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

NOAA Award: NA16NOS0120019 Reporting period: 12/01/2021 to 05/31/2022

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 the 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 FY20 period (= Y5 of this award; Y14 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 and expand 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 enhance 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), and 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.**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.
6) **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.
7) **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.
8) **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.

During FY20, NANOOS has the following additional tasks in our award letter. Tasks 1-4 were "add to base" enhancements and are thus covered within the original NANOOS objectives reporting here; the remaining tasks are presented individually within this report. Tasks 5, 13, and 14 are from IOOS; tasks 7-11 are from the NOAA Ocean Acidification Program, tasks 6 and 12 originate from other NOAA offices coordinated via

IOOS.

5. $250,000 to further HABs understanding and prediction
6. $160,000 to fund the Columbia River extension (Salish Sea model)
7. $123,895 for NANOOS NOA-ON NH-10 observing (OSU)
8. $90,000 for GOA-ON data portal and support for GOA-ON Co-Chair (Newton, UW)
9. $80,000 for ocean acidification observing in support of Pacific coast shellfish growers, "Headlights Project"
10. $66,291 for NANOOS NOA-ON Cha'ba observing (UW)
11. $13,000 for NANOOS NOA-ON OA Mooring Test-beds (UW)
12. $108,000 transfer to CRITFC to continue the observations, modeling, and DMAC activities
13. $16,500 for biological data stewardship
14. $7,500 for OceanHackWeek

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 on progress for: a) Observations (shelf, estuaries, shorelines, and currents); b) Modeling (estuaries and shelves); c) Data Management and Communication (DMAC); d) User Products; e) Education and Outreach; and f) Administration.

Table 1. NANOOS Milestones for FY20; Y5 specific milestones are in bold.

Area	Y5 Award = Y14 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 CB-06; 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 **-Re-establish Columbia glider; deliver data via NVS** **-Begin La Push glider operations** **-Support OA observing as an aid to Pacific coast shellfish growers; deliver data to IPACOA** -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
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** **-Support OceanHackWeek**

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 effective 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 public relevance 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. **-Coordinate a west-coast wide regional collaboration team workshop with NOAA West (Y4)**
Accountability	-Submit required IOOS progress reports and respond to other requests. -Comply with 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 Observations*:**

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

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

The Washington Coast buoy observation program continued the work of maintaining and operating two real-time moorings 13 miles NNW of La Push, Washington. The spring 2022 Coastal Buoy deployment cruise occurred May 3, 2022 - May 6, 2022. Work was conducted aboard the R/V Robertson out of La Push, WA. The cruise included 3 mooring deployments (Summer Cha'Ba, NEMO-Subsurface profiling mooring, and the Environmental Sampling Processor (ESP) mooring), and the deployment of NANOOS seaglider SN 236. CTD casts were conducted at the Cha'Ba site, and at stations through the Strait of Juan de Fuca. Because the winter Cha'Ba mooring broke away from its anchor in February 2022 and was subsequently recovered the same month on an emergency recovery charter of the F/V Alyeska, no moorings were recovered during this cruise.

The summer Cha'Ba and NEMO-SS moorings are deployed in 100m of water and collectively support instrumentation for measuring temperature, salinity, dissolved oxygen, water current, chlorophyll, and pH from near the seabed to the sea surface, in addition to surface water and air pCO_2 and meteorological variables. The ESP mooring supports an Environmental Sampling Processor, supporting analysis of certain organisms and biotoxins present in the water. All three moorings include telemetry to shore for near-real-time data analysis and publishing.

Task 10: Support collection of OA data from La Push buoys with NOAA OAP funding *[Manalang, Mickett, Newton]*

This element was completed prior to 1 December 2021.

Task 11: Support NOA-ON OA Mooring Test-beds *[Mickett, Newton]*

This element was completed prior to 1 December 2021.

Shelf Glider Observations:
-Maintain N CA shelf glider transect; deliver data via NVS [Barth]
-Bring all data QA/QC to meet Certification standards [Barth]
This element was completed prior to 1 December 2021.

Re-establish Columbia glider; deliver data via NVS *[Barth/Seaton]*
This element was completed prior to 1 December 2021.

La Push glider *[Lee]*
This element was completed prior to 1 December 2021.

Oregon Shelf Mooring Observations:
-Maintain Coos Bay buoy; deliver NRT data streams via NVS [Hales, Kosro]
-Bring all data QA/QC to meet Certification standards [Kosro, Hales]

Task 7: Support collection of OA data from CB-06 buoy with NOAA OAP funding *[Hales]*
The CB06 mooring off Coos Bay, Oregon has been deployed since June 2017. The mooring measures water temperature at 11 depths, horizontal current at more than 40 depths (2 m separation), salinity near surface, and pressure at 2 depths, as well as surface meteorological data. In addition, the MAPCO2 system measures O_2, pCO_2 and pH. A subset of the near surface data and ADCP currents are sampled and telemetered in near-real time back to shore. A clear pattern is being established with more quiescent dynamics in wintertime, with O_2 and pCO_2 values near atmospheric equilibrium, and pH_t staying broadly within a range of 8.0 - 8.1. In contrast, summer conditions show large dynamic ranges in all conditions, with O_2 ranging from far below saturation (<175 µmol/kg) to far above (> 450 µmol/kg), pCO_2 from <250 - >1000 µatm, and pH <7.7 - >8.3.

No CB-06 activities took place using NCE funds between Dec 2021 and may 2022.

Task 9a: Support OA observing as an aid to Pacific coast shellfish growers; deliver data to IPACOA
[Hales]
Hales has obtained a low-quality highly-smoothed data record from Carlsbad AquaFarms for the 2018 year, which is part of an in-progress ms and a chapter in K. Shipley's (SIO) PhD dissertation. Hales has notified Shipley and Martz (SIO PI) that this data will be submitted to IPACOA. Hales has processed low-quality data from Hog Island Oyster Company's Tomales Bay facility for the year 2014, and is developing the metadata necessary for submission to IPACOA. A 6-year record of data from the Whiskey Creek Shellfish has been published in Fairchild and Hales, 2021, and is ready for submission to IPACOA. Colleague W. Evans has assembled long records of OA-relevant data from Burke-o-Lators in Alaska and British Columbia. Evans is leading a synthesis effort to merge these data with those from Taylor Shellfish's Quilcene hatchery (see 9b), and a high-quality record from Hog Island's Humboldt Bay hatchery in collaboration with colleagues J. Abel (HSU) and J. Tyburczy (CA SeaGrant). These will be the subject of a presentation at the upcoming Lima Oceans in a High CO2 world (abstract accepted).

Task 9b: Support OA observing as an aid to Pacific coast shellfish growers; deliver data to IPACOA
[Carter]
Via UW technician, Mr. Julian Herndon, we continued to provide ongoing technical assistance for the Burke-o-lator (BOL) seawater chemistry analytical system at Taylor Shellfish Hatchery (TSH). The BOL

system sent to Oregon State University for repairs has been repaired and is ready to be re-installed. Following a long delay necessitated by OSU campus closure due to COVID, we discovered a new computer was needed to operate the system; that computer is ready and soon to be installed, such that this system can be back online. Mr. Herndon continues to make liquid standards for TSH and another BOL system from the Washington State network (from Willapa Bay) to use during BOL operation. This year will definitely have data gaps, due to the above challenges. The deployment of the ACDC was never possible due to project partners not having supplied the repaired sensors to support the final stages of this technology transfer project, due to their own lengthy run of pandemic closure and personnel turnover challenges.

Northern Oregon to Central Washington Shelf Observations:

-Maintain Columbia R. buoy; deliver NRT data streams via NVS [Seaton]
-Bring all data QA/QC to meet Certificasandards [Seaton]

SATURN-02 is 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 on May 20, 2022. Parameters measured are (a) wind speed, direction and gust, air temperature, barometric pressure and PAR; (b) water velocity profile; and (c) the scalar water parameters: (in-situ) temperature, salinity, dissolved oxygen/oxygen saturation, chlorophyll, turbidity, CDOM, and phytoplankton health/quantum yield. Scalar water measurements (except temperature) are made through single at-surface sensors and a multi-level pumping system. Levels measured are 1, 6, 11, 16, 21 and 35m depth.

