On the cover: Gavin Brady (JISAO, left) and Shawn Dahle (NOAA, right) scanning for ice-associated seals atop an ice floe in the Bering Sea during an ice seal capture cruise in March/April 2018. Photo by Stacy DiRocco.
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EXECUTIVE SUMMARY
INTRODUCTION

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

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

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

• 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, Electrical Engineering, Washington Sea Grant, 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) and the Alaska Fisheries Science Center (AFSC). 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 of JISAO's current research is featured in the Research Activities 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.
RESEARCH ACTIVITY HIGHLIGHTS

THE ALASKA CLIMATE CHANGE INTEGRATED MODELING (ACLIM) PROJECT

This research represents a comprehensive, collaborative effort to characterize and project climate-driven changes to the Bering Sea ecosystem, from physics to fishing communities, and to understand how different fisheries management approaches might help promote adaptation to climate-driven changes and long-term sustainability in fish and shellfish populations.

To address this goal, ACLIM strives to evaluate fishery management strategies under 10+ different climate change scenarios (spanning high and low CO2 futures) in the Bering Sea. It connects research on scaling of climate models, climate-enhanced biological models, and socio-economic and harvest scenarios. ACLIM is a multi-year project and a collaboration between 20+ physical oceanographers, ecosystem modelers, socioeconomic researchers, and fishery management analysts from NOAA AFSC, NOAA PMEL, and the University of Washington. A major focus of the project is to quantify scenario, parameter, and structural uncertainty through a multi-model projection suite which will aid in evaluating the performance of resource management strategies under different future scenarios.

Projections of climate conditions are complete, and projections of catch for core species under baseline status quo fishing conditions are underway for several fish and invertebrate species from the Eastern Bering Sea (EBS), for which changes in productivity have been linked to climate variability. Results will include projections of the future ecosystem state of the Bering Sea, risk of changes in catch under different management tools, and spatial and temporal schedules of expected change. A core component of the work is to evaluate alternative climate-ready management strategies to adapt to changing conditions.

THE ECOSYSTEMS AND FISHERIES-OCEANOGRAPHY COORDINATED INVESTIGATIONS (ECOFOCI)

FY17 saw one of the most ambitious field efforts for EcoFOCI ever - with a large presence in four out of five of Alaska’s Large Marine Ecosystems. To provide the necessary data to make informed management decisions, NOAA and JISAO scientists worked together to conduct in-the-field science on over 20,000 nautical miles traveled aboard research ships, 53 biophysical moorings were deployed and recovered, 492 key-stations were sampled with a conductivity, temperature and depth and 11 drifters deployed - totaling the effort of 969 person-at-sea days. Further, ecosystem science in 2016 and 2017 directly influenced decision-making by the North Pacific Fishery Management Council in determining the Alaska walleye pollock total allowable catch and contributed to the Alaska Marine Ecosystems Considerations Report, used by the Council and other stakeholders, to evaluate current ecosystem status and project near-future conditions.

INNOVATED TECHNOLOGY FOR ARCTIC EXPLORATION (ITAE)

In FY17 ITAE achieved many of its goals by building operational capacity that connected sustained arctic observing systems and explored new scientific frontiers. ITAE continued to build on previous successes with 15 types of new technology, connecting over 30 partners in academia, industry and government including five of the six NOAA line offices. In 2017 alone, the program more than doubled its cumulative exploration of remote territory, traveling over 24,240 km and reaching record new latitudes through more than 500 days of at-sea data collection.
EDUCATION AND OUTREACH

“The JISAO internship lined up perfectly with the areas of study that I’m most interested in. JISAO’s connection with NOAA was also a very enticing aspect as I am interested in working for them in the future.” – 2017 JISAO Summer Intern

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

Perhaps the most noteworthy project supported by the E/O Program is the success of the JISAO Summer Undergraduate Internship Program. The internship program began with one student in 2008, and has since hosted 70 students from colleges and universities across the United States. Nine of JISAO’s former interns have received graduate degrees, including two with Ph.D’s. Twenty former interns have completed undergraduate degrees and are currently enrolled in graduate school, including five at the University of Washington.

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

INTERNATIONAL OUTREACH

Climate Interviews on Romanian Television – JISAO Research Associate Cristian Proistosescu answered questions on ProTV’s evening news about climate change and the Paris Agreement. He appeared a second time to talk about climate change and extreme events. The segment was in the wake of two particularly destructive storms. He also appeared on Antena 1 TV to talked about large scale climatic changes, part of a Documentary on aridification of Southern Romania and the spread of the European Jackal.

K-12 EVENTS

Orca Bowl – JISAO scientists were judges and scorekeepers at Washington Sea Grant’s 2017 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. The judges interact with students and explain a wide range of topics to the high school students and parents/coaches, including physical oceanography, social science, and marine policy.

NOAA Science Camp – Eleven JISAO scientists led sessions for the 2017 NOAA Science Camp at the Pacific Marine Environmental Laboratory (PMEL). 2017 was the 12th year that JISAO funded NOAA Science Camp scholarships for low income and
underrepresented students. This year, for the third time, we partnered with the Tukwilla School District’s STEAM program and provided enough funding for 25 middle school students to attend the camp.

Sound Day at Seattle Marine Academy – Tom Walton, Sophie Chu and Adi Hanein met with students as they rotated through various stations during the day. They had various parts that were made in the machine shop for students to touch and see the process of machining, as well as various sensors and how engineering works with ocean technology.

Ocean Science Week at Eagle River Elementary School – Heather Tabisola was a guest for the “Scientist in the Classroom” segment of the event. She presented to two classrooms with a long Q&A from both Teachers and Students.

Science Discovery Night at Lake Forest Park Elementary – Adi Hanein met students and taught them about the Pacific Marine Environmental Lab, letting them guess sounds made from hydrophone recordings to learned more about ocean noise and how PMEL studies it.

Additional Events – Researchers donated their time and expertise for a science Olympiad for middle school students (Nick Bond), The Seattle Youth CAN event (Nick Bond), a Citizen Science Institute Tour of PMEL (Adi Hanein and Nick Bond) and Career Day at Aki Kurose Middle School as part of the Kids Envisioning Careers program, and Blue Heron Middle School’s career day presented by the American Association of University Women.

ONLINE COMMUNICATION

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

- Is it okay to tinker with the environment to fight climate change? – New York Times Magazine
- Seattle’s ‘amazing transition’ from wet to dry probably just a coincidence, scientists say – Seattle Times
- Seasonal forecasts, fisheries management, and the fish you eat – UW News
- Shock and thaw – Alaskan sea ice just took a steep, unprecedented dive – Scientific American
- Partnering with indigenous communities to anticipate and adapt to ocean change – UW News

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

Polar Science Weekend – This annual event at Pacific Science Center is three days of hands-on educational activities, live demonstrations, and exhibits presented by scientists who work in polar regions. Erin Richmond and Cynthia Christman volunteered and showed “How to Detect Animals on Ice Using Infrared Thermal Cameras.” The activity entailed an infrared camera demo, an animal matching game and a seal coloring station.

Discover Science Weekend at the Seattle Aquarium – Erin Richmond and Cynthia Christman organized a table with an activity called “How to Detect Animals on Ice Using Infrared Thermal Cameras.” The activity entailed an infrared camera demo, an animal matching game and a seal coloring station. Al Hermann led a 3D visualization of particle dispersal in the J-SCOPE ocean forecasting model. Participants got to use 3D glasses to view the ocean model output.

NOAA Open House – JISAO researchers joined NOAA employees at an open house event at the Western Regional Center giving the public an opportunity to learn about a variety of NOAA programs, including the National Weather Service, the Pacific Marine Environmental Laboratory, NOAA Fisheries, the National Ocean Service, and NOAA Corps. Katie Luxa was one of three tour guides in the Marine Mammal Laboratory’s marine mammal osteological collection where they gave guests an up-close look at cetacean and pinniped bones. They used the collection to highlight the physical and behavioral characteristics of these marine mammal groups, and talked about marine mammal research and conservation.

Seattle Maritime Festival – Heather Tabisola had a booth at the festival’s Family Fun Day where we had model buoys, underwater volcano lava samples, drift cards and various sensors for people to touch and learn more about.

Glacier Bay National Park Ranger/Interpreter training session. The training session was held in Gustavus, Alaska, which is the base of operations for Glacier Bay National Park. Sarah Doherty led a half-day training of the rangers/interpreters in two talks: The first on what controls the Earth’s climate, and the second going over a) the results of the recently published USGCRP Climate Science Special Report, on which she was a lead author, and b) answers to commonly-asked questions about climate.
Radio and Television – Nick Bond is a frequent guest on local radio broadcasts speaking about the region’s climate. He also appears on other stations such as KCBS Radio in San Francisco where he speaks on subjects such as summer temperature and rain average, pollen allergies, The Blob, and the winter weather outlook. Bond is also a frequent guest on King5 News weather programs.

Public talks – JISAO researchers gave talks at the Corinthian Yacht Club (Adi Hanein), The Nordic Heritage Museum (Sarah Doherty), the Bainbridge Island Science Café (Nick Bond), the Seattle Mountaineers Club (Nick Bond), the Hood Canal Climate Forum (Nick Bond), and the Tulalip Tribe’s Climate Core Team Meeting (Nick Bond).

SUMMER INTERN PROGRAM

JISAO welcomed 13 undergraduate students to the JISAO Summer Internship Program in 2017. Students were matched with mentors from JISAO, the UW Department of Atmospheric Sciences, the UW School of Oceanography, the UW School of Aquatic and Fishery Sciences, the NOAA Pacific Hydrographic Branch, the NOAA Marine Mammal Laboratory, and the NOAA Alaska Fisheries Science Center. Student web pages and videos are available on JISAO’s website. The interns and their universities are listed below:

- Kallista Angeloff – University of Washington
- Cassidy Barrientos – Humboldt State University
- Will Christian – Michigan Tech University
- Lillian Henderson – University of Rochester
- Carter Johnson – University of Washington
- Tai Koester – University of Colorado
- Stephen Maldonado – Ohio State University
- Tarenina Max – San Juan College
- Anita Montero – Barnard College of Columbia University
- Laura Moore – St. Olaf College
- Peter Sumner – Fort Lewis College
- Karen Valadares – Mount San Antonio College
- Miranda Wittmond – Santa Clara University

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

UNIVERSITY EVENTS

SACNAS (Advancing Hispanics, Chicanos and Native Americans in Science) National Conference in Long Beach, CA – JISAO sponsored the registration for Kimberly Yazzie, a student in the College of the Environment at UW, who represented JISAO and distributed applications for JISAO’s internship program.

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

Guest Lectures – JISAO researchers gave talks at local colleges and universities including Northwest Indian College (Nick Bond), the Seattle Art Institute (Brendan Carter), Seattle University (David Butterfield), and the University of Alaska, Anchorage (Nick Bond), where he spoke about scientific story writing.
FORTY YEARS OF JISAO

JISAO celebrated its 40th anniversary in 2017 and JISAO Executive Director Tom Ackerman and Dean of UW’s College of the Environment Lisa Graumlich led a celebratory event in June at the university’s Center for Urban Horticulture attended by over 125 guests. Founding JISAO director John M. (Mike) Wallace gave the keynote address and spoke of the founding of JISAO in 1977 and highlights of his nearly 25 years leading the institute. At this event, we also announced the creation of the MariAnna Award—a travel award for summer interns, named for Cara MariAnna, a former JISAO staff member who initiated the summer internship program and help found JISAO’s Education and Outreach program.

FINANCIAL MANAGEMENT AND ADMINISTRATION

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

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

- Thomas Ackerman, Executive Director
- Nicholas Bond, Deputy Director (JISAO management representative at NOAA/PMEL)
- Fred Averick, Assistant Director, Finance & Administration
- 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 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:
JOINT INSTITUTE FOR THE STUDY OF THE ATMOSPHERE AND OCEAN
ANNUAL REPORT
2017-2018

TASK I

• Three to six postdoctoral fellows on annual appointments, renewable for a second year.
• Internal mini-grants to JISAO PIs, mainly to provide seed funding for new areas of research
• 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:

POSTDOC FUNDING: 51%
INTERNATIONAL RESEARCH GRANTS: 18%
ADMINISTRATION: 10%
OUTREACH: 10%
VISITORS' FUND: 5%
OTHER: 5%
UW FISHERIES LECTURE SERIES: 1%

JISAO provides space, network access and computer and administrative support for postdoctoral researchers and visitors supported on Task I. The current group of postdoctoral research associates includes:

Hannah Horowitz, PhD, Earth and Planetary Sciences, Harvard, 2017
Horowitz is working with Cecelia Bitz and Lyatt Jaegle, of the UW Department of Atmospheric Sciences, on the first study to examine climate change impacts on the sea ice source of sea-salt aerosol, and to estimate the direct and indirect climate impacts of potential changes to sea-salt aerosol resulting from changing sea ice and warming ocean temperatures in a future climate scenario. Horowitz will investigate the full range of cascading chemistry-climate effects: from changes to sea-salt aerosol production, to reactive halogens and atmospheric oxidant concentrations, and finally to impacts on the greenhouse gases methane and ozone and the toxic pollutant mercury. The process-level understanding gained from these results will improve future studies of chemistry-climate interactions and climate change impacts and inform parameterizations in simpler, computationally inexpensive models. During the year, Horowitz was awarded an NSF Atmospheric and Geospace Sciences Postdoctoral Research Fellowship.

Cristian Proistosescu, PhD, Earth and Planetary Sciences, Harvard, 2017
Proistosescu is working on a research project that will investigate the interaction between ocean heat uptake and regional climate feedbacks across a range of temporal and spatial scales, with the aim of exploring the prospects for (and limitations of) what can be learned about Earth’s climate sensitivity from the instrumental and paleo records of climate variability and change. Further, his research will build a process-level understanding of how modes of climate variability (such as the PDO, AMOC and ENSO) have consequences for Earth’s global energy budget. These are timely and important topics, given the recent evidence that climate sensitivity is variable, and that future warming may be underestimated from modern climate observations. His research interests dovetail perfectly with several ongoing projects to understand
the operation of climate feedbacks under climate variability and change, with Gerard Roe, UW Earth and Space Sciences, and Kyle Armour, UW Oceanography.

Hannah Zanowski, PhD, Atmospheric and Oceanic Sciences, Princeton, 2017
Zanowski is working with Cecelia Bitz, UW Atmospheric Sciences, and Kyle Armour, UW Oceanography, here on campus, and with Greg Johnson of NOAA Pacific Marine Environmental Laboratory, on a research project that will include both observational analysis of decade-to-decade historical water-mass changes in the Southern Ocean, as well as diagnosis of model output, specifically to study full-depth southern ocean responses to changes in wind and freshwater (buoyancy) forcing when they are applied in the open ocean vs. along the coast. By comparing observations and different climate models (developed at GFDL and NCAR), Zanowski hopes to elucidate key mechanisms for variability in the Southern Ocean limbs of the meridional overturning circulation. This work, incorporating observations and working through the water column, should substantially broaden her research horizons and has the potential to provide substantial insights into Southern Ocean variability that is in turn important to climate.

JISAO’s education and outreach program activities are partially supported by 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, Task I supports a fraction of administrative salaries.

TASK II
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
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, 2017 - March 31, 2018 totals $20,849,886; JISAO’s funding for non-Cooperative Agreement grants for the same period is an additional
$2,984,164. The charts below break down Cooperative Agreement funding by tasks and themes. Besides providing the ongoing infrastructure and support to successfully manage JISAO, the administration worked on the following initiatives over the past year to improve and strengthen JISAO as an organization:

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

2. JISAO Staff Recognition Program
   a. Recognized outstanding research, papers, honors and awards on JISAO website.
   b. Presented UW service awards to JISAO employees.
   c. Several JISAO scientists and team members in the JISAO administrative group received cash awards for outstanding work over the past year in various capacities.

3. Communications
   a. Continued joint quarterly meetings with JISAO and NOAA employees.
   b. Held JISAO 40th Anniversary event, mentioned previously.
   c. The JISAO website was completely revamped and modernized this year.
   d. Participated on both the NOAA and UW CoEnv communications teams to regularly share information and best practices.
   e. 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.
   f. Continued social networking via Facebook, YouTube and Twitter.
   g. Continued to track media coverage and publications of JISAO researchers.

4. Organization and Infrastructure
   a. Continued strengthening overall organizational structure, working directly with JISAO scientific and technical staff to ensure meaningful supervisory and mentoring relationships.
   b. Thomas Ackerman, JISAO Executive Director, is a member of the CoEnv Executive Committee and served the College in various capacities.
   c. JISAO staff worked on university-wide initiatives and on committees addressing financial, human resources, diversity, equity and inclusion, communications and safety matters.
CLIMATE RESEARCH AND IMPACTS
CONTRIBUTION TO NATIONAL CLIMATE ASSESSMENT 4

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

TASK III

NOAA SPONSOR
David Fahey – Earth Systems Research Lab (ESRL)

NOAA GOALS
Climate Adaptation and Mitigation

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

1. Assist in the writing and management of a Climate Science Special Report (CSSR) being generated in advance of the 4th National Climate Assessment (NCA4). The periodically produced NCA summarizes the impacts of climate change on the United States, now and in the future (e.g. see the last assessment at nca2014.globalchange.gov). A key element of NCA4 is a special, stand-alone report of the state-of-the-science report relating to climate change and its physical impacts, the CSSR. Following finalization of CSSR, the author team is to work with the NCA4 authors to ensure consistency across regions and sectors in analyses, interpretation, and explanation. Writing of NCA4 started in March, 2017, and expected completion is late 2018. David Fahey (ESRL) is one of three coordinating lead authors of the CSSR report, as well as lead author on Chapter 2 of the report. Sarah Doherty (JISAO) is assisting him in both of these roles.

2. Act as assessment coordinator for the 2018 Ozone Assessment. Fahey is one of four co-chairs of this assessment. Doherty will assist Fahey and the other co-chairs in all aspects of report preparation. She will be the main communication hub between the co-chairs, the assessment Scientific Steering Committee (SSC; five members), the author team (12 lead authors plus approximately 35 to 40 authors) and the review editors (12), as well as with the assessment Technical Support Unit at NOAA, and the sponsoring office at the United Nations Environment Program (UNEP Ozone Secretariat).

OBJECTIVES
1. Successful completion of the Climate Science Special Report (CSSR) to the 4th National Climate Assessment (NCA4). In particular, Doherty is one of the authors on Chapter 2 of the report “Physical Drivers of Climate Change,” (March 2016 through mid-2017).

2. Assure consistency in quality and messaging across all chapters of the CSSR report. Doherty is assisting the coordinating lead author team and CSSR Technical Support Unit in achieving this goal (March 2016 through mid-2017).

3. Completion of Chapter 1 of the 4th National Climate Assessment, which will summarize the CSSR (activity started in March 2017).

ACCOMPLISHMENTS

1. Over the past year under this grant, Doherty worked on producing the fifth and final drafts of Chapter 2 of the CSSR, and assisted on completion of several other chapters of the report as well as the report’s Executive Summary. This included addressing review comments from the U.S. Global Change Research Program (USGCRP) Subcommittee on Global Change Research.

2. Participated as a member of the core writing team of the CSSR Executive Summary on identifying and wording key messages of the overall CSSR report, which will feed into the writing of Chapter 1 of NCA4. Assisted with figure selection and generation for the Executive Summary.

3. Was identified as one of a subset of CSSR authors whose contact information was given to the press to field questions when the report was released in early November 2017. Fielded multiple calls from press outlets. Specific higher-profile outreach activities included:

   
   b. Co-hosted a Reddit “Ask Me Anything” event with CSSR co-author Radley Horton to address the public’s questions about the report results (reddit.com/r/science/comments/7c0fpz/hi_reddit_were_radley_horton_and_sarah_doherty/?st=jfu8l0gf&sh=5478c798). The event was organized by the American Geophysical Union.
   
   c. Participated in a “Facebook Live” event as a panelist, along with several other CSSR co-authors. The event was organized by the American Association for the Advancement of Science (aaas.org/event/aaaslive-advances-climate-change-science).

4. Contributed as a co-author on Chapter 2 of the National Climate Assessment Volume II. This chapter summarizes the results of CSSR for the main NCA report, the latter of which focuses on climate impacts. The chapter is still in the review phase. Assisted with responding to review comments from the public and the National Academy of Sciences. NCA Volume II is expected to be published at the end of calendar year 2018.

5. Worked with the coordinating lead authors of the 2018 Quadrennial Ozone Assessment on the following:

   
   b. Organized the external review of the assessment First Order Draft (130 external reviewers across six chapters with more than 5,000 review comments submitted).
LIGHTNING STUDIES

PI
Robert H Holzworth – UW Department of Earth and Space Sciences

TASK III

NOAA SPONSOR
Steven J. Goodman – GOES-R Satellite 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. This year we continued with our on-orbit validation phase of the mission following the successful launch last autumn 2016. First light for the NOAA-GOES-R-GLM occurred the first week of January 2017, and the data will be available to the public by mid-June 2017. We began regular access to the GLM data in summer 2017, and worked through the grant year to help identify GLM problems, and to compare with the World Wide Lightning Location Network (WWLLN) lightning location data. Late in 2017, the NOAA GLM team made yet another adjustment to the L2-level data, and we will show here that this adjustment greatly improved the match rate with WWLLN strokes.

OBJECTIVES
1. Estimate fraction of WWLLN strokes that match/do not match with GLM flashes, and fraction of GLM flashes that match/do not match with WWLLN strokes.
2. Understand why strokes are missed by GLM, and why flashes are missed by WWLLN.
3. Make a full field of view comparison between WWLLN and GLM. Because WWLLN covers the globe, WWLLN strokes were filtered to fall within the longitude extremes of the GLM field of view – no latitude restriction was imposed. A match criterion was selected: |flash_start-wwlln_time| + k(|flash_lat - wwlln_lat| + |flash_lon - wwlln_lon|) < tolerance, where k converts angle difference to light travel time, and various tolerance choices were investigated.

ACCOMPLISHMENTS
WWLLN combined with Earth Networks data at the sensor level to form ENGLN (Earth Networks Global Lightning Network). WWLLN is now processing raw Earth Networks sensor very low frequency (VLF) waveforms, just as would be done for a regular WWLLN station, and combining these sferic times of group arrival (TOGAs) with those from the regular WWLN stations to form a new WWLN product which more than doubles the number of WWLLN strokes located globally. This grant has helped with the analysis of these combined data to validate the new system for direct comparison to the NOAA GOES-R data.

As an example of the counts: for July 27, 2017, there were 298,733 WWLLN strokes and an order of magnitude more GLM flashes, 3,218,840. Generally, about 7% of WWLLN strokes matched a GLM flash. The low match fraction was later found to be largely a consequence of the choice of match criteria.
The non-lightning “flashes” were found to be associated with either low optical energy, or a small number of illuminated pixels. Figure 1 shows a histogram of the illuminated pixels (events) and energy bins for all flashes on this day. Note that there a few flashes with no (zero events) illuminated pixels.

Figures 2-4 show GLM and WWLLN strokes for various energies. Figure 2 shows GLM flashes at lowest energy (red) together with WWLLN strokes (blue) for all of July 27, 2017. Most of these GLM flashes are non-lightning detections. Figure 3 shows single pixel GLM flashes (red) over WWLLN strokes (blue) for the same day. By requiring five pixels, contiguous in space or time with each other, much of the GLM haze vanishes (Figure 4), but non-lightning flashes and artifacts, such as the linear feature over Panama, remain.

Late in 2017, there was a new release of the GLM Level-2 processing software that addressed several of the earlier problems. The matching algorithm was modified so that the WWLLN stroke time can occur any time within the start and end times of a flash (up to 3 seconds duration), and the GLM flash location must lie within a square of side 100km centered on the WWLLN stroke location. The timing modification is justified by the fact that a flash can begin with low energy discharges that are weak in the VLF band, and so are undetectable by WWLLN, with a larger radio frequency (RF) discharge still occurring within the long-lived flash. Furthermore, the WWLLN strokes were filtered to be within the field of view of GLM rather than merely within the two extremal longitudes of the field of view. Generally, the GLM flash count is decreased by about a factor of 5 to 10, and the match fraction of WWLLN strokes has risen from about 7% to above 60%.

Figure 1. Significant number of zero-event flashes.

Figure 2. GLM flashes at lowest energy (red) together with WWLLN strokes (blue) for all of July 27, 2017.

Figure 3. Single pixel GLM flashes (red) over WWLLN strokes (blue) for the same day.

Figure 4. By requiring five pixels, contiguous in space or time with each other, much of the GLM haze vanishes, but non-lightning flashes and artifacts, such as the linear feature over Panama, remain.
Figure 5a shows the match rate during January 2018 as scatterplot and daily time series. A significant fraction of WWLLN strokes do not match to a GLM flash, indicating either an issue with the data processing, the matching algorithm, or that GLM misses many relatively energetic lightning strokes. Figures 5a and 5b indicate that a significant number of WWLLN strokes are missed by GLM even after the L2 processing adjustment in Dec 2017.

PRESENTATIONS
Robert Holzworth – Post Launch Comparison of GLM with WWLLN, at 2017 GLM Annual Science Team Meeting: GLM Post Launch Test Results and the Path to Provisional Validation Maturity.

Figure 5a. Scatter plot of WWLLN matches for each of the 31 days of January 2018, showing the rate is about the same for the whole month, independent of how many total flashes GLM found in the field of view that day.

Figure 5b. Match rate of WWLLN strokes for each day matched by GLM flashes (see text for match formula). The daily average is about 67% for the month.
ALASKA CLIMATE PROJECT: A MULTI-MODEL ASSESSMENT OF CLIMATE CHANGE IMPACTS ON FISH, FOOD-WEBs, AND FISHERIES IN ALASKA

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TASK II

NOAA SPONSOR
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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

Sixty-four presentations to scientific and non-scientific audiences have been given by Alaska Climate Integrated Modeling (ACLIM) personnel (23 by participants funded by this project). Two papers have been published, one is in press, and two papers are in prep.

Considerable progress has been made with ACLIM towards evaluating “climate-ready” fisheries management approaches in the Bering Sea. This has occurred in collaboration with the North Pacific Fisheries Management Council (the “Council”) through multiple briefings and presentations at Council meetings in 2017, outreach to stakeholders through evening workshops and presentations at the pollock skippers’ meeting, interactive workshop discussions with the Council in May 2017, and a larger comprehensive facilitated workshop held in Seattle in February 2018. Projections of the physical and lower trophic dynamics of the EBS (Eastern Bering Sea) ecosystem, based on CMIP 5 (Coupled Model Intercomparison Project Phase 5) were completed in 2016. Coupling to biological and economic models was conducted in 2017, access to high speed computing resources was initiated in 2017 and are operational, and in early 2018 initial projections of key species and ecosystem condition under “status quo” management actions (including existing control rules and ecosystem cap on total yield) were completed and presented to the council and stakeholders for feedback. This work is presently being summarized in “in prep” publications. This has provided the starting place for iterative and ongoing discussions with the Council and regional stakeholders that have highlighted the following scenarios as important to evaluate in the upcoming months:

1. Sensitivity to future populations and harvest rates under a subset of “climate-ready” harvest control rules;

2. Evaluation of the added value of eco forecasts (<1 year) of ecosystem indicators to providing management with “foresight” into changing conditions;

3. Evaluation of different impacts and adaptive capacity of changing conditions across fishery groups and on-shore based versus offshore processing sectors; and

4. Evaluation of changes in access to subsistence resources.

The following accomplishments were made in FY 17:

1. The project team continued to interpret derived model indices in the context of climate change (i.e., comparison with 20th century hindcast simulation) and inter-model spread. An updated hindcast of the ROMS (Regional Ocean Modeling System) NPZ (nutrient, photoplankton, and zooplankton) model was completed, providing a hindcast that now spans 1970-2017. The hindcast was coupled to CEATTLE (a multi-species stock assessment model) and compared to the previous hindcast; bottom temp, fall and spring zooplankton, and cross shelf transport remain important covariates of recruitment.

2. Jon Reum returned to Hobart, Australia to follow up on previous work with Julia Blanchard on the climate- and species-specific size spectrum model calibration (i.e., refinement of the MIZER model). Two submitted papers outline the novel extensions over earlier versions (e.g., MIZER) that allow representation of key processes of the EBS. These include:
   - A size-structured benthos functional group that is dynamically coupled to pelagic production;
   - Species-specific ontogenetic shifts in pelagic versus benthic habitat preference;
   - Sex-specific fishery selectivities and life history traits; and
• Predation interactions between species calibrated to empirical diet data. The model has been successfully coupled with the ATTACH socioeconomic catch model and initial projections are complete.

3. Alan Haynie and Amanda Faig developed the ATTACH model, which is a socioeconomic model that can couple to the CE-single species, CEATTLE, Sizespectrum, and EBS rpath model to convert ABC (Allowable Biological Catch) to catch using current management constraints and fisher behavior.

