fishes (juvenile walleye pollock, eulachon, capelin, sand lance), which occur throughout the Gulf of Alaska (GOA), as well as those of co-occurring aggregations of adult walleye pollock and rockfish species that commonly occur along the GOA shelf-break.

Some examples of preliminary results from this effort are shown below. Comparison of the broadband data from this study with narrowband data collected earlier (De Robertis et al. 2010) showed good agreement for several semi-demersal and mesopelagic fish species, as well as for euphausiids (Figure 2). The use of broadband acoustics may facilitate classification of some diverse taxa, which can be detected as mixed species aggregations (Figure 3). Although differences between fishes with gas bladders and zooplankton are detectable using broadband acoustics, differences among fishes with gas bladders are very subtle (Figure 4), and will likely be difficult to implement in an operational manner for large-scale AT survey work.

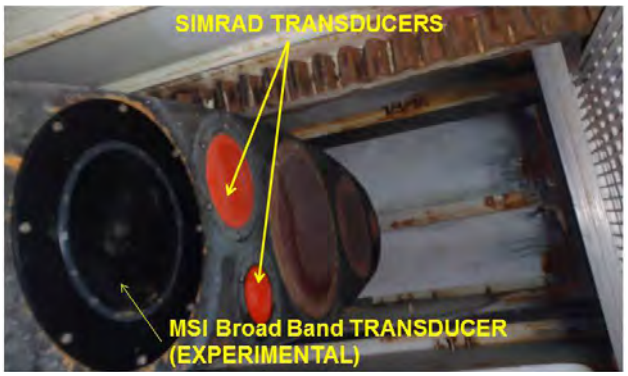

Figure 1. Photograph made within the vessel centerboard showing the Simrad transducers (the orange and red ones) and the experimental MSI broadband transducer (black). Upon deployment through the centerboard opening the transducers will be pointing downward.

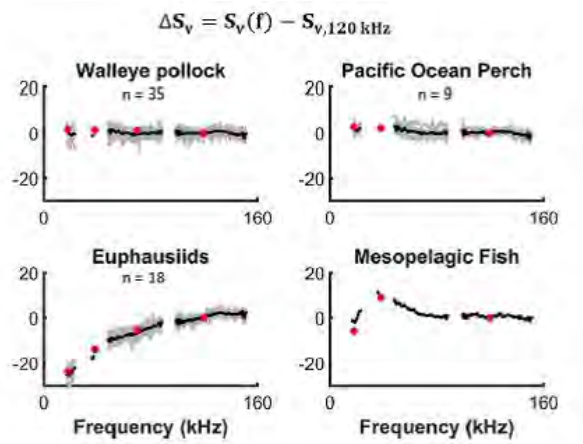

Figure 2. Volumetric scattering strength data (Sv) from summer 2015. Black lines are representative curves derived by averages of the data (gray). Major structural differences are seen in the scattering for different fish species and euphausiids. The red dots are from A. DeRobertis, D. R. McKelvey, and P. H. Ressler, Development and application of an empirical multifrequency method for backscatter classification, Can. J. Fish. Aquat. Sci. 67: 1459–1474 (2010) doi:10.1139/F10-075.

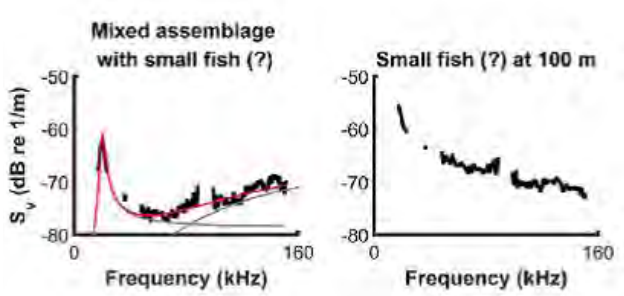

Figure 3. Plot of broadband scattering from a suspected (i.e., no available confirmation trawl samples) mixed assemblage aggregation suggests that the dominant low-frequency scattering may be due to the swimbladder resonance from age-0 pollock (fork length ~ 3 cm) and higher frequency scattering likely from euphausiids. This illustrates the potential value of broadband acoustics as a powerful remote sensing tool.

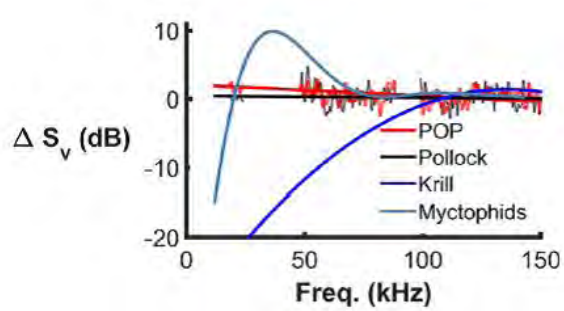

Figure 4. Showing data fits to the different result from Figure 1. For the case of Pacific Ocean perch and walleye pollock, the results suggest that it will be hard to differentiate between species using acoustics alone.

LINKS BETWEEN THE EARLY LIFE HISTORY DYNAMICS OF FISH, CLIMATE, AND OCEAN CONDITIONS IN THE LARGE MARINE ECOSYSTEMS OF ALASKA

PI

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Task II

NOAA Sponsor

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NOAA Goals

Healthy Oceans
Climate Adaptation and Mitigation

Description

This research has been carried out in conjunction with the NOAA Alaska Fisheries Science Center's (AFSC) Recruitment Processes and the Ecosystems and Fisheries-Oceanography Coordinated Investigations (EcoFOCI) groups. Data are from ongoing collections of ichthyoplankton samples and associated oceanographic and climate measurements in the Gulf of Alaska (GOA). 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 carried out in order to understand species pelagic ecology patterns and response outcomes during early ontogeny. The research contributes to a mechanistic understanding of environmental forcing on early life history aspects of recruitment processes, and population fluctuations among marine fish species.

Objectives

1. Participation in the North Pacific Research Board (NPRB) sponsored Gulf of Alaska Integrated Ecosystem Research Program (GOAIERP) – Integration phase and beginning of Synthesis phase:
   a. Complete the revision of the manuscript reviewing the early life history of the GOAIERP focal species; walleye pollock, Pacific cod, Pacific ocean perch, sablefish, and arrowtooth flounder (for *Deep Sea Research II*, GOAIERP special issue I).
   b. Continue collaboration with other GOAIERP principal investigators in integrating this early life history synthesis into different components of the project, including the upper trophic level, lower trophic level, and modeling components.

c. Contribute relevant sections to the Final Reports for the Retrospective and Lower Trophic Level components of the program.

d. Collaborate with other AFSC Recruitment Processes program (RP) scientists to complete NOAA internal review and submission of a manuscript describing ecological patterns of eggs and larvae of the focal species based on ichthyoplankton data collected during the GOAIERP field years 2011 and 2013.

e. Collaborate with other AFSC scientists to initiate and lead the development of a synthesis paper for arrowtooth flounder ecology in the GOA, integrating ichthyoplankton and juvenile data from AFSC's Ecosystem Management and Assessment program in Juneau, as well as the RP program and Groundfish Assessment program in Seattle.

f. Attend the first workshop in the synthesis phase of the GOAIERP program in spring 2016, and lead the development of a manuscript investigating fish species early life history phenology in relation to physical and biological seasonal cycles in the GOA pelagic ecosystem.

2. Completion of the Marine Debris Program funded project "Quantification of Marine Microplastics in the Surface Waters of the Gulf of Alaska," (Baker, Masura, and Doyle, Annual Report 2015, Environmental Chemistry section).

Accomplishments

1. NPRB-sponsored GOAIERP program:

a. The early life history review manuscript for the GOAIERP focal fish species is now published in the first GOAIERP Special Issue of *Deep Sea Research II* (Doyle and Mier, 2016).

b. Based on data synthesized in this paper, Doyle also contributed to and co-authored several manuscripts with the scientists that developed the biophysical Individual Based Models for the focal fish species (Gibson et al., Hinckley et al., Parada et al., Stockhausen et al., all submitted). Doyle also co-authored a manuscript with the GOAIERP physical oceanographers that examines the role of canyons intersecting the continental slope in facilitating transport of nutrients, zooplankton and larval fish onto the shelf in the GOA (Mordy et al., submitted).

c. Sections describing the ichthyoplankton research accomplished by Doyle and others have been contributed to the Retrospective and Lower Trophic Level components of the GOAIERP Final Reports.

d. The manuscript describing ecological patterns of eggs and larvae of the focal species based on ichthyoplankton data collected during the GOAIERP field years 2011 and 2013 has been completed and submitted to *Deep Sea Research II* for the second GOAIERP Special Issue (Siddon et al.).

e. Doyle has collaborated with AFSC scientists in utilizing all sources of arrowtooth flounder data in the development of an integrated review paper for the ecology of this important species which is the most abundant groundfish at present in the GOA. The data spans early life history stages in the plankton, juvenile stages that settle in coastal and shelf habitat, and adults that are caught in NOAA's Groundfish Assessment Surveys in the GOA. Temporal and spatial patterns in occurrence and abundance of early life stages and different size categories of adults are evaluated in relation to aspects of the physical and biological environment in the GOA. Predation of, and feeding by arrowtooth flounder is addressed using food habits data from the assessment surveys. Synthesis of results is completed and a draft of the manuscript is being written; "A full life history synthesis of arrowtooth flounder ecology in the Gulf of Alaska".

f. A new manuscript is being developed which describes the early life history phenology (timing, duration, and seasonal variation in spatial patterns of egg and larval phases) of commercially and ecologically important fish species in the GOA. The associations of these patterns with prevailing seasonal cycles in physical and biological components of the ecosystem are being evaluated with respect to optimal conditions for development and survival among species early life stages, and potential for mismatch especially between

larval fish and suitable prey organisms. The development of this manuscript in collaboration with other NOAA and academic scientists was initiated at the first GOAIERP Synthesis Phase – a workshop held at the UW's Friday Harbor Labs March 1-4, 2016. Results are being synthesized, and the manuscript is being written under the title "Early life history phenology among Gulf of Alaska fish species: Synchronies with seasonal cycles and implications for disruptions."

2. The marine debris microplastics project was completed and a report presenting and interpreting the results was submitted to NOAA's Marine Debris Program (Baker et al., 2015). Subsequent analysis of the plastic samples was carried out at the UW Tacoma labs to further assess the amount of microplastics in each sample by number, type (fragment, fiber etc.), and size category. Along with results presented in the Baker et al. report (dry mass of plastic in mg m-3 for each sample), these data will be incorporated into a manuscript for publication in a peer-reviewed journal.

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

PI

Timothy Essington – UW School of Aquatic and Fishery Sciences

Other UW Personnel

Jin Gao, School of Aquatic and Fishery Sciences

Task II

NOAA Sponsor

James Thorson, Fishery Resource Analysis and Monitoring (FRAM)

NOAA Goals

Healthy Oceans

Description

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

Objectives

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

Recent research has shown the value of using spatial models to generate annual estimates of stock abundance from bottom trawl survey data for West Coast groundfishes. For example, Shelton et al. (2014) showed that spatial variation in density for darkblotched rockfish explained a substantial portion of variation in catch rates, and Thorson et al. (2015) showed that spatial models improved precision for estimated indices using simulated data relative to a nonspatial model. Spatial models can incorporate measured habitat variables (e.g., bottom substrate type) or infer habitat from biological sampling (e.g., infer rocky substrate from the presence of rock-associated species), and these measured or inferred habitat variables are then incorporated into the stock assessment process

when the estimated index of abundance is used in a stock assessment model. Spatial models have subsequently been approved for consideration in stock assessments by the Pacific Fishery Management Council Scientific and Statistical Committee for the 2015 assessment cycle.

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

Accomplishments

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

Results for northern shrimp in the Gulf of Maine are currently being compared against results using a conventional design-based method (Cao et al., in review). We are also working to compare estimates of density-dependent range shift arising from the geostatistical index model with previous analysis for multiple regions worldwide, including in the Northeast Atlantic, Bering Sea, and Gulf of Alaska (Thorson et al., in preparation). Finally, Gao is working to compare predictions of spatial variation in density from the geostatistical index tool with alternative methods that use delay-embedding to reconstruct species dynamics. Gao is comparing these methods using data for larval densities in the CalCOFI data set, and potentially the Eastern Bering Sea bottom trawl survey.

INCORPORATING TIME-VARYING FACTORS IN STOCK ASSESSMENT MODELS

PI

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Task II

NOAA Sponsor

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James Thorson – Northwest Fisheries Science Center

NOAA Goals

Healthy Oceans

Description

Individual body growth is one of the basic processes by which biomass changes in fish populations. Individual growth is likely to vary over time in response to environmental, ecosystem and population factors, for example, weight at age for Pacific halibut has decreased nearly 50 percent over recent decades. Recent research indicates nearly two-thirds of variability in weight at age can be explained via random variation in growth among years, ages, and cohorts, while half of variability can be explained with a single random process.

Variation in growth is not often modeled explicitly in stock assessment models. When variation in growth is explored, it is usually done using one of two possible approaches. In the "empirical size at age" approach, average weight is assumed to be measured precisely for every year and age, and this average weight at age is then used when converting from numbers to biomass within the assessment model. In the "explicit estimation" approach, additional parameters are estimated representing annual variation in growth rates, and predictions of weight at age from this time-varying growth model are used in the assessment model. The empirical approach does not propagate uncertainty regarding growth into the assessment results, whereas the estimation approach does. The estimation approach allows for the inclusion of covariates to predict parameters representing time-variation in growth, but covariates must then enter via a link-function.

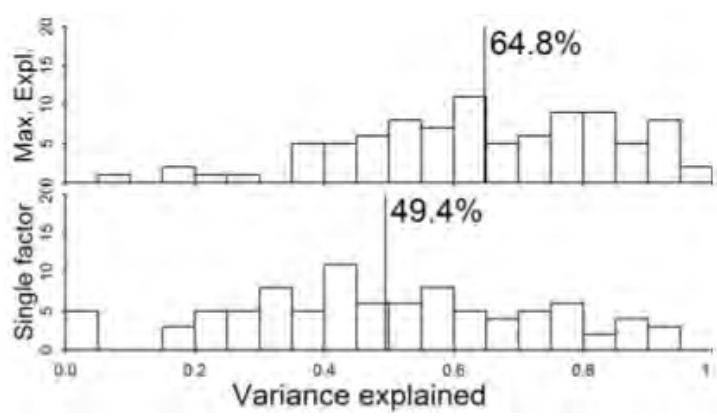

Figure 1. Proportion of variance explained by multiple random factors (top row), or single best factors (bottom row), for 91 marine species (Thorson and Minte-Vera *In Press* Fish. Res.)

There has been little comparison of "empirical size at age" and "explicit estimation" approaches to time-varying

growth in stock assessment models. Stock Synthesis is widely used for stock assessment in the U.S. and abroad, and is capable of implementing either approach. These approaches can be compared using Stock Synthesis, either via simulation (using the ss3sim package) or using real data for previously assessed species (e.g., Pacific hake).

Objectives

1. Compare empirical size at age and explicit-estimation approaches to time-varying growth for a well-studied and previously assessed species (e.g., Pacific hake).
2. Simulate data generated when growth either varies or does not vary over time. In each case, generate data for use in either empirical size at age or explicit estimation approaches. Then, compare estimates from each approach with the "true" variation in growth, as well as estimates of bias and variance in assessment results.
3. Propose potential link-functions for use when linking a measured covariate to time-varying growth parameters in the "explicit estimation" approach. Then, explore the benefit of including this measured covariate on growth for the case study species (e.g., northward transport affecting growth of Pacific hake).
4. Work with the Stock Synthesis team to implement results into the software package.

Reasons Why Objectives Were Not Met

The hiring of a research assistant to conduct this investigation has been delayed. One candidate was selected and scheduled to start in January 2016, but instead took a different position. Another candidate has been identified to potentially start in September 2016. A broader search will be initiated in May 2016, if necessary, to help assure that a candidate can start this work by Fall 2016. Consequently, there will be a one-year delay in completing the project objectives.

AUTOMATED IMAGE PROCESSING FOR FISHERIES APPLICATIONS

PI
Jenq-Neng Hwang – UW Electrical Engineering

Task III

NOAA Sponsor
Kresimir Williams – Alaska Fisheries Science Center

NOAA Goals
Healthy Oceans

Description
The research aims at building a fully automatic fish tracking and counting system based on ROV (remotely operated underwater vehicle) video data. Firstly, we use a Deformable Part Model (DPM) fish detector to identify fish locations for input video frames. In the meantime, we define a motion score for each bounding box surrounding the detected fish. Since the background is complicated and fish body is deformable, the detection results are not robust and reliable. Then, we construct tracklets with all the detections we get from the detection results. Based on the DPM detection scores, motion scores, and tracklets, we design an adaboost classifier to determine whether each input tracklet is reliable.

After the classification, we remove unreliable detections and use the rest of the detections in the tracking. With this closed loop, the accuracy of tracking and counting largely increases, and makes the tracking and counting fully automatic.

Objectives
1. Detect fish for each video frame.
2. Track multiple fish for video clips and check whether there are new entering fish and leaving fish.
3. Count the number of fish during each video clip.

Accomplishments
We used several clips and manually labeled the fish position. And we trained a new DPM fish detector according to the labeled data. The DPM detector is used for fish detection for each video frame.
We designed motion features to describe the motion of underwater objects, and also designed a classifier to modify the detection results from DPM detection. Motion features are used to distinguish fish and non-moving objects for underwater scenarios. The classifier combines both DPM features and motion features to remove non-fish objects. This greatly decreases the false detection counting errors.
We also modified the tracking system of fish entering and leaving criteria. The system can also track the fish successfully, even if there are missed detections for a couple of frames.

Reasons Why Objectives Were Not Met

There are some missed detections for fish due to their diverse poses, and the similarities of body shapes and background colors. If one fish has more than 100 missed detection frames, after it is re-detected, the system may miscount it as a new fish. Some fish have very similar colors to the background, which makes drift problems occur in the tracking.background colors. If one fish has more than 100 missed detection frames, after it is re-detected, the system may miscount it as a new fish. Some fish have very similar colors to the background, which makes drift problems occur in the tracking.

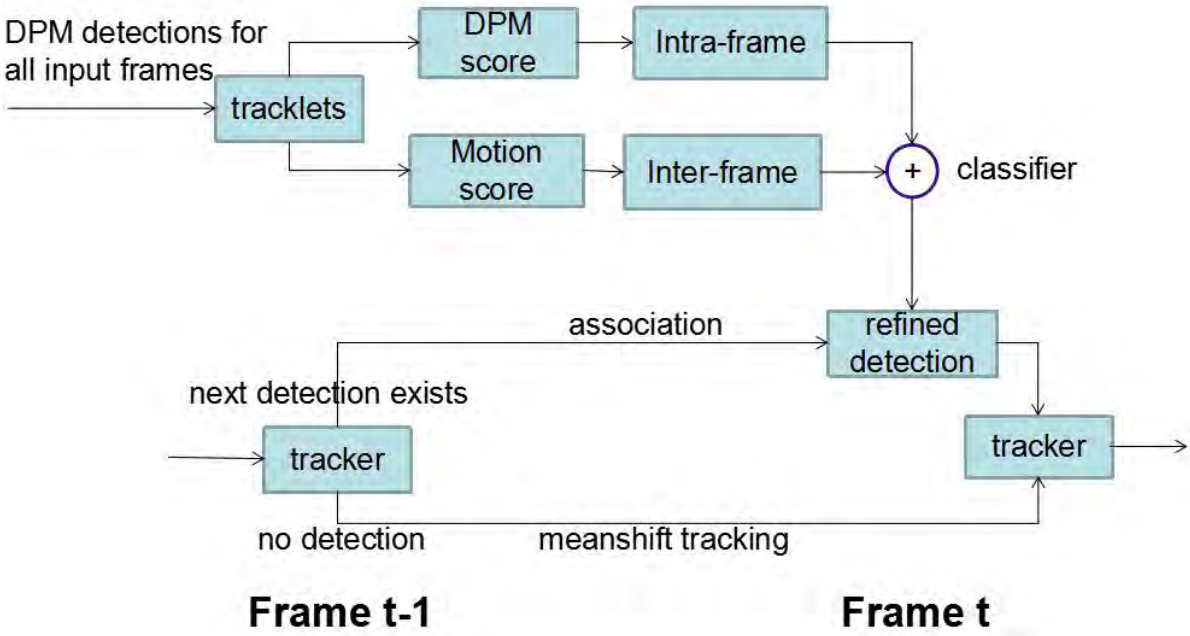

Figure 1. The flowchart of the tracking system

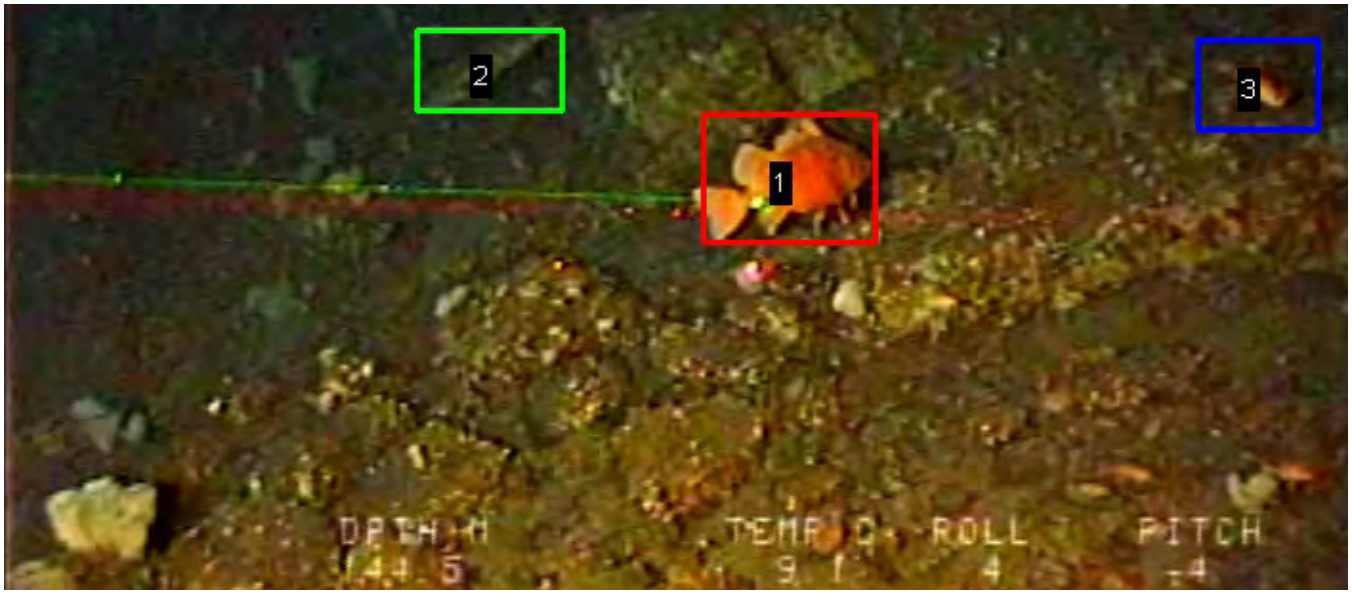

Figure 2. Some tracking results of the system – each fish is marked with a bounding box. The number inside each bounding box is the counting number index of the fish in the clip.

MARINE BIOLOGICAL INTERACTIONS IN THE NORTH PACIFIC – FISH INTERACTIONS TASK

PIs

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

Other UW Personnel

Richard Hibpshman – School of Aquatic and Fishery Sciences
Andrew Whitehouse, Kelly Kearney, and Ivonne Ortiz – Joint Institute for the Study of the Atmosphere and Ocean

Task II

NOAA Sponsor

Kerim Aydin – Alaska Fisheries Science Center

Other NOAA Personnel

Stephani Zador – Alaska Fisheries Science Center

NOAA Goals

Resilient Coastal Communities and Economies
Healthy Oceans

Description

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

Objectives

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

Accomplishments

Objectives 1 and 2 – Feeding ecology and sample collections:
In collaboration with the Resource Ecology and Ecosystem Modeling (REEM) Program at the Alaska Fisheries Science Center (AFSC), staff researchers continued regular collection of food habits information on key fish predators in Alaska's marine environment. During 2015, staff analyzed the stomach contents of more than 40 species sampled from the eastern Bering Sea and Gulf of Alaska. The contents of 12,589 stomach samples were analyzed including 3,557 stomach samples analyzed at sea during the Gulf of Alaska groundfish survey. This resulted in the addition of 32,044 records to AFSC's Groundfish Food Habits Database. In addition to stomach samples from groundfish, bill-load and regurgitation samples from 1,285 seabirds were analyzed for the Alaska Department of Fish and Game. Staff also analyzed 48 zooplankton samples and nine benthic-grab samples for

special investigations, comparing food habits with prey types available in the environment. All four staff members attended and presented (talks and/or posters) at the 2015 American Fisheries Society Annual Meeting.

Collection of additional stomach samples was accomplished through resource surveys, research surveys, and special studies comparing stomach contents with prey-sampling in collaboration with AFSC. Over 7,500 stomach samples were collected from large and abundant predators during the eastern Bering Sea bottom trawl survey of the continental shelf. Over 1,700 stomach samples were collected from the Gulf of Alaska to supplement the 3,557 stomach contents that were analyzed at sea in that region. No stomach samples were collected from Alaskan fishing grounds by Fishery Observers in 2015, but seven buckets of samples collected in previous years were returned to the AFSC. In cooperation with a special tag-recovery study conducted by the Fisheries Interaction Team Program in the Aleutian Islands, stomach samples were collected from 1,080 Atka mackerel and 1,336 samples were collected from other species.

Objective 3 – Multispecies and Ecosystem Models:
The food web model for the Chukchi Sea developed by Whitehouse (2015) was updated based on new stomach data from samples collected in the Arctic. This update was part of the study conducted for the Bureau of Ocean Energy Management. In addition to updating the model, and in collaboration with the Northeast Fisheries Science Center, the ecosystem modeling software Ecopath with Ecosim (EwE) has been rewritten in R (Rpath), with several new routines for analysis in development. The new Rpath allows for increased speed in simulations and parameter sampling, as well as taking advantage of the libraries available for statistical analysis in R. EwE is a widely used software program, and its implementation in R will facilitate parameter evaluation and incorporation of uncertainty in the food web structure by facilitating its implementation using high performance computing.

The Bering10k-ROMS-BESTNPZD model for the Bering Sea was updated with forcing files standardized in format and spatial resolution, and a bug fixed in the large copepods biology in the diapause routine. As part of this code-cleanup, best practices for software version management were implemented by Kelly Kearney of the Joint Institute for the Study of the Atmosphere and Ocean (JISAO). Code and version are now managed via GitHub, which allows rapid sharing and cloning of the model code. The forcing file for freshwater input (rivers) was also updated by Kearney based on Alaska river data; this was a particularly important improvement for the Northern Bering Sea where the Yukon River has a large influence in Norton Sound and nearby areas. Several places to improve the code were identified by Kearney and Ivonne Ortiz (JISAO), which include improvements in the ice algae and nutrients dynamics, as well as incorporating an environmentally driven start of diapause. These code improvements will be the focus of work in FY2017. For this year, Kearney also conducted several multiyear simulations, as well as a full hindcast simulation with the revised forcing files and fixed diapause of large copepods. Kearney has also been working on food-web visualizations and presented a poster of visualizations for Alaskan systems at the Alaska Marine Science Symposium. This model has been selected for programmatic use, and is now used for short-term forecasts. Long-term forecasts have been conducted since 2012.

The Bering10k-ROMS-BESTNPZD-FEAST has also been selected for programmatic use, and is being streamlined for annual updates by Ortiz. The focus of this year has been on obtaining updated catch files and streamlining the generation of catch forcing files. Also, as part of a collaboration with the North Pacific Research Board project "Defining Critical Periods for Yukon and Kuskokwim River Chinook Salmon," the dynamics and initial conditions of herring and capelin are under active improvement. Several shortcomings were identified from the hindcast simulation, including but not restricted to: underestimated biomass-at-length in older fish, underestimation of natural mortality of arrowtooth flounder, performance of the fish dynamics, distribution of fish with respect to bottom temperature, and high mortality of age-0 and age-1 pollock. The first three will be the focus of improvements for next year. Most of the effort regarding this model has been on finalizing several manuscripts that have now been accepted and are in press. Additionally, and in order to continue the development of the ROMS

models, Ortiz has started an evaluation process of several high performance computing platforms to conduct simulations and analyze model ouput. These evaluations will be conducted through FY2017.

Objective 4 – Ecosystem Considerations Report and Ecosystem Indicators:
The Ecosystems Considerations report (access.afsc.noaa.gov/reem/ecoweb/Index.php) for the North Pacific Fishery Management Council contains ecosystem assessments for four large marine ecosystems in Alaska. The ecosystem Assessment of the Alaska Arctic (Chukchi Sea) was updated this year, highlighting threats to polar bears in the section "Hot Topics." Ortiz contributed to the Ecosystem Assessments for the eastern Bering Sea, as well as that for the Gulf of Alaska.

In addition, the Fisheries and the Environment (FATE) project "Evaluating ecosystem indicator performance under climate change" aims to: a) assess the model's ability to replicate the time series of selected ecosystem indicators using a hindcast from 1970 through 2012 (Hermann et al., 2013); and b) evaluate nine forecasts using forcing files extracted from multiple realizations of six Intergovernmental Panel on Climate Change (IPCC) climate models proven to perform best in the Eastern Bering Sea based on their ability to capture decadal variability and ice dynamics. This project will provide a first attempt at incorporating risk analysis of environmental conditions fundamental to assess ecosystem status that incorporates vulnerability to climate change. Preliminary results were presented at the FATE annual science meeting. The downscaled forecasts are also the source for future environmental conditions to be applied in a variety of models and projects which will be the focus of FY 2017. Ortiz also got accepted a proposal to use forecast outputs to evaluate the effect of future climate on essential fish habitat.

Outreach activities

REEM Research Biologist Assistants Sean Rohan, Caroline Robinson, and Kimberly Sawyer and Research Biologist Richard Hibpshman attended the Science Communication Workshop and/or conducted outreach with hands-on activities during the Polar Science Weekend and other events at the Pacific Science Center, Discovery Week at the Seattle Aquarium, and various NOAA outreach events. Research biologist assistants and research biologists also assisted students from Nathan Hale School with (for credit) science projects related to fish feeding habits and participated on career day and lab tours for mid and high-school classes.

Ortiz is a science communication fellow at the Pacific Science Center, and through this program participated in two Portal to the Public Network events (workshops aimed at developing events between scientists and public at other national museums) and three Meet the Scientist events, where scientists interact with then public via hands-on activities showcasing key aspects of their research.