Real time data from SATURN coastal stations are displayed on NVS while the station is deployed. CMOP also provides access to SATURN long-term datasets via a newly established ERDDAP data server, including QA flagging. CMOP stations are expected to be the next batch of NANOOS stations integrated into the NANOOS centralized ERDDAP server for delivery to NDBC.

Task 5: HAB observations, understanding, and prediction *[McCabe, Osborne, MacCready, Callender/King, Newton]*

[Osborne]: UW Olympic Natural Resources Center, in collaboration with the ORHAB (Olympic Region Harmful Algae Bloom Partnership) Steering Committee, which includes representation of the four Coastal Treaty Tribes (Hoh, Quileute, and Makah and the Quinault Indian Nation), serves as a primary data source for state and tribal shellfish managers and the PNW HAB Bulletin. The first phase budgetary allocation of $40,000 ($10,000 a piece for each of the four tribes) has been fully allocated, as has more than half of the second phase. These funds have been used to enhance the capacity of each tribe to undertake offshore sampling, over-and-above the weekly shore-side sampling they do as part of ORHAB's longitudinal monitoring program. At this point in the contract offshore sampling activities and equipment needs for each tribe have been purchased and distributed to each tribal lab. This includes new microscopes that will allow fluorescent analysis for enhanced taxonomic identification, and equipment upgrades necessary to process the higher volumes of samples these new activities require. Some tribes have already initiated offshore sampling operations this year that are drawing on their allocations, others are still working on the staffing and platforms needed to bring them up to independent nearshore sampling. A welcome synergy for increasing enhanced tribal near-shore sampling platforms has come with a collaborating Technology Transfer grant that UW APL, ORHAB and the tribes are currently partnering on. This new AAUV technology has introduced the pivotal role of using remote sensing vehicles and having tribal labs available to process the samples and host the remote vehicle missions. The time extension for the first phase funding and the additional second round was critical in helping make this a success while accommodating the independence of each tribe.

[MacCready]: This element was completed prior to 1 December 2021.

[King]: Daily coordination and communication for partners continues as our partners take samples during the COVID 19 pandemic. We fielded 16 emails or calls from participants regarding data recording, phytoplankton identification and other program questions. The alert provided to the Washington State Deparment of Health between December 1, 2021 and January 1, 2022 was related to a dock being out of commission and therefore samples could not be taken.

[McCabe]: PI McCabe has continued to collaborate with Barbara Hickey (UW School of Oceanography) and Vera Trainer (NOAA NWFSC) to produce the Pacific Northwest Harmful Algal Blooms Bulletin (PNW HAB Bulletin) for coastal shellfish managers. A total of eight PNW HAB Bulletins are typically produced each calendar year, with nominally four Bulletins during spring razor clam digs and another four during fall razor clam digs.

McCabe, Hickey, and Trainer produced four PNW HAB Bulletins to support coastal shellfish managers during the reporting period. These included the 7-Apr-2022, 21-Apr-2022, 13-May-2022, and 26-May-2022 Bulletins. Since Washington Department of Fish and Wildlife managers ended their public recreational razor clam season early on 7-May-2022, the final two spring Bulletins specifically targeted digs conducted by the Quinault Indian Nation (and supported Oregon Department of Fish and Wildlife shellfish managers as well). All PNW HAB Bulletins issued during spring 2022 received a "low" risk assessment rating, thanks to the low *Pseudo-nitzschia* abundances observed in the region and overall cool ocean conditions. Prior to the final Bulletin on 26-May-2022, *Pseudo-nitzschia* cell concentrations increased dramatically to levels beyond established toxin testing thresholds (as high as 119,000 cells/L of large morphology cells in northern Oregon). No shore-based toxin results were available for the 26-May Bulletin, but an analysis of conditions suggested that a large toxic *Pseudo-nitzschia* bloom was unlikely at that time. Subsequent analysis of samples collected at sites off both northern OR and WA indicated that domoic acid was undetectable, confirming the "low" risk rating. Results from the ESP mooring off La Push, WA, also continue to be incorporated into the temporally overlapping Bulletins. The PNW HAB Bulletins are made publically available on both the ORHAB (https://orhab.uw.edu/pnw-hab-bulletin/) and NANOOS (http://www.nanoos.org/products/habs/forecasts/bulletins.php) websites.

FY19 Task 17: HAB ESP deploy *[Mickett, UW]*
Originally planned for the spring of 2021 but delayed due to the inability of NOAA PIs to access their NOAA NWFSC lab, this was rescheduled to the spring of 2022. Numerous preparations for this deployment were carried out over the winter and early spring of 2022 by APL and partners (NWFSC, MBARI, CCEHBR), with the successful deployment of the ESP mooring adjacent to the Cha'Ba and NEMO-subsurface moorings on May 3rd. As of the end of the reporting period (May 31, 2022), the ESP is performing perfectly with real-time domoic acid observations posted on the NANOOS-hosted Real-time HABs website (http://www.nanoos.org/products/habs/real-time/esp_now/hab_measurements.php). Sampling is scheduled to continue through June 23rd. We have been issuing weekly email summaries of the ESP measurements as well as contextual observations to a Pacific Northwest HAB distribution list as well as providing observations for the HAB Bulletin.

ESTUARIES

Puget Sound Buoy Observations:

-Maintain Puget Sound estuarine moorings; deliver data via NVS [Manalang]
-Bring all data QA/QC to meet Certification standards [Manalang]

The Northwest Environmental Moorings (NWEM) program continues to maintain six Oceanic Remote Chemical Analyzer (ORCA) moorings and a Bellingham Bay Se'lhaem buoy. Aging winch systems have contributed to downtime of water column profiling equipment on ORCA buoys during this period, but the NWEM team continues to adapt and repair failed systems, and has implemented qualitative tracking systems to better evaluate ORCA uptime, data availability, and maintenance activities.

We continue to work with A. Sutton, S. Alin, and R. Feely (NOAA PMEL Carbon Group) deploying pCO_2 systems on Twanoh and Dabob Bay buoys and collecting water samples for system calibration. Data continue to be made available through NANOOS NVS and through the NWEM ORCA server.

Washington State Estuarine Observations:

-Maintain US-Canada ferry-box; deliver data via NVS [Krembs]
-Bring all data QA/QC to meet Certification standards [Krembs]
Cross Border Ferry Monitoring, Environmental monitoring

Victoria Clipper: Ecology has capitalized on a long standing collaboration with Victoria Clipper vacation to allow the installation of en route flow-through sensors. In the last two years, Covid travel restrictions and declining passage numbers have severely affected Victoria Clipper runs between Canada and the US. We had consequently less opportunity to work with Clipper staff due to company layoffs, which also has slowed our progress of implementing an improved sensor system on the newer Vessel Victoria Clipper VI. Fortunately, the Victoria Clipper has recently resumed some operation between Victoria and Seattle, but with a reduced operating schedule as a result of high fuel cost and low occupancy.

We have been using this window of opportunity effectively for one-on-one conversations with ship engineers and made important decisions on how to physically install the new pumped system on the ferry. The current configuration includes a thermosalinograph and a pCO2 sensor running in an automated mode and relaying data daily to a publicly accessible database.

We received the Pro-Oceanus pCO2 Pro-ATM sensor on May 16th 2022. This instrument will be used to measure pCO2 in air and in surface seawater along the route between Seattle and Victoria. Similar underway sensing has been implemented on ferry routes in British Columbia. We are now integrating this sensor with our electronics system. A dedicated Raspberry Pi will receive ascii data from the pCO2 Pro-ATM sensor, and integrate measurements with contemporaneous position data collected by a separate GPS receiver. This integrated dataset will be transmitted to a cloud data service, where it can be accessed remotely and potentially run through automated QC procedures.