ORAL PRESENTATIONS
3. Faig, A.D. “Predicting future management and catch under the Bering Sea and Aleutian Islands ecosystem cap,” 21 Feb 2018, Alaska Fisheries Science Center Mini-AMSS, Seattle, WA.
7. Faig, A.D. “Predicting future management under the BSAI ecosystem cap,” 16 Jan 2018, Alaska Fisheries Science Center Seminar Series, Seattle, WA.
University of New England, Biddeford, ME.


21. Hermann, A. J. and W. Cheng, “Regional modeling and related activities at PMEL”. Lecture and electronic display for visiting high school students, 4 Apr 2017, Pacific Marine Environmental Laboratory, Seattle, WA.


ROLE OF AIR-SEA-LAND INTERACTION IN THE MJO PREDICTION BARRIER OVER THE MARITIME CONTINENT: A CLOUD-RESOLVING COUPLED MODELING STUDY

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TASK III

NOAA SPONSOR
Sandy Lucas – Climate Program Office

NOAA GOALS
Climate Research and Impacts

DESCRIPTION
In this proposed research, we plan to investigate the Madden-Julian Oscillation (MJO) prediction barrier problem. We will treat air-sea-land interaction within the Maritime Continent (MC) region as a centerpiece linking other processes that possibly are crucial to the MJO barrier problem. These processes include the diurnal cycle, land, topography, and atmospheric convection. An important aspect of air-sea-land interaction in the MC is its close connection with the unique land-sea geography, where the local land-sea circulation on the diurnal timescale interacts with the MJO. The focus on air-sea-land interaction is motivated by observational and modeling results that main convection signals of the MJO in the MC are over water, and sea surface temperature and convection of the MC are sensitive to upper-ocean mixing within the MC. We hypothesize that the MJO barrier effect of the MC is exaggerated in models because air-sea-land interaction processes are not adequately represented, even by coupled models of coarse resolutions. We propose to test this hypothesis through modeling experiments using a cloud-resolving coupled atmosphere-ocean model that has demonstrated its capability of reproducing the MJO propagation through the MC.

The general strategy of this study is to first select MJO events that propagated through the MC in observations, but failed in global model forecasts. For a given MJO event, a set of model simulations will be made, with a specific model configuration for each simulation (with or without land, air-sea coupling, tidal mixing, and the diurnal cycle; high- or low-resolution representation of topography; parameterized or explicit atmospheric convection). Through diagnosing these simulations, we will isolate and quantify effects on simulated MJO propagation through the MC by air-sea-land interaction, the diurnal cycle, topography, and treatment of convection. Observations from the Office of Naval Research Propagation of Intra-Seasonal Tropical Oscillations and international Years of the Maritime Continent field campaigns will be used to evaluate coupled model results when they become available during this proposed study.

OBJECTIVES
The objective of this proposed research is to investigate the relative importance of air-sea-land interaction and other processes (the diurnal cycle, tidal mixing, topography, and atmospheric convection) in the MC to MJO propagation through the MC. Results from this study would demonstrate how accurately numerical
models must represent these processes to overcome the MJO prediction barrier problem over the MC.

ACCOMPLISHMENTS
We have made significant progress in both observational data analysis and coupled atmosphere-ocean modeling of the MJO and diurnal cycle. Using the Large-scale Precipitation Tracking method described in Kerns and Chen (2016), we were able to track the MJO events using more than 20 years of satellite data. This capability enabled us to composite the diurnal cycle of precipitation for MJO and non-MJO conditions. We found that the MJO could modulate the diurnal cycle substantially. This result was summarized in a peer-reviewed publication of Kerns and Chen (2018) that was recently accepted for publication by the Journal of Geophysical Research - Atmospheres.

To test the science hypothesis of this study, we have conducted three numerical experiments using the coupled atmosphere-ocean model. We first conducted a control coupled model simulation of the MJO event in November 2011, which propagated into the MC region. Two additional simulations were conducted to investigate the effects of the complex topography and landmass on the diurnal cycle and the MJO, respectively. We flattened the mountains over the large islands in the first experiment, whereas the landmass was replaced with water surface in the second experiment. We found that the diurnal cycle of precipitation was strong over land in the control and first experiment and the MJO did not propagate through the MC to the eastside as observed. When the land was replaced with water, the diurnal cycle of precipitation has a nighttime maximum as observed over the open ocean. The MJO propagated through the MC in the second experiment. These results support our hypothesis that the strong diurnal cycle over land in the MC is disruptive to the MJO eastward propagation. This result was presented at the 2017 American Geophysical Union (AGU) Fall meeting, and can be accessed from the AGU website (Savarin and Chen 2017). We are in the process of writing a manuscript for publication.
ARCTIC PROJECT

PI
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TASK II

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Jeremy T. Mathis – Arctic Research Program/Climate Program Office
Sandy Starkweather - Climate Program Office

OTHER NOAA PERSONNEL
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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.

The NOAA goals associated with our projects are:

Among the six prioritized elements below from NOAA's 2011 “Arctic Vision and Strategy” document, Pacific Marine Environmental Laboratory (PMEL)/JISAO are leaders in elements 1, 2 and 5:

1. Forecast sea ice on time scale from a few days to multi-decades, and at sub-seasonal to seasonal (S2S)
2. Strengthen foundational science to improve our understanding and to detect Arctic climate and ecosystem changes
3. Improve weather and water forecasts and warnings
4. Enhance international and national partnerships
5. Improve stewardship and management of ocean and coastal resources in the Arctic

6. Advance resilient and healthy Arctic communities and economies

PROJECT AREAS

1. Arctic Change Detection: We continue to improve our understanding on recent rapid changes in the Arctic, with special focus on climate impacts of sea ice loss, the connection of Arctic sea-ice loss and mid-latitude weather events, and evaluation of future projections of sea ice in the Pacific Arctic. 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 (AMAP). Muyin Wang (JISAO) and J.E. Overland (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 2017.

   b. The Sea Ice Outlook – The Sea Ice Outlook builds a community consensus of the sea ice retreat season. The second phase of Sea Ice Prediction Network (SiPN2) continues with additional funding from NSF. Wang and Overland have served as members of the leadership team since 2014 and will continue to play these roles. Based on data acquired by the Arctic Heat project, the PMEL Arctic group issued a successful long range S2S sea-ice freeze-up projection for an operational area northwest of Icy Cape adjacent to oil industry lease blocks in the Chukchi Sea in 2017.

   c. Coupled Climate Models Assessments – We continue our efforts of climate model assessment and evaluations with a focus on the pan-Arctic as well as the sub-Arctic Seas (e.g., the Chukchi, Beaufort, Bering, and Barents seas), on sea ice, surface air temperature, and other atmospheric forcing fields. We are preparing for the CMIP6 assessments, and have been working with modeling centers to set up direct data transfer.

   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. We identified two distinct patterns – the Alaskan Ridge and the Greenland-Baffin Bay Blocking – which are associated with the extreme cold temperature anomalies in the Northeast American winter.

   e. Data Recovery – Arctic sea-ice and weather data recovery is proceeding at pace. The primary historical sea-ice data set for the Pacific Arctic is in the process of editing and re-navigation, with more than 50,000 new-to-science sea ice observations recorded so far for the period 1879-1955. Collaborators (Brohan, United Kingdom Met Office; Compo CIRES/ESRL) continue to lead quality-control and data set integration of weather observations into the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) and the International Surface Pressure Data Bank (ISPD).

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

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

   b. Historical analysis of Pacific Arctic region climate, developing data rescue, and analyses products for the region.
c. The Bering Climate Website (beringclimate.noaa.gov) is maintained and updated annually.

ACCOMPLISHMENTS

1. Arctic Sea Ice – We continue our ongoing research on the past, present, and future climate of the Arctic. This work represents an important foundation for the Arctic Report Card (arctic.noaa.gov/Report-Card/Report-Card-2017). This year’s edition showed that Arctic mean annual air temperature continues to increase at a rate of warming that is more than twice the rate of the global mean. Persistent warming trend and loss of sea ice are triggering extensive Arctic changes. The average annual surface air temperature anomaly over land north of 60° N for October 2016-September 2017 was the second warmest since 1900. Other highlights include: the sea ice cover continues to be relatively young and thin with older, thicker ice comprising only 21% of the ice cover in 2017 compared to 45% in 1985; In August 2017, sea surface temperatures in the Barents and Chukchi seas were up to 4°C warmer than average, contributing to a delay in the autumn freeze-up in these regions.

2. CMIP5 model assessment over the Arctic on ice and atmosphere – Wang and the team expanded their study to finer time scales, with a focus on sea-ice duration, sea-ice freeze-up and break-up dates in the Pacific Arctic. A manuscript has been published in Deep Sea Research II. We also evaluated the atmospheric temperature change in the Arctic and compared it with global means. The results show that the warming in the Arctic is twice as much as the global mean, and the signal is even bigger in the winter season (November to March). The result is published in Snow, Water, Ice, Permafrost in the Arctic – 2017.

3. Arctic Heat Open Science Project. Arctic Heat Open Science Experiment – In 2017 we continued our airborne R&D campaign in Alaska between May and September, in collaboration with the Innovative Technologies for Arctic Exploration program and the Woods Hole Oceanographic Institution. On the basis of data collected by autonomous floats deployed by the project we were able to issue our first long range S2S freeze-up projection. In 2018 we will continue developing collaborations within NOAA and across agencies, including the Office of Naval Research Stratified Ocean Dynamics of the Arctic program, as part an Office of Science and Technology Policy initiative. The first results flowing from Arctic Heat have been published in the Bulletin of the American Meteorological Society (journals.ametsoc.org/doi/abs/10.1175/BAMS-D-16-0323.1), and presented at the annual Alaska Marine Science Symposium in January 2018. See also: pmel.noaa.gov/arctic-heat/.


5. Kevin Wood (JISAO) continues his leadership role in the joint imaging program at the U.S. National Archives and elsewhere. Weather collected via the Old Weather Citizen-Science Program continues to be quality-controlled and integrated into global data sets (ICOADS and ISPD). The sea-ice dataset for the Pacific Arctic is nearing completion and will be published in 2018. To date more than 50,000 new-to-science ice observations have been extracted. In 2017, Wood successfully competed for a 3-year grant from the Council on Library and Information Resources and the Andrew W. Mellon Foundation to continue digital imaging of primary source documents at the National Archives (archives.gov/press/press-releases/nr18-24).

6. Wang continued to serve as USCLIVAR PPAI panel member and Arctic Mid-Latitude working group member. A white paper, entitled “Arctic Change and Possible Influence on Mid-Latitude Climate and Weather,” has been published with Overland and Wang as co-authors.
ENVIRONMENTAL CHEMISTRY
ATMOSPHERIC CHEMISTRY – AEROSOL PROGRAM

PI
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TASK II

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NOAA GOALS
Climate Adaptation and Mitigation
Weather-Ready Nation

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

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

ACCOMPLISHMENTS
We participated in the third and fourth North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) cruises aboard the R/V Atlantis in September 2017 and March/April 2018. 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 and the Marine Aerosol Reference Tank (MART) to measure the physical, chemical, optical and cloud nucleating properties of these SSA, to compare these measurements to measurements of ambient atmospheric aerosols, and to ultimately assess the contribution of SSA to the CCN population in the marine boundary layer. Sea Sweep was deployed at five stations along the cruise tracks. Near continuous ambient aerosol and gas sampling was conducted between Sea Sweep stations. Preliminary results show that the CCN activity of SSA was roughly half that of NaCl, as a result of the organic component in the sub 180 nm aerosol.

The PMEL/JISAO Unmanned Aircraft System (UAS) aerosol payload was rebuilt this year, and now includes a printed optical particle spectrometer (POPS). The POPS measures the aerosol number size distribution.
The payload also now includes a miniature sun photometer that makes continuous almucantar scans to measure solar irradiance and sky radiance in four wavelength bands. These new instruments were developed at NOAA's Earth Systems Research Lab Chemical Sciences Division in Boulder, CO. Work continues with Latitude Engineering on developing the 55-pound vertical take-off fixed wing UAS.

MARINE CARBON PROGRAM

PI
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TASK II

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

DESCRIPTION
The Marine Carbon Program provides a mechanism for research collaboration between the 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 (CO₂) and climate. The program focuses on multidisciplinary research involving atmosphere-ocean CO₂ exchange fluxes, water column CO₂ distributions and transport, data interpretation and modeling, and ocean acidification (OA). Special emphasis is placed on the continuing effort to enhance our understanding of the role of the ocean in sequestering the increasing burden of anthropogenic CO₂ in the atmosphere, and the changes that are occurring due to OA. Project goals include: 1) determining the air-sea exchange of CO₂ from measurements collected on research ships, volunteer observing ships, and moorings; 2) determining the distribution and transport of CO₂ into the ocean interior from measurements collected onboard NOAA and University-National Oceanographic Laboratory System research ships; and, 3) determining the extent of the chemical changes that are occurring in the oceans as a direct result of OA.
OBJECTIVES
1. Perform a variety of essential functions and provide equipment for analyses on a Pacific Ocean (P06) cruise and a Pacific sector of the Southern Ocean (S04P) cruise: the carbon group supplied dissolved inorganic carbon (DIC) analysts (Collins) for both of these cruises in 2017/2018.

2. Service 36 CO$_2$ and OA 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 CO$_2$ systems: we maintain four underway and two shore-based CO$_2$ systems that require regular servicing.

4. Collect and analyze discrete samples from 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 to deploy autonomous sensors in shellfish hatcheries.

5. Use newly-implemented carbon variables in a regional seasonal forecast system (J-SCOPE) to provide seasonal OA forecasts, and to develop OA indices for shellfish and crabs in the region.

6. Prepare for the I07 and I06 GO-SHIP cruises which depart imminently and mid 2018/2019 respectively. JISAO scientists are serving on these cruises as technicians and analysts.

ACCOMPLISHMENTS
1. Data collection and QC objectives were completed for both the P18 (2016/2017) and P06 cruises. Final data have been submitted to national repositories and are available on the CCHDO.ucsd.edu data portal.

2. Maintained and submitted data from four underway pCO$_2$ systems.

3. Maintained and processed data from 36 moored CO$_2$ systems. Prepared to deploy one additional moored system in the Chesapeake Bay in 2018/2019.

4. Maintained pCO$_2$ systems within the laboratory and located at the Seattle Aquarium used for research and as part of a community outreach effort, respectively.

5. Continued analyzing discrete samples collected on a number of cruises conducted with our collaborators including samples collected in partnership with WOAC; sampling the Newport Hydrographic Line with Oregon State University and 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 OA surveys conducted by scientists at the Pacific Islands Fisheries Science Center around many of the remote island chains in the Pacific Ocean.

6. Developed and refined algorithms for global pH, NO$_3^-$, and total titration seawater alkalinity estimation.
from other measured seawater properties (Carter et al. 2017b). This effort involved a major synthesis of seawater pH measurements (Figure 1) that has since inspired a Scientific Committee on Oceanic Research (SCOR) Working Group proposal for improving carbonate measurement-calculation comparability.

7. Assessed the performance of a prototype $p_{CO_2}$ optical sensor on a Profiling Crawler (PRAWLER) mooring by comparing measurements to $p_{CO_2}$ estimated with a regional algorithm as well as $p_{CO_2}$ from nearby moorings (Figure 2). The data allowed for insight into the dynamics of summer upwelling of deep, corrosive waters. Results were presented at Ocean Sciences 2018 in Portland, and a manuscript is in preparation.

8. Extended a recent analysis of data from GO-SHIP Repeat Hydrography sections P02 and P16 quantifying anthropogenic contributions to DIC and OA (Carter et al. 2017a) to include data from 13+ hydrographic sections over 25 years (figure 3). These results have been presented at Ocean Sciences 2018, and will be submitted for publication early in 2018/2019.

9. Used historical simulations of carbonate parameters from the JSCOPE model to determine the exposure history of pteropods to corrosive waters, and from that infer the impact of past exposure on pteropod sensitivity to experimental stress responses (Bednaršek et al. 2017).


11. Contributed to or led publications comparing the impacts of remineralized CO$_2$ in hypoxic waters in the Gulf of Mexico to off the U.S. West Coast (Feely et al. 2018), a synthesis of sensor assessments completed on behalf of XPRIZE (Okazaki et al. 2017), and an assessment of variability associated with moored $p_{CO_2}$ observations (Sutton et al. 2017).
REFERENCES


Figure 3. Anthropogenic carbon distributions estimated along 14 Pacific sections in 2015. This synthesis of 25 years of repeat hydrography was presented at Ocean Sciences 2018, and is expected to be submitted for publication in early 2018/2019.
CARBONATE MINERAL SATURATION STATES IN ALASKAN WATERS FROM CESM LARGE ENSEMBLE SIMULATIONS

PI
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TASK II

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NOAA GOALS
Climate Adaptation and Mitigation

DESCRIPTION
The project goal is to examine aragonite and calcite saturation states in the Alaskan waters (including the Gulf of Alaska, Bering Sea, and Chukchi Sea) simulated by the Community Earth System Model (CESM) large ensemble for years 1920-2080. CESM is a well-established global earth system model with interactive ocean, sea ice, and land processes. This project provides a large-scale context for regional biochemical interactions in the Alaskan waters. In particular, we focus on understanding spatial (horizontally and vertically) and temporal (from seasonal to decadal) variability of carbonate chemistry in the coupled system, and quantifying uncertainties in future projections associated with natural variability.

OBJECTIVES
1. Quantify across-region differences in aragonite and calcite saturation states and identify spatial ‘hot spots’ of undersaturation.
2. Examine how the above ‘hot spots’ change seasonally and interannually, and ascertain their forcing mechanisms.
3. Quantify the uncertainties of future projections, and identify critical temporal thresholds.
4. Compare the large-scale simulations with regional high-resolution modeling results.

ACCOMPLISHMENTS
We have identified key metrics for examining carbonate chemistry and grouped them into three different categories: 1) across-shore patterns in seasonal and interannual changes, 2) vertical movement of saturation horizon, and 3) saturation state at the ocean bottom as an indicator for potential habitat loss. Quantification of these metrics will be summarized in a forthcoming paper. We also collaborated extensively with Bob Stone at the Alaska Fisheries Science Center in Juneau to apply the above metrics to an analysis of the relative resilience of Alaskan coral communities to ocean acidification.
PROJECTED CHANGES IN CARBON CYCLING AND ARAGONITE SATURATION IN THE BERING SEA

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TASK II

NOAA SPONSOR
Jessica Cross – Pacific Marine Environmental Laboratory

NOAA GOALS
Climate Adaptation and Mitigation

DESCRIPTION
This project adds carbonate chemistry to an existing biogeochemical model for the Bering Sea (Bering10k) in order to improve understanding of carbon cycling and ocean acidification. The project will produce a 10-year hindcast model simulation (2003 – 2012) and multiple future projection simulations up to 2100, using dynamical downscaling forced by output from multiple Earth System Models (ESMs) and their RCP 8.5 (representative concentration pathway) and RCP 4.5 scenarios. The model hindcast will be used for model validation and to determine the underlying, baseline carbon cycle and extent of waters with an aragonite saturation state ($\Omega_{\text{Arag}} < 1$, indicating corrosive conditions. The future projections will provide much finer spatial resolution compared to ESM projections and elucidate critical threshold years. The range in model scenarios will provide uncertainty bounds for the projections.

OBJECTIVES
2. Use the hindcast to determine the spatial pattern and extent of aragonite under-saturation and the underlying physical and biological mechanisms.
3. Quantify the impact of inter-annual variability on $\Omega_{\text{Arag}}$, specifically between the warmer, low sea ice extent years (2003 – 2005) and the colder, greater sea ice extent years (2010 – 2012).
4. Determine how these processes change under scenarios of future climate change and quantify the change in $\Omega_{\text{Arag}}$.

5. Compare the change in $\Omega_{\text{Arag}}$ to additional marine stressors such as warming water temperatures and decreased subsurface oxygen concentrations.

ACCOMPLISHMENTS
Carbonate chemistry and oxygen cycling were successfully added to the Bering10k model, and the hindcast simulation was completed. Model comparisons to observed data suggest that the model is skillful at reproducing carbon chemistry variables. Analysis of the hindcast illustrates that regions on the inner Bering Sea shelf near the Yukon River Delta experience persistent corrosive water conditions of $\Omega_{\text{Arag}} < 1$ (Figure 1). This results from Yukon River inflow supersaturated with carbon. Conversely, the outer Bering Sea shelf has much greater $\Omega_{\text{Arag}}$ values due to significant fixation of carbon by phytoplankton. A statistically significant trend of decreasing $\Omega_{\text{Arag}}$ is also present on the Bering Sea shelf, caused by an increase in water carbon concentration (Figure 2). These results are being prepared in an upcoming manuscript (Pilcher et al., in prep).

This project also supported an undergraduate, NOAA Hollings Scholar Danielle Naiman, during the summer of 2017. Naiman worked with output from the model hindcast to illustrate the underlying mechanisms of spatial variability in $\Omega_{\text{Arag}}$ and differences between the warm and cold regimes. She won an award for her presentation of this work at the student symposium at NOAA Headquarters. She also presented at the Eastern Pacific Ocean Conference and at Ocean Sciences 2018. She is the second author on an upcoming manuscript (Pilcher et al., in prep).
CHLOROFLUOROCARBON TRACER PROGRAM

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TASK II

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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 CO₂, increased significantly in the global atmosphere during the past century. Sea surface CFC concentrations and their history are well understood, so ocean interior CFC concentrations can be used to quantify how much of the ocean communicates with the atmosphere and how quickly. 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 CO₂ and heat. These tracer data can be used to estimate the rates and pathways of ocean circulation and mixing processes and as a means of evaluating numerical models of ocean circulation. The development and testing of such models is critical for understanding the present state of the ocean-atmosphere system, in quantifying the role of the oceans in the uptake of climatically important trace gases such as CO₂, and improving predictions of climate change for the upcoming century. Finally, the tracer data themselves have made important contributions to data-based estimates of oceanic uptake of anthropogenic CO₂, decadal ventilation timescales, changes in ventilation, and ocean biological cycling rates.

To enhance the utility of ocean CFC measurements, our group has pioneered efficient methods for measuring sulfur hexafluoride (SF₆) in the ocean interior (Bullister and Wisegarver, 2008), and the use of simultaneous determinations of independent transient tracers in the ocean to estimate mixing in the ocean interior, and its impacts on transient tracer ages (Sonnerup, 2001, Bullister et al., 2006). The simultaneous use of two transient tracers to account for the effects of mixing provides improved accuracy in estimating ocean CO₂ uptake and ocean acidification from CFCs (Sonnerup et al., 2008). In addition, the availability of concurrent CFC and SF₆ measurements now makes it possible to estimate circulation rate changes from transient tracers, and provide carbon remineralization rates in the ocean interior that can be used as benchmarks to evaluate carbon export rates from overlying surface waters (Sonnerup et al., 2013; 2015). A further refinement to our measurement techniques also allows for precise measurements of dissolved nitrous oxide (N₂O) in seawater. Because N₂O plays an important role in the marine nitrogen cycle, this affords an opportunity to use the tracer and N₂O measurements in combination to estimate key rates of denitrification in the ocean.

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

2. Use CFC and SF$_6$ observations to improve estimates of the uptake of anthropogenic carbon dioxide in the ocean.

3. Use CFC and SF$_6$ observations to quantify oxygen utilization rates in the ocean interior.

4. Use combined CFC and SF$_6$ observations as a means of testing and evaluating large-scale numerical models of the ocean.

5. Use 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 expedition I-07 as part of the global CLIVAR/GO-SHIP Repeat Hydrography Program.

7. Quantify regional oceanic denitrification rates via dissolved nutrients, N$_2$O and CFC/SF$_6$ observations.

8. Identify dominant biological metabolic pathways controlling the distribution of marine dissolved N$_2$O.
ACCOMPLISHMENTS
1. Updated the system control and data analysis software for the PMEL CFC laboratory.
2. Prepared the NOAA CFC lab with updated systems for a long deployment in the Indian Ocean.
3. Finalized the PMEL bottle data management system to allow streamlined data management on NOAA-led hydrographic cruises.
4. Submitted a manuscript on ventilation timescales and oxygen and fixed nitrogen consumption rates in the eastern tropical South Pacific based on a dataset collected in 2013.
5. Evaluated methods to determine oxygen utilization rates and denitrification rates from tracers using a state-of-the-art ocean model.
6. Developed standard code for the invasion of SF$_6$ into ocean models and furnished these to national climate modeling centers like the Geophysical Fluid Dynamics Laboratory and the National Center for Atmospheric Research, where they are included in the climate model intercomparison project CMIP.
7. Evaluated the ocean component of an earth system model using its uptake of CFCs and SF$_6$.

RESEARCH HIGHLIGHT
N$_2$O is a trace atmospheric gas that plays an important role in Earth's climate. In the troposphere, it exerts strong radiative forcing, and in the stratosphere, is involved with the depletion of the ozone. N$_2$O is relatively long-lived in the troposphere (114 – 120 years, Prather, 2002), and is currently increasing at a rate of $\sim$0.25% yr$^{-1}$ (Saikawa et al., 2014) from its preindustrial value of 270 ppb (parts per billion) to $\sim$325 ppb at present. The ocean's role in this change is unknown.

The ocean is a significant source of N$_2$O to the atmosphere (Saikawa et al., 2014). However, both the magnitude and production mechanism of marine N$_2$O are uncertain. The highest N$_2$O levels, and thus inferred oceanic N$_2$O production, correspond with oxygen deficient zones.

Climate change may result in changes in the magnitude and intensity of oceanic oxygen deficient zones, as well as changes in oceanic ventilation rates and patterns of productivity, all of which can significantly affect marine N$_2$O production. Understanding how the marine N-cycle will respond to changes in climate and circulation relies on a solid understanding of how the present-day marine N-cycle works.

At PMEL, we have modified our purge/trap analytical system for dissolved CFCs and SF$_6$, such that we also extract, isolate, and concentrate dissolved N$_2$O, quantifying it on an electron capture detector to approximately 1.5% on all samples collected for CFC/SF$_6$ analysis. In 2017, we completed the third of three meridional sections in the Pacific Basin measuring dissolved N$_2$O concentrations. These measurements provide a baseline against which future observations can be compared, and datasets of unprecedented quality and coverage for understanding the present-day marine N$_2$O cycle.
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) array 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 (GTMB). 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 autonomous temperature line acquisition system (ATLAS) and Tropical Flex (T-Flex) surface moorings and maintain acoustic Doppler current profiler sub-surface moorings in RAMA.
3. Develop new moored observing technologies to enhance and sustain climate quality observations in the tropical oceans.
4. Improve understanding of ENSO variability in the Pacific.
5. Advance understanding of the seasonal variability in the Indian Ocean.
7. Improve understanding of ENSO impacts on extreme weather events worldwide.

ACCOMPLISHMENTS
1. Research carried out at JISAO and elsewhere using data from the TAO/TRITON, PIRATA and RAMA arrays depends critically on the collection, quality control, archival, and web-based display and dissemination of mooring data sets. At JISAO, considerable effort is devoted to providing easy access to high quality multi-variate time series through the TAO web page pmel.noaa.gov/gtmba/. Between April 1, 2017 and March 31, 2018, GTMBA web pages received more than 19 million hits, delivered more than 1.9 million mooring data files via the web, and more than 3.7 million files via file transfer protocol (FTP) to the international community.

2. RAMA principal investigators in the U.S., China, India, and Japan have proposed a revised array design referred to as RAMA-2.0 in the context of the 2017-18 Indian Ocean Observing System (IndOOS) review. This redesign is intended to make the array more robust, cost-effective, and less dependent on ship time, which is the most limiting resource for sustaining the array. RAMA-2.0 has fewer moorings than the original design and eliminates moorings in regions prone to heavy fishing, vandalism, or where it has not been possible to find reliable ship support. As part of the initial IndOOS review process the RAMA-2.0 proposal has been accepted by the IndOOS review panel, but not formally documented for final endorsement by the IndOOS review community. We are proceeding for practical reasons with adoption of the RAMA-2.0 strategy. These updates represent progress in developing RAMA, which is now 82% complete, with 27 of 33 planned RAMA-2.0 moorings in place.

3. As the ATLAS system ages, several key components have gone out of production and replacements have been difficult to locate. At the same time, new and improved sensors have become commercially available. PMEL has developed a new instrument system, dubbed 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. Eighteen sites (10 in PIRATA and 8 in RAMA) are now occupied with T-Flex systems.

4. In early 2014, strong westerly wind bursts and high heat content in the equatorial Pacific favored development of a major El Niño. However, significant coupling between the Pacific Ocean and atmosphere failed to take hold during boreal summer of 2014 such that only borderline El Niño conditions were evident by the end of the year. Observational analysis suggests that warm sea surface temperatures (SSTs) in the Indian Ocean in 2014 weakened westerly wind anomalies in the Pacific and may have helped to arrest the development of the El Niño. We test this hypothesis using an ensemble of coupled numerical experiments in which observed Indian Ocean SST anomalies in 2014–15 are prescribed but the Pacific Ocean-atmosphere system is free to evolve. Results confirm that warm SST anomalies in the Indian Ocean created conditions that would have favored a weakening of El Niño by suppressing the Bjerknes feedback in boreal summer of 2014. This process does not preclude others that have been proposed in the unusual evolution of El Niño SSTs in 2014, but it adds to the list a forcing mechanism
5. This study investigates the seasonal cycle of meridional currents in the upper layers of central equatorial Indian Ocean using acoustic Doppler current profiler (ADCP) and other data over the period 2004–2013. The ADCP data set collected along 80.5°E is the most comprehensive collection of direct velocity measurements in the central Indian Ocean to date, providing new insights into the meridional circulation in this region. We find that mean volume transport is southward across the equator in the central Indian Ocean in approximate Sverdrup balance with the wind stress curl. In addition, mean westerly wind stress near the equator drives convergent Ekman flow in the surface layer and subsurface divergent geostrophic flow in the thermocline at 50–150 meter depths. In response to a mean northward component of the surface wind stress, the maximum surface layer convergence is shifted off the equator to between 0.5° and 1°N. Evidence is also presented for the existence of a shallow equatorial roll consisting of a northward wind-driven surface drift overlaying the southward directed subsurface Sverdrup transport. Seasonal variations are characterized by cross-equatorial transports flowing from the summer to the winter hemisphere in quasi-steady Sverdrup balance with the wind stress curl. In addition, semiannually varying westerly monsoon transition winds lead to semiannual enhancements of surface layer Ekman convergence and geostrophic divergence in the thermocline. These results quantify expectations from ocean circulation theories for equatorial Indian Ocean meridional circulation patterns with a high degree of confidence given the length of the data records (Wang and McPhaden, 2017).

6. Multidecadal shifts in ENSO variability have been observed, but it is unclear if this variability is just a random variation in the ENSO cycle or whether it is forced by other modes of climate variability. Here we show a strong influence of the Atlantic on the multidecadal variability of ENSO. The AMO is the dominant mode of multidecadal SST variability in the Atlantic Ocean. Changes in AMO-related tropical Atlantic SSTs are known to force changes in the Walker circulation in the tropical Pacific Ocean. Using conceptual and coupled model experiments, we show that these changes to the Walker circulation modify ENSO stability on both annual and multidecadal time scales leading to a distinctive pattern of multidecadal ENSO variability that we find in observations and ocean reanalyses (Levine and McPhaden, 2017).

7. ENSO is the most prominent year-to-year climate fluctuation on Earth, alternating between anomalously warm (El Niño) and cold (La Niña) SST conditions in the tropical Pacific. ENSO exerts its impacts on remote regions of the globe through atmospheric teleconnections, affecting extreme weather events worldwide. However, these teleconnections are inherently nonlinear and sensitive to ENSO SST anomaly patterns and amplitudes. In addition, teleconnections are modulated by variability in the oceanic and atmospheric mean state outside the tropics and by land and sea ice extent. The character of ENSO as well as the ocean mean state have changed since the 1990s, which might be due to either natural variability or anthropogenic forcing, or their combined influences. This has resulted in changes in ENSO atmospheric teleconnections in terms of precipitation and temperature in various parts of the globe. In
addition, changes in ENSO teleconnection patterns have affected their predictability and the statistics of extreme events. However, the short observational record does not allow us to clearly distinguish which changes are robust and which are not. Our analysis of climate model simulations suggest that ENSO teleconnections will change because the mean atmospheric circulation will change due to anthropogenic forcing in the 21st century, which is independent of whether ENSO properties change or not. However, future ENSO teleconnection changes do not currently show strong intermodel agreement from region to region, highlighting the importance of identifying factors that affect uncertainty in future model projections (Yeh et al., 2018).

REFERENCES


GO-SHIP REPEAT HYDROGRAPHY: NUTRIENTS

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**NOAA GOALS**
Healthy Oceans

**DESCRIPTION**
The Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP) is a systematic and global reoccupation of select hydrographic sections to quantify changes in storage and transport of heat, fresh water, carbon dioxide (CO₂), 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 GO-SHIP Program reveals much about internal pathways and changing patterns that impact 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 meters, 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
The objectives of this project are:

1. To make high-quality measurements of inorganic nutrient (nitrate, nitrite, phosphate, and silicate) concentrations in seawater on GO-SHIP 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 and quality control and submission of nutrient data collected during the repeat hydrographic line P18 in the Pacific Ocean. On P18, 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 casts. Final data is now available at the CLIVAR & Carbon Hydrographic Data Office website (cchdo.ucsd.edu/cruise/33RO20161119). In addition, preparations were made for occupation of the repeat hydrographic line I07N in the Indian Ocean.
ALASKA FISHERIES SCIENCE CENTER INTERNSHIP OPPORTUNITIES

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NOAA GOALS
Healthy Oceans
Resilient Coastal Communities and Economies

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

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

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

Tarenina Max (center, wearing the black UW sweatshirt) with her research team at the Alaska Fisheries Science Center.
ACCOMPLISHMENTS
The two interns were placed with research mentors based at AFSC. Carter Johnson of the University of Washington worked with the Marine Mammal Laboratory to analyze aerial survey images of sea ice looking for the presence of seals and polar bears to quantify the abundance and distribution of the mammals. Tarenina Max from San Juan College also worked with the Marine Mammal Laboratory doing passive acoustic monitoring of bowhead whales in the Chukchi Sea to help researchers understand distribution and migration patterns of the whales. The students produced 2-minute videos and conference-quality posters that were presented at a forum at the end of the summer session.

ECOSYSTEMS AND FISHERIES-OCEANOGRAPHY COORDINATED INVESTIGATIONS (EcoFOCI)

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NOAA GOALS
Healthy Oceans
Climate Adaptation and Mitigation

DESCRIPTION
Ecosystems and Fisheries-Oceanography Coordinated Investigations (EcoFOCI) continued to maintain a biophysical mooring array on the eastern Bering Sea shelf, conduct hydrographic surveys, deploy satellite-tracked drifters, and supplement research efforts with new technologies to monitor the large marine ecosystems of Alaska. In 2016, dedicated surveys in the Bering Sea to study the progression of ocean heating and ecosystem response yielded surprising results; that not all warm stanzas in the Bering Sea are the same.
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 instrumentation on moorings to measure ice keel depth, zooplankton abundance, nitrate, and oxygen; and introducing new technology to enable these moorings to report in real time.

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

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

4. Projecting impacts of a changing climate – JISAO scientists are involved in an effort to apply simulations of future climate to issues related to marine ecosystems. The output from these models is being used to force local dynamical models of the North Pacific and Bering Sea, and to make projections based on empirical methods.

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

ACCOMPLISHMENTS
1. EcoFOCI continues to maintain observational infrastructure such as the biophysical mooring array on the eastern Bering Sea shelf (mooring sites M2, M4, M5, and M8), conduct hydrographic surveys, and deploy satellite-tracked drifters. 2017 marked the 23rd consecutive year of observations at the M2 mooring. EcoFOCI also continues the use of Argos drifters, research cruises, and most recently, new technologies to collect data in the large marine ecosystems of Alaska.

2. The EcoFOCI Program continues to conduct comprehensive ecosystem surveys and provide scientific results for inclusion in critical documentation used by stakeholders. FY17 saw one of the most ambitious field efforts ever – with a large presence in four out of five of Alaska’s large marine ecosystems. To provide the necessary data to make informed management decisions, NOAA research and fisheries scientists worked together to conduct in-the-field science, on over 20,000 nautical miles traveled aboard research ships. Fifty-three biophysical moorings were deployed and recovered, 492 key stations were sampled for conductivity, temperature and depth, and 11 drifters were deployed.
deployed – totaling an effort of 969 person at-sea days.

3. EcoFOCI scientists continue disseminating data through websites, presentations, publications, and workshops. In 2017, EcoFOCI JISAO scientists prepared 21 publications (8 published, 13 in progress) related to the work outlined here. Scientists also participated in a variety of presentations and workshops including the Alaska Marine Science Symposium – Anchorage (January 2018), and AGU Ocean Sciences – Portland (February 2018).

4. In 2017, EcoFOCI, under the umbrella of the North Pacific Climate Regimes and Ecosystem Productivity program, provided key scientific information that enabled effective management and sustainable use of Alaska marine resources. Ecosystem science in 2016 and 2017 directly influenced decision-making by the North Pacific Fishery Management Council in determining the Alaska walleye pollock total allowable catch, and contributed to the Alaska Marine Ecosystems Considerations Report used by the Council and other stakeholders to evaluate current ecosystem status and project near-future conditions.

5. EcoFOCI scientists completed two publications covering the return of warm conditions in the southeastern Bering Sea that document development of an anomalous warm stanza over the shelf, the mechanisms of warming, and the ability of young walleye pollock to refuge from warm conditions, which is key to cohort success during prolonged warm phases. EcoFOCI is poised to continue advancing ecosystem science in the North Pacific to understand and predict changes in climate, weather, and oceans, and to share that knowledge with scientists, managers, stakeholders, and the public. JISAO employees play an integral role in the success of this work.

6. The first field season of the Arctic Integrated Ecosystem Research Program (funded by the North Pacific Research Board) was completed during the summer/fall of 2017. EcoFOCI deployed and recovered over 25 moorings, deployed drifters, and conducted shipboard sampling of the physical and biological environment in the Chukchi Sea. The objective of this multi-institutional, multi-disciplinary program is to understand how reductions in Arctic sea ice and the associated changes in the physical environment influence the flow of energy through the ecosystems of the Chukchi and Beaufort seas. A principal investigator meeting was held March 6-8, 2018 in Anchorage to discuss preliminary results from the first field season, to plan research directions and manuscripts, and to plan future field work. EcoFOCI scientists led the Oceanography and Lower Trophic Level Productivity portion of the program.

7. The Synthesis of Arctic Research (SOAR) project is a 7-year Bureau of Ocean Energy Management (BOEM) supported effort to bring together a multidisciplinary group of Arctic scientists and residents to explore and integrate information from completed and ongoing marine research in the Pacific Arctic. With continued support from BOEM, a second phase building on and extending synthesis topics is now nearing completion, with a final special issue expected for publication in summer 2018. This issue will include 16 papers co-authored by a wide range of specialists and local experts. A total of 74 unique individuals are authors or co-authors of these synthesis papers, representing 40 institutions from 10 different nations, spanning university departments, federal, state, and local governments, resource-specific co-management groups, conservation organizations, private industry, and others. Authors from JISAO contributed to several papers in this forthcoming special issue.


9. EcoFOCI scientists continue to make data and analysis results available. The scientists are active in ongoing efforts toward modernizing EcoFOCI data formats and storage infrastructure. Success from a small-scale prototype of NetCDF file-conversions in FY2016 is being expanded to encompass additional data. These updates increase EcoFOCI data functionality for external data users, and are accessible using dominant software tools.
10. EcoFOCI scientists continue to develop and enhance a database-driven information portal, providing multi-layered access to EcoFOCI field data collection details such as research instrument, cruise, and station information. This interface utilizes new web technologies and provides limited mapping and plotting capabilities. The portal is an integral tool for field-season planning and is imperative to the success of the EcoFOCI field programs. The database also provides well-formed information towards ISO-compliant (International Organization for Standardization) metadata documents.

11. EcoFOCI continues to collaborate 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 complement to EcoFOCI data-collection and research.

12. The Arctic Whale Ecology Study completed its final field year in 2016 alongside the Chuckchi Acoustics, Oceanography, and Zooplankton Extension study, both focusing on specific regions in the Chukchi Sea. EcoFOCI conducted physical and biological oceanographic sampling and data collection to support the project’s objectives. The final reports will be available in 2018 through BOEM.

13. EcoFOCI continues to work with projecting impacts of climate change including sea ice predictability in the U.S. Arctic. These scientists are active participants of the Sea Ice Prediction Network (phase II) leadership team.

14. A JISAO post-doc working with EcoFOCI scientists integrated into a numerical model a 10-year synthesis of data investigating the distributional shifts of groundfish to anomalous ocean conditions. This study focused on the recent anomalously warm period (2014-2016) based on the bottom trawl survey in the Gulf of Alaska collected during 10 summers between 1996 and 2015. A manuscript titled “How ‘The Blob’ affected ground-fish distributions in the Gulf of Alaska” is in preparation.

15. EcoFOCI continued a 4-year partnership with the PMEL/JISAO program Innovative Technology for Arctic Exploration in 2017. EcoFOCI scientists provided oceanographic data analysis and expertise for technologies such as the saildrone, Alamo float, Oculus coastal glider, and Prawler. EcoFOCI also provided in-kind support for field deployment ship time.

16. EcoFOCI continues the past decade of partnership with the Arctic Climate Change program at PMEL
focusing on atmosphere-oceanography-sea ice relationships in the Arctic region, including the sub-Arctic Chukchi, Beaufort, and Bering seas. In a large collaboration, they lead ongoing research on the past, present, and future climate of the Arctic. This work represents an important foundation for the Arctic Report Card (arctic.noaa.gov/report-card).

17. EcoFOCI scientists continue to contribute research resulting in the Alaska Marine Ecosystem Status Reports for the Stock Assessment and Fishery Evaluation reports to provide ecosystem indicators for the Bering Sea and Gulf of Alaska. The Ecosystem Status Reports are produced annually to compile and summarize information about Alaska’s large marine ecosystems for the North Pacific Fisheries Management Council, the scientific community, stakeholders, and the public. The reports include ecosystem report cards, ecosystem assessments, contributions with updated status and trend indicators, and ecosystem-based management indicators and information. The reports are presented concurrently with stock assessment recommendations, thereby providing an ecosystem context within which the quota-setting process occurs, supporting ecosystem-based fisheries management in Alaska (access.afsc.noaa.gov/reem/ecoweb/index.php).

18. EcoFOCI scientists also continued their longtime commitment to outreach by participating in NOAA campus tours, NOAA Science Camp, Seattle Aquarium Discover Science Weekend, and Washington Sea Grant’s Orca Bowl, among other outreach opportunities.

19. The EcoFOCI Seminar Series, now in its 31st year, provides an opportunity for scientists to meet, present, and develop their ideas on subjects pertaining to fisheries and oceanography. The EcoFOCI Seminar Series is a ‘working seminar,’ and provides a connecting point for visiting scientists. Held at PMEL in Seattle, the seminar runs from five to seven weeks in the spring and fall. The EcoFOCI Seminar is also now a listed partner with the OneNOAA Science Seminar listserv. As our remote connection numbers increase, so does the potential for collaboration or cross-field discussion with peers and stakeholders.
ACCOUNTING FOR VARIABLE FISHING MORTALITY AND RECRUITMENT IN LENGTH-BASED DATA-LIMITED STOCK ASSESSMENT

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

OTHER UW PERSONNEL
Merrill Rudd – School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
James Thorson – Northwest Fisheries Science Center

OTHER NOAA PERSONNEL
Skyler Sagarese – Southeast Fisheries Science Center
Marc Nadon – West Pacific Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
With the mandate by the Magnuson-Stevens Act (1976) to prevent overfishing, U.S. stocks previously unassessed now require catch limits based on best available science. Previous research has addressed assessment methods when only catch data and some biological information are available. Many non-commercial and bycatch species do not have reliable catch data and currently only have length data, which along with biological information could inform fishing rates. In the Caribbean region, assessment scientists have previously used the Data-Limited Methods Toolbox (DLMtool) to explore potential harvest strategies, but this approach does not attempt to estimate processes underlying the biology or fishery, key goals of stock assessment. Mean-length and length-based assessments in both the Caribbean and West Pacific regions have faced challenges relating to uncertain biological information and/or multiple years harvesting a single stock, the complexities of which may violate key assumptions of the assessment methods available.

Since this project’s inception in November 2017, JISAO scientists have become familiar with the region-specific issues for coral reef fisheries assessment with the NOAA personnel affiliated with this project. Caribbean assessments of coral reef fish have used mean-length mortality estimators to estimate the total mortality rate by species, but the Scientific and Statistical Committee (SSC) has not incorporated these assessments into management advice due to several concerns:

1. The biological studies used to estimate life history parameters are inadequate, thus the growth and natural mortality estimates from these studies should not be used in the assessments.
2. The assumption of knife-edge selectivity with the mean-length mortality estimator is not appropriate for the coral reef fisheries on which the methods are applied.
3. The equilibrium assumption is likely violated.
Recently the Length-Based Spawning Potential Ratio (LB-SPR) method was applied to coral reef fisheries in Guam, and the assessment review panel also brought up concerns regarding the assumption of knife-edge or logistic selectivity when the selectivity acting on the fishery is likely dome-shaped or bimodal, including a high selectivity for a juvenile phase, as well as larger individuals.

To address the above issues in conducting assessments for length-based, data-limited fisheries in the U.S., JISAO scientists are exploring and improving the Length-based Integrated Mixed Effects (LIME) model to account for variability in fishing mortality and recruitment over time using length data and biological information. LIME already has features that address the concerns of the SSC and review panel members for other length-based assessments in the U.S. These features include:

1. Estimating length at 50% and 95% selectivity when assuming a logistic selectivity curve (identical to LB-SPR), but allowing the user to input an alternate selectivity curve that could represent dome-shaped or bimodal selectivity.
2. Relaxing equilibrium assumptions by estimating time-varying fishing mortality and recruitment deviations in an integrated assessment approach.

Since the beginning of this project in November 2017, JISAO scientists have:

1. Added a multi-fleet feature to the LIME program to allow for the input of length composition data by fleet, to estimate or fix selectivity curves specific to each fleet as is necessary to model many small-scale, coral reef fisheries.
2. Explored the use of the FishLife R package as an option for setting life history values for species with inadequate local biological studies.
3. Simulation-tested a predictive stacking approach as an ensemble method to incorporate uncertainty in biological information used in LIME.

JISAO scientists have access to length composition from the Caribbean and Guam catch to explore applying LIME for each fishery, with the option of using the multi-fleet feature and predictive stacking to incorporate...

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**Figure 1.** Predictive stacking overview. (a) Shows 30 quadrature nodes calculated over the distribution of von Bertalanffy growth coefficient and natural mortality for an example species, where the distributions are based on the FishLife multivariate model with taxonomic levels. (b) Shows LIME estimates of relative spawning biomass over time run at each of the 30 nodes (gray), and the result of predictive stacking (red) which is the weighted mean of the multivariate normal PDF multiplied by the model likelihood. (c) shows the density of relative spawning biomass in the last year of data using the maximum likelihood estimates and standard errors at each of the 30 nodes (gray distributions), with the resulting distribution from predictive stacking (red).
uncertainty in biological information.

OBJECTIVES
1. Explore options for integrating uncertainty in life history information (e.g. predictive stacking).
2. Explore options for accounting for selectivity of multiple fleets, either by using an explicit multi-fleet approach or by combining length data from multiple fleets.
3. Apply LIME to coral reef fish stocks in the Caribbean and Guam given considerations of life history and selectivity.
4. Compare LIME results with other equilibrium-based, length-based methods used for these stocks.

ACCOMPLISHMENTS
1. Simulation-tested the predictive stacking approach as an option for integrating uncertainty in life history information for length-based assessments. This was presented at a UW/NOAA Think Tank, will be presented at the National Stock Assessment Workshop on May 24, 2018, and is being prepared for publication (relates to objective 1).
2. Added new features to LIME to estimate selectivity for multiple fleets. This allows the flexibility to explore different options for either considering length compositions from multiple fleets separately or combining lengths from multiple fleets (currently the norm). This new version of LIME replaced the old version online (relates to objective 2).
3. Objectives 3 and 4 are in progress.
of Washington and the Northwest Fisheries Science Center (NWFSC) to provide education and training to undergraduate students interested in fisheries research. This project is designed to engage undergraduates from a range of scientific and other relevant disciplines in internships with scientists and leaders at NWFSC to develop their research interests and skills. These research experiences extend and enhance students’ classroom learning at the UW. At the same time, it provides scientists at NWFSC opportunities to prepare promising students for careers in fisheries science research.

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

ACCOMPLISHMENTS
This year, one student participated in the internship program. This year’s participant was Sara A. Bunker, a senior majoring in Aquatic and Fishery Sciences. Bunker participated in networking activities and poster sessions at NWFSC, and presented her research at the Western Society of Naturalists annual meeting in fall 2017.
EFFECTS OF HIGH- AND LOW-FREQUENCY ENVIRONMENTAL VARIATION ON FISH GROWTH AND STOCK ASSESSMENT REFERENCE POINTS: A CASE STUDY USING YELLOWFIN SOLE AND PACIFIC OCEAN PERCH OTOLITHS

PI
Timothy Essington – UW School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
Beth Matta – Alaska Fisheries Science Center

OTHER NOAA PERSONNEL
Thomas Helser, Paul Spencer, and Tom Wilderbuer – Alaska Fisheries Science Center
Kathleen Jewett – Northwest Fisheries Science Center

NON-UW/NON-NOAA PERSONNEL
Bryan Black – University of Texas

NOAA GOALS
Healthy Oceans

DESCRIPTION
Climate variability heavily influences the structure, functioning, and productivity of North Pacific and Bering Sea marine ecosystems. In particular, decadal-scale transitions between warm and cool climate phases have been linked to profound changes in species composition and biodiversity, trophic linkages, and ecosystem control. These transitions directly affect growth of commercially targeted fish. This work aims to better relate environment to fish growth, and to explore whether there are reliable indicators that can be used in population assessment to improve ability to set catch quotas and judge population health.

OBJECTIVES
Note that this JISAO award is part of a larger award from the NOAA FATE program. The components of the work specifically associated with the JISAO subcontract is as follows:

1. Incorporate environmental effects, as indexed by growth-increment chronologies, into the stock assessment models for yellowfin sole and Pacific ocean perch.
2. Evaluate alternative harvest strategies for yellowfin sole and Pacific ocean perch based on inclusion of environmental covariates.

REASONS WHY GOALS 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 2018, but that individual was offered a permanent position at the Inter-American Tropical Tuna Commission. A second candidate declined our offer. We have since restructured the work to staff the analysis with a Quantitative Ecology and Resource Management (QERM) graduate student instead of a post-doc. That individual started the project on March 16, 2018 and is working
closely with Alaska Fisheries Science Center stock assessment scientists to learn ADMB code and learn more about the biochronology. Meanwhile, work continues on the other components of the parent project.

DETECTING CHANGES IN LIFE HISTORY TRAITS AND DISTRIBUTION SHIFTS IN EASTERN BERING SEA FISHES IN RESPONSE TO CLIMATE CHANGE

PI
Timothy Essington – UW School of Aquatic and Fishery Sciences

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

TASK III

NOAA SPONSOR
James Thorson – Northwest Fisheries Science Center
Chris Rooper – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
Jin Gao of the UW School of Aquatic and Fishery Sciences is the chief analyst for this project. She has developed a set of analyses that makes use of the VAST geostatistical tool to identify impacts of physical (temperature) and biological (food availability) habitat on demersal fishes using a suite of potential indicators in the Eastern Bering Sea bottom trawl surveys. Gao has written the computer code for the fish condition factor analysis in a single species scenario. She will extrapolate the method to more species in the next step.

OBJECTIVES
1. Develop code to simultaneously estimate spatial variation in fish density and fish condition.
2. Identify impacts of physical (temperature) and biological (food availability) habitat on demersal fishes using a suite of potential indicators.
3. Test the hypothesis that distribution shifts and changes in fish condition will be synchronous among related species.

Fish populations depend on the availability of suitable habitat for feeding, growth, and survival to recruitment. Habitat variables, such as temperature, interact directly with vital parameters to affect fish population dynamics and biomass of fish available to fisheries. Thus analyses to explicitly incorporate habitat information and reduce the overall uncertainty in abundance index estimation can improve stock assessments. Both physical and biological habitats affect fish populations through processes such as growth and predation, and habitat variables may work synergistically or antagonistically to define different local regimes when examined spatially. Environmental impacts are time dependent, so understanding the temporal attribution of environmental variables is crucial.
Condition is an integrated measure of physiology for fish populations that accounts for behavior, life history, environmental, and species interactions. In the eastern Bering Sea (EBS), it has been found that the shift from sequential cold years to warm years is positively correlated with an increase in the length-weight residuals in groundfish species. The increase in condition during warm years is also accompanied by expansions in the habitat occupied by pollock and arrowtooth flounder. The reduction of the extent of the cold pool in warm years allows the species to access the middle shelf of the EBS where the cold pool would usually persist. Quality of foraging condition also affects the fish condition in the EBS.

This project will identify impacts of physical (temperature) and biological (food availability) habitat on demersal fishes using a suite of potential indicators. We will simultaneously estimate spatial variation in: 1) fish density (biomass per area); and 2) fish condition (residuals around the average length-weight relationship). We will decompose variation in these variables into patterns that are stable over time (spatial variation) and patterns that change between years (spatio-temporal variation). We will then attribute these patterns to variables representing physical habitat (bottom and surface temperature) and biological habitat (net primary productivity, from ERDDAP 2002-2015). Most current stock assessments in the EBS will benefit from the development and application of this method. For example, the EBS Pacific cod stock assessment has listed the need for understanding of “spatial dynamics, trophic, and other interspecific relationships and the relationship between climate and recruitment” for a number of years as a long-term research gap. This research gap occurs across multiple assessments for the EBS (and other regions of Alaska) and should be informed by the further development and application of spatial-temporal modeling to Alaska trawl survey data.

ACCOMPLISHMENTS
We have been testing the computer code for the fish condition factor analysis in a single species scenario using EBS cod. This effort has required more time than expected due to difficulties when incorporating multiple heterogenous data types (e.g., condition measurements for individual fish and catch-rates for individual bottom trawl tows simultaneously). Gao will expand the method to more species in the next step.

From April 2017 to March 2018, Gao has also applied the VAST toolbox to more datasets including: 1) a multispecies fishery-dependent CPUE (catch per unit effort) dataset in the East and South China seas and; 2) CalCOFI larval survey dataset. The CalCOFI data set is currently in review at Journal of Geophysical Research, and the East and South China seas analysis is prepared for submission to a special issue at Fisheries Research. Finally, Gao has continued work developing and testing a new statistical model to conduct delay-embedding forecasts where the attractor varies slowly over space. This work is ongoing, but has resulted in a rough draft manuscript currently being revised to achieve a quality appropriate for journal submission.
IMPROVING STOCK ASSESSMENTS OF A WIDE-RANGING SPECIES:
ESTIMATION OF SPATIAL AND TEMPORAL VARIABILITY IN LIFE HISTORY PARAMETERS OF LONGNOSE SKATE (RAJA RHINA)

PI
Timothy Essington – UW School of Aquatic and Fishery Sciences

OTHER UW PERSONNEL
Morgan Arrington – School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
Thomas Helser – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
Skates are commonly taken as bycatch in Pacific groundfish fisheries, yet most species are managed as data-poor stocks because relatively little is known regarding their life history parameters. Increasing exploitation of this group is of concern, because their biological traits (e.g., long life span, slow growth, low fecundity, and late age at maturity) make them vulnerable to overfishing and prone to slow recovery. Key data limitations are the paucity of age estimates across all three regions and potential biases owing to inconsistency in age determination procedures among laboratories. However, due to recent cooperative efforts between the Alaska Fisheries Science Center (AFSC), Northwest Fisheries Science Center (NWFSC), and Canadian Department of Fisheries and Oceans (DFO), longnose skate age estimation at AFSC was found to be accurate based on bomb-derived radiocarbon (14C) validation. Further, over 2,000 age structures have been collected from longnose skate across all three management regions since 2008 and are awaiting age determination.

Current assessments in Canadian and U.S. West Coast waters have a high degree of uncertainty in estimates of maturity and maximum age, due to relatively little information available about fisheries and basic biology of this species. The U.S. West Coast assessment relies on a very limited amount of age data, and the proposed work would fill this data gap, as well as reduce uncertainty in life history parameter estimates, which in turn will improve the accuracy and precision in stock status estimates for this species.

Due to the coast-wide, inter-regional collaborative nature of this work, we will reduce bias and improve reliability in life history parameter estimates and gain a better understanding of spatial and temporal life history variability.

OBJECTIVES
1. Graduate student master’s thesis.
2. New age data generated via a reliable ageing method validated with bomb-derived radiocarbon ($^{14}$C) technique. These data will be used in upcoming longnose skate stock assessments in the Gulf of Alaska, the U.S. West Coast, and British Columbia.

3. Improved estimates of life history parameters (growth, age at maturity, and natural mortality) for longnose skate across its range (three large management regions) for use in stock assessments.

4. At least one published paper on regional and temporal variation in longnose skate life history parameters.

5. Priors on life history parameters that incorporate age reading error and possible other process error for use in stock assessments.

ACCOMPLISHMENTS
Since beginning work on this project, 164 longnose skate vertebrae from the Gulf of Alaska have been prepared and aged via validated methods. This set was used to teach the graduate student sample processing and age-determination protocols. A reference collection (n=100) was compiled that will be circulated among agencies (NWFSC and DFO) to calibrate age-determination methods. The reference collection includes 100 prepared specimens, an image of each specimen enhanced in Adobe Photoshop to clarify the annual banding pattern, as well as annotations on each image showing final age agreed upon by two experienced age readers and the graduate student. A workshop was held with age readers from NWFSC to discuss validated age-determination methods, to standardize protocol, and to plan for an age structure exchange to take place summer 2018, wherein specimens will be aged independently by multiple agencies to assess reproducibility of the established age reading methods.

Longnose skate vertebrae from the rest of the West Coast await age determination and a new, more efficient method of age estimation is being investigated. This method involves collecting spectral data for whole vertebrae using a near-infrared spectrometer and converting those data into age estimates using a calibration model. Currently, spectral data for 100 longnose skate vertebrae have been collected and the method is undergoing investigation. If this method is successful, it will increase the number of age data able to be generated in this study.

A data gap was identified in a region off the coast of British Columbia and a request was submitted and approved by the International Pacific Halibut Commission (IPHC) for the collection of additional longnose skate vertebrae. The collection will take place on the 2018 IPHC survey to enhance data coverage and improve understanding of spatial variability in longnose skate growth.

In addition, the graduate student presented this project at the Western Groundfish Conference with a poster entitled, “Exploring growth of longnose skate (Raja rhina) along the North American West Coast,” and has completed coursework that will contribute toward her master's thesis. Courses include: Statistical Inference in Applied Research: Hypothesis Testing and Estimation for Ecologists and Resource Managers, Introduction and Advanced R Programming for Natural Scientists, Hot Topics in Aquatic and Fishery Sciences, Seminar in Quantitative Ecology, Ecological Modeling, Research Proposal Writing for Graduate Students, and Analysis of Ecological and Environmental Data.
AUTOMATED IMAGE PROCESSING FOR FISHERIES APPLICATIONS

PI
Jenq-Neng Hwang – UW Electrical Engineering

OTHER UW PERSONNEL
Gaoang Wang – Electrical Engineering

TASK III

NOAA SPONSOR
Kresimir Williams – Alaska Fisheries Science Center

NOAA GOAL
Healthy Oceans

DESCRIPTION
The research aims at estimating the fish density based on stereo cameras for underwater scenario. The project includes four parts – disparity estimation, water volume estimation, fish detection, and density estimation.

1. Disparity estimation – First, a color histogram adjustment is used for balancing the color between the left and right cameras. Then left and right images are rectified based on matched features. In order to estimate the depth of the object, the disparity map is estimated by using a semi-global matching method. A uniform disparity plane is estimated to replace the dark water area, since the disparity estimation is not reliable for such regions.

2. Water volume estimation – For the water volume estimation, we connect each pixel area to the camera center and treat it as a cone. Then we sum up all the volumes related to each pixel as the total volume of the water.

3. Fish detection – We combine Gaussian mixture models (GMM) and a deep learning-based method, single shot detector (SSD) to detect underwater fish. GMM is good at capturing a moving object if the background is stable, while SSD can detect fish without further assumptions when large training data is available. We combine these two approaches together with non-maximum suppression.

4. Density estimation – We split the depth into 20 bins from 1 to 20 meters. For each depth, we calculate the fish density (number/m³) and plot the average density along the depth.

Figure 1. An example of fish detection.
OBJECTIVES
Estimate the fish density for underwater scenario given a pair of stereo cameras.

ACCOMPLISHMENTS
1. We estimated the disparity map for the underwater scenario.
2. We estimated the water volume for the camera view.
3. We estimated the density of fish along the depth (meter).

Figure 2. Estimated density along the depth.

MARINE BIOLOGICAL INTERACTIONS IN THE NORTH PACIFIC – FISH INTERACTIONS TASK

PIS
Bruce Miller – UW School of Aquatic and Fishery Sciences
Ivonne Ortiz – UW Joint Institute for the Study of the Atmosphere and Ocean

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

TASK II

NOAA SPONSOR
Kerim Aydin – Alaska Fisheries Science Center

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

NOAA GOALS
Resilient Coastal Communities and Economies
Healthy Oceans
DESCRIPTION
The research 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 (access.afsc.noaa.gov/reem/ecoweb/index.php) and develop ecosystem indicators.

ACCOMPLISHMENTS
1. Feeding ecology and sample collections:
   In collaboration with the Resource Ecology and Ecosystem Modeling (REEM) Program at the Alaska Fisheries Science Center (AFSC), analyzed the stomach contents of 33 species sampled from the eastern Bering Sea, Gulf of Alaska, and Aleutian Islands regions. We analyzed the contents of 16,177 stomach samples at the laboratory, in addition to 3,073 stomach samples analyzed at sea during the Gulf of Alaska groundfish survey. This resulted in the addition of 56,554 records to AFSC's Groundfish Trophic Interactions Database. We also analyzed bill-load and diet samples from 1,155 seabirds for the U.S. Fish and Wildlife Service, and 22 benthic grab samples for an Essential Fish Habitat study. We added new information to the Stomach Examiner's Tool, including 413 new images to aid in prey identification. The School of Aquatic and Fishery Sciences' (SAFS) Kim Sawyer, Caroline Robinson, Sean Rohan, and Richard Hibpshman conducted stomach analyses.

2. We collected additional stomach samples through resource surveys, research surveys, and special studies comparing stomach contents with prey sampling. We collected approximately 8,240 stomach samples from the eastern Bering Sea and northern Bering Sea continental shelf. We collected over 1,500 stomach samples from the Gulf of Alaska to supplement the 3,073 stomach samples analyzed at sea. Fishery observers continued collection of stomach samples from Alaskan fishing grounds in 2017, resulting in 194 additional samples. Robinson, Sawyer, Rohan, Hibpshman, and JISAO's Andy Whitehouse collected stomach samples. Both Kelly Kearney and Ivonne Ortiz of JISAO collected samples during the Groundfish Bottom Trawl Survey for the northern Bering Sea in summer 2017.

3. Rohan has continued working on his graduate studies at SAFS, studying consumption of octopus by Pacific cod, and the limitations of the consumption-based octopus stock assessment in the eastern Bering Sea and Aleutian Islands. Rohan also coauthored a paper with Buckley on octopus predation and another paper with Drumm on a new species of shrimp.

4. JISAO's Andy Whitehouse and AFSC's Troy Buckley coauthored a paper on arctic cod diets, now published.

5. Whitehouse contributed several indicators to the Ecosystem Considerations for the eastern Bering Sea in 2017.

6. Ortiz coauthored a paper currently in press on pink salmon, zooplankton and phytoplankton trophic cascade.

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

8. Ecosystem considerations report and ecosystem indicators:
Whitehouse has updated five indicators for the Ecosystem Status Report for the eastern Bering Sea and two for Ecosystem Status Report for the Gulf of Alaska. These are part of the Ecosystem Considerations Report for the North Pacific Fishery Management Council, which contains ecosystem assessments for four large marine ecosystems in Alaska (access.afsc.noaa.gov/reem/ecoweb/index.php).

9. Presentations and workshops:
Ortiz and Whitehouse attended the 3-day workshop on Integrated Ecosystem Assessments conducted at the AFSC in April 2018. Ortiz presented the talk “The Evolution of a Management – Operational Atmosphere-to-Fish Ecosystem Modeling Suite from the Bering Sea Project” by the AFSC’s Kerim Aydin, JISAO’s Al Hermann, Kearney, and Ortiz at the Alaska Marine Sciences Symposium (AMSS) in January 2018. Ortiz also attended the Alaska Climate Integrated Modeling workshop during AMSS.

10. Outreach:
Robinson, Sawyer, Hibpshman, and Roshan trained and helped eight volunteers/interns from various high schools and graduate programs, totaling 800 hours of supervised volunteer/intern work. Whitehouse participated in the Polar Science Weekend at the Pacific Science Center in March 2018, facilitating the activity “Stinky, Slimy Fish Stomachs.”
INNOVATIVE TECHNOLOGY FOR ARCTIC EXPLORATION

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

OTHER UW PERSONNEL
Thomas Ackerman, Steven Anderson, Shaun Bell, Bonnie Chang, Giovanni Learned, Geoffrey Lebon, Ryan McCabe, Kevin O’Brien, James Osse, David Rivera, David Strausz, Margaret Sullivan, Heather Tabisola, Alex Turpin, Thomas Van Pelt, Tom Walton, and Kevin Wood – Joint Institute for the Study of the Atmosphere and Ocean

TASK II

NOAA SPONSOR
Chidong Zhang – Pacific Marine Environmental Laboratory

OTHER NOAA PERSONNEL
Jessica Cross, Thomas Peltzer, Edward Cokelet, Eugene Burger, Daniel Langis, Matthew Casari, Mike Craig, Nick Delich, Daniel Devereaux, Phyllis Stabeno, Carol Ladd, Noah Lawrence, Chris Meinig, Timothy Nesseth, John Shanley, Stephen Smith, Scott Stalin, and Dirk Tagawa – Pacific Marine Environmental Laboratory

NOAA GOALS
Healthy Oceans
Climate Adaptation and Mitigation

DESCRIPTION
The Innovative Technology for Arctic Exploration (ITAE) program at NOAA’s Pacific Marine Environmental Laboratory conceptualizes and builds effective research equipment for the assessment of the arctic environment and ecosystem. The program was formed in 2015 to build new operational capabilities that connect to NOAA’s Arctic Observing System, explore remote territories, and address emerging scientific themes related to NOAA’s Arctic Mission goals. ITAE is comprised of four core people, three PIs (Chris Meinig, Jessica Cross, and Calvin Mordy) and a research coordinator (Heather Tabisola) who together, led innovative strategies by collaborating with internal and external partners to develop science-driven approaches.

Deployment of an oceanographic buoy to test a new profiling crawler (Prawler) along the mooring line, providing real-time information on seasonal changes in the Bering and Chukchi Seas. Photo: ITAE
technologies. Today, each technology is assigned an ITAE PI, PMEL Engineering Lead, and an ITAE Lead, and the program brings together over 30 partners in academia, government, and industry. This structure supports rapid innovation and a science-driven mission guided by an interested operational party.

OBJECTIVES
1. To improve the operational capabilities of autonomous platforms for the Arctic environment.
2. To develop and integrate cutting-edge, high-resolution sensing technologies with these platforms. Implementation will leverage NOAA Cooperative Institutes with diverse engineering expertise, infrastructure, and technological assets necessary to execute these objectives.
3. To share data through websites, presentations, publications, and workshops.

ACCOMPLISHMENTS
The program continued to build on previous successes with 15 types of new technology, connecting over 30 partners in academia, government, and industry, including five of the six NOAA line offices. In 2017 alone, the program more than doubled its cumulative exploration of remote territory, traveling over 40,000 km and reaching record new latitudes through more than 500 days of at-sea data collection.

Saildrone
ITAE scientists utilized the Saildrone unmanned surface vehicle (USV) to conduct an acoustic survey in the Bering Sea, including passive and active acoustics. The project included the successful use of a) WBT-mini (active) to examine the prey field (primarily walleye pollock) of northern fur seals equipped with GPS and video, and b) an Acousonde (passive) with positive detections of killer whales and probable detections of North Pacific right whales. Video of northern fur seals allowed ITAE to observe ecosystems up close by collecting a seals' eye view video during animal feeding trips.

ITAE pushed observational boundaries by completing many firsts for an unassisted USV including traversing through the Bering Strait, capturing the first Arctic Basin observations, reaching within 7 nautical miles from the sea ice edge, and travelling the farthest north of any USV.

Oculus Coastal Glider
ITAE scientists field tested the Oculus Coastal Glider for 62 days in the Bering Sea. The glider navigated 480 nautical miles, completed 3,600 dives, and sampled salinity, temperature, dissolved oxygen, sunlight, and chlorophyll at a frequency of ~3.0 dives per hour. Observations suggest the existence of numerous previously unknown eddies that may influence prey availability for higher trophic levels.

Alkalinity Mooring
A new alkalinity sensor was moored for 36 days in the Chukchi Sea as part of an initial field test of this innovative sensor.

Prawler Mooring
We conducted field tests of the Prawler moorings in the Bering Sea (150 days) and the Chukchi Sea (39 days). The Chukchi mooring is undergoing additional development to extend the deployment.

Air-Launched Autonomous Micro Observer (ALAMO) Floats
We deployed two next-generation ALAMO floats in the summer and fall in the Chukchi Sea, and collected 608 profiles. The ALAMO floats observed anomalous heat in the Chukchi Sea, and were used to forecast the late arrival of sea-ice.

Pop-Up Floats
We deployed five next-generation pop-up floats in the Bering Sea, and they are scheduled to pop up under the ice in spring. Pop-up dates were February 20, March 1, March 5, March 10, and March 15.
Arctic Shield
ITAE scientists participated in the 17-day Arctic Shield campaign aboard the USCGC Healy to deploy moorings and an Oculus glider, and to conduct joint operations with two Saildrones.

ITAE is implementing new strategies for data management and visualization. Select measurements from the Saildrone missions were transmitted via the Global Telecommunications System to provide forecast-ready meteorological data to the U.S. and global weather forecasting community. We initiated a partnership with the U.S. National Ice Center to provide satellite ice-tracking information for navigation (quantifying in FY18).

Communications and outreach are a core component of the ITAE program, including the program’s online presence (website, blog), official NOAA communications, press enquiries, and operational safety briefings for Alaskan stakeholders. ITAE also hosts occasional special outreach and communication events.

ITAE maintains an online presence through its website (pmel.noaa.gov/itae), including a blog about the Saildrone missions entitled “Follow the Saildrone,” to engage non-project personnel in this new and exciting science. Stories from our website and blog were featured on NOAA.gov, OAR.gov, NOAAArctic.gov, Instagram (NOAA, NOAA OAR, and NOAA Fisheries), Facebook, and Twitter. ITAE also provides internal-only mission updates to our laboratory colleagues, funding partners, and leadership through Google Drive. In 2018, we will continue to maintain our external and internal online presence, as well as promote operational safety and awareness associated with our missions. As opportunities arise, ITAE PIs will also plan to participate actively in program outreach with Alaskan communities, similar to the 2017 achievements listed above.
ENHANCED NOAA-UW TRAINING AND COLLABORATION THROUGH THE BEVAN SERIES ON SUSTAINABLE FISHERIES

PI
André Punt – UW School of Aquatic and Fishery Sciences

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

TASK I

NOAA SPONSOR
Mark Strom - Northwest Fisheries Science Center
Steven Ignell - Alaska Fisheries Science Center

NOAA GOAL
Healthy Oceans

DESCRIPTION
The purpose of this project is to provide partial support for the Bevan Series on Sustainable Fisheries for winter quarter 2018. Project costs include speaker travel, per diem, accommodations, advertising, and support for the two associated University of Washington courses (one graduate and one undergraduate).

The Bevan Series on Sustainable Fisheries is a prestigious public seminar series administered by the UW School of Aquatic and Fishery Sciences (SAFS). Ten internationally renowned speakers are invited to speak on a wide range of topics. They were Ray Hilborn, Malin Pinsky, Lynda V. Mapes, Eva Plagany, Terrie Klinger, Angela Bednarek, Christina Hicks, Loren McClanachan, William Cheung, and Liz Neeley. In addition, an undergraduate class and a graduate class read papers selected by the speakers, meet the speakers, and discuss the seminars through an online website and in weekly, in-person discussion groups. Each speaker comes for at least two days, allowing ample time for meetings with NOAA researchers and UW academics.

The expenses associated with running the series were also covered during 2017-18 by donations received from the Donald E. Bevan Fund in Fisheries, SAFS, and the Bering Sea Fisheries Research Foundation.

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

ACCOMPLISHMENTS
1. The 2018 series was focused on the general issue of “climate and adaptation.” This issue was examined throughout the 2018 series through various talks, including those that highlighted fisheries management, science communication, spanning the gap between science and policy, and historical ecology (fish.uw.edu/...
news-events/seminar-series/bevan-series/bevan-speakers/).

2. Organized events allowed collaborative discussions in a more informal setting, especially over dinners following the seminars. These events have included SAFS Director André Punt, SAFS Associate Director Tim Essington, Associate Dean, Academic Affairs of the College of the Environment Julia Parrish, as well as AFSC and NWFSC members. Dinners also included members from other departments at the University of Washington, NGOs, fishermen, and a wide cross-section of people from diverse backgrounds.

3. Fifteen students registered for the graduate class, and 12 for the undergraduate class.

4. Public participation in the series has been excellent. The venue seats 150, attendance varied between about 100 and 150.

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

PI
André Punt – UW School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
Daniel Holland – Northwest Fisheries Science Center

NOAA GOALS
Resilient Coastal Communities and Economies

DESCRIPTION
Fishermen and fishing communities along the West Coast of the United States depend on several 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 various 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.

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 several 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.

**ACCOMPLISHMENTS**
1. A modeling framework was created to assess the behavioral responses of fishermen to fishery closures.
2. The new model was applied to the U.S. West Coast salmon fishery to create a predictive analysis of the economic impacts of the 2017 partial salmon troll fishery closure.
3. The historical abundance of U.S. West Coast Dungeness crab was recreated using catch and effort data.

**PRESENTATIONS**
1. “Quantifying and predicting responses to a West Coast salmon fishery closure.” Talk given as part of the OneNOAA Science Seminar Series on July 19 2017.
3. “Reconstructing the historical abundance of West Coast Dungeness crab”. Talk given at the Northwest Fisheries Science Center Symposium on March 26 2018.

**WEST COAST GROUNDFISH STOCK ASSESSMENT**

**PI**
André Punt – UW School of Aquatic and Fishery Sciences

**OTHER UW PERSONNEL**
Lee Qi and Caitlin Allen Akselrud – 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 the 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 of the UW School of Aquatic and Fishery Sciences (SAFS) and SAFS graduate student Kristin Privitera-Johnson (funded by an NSF fellowship) working with Northwest Fisheries Science Center scientists Chantel Wetzel and Owen Hamel updated the meta-analysis used to define “sigma” for data-rich stock assessments. The value for “sigma” is used to calculate the buffer between the overfishing limit (OFL) and the Allowable Biological Catch (ABC) for groundfish and coastal pelagic species. Unlike the previous analysis that focused on biomass estimation, the current analysis is focused on OFL estimation. Punt and Privitera-Johnson are currently evaluating the uncertainty in projected estimates of OFLs directly by evaluating the among-assessment variation in OFLs based on projections of assessments conducted using Stock Synthesis. This work will be presented to the Pacific Fishery Management Council Scientific and Statistical Committee (SSC) in September 2018.

2. Punt conducted a review of methods for handling spatial structure in recruitment in stock assessments, and conducted simulations to compare some of the alternative methods. This work formed the basis for a keynote address at the 2017 Center for the Advancement of Population Assessment Methodology (CAPAM) workshop on recruitment, and the work has been accepted for publication in the Special Issue of Fisheries Research arising from the workshop (Punt is one of the guest editors of that Special Issue).

3. Punt continued to be a member of Pacific Fishery Management Council (PFMC) SSC, and chair of its Coastal Pelagic Species (CPS) Subcommittee, as well as a member of North Pacific Fishery Management Crab PLAN Team. He ran several workshops and Stock Assessment Review meetings for the PFMC related to assessment and management of CPS.

4. Qi Lee of UCSB’s Marine Science Institute was partially funded by the grant during the reporting period. She completed her research to evaluate when it is possible to extract an index of growth from otolith data. The work was written up and published in the journal Fisheries Research. Lee defended her master’s thesis in spring 2017.

5. Caitlin Allen Akselrud of SAFS was partially funded by the grant during the reporting period. She worked with Punt and QERM PhD student Lee Cronin-Fine to compare assessment methods based on age-structured, size-structured and age-size-structured models, as applied to Pacific cod in the eastern Bering Sea. This work is a follow-up to a North Pacific Research Board funded grant to Punt, and a paper was published in the journal Fisheries Research. Allen Akselrud defended her thesis in spring 2017, and is now a UW PhD student with co-chairs Punt and Trevor Branch.

6. The series of regular (generally bi-weekly) UW/NWFSC/AFSC Fisheries Think Tanks continued during the reporting period, coordinated by Cronin-Fine. NMFS scientists, 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.
PRESENTATIONS

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 SPONSORS
Mark Strom – Northwest Fisheries Science Center
Steve Ignell – 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 to increase collaboration between SAFS and NOAA. His lecturing has covered courses in introductory and advanced R programming, introductory biostatistics, preparing polished scientific figures from data in R, and fisheries population dynamics. Branch serves on the scientific review group for the Pacific Hake Treaty between the U.S. and Canada. Since being hired, Branch has published 54 scientific papers, and his lab has published an additional 19 scientific papers. Branch was awarded tenure in 2015, and is now an Associate Professor. Branch has used funds from this award to partially support a number of graduate students: Cole Monnahan, in the QERM (Quantitative Ecology and Resource Management) program, and John Trochta, Melissa Muradian, Peter Kuriyama, and Caitlin Allen...
Akselrud in SAFS.

2. Cole Monnahan received his MS in 2013, and his PhD in 2017 under Branch. Monnahan received the Sea Grant/National Marine Fisheries Service (NMFS) population dynamics PhD fellowship, which supplemented NOAA funds in this grant. His MS involved using a spatial model to separate catches of eastern and western North Pacific blue whales, and constructing and fitting a Bayesian population model of northeast Pacific blue whales. Two peer-reviewed papers have been published in *PloS ONE* and *Marine Mammal Science* from this work. Monnahan has coauthored 11 peer-reviewed papers (several with other graduate students in Branch's group), many involving simulation testing of the Stock Synthesis stock assessment software developed by NWFSC scientists. Monnahan and Branch, together with NWFSC scientist James Thorson, recently published a transformative paper on new algorithms to improve Bayesian convergence time, and explain how the NUTS algorithm in software package STAN is far more efficient at converging for large complex models (published in *Methods in Ecology and Evolution*). Monnahan has implemented this method in AD Model Builder and Template Model Builder, and his final PhD chapter examines how NUTS and other methods can greatly speed up Bayesian convergence, allowing uncertainty to be estimated within stock assessment models in short enough time periods to be implemented in management.

3. Branch has one graduated MS student (Melissa Muradian) who trained in stock assessment of Prince William Sound Alaska herring, and partial funding from this grant led to a recent stock assessment publication of Prince William Sound herring in *PloS One*. Three other PhD students include Merrill Rudd (working on data-poor stock assessment methods, with multiple published papers), Peter Kuriyama (working on the effects of catch shares on fishing behavior, and the analysis of hook-and-line surveys for rockfish off California, with multiple published papers), and John Trochta (working on modeling herring in Prince William Sound). Rudd is funded from National Science Foundation and SAFS funds, Kuriyama from the Moore Foundation, Washington Sea Grant, and a NOAA population dynamics fellowship, and Trochta from the Exxon Valdez Oil Spill Trustee Council. Branch has had five postdocs: Sean Anderson, who worked with Eric Ward at NWFSC on the influence of catastrophes and black swan events in fisheries; Lewis Barnett, who worked with Michelle McClure at the NWFSC on the effects of West Coast groundfish fisheries management; Cole Monnahan, who worked with Scott Gende of the National Parks Service on population dynamics models of humpback whales; and currently Merrill Rudd working with the NWFSC's Jim Thorson on data-poor assessment methods, and David McGowan who is conducting an ecosystem-wide synthesis of Prince William Sound. In total, 29 scientific papers have been coauthored by graduate students and postdocs in Branch's lab, of which 23 are directly related to stock assessment research topics or U.S. fisheries in general.

4. 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 large-lecture 200-level introduction to economics for students primarily interested in the environment and resource use issues. In 2017 and 2018, he additionally taught a special topics class for SAFS and SMEA graduate students on how commercial fishing efforts are managed. Since being hired, Anderson has published 14 papers, and serves on the Scientific and Statistical Committee for the North Pacific Fishery Management Council.

5. 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. His students have had significant experiences at AFSC, NWFSC, in Bristol Bay, Alaska, and at The World Bank. Anderson's lab will graduate five PhD students in 2018, and has a bypass stage Masters student (Melissa Krigbaum) and a first year Masters student (Kamaluddin Kasim). Krigbaum is funded by an external contract at NWFSC to collect and analyze economic data on the trawl Individual Transferable/Fishing Quota (ITQ) program, with an analytical focus on the role of sablefish in quota utilization. Kasim is funded by a U.S. Agency for International Development fellowship, looking at production of trawl fishing fleets in Indonesia.
6. Anderson Advisee Andrew Scheld (SAFS PhD) 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. Andrew used a Sea Grant Marine Resource Economics fellowship to analyze the effects of catch share programs in New England.

7. Anderson Advisee Zhi Li (Economics PhD) started as an Assistant Professor at Xiamen University in fall 2015. Li studies economic theory and conducts experiments on mechanisms for providing public goods.

8. Anderson Advisee Thomas Fillebeen (Economics PhD) turned down an Assistant Professor offer at Texas A&M to work at Amazon in Fall 2016. Fillebeen's dissertation looked at Texas shale oil producers' drilling decisions.

9. Anderson Advisee Jocelyn Wang (Economics PhD) defended in winter 2018, and is employed as an economist at T-Mobile. Her dissertation examined markets and management policies in the sockeye salmon fishery in Bristol Bay, AK.

10. Anderson Advisee Allen Chen (Economics PhD) defended in winter 2018, and is a contractor at the AFSC. His dissertation looked at novel statistical methods for analyzing harvest timing and location choices in the Bering Sea pollock fishery.

11. Anderson Advisee Jennifer Meredith (Economics PhD, defending Spring 18) will start as an Assistant Professor at Colby College in fall 2018. She used a Sea Grant Marine Resource Economics Fellowship with mentorship at AFSC to collect primary data on over 800 people in Bristol Bay at the time limited entry salmon permits were issued to assess whether enclosure of those fisheries influences outmigration decisions of permit recipients or their family members. She won the Best Student Presentation award at the 2017 North American Association of Fisheries Economists (NAAFE) conference.

12. Anderson Advisee Keita Abe (Economics PhD, defending spring 18) will be a postdoc at the Norwegian School of Economics. He developed new methods for empirical analysis of dynamic decision making in Bering Sea pollock and Alaska longline fisheries. He won the Best Student Paper award at the 2017 NAAFE conference.

13. Anderson Advisee Marie Guldin (Economics PhD, defending fall 18) has been hired as a federal Economist at the NWFSC. She is examining the effects of the West Coast trawl groundfish ITQ program on the processing sector.


16. Anderson has partnered with NOAA economists Dan Holland (NWFSC) and Alan Haynie (AFSC) to win the bid to host the 2018 conference of the International Institute of Fishery Economics and Trade (a conference last held in North America 20 years ago) at the University of Washington.

PRESENTATIONS
Heard S, Fournier A, Branch T.A. and Skelly D. Why most studied populations should decline. Canadian Society for Ecology and Evolution. 04/2017
Branch, T.A. Management strategy evaluation of Southern Bluefin Tuna: many models. ICES Annual Science Conference, special QUEST workshop. One hour presentation. 07/22/2017
Branch, T.A. Stock recruitment curves: what are they, and should we use them? CAPAM workshop, Miami.
10/31/2017
Branch, T.A. The near extinction and variable recovery of blue whale populations. Student-invited talk, Simon Fraser University, Vancouver, Canada. 3/21/2018
Branch, T.A. Graphics workshop. Invited 90-min workshop, Simon Fraser University, Vancouver, Canada. 3/22/2018.
Anderson, C. Developing Economically Sophisticated Management Strategy Evaluations. ICES Annual Science Conference, special QUEST workshop. One hour presentation. 07/22/2017
Anderson, C. Developing Methods for Social and Economic Effects of Marine Stewardship Council Certification. Co-led 2.5-day workshop at MSC headquarters. 10/31/17

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

PI
André Punt – UW School of Aquatic and Fishery Sciences

OTHER UW PERSONNEL
Jie Cao – School of Aquatic and Fishery Sciences

TASK III

NOAA SPONSOR
James Thorson – Northwest Fisheries Science Center

NOAA GOALS
Climate Adaptation and Mitigation
Healthy Oceans

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

OBJECTIVES
1. An R-package SpatialVAM (an existing size-structured spatio-temporal model) will be modified to add a
growth-transition matrix, as well as mortality due to human harvest.

2. The model will then estimate 35 years of spatial dynamics for snow crab.

ACCOMPLISHMENTS

1. A size-structured spatio-temporal model has been developed for application to snow crab. This model captures the population dynamics of snow crab by representing the growth-transition matrix, natural mortality, and fishing mortality.

2. An operating model that simulates the spatio-temporal dynamics of the snow crab population and its fisheries has been developed. This operating model provides the basis for testing and validation of the newly developed size-structured spatio-temporal model.

3. A movement component has been added to the operating model, which allows an evaluation of how well the size-structured spatio-temporal model implicitly accounts for unmodeled spatial processes.

4. Simulation experiments have been conducted to: 1) verify the model works correctly (recovered the simulated ‘true’ population); and 2) evaluate the performance and limitations of the model under various scenarios related to model mis-specification and errors (e.g., mis-specified movement, mis-specified growth, and the presence of both sampling and process errors).

5. A general version of size-structured spatio-temporal model has been developed by modifying that developed for snow crab. This model can be used for fish and invertebrate populations that do not exhibit an effective cessation of growth at some life history stage.

6. An operating model that simulates a general size-structured population dynamics model has been developed. This model can generate data for a size-structured spatio-temporal model and a conventional non-spatial size-structured assessment model.

7. Preliminary comparisons between the spatio-temporal model and the non-spatial model have been conducted using simulation experiments.

PRESENTATIONS

DEVELOPMENT AND DELIVERY OF A TRAINING COURSE IN FISHERIES MANAGEMENT STRATEGY EVALUATION

PI
André Punt – UW School of Aquatic and Fishery Sciences

TASK III

NOAA SPONSOR
Beth Lumsden – Pacific Islands Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
Management strategy evaluation (MSE) is a process for exploring the consequences of alternative management approaches on a set of objectives established in collaboration with appropriate stakeholder groups. Simulation testing is at the heart of the process. A typical application of an MSE consists of using a set of operating models that incorporate sufficient complexity to simulate variability in a state process (e.g., fish population, ecosystem or economic dynamics), and an estimation model to perform virtual data collection, analysis, system response, and management advice. The effects of alternative management strategies (e.g., data collection systems, assessment methods, harvest control rules, adapting management to a changing climate, protected resource take reduction strategies, etc.) can then be examined relative to multiple objectives associated with the system (e.g. catch, abundance, economic gain, annual variation in catch, emergent ecosystem properties, conservation level achieved, biodiversity, etc.). The MSE process is iterative and is most effective when stakeholders are involved throughout the process.

The strength of the approach is that instead of using a single model to find an optimal solution, multiple candidate models are put forward to evaluate alternate hypotheses. By modelling each step of a management approach, the consequences of alternate scenarios can be evaluated across models. The approach demands clear objectives to do the evaluations against, and the method forces participants to be clear about their objectives and to specify performance indicators. Within an MSE context performance indicators must be directly related to the objectives and be able to be simulated. Though this technique was developed over 20 years ago, it is still changing rapidly, and its use is becoming more widespread. Outcomes from an MSE may be applied directly in management or may be more exploratory in nature.

The MSE approach is not new, but it is applied unevenly across the National Marine Fisheries Service (NMFS). This project supported the development of an advanced MSE short course that can be taught at any NMFS facility.

OBJECTIVES
1. Pacific Islands Fisheries Science Center (PIFSC) staff, in consultation with the NMFS MSE working group, will work with the PI on the technical details of the course.
2. A weeklong intensive short course will be held at the conclusion of the course development.
3. The execution of the training, resulting comments from the trainees, and delivery of final course materials will constitute the final report.

ACCOMPLISHMENTS
1. The course was developed in consultation with members of the NMFS MSE working group.
2. The course was given at the PIFSC January 8-12, 2018.
3. The course material (lectures, example implementations of MSE, assignments) was made available to the students who took the class.
4. The course evaluations indicate that the class met the expectations of the participants, it was adequately paced, it provided material that the participants are likely to use in their daily work, and the instructor communicated the work effectively.

INDIVIDUAL-BASED STOCK ASSESSMENT MODEL FOR CETACEANS

PI
André Punt – UW School of Aquatic and Fishery Sciences

OTHER UW PERSONNEL
Charlotte Boyd and Eiren Jacobson – School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
Paul Wade – Alaska Fisheries Science Center

NOAA GOALS
Healthy Ocean

DESCRIPTION
Marine mammal stock assessments have traditionally been based on simple aggregated population models or age- and/or sex-structured models. However, new methods and technology have dramatically increased the collection of individual-based data. Individual mark-recapture datasets derived from high-resolution digital photographs are available for a growing range of cetacean species (e.g., the endangered Cook Inlet beluga (*Delphinapterus leucas*), the endangered Main Hawaiian Islands insular false killer whale (*Pseudorca crassidens*), and the endangered Southern Resident killer whale (*Orcinus orca*)). Individual-level data are also available on movement patterns from telemetry and photographic/genetic identification, reproductive status from biopsy hormone analysis, calf production from photo-identification surveys, body condition from photogrammetry, health assessment from sampling of blow exhalations by unmanned aircraft systems or poles, and gene expression from genetic biopsy samples. These data sources provide valuable information on stock structure, demography, and population health and status that is currently being ignored in cetacean stock assessment. New modeling approaches are needed to incorporate these data into stock assessment and management strategy evaluation.

A cetacean stock assessment model will be designed to estimate abundance, trends, recruitment, and survival rates through integrated analysis of aggregate population survey data (e.g. aerial or vessel-based
line transect data) and individual mark-recapture data (e.g. photo-identification data) using Bayesian estimation and simulation techniques in R. We will use a spatially explicit hierarchical (state-space) model structure that allows for the separate, but simultaneous, estimation of an underlying ecological (or state) process, with one or more observation process models. Cetacean stock assessments are typically based on the application of distance sampling methods to line transect data. NOAA stock assessment biologists have recently started using Bayesian hierarchical models to analyze these datasets. Separately, there have been recent advances in the application of Bayesian hierarchical models to mark-recapture data using data augmentation. Building on this prior research, our integrated stock assessment model will incorporate an observation model for distance sampling data and a separate observation model for mark-recapture data collected a) from the same survey platform as the distance sampling data (e.g. photo-identification data collected during vessel-based line transect surveys), and/or b) from a separate mark-recapture study. The ecological process model will allow for individual variation in reproductive success and/or survival dependent on health or body condition covariates.

We will test the model extensively using simulated data representative of typical cetacean datasets. We will also demonstrate its real-world applicability through a case study of the Cook Inlet beluga population. Current abundance estimates for Cook Inlet beluga are based on aerial surveys conducted every two years after applying various correction factors to account for perception and availability bias. These estimates indicate a continuing slow decline to a current population size of approximately 340 individuals. Since 2005, a photo-identification project has collected thousands of photographs each year that have been used to identify 376 unique individuals. However, these photo-identification data have not yet been used to estimate population abundance or trends and information derived from these data have not been incorporated into stock assessment.

OBJECTIVES
1. Develop a flexible, spatially explicit individual-based cetacean stock assessment model in R, with parameter estimation accomplished through fitting to both conventional aggregate population survey data (such as aerial or vessel-based surveys) and individual-based mark-recapture data (such as photo-identification data).

2. Demonstrate the model with an application to the endangered Cook Inlet beluga.

ACCOMPLISHMENTS
1. To address Objective 1, we investigated methods for integrated analysis of a small cetacean population using simulation. We simulated the collection of line-transect and mark-recapture data under different scenarios of population trend (stable, increasing, or decreasing) and habitat use (random or shifting). We then evaluated the ability of different combinations of modeling approaches (population-level vs individual-level) using various combinations of simulated datasets to accurately describe the simulated trend in the population. Preliminary results demonstrate the value of integrating small boat mark-recapture studies and large-scale line-transect surveys to improve the precision of resulting abundance estimates.

2. To address Objective 2, we developed an integrated population model combing aerial survey, mark recapture, and historical hunting data for Cook Inlet beluga whales. We applied this integrated model to current and historical abundance, trend, and survival rates for this population. Preliminary results indicate a higher current population size than has been reported previously. Additionally, the estimation of life history parameters using this model will inform conservation and management of Cook Inlet beluga whales, and enable a population viability analysis to be conducted in the future.

PRESENTATIONS
FORECAST EFFECTS OF OCEAN ACIDIFICATION AND OCEAN TEMPERATURE ON ABUNDANCE AND ECONOMICS OF BRISTOL BAY RED KING CRAB

PI
André Punt – UW School of Aquatic and Fishery Sciences

TASK III

NOAA SPONSOR
Michael Dalton – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
The increase in atmospheric CO₂ concentrations, caused primarily by fossil fuel emissions, deforestation, and concrete production, has led to a corresponding increase in the CO₂ concentrations in the ocean. This increase is leading to changes in the carbonate chemistry of the oceans and a decrease in pH. As CO₂ levels continue to rise over the coming decades, the pH in the ocean will fall even further. This reduction in pH, and increase in pCO₂, can have substantial physiological effects on marine organisms, affecting growth, survival, reproduction, and behavior. Calcifying organisms could be particularly affected, because the reduction in pH makes it more difficult to excrete and sustain a calcified shell or exoskeleton. There is already some evidence that ocean acidification (OA) is likely to impact crabs. While the focus of the impacts of OA has been mainly on the biological effects, species such as crabs support valuable fishery resources, and OA may have major consequences for these fisheries and how they are managed. To forecast potential consequences of OA on the future abundance of vulnerable and commercially important North Pacific crab stocks, a work plan is proposed to extend an existing bio-economic model for Bristol Bay red king crab (BBRKC) that already allows for OA impacts on juvenile survival to also account for the impacts of changing temperature on the population dynamics of this stock. This work plan builds on past and ongoing NOAA-supported research in this area. In particular, model input will be taken from physiological research for these species that is being conducted at the Alaska Fisheries Science Center to characterize the susceptibility of juvenile BBRKC to OA and temperature changes and the interaction between changes in pH and temperature.

OBJECTIVES
1. Develop linked stage-structured pre- and post-recruitment dynamics models. These models relate pre-recruit mortality, and the time to grow from one stage to the others given changes in ocean pH and ocean temperature, and will be used to forecast how the proportion of BBRKC eggs, which lead to recruits, will change over time.

2. The series of linked models will be used for different rates and trends in future ocean pH and ocean temperature to compute:
   a. Maximum sustainable yield (MSY) and maximum economic yield (MEY) for BBRKC, as well as the uncertainty associated with these estimates due to:
      i. Observational error associated with the data,
      ii. The relationship between pH and temperature and impacts on juvenile mortality and growth, and
iii. Other sources of process error such as inter-annual variation in egg production and natural mortality.

b. The consequences of applying the allowable biological catch (ABC) control rule for BBRKC,
c. The consequences of applying the rule for setting total allowable catches (TACs) used by the Alaska Department of Fish and Game, and
d. The benefits (or otherwise) of area-specific minimum sizes.

3. The metrics that will be used to assess consequences for issues b-d above will be:
a. Trends in mature male biomass,
b. Key measure of reproductive output,
c. Catches,
d. Probability of the BBRKC stock dropping below management reference points, and
e. Annual discounted revenue.

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

OPERATIONALIZATION OF ALASKA’S CLIMATE CHANGE INTEGRATED MODELING PROGRAM

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OTHER UW PERSONNEL
Al Hermann – Joint Institute for the Study of the Atmosphere and Ocean

TASK II

NOAA SPONSOR
Anne Hollowed – Alaska Fisheries Science Center

OTHER NOAA PERSONNEL
Kirstin Holsman – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
Through this project, we will put into operation the Alaska Climate Change Integrated Modeling Program (ACLIM) projection modeling framework to facilitate the rapid uptake of the most recent global climate projections from the Intergovernmental Panel on Climate Change (IPCC). We will examine these under a range of carbon emission scenarios, applying the global projections into regional coupled physical-biological-economic models for the eastern Bering Sea. We will also coordinate with regional management councils and fishery stakeholders to evaluate the performance and implications of current and alternative “climate-ready” harvest strategies under future climate scenarios. Completion of this project will accelerate
our ability to evaluate the short and long-term risk of climate change to fish and fishery-dependent communities, as well as consider the implications of these changes on marine food security. We will use the impact scenarios to assess the adaptive capacity of fish, fishers and fishery-dependent communities through climate-ready management actions.

OBJECTIVES
The goal of the Research Transition Acceleration Program (RTAP) is to operationalize the ACLIM modeling enterprise. That will provide direct benefits to the North Pacific Fishery Management Council (NPFMC) by providing a tool to inform management of the risks of climate change on fish and fisheries, as well as informing managers of the performance of a range of adaptation strategies. This is important for two reasons:

1. Fishery management in Alaska is uniquely poised to incorporate projections of change and management evaluations into existing ecosystem-based management advice, and

2. Translation of the Coupled Model Intercomparison Project Phase 6 (CMIP6) projections of climate impacts on eastern Bering Sea fisheries will be the first inclusion of CMIP projections on the biological impacts on marine environments in the same IPCC report.

ACCOMPLISHMENTS
Under the coupled project, stakeholders and workshop participants identified a number of additional priorities, highlighting the importance of the ACLIM framework. Under RTAP, projections and scenario evaluations will be updated with the CMIP6 projections (anticipated to be available in the next 12 months) to provide the most up-to-date advice for risk management of Bering Sea fisheries. Recent declines in regionally important fish stocks (e.g., Pacific cod) following anomalously warm conditions in the region from 2014-2016, have further elevated the need to understand the performance of management measures under changing conditions. The relationship between the climate and the health of fish stocks and fishing communities remains a central concern for the NPFMC and the Alaska fishing industry in 2018.
USING HABITAT CHARACTERISTICS AND PREY ABUNDANCE TO PREDICT DISTRIBUTION, ABUNDANCE, AND CONDITION OF GROUNDFISH IN THE GULF OF ALASKA

PI
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OTHER UW PERSONNEL
Kirsten Simonsen – School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
Patrick Ressler and Chris Rooper – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
Simonsen et al. (2016) created a time series of euphausiid distribution and abundance in the Gulf of Alaska (GOA) based on summer acoustic-trawl surveys from 2003, 2005, 2011, and 2013. Acoustic backscatter was classified to determine abundance of euphausiids using techniques developed by De Robertis et al. (2010) and Ressler et al. (2012). These methods used Echoview templates and custom Matlab functions. Backscatter identified as euphausiids was ground truthed using both targeted Methot net tows and an intrawl camera system. These same methods will be used to examine the spatial distribution and abundance for euphausiids with additional data collected during 2015. Patterns in abundance of euphausiids will be examined to determine and quantify consistent areas of increased or depressed euphausiids abundance (groundfish prey availability).

OBJECTIVES
1. Complete data analysis/modeling of distribution data.
2. Complete groundfish condition factor modeling.
3. Prepare and deliver presentation of results at a national conference.
4. Complete draft of manuscript.

ACCOMPLISHMENTS
1. Data analysis and modeling of distribution data is nearly complete. Best models were determined using backward variable selection, and model diagnostics were examined.
2. Condition factor modeling is nearly complete for pollock.
3. Two presentations were delivered this year. A poster on the modeling portion of this project was presented at the Alaska Marine Science Symposium in January 2018. An oral presentation was delivered at the Western Groundfish Conference in February 2018.
4. A draft of the manuscript focusing on the modeling component was started. A draft of the manuscript for the condition factor will be started in May 2018.

PRESENTATIONS

Oral Presentation: Condition of walleye pollock (*Gadus chalcogrammus*) in relation to prey abundance. 20th Western Groundfish Conference, Seaside, California.

THE INTEGRATION OF SPATIOTEMPORAL FISHERY AND BIOLOGICAL SURVEY DATA

PI
André Punt – UW School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
Alan Haynie – Alaska Fisheries Science Center

NOAA GOALS
Resilient Coastal Communities and Economies

DESCRIPTION
A primary challenge in fisheries management is the estimation of fish abundance. Fishery-independent biological surveys generate catch rate data using a standardized design, and hence can provide information about fish densities divided into different categories (sex, length, age, etc.). However, the analysis of survey catch rates generally involves assuming that the proportion of local fish that are captured (termed “catchability”) is constant spatially and over time. This assumption may be violated (e.g., when bottom trawl gear have varying performances for different substrates, or when different ages/lengths move into or out of surveyed areas seasonally), and its violation can be mitigated using paired sampling gears. Currently in fisheries, we typically have one relatively synoptic view of fish densities and demographics taken by a survey. In other cases, this survey may be several times a year, or once over several years. In either case, the survey is restricted to short intervals within each year, and provides no information about population density during other months or seasons.

Annual fishery or seasonal catch per unit effort (CPUE) is sometimes used as a proxy for abundance in situations where we do not have a biological survey, or is used in addition to estimate population density in areas or seasons without survey sampling. Fishery-dependent data in data-rich fisheries can provide an extensive view of fishing effort across large spatial areas and many months or seasons. However, these data also have significant limitations for estimating stock abundance. Because fishing only occurs where fishers feel fishing is most profitable, fishing does not capture the entire distribution of a stock. The locations where the fleet fishes, given its characteristics and the nature of the fish stock, are limited to areas with the best combination of catch rates, fish size, and distance from port. Although spatio-temporal analysis can account...
for locational decisions by fishers, fine-scale targeting can also cause catchability to differ systematically between fishing operations, thus potentially biasing the analysis of fishery data when calculating spatial average CPUE.

An important component to interpreting fishery-dependent data is recognizing the management context in which it occurs. The implementation of catch shares, changes in alternative or substitute fisheries, or the closing of fishing grounds can have a significant effect on catch rates, fishing timing, and fishing locations.

The goal of this project is to directly improve fisheries management by integrating the work of both the spatial stock assessment and spatial fisher behavior research areas. The proposed research meets Urgent and Critical Ongoing Monitoring Council/SSC research priorities to “Develop spatially explicit stock assessment models” (priority 174). This priority is listed for the Gulf of Alaska, Bering Sea, and Aleutian Islands regions, and influences council decisions about harvest specification.

OBJECTIVES
1. Determine whether estimates of fish density in fished locations from a Fishery CPUE model in the summer months are consistent with fish density estimates from a Survey model.

2. Develop a regression model that predicts the quantity of fishing effort at a given location, year, and season (the response variable) from estimates of fish density from the Survey model and Fishery CPUE model. This objective will be achieved by applying the FishSET discrete choice model, using covariates including: pre/post changes in management action, and distance from port, environmental factors and the interaction of distance-from-port and year.

REASONS WHY OBJECTIVES WERE NOT MET
The postdoctoral research fellow who we wish to use for this work is currently funded under another project.
DEVELOPMENT AND APPLICATION OF A CLIMATE ENHANCED MULTI-SPECIES STOCK ASSESSMENT MODEL FOR THE GULF OF ALASKA TO EVALUATE ALTERNATIVE HARVEST STRATEGIES UNDER CLIMATE CHANGE

PI
André Punt – UW School of Aquatic and Fishery Sciences

OTHER UW PERSONNEL
Grant Adams – School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
Kirstin Holsman – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
The goal of this study is to advance the existing climate-enhanced multispecies stock assessment model developed for the Bering Sea and apply it initially to four Gulf of Alaska (GOA) groundfish species (walleye pollock, Gadus chalcogrammus; Pacific cod, Gadus macrocephalus; arrowtooth flounder, Atheresthes stomias; and Pacific halibut, Hippoglossus stenolepis). Specifically, we aim to:

1. Apply biomass, growth, temperature, and diet data available from the National Marine Fisheries Service (NMFS) biennial GOA summer trawl surveys to parameterize the model.
2. Evaluate historical species interactions and alternative models to account for climate-, trophic-, and fishery-induced changes in biomass and growth of these species.
3. Use these models and future climate and management scenarios to project stock biomass, size structure, and catches under alternative approaches to managing GOA groundfish species under climate change.

OBJECTIVES
1. Compare model estimates based on temperature and trophic interactions with the same model fit retrospectively without trophic interactions, without temperature effects, and without trophic or temperature effects. Models will be compared for explanatory power and for sensitivity to trophic or climate impacts on recruitment and mortality parameters.
2. Project each model under ensemble mean estimates of future sea surface temperature (SST) from three climate scenarios:
   a. Mean historical SST (i.e., stable future climate)
   b. Climate scenarios representing status quo climate emission pathways and high future warming in the GOA (i.e., IPCC RCP 8.5)
   c. Scenarios of reduced future carbon emissions and lower future warming (i.e., IPCC RCP 4.5)
ACCOMPLISHMENTS
1. Code is being developed for a climate-enhanced multispecies stock assessment in Template Model Builder to allow the extent of recruitment variability to be estimated.

USING SPATIAL ANALYSIS TOOLS TO INTEGRATE FISHERY AND SURVEY DATA

PI
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OTHER UW PERSONNEL
John Best – School of Aquatic and Fishery Sciences

TASK III

NOAA SPONSOR
Richard Methot – Northwest Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
Spatio-temporal methods are increasingly used both to process inputs to stock assessment models, and to explore climate, habitat, and ecosystem impacts for marine species under fisheries management plans. This project involves exploring two inter-related tasks using spatio-temporal models:

1. Integrating catch-rate data from both fishery operations, and planned experimental surveys for the same stock. These “data-integrated spatio-temporal models” could be used to predict density in seasons or locations that are not otherwise sampled by surveys, or to inter-calibrate catch rates from non-overlapping surveys via their overlap with a given fishery. We will identify a suitable case-study application for this method, and use simulation testing to explore the potential benefits and pitfalls of the proposed approach.

2. Using spatio-temporal models to conduct second-stage expansion of age and/or length-composition samples (e.g., from samples of proportion at age/length for each tow or trip, to proportion for a given spatial domain). This task has historically been done using design-based estimators, but model-based estimators are increasingly used for estimating abundance-indices from these sample fishery operations. Therefore, using spatio-temporal models for both index-standardization and compositional-expansion promises to unify these two approaches that are currently done separately.

OBJECTIVES
1. Integrate catch-rate data from both fishery operations, and planned experimental surveys for the same stock, and use these models to predict density in seasons or locations that are not otherwise sampled by surveys, or to inter-calibrate catch rates from non-overlapping surveys via their overlap with a given fishery.

2. Use spatio-temporal models to conduct second-stage expansion of age and/or length-composition sample.
ACCOMPLISHMENTS
UW's John Best has been developing a model for combining survey and fishery data. An operating model to simulate fishery dynamics was developed, and the VAST package was used for estimation. Initial results were presented at the Center for the Advancement of Population Assessment Methodology (CAPAM) Workshop on Spatio-Temporal Modeling.

PRESENTATIONS

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
Luke Tornabene – UW School of Aquatic and Fishery Sciences

OTHER UW PERSONNEL
Katherine P. Maslenikov, Rachel Manning, Samuel Ghods, and Calder Atta – School of Aquatic and Fishery Sciences

TASK II

NOAA SPONSOR
James W. Orr – Alaska Fisheries Science Center

OTHER NOAA PERSONNEL
Alison Deary and Jessica Randall – Alaska Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
The Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering (RACE) Division annually collects ichthyoplankton and adult fishes from Alaska. The National Marine Fisheries Service is mandated to transfer important fish collections to the U.S. National Museum or other designated museums for permanent archival storage. The University of Washington Fish Collection (UWFC) has been designated as one of four such institutions in the United States, and is the only one that specializes in fishes from the boreal North Pacific. The facilities and personnel of the UWFC are superbly suited to perform the tasks described here. The UWFC is a fully computerized, well-documented, archival research collection of freshwater and marine fishes of Washington State, the Pacific Northwest, and the Pacific Rim. It exists 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. Under the current grant, the RACE Division
Groundfish Task and Recruitment Processes Task each transfers significant numbers of specimens to the UWFC archive.

Financial support was provided to continue a long-standing cooperative relationship with the UWFC as the repository of ichthyoplankton. Because of previous AFSC support, we have transferred approximately 131,655 lots of eggs and larvae collected between 1977 and 2010. This consolidation of material has made the UWFC the largest repository of early life history stages of fishes in North America. Database records for 9,142,098 individual specimens are now available online from the UWFC website.

At the same time, support was 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 to 2017 have already been transferred to UWFC during recent years. Database records for 57,111 cataloged lots of juveniles and adults (totaling 393,050 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 archive 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, UW School of Aquatic and Fishery Sciences staff member Rachel Manning continued to curate the Early Life History (ELH) collection, in particular the fish eggs and larvae from AFSC, until the arrival of new graduate student Calder Atta. Manning worked with two undergraduate assistants to complete the large transfer of more than 11,000 lots of eggs and larvae that we received as part of the transfer that started in the fall of 2016, comprised of samples with taxa that had never before been transferred from AFSC to the UW collection. With the help of the undergraduate assistants and Jessica Randall (formerly working with the FOCI lab at AFSC), Manning was able to finish cataloging and shelving this material prior to the arrival of Atta in late August 2017, leaving no backlog for the new student. These data have been uploaded to the collection database. 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. In August 2017, Calder Atta took over as the main research assistant on the grant to curate this year’s transfer of eggs and larvae, which consisted of 2010 survey material. This year’s transfer was 2,533 lots of larvae and 788 lots of eggs. The larvae were brought to UWFC from AFSC, and have now been cataloged, and are ready to be shelved. The eggs have been checked against an inventory checklist, and will be transferred, cataloged, and shelved by the end of April 2018.

3. 106 lots of adult fishes, including a total of 140 specimens, all obtained from AFSC sources, were identified, curated, and archived (a complete list of species is available on request). The UWFC internet database was updated to reflect these additional cataloged lots. At the same time, tissues for future DNA studies were taken from 86 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 7,604 representing 961 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.


5. The UWFC has continued to support AFSC scientists by handling their incoming specimen loans from other natural history collections in the U.S. and abroad, helping to support systematic research at AFSC.

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
Kathleen Jewett – Northwest Fisheries Science Center

OTHER NOAA PERSONNEL
Krista Nichols – 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
The aim of this study is to examine the effects of early rearing environment on genetic variation and epigenetic programming in steelhead. This work is a continuation of a study started in 2014. The work takes advantage of a long-term project on Methow River steelhead at the Winthrop National Fish Hatchery (WNFH) and the NOAA Manchester Field Station, both in Washington state, 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 (S1 or S2 respectively). As part of this study, natural origin and hatchery adults are collected from the Methow River by US Fish and Wildlife Service staff and spawned at the WNFH.

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

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

ACCOMPLISHMENTS
1. Characterized epigenetic variation in the genome of steelhead raised in experimental ‘hatchery’ and ‘natural’ environments – Previous results from our study showed significant differences in DNA methylation patterns of both sperm and red blood cells between hatchery and natural-origin steelhead. We also found a high degree of epigenetic variation among individuals necessitating future studies on how epigenetic and genetic variation interplay to promote such differences. To address this, a second study using controlled genetic backgrounds and simulated ‘hatchery’ and ‘natural’ environments was performed to limit the effects of background genetic variation in order to directly address if early-rearing environment influences DNA methylation in hatchery steelhead. Steelhead embryos from 20 families were split across hatchery and natural treatments. After 8 months in the treatment environments, fish were tagged and raised to maturity (2 years of age) in a common environment. We performed RRBS on livers of male fish at 8 months (directly out of treatments), to identify immediate effects of rearing environment on DNA methylation as well as sperm of 2-year-old males (1 year common environment) to identify long-term effects of rearing environment on the epigenome. Hierarchical clustering of genome-wide methylation patterns in liver show strong immediate effects of rearing environment on DNA methylation patterns. In contrast, sperm show strong clustering within family regardless of rearing environment. Results from sperm do not indicate a strong persistent effect of rearing environment on male gametes. Results from this study were presented at the meeting of the Society for the Study of Reproduction in July 2017, and a manuscript is expected to be complete in May 2018.

2. Characterized epigenetic variation in the genome of steelhead raised under rearing regimes designed to generate either yearling or 2-year old smolts – Sperm and red blood cells were collected from returning Methow River hatchery-origin adult steelhead reared either as S1 or S2 (n=20 per group). DNA was
isolated, RRBS libraries prepared and sequenced in 2016 and bioinformatics processing and data analysis were performed in 2017. We hypothesized that the incubation and early rearing conditions used to produce S1s versus S2s may affect epigenetic programming of the germline. The results of our analysis show no difference in global patterns of DNA methylation variation between S1s and S2s in either cell type. However, there are a few distinct genomic regions that are differentially methylated between S1s and S2 adults in both sperm and red blood cells. Many of these regions are located in close proximity to genes, indicating that DNA methylation may be regulating expression of particular genes in both sperm and red blood cells. While these results are intriguing and warrant further investigation, caution should be taken when extrapolating functional consequences of the observed DNA methylation differences as age and genetic background are confounding factors in this study. A manuscript was initiated in 2017 and is expected to be complete in late 2018.
OBSERVING SYSTEM RESEARCH STUDIES

PI
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TASK II

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NOAA GOALS
Healthy Oceans

DESCRIPTION
The Observing System Research Studies project performs data and modeling studies to identify climatically significant ocean-atmosphere interaction patterns, as well as indices that usefully characterize their amplitudes and linkages to U.S. and global weather and climate anomalies, with the goals of understanding and improving the effectiveness of the global ocean observing system, improving our awareness and understanding of present weather and climate conditions, and helping to improve upon our current ability to usefully forecast sub-seasonal, seasonal, and longer term weather anomalies. Often this involves using the data made available by the observing system to try and answer outstanding scientific questions so that effectiveness of the current observing system components can be evaluated in an up-to-date and scientifically relevant context. It also involves estimating the uncertainty in our ability to provide up-to-date estimates of the ocean state and air-sea interaction conditions necessary for confident initialization and validation of coupled forecast models based on the information collected by the observing system.

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. 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. To undertake other observing system research studies deemed important by the Office of Climate Observations, including studies supporting the underway effort to redesign the Tropical Pacific Observing System (TPOS) to meet the research and forecasting needs of the coming decades, and support understanding of coupled air-sea phenomena that offer a means of predicting weather conditions over subseasonal-to-seasonal (S2S) timescales. We also work to develop and maintain information technology
solutions that make global oceanographic and climate datasets more accessible to the wider scientific community.

ACCOMPLISHMENTS
1. Shown that the TAO/Triton moored buoy array works as designed in the 1980s (based on island wind-covariance studies) for the purpose of providing the equatorial Pacific wind variability knowledge necessary to adequately simulate El Niño-Southern Oscillation (ENSO) Sea Surface Temperature Anomaly (SSTA) development (described in Chiodi and Harrison 2017a).

2. Shown that, although they have the moored buoy winds available for assimilation, the wind data sets most commonly used in recent ENSO studies, which are produced by running numerical weather models in data-assimilation mode, have oceanically important shortcomings in variability and trend that make them deficient for this purpose (simulating ENSO) relative to using the TAO/Triton winds on their own.

3. Demonstrated that there are advantages to joint integration of satellite-based scatterometer and moored buoy wind measurements that are not being exploited by the current suite of satellite wind-synthesis products.

4. Used surface carbon mooring data in the equatorial Pacific to show that, over the timescales that can be analyzed with statistical stability based on the available high frequency observational records of near surface winds and pCO₂-differential (up to seasonal averages spaced across several years) it is the wind variability, rather than pCO₂ variability, that dominates the variability of ocean-atmosphere carbon flux.

Figure 1. The Chiodi and Harrison OLR El Niño index illustrating the index behavior over the time for which satellite based OLR information is available. Five OLR El Niño events in this period are clearly identified by the five large interannual troughs in OLR. The wintertime temperature anomalies associated with these five interannual events are shown by the maps inset; each has basically similar anomaly pattern with >3° warming over the north-central U.S. The other non-OLR years (marked by red arrows) do not share this association, and instead have different weather anomaly patterns in each case (not very helpful from a seasonal forecasting perspective; see Figure 2 for their composite, and description in Chiodi and Harrison 2017c).
5. Used the wind observations made available by the full TAO/Triton array to show that regional wind speed biases contained in the wind analysis products most commonly used in recent equatorial Pacific carbon flux studies impart substantial biases in calculations of air-sea carbon flux mean, variability and trend.

6. Observed that the global seasonal weather anomaly patterns associated with the 2015/16 outgoing longwave radiation (OLR) El Niño basically match those expected based on composite analysis of the previous OLR El Niño events: The OLR El Niño perspective held up well in 2015/16, as described in our contribution to the NOAA Climate Diagnostic and Prediction Workshop's digest.

ACCOMPLISHMENTS (INFORMATION TECHNOLOGY)

1. 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.

2. 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 U.S. IOOS (Integrated Ocean Observing System) group to leverage this tool to improve data catalogs from IOOS Regional Association members.

3. 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. 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 types of ocean observations, both in real time and delayed mode. After a successful demonstration of data integration among various platform networks through the WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology Observation Coordination Group (JCOMM OCG), we have been working closely with many global ocean observing networks to integrate their data into the ERDDAP data platform.

4. In the past year, JISAO's Kevin O'Brien, who is a JCOMM OCG member, has led a new pilot project which attempts to improve how data is sent via real time through the Global Telecommunications System (GTS), which is managed by the World Meteorological Organization (WMO). This project, named Open Access to the GTS, aimed to ease the burden for getting data on and off of the GTS. It was a highly successful and well-received project. The momentum that the project has generated will likely, in the following year, move more toward operational status.

Figure 2. Composites of wintertime temperature based on the subset of OLR-identified El Niño events and the other not-OLR-distinct years that have El Nino status based on SST. The useful (from a forecasting perspective) weather association is contributed by the OLR events.
5. In addition to leading the community in attempts to improve data integration and interoperability, the Observing System Research Studies group continues to help scientists visualize and analyze data. The group has also been involved in assisting scientists in creating very high quality data products.

6. PyFerret v7.3, the python version of the popular application Ferret, has been officially released for public use. In fact, it is currently being widely used at NOAA’s Geophysical Fluid Dynamics Laboratory (GFDL) in the post-processing workflow that is integrated with all of their model runs, including those as part of the Coupled Model Intercomparison Project. 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 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. At our most recent GFDL/PMEL technical meeting in 2017, the capability of PyFerret to easily create on-the-fly, six dimensional aggregations was enthusiastically endorsed by the GFDL scientific community.

7. 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 v5 synthesis product was released in summer 2017 for the community at large. SOCAT v5 continued the use of data ingestion and QC workflow, which has made the releases of SOCAT products much more efficient. Scientists are able to submit their data and metadata through a data ingestion dashboard, and have the data automatically become first-level quality controlled in order to find outliers that would otherwise derail QC work further into 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 as part of their calculation of the global carbon budget. As SOCAT v5 was being quality-controlled for release, data for SOCAT v6 was already being ingested into the system. At the time of this report, SOCAT v6 has completed its community-driven quality control and is being prepared for release. The release is slated for June, 2018.

8. In the coming year, the work done through the successful SOCAT project will be leveraged by the Observing Systems group to address similar issues in the Ocean Acidification community.

PRESENTATIONS

2. “Data Integration Progress and Connection to Other Activities,” Eight Meeting of the JCOMM Observations Coordination Group, Session 5.2, Qingdao, China, 5/2017.


OCEAN CLIMATE STATIONS

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TASK II

NOAA SPONSOR
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NOAA GOALS
Climate Adaptation and Mitigation

DESCRIPTION
NOAA's Ocean Climate Stations Project (OCS) aims to make climate quality air-sea interaction observations from moored buoys 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) off the coast of Japan, and Station Papa in the Gulf of Alaska.

During the summer of 2017, the OCS group successfully performed recovery and redeployment operations for all OCS moorings. The KEO mooring was first established in 2004, deployed now for 14 years. Data from the KEO mooring have become valuable for improving understanding of the effects of tropical cyclones and typhoons. The KEO site was also chosen as the focus of the international “Carbon Hot Spot” field mission in January 2018.

For Station Papa, 2017 was the 11th 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, and will be a major component of the NASA EXPORTS field program beginning in July 2018.

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 of numerical model or satellite products that have been validated against reference data.
ACCOMPLISHMENTS
The OCS moorings deliver continuous instrumental records for global climate analyses. Data returns were more than 80% in FY17, successfully meeting Objectives 1 & 2. Measurements include upper ocean temperature and surface currents, ocean heat content and transport, air-sea exchanges of heat, momentum and freshwater, and ocean carbon uptake and content. The long-term data sets being established at these sites are valuable for monitoring ocean climate, both in the short term for improving weather forecasts and the long term for understanding and predicting climate variability and change.

Researchers from around the world use data from the OCS moorings to study the state of the world ocean and its regional variations. Broad use of the OCS data is encouraged through making it freely available to the public (Objective 2). A total of 7,346 data files were downloaded from the OCS website during FY17. OCS data are also served on several other external sites where downloads are not tracked, so the total number of data files downloaded is likely much higher.

In order to ensure the OCS project stays relevant and produces good science, a strong focus is placed on writing peer-reviewed papers. Data from the OCS moorings were used in 18 peer-reviewed papers in FY17. Of these, five were studies in which the OCS data were used as a reference to assess uncertainties in gridded products. The scientific advances and analyses performed for these publications fulfill Objective 3.

The OCS group also places a high value on partnerships. By working with other groups and organizations, the project is able to share ship time, deploy additional instrumentation, perform process studies, collaborate on research, and extend the project reach. Of the 19 total project partners, five deploy instrumentation directly on the OCS moorings and six others make their own observations nearby to the OCS sites. This allows for a more thorough understanding of observations by knowing additional details from partner studies.

In April 2017, the OCS group hired a new instrument technician, JISAO’s Patrick Berk. For more detail on the OCS project, see pmel.noaa.gov/OCS.
NOAA COAST SURVEY INTERNSHIP: OCEAN MAPPING METADATA COLLECTION WIZARD

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OTHER UW PERSONNEL
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TASK II

NOAA SPONSOR
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OTHER NOAA PERSONNEL
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NOAA GOALS
Healthy Oceans

DESCRIPTION
NOAA’s Office of Coast Survey (OCS) is responsible for producing nautical charts of the U.S. Exclusive Economic Zone, which is 3.4 million square nautical miles of ocean. This is a monumental task that cannot be accomplished through the use of dedicated NOAA hydrographic platforms and contractors alone. Fortunately, many other groups collect good ocean mapping data too, much of which can be used to update NOAA’s nautical charts and/or guide deployment of NOAA survey assets. NOAA Coast Survey refers to this as “Outside Source Data” (OSD), and seeks to utilize it in cases where it adds to the knowledge of the seafloor.

Utilizing data acquired for other purposes presents NOAA with several challenges. One of the most significant is assessing the quality of the data. OSD providers follow a wide range of procedures to collect, process, and document their surveys. Without consistent, complete metadata for OSD, it is difficult for Coast Survey to estimate the quality of the survey data and decide how best to utilize it. Examples of particularly critical information include the horizontal and vertical reference system (datum) in which the data were acquired and processed, descriptions of the echosounder and positioning systems used, measurements of the relative position and orientation of these systems as installed on the vessel, corrections applied to the data (if any) to account for

Stephen Maldonado presenting his research poster at the end of the nine-week internship in Seattle.
factors such as tide and sound speed, and the processing algorithms used to convert the raw data to the submitted product.

OBJECTIVES
The intern's assignment is to create a user-friendly, software-based, metadata capture wizard which will guide OSD providers through a series of questions that capture the critical information needed to evaluate and incorporate the data into our data holdings. The wizard's output will be a metadata file in a machine-readable format such as .xml, which can be transmitted to Coast Survey with the dataset. The intern will have the opportunity to test the metadata capture wizard while sailing aboard a vessel collecting multibeam echosounder data. If time permits, the project could be extended to begin the process of semi-automatically estimating OSD uncertainty based on the metadata collected.

ACCOMPLISHMENTS
Through JISAO’s summer internship program undergraduate intern Stephen Maldonado, from Ohio State University, worked under the supervision of Cecilia Linder from NOAA’s Pacific Hydrographic Branch at the Western Regional Center in Seattle. During the nine-week program, Stephen was able to complete a functional beta version of the OSD Metadata Collection application. He also became more familiar with the hydrographic data collection process by accompanying hydrographers on the NOAA Research Vessel Bay Hydro II for a survey of the Hudson River in New York State, where he helped collect data using the vessel’s multibeam echosounder, an acoustic instrument used to calculate ocean depth. Stephen also produced a 2-minute video and conference-quality research poster that were presented at a forum at the end of the summer session.
CONSTRUCTION OF SUBSURFACE BATTERY MODULES FOR THE ENVIRONMENTAL SAMPLE PROCESSOR (ESP)

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TASK III

NOAA SPONSOR
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NOAA GOALS
Healthy Oceans
Resilient Coastal Communities and Economies

DESCRIPTION
The project goal was to build two pressure-rated, underwater battery modules to power the Environmental Sample Processor (ESP) so that it can be deployed underwater in remote environments. These battery modules were identical to two previously built for the Great Lakes Environmental Research Laboratory (GLERL), with the exception of the modification of a pressure release valve and purge port to ensure greater durability of the packs with repeated use.

OBJECTIVES
To build two underwater battery modules: pressure housings that hold individual D-cell packs that will be used to power the ESP for a full 60-day deployment. Each will have nominally 300 Ah of capacity at 15 volts with a total of 200 D-cell batteries in each. Battery module pressure housings will be fabricated from chlorinated polyvinyl chloride with a double piston O-ring seal, wet-pluggable Subconn bulkhead connectors and Deep Sea Power and Light stainless pressure release valves.

ACCOMPLISHMENTS
We completed the battery modules on schedule, delivering the functioning finished product to GLERL in September 2017. Because of our on-time and skilled work, GLERL was able to carry out their planned ESP deployments. Also, GLERL has requested that we build them two more full ESP systems.

Figure 1: Solidworks drawing of ESP battery module.

PI
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TASK III

NOAA SPONSOR
Debbie Galo – OAR Climate Program Office

NOAA GOALS
Climate Adaptation and Mitigation

DESCRIPTION
Our ability to predict weather and sea ice conditions requires \textit{in situ} observations of surface meteorology and ice motion. These observations are assimilated into Numerical Weather Prediction (NWP) models that are used to forecast weather on synoptic time scales and into the many long-term atmospheric reanalyses (e.g., National Centers for Environmental Prediction/National Center for Atmospheric Research Reanalysis) that are used for innumerable climate studies. The impact of these \textit{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. \textit{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

\textbf{Figure 1.} Deployment of an AXIB buoy by a Royal Danish Air Force C-130 flying from Thule, Greenland to the high Arctic on September 7, 2017. Photo courtesy of John Williams, ONR.
Observing Network (AON).

The International Programme for Antarctic Buoys (IPAB) was established in 1993 to provide commensurate observations for the Antarctic as has been developed for the Arctic. The United States contribution to the IABP and IPAB are coordinated through the USIABP and USIPAB, which are managed by the National Ice Center (NIC) and the Polar Science Center (PSC).

The funds from this particular IABP/IPAB grant are focused on maintaining a well-spaced AON, and Southern Ocean Observing System that provides ground truth for satellites. It also supports ice analyses by the NIC to provide meteorological and oceanographic observations for real-time operational requirements and research purposes, including support to the World Climate Research Programme (WCRP) and the World Weather Watch (WWW) Programme. These observations will also support the WCRP and WWW Polar Prediction Project.

ACCOMPLISHMENTS

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

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 NIC and Rigor. The USIABP is also a collaborative program that draws operating funds and services from a number of U.S. government organizations and research programs, which include the National Aeronautics and Space Administration, the Coast Guard, the Department of Energy (DOE), NOAA, the National Science Foundation, the Naval Oceanographic Office, the NIC, and the Office of Naval Research (ONR). 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 2017, we deployed:

1. Two CALIBs and one Ice Tracker with the NRL DISTANCE project in the Beaufort Sea in March 2017.
2. Two SVP-B buoys with the Arctic Submarine Labs mini-ICEX efforts in the Beaufort Sea in March 2017.
3. Two GPS trackers with adventurers traversing to the North Pole from Barneo in April 2017.
4. One ICEAIR and one SVP north of Deadhorse, AK in the Beaufort Sea in collaboration with the NSF-funded Warming and iRadiance Measurement buoy project in April 2017.

Figure 2. Map of buoys reporting from the Arctic Ocean near the end of our deployment season (September 22, 2017). There were 117 buoys reporting in the IABP observing network, and posted on the WMO/IOC GTS.
5. Four SVP-Bs in the Bering and Chukchi Seas, June and July by R/V Siquliaq.

6. Nine SVPs in the Bering and Chukchi Seas, deployed by the Norseman 2 from June through September, 2017.

7. Four SVP-Bs deployed by the CGC Sir Wilfrid Laurier in the Canadian Beaufort Sea in September 2017.

8. Eight SVP-Bs, and 2 XIBs deployed by the CGC Healy in the Chukchi and Beaufort seas from July through October 2017.

9. Three AXIBs owned by Environment and Climate Change Canada were deployed by USIABP personnel from a Royal Danish Air Force flying from Thule to the high Arctic (Figure 1).

Maps of the IABP buoys reporting on the GTS are shown in Figure 2.

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

2. Antarctic Buoy Deployments
During the Austral Summer of 2017/2018 in the Southern Ocean, the USIPAB in collaboration with the U.S. Global Drifter Program deployed SVP-B Buoys from the following vessels:

1. R/V Gould: 24 SVP-B, 2/month
2. R/V Shirase: 4 SVP-B
3. R/V Nathaniel B. Palmer: 40 SVP-B
4. R/V Polarstern: 10 SVP-B
5. NIWA (New Zealand): 20 SVP-B

Maps of the IPAB buoys reporting on the GTS are shown in Figure 3.

3. IABP and IPAB 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 and IPAB (Figs. 2 & 3).

4. 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

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TASK III

NOAA SPONSOR
Steve Piotrowicz and Emily Smith – 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. More than 30 countries are now participating in Argo, with the U.S. providing about half the total number of floats. UW is one of four U.S. sites that provide Argo floats. In addition to constructing and deploying floats, the JISAO 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 more than 300 floats per year, split among four institutions: Scripps Institution of Oceanography (SIO), Woods Hole Oceanographic Institution (WHOI), Pacific Marine Environmental Laboratory (PMEL), and JISAO.
3. In the past year, funds were received to build and deploy 90 floats. The JISAO 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 93 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 JISAO floats in the Antarctic have now been operating for four winter seasons. A majority of the JISAO 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 33) were deployed in the Southern Ocean, for the fourth year in a row. These floats used JISAO-developed 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. Eight papers were published in refereed journals using Argo data, and a graduate student supported on this grant - Earle Wilson - made excellent progress on finishing his PhD dissertation. It is expected that Wilson will finish his dissertation during the autumn quarter of this year at UW.
EVALUATING DEMERSAL FISH IDENTIFICATION AND RESPONSE TO ARTIFICIAL LIGHT AND ACOUSTIC NOISE USING A 360-DEGREE CAMERA AND IMAGING SONARS

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Brian Polagye – Mechanical Engineering

TASK III

NOAA SPONSOR
Elizabeth Clarke – Northwest Fisheries Science Center

NOAA GOALS
Healthy Oceans

DESCRIPTION
We successfully integrated the key pieces of hardware onto a subsea monitoring platform – the Adaptable Monitoring Package (iAMP) – and executed two deployments in Puget Sound. The iAMP was outfitted with the HorizonVue 360 camera, around which this project was originally designed, an M900 BlueView sonar, and a standard machine vision camera. We also had the opportunity to test newly developed LED strobe lights, both red and white, and chose to delay our original deployment dates in order to do so. In addition, for our second deployment, we introduced a small, GoPro-like sports camera, the Garmin VIRB 360, to provide a comparison between the HorizonVue camera and an example of a commercially available spherical camera, which is natively waterproof down to 10 meters.

For both deployments we used APL’s R/V Robertson, a 56-foot research vessel. We first inspected several sites with divers, to determine presence of fish and suitability for anchoring, and chose the fish haven at the outflow of Boeing Creek, north of Shilshole (47° 44’ 55.7” N 122° 23’ 02.9” W). The site is shallow, requiring us to work after dark in order to adequately test the strobes. For the first deployment, on February 21, 2018 we anchored as close as possible to the fish haven in a 3-point mooring to keep the boat stationary while the AMP was deployed onto the seafloor. We were only able to draw small water column fish over to the AMP deployment site,
but we were able to determine that the geometry of the HorizonVue camera makes it unsuitable for ground fish monitoring, and the relatively low resolution of the camera compared to commercially available cameras made fish identification challenging. In addition, we determined, with help from the manufacturer, that a previously undisclosed infrared filter on the HorizonVue camera was blocking all light from the red LED strobe lights.

For our second deployment, on March 1, 2018 we chose to add the commercially available Garmin VIRB 360 sports camera for comparison, and performed a more systematic test with divers using a standard camera target, held at 20 cm increments up to 5 m away from the cameras. The Garmin VIRB was chosen based on the recommendation of researchers at the Alaska Fisheries Science Center who have tested a variety of the small sports cameras now available on the market. The second deployment took place dockside in Shilshole Marina because it did not require the presence of fish and provides a more controlled and accessible environment for the divers. The test was designed to enable us to quantify the differences between the HorizonVue camera and the Garmin VIRB 360 camera. In addition, we collected imagery around the Garmin VIRB 360 using a large standard camera calibration target, which we intend to use to calibrate one of the two hemispherical cameras. An electrical problem prevented us from collecting imagery using the strobe lights during the second test, so we are planning a follow-up test with the Garmin VIRB 360 this summer when the iAMP is next deployed. We are currently in the process of analyzing imagery data from both the HorizonVue 360 and the Garmin VIRB 306.

OBJECTIVES
We proposed to develop and test a fixed camera platform that includes both a 360° camera and imaging sonar in order to: 1) improve information gained from fixed camera systems by simultaneously viewing the entire circumference around camera; and 2) to determine fish avoidance around the platform to allow determination of absolute abundance. We also proposed to test fish reaction to both red and white strobes.

ACCOMPLISHMENTS
We deployed the iAMP with the integrated HorizonVue camera as well as newly designed LED strobes, both red and white, as described above. We collected imagery and sonar data of some water column fish during the first deployment, and we saw anecdotal evidence of fish startle and scatter in the sonar when turning on the white strobe lights with a 100 ms pulse. During the second deployment we collected imagery from both the HorizonVue and a small, GoPro-like 360° action camera, the Garmin VIRB 360, which has superior resolution and efficiency, especially in the red spectrum. For this deployment we performed a more quantitative assessment of the two cameras using a handheld imaging target.

REASON WHY OBJECTIVES NOT MET
Our initial objective, to ID fish and fish behavior with the HorizonVue camera, proved challenging due to the relatively low resolution and efficiency of the camera used in the HorizonVue. Because of the large number and quality of 360° action cameras that have become commercially available since this project was first proposed, we chose, with the NOAA sponsor’s approval, to focus on quantifying the differences between the HorizonVue camera and a commercially available 360° action camera and also were able to take advantage of the opportunity to test newly designed white and red LED strobe lights. We completed tests in daylight,
but were unable to perform strobe tests with the Garmin VIRB 360 because of some system electrical problems. We plan to perform follow-up tests with the Garmin VIRB 360 and the red and white strobes when the iAMP system is next deployed this summer.
PROTECTION AND RESTORATION OF MARINE RESOURCES
ALASKA ECOSYSTEMS PROGRAM

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TASK II

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

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

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

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

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

ACCOMPLISHMENTS
1. JISAO's Joshua Cutler developed and maintained database repositories and software application to interface with databases. This included general-use applications to read and write to all AEP databases, and project-specific applications for aerial imagery counts, recording fur seal captures and sightings in the field, and automated data migrations.

2. Cutler developed and field-tested data systems for northern fur seal tag vital rates projects.

3. Cutler collected northern fur seal vital rates information at St. Paul Island, Alaska, including tag resights and a pilot-radio telemetry project.

4. JISAO's Kathryn Luxa organized and supported AEP's three remote Steller sea lion field camps on Marmot Island and Ugamak Island. Her duties included gear shipping, preparation of field manuals and instructions, personnel training, safety monitoring, and data and photo management. The 2017 field
camp crew (including five experienced and two new “campers”) attended a week of training in Seattle, co-lead by Luxa, before traveling to Alaska for the field season. Over the next nine weeks, observers resighted 349 unique branded animals, counted sea lions daily, performed camp maintenance, and assisted AEP staff during Steller sea lion branding on Ugamak Island.

5. Luxa resighted branded Steller sea lions at 18 sites in the eastern Aleutian Islands aboard the M/V Miss Alyssa, including several pups that had been branded a few weeks earlier at Ugamak Island.

6. Luxa spent much of the last year honing her Steller sea lion and northern fur seal prey identification skills. Working with one other food habits scientist, she records the presence of key hard parts (e.g., otoliths, vertebrae) from species such as walleye pollock (Gadus chalcogrammus), Pacific cod (Gadus macrocephalus), Atka mackerel (Pleuragrammus monopterygius), salmon (Oncorhynchus sp.), northern smoothtongue (Leuroglossus schmidti), and Pacific sand lance (Ammodytes hexapterus), to name just a few. Most recently, she has been reviewing samples in preparation for a multi-decade analysis comparing the diets of sympatric Steller sea lions and northern fur seals at Bogoslof Island and the Pribilof Islands. Luxa also serves as the curator of MML’s Food Habits Reference Collection, which includes remains from over 4,000 fish and 3,000 cephalopods. It is one of the largest collections of its kind in the United States.

7. Cutler and Luxa migrated AEP’s inventory of Steller sea lion and northern fur seal blood and genetics samples to a SQL database. Sample information can now be accessed more readily by AEP staff for ongoing studies, as well as collaborative research with other agencies (e.g., the Alaska Department of Fish and Game and the University of Alaska Fairbanks). They also made improvements to an application that AEP staff use to record new samples collected in the field.

8. Cutler and Luxa participated in the 2017 aerial survey of Steller sea lions in southeast Alaska and the Gulf of Alaska. Over the course of approximately 40 flight hours, they surveyed 196 sites and took over 22,000 photographs. Cutler wrote a summary of their experience for the Alaska Fisheries Science Center’s ‘Dispatches from the Field’ blog.
ECOLOGY OF ARCTIC SEALS

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

OTHER UW PERSONNEL
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TASK II

NOAA SPONSOR
Peter Boveng – Marine Mammal Laboratory

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.
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
Project Component 1: Aerial Surveys
Aerial surveys contribute to long-term databases on marine mammal distribution, abundance or relative abundance, habitat, and behavior using photographic detection and species identification, systematic searches, and line- and strip-transect protocols.

To address the objectives of this project, aerial surveys will be conducted in the following regions: Southeast Alaska, the Gulf of Alaska, the eastern Bering Sea, and the Chukchi and Beaufort seas. 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 will be used for detection of seals, and the color photos will be used for identification of species.
The overarching objectives of aerial surveys conducted for this project are to:

1. Document abundance and trends, which are needed for population assessments under the Marine Mammal Protection Act and the Endangered Species Act and for inclusion of seals in integrated ecosystems studies and models. For the ice-associated seals, obtaining the first reliable population estimates will provide a reference from which to judge future trends and evaluate population consequences of Arctic warming and ocean acidification.

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.

ACCOMPLISHMENTS

Project Component 1: Aerial Surveys

1. Participated in planning and logistics for harbor seal surveys that were conducted during the summer and fall of 2017, and that are scheduled for the summer and fall of 2018.

2. Completed field research assignments for harbor seal aerial surveys that were conducted in 2017.

3. Processed and analyzed images from 33 aerial survey flights of harbor seals in coastal Alaska conducted during the 2015 field season. This effort resulted 9,894 images processed and 1,648 images used for enumeration of seals.

4. Managed field data forms and geospatial survey data.
5. Produced summary statistics, maps, and other graphics for field operations, community outreach, reports, and presentations (e.g., maps of effort and sightings from the joint U.S.-Russia Chukchi and East Siberian Surveys.

6. Developed a new educational outreach exhibit to demonstrate how to detect ice-associated seals using aerial thermography.

7. Coordinated and attended two educational outreach events: Discover Science Weekend at the Seattle Aquarium and Polar Science Weekend at the Pacific Science Center in Seattle.

8. Attended and presented preliminary results from aerial surveys at the Alaska Marine Science Symposium in Anchorage.

9. Assisted with writing reports, peer-reviewing manuscripts, and preparing presentations.

10. Collaborated with researchers and stakeholders within and outside of NOAA and UW, including agency resource managers, Alaska Native organizations, and other entities to ensure maximum utility and impact of data collected from this project.

OBJECTIVES
Project Component 2: Satellite Telemetry Studies of Seal Movements and Foraging Behavior

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

The overarching objectives of telemetry studies during this project are to:

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. Estimate proportions of each seal species hauled out as functions of date, time of day, and other influential covariates; and

ACCOMPLISHMENTS
Project Component 2: Satellite Telemetry Studies of Seal Movements and Foraging Behavior

1. Participated in planning, preparation of equipment, and logistics for a major telemetry study of ice-associated seals in the Bering Sea during March and April 2018.
2. Conducted field research assignments during ice seal capture and tagging operations in the Bering Sea.
3. Processed, managed, and analyzed Argos telemetry data.
4. Produced summary statistics, maps, and other graphics.
5. Assisted with writing reports, peer-reviewing manuscripts, and preparing presentations.
6. Collaborated with researchers and stakeholders within and outside of NOAA and UW including agency resource managers, Alaska Native organizations, and other entities to ensure maximum utility and impact of data collected from this project.
OBJECTIVES
Project Component 3: Assessment of Seal Health, Condition, Diet, and Stock Structure

Samples and measurements collected during live-animal handling for telemetry studies support collaborative studies on health, condition, diet, contaminants, and genetic structure of seal populations.

The overarching objectives of health, condition, diet, and stock structure studies during this project are to:

1. Assess individual-based indicators of population status (i.e., health and condition) for comparison with population-based indicators (i.e., abundance, trends, and distribution);
2. Assess threats such as disease and contaminants, relevant to ESA status reviews and listing decisions;
3. Determine population structure to inform stock assessments, survey design, and threat assessments; and
4. Quantify individual covariates of potential importance for interpretation of telemetry data.

ACCOMPLISHMENTS
Project Component 3: Assessment of Seal Health, Condition, Diet, and Stock Structure

1. Participated in health, condition, diet, and stock structure studies planning and logistics, including the preparation of equipment for research on ice-associated seals in the Bering Sea.
2. Conducted field research assignments to collect samples from free-ranging seals during capture and tagging operations in the Bering Sea.
3. Processed and curated biological samples and associated field data.
4. Produced summary statistics, maps, and other graphics.
5. Assisted with writing reports, peer-reviewing manuscripts, and preparing presentations.
6. Collaborated with researchers and stakeholders within and outside of NOAA and UW including agency resource managers, Alaska Native organizations, and other entities, to ensure maximum utility and impact of data collected from this project.

Figure 2. Gavin Brady (UW JISAO, left) and Shawn Dahle (NOAA, right) scanning for ice-associated seals atop an ice floe in the Bering Sea during an ice seal capture cruise in March/April 2018. Erin Richmond, Gavin Brady, and Cynthia Christman (UW JISAO) collaborated with NOAA during the planning, data collection, and post-processing stages of this project. Image courtesy of Stacy DiRocco.
CETACEAN ASSESSMENT AND ECOLOGY PROGRAM (CAEP)

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TASK II

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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. 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 JISAO, AFSC, 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

Figure 1. Cetaceans sighted by ASAMM in 2017, transect, search, and circling effort.
The Aerial Surveys of Arctic Marine Mammals (ASAMM) is a Bureau of Ocean 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 38-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 2017 season has been drafted, and preliminary results were presented at the Alaska Marine Science Symposium in Anchorage, January 2018. Figure 1 shows cetaceans sighted by ASAMM in 2017. Figure 2 is a group of belugas photographed in 2017. Figure 3 is the survey team getting ready for a survey flight. Data analysis, writing for scientific publication, and field preparations for the 2018 field season continue.

The MML acoustics program deploys numerous passive acoustic recorders throughout the Bering, Chukchi, and Beaufort seas to document the spatial and temporal distribution of marine mammals in the area. These moorings, deployed every summer, collect acoustic data on a duty cycle for a year, and are retrieved and redeployed the following year. Figure 4 shows the location of all passive acoustic recorders.
deployed by the Acoustics group.

3. The Acoustics group at MML also analyzed 24 mooring-years of data (spanning 2011-2017) from the Bering Sea to document the temporal and spatial distribution of baleen whales, including the International Union for Conservation of Nature (IUCN) red-listed North Pacific right whale, from the Aleutian Islands to the Bering Strait. These data were incorporated into a final report submitted to the National Fish and Wildlife Foundation, and are being incorporated into at least two manuscripts that will be submitted for publication in 2018.

4. 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 were determined using biophysical sampling and moorings. The nature of those relationships relative to whale distribution and habitat utilization were also explored. 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 and 2016, respectively. Data from these project components have been processed and synthesized, and a manuscript is in preparation for peer review publication. Results from the ARCWEST project have been submitted to BOEM in a draft final report that is under review. The final pdf will be made available online at the following link once it is officially accepted (afsc.noaa.gov/nmml/cetacean/arcwest.php).

5. Because the field seasons for ARCWEST and Chuckchi Acoustics, Oceanography and Zooplankton Extension Study (CHAOZ-X) ended in 2015, the full array of moorings deployed under these two projects was continued under the Arctic Long-Term Integrated Mooring Array (ALTIMA) project (Figure 4). Data collected from the ALTIMA moorings are currently being analyzed, and will be integrated into the long-term dataset obtained from the CHAOZ, CHAOZ-X, and ARCWEST projects for an integrated, near-decadal dataset on marine mammal distribution in the Alaskan Arctic.

6. The Acoustics group at MML again participated in an educational outreach program called Expanding Your Horizons (EYH) in March 2018. The goal of EYH is to inspire young girls (grade 7-8) and spark an interest in careers in 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 eighth year participating in this program, which is hosted by Highline Community College. Additionally, they participated in Family STEM (Science, Technology, Engineering, and Math) Night at John Rogers Elementary School, where two booths were set up. One booth focused on marine mammal acoustics and the other was a hands-on booth with various furs, teeth, and bones.

7. Analysis of images and sighting data from the Aerial Calibration Experiments (ACEs) project (field dates:
August 26-September 07, 2015), which was designed to test the feasibility and efficacy of using unmanned aircraft to calculate large whale abundance in the arctic, is complete. The survey was designed to: 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. Of the 65,451 images collected during the ACEs experiment, 16,633 were manually analyzed by trained observers; this equates to 332.5 hours of image analysis. In all, 23 bowhead whales, 22 beluga whales, and 3 gray whales were recorded. In 2017, researchers worked on comparing the manual analysis results to automated detection software results. Two manuscripts detailing the performance of unmanned aerial vehicles vs. manned observation in terms of accuracy, efficiency, logistics and cost have been accepted to the Journal of Unmanned Vehicle systems. A third publication (a detailed statistical power analysis of survey design and predicted results) is currently underway, and will be submitted for peer review within the next few months.

8. The Cook Inlet beluga (CIB) project is NOAA funded and conducts research on the endangered stock of belugas tracking abundance, distribution, and habitat use. The first part of the year was spent preparing for Cook Inlet beluga hexacopter drone surveys in the summer of 2017. Post-survey work included organizing workflow for photo-identification and designing a database for logging all photographic data. Photo identification of survey data is ongoing, as are the preparations for photogrammetry analysis. Data queries of legacy CIB video analysis results and aerial survey data have been ongoing to support a new statistical analysis project. A cross collaborative winter distribution survey (Alaska Region office funded) for CI belugas was conducted over the course of seven days in March 2018 with staff from the Alaska Region office, BOEM, MML, and JISAO staff. Logistical planning and data management preparations are being made for the upcoming biennial aerial abundance survey for CI belugas.

Figure 4. Location of all passive acoustic recorders and oceanographic moorings deployed under the ARCWEST, CHAOZ-X, and ALTIMA studies.
ASSESSING THE CAPACITY FOR EVOLUTIONARY ADAPTION TO OCEAN ACIDIFICATION IN GEODUCK

PI
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TASK II

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OTHER NOAA PERSONNEL
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NOAA GOALS
Healthy Oceans

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

OBJECTIVE
1. Determine the change in allele frequencies under OA stress at single nucleotide polymorphisms (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 a larval OA trial that included the microbiome sampling. We are currently analyzing proteomic data to determine how OA exposure impacts physiology. In addition, we have made significant advances in the sequencing of the genome. This will allow us to effectively assess allele and epiallele variation under OA stress. The assembled draft genome is currently being scaffolded to improve assembly and we expect to implement it in our analysis this summer.
IMPROVING GENOMIC RESOURCES TO SUPPORT RESTORATION AND PROTECTION OF THE OLYMPIA OYSTER IN PUGET SOUND

PI
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TASK II

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NOAA GOALS
Healthy Oceans

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

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

ACCOMPLISHMENTS
Major accomplishments of the current reporting period include an improved genome assembly using new bioinformatics approaches. In addition, during this reporting period an experiment was conducted at the NOAA Manchester Field Station to evaluate how parental temperature exposure influences offspring performance. This experiment will conclude in spring 2018 with data analyses predicted to be completed by the end of the year.
EARTH-OCEAN INTERACTION PROGRAM

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TASK II

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Helene Planquette – University of Brest

NOAA GOALS
Healthy Oceans

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

OBJECTIVES
1. Explore the deep ocean to discover resources produced within neovolcanic areas; locate and characterize hydrothermal ecosystems, mineral deposits, and biological resources; understand the links between these systems and global ocean biology and chemistry.
2. Understand the interplay between biodiversity, the chemical environment of deep ocean habitats, and the structure and function of deep-ocean ecosystems.

3. Assess the impact of hydrothermal and volcanic activity on global ocean chemistry, biological production, and carbon export.

4. Assess the impact of the chemical exchange between solid Earth and the oceans, especially as regards the identification of hydrocarbon resources and areas where chemical exchange between the solid Earth and the ocean impacts ocean chemistry and biological productivity in the oceans.

ACCOMPLISHMENTS

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

The EOI program explores volcanic areas of the world's oceans to discover locations of hydrothermal activity that produce both mineral and biological resources. In order to address the large issue of how tectonics is linked to seafloor biology, we need improved global and regional knowledge of hydrothermal systems. After completing a two-year, two-cruise expedition with the Schmidt Ocean Institute vessel Falkor and the ROV Subastian on the southern half of the Mariana back-arc (13.5-18.2°N) in 2015 and 2016, we analyzed the collected vent fluid samples in the lab for chemical composition. JISAO's David A. Butterfield made a presentation at the February 2018 Ocean Sciences meeting in Portland, characterizing four different types of hydrothermal environments found in the Mariana arc and back-arc, and describing how the chemistry of the different sites may affect biological communities through the availability of chemosynthetic energy sources. A manuscript on this subject is expected within the next year.

Using water column and seafloor mapping data from the same two cruises, JISAO's Edward T. Baker and others (including PMEL's Sharon Walker and William W. Chadwick Jr., along with JISAO's Joseph A. Resing, Nathaniel Buck, and Butterfield) published a manuscript comparing hydrothermal activity among global back-arc spreading centers. We used water column mapping and seafloor imaging to identify 19 active vent sites, an increase of 13 over the current listing in the InterRidge Database, on the bathymetric highs of 7 of the 11 segments. We identified both high and low (i.e., characterized by a weak or negligible particle plume) temperature discharge occurring on segment types spanning dominantly magmatic to dominantly tectonic. Active sites are concentrated on the two southernmost segments, where distance to the adjacent arc is shortest (<40 km), spreading rate is highest (>48 mm/yr), and tectonic extension is pervasive. Re-examination of hydrothermal data from other Back Arc spreading centers (BASCs) supports the generalization that hydrothermal site density increases on segments <90 km from an adjacent arc. Although exploration quality varies greatly among BASCs, present data suggest that, for a given spreading rate, the mean spatial density of hydrothermal activity varies little between mid-ocean ridges and back-arc spreading centers. Baker presented results from this study at the 2018 Ocean Sciences meeting in Portland.

In November and December of 2017, most of the scientists in the EOI group, including Baker, Buck, Butterfield, Resing and JISAO's Kevin K. Roe, participated in a two-leg expedition to the NE Lau Basin on the Falkor to continue our in-depth exploration of one of the most volcanically active regions on the planet. The NE Lau Basin hosts the only known active boninite-producing volcanoes. Boninite is a volcanic rock type thought to be produced in the early stages of subduction zone evolution, when proto-arc volcanoes and back-arc ridges form above the newly forming subduction zone. Boninites are rare compared to the ubiquitous mid-ocean ridge basalts or basaltic andesites that make up most of the volcanic seafloor. During these expeditions, we mapped the water column for the presence of hydrothermal plumes and surveyed and sampled spectacular hydrothermal vent sites on several of the ‘Mata’ chain of boninite volcanoes. The sampling was highly successful, and laboratory analysis is in progress in 2018.

Objective 2: Accomplishments in Ecosystem Studies
The EOI group has conducted detailed ecosystem process studies and monitored the volcanic and hydrothermal systems of Axial Seamount since 1995. Since 2013, an interdisciplinary team of microbiologists, chemists, and modelers funded by the Gordon and Betty Moore Foundation has focused attention on the interdependence of chemistry and microbiology and the role of viruses in gene transfer and microbial evolution, using Axial Seamount as the field study site. We have made significant progress in developing instrumentation, conducting novel experiments (high-temperature in-situ incubations for DNA stable isotope probing), and developing models that use field observations and microbial culture experiment results to model how microbes grow in the subsurface and how fluid chemistry and flow pathways affect growth rate and microbial community structure. A paper showing correlations between functional genes (microbial activity) and fluid chemistry across three vent sites over three years was published (Fortunato et al, 2018). The first paper describing a model of fluid flow and microbial growth has been submitted (Stewart et al., submitted 2018). A manuscript considering the balance of magmatic input and hydrothermal output of carbon dioxide using a long-term time series is in the final stage of preparation for submission (Butterfield et al, in prep 2018). A separate manuscript on the long-term hydrothermal output at Axial based on analysis of hydrothermal plume data is also in preparation (Baker et al., in prep 2018). A recent paper (Spietz et al., 2018) showed that there were distinct microbial populations in the hydrothermal plume, related to differences in sub-seafloor habitat in individual lava flows from the 2015 Axial North Rift Zone eruption. The Butterfield lab is working with the Ocean Observatories Initiative group to monitor changes in chemistry at specific vent sites at Axial and produce a chemical database that should soon become available online. Axial Seamount is probably the most thoroughly studied submarine volcano on the planet, and remains an important research area for EOI scientists.

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

The chemical composition of the oceans is altered by the interaction between the solid Earth and the ocean
through hydrothermal activity. Of particular interest is the impact of these processes on the supply of trace metals that act as nutrients in the ocean. Iron (Fe) often limits primary productivity, and iron supply may control the fixation of CO₂ and its transfer from the atmosphere to the deep ocean and sediments via the export of fixed carbon from the surface ocean. Our past efforts have examined the long range transport and biogeochemical importance of hydrothermal Fe in the ocean. We also evaluated the most important ridge crest sources for providing Fe to the Southern Ocean.

We examined the flux of a variety of chemical components from the summit of Ahyi volcano into the surface ocean where they would be readily available to phytoplankton and thus promote primary production and carbon uptake along the Mariana Arc. This flux study relied on our observations that the currents at Ahyi and other volcanoes in this region are unidirectional, and that by conducting a CTD section (conductivity temperature depth) orthogonal to the flow, we could determine the flux of chemicals from the volcano. The flux estimates from Ahyi are the subject of a published manuscript by Buck et al., 2018. A similar study was conducted at the Daikoku volcano, and will be the subject of another manuscript in 2018.

Resing participated in the FeRIDGE cruise to the Mid-Atlantic Ridge with UK collaborators Alessandro Tagliabue (University of Liverpool) and Maeve Lohan (Southampton University). The cruise departed Southampton on December 20, 2017 and arrived in Guadalupe, France on February 2, 2018. This study aimed to fully determine the ‘Fe footprint’ associated with a mid-ocean ridge in terms of the supply, longevity, and mixing of hydrothermal Fe. The main object was to provide understanding on the mechanisms that regulate the longevity of hydrothermal Fe in hydrothermal plumes, and to better understand how this longevity relates to providing Fe to the surface ocean where it might impact primary productivity, and thus carbon uptake and climate. An extensive suite of chemicals were sampled for and/or determined as a part of this project. Resing analyzed samples while at sea for dissolved aluminum (Al) and manganese (Mn). Mn is a good conservative near-field tracer of hydrothermal activity, and our findings support the idea that Al is good tracer of diffuse low-temperature activity.

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

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

Ocean margin sediments, especially those below oxygen minimum zones, are important sources of trace nutrient metals (e.g., Fe and Mn) to the ocean. In Sanial et al., 2017, we demonstrated that elevated $^{228}$Ra (radium) sourced from coastal sediments was present in surface waters 8500 km away from the coast. These studies confirm that the continental shelf is an important source of sediment-derived trace elements to both coastal and central Pacific Ocean waters. $^{228}$Ra measurements, combined with Mn and Fe data reported by us previously, enabled the calculation of coastal Mn and Fe fluxes to the ocean, thus providing a quantitative measure of the impact of the solid Earth on ocean chemistry.

Primary productivity in the Gulf of Alaska (GOA) is limited by availability of the micronutrient iron. Our understanding of key processes controlling nutrient supply to surface waters in the GOA is limited. We participated in two efforts that looked at Fe transport from coastal sources to the iron-depleted waters of the GOA. We examined the impact of shelf-sediment resuspension and summertime meltwater input to rivers on Fe distributions in and transport to the GOA (Crusius et al, 2017), and we also examined the role of atmospheric transport glacial dust on the provision of Fe to the open GOA (Schroth et al, 2017). UW graduate student Susanna Michael has extended these studies and presented data on manganese and aluminum distributions from samples collected across a range of seasons on the GOA shelf at the 2018 Ocean Sciences Meeting in Portland, Oregon.

Michael also defended her Master's Thesis in September 2017 on understanding the sources of iron and other trace metals to the Equatorial Under Current (EUC). The EUC carries nutrient-rich waters eastward
to high nutrient, low-chlorophyll regions in the Eastern Equatorial Pacific, thus potentially impacting one of the more biologically productive regions in the ocean. She found that the waters entering the EUC do not acquire their trace element loads from the Solomon Sea, but must acquire most of their trace elements prior to entering the Solomon Sea, with a significant fraction also coming either just beyond the Solomon Sea or from source waters originating to the north of the equator. This study is a collaboration with Cathrine Jeandel and colleagues at the Laboratoire d'Études en Géophysique et Océanographie Spatiales (LEGOS) in Toulouse France.

The Indian Ocean is one of the most under-sampled regions of the world ocean for trace elements. As a part of trace metal component of the CLIVAR repeat hydrography program, we examined the trace metal chemistry of the Indian Ocean on four separate basin-scale sections including three N-S sections from the Southern Ocean to the Bay of Bengal at 95°E, and from the South African margin to the Antarctic shelf edge at 30°E. We previously reported on the distribution of dissolved Fe and Al from the upper 1000 m on each section. We submitted a manuscript (Barrett et al, 2018) on the chemistry of particulate matter along these same sections. Barrett reported on a wide array of chemical features associated with the Southern Ocean. Among these are features that reflect inputs of lithogenic material close to the Antarctic margin and resuspended shelf sediments close to the South African coast. At intermediate depths, impacts are also observed downstream of the Kerguelen Plateau, reflecting lateral transport of resuspended plateau sediments or glacial runoff. In addition, Resing has been part of a French-led effort by Helene Planquette (University of Brest) and Jeandel (LEGOS) to return to the Indian sector of the Southern ocean to examine trace-element impacts from the Indian Ridge and from Kerguelen Plateau.
TSUNAMI OBSERVATIONS AND MODELING
TSUNAMI RESEARCH

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

OTHER UW PERSONNEL
Donald Denbo, Edison Gica, Linus Kamb, Jean Newman, Clinton Pells, Lindsey Wright, and Hongqiang Zhou – Joint Institute for the Study of the Atmosphere and Ocean

TASK II

NOAA SPONSOR
Diego Arcas – Pacific Marine Environmental Laboratory

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

NOAA GOALS
Weather-Ready Nation
Resilient Coastal Communities and Economies

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

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

Other aspects of NOAA's tsunami-related activities include the U.S. National Tsunami Hazard Mitigation Program (NTHMP), a Federal/State collaborative partnership of NOAA, the U.S. Geological Survey, the Federal Emergency Management Agency, the National Science Foundation, and the Emergency Management and Geotechnical agencies of the U.S. coastal states. Modeling efforts at NCTR facilitate risk assessment.
for exposed communities and existing or planned infrastructure. Public education, both within the U.S. and internationally, training and capacity building for scientific and emergency planning and response, and the development of partnerships are vital to combating the tsunami threat. NCTR seeks to achieve these goals through presentations and workshops worldwide. In particular, modeling and forecast tools are customized to facilitate this mission and establish warning services for global coastal communities.

OBJECTIVES
1. To provide scientific and operational support for the tsunami forecast system SIFT for use at the U.S. Tsunami Warning Centers (TWC) in Hawaii (Pacific Tsunami Warning Center) and Alaska (National Tsunami Warning Center).

2. To continue development, testing and updating of the SIFT components, specifically, high-resolution forecast models for U.S. coastal communities.

3. To develop new tools and methodology for next-generation tsunami forecast system.

4. To conduct tsunami hazard assessment studies for coastal locations in collaboration with state and federal partners.

5. To work with federal partners to develop tsunami hazard maps conforming to standard building codes for structures in the tsunami flooding zone.

6. To promote accessibility and usability of historical tsunami data.

7. To help develop tsunami forecast and warning capabilities in the Pacific, Indian, and Atlantic oceans in collaboration with international partners using community modeling tools, including training, education, and capacity building.

ACCOMPLISHMENTS
1. Development and improvements to the SIFT software continues. During the year of 2017-2018, JISAO/NCTR completed the development and testing of the operational version of SIFT (version 4.0) for the Tsunami Warning Centers.

   a. JISAO/NCTR provided support for the Tsunami Warning Center Operations System project by answering emails and participating in conference calls and preparing virtual machines.

   b. JISAO/NCTR staff traveled to Chile, Hawaii, and Alaska for SIFT 4.0 installation.

   c. Created centralized service for updating inundation models, model code.

   d. Updated SIFT to use fewer external libraries and removed code libraries that are not actively maintained.
2. The JISAO/NCTR tsunami group developed high-resolution forecast models for Kailua, Hawaii, Easter Island (Chile), and the Marquesas Islands (French Polynesia). They are now included in the SIFT system.

3. JISAO/NCTR has been developing a new methodology to compute tsunami propagation on the fly based on early-stage earthquake CMT solutions, which will allow the SIFT forecast to be independent from precomputed tsunami unit source propagation. This method is being tested for a simple CMT solution as the first phase for its integration into SIFT and on-the-fly finite-source inversion for further upgrades at the second phase. This new method is expected to improve the speed and accuracy of next-generation tsunami forecasts.

4. JISAO/NCTR tsunami research 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 on the Pacific Coast have been developed for the localities of Bainbridge Island and Snohomish County. These new hazard assessments evaluate the exposure of all communities to a tsunami generated by a large seismic event along the Cascadia subduction zone. The hazard assessment for Southwest Washington, done previously, has been adopted in the Washington State tsunami hazard maps in 2017-2018 (Eungard et al., 2018, Figure 1). A proposal to fund the next stage of the project has been submitted to the U.S. National Tsunami Hazard Mitigation Program (NTHMP) for evaluation.

   b. JISAO completed a high-resolution site-specific model study, sponsored by Yorst-Grube-Hall Architecture, to assess the tsunami impact for the proposed Oregon State University Marine Science Building at Newport, Oregon (Figure 2). This study is composed of two phases: 1) Tsunami inundation modelling, and 2) Site-specific modelling of debris tracking. The project was successfully completed in May of 2017 (Wei and Zhou, 2017; Wei, 2017).

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Figure 2. Model simulation of debris trajectories to conform to the new building design criteria: (a) Debris trajectories of massless particles for a major XXL1 tsunami generated in the Cascadia Subduction Zone; (b) Trajectories of ships and large mass objects for the XXL1 tsunami scenario.
c. Through collaboration with the University of Málaga, NCTR has installed the tsunami simulation code HySEA, developed at the University of Málaga, on NCTR servers as an additional tool for tsunami simulation. The capability of HySEA to model frequency dispersion effects in wave propagation will become fundamental in the computation of tsunamis generated by landslides and other small-scale sources. NCTR is using HySEA for a full-coastline high resolution (1/3 arc second) inundation study for the U.S. Virgin Islands. The HySEA code is capable of running in parallel across multiple GPUs, giving NCTR the ability to run 30-hour simulations of the three largest inhabited islands (St. Thomas, St. John, and St. Croix) in less than two days per simulation. Composite inundation maps will be made of all simulated tsunamis, including maximum inundation, flooding depth, current speeds in the harbors, and attenuation time.

d. JISAO is currently working on a project through the National Institute of Building Sciences sponsored by the Department of Defense (DoD) Naval Facilities Engineering Command (NAVFAC) to update UFC for tsunami coastal inundation mapping for the DoD outside the continental U.S. This study performs modelling studies for a number of NAVFAC oversea bases to produce tsunami hazard maps conforming to the American Society of Civil Engineers 7-16 standard. This project is to be completed by August 31, 2018.

5. The Big Earth Data Initiative (BEDI) was promoted by the White House Office of Science to foster the sharing and usability of satellite, airborne, and Earth System datasets collected and held across multiple federal agencies. The 2017 BEDI project was funded to continue the rescue of segments of
paper marigrams started in 2016 in collaboration with the NOAA National Centers for Environmental Information (NCEI). In 2017, a subset of marigram traces of tsunami waves generated after earthquakes in 1896, 1854, 1933, and 1968 are undergoing rescue. These events are historically important because they impacted coastal communities and were generated in different regions of the Pacific Ocean. Each record is digitally represented by thousands of data points manually selected to ensure the capture of all features. A spline fit is then applied to generate regularly sampled time series from irregular samples. The data are documented and archived at NCEI where they are discoverable to the all federal agencies and to the public. They are relevant to ongoing investigations into tsunami generation, propagation, and flooding and for tsunami model validation, as they provide measurements of scarcely recorded waves. The December 2017 TsuInfo Alert publication provides detail on the 2016 marigram rescue effort: dnr.wa.gov/publications/ger_tsuninfo_2017_v19_no6.pdf?uj3wzy3nmi.

6. In further collaboration between NCTR and the United Nations Educational, Scientific and Cultural Organization's International Tsunami Information Center, a ComMIT (Community Modeling Interface for Tsunamis) tsunami model workshop was held in St. George's, Grenada June 19-23rd, and using the procedures defined in the Tsunami Evacuation Maps, Plans and Procedures project, a full hazard assessment was performed, and a composite evacuation map was produced with model runs performed by ComMIT users from Grenada (Figure 3). A second workshop was taught in Citeko, Indonesia November 13-17th as part of regional capacity-building efforts. Participants attended from the Seychelles, the Maldives, India, and Indonesia and continue to use ComMIT to provide inundation maps for their respective countries.

7. To support ComMIT workshops and tsunami exercises in the Caribbean and Pacific, the NCTR development team released new versions of two tsunami tools: TsuCAT version 2.2 was released in October, and ComMIT version 1.8.0 was released in November. The ComMIT release was timed for the Citeko training, and included new features allowing access to tide gauge and inundation data from any event in NOAA’s Global Historical Tsunami Database. The TsuCAT tool was used during the Caribe Wave 2018 exercise to allow rapid assessment of general wave directionality and arrival time during the exercise. TsuCAT uses pre-computed results from thousands of model runs to give a rapid assessment of tsunamis generated anywhere along the global subduction zones.

8. Two major tsunami events have occurred during the present reporting period: September 8, 2017 in Mexico and January 23, 2018 in Alaska. NCTR has continued to analyze and validate NCTR’s forecast tools and methodology with both events. More importantly, these two events were well tested with the new forecast methodology to compute tsunami propagation on-the-fly based on early-stage seismic CMT solutions using the GPU technology. Using on-the-fly finite unit sources, NCTR was able to perform source inversions to improve the forecast model results.

9. Over the reporting period, JISAO/NCTR has actively collaborated with national and international experts in submitting research proposals:

   a. As a result of the collaboration between the University of Washington and the Scripps Oceanographic Institution to help identify the connection between tsunami impact along the Ross Sea ice shelf in Antarctica and the occurrence of fracture events in the ice shelf (Figure 4). One research paper has been accepted for publication on JGR-Oceans (Bromisrski et al., 2017). A collaborative research between JISAO and Scripps titled “Tsunami hazards to West Antarctica ice shelves” is expected to be sponsored by the NSF Division of Polar Programs in 2018 to study tsunamis as an important role in Antarctica iceberg calving events due to associated infragravity waves (Figure 4).

   b. In December 2017, JISAO, and two Hawaiian local companies, INR and ARI, submitted a collaborative proposal titled “Development of comprehensive high resolution probabilistic tsunami design zone maps compatible with ASCE 7-16 for the Island of Oahu, State of Hawaii” in response to a RFP from the State of Hawaii Office of Planning. This proposal is expected to be awarded in 2018.

   c. JISAO, UW Applied Math, and the Northwest Association of Networked Ocean Observing Systems

10. NCTR has kept publishing high-quality peer-review journal articles with collaborators from different disciplines over the reporting period (see “REFERENCES” section).

REFERENCES


Wei, Y. (2017), Site-specific modeling of debris tracking for the OSU Marnie Science Building at Newport, OR, submitted to YGH architecture, p17.
APPENDIX 1

JISAO SENIOR FELLOWS AND COUNCIL MEMBERS

University of Washington

*Ackerman, Thomas, Professor, Atmospheric Sciences, Executive Director, JISAO
Armstrong, David, Professor, Aquatic and Fishery Sciences
Baker, Edward T., Senior Research Scientist, Affiliate Professor, Oceanography
Bates, Timothy S., Senior Research Scientist, Affiliate Associate Professor, Oceanography
Battisti, David S., Professor, Atmospheric Sciences, Tamaki Endowed Chair
*Bitz, Cecilia, Professor, Atmospheric Sciences, Program on Climate Change, Future of Ice Initiative
Bretherton, Christopher, Professor, Atmospheric Sciences/Applied Mathematics
Charlson, Robert J., Professor Emeritus, Atmospheric Sciences
Covert, David S., Research Professor Emeritus, Atmospheric Sciences
Emerson, Steven R., Professor Emeritus, Oceanography
Eriksen, Charles C., Professor, Oceanography
Friedman, Carolyn, Professor, Aquatic & Fishery Sciences
Fu, Qiang, Professor, Atmospheric Sciences
Gammon, Richard H., Professor Emeritus, Chemistry, Professor, Oceanography
Hartmann, Dennis L., Professor, Atmospheric Sciences
Hilborn, Ray, Professor, Aquatic & Fishery Sciences
*Horne, John, Professor, Aquatic & Fishery Sciences, Quantitative Ecology & Resource Management, Center for Quantitative Science
Jaeglé, Lyatt, Professor, Atmospheric Sciences
Jaffe, Dan, Professor, Interdisciplinary Arts & Sciences and Atmospheric Sciences
McDuff, Russell, Professor Emeritus, Oceanography
Murray, James W., Professor Emeritus, Oceanography
Punt, Andre E., Professor and Director, Aquatic and Fishery Sciences, Quantitative Ecology & Resource Management
Quay, Paul D., Professor, Oceanography
Rhines, Peter B., Professor, Oceanography and Atmospheric Sciences
Ruesink, Jennifer, Professor, Biology
Thompson, LuAnne, Professor, Oceanography, Director, Program on Climate Change
Wallace, John M., Professor Emeritus, Atmospheric Sciences

NOAA Pacific Marine Environmental Laboratory

Bullister, John, Oceanographer, Ocean Climate Research Division, Affiliate Associate Professor, Oceanography (in memoriam 2018)
*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
Johnston, Gregory C., Oceanographer, Ocean Climate Research Division, Affiliate Professor, Oceanography
Kessler, William S., Oceanographer, Ocean Climate Research Division, Affiliate Professor, Oceanography
McPhaden, Michael J., Senior Research Scientist, Ocean Climate Research Division, Affiliate Professor, Oceanography
Overland, James E., Division Leader, Coastal and Arctic Research Division, Affiliate Professor, Atmospheric Sciences
Quinn, Patricia K., Research Chemist, Ocean Climate Research Division
Sabine, Christopher, Director, Pacific Marine Environmental Lab, Affiliate Professor, Oceanography (resigned end of 2017)
Stabeno, Phyllis, Supervisory Oceanographer, Ocean Climate Research Division
*Stepien, Carol, Division Leader, Ocean Environment Research, Affiliate Professor, Oceanography
Titov, Vasily, Oceanographer, NOAA Center for Tsunami Research, Affiliate Assistant Professor, Earth and Space Sciences
*Zhang, Chidong, Division Leader, Ocean Climate Research Division, Affiliate Professor, Atmospheric Sciences (took on Acting Director duties, replaced by Stepien)

*2017-2018 Council Members
### APPENDIX 2

**NOAA COOPERATIVE AGREEMENT AWARDS FUNDED IN 2017-2018**

<table>
<thead>
<tr>
<th>Task</th>
<th>PI</th>
<th>Title</th>
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<td>Punt, Andre</td>
<td>Bevan Workshop</td>
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<td>&quot;Assessment and Ecology Program: Understanding Cetacean Distribution in Alaskan Waters in Relation to the Impacts of Climate Change and Anthropogenic Activities&quot;</td>
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<td>Bond, Nicholas</td>
<td>&quot;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&quot;</td>
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<td>Accounting for variable fishing mortality and recruitment in length-based data-limited stock</td>
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<td>Butterfield, David Lilley, Marvin Resing, Joseph Baker, Edward</td>
<td>Earth-Ocean Interaction Program (Vents Hydrothermal Research Group)</td>
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<td>Chen, Shuyi</td>
<td>Role of Air-Sea-Land Interaction in the MJO Prediction Barrier over the Maritime Continent: A Cloud-Resolving Coupled Modeling Study</td>
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<td>Using habitat characteristics and prey abundance to predict distribution, abundance, and condition of groundfish in the Gulf of Alaska</td>
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<td>Assessing the Capacity for Evolutionary Adaptation to Ocean Acidification in Geoduck</td>
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<td>Roberts, Steven</td>
<td>Improving genomic resources to support restoration and protection of the Olympia Oyster in Puget Sound</td>
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<td>Sonnerup, Rolf</td>
<td>Chlorofluorocarbon Tracer Program</td>
<td>$183,840</td>
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<td>Tornabene, Luke</td>
<td>Archival Storage and Dissemination of Data on Northeast Pacific Fish Eggs, Larvae, and Adults</td>
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<td>Arctic Project</td>
<td>$168,999</td>
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<td>Young, Graham</td>
<td>Steelhead Reproduction and Epigenetics</td>
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<td>Zhang, Dongxiao</td>
<td>CPO</td>
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<td>OCS Saildrone</td>
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<td>Tropical Atmosphere-Ocean Interaction</td>
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<td>Doherty, Sarah</td>
<td>Contribution to National Climate Assessment 4</td>
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<td>Holzworth, Robert</td>
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<td>Automated Image Processing for Fisheries Applications III</td>
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<td>Mickett, John</td>
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<td>Punt, Andre</td>
<td>Development and delivery of a training course in Fisheries Management Strategy Evaluation</td>
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<td>III</td>
<td>Punt, Andre</td>
<td>Forecast Effects of Ocean Acidification and Ocean Temperature on Abundance and Economics of Bristol Bay Red King Crab</td>
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<td>Punt, Andre</td>
<td>Partnership with the Northwest Fisheries Science Center and Alaska Fishery Science Center to Develop Increased Capacity in the School of Aquatic &amp; Fishery Sciences to Enhance Teaching and Research</td>
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<td>Using spatial analysis tools to integrate fishery and survey data</td>
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<td>West Coast Groundfish Stock Assessment</td>
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<td>Rigor, Ignatius</td>
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<td>The Argo Project: Global Observations for Understanding and Prediction of Climate Variability</td>
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<td>III</td>
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<td>Advanced Sensor Development and Integration for Fish Assessments</td>
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<td>III</td>
<td>Wei, Yong</td>
<td>Tsunami Research</td>
<td>$347,162</td>
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## APPENDIX 3

### NON-COOPERATIVE AGREEMENT AWARDS FUNDED IN 2017-2018

<table>
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<tr>
<th>PI</th>
<th>Sponsor</th>
<th>Full Title</th>
<th>Total Award</th>
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<td>Thomas Ackerman</td>
<td>University of Toledo</td>
<td>Collaborative Research: Gene Diversity of the VHS Fish Virus: Evolution of the Cellular Immune Response</td>
<td>$67,356</td>
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<td>Thomas Ackerman</td>
<td>University of Toledo</td>
<td>Invasive Invertebrate Species Prevention, Detection, and Control: A New Next Generation Sequencing Assay</td>
<td>$117,432</td>
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<td>Thomas Ackerman</td>
<td>JPL</td>
<td>Validation and Application of MISR Cloud Retrievals</td>
<td>$180,000</td>
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<td>Timothy Bates</td>
<td>NASA</td>
<td>Sea Spray Aerosol Production over the North Atlantic during NAAMES-4</td>
<td>$249,511</td>
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<td>Nicholas Bond</td>
<td>NOAA</td>
<td>Downscaled seasonal forecasts for living marine resource management off the US west coast</td>
<td>$14,945</td>
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<td>Nicholas Bond</td>
<td>NOAA</td>
<td>Experiments with Seasonal Forecasts of ocean conditions in the Pacific Northwest to aid the crab fishery</td>
<td>$131,561</td>
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<td>Nicholas Bond</td>
<td>UAF</td>
<td>Yakutat Wave Energy Converter Impact Assessment</td>
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<tr>
<td>Brendan Carter</td>
<td>NOAA</td>
<td>NANOOS</td>
<td>$25,000</td>
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<tr>
<td>Wei Cheng</td>
<td>NOAA</td>
<td>Collaborative Research: Understanding the freshwater budget of the Atlantic Ocean: Controls, Responses, and the Role of the AMOC</td>
<td>$154,665</td>
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<td>Andrew Chiodi</td>
<td>USFS</td>
<td>Climate research for wildland fire management</td>
<td>$45,826</td>
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<td>Albert Hermann</td>
<td>NOAA</td>
<td>Seasonal Forecasting Applications for Ecosystem Based Fisheries Management in the Eastern Bering Sea</td>
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<td>Roger Marchand</td>
<td>JPL</td>
<td>CloudSat Global Summary and Geometric Profile (GeoProf) Datasets</td>
<td>$28,000</td>
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<td>Ryan McCabe</td>
<td>NPRB</td>
<td>Arctic Integrated Ecosystem Survey (IES) Phase II: Oceanography and Lower Trophic Level Productivity</td>
<td>$319,094</td>
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<td>Ryan McCabe</td>
<td>NOAA</td>
<td>MERHAB: An early warning system for Pseudo-nitzschia HABs on Pacific Northwest outer-coast beaches</td>
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<tr>
<td>Name</td>
<td>Institute</td>
<td>Description</td>
<td>Amount</td>
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<tr>
<td>Ivonne Ortiz</td>
<td>Lenfest</td>
<td>An integrative bioenergetics and spatial approach for quantifying relationships between northern fur seals, their prey, fisheries, and climate</td>
<td>$483,233</td>
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<td>Casey Saanger</td>
<td>NSF</td>
<td>Reducing uncertainty in clumped isotope thermometry by evaluating the effect of 17O excess</td>
<td>$69,304</td>
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<td>Rolf Sonnerup</td>
<td>AOOS</td>
<td>Alaska Marine Highway System Ferry CO2 System Installation: Part II: MAP CO2 Instrument Installation and Validation Onboard the M/V Columbia</td>
<td>$6,824</td>
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<td>Rolf Sonnerup</td>
<td>X Prize Fdn</td>
<td>Xprize autonomous ocean explorers</td>
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<td>Muyin Wang</td>
<td>NSF</td>
<td>NSF GEO-NERC Collaborative Research: Advancing Predictability of Sea Ice: Phase 2 of the Sea Ice Prediction Network</td>
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<td>Yong Wei</td>
<td>KPFF</td>
<td>Site-specific modeling of debris tracking for the OSU Marine Science building at Newport, OR</td>
<td>$36,145</td>
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<td>Yong Wei</td>
<td>NIBS</td>
<td>Update UFC for Tsunami Coastal Inundation Mapping for DOD OCONUS</td>
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<td>$2,984,164</td>
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APPENDIX 4

PROFESSIONAL AWARDS

CHENG — PROJECTED CHANGES IN CARBON CYCLING AND ARAGONITE SATURATION IN THE BERING SEA
This project supported undergraduate NOAA Hollings Scholar, Danielle Naiman, during the summer of 2017. Naiman worked with output from the model hindcast to illustrate the underlying mechanisms of spatial variability in ΩArag and differences between the warm and cold regimes. She won an award for her presentation of this work at the student symposium at NOAA Headquarters.

ESSINGTON — EFFECTS OF HIGH- AND LOW-FREQUENCY ENVIRONMENTAL VARIATION ON FISH GROWTH AND STOCK ASSESSMENT REFERENCE POINTS: A CASE STUDY USING YELLOWFIN SOLE AND PACIFIC OCEAN PERCH OTOLITHS
Tim Essington - Oscar Eldon Sette Award for Outstanding Marine Fishery Biologist given by the Marine Fisheries Section of the American Fisheries Society.

MORDY — INNOVATIVE TECHNOLOGY FOR ARCTIC EXPLORATION
NOAA Bronze Medal Award to Pacific Marine Environmental Laboratory 2016 Saildrone Team and the Alaska Fisheries Science Center 2016 Saildrone Team (NMFS) for strengthening NMFS-OAR collaborations through the pioneering use of a Saildrone for next-generation ecosystem surveys in the Bering Sea (announced April 3, 2018).

ANDERSON — 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
Anderson Advisee Jennifer Meredith (Economics PhD; defending Spring 18) - Best Student Presentation award at the 2017 North American Association of Fisheries Economists (NAAFE) conference. She will start as an Assistant Professor at Colby College in fall 2018. Meredith used her Sea Grant Marine Resource Economics Fellowship, with mentorship at AFSC, to collect primary data on over 800 people in Bristol Bay. At that time limited entry salmon permits were issued to assess whether enclosure of those fisheries influences outmigration decisions of permit recipients or their family members.

Anderson Advisee Keita Abe (Economics PhD; defending Spring 18) - Best Student Paper award at the 2017 NAAFE conference. Abe will be a postdoc at the Norwegian School of Economics. He developed new methods for empirical analysis of dynamic decision making in Bering Sea pollock and Alaska longline fisheries.

Anderson undergraduate thesis Advisee Joshua Kim (Economics 2015) - Best Thesis award, College of Arts & Sciences Dean's Medal in Social Science, and is now a PhD student in Stanford's Economics program.
## APPENDIX 5

### GRADUATE STUDENTS

<table>
<thead>
<tr>
<th>Student Name</th>
<th>Academic Unit</th>
<th>Degree</th>
<th>Degree Advisor</th>
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<tr>
<td>Adams, Grant</td>
<td>School of Aquatic and Fishery Sciences</td>
<td>Ph.D.</td>
<td>Andre Punt</td>
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<tr>
<td>Allen Akselrud, Caitlin</td>
<td>School of Aquatic and Fishery Sciences</td>
<td>Ph.D.</td>
<td>Andre Punt</td>
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<td>Anderson, Jessica E</td>
<td>School of Oceanography</td>
<td>Ph.D.</td>
<td>Stephen Riser</td>
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<td>Arrington, Morgan B</td>
<td>School of Aquatic and Fishery Sciences</td>
<td>M.S.</td>
<td>Tim Essington</td>
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<td>Atta, Calder Jong</td>
<td>School of Aquatic and Fishery Sciences</td>
<td>M.S.</td>
<td>Luke Tornabene</td>
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<tr>
<td>Best, John Kevin Jr</td>
<td>School of Aquatic and Fishery Sciences</td>
<td>Ph.D.</td>
<td>Andre Punt</td>
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<tr>
<td>Christensen, Katy</td>
<td>School of Oceanography</td>
<td>M.S.</td>
<td>Stephen Riser</td>
</tr>
<tr>
<td>Clark, Elizabeth A</td>
<td>Computer Science &amp; Engineering</td>
<td>Ph.D.</td>
<td>Bart Nijssen</td>
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<td>Huang, Tsung-Wei</td>
<td>Electrical Engineering</td>
<td>M.S.</td>
<td>Jenq-Neng Hwang</td>
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<td>Lee, Qi</td>
<td>School of Aquatic and Fishery Sciences</td>
<td>M.S.</td>
<td>Andre Punt</td>
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<td>Rohan, Sean K.</td>
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<td>Kerim Aydin</td>
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<td>Scannell, Hillary A</td>
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<td>Michael McPhaden</td>
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<td>Wang, Gaoang</td>
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<td>Wilson, Earle</td>
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<td>Steve Riser</td>
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<td>Wilson, Shane Davis</td>
<td>School of Aquatic and Fishery Sciences</td>
<td>M.S.</td>
<td>Tim Essington</td>
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<tr>
<td>Zheng, Hao</td>
<td>Earth and Space Sciences</td>
<td>Ph.D.</td>
<td>Robert Holsworth</td>
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APPENDIX 6

POSTDOCTORAL RESEARCH ASSOCIATES

Barnett, Lewis
Boyd, Charlotte
Cao, Jie
Chu, Sophie N.
Faig, Amanda D.
Gao, Jin
Gavery, Mackenzie R.
Gothmann, Anne M.
Hauser, Donna D. **
Horowitz, Hannah Marie **
Jacobson, Eiren Kate
Lee, Wu-Jung **
Letaw, Alathea Diana
O'Donnell, James L. **
Proistosescu, Cristian
Richerson, Kate
Stawitz, Christine C.
Trukhanova, Irina S.
Webber, D'Arcy N. **
White, Rachel H. **
Xu, Haikun
Zanowski, Hannah Marie

** Received less than 50% support from JISAO.
APPENDIX 7

PERSONNEL COUNT

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APPENDIX 9

PUBLICATIONS: APRIL 1, 2017 - MARCH 31, 2018

Not Previously Reported as Published:


Published:


46. Huang, J., et al. (2017) Recently amplified arctic warming has contributed to a continual global warming trend, Nature Climate Change, 7(12), 875-879, doi:10.1038/s41558-017-0009-5.


70. Morison, J. (2017) Ocean Profile Measurements during the Seasonal Ice Zone Reconnaissance Surveys Ocean Profiles, edited by APL-UW Polar Science Center, Seattle, WA.


100. Sanial, V., et al. (2018) Radium-228 as a tracer of dissolved trace element inputs from the Peruvian
continental margin, Marine Chemistry, 201, 20-34, doi:10.1016/j.marchem.2017.05.008.


Climate Assessment, Volume I, U.S. Global Change Research Program, Washington, DC, USA.


## APPENDIX 10

### ACRONYMS

<table>
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<tr>
<th>Acronym</th>
<th>Definition</th>
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<td>ABC</td>
<td>Allowable Biological Catch</td>
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<tr>
<td>ACEs</td>
<td>Aerial Calibration Experiments</td>
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<tr>
<td>ACLIM</td>
<td>Alaska Climate Integrated Modeling</td>
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<tr>
<td>ADCP</td>
<td>acoustic Doppler current profiler</td>
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<tr>
<td>AEP</td>
<td>Alaska Ecosystems Program</td>
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<td>AGU</td>
<td>American Geophysical Union</td>
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<tr>
<td>AFSC</td>
<td>Alaska Fisheries Science Center</td>
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<tr>
<td>ALTIMA</td>
<td>Arctic Long-Term Integrated Mooring Array</td>
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<tr>
<td>AMAP</td>
<td>Arctic Monitoring and Assessment Program</td>
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<tr>
<td>AMO</td>
<td>Atlantic Multidecadal Oscillation</td>
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<td>AMSS</td>
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<tr>
<td>AON</td>
<td>Arctic Observing Network</td>
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<tr>
<td>AOX</td>
<td>Arctic Observations Experiment</td>
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<tr>
<td>ARCWEST</td>
<td>Arctic Whale Ecology Study</td>
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<tr>
<td>ASAMM</td>
<td>Aerial Surveys of Arctic Marine Mammals</td>
</tr>
<tr>
<td>ATLAS</td>
<td>autonomous temperature line acquisition system</td>
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<tr>
<td>BASC</td>
<td>Back Arc spreading center</td>
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<td>BBRKC</td>
<td>Bristol Bay red king crab</td>
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<tr>
<td>BEDI</td>
<td>Big Earth Data Initiative</td>
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<tr>
<td>BOEM</td>
<td>Bureau of Ocean Energy Management</td>
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<tr>
<td>CAEP</td>
<td>Cetacean Assessment and Ecology Program</td>
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<td>CAPAM</td>
<td>Center for the Advancement of Population Assessment Methodology</td>
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<tr>
<td>CCN</td>
<td>cloud condensation nuclei</td>
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<td>CESM</td>
<td>Community Earth System Model</td>
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<td>CFC</td>
<td>chlorofluorocarbon</td>
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<tr>
<td>CHAOZ-X</td>
<td>Chuckchi Acoustics, Oceanography and Zooplankton Extension Study</td>
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<td>CIB</td>
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<td>CMIP6</td>
<td>Coupled Model Intercomparison Project Phase 6</td>
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<td>Acronym</td>
<td>Full Form</td>
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<td>CPUE</td>
<td>catch per unit effort</td>
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<tr>
<td>CSSR</td>
<td>Climate Science Special Report</td>
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<tr>
<td>DARTâs</td>
<td>Deep-ocean Assessment and Reporting of Tsunamis</td>
</tr>
<tr>
<td>DFO</td>
<td>Canadian Department of Fisheries and Oceans</td>
</tr>
<tr>
<td>DIC</td>
<td>dissolved inorganic carbon</td>
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<tr>
<td>DoD</td>
<td>Department of Defense</td>
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<tr>
<td>DOE</td>
<td>Department of Energy</td>
</tr>
<tr>
<td>EBS</td>
<td>eastern Bering Sea</td>
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<tr>
<td>Eco-FOCI</td>
<td>Ecosystems and Fisheries-Oceanography Coordinated Investigations</td>
</tr>
<tr>
<td>ELH</td>
<td>Early Life History</td>
</tr>
<tr>
<td>ENGLN</td>
<td>Earth Networks Global Lightning Network</td>
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<tr>
<td>ENSO</td>
<td>El Niño-Southern Oscillation</td>
</tr>
<tr>
<td>EOI</td>
<td>Earth-Ocean Interaction</td>
</tr>
<tr>
<td>ESA</td>
<td>Endangered Species Act</td>
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<td>ESD</td>
<td>External Source Data</td>
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<tr>
<td>ESM</td>
<td>Earth system model</td>
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<tr>
<td>ESP</td>
<td>Environmental Sample Processor</td>
</tr>
<tr>
<td>ESRL</td>
<td>Earth Systems Research Lab</td>
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<td>Equatorial Under Curren</td>
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<tr>
<td>EYH</td>
<td>Expanding Your Horizons</td>
</tr>
<tr>
<td>GCM</td>
<td>Global climate model</td>
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<tr>
<td>GFDL</td>
<td>Geophysical Fluid Dynamics Laboratory</td>
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<tr>
<td>GLERL</td>
<td>Great Lakes Environmental Research Laboratory</td>
</tr>
<tr>
<td>GLM</td>
<td>Global Lightning Mapper</td>
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<tr>
<td>GMM</td>
<td>Gaussian mixture model</td>
</tr>
<tr>
<td>GOA</td>
<td>Gulf of Alaska</td>
</tr>
<tr>
<td>GO-SHIP</td>
<td>Global Ocean Ship-based Hydrographic Investigations Program</td>
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<tr>
<td>GPU</td>
<td>graphic processor unit</td>
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<tr>
<td>GTMBA</td>
<td>Global Tropical Moored Buoy Array</td>
</tr>
<tr>
<td>GTS</td>
<td>Global Telecommunications System</td>
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<tr>
<td>IABP</td>
<td>International Arctic Buoy Programme</td>
</tr>
<tr>
<td>iAMP</td>
<td>Adaptable Monitoring Package</td>
</tr>
<tr>
<td>ICOADS</td>
<td>International Comprehensive Ocean-Atmosphere Data Set</td>
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<tr>
<td>IndOOS</td>
<td>Indian Ocean Observing System</td>
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<tr>
<td>IOD</td>
<td>Indian Ocean Dipole</td>
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<tr>
<td>IOOS</td>
<td>Integrated Ocean Observing System</td>
</tr>
<tr>
<td>IPAB</td>
<td>International Programme for Antarctic Buoys</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>IPHC</td>
<td>International Pacific Halibut Commission</td>
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<tr>
<td>Abbreviation</td>
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<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
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<td>ISPD</td>
<td>International Surface Pressure Data Bank</td>
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<tr>
<td>ITAE</td>
<td>Innovative Technology for Arctic Exploration</td>
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<td>ITQ</td>
<td>Individual Transferable/Fishing Quota program</td>
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<td>IUCN</td>
<td>International Union for Conservation of Nature</td>
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<tr>
<td>JCOMM OCG</td>
<td>Joint Technical Commission for Oceanography and Marine Meteorology Observation Coordination Group</td>
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<tr>
<td>KEO</td>
<td>Kuroshio Extension Observatory</td>
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<tr>
<td>LB-SPR</td>
<td>Length-Based Spawning Potential Ratio</td>
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<tr>
<td>LEGOS</td>
<td>Laboratoire d'Etudes en Géophysique et Océanographie Spatiales</td>
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<tr>
<td>LIME</td>
<td>Length-based Integrated Mixed Effects</td>
</tr>
<tr>
<td>MART</td>
<td>Marine Aerosol Reference Tank</td>
</tr>
<tr>
<td>MC</td>
<td>Maritime Continent</td>
</tr>
<tr>
<td>MEY</td>
<td>maximum economic yield</td>
</tr>
<tr>
<td>MJO</td>
<td>Madden-Julian Oscillation</td>
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<td>MML</td>
<td>Marine Mammal Laboratory</td>
</tr>
<tr>
<td>MOST</td>
<td>method of splitting tsunami</td>
</tr>
<tr>
<td>MSE</td>
<td>management strategy evaluation</td>
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<tr>
<td>MSY</td>
<td>maximum sustainable yield</td>
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<td>N2O</td>
<td>nitrous oxide</td>
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<td>NAVFAC</td>
<td>Naval Facilities Engineering Command</td>
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<td>NCA4</td>
<td>4th National Climate Assessment</td>
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<tr>
<td>NCEI</td>
<td>National Centers for Environmental Information</td>
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<td>NCTR</td>
<td>NOAA Center for Tsunami Research</td>
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<td>NGO</td>
<td>non-governmental organization</td>
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<tr>
<td>NIC</td>
<td>National Ice Center</td>
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<tr>
<td>NMFS</td>
<td>National Marine Fisheries Service</td>
</tr>
<tr>
<td>NPFMC</td>
<td>North Pacific Fishery Management Council</td>
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<tr>
<td>NPZ</td>
<td>nutrient, photoplankton, zooplankton</td>
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<tr>
<td>NTHMP</td>
<td>National Tsunami Hazard Mitigation Program</td>
</tr>
<tr>
<td>NWFSU</td>
<td>Northwest Fisheries Science Center</td>
</tr>
<tr>
<td>NWP</td>
<td>Numerical Weather Prediction</td>
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<tr>
<td>OA</td>
<td>ocean acidification</td>
</tr>
<tr>
<td>OCS</td>
<td>Ocean Climate Stations</td>
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<tr>
<td>OCS</td>
<td>Office of Coast Survey</td>
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<tr>
<td>OFL</td>
<td>overfishing limit</td>
</tr>
<tr>
<td>OLR</td>
<td>outgoing longwave radiation</td>
</tr>
<tr>
<td>ONR</td>
<td>Office of Naval Research</td>
</tr>
<tr>
<td>pCO2</td>
<td>partial pressure of carbon dioxide</td>
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<tr>
<td>PFMC</td>
<td>Pacific Fishery Management Council</td>
</tr>
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<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>PIFSC</td>
<td>Pacific Islands Fisheries Science Center</td>
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<tr>
<td>PIRATA</td>
<td>Prediction and Research Moored Array in the Tropical Atlantic</td>
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<tr>
<td>PMEL</td>
<td>Pacific Marine Environmental Laboratory</td>
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<tr>
<td>POPS</td>
<td>printed optical particle spectrometer</td>
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<tr>
<td>PSC</td>
<td>Polar Science Center</td>
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<tr>
<td>QERM</td>
<td>Quantitative Ecology and Resource Management</td>
</tr>
<tr>
<td>RACE</td>
<td>Resource Assessment and Conservation Engineering</td>
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<tr>
<td>RAMA</td>
<td>Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction</td>
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<tr>
<td>RBC</td>
<td>red blood cells</td>
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<tr>
<td>RCP</td>
<td>representative concentration pathway</td>
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<td>REEM</td>
<td>Resource Ecology and Ecosystem Modeling</td>
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<tr>
<td>ROMS</td>
<td>Regional Ocean Modeling System</td>
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<tr>
<td>RRBS</td>
<td>Reduced Representation Bisulfite Sequencing</td>
</tr>
<tr>
<td>RTAP</td>
<td>Research Transition Acceleration Program</td>
</tr>
<tr>
<td>S2S</td>
<td>sub-seasonal to seasonal</td>
</tr>
<tr>
<td>SAFS</td>
<td>UW School of Aquatic and Fishery Sciences</td>
</tr>
<tr>
<td>SCOR</td>
<td>Scientific Committee on Oceanic Research</td>
</tr>
<tr>
<td>SF6</td>
<td>sulfur hexafluoride</td>
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<tr>
<td>SIFT</td>
<td>Short-term Inundation Forecasting for Tsunamis</td>
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<tr>
<td>SiPN2</td>
<td>Sea Ice Prediction Network</td>
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<tr>
<td>SLP</td>
<td>sea level pressure</td>
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<tr>
<td>SNPs</td>
<td>single nucleotide polymorphisms</td>
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<td>SOAR</td>
<td>Synthesis of Arctic Research</td>
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<tr>
<td>SOCAT</td>
<td>Surface Ocean Carbon Atlas</td>
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<td>SSA</td>
<td>Sea spray aerosol</td>
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<tr>
<td>SSC</td>
<td>Scientific and Statistical Committee</td>
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<tr>
<td>SSD</td>
<td>single shot detector</td>
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<tr>
<td>SSTA</td>
<td>Sea surface Temperature Anomaly</td>
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<tr>
<td>SST</td>
<td>sea surface temperature</td>
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<tr>
<td>STEM</td>
<td>science, technology, engineering, and math</td>
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<tr>
<td>TAO</td>
<td>Tropical Atmosphere Ocean</td>
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<tr>
<td>T-Flex</td>
<td>Tropical Flex</td>
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<tr>
<td>TPOS</td>
<td>Tropical Pacific Observing System</td>
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<td>TRITON</td>
<td>Triangle Trans-Ocean Buoy Network</td>
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<tr>
<td>UAF</td>
<td>Unified Access Framework</td>
</tr>
<tr>
<td>UAS</td>
<td>unmanned aerial systems</td>
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<tr>
<td>UNEP</td>
<td>United Nations Environment Program</td>
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<tr>
<td>USGCRP</td>
<td>U.S. Global Change Research Program</td>
</tr>
<tr>
<td>USIABP</td>
<td>U.S. Interagency Arctic Buoy Program</td>
</tr>
<tr>
<td>USV</td>
<td>unmanned surface vehicle</td>
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<tr>
<td>UWFC</td>
<td>University of Washington Fish Collection</td>
</tr>
<tr>
<td>VLF</td>
<td>very low frequency</td>
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<td>WCRP</td>
<td>World Climate Research Programme</td>
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<td>WMO</td>
<td>World Meteorological Organization</td>
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<td>WNFH</td>
<td>Winthrop National Fish Hatchery</td>
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<td>WOAC</td>
<td>Washington Ocean Acidification Center</td>
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<td>WWW</td>
<td>World Weather Watch</td>
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<tr>
<td>WWLLN</td>
<td>World Wide Lightning Location Network</td>
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