Sustaining NANOOS, the Pacific Northwest component of the U.S. IOOS

NOAA Award: NA16NOS0120019 Reporting period: 6/01/2018 to 11/30/2018

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 FY18 period (= Y3 of this award; Y12 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.
11) Support collection of OA measurements at shellfish hatchery locations via technical expertise (B. Hales, OSU and B. Carter, UW JISAO), as part of Ocean Technology Transition in support of ocean acidification observing in support of Pacific coast shellfish growers.
12) Support Pacific Northwest Harmful Algal Bloom observing with an Environmental Sampling Processor (J. Mickett, UW).
13) Support HAB sampling with a Submaran Platform (J. Mickett, UW; N. Trenaman, OceanAero).
14) Support various GOA-ON activities (J. Newton, UW; E. Mayorga, UW).

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 18:

Area	**Y3 Award = Y12 NANOOS**
Observations	
Shelf:	-Maintain La Push buoy; deliver NRT data streams via NANOOS Visualization System (NVS) **-Support collection of OA data from La Push buoys with NOAA OAP funding** -Maintain Coos Bay buoy; deliver NRT data streams via NVS **-Support collection of OA data from CB-06 buoy with NOAA OAP funding** -Maintain Columbia R. buoy; deliver NRT data streams via NVS -Maintain N CA shelf glider transect; deliver data via NVS **-Support OA observing as an aid to Pacific coast shellfish growers; deliver data to IPACOA** **-Support Environmental Sampling Platform for PNW HAB observing**

	-Test Submaran platform as an aid to sampling HABs in Juan de Fuca eddy -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 WA; deliver data via NVS -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 **- Fill gaps in HF Radar operations and maintenance by OSU to complete west coast coverage for health and safety** -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; deliver model output via NVS -Maintain modeling & forecasting capabilities at OHSU; deliver model output via NVS -Maintain modeling & forecasting capabilities at OSU; deliver model output via NVS -Model verification and validation **-Data denial tests at OSU**
DMAC	
Data Portal and 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 **-Enhance GOA-ON data portal an OA dashboard to the world** **-Enhance biological data stewardship within NANOOS**
Tailored Product Development	-Climatology, Tsunami resilience SeaCast, Surfer, and Beachview web app development -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. **-Engage in GOA-ON support activities (including North American Hub, Timeseries, and GOA-ON workshops)**
Accountability	-Submit required IOOS progress reports and respond to other requests. -Comply with certification as a Regional Information Coordination Entity of US IOOS.

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

• ***Shelf***

***Washington Shelf Buoy Observations*:**

-Maintain La Push buoy; deliver NRT data streams via NANOOS Visualization System (NVS) [Szuts]

-Bring all data QA/QC to meet Certification standards [Szuts, Mickett]

The Washington Coast buoy observation program, led by J. Mickett, Applied Physics Laboratory, University of Washington (APL-UW), continued to maintain and operate two real-time moorings 13 miles NNW of La Push, Washington. During this reporting period, leadership of this project transitioned from J. Mickett to Z. Szuts, both at the Applied Physics Laboratory, University of Washington, APL-UW. The two moorings were successfully recovered and redeployed on 16-17 Oct 2018 with funding from NOAA OAP. The cruise was successful due to excellent weather, but the chartered vessel used (R/V Norseman II) is not well suited for this project. Real-time measurements are reported on NANOOS NVS. We have established a protocol of annual calibrations for sensors deployed on the Washington shelf (for CTDs, dissolved oxygen, pH).

The winter surface mooring that was built last year was deployed for the first time in Oct. It has a reduced number of sensors, to avoid loss or damage by winter storms, including internally-recording moored CTDs, an internally-recording updated pH sensor (SeaFET v2) deployed deep at 30 m, and a real-time pCO2 and pH system from NOAA PMEL (Drs. Sutton, Alin and Feely). After the October cruise, a detailed CTD transect and OA/HAB water sampling was collected north along the shelf and through the Strait of Juan de Fuca, with a few profiles through Puget Sound to end at Seattle. HAB sampling was coordinated with the Quileute Tribe through biologist J. Hagen, who participated on this cruise.

The two summer moorings worked well overall, with real-time data provided by the surface mooring over the whole period. Sensor problems have been diagnosed and design changes or preparation procedures modified to avoid such issues in the future. We continue to provide useful feedback to

Seabird as a first-user of their new SeaFET v2 sensor. One of the sensors provided excellent data with minimal drift over the summer.

At the mooring site, dissolved oxygen measurements near the bottom show typical levels of 3-4 mg/L during the spring and early summer. At the end of summer, 3 large anoxic (below 2 mg/L) events occurred between late August and the beginning of October with minimum values below 0.5 mg/L.

-Support Environmental Sampling Platform for PNW HAB observing *[Mickett]*
Working with the NWFSC (PI Moore) and coordinating with NANOOS/APL mooring operations (Szuts) the Applied Physics Lab, University of Washington (lead PI J. Mickett) deployed the Environmental Sample Processor on the NEMO subsurface mooring at the NANOOS Washington Shelf mooring site on September 6th, 2018, with the mooring recovered on October 16th, 2018. Prior to deploying the ESP APL/UW worked to improve the communications system by integrating a new antenna with a greater gain (more range) and that was positioned higher off the water. Despite these improvements, at three weeks into the 6-week deployment the ESP began experiencing communication issues, with regular dropped calls. As ESP firmware did not yet have logic to stop attempting calls if signal quality is too low, the ESP tried to call continuously, draining available battery power rapidly and ending the mission prematurely. Subsequent analysis and research also showed that the higher gain antenna may not have been an improvement for a platform (such as a small surface buoy) that experiences a lot of motion. Despite this unfortunate technical issue, the ESP deployment was successful in monitoring for HABs in a critical area off the Washington Shelf for 3+ weeks at a critical time of the year (razor clam harvest season). Data/observations were made available to stakeholders via the NANOOS Real-time HABS website that was developed via the NANOOS NOAA OTT ESP Program that ended this year. Due to the somewhat late arrival of funding (almost July) relative to the early September deploy time, the ESP team was not able to purchase a new telemetry cable, which requires at least a 10-week lead time. As such, we had to repair an old cable---which inherently has greater risk than using new cables for the deployment. To prevent this in the future, we will need funds at least 3 months prior to the planned deployment.

-Support collection of OA data from La Push buoys with NOAA OAP funding *[Szuts, Mickett, Newton]*
We have continued to work with NOAA PMEL scientists Drs. Adrienne Sutton, Simone Alin, and Richard Feely, to maintain pCO2 and pH data streams 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. Newton, Mickett, and Szuts have also continued to work closely with both the Olympic Coast National Marine Sanctuary and coast First Nations (Quileute) in maintaining and operating the two moorings, with the Quileute Marine Biologist, J. Hagen participating on several deployment cruises.

A summary of the 2016 observations collected by these moorings were submitted for inclusion in the 2016 Puget Sound Marine Waters Report.

-Test Submaran platform as an aid to sampling HABs in Juan de Fuca eddy *[Mickett]*
This work, which was initiated under the oversight of T. Vance of IOOS, involved carrying out several test missions using the Ocean Aero ASV (autonomous surface/underwater vehicle) Submaran to collect offshore HAB water samples and return these samples to shore for processing. Partners

included NANOOS, Ocean Aero, Olympic Region HAB partnership (ORHAB), NOAA NWFSC, the Makah, and the Applied Physics Laboratory, University of Washington (APL-UW). As the weather and sea-state in the Pacific NW can often limit HAB sample collection by small vessel, a successful test of an ASV water sampling system that can withstand these rough conditions would be a significant advancement for HAB monitoring in the region.

APL-UW efforts, led by Mickett, involved providing on-site vessel support with the APL R/V Sounder for testing operations. The test missions, which departed from Neah Bay over the period of September 24-27, were in general successful, although the winds were so light that the largely wind-powered Submaran was not able to travel as rapidly as predicted and, thus, was only able to reach roughly 5 nm offshore compared to the 15+ desired. In addition, due to the light winds the R/V Sounder was needed to tow the Submaran in and out of the port of Neah Bay and part of the way offshore. T. Vance and partners still plan to conduct a de-brief of this operation. As this was the first operation of its kind---specifically an ASV used to collect offshore HAB samples---the group drafted a press release that was sent to appropriate outlets prior to the tests.

APL has also begun work with Ocean Aero to take the first steps to develop a prototype of a sampling system that can collect and store up to 12 1-liter samples during a 48-hour mission. This development work will continue over the winter of 2018-2019.

Oregon Shelf Glider Observations:
-Maintain N CA shelf glider transect; deliver data via NVS [Barth]
-Bring all data QA/QC to meet Certification standards [Barth]
Starting in early December 2014, the Oregon State University glider research group has been obtaining vertical sections of ocean properties from off Trinidad Head, CA (41° 3.5'N) using an underwater glider. We used 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 measured depth-averaged velocity, which can be combined with geostrophic estimates of relative velocity to get absolute velocity and hence transport. The glider was flying from approximately the 100-m isobath (~10km offshore) to 130W (~500 km offshore), repeating the line every 30 days. We collaborated with Dr. Eric Bjorkstedt (NOAA Southwest Fisheries Science Center, Humboldt State University) to facilitate fieldwork off Trinidad Head. We used two of our Seagliders in order to "hot swap" them on the line when their batteries run low. During this reporting period, this effort was 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 (11/30/2018), the glider was on the TH line for 1251 days during eight deployments, sampled along approximately 22,800 km of track line covering the transect about 60 times, and collected about 10,066 vertical profiles of ocean properties. For the reporting period 6/1/2018 to 11/30/2018 the glider was on the TH line for 146 days during two deployments, sampled along nearly 2525 km of track line covering the transect about 6 times, and collected about 1080 vertical profiles of ocean properties. The glider "uptime" was 81%, less than the usual 99+% because of a sampling hiatus between recovering a glider that had run out of battery prematurely and the redeployment of a second glider on the TH line. Data are being sent in near real-time to the IOOS Glider Data Acquisition Center and, simultaneously, to the

CeNCOOS and NANOOS 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 the demise of the 2014-2017 "Warm Blob" and the potential for a 2018-2019 El Niño. Water at depth is warm during Fall 2018, similar to the subsurface warming associated with the 2015-2016 El Niño (Figure 1). These temperature anomaly data are also being compared to similar information from farther south on the CalCOFI lines and farther north off Oregon and Washington from the Ocean Observatories Initiative gliders.