Specifically we met with ship engineer on 6/8/2022 to arrive at technical solutions for the remaining plumbing adjustments and mounting of our equipment:

- Mounting the heavy pump on existing aluminum brackets and struts in the starboard forward hull compartment 2m above the water line.
- Choosing material of plumbing lines to the sensors.
- Deciding on the location and configuration of an in-line bubble trap and and bypass.
- Deciding on parallel ports for additional sensors that can be used by collaborators.

- Mounting of the electronic box and power supply for the pump controller, power backer, sensor electronics, telemetry and 230 V power supply.

Configuration and improvement to the pump water effluent and an air intake for atmospheric pCO2 measurement in conjunction with water pCO2 measurements. Two potential options need clearance from Victoria Clipper passenger safety board option:

- Building a new hull penetration above the water line, (desired),
- Tapping into an existing effluent from a deck drain.

Additional decisions:

- Removal of an old existing pump next to the sea chest in the engine room.

Columbia River Estuarine Observations:

-Maintain Columbia R. estuarine moorings; deliver data via NVS [Seaton]
-Bring all data QA/QC to meet Certification standards [Seaton]

The NANOOS supported estuarine stations that are maintained on a permanent or seasonal basis are SATURN-03, SATURN-04, SATURN-07, SATURN-09, CBNC3, Elliott Point and Woody Island. The previously occupied SATURN-01 station, located on the Astoria-Megler bridge platform, has become impossible to reoccupy due to the relocation of a major cormorant colony to the location, and changes in Oregon Department of Transportation regulations. All stations except CBNC3 have real-time telemetry. All but CBNC3, Elliot Point and Woody Island (which currently only measure salinity and temperature, or only temperature in the case of Woody Island) are interdisciplinary (physics and biogeochemistry). Each of the stations is designed to capture specific features of the estuary. SATURN-09 was redeployed in January after servicing. SATURN-07 is on-station after being recovered for servicing in early 2022. The Elliott Point buoy was recovered in May and will be redeployed in summer or fall 2022.

Real time data from SATURN coastal stations are displayed on NVS. CMOP also provides access to SATURN long-term datasets via a recently deployed ERDDAP server. Data is subject to QA/QC, which is included in data submitted to NCEI via NANOOS, and included in the ERDDAP server. Nitrate observations have been successfully restored at SATURN-03, and calibration of existing nitrate data through laboratory analysis of archived water samples is currently being planned.

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 (Research Technician) at the South Slough National Estuarine Research Reserve (SSNERR) in Coos Bay, OR. South Slough Reserve continued operation of a network of moored estuarine water quality observing stations as part of the NERRS System-Wide Monitoring Program with additional support provided by NANOOS. There are four real-time water quality monitoring stations located along the salinity gradient of the South Slough estuary that provided continuous water temperature, salinity, dissolved oxygen, pH, turbidity, and water level measurements every 15 minutes over the period 12/01/21 –05/30/22. Tom's Creek weather station provided measurements of air temperature, relative humidity, barometric pressure, and wind speed/direction. Weather station sensors and data logger were swapped in March 2022 for calibrated instruments to complete requirements for annual (sensor) to 5 year (logger) calibration protocols.

Telemetry transmissions were continuous for Winchester Arm water quality and Tom's Creek weather platforms. The Charleston Bridge, Valino Island and Elliot Creek water quality stations continued data collection, but telemetry is offline in preparation for installation of new data collection platforms with Yellow Springs Instruments Turnkey Storm3 systems; purchases for these telemetry systems were completed Spring 2022. In collaboration with the Confederated Tribes of the Coos, Lower Umpqua and Siuslaw Indians (CTCLUSI), SSNERR maintains telemetry for the North Spit BLM water quality station, located in the lower Coos estuary with data available through NVS. Monthly instrument deployments and retrievals, station maintenance, and data download, quality assurance/control, and management were completed for the water quality and weather stations following NOAA NERRS Centralized Data Management Office.

In addition to the lower Coos Bay CTCLUSI station, South Slough expanded the network of water quality stations into the upper Coos estuary, which includes three stations located at Isthmus Slough, Catching Slough, and Coos River. Data collection at the 3 Coos estuary locations was continuous for the reporting period. The Reserve completed purchase of a NOAA Nile radar water level sensor for a tide gauge at Hidden Creek, South Slough and old infrastructure associated with an acoustic sensor was removed in May 2022.

The SSNERR water quality and weather stations provide real-time data for five shellfish growers in the Coos estuary. The South Slough 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 environmental modeling analyses to characterize drivers of eelgrass declines. The Reserve's current Margaret Davidson Fellow (Taylor Dodrill) is utilizing water quality data for her research on phytoplankton communities and prediction of HABs, including monthly sampling at the water quality/NANOOS stations. The Reserve education and science programs used water quality data for outreach on tidal marsh metrics for evaluating wetland resilience to sea level rise and are developing a SWMP water quality exhibit for the Reserve Visitor Center.

SSNERR is currently recruiting applicants for a part-time Fall 2022 SWMP/NANOOS water quality intern that will assist the science team with monthly field and lab work associated with water quality instrument exchanges, cleanings, and calibrations.

SHORELINES

Washington Shoreline Observations:

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

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

This element was completed prior to 1 December 2021.

Oregon Shoreline Observations:

-Maintain shoreline observations in OR; deliver data via NVS [Allan]

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

This element was completed prior to 1 December 2021.

Nearshore Bathymetry Observations *[Ruggiero]*

-Maintain bathymetric observations in WA and OR; deliver data via NVS

-Bring all data QA/QC to meet Certification standards

This element was completed prior to 1 December 2021.

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.

During this period, NANOOS scored an HFR Net Performance metric for the 2 main reporting quarters (Q2 and Q3 of FY2022) of 81% and 79% respectively (https://hfrnet.ucsd.edu/diagnostics/), ranking 4th and 2nd respectively among the nine measured regions. Matthew Sroufe, our new HF technician, is spinning up well.

Fill gaps in HF Radar operations and maintenance by OSU to complete west coast coverage for health and safety *[Kosro]*

We have obtained FCC licenses for our newest Washington sites, WSP1 (Westport), which is installed and undergoing testing, and KAL1 (Kalaloch), for which a candidate site has been identified and permission is being sought. For the older sites, 10 of 11 have been FCC licensed for the new ITU frequencies. The last site, WLD1, needed to receive FAA clearance, which has been granted, but still needs FCC approval. Operation at the new ITU frequencies likely will require new antennas tuned to the new frequencies.

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]

During this period we continued to maintain and operate the radar station at the Yaquina Bay inlet in Newport, OR. Imagery, videos, and spectrum plots are posted to our webpage. Funding for this no cost extension was completed on Dec. 31, 2021 and our further efforts on this project were covered under the new 5-year grant.

b) NANOOS Modeling Subsystem:

Shelf Modeling:

-Maintain modeling & forecasting capabilities at OSU; deliver model output via NVS [Zaron]

-Model verification and validation [Zaron]

This element was completed prior to 1 December 2021.

Shelf and Salish Sea Modeling:

-Maintain modeling & forecasting capabilities at UW; deliver model output via NVS [MacCready]

-Model development, verification and validation [MacCready]

This element was completed prior to 1 December 2021.

Columbia River Modeling:

-Maintain modeling & forecasting capabilities at CRITFC; deliver model output via NVS [Seaton]

-Model verification and validation [Seaton]

CRITFC has maintained 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.

Anchoring the system are simulations of circulation, conducted in four distinct forms: (1) daily forecasts, (2) multi-year simulation databases, currently 1999-2018, (3) scenario simulations, and (4) process simulations. Of these, daily forecasts 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 have experimented with—and contrasted among—multiple codes (Thetis, SLIM, SELFE and SCHISM) representing different classes of unstructured-grid finite element methods. During this reporting period we have begun evaluating the implications of the Pacific model developed under task 12 with the next generation SCHISM model for a new multi-year simulation database and eventual updated forecast.

Task 12: CRITFC observations, modeling, and DMAC transfer [Seaton]

Leveraging the existing modeling system and prior work on implementing SCHISM modeling of the estuary, CMOP worked in collaboration with NOAA/NOS/OCS/Coast Survey Development Lab-Coastal Marine Modeling Branch (with joint funding from OCS, IOOS, NGS and CO-OPS transferred through IOOS/NANOOS, for Task 12) on the development of a new SCHISM model for the northern and tropical Pacific Ocean. After initial work on development of a 2D tide model, the focus of development shifted to 3D model development with the potential for trans-Pacific port-to-port modeling of surface currents in support of navigation. Work during this period included continued skill assessment of a 3-D basin-scale simulation, with a focus on the representation of the Oregon and Washington coastal shelf. Results of this task were presented at Ocean Sciences.

Task 6: Columbia River extension of the Salish Sea model *[Khangaonkar]*
Progress Report Prepared by the Salish Sea Modeling Center (SSMC), University of Washington Tacoma
Subaward Title: Addition of Columbia River to SSM-OFS - Refinement and Robust Testing

The overall objective of this project was to incorporate 146 miles of Lower Columbia River domain from Astoria, OR at the mouth, to Bonneville Dam into the high-resolution version of the Salish Sea Model developed for CO-OPS for deployment in an operational forecast system for the Salish Sea (SSM-OFS) to be transitioned to, and maintained, and operated by CO-OPS at NOS. The SSM-OFS is currently undergoing final testing, and transition to NOS. This sub-award to the Salish Sea Modeling Center (SSMC), UW Tacoma, through NANOOS supplements that effort with the scope of work, focused on Columbia River specific data acquisition and synthesis, iterative model refinement, skill assessment, and reporting. The resulting system that combines the Salish Sea and Columbia River domains is now the Salish Sea & Columbia River Operational Forecast System (SSCOFS). The model tests and skill assessment have been completed successfully, and the transition to NOS is in the final stages. ***The final report for this work is appended to the end of this NANOOS project report.***

c) NANOOS Data Management and Communications (DMAC) Subsystem:
See Table 1 for milestones [Risien, Tanner, Carini]
This committee is composed of members from CRITFC (formally 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.

NANOOS and IOOS DMAC system implementation. *[Risien, Tanner, Carini]*

- Climatology Data. Previously, climatology data (buoys, indices, etc.) were manually downloaded and processed from external data sources. As a result, there were often high latencies between new data being available and making the new data available with NVS. The climatology data downloading and processing has been replaced with a new automated process that runs at an appropriate interval for each data source to ensure values are as up-to-date as possible.

Task 8: Enhance GOA-ON data portal an OA dashboard to the world and support for GOA-ON co-chair *[Tanner, Newton]*

The GOA-ON Portal content is constantly updated, often with 2-3 new slideshow items, information pages, or resource links per week. Past and archived webinars are also listed to allow users to revisit past talks. Newton provided duties as GOA-ON's co-chair, as outlined in section f. These are placed in this section as there are multiple synergies between NANOOS and GOA-ON.

Task 14: Support OceanHackWeek *[Mayorga]*

This element was completed prior to 1 December 2021.

Task 13: Enhance biological data stewardship within NANOOS *[Mayorga]*

The primary goal of this task is to lay the groundwork for NANOOS stewardship of biological data through integration into international and national biological data systems supported by US IOOS, specifically OBIS (Ocean Biodiversity Information System) and the MBON (Marine Biodiversity Observation Network) Data Portal. Such integration starts with the reorganization and reformatting ("alignment") of a dataset's data and metadata into the standards required by those systems. The target standards are the Darwin Core "extended Measurement or Fact" extension (DwC eMoF) and the Ecological Metadata Language (EML).

This task is led by E. Mayorga (UW) and has focused on the Hood Canal zooplankton densities dataset Prof. Julie Keister (UW) submitted to BCO-DMO in 2017 as part of the project "Consequences of hypoxia on food web linkages in a pelagic marine ecosystem". The dataset is based on depth-stratified net tow sampling at several stations in Hood Canal (part of the Salish Sea), carried out through monthly June to October cruises in 2012 and 2013. Zooplankton density is reported by taxon, with discrimination by life stage in most cases and sex in many cases. Substantial progress in aligning the data to Darwin Core was made in the 6 months prior to the current reporting period, using a Python-based workflow to create Event and Occurrence tables -- two of the three target tables. In the current period, Mayorga completed a thorough draft of the three tables (in CSV format), including the eMoF table using a Python workflow implemented in 4 Jupyter notebooks. The draft code and data tables have been posted in a public GitHub repository (https://github.com/nanoos-pnw/obis-keisterhczoop) to facilitate review by peers in the Standardizing Marine Biological Data (SMBD) working group, IOOS staff (particularly Matt Biddle) and the OBIS-USA node manager, Abby Benson (USGS). Mayorga received substantial input from the SMBD group during the development of the data alignment process. In the data tables, Events have been hierarchically partitioned into cruises (10), station visits (64) and samples (271). The Occurrence table consists of 6,702 records associated with 130 distinct taxa matched to the World Register of Marine Species (WoRMS) and identified at taxonomic ranks ranging from species to suborder, with 66% identified at the most detailed ranks, species or genus. Many of these occurrences are discriminated by sex and life stage, with life stage codes mapped to the British Oceanographic Data Centre (BODC) biological entity development stage terms-controlled vocabulary. Finally, the eMoF table contains zooplankton density measurements corresponding to the unique occurrences, plus standardized information for each sample describing the sampling method, net type and net mesh size.

Abby Benson has provided an initial verification of the aligned draft tables. The next steps before submission to OBIS will be engagement with the data originator (Julie Keister) to resolve a few remaining data ambiguities and solicit a review of the data alignment process; and submitting a request to the BODC-managed NERC Vocabulary Server to add missing life stage terms. Once final revisions are in place, Mayorga will work with Benson to submit the aligned dataset to OBIS via the USGS-hosted Integrated Publishing Toolkit (IPT). The process will generate the required EML metadata files. Mayorga participated in the Marine Biological Data Mobilization Workshop in March, during which he and Benson discussed the IPT submission process in detail. We plan to complete the submission to OBIS in Summer 2022. The work involved in aligning and submitting this Hood Canal zooplankton dataset will serve as a template for future NANOOS biological data stewardship and alignment efforts.

d) User Products Committee (UPC):
See table for milestones [Allan]
This element was completed prior to 1 December 2021.

e) NANOOS Education and Outreach Subsystem:
See table for milestones [Wold, Newton]
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, Wold, Carini, and Rome, with support from DMAC and UPC subsystems and many NANOOS member collaborators. Newton and Wold were active members of the weekly DMAC/UPC tag-up conference calls, regularly providing support and feedback on UPC and DMAC developments. Wold continued 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.

- NANOOS has been partnering with a small local non-profit, Whidbey Watershed Stewards, to work with the 7th & 8th graders at South Whidbey Middle School ocean science and technology program. In previous years students design, build, and deploy buoys at the Langley Marina then retrieve and analyze their data.
- NANOOS staff engaged with high school students through the non-profit Sea Potential as part of the Enabling Change effort. Activities included campus lab tours, descriptions of STEM career pathways, etc.

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.

- Wold engaged with the recreational boating community, presenting virtually at group meetings to demonstrate the NVS Boaters App while gaining direct feedback.
- Wold engaged with various recreational, educational and stewardship organizations and

maintained communication with other groups whose regular meetings and events were on hold due to COVID.

- Wold, Carini, and Rome continued to update content on the NANOOS portal.
- NANOOS maintained a growing Facebook and Twitter audience, regularly posting on Facebook and Twitter accounts with news, photos and interesting data. NANOOS also has a growing audience for its bimonthly newsletter, the "NANOOS Observer."

f) NANOOS Administration:

See table for milestones [Newton]

J. Newton (NANOOS Executive Director), Andrew Barnard (NANOOS Board Chair), M. Kosro (NANOOS Board Vice Chair), N. Rome (NANOOS Program Manager), and R. Carini (NANOOS Research Assistant) continued to provide leadership to NANOOS operations and connection to the US IOOS enterprise. R. Carini, NANOOS Research Associate, supported NANOOS Administration, Outreach, and DMAC. Newton, Rome, and Carini participated in IOOS Program Office and IOOS Association calls. Newton served on the IOOS Association Executive Committee and attended IOOS Program and IOOS Association calls as available. Newton is Vice Chair of the IOOS Association board of directors. Charles Seaton (CRITFC), and Roxanne Carini (UW), represented NANOOS at monthly, virtual IOOS DMAC meetings. Newton represented NANOOS and IOOS at several NOAA or IOOS-related events during the period. Newton, Rome, Carini, and Kosro participated in weekly Tri-Com calls. Key events for this period included:

- NANOOS held its Community Workshop at the end of March. Discussions focused on Fisheries, Coastal Hazards, and Maritime Safety were filled with rich conversation about how we can improve NANOOS services in each area and how we can expand the reach of NANOOS within and beyond existing user communities. We included a focus on: Tuna Fishers, TsunamiEvac, and Boaters NVS apps, featuring stakeholder talks by Oregon Fisher Mark McCulloch, Nehalem Emergency Volunteer Corps members Lee Hiltenbrand and Linda Koslowski, and NASBLA Safe Boating Instructor Margaret Pommert, respectively.
- Through the Community Workshop, NANOOS identified priorities on how to improve the system in these areas via product customizations, accuracy improvements, partnerships, and expansion. Additionally, the NANOOS community offered clear steps on how to increase the visibility of NANOOS through messaging, advertising, and marketing. You can view the proceedings of the workshop here.
- We continued bi-monthly EC meetings to discuss strategic planning and synergies focusing on planning the NANOOS Community Workshop in Astoria OR held on 24-25 March 2022.
- Newton spoke to the IOOS Advisory Committee Meeting giving a talk on the coastal climate signal "Insights on Climate Impacts affecting the West Coast" on 13 May 2022.
- NANOOS held its annual PI meeting virtually on 3-4 August 2021 plans for these meetings on 1-2 August 2022.NANOOS held its Tri-Com meeting on 28 April 2022.The Tri-Committee (reps from DMAC, User Products, and Education, Engagement and Outreach) met weekly and input from these meetings continues to guide NANOOS priorities as we transition from one 5-year award to the next. In her role as PI Liaison, Associate Carini maintained regular contact with PIs on topics of data management and data visualization improvements.
- Newton was the lead author for "Multi-stressor observations and modeling to build understanding of and resilience to the coastal impacts of climate change" published in the Oceanography Magazine edition focused on ocean observations. The manuscript had tribal, academic, and federal partners from throughout NANOOS. https://doi.org/10.5670/oceanog.2021.supplement.02-31.

- Newton was invited to be a moderator on OAH for the California OOS meeting hosted by CeNCOOS and SCCOOS on 24-25 May 2022. She represented NANOOS on the California Current Acidification Network (C-CAN). Newton contributed NANOOS updates on oceanographic conditions in the Pacific Northwest for the NOAA WestWatch webinar series during the period, along with the CeNCOOS and SCCOOS.

DEI focus:

- NANOOS sustained the **NANOOS Enabling Change Working Group** with monthly meetings during this period. See Objective 9 for details.
- NANOOS will engage three interns through the UW EarthLab for summer.
- The NSF Convergence Accelerator proposal NANOOS led with AOOS, PacIOOS, Sofar Ocean (a low-cost buoy and sensor company) and Indigenous partners from the Pacific Islands (villages in the Marshall Islands and American Samoa), the Washington coast (Quileute Tribe and Quinault Indian Nation), and Alaska (Alaska Eskimo Whaling Commission) was funded to collectively work to develop solutions to overcome existing hurdles of observing technologies that are too expensive to purchase and too expensive to sustain when conducted in isolation. The goal of the project is to get oceanographic data into the hands of Indigenous communities in a way that takes advantage of existing, lower cost wave buoy technology and enables sustained community-led stewardship of the buoys. Through co-design, the team aims to revolutionize the status quo by providing new tools and new connections that will focus on the hyper-local scale.

Additional coordination and representation included:

- Newton and AOOS Director Molly McCammon are members of the Ecosystem Sciences and Management Working Group and participated in meetings during the period. Both are serving as co-chairs of the WG.
- Newton and Barnard represented PNW priorities and concerns via requested updates from the Washington and Oregon congressional delegations throughout the period. Newton, Rome, Carini, and Barnard conducted Hill visits with 12 WA and OR elected congressional officials during spring 2022.
- Carini, and Newton provided a poster on NANOOS observations at the Salish Sea Ecosystem Conference 26 April 2022.
- Newton contributed results from the NOAA OAP Olympic Coast Regional Vulnerability to OA study on the Washington coast during the OASeS Symposium on 10-12 May 2022 "The Olympic Coast as a Sentinel: An Integrated Social-Ecological Regional Vulnerability Assessment to Ocean Acidification" 10-12 May. This project involves several NANOOS partners, including the four WA coastal treaty tribes (Quinault Indian Nation, Hoh, Quileute, and Makah), OCNMS, ONP, and NOAA PMEL.
- Newton represented NANOOS on the California Current Acidification Network (C-CAN).

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

- Newton stayed involved in Canadian observing activities including for MEOPAR and CIOOS-Pacific. Newton is a member of the Canadian IOOS (CIOOS) Pacific Regional Oversight Committee. Newton chairs the Marine Environmental Observation, Prediction, and Response Network, a Canadian Center of Excellence (MEOPAR) International Science Advisory Committee.
- Newton was invited to speak on "NANOOS, US IOOS, and Global Observations: Local to Global Linkage" COAST Talks: Global Ocean Observation - Opportunities for Pacific Canada on 23 March 2022.
- Newton continued to serve on several international scale coordination committees during the period.

Newton is a co-Chair of GOA-ON, along with Steve Widecombe, Plymouth Marine Labs. She represented IOOS on Global Ocean Acidification Network Executive Committee (EC) calls and activities. She co-chaired the North American GOA-ON Hub Meeting on 3 May.

- Newton provided leadership to GOA-ON's UN-endorsed programme "Ocean Acidification Research for Sustainability (OARS)", representing it at the "Our Ocean Conference" in Palau and other venues. She chaired an "Our Ocean Conference" Side Event with PI-TOA on 13 April 2022 representing ocean acidification work in the Pacific Islands and Territories hub of GOA-ON.
- Newton is a member of the Science Advisory Team for the Joint European Research Infrastructure in the Coastal Ocean (JERICO) and reviewed their TransNational Access proposals on 31 May.

Additional NANOOS coordination:

- Newton was invited to serve on the External Advisory Committee (EAC) for the Cascadia Coastlines and Peoples Hazards Research Hub (or Cascadia CoPes Hub). NANOOS PI Peter Ruggiero is a CoPes PI. The NSF-funded Hub's goal is to advance fundamental hazards sciences in collaboration with Pacific Northwest coastal communities to increase their adaptive capacity and resilience. EAC members provide scientific guidance and expert advice on project implementation from a range of perspectives to ensure that the Cascadia CoPes Hub meets its goals and objectives. She attended their first meeting on 19 April.
- Newton serves as the Research Seat for the Olympic Coast National Marine Sanctuary (OCNMS) Advisory Council; she participated in meetings on 1 April and 20 May. She is a member of the OCNMS science subcommittee for OASeS (Ocean Acidification Sentinel Site).
- Newton was asked by the state of Oregon Department of Environmental Quality to serve on its OAH working group for assessing water quality standards and practices.
- Newton participated in the Olympic Region Harmful Algal Bloom (ORHAB) Steering Committee calls throughout the period.
- *Newton participated in 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 other regional efforts, e.g., PSEMP, Pacific Salmon Marine Survival, and the West Coast Ocean Data Portal.*
- Newton continued to represent NANOOS in regional efforts, e.g., C-CAN, PSEMP, Pacific Salmon Marine Survival, and the West Coast Ocean Data Portal.
- Newton contributed NANOOS updates on oceanographic conditions in the Pacific Northwest for the NOAA WestWatch webinar series on 26 April, along with the other two west coast RAs. We provided NANOOS contributions to PSEMP Puget Sound Marine Condition Updates on 19 January, 5 April, and 18 May 2022.

Coordinate a west-coast wide regional collaboration team workshop with NOAA West and west coast IOOS RAs *[Newton]* The paper on best practices continued to be crafted during this period, and a virtual west coast workshop was partially satisfied by the CA-OOS workshop but a broader follow-up will be planned for fall 2022.

Presentations and Publications acknowledging NANOOS or IOOS support: underline indicates NANOOS PI

Presentations:

Helms, A.R., Magel, C.L., and J. Schaefer, J. 'Where the Rivers Meets the Sea: Coos Bay Estuary Webinar Series, The Superpowers of Eelgrass (Rogue Climate)', virtual, 26 May 2022, 5:30 pm -7pm.

Helms, A.R. Environmental drivers of eelgrass declines in the South Slough estuary, OR. South Slough National Estuarine Research Reserve, 161st Management Commission Meeting, virtual, 17 March 2022.

Helms, A.R. and McIntosh, J. Creative Capacity: Leveraging $10K Into Your Next Science Collaborative Project: Building capacity to respond to an eelgrass (*Zostera marina*) decline in the South Slough estuary, OR. NERRS Science Collaborative Webinar Series, virtual, 3 March 2022.

Khangaonkar T.P., A. Nugraha, S. Yun, and M. Premathilake. 06/15/2022. "Overview of the Salish Sea Model (SSM) including Columbia River for transition to and deployment at NOS as the "Salish Sea Columbia River Operational Forecast System" (SSCOFS)." Presented by T.P. Khangaonkar at FVCOM Workshop 2022, Online Conference, Washington. PNNL-SA-174163.

Newton, J.A. 'Explaining Ocean Acidification Science, Observation and Mitigation,' MARES TA Webinar Series, virtual, 7 January 2022.

Newton, J.A. 'Puget Sound Marine Condition Update from NANOOS', Puget Sound Ecosystem Monitoring Program, virtual, 19 January and 18 May 2022.

Newton, J.A. 'Community-led Ocean Observing,' National Science Foundation Convergence Accelerator project presentation, virtual, 9 Feb 2022.

Newton, J.A. 'Sensing oxygen in the ocean: invisible history,' Ocean Memory Project, virtual, 10 Feb 2022.

Newton, J.A. 'The Olympic Coast as a Sentinel: *Biological risk results from an Integrated Social-Ecological Vulnerability Assessment for Ocean Acidification*' Ocean Sciences 2022 Virtual Meeting, 04 Mar 2022

Newton, J.A. 'NANOOS, US IOOS, and Global Observations: Local to Global Linkage,' COAST Talks: Global Ocean Observation - Opportunities for Pacific Canada, virtual, 23 March 2022.

Newton, J.A. 'Backyard Buoys' All Partners Meeting, virtual, 4 April 2022.

Newton, J.A. 'NANOOS Buoy Data: patterns over 2021,' PSEMP Marine Waters Annual Overview Workshop, virtual, 5 April 2022.

Newton, J.A. Moderator: 'Ocean Acidification in the Pacific Islands: From Local to Global Scales,' Our Ocean Conference Side Event with the PI-TOA GOA-ON regional hub, Palau, 13 April 2022.

Newton, J.A. GOA-ON & OARS representative, UN Decade Biological Observation Workshop, virtual, 19-21 April 2022.

Newton, J.A. External Advisory Committee for the Cascadia Coastlines and Peoples Hazards Research Hub (or Cascadia CoPes Hub), virtual, 19 April 2022.

Newton, J.A. and Carini, R. 'Salish Sea ORCA buoy observations over the last decade: warmer and saltier than normal anomalies and their persistence,' Salish Sea Ecosystem Conference poster, virtual, 26 April 2022 https://wwu.eventsair.com/ssec2022

Newton, J.A. 'What is OARS?' North American GOA-ON Hub Meeting, virtual, 3 May 2022.

Newton, J.A. 'Ocean Acidification 101' & 'The Olympic Coast as a Sentinel: *An Integrated Social-Ecological Regional Vulnerability Assessment to Ocean Acidification'* OASeS Symposium, Ocean Shores, 10-12 May 2022.

Newton, J.A. 'Insights on Climate Impacts affecting the West Coast,' IOOS Advisory Committee Meeting, virtual, 13 May 2022.

Newton, J.A. 'Co-designing applied ocean models to support communities in the NE Pacific though NANOOS,' Co-Designing Models in the NE Pacific, Tula Foundation, UN Decade Collaborative Center for the North Pacific, virtual, 13 May 2022.

Newton, J.A. Moderator: OAH Panel on Science and Policy, CA OOS (CeNCOOS & SCCOOS) meeting, Avila Beach, 24-25 May 2022.

Publications:

OAIE article: https://express.adobe.com/page/IbggU45Xy8Erx/

Newton, J., P. MacCready, S. Siedlecki, D. Manalang, J. Mickett, S. Alin, E. Schumacker, J. Hagen, S. Moore, A. Sutton, and R. Carini. 2021. Multi-stressor observations and modeling to build understanding of and resilience to the coastal impacts of climate change. Pp. 86–87 in Frontiers in Ocean Observing: Documenting Ecosystems, Understanding Environmental Changes, Forecasting Hazards. E.S. Kappel, S.K. Juniper, S. Seeyave, E. Smith, and M. Visbeck, eds, A Supplement to Oceanography 34(4), https://doi.org/10.5670/oceanog.2021.supplement.02-31.

Addendum:
Final Report: ***Columbia River extension of the Salish Sea model*** *[Khangaonkar]*
Final Report Prepared by the Salish Sea Modeling Center (SSMC), University of Washington Tacoma
Subaward Title: Addition of Columbia River to SSM-OFS - Refinement and Robust Testing

Project Scope Summary and Objective
The overall objective of this project is to incorporate 146 miles of Lower Columbia River domain from Astoria, OR at the mouth, to Bonneville Dam into the high-resolution version of the Salish Sea Model developed for CO-OPS for deployment in an operational forecast system for the Salish Sea (SSM-OFS) to be transitioned to, and maintained, and operated by CO-OPS at NOS. The SSM-OFS is currently undergoing final testing, and transition to NOS. This sub-award to the Salish Sea Modeling Center (SSMC), UW Tacoma, through NANOOS supplements that effort with the scope of work, focused on Columbia River specific data acquisition and synthesis, iterative model refinement, skill assessment, and reporting. The resulting system that combines the Salish Sea and Columbia River domains is now the Salish Sea & Columbia River Operational Forecast System (SSCOFS). The model tests and skill assessment have been completed successfully, and the transition to NOS is in the final stages. Project background, data acquisition and processing, model development and testing, and skill assessment results are documented below in the form of this final project report.

Background
A “shoreline resolving” operational forecast system (OFS) for the region encompassing Puget Sound, Strait of Juan De Fuca, and Georgia Basin, collectively known as the Salish Sea has been pursued by the Pacific Northwest community for several decades now. Our target historically has always been real-time oceanographic information for these inner fjord-like deep estuarine waters with complex shorelines, numerous islands, presence of sills, and 161 streams and 99 wastewater discharges. This OFS is expected to support navigation and emergency response operations, as well as marine ecological resource management. In recent years, the urgency for an OFS for the Salish Sea has increased. The NOAA office of Response and Restoration and Navigation (OR&R), and U.S. Coast Guard depend on the availability of accurate nowcasts and forecasts of oceanographic data (tides, currents, temperature, and salinity) during maritime emergencies such as an oil spill or search and rescue. This was identified as a major data gap by the NOAA National Ocean Services (NOS)’s Coast Survey Development Laboratory (CSDL) and the Center for Operational Oceanographic Products and Services CO-OPS. The ship traffic through the Strait of Juan de Fuca to the Salish Sea is expected to see a 7-fold increase in tanker traffic. Similarly, there is a need for real-time water quality information and pollution exposure forecasts_for use by the state and local environmental protection agencies responsible for marine water quality, fisheries, recreation, and public health.

In response to this need, the IOOS COMT18 program funded a project titled “Towards an Operational Forecast System for the Salish Sea – Refinement, Improvement, and Testing for Transitioning of the Salish Sea Model to NOS”. Through this project led by the Pacific Northwest National Laboratory (PNNL), the coupled system of hydrodynamic and biogeochemical models of the Salish Sea developed previously (Khangaonkar et al. 2017, 2018, and 2019) were subjected to a » 10-fold increase in grid resolution, and robust testing using NOS skill assessment procedures (Zhang et al. 2009, 2010). The resulting system based on the finite volume community ocean model – FVCOM (Chen et al. 2003) was titled SSM-OFS.
The SSM focuses on the inner Salish Sea geographical region, but the model domain extends out to the continental shelf boundary and includes several major coastal estuaries as placeholders for future development and completeness with respect to conveyance of freshwater to the coastline. One of those waterbodies is the Columbia River and the estuary: extending from the Bonneville Dam upstream (RM 146)

to its mouth near Astoria, OR (RM 0). The CO-OPS already maintains a Columbia River Estuary Operational Forecast System (CREOFS). However, it is based on a modeling framework that is no longer supported at NOAA. NOS strongly recommended CO-OPS fold Columbia River and the Salish Sea regions into a single modeling framework facilitating a common operational forecast system.
This report summarizes a two-year project effort titled “Addition of Columbia River to SSM-OFS - Refinement and Robust Testing” that was conducted out of the Salish Sea Modeling Center (SSMC) at the University of Washington, Tacoma. Review of available data, model refinement, and skill assessment focused on the Columbia River region of the domain are presented. The resulting modeling system SSCOFS has been transitioned to NOS where testing and independent skill assessment is in progress. The work was funded by the IOOS through the regional association Northwest Association of Networked Ocean Observing Systems (NANOOS).

Project Narrative
The subaward scope consists of four tasks. They are described below along with a summary of results and finding.

Task 1: Review and Processing of 2020 Data: Columbia River ADCP/CTD Survey
The scope originally was written based on the understanding that CO-OPS had planned a comprehensive data collection Program for the Columbia River and that resulting data would be available for this effort. NOAA scientists planned to collect ADCP and CTD data from 26 stations on the Columbia River in the 2020-2021 period. However, due to travel restrictions from COVID19 the currents and stratification survey of the Columbia River was postponed to a future date. Therefore, in consultation with IOOS, the Salish Sea Modeling Center (SSMC) modified the data acquisition and calibration plan to conduct the work using data previously collected through monitoring programs in place. Figure 1 below shows the available network of observation nearly 40 stations. The data from these stations provided adequate coverage of the tidally influenced reaches of the Lower Columbia River extending from the Bonneville Dam (RM 146) to the river mouth RM 0. Primary sources of data include stations maintained by NOAA CO-OPS, the Center for Coastal Margin Observation & Prediction (CMOP), and the United State Geological Survey (USGS)

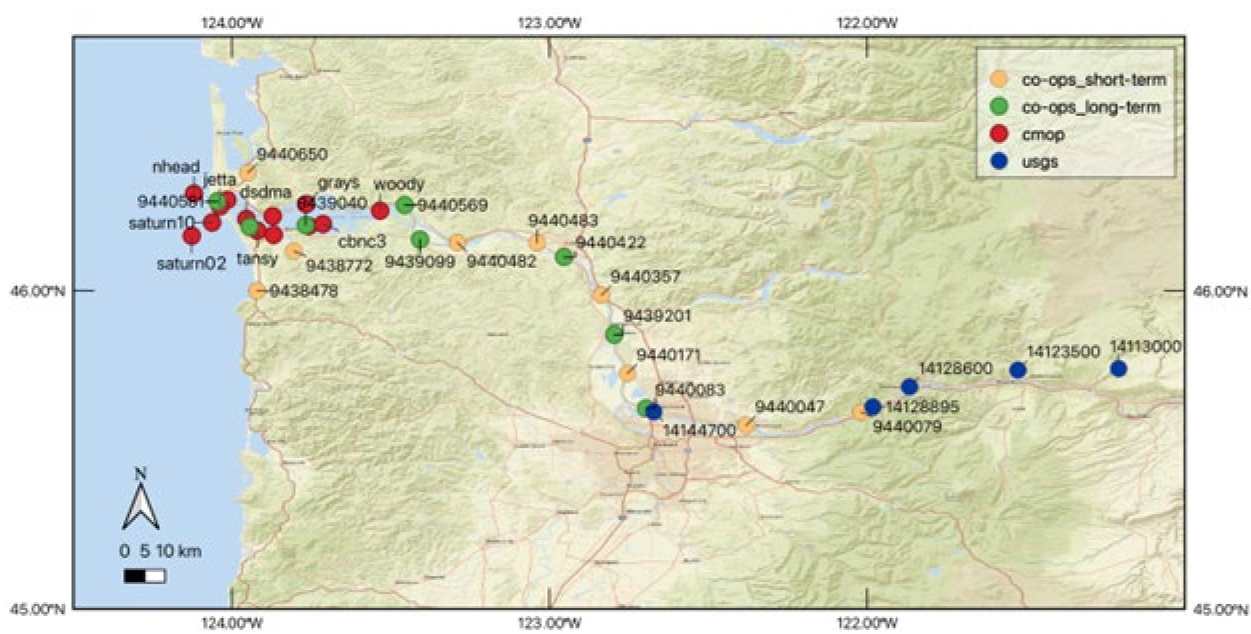


Figure 1: NOAA CO-OPS, CMOP, and USGS stations that were used for calibration

SSMC downloaded available 2014-2017 water quality data collected by CMOP and assembled by NANOOS via the CMOP website. Table 1 below shows the location information for the 14 CMOP stations.

Table 1: CMOP stations on the Lower Columbia River Estuary used in SSCOFS development

Station ID	Station Name	Lat	Lon	Station ID	Station Name	Lat	Lon
saturn01	Saturn01	46.24	123.87	jetta	Jetty A	46.27	124.04
saturn02	Saturn02	46.17	124.13	grays	Grays	46.27	123.77
saturn03	Saturn03	46.20	123.94	dsdma	Desdemona Sands Light	46.23	123.96
saturn04	Saturn04	46.20	123.76	cbnc3	Cathlamet Bay North Channel	46.21	123.71
saturn07	Saturn07	46.29	124.02	tansy	Tansy Point	46.19	123.92
saturn09	Saturn09	46.18	123.87	woody	Woody	46.25	123.53
saturn10	Saturn10	46.22	124.06	nhead	North Head	46.31	124.12

These data were first processed by CMOP (Quality checked text files), and further processed at SSMC to a suitable format for visualization and comparison with model results for skill assessment.

SSMC also used data from 17 NOAA CO-OPS stations. These include 9 short-term survey stations and 8 long-term data collection stations listed in Table 2. Five USGS gages listed in Table 3 provided additional water level and current data.

Table 2: NOAA CO-OPS stations used in SSCOFS development

Station ID	Station Name	Latitude	Longitude
9440079	Beacon Rock State Park	45.62	-122.02
9440047	Washougal, Columbia River, WA	45.58	-122.38
9440171	KNAPP (Thornes) LNDG, Willow Bar, WA	45.74	-122.76
9440357	TEMCO Kalama Terminal	45.99	-122.84
9440483	Barlow Point	46.15	-123.04
9440482	Cape Horn Columbia River, WA	46.15	-123.29
9438772	Cathcart Landing, OR	46.13	-123.81

9438478	Seaside	46.00	-123.92
9440650	Greenhead Slough	46.37	-123.95

Station ID	Station Name	Latitude	Longitude
9440083	Vancouver, WA	45.63	-122.70
9439201	Saint Helens, OR	45.86	-122.80
9440422	Longview, WA	46.11	-122.96
9439099	Wauna, OR	46.16	-123.41
9440569	Skamokawa, WA	46.27	-123.46
9439040	Astoria, OR	46.21	-123.77
9439011	Hammond, OR	46.20	-123.95
9440581	Cape Disappointment, WA	46.28	-124.05

Table 3: USGS station used in SSCOFS development

Station ID	Station Name	Latitude	Longitude
14144700	Columbia River at Vancouver, WA	45.62	-122.67
14128895	Hamilton Creek Near Mouth, at N Bonneville, WA	45.64	-121.98
14128600	Columbia River at Stevenson, WA	45.70	-121.87
14123500	White Salmon River near Underwood, WA	45.75	-121.53
14113000	KLICKIT at River near Pitt, WA	45.76	-121.21

CMOP data include the vertical profile of water quality constituents: Chlorophyll *a*, dissolved oxygen, turbidity, nitrate, pH, salinity (S), and temperature (T). They were measured at depths varying from 3 m to 35 m depending on the tide and station location.

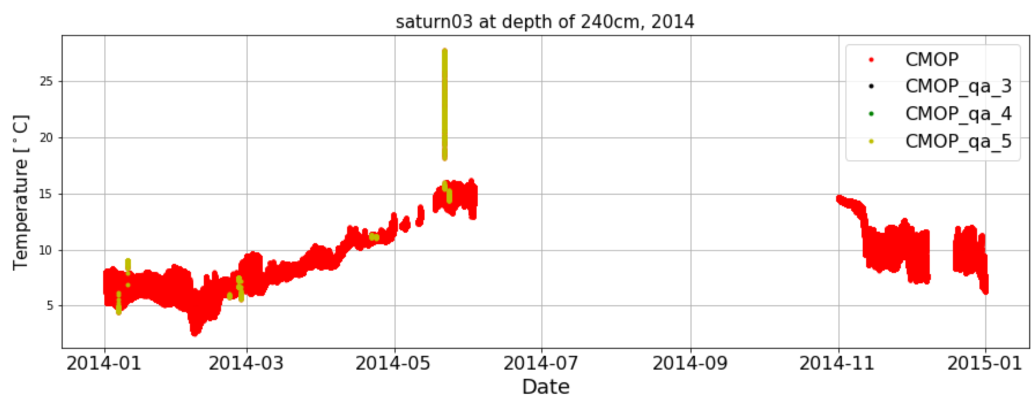
Table 4 lists available water quality constituents and the associated stations. For this study, we only used water quality variables T and S at station saturn01, saturn02, saturn03, saturn04, Saturn07, nhead, eliot, and cbnc.

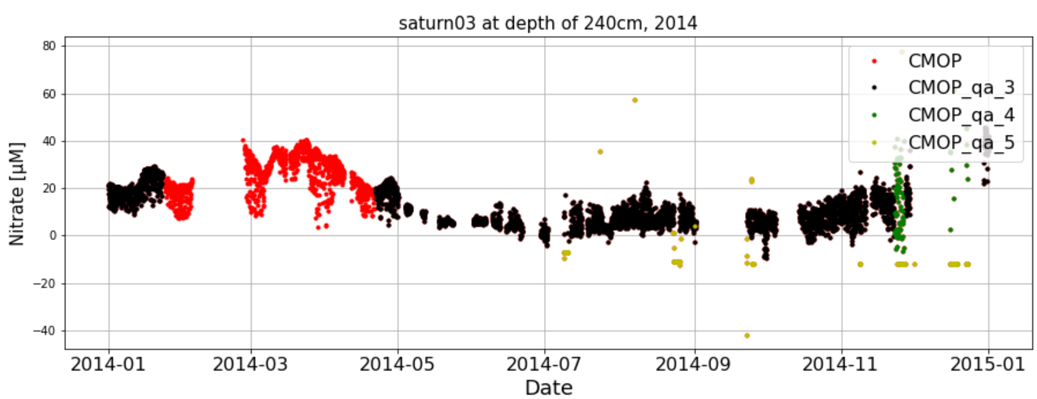
Table 4: The water quality constituents data available from CMOP stations

Water Quality Constituents	Unit	Station	Measure Type
Chlorophyll	µg/L	saturn01, saturn02, saturn03, saturn04, saturn07, saturn09, saturn10, nhead	FLNTU, Multi-exciter, AlgaeWatch, Fluorometer
Dissolved oxygen	mL/L	saturn01, saturn02, saturn03, saturn04, saturn07, saturn09, saturn10, nhead	Oxygen, CTO

Turbidity	ntu	saturn01, saturn02, saturn03, saturn04, saturn07, saturn09, saturn10, nhead	FLNTU, Multi-exciter, Turbidity
Nitrate	µM	saturn01, saturn02, saturn03, saturn04	ISUS, SUNA
pH	pH	saturn03, saturn04	pH
Salinity	psu	saturn02, saturn07, saturn10, nhead, dsdma, jetta, grays, cbnc3, tansy	CTO, CT, CTD
Temperature	°C	saturn02, saturn03, saturn07, saturn10, nhead, dsdma, jetta, grays, cbnc3, tansy, woody	CTO, CT, CTD, Thermistor, Temperature

Figure 2(a) below shows an example time series data of temperature, nitrate, and pH collected from saturn03 station at 2.4m in 2014. The data are indicated with different Quality Assurance (QA) Level 3 (black), 4 (green), and 5 (yellow). QA Level 1, and 2 which are regarded as good or good enough are included in CMOP data (red).





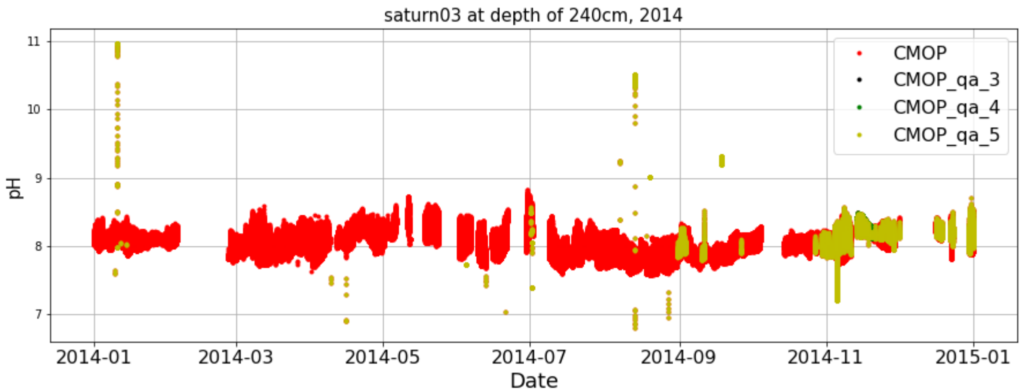


Figure 2(a): Temperature, Nitrate, and pH data time series for 2014 CMOP data collected from saturn03 station at depth of 2.4m in 2014.

Although considerable water quality data were downloaded, a biogeochemical model of the Lower Columbia River is beyond the scope of this effort. Only temperature and salinity from this data set were utilized for validation and assessment of the hydrodynamic model. At the direction of the CO-OPS project team, the SSCOFS skill assessment effort targeted water surface elevation (WSE) as the primary performance measure in this phase of the project with navigation support being the mission objective.

The processes affecting WSE in the Lower Columbia River are complex. The hydraulics near the mouth of the estuary are controlled by two jetties along the north and south banks that protect the entrance from the impacts of longshore sediment transport. They also protect the navigation channel that is dredged and maintained by the U.S. Army Corps of Engineers at 40 ft depth. The estuary, extending up to RM37, supports many internal channels, numerous shoals, and islands. The navigation channel and mainstem of the Columbia River continue upstream all the way to Belleville Dam at RM146. The thalweg up to St. Helens (RM86) is on a relatively mild slope and the tidal effects on WSE are noticeable throughout the year. The region from St. Helens to Vancouver (RM100) and on to Bonneville is a faster moving reach with a higher slope and narrower cross-section that is sensitive to river flow. Figure 2(b) below shows time series plots of water surface elevations from Astoria near the river mouth and Vancouver from NOAA/ NOS/ CO-OPS stations. The effect of river flