Sustaining NANOOS, the Pacific Northwest component of the U.S. IOOS
NOAA Award: NA16NOS0120019 Reporting period: 6/01/2016 to 11/30/2016

1) Project Summary

Our overall project goal is to sustain the Northwest Association of Networked Ocean Observing Systems, NANOOS, as the Regional Coastal Ocean Observing System for the U.S. Pacific Northwest that serves regional stakeholders in alignment with the vision of U.S. Integrated Ocean Observing System (IOOS®). NANOOS, with its essential subcomponents (integrated in-water and land-based Observing Systems, Data Management and Communications, Modeling and Analysis, and Education and Outreach) that are closely integrated within the national IOOS® system, provides significant societal benefits across a wide spectrum of users including federal, tribal, state and local governments, marine industries, scientific researchers, Non-Governmental Organizations (NGOs), educators and the general public.

For this FY16 period (= Y1 of this award; Y10 of NANOOS RCOOS operations) our objectives were to:

1) **Maintain NANOOS as the U.S IOOS PNW Regional Association:** Sustain our proven role for regional coordination, administrative infrastructure, and stakeholder engagement, engaging federal and non-federal (tribal, academic, state, local, industry, NGO, etc.) partners.
2) **Maintain surface current and wave mapping capability.** Maintain existing HF-radar foundational capability providing critical national capacity; continue, to the extent possible, existing investment in wave mapping at critical ports.
3) **Sustain existing buoys and gliders in the PNW coastal ocean, in coordination with national programs.** Maintain these essential assets providing regional observations, with focus, to the extent possible, on hypoxia, HABs, ocean acidification (OA), climate change detection.
4) **Maintain observation capabilities in PNW estuaries, in coordination with local and regional programs.** Maintain these to aid sustainable resource management, water quality assessment and sub-regional climate change evaluation. Sustain observing ability including to the extent possible, hypoxia and OA.
5) **Maintain core elements of beach and shoreline observing programs.** Contribute to hazard mitigation by providing, to the extent possible, essential observations and better decision support tools for coastal managers, planners and engineers.
6) **Provide sustained support to a community of complementary regional numerical models.** Contribute, to the extent possible, to the operation of regional models, and the tools and products they support, covering the head of tide of estuaries to the outer edges of the EEZ in both OR and WA.
7) **Maintain NANOOS' Data Management and Communications.** Sustain, to the extent possible, the DMAC system NANOOS has built, including the NANOOS Visualization System (NVS), for dynamic and distributed data access and visualization for IOOS.
8) **Continue to deliver existing and, to the extent possible, create innovative and transformative user-defined products and services for PNW stakeholders**. Continue our NVS innovation to succeed in this vital translation: meaningful and informative data products that connect with user applications and serve society.
9) **Sustain NANOOS outreach, engagement and education.** Foster ocean literacy and facilitate use of NANOOS products for IOOS objectives, the core task for which NANOOS was constructed, via existing approaches for engaging users and increasing ocean

awareness.

NANOOS has the following additional task during FY16 from the NOAA Ocean Acidification Program, coordinated via IOOS:

10) Support collection of OA measurements on our La Push [J. Newton, J. Mickett, UW] and NH10 [B. Hales, OSU] moorings, working with NOAA PMEL and the NOAA OA Program Office through the IOOS Program Office.

2) Progress and Accomplishments

During the project period, NANOOS accomplished its objectives outlined above. NANOOS maintained the RCOOS subsystems it has developed, implemented, and integrated with NOAA IOOS funding and substantial external leverage. NANOOS remained focused on delivering data-based products and services that are easy to use to diverse stakeholders to address high-priority issues and aid decision making. NANOOS continued its proactive interactions and regional coordination with a wide range of PNW stakeholders, to prioritize and refine our observations, products, and outreach efforts as funding allowed.

NANOOS milestones for this award are provided in Table 1. Our assessment is that NANOOS has met these milestones for the reporting period. We report here progress for following: a) observing systems (shelf, estuaries, shorelines, and currents); b) modeling (estuaries and shelves); c) Data management and Communications (DMAC); d) User Products; e) Education and Outreach; and, f) Administrative.

Table 1. NANOOS Milestones for FY 16:

Area	**Y1 Award = Y10 NANOOS**
Observations	
Shelf:	-Maintain La Push buoy; deliver NRT datastreams via NANOOS Visualization System (NVS) -Support collection of OA data from La Push buoys with NOAA OAP funding -Maintain Newport buoy; deliver NRT datastreams via NVS -Support collection of OA data from NH-10 buoys with NOAA OAP funding -Maintain Columbia R. buoy; deliver NRT datastreams via NVS -Maintain N CA shelf glider transect; deliver data via NVS -Bring all data QA/QC to meet Certification standards
Estuaries:	-Maintain Puget Sound estuarine moorings; deliver data via NVS -Maintain US-Canada ferry-box; deliver data via NVS -Maintain Columbia R. estuarine moorings; deliver data via NVS -Maintain South Slough estuarine moorings; deliver data via NVS -Bring all data QA/QC to meet Certification standards
Shorelines:	-Maintain shoreline observations in OR; deliver data via NVS -Maintain bathymetric observations in WA and OR; deliver data via NVS -Bring all data QA/QC to meet Certification standards

Currents:	-Maintain OR Priority-One HF radar sites to the national operations standard; deliver data via NVS and the National HF Radar system -Maintain X-band radar sites; deliver data via NVS -Bring all data QA/QC to meet Certification standards
Modeling	
OR/WA estuaries and coast models	-Maintain modeling & forecasting capabilities at UW at reduced level; make model output available via NVS -Maintain modeling & forecasting capabilities at OHSU at reduced level; make model output available via NVS -Maintain modeling & forecasting capabilities at OSU at reduced level; make model output available via NVS -Model verification and validation
DMAC	
Web Site Improvement	-Sustain & enhance existing data streams, IOOS web services, GTS submission -Sustain, refresh and enhance hardware and software environment; appropriate staffing; and operations documentation -Initial, limited implementation of NCEI data archiving, Glider DAC submission, QARTOD -Engage new local providers (not NANOOS funded), integrate their data into NVS and IOOS DMAC services, and assist with their data management & workflows -Strengthen DAC capabilities and resources through regional and thematic partnerships -Deploy ERDDAP to leverage web services, serve NANOOS applications and users -Sustain participation in IOOS DMAC community activities, including QARTOD development, semantic mapping, OGC WMS/WFS support, climatology data development, UGRID support, and shared code development and testing -Engage and leverage OOI and NSF EarthCube, international GOA-ON activities and Canadian collaborations -Engage West Coast and Pacific efforts, including WCGA and IPACOA -Improve ease of usability and user tracking capabilities -Develop and implement user customization and notification capability on NVS -Depth vs. time plots and multivariate plotting
Tailored Product Development	-Climatology and Tsunami resilience apps -Tsunami mobile app re-build -With E&O committee, evaluate usefulness of web and product suite
Education and Outreach	
Networking	-Maintain existing and build new relationships to stakeholder user groups and the education community enabling NANOOS to achieve affective outreach, engagement, and education -Engage with regional formal education communities to use ocean observing and NANOOS products to support STEM education.
Product Development	-Work with DMAC and User Products Committee on tailored product development to meet specific user needs, as per above, and through Tri-Committee meetings; for each new product engage users in product development. -Evaluate website and product suite annually; interpret evaluation results with recommendations discussed at weekly Tri-Com tag-up calls

User Engagement	-Gain feedback and conduct self-assessment after product release. -Conduct trainings to broader user groups and evaluate trainings to optimize NANOOS help functions -Engage with regional non-formal education communities to facilitate the use of NANOOS products to engage citizens to increase their ocean literacy. -Maintain up-to-date success stories, employing effective use of social media -Be responsive to regional and local events (e.g., blooms, floods, etc.) to enhance relevancy to public and highlight regional stories with NANOOS members and partners. -Support national communication through IOOS Program Office and IOOS Association collaborations.
Administration	
Meetings	-Represent NANOOS at IOOS Program Office and IOOS Association meetings, and at national meetings of significance (e.g., Oceans 20xx, or bi-annual meetings of CERF and Ocean Sciences). -Engage at a regional level at meetings and workshops affecting PNW stakeholders and NANOOS. -Conduct annual GC meeting.
Project oversight	-Provide NANOOS with oversight, coordination, and management of the full suite of activities that comprise NANOOS. -Share project evaluation at the annual PI meeting.
Coordination	-Assure that NANOOS has transparent, effective, and representational governance via its Governing Council and the NANOOS Executive Committee composed of its elected Board and its functional committee chairs. -Assure these bodies are engaged in NANOOS prioritization of regional needs, work effort, and product development. -Assure balance of stakeholders represented in NANOOS reflects the diversity found in PNW. -Conduct annual all-PI meetings and Tri-Committee meetings, providing clear feedback and direction. -Coordinate with West Coast RAs and other RAs to optimize and leverage capabilities and assure consistencies. -Engage in sub-regional and user-group specific workshops to aid coordination and optimization of effort.
Accountability	-Submit required IOOS progress reports and respond to other requests. -Seek certification as a Regional Information Coordination Entity of US IOOS.

a) NANOOS Observing Sub-system: Data from all assets reported here are served via NANOOS NVS.

• ***Shelf***

***Washington Shelf Buoy*:** This was an exceptionally challenging period for the Washington Coast buoy observation program led by J. Mickett, Applied Physics Laboratory, University of Washington (APLUW), but also had significant successes. At the beginning of this period, three moorings were in place at the mooring site 13 miles WNW of La Push--- the large surface mooring Cha'Ba, a subsurface mooring equipped with a McLane crawler and a real-time HAB-detection system (the Environmental Sample Processor, or ESP, funded through IOOS-OTT) and an add-on subsurface mooring deployed to

better resolve deep temperature and pH changes (El Nino). At the beginning of the reporting period all systems were working well. Around the 20th of June the tower broke off the Cha'Ba mooring—we suspect either by cyclic fatigue exacerbated by several sea lions hauling out on the mooring or from vessel strike. Several weeks after this casualty we were able to place a temporary tower on the mooring with a Coast Guard light and a satellite beacon. In early September we visited the mooring again, removing the deck-mounted components of the pCO2 system from the buoy as we were not able to recover the mooring due to the sea state and limited size of our vessel. In late September the satellite beacon stopped reporting (manufacturer said because of a firmware issue). When we arrived at the mooring site to recover the mooring from the larger R/V Aquila in late October, we found that the mooring was missing. We have not yet been able to locate the mooring, having inquired about it up and down the coast and surveying a large section of shoreline on an overflight. We hope to replace this mooring by the fall of 2017 with funds from NOAA OAP. Additionally, we hope to recover any gear and instruments remaining on the bottom during the summer of 2017.

Highlights during this period include a very successful first season of the deployment of the HAB-detecting ESP mooring on the NANOOS subsurface profiling mooring, with more than 80 remote samples taken over roughly 100 days—many indicating the presence of HAB species and the toxin domoic acid. A new product page on the NANOOS website delivered the observations to stakeholders in near real-time. Although we lost the surface mooring during this period, the two subsurface moorings collected an exceptional time series of data over much of the water column from late spring until the moorings were recovered in late October.

We carried out two highly successful outreach events for this ESP project, both with local elementary school students in La Push. The event we hosted on the R/V Robertson in September drew more than 50 students. Another significant success was the design and construction of a new "winter" Cha'Ba surface mooring, which was funded by OAP to help move toward year-round data coverage. This mooring was deployed from the R/V Aquila in late October.

Figure 1. "Winter" Cha'Ba buoy on the R/V Aquila prior to deployment in October 2016

J. Newton (APL-UW) and J. Mickett have continued to work with NOAA PMEL scientists Drs. Adrienne Sutton, Simone Alin, and Richard Feely, to maintain pCO_2 and pH datastreams and provide calibration samples for NOAA OAP-IOOS Ocean Acidification Monitoring. Sensor data have been transmitted to the NOAA OA and PMEL Carbon Programs and to NANOOS. Using Cha'ba data, Washington Ocean Acidification Center (WOAC) postdoc Dr. Beth Curry has continued work with the PMEL Carbon Group to test pH proxies on the Washington Shelf.

Oregon Shelf Glider: Starting in early December, 2014, the Oregon State University glider research group led by J. Barth and K. Shearman (OSU) is obtaining vertical sections of ocean properties from off Trinidad Head, CA (41° 3.5'N) using an underwater glider. We use a 1000-m capable Seaglider equipped with the following sensors: CTD, dissolved oxygen (Aanderaa 4831 optode), light backscatter (700 nm), chlorophyll fluorescence and Colored Dissolved Organic Matter (CDOM) fluorescence (WET Labs Ecopuck). The gliders also measure depth-averaged velocity which can be combined with geostrophic estimates of relative velocity to get absolute velocity and hence transport. The glider is flying from approximately the 100-m isobath (~10km offshore) to 130W (~500 km offshore), repeating the line every 30 days. We are collaborating with Dr. Eric Bjorkstedt (NOAA Southwest Fisheries Science Center, Humboldt State University) to facilitate field work off Trinidad Head. We are using two of our Seagliders in order to "hot swap" them on the line when their batteries run low. During this reporting period, this effort is jointly funded by NANOOS and CeNCOOS.

From its first occupation of the TH line on December 4, 2014, until the end of this reporting period (11/30/2016), the glider was on the TH line for 730 days during five deployments, sampled along

nearly 13,000 km of track line covering the transect about 23 times, and collected about 6060 vertical profiles of ocean properties. For the reporting period 6/1/2016 to 11/30/2016 the glider was on the TH line for 184 days during two deployments, sampled along nearly 3307 km of track line covering the transect about 6 times, and collected about 1486 vertical profiles of ocean properties. The glider "uptime" was 99%. Data are being sent in near real-time to the IOOS Data Acquisition Center and, simultaneously, to the NANOOS and CeNCOOS data centers. When an individual glider deployment is complete, we submit the data to NODC.

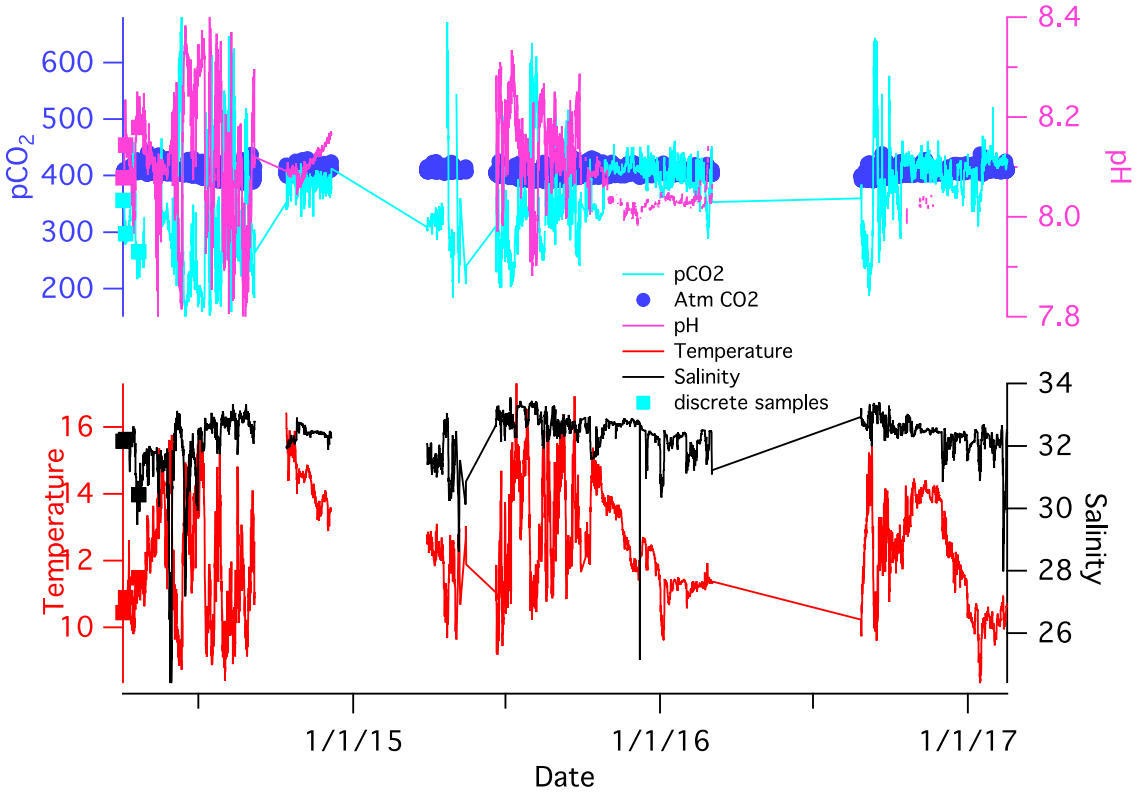
Data from the Trinidad Head glider line are being used to monitor and understand the contributions of both the "Warm Blob" and the 2015-2016 El Niño to the warm anomalies observed in the northeast Pacific over the last several years. The glider data show that for the January to September 2015 period, the 50-m temperature, when averaged from the coast out to 200 km offshore, was 1-3 degrees C warmer than the historical average for this area. Temperatures over the continental shelf during the 2015 and 2016 summer upwelling seasons varied from slightly above normal to average, due to wind-driven coastal upwelling bringing cold, deeper water up to 50-m depth. Starting in September 2015, warm water associated with the 2015-2016 El Niño arrived at the TH line, with a positive 0.5-degree C anomaly extending to 500 m depth. The maximum temperature anomaly of over 2-degree C descended from the surface during the Warm Blob event to a depth of around 100 m during early 2016.

PI Barth participated in the US CLIVAR Workshop "Forecasting ENSO impacts on marine ecosystems of the US west coast" held in August 2016 in La Jolla, CA. He also attended the 2016 PICES (North Pacific Marine Science Organization) Annual Meeting held in November 2016 in San Diego, CA, and represented NANOOS by presenting an overview of NANOOS activities, on behalf of Jan Newton, at the meeting of the PICES MONITOR Committee.

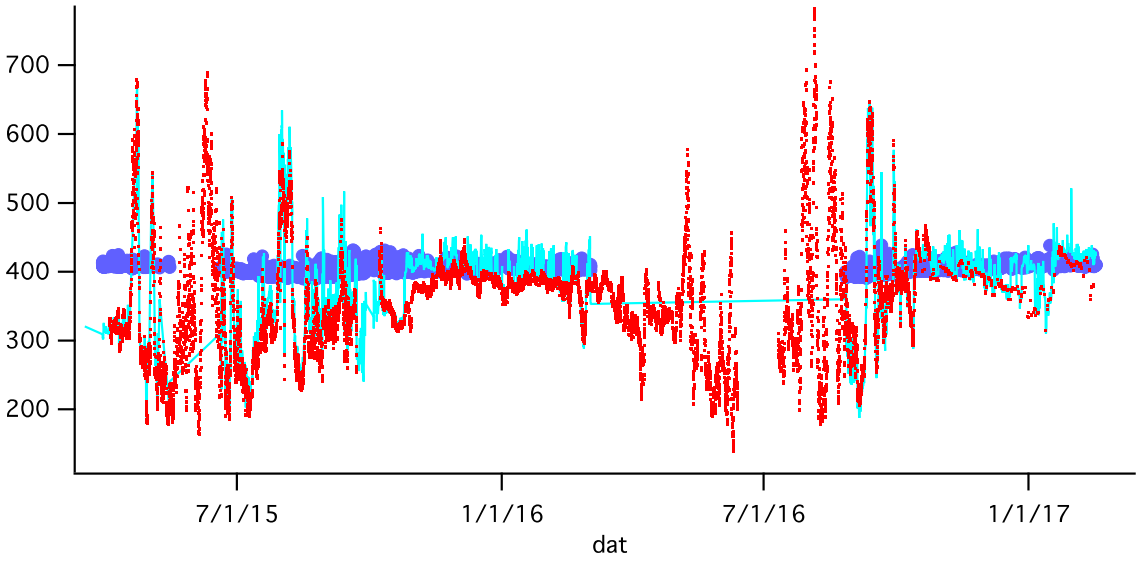
Oregon Shelf Moorings: A mooring about 10 miles off Newport, Oregon, in 80 m of water (site NH-10) has been maintained since mid-2006, primarily through support by NANOOS (present PI is Kosro). On 8/26/2016 we redeployed NH10 from the Pacific Storm, with a modified anchor and tether to improve response in strong waves and currents. The mooring was soon tested – NDBC buoy 46050 nearby has measured 12 storms in the 5 months since deployment with waves exceeding 20 ft (one storm in January with waves exceeding 25 ft) and so far the buoy has remained in place, as indicated by the satellite tracking unit. Unfortunately, the real-time telemetry of science data was interrupted on Oct 14 by a strong storm, and external inspection did not show any dangling cables which could be repaired in place, so physical oceanographic data recovery will await mooring recovery in April. The buoy and instruments will be turned around and redeployed from an OSU student cruise in June 2017 on Oceanus. In the interim, a second buoy is planned to be refurbished, to allow live turnarounds going forward.
Erik Arnesen and Dale Hubbard of OSU provide the technical leads on the mooring; Mike Kosro and Burke Hales are the science PIs.

After the NH10 Shelf mooring broke free during a late winter storm in 2016, we redesigned the mooring to include a self-burying anchor and a non-catenary tether. The Mooring was re-deployed in August, and has stayed in position despite an even more intense and persistent winter stormy season than in the previous winter. The new mooring design is simpler and less expensive to construct, and

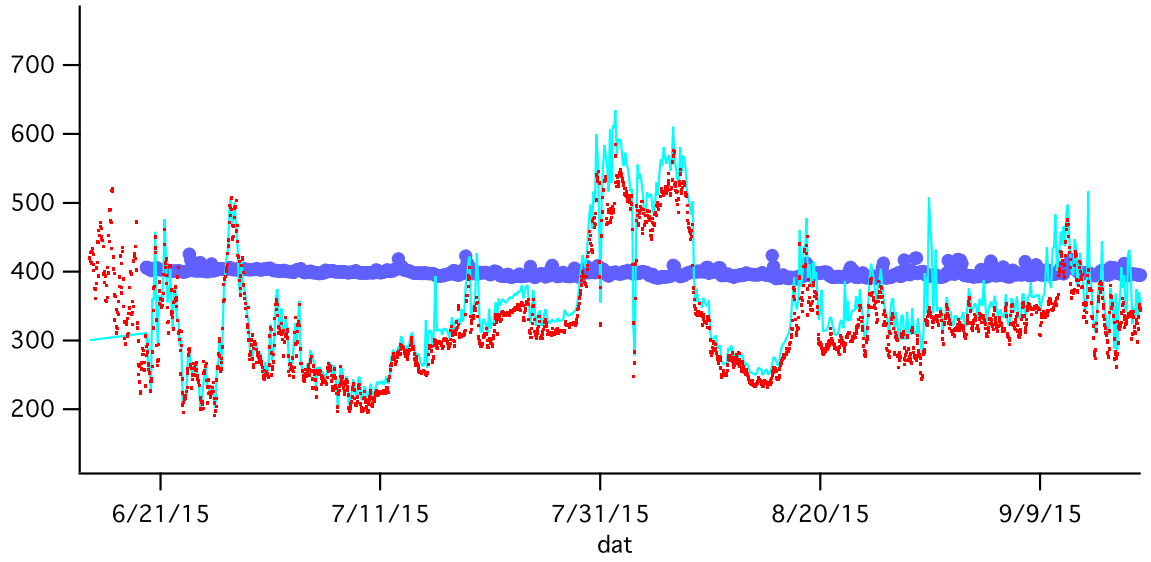
easier to deploy and recover than the old design. The mooring is currently in the field, and the complete up-to-date record of surface and atmospheric pCO2 are shown below.



In addition to the basic observations at NH10, we have now been able to generate a multi-season comparison of the MAPCO2 and the Pro-Oceanus CO2 system deployed aboard the adjacent OOI Coastal Endurance mooring:



The OOI values (red dots) are predominantly in close agreement with the Map values (cyan, as in previous figure), with few exceptions. The high-dynamic variability in the summer upwelling season is reproduced in both sensors, as is the near-atmospheric equilibrium in winter downwelling seasons. While some of the disagreements are artifactual (e.g. an instance of a 'stuck' MAP equilibrator in late October 2015 led to atmospheric contamination of that signal), there does appear to be a persistent low-bias of the OOI Pro-Oceanus system of about 15 ppm. It is likely this can be resolved and corrected via our ongoing check-sample collection and analysis efforts, and we are likely to relocate the current MAP buoy to a point south of Heceta Bank off Coos Bay for our next deployment.



The second subcomponent of Hales' work was the support of the nutrient and O_2 sample-collection and analyses during the recently completed WCOA cruise. Hales' team finalized the analyses of nearly 2000 nutrient measurements in November of 2016, and delivered the QC'd data to our PMEL partners then.

Northern Oregon to Central Washington shelf: Led by A. Baptista (OHSU), the Center for Coastal Margin Observation & Prediction (CMOP) maintains observational assets in the Columbia River coastal margin, with partial support from NANOOS and the National Science Foundation. As discussed in previous reports, these assets are anchored on SATURN-02 (a seasonal inter-disciplinary buoy at ~30m depth, off the mouth of the Columbia River; deployed during the reporting period) with additional data collected by glider operations ((as allowed by available funding; no deployment during the reporting period). Presentations during the reporting period that used data from SATURN-02 were focused on the recent evolution of the Pacific Warm Blob (Baptista 2016a and Seaton et al. 2016); the first of these presentations was an invited presentation to an industry forum: the International Cold Water Prawn Forum.

During the reporting period, a second seasonal shelf station (SATURN-10) was deployed for the second year outside the mouth of the estuary, south of the South Jetty, with funding of the Corps of Engineers. SATURN-10 provides ocean conditions context and guidance on timing for crab monitoring. The station measured temperature, salinity, chlorophyll, DO and turbidity, in support of the adaptive

management program for the Corps of Engineers Mouth of the Columbia River Regional Sediment Management Plan (RMCR 2011). A main goal of the RSMP is to increase the beneficial use of dredged sediment at the MCR to help protect shipping channel jetties, coastal beaches and nearshore habitats from erosion while avoiding and minimizing adverse environmental, resource and navigational safety effects. This process requires research and monitoring to ensure that disposal practices will not result in unacceptable adverse effects on the nearshore ocean ecosystem, especially commercial and recreational Dungeness crab populations, deemed among the most susceptible of local fisheries.

• **Estuaries**

Puget Sound, ORCA Buoy program: Led by J. Mickett, J. Newton, and A. Devol (UW), during this report period the ORCA (Oceanic Remote Chemical Analyzer) mooring system continued to undergo significant refurbishment and upgrade, while the field team carried out regular maintenance and repairs to keep this real-time system operational. Over this reporting period this mooring system continued to be critical in assessing the lingering influence of the North Pacific Heat Wave (aka Blob) and unprecedented large air temperature and rainfall anomalies on inshore waters. As with the summer of 2015, the moorings in Hood Canal allowed assessment and early warning of potential hypoxia-driven fish kills at the southern end of Hood Canal. As a consequence of low summer precipitation and relatively low density of water within Hood Canal, the "fall intrustion" entered Hood Canal roughly a month earlier than typical—somewhat of a repeat of 2015. However, as deep DO levels in the late spring were "normal" compared to the very low values in 2015, we did not see atypically low DO levels in the deep water in mid to late summer and consequently we did not observe a fish kill. This mooring system also helped us to track the influence of the rainiest October on record for the region on the water properties of Puget Sound. At several locations, including our North Buoy near Admiralty Inlet, both surface and deep salinity values were at record low values for that time of year with nearly a decade of measurements at this site. The ability to track the influence of these events in real time and have some predictive success (as with the 2015 fish kill or reduced concern in 2016) highlights the importance and utility of the ORCA program---specifically a long-term, high-frequency (> daily), real-time system that collects *profiles* of oceanic properties.

Non-routine work during this period included the continued successful testing of a prototype profiling mooring at the Dabob site, with the primary benefits of this system increased sampling frequency, lower maintenance costs and more reliable operation. This float was recovered for maintenance and upgrades in September. The integration of shallow SeaFET pH sensors at the Carr Inlet and Point Wells moorings, funded through the Washington Ocean Acidification Center, continued to provide invaluable, unprecedented time series of shallow pH changes in the South Sound and Main Basin respectively. Unfortuantely, the reliability of these instruments has been less than acceptable, and we have been working actively with SeaBird Scientific to resolve the issues.

During this period, we also continued our organized, formal effort to increase mooring reliability and to decrease maintenance costs. Prototype designs for a new, more robust winch control module and communications system have been deployed on several moorings and initial trials have been very successful. It is important to note that much of this work has been accomplished with significant contributions from non-NANOOS funding sources such as NOAA OAP and the Washington Ocean Acidification Center.

The project PIs and oceanographer W. Ruef, the ORCA operational lead, published a summary of 2015 ORCA observations in the Puget Sound Marine Waters 2015 Overview Report, highlighting the historically-large temperature, salinity and DO anomalies observed throughout the year and the fish kill observed in August at the south end of Hood Canal. In September Mickett presented ORCA observations at the Eastern Pacific Ocean Conference at Mount Hood, OR, focusing on the Blob's impact on Puget Sound water properties. Mickett also presented these observations and an overview of the ORCA mooring system in early November at the UW Physical Oceanography fall lunch seminar series. Additionlly, the team has regularly been contributing to bi-monthly condition report updates with Washington State Department of Ecology.

We continued to collaborate with the NOAA PMEL Carbon Group (A. Sutton, S. Alin, R. Feely) to support the deployment of the pCO_2 systems operated on the Twanoh and Dabob Bay moorings through system maintenance and collection of water samples to aid system calibration. Additional collaborations included work with King County to deploy a pH sensor on the Pt. Wells mooring and with Wetlabs to test a bioluminescence sensor on an ORCA mooring.

Washington State estuarine monitoring: Led by C. Maloy and C. Krembs (WA State Department of Ecology), en-route ferry-based monitoring is one part of Ecology's extensive long-term monitoring program covering Puget Sound and the coastal estuaries. Ferry monitoring compliments Ecology's larger program by focusing on surface processes, not typically captured in monitoring efforts. It can capture near-surface events such as blooms, river input, and tidal exchange over a large geographic area and at a fine-scale temporal resolution. Ecology has two sensors (measuring temperature and chlorophyll fluorescence) and a GPS on the *Victoria Clipper IV* passenger ferry vessel that runs twice daily between Seattle and Victoria, BC. Data are uploaded daily to a cloud computing server at: http://107.170.217.21/VictoriaClipper30/level2/ and stored as daily files in a NetCDF database, the repository of the monitoring data. Due to a tight budget, Ecology lost the one technician position at the end of November that was supporting the ferry monitoring. NANOOS funds only partially supported this position. Ecology will be exploring options for reduced ferry monitoring operations.

During the reporting period, Ecology published ferry sensor data in the annual Puget Sound Marine Waters: 2015 Overview report (Moore, et al., 2016). Ferry observations are powerful tools to capture large scale surface temperature and chlorophyll patterns, including grazing impacts from Noctiluca, considered an indicator species of eutrophication. Data from regular ferry routes were analyzed in combination with data from Ecology's monthly water column stations and aerial photographs. Ferry observations of low chlorophyll fluorescence coincided with Noctiluca blooms and increased ammonium, all indications of grazing on phytoplankton. Chlorophyll fluorescence was high during summer periods when no accumulations of Noctiluca were visible from aerial overflights.

During June to November 2016, waters at the entrance to Puget Sound were anomalously warm, conditions favorable to support HAB species, reaching 15 °C. Within Puget Sound, surface water temperatures continued to warm to ~15-20 °C during summer. In response to unusual conditions, phytoplankton were abundant (chlorophyll was high) earlier than normal and persisted throughout the summer. Two periods of chlorophyll decline – late May and early July – normally coinciding with Noctiluca, followed patterns from previous years but occurred earlier than usual.

Ferry-based data products were included in Ecology's award-winning "Eyes Over Puget Sound" monthly reports and subsequent publications (Washington State Department of Ecology, 2016a-e).

Columbia River estuarine monitoring: Under the direction of A. Baptista, and with a mix of NSF, NANOOS, and regional-stakeholder funding, CMOP maintains a network of 15 endurance stations in the Columbia River estuary, which anchor CMOP's SATURN observation network. Also integral to SATURN, but not funded by NANOOS, are three freshwater stations: SATURN-06, maintained directly by the USGS, and SATURN-05 and SATURN-08, maintained by Dr. Joseph Needoba with CMOP/NSF and regional stakeholder funding.

SATURN physical and biogeochemical observations are used extensively in support (directly or via data-informed modeling) of regional management and decision making associated with Endangered Species Act (ESA) biological opinions, salmon restoration, navigation improvements and hydropower operations. These observations have also been integral to CMOP science, which addresses estuarine the estuary as a physically mediate bioreactor.

We are adaptive sampling of microbial communities through the deployment of an Environmental Sampling Processor (ESP) at SATURN-03, with automated sampling targeted by select aspects of the function of the estuarine bioreactor (Herfort et al. 2016). This adaptive sampling offers a new window into the microbiology of the estuary.

Of particular interest during the period, SATURN stations have enabled the characterization of the effects on the Columbia River estuary of the PNW "blob," a phenomenon of warm surface waters that that persisted in the North Pacific since the winter of 2013-2014. Recent reports on the "blob" as viewed from the Columbia River include (Baptista 2016a) and (Seaton et al. 2016).

Also, SATURN stations continue to be used to support multi-disciplinary modeling efforts in the Columbia River (Kärnä and Baptista 2016; Baptista 2016b; Baptista et al. 2016).

Oregon South Slough: Participation by the Oregon Department of State Lands (ODSL) in NANOOS is led by A. Helms (Estuarine Monitoring Coordinator) and A. DeMarzo (Estuarine Monitoring Assistant) at the South Slough National Estuarine Research Reserve (SSNERR).

South Slough NERR continued operating a network of moored water quality observing stations as part of the NERRS System-Wide Monitoring Program with additional support provided by NANOOS. Four real-time water quality monitoring stations located along the estuarine salinity gradient provided continuous water temperature, salinity, dissolved oxygen, pH, turbidity, and water level data over the period 06/01/16 – 11/30/16. The telemetry transmissions at the Valino Island station were interrupted temporarily during this period from 6/1/16-11/10/16 due to malfunctioning equipment. The Valino Island station antenna was replaced 10/17/16 and the SatLink Transmitter was replaced 10/18/16 and telemetered data began correct transmissions on 10/18/16 13:45 PST but began failing intermittently on 10/25/16. The Valino Island station resumed transmissions beginning 11/10/16. Real-time data transmissions at the Elliot Creek station were down from the period 6/1/16-11/30/16 due to platform changes associated with the new EXO2 sonde equipment. This site is being prepared for a new enclosure and telemetry equipment to be installed January 2017. Currently, no instruments are

deployed at the fifth water quality station (Boathouse) due to platform evaluation and assessment. The Reserve relocated the weather station from the University of Oregon Institute of Marine Biology campus to Tom's Creek Marsh at the south end of the reserve due to an OIMB wind turbine installed adjacent to the weather station. In June-October, 2016 the rain gauge was secured and wired to the datalogger, the wind sensor propeller was installed and oriented north, the Stevens V2TH antenna was installed and oriented south and at 40° elevation, the solar panel was mounted and secured with hose clamps. Data collection for the new weather station began 10/19/16 15:00 PST.

We maintain one water quality station in partnership with one of our local tribes, the Confederated Tribes of the Coos, Lower Umpqua and Siuslaw Indians (CTCLUSI). This station, North Spit BLM, is located in lower Coos Bay (NESDID ID # 346F229A; sosnswq) and data are available via the NVS. Real-time data transmissions were continuous for the period 6/1/16-11/30/16. E. Mayorga developed Python code and utilized common software libraries from IOOS DMAC to ingest water quality data from HADS (Hydrometeorological Automated Data System) to display through NVS; this effort will help with future stations that are maintained through partnerships or are outside of the scope of the NERRS CDMO.

The South Slough water quality stations provide real-time data access for shellfish growers in South Slough, including North Bend and Coos Bay Oyster Companies, Clausen Oysters, and Qualman Oyster Farms. The
South Slough and CTCLUSI stations also provide environmental data for research, monitoring and education programs conducted at the reserve. During this reporting period, data from SWMP/NANOOS stations were summarized and analyzed for a National Estuarine Research Reserve Tidal Marsh Resilience to Sea-Level Rise study. The manuscript was published as 'Assessing tidal marsh resilience to sea-level rise at broad geographic scales with multi-metric indices' in Biological Conservation. Two examples of Reserve education programs incorporating NANOOS data were an Oregon Master Naturalist program in June 2016 and an Oregon State University online Estuarine Ecology course.

South Slough expanded the network of water quality stations to include four stations (North Point, Isthmus
Slough, Catching Slough, and Coos River) located in the upper Coos estuary through the NERRS Science Collaborative Partnership for Coastal Watersheds. One station, North Point, is located near commercial oyster cultivation areas and will be prioritized for adding real-time capability for growers and Bar Pilots to provide water level data along with incorporating this site into NVS once telemetry is installed. Through NOAA Ocean Acidification program funding, South Slough added pCO2/pH monitoring equipment at the Valino Island station in April 2015. In the future, we plan to explore ways to include these datasets through NVS, but currently are focusing on instrument maintenance, data collection and protocols in the estuary for these ocean-built monitoring instruments.

- **Shorelines**

Washington Shorelines: NANOOS funds contribute to the Washington State Department of Ecology Coastal Monitoring & Analysis Program (CMAP) led by G. Kaminsky. In June CMAP Collected 38 quarterly Spring 2016 beach profiles and two surface maps along the southwest Washington portion of the Columbia River Littoral Cell. At Ocean Shores an additional 12 supplementary beach profiles

were collected, and at Westport, and additional 6 beach profiles were collected. The additional profiles are providing measurements of beach change in high erosion areas to help inform short- and long term actions to reduce the impacts of erosion.

On July 6, 2016, G. Kaminsky gave a presentation at the Grays Harbor Resilience Coalition Legislative Briefing to provide an overview of recent coastal erosion problems in Grays Harbor County, current research, and preliminary findings at several sites of particular concern. He also participated in follow-on meetings of technical committees to facilitate onsite evaluation of existing conditions and development of strategies to address long-term solutions.

In July, CMAP worked with the USGS to perform surveys of beach topography, nearshore bathymetry, and surface sediment grain size to quantify changes in delta morphology and texture following the dam removals between 2011 and 2014.

In August, CMAP used the R/V George Davidson to assist Oregon State University with the National Science Foundation funded study, SEDEX^2, on beach and dune sediment dynamics along the Long Beach Peninsula near Oysterville. CMAP deployed two wave gauges and performed a nearshore multibeam survey. CMAP recovered the instruments in September.

In August and September, CMAP performed summer seasonal Columbia River Littoral Cell (CRLC) surveys, collecting 50 seasonal beach profiles and 14 surface maps, as well as 55 sediment samples from multiple cross-shore locations along 13 of the profiles. In addition, 209 beach profiles were collected to coincide with single-beam sonar bathymetric transects collected by USGS and OSU. In support of the Westport and Ocean Shores sites of the Gray Harbor Resilience Coalition, CMAP collected 3 supplementary beach profiles at Westport and 31 supplementary beach profiles at Ocean Shores. CMAP also collected beach topography along the sand fences installed at Ocean Shores this summer, and performed grain size analyses for 3 samples collected on Damon Spit by the City of Ocean Shores.

In November CMAP initiated the fall CRLC beach surveys including 46 beach profiles, and an additional 6 profiles in Westport and 13 profiles in Ocean Shores (completed in December).

The CMAP team performed detailed analyses of the survey data collected at Westport and Ocean Shores to put the observed changes in the beach and dune over the past two years in context with longer term and regional patterns of change. The long time series of beach profiles provide for derivation of robust trends and volume changes important to coastal management, planning, and project implantation.

- At Ocean Shores, the dune erosion scarp extends from the jetty to 1.9 km north along shoreline. Ocean Shores has experienced 25,800 cubic yards/year of sediment from beaches and dunes, but beach and dune nourishment offers only a temporary solution because jetty deterioration is reducing the amount of sand that can be held on the beach. In the shorter term, aggravated erosion is occurring at the end of the rock revetment structures, and there remains a lack of suitable transitions between the rock and the dune sand.
- At Westport, coastal erosion threatens condominiums and houses fronting Dune Crest Drive with a dune erosion scarp extending from the jetty to 5.1 km south along shoreline. The shoreline position is dependent on jetty breach fill condition. A lack of summer beach and

dune recovery has resulted in an average erosion of 63,100 cubic yards/year of sediment from beaches and dunes. Beach and dune nourishment in Westport is essential to avoid catastrophic losses to upland development and infrastructure.

- At the Quinault RV Park and Marina, long term erosion threatens the loss of park and marina facilities and boat access. Damon Spit becoming narrower, flatter, and migrating toward Marina, with overwash of Damon Spit contributing to sedimentation of the boat access channel and marina. Long term viability of RV Park will require beach nourishment and erosion protection and the Marina will require considerable engineering and maintenance dredging.

G. Kaminsky provided an update of the beach monitoring and a summary of data analyses at the above project sites to the Grays Harbor Resilience Coalition on November 29, 2016. The data results helped to clarify and support actions needed to improve resilience at each project site, both in short term (e.g., installing sand fences, and increasing dune elevation and volume) and longer term (e.g., jetty rehabilitation and beach nourishment).

Oregon Shorelines: Leveraging NANOOS, the Oregon Beach and Shoreline mapping Analysis Program (OBSMAP) efforts are led by J. Allan of the Oregon Department of Geology and Mineral Industries (DOGAMI). As part of DOGAMI's commitment to NANOOS, the OBSMAP network continues to be sustained, with surveys of beach observation sites having been undertaken in August/September 2016 (Rockaway cell (25 sites), along the Clatsop Plains (6 sites), and in the Neskowin cell (15 sites)). Data for the OBSMAP monitoring sites are made available through the NANOOS Visualization System.

Results from analyses of the OBSMAP beach and shoreline data along with monitoring efforts being implemented in Washington state and California have been integrated into a Geophysical Research Letters paper that explored the US West Coast beach response to the 2009-10 El Niño (Barnard et al., 2011). Most recently, similar analyses were undertaken to assess the effect of the 2015-16 '*Godzilla*' El Niño, one of the strongest events on record (Barnard et al., *2017*). Our combined analyses demonstrated the strong coupling between coastal change measurements and ocean processes operating in the North Pacific, including anomalous increases in wave energy and regional sea levels along the US West Coast, and anomalously large beach erosion across the region. With the end of El Niño in March/April 2016, the beaches of Oregon have transitioned from a predominantly erosional to accretional state. Our most recent surveys (late summer 2016) indicate that beach recovery in Oregon was slightly above normal following the 2015-16 El Niño winter, with significant volumes of sand having returned to the beaches over the summer, especially on the lower (inter-tidal) portions of the beaches. Higher up on the beach, changes were generally within the typical range. Some beaches continue to experience low sand volumes, while others have accreted significantly.

Data from the OBSMAP beach monitoring continues to be used by agencies such as the Oregon Parks and Recreation Department to help guide permitting for engineering structures, by local community groups and geotechnical consultants in Neskowin and Rockaway to help guide their understanding of changes taking place along their beach, by residents in the Cannon beach area, who are concerned about plans to lower dunes in their area, and by the USACE interested in beach morphological changes taking place adjacent to the mouth of the Columbia River.

No significant issues were experienced with equipment during this period. However, as stated in previous reports, problems with aging infrastructure remain an ongoing area of concern.

***Nearshore Bathymetry*:** During summer 2016, P. Ruggiero's group at Oregon State University collected nearshore bathymetry data along the four sub-cells of the Columbia River littoral cell (CRLC). Over 220 individual cross-shore profiles were collected extending from the lower inter-tidal to ~12 m of water depth (~2000 m from the shoreline). Approximately 400 kilometers of nearshore mapping took place within 10 days of field data collection. These data have been processed from their raw format into deliverable text files and have passed a rigorous quality assurance process. In all cases these nearshore bathymetry measurements have been combined with topographic measurement collected by PI Kaminsky's group at Ecology developing complete maps of the nearshore planform. Also, in summer 2016 Ruggiero's group also collected nearshore bathymetric data within the Rockaway littoral cell in Oregon. Over 80 individual cross-shore beach profiles were processed from the lower intertidal to approximately 25 m of water depth (~1500 m from the shoreline). These data have been combined with topographic data collected synoptically by DOGAMI, and have been processed from their raw format into deliverable text files and have passed a rigorous quality assurance process.

These nearshore bathymetric data continue to provide a critical source of information for improving coastal hazard mitigation along the coastlines of the CRLC and portions of the northern Oregon coastline. This NANOOS funded nearshore bathymetric data is being incorporated in coastal hazards decision support tools supported by NOAA's Climate Program Office through their RISA and Coastal and Ocean Climate Applications (COCA) program. The El Niño winter of 2015-2016 was one of the strongest climate events in recent history with extraordinary winter wave energy. Documenting the recovery of beaches following the event was critical for projecting possible coastal hazards in subsequent winters. Although Northwest beaches were buffered from catastrophic damage during the event, they did experience significant retreat. Beaches did not completely recover during the summer of 2016 and it may take a while for the beaches to rebuild. After the 1997-98 El Niño, it took some beaches a decade to recover.

The PWC-based nearshore surveying system used by Ruggiero's group is now over 9 years old and the equipment continues to show some wear and tear. In particular, the PWCs themselves have been driven for hundreds of hours in very demanding conditions and may only have one to two years left of being able to safely collect this data before needing to be replaced or extensively serviced.

- **Currents**

Coastal Currents: Surface current maps determined from an 11-site Seasonde array along the Pacific Northwest coast continue to be obtained hourly, and provided to the public through NANOOS NVS, and via the national network to NDBC, the USCG, and other agencies, led by M. Kosro, OSU.

During this period, we concentrated on repairs and replacements. We used a MFJ-269 antenna analyzer to optimize performance at YHS2 and at STV2. We inspected cables and measured the power out at STV2. We took return shipment of our receiver antenna box after repair at CODAR, but found

little improvement. Low SNR was found at LOO1 on the monopole; returned its antenna box for repair at CODAR and installed the box from WIN, after first attempting repair in the lab. WIN1 Tx power was low in Nov 2016; the transmitter was returned to the lab, tested, cleaned. A corroded component on the Blanking Board was detected, replaced, and the system returned to working order. Cooling infrastructure has been increased at PSG1 with new fans in the transmitter and in the rack.
We have been replacing old and delicate equipment as funds allow. In mid-June, we took delivery of a new dome-style receive antenna, as well as a new Tx and Rx. The Tx and Rx were then tested at YHL, with good results. The Rx antenna was tested later (more difficult, logistically), and a broken connector was found internally; this was repaired at OSU.

Erik did some original development using inexpensive Raspberry Pi computers to monitor our UPS for power outages, and send a text message when detected. These have provided notice of subsequent power outages at STV2. Two processing computers have been replaced.

Port X-band Radar: Led by M. Haller (OSU), wave imaging radar operations continue at both the Yaquina Bay station and the temporary station at the Columbia River mouth (Cape Disappointment station), with some hardware-related interruptions and degradations. The big news this period is the Yaquina Bay station was moved to the top of the observation tower at the USCG Yaquina Bay station (next to the Yaquina Bay Lighthouse). We are very excited by this opportunity; the new location on top of the USCG tower provides a significant increase in the quality of the radar observations. After transitioning, this station is up and operating again. We have also developed a standardized NetCDF data format and are sharing data with NOAA Office of Coast Survey for use in an SBIR they are funding regarding radar-derived bathymetry estimates.

b) NANOOS Modeling Subsystem:

Shelf: Computer circulation modeling and forecasting of PNW coastal ocean shelf conditions has been conducted by A. Kurapov's group at OSU. The system utilizes the Regional Ocean Modeling System (ROMS) as the forecast model. Along-track altimetry observations from Jason-2, CryoSat, and Altika, hourly GOES SST, and surface currents from land-based high-frequency (HF) radars have been assimilated to improve initial conditions for the forecasts, using the assimilation system developed at OSU. Results are provided to fishermen and public via the NANOOS Visualization System. Via the OpenDAP server, forecast currents are also provided to the NOAA Office of Response and Restoration Lab in Seattle, where they can be used with the tools for oil spill mitigation. The OpenDAP link also provides access to the real-time fields by the Cyberinfrastructure group of the IOOS-sponsored Coastal Ocean Modeling Testbed (COMT) project. Routines for pre- and post-assimilation quality control have been established, along with new online tools (http:// http://ingria.coas.oregonstate.edu/rtdavow/, L. Erofeeva, OSU).

In the past, our real-time OR forecast system was run at the 3-km horizontal resolution in the domain that extended only between 41-47N in the alongshore direction. During the report period, we completed testing new the model configuration that has the domain extended to 41-50N (including both OR and WA shelves), improved resolution (2-km), river discharges included (Columbia, Fraser, Puget Sound sources), and tides. The new OR-WA model is routinely run in near real-time with data assimilation.

As a companion effort, OSU PhD student I. Pasmans has continued tests of a hybrid ensemble variational data assimilation method, applied to the OR-WA model. This work is a part of the companion Coastal Ocean Modeling Testbed project. In this method, the initial condition error covariance is computed using an ensemble of model forecasts. This project has been transitioned to the XCEDE supercomputer, to speed up analyses and computations. Efficiency and accuracy of ensemble methods depend on how localization of the ensemble-based covariance is done. Localization is done to remove spurious long-tail correlations in the model error covariance that generally appear in ensembles of limited size. The paper on the new effective localization method has been submitted (Pasmans and Kurapov, 2017).

Methods for accurate model set-ups and data assimilation are being transferred to NOAA NOS, where we contribute to development of the West Coast Ocean Forecast System (WCOFS) (Kurapov et al., 2017a, 2017b).

Estuaries

Puget Sound:

NANOOS PI P. MacCready (UW School of Oceanography), working with Drs. Siedlecki, McCabe (UW Joint Institute for the Study of Atmosphere and Ocean), and Banas (U. Of Strathclyde), , have created a pre-operational forecast model, called *LiveOcean*, of ocean circulation in Puget Sound and adjacent waters. In the past six months the team used NANOOS support to (i) continue model validation of carbon chemistry using 2016 NOAA cruise data and moored data from Netarts Bay, (ii) develop methods to improve modeled tides in Puget Sound, (iii) expand the river database from 16 to 45, and (iv) develop a high resolution grid. All of these are moving rapidly toward implementation of a high resolution (~300 m) Salish Sea grid for the next generation of the daily forecast system. In addition, pH and Aragonite saturation state have been added to the model fields being sent daily to NANOOS NVS. NANOOS also supported salary for Dr. MacCready's system administrator, David Darr, who oversees computer operations and assists with the gathering and archiving of model atmospheric fields from Dr. Cliff Mass (UW). The forecast work is also supported by a grant of state funds made through the Washington Ocean Acidification Center (WOAC), greatly accelerating the work and leveraging the impact of NANOOS funds. During these past 6 months, in addition to the model development, MacCready gave a total of 4 scientific or outreach talks on the project (see Presentations). MacCready is a member of the NOAA West Coast Ocean Forecast System Technical Working Group, and this model is a candidate for nesting inside of the NOAA operational models of the California Current that are being developed. The model system is being used in the new NOAA-funded MERHAB PNW project to make short-term forecasts of when Pseudo nitzschia HABs may reach WA beaches.

Columbia River: With a mix of NSF funding, regional stakeholder funding, and modest NANOOS funding, CMOP maintains an extensive modeling system for the Columbia River coastal margin, denoted *Virtual Columbia River* (VCR). The VCR is operated under the direction of A. Baptista, but it is a multi-institutional collaboration involving modelers and non-modelers, in academia and across regional, federal and tribal agencies.

The modeling capabilities of the VCR continue to assist the region in the study of salmon life cycle, habitat and status under the Endangered Species Act and in relation to hydropower management and

climate change. Recent peer-reviewed publications report on rigorous benchmarking of the circulation (Karna and Baptista 2016a) and sediment (a 2017 publication) models, and offer insights into important estuarine processes, including water age (Karna and Baptista 2016b). Recent presentations use models to gain insights into **climate change impacts in the estuary** (Baptista 2016b; Baptista et al. 2016) and on the role of local winds on estuarine physics (Scroccaro 2016a, b). Recent applications of the Virtual Columbia River include (a) the Columbia River Treaty Review, a collaboration with the USGS, Army Corps of Engineers, Bonneville Power Administration, Columbia River Inter-Tribal Fish Commission and others; and (b) the post-construction assessment of the ecological impact of the Columbia River Channel Improvement Project, a collaboration with the Army Corps of Engineers, NOAA, and a large number of state and federal agencies.

c) Data Management and Communications (DMAC) Subsystem:

Chaired by E. Mayorga (APL-UW), this committee is composed of members from CMOP-OHSU, DOGAMI, OSU and UW. The DMAC and User Products (UPC) teams work in an integrated fashion on the prioritization, development and evaluation of data services and user products. NANOOS is also an active collaborator in national IOOS DMAC efforts.

Open Data Sharing: With few exceptions, all IOOS-funded observations and model output are already available for public access via the NANOOS Visualization System (NVS), which in addition to data browsing and visualization incorporates custom, machine-readable data services. Current exceptions include more technically challenging data types such as ADCP. These will be addressed in the next year.

These data streams are also made available freely and via machine-readable, IOOS-registered, IOOS-recommended services, as described in other sections below. In limited cases these efforts lag data distribution via NVS due to technical challenges and prioritization of limited resources. Incorporation of these data streams is an ongoing effort.

NANOOS also invests substantial efforts to engage (server as “clearinghouse”) other, non IOOS-supported regional and non-traditional data providers, including Canadian ones, to integrate and redistribute their data streams, particularly via NVS. These data streams are also made available via machine-readable, IOOS-registered, IOOS-recommended services, except where restrictions from providers exist or have not been clarified. Partnership agreements and documentation in the future will help clarify or resolve these situations. For example, OOI data streams currently integrated into NVS are not being distributed via the NANOOS SOS service, until appropriate discussions between NANOOS, IOOS and OOI can be had about who is the proper entity to register and advertise such data via the IOOS registry and catalog.

Data management planning and coordination: As documented in other sections, NANOOS: Enables open data sharing, Offers data in approved common data formats, Provides data feeds to GTS, Implements a service oriented architecture, Implements ontologies, controlled vocabularies and identifiers, Implements metadata standards and metadata management and query capabilities, Provides this information to the IOOS Catalog, and Ensures local storage and offsite, permanent archiving of data at approved facilities.

NANOOS has continually improved its data management and coordination capabilities. Important discussion of problems, new capabilities, and standard operations both among the distributed NANOOS DMAC team and between the team and IOOS and related staff have largely shifted to the NANOOS presence on github, http://github.com/nanoos-pnw. Procedure automation and improvements include asset inventory extraction and distribution via GeoServer, server monitoring

tools, and server hardware and software refreshments. We engaged the IOOS Modeling and Analysis Subsystem via discussions and testing with the EDS Model Viewer and NOAA ORR teams regarding access to OSU ROMS (via both THREDDS and Hyrax) and UW LiveOcean model output.

NANOOS has also strongly coordinated efforts with IOOS staff and the IOOS and wider community. This coordination has included IOOS system testing (registry and catalog), reporting and discussing issues (largely publicly via github) with IOOS convention implementation in IOOS supported software, particularly 52N SOS and pyoos, and including code contributions to pyoos, support for the release of pyoos 0.7.0, and support to the development of sensorml2iso. We have actively engaged with QARTOD via expert feedback on the Glider DAC QC Manual for Temperature and Salinity Data and active participation in the IOOS DMAC QARTOD Working Group. NANOOS attends and actively participates in the annual IOOS DMAC coordination meeting, and helped with the planning of the 2017 coordination meeting as well as with the October 12 Big Data IOOC meeting / workshop in Seattle and the November workshop on carbon and biogeochemical data, convened by Kathy Tedesco (NOAA COD).

NANOOS DMAC has actively engaged overlapping communities, including the Ocean Acidification monitoring community (from cross-regional to national and global), the West Coast Ocean Partnership, and NSF-supported Cyberinfrastructure initiatives, including EarthCube, CUAHSI, the Observations Data Model 2 ("ODM2"), NEON, and particularly OOI. The partnership with OOI led to the integration into NVS of OOI near-real-time data streams from the core moorings (6) and sensors in the Pacific NW Endurance Array, including contributions (via github) to the OOI raw-data access code; it also led to discussions and additional code development for OOI global asset inventory integration into the newly developed, NANOOS-led Global Ocean Acidification Observation Network (GOA-ON) data portal (http://portal.goa- on.org).

Provision of data to the Global Telecommunication System (GTS): NANOOS makes all its IOOS supported, near-real-time observing data streams available to the GTS via NDBC (for fixed in situ assets) and the Glider DAC.

Data access services: NANOOS hosts IOOS recommended services to serve observing and modeled data. These include two THREDDS server and one Hyrax server for model output (which are being leveraged to support historical observing data and data synthesis products in the near future), and an IOOS 52North SOS for fixed-location observing data. These services are registered with the IOOS Registry. Improvements in CY 2016 included the addition of a ugrid-compliant WMS service based on ncWMS2 to the CMOP-OHSU THREDDS, updates to the WMS services (THREDDS / OSU & GeoServer / APL-UW), and additions to the data and metadata content of the NANOOS 52N SOS.

Glider and HFR data are distributed via IOOS supported thematic DACs. In addition, NANOOS hosts standard-compliant services OGC WMS and WFS services via GeoServer.

Catalog registration: The IOOS registration and catalog system underwent a large overhaul in CY 2016. Nonetheless, NANOOS worked closely with the IOOS staff to help test the new registry and catalog system, develop capabilities that benefit other RA's (particularly regarding metadata parsing from IOOS SOS services), and implement the mechanisms to provide the metadata to register in the new registry. Three NANOOS WAFs (Web Accessible Folders) at http://data.nanoos.org/metadata/ are hosting metadata records registered at https://registry.ioos.us, providing 74 metadata records. The NANOOS present on the new IOOS Catalog can be seen at https://data.ioos.us/organization/nanoos. The extent, comprehensiveness and currency of these records will be refined and expanded in the next 6 months, to match – and in some cases help strengthen – IOOS catalog capabilities.

Common data formats: All data served by NANOOS via IOOS recommended services (see #4) are also provided via IOOS recommended data formats, including IOOS SOS SWE and NetCDF-CF. Similarly, such formats are also used in data submitted via thematic DACs, particularly the Glider DAC and HFR DAC.

Metadata standards: All metadata served by NANOOS via IOOS recommended services (see #4) are also provided via IOOS recommended metadata formats, including IOOS SOS SensorML (Network and Station), NetCDF-CF ACDD, and ISO 19115-2. The quality and extent of the metadata content are under regular revision, as areas of improvement are identified, particularly via engagement with IOOS.

Storage and archiving: NANOOS engaged NCEI throughout 2016 to develop procedures for both delayed-mode and automated archiving historical and current observing data. In particular, a large data collection from OHSU-CMOP (a core NANOOS partner) is being used for this initial stage, being managed through the NCEI ATRAC system. On November 30, NANOOS submitted the first formal test batch of data for NCEI assessment. After substantial feedback and discussions, a second, improved test batch was submitted on December 13. This batch is undergoing final evaluation by NCEI. When the NCEI assessment is completed (expected Winter 2016-2017), NANOOS will submit the complete data set for official archiving and establish monthly automated submissions from OHSU-CMOP. Afterwards, NANOOS will start applying the workflows and procedures put in place to other IOOS supported providers.

In addition, all CY 2016 IOOS supported glider data from NANOOS also were archived with NCEI via submission to the Glider DAC. NANOOS has worked with NCEI and the Glider DAC to help improve Glider DAC metadata encoding to ensure RA-submitted glider data submitted to the Glider DAC are readily identifiable by RA at both the Glider DAC catalog and NCEI; these challenges have not been fully resolved at the Glider DAC catalog and NCEI.

Ontologies, vocabularies, common identifiers: NANOOS makes comprehensive use of IOOS recommended ontologies and vocabularies in all its hosted, IOOS recommended services and metadata. IOOS recommended identifiers (urn's, as well as WMO/NWS ID's when available) are used in the NANOOS SOS service.

d) User Products Committee (UPC):

The UPC operates in concert with and is informed by both the DMAC and Education & Outreach subsystems. The objective of the NANOOS UPC is to guide the conceptual development of the data/analysis products (i.e. observations, time series, models, applications, etc.) identified by NANOOS stakeholders, and guide the development of appropriate graphical formats and lines of communications for product dissemination. Critical to this process has been the recognition that the UPC works closely with other NANOOS committees, most importantly the DMAC and Education/Outreach teams to ensure product concepts are effectively developed and tested prior to their release.

Chaired by J. Allan (DOGAMI) this committee is composed of members from Boeing, OHSU, UW, OSU, NANOOS E&O, OR Sea Grant, and NOAA. NANOOS UPC chair Allan participates in weekly "tag-up" calls with a smaller sub-group comprised of members from DMAC, UPC, E&O, and Web development in order to facilitate consistent work efforts, synergy across the committees, and improvements to product development and enhancements. Activities for this 2016 period included: 1) multiple weekly NANOOS DMAC and UPC teleconferences; 2) Attendance at the annual NANOOS governing council and all PI meeting.

NVS: The backbone of the NANOOS RCOOS is the NANOOS Visualization System (NVS) that currently distributes data from a myriad of regional and federal assets.

On May 3rd, **NANOOS released NVS v4.5**. This updated version of NVS was directed mainly at several minor enhancements to the overall NVS experience, including a cleaner interface and the addition of several new mobile platforms and a new glider app. **v4.6 (released on May 23rd)** continued along the same vein. With this release, variables in the data explorer are now grouped by "type" e.g. atmospheric, hydrographic, and biological etc.

NVS v 5.0 was released on September 28th. This version enables the user to now view profile depth/time (heatmap) plots, with each cast being displayed based on time in the NVS timeline. In addition, NVS released its "Current Conditions" overlay, which allows the user to evaluate values measured for a number of variables, from multiple stations where data is available. This development allows the user to visualize synoptically, the most current conditions across the entire region.

Updates to the NVS Climatology web app continued throughout this period focused mainly on refinements to the web app, including improvements to the code used for downloading and processing the time series data. Ongoing efforts are being directed at enabling the user to visualize plots from past years (currently not available in NVS).

NVS Mobile App: Work commenced to completely rebuild the NVS mobile app.

Website: Efforts during this period were largely directed at further improvements in the overall NANOOS web experience (http://www.nanoos.org/products/products.php).

e) NANOOS Education and Outreach Subsystem:

NANOOS Education and Outreach efforts are focused on growing NANOOS' audience of engaged citizens, promoting and facilitating the use of ocean observing data and increasing ocean literacy in our region. These efforts are largely completed by NANOOS staff Newton, Sprenger, Lebrec, and Wold, with support from DMAC and UPC subsystems and many NANOOS member collaborators. Newton, Sprenger Lebrec, and Wold are all active members of the weekly DMAC/UPC tag-up conference calls, regularly providing support and feedback on UPC and DMAC developments. Sprenger and Wold continue participation with IOOS E&O calls as they occur.

Summary of Education Accomplishments: NANOOS education efforts have continued to focus on building and sustaining connections with Pacific Northwest educators and partnering with local and regional science and marine science education efforts.

- Newton worked with Quileute Tribal School children on how to use NVS to look for signs of blooms or upwelling as part of the Northwest Indian College's Summer Science and Art Camp at La Push, WA, June 28-29.
- Sprenger was a presenter at two workshops, one in Coos Bay and one in Newport, as part of the Oregon Coast Education Program (OCEP)'s summer field workshops for classroom educators. OCEP, a BWET funded program coordinated by Oregon Sea Grant and South Slough NERR, works with teachers on bringing students into the field for meaningful education experiences.

- Sprenger worked with teachers on collecting water quality data and using online teaching and data resources.
- Sprenger supported the WA Sea Grant led “NOAA Summer Science Camp”, facilitating the high-school aged Junior Leadership Program’s ocean science field research experiences, including a one-day oceanography cruise and week-long buoy building and data collection project.
- An undergraduate student in the University of Washington's School of Oceanography was a part of a 5-day research cruise funded by the Washington Ocean Acidification Center in Puget Sound with NANOOS staff Marine Lebrec and Beth Curry. This student learned how to do CTD casts, processing seawater samples, and net tows.
- In June, Wold presented on NANOOS data access and an overview of the Se'lhaem buoy at a Joint Bellingham Bay meeting held at the Northwest Indian College.

Summary of Outreach Accomplishments: NANOOS outreach efforts have been focused on engaging with target user groups, including shellfish growers, boaters and scientists, improving and updating the content on the NANOOS web portal, and energizing social media outreach efforts.

- In June, Wold presented on NANOOS data access and an overview of the Se'lhaem buoy at a Joint Bellingham Bay meeting held at the Northwest Indian College
- NANOOS provided the "Great Build a Buoy Challenge" activity at Seattle Aquarium's annual Discover Science Weekend. The buoy challenge was incredibly popular among attendees throughout the weekend, and allowed members of the public to learn about some of NANOOS’ work.
- NANOOS continues to engage with shellfish growers, in October, Sprenger gave a talk and staffed an exhibit table at the Pacific Coast Shellfish Growers meeting in Lake Chelan WA.
- NANOOS continues efforts on social media, regularly posting on Facebook with news, pictures, and interesting data. NANOOS also has a growing audience for its quarterly newsletter, the NANOOS Observer.
- Sprenger, Lebrec, and Wold continue to update content on the NANOOS portal, as well as continue to improve the site’s usability by updating the search tool on the products page and streamlining the documents archive. NANOOS staff supported the content development of the new Real-Time HABs website: http://www.nanoos.org/products/real-time_habs/
- NANOOS staff advised on usability of the NVS 5.0 release, including modification to the “Current Conditions” feature.

f) NANOOS Administration:

J. Newton (NANOOS Executive Director) and D. Martin (NANOOS Board Chair) continued to provide leadership to NANOOS operations and connection to the US IOOS enterprise. They and M. Kosro (NANOOS Board Vice Chair) participate in IOOS Program Office and IOOS Association calls. Newton is a member of the IOOS Association Executive Committee and participated in their teleconferences during the period. Newton participated in weekly Tri-Comm calls. Key events for this period included:

- Newton and Martin led the annual NANOOS PI meeting and the annual NANOOS Governing Council meeting over August 10-11, 2016. Newton led the PI meeting discussions and Martin served as Chair of the NANOOS Board during the GC meeting.
    - NANOOS held its annual all-PI meeting on 10 August in Vancouver, WA, at the Washington State University – Vancouver campus. It was well-attended and much discussion and prioritization of new data product occurred.
    - NANOOS held its annual GC meeting on 11 August in Vancouver, WA, at the Washington State University – Vancouver campus. The meeting included a brief tele-chat with Dr. Sullivan, NOAA Administer, who was visiting NANOOS member NOAA PMEL in Seattle.
    - By vote, NANOOS replaced two vacant seats on NANOOS Executive Committee, Paul Dye, Washington Sea Grant, will be "At Large" and Gus Gates, Surfrider Foundation, will be one of the NGO representatives.

- New members of the NANOOS Governing Council include NOAA PMEL, Hakai Institute (Canada), and Salish Sea Expeditions

Assuring coordination within NANOOS, throughout the reporting period, Martin and Newton remained deeply involved with a complimentary research ocean observing effort in the Pacific Northwest, the NSF-funded Science and Technology Center (STC) for Coastal Margin Observation and Prediction, which NANOOS leverages in the areas of DMAC and Education and Outreach. Martin serves as Co-Director for the Center and Newton directs the UW Education efforts for this multi-institution project.

Additional coordination and representation included:

- Newton was invited to serve on the Blue Planet Steering Committee, and attended calls to plan the 3rd Blue Planet Symposium, 31 May – 2 June 2017. She attended they Symposium in College Park Maryland, co-chaired a session on "Threats from Pollution, Warming, and Acidification", and presented on the IOOS OTT OA project with shellfish growers that NANOOS leads along with three other IOOS RAs.
- Newton attended the IOOS ExCom meeting in Washington, DC, 7-9 June, and the IOOS Fall Meetings in Anchorage, AK, 25-27 September. She also attended the IOOS Advisory Committee meeting in La Push, WA, giving talks on OA, HABs, maritime ops, and coastal hazards. Newton participated in IOOS Board and ExCom calls throughout the period.
- Newton represented NANOOS speaking at the 2016 Science to Policy Summit on Climate Change, hosted by the Columbia River Estuary NEP on 17 June in Vancouver, WA, delivering a talk "Ocean Acidification and Hypoxia". http://www.estuarypartnership.org/StoP2016
- Newton worked with Quileute Tribal School children on how to use NVS to look for signs of blooms or upwelling as part of the Northwest Indian College's Summer Science and Art Camp at La Push, WA, June 28-29.
- Newton was invited to present on "Operational Oceanography Application for Fisheries and Aquaculture" at a Joint Workshop on Marine Ecosystem Analysis and Predictions & Data Assimilation of the GODAE OceanView Programme, held at the University of California Santa Cruz on July 11-13, 2016.
- Newton participated in the Olympic Coast NMS Sentinel Site Workshop: Exploring Options for an Olympic Coast Ocean Acidification Sentinel Site held in Forks, WA on September 12th-13th 2016, giving a talk on NANOOS OA observations in the region.

- Newton was invited to speak at the North East Pacific OOI Community Workshop in Portland, OR, 28-29 September, to represent NANOOS data capabilities and user outreach and gave a talk: “The Northwest Association of Networked Ocean Observing Systems”.
- Newton was a working group member and author for the “National Strategy for Sustained Coastal Moorings” along with the IOOS PO, NDBC, and other RA authors.
- Newton gave an invited talk: “Challenges and opportunities for monitoring chemical indicators of acidification in estuaries and coasts” at the Monitoring for Acidification Threats in West Coast Estuaries: A San Francisco Bay Case Study Workshop held in Richmond, California, 19 October 2016.
- Newton was invited to give the Keynote Neal Thorpe Memorial Lecture: “Observing the Ocean from the Pacific Northwest and Beyond: Why it Matters” at the 25th Annual Murdock College Science Research Conference, Spokane, Washington, 4 November 2016.
- Newton attended PICES-2016 in San Diego, CA, 8-10 November presenting a poster - “NANOOS: Northwest Association of Networked Ocean Observing System”. Newton also participated in the PICES Technical Committee on Monitoring (MONITOR Committee) meeting, representing NANOOS.
- Newton was invited to and participated in the Alaska Ocean Acidification Network’s State of the Science workshops on Nov 30-Dec 1 2016 in Anchorage, Alaska. Newton presented “Ocean Acidification in the Pacific Northwest”, offering insights from the PNW and NANOOS, as well as IPACOA. Newton assured that the three west coast and Alaska RA Directors were on the Pacific Coast Collaborative/OA-IWG Task Force to identify monitoring assets for OA and hypoxia and their biological responses.
- Newton coordinated with other West Coast RAs, following the intent of our mutual MOU, as well as several other RAs to optimize and leverage capabilities and assure consistencies. This included: coordination with AOOS, CeNCOOS, SCCOOS and PacIOOS on the IPACOA data portal; participation advising the COMT effort.
- NANOOS PI Barth and Newton continued to support the West Coast Ocean Acidification and Hypoxia Science Panel (http://calost.org/science-advising/?page=ocean-acidification-and-hypoxiapanel), working on scientific manuscripts and public interest documents regarding west coast US and Canadian OA issues and effects.

Keeping the goals and capabilities of NANOOS and IOOS represented internationally, NANOOS Administration and PIs made several important contributions:

- Martin participated in the semi-annual meeting of the Ocean Networks Canada (ONC) International Science Advisory Board (ISAB) that provides guidance and counsel to the Canadian effort to field, evolve and improve two research-focused ocean observatories (VENUS and
  NEPTUNE Canada) that simultaneously serve emergent operational societal needs. In this context, Martin provides both scientific expertise and as well as serves to communicate the U.S. experience with IOOS and operational ocean observing efforts that are part of the unique hybrid nature of ONC.
- Newton represented IOOS on the Global Ocean Acidification Observing Network Executive Committee calls and activities. Newton was involved in the GOA-ON Executive Committee and Biology Working Group.
- Newton represented IOOS on JERICO SAC, fostering international collaboration.

- Newton, a member of MEOPAR's International Science Advisory Committee, provided input and review support throughout the period.

Additional NANOOS coordination:
Newton led two OTT coordination calls for the OA project with AOOS, CeNCOOS, and SCCOOS.
Newton helped coordinate the C-CAN webinar series on OA
Newton participated in "OA Round Tables" organized by PMEL and NWFSC
Newton participated in NOAA FATE meetings for J-SCOPE, the ecological forecasting model for seasonal coastal ocean prediction on NANOOS' portal: http://www.nanoos.org/products/j-scope/.
Newton continued to represent NANOOS in regional efforts, e.g., C-CAN, PSEMP, Pacific Salmon Marine Survival, and West Coast Ocean Data Portal.
Newton continued to fill the Research seat as a member of the Olympic Coast National Marine Sanctuary Advisory Council, and attended their meetings in July and September 2016.

Presentations and Publications acknowledging NANOOS support: underline indicates NANOOS PI

Presentations:

Baptista, A.M. (2016a). The Pacific Blob and other climate tales. International Cold Water Prawn Forum, Portland, Oregon

Baptista, A.M. (2016b). Climate Change and the Estuary. Future of our Salmon Conference, Portland, Oregon

Baptista, A. M., M. Davis, M. Leinen (2016a). Estuarine observing in the era of Our Global Estuary. 17th Meeting of the Partnership for the Observation of the Global Ocean (POGO-17), Yokohama, Japan.

Baptista, A. M., M. Rostaminia, P. J. Turner, T. Kärnä and J. Lopez (2016b). Salinity in the Willamette River? Seriously?!? Estuarine tales of rising seas, seismic subsidence and uncertainty. 2016 Columbia River Estuary Conference: Recent Anomalous Environmental Conditions – Drivers and Consequences, Astoria, OR.

Barth, J.A., S. Pierce and S. Durski, 2016. The subsurface and inner-shelf structure of 25 years of variability in the Northern California Current. PICES Annual Science Meeting, San Diego, California, U.S.A., November, 2016.

Honegger D., Z. Zhou, G. Gelfenbaum, R. Geyer, M. Haller, T.-J. Hsu, J.T. Kirby, and F. Shi, Remotely-sensed horizontal structure and evolution of the leading and trailing edges of the salt wedge at the Columbia River mouth, Paper: OS31E-06, *AGU Fall Meeting*, San Francisco, CA, 2016.

Kaminsky G., Coastal Erosion in Grays Harbor County, Grays Harbor Resilience Coalition Legislative Briefing, Aberdeen, WA, July 6, 2016.

Kaminsky G., Grays Harbor Coastal Resilience, Grays Harbor Resilience Coalition Meeting, Aberdeen, WA, November, 29, 2016.

MacCready, P., S. Siedlecki, R. McCabe, N. Banas, New modeling tools for Ocean Acidification and Harmful Algal Blooms on the Washington Coast. Talk for Olympic Coastal National Marine Sanctuary Advisory Council, Seattle, WA, 9/23/2016.

MacCready, P., New modeling tools for Ocean Acidification and Harmful Algal Blooms on the Washington Coast. Public talk at UW Olympic Natural Resources Center, Forks, WA, 9/13/2016.

MacCready, P., Oysters, Upwelling, and Ocean Acidification. Public talk for Climate Science on Tap series, ad Peddler Brewing Co., Seattle, WA, 8/31/2016.

MacCready, P., Oysters, Upwelling, and Ocean Acidification. Public talk at Ada's Technical Books, Seattle, WA, 7/27/2016.

Mickett, J., The Response of Puget Sound to the 2014-2015 North Pacific Warm Anomaly. East Pacific Ocean Conference, Mt. Hood, OR 21-24 September 2016.

Mickett, J., The Response of Puget Sound to the Blob: Insights from ORCA and Washington Coast Moored Observations. UW Physical Oceanography Lunch Seminar, Nov 9, 2016.

Newton, J., Ocean Acidification and Hypoxia. 2016 Science to Policy Summit on Climate Change, hosted by the Columbia River Estuary NEP, Vancouver, WA, 17 June 2016. http://www.estuarypartnership.org/StoP2016

Newton, J., Invited talk: "Operational Oceanography for Shellfish Aquaculture in a Changing Ocean: meeting needs through IOOS." GODAE OceanView DA-MEAP-TT Joint Workshop, Santa Cruz, California, 13 July 2016.

Newton, J., The Northwest Association of Networked Ocean Observing Systems. North East Pacific OOI Community Workshop in Portland, OR, 28-29 September 2016.

Newton, J., NANOOS and WOAC contributions to OA observations in the Olympic Coast Sentinel Area. Olympic Coast NMS Sentinel Site Workshop: Exploring Options for an Olympic Coast Ocean Acidification Sentinel Site, Forks, WA, September 12th-13th 2016,

Newton, J., Invited talk: "Challenges and opportunities for monitoring chemical indicators of acidification in estuaries and coasts" Monitoring for Acidification Threats in West Coast Estuaries: A San Francisco Bay Case Study, Richmond, California, 19 October 2016.

Newton, J., Keynote Neal Thorpe Memorial Lecture: "Observing the Ocean from the Pacific Northwest and Beyond: Why it Matters" 25th Annual Murdock College Science Research Conference, Spokane, Washington, 4 November 2016.

Ruggiero, P., Beach and dune building processes: Linking Nearshore to Backshore and Events to Decades, AGU Fall Meeting, San Francisco, CA, December 2016.

Scroccaro, I., A. M. Baptista, P. J. Turner (2016a). Local atmospheric effects in the Columbia River estuary: can we simulate them, and do they matter? 2016 Columbia River Estuary Conference: Recent Anomalous Environmental Conditions – Drivers and Consequences, Astoria, OR.

Scroccaro, I., A. M. Baptista, P. J. Turner, T. Kärnä, J. Lopez, C. Seaton (2016b). Modeling study of the Columbia River estuary (USA) with different meteorological models. ECSA 56 Coastal systems in transition: From a 'natural' to an 'anthropogenically-modified' state, Bremen, Germany.

Seaton, C., S. Riseman, M. P. Wilkin, J. Goodman, P. J. Turner, J. A. Needoba, A. M. Baptista (2016). Columbia River endurance stations: eyes on the Warm Blob, and beyond. 2016 Columbia River Estuary Conference: Recent Anomalous Environmental Conditions – Drivers and Consequences, Astoria, OR.

Publications:

Barnard, P., Hoover, D., Hubbard, D., Snyder, A., Ludka, B., Gallien, T., Allan, J., Kaminsky, G., Ruggiero, P., Gallien T., Gabel, L., McCandless, D., Weiner, H.M., Cohn, N., Anderson, D., Serafin, K., accepted and in press. Historically significant oceanographic forcing and coastal response due to the 2015-2016 El Niño. Nature Communications, DOI: 10.1038/ncomms14365.

Chan, F., Boehm, A.B., Barth, J.A., Chornesky, E.A., Dickson, A.G., Feely, R.A., Hales, B., Hill, T.M., Hofmann, G., Ianson, D., Klinger, T., Largier, J., Newton, J., Pedersen, T.F., Somero, G.N., Sutula, M., Wakefield, W.W., Waldbusser, G.G., Weisberg, S.B., and Whiteman, E.A. The West Coast Ocean Acidification and Hypoxia Science Panel: Major Findings, Recommendations, and Actions. California Ocean Science Trust, Oakland, California, USA. April 2016.

Herfort, L., C. Seaton, M. Wilkin, K. Seitz, J. Lopez, M. Smith, V. Haynes, A. M. Baptista and H. M. Simon (2016). Use of continuous, real-time observations and model simulations to achieve autonomous, adaptive sampling of microbial processes with a robotic sampler. Limnology & Oceanography: Methods. 14(1):50–67. 10.1002/lom3.10069.

Hickey, B., S. Geier, N. Kachel, S. Ramp, P. M. Kosro, and T. Connolly (2016). Alongcoast structure and interannual variability of seasonal midshelf water properties and velocity in the Northern California Current System, *J. Geophys. Res. Oceans*, **121**, 7408–7430, doi:10.1002/2015JC011424.

Honegger, D.A, M.C. Haller, W.R. Geyer, and G. Farquharson, Oblique internal hydraulic jumps at a stratified estuary mouth, *J. Phys. Oceanography*, **47**, 85—100, doi:10.1175/JPO-D-15-0234.1, 2017.

Kaminsky, G., B. von Twistern, M. Brissette, J. Beaudoin, H. Weiner, and A. Hacking, 2016. Dual-head Mapping. xyHt, 3(8):16-23.

Kärnä, T. and A. M. Baptista (2016a). Water age in the Columbia River estuary. Estuarine, Coastal and Shelf Science, 183(A):249-259. 10.1016/j.ecss.2016.09.001

Kärnä, T. and A. M. Baptista (2016b). Evaluation of a long-term hindcast simulation for the Columbia River estuary. Ocean Modelling, 99:1-14. 10.1016/j.ocemod.2015.12.007

Kurapov, A. L., N. Pelland, and D. L. Rudnick, 2017b: Seasonal and interannual variability in oceanic properties along the US West Coast continental slope: inferences from a high-resolution regional model, J. Geophys. Res., submitted.

Kurapov, A.L., S. Y. Erofeeva, and E. Myers, 2017a: Coastal sea level variability in the US West Coast Ocean Forecast System (WCOFS), Ocean Dynamics, 67: 23. doi:10.1007/s10236-016-1013-4.

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Pool, S., C. Krembs, J. Bos and B. Sackmann. "Ferry observations" in Puget Sound Marine Waters: 2015 Overview. S.K. Moore, R. Wold, K. Stark, J. Bos, P. Williams, K. Dzinbal, C. Krembs, and J. Newton, Eds., http://www.psp.wa.gov/PSmarinewatersoverview.php

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Washington State Department of Ecology. 2016b. Eyes Over Puget Sound, Surface Conditions Report, July 20, 2016. Ecology Publication No. 16-03-075. https://fortress.wa.gov/ecy/publications/documents/1603075.pdf

Washington State Department of Ecology. 2016c. Eyes Over Puget Sound, Surface Conditions Report, August 24, 2016. Ecology Publication No. 16-03-076. https://fortress.wa.gov/ecy/publications/documents/1603076.pdf

Washington State Department of Ecology. 2016d. Eyes Over Puget Sound, Surface Conditions Report, September 26, 2016. Ecology Publication No. 16-03-077. https://fortress.wa.gov/ecy/publications/documents/1603077.pdf

Washington State Department of Ecology. 2016e. Eyes Over Puget Sound, Surface Conditions Report, November 22, 2016. Ecology Publication No. 16-03-078. https://fortress.wa.gov/ecy/publications/documents/1603078.pdf