INNOVATIVE TECHNOLOGY FOR ARCTIC EXPLORATION (ITAE)

PI

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Other UW Personnel

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

Task II

NOAA Sponsor

Chris Sabine – Pacific Marine Environmental Laboratory

Other NOAA Personnel

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NOAA Goals

Healthy Oceans

Description

The U.S. Arctic, including the Chukchi and Bering seas, are big, remote, and harsh environments that are often difficult or costly to explore. To better study these marine ecosystems and the rapid changes that are occurring, the Innovative Technology for Arctic Exploration (ITAE) program is developing new sensors and platforms to meet the scientific demand in these regions. ITAE is a collaborative research effort by the University of Washington's Joint Institute for the Study of the Atmosphere and Ocean (JISAO), the University of Alaska Fairbanks (Cooperative Institute for Arctic Research), and NOAA scientists at the Pacific Marine Environmental Laboratory (PMEL). The mission of the ITAE program is to conceptualize and build mission-proof and transfer-effective technologies for the assessment of the Arctic environment and ecosystem.

Objectives

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

Accomplishments

1. In FY16, ITAE and Saildrone Inc. explored the use of a novel surface vehicle technology called Saildrone. The ambitious 18-month project of integrating, testing, and deploying this technology in the U.S. Arctic was successfully completed through cooperative development, resulting in a platform that is ready for ocean

Figure 1. The Saildrone, shortly after launch in Captain's Bay, Dutch Harbor. Photo by Richard Jenkins

research missions from the tropics to the Arctic. ITAE worked with Saildrone Inc. engineers to incorporate a basic suite of meteorological and oceanographic sensors into the Saildrone, including winds, air temperature and humidity, barometric pressure, ocean surface temperature, and water properties of temperature, salinity, dissolved oxygen, and fluorescence. The first mission was a test deployment of two Saildrones that followed ice retreat for 97 days in the Bering Sea (Dutch Harbor to Dutch Harbor, April 23-24 to July 28).

2. ITAE completed a second Arctic mission with the deployment of the ITAE Buoy and Wave Gliders. The platforms were launched from the USCGC *Healy* on July 10, 2015. The Carbon and Ecosystem Wave Gliders collected data for 52 days, and were recovered by the F/V *Aquila* at the end of August. The buoy collected data for 69 days and was recovered from the NOAAS *Fairweather* in mid-September. The mission was partially funded by NOAA's Office of Ocean Exploration and Research, and ITAE leveraged these platforms for testing of several new innovations; a profiling mooring called a PRAWLER (Profiler + Crawler) and a condensed nitrate sensor (Lab-on-a-Chip). The PRAWLER is a new-generation autonomous platform that harnesses wave energy to ratchet along the mooring line with shore-based command and control. It is equipped with temperature, salinity and oxygen sensors. The Lab-on-a-Chip (LOC) was developed, and on-loan from the National Oceanography Centre, Southampton UK. This sensor conducts *in situ* chemistry on a microplate with on-board reagents and standards. The LOC was mounted in the bridle of the buoy in parallel with a submersible ultraviolet nitrate sensor (SUNA), an optical nitrate sensor that samples at a higher frequency, but does not provide calibrated data.

3. Two types of profiling floats were explored in FY16 to examine seasonal changes in the water column, the water-ice boundary and to study how the system is modified during and after ice retreat. Pop-up floats (previously referred to as the ExFloat or EXIT float) are moored in the fall and sequentially released during the winter and spring. The floats collect data while moored along the bottom, during ascent through the water column, and while positioned directly underneath the ice. Once free from the ice, all data from the float is telemetered to shore. The floats vary in sophistication (less sophistication required in winter) with more sophisticated floats designed to include T, S, depth, PAR, tilt, and fluorescence (for spring). Two prototype pop-up floats were deployed from the USCGC *Healy* in Spring 2015. One float operated as designed and successfully returned data. The second instrument was lost. Early versions of the sensor package were derived from marine mammal dive tags and purchased from the University of St. Andrews (Scotland, UK). To reduce production costs (<$2500),

the sensor package has been redesigned and is being built in-house at PMEL. The ALAMO float is an aircraft deployed Argo float built by MRV Systems, LLC. The float is currently being modified for operations under the sea ice with initial tests planned for 2017.

4. The Oculus Glider is a variable speed buoyancy glider designed for coastal environments. It was designed and built in collaboration with the Office of Ocean and Atmospheric Research's Autonomous Marine Sampling Technology Testbed program. For operation on the shallow arctic shelves, the variable-speed coastal glider can quickly change buoyancy (and therefore avoid bottom), escape strong currents (boost speed of ~2 knots), and punch through a buoyant surface layer. Final assembly of the glider and initial flight tests are scheduled for summer 2016. The base sensor package on the Oculus will include CTD (conductivity, temperature, and depth), oxygen, nitrate, chlorophyll fluorescence, turbidity, CDOM (chromophoric dissolved organic matter) and PAR (photosynthetically available radiation). A Video Plankton Recorder with a holographic camera is being designed by SeaScan for incorporation into the nose cone of the glider.

5. All data streams from platforms and sensors deployed in 2015 (two Saildrones, PRAWLER, SUNA, Lab-on-a-Chip, Pop-up float) have been processed and quality controlled.

6. ITAE team members attended three conferences during FY16 to present the program details and preliminary data. Details of the program were presented in one manuscript (Cross et al., 2016) and a poster presentation (Tabisola et. al, 2016) at the Alaska Marine Science Symposium (January, Anchorage, AK). Details of the Saildrone mission and preliminary results were presented in two manuscripts (Cokelet et al., 2016; Meinig et al., 2016) and at three meetings: MTS/IEES Oceans'15 (October, Washington D.C.), the Alaska Marine Science Symposium (January, Anchorage, AK), and at Ocean Sciences (February, New Orleans). Details of the PRAWLER were presented in one manuscript (Osse et al., 2016).

7. The ITAE website (pmel.noaa.gov/itae/) was launched and provides information on the team, technologies and missions, as well as outreach with features such as "Join the Adventure!" which allows the public to follow the Saildrone and other technologies as they are deployed and move about the U.S. Arctic.

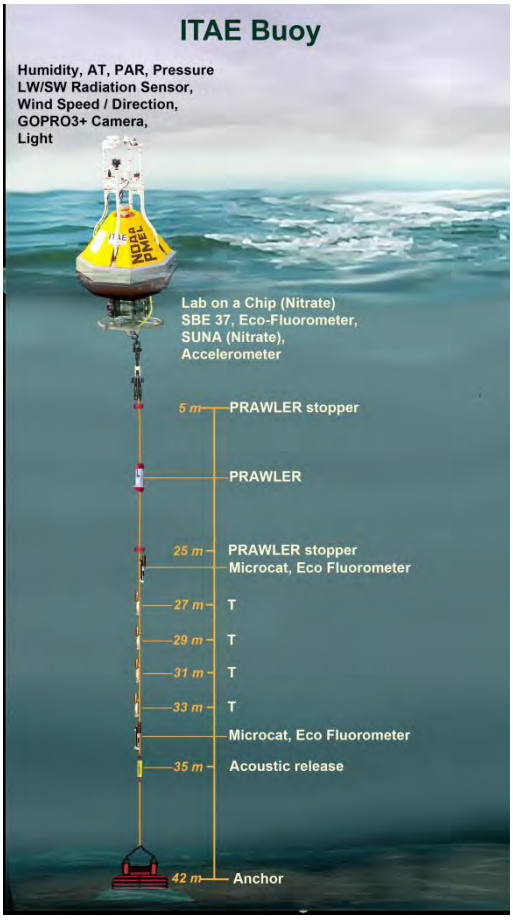

Figure 2. The ITAE buoy (top) and a schematic (bottom) showing the position of various sensors including the LOC (surface package) and the sub–surface PRAWLER

8. ITAE hosted a special workshop for the NOAA Science Camp Junior Leadership Program at PMEL for a 'tour' of the facility. After a brief walk-around the students were led to the conference room and given a task. That task was to develop a program or technology (or both) to investigate the Arctic, and to then present their idea to the

group. Student's presentations were judged on four areas: content, communication, engagement, and originality. A bonus was given for utilizing visual components (provided) in their presentation. The idea was to introduce how the ITAE program and scientists translate concepts and designs into innovative technologies and research missions.

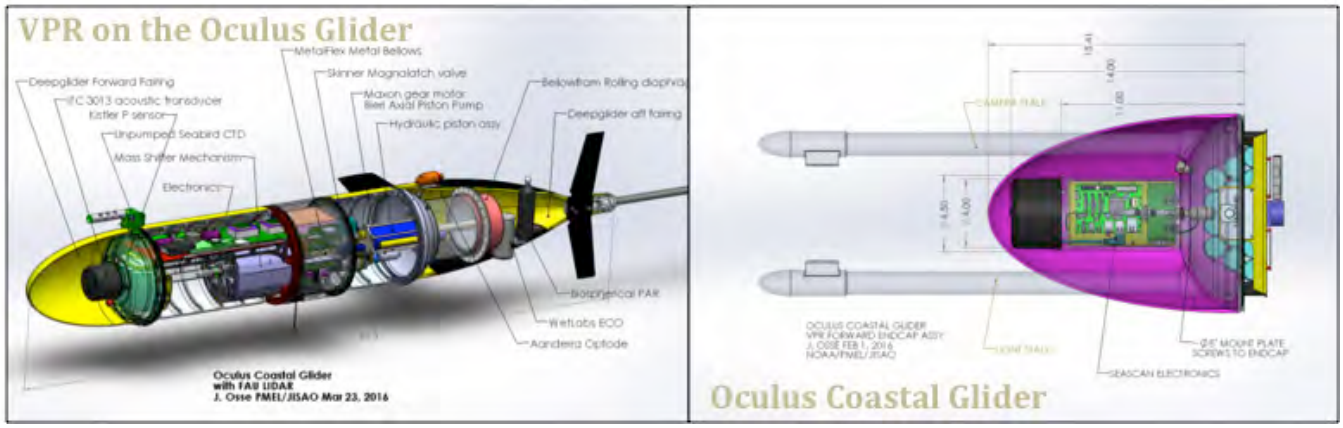

Figure 3. Oculus Coastal Glider (left) and the video plankton recorder with a holographic camera extending out of the nose cone of the glider (right).

ARCHIVAL AND DISSEMINATION OF SPECIMENS AND DATA FOR THE NORTHEAST PACIFIC OCEAN AND BERING SEA FISH EGGS, LARVAE, AND ADULTS COLLECTED DURING NMFS SURVEYS

PI
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Other UW Personnel
Katherine P. Maslenikov, School of Aquatic and Fishery Sciences

Task II

NOAA Sponsor
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NOAA Goals
Healthy Oceans

Description
The Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering (RACE) Division annually collects ichthyoplankton and adult fishes from Alaska. The National Marine Fisheries Service 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 Groundfish Task, and Recruitment Processes Task, each transfers significant numbers of specimens to the UWFC to be archived.

Financial support has been provided to continue a long-standing cooperative relationship with the UWFC as the repository of ichthyoplankton. As a result of previous AFSC support, we have transferred approximately 118,000 lots of eggs and larvae collected between 1977–2007. This consolidation of material has made the UWFC the largest repository of early life history stages of fishes in North America. Database records for 8,056,287 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 adults fishes collected since the 1970s through the Center's activities. Thousands of lots of adult fishes collected from 1995–2015 have already been transferred to UWFC during recent years. Database records for 55,284 cataloged lots of juveniles and adults (totaling 386,860 individual specimens) are now available online from the UWFC website. These efforts will continue as we also transfer locality data and maintain a full web-based inventory of lots presently housed at UWFC.

Objectives

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

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

Accomplishments

1. During the current reporting period from March 2, 2015 through September 25, 2015, graduate student Alicia Godersky made good progress toward curating and cataloging the Early Life History (ELH) collection. Material received in the 2013 transfer, which included 30,612 larvae in 1,590 vials, 74,005 eggs in 2,150 vials, and 85 juveniles in 42 vials, was cataloged, and shelving and online posting of this material is now underway. She also made significant progress toward cataloging the 2014 transfer of larvae and eggs collected in 2007, plus a small amount of odd material from the past few years. The 2014 transfer included 27,856 larvae in 2,649 vials, 56,893 eggs in 1,202 vials, and 586 juveniles in 194 vials. Together with fish collection volunteers, Godersky also continued to curate old lots of larvae, which amounted, in part, to adjusting fluid levels and replacing caps. During this period, the ELH collections staff has maintained their ability to fulfill all data and cataloging requests received from AFSC personnel, as well as those from outside user groups.
2. During this same period, 326 lots of adult fishes, including a total of 661 specimens, all obtained from AFSC sources, were identified, curated, and archived (a complete list of species is available upon request). The UWFC Internet database was updated to reflect these additional cataloged lots (thus fulfilling part of deliverable number 3 listed above; see UWFishcollection.org. At the same time, tissues for future DNA studies were taken from 138 AFSC lots, transferred to appropriate vials, and placed for long-term storage in our -86° C freezer, thus

adding to our ever-growing collection of genetic resources. The number of lots with tissues samples has now reached 6,317, representing 820 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 current reporting period from September 26, 2015 through February 25, 2016, Godersky continued to curate the ELH collection, in particular the curation of fish eggs and larvae from AFSC. She continued to curate material received in the 2014 transfer, which included larvae and eggs collected in 2007 and a small amount of odd material from the past few years. The 2014 transfer included 27,856 larvae in 2,649 vials, 56,893 eggs in 1,202 vials, and 586 juveniles in 194 vials. These samples are almost finished being shelved, after which time the data will be uploaded to the collection database and website. Godersky also collaborated with Jessica Randall (AFSC) to receive the material from the 2015 transfer (collected in 2008). This year Godersky worked at the AFSC rather than in the collection to receive the transfer material, so she collaborated with Randall to streamline the transfer process. This allowed for more efficient and clear communication and allowed the transfer to run much more smoothly than in past years. The 2015 transfer included 98,645 eggs in 707 vials and 28,197 larvae in 2,184 vials, plus some odd material from past years. During this period, the ELH collections staff has maintained their ability to fulfill all data and cataloging requests received from AFSC personnel as well as those from outside user groups.

4. During this same period, 29 lots of adult fishes, including a total of 73 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 UWFishcollection.org. At the same time, tissues for future DNA studies were taken from 25 AFSC lots, transferred to appropriate vials, and placed for long-term storage in our -86° C freezer, thus adding to our ever-growing collection of genetic resources. The number of lots with tissues samples has now reached 6,584, representing 823 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.

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

PI
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Task II

NOAA Sponsor
Daniel Holland - Northwest Fisheries Science Center

NOAA Goals
Resilient Coastal Communities and Economies

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

Objectives
1. Develop a behavioral analysis that will provide an understanding of the determinants of the levels of effort and movement of fishermen in, out, and between a number of West Coast state and federal fisheries that are regulated primarily with indirect controls (e.g., limited licenses, gear restrictions, and season-time-area closures) as opposed to strict overall or individual catch limits.

2. Provide results that will feed into a proposal for funding of a larger, multi-disciplinary project that incorporates a broader focus to include modeling of these fisheries, providing insights into how they are likely to be impacted by changes in management, and by exogenous factors including climate change.

Reasons Why Objectives Were Not Met
This project has not started yet, because while a postdoctoral fellow has been selected, she is not yet available to work on the project.

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

PI
André Punt – UW School of Aquatic and Fishery Sciences

Other UW Personnel
Jonathan Reum, School of Aquatic and Fishery Sciences

Task II

NOAA Sponsor
Anne Hollowed – Alaska Fisheries Science Center

Other NOAA Personnel
Kristin Holsman – Alaska Fisheries Science Center

NOAA Goals
Healthy Oceans

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

Objectives

1. How will climate change impact the productivity (in terms of biomass, growth, and recruitment) and survival of key species?
2. Are current fishery management approaches robust to climate-driven changes or should additional alternative harvest control rules be used?
3. What is the expected change in future fishable biomass and recommended harvest rates under climate change?

Accomplishments

1. Alaska CLIMate Project (ACLIM) researchers Albert Hermann, Wei Cheng, and Kerim Aydin worked to download projections from three GCMs under two future climate forcing scenarios (representative concentration pathway [RCP] 4.5 and 8.5) and set up/execute the regional downscaling runs. In December 2015, two dynamical downscaling runs (under the RCP 4.5 and 8.5 forcing, respectively) to 2100 of the Regional Ocean Modeling System/nutrient-phytoplankton-zooplankton (ROMS/NPZ) model forced by the Geophysical Fluid Dynamics Laboratory (GFDL) Earth System Model (ESM2M) were completed and archived. These runs have exceeded the proposed mid-21st century projection time frame. ROMS/NPZ downscaling runs driven by the U.S. National Science Foundation (NSF) Department of Energy (DOE) Community Earth System Model (CESM) and Japanese Model for Interdisciplinary Research on Climate (MIROC) ESM are underway, and the remaining six projection runs are on schedule to be completed by June 30, 2016. Kristin Holsman has queried the model outputs and derived model indices for the forcing functions of the climate-enhanced assessment models. The team has started interpreting derived model indices in the context of climate change (i.e., comparison with 20th century hindcast simulation) and inter-model spread. UW research scientist Jonathan Reum was hired in October to build and parameterize the new climate-enhanced size-spectrum model for the Engineered Barrier Systems (EBS).
2. In January 2016, Reum and Holsman met with Woodworth Jeffcoats at Pacific Islands Fisheries Science Center (PIFSC) and colleague Julia Blanchard from the University of Sheffield to commence a collaborative project to modify the multi-species spectrum modeling (MIZER) R package for size-spectrum models (developed by Blanchard and colleagues) to include climate forcing. The climate enhanced MIZER package will be broadly available when complete. It will be implemented for the eastern Bering Sea as part of the ACLIM project, as well as the Central Pacific and the North Atlantic as part of ongoing projects in those regions. This exciting comparative collaboration will help facilitate cross-regional analyses and help ensure synergy between ACLIM advancements and climate change evaluations in other regions. We anticipate this will be a topic of much interest for a future webinar.
3. During the same visit Holsman gave a seminar on ACLIM to researchers at PIFSC and met with modelers, including Jeffrey Polovina, to discuss methods for implementing climate forcing into predator and prey interactions in Ecopath with Ecoism (EwE), as well as coordinate climate projections for end-to-end models in other regions.

Oral Presentations

1. Holsman presented ACLIM during the UW School of Aquatic and Fisheries Sciences departmental Fall Seminar Series, "Managing an uncertain future: Multi-scale approaches to evaluating climate change impacts and adaptive solutions in the Bering Sea, AK." January 2016.
2. In January 2016, Holsman gave a seminar on ACLIM to researchers at PIFSC, "A multi-model approach to evaluate climate change impacts and adaptive solutions in Alaska."
3. In September 2015, Anne Hollowed gave a presentation, "Multidisciplinary research tools and methodologies

for projecting the impacts of climate change on Bering Sea commercial fish and fisheries," at the ICES Annual Science Conference, Copenhagen, Denmark.

4. In September 2015, Hollowed presented the "Summary of SICCME accomplishments, SICCME Open Science Session, Theme Session G," at the ICES Annual Science Conference, Copenhagen, Denmark.
5. In September 2015, Holsman presented "Evidence for trophic amplification and attenuation of climate change impacts on groundfish species," at the ICES Annual Science Conference, Copenhagen, Denmark.
6. In September 2015, Holsman presented ACLIM as part of an EBM talk at the AFSC center in Juneau titled, "Ecosystem-Based Fisheries Management."
7. Hollowed delivered the keynote presentation, "Incorporating Ecosystem Dynamics in Fishery Stock Assessments and Management: Case Studies from the North Pacific Fishery Management Council, In Topic Session: Incorporating Ecosystem Dynamics in Fishery Stock Assessment and Management: Progress and Challenges," at the American Fisheries Society Annual Meeting, Portland, OR, August 2015.
8. In August 2015, Hollowed presented, "Projected Contributions to the IPCC: A Global Climate Impact Assessment for Fish and Fisheries," at the International Council for the Exploration of the Sea (ICES) and the North Pacific Marine Science Organization (PICES) workshop on changes in spatial distribution (WKSICCME-Spatial), Seattle, WA.
9. In July 2015, Hollowed was invited to a symposium titled, "Projecting Climate-Induced Changes in Fisheries and Ecosystem-Based Management, U.S. – Korea Joint Project Agreement Symposium," in Washington, DC.
10. In April 2015, Hollowed was invited to participate in, "A Framework for an Ecosystem Approach to Fisheries Management under Projected Climate Change," at the NOAA Science Advisory Board in Washington, DC.
11. In March 2015, Hollowed delivered the presentation, "A Framework for Evaluating Management Strategies under Projected Climate Change Scenarios for the Bering Sea," at the 3rd Annual Effects of Climate Change on the World's Oceans Symposium in Santos, Brazil.
12. In March 2015, Hollowed was invited to give the oral presentation, "A Framework for Identifying Climate-Ready Strategies for Fisheries in the Northeast Pacific," at the Northwest Fisheries Science Center (NWFSC) Monster Jam.
13. Alan Haynie presented, "Climate Change and Fisher Behavior in the Bering Sea Pollock Trawl and Pacific Cod Longline Fisheries," at the 3rd Annual Effects of Climate Change on the World's Oceans Symposium in Santos, Brazil. Haynie also served as the session co-chair.
14. Hollowed was invited to give the oral presentation, "Strategies for Developing Climate-Ready Commercial Fisheries in Northeast Pacific Ecosystems," at the National Science and Statistical Committee meeting in Honolulu, Hawaii in February 2015.
15. In October 2015, Haynie delivered the keynote address, "Management, the Environment, and Fisher Behavior Lessons from the United States Bering Sea," at the Conference on Arctic Marine Resource Governance in Reykjavik, Iceland.
16. In July 2015, Haynie presented, "Modeling Fisher Behavior under Changing Policies, Economics, and Environmental Conditions," at a meeting of the U.N. Food and Agriculture Organization in Rome, Italy.

Posters at Professional Meetings

1. Holsman, K., A. Hollowed, K. Aydin, J. Ianelli, A. Punt, A. Hermann, P. Spencer. "Trophic amplification of climate change impacts on groundfish species in the eastern Bering Sea". Our Common Future under Climate Change, International Scientific Conference, special SICCME Session. Paris, France. July, 2015.

Press Releases

1. AFSC News: August 26, 2015 (www.afsc.noaa.gov/News/BS_climate-change-study.htm). New comprehensive Bering Sea Climate Change Study to focus on fish and fishing and provide insights for management in a changing environment.
2. UW News: August 26, 2015 (www.washington.edu/news/blog/new-bering-sea-climate-change-project-focuses-on-fish-management-strategies/). New Bering Sea climate change project focuses on fish, management strategies.
3. IntraFish, August 27, 2015 (www.intrafish.com/news/article1418492.ece). New Bering Sea study to help shape fishery management.
4. PMEL News: August 31, 2015 (www.pmel.noaa.gov/news-story/new-bering-sea-climate-change-project). New Bering Sea Climate Change Project.

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

PI

André Punt – UW School of Aquatic and Fishery Sciences

Other UW Personnel

Kotaro Ono – School of Aquatic and Fishery Sciences

Task II

NOAA Sponsor

Anne Hollowed – Alaska Fisheries Science Center

NOAA Goals

Healthy Oceans
Resilient Coastal Communities and Economies

Description

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

Objective

1. Develop a multi-species Management Strategy Evaluation (MSE) by constructing an operating model in FORTRAN and linking the operating model to an Automatic Differentiation Model Builder (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.

Accomplishments

1. Kotaro Ono is developing a multi-species MSE that includes a technical interaction subroutine (based on a few major BSAI groundfish species and halibut). The work was presented at a UW-NOAA mini-workshop in June 2015, at the American Fisheries Society in August 2015, at the Western Groundfish Conference in February 2016, and to the Statistical and Scientific Committee of NPFMC in April 2016.

2. Ono is working with Carey McGilliard, a NOAA scientist previously funded under this project, to develop an MSE framework that can both be used in research on the P* approach, as well as on multi-species technical interactions.
3. Ono worked on three collaborative projects with graduate students from the School of Aquatic and Fishery Sciences (SAFS), and scientists from NOAA and the Center for the Advancement of Population Assessment Methodology to evaluate: a) when growth parameters should be estimated within or outside an integrated assessment model; b) the effect of alternative binning approaches for composition data in integrated assessment model; and c) when to use empirical weight-at-age instead of modeling parametric growth in integrated assessment model. All of the work is based on the R package "ss3sim", which uses Stock Synthesis as both the operating and estimation model.
4. Ono extended the length-based spawning potential ratio method (developed during 2014) with Adrian Hordyk, Carl Walters, and Jeremy Prince.
5. Ono developed spatio-temporal species distribution models to identify temporally evolving hotspots of species co-occurrence with NOAA employees.
6. Ono worked on a collaborative project with NOAA employees to standardize catch per unit data from a multispecies fishery based on a method that accounts for spatio-temporal variations in species abundance and fishermen targeting behavior.
7. Ono used simulation to assess the impact of marine closures on the analysis of CPUE data. He also developed a more objective way to define spatial strata for catch per unit effort (CPUE) standardization.
8. Ono developed a delay difference model that accounts for spatio-temporal dependence in collaboration with NOAA employees.
9. Ono developed a method to analyze the genomic basis and evolution of run timing in Chinook salmon with fishery geneticists at SAFS. He worked with fishery epidemiologists at the U.S. Geological Survey to analyze the virulence of rhabdovirus on the trout population.

IMPROVING STOCK ASSESSMENTS WITH ACOUSTIC DATA FROM COMMERCIAL FISHING VESSELS

PI
André Punt – UW School of Aquatic and Fishery Sciences

Other UW Personnel
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Task II

NOAA Sponsor
Steven Barbeaux – Alaska Fisheries Science Center

Other NOAA Personnel
Chris Wilson and Jim Ianelli – Alaska Fisheries Science Center

NOAA Goals
Healthy Oceans

Description
The goal of this project is to make use of acoustic data collected on board factory trawler vessels participating in the Bering Sea winter walleye pollock fishery. These data will help to determine the distribution and relative abundance of pollock during a time when scientific surveys are not conducted.

Objectives
1. Develop customized software to batch process acoustic vessels of opportunity (AVO) data.
2. Process historical AVO data collected during the winters of 2002-2014 eastern Bering Sea pollock fishery (~3TB of raw acoustic data) using the customized software.
3. Construct a geo- and temporal-referenced database of the processed AVO data housed on the Alaska Fisheries Science Center (AFSC) Oracle server.
4. Develop a pollock spawning stock biomass index from the processed data for comparison with stock assessment model estimates.
5. Examine size at maturity (from NOAA observer data) as a function of pollock density.

Accomplishments
1. AFSC staff have constructed the customized software to batch process the AVO data. To date, data from 2006, 2007, 2009, and 2010 have been processed. With feedback from Kirsten Simonsen and Steven Barbeaux, the software has been optimized for the needs of the AVO project, and processing of the remaining historical data has begun.
2. A geo- and temporal referenced database has been constructed to house the AVO data on the AFSC Oracle server. All investigators involved have access to this database.

3. Preliminary analysis of data has begun. The first look at the data was designed to assess the effectiveness of the customized software, and identify any possible issues. Simonsen examined the data for possible outliers and sources of error, and determined whether adjustments needed to be made to the processing software, or whether bad data could be excluded via thresholding.
4. Simonsen and Barbeaux have begun an analysis to determine the most effective method to eliminate "bad" data from these datasets. Currently, there is no standard metric for determining what the cut-off for "bad" data should be, though in two previous studies, if more than 10% and 15% of pings in an interval were determined to be "bad" data, mostly from ringdown, then the interval was dropped from analysis. Simonsen and Barbeaux are hoping to determine the optimal cut-off, where enough data is retained for an effective analysis, and where the majority of bad data is eliminated, so as not to bias results. Simonsen and Barbeaux, with assistance of AFSC colleagues, are hoping to have a manuscript in prep by the summer.

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

PI

André Punt – UW School of Aquatic and Fishery Sciences

Other UW Personnel

D'Arcy Webber – School of Aquatic and Fishery Sciences

Task II

NOAA Sponsor

Anne Hollowed – Alaska Fisheries Science Center

NOAA Goals

Healthy Oceans
Resilient Coastal Communities and Economies

Description

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

Objectives

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

Accomplishments

1. D'Arcy Webber is working on Gmacs together with Jim Ianelli of the AFSC, sharing code through GitHub, an open source repository that facilitates code sharing and collaboration.
2. Webber is working on further development of Gmacs. The model is written in the Automatic Differentiation Model Builder (ADMB) programming language. Specifically, Webber has restructured the code to include seasons within years, and the ability to allocate catch (fishing mortality) to specific seasons while keeping the dynamics continuous within those seasons. The amount of natural mortality occurring within each season can also be specified and is continuous. The remaining population dynamics, including recruitment, molting and growth, and when spawning stock biomass is calculated, can also be specified. Webber has also modified the structure of the input files for Gmacs and the code used to display model output.

3. Webber is working with Jie Zheng of the Alaska Department of Fish and Game on an assessment of St. Mathews Island blue king crab. A preliminary version of this assessment will be presented to the North Pacific Fishery Management Council Crab Plan Team in May 2016.

SPATIAL ANALYSIS TO SUPPORT MANAGEMENT OF CETACEANS AND OTHER HIGHLY MOBILE MARINE SPECIES UNDER THE ENDANGERED SPECIES ACT AND MARINE MAMMAL PROTECTION ACT

PI
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Other UW Personnel
Charlotte Boyd – School of Aquatic and Fishery Sciences

Task II

NOAA Sponsor
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Other NOAA Personnel
Jessica Redfern –Southwest Fisheries Science Center

NOAA Goals
Healthy Oceans

Description
This research project comprises two interconnected projects:

1. A needs assessment of current modeling tools for estimating the abundance, trends, and spatial distributions of cetaceans. This research represents Year 1 of the cetacean component of NOAA's Protected Species Spatial Analysis Toolbox Initiative.

2. Development, adaptation, and testing of new modeling tools for estimating the abundance of highly mobile marine species at the spatial and temporal scales required for ecosystem management. This research is part of NOAA's California Current Integrated Ecosystem Assessment program.

Objectives
1. Conduct an agency-wide needs assessment of spatial analysis tools for cetaceans, focusing on tools that provide managers with information on the abundance, trends, and spatial distribution of cetaceans at spatial and temporal scales needed by managers.

2. Develop, adapt, and test new modeling tools for estimating the abundance of highly mobile marine species at the spatial and temporal scales required for integrated ecosystem assessment.

Accomplishments
1. The needs assessment is currently in process. Two agency-wide webinars have been held, led by the Southwest Fisheries Science Center, the Greater Atlantic Regional Fisheries Office, and the Northwest Fisheries Science Center; a third webinar to be led by the Alaska Fisheries Science Center is scheduled for April 2016; and a

fourth webinar to be led by the Pacific Islands Fisheries Science Center has yet to be scheduled. The results of this webinar series will be summarized in a peer-reviewed journal article: Boyd C., Redfern J. et al. (in prep.) Predicting the spatial density distributions of cetaceans to support conservation and management.

2. A series of four Bayesian hierarchical models has been developed and applied to simulated data to assess the potential contributions of habitat data and individual capture-recapture data to improved estimates of cetacean abundance and trends in abundance based on distance-sampling data. A peer-reviewed journal article is in preparation: Boyd C. et al. (in prep.) Integrated analysis of abundance, trends, and spatial distributions using distance sampling, individual capture-recapture, and habitat data.