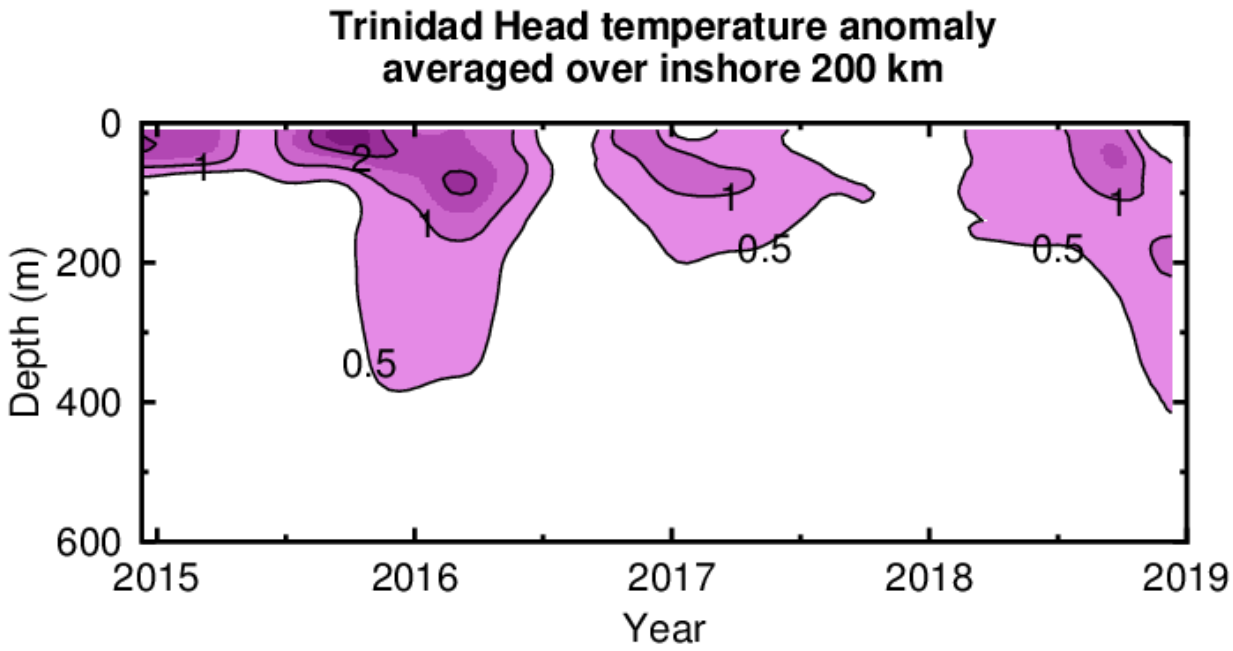

Figure 1: Temperature anomaly from the Trinidad Head, CA (41° 3.5'N) glider line.

Oregon Shelf Mooring Observations:

-Maintain Coos Bay buoy; deliver NRT data streams via NVS [Kosro, Hales]

-Bring all data QA/QC to meet Certification standards [Kosro, Hales]

The Oregon shelf mooring, CB-06, was recovered on October 7, 2018, from its location in about 100m of water near Coos Bay, at 43° 17.607' N, 124° 32.234' W, using the R/V Oceanus, piggy-backing on a cruise led by chief scientist Clare Reimers. Erik Arnesen served as the chief mooring technician for the recovery. From the physical-oceanography sensors, the mooring provided time series of temperature at 18 depths, salinity at 4 depths, pressure at 6 depths, dissolved oxygen at a median depth of 85m, and a downward-looking ADCP providing current profiles at up to 43 two-meter-wide depth bins. All of these data were recorded internally and downloaded upon mooring recovery; a subset was telemetered to shore in near real-time and made public through the NANOOS Visualization System (NVS) and through the National Data Buoy Center using our ID 46128. Meteorological data collected included winds, solar insolation, barometric pressure, all telemetered to shore and made public. In addition, the MAPCO2 suite of biogeochemical sensors was included in the mooring buoy, measuring CO2 in the air and in the surface water, pH, surface Salinity and temperature; these data were reported in near real-time through PMEL and through NVS.

Signatures of strong internal bores were observed from the high-vertical-resolution temperature data in the water column; such bores have been implicated in cross-shelf transport events in other regions.

A new second buoy has been constructed, which will greatly speed the turnaround process at future mooring recovery/redeployment. For the current deployment, we have the buoy ready to deploy, but are waiting for a workable weather window accompanied by vessel availability.

-Support collection of OA data from CB-06 buoy with NOAA OAP funding *[Hales]*
The shift of the MApCO2 mooring from NH10 to CB06 occurred in June of 2017, when an opportunity for ship access was presented via state-funded educational days aboard the RV Oceanus. Figure 2 shows the first season of mooring data from this location, which has already been reported on but is included here for reference. In the last progress report, we noted the absence of clear freshwater signals associated with the periodic impingement of the Columbia River plume on NH10, and the relatively muted signals of upwelling and biological response. We attributed those to CB06's location downstream of the cross-shelf isobaths of the south end of Heceta Bank, and hypothesized that direct cross-shelf upwelling was limited here and those signals mostly reflected the net effect of community metabolism on Heceta Bank. In 2018 (Figure 3), there is a clear pulse of low-salinity (~28) in the record in mid-June. The source is not clear but is likely a remnant of Rogue or Umpqua winter/spring freshets that had not yet been pushed south by prevailing equatorward upwelling-season flow. Also distinct from the 2017 record are the strong signals of local upwelling, with cold (~8 C) and salty (>33.7) waters accompanied by high pCO_2 and low O_2 and pH. In the most extreme of these events, pCO_2 exceeds 1100 µatm, while pH and O_2 are below 7.7 and 140 µmol/kg, respectively. This can only be due to recent, local, upwelling of shelf-break source waters. While calculation of carbonate-system parameters from pH and pCO_2 is tenuous, these values suggest surface waters were corrosive to aragonite during this event. Following the intense expressions of upwelling, pCO_2, pH, and O_2 all closely covary in ways that suggest the primary control on all three is due to rapid net community productivity.

-Support OA observing as an aid to Pacific coast shellfish growers; deliver data to IPACOA *[Hales]*
Hales continued to work with Whiskey Creek Shellfish Hatchery to provide technical assistance to maintain the Burke-o-Lator and field-test the ACDC sensor. This work was also partially supported by our OTT award, through 30 September 2018. Details are in that report, but now will be solely sustained by and reported on this award.

-Support OA observing as an aid to Pacific coast shellfish growers; deliver data to IPACOA *[Carter]*
Technical assistance to maintain the Burke-o-Lator and field test the ACDC sensor was provided by Julian Herndon (UW JISAO) at the Taylor Shellfish Hatchery. This work was also partially supported by our OTT award, through 30 September 2018. Details are in that report, but now will be solely sustained by and reported on this award.

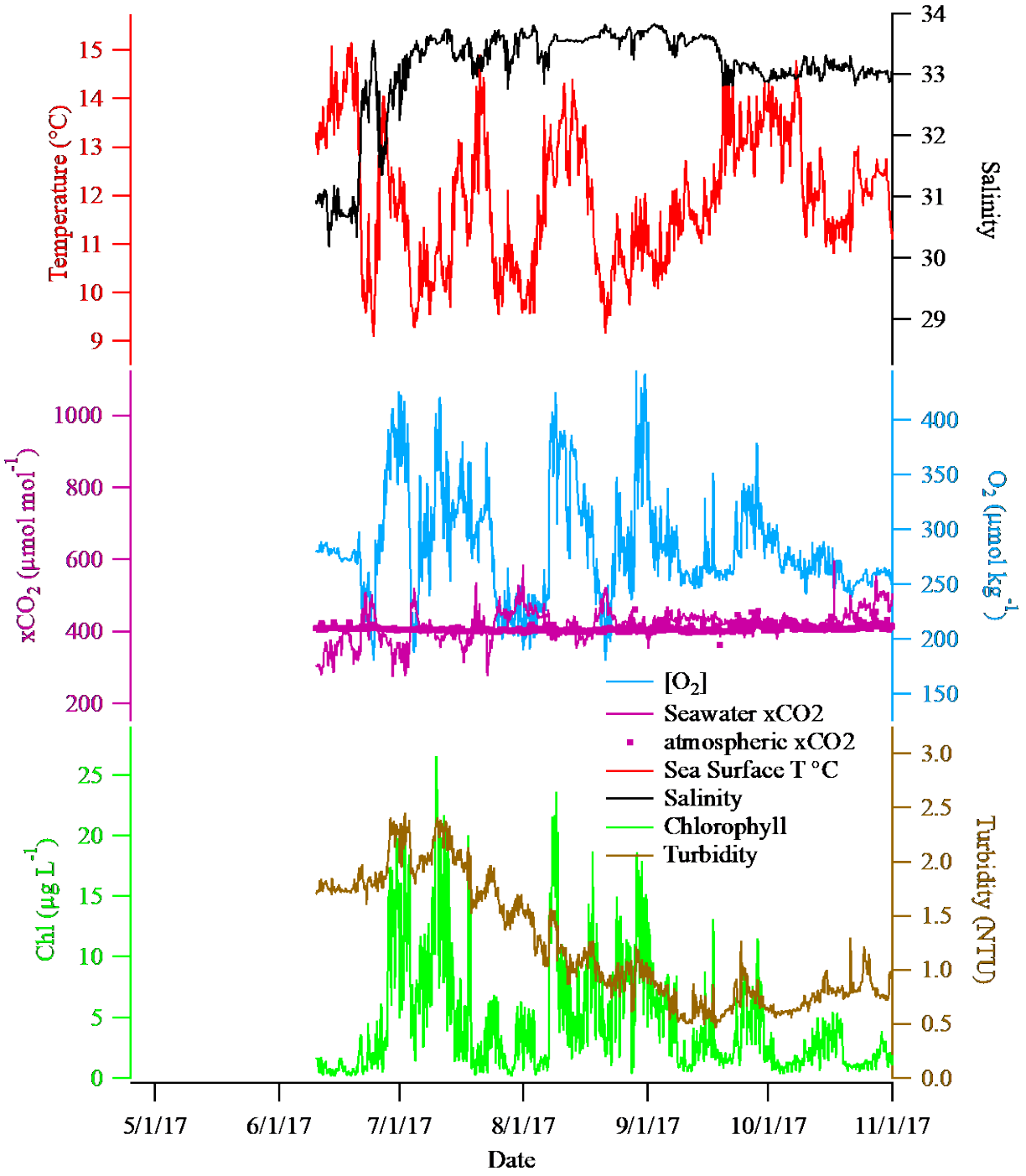

Figure 2. Summer-Fall 2017 CB06 OA-relevant data, from prior progress report. SeaFET-based pH sensor failed on this deployment.

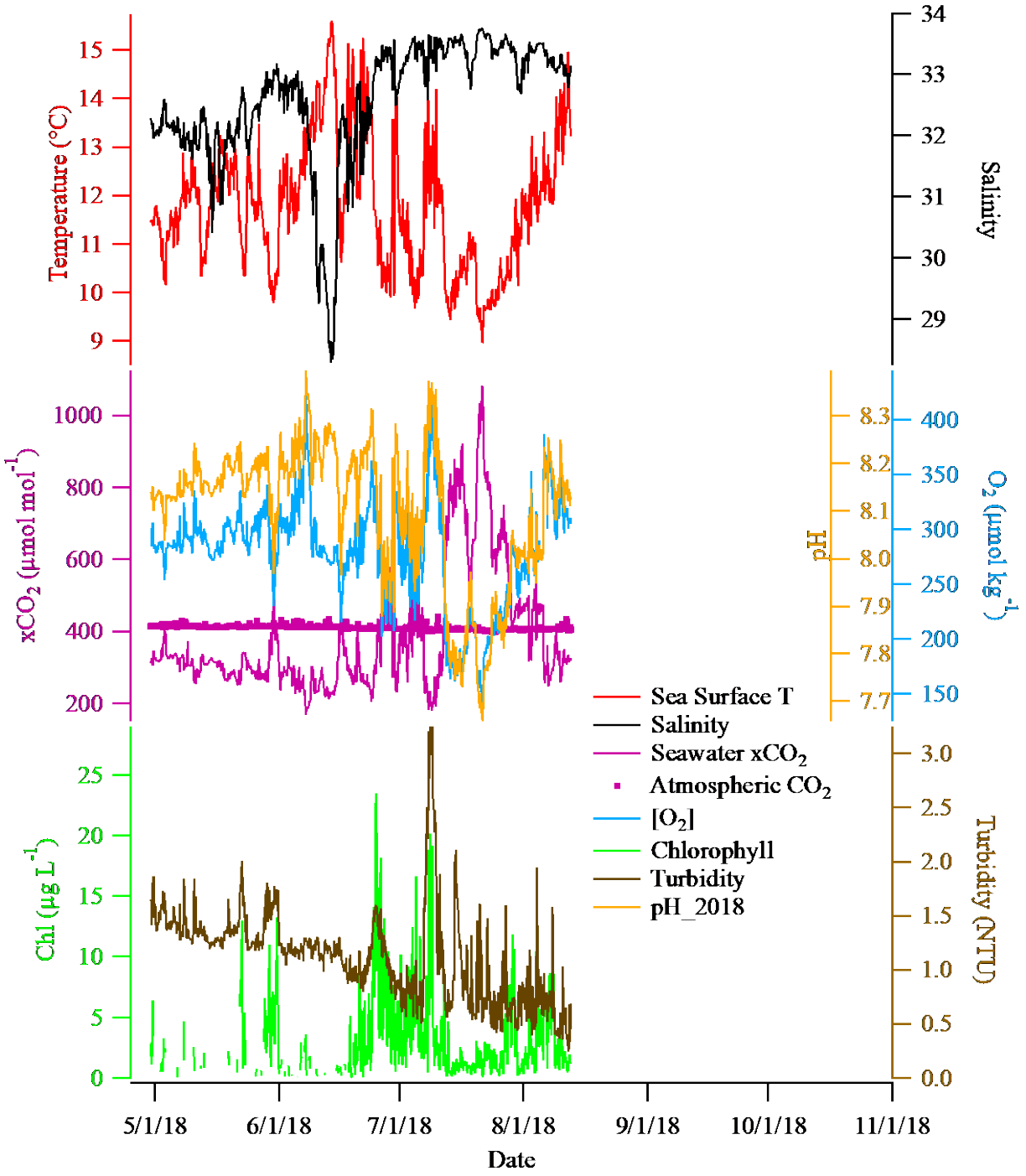

Figure 3. Spring-Summer 2018 CB06 OA-relevant data.

Northern Oregon to Central Washington Shelf Observations:

-Maintain Columbia R. buoy; deliver NRT data streams via NVS [Baptista]
-Bring all data QA/QC to meet Certification standards [Baptista]
OHSU maintains observational assets in the Columbia River coastal margin. These assets are anchored on SATURN-02, a seasonal inter-disciplinary buoy, with real-time telemetry, located off the mouth of the Columbia River at ~35m depth. SATURN-02 data routinely contributes to model validation, capturing near-field Columbia River plume dynamics. Data also routinely offer local temporal context and for specialty buoy deployments and for cruises.

SATURN-02 was deployed June 27 – October25, 2018. Parameters measured were (a) wind speed, direction and gust, air temperature and atmospheric pressure; (b) water velocity; and (c) the scalar water parameters: temperature, salinity, dissolved oxygen/oxygen saturation, chlorophyll, turbidity, CDOM, phycoerythrin and nitrate. Scalar water measurements were made through single at-surface sensors and a multi-level pumping system. Levels measured are 1, 6, 11, 16, 21 and 35m depth.

We also deployed North Head, a temporary real-time buoy to support NOAA/USACE studies of the impact of dredged disposal on crabs. The station was deployed north of the Columbia River mouth, for September 8 – November 15, 2018. Measurements include: (a) wind speed, direction and gust, air temperature and atmospheric pressure; and (b) scalar water parameters: temperature, salinity, dissolved oxygen/oxygen saturation, chlorophyll, and turbidity. Scalar water measurements were made with a set-up similar to SATURN-02, but only at three levels: 1, 6 and 14m below sea level.

All SATURN-02 data are displayed on NVS, when the station is deployed. Data from temporary stations (such as North Head) are typically not displayed on NVS, although they are stored in national archives. We investigated options and planned QARTOD flagging for real-time data, but implementation will occur only in 2019.

- **Estuaries**

Puget Sound Buoy Observations:

-Maintain Puget Sound estuarine moorings; deliver data via NVS [Szuts]
-Bring all data QA/QC to meet Certification standards [Szuts]
Led by Z. Szuts, J. Mickett, J. Newton, and A. Devol (UW), during this report period 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. There were many personnel changes on the team during this reporting interval, including a leadership transition from Mickett to Szuts.

The ORCA moorings continue to be upgraded with newer designs to improve their performance and minimize maintenance effort. System upgrades include many improved designs for system components that have been built up to put on all moorings. Improved components included: winch control module, capacitor bank and housing, testing/shorting plug, duplicate/spare assemblies, new computer components with more serial inputs, thicker gauge wire to reduce weak points, marine-grade winch drive chain, and heavy-duty lubricant. The moored float deployed in Dabob was replaced with a temporary winch system while the float is being repaired. When possible, we have been performing

mooring inspection during dives. Such dives identified a previously unknown failure or one mooring leg from the Pt Wells ORCA buoy this summer. The Bellingham Bay Buoy Se'lhaem, part of this network, provided near full data up-time and minimal field servicing.

Collaborations continued with multiple ongoing projects that required lots of summer fieldwork. For NOAA Ocean Acidification, we have been maintaining and deploying pH sensors, now mostly upgraded to version 2. For work with A. Sutton, S. Alin, and R. Feely (NOAA PMEL Carbon Group), we supported deploying pCO_2 systems on Twanoh and Dabob Bay, including water samples for system calibration. For a collaboration with J. Keister and D. Grunbaum (UW Oceanography), we deployed and serviced a zooplankton camera on the Hoodsport ORCA mooring, including adding a more powerful solar panel and performing frequency battery swaps for the power-intensive system. For a Bivalve study by J. Padilla-Gamino (UW Fishery Sciences), we have attached and serviced cages for bivalve to grow in. A new project was started to support a study by investigators at the Smithsonian Museum of Natural History to investigate biofouling by placing plates on 3 moorings.

ORCA observations continue to be critical to helping us understand how Puget Sound recovers from the unprecedented warm anomalies of 2015 and 2016 and from hydrological anomalies. Data continue to be made available through NANOOS NVS and through the NWEM ORCA server. We have established a protocol of annual calibrations for CTDs and other sensors (dissolved oxygen, pH). At the end of this reporting period, in general most water properties had returned to "normal" levels. Hypoxia in south Hood Canal barely reached the surface at the end of September. The hypoxic levels eroded slowly from below during Sept, and surface forcing eroded it suddenly at the end of Sept as less stratified conditions returned. This transition was to water warmer and saltier than the seasonal average. Also of note, the Carr ORCA mooring in South Sound showed salty conditions since April 2018 that were 0.5 to currently 1.0 PSU saltier than the seasonal average, likely due to reduced river flow during a dry summer.

Washington State Estuarine Observations:

-Maintain US-Canada ferry-box; deliver data via NVS [Maloy]

-Bring all data QA/QC to meet Certification standards [Maloy]

Led by C. Maloy and C. Krembs (WA State Department of Ecology), en-route ferry-based monitoring and moorings are two parts of Ecology's extensive long-term monitoring program that covers Puget Sound and the Washington coastal estuaries. Ferry monitoring complements Ecology's larger program by focusing on surface processes (e.g., temperature variations, frontal systems, tidal currents, blooms, river plumes, etc.). It also provides a means of continuously ground-truthing remote sensing techniques to greatly leverage and expand capabilities for Puget Sound environmental monitoring. Moorings were previously deployed to provide continuous information on estuarine water conditions and to complement Ecology's monthly marine water sampling. Since the moorings program ended, we focused our efforts on performing data quality control and conducting data analysis.

In the ferry-based monitoring program, we have about eight years of data (2010 to 2017) from the optical fluorometer. The sensor collected 22.5 million measurements on water temperature, chlorophyll fluorescence, turbidity, and colored dissolved organic matter. The initial data processing performed this spring was repeated to correct for criteria used to exclude Elliott Bay and Victoria Harbour. The correction was applied to the entire fluorometer data set, which is now ready for the next step in the data QA/QC process.

For the moorings, we focused our efforts on four that were deployed in Willapa Bay from mid-1997 to 2013. The instruments measured temperature, salinity, and chlorophyll fluorescence near the water surface and while floating with the tides. Starting with the mooring near Bay Center, WA, we are reviewing temperature and salinity data (~436,000 scans) and have identified most outliers through scatter, temporal, and baseline plots (Figure 4). Currently, we are examining the value of including pressure data in our analysis, particularly since the instruments did not have a pressure sensor from 1997 to 2007. After this step is completed, we will transfer the Bay Center mooring's temperature and salinity data into Ecology's Environmental Information Management database system. This database is publicly accessible and thus will allow researchers, scientists, and interested citizens to freely obtain the mooring data.

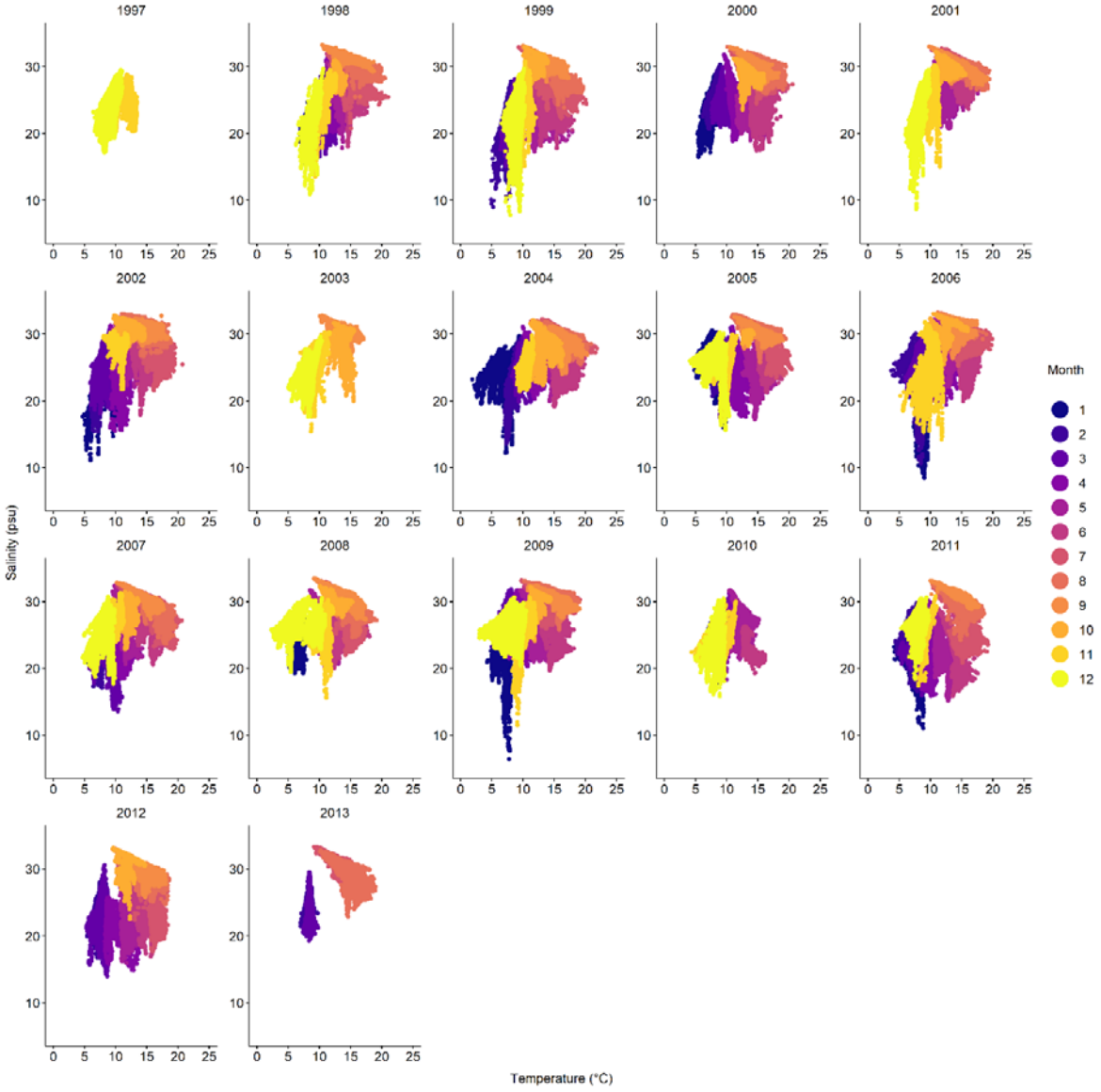

Figure 4. Monthly temperature-salinity patterns at Willapa Bay, Bay Center near-surface mooring, 1997 to 2013. Data were collected over 15-min intervals.

Columbia River Estuarine Observations:

-Maintain Columbia R. estuarine moorings; deliver data via NVS [Baptista]

-Bring all data QA/QC to meet Certification standards [Baptista]

OHSU maintains multiple endurance stations for the lower Columbia River estuary, anchoring the CMOP/SATURN network. Also associate to SATURN, but not funded by NANOOS, are two freshwater stations: SATURN-05 and SATURN-08, maintained by J. Needoba (OHSU) with regional stakeholder funding.

The NANOOS supported estuarine stations that are maintained on a permanent or seasonal basis are SATURN-01, SATURN-03, SATURN-04, SATURN-07, SATURN-09, CBNC3 and Elliot Point. All except CBNC3 have real-time telemetry. All but CBNC3 and Elliot Point (which only measure salinity and temperature) are inter-disciplinary (physics and biogeochemistry). SATURN-01 and SATURN-09 were not operated during 2018, but will be redeployed during 2019. Multiple other estuarine stations have collected historically important data, and we re-deploy some of these stations on occasion, as resources allow and scientific or regional needs recommend. While none of these stations were deployed in 2018, Grays Point might be re-occupied in 2019, to help better understand salt propagation in the northern flats of the estuary.

Data from all real-time estuarine stations are displayed on NVS, when stations are deployed. Data from stations without telemetry are not displayed on NVS, but are retroactively stored in national oceanographic archives. We investigated options and planned QARTOD flagging for real-time data, but implementation will occur only in 2019.

South Slough Estuarine Observations:

-Maintain South Slough estuarine moorings; deliver data via NVS [Helms]

-Bring all data QA/QC to meet Certification standards [Helms]

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 operated 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 salinity gradient of the South Slough estuary provided continuous water temperature, salinity, dissolved oxygen, pH, turbidity, and water level data over the period 06/01/18 –11/30/18, and telemetry transmissions were continuous. Monthly instrument deployments, routine station maintenance, and data QA/QC, upload and management were completed for the weather and water quality stations during the reporting period following NOAA NERRS Centralized Data Management Office protocols.

We maintain one Coos Bay 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 (NESDID ID # 346F229A; sosnswq), is located in the lower Coos estuary with data available via the NVS. Real-time data transmissions were uninterrupted for the reporting period.

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 Reserve and CTCLUSI stations provide environmental data for research, monitoring and education programs conducted at the reserve. During this reporting period, data from SWMP/NANOOS stations were incorporated into three summer research projects at the Reserve: 1) NSF Research Experience for Undergraduate (REU) project to understand how long-term changes in water quality (water temp, salinity, turbidity, and DO accessed from 2010-2018 at Valino Island) may be contributing to eelgrass declines in South Slough estuary; 2) NSF REU project tracking green crab abundance related to abiotic condition evaluations in Coos estuary during trapping periods using water temperature, salinity, and pH data from 2016-2018 at Charleston Bridge, Valino Island, and Winchester Creek stations; and 3) NOAA Hollings Scholar project assessing different marsh vulnerabilities to sea level rise by comparing eight South Slough emergent marshes with one Coos Bay, Bull Island marsh; this project utilized salinity and water level data from 4 water quality stations, including Charleston Bridge, Valino Island, Winchester Creek, and Catching Slough. NANOOS Visualization System tools were utilized for NOAA NERRS Teachers on the Estuary Workshop July 2018 with 19 Oregon and Washington K-16 teachers participating.

South Slough expanded the network of water quality stations into the Coos estuary to include four stations (North Point, Isthmus Slough, Catching Slough, and Coos River). The North Point station is located near commercial oyster cultivation areas and will be prioritized for adding telemetry and hosting data via NVS. South Slough added pCO2/ pH monitoring equipment at the Valino Island station as well as the Charleston Bridge station through OSU collaboration and continued data collection and maintenance, including annual SeapHOx and SAMI-CO2 refurbishment supported through NANOOS.

- **Shorelines**

Washington Shoreline Observations:

-Maintain shoreline observations in WA; deliver data via NVS [Kaminsky]

-Bring all data QA/QC to meet Certification standards [Kaminsky]

NANOOS funds contribute to the Washington State Department of Ecology Coastal Monitoring & Analysis Program (CMAP) led by G. Kaminsky. In June 2018, CMAP completed spring seasonal beach monitoring surveys in the Columbia River Littoral Cell (CRLC). Forty-six beach profiles and two surface maps were collected. In addition, CMAP collected 15 supplemental profiles in Westport and 13 in Ocean Shores, in two locations of the CRLC where erosion is threatening property. Significant erosion is also occurring at Benson Beach just north of the Columbia River, where the southernmost profiles in the sub-cell are at their most eroded state since monitoring ensued. Seasonal beach profile data and contour change plots are made available through the NANOOS Visualization System.

Also in June 2018, CMAP conducted a comprehensive beach and nearshore survey of the North Cove area. Using a combination of boat-based lidar, multibeam sonar, GPS mounted on backpacks, and an ATV, a high-resolution digital elevation model of 7 km of shoreline was produced. This work was funded by Mott MacDonald, a consulting firm that has been hired by Pacific County to evaluate alternatives and propose a protection project to mitigate chronic erosion hazard impacts, to augment the dynamic

revetment constructed by the Pacific County Conservation District this fall. CMAP will be monitoring the performance of the dynamic revetment over the winter of 2018-2019.

In July 2018, CMAP worked with surveyors from the USGS to collect beach profiles at the Elwha river delta. The Elwha monitoring surveys have cut back to once per year as changes to the river mouth slow and funding declines. In August and September 2018, CMAP conducted summer seasonal beach monitoring surveys in the CRLC, collecting 50 beach profiles (plus 33 supplemental profiles), 14 surface maps, and 62 sediment samples from multiple cross-shore locations along 13 of the profiles. In addition, over 200 beach profiles were collected to extend the nearshore bathymetry profiles collected by the USGS and OSU using personal watercraft. CMAP also collected an extra surface map on Clatsop Spit in September for the Army Corps of Engineers, as well as 7 beach profiles on the Spit, 4 south of the South Jetty, and 4 perpendicular to the South Jetty on the north side to capture the ridge-runnel morphology.

In October 2018, CMAP was asked to participate in an oil spill drill hosted by the Washington State Department of Ecology. CMAP was able to demonstrate how high-resolution multibeam sonar bathymetry data could be used in detecting low spots that may accumulate sunken oil and potentially to locate non-floating oil that has settled on the seafloor.

Over the entire CRLC in Washington, fall storms had the greatest impact on Benson Beach just north of the Columbia River North Jetty. A dune restoration project was implemented in Westport in front of a condominium complex where erosion during the 2015-2016 El Niño winter resulted in the loss of the primary dune. The newly constructed dune was surveyed in summer 2018 and will continued to be monitored.

In September 2018, George Kaminsky gave a presentation for the Washington Coastal Marine Advisory Council in Aberdeen. The presentation gave an overview of coastal erosion in Washington, focusing on changes to the southwest coast where the bulk of our knowledge and information is from given CMAP's 20+ years of research and monitoring. In October 2018, George Kaminsky gave a similar presentation at the 9th annual Coastal Marine Resources Committee Summit. These meetings are meant to better inform the Washington coastal policy community about coastal erosion in the present and future, recommending a coast-wide approach and strategic plan to address the issues.

Oregon Shoreline Observations:
-Maintain shoreline observations in OR; deliver data via NVS [Allan]
-Bring all data QA/QC to meet Certification standards [Allan]
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). Beach profile data – summer surveys – were collected in the Neskowin (15 sites) and Rockaway littoral cells (25 sites), as well as along Clatsop Spit (6 sites) this past summer (August/September 2017). In response to needed coastal change hazard information requested by the Oregon State Parks and Recreation Department (OPRD) who manages Oregon's public beach, PI Allan implemented a new monitoring effort along Gleneden Beach/Siletz Spit to assist OPRD with their decision making. The new network was implemented early in November and includes 31 transect sites. In time, we anticipate expanding this network to the north to include Lincoln Beach. In addition to the transects, datum-based shorelines

were also collected during the same beach monitoring campaigns. Beach profile data have been processed, QA/QC'd, and archived both locally and remotely. The reduced profile plots, change plots, and trends have been posted to the NANOOS beach and shoreline portal (http://nvs.nanoos.org/BeachMapping). As of late summer 2018, our monitoring data indicated that Oregon's beaches were generally in a strongly accreted state. This is an ideal state to be in given the prospect of a moderate El Niño developing over the 2018/19 winter, bringing with it generally above average wave and water level conditions that tend to promote beach and shoreline erosion.

***Nearshore Bathymetry Observations*:**
-Maintain bathymetric observations in WA and OR; deliver data via NVS [Ruggiero]
-Bring all data QA/QC to meet Certification standards [Ruggiero]
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 during summer 2018 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 Ecology developing complete maps of the nearshore planform.

After conversations with various NANOOS PIs at the 2018 annual meeting, it was decide that Ruggiero's group would collect nearshore bathymetry in the Newport area during summer 2018 as opposed to working in the Rockaway littoral cell. Figure 5 shows a gridded bathymetry product derived from this survey. This data will be used, among other applications, to ground-truth the radar derived bathymetry products that PI Haller's group is developing in the region.

These data continue to provide a critical source of information for improving coastal hazard mitigation along the coastlines of the CRLC and portions of the Oregon coast and for understanding the morphodynamics of high-energy beaches. In collaboration with the US Geological Survey and the Washington Department of Ecology the nearshore bathymetry and topographic data being collected via NANOOS at the mouth of the Columbia River is being used to inform regional sediment management practices.

- **Currents**

Coastal Current Observations:
-Maintain OR Priority-One HF radar sites to the national operations standard; deliver data via NVS and the National HF Radar system [Kosro]
-Bring all data QA/QC to meet Certification standards [Kosro]
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.

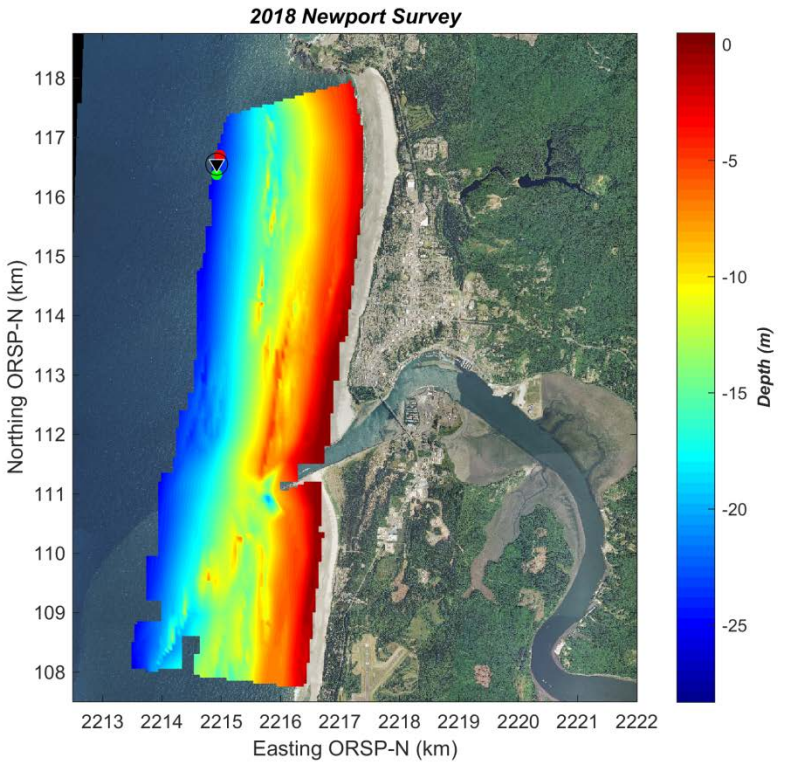

Figure 5. Gridded nearshore bathymetry from 2018 Newport survey.

During this period, NANOOS scored an HFRNet Performance metric for the 2 main reporting quarters (Q4FY2018 and Q1FY2019) of 89% and 92% respectively (https://hfrnet.ucsd.edu/diagnostics), or 90% for the full FY2018 (highest in the national system). This well exceeds the target figure of 80%.

IOOS has offered to upgrade the Codar-produced site-operation software for all sites, which is a generous investment. To accommodate, we are buying new site computers for most of the sites, which will be capable of running the new software. We have also installed Carbon Copy Cloner for redundant backup at the field sites.

Use of Raspberry Pi monitors, designed and programmed by Erik Arnesen for UPS alerts (especially) has been very helpful, providing quick notice of power outages for prompt repair. Numerous repairs were conducted in the reporting period: e.g., replaced transmitter amplifier fan at WLD2 on Oct 01; improved external cell modem placement at YHL1, on Sep 25; replaced cell-phone antenna with superior model, 06 Sept, improved; PSG1 was back to operation after installation of repaired transmitter chassis and wring-out of cables, 24 Aug; using Web Power Switch (remote control of wall power), was able to return SEA1 computer to operation; and 18 July, replaced SMART UPS at WIN1 and got warranty. The DSL modem at MAN was replaced in Aug 2018.

At SEA1, we worked with the home-owner to allow continued operation on his property; CBL1, cleaned up cable runs and computer rack; YHS2, installed a Temperature and Humidity sensor via a

Raspberry Pi at six sites; PSG1 exhaust fan adjusted to fix overheating in hut, Jun 2018; replaced air conditioner at STV2, which was drawing too much current and tripping the breaker.

We detected interference at our northernmost site LOO that appeared to be from another site. We coordinated a test with Bodega Marine Lab, and did detect interference. We are working with Codar to adjust blanking and to obtain new timing offsets to avoid interference.

Kosro attended the Radiowave Operators Working Group (ROWG) meeting in Santa Cruz during October, which proved to be very useful. He also is a member of the PhD committee for Ivo Pasmans, who is anticipating defending on December 7, 2018.

- Fill gaps in HF Radar operations and maintenance by OSU to complete west coast coverage for health and safety [Kosro]
We continue to explore possible site locations for the coastal Washington radars. An unforeseen limitation is the great width of many southern beaches, which would attenuate the radar signal and lower signal-to-noise. We hope to be able to use one southern site without this problem, but will need to make arrangements for installation of power.

Port X-band Radar Observations:
-Maintain X-band radar sites; deliver data via NVS [Haller]
-Bring all data QA/QC to meet Certification standards [Haller]
Led by M. Haller (OSU), the X-band radar station at the Yaquina Bay Inlet in Newport continues to operate atop the US Coast Guard watchtower near the Yaquina Bay lighthouse. We are grateful for the continued provision and cooperation of the USCG. The radar system was out of operation from mid-August through September due to a series of hardware failures, but has been operating nearly continuously since October. The system produces snapshot imagery, spectral diagrams, and movies of slow-moving surface roughness features such as tidal fronts, all of which are available for view at the group's OSU website: http://research.engr.oregonstate.edu/haller/Newport. We are presently working with Craig Risien to link our web site to NVS and incorporate select data products as well. All data follow the certification QA/QC standards.

We have a new data product this year, which is bathymetry estimates for the Newport nearshore zone. Included in this product we have developed some quality control indicators that feed into the Kalman filtered product. In the development of this new data product, we have also coordinated with P. Ruggiero's group to obtain ground truth nearshore survey data for the Newport nearshore zone. These data were a special collection of Ruggiero's group that were collected in Sept. 2018 and span from the Newport jetties to Yaquina Head. These will be used as verification for our radar-derived bathy estimates.

b) <u>NANOOS Modeling Subsystem:</u>
Shelf Modeling:
-Maintain modeling & forecasting capabilities at OSU; deliver model output via NVS [Kurapov]
-Model verification and validation [Kurapov]
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 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://ingria.coas.oregonstate.edu/rtdavow/, L. Erofeeva, OSU). We also continue to provide the forecast fields to the SeaCast.Org project aimed at development of an interactive online ocean forecast tool using recommendations from local fishermen. The seacast.org tool was merged into NANOOS NVS as one of the applications.

During the report period, we continued our real-time operation. We have prepared the system to assimilate the polar-orbiting NPSS VIIRS L3U SST (A. Ignatov, NOAA/NESDIS/STAR) but have not made the switch to this SST product yet, since the currently utilized GOES SST L2 product is still available. One of the major upgrades to the system included daily assimilation cycles (instead of once every three days cycles). Every day assimilation still proceeds using 4DVAR in a 3-day window such that assimilation windows overlap, which allows better utilization of the observations and smoother transition from one window to another. Most recently, the global Navy NYCOM system, from where we obtain the boundary conditions, transitioned to a new version (3.0 to 3.1), on a different grid. We changed the scripts for boundary condition generation to provide transition to this new product, with minimal interruption to our operation. Methods for accurate model set-ups and data assimilation are being transferred to NOAA/OCS/CSDL, where we contribute to development of the West Coast Ocean Forecast System (WCOFS).

-Data denial tests at OSU [Kurapov]
Using leveraging by the Qualitative Observing System Assessment Program (QOSAP), the OSU student Ivo Pasmans ran comparative data-denial tests assimilating the glider data alone and in combination with the surface data, with application to the OSU OR-WA coastal ocean forecast system. A publication on this topic has been submitted (Pasmans et al., 2018).

Shelf and Salish Sea Modeling:
-Maintain modeling & forecasting capabilities at UW; deliver model output via NVS [MacCready]
-Model development, verification and validation [MacCready]
NANOOS PI P. MacCready (UW School of Oceanography), working with Drs. Siedlecki (Univ. Of Connecticut), McCabe (UW Joint Institute for the Study of Atmosphere and Ocean), and Banas (U. Of Strathclyde) run a pre-operational forecast model, called LiveOcean, of ocean circulation in Puget Sound and adjacent coastal waters. In the past six months, a new high-resolution version of the LiveOcean model was tested and brought online as the daily forecast. The new model has 500 m horizontal grid size in the Salish Sea and coastal estuaries (three times finer than the old version) and three times as many rivers, now 45. Improvements were also made to river chemistry. The result is that the new model resolves biogeochemical fields, including carbon variables, across the whole domain, from estuaries to beyond the shelf break. Extensive new model validation was performed using tide gauges,

CTD and bottle casts from WA Ecology, and OCNMS moorings on the shelf. Results of the validation, and movies of the daily forecast focused on different stakeholders, are presented in a completely-revised version of the LiveOcean website: http://faculty.washington.edu/pmacc/LO/LiveOcean.html. Model fields are available through NANOOS NVS. The model fields are also made available through the NOAA IOOS EDS system, and are used as open boundary conditions by Dr. Susan Allen at UBC and Co-PI Baptista for their forecast systems. 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), and by ONR, greatly accelerating the work and leveraging the impact of NANOOS funds. During this past 6 months in addition to the model development gave 8 talks (5 invited) at scientific and stakeholder meetings. 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 NOAA-funded MERHAB PNW project to make short-term forecasts of when *Pseudo-nitzschia* HABs may reach WA beaches.

Columbia River Modeling:

-Maintain modeling & forecasting capabilities at OHSU; deliver model output via NVS [Baptista]

-Model verification and validation [Baptista]

Led by A. Baptista, OHSU maintains an extensive modeling system for the Columbia River coastal margin, denoted Virtual Columbia River (VCR). The VCR has evolved from multi-institutional collaborations involving modelers and non-modelers, in academia and across regional, federal, and tribal agencies. The modeling capabilities of the VCR has assisted the region in the study of salmon life cycle, habitat, estuarine pathways, and status under the Endangered Species Act and in relation to hydropower management and climate change (see previous NANOOS reports). Daily forecasts of salinity and temperature are displayed on NVS.

To meet the challenges that the highly energetic and strongly stratified Columbia River estuary and plume pose to numerical models, we are experimenting with a different class (Discontinuous Galerkin [DG]) of unstructured-grid finite element models, both using an existing code SLIM and a newly developed code Thetis (Karna et al. 2018). Results are promising, as are newly developed simulations with a high-order (TVD-based) version of the SELFE-derivative code SCHISM (Baptista 2018). Results for the SCHISM application have led to the development of a simulation database that offers (over an equivalent SELFE database) improvements in the representation of: estuarine classification, salinity intrusion, inflow numbers, vertical stratification, salt retention in ebbs, and residuals.
Our model skill inter-comparison relies heavily on the SATURN observation stations. Model-data comparisons use quantitative error metrics as well as process-based benchmarks.

c) Data Management and Communications (DMAC) Subsystem:

See table for milestones [Mayorga]

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; in CY2018, we integrated an ADCP dataset.
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 (serving as clearinghouse) non IOOS-supported local and regional data providers, including Canadian ones, to integrate and redistribute their data streams, particularly via NVS. In CY2018, two Canadian assets were integrated: a mooring and a nowcast model. 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.

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. We plan to extend this capability to non-RA stations operated by local providers in 2019, as an opt-in service contingent on provider engagement.

Data access services: NANOOS serves observing and modeled data via IOOS recommended services. These include two THREDDS server and one Hyrax server for model output, historical observing data and data synthesis products (Hyrax server provides model output only); and an IOOS 52North SOS server for recent and near-real-time fixed-location observing data. These services are registered with the IOOS Registry. System improvements in CY 2018 focused on development work on a test ERDDAP server with the goal of serving the same data currently available on the IOOS 52 North SOS, supporting QARTOD flags, and serving historical data from NANOOS providers, non-RA local providers, and federal sources; this server is expected to be made public by June 2019. An additional NANOOS server hosted at OSU is providing an increasing number of datasets, recently including OOI datasets for public use. Glider and HFR data are distributed via IOOS supported thematic DACs. In addition, NANOOS hosts standard-compliant OGC WMS and WFS services via GeoServer.

Catalog registration: Three NANOOS WAFs (Web Accessible Folders) at http://data.nanoos.org/metadata/ continue to host metadata records registered at https://registry.ioos.us, currently providing 78 metadata records to the IOOS Catalog (https://data.ioos.us/organization/nanoos). The extent, comprehensiveness and currency of these records continues to be refined and expanded to match IOOS catalog capabilities. In addition to these IOOS Catalog records provided directly by NANOOS, 15 additional metadata records affiliated with NANOOS are also available in the Catalog, at https://data.ioos.us/dataset?q=NANOOS

Common data formats: All data served by NANOOS via IOOS recommended services (see #4) are 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 (Glider DAC and HFR DAC) and to NCEI.

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 continued to submit data for NCEI archiving from the NANOOS-supported OHSU-CMOP SATURN network. The NANOOS DAC automatically stages monthly incremental archive updates on the 10th of the month at http://data.nanoos.org/ncei/ohsucmop/, and these are pulled by NCEI by the 15th of the month. Archival files are in the NCEI NetCDF Templates v2.0 format and follow ACDD and CF conventions. In CY2018, the metadata conventions, file segmentation and archival procedures developed for this NANOOS dataset were compiled into an internal document that will be used for application in 2019 to other NANOOS in-situ datasets. Archiving plans and expectations were discussed with NANOOS monitoring platform operators at the annual NANOOS PI meeting in August 2018. We have contacted NCEI to initiate archiving of nearshore elevation profile data, and plan to formally initiate the process with NCEI for all NANOOS Fixed-location Sensor Platforms in early 2019; the date for completion will vary depending on issues that arise in discussions with NCEI.
In addition, all CY 2018 IOOS supported glider data from NANOOS were archived with NCEI via submission to the Glider DAC. Data from the operational OSU Trinidad Head Glider are submitted to the DAC by CeNCOOS, as part of a collaboration with NANOOS that supports and co-funds this glider.

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):

See table for milestones [Allan]

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 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 to facilitate consistent work efforts, synergy across the committees, and improvements to product development and

enhancements. Activities for this 2018 period included: 1) multiple weekly NANOOS DMAC and UPC teleconferences; and 2) Attendance at the annual NANOOS governing council and all PI meeting on August 16-17, 2018.

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. During this period, NANOOS released one major update. V6.1 released in June, included the release of two new web apps: Beach View and Surfers Apps. The Beach View web app provides easy access to a suite of beach/ocean and weather-related information that can be used by the public intent on visiting and recreating on the coast. Simple synoptic scale information that includes current observations of air and water temperature, winds and waves may be easily selected at a click of a button for multiple stations along the coast. These datasets are aided by access to weather related forecasts of air/water temperature and wind speeds, as well as forecasts of waves. The site also provides access to a suite of webcams distributed along the coast that may be used to visualize actual conditions at the beach.

The Surfers app is designed for surfers wishing to engage in more detailed information at sites along the NANOOS coastline. The site contains many of the same capabilities as described previously for Beach View, but now including more detailed information of wave characteristics (primary/ secondary swells and periods, combined waves, wind waves, as well as winds, tidal currents, tidal height, and water temperature)

During this period updates were also implemented in the Climatology web app that included updates to all model overlays and climate indices. Updates were also implemented to the buoy climatologies due to changes in NDBC data sampling and reporting that broke our codes.

Finally, a major update to the Tsunami web app was released during this period that reflected the completion of a new build-your-own customized tsunami evacuation brochure (Figure 6). The tool, funded separately by DOGAMI (Allan is a PI with NANOOS), essentially allows the user to develop their own tsunami evacuation brochure for any location along the Oregon coast. In time, we anticipate expanding this capability to the Washington coast.

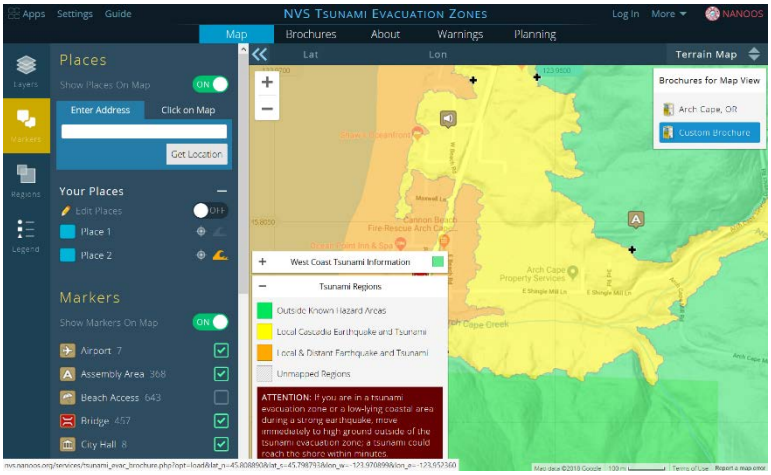

Figure 6. NVS Tsunami Evacuation Zones web app and the new 'Custom Brochure' capability (top right box) built into the portal.

NVS Mobile App: NANOOS released a beta (v1) version of its TsunamiEvac mobile phone app for both Android and iOS version (Figure 7). The phone app has subsequently been tested and problems identified. NANOOS software engineer Troy Tanner and his team are currently working on corrections to the phone app. At the time of writing, a v2 beta test version of TsunamiEvac was released and is currently being tested. We anticipate a public release of this app early in 2019.

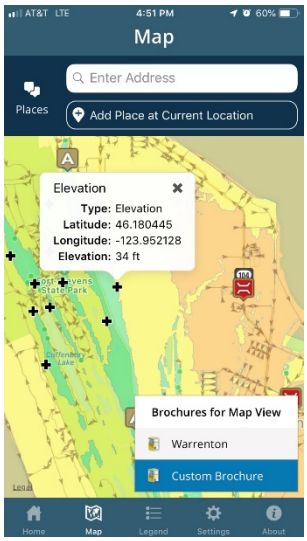

Figure 7. Screenshot of v2 of the TsunamiEvac smartphone app for iOS. Functionality built into the app are broadly the same as the web portal, with the added benefit of being able to locate oneself in the tsunami zone.

e) NANOOS Education and Outreach Subsystem:

See table for milestones [Wold, Mitchell-Morton]

NANOOS Education and Outreach efforts 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 were largely completed by NANOOS staff Newton, Sprenger, Mitchell-Morton and Wold, with support from DMAC and UPC subsystems and many NANOOS member collaborators. Newton, Sprenger, Mitchell-Morton, and Wold were active members of the weekly DMAC/UPC tag-up conference calls, regularly providing support and feedback on UPC and DMAC developments. Mitchell-Morton and Wold continued participation with IOOS E&O calls as they occur. As of 30 June, Sprenger moved on from NANOOS.

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.

- For the eighth year, NANOOS E&O partnered with WA Sea Grant to co-instruct the NOAA Science Camp's Junior Leadership Program's research project.
- Sprenger updated NANOOS lesson plans for use of NVS in classrooms

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.

- Mitchell-Morton and Wold represented NANOOS with NVS demonstrations and the "Great Build a Buoy Challenge" at the NOAA Open House on June 8.
- Newton presented on ocean acidification, ocean observing, and NANOOS to the Northwest Women in Boating Association in Seattle, WA, on July 16.
- NANOOS conducted a web user survey in August to improve understanding of users' backgrounds, and their familiarity and satisfaction with the NVS data portal, receiving 200+ unique responses.
- Mitchell-Morton and Sprenger attended the annual Seattle Aquarium Discover Science Weekend, November 10-11, with over a thousand visitors each day. The exhibit by NANOOS, which included a "Great Build a Buoy Challenge" and NVS demonstrations, was very popular.
- Wold demonstrated the new NVS Surfers app to the Surfrider Cascadia Chapter Leadership Conference in Lake Crescent, WA, on Oct 20-21.
- Wold engaged with the recreational boating community, presenting at various yacht club and boating organization meetings to showcase the NVS Boaters App while gaining their direct feedback. Wold gave a seminar to the Semiahmoo Yacht Club and local US Power Squadron in Blaine, WA, on Nov 7.
- NANOOS had an exhibit table during the Pacific Coast Shellfish Growers Annual Conference in Blaine, WA, Sept. 18-22; Mitchell-Morton demonstrated and gathered feedback on NVS, IPACOA, and GOA-ON web portals from the shellfish growing community.
- Mitchell-Morton and Wold continued to update content on the NANOOS portal.
- NANOOS maintained Facebook and Twitter accounts, each with growing audiences. NANOOS also has a growing audience for its bimonthly newsletter, the "NANOOS Observer."

f) <u>NANOOS Administration:</u>

See table for milestones [Newton]

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 16-17, 2018 at the Washington State University – Vancouver campus. Newton led the PI meeting discussions and Martin served as Chair of the NANOOS Board during the GC meeting. This year, IOOS Director Carl Gouldman and IOOS Association Director Josie Quintrell joined us. Over 20 attendees from diverse NANOOS member institutions were present to review progress to date as well as plans for the upcoming year. PIs stayed on for a second half-day to discuss and present observing and modeling results and issues.
- New members of the NANOOS Governing Council include Rockland Scientific and the Salish Sea Institute of Western Washington University. The NANOOS Executive Council has no current vacancies.

Additional coordination and representation included:

- Newton attended the IOOS Executive Committee Strategic Meeting with the IOOS PO Leadership on 14-15 August in Chicago. She also attended the annual fall IOOS Program meeting on 18-20 September, in Annapolis, Maryland. Additionally, Newton served on the IOOS Association Executive Committee and attended IOOS Program and IOOS Association calls as available.
- Newton represented NANOOS and IOOS at the Capitol Hill Ocean Week and at the 4th Symposium of the Effects of Climate Change on the World's Oceans (ECCWO), both held in Washington, D.C. during 4-8 June 2018. Newton was invited by the National Marine Sanctuary Foundation to speak on a panel at the Capitol Hill Ocean Week. She gave a talk on NANOOS coastal ocean observing results at ECCWO, with implications of how warming and acidification may have unique effects on coastal upwelling systems due to dramatic shifts between upwelling and downwelling conditions.
- Newton contributed NANOOS updates on oceanographic conditions in the Pacific Northwest for the NOAA WestWatch webinar series on July 24, September 25, and November 27, along with the other two west coast RAs.
- Newton was invited to participate in the Ocean Observing Initiative workshop on the Deep Ocean in Seattle 27-29 August. She was a member of the Steering Committee for that workshop. She presented on NANOOS to stimulate development of realistic ideas and concepts that can be turned into proposals to carry forward use of OOI and extended observations.
- Newton prepared a talk that was delivered by Dr. Wiley Evans (Hakai Institute) at the Pacific Coast Shellfish Growers Association conference 18-20 September in Bellingham, WA, on the IOOS OTT "Headlights" work to improve OA observation systems to support shellfish growers.
- Newton attended the U.S. West Coast Biological Data Workshop put on by NANOOS, CeNCOOS, and SCCOOS on November 7-9 in Santa Cruz, CA.

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

- Jack Barth participated from June 13-14, 2018 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, Barth provides both scientific expertise as they communicate the U.S. experience with IOOS and operational ocean observing efforts that are part of the unique hybrid nature of ONC.
- Newton, a member of the International Science Advisory Committee for the Canadian Marine Environmental Observation Prediction and Response (MEOPAR) program, provided input and review support throughout the period. She helped review proposals for the CIOOS effort.
- Newton, a member of the Science Advisory Team for the Joint European Research Infrastructure in the Coastal Ocean (JERICO), reviewed proposals fostering international collaboration and advised JERICO on ocean observing practices on 26-28 June in Rome, Italy.
- Newton is on the Program Committee for the OceanObs'19 meeting to be held in Honolulu in September 2019. She participated in several teleconference calls and a site visit in September 2018, with follow-on meetings at the University of Hawaii and Western Pacific Fisheries Council to develop indigenous participation in the conference.

- Newton represented IOOS on the Global Ocean Acidification Observing Network Executive Committee calls and activities. Newton was involved in the Biology Working Group and brought NANOOS capabilities for GOA-ON's web and data portal. She attended three meetings during this period:
    - GOA-ON Executive Committee meeting on June 28-31 in Sopot, Poland, where she briefed on the Implementation Strategy
    - GOA-ON Data Training workshop on October 22-26 in Monaco, where she was a trainer.
    - GOA-ON North American Hub meeting on October 17-18 in Victoria, Canada, where she helped plan the agenda and introduced GOA-ON and its data portal. This first meeting of the NA Hub brought together ~30 scientists from Canada, Mexico and the U.S.

Additional NANOOS coordination:

- Newton participated in NOAA 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, the West Coast Ocean Data Portal, and "OA Round Tables" organized by NOAA PMEL and NWFSC.
- Newton continued to fill the Research seat as a member of the Olympic Coast National Marine Sanctuary Advisory Council.
- Barth serves on the Oregon Ocean Policy Advisory Council's (OPAC) Scientific and Technical Advisory Committee (STAC) responsible for providing expertise on ocean issues including the implementation and monitoring of Oregon's marine reserves and ocean acidification monitoring efforts.
- Barth serves as the Co-Chair of the new Oregon Ocean Acidification and Hypoxia Coordinating Council, enacted as a state law in fall 2017. The OAH Council submitted their first biennial report to the Oregon legislature in September 2018 that included recommendations for action on dealing with ocean acidifcation and hypoxia.

Presentations and Publications acknowledging NANOOS support: underline indicates NANOOS PI

Presentations:

Barth, J. A., F. Chan, S.D. Pierce. Changes in coastal ocean hypoxia off Oregon as influenced by multiple, climate-sensitive drivers. The Effects of Climate Change on the World's Ocean, Washington, DC, June 2018.

Barth, J. A., Oregon's dynamic ocean: Some insights from summer 2018 and recommendations for the future. Cape Perpetua Land-Sea Symposium, Yachats, Oregon, November 2018.

Haller, M. Vortex shedding from rip currents via remote sensing, 8th International Symposium on Environmental Hydraulics (ISEH 2018), Notre Dame, IN, June 6, 2018.

Haller, M., R. Pittman. Wave imaging marine radar at Newport, OR, *NANOOS Annual PI Meeting*, Vancouver, WA, August 17, 2018.

Kaminsky, G. Overview of Washington Coastal Erosion. Washington Coastal Marine Advisory Council Meeting. Aberdeen, WA, September 26, 2018.

Kaminsky, G. Overview of Washington Coastal Erosion, Coastal Marine Resources Committee Summit. Ocean Shores, WA, October 26, 2018.

MacCready, P. Challenges in Realistic Modeling of Complex Estuarine-Fjord Systems. NSF Coastal Ocean Modeling Workshop, Raleigh, NC, July 2018.

MacCready, P. Mechanisms and trends in ocean transport of nutrients and low DO water to the Salish Sea and Puget Sound, WA Dept. of Ecology Nutrient Reduction Forum, Olympia, WA July 2018.

MacCready, P., S. Siedlecki, R. McCabe, N. Banas, H. Stone, E. Brasseale, B. Ovall, D. Darr, LiveOcean: A daily forecast model of currents and water properties for the Pacific Northwest coast and Salish Sea, Puget Sound Ecosystem Monitoring Program (PSEMP) Workshop, Tacoma, WA, July 2018

MacCready, P., S. Siedlecki, R. McCabe, Processes Affecting Water Properties in Willapa Bay. Eastern Pacific Ocean Conference, Mt. Hood, OR, September 2018.

MacCready, P. Thoughts on Coastal Ocean Forecasting: Differences from weather, and differences from science. Mooers Symposium on Prediction, Mt. Hood, OR, September 2018.

MacCready, P. The Estuarine Circulation of the Salish Sea. Inst. Of Ocean Sciences (IOS) Sydney, BC, September 2018

MacCready, P. How to Make a Simple Model of a Fjord? Physics of Estuaries and Coastal Seas (PECS) Conference, Galveston, TX, October 2018.

Murdock, C. Interannual nearshore morphological change analysis of the Columbia River Littoral Cell (CRLC). MS thesis presentation. P. Ruggiero, Chair.

Newton, J. Understanding how extreme conditions and ocean acidification uniquely influence coastal upwelling zones: A case study from the Pacific Northwest U.S. The Effects of Climate Change on the World's Oceans, Washington, D.C., June 5, 2018.

Newton, J. Predicting, Detecting, and Preparing for Increasing Acidification. Capitol Hill Ocean Week Panel, Washington, D.C. June 6, 2018

Newton, J. The Effects of Ocean Acidification on Local Waters. Northwest Women in Boating July meeting, Seattle, WA, July 10, 2018

Newton, J. Puget Sound basin dynamics: what a concentration actually represents, mechanisms for nutrient fluxes, WA Dept. of Ecology Nutrient Forum, Olympia, WA August 22, 2018.

Newton, J. Northwest Association of Networked Ocean Observing Systems. Deep Ocean Observing Workshop, Seattle, WA, August 27, 2018.

Newton, J. and Evans, W. NANOOS – Progress on measuring ocean acidification variables with data delivery to support shellfish aquaculture. Pacific Coast Shellfish Growers' Association Conference and Tradeshow, Bellingham, WA, September 19, 2018.

Newton, J. The Global Ocean Acidification Observing System and its Data Portal. GOA-ON North American Ocean Acidification Regional Hub Workshop, Victoria, CA, October 16 2018.

Newton, J. and M. Poe. The Olympic Coast as a Sentinel Site for Ocean Acidification. UW School of Oceanography Seminar, Seattle, WA, November 14, 2018.

Pasmans, I. and A. Kurapov. Ensemble-variational data assimilation in the coastal ocean circulation model off Oregon-Washington (at the US West Coast)

Pollard, M. Exploring temporal and spatial sandbar variability on the southwest Washington coast. MS thesis presentation. P. Ruggiero, Chair

Publications:

Barth, J. A., S. E. Allen, E. P. Dever, R. K. Dewey, W. Evans, R. A. Feely, J. Fisher, J. P. Fram, B. Hales, D. Ianson, J. Jackson, K. Juniper, O. Kawka, D. Kelly, J. M. Klymak, J. Konovsky, P. M. Kosro, A. Kurapov, E. Mayorga, P. McCready, J. Newton, R. I. Perry, C. M. Risien, M. Robert, T. Ross, R. K. Shearman, J. Schumacker, S. Siedlecki, V. L. Trainer, S. Waterman, and C. E. Wingard, 2019. Better regional ocean observing through cross-nation cooperation: A case study from the Northeast Pacific. Frontiers in Marine Science, submitted.

Honegger, D.A., M.C. Haller, and R.A. Holman, High-resolution bathymetry estimates via X-band marine radar: 1. Beaches, revision submitted to Coastal Engineering, Nov. 2018.

Pasmans, I., A. L. Kurapov, J. A. Barth, P. M. Kosro, and R. K. Shearman, 2018: Why gliders appreciate good company: glider assimilation in a 4DVAR system with and without surface observations, JGR-Oceans, submitted.