"FIXING" RETROSPECTIVE BIASES IN STOCK ASSESSMENT AND IMPLICATIONS FOR MANAGEMENT TARGETS

PI

André Punt – UW School of Aquatic and Fishery Sciences

Task III

NOAA Sponsor

Jim Ianelli – Alaska Fisheries Science Center

NOAA Goals

Healthy Oceans
Resilient Coastal Communities and Economies

Description

A retrospective bias in a stock assessment is a "systematic inconsistency among a series of estimates of population size, or related assessment variables, based on increasing periods of data." Retrospective biases have been identified for a number of stock assessments and are thought to generally arise from contradictory data or unaccounted for variation over time in population processes. Retrospective biases are often "fixed" by allowing population processes such as natural mortality, selectivity, growth and catchability to vary over time, but reference points used in setting management targets generally assume constant population processes. It is unclear how allowing variability over time in these processes will influence the calculation of reference points. A simulation study in which population processes (e.g. growth, natural mortality, and selectivity) for two simulated stocks (a flatfish-like and a cod-like species) vary over time is to be undertaken. Stock Synthesis 3 will be applied to estimate management quantities and calculate reference points, both while allowing processes to be time-varying. The results of the simulations will be used to address questions of key management importance including the relationship between the magnitude in bias caused by incorrect choices for the parameters that are assumed to be time-varying, how such biases change depending on the nature and timing of how a parameter changes, how large retrospective bias needs to be before it is worthwhile changing the assessment framework, and identification of "best practices" that can minimize the biases and error in assessments when a process is suspected to be time-varying.

Objectives

1. Construct an experimental design for simulations to explore retrospective patterns.
2. Explore the size of biases in model outputs, including reference points.
3. Assess whether there are clues in the residual patterns of fits from mis-specified models that may indicate what process is varying
4. Identify whether there are "better practices" that can minimize the biases and error in assessments when a process is suspected to be time-varying.

Reasons Why Objectives Were Not Met

This project has not started yet, because the student assigned to the project (Felipe Hurtado) is still working on another project.

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

PI

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

Task III

NOAA Sponsor

Mark Strom – Northwest Fisheries Science Center

Other NOAA Personnel

Steve Ignell and John Stein – Alaska Fisheries Science Center

NOAA Goals

Healthy Oceans

Description

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

Objectives

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

Accomplishments

1. SAFS hired Trevor A. Branch as an assistant professor, tenure track as of September 16, 2010. 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 preparing polished scientific figures from data in R, and in fisheries population dynamics. He taught a one-week fisheries population dynamics course to the Pacific Islands Fisheries Science Center in April 2015, and to the Bren School, UC Santa Barbara in February 2016. Since being hired, Branch has published 42 scientific papers. Branch was awarded tenure in 2015, and is now an Associate Professor.

2. Branch is using money from this award to support Cole Monnahan, a graduate student who is registered in the QERM (Quantitative Ecology and Resource Management) program. Monnahan received his MS in 2013, and is now pursuing a PhD under Branch. Monnahan received the prestigious Sea Grant/National Marine Fisheries Service (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 have been published in *PLOS ONE* and *Marine Mammal Science* from this work. The latter paper was featured in the New York Times, BBC World TV, and other top news outlets, and received more news attention than any paper previously published in *Marine Mammal Science*. His MS committee included Brett McClintock from NOAA's Marine Mammal Laboratory. In addition he has coauthored seven additional peer-reviewed papers (several with other graduate students in Branch's group), involving simulation testing of the Stock Synthesis 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 the NWFSC that is one chapter of his PhD. Branch has one graduated MS student (Melissa Muradian), training in stock assessment of Prince William Sound Alaska herring; and two other PhD students: Merrill Rudd (working on data-poor stock assessment methods), and Peter Kuriyama (working on the effects of catch shares on fishing behavior, and the analysis of hook-and-line surveys for rockfish off California). Rudd is funded from National Science Foundation (NSF) and SAFS funds, Kuriyama from the Moore Foundation, Washington Sea Grant, and a NOAA population dynamics fellowship. Branch also has two postdocs: Sean Anderson, who is working with Eric Ward at NWFSC on the influence of catastrophes and black swan events in fisheries; and Lewis Barnett, who is working with Michelle McClure at the NWFSC on the effects of West Coast groundfish fisheries management. In total, 13 scientific papers have been coauthored by graduate students and postdocs in Branch's lab, of which eight are directly related to stock assessment research topics.

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 10 papers. Anderson serves on the Scientific and Statistical Committee for the North Pacific Fishery Management Council.

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: five dissertation-stage economics PhD students, one of whom (Jennifer Meredith) has a NMFS Marine Resource Economics Fellowship with mentorship at AFSC; two third-year Economics PhD students, one of whom won an NSF Postgraduate Fellowship; a second-year Masters SAFS student, and a dissertation-stage co-advised QERM student. His students have had significant experiences in Bristol Bay, Alaska, and at The World Bank. One economics PhD student (Marie Guldin) is on a long-term contract at the NWFSC; one economics PhD student (Allen Chen) is on a contract at the AFSC; one economics PhD student (Christopher Martin) is on an NSF-GRIP fellowship at the NWFSC. In addition, two students are involved in contracts with NOAA (Jennifer Meredith and Melissa Krigbaum). Graduates include Andrew Scheld (SAFS PhD), who started as an Assistant Professor of Marine Resource Economics at the Virginia Institute of Marine Science at the College of William and Mary in Fall 2014, and Zhi Li (Economics PhD), who started as an Assistant Professor at Xiamen University in Fall 2015.

WEST COAST GROUNDFISH STOCK ASSESSMENT

PI
André Punt – UW School of Aquatic and Fishery Sciences

Other UW Personnel
Lee Cronin-Fine 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 assessments of groundfish species occurring off the coasts of Washington, Oregon, and California (West Coast).

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

Accomplishments
1. André Punt continued to work on methods to weight length composition and conditional age-at-length data in integrated stock assessments. This work resulted in a paper currently in press at *Fisheries Research* and an addition to the r4ss packages. He also initiated a study on how to weight tagging data in integrated size-based stock assessments. This work led to a paper currently in press at *Fisheries Research*, and to a method now used by the Alaska Department of Fish and Game scientists when they conduct assessments of Alaskan crab stocks.
2. In collaboration with Australian and NOAA scientists, Punt conducted a review of stock assessment packages used in the U.S., highlighting the advantages and disadvantages of each. A paper based on this work is currently being revised for resubmission to *Fisheries Research*.
3. Punt further explored the performance of spatially- and non-spatially-structured population dynamics models in the face of spatial heterogeneity. This work has led to a paper on the impact of Marine Protected Areas on

estimation performance that was published in *Fisheries Research*, as well as a paper that is currently in review at the *Canadian Journal of Fisheries and Aquatic Sciences*.

4. Kelli Johnson (UW PhD student) and Kotaro Ono (UW postdoctoral scientist) worked on a collaborative project with other UW School of Aquatic and Fishery Sciences (SAFS) students and a scientist from the Center for the Advancement of Population Assessment Methodology (CAPAM) to assess the performance of Stock Synthesis when natural mortality or growth varies with time, growth is fixed at externally estimated values, length- and age-composition data are binned in different increments, empirical weight-at-age data is modelled, and increasing amounts of age- and length-composition data are available. Within the reporting period, two presentations were given at the 2015 CAPAM workshop on this work. Two papers describing this work were recently accepted to the journal *Fisheries Research*. Johnson and Ono were co-authors of an R package to facilitate simulation with Stock Synthesis, which is currently available on the Comprehensive R Archive Network, and is being used for research at the Northwest Fisheries Science Center (NWFSC) and the Alaska Fisheries Science Center (AFSC).

5. Johnson is working on methods to improve the estimation of initial conditions and the effects of data weighting in a multi-species statistical catch-at-age stock assessment framework developed by Doug Kinzey (Southwest Fisheries Science Center) and Punt. The framework allows for uncertainty in the functional response using both integrated analysis and model selection. Additionally, Johnson is using spatially-structured state-space models and survey trawl data to assess stock boundaries for the Pacific cod, one of the species included in the multi-species model. She was also involved in two collaborative projects with the NWFSC that worked to improve the performance of Stock Synthesis. The first project added the Dirichlet-multinomial likelihood function for compositional data, such that scientists no longer have to iteratively estimate effective sample sizes, and the second improved the estimation of autocorrelation in recruitment deviations, which is vital for forecasting. Two papers have since been submitted to the journal *Fisheries Research*.

6. Johnson successfully defended the 2015 stock assessment update for sablefish to the Pacific Fisheries Management Council, and was a co-author on the petrale sole update. Her work was part of a collaborative effort between NOAA scientists Owen Hamel and Melissa Haltuch (NWFSC) and SAFS graduate students.

7. Lee Cronin-Fine (QERM PhD Student) is conducting research on size-structured population dynamics models for hard-to-age species such as crabs and lobsters. Specifically, he is examining the development, use, and construction of size-transition matrices, as well as analyzing selectivity and the impacts of ocean acidification. His is currently working on a simulation study to compare the impacts of using time-varying versus non-time varying selectivity in size-structured models. 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 puntlab.washington.edu/fisheries-think-tank. Furthermore, efforts remain ongoing to include presentations from researchers working outside of UW/NWFSC/AFSC, and increase the remote audience participation.

PARTICIPATION IN BERING STRAIT MOORING DEPLOYMENT ANADYR, RUSSIA – JULY 2015

PI
Kathleen M. Stafford – UW Applied Physics Laboratory

Task II

NOAA Sponsor
Kathleen Crane – Arctic Program

NOAA Goals
Resilient Coastal Communities and Economies
Healthy Oceans

Description
As part of the Russian-U.S. Long Term Census of the Arctic (RUSALCA) program, an acoustic recording component was incorporated into oceanographic moorings in the Bering Strait region. Instrument programming and mooring support will be provided to deploy a hydrophone on the Russian side of the Bering Strait.

Objectives
Participate in the planned cruise to the Russian Far East to:
1. Collect visual observations.
2. Train Russian colleagues how to refurnish the passive acoustic instrument.
3. Download the data from the instrument currently in the Strait, and create multiple copies to be provided to Russian colleagues.

Reasons Why Objectives Were Not Met
Due to ship equipment and permitting issues, the 2015 Bering Strait cruise did not take place. It was canceled the day before the U.S. party was to fly from Nome, Alaska, to Anadyr. The ship was going to be delayed by at least six days (of a planned 10-day cruise) and the U.S. party's Chukotka permits did not come through. Plans are currently underway to attempt a mooring recovery in Fall 2016.

BOWHEAD WHALE FEEDING IN THE WESTERN BEAUFORT SEA: PASSIVE ACOUSTIC SURVEY COMPONENT

PI

Kathleen M. Stafford – UW Applied Physics Laboratory

Task III

NOAA Sponsor

Catherine Berchok – 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 beginning in 2007, an acoustic recording component was incorporated with other sampling regimes undertaken by the Marine Mammal Laboratory (MML), 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. 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, and in relation to oil and gas development activities offshore of Prudhoe Bay. In 2008, NOAA ST7 (Marine Ecosystems) and MML capitalized on an opportunity to join three International Polar Year projects by inclusion of a passive acoustic recorder on existing oceanographic moorings in the High Arctic, capable of year-long sub-sampled recordings of whale and ice seal calls. In addition to recorders deployed biennially on two moorings in the Fram Strait, we have deployed a recorder at a mooring site on the Chukchi Plateau since 2008. In addition to these three mooring sites, MML, with funding from the Bureau of Ocean Energy Management/Alaska Region, has been deploying passive acoustic recorder moorings in the Alaskan Beaufort and Bering Seas since 2007, and in the Alaskan Chukchi Sea since 2010. Since 2009, Stafford's National Oceanographic Partnership Program/ National Science Foundation funded projects have deployed additional recorders in the Alaskan Beaufort Sea. Comparisons among mooring sites have proven invaluable to our

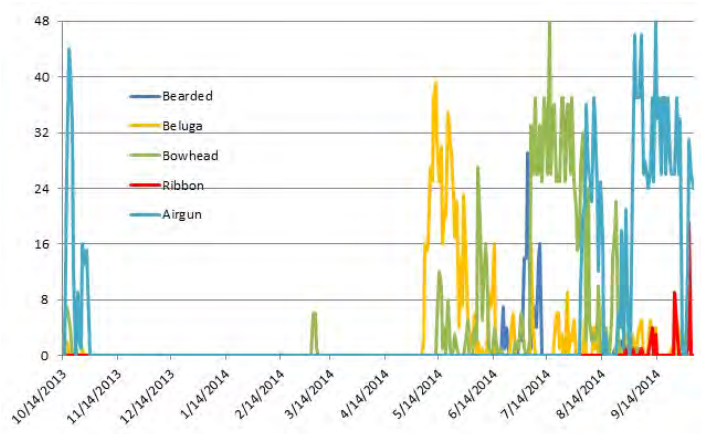


Figure 1. Call detection rates (files per day with at least one detection) for beluga and bowhead whales, bearded and ribbon seals and airgun sounds at the Chukchi Plateau site, 2013–14.

understanding of marine mammal seasonal occurrence, calling behavior, and movements in relation to regional oceanography in the High Arctic. Year-round deployment will provide previously unattainable assessment of the seasonal occurrence of bowhead whales and other marine mammals in the study area. The continuation of this project focuses on the Chukchi Plateau and Barrow-vicinity moorings.

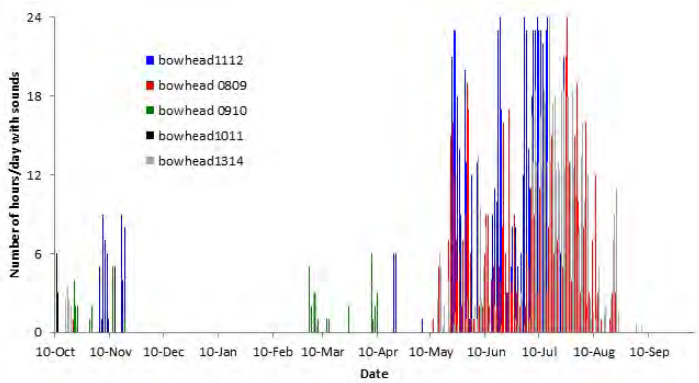


Figure 2. Bowhead whale call detections in hours/day by year.

Objectives

1. Analyze passive acoustic data from the Chukchi Plateau from 2014-15 for acoustic occurrence of bowhead, beluga, bearded seals, and airguns.
2. Provide a report to Catherine Berchok of MML with analysis of data from 2014-15 in comparison with data from 2008-13.
3. Work with Humfrey Melling of the Department of Fisheries and Oceans Canada, Sue Moore of NOAA Science and Technology, and Berchok to produce a manuscript for peer-review publication.

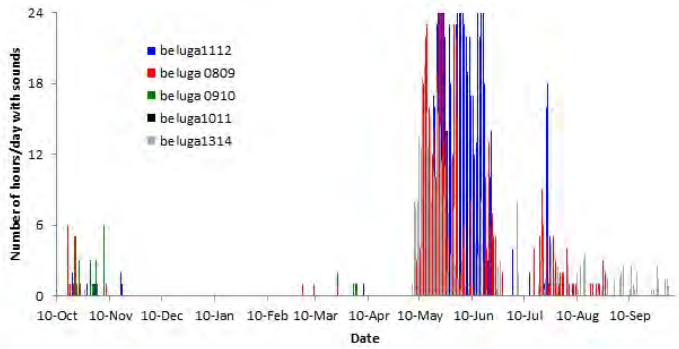


Figure 3. Beluga whale call detections in hours/day by year.

Accomplishments

1. Provided detections to Berchok for a report to the funding agency for data from 2013-14. The 2014-15 data were not received until early 2016, and are still under analysis.
2. Provided data to Berchok for a report to NOAA Science and Technology.
3. Presently collaborating with Melling, Moore, and Berchok to write a manuscript on the Chukchi Plateau data.

The Chukchi Plateau recorder has been deployed by Canadian colleagues each October since 2008. Due to battery failure issues, only three of those years (2008-09, 2011-12, and 2013-14) have 10 to 12 months of recording duration (12 months for 2008-09, 2013-14 and 10 months for 2011-12). In both 2009-10 and 2010-11, data were only recorded from mid-October to early April. The Chukchi Plateau recorder was not serviced in 2012, so no data are available for 2012-13. PI Kathleen Stafford of the University of Washington's Applied Physics Laboratory completed analysis on the partial data sets from 2011-12 in FY14, and results from the 2008-09 data were published (Moore et al., 2012). Seasonal patterns in call detections from 2014-15 for bowhead whales, beluga and bearded seals were similar to past years (Figure 1). Ribbon seal calls were detected in late summer, and airgun sounds were recorded in Autumn 2013, as well as August through October 2014.

In all years of available data, bowhead and beluga whales were heard from summer through fall, prior to seasonal sea ice formation. Bowhead whales were recorded primarily from mid-May until early September, with occasional

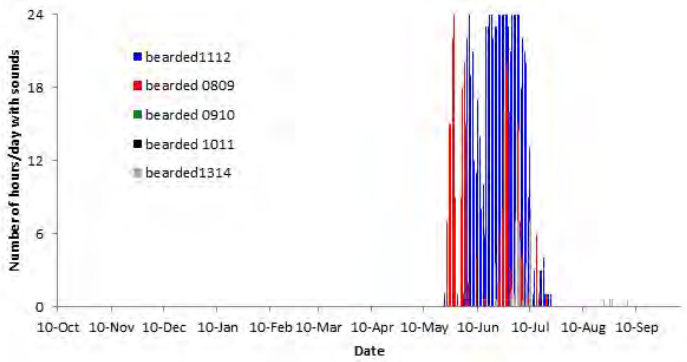


Figure 4. Bearded seal detections in hours/day by year.

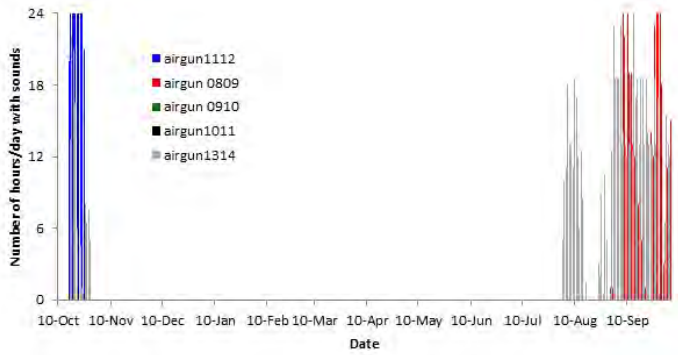


Figure 5. Detections of airgun signals in hours/day by year.

detections in October and as early as March (Figure 2), while beluga were primarily recorded in May and June (Figure 3). In spring 2013 and 2014, bowhead whales were first heard on May 13, which is a week earlier than in 2009 or 2012 (the other years for which there are spring data). For the following summer and early fall, bowhead whales were only reliably detected until the third week of August (Figure 2). Bowhead whales generally remain in the Canadian Beaufort until early to mid- September, at which time they begin to migrate westward towards Chukotka before turning south through the Bering Strait. The acoustic backscatter record suggests that, at least in summer 2014, there were high levels of zooplankton near the Arctic Ice Mooring site from late June through late September. Beluga whales were detected about one month earlier in the spring compared to previous years (Figure 3). Bearded seals were only recorded in the spring months with many fewer heard in Spring 2014 (Figure 4). In Fall 2009, 2011, 2013, and 2014 seismic airgun signals were often recorded 24 hours/day in this region, occasionally from more than one seismic survey (Figure 5). Airgun signals continued into late October in 2011 and 2014.

OCEAN AND COASTAL OBSERVATIONS

OBSERVING SYSTEM RESEARCH STUDIES

PI

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

Other UW Personnel

Andrew Chiodi, Kevin O'Brien, and Karl Smith – Joint Institute for the Study of the Atmosphere and Ocean

Task II

NOAA Sponsor

D.E. Harrison – Pacific Marine Environmental Laboratory

NOAA Goals

Healthy Oceans

Description

The Observing System Research Studies group performs data and modeling studies to identify climatically significant ocean-atmosphere interaction patterns and their linkages to U.S. and global weather anomalies with the goals of improving our awareness and understanding of present climate conditions and the effectiveness of the global observing system for climate. 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

It has been another successful year for our small group with three papers published in peer-reviewed journals in fiscal year 2015, and four other papers currently in the review process. The group's work has also resulted in the following accomplishment highlights:

1. "State of the Ocean" website successfully transitioned to a new server – The website offers users an at-a-glance view of the state of the ocean climate by providing current values of ocean climate and related atmospheric indices with societal implications, as can be seen at stateoftheocean.osmc.noaa.gov/all/. The computational algorithms, or "back-end", needed to provide and maintain the "State of the Ocean" website was transitioned to a newer Pacific Marine Environmental Laboratory server. The old server was showing signs of age, and the transition to a newer machine helps ensure that the website continues to be reliably refreshed with up-to-date information.

2. Established the importance of "Easterly Wind Surges" to El Niño Southern Oscillation (ENSO) sea surface temperature anomaly (SSTA) development (*Chiodi and Harrison, doi: 10.1175/JCLI-D-14-00227.1*) – This demonstrated that synoptic scale easterly wind events, which are termed "Easterly Wind Surges," are a prominent component of equatorial Pacific wind stress variability, and play an important role in the onset and development of La Niña events, akin to the role that their much more heavily studied westerly counterparts, the Westerly Wind Events, play in El Niño events.

3. Extended the OLR (outgoing longwave radiation) El Niño and OLR La Niña perspective to global seasonal precipitation anomalies – We have previously shown that using OLR conditions to characterize ENSO state identifies a subset of the conventionally defined ENSO years that accounts for the vast majority of familiar ENSO seasonal weather associations seen over the U.S. Recent work demonstrates that treating the OLR-identified subset of years differently can usefully strengthen both the level of statistical significance in the average (composite) and also greatly reduce the year-to-year deviations in the composite global precipitation anomalies. On average, over most of the planet, it is the OLR El Niño and OLR La Niña subsets of years that mainly account for the familiar seasonal weather associations. The non-OLR El Niño and non-OLR La Niña years have much more limited statistical utility for precipitation.

4. Shown that it is the handful of OLR El Niño events that dominate the ENSO wintertime temperature association over the U.S.; the OLR La Niña temperature association is substantially different from and weaker than the El Nino association over the contiguous 48 states. The OLR-perspective on ENSO seasonal weather associations began with our 2013 paper, which looked at the case of El Niño associations over the lower 48 states. The 2015 published paper (*Chiodi and Harrison, doi: 10.1175/JCLI-D-14-00387.1*) extends this perspective to global precipitation anomalies as well as La Niña. More recently, we have extended this body of work to both La Niña and El Niño seasonal temperature and atmospheric circulation associations over all of North America. In this case, we again find that it is the same OLR-identified subset of ENSO events that account for the familiar seasonal weather associations. We also find that the La Niña surface temperature associations are different from their El Niño counterparts, and that a linear analysis approach yields results that are inconsistent with the observed La Niña-averaged associations. Our recent work on the associations between ENSO state and North American atmospheric circulation and surface temperature anomalies has resulted in a manuscript currently in the review process at *Journal of Climate* (see Figure 1).

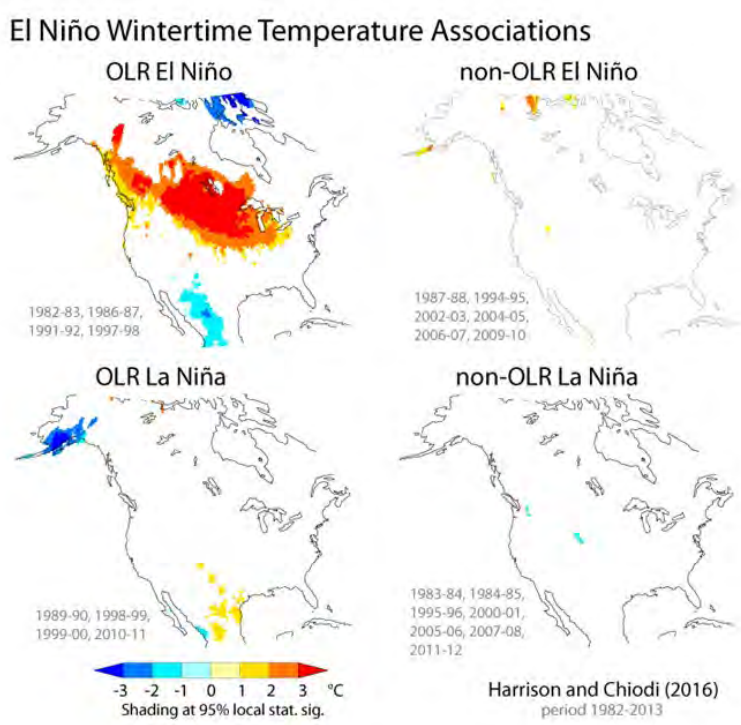


Figure 1. As documented in Harrison and Chiodi (2016), it is ENSO events with a strong expression in outgoing OLR in the eastern tropical Pacific that account for the familiar associations between ENSO and the winter weather in the United States. Moreover, the temperature signal has been much more substantial with recent El Niño events as compared with their La Niña counterparts.

5. Proven that the TAO/Triton array is a capable observation system for measuring the wind variability associated with ENSO and simulating observed SSTA development – This has not been proven before now. We have done this by showing that TAO/Triton wind observations alone, when used to drive an ocean generated circulation model (OGCM), are able to simulate equatorial Pacific ENSO SSTA development with sufficient accuracy to provide a useful basis for understanding the observed SSTA variability associated with ENSO (October through December average model-to-observation Niño 3.4 correlation =0.9, rmse=0.49°C). Our results also reveal that the TAO/Triton reconstructions of SSTA are more accurate than those driven by the ERA-Interim, NCEP and NCEP2 reanalysis wind stress products, which have biases in them that make them inadequate for diagnosing ENSO SSTA development, even though they assimilate the TAO/Triton observations.

Information Technology Accomplishments

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

Through projects that we lead, including the Observing System Monitoring Center and the Unified Access Framework (UAF), we have been working to promote the use of data standards to improve data interoperability. We continue to support, through the UAF project, a tool that allows us to crawl remote data catalogs, analyze the information collected, and then create a new, publicly available catalog that serves data through a wide variety of data access services. We are currently in the process of transforming this tool into a web-accessible tool that will be able to serve a broader community of users, helping other data managers create higher quality data catalogs through the use of THREDDS and OPeNDAP. We are also working with the NOAA U.S. Integrated Ocean Observing System (IOOS) group to leverage this tool to improve data catalogs from IOOS Regional Association members.

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

In addition to leading the community in attempts to improve data integration and interoperability, the Observing System Research Studies group continues to help scientist visualize and analyze data. The group has also been involved in assisting scientists in creating very high quality data products.

PyFerret, the python version of the popular application Ferret, version 1.2 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. PyFerret has greatly improved graphics creation and integration of numerical and scientific libraries. In addition, the recently added dimensions to the computational facilities of Ferret/PyFerret have allowed scientists to extend their analysis to a total of six dimensions. Typically, the additional

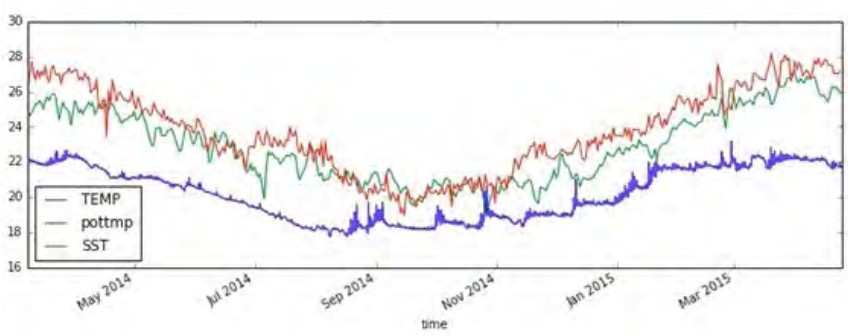


Figure 2. Comparing OceanSITES Stratus mooring temperature (blue), with GHRSST SST data (red) and NCEP reanalysis model data (green) using data from TPOS 2020 integration pilot project.

dimensions will be used for ensemble and forecast analysis, both of which are becoming increasingly important to large-scale modeling projects. We are working closely with our GFDL colleagues through our joint Memorandum of Understanding to further integrate PyFerret into the GFDL community at large, which is quickly embracing python as their analysis tool of choice. Currently under development in Ferret/PyFerret is the ability to create ensemble and forecast aggregations on the fly from model data. This capability is enthusiastically endorsed by the GFDL scientific community, and will be presented to them for review in April, 2016.

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. The SOCAT v3 update was released in September 2015 at the SOLAS Open Science Conference in Kiel, Germany. With the release of SOCAT v3, a new era of SOCAT data management was born. Starting with v3, an automated ingestion and QC workflow has been implemented. Scientists are able to submit their data and metadata through a data ingestion dashboard, and have the data automatically first-level quality controlled in order to find outliers that would otherwise derail QC work further in the process. The data is then integrated into a highly flexible QC system, which allows the manual QC that is necessary to create such a high value data product. This automated framework has significantly improved efficiency, and allows for an annual release of the high quality SOCAT data product. In fact, the Global Carbon Project's Annual Carbon Budget (globalcarbonproject.org/carbonbudget/) is now exclusively using SOCAT data to calculate the global carbon budget. As SOCAT v3 was being QC'd for release, data for SOCAT v4 was already being ingested into the system. At the time of this report, SOCAT v4 is in the process of being quality controlled and will be released in June to support the 2016 Annual Carbon Budget calculations.

Information Technology Presentations and Services

1. "Observing System Monitoring Center -Integrating data and information across observing system networks", NOAA Climate Observation Division Annual PI meeting, Camp Park, MD, June 2015.
2. "Lies, Damned Lies, and Observing System Metrics", NOAA Climate Observation Division Annual PI meeting, Camp Park, MD, June 2015.
3. "SOCAT V3 release and V4 Data Automation and Quality Control," SOLAS Open Science Conference; Kiel, Germany, September 2015.
4. "Integrating Data and Information Across Observing Systems," ARGO/GO-SHIP/IOCCP Annual Meeting; Galway, Ireland, September 2015.
5. "Integrating Data and Information Across Observing Systems," 31st Session of the Data Buoy Cooperation Panel, Geneva, Switzerland, October 2015.

6. "SOCAT V4 Data Framework and Potential Relevance to GOA-ON," GOA-ON Executive Council meeting on data synthesis products, IAEA Environment Laboratories, Monaco, November 2015.
7. "A Free and Open Source Web-based Data Catalog Evaluation Tool," AGU, San Francisco, December 2015.
8. "The Surface Ocean CO2 Atlas: Stewarding Underway Carbon Data from Collection to Archival," NOAA Environmental Data Management Workshop, Washington, D.C., January 2016.
9. "The Surface Ocean CO2 Atlas: Stewarding Underway Carbon Data from Collection to Archival," AGU Ocean Sciences, New Orleans, March 2016.
10. "Data Integration Update and Progress," 7th Annual JCOMM Observations Coordination Group meeting, Esporles, Spain, April 2016.
11. "Advancing netCDF-CF for the Geoscience Community," European Geosciences Union General Assembly, Vienna, Austria, April 2016.
12. "Products and Services for promoting OceanSITES Data Visualization," OceanSITES 2016, Southampton, UK, April 2016.
13. "Gory Details of Ingesting OceanSITES data into ERDDAP," OceanSITES 2016, Southampton, UK, April 2016.
14. Chair of Data Access Session at NOAA Environmental Data Management Workshop, Washington, D.C, January 2016.
15. Current member of UNIDATA's THREDDS Data Server Steering Team.
16. Current member of JCOMM Observation Coordination Group.
17. Co-chair of JCOMM Data Integration Task Team.

OCEAN CLIMATE STATIONS

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

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

Task II

NOAA Sponsor
Diane Stanitski – Climate Program Office

Other NOAA Personnel
Meghan F. Cronin and Christian Meinig – Pacific Marine Environmental Laboratory

NOAA Goals
Climate Adaptation and Mitigation

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

OCS currently maintains two reference station moorings in the North Pacific (Figure 1): The Kuroshio Extension Observatory (KEO) and Station Papa. KEO is located in the North Pacific's western boundary current region, which is characterized by extremely large ocean heat losses to the atmosphere and carbon dioxide uptake by the ocean. Station Papa is where an ocean weather ship was stationed from 1949-1981. 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 the Climate Observation Division's program delivering global climate analysis products.

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

OCS surface moorings carry a suite of sensors on the buoy tower and underwater on the buoy bridle. Sensors are also mounted on the mooring line and on the release connecting the mooring line to 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

Figure 2. Typical OCS surface mooring configuration.

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 1) assess biases and uncertainties in forecasting model and observational product analyses, 2) detect rapid changes, episodic events, and long-term changes in the climate system, and 3) identify mechanisms and relationships within the climate system.

Objectives

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

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

Accomplishments

Successful ongoing operation of OCS moorings:
During the summer of 2015, the OCS group successfully performed deployment/recovery operations for all OCS moorings. The KEO mooring was first established in 2004, and has now been deployed for its 12th year. Data from the KEO mooring has become valuable for improving understanding of the effects of tropical cyclones and typhoons. For Station Papa, 2015 was the ninth year an OCS buoy was deployed at the site. The OCS mooring at Station Papa has become the primary observing platform at a site where weather has been monitored in some form since 1949. It now also serves as the central mooring of an Ocean Observatories Initiative global node established at Station Papa in July 2013. The long-term data sets being established at these sites are valuable for monitoring ocean climate, both in the short term for improving weather forecasts, and long term for understanding and predicting climate variability and change.

Fluxes computed from OCS mooring data are made available to public:
During 2015, the OCS group developed a new data display and delivery website for fluxes computed from OCS hourly data. Flux components provided on this web page include: Sensible heat flux due to air-sea temperature difference, latent heat flux, net shortwave radiation, net longwave radiation, net heat flux, evaporation, precipitation, evaporation minus precipitation, zonal wind stress, meridional wind stress, wind stress magnitude, stress direction, and buoyancy flux. Turbulent fluxes (e.g. sensible and latent heat fluxes, wind stress, and evaporation) are computed from hourly state variables using the COARE v3.0b bulk algorithm (Fairall et al. 2003) and are provided along with other flux quantities as hourly, daily, pentad, monthly and quarterly averages.

Assessing surface heat fluxes in atmospheric reanalyses:
Air-sea fluxes of heat are the primary mechanism by which the ocean influences the atmosphere. The intense heat release along the western boundary current and its extension, on the other hand, plays a key role in setting and modulating the upper ocean stratification, mode water formation, and large-scale ocean circulations. Potential biases and uncertainties in the air-sea fluxes from Numerical Weather Prediction model reanalyses must be identified and reduced in order to make progress on weather and climate predictions.

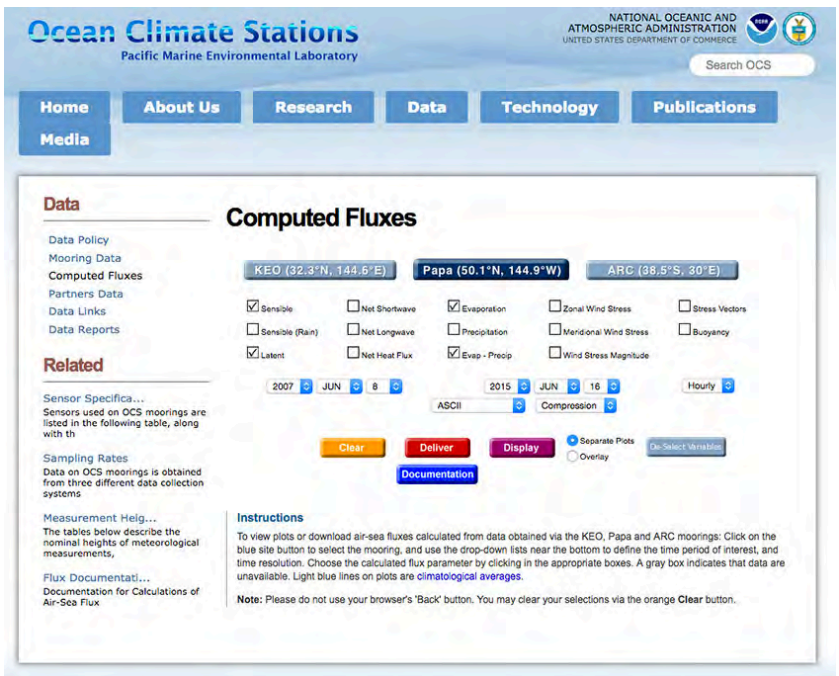


Figure 3. OCS flux data display and delivery web page pmel.noaa.gov/ocs/data/fluxdisdel/

Using the computed fluxes described above, with a decade of data from the OCS KEO mooring, OCS personnel assessed two Numerical Weather Prediction model reanalyses; the National Center for Environmental Prediction's (NCEP's) Climate Forecast System Reanalysis (CFSR) and the European Centre for Medium-Range Weather Forecasts' Reanalysis-Interim (ERA-I).
In both reanalyses, all four flux components (sensible and latent heat flux and net longwave and shortwave radiation) were found to be highly correlated with observation, with the correlation of total net surface heat fluxes above 0.96. Although errors of the net surface heat flux have significantly reduced from older generation reanalyses, the Root Mean Square Errors (RMSEs) and biases remain high especially for CFSR. The CFSR overestimates the winter heat release by 90 W/m2. The main cause of biases is the latent heat flux, while RMS errors are primarily due to latent heat flux and shortwave radiation errors.

Both reanalyses overestimate the wind speed associated with winter storms, and underestimate specific humidity in summer. However, the ERA-I latent heat flux, and total net surface heat flux, are both closer to observation. This analysis found that it is the bulk algorithm in CFSR that is mainly responsible for overestimating the winter heat release. These results have been submitted to the *Journal of Geophysical Research: Oceans* for publication, with the recommendation that next-generation NCEP reanalysis implement more advanced bulk algorithms.

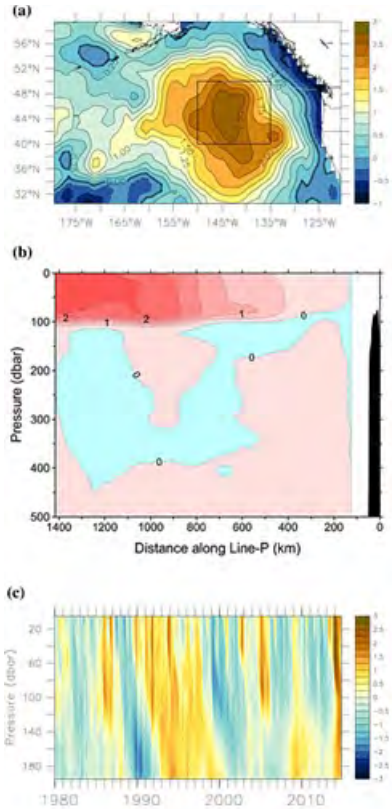


Figure 4. (a) Sea surface temperature anomalies (°C) in NE Pacific Ocean for February 2014. Anomalies are calculated relative to the mean from 1981 to 2010. (b) Upper ocean temperature anomalies (°C) along "Line P" (heavy gray line shown in part a) from 48°34.5N, 125°30.0°W to 50°145°W for February 2014. Anomalies are relative to the mean from 1956–1991. (c) Monthly temperature anomalies (normalized) from the surface to 200 m averaged over the area of 50 to 40°N, 150 to 135°W (indicated by the box shown in part a) for the period of January 1980 through November 2014.

Papa mooring in the midst of a warm water anomaly:
In the NE Pacific region around the OCS Papa mooring, offshore sea surface temperatures (SSTs) were remarkably warm during the winter of 2013–2014. By February 2014, peak temperature anomalies of the near-surface (upper ~100 m) waters were greater than 2.5°C, while temperature anomalies were below normal in the immediate vicinity of the coast. This anomaly was the greatest observed in this region since at least the 1980s. The region of warm sea surface temperature anomalies subsequently expanded and reached coastal waters in spring and summer 2014, and anomalously warm SSTs persisted in the NE Pacific Ocean through March 2015.

Based on a mixed layer temperature budget as described above, these anomalies were caused by lower than normal rates of the loss of heat from the ocean to the atmosphere, and of relatively weak cold advection in the upper ocean. Both of these mechanisms can be attributed to an unusually strong and persistent weather pattern in the region, featuring much higher than normal sea level pressure over the affected region.

The extensive and extraordinary magnitude of this warm anomaly has attracted public interest, particularly for its potential for impacting both the regional weather and fisheries. Direct measurements of climate conditions continue to be made by the OCS Papa mooring, and are made publicly available. PI Nick Bond of the Joint Institute for the Study of the Atmosphere and Ocean has participated in multiple public outreach and informational events on this topic.

Continued growth in online data users:
During 2015, there were substantial changes made to the OCS website and online data download portals. Users now experience a newly updated site that is more mobile-device friendly, with centralized data access.

In FY15, OCS web pages received over 186,000 site hits, showing an increase of more than 10k over FY14. The amount of text and data downloaded by visitors increased by nearly a factor of four over FY14, going from 247 GB in FY14 to 983 GB downloaded in FY15. The OCS Data Display and Delivery page had 1,427 download requests, yielding over 7,000 data files to users from around the world (U.S., Japan, Canada, China, Sweden, and South Korea). This is another large increase over previous years. From FY13 to FY14, there was more than a factor of two increase in the number of data file requests, and more than a factor of three increase in the number of data files provided. Again, from FY14 to FY15, download requests increased by a factor of three (500 to 1,427), and the number of files provided also increased by more than three times (1,900 to 7,000). Interest and use of OCS data continues to rise.

DESIGN AND FABRICATION OF A REAL-TIME, SHALLOW-WATER BOTTOM MOORING FOR THE ENVIRONMENTAL SAMPLE PROCESSOR (ESP)

PIs

John Mickett and Nicolas Michel-Hart – UW Applied Physics Laboratory

Other UW Personnel

Chris Siani, Justin Burnett, Keith Magness, and Derek Martin – Applied Physics Laboratory

Task III

NOAA Sponsor

Rita Williams – Great Lakes Environmental Research Laboratory

Other NOAA Personnel

Steve Ruberg, Tim Davis, and Greg Doucette – Great Lakes Environmental Research Laboratory/Center for Coastal Environmental Health and Biomolecular Research

NOAA Goals

Healthy Oceans
Resilient Coastal Communities and Economies

Description

The project goal was to design and fabricate a complete ESP (Environmental Sample Processor) real-time Harmful Algal Bloom detection mooring system, including: 1) the mooring infrastructure (a bottom lander), 2) the ESP pressure case, 3) a real-time telemetry system, 4) an ESP-controlled pump system to allow sampling of water from two different depths, and 5) a power system to run the ESP, telemetry and pump systems. This mooring system was to be delivered to the NOAA Great Lakes Environmental Research Laboratory (GLERL) in the spring of 2016 to allow a June 2016 deployment.

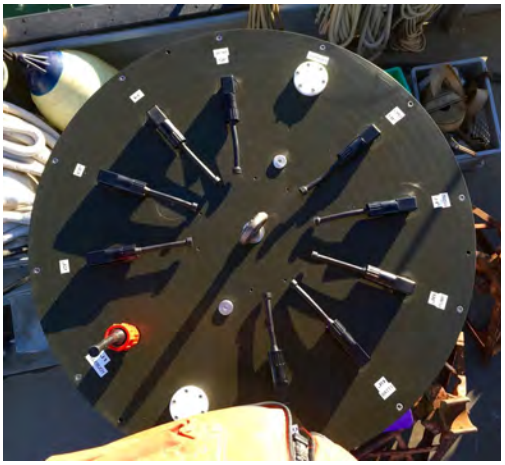


Figure 1. Lid of the ESP pressure case

Objectives

1. Design and build a lander system that: 1) will hold the large ESP, 2) be stable in strong wave/current environments, 3) be deployable from GLERL vessels, and 4) be sufficiently robust to last for many deployments.
2. Fabricate a pressure case for the ESP that will allow deployment to depths of up to 50 m.
3. Design and build a telemetry or communications system that will allow two-way, real-time communications with the ESP throughout the deployments.
4. Design and build a power system that will supply the ESP with

sufficient power to complete a full deployment.

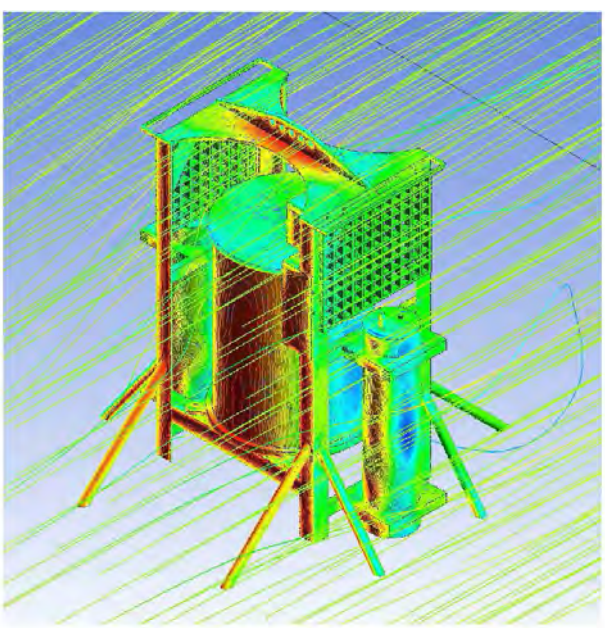
5. Design and build a pump and valve system that will allow the ESP to either sample water from near the surface or at the ESP depth (7 or 8 meters).

Accomplishments

1. We completed all of the objectives listed above on schedule. The lander system was delivered to the GLERL at the beginning of March 2016, with Mickett and electrical engineer Chris Siani traveling to GLERL in Ann Arbor for several days to conduct testing of and training on the new system, and to integrate the instrument electronics with the pressure case and other system components.

2. In addition to providing classroom-style and hands-on training, we assembled and provided extensive documentation to GLERL describing the system, including mechanical drawings, electrical drawings, spec sheets for specific items, and suppliers information for purchased items.

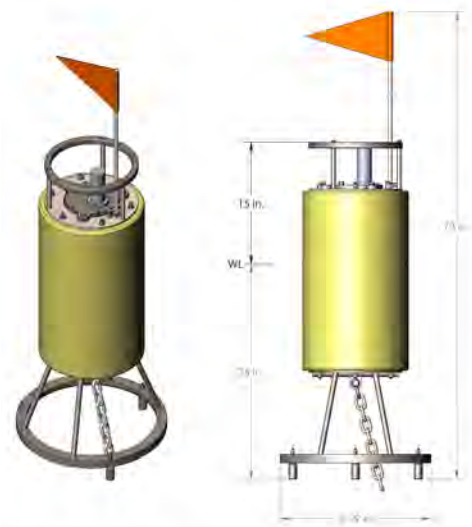
3. In developing this system, we significantly expanded the range of potential operating environments of the ESP, providing a platform that will allow critical real-time monitoring of toxic Microcystis blooms that can contaminate drinking water supplies in western Lake Erie.



Drag Characteristics

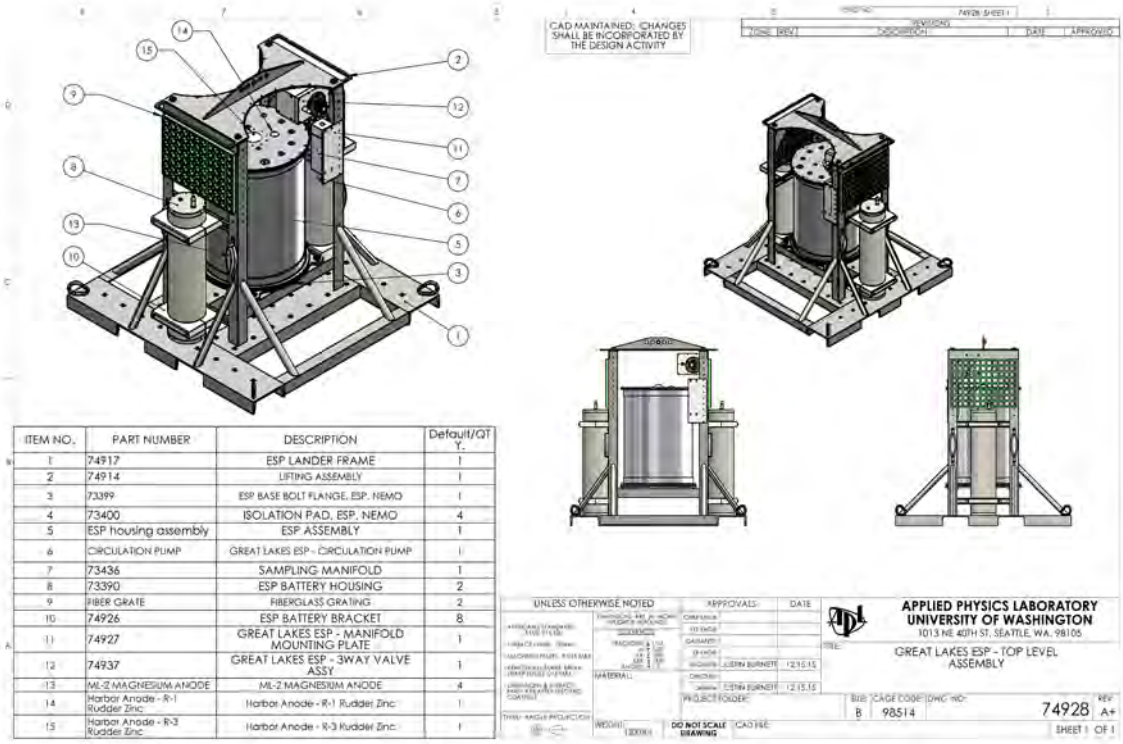
Frontal Area:	15.3 ft^2
Coefficient of Drag:	1.15
Center of Drag Location:	31 inches (from top surface of lander foot)
Approximate Tipping Water Velocity:	2.1 knots

Figure 2. ANSYS modeling of the ESP lander to test stability at various current speeds



Weight	approx. 60 lb (28 Kg)
Reserve Buoyancy	approx. 45 lb (20 kg)
Materials	all external metals: 316 stainless steel electronics housing: CPVC float: Surlyn ionomer foam
Hardware	316 stainless steel inch fasteners ⅜ in. stainless steel chain
Bulkhead Connector	SubConn DHB13MAS
Cellular Modem	MultiTech MTC-EV3-BO1
Cellular Antenna	Antcom 52-0.82-1.99V-O-XTB-2-U

Figure 3. "Telebuoy" or telemetry–buoy specification sheet



ITEM NO.	PART NUMBER	DESCRIPTION	Default/QTY.
1	74917	ESP LANDER FRAME	1
2	74914	LIFTING ASSEMBLY	1
3	73399	ESP BASE BOLT FLANGE, ESP, NEMO	1
4	73400	ISOLATION PAD, ESP, NEMO	4
5	ESP housing assembly	ESP ASSEMBLY	1
6	CIRCULATION PUMP	GREAT LAKES ESP - CIRCULATION PUMP	1
7	73436	SAMPLING MANIFOLD	1
8	73390	ESP BATTERY HOUSING	2
9	FIBER GRATE	FIBERGLASS GRATING	2
10	74926	ESP BATTERY BRACKET	8
11	74927	GREAT LAKES ESP - MANIFOLD MOUNTING PLATE	1
12	74937	GREAT LAKES ESP - 3WAY VALVE ASSY	1
13	ML-Z MAGNESIUM ANODE	ML-Z MAGNESIUM ANODE	4
14	Harbor Anode - R-1 Rudder Zinc	Harbor Anode - R-1 Rudder Zinc	1
15	Harbor Anode - R-3 Rudder Zinc	Harbor Anode - R-3 Rudder Zinc	1

Figure 4. Solidworks model of the lander system

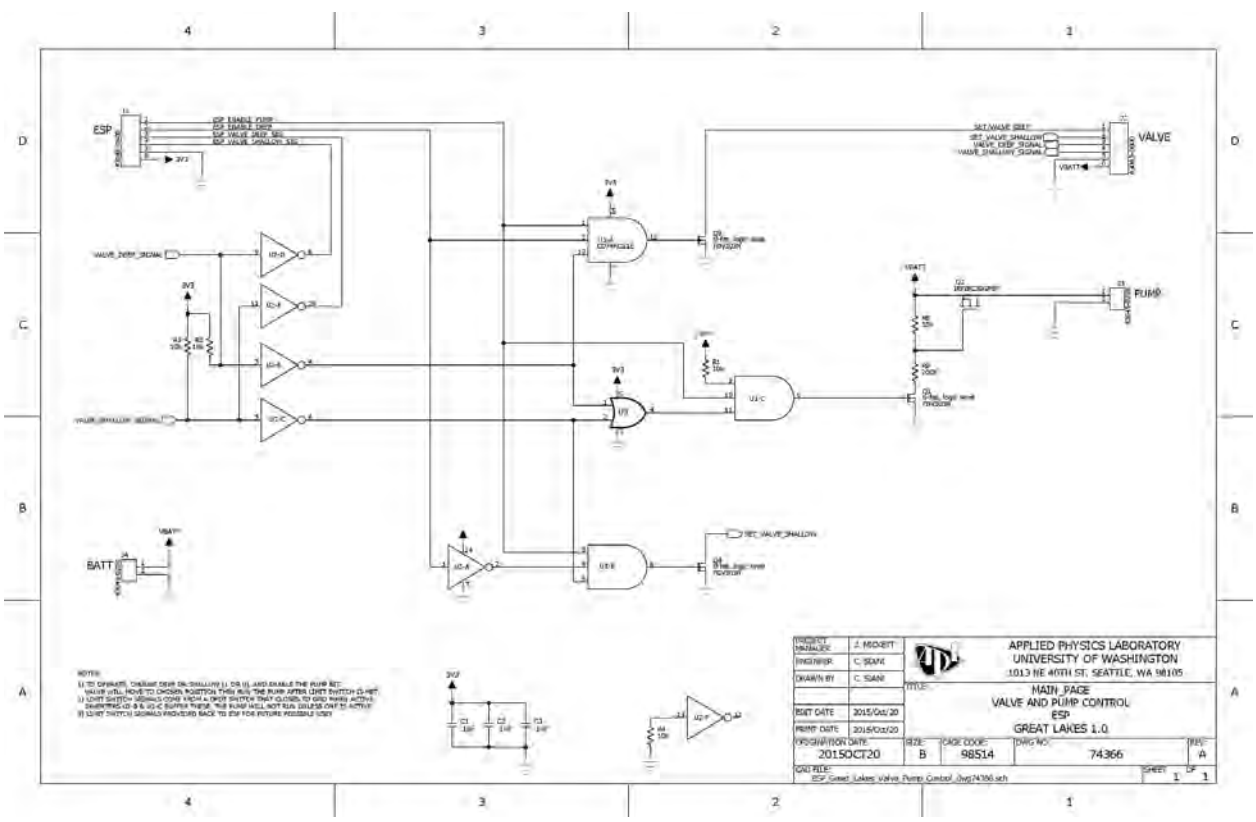


Figure 5. Example of an electrical drawing provided to GLERL

COORDINATION AND DATA MANAGEMENT OF THE U.S. INTERAGENCY ARCTIC BUOY PROGRAM AND INTERNATIONAL ARCTIC BUOY PROGRAMME

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

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

Task III

NOAA Sponsor
Sean Helfrich – National Environmental Satellite, Data, and Information Service

Other NOAA Personnel
Pablo Clemente-Colón, Curtis Reinking, and Micki Reams– National Ice Center

NOAA Goals
Climate Adaptation and Mitigation

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

Objectives
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 AON.

Accomplishments

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

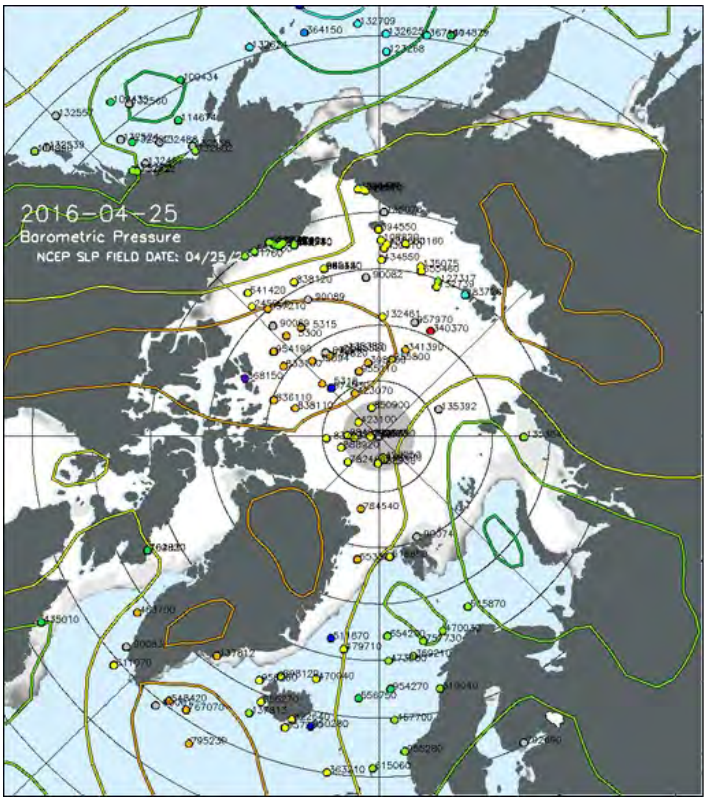


Figure 1. Map of buoys reporting from the Arctic Ocean on April 25, 2016. There are currently 149 buoys reporting in the IABP observing network, 122 of which are reporting on the WMO GTS.

The U.S. contribution to the IABP is coordinated through the U.S. Interagency Arctic Buoy Program (USIABP) which is managed by Curtis Reinking at the Naval Ice Center and Rigor at the UW Polar Science Center/Applied Physics Laboratory. The USIABP is also a collaborative program that draws operating funds and services from a number of U.S. government organizations and research programs, which include the National Aeronautics and Space Administration, the Coast Guard, Department of Energy (DOE), NOAA, the National Science Foundation, the Naval Oceanographic Office, the National Ice Center, and the Office of Naval Research. From these contributions, the USIABP acquires and deploys buoys on the Arctic Ocean, and supports the coordination and data management for the IABP.

1. Arctic Buoy Deployments
   In 2015, we deployed six Airborne eXpendable Ice Buoys (AXIB), 4 Ice Beacons, 1 Polar Area Weather Station (PAWS), 53 Surface Velocity Program (SVP), and one Upper Layer Temperature of the Ocean buoys. So far this year, we have deployed one Ice Beacon northwest of Barrow, and two SVPs and one Ice Tracker at the APL Ice Station in March 2016. We currently have nine AXIBs and 36 SVPs that we plan to deploy during summer and fall from aircraft and ice breakers.

   The USIABP buoys are deployed during various field campaigns. In 2015, these include:
   a. USIABP Beaufort and Chukchi Observing Network: 26 buoys on fast ice and on icebergs and other navigation hazards in the Beaufort and Chukchi seas. Logistics were supported by a contract from Shell Exploration and Production Company.
   b. North Pole Environmental Observatory: one PAWS and eight SVP buoys. Logistics were primarily supported by the NSF.
   c. Coast Guard Arctic Domain Awareness Flights: 3 AXIBs deployed in July and September 2015.
   d. Coast Guard ice breaker CGC *Healy*: three AXIBs and 20 SVPs.

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

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

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

PI

Stephen C. Riser – UW School of Oceanography

Other UW Personnel

Dana Swift, Annie Wong, Anil Rupan, Rachel Herbert, Christina Ramirez, Tyler Hennon, and Rosalind Echols – School of Oceanography

Task III

NOAA Sponsor

Steve Piotrowicz – Climate Program Office

NOAA Goals

Climate Adaptation and Mitigation
Healthy Oceans

Description

Argo is an international project that has deployed over 3,000 profiling floats in the world ocean since the year 2000. Each of these floats collects temperature and salinity profiles at about 10-day intervals, between the ocean surface and a depth of 2,000 m, and transmits the data to shore stations in real-time while on the sea surface. Over 30 countries are now participating in Argo, with the U.S. providing about half the total number of floats. The University of Washington (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, Stephen Riser serves as a member of the U.S. and International Argo Steering Teams.

Objectives

1. To continue participation in the Argo program. This international program is designed to deploy 3,000 profiling floats in the world ocean (approximately 300 km resolution over the globe) that will collect profiles of temperature and salinity over the upper 1,000 m of the world ocean at approximately 10-day intervals. This is the first subsurface global ocean observing system.

2. The U.S. is committed to providing about half of these floats. For the past several years, the U.S. has been providing over 300 floats per year, split among four institutions: Scripps Institution of Oceanography (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

1. During the past year, the team deployed 99 profiling floats as part of Argo, the largest number of any single float group in the world. Floats were deployed in the Atlantic, Pacific, and Indian Oceans, as well as around Antarctica. Some of the UW floats in the Antarctic have now been operating for four winter seasons. A majority of the UW floats were deployed in the subtropical South Pacific using a charter vessel, the R/V *Kaharoa* from New Zealand, paid for using Argo funds.

2. Some of the floats deployed in the past year (about 17) were deployed in the Southern Ocean, for the third year in a row. These floats used new software that allowed them to operate for extended periods under seasonal Antarctic ice. All of the Antarctic floats used the Iridium communication system, and many carried dissolved oxygen sensors. In some cases the cost of these floats was shared with the National Science Foundation, through the Southern Ocean Carbon and Climate Observations and Modeling program.

3. Seven papers were published in refereed journals using Argo data, and a graduate student, Tyler Hennon (supported in recent years by this project) will have his Ph.D. final examination during the first week of June 2016. Hennon has accepted a post-doc at Columbia University.

ADVANCED SENSOR INTEGRATION FOR FISH ASSESSMENTS FROM AUTONOMOUS AND REMOTE PLATFORMS

PI
Sarah Webster – UW Applied Physics Laboratory

Task III

NOAA Sponsor
Elizabeth Clarke – Northwest Fisheries Science Center

NOAA Goals
Healthy Oceans

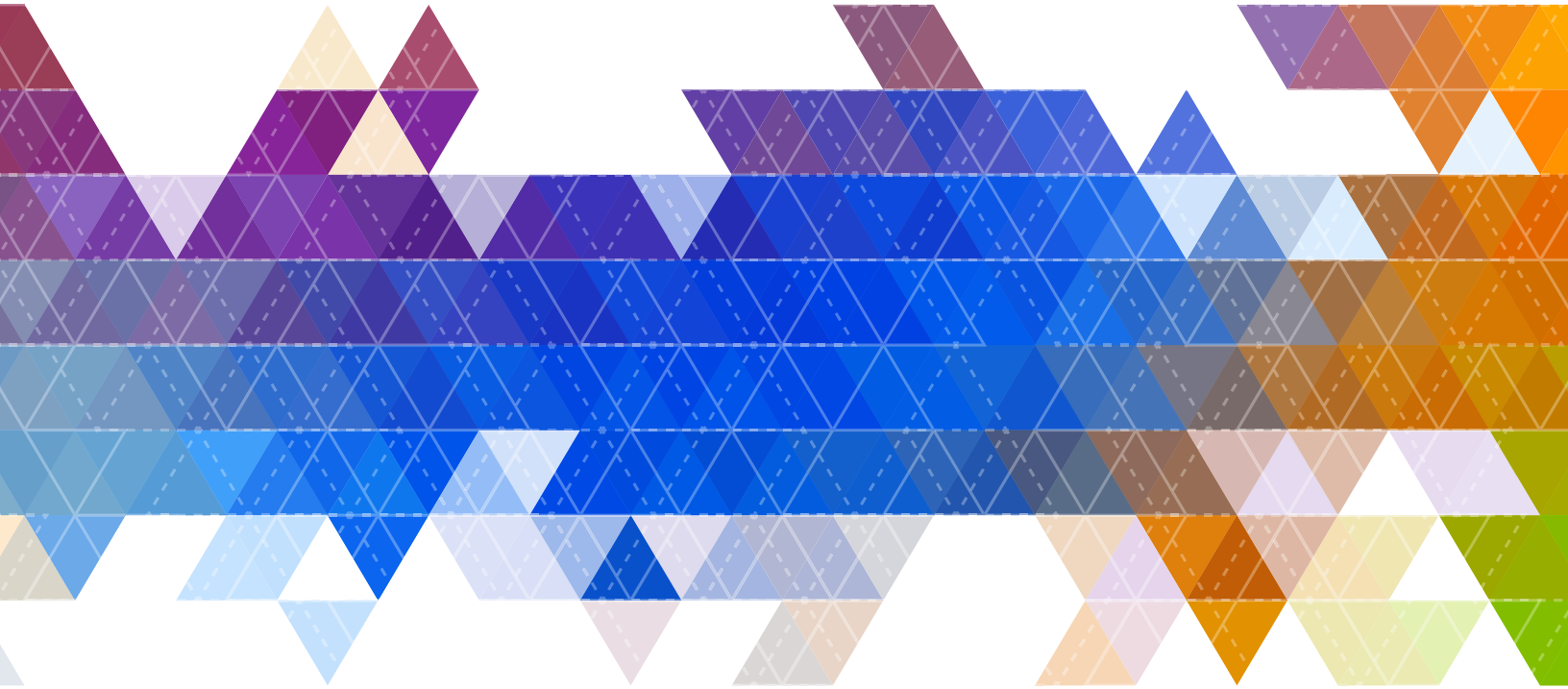
Description
The goal of this project is to provide technical support and advice to integrate new sensors and technologies for fish assessments onto existing platforms and systems such as Autonomous Underwater Vehicles, gliders, and towed systems.

Objectives
The objectives of this project are to provide in-depth engineering expertise and access to state-of-the-art machine shop and fabrication facilities, in order to assist with the integration of new sensors onto existing platforms. The long-range goal is to facilitate the use of advanced technology for assessing fish populations and habitat. New sensors, both optical and acoustic, can improve data quality (e.g., higher fidelity sensors and complementary sensing modalities), and improve performance of platforms (e.g., obstacle avoidance, high precision underwater positioning). However, integration of new sensors is not simple, and requires in-depth engineering knowledge of the sensors and the challenges associated with marine deployments.

Accomplishments
We are currently developing a plan with the National Marine Fisheries Service (NMFS) to complete the assembly of a cylindrical pressure vessel to support a reevaluation of the acoustic absorption coefficient of seawater at frequencies used to detect fish and plankton.

Reason Why Objectives Not Met
Progress on this grant is ongoing as we work with NMFS.

PROTECTION AND RESTORATION OF MARINE RESOURCES



CETACEAN ASSESSMENT AND ECOLOGY PROGRAM

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

Other UW Personnel
Eric Braen, Amelia Brower, Stephanie Grassia, Jenna Harlacher, Eliza Ives, Amy Kennedy, Brynn Kimber, Julie Mocklin, Christy Sims, Alexandra Ulmke, Amy Willoughby, Megan Wood, and Linda Vate Brattström – Joint Institute for the Study of the Atmosphere and Ocean

Task II

NOAA Sponsor
Phillip Clapham – Marine Mammal Laboratory

Other NOAA Personnel
Catherine Berchok, Jessica Crance, Megan Ferguson, and Nancy Friday - Alaska Fisheries Science Center

NOAA Goals
Healthy Oceans

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

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

Objectives
1. Assess patterns of spatial and temporal use of Alaskan waters by marine mammals (endangered bowhead, fin, and humpback whales, other cetaceans, ice seals, walruses, and polar bears) through aerial and vessel surveys and acoustic monitoring.

2. Describe the annual migration of bowhead whales across the Alaskan Arctic, significant inter-year differences, and long-term trends in the spatial distribution and timing (duration and start date) of the migration.

3. Document relative abundance and behavior (including calving/pupping, feeding, hauling out) of marine mammals in the Alaskan Arctic.
4. Investigate the movements of individual whales and assess the population structure and origin of whales in the region.
5. Provide an objective wide-area context for understanding marine mammal ecology in Alaskan waters, to help inform management decisions and interpret results of other small-scale studies.
6. Evaluate the extent to which variability in environmental conditions such as sea ice, oceanic currents, water temperature and salinity, and prey abundance influence cetacean distribution and relative abundance.

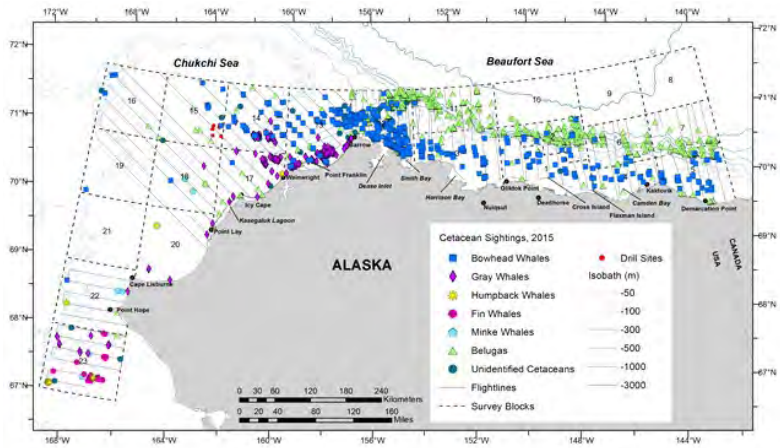


Figure 1. Cetaceans sighted by ASAMM in 2015, transect, search, and circling effort.

Accomplishments

1. The Aerial Surveys of Arctic Marine Mammals (ASAMM) is a Bureau of Energy Management (BOEM) funded project that describes the annual migration of bowhead whales in the Alaskan Arctic and documents the relative abundance, spatial and temporal distribution, and behavior of marine mammals in the Alaskan Arctic. ASAMM is an ongoing 36-year time series and provides an objective wide-area context for understanding marine mammal ecology in the Alaskan Arctic, to help inform management decisions and interpret results of other small-scale studies. The extensive annual report for the 2015 season has been drafted, and preliminary results were presented at the Alaska Marine Science Symposium in Anchorage, January 2016. Figure 1 shows cetaceans sighted by ASAMM in 2015. Data analysis, writing for scientific publication, and field preparations for the 2016 field season continue.
2. The MML acoustics program deploys numerous autonomous passive acoustic recorders throughout the Bering, Chukchi, and Beaufort Seas. These moorings, deployed every summer, collect acoustic data on a duty cycle for a year, and are retrieved and redeployed the following year. Figure 2 shows the location of all passive acoustic recorders deployed by the Acoustics group.

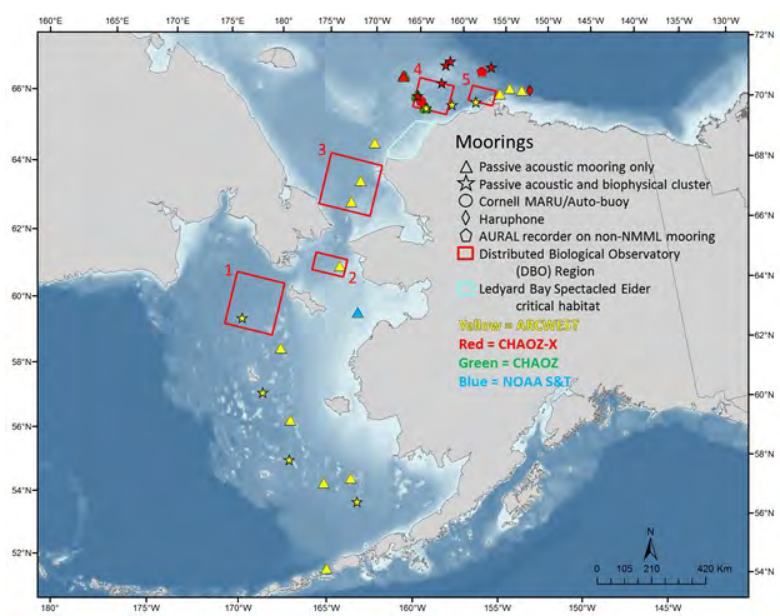


Figure 2. Location of all MML passive acoustic recorders.

3. The Arctic Whale Ecology Study (ARCWEST) is a BOEM-funded, multi-year project to investigate baleen whales in the Chukchi Sea relative to ocean currents, and prey resources. Large numbers of baleen whales pass through the Bering Strait during seasonal migrations to feeding grounds further north. Beginning south of the Bering Strait, important baseline data on the occurrence, distribution, and habitat use of baleen whales are being collected using passive acoustic monitoring, visual surveys, and satellite telemetry. Relationships between dominant currents flowing through the Bering Strait and delivering resources to the Barrow Arch area are being determined using biophysical sampling and moorings. The nature of those relationships relative to whale distribution and habitat utilization are also being explored. We have begun processing the data from the moored passive acoustic recorders to obtain the seasonal distribution of marine mammals, as well as environmental and anthropogenic sounds. All sonobuoy data for the ARCWEST project have been processed and uploaded to the Distributed Biological Observatory (DBO) website. The visual and telemetry field work for this project concluded in 2014. Currently, data from these project components are being processed and synthesized for peer review publication. Preliminary results have been included in the ARCWEST annual report (www.afsc.noaa.gov/nmml/PDF/ARCWEST_AnnualReport_201601.pdf) submitted to BOEM on January 15, 2016.

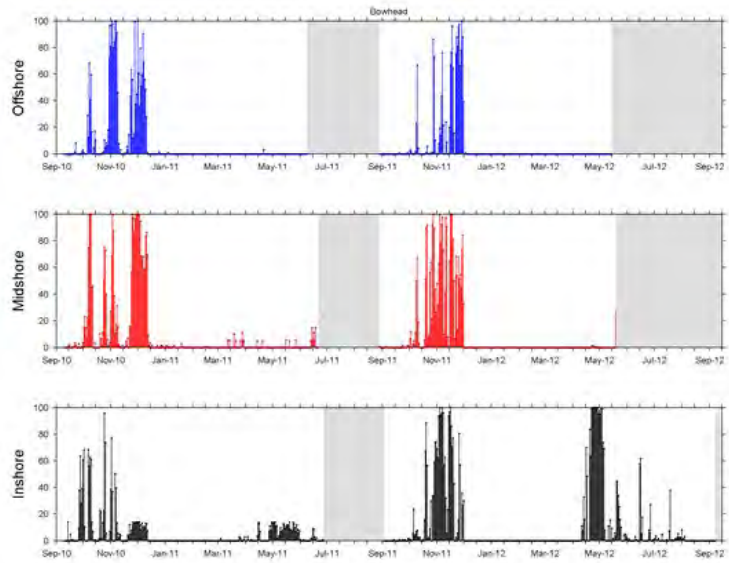


Figure 3. A two-year time series of bowhead whale calls detected on three moorings off Icy Cape, AK. Moorings are located ~40 miles ("inshore"), ~70 miles ("midshore"), and 110 miles ("offshore") off Icy Cape. The Y-axis shows the percentage of 3-minute time intervals with bowhead calls detected per day. The data were collected and analyzed as part of the BOEM-funded CHAOZ project. Gray areas represent no data.

4. The Chukchi Acoustics, Oceanography, and Zooplankton (CHAOZ) study is a BOEM-funded, multi-year, multi-disciplinary study to document the distribution and relative abundance of endangered whales in the Chukchi Sea Planning Area and relate variation in those parameters to oceanographic conditions, indices of potential prey density, and anthropogenic activities. This project, which began in 2010, was completed in 2015 and the final report (www.afsc.noaa.gov/nmml/PDF/CHAOZ_final_report.pdf) was submitted in summer, 2015. All data from the passive acoustic moorings were analyzed (e.g., Figure 3), and data included in a general additive model to determine correlations with oceanographic conditions (e.g., Figure 4). All sonobuoy data from the CHAOZ project field surveys have been processed and uploaded to the DBO website, and were presented in the final report. All visual and telemetry data have been processed and synthesized, and are in the final report.

5. The CHAOZ Extension Study (CHAOZ-X) is a BOEM-funded, multi-year, multi-disciplinary study to document the temporal and spatial distribution of baleen whales near Hanna Shoal in the northeast Chukchi Sea and to relate variations to oceanographic conditions, indices of potential prey density, and anthropogenic activities to improve understanding of the mechanisms responsible for observed high levels of biological activity around the shoal. We have begun processing the data from the moored passive acoustic recorders to obtain the seasonal distribution of marine mammals, as well as environmental and anthropogenic sounds.

6. The Acoustics group at MML participated in an educational outreach program called Expanding Your Horizons (EYH) in March. The goal of EYH is to inspire young girls (grade 7-8) and spark an interest in careers in science, technology, engineering, and mathematics (STEM), and to provide them with hands-on experience and an opportunity to interact with females with careers in STEM. This is the Acoustics group's sixth year participating in this program, which is hosted by Highline Community College.

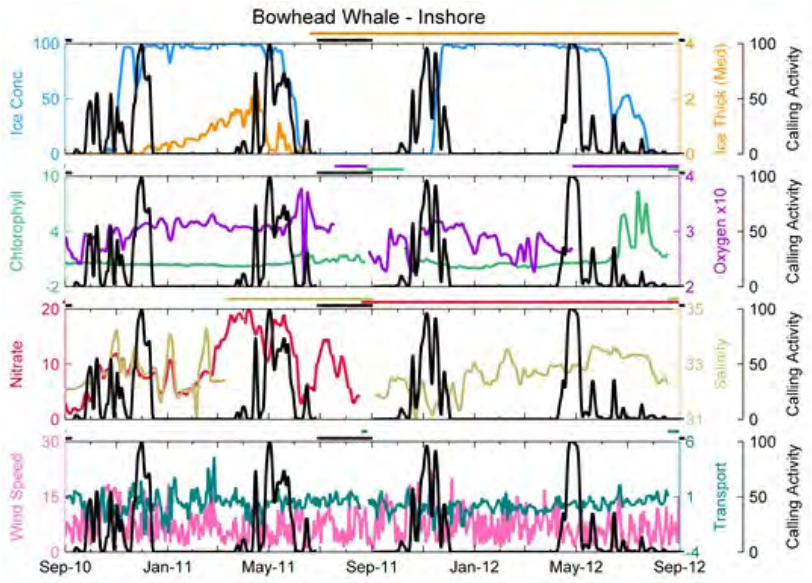


Figure 4. Bowhead whale calling activity as it relates to oceanographic variables at the inshore location, 2010–2012. Black line = % of time intervals with calls. Top row: % ice concentration (blue line) and ice thickness (m; orange line). Second row: chlorophyll (µg/L; green line) and oxygen (M x 10; purple line). Third row: nitrate (µM; red line) and salinity (psu; tan line). Bottom row: wind speed (m/s; pink line) and transport (Sv; teal line). Horizontal bars above each row indicate times with no data. All data except wind speed are presented as a 3–day moving average.

7. The Aerial Calibration Experiments project, which was designed to test the feasibility and efficacy of using unmanned aircraft to calculate large whale abundance in the arctic, was completed this year. The survey was designed to: 1) conduct a three-way comparison of whale data collected via observers in a manned aircraft, digital photographs from manned aircraft, and digital photos from an unmanned aircraft; and 2) to test meteorological sensors recording atmospheric conditions. In all, over 215,000 vertical aerial images were collected. To date, nearly 17,000 images have been manually reviewed, resulting in 66 sightings of bowhead whales, gray whales, belugas, and walrus.

8. The Cook Inlet beluga (CIB) project conducts research on the endangered stock of belugas tracking abundance, distribution and habitat use. Although 2015 was not a survey year, staff worked on organizing historical data and data quality checking multi-year databases of Cook Inlet beluga research for online publication in accordance with the NOAA Plan for Public Access to Research Results. CIB staff participated in educational outreach through NOAA Science Camp, highlighting marine mammal conservation and survey techniques, and showed students how aerial video of belugas is counted and assessed with specialized computer software. Several papers on CIB were produced for publication in a special edition of *Marine Fisheries Review* on Cook Inlet belugas. Preparations for the upcoming June 2016 aerial survey for Cook Inlet belugas included purchasing and testing of new camera equipment and software along with other field prep logistics.

ECOLOGY OF ARCTIC SEALS

PI
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Task II

NOAA Sponsor
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NOAA Goals
Healthy Oceans

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

Objectives
Aerial Surveys:
Aerial surveys for harbor seals will be conducted along the coasts and over floating ice in glacial fjords.

Surveys for bearded, ringed, spotted, and ribbon seals will be conducted over sea ice using a system of paired infrared and color cameras; the infrared images are used for detection of seals and the color photos are used for identification of species. The survey regions will include Southeast Alaska, the Gulf of Alaska, the eastern Bering Sea, and the Chukchi and Beaufort seas.

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

The overarching objectives that aerial surveys can address are as follows:
1. Document abundance and trends, which are needed for population assessments under the Marine Mammal Protection Act and the Endangered Species Act (ESA) and for inclusion of seals in integrated ecosystems studies

and models. For the ice-associated seals, obtaining the first reliable population estimates will provide a reference from which to judge future trends and evaluate population consequences of Arctic warming and ocean acidification.

2. Provide the basis for species distribution maps, which are fundamental for investigation of habitat requirements, impacts assessment and disaster planning, and for spatial models of population and ecosystem dynamics.

During the 2015 to 2016 period, the aerial survey component included the following activities:

1. Participated in aerial survey planning and logistics; including the creation of a Quantum Geographic Information Systems (QGIS) mapping project for observers to use to plan daily flights and view ice imagery.
2. Participated in aerial surveys by operating remote sensing equipment, operating color camera equipment, and managing the collection of images and related data.
3. Processed and analyzed images (e.g., seal detection, enumeration of seals, and species identification) from the extensive aerial surveys of seals in the Bering Sea, 2012-2013.
4. Managed field data forms and geospatial survey data.
5. Produced summary statistics, maps, and other graphics for field operations, community outreach, and reports (e.g., map of planned survey tracks in the joint U.S. - Russia Chukchi-East Siberian Surveys.
6. Assisted with writing reports, peer-reviewed manuscripts, and preparing presentations.
7. Collaborated with researchers and stakeholders within and outside of NOAA and UW (agency resource managers, Alaska Native organizations, and other entities) to ensure maximum utility and impact of data collected in this project.

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

The overarching objectives that telemetry studies can address are as follows:

1. Assess patterns of spatial and temporal use by seals.
2. Investigate the relationships of seal movements and diving behavior to biological and environmental habitat factors.
3. For each species, estimate proportions of seals hauled out as functions of date, time of day, and other influential covariates.
4. Develop and refine telemetry methods for multi-disciplinary studies of marine mammal ecology and oceanography utilizing new animal-borne sensors.

During the 2015 to 2016 period, the satellite-telemetry component included the following activities:

1. Participated in planning, preparation of equipment, and logistics for two major telemetry studies: a harbor seal cruise in the central Aleutians (planned for September 2016), and an ice seal cruise in the Bering Sea (completed in April 2016).

2. Participated in the Bering Sea ice seals cruise aboard *Oscar Dyson* to capture, tag, sample, and release free-ranging seals.
3. Processed, managed, and analyzed Argos telemetry data.
4. Produced summary statistics, maps, and other graphics.
5. Assisted with writing reports, peer-reviewed manuscripts, and preparing presentations.
6. Collaborated with researchers and stakeholders within and outside of NOAA and UW (agency resource managers, Alaska Native organizations, and other entities) to ensure maximum utility and impact of data collected for this project.

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

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

During the 2015 to 2016 period, the health, condition, diet, and stock structure component included the following activities:
1. Participated in health, condition, diet, and stock structure studies planning and logistics, including the preparation of equipment for Aleutian harbor seal and Bering Sea ice seal research cruises.
2. Participated in a field studies aboard the NOAA vessel *Oscar Dyson* to collect samples from free-ranging seals.
3. Processed and curated biological samples and data in the field.
4. Produced summary statistics, maps, and other graphics.
5. Assisted with writing reports, peer-reviewed manuscripts, and preparing presentations.
6. Collaborated with researchers and stakeholders within and outside of NOAA and UW (agency resource managers, Alaska Native organizations, and other entities) to ensure maximum utility and impact of data collected in this project.

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

PI

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Other UW Personnel

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Task II

NOAA Sponsor

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NOAA Goals

Healthy Oceans

Description

The Alaska Ecosystems Program (AEP) of the Marine Mammal Laboratory (MML) conducts research on Steller sea lions and northern fur seals. Research projects are designed to assess the status of these species under the Endangered Species Act (ESA) and the Marine Mammal Protection Act, and to improve knowledge of their ecology and behavior. Steller sea lions and northern fur seals consume a large variety of fish and cephalopod species, but while in Alaskan waters, their primary prey are also targets of commercial fisheries, principally walleye pollock, Atka mackerel, Pacific cod, salmon, rockfish, and Pacific herring. There continues to be considerable controversy about the relative roles of anthropogenic (e.g., competition with fisheries) and environmental variability (e.g., oceanographic and fish community changes related to regime shifts) in their impact on the populations trends of these two apex predators. For instance, the National Marine Fisheries Service (NMFS) has been sued by both the fishing industry and environmental groups at different times

Figure 1. Steller sea lions on Ugamak Island rookery.

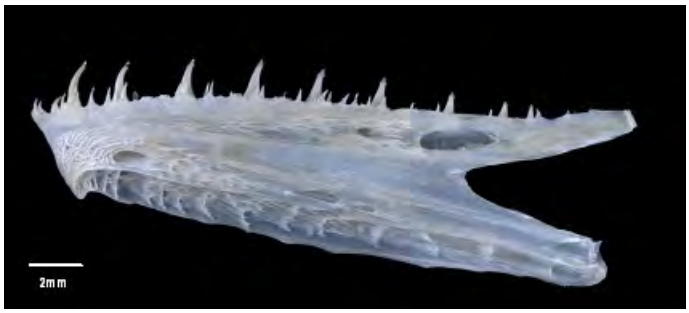

Figure 2. Arrowtooth flounder dentary from the MML fish bone reference collection.

since 1990 for either implementing or not implementing regulations to minimize the potential competitive interactions between fisheries and western Steller sea lions to allow for the latter's recovery. AEP conducts long-term research on sea lion and fur seal abundance, vital rates (survival, reproduction, and movement) and diet in order to better understand their biology and ecology, and provide information to managers who write documents required by the ESA and other environmental laws governing federal actions (e.g., the National Environmental Policy Act).

Objectives

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

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

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

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

Accomplishments

1. Joshua Cutler trained and prepared to be a pilot in command for summer and fall 2016 University of Alaska Southeast surveys of Steller sea lions and northern fur seals.

2. Cutler developed, migrated data to, and normalized a relational database to host the Steller sea lion and northern fur seal food habits databases. He developed user-driven database interface solutions based on the needs expressed by Kathryn Luxa and other AEP personnel.

3. Cutler developed, migrated data, and normalized a centralized database to host the main northern fur seal project data. This allows researchers to connect the data collected on marked animals, locations, population counts, food habits, and biological samples. Cutler developed user-driven database interface solutions based on the needs of individual projects, including hand-held data entry systems for the field.
4. Luxa organized the 2015 Steller sea lion vital rates data and photos collected at field camps on Marmot Island and Ugamak Island and transferred them to AEP's master databases.
5. Luxa completed several tasks related to the Steller sea lion and northern fur seal food habits databases. First, she reformatted the existing Access databases, standardizing table names, column names, and prey identification codes and definitions. She also entered historical and recent datasets that were not yet included in the databases. After the data were migrated to their new databases, she ran a suite of basic error-checking queries. Additionally, she began an extensive inventory of physical samples (i.e., vials of prey remains), hard copy datasheets, and digital data back-ups. These databases now include identified prey remains from over 25,000 scats, regurgitations (spews), enemas, and GI tracts (stomach, small intestine, colon) collected since 1985.

CHANGES IN U.S. WEST COAST GROUNDFISH ECOLOGY

PI
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Other UW Personnel
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Task II

NOAA Sponsor
Michelle McClure – Northwest Fisheries Science Center

NOAA Goals
Healthy Oceans

Description
The West Coast groundfish fishery has been through substantial changes over the last 25 years, driven by the low productivity of many of the target species (long-lived rockfish), and the overfished designation of several stocks. Rebuilding plans have required steep reductions in exploitation rates to around 1% per year, the closure of much of the productive fishing areas, and most recently a switch to managing the fishery to an Individual Fishing Quota (IFQ) system. IFQs involve allocating individual quota of both target and restricted species, requiring fishermen to keep a positive balance of both types of species in their accounts before fishing is initiated. To date, we have seen a dramatic decline in discard, and a very low ratio of catch to allowable catch, as well as shifts in fishing effort and the timing of the fishery. The postdoctoral scholar has access to fishery, observer, and survey data to compare and contrast characteristics of Pacific Coast groundfish species and communities before and after the implementation of the IFQ program. Wide arrays of projects are being explored, have been conducted, or are in preparation, as listed below.

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

Accomplishments
1. The project has been awarded a Hollings Scholar to synthesize age truncation in fished populations, and to test how fishing might alter recruitment variation.
2. A web-based survey has been planned to contrast people's perceptions of natural mortality and how this differs depending on the method used to obtain these estimates.
3. Preliminary analyses have been conducted on correlations between genotypes, phenotypes and life history parameters in rockfishes.
4. A manuscript in preparation looks at trends in space and time on the impact of groundfish trawling on biogenic habitat (e.g., corals and sponges) off the U.S. West Coast, and how these have been affected by IFQs, spatial closures, and vessel buybacks.

5. We are developing a modeling framework to assess tradeoffs between protection of habitat and fishery yield from bottom trawling.
6. We have a manuscript in preparation evaluating how environmental variation propagates through food webs, in application to Pacific hake and forage fish predator-prey interactions.
7. We had two papers published on the ecological impacts of marine protected areas, demonstrating how reserves can increase ecological resilience and decrease population variation in U.S. West Coast rockfish communities.
8. We have completed two NOAA climate vulnerability assessments for U.S. West Coast sablefish and Aurora rockfish.
9. Two additional published papers look at how design elements of IFQs impact fisheries, and a method for detecting growth variation in North Pacific groundfish.

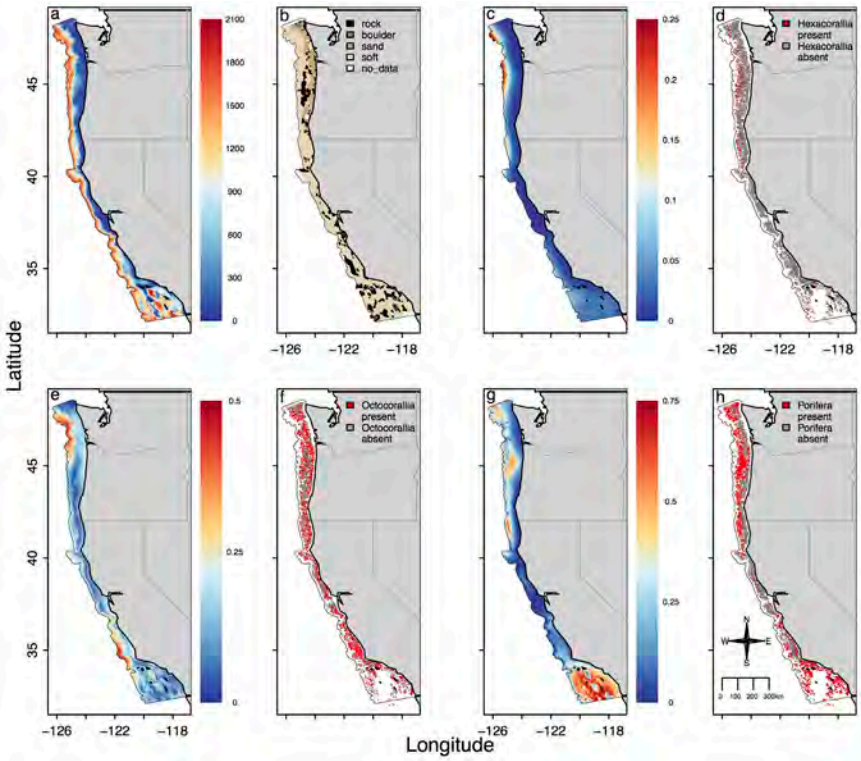


Figure 1. Maps of spatial distribution of (a) depth and (b) substrate categories across the model prediction area. Maps (c–h) show best-fit model predictions of the probability of encounter of bottom trawls with biogenic habitat (c, e, and g) and raw survey trawl data (d, f, and h) for (c–d) stony corals, (e–f) soft corals, and (g–h) sponges.

EVALUATING PREDATOR MOVEMENTS TO DETERMINE THE VULNERABILITY OF SALMON SMOLTS TO PREDATION IN THE SAN JOAQUIN DELTA

PI

Thomas P. Quinn – UW School of Aquatic and Fishery Sciences

Other UW Personnel

Joseph Smith – Department of Biology/School of Aquatic and Fishery Sciences

Task III

NOAA Sponsor

Sean Hayes – Southwest Fisheries Science Center

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, white catfish, and channel catfish). The purpose of this study is to assess the movement of predators in relation to the ESA-listed and economically important salmonid smolts in an area of known high mortality and high predator densities. The National Marine Fisheries Service (NMFS) and University of Washington (UW) have collaborated to obtain two years of empirical data on predator fish movement (collected by UW), predator diets (collected by NMFS), and predation rates (collected by NMFS). This proposal included funds to analyze the two years of data collected by UW and NMFS, write peer reviewed manuscripts, and attend conferences to present the research findings.

Objective

1. 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.

2. Analyze diet and predation event recorder data collected by NOAA.

Accomplishments

Objective 1

1. To meet our objective, the second year of field work was conducted in March, April, and May of 2015 to

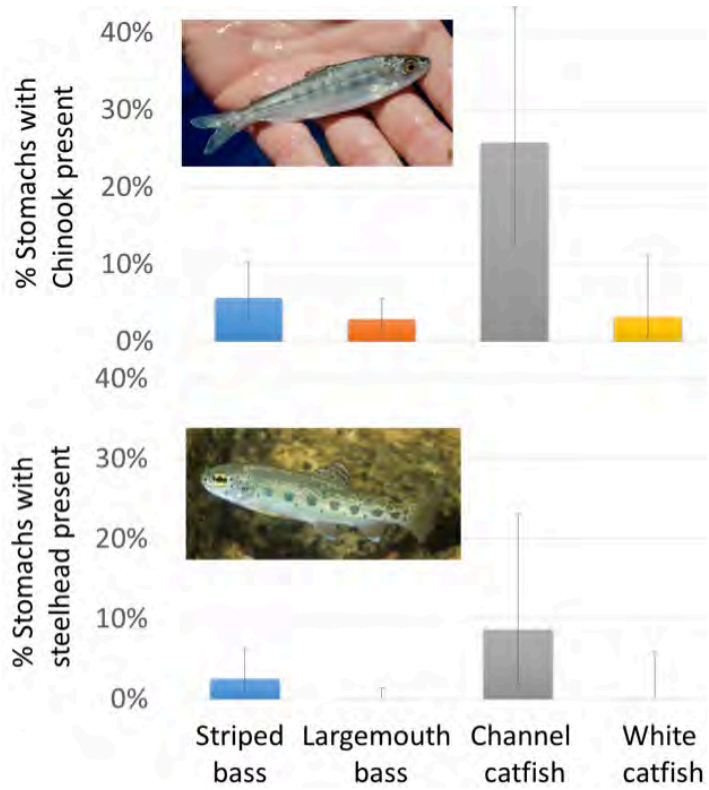
				Fork length (mm)			Weight (kg)		
Species	Year	# tagged	# transported	mean	min	max	mean	min	max
Largemouth bass	2014	66	36	367	226	548	0.99	0.20	3.22
	2015	62	38	351	248	560	0.84	0.25	2.60
Striped bass	2014	37	27	391	271	853	1.20	0.25	9.00
	2015	41	24	374	238	950	1.21	0.15	11.1
White catfish	2014	29	19	282	240	365	0.37	0.20	0.85
	2015	31	19	278	228	378	0.37	0.15	0.97
Channel Catfish	2014	18	8	447	322	572	1.13	0.45	2.16
	2015	16	10	473	318	613	1.47	0.42	3.20

coincide with juvenile salmon migration. Predators (striped bass, largemouth bass, channel catfish and white catfish) were surgically implanted with acoustic tags that are expected to transmit for two years. This is the second year of two years of tagging. Above is a table of the number of each species tagged, mean fork length, range of fork lengths, mean weight, and range of weights.

2. A photograph of surgery being performed on a largemouth bass is shown on the following page.
3. Fish movement was recorded with stationary acoustic receivers. These were downloaded in December of 2015, resulting in over 3 million detections of tagged fish.
4. Fish movement data are currently being analyzed to replicate the analysis of the 2014 telemetry data.

Objective 2

1. Predator diet data have been analyzed and a manuscript is currently in preparation. Preliminary results of the analysis are shown to the right.
2. Predation event recorder data are being cleaned and analyzed, including over 11 million data records over two years. Data from multiple sources (USGS river gauges, temperature and light loggers, GPS units, and GoPro video footage) have all been compiled into one dataset. Preliminary analysis on a subset of these data has been conducted and the findings were incorporated into Demetras et al. (2016, listed below).



Publications and Presentations

The results include two years of data compilation and analysis. One peer reviewed manuscript has been published, and two manuscripts are in preparation.

Preliminary results have been presented at the following conferences, seminars and lectures.

Presentations

1. State of the San Francisco Estuary Conference. Oakland, CA. September, 2015.
2. Wildlife Science Seminar. School of Environmental and Forest Sciences, University of Washington. February, 2016.
3. Guest Lecture: Salmon & Society FISH 493. University of Alaska, Fairbanks. Instructor: Peter Westley. March, 2016.

ASSESSING THE CAPACITY FOR EVOLUTIONARY ADAPTION TO OCEAN ACIDIFICATION IN GEODUCK

PI

Steven Roberts – UW School of Aquatic and Fishery Sciences

Task II

NOAA Sponsor

Frederick Goetz – Northwest Fisheries Science Center, Manchester Research Station

Other NOAA Personnel

Walt Dickhoff – Northwest Fisheries Science Center

NOAA Goals

Healthy Oceans

Description

The combination of increasing temperatures and ocean acidification (OA) are expected to have important and broad-ranging effects on the marine environment, and consequently on ecologically and economically important marine species. Puget Sound is one of the first regions likely to experience the effects of OA on important marine species due to the combination of local upwelling events, sea surface temperature anomalies, and the relatively low buffering capacity of local seawater. We propose to examine the effects of OA conditions on the adaptive response of a potentially vulnerable native marine mollusc species with ecological, economic, and social importance in the Pacific Northwest: geoduck clams (*Panopea generosa*). We know that elevated pCO_2 alone and in combination with other environmental stressors will result in selection, with survival of larvae based on the possession of beneficial phenotypic traits. However, there are several things we do not know including: a) What underlying factors (e.g., genetic/epigenetic) control these traits? b) What combinations of phenotypic traits will result in survival? and c) How will post-selection populations respond to subsequent environmental stress? This research effort is specifically designed to identify the underlying factors by performing a controlled within-generation selection experiment, and examining alterations in

Figure 1. Photographs of the Ocean Acidification system at the Kenneth K. Chew Center for Shellfish Research and Restoration.

population structure caused by OA.

Objective

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

Accomplishments

The major accomplishments of the current reporting period were the completion of three larval trials at the Kenneth K. Chew Center for Shellfish Research and Restoration, and generating a draft genome for geoducks. Larval trials were carried out from February through April 2016, with samples collected for later morphometric and molecular analysis. We plan to begin examining allele and epiallele variation over the next year. A draft genome has been sequenced, and we are currently involved in assembly and annotation. At this point we have 22 scaffolds greater than 100 kilobases and have developed a genome browser with this early draft.

We have published a website that documents real-time progress on the OA research at safsoa.wordpress.com/, and have a dedicated GitHub repository that contains all data and protocols at github.com/RobertsLab/project-geoduck-oa. The draft genome assembly is available at oystergen.es/geoduck/.

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

PI
Steven Roberts – UW School of Aquatic and Fishery Sciences

Other UW Personnel
Giles Goetz and Crystal Simchick – School of Aquatic and Fishery Sciences

Task III

NOAA Sponsor
Walton W. Dickhoff – Northwest Fisheries Science Center

NOAA Goals
Healthy Oceans

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

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

Accomplishments
The major accomplishments of the current reporting period include an early draft genome sequence and a genome browser platform. Six mate-paired libraries (insert size: 300, 500, 800, 2000, 5000, and 10000bp) were constructed and sequenced on the HiSeq4000 platform. Assembly and annotation are currently underway with the current version (v0.0.2) having 11,495 scaffolds greater than 10,000bp. This genome version is being used as framework for a new genome browser to aggregate data.

Publications

We have published a website that provides access to the draft genome data, as well as access to the new genome browser (oystergen.es/olympia).

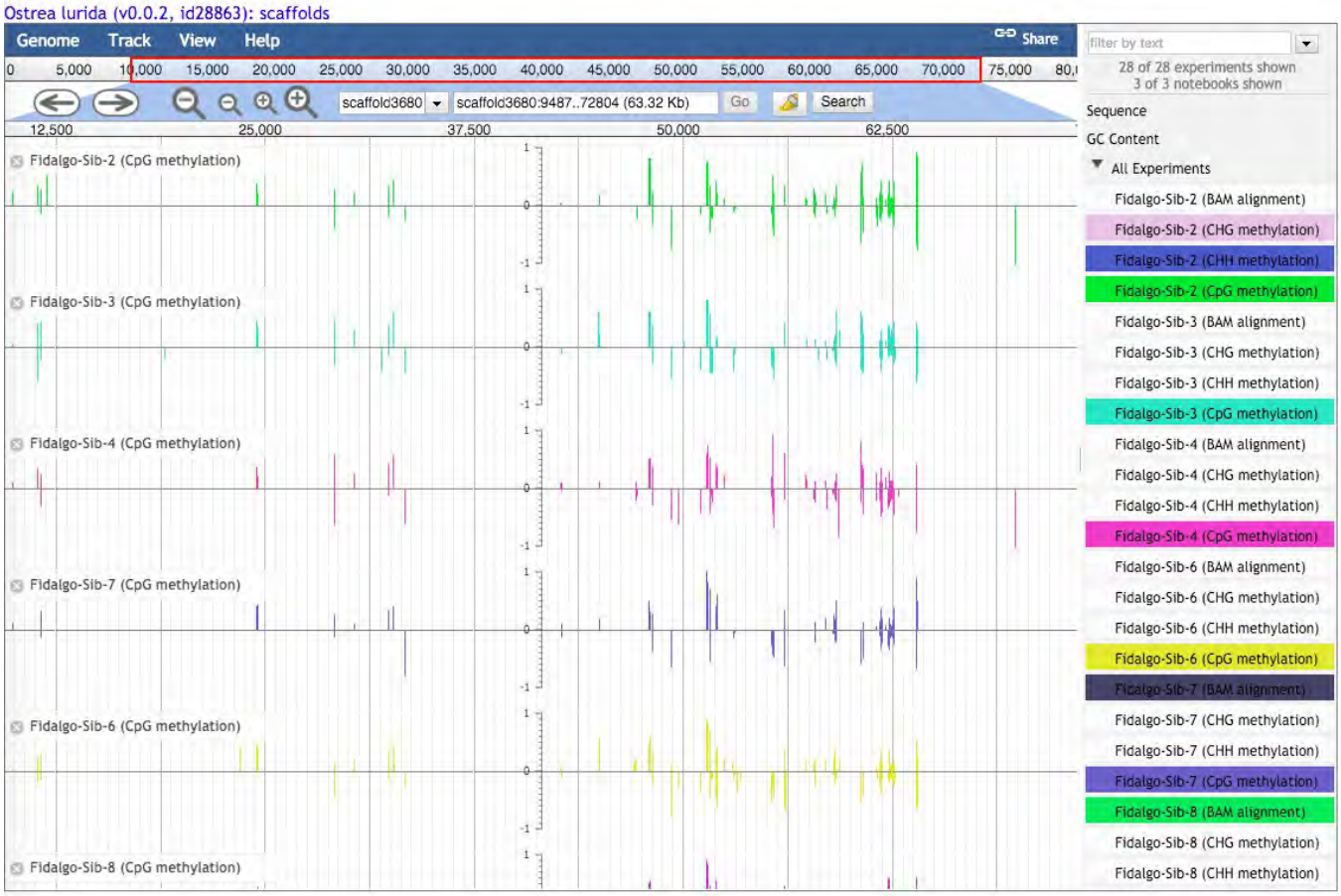


Figure 1. Screenshot of Olympia oyster genome browser.

STEELHEAD REPRODUCTION AND GENETICS

PI
Graham Young – UW School of Aquatic and Fishery Sciences

Other UW Personnel
Mackenzie Gavery – School of Aquatic and Fishery Sciences

Task II

NOAA Sponsor
Krista Nichols – Northwest Fisheries Science Center

Other NOAA Personnel
Kathleen Jewett – Northwest Fisheries Science Center

NOAA Goals
Healthy Oceans

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

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

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

Objectives

1. Characterize the epigenome (DNA methylation) of sperm and red blood cells (RBCs) collected from hatchery and natural origin adult Methow River steelhead using Reduced Representation Bisulfite Sequencing (RRBS).
2. Characterize genomic DNA variation in hatchery and natural origin adult Methow River steelhead using Restriction Site Associated DNA Sequencing (RADSeq).
3. Characterize epigenetic and gene expression variation in juveniles reared in experimental 'natural' and 'hatchery' settings.

Accomplishments

1. Characterized genetic and epigenetic variation in the genome of natural and hatchery origin adult steelhead: Methow River natural and hatchery origin adult steelhead spawning in spring 2014 were collected for genetic (RADSeq) and epigenetic analysis (RRBS). Genetic analysis using RADSeq did not reveal differences between the Methow River hatchery and natural fish, however, significant differences in epigenetic programming in both somatic (RBCs) and germ cells (sperm) were identified. Using RRBS, we generated the first genome-wide characterization of somatic cell and germline derived DNA methylomes in a salmonid fish, from which we identified both cell type specific and origin specific methylation. Because hatchery fish experience similar environmental conditions as their wild conspecifics once they leave the hatchery, our results raise the possibility that these DNA methylation changes occurred during the first year in the hatchery and persisted into adulthood in the form of an 'epigenetic memory' of the hatchery environment. This work provides the first evidence that epigenetic mechanisms may serve as a link between hatchery rearing and adult phenotype in steelhead. A manuscript has been drafted for publication and submission is expected in May of 2016. In addition, in March of 2016, Mackenzie Gavery, the UW postdoctoral associate on the project, presented these data at the Northwest Fisheries Science Center (NWFSC) Monster Jam Seminar Series.
2. Initiated characterization of genetic variation in the genome of natural and hatchery origin adult steelhead collected in 2015: Methow River natural and hatchery origin adult steelhead spawning in spring 2015 (144 samples) were collected and genetic analysis was conducted using RADSeq. We expect this analysis to be completed by Summer 2016. These data will be incorporated with the 2014 dataset to provide a more complete picture of the genetic variation in this system.
3. Initiated characterization of gene expression patterns in olfactory rosettes of juvenile steelhead raised in experimental 'hatchery' and 'natural' environments: Olfactory rosettes were dissected from 20 fish (n=10 per treatment). Ribonucleic acid (RNA) was isolated from a single olfactory rosette per fish (the paired rosette is being stored for future DNA isolation and RRBS analysis). RNA-Seq libraries were generated and sequenced. Bioinformatics processing and data analyses for differential gene expression are being conducted by a UW bioinformatics technician and postdoctoral associate using a computer cluster at the NWFSC. Analysis is expected to be complete in Summer 2016.

SEAFLOOR PROCESSES

EARTH–OCEAN INTERACTION PROGRAM

PIs

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Other UW Personnel

Ben Larson, Kevin K. Roe, and Nathaniel Buck – Joint Institute for the Study of the Atmosphere and Ocean
Marvin D. Lilley, John Baross, Eric Olson, James Murray, Pamela Barrett, and Susanna Michael – School of Oceanography
Visiting Scientist – Hu Wang, Tongji University

Task II

NOAA Sponsor

James Shambaugh – Pacific Marine Environmental Laboratory

Other NOAA Personnel

Jeremy Mathis, Chris Sabine, Stephen Hammond, Robert Embley, William Lavelle, John Lupton, and Sharon Walker – Pacific Marine Environmental Laboratory

NOAA Goals

Healthy Oceans

Description

Physical and chemical interactions between the oceans and solid earth, and the ecological effects of those interactions are of great interest to scientists in the College of the Environment at the University of Washington and at the Pacific Marine Environmental Laboratory (PMEL). More than 70% of the volcanic activity on Earth occurs below the ocean surface, with significant implications for ocean chemistry and ecology. Research within the Earth-Ocean Interaction (EOI) group is focused on understanding and quantifying the impact of submarine volcanism on ocean ecosystems. The approach includes global exploration and mapping, mineral and biological resource discovery and characterization, and detailed studies of physical, chemical, and biological processes from the sub-seafloor up into the ocean water column. By addressing ocean acidification, global biogeochemical cycles, microbial ecology, technology development, long-term ocean observations, and resource discovery, the EOI group conducts scientific studies that address NOAA strategic goals and are important to society and a broad scientific community.

Objectives

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

deposition to the ocean, exchange at active ocean margins, and submarine volcanic and hydrothermal activity.

Accomplishments

Objective 1 – Accomplishments in Exploration:
The EOI program studies submarine volcanic and hydrothermal systems and their impacts on ocean chemistry and ecosystems through multi-year projects funded by NOAA Ocean Exploration, NOAA-PMEL, the National Science Foundation, and private entities. This year we highlight the Mariana Arc and Back Arc and the Southern Ocean.

Mariana Arc and Back Arc – The submarine volcanic and hydrothermal systems of the Mariana Arc have been studied by EOI since 2003, and our work there influenced the creation and definition of the Mariana Trench Marine National Monument. We have recently expanded our focus to include the Mariana Back Arc. From November 20 – December 17, 2015 the EOI program participated in the Hydrothermal Hunt on the Mariana Back Arc cruise aboard the Schmidt Ocean Institute R/V *Falkor* (Cruise # FK15112, Chief Scientist Joseph A. Resing, PIs David A. Butterfield and Edward T. Baker, Technical Support Nathaniel Buck, students Pamela Barrett and Susanna Michael, and Visiting Scientist Hu Wang). This expedition on R/V *Falkor* systematically explored 600 km of the southern Mariana Back Arc for the first time, roughly from 13°N to 18.5°N. We made 12 tow-yos and seven vertical casts with our hydrothermal CTD (conductivity, temperature and depth) to search for hydrothermal plumes along the axis of the deep back-arc spreading center (3000-5000 m). We also made 17 trace metal CTD casts (<1000 m) on and off the back-arc axis to look for hydrothermal effluent coming from the shallower Mariana Arc, located further to the east. This work is aimed at understanding the potential sources and contribution of hydrothermal iron to the Pacific Ocean basin. In addition, we made seven dives with our autonomous underwater vehicle, AUV Sentry. The first two Sentry dives (364 & 365) surveyed the water column for plumes to supplement the CTD work, and the last five dives (365-370) focused on collecting high-resolution multibeam bathymetry of the seafloor. Two of the Sentry dives (367 & 370) also made photographic surveys of the seafloor.

The remarkably successful 2015 expedition discovered four new hydrothermal vent fields in the Mariana Back Arc, more than doubling the number of known hydrothermal sites in the region from three to seven. One newly discovered vent site is one of the deepest ever found - at a depth of 4230 m. There are nearly 700 known vents around the world, and only three are deeper. Another

Figure 1. To be able to conduct studies of the trace nutrient Fe in the ocean requires specialized "metal–free" sampling equipment. In 2015 the NOAA's Ocean Exploration program funded the acquisition of a trace metal rosette sampling package (left) that is outfitted with specialized sampling bottles; the individual bottles have multi–colored shower caps on them to prevent contamination. When this package returns to the surface, the bottles are transported to a clean area for subsampling. Above is the clean bubble fabricated for this purpose on board the R/V *Falkor*.

remarkable and surprising discovery was finding a newly erupted lava flow on the back-arc axis that was still cooling and likely only a few months old. This eruption occurred between a February 2013 multibeam sonar survey by R/V *Melville* and our December 2015 multibeam resurvey on *Falkor*. The 24,050 km2 of high-quality multibeam bathymetry data collected with *Falkor*'s EM302 sonar system is another important product from the 2015 expedition. The preliminary results were presented at the Ocean Sciences Meeting in New Orleans in February 2016.

The December 2015 expedition was the first in a two-part project to locate and explore new vent sites. The second cruise will be conducted on R/V *Falkor* in the fall of 2016, using the Schmidt Ocean Institute's new 4500-m rated ROV (remotely operated underwater vehicle) to visually explore, sample, and characterize the geology, chemistry, and biology of new vent sites on the seafloor. The data from the 2015 expedition resulted in ROV dive plans for the NOAA *Okeanos Explorer* for May of 2016, and have set the stage for success in the 2016 *Falkor* ROV expedition. The combined results will have a big impact in the context of our larger science goals in the Mariana region, and will help test the idea that arc and back-arc hydrothermal sites have distinct ecosystems, controlled by differences in fluid chemistry between arc and back-arc geological settings.

Southern Ocean exploration – The Australian-Antarctic Ridge (AAR) is one of the largest unexplored regions of the global mid-ocean ridge system. As discussed under Objective 4, the mid-ocean ridges in the Southern Ocean provide a significant portion of the iron from the global mid-ocean ridge system that ultimately reaches the surface ocean as discussed in Resing et al., (2015). In 2013, we used the Korean icebreaker Araon to explore for hydrothermal activity along two first-order ridge segments on the AAR. These segments – KR1 and KR2 – lie between 151°E, 60°S and 161°E, 62°S, one of the most southerly portions of the Circum-Antarctic ridges. We found abundant active venting on the shallowest portions of both segments. The chemistry of the venting fluids on KR1 is similar to that found on other intermediate-rate spreading ridges. The presence of yeti crabs in this ridge raises the possibility that all southern ocean ridges might be biogeographically connected. A paper reporting the results (Hahm et al., 2015) was published.

We continue to have exploration interest in the region of the Lau Basin. In 2016, we collaborated with French colleagues on extensive hydrothermal activity north of our previous study sites in the Lau region near Wallis and Futuna islands. The hydrothermal plumes found here are extensive, indicating pervasive submarine hydrothermal activities. A manuscript was submitted and is now in revision.

Objective 2 – Accomplishments in Ecosystem Studies:
There was significant progress in the study of ecological processes on submarine volcanoes in the past year. Axial Seamount erupted again in late April of 2015, just one day after a workshop held in Seattle to discuss how the new cabled underwater observatory can increase the scientific understanding of this deep-sea volcano. With well-documented eruptions in 1998, 2011, and 2015, we are now starting to see some patterns in the evolution of hydrothermal chemistry over eruptive cycles, and making connections to how changing chemistry affects the microbial ecosystem (Stewart et al., 2016, Topcuoglu et al., 2016). The most recent volcanic eruptions at Axial have all been on the south rift zone, with an apparent eruption interval of 10 to 15 years, but the 2015 eruption occurred primarily on the north rift zone just four years after the previous eruption, showing that Axial Seamount is both extremely active and less predictable than our limited monitoring experience would suggest.

As part of our efforts to understand how microbial ecosystems function, we developed a new deep-sea incubator capable of growing high-temperature microbes at *in situ* temperature and pressure. This unique new instrument, (developed by JISAO scientists Butterfield and Ben Larson, PMEL engineer Noah Lawrence-Slavas, and microbiology colleagues Julie Huber and Jim Holden) utilized the technique of *in situ* Stable Isotope Probing (SIP), whereby 13C-labeled bicarbonate is incorporated into an actively growing microbial community, preserved *in*

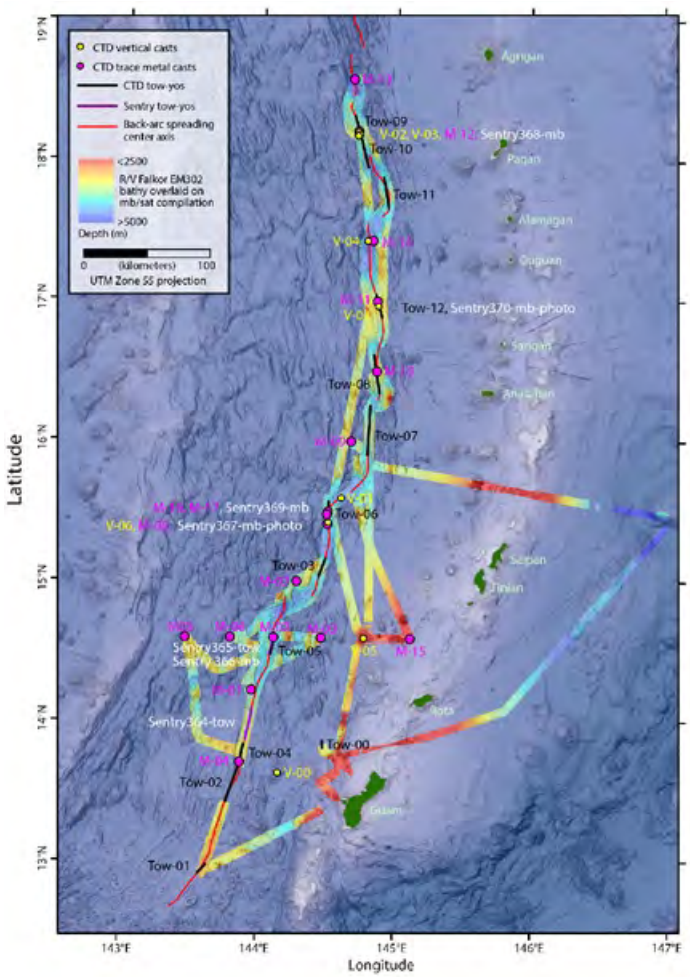


Figure 2. Field Operations during the Hydrothermal Hunt in the Mariana cruise aboard the Schmidt Ocean Institute's RV *Falkor.*

situ, followed by sequencing of the isolated, isotopically enriched RNA (ribonucleic acid) fraction. The SIP technique is new and has never been attempted on the seafloor. The successful deployment of the *in situ* incubator in 2015 is a significant technical achievement, and the initial results are being analyzed for publication.

Larson has been pursuing numerical modeling of coupled reaction and transport by hydrothermal fluids, and investigating the role of sub-seafloor mixing on microbial habitability (Larson et al., 2015b, Lowell et al., 2015). Ongoing work includes combining reaction kinetics with equilibrium thermodynamic calculations to understand the time-scale of sub-seafloor fluid transport and incorporating recent microbial reaction rates determined by our colleague Holden to understand how much of the available chemical energy can be harnessed by sub-seafloor microbes, and how much their metabolic reactions may alter the chemical output of hydrothermal systems. Other ongoing work includes detailed studies of the formation of hydrothermal mineral deposits (Jamieson et al., 2015) and the potential connection between the mineralogy of mineral deposits and the microbial communities that inhabit them (Lin et al., 2016).

Objective 3 – Accomplishments in Ocean Acidification:
The long-term increase in atmospheric carbon dioxide and the consequent increased CO_2 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 CO_2 and lower pH? Which species will survive, and which will perish? The EOI group has promoted the concept of using shallow volcanic CO_2 venting sites to study communities chronically exposed to low-pH conditions in the natural environment.

During the May 2014 expedition to Maug to investigate the effects of shallow hydrothermal venting on a coral reef, a videographer (Stephani Gordon) shot many hours of underwater video and conducted interviews of the scientists involved. In March of 2016, South Florida Public TV station WPBT sent Stephani to Seattle to interview Butterfield for a television program being produced for their Changing Seas series (www.changingseas.tv/). The show is expected to be broadcast in 2016.

In 2015 and 2016, Resing and Baker worked with Spanish colleagues to examine acidification in the Canary Islands caused by shallow CO_2–rich venting on the flanks of the island of El Heirro. We found an area of extensive

venting and calculated a flux of CO_2 to the ocean that represents about 0.1% of the total emissions from submarine volcanoes (see Santana-Casiano et al., 2016).

Objective 4 – Accomplishment on the impact of chemical exchange between solid earth and the oceans:
The chemical composition of the oceans is altered by the interaction between the solid earth and the ocean. This takes place by a variety of processes including hydrothermal activity, the deposition of aerosols to the surface ocean, and the exchange between the ocean margins and coastal waters. Of particular interest is the impact of these processes on provision of trace metals that act as nutrients to the ocean. Iron and cobalt availability often limit primary productivity, and iron supply (and to a lesser degree cobalt supply) may control the fixation of CO_2 and its export from the atmosphere to the deep ocean and sediments via the export of ocean productivity from the surface ocean. In this section we report on these processes through basin scale surveys in the Atlantic, Pacific, and Indian Oceans.

U.S. GEOTRACES Eastern Pacific Zonal Transect (EPZT) – Hydrothermal venting along mid-ocean ridges exerts an important control on the chemical composition of seawater by serving as a major source for a number of trace elements. We examined dissolved iron, manganese, and aluminum collected during the Geotraces Eastern Pacific Zonal Section. The long-standing paradigm that most dissolved iron discharged by hydrothermal vents is lost from solution close to its source is challenged by our observation of the extraordinary lateral transport of hydrothermal dissolved iron, manganese, and aluminum from the Southern East Pacific Rise > 4000 km westward into the South Pacific Ocean. The dissolved iron exhibits unexpectedly conservative behavior, indicating a much longer lifetime than previously assumed. Global-scale model simulations suggest that some form of stabilization of the hydrothermal iron is required to enable its long-range transport, and indicate that this iron has significant impacts on the oceanic iron budget and on carbon export production in the Southern Ocean where phytoplankton growth is limited by iron supply. These data are reported in a high impact paper in the Journal *Nature* by Resing et al., 2015.

The Resing et al., 2015 effort led to the suggestion that we should expect that ridge crests closer to the Southern Ocean are more important to carbon export than are ones further away. This idea was tested using a global climate model in Tagliabue and Resing (2016; submitted). We found this hypothesis to be true, making further exploration of the Southern Ocean ridge system (as done in Hahm et al., 2015; discussed in Objective 1 above) quite important in understanding the global carbon cycle. Our findings also revealed that ridges south of 40°S in both the Pacific and Southern Ocean are much more important than those in either the Atlantic or Indian Oceans.

In addition to iron, the U.S. Geotraces section revealed that the ocean margins, especially the sediments below oxygen minimum zones, are the primary source of cobalt to the South Pacific Ocean. Cyanobacteria (nitrogen fixing organisms) have an absolute requirement for cobalt, and, additionally, cobalt can partially substitute for zinc in coccolithophores and diatoms when zinc is scarce. Since the majority of cobalt and zinc in diatoms is allocated to carbonic anhydrase free cobalt and zinc are crucial to diatoms' capacity to fix and export carbon thus implicating the importance of cobalt in global carbon fixation and climate regulation. This study is reported in Hawco et al. (2016; in preparation).

North Atlantic Ocean, Trace Metals on the CLIVAR/Repeat Hydrography Section A16N – In 2013 we reoccupied the A16N CLIVAR line through the Atlantic Ocean, collected data on dissolved and particulate iron and aluminum, and compared these data to those collected by us in 2003 (Barrett et al., December, 2015). We estimate that deposition of Saharan dust to surface waters in the eastern North Atlantic increased by approximately 15% between 2003 and 2013, and that increased concentrations of dissolved aluminum in subtropical mode waters suggest that dust deposition may have increased in the western Atlantic as well. Our observations are generally consistent with recent reports linking increasing sea surface temperatures in the tropical North Atlantic to

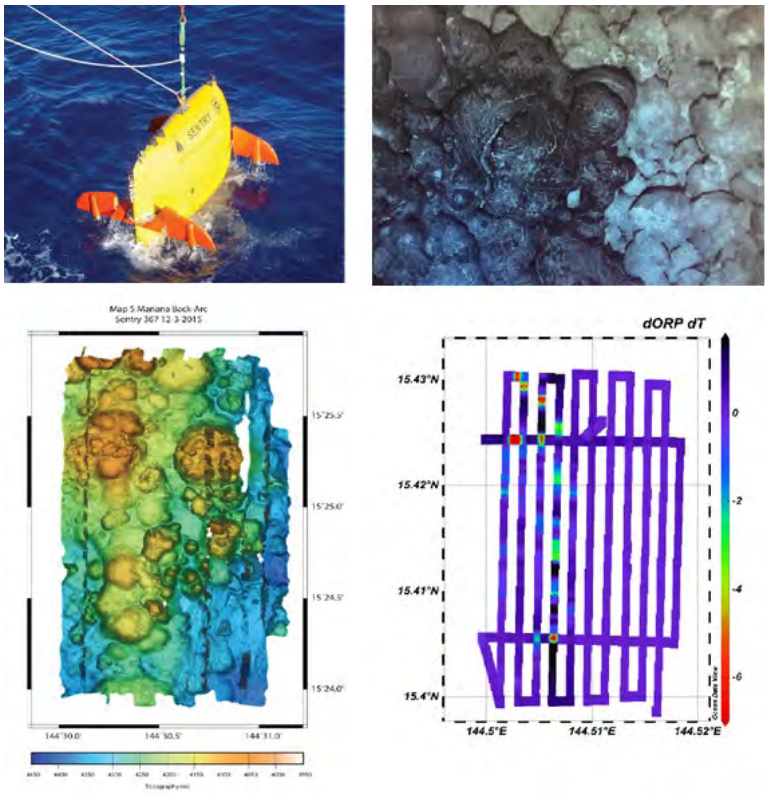


Figure 3. Exploring the Mariana Back Arc using the Sentry AUV Sentry. A. Sentry AUV is suspended from the fantail of the RV *Falkor* during deployment. B. Picture of the seafloor showing fresh black lava overlaying old lava covered with white sediments. C. Bathymetric map made during Sentry dive above area of recent eruption. D. Heat map showing areas where chemically enriched seawater is exiting the seafloor above the fresh lavas.

increased precipitation resulting in enhanced scavenging of dust from atmosphere over the past decades.

Indian Ocean CLIVAR Repeat Hydrography I08, I09, I05, I06 – We examined dissolved and particulate iron and aluminum chemistry in the upper 1000m of the Indian Ocean on four separate basin scale sections. We found that dust deposition, riverine flow, and interactions with sediments at the ocean bottom were important sources of iron and aluminum to the Indian and Southern Oceans. Ultimately, it was the major oceanic currents that were responsible for the distribution of these elements throughout the Indian Ocean. These data revealed strong gradients in particulate silicon and calcium that delineate a major transition in carbon fixing phytoplankton from coccolithophores to diatoms from north to south across the Southern Ocean. The results are reported in Grand et al., 2015 and Barrett et al., 2017, (in preparation).

We continue to examine the impact of submarine volcanic and hydrothermal activities on the biogeochemical cycles in the ocean. As mentioned under Objective 1, during our cruise in November and December 2015, we made 17 trace metal CTD casts (<1000 m) in the shallow waters above the back-arc to determine if hydrothermal effluent coming from the shallower Mariana Arc, located further to the east is transported westward. This work is aimed at understanding the potential sources and contribution of hydrothermal iron to the Pacific Ocean basin. We are particularly curious about how activity along the Mariana Arc, especially how eruptions at Ahyi and Daikoku volcanoes play a role in the providing iron from the volcanic rocks to the shallow ocean waters in this region. Understanding these impacts is a continual focus of our research. Colleague Alessandro Tagliabue(University of Liverpool) and Resing were recently awarded a grant by the Royal Society of London to continue their collaborative work on these impacts. The project is titled "Quantifying global ocean hydrothermal iron inputs" and is vested at the University of Liverpool.

We continue to work on understanding the sources of iron to the Equatorial Undercurrent (EUC). The EUC carries nutrient rich waters eastward to high nutrient low chlorophyll regions in the Eastern Equatorial Pacific. Much is still unknown about the sources of trace nutrients to the EUC, however exchange between the iron-rich solid earth and the iron-poor ocean is clearly implicated. We are investigating whether the Solomon Sea, located north and east of Papua, New Guinea is possibly a source of iron and other trace metals to the EUC. Samples were collected for our lab during a study on board the RV *L'Atlante* in and around the Solomon Sea, which aimed to measure ocean currents and the geochemical makeup of waters within the basin. Different trace elements inform

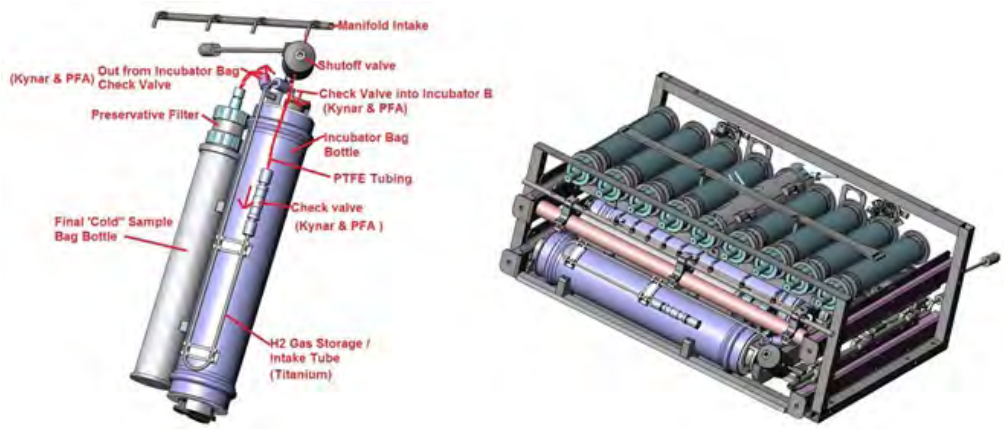


Figure 4. Drawing of a single incubator unit showing (left) the insulated incubation chamber and the secondary sample preservation unit, and (right) the assembled incubation unit with four chambers incorporated into the Hydrothermal Fluid and Particle Sampler for mounting on an ROV.

the distributions and transport of other trace metals in the ocean, most notably iron. We analyzed these samples for aluminum and manganese. We observed that at many stations, aluminum distributions exhibit a sub-surface minimum, located at approximately the same depth as a salinity maximum. Additionally, aluminum is enriched along coastal areas, particularly in the outflow of the Vitiaz Strait, which is concurrent with the findings of Slemons et al., 2010. These regions of high aluminum are also likely regions of iron enrichment. Manganese distributions in the Solomon Sea are remarkably similar to past data, and show a scavenged distribution, with local inputs in the surface and concentrations decreasing at depth. This region has strong western boundary currents that carry the input along the coastal margins from two large rivers, island mining sites, and hydrothermal venting. This area is at the head waters to the EUC, making it an important site to study how trace nutrients are transported to the EUC and ultimately the Eastern Tropical Pacific Ocean. These data were presented by graduate student Susanna Michael at the February Ocean Sciences meeting in New Orleans.

Presentations at National Meetings

1. Resing, J. A., Chadwick, W., Hydrothermal Hunt In the Mariana Team.(2016): Transport of Trace Fe from the Mariana Arc and Hydrothermal Exploration of the Mariana Back Arc Basin, CT24A-0158, 2016 Ocean Sciences Meeting, New Orleans, LA. Poster.

2. Larson, B.I., Xu, G., Lilley M.D., Bemis K.G., Butterfield D.A. (2015) Integrated Data from the NEPTUNE Observatory Highlight the Role of Sub-seafloor Processes in Rapid Temperature, Salinity, and Heat spiking after Seismic Activity., Abstract OS43A-1994 presented at 2015 Fall Meeting, AGU, San Francisco, Calif., 14-18 Dec.

3. Michael, S.M., Resing, J.A., Jeandel, C., Lacan, F.. (2016) Aluminum and Manganese Distributions in the Solomon Sea: Results from the 2012 PANDORA Cruise, CT34B-0188: 2016 Ocean Sciences Meeting, New Orleans, LA.

4. Summers, B.A., Morton, P.L., Buck, N.J., Landing, W.M., Buck, C.S., Barrett, P.M., Resing, J.A.. (2016)Supply of Natural and Industrial Aerosols to the Indian Ocean, CT14A-0116: 2016 Ocean Sciences Meeting, New Orleans, LA.

5. Crusius, J., Schroth, A. W., Campbell, R. W., Gasso, S., Resing, J., Cullen, .T. (2016) Iron sources to the Fe-poor northern Gulf of Alaska: insights from water column and atmospheric dust time series, EC52A-02: Ocean Sciences Meeting, New Orleans, LA

6. Rachel Weisend, Morton, P.L., Barrett,P.M., Buck,N.J., Resing, J.A., Landing, W.M. (2016) Elemental Ratios of

Bioactive Trace Metals in the Bay of Bengal, CT24A-0154: 2016 Ocean Sciences Meeting, New Orleans, LA.

7. Michael, S.M., Resing, J.A., Jeandel, C., Lacan, F.. (2016) Aluminum and Manganese Distributions in the Solomon Sea: Results from the 2012 PANDORA Cruise, CT34B-0188: 2016 Ocean Sciences Meeting, New Orleans, LA.

8. Barrett, P.M., Resing, J.A., Nelson,B.K., Morton, P.L., Shelley, R., Landing, W.M..(2016)Isotopic composition of dissolved and particulate Cu in the North Atlantic: Constraining the atmospheric deposition of aerosol Cu, CT14B-0132: 2016 Ocean Sciences Meeting, New Orleans, LA.Presentations

Outreach and General Presentations

1. July 29, 2015: One-NOAA Science Seminars, Washington DC. Basin Scale Transport of Hydrothermal Iron, Manganese, and Aluminum across the Eastern South Pacific Ocean

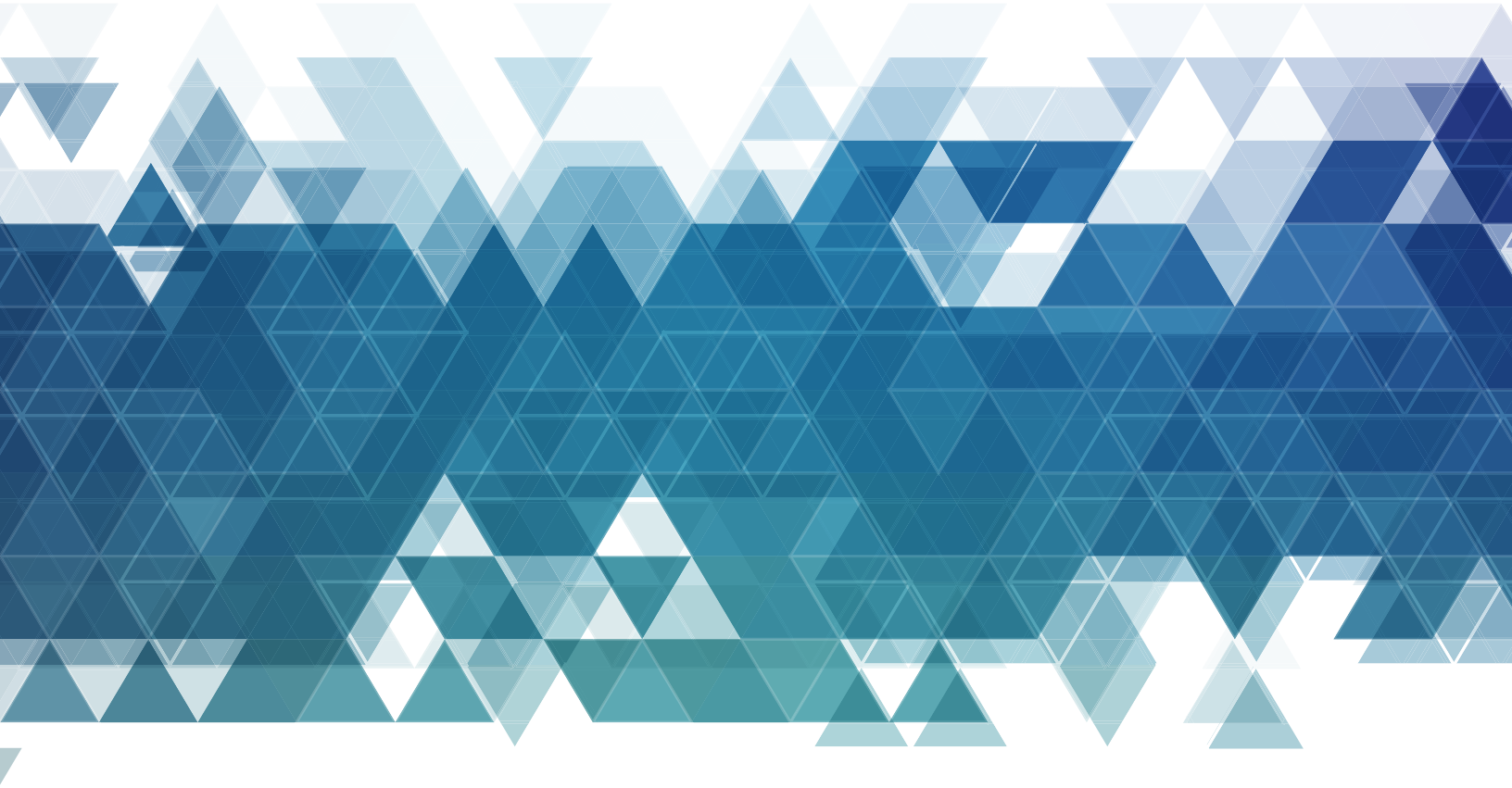
2. September 23, 2015: University of Washington, Chemical Oceanography lunch Seminar: Basin Scale Transport of Hydrothermal Iron, Manganese, and Aluminum across the Eastern South Pacific Ocean

3. January 14, 2016: Presentation to two AP-Environmental Science Classes, York HS, Elmhurst, IL. Exploring the Ocean for Volcanic and Hydrothermal Activity

4. January 15, 2016: Presentation to multiple Science Classes, Homewood-Flossmoor HS, Flossmoor, IL. Exploring the Ocean for Volcanic and Hydrothermal Activity Workshops

5. November 2015: Geotraces Eastern Pacific Zonal Transect-Data Workshop, Catalina Island

TSUNAMI OBSERVATIONS AND MODELING



TSUNAMI RESEARCH

PI
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Other UW Personnel
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Task III

NOAA Sponsor
James Shambaugh – Pacific Marine Environmental Laboratory

Other NOAA Personnel
Vasily Titov, Marie Eble, Nancy Soreide, and Christopher Moore – Pacific Marine Environmental Laboratory

NOAA Goals
Weather-Ready Nation
Resilient Coastal Communities and Economies

Description
NOAA bears a national responsibility to address issues of public safety and economic costs associated with extreme weather and ocean hazards and, in particular, to "Increase Lead Time and Accuracy for Weather and Water Forecasts." Tsunami waves, having the potential for devastating effects, can in many cases be detected well in advance of coastal impact, and clearly fall within that mandate. Following the horrific Indian Ocean tsunami of December 2004, the U.S. Congress passed the Tsunami Education and Warning Act which identifies four activities – tsunami forecast and warnings, mitigation, research, and international coordination – 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 UW Joint Institute for the Study of the Atmosphere and Ocean (JISAO) scientists in the Tsunami Research Program. NCTR is comprised mainly of JISAO scientists. Basic research into tsunami generation, and numerical modeling of propagation and inundation provide the basis for forecasting, and the SIFT (Short-term Inundation Forecasting for Tsunamis) tool, developed at NCTR, is employed at NOAA's Tsunami Warning Centers, which have the operational responsibility for disseminating timely warnings. Input to the forecast system is provided by an array of bottom pressure recorders in the Pacific, Atlantic, and Indian oceans, which detect and report in real time the passage of a tsunami wave. The instruments, called DART®s (Deep-ocean Assessment and Reporting of Tsunamis – developed at PMEL) are deployed and serviced by the National Data Buoy Center. Array studies, conducted at NCTR, assist in the choice of the optimal locations for the DART® buoys and assessment of the impact of instrument outages.

Other aspects of NOAA's tsunami-related activities include the National Tsunami Hazard Mitigation Program (NTHMP), 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.

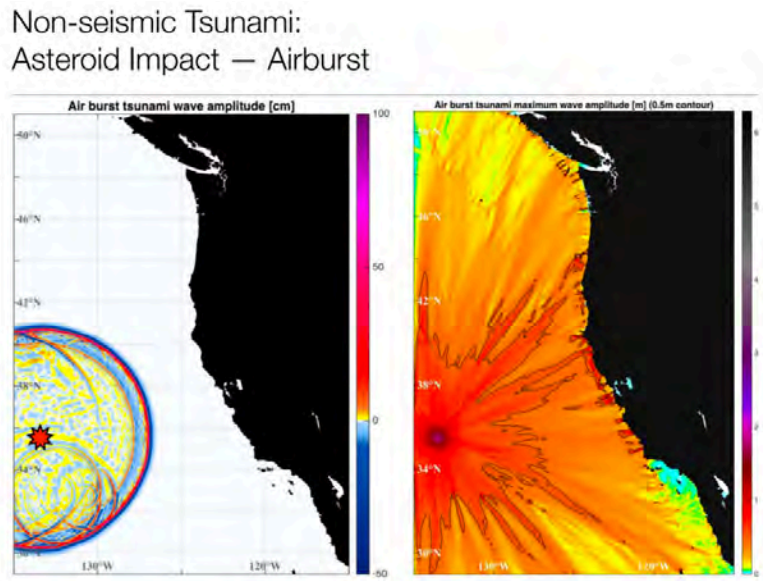


Figure 1. Wave front from an asteroid exploding at 12km high altitude with 5MT force. The left panel shows ocean surface disturbance induced by the shock wave. The right panel shows maximum tsunami elevation impacting the U.S. West Coast.

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. Development of the SIFT software continued, and has been primarily focused on correcting minor glitches in previous versions and enhancing the SIFT's functionality with added capabilities.
   a. Version 3.2.4 of the tsunami forecast software SIFT has been installed at the National Weather Service Tsunami Warning Centers. This new version features a number of bug fixes from previous versions.
   b. The capability to ingest data from non-DART ocean observing systems has been added to SIFT. In particular, data from the Canadian NEPTUNE network is currently being ingested into the software and can be used for tsunami source inversion.
   c. A feature to graphically visualize tsunami currents in the site-specific tsunami forecast models has been included in the software.

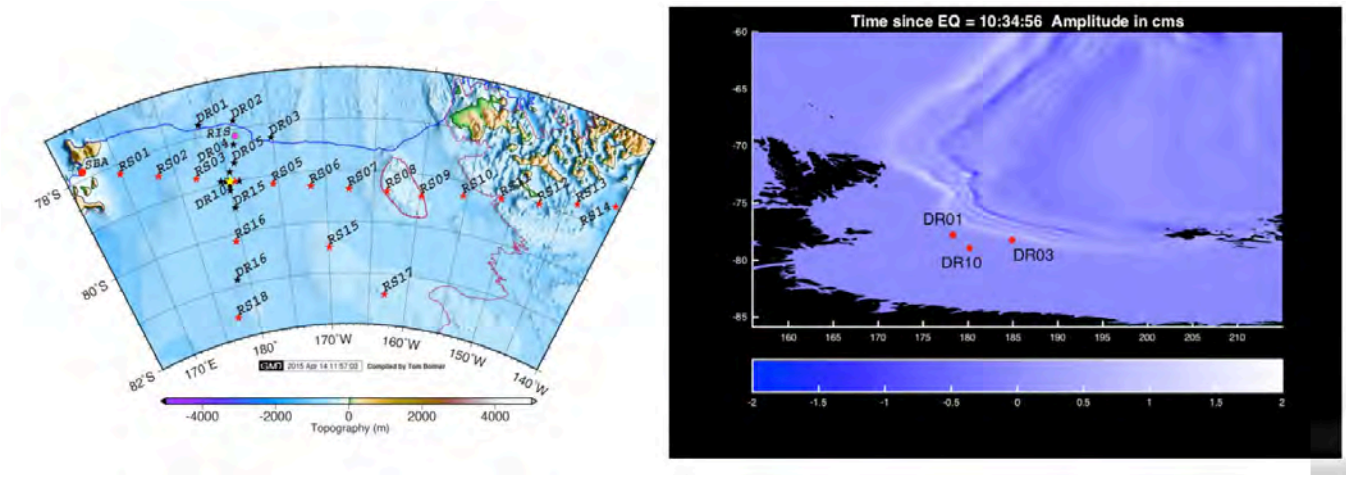


Figure 2. Location of observational instruments on the Antarctic ice shelf in the Ross Sea (Left Panel). Image from a computer simulation of the September 16, 2015 tsunami on impact with the Ross Sea ice shelf (Right Panel).

d. Two new site-specific tsunami forecast models are being developed for future inclusion in the SIFT system: Galapagos Islands and Barbers Point, Hawaii.

e. The ability to trigger the computation of tsunami forecast models at the National Center for Environmental Prediction (NCEP) directly from SIFT is being implemented.

f. A new feature is being added that will allow visualization of forecast results corrected for the local state of the tide.

g. Ingestion and display of real-time tide gauge data for both comparison with forecast and for use in tsunami source inversion will be added in the near future.

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

   a. In collaboration with the Washington State Emergency Management Division, two tsunami hazard assessments in the Puget Sound and Salish Sea area are being developed for the localities of Anacortes and Bellingham. This new hazard assessment will evaluate the exposure of both communities to a tsunami generated by a large seismic event along the Cascadia subduction zone. This project is expected to continue into fiscal year 2017 with the development of similar studies for communities along the Hood Canal and the Kitsap Peninsula. A proposal to fund the second stage of the project has been submitted to NTHMP for evaluation.

   b. NCTR has been actively engaged with the U.S. Coast Guard to address tsunami hazard issues in Washington State of particular relevance to the Coast Guard after a large Cascadia mega-thrust seismic event. NCTR has also been collaborating with the Federal Emergency Management Agency by providing information for a large emergency exercise addressing a Cascadia seismic event (Cascadia Rising).

   c. NCTR is nearing the completion of a nuclear regulatory document that will regulate tsunami hazard assessment studies for nuclear power plants in the U.S. A final version of the report has been submitted to the Nuclear Regulatory Commission.

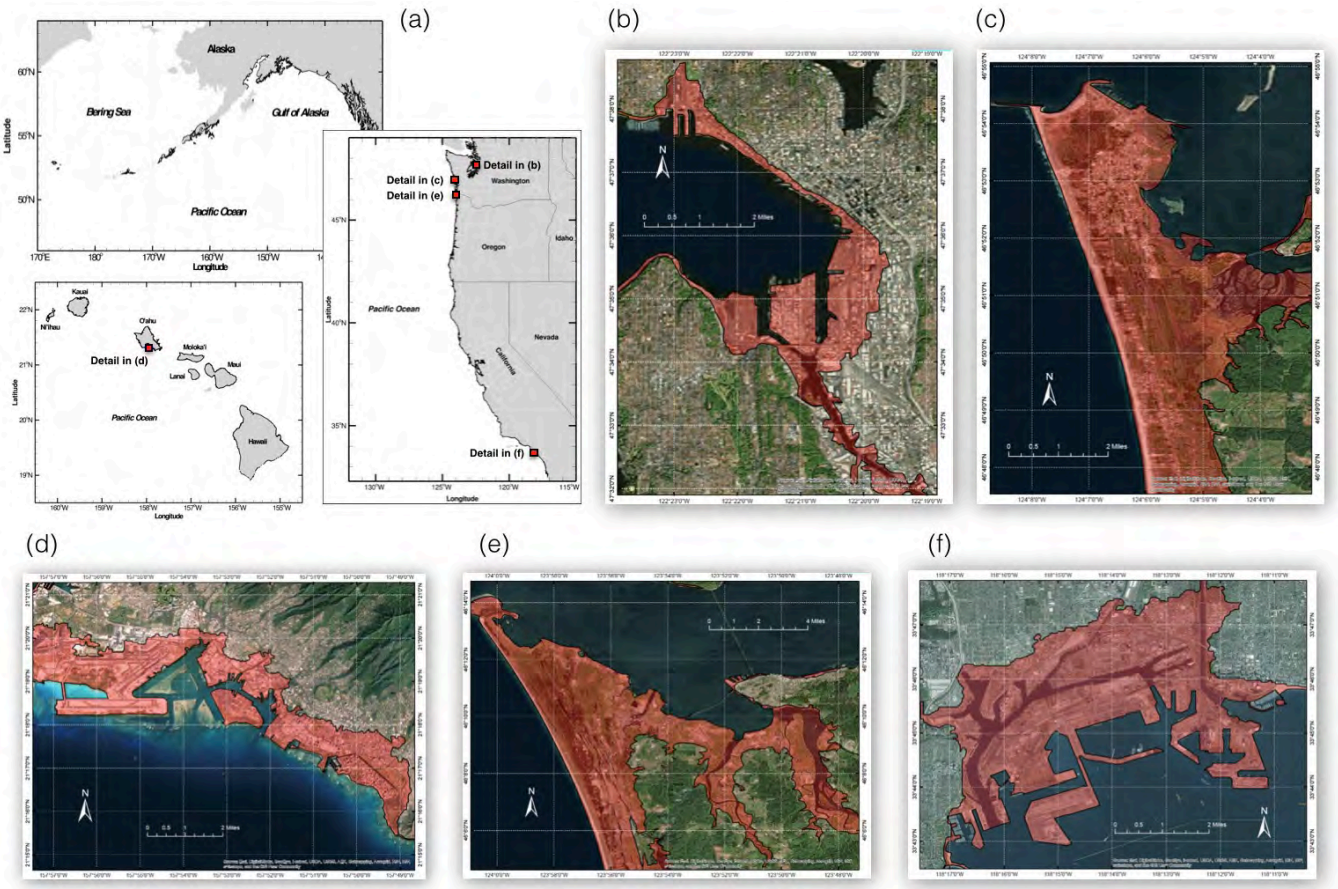


Figure 3. Probabilistic Tsunami Design Zone (TDZ) maps developed for the new tsunami design chapter of ASCE 7–2016 standard. A TDZ map designates the potential horizontal inundation limit of the maximum considered tsunami, or a state or local jurisdiction's probabilistic map produced in accordance with the ASCE 7–2016 provisions (a) Coverage of the TDZ maps in Alaska, California, Hawaii, Oregon and Washington, where the heavy, solid line indicates the coastlines that a TDZ map has been developed for, (b) Sample TDZ for the Port of Seattle, Washington, (c) Sample TDZ for West Port, Washington, (d) Sample TDZ for Honolulu, Hawaii, (e) Sample TDZ for Warrenton, Oregon, (f) Sample TDZ for the Port of Los Angeles.

3. The online tsunami forecasting capabilities project has been focused on implementing operational uses of the online Tsunami Forecast tool – T-web – and related systems during the current reporting period.

   a. The operational deployment of tsunami forecast models running at the NOAA NCEP computing facility was completed. T-web provides the stand-in launch client, allowing the Tsunami Warning Centers to run Inundation Forecast models at NCEP.

   b. We are currently working on the operational installation of the T-web View-Only component to be installed at NCEP for the display and dissemination of tsunami warning and forecast information to emergency personnel.

   c. T-web was again used for several tsunami preparedness and simulation exercises for Caribbean and Pacific emergency personnel.

   d. There is ongoing collaborative research into providing tsunami forecast results to international collaborators.

4. Collaboration between NCTR and the United Nations Educational, Scientific and Cultural Organization's (UNESCO's) International Tsunami Information Center has crystalized in the Tsunami Evacuation Maps, Plans and Procedures (TEMPP) project. Within the framework of this project two ComMIT (Community Modeling Interface for Tsunamis) workshops have been offered in Tegucigalpa, Honduras. The first of these two was focused on the use of ComMIT as a modeling tool. The second one was focused on the creation of inundation maps as a previous step to the generation of tsunami evacuation maps by the host country.

5. The collaboration with the University of Málaga has continued over the current reporting period. The GPU version of the tsunami inundation code generated last year underwent a thorough testing process and some glitches that surfaced were resolved. A new version of the GPU tsunami propagation code was further parallelized to run on multiple GPUs simultaneously. This version is capable of providing a Pacific-wide solution in under a minute using eight GPUs. This capability is fundamental for SIFT to provide basin-wide estimates of arbitrary tsunami sources.

6. NCTR has been actively working with NASA on two fronts:

   a. To address the problem of tsunamis generated by asteroid impact. A NOAA/NASA workshop in the summer of 2016 at NCTR is being organized.

   b. To investigate the use of the Global Navigation Satellite System via GPS to assist in the inversion of the tsunami sources in real time.

7. NCTR has been collaborating with the Scripps Institution of Oceanography to help identify the connection between tsunami impact along the Ross Sea ice shelf in Antarctica and the occurrence of fracture events in the ice shelf. The possibility of securing funding to guarantee further investigation along this line will be pursued in upcoming months.

8. NCTR has worked closely with the American Society of Civil Engineers (ASCE) to help develop Chapter 6 in ASCE 7-16 standards. Chapter 6 provides the first comprehensive tsunami design provisions in the world and represents the state-of-the-art tsunami design knowledge presented in enforceable code language.

9. Two large tsunami events have occurred during the present reporting period in Chile on September 16, 2015, and in the Indian Ocean on March 2, 2016. NCTR has continued to analyze and validate NCTR's forecast tools and methodology with both events. Comparative experimental forecasts are published online.

10. One additional training workshop using the ComMIT software, in addition to the ones already mentioned for the TEMPP project, was conducted during the current reporting period in Honolulu, Hawaii. The next ComMIT workshop is planned to take place in the Caribbean (TBD) during the summer of 2016.

EVALUATION OF SENSOR NETWORKS FOR DETECTING AND FORECASTING TSUNAMIS

PI

Donald B. Percival – UW Applied Physics Laboratory

Task III

NOAA Sponsor

James Shambaugh – Pacific Marine Environmental Laboratory

NOAA Goals

Weather-Ready Nation

Description

NOAA's Tsunami Warning Centers use data collected in near-real time to detect tsunamis and then to predict their impact at U.S. coastal communities. The data are collected by a network of sensors consisting primarily of Deep-ocean Assessment and Reporting of Tsunamis (DART) buoys placed at strategic locations in the open ocean, and of tidal gauges in coastal regions. The effectiveness of any particular network (existing or under consideration) depends upon many factors including the reliability and geographical location of the various sensors, the location of the potential tsunami sources, and the location of the coastal communities. To sensibly manage the network, there is a need to evaluate the effectiveness of an existing network, particularly with respect to proposed or unforeseen changes in the network. The task at hand is to look at statistical methods for evaluating the overall effectiveness of a given network in terms of providing accurate and timely predictions of coastal inundations. The first step in this task is to define metrics to quantify how well a particular network can predict inundations at a particular location if all the sensors in the network are fully functional. The second step is to consider how to adjust these metrics to take into account the historical reliability of the sensors in the network (i.e., to quantify the expected degradation due to sensors being unavailable during a tsunami event). The third step is to investigate ways to integrate the metrics for particular locations into an overall metric that summarizes the overall effectiveness of the network of sensors. The fourth step is to consider how the performance of an existing network of sensors will change when the network of sensors is changed (e.g., by upgrading equipment at an existing sensor location, by moving a sensor to a different location, or by adding or removing a sensor altogether).

Objectives

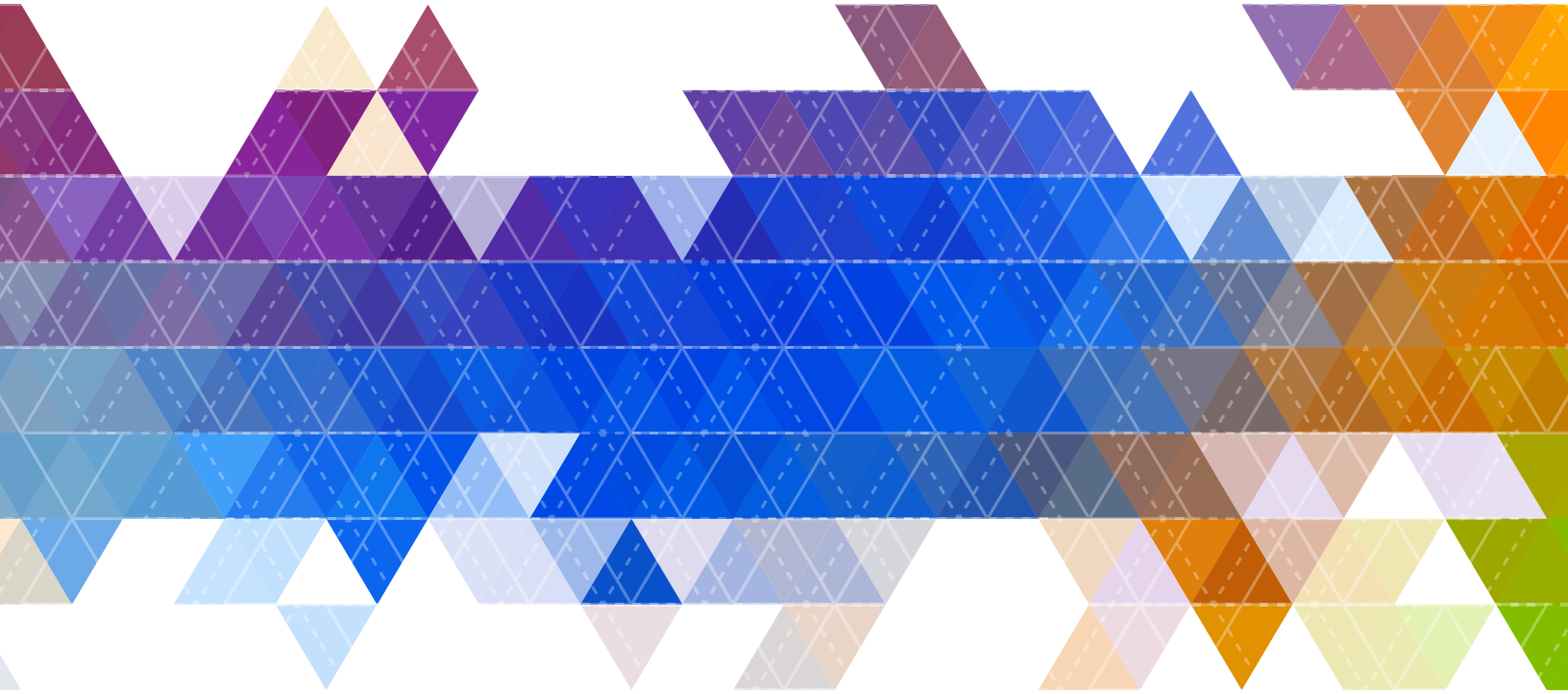
1. To define metrics to quantify effectiveness of particular sensors in a network.
2. To adjust metrics to take into account reliability of sensors.
3. To integrate metrics to provide overall evaluation of network of sensors.
4. To investigate how changes in the network alter its overall performance rating.

Accomplishments

The scientists have developed a performance measure for the DART tsunami buoy network in a given ocean based on a statistical analysis of how well simulated data from each buoy leads to accurate forecasts of maximum wave heights in the open ocean outside of impact sites, and how much the forecasts are degraded in accuracy when one or more of the buoys becomes inoperative. The analysis uses simulated tsunami time series (the signal) with known – but randomly generated – source coefficients that describe what would be seen – under noise-free conditions – at various deep ocean locations due to an M4.0 earthquake originating from within a unit source (rectangular

region) near a subduction zone (SZ). Some of the deep ocean locations correspond to locations of DART buoys, while others, to locations outside of impact sites. The simulated signals are linear combinations of predictions stored in a precomputed database used by the SIFT application (Short-term Inundation Forecast for Tsunamis). Sets consisting of 1,000 noisy time series were constructed for each unit source/buoy pair by the addition of real oceanic noise recorded at the buoy under ambient conditions to the simulated tsunami time series. The noisy time series were used to estimate the source coefficients through constrained least squares with terms in the corresponding regression model both for the tsunami signal and for the tidal component. Errors in the estimated source coefficients are induced by uncertainties in the source location specifying the signal, by addition of real oceanic noise and by imperfect tidal removal due to a simplistic tidal model. The estimated source coefficients are then used to forecast the maximum wave height in the open ocean outside of an impact site for comparison with the error-free standard. The results for the 1,000 noisy time series are summarized by root mean square errors (RMSEs), with one RMSE for each triad consisting of a unit source, a DART buoy and an impact site. The RMSEs quantify which buoy provides the best forecast (lowest RMSE) for various unit sources within an SZ under a warning-time constraint for the forecasts of 30 minutes and 3 hours for local and distant impact sites, respectively. The analysis also shows how the forecasts are degraded (larger minimum RMSE among the remaining buoys) when 1, 2, or 3 buoys in the region become inoperative. Examples of the performance measure are presented in a forthcoming paper (to be submitted to the journal *Natural Hazards* and tentatively titled "Evaluating Effectiveness of DART Buoy Networks") for buoys off the Aleutian-Alaskan SZ, for Hilo, Hawaii, and two U.S. West Coast impact sites (Crescent City, California and Port San Luis California), and also for those off the Chile-Peru SZ for local Chilean sites, islands, and Gisborne, New Zealand. The status of the overall network (e.g., coded green, yellow or red) is the aggregate over the network in its ability to deliver accurate forecasts. The measure also provides a tool for ongoing array design such as moving buoys to more optimal locations and assessing the urgency of buoy repair.

APPENDICES



APPENDIX 1

JISAO Senior Fellows and Council Members*

University of Washington:

*Ackerman, Thomas, Professor, Atmospheric Sciences, Executive Director, JISAO
Armstrong, David, Professor, Aquatic and Fishery Sciences
Baker, Edward T., Senior Research Scientist, Affiliate Professor, Oceanography
Bates, Timothy S., Senior Research Scientist, Affiliate Associate Professor, Oceanography
Battisti, David S., Professor, Atmospheric Sciences
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, Carolyn, 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, Interdisciplinary Arts & Sciences and Atmospheric Sciences
McDuff, Russell, Professor, Oceanography
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 Pacific Marine Environmental Laboratory:

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

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

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

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

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

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

*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, NOAA Center for Tsunami Research, Affiliate Assistant Professor, Earth and Space Sciences

*2014-2015 Council Members

APPENDIX 2

JISAO Funded Events and Visiting Scientists

Funded Events

May 5 – 9, 2015
Dr. Lynn Russell
UC San Diego Scripps Institution of Oceanography, Atmospheric Aerosol Group, Professor
Sea spray/Southern Ocean and related modeling meeting at NOAA PMEL with Tom Ackerman, Tim Bates, Robert Wood, Patricia Quinn and others

June 16 – 21, 2015
Alexander Beaton
Researcher and technology developer
National Oceanography Center (NOC), Southampton, UK
Innovative Technology for Arctic Exploration Project collaborator
Speaker at NOAA PMEL on "Lab-on-a-Chip" technology and calibration and installation of technology for Arctic AUV

August 14 – 31, 2015
Dr. Chris Algar
Dalhousie University Department of Oceanography, Assistant Professor
Dr. David Butterfield collaborator on the Moore Foundation Marine Microbiology Initiative research expedition aboard the R/V *Thompson* out of Seattle, WA

February 7 – 13, 2016
Mariona Claret Cortes
McGill University Earth System Dynamics, Postdoctoral Researcher
Collaborate with Drs. Rolf Sonnerup and Paul Quay

Visiting Scientists

April 1 – December 31, 2016
Dr. Hu Wang
Visiting Scientist, Tonji University, China

APPENDIX 3

NOAA Cooperative Agreement Awards Funded in 2015–2016

Task #	Principal Investigator	Department	Title	Award Amount
I	Ackerman, Thomas	JISAO	JISAO Task I	$401,442
I	Punt, Andre	SAFS	Bevan Lecture Series	$20,000
I/II	Ackerman, Thomas	JISAO	Joint Institute for the Study of the Atmosphere and Ocean--Task II PMEL	$8,000,792
II	Arcas, Diego	JISAO	Tsunami Research	$1,299,729
II	Bond, Nicholas	JISAO	Alaska Fisheries Science Center Internship Opportunities	$27,604
II	Bond, Nicholas	JISAO	Assessment and Ecology Program: Understanding Cetacean Distribution in Alaskan Waters in Relation to the Impacts of Climate Change and Anthropogenic Activities	$1,112,331
II	Bond, Nicholas	JISAO	Ecology of Seals in the Arctic	$397,752
II	Bond, Nicholas	JISAO	Incorporating recruitment–environment linkages into stock assessment models for Alaskan groundfish with application to population projections in a changing climate	$35,837
II	Bond, Nicholas	JISAO	Population trends, vital rates, and diets of otariid pinnipeds in Alaska: What can they tell us about the relative effects of climate change and human activities	$166,393
II	Branch, Trevor	SAFS	Changes in US West Coast groundfish ecology	$89,999
II	Doyle, Miriam	JISAO	Links between the early life history dynamics of fish, climate and ocean conditions in the large marine ecosystems of Alaska	$44,927

Task #	Principal Investigator	Department	Title	Award Amount
II	Essington, Timothy	SAFS	Distribution & application of a new geostatistical index standardization & habitat modeling tool for stock assessments & essential fish habitat designation in AK & NW Atlantic regions	$193,000
II	Essington, Timothy	SAFS	Incorporating time-varying factors in stock assessment models	$187,564
II	Miller, Bruce	SAFS	Marine Biological Interactions in the North Pacific – Fish Interactions Task	$505,247
II	Mordy, Calvin	JISAO	Innovation Technology in the Arctic	$677,535
II	Pietsch, Ted	SAFS	Archival Storage and Dissemination of Data on Northeast Pacific Fish Eggs, Larvae, and Adults"	$101,394
II	Punt, Andre	SAFS	Understanding Participation and Effort in State and Federal Fisheries Along the West Coast	$105,000
II	Punt, Andre	SAFS	Alaska CLIMate Project: A multi-model assessment of climate change impacts on fish, food-webs, and fisheries in Alaska	$220,500
II	Punt, Andre	SAFS	An Evaluation of Management Strategies for Implementation of Annual Catch Limits for Alaska Groundfish	$90,001
II	Punt, Andre	SAFS	Improving Stock Assessments with Acoustic Data from Commercial Fishing Vessels	$117,000
II	Punt, Andre	SAFS	Management strategy evaluation using the Generic Modeling for Alaska Crab stocks (Gmacs)	$90,000
II	Punt, Andre	SAFS	Spatial Analysis to support Management of Cetaceans and other Highly-Mobile Marine Species under the Endangered Species Act and Marine Mammal Protection Act	$106,000
II	Resing, Joseph	JISAO	Hydrothermal Exploration in the Mariana Back-arcusing R/V Falkor and AUV Sentry in November-December 2015	$199,962

Task #	Principal Investigator	Department	Title	Award Amount
II	Stafford, Kathleen	APL	Task II: Participation in Bering Strait mooring deployment Anadyr, Russia – July 2015	$32,747
II	Sutton, Adrienne	JISAO	Turning the headlights on high: Improving an ocean acidification observation system in support of Pacific coast shellfish growers	$117,337
II	Young, Graham	SAFS	Steelhead Reproduction and Epigenetics	$101,499
II	Roberts, Steven	SAFS	Assessing the Capacity for Evolutionary Adaptation to Ocean Acidification in Geoduck	$81,022
III	Cheng, Wei	JISAO	Assessing regional sea-ice predictability in the U.S. Arctic: A multi-model approach	$77,157
III	Dahl, Peter	APL	Using Acoustics to Improve Species Identification of Marine Organisms in the North Pacific	$57,193
III	Holzworth, Robert	ESS	Lightning Studies	$173,625
III	Hwang, Jenq-Neng	EE	Automated Image Processing for Fisheries Applications	$69,986
III	Mickett, John	APL	Design and Fabrication of a Real-Time, Shallow-Water Bottom Mooring for the Environmental Sample Processor (ESP)	$119,374
III	Newton, Jan	APL	Pacific Anomalies Workshop Support	$5,155
III	Nijssen, Bart	CEE	An Experimental Demonstration and Evaluation of Real-Time, Over-the-Loop Streamflow Forecasting	$150,000
III	Percival, Donald	APL	Evaluation of Networks of DART Buoys for Forecasting Tsunami Wave Heights	$30,000
III	Punt, Andre	SAFS	"Fixing" retrospective biases in stock assessment and implications for management targets	$33,011

Task #	Principal Investigator	Department	Title	Award Amount
III	Punt, Andre	SAFS	Partnership with the Northwest Fisheries Science Center and Alaska Fishery Science Center to Develop Increased Capacity in the School of Aquatic & Fishery Sciences to Enhance Teaching and Research	$200,000
III	Punt, Andre	SAFS	West Coast Groundfish Stock Assessment	$150,000
III	Quinn, Thomas	SAFS	Evaluating Predator Movements to Determine the Vulnerability of Salmon Smolts to Predation in the San Joaquin Delta	$123,534
III	Rigor, Ignatius	APL	COORDINATION AND DATA COLLECTION OF THE U.S. INTERAGENCY ARCTIC BUOY PROGRAM AND US INTERAGENCY PROGRAM FOR ANTARCTIC BUOYS Sea Ice Age	$250,000
III	Riser, Stephen	OCE	The Argo Project: Global Observations for Understanding and Prediction of Climate Variability	$3,579,469
III	Roberts, Steven	SAFS	Developing genomic resources to support restoration and protection of the Olympia Oyster in Puget Sound	$190,540
III	Stafford, Kathleen	APL	Beluga Whales in the western Beaufort Sea And Marine Mammal Acoustic Ecology in the Pacific Arctic	$50,000
III	Stafford, Kathleen	APL	Task III: Chukchi Plateau Passive Acoustic data analysis	$20,000
III	Wang, Muyin	JISAO	Improving CFS sea ice predictability through understanding the role of atmospheric forcing and ice thickness contributions	$72,907
III	Webster, Sarah	APL	Task III Sensor Integration – Advanced Sensor Integration for Fish Assessments from Autonomous and Remote Platforms	$60,000
TOTAL				$19,934,565

APPENDIX 4

Non-Cooperative Agreement Awards Funded in 2015-2016

Project Title	Principal Investigator	Awarding Agency	Award Amount
NEMO ESP	Ryan McCabe	NOAA	$3,140
Tsunami Hazard Modeling for U.S. Coastlines	Diego Arcas	NRC	$15,426
Collaborative Research: Event response to an eruption at Axial Seamount (RAPID)	David Butterfield	NSF	$36,658
Collaborative Research: Trace Metal Deposition And Cycling In The North Atlantic On The 2013 CLIVAR/Repeat Hydrography A16N Expedition	Joseph Resing	NSF	$23,022
Impact of total column water vapor measurements on short- to medium-range forecasts of North American monsoon precipitation	Yolande Serra	NSF	$178,027
Evaluation of MERRA Cloud and Radiative Variables using Integrated CALIPSO-CloudSat Data Products	Laura Hinkelman	NASA	$205,244
Decadal changes in ventilation of the abyssal Southwest Pacific ocean from repeated CFC and new SF6 measurements	Rolf Sonnerup	NSF	$141,072
Sea Spray Aerosol Production over the North Atlantic	Timothy Bates	NSF	$192,072
Sustaining the NANOOS Regional Coastal Ocean Observing System (RCOOS)	Ryan McCabe	NOAA	$43,184
The Predictability of Extreme Arctic Sea Ice Variations in a Rapidly Changing Climate	Muyin Wang	NOAA	$90,501
Collaborative Research: Common Era Climate Variability from Marine Proxy Surrogate Reconstructions	Casey Saenger	NSF	$145,776
Dinitrogen fixation rates in eastern tropical Pacific Ocean	Rolf Sonnerup	Princeton Univ	$37,620
CloudSat Global Summary and Geometric Profile (GeoProf) Datasets	Roger Marchand	JPL	$35,000

Project Title	Principal Investigator	Awarding Agency	Award Amount
Historical Data Recovery for the Western Tropical Pacific: 1850 – 1939	Kevin Wood	UK Met Office	$38,503
Validation and Application of MISR Cloud Retrievals	Thomas Ackerman	JPL	$80,000
EarthCube IA: Collaborative Proposal: Advancing netCDF-CF for the Geoscience Community	Nicholas Bond	UCAR	$79,931
The Water Column Profiler Data Processing Project	Nicholas Bond	IPHC	$61,818
A citizen science mediated Optical Character Recognition (OCR) module for large-scale data rescue	Kevin Wood	NPRB	$12,153
A citizen science mediated Optical Character Recognition (OCR) module for large-scale data rescue	Kevin Wood	Sloan Fdn	$36,500
Historical data recovery for multidisciplinary research on Alaska and the Arctic	Kevin Wood	NPRB	$79,318
Understanding and predicting patterns in northeast Pacific groundfish species movement and spatial distribution in response to anomalously warm ocean conditions	Nicholas Bond	NPRB	$63,375
Connectivity in the Gulf of Alaska: a synthesis based on the Gulf of Alaska Integrated Ecosystem Research Program	Calvin Mordy	NPRB	$169,044
O&M RSN IO	David Butterfield	NSF	$17,502
Marine Cloud Brightening	Thomas Ackerman	Various	$202,755
Reconstructing hydrological variability using carbonate mineral triple oxygen isotopes	Casey Saenger	Univ of WA	$38,719
Novel Blending of Numerical /Statistical Models and Satellite Data to Improve Coastal Ocean Water Quality Predictions	Samantha Siedlecki	Univ of CA SC	$57,531

Project Title	Principal Investigator	Awarding Agency	Award Amount
Functional Dynamics, Interactions and Biogeochemical Impact of Chemolithoautotrophic Subseafloor Microbial Ecosystems at Axial Seamount, a Mid-Ocean Ridge Cabled Observator	David Butterfield	MBL	$31,413
Defining critical periods for Yukon and Kuskokwim river Chinook salmon	Albert Hermann	NPRB	$202,500
TOTAL			$2,317,804

APPENDIX 5

Graduate Students

Student Name	Academic Unit	Degree	Degree Advisor
ABE, KEITA	Economics	Ph.D.	Chris Anderson
ANDERSON, TODD S	Earth And Space Sciences	Ph.D.	Robert Holzworth
CLARK, ALICIA M	Mechanical Engineering	Ph.D.	Alberto Aliseda
CRONIN FINE, LEE	Quantitative Ecology & Resource Mgmt	Ph.D.	Andre Punt
DAVIS, BROOKE MARGARET	Quantitative Ecology & Resource Mgmt	M.S.	Daniel Schindler
DILMEN, DERYA ITIR	Earth And Space Sciences	Ph.D.	Vasily Titov, Joanne Bourgeois
ECHOLS, ROSALIND	School of Oceanography	Ph.D.	Steve Riser
FILLEBEEN, THOMAS D	conomics	Ph.D.	Chris Anderson, Robert Halvorsen
GODERSKY, ALICIA J.	chool of Aquatic and Fishery Sciences	M.S.	Theodore Pietsch
HURTADO FERRO, FELIPE	School of Aquatic and Fishery Sciences	Ph.D.	Andre Punt
JOHNSON, KELLI F.	School of Aquatic and Fishery Sciences	Ph.D.	Andre Punt
KRIGBAUM, MELISSA J.	School of Aquatic and Fishery Sciences	Ph.D.	Chris Anderson
KURIYAMA, PETER T.	School of Aquatic and Fishery Sciences	Ph.D.	Trevor Branch
LEE, QI	School of Aquatic and Fishery Sciences	M.S.	Andre Punt
LOGAN, PAIGE D	School of Oceanography	Ph.D.	Gregory Johnson
MONNAHAN, COLE C	Quantitative Ecology & Resource Mgmt	Ph.D.	Trevor Branch
MOYER, KATHERINE R.	School of Aquatic and Fishery Sciences	M.S.	Theodore Pietsch

Student Name	Academic Unit	Degree	Degree Advisor
NG, CHIN HEI	Mechanical Engineering	M.S.	Alberto Aliseda
TROCHTA, JOHN T.	School of Aquatic and Fishery Sciences	M.S.	Trevor Branch
WENEGRAT, JACOB O	School of Oceanography	Ph.D.	Mike McPhaden
WILLIAMS, NANCY L	School of Oceanography	Ph.D.	Richard Feely, Chris Sabine
WILSON, EARLE	School of Oceanography	M.S.	Steve Riser

APPENDIX 6

Postdoctoral Research Associates

Barnett, Lewis
Carter, Brendan RAE**
Chang, Bonnie
Councill, Elizabeth L.
Gavery, Mackenzie R.
Giglio, Donata
Martini, Kim
Ono, Kotaro
Potter, Samuel F.
Raudzens Bailey, Adriana
Smith, Joseph M.
Sun, Ning**
White, Rachel H.
Yang, Qiong**
Zhou, Hongqiang

**Received less than 50% support from JISAO

APPENDIX 7

Personnel Count

Category	Number	B.S.	M.S.	Ph.D.
Faculty	1			1
Research Scientist	59	11	22	26
Visiting Scientist	0			
Postdoctoral Fellow**	12			12
Research Support Staff	16	13	3	
Administrative	0			
Total (> or = 50%)	88			
Undergarduate Students	9			
Graduate Students	22			
Employees receiving less than 50% NOAA support	81			
Located at Lab	85 (PMEL), 20 (AFSC), 2 (NWFSC)			
Obtained NOAA employment within the last year	0			

**an additional 3 PostDocs received less than 50% support

APPENDIX 8

Publications Count*

JISAO Lead Author	2014 – 2015	2015 – 2016
Peer-reviewed	87	50
Non-peer reviewed	0	2
Total	87	52
NOAA Lead Author		
Peer-reviewed	19	21
Non-peer-reviewed	2	2
Total	21	23
Other Lead Author		
Peer-reviewed	53	45
Non-peer-reviewed	0	0
Total	53	45
Total peer-reviewed	**159**	**116**
Total non-peer-reviewed	2	4
Grand Total	161	120

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

APPENDIX 9

Publications – April 1, 2015 – March 31, 2016

Not Previously Reported:

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Published:

11. Banas, N. S., J. Zhang, R. G. Campbell, R. N. Sambrotto, M. W. Lomas, E. Sherr, B. Sherr, C. Ashjian, D. Stoecker, and E. J. Lessard (2016), Spring plankton dynamics in the Eastern Bering Sea, 1971–2050: Mechanisms of interannual variability diagnosed with a numerical model, *Journal of Geophysical Research: Oceans*, 121(2), 1476-1501, doi:10.1002/2015JC011449.
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APPENDIX 10

Acronyms

Acronym	Definition
AAR	Australian–Antarctic Ridge
ACLIM	Alaska CLIMate Project
ADF&G	Alaska Department of Fish and Game
ADMB	Automatic Differentiation Model Builder
AEP	Alaska Ecosystems Program
AFSC	Alaska Fisheries Science Center
AGU	American Geophysical Union
AON	Arctic Observing Network
AOX	Arctic Observations Experiment
ARCWEST	Arctic Whale Ecology Study
ASAMM	Aerial Surveys of Arctic Marine Mammals
ASCE	American Society of Civil Engineers
AT	acoustic trawl
ATLAS	autonomous temperature line acquisition system
AUV	autonomous underwater vehicle
AVO	acoustic vessels of opportunity
AXIB	Airborne eXpendable Ice Buoys
BOEM	Bureau of Energy Management
BSAI	Bering Sea Aleutian Islands
CAEP	Cetacean Assessment and Ecology Program

Acronym	Definition
CAPAM	Center for the Advancement of Population Assessment Methodology
CCHDO	CLIVAR & Carbon Hydrographic Data Office
CCN	cloud condensation nuclei
CESM	Community Earth System Model
CFC	chlorofluorocarbon
CFSR	Climate Forecast System Reanalysis
CFSv2	Coupled Forecast System version 2
CHAOZ	Chuckchi Acoustics, Oceanography, and Zooplankton
CHAOZ–X	CHAOZ Extension Study
CIB	Cook Inlet beluga project
CLIVAR	Climate Variability and Predictability program
CO2	carbon dioxide
ComMIT	Community Modeling Interface for Tsunamis
CPUE	catch per unit effort
CTD	conductivity, temperature and depth
DART	Deep–ocean Assessment and Reporting of Tsunamis
DBO	Distributed Biological Observatory

Acronym	Definition
DIC	dissolved inorganic carbon
DOE	Department of Energy
DO–IT	Disabilities, Opportunities, Internetworking, and Technology
DPM	Deformable Part Model
EBS	Engineered Barrier Systems
ECMWF	European Centre for Medium–Range Weather Forecasts
EcoFOCI	Ecosystems and Fisheries–Oceanography Coordinated Investigations
ELH	Early Life History
ENSO	El Niño–Southern Oscillation
EOI	Earth–Ocean Interaction
EPZT	Eastern Pacific Zonal Transect
ESA	Endangered Species Act
ESM	Earth system model
ESP	environmental sample processor
EUC	Equatorial Undercurrent
EwE	Ecopath with Ecoism
EYH	Expanding Your Horizons
FATE	Fisheries and the Environment
FRAM	Fishery Resource Analysis and Monitoring
FTP	file transfer protocol
GARFO	Greater Atlantic Regional Fisheries Office
GCM	global climate model

Acronym	Definition
GFDL	Geophysical Fluid Dynamics Laboratory
GLERL	Great Lakes Environmental Research Laboratory
GLM	Global Lightning Mapper
Gmacs	generalized model for Alaskan crab stocks
GOA	Gulf of Alaska
GOAIERP	Gulf of Alaska Integrated Ecosystem Research Program
IABP	Iternational Arctic Buoy Programme
IASC	International Arctic Science Committee
ICES	International Council for the Exploration of the Sea
IFQ	Individual Fishing Quota
IOD	Indian Ocean Dipole
IOOS	Integrated Ocean Observing System
IPCC	Intergovernmental Panel on Climate Change
IPHC	International Pacific Halibut Commission
ITAE	Innovative Technology for Arctic Exploration
JCOMM	Joint Technical Commission for Oceanography and Marine Meteorology
JISAO	Joint Institute for the Study of the Atmosphere and Ocean
KEO	Kuroshio Extension Observatory

Acronym	Definition
LOC	Lab-on-a-Chip
MIROC	Model for Interdisciplinary Research on Climate
MIZER	multi-species spectrum modeling
MML	Marine Mammal Laboratory
MSE	Management Strategy Evaluation
N2O	nitrous oxide
NaCl	sodium chloride (salt)
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NCTR	NOAA Center for Tsunami Research
NEFSC	Northeast Fisheries Science Center
NMFS	National Marine Fisheries Service
NPFMC	North Pacific Fishery Management Council
NPRB	North Pacific Research Board
NPZ	nutrient, photoplankton, zooplankton
NSF	National Science Foundation
NTHMP	National Tsunami Hazard Mitigation Program
NWFSC	Northwest Fisheries Science Center
OA	ocean acidification
OCS	Ocean Climate Stations

Acronym	Definition
OGCM	ocean generated circulation model
OLR	outgoing longwave radiation
OM	operating model
PAW	Pacific Anomalies Workshop
PAWS	Polar area weather station
PICES	North Pacific Marine Science Organization
PIFSC	Pacific Islands Fisheries Science Center
PIOMAS	Pan-Arctic Ice Ocean Modeling and Assimilation System
PIRATA	Prediction and Research Moored Array in the Tropical Atlantic
PMEL	Pacific Marine Environmental Laboratory
QERM	Quantitative Ecology and Resource Management
QGIS	Quantum Geographic Information Systems
RACE	Resource Assessment and Conservation Engineering
RADSeq	Restriction Site Associated DNA Sequencing
RAMA	Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction
RBCs	red blood cells
RCP	representative concentration pathway
REEM	Resource Ecology and Ecosystem Modeling

Acronym	Definition
RMSE	root mean square errors
RNA	ribonucleic acid
ROMS	Regional Ocean Modeling System
ROV	remotely operated underwater vehicle
RP	Recruitment Processes program
RRBS	Reduced Representation Bisulfite Sequencing
SAFS	UW School of Aquatic and Fishery Sciences
SF6	sulfur hexafluoride
SIFT	Short-term Inundation Forecasting for Tsunamis
SIO	Scripps Institution of Oceanography
SiPN	Stable Isotope Probing
SiPN	Sea ice Prediction Network
SLP	sea level pressure
SNP	single nucleotide polymorphism
SOAR	Synthesis of Arctic Research
SOCAT	Surface Ocean Carbon Atlas
SSA	sea spray aerosol
SSTA	sea surface temperature anomaly
STEM	science, technology, engineering, and mathematics
SUNA	submersible ultraviolet nitrate sensor
SVP	Surface Velocity Program

Acronym	Definition
SWFSC	Southwest Fisheries Science Center
SZ	subduction zone
TAO	Tropical Atmosphere Ocean
TDZ	Tsunami Design Zone
TEMPP	Tsunami Evacuation Maps, Plans and Procedures
TPOS	Tropical Pacific Observing System
TRITON	Triangle Trans-Ocean Buoy Network
TSH	Taylor Shellfish Hatchery
UAF	Unified Access Framework
USIABP	U.S. Interagency Arctic Buoy Program
UW	University of Washington
UWFC	University of Washington Fish Collection
WCOA	West Coast Ocean Acidification
WHOI	Woods Hole Oceanographic Institution
WKSICCME	Workshop on changes in spatial distribution
WNFH	Winthrop National Fish Hatchery
WOAC	Washington Ocean Acidification Center
WWLLN	World Wide Lightning Location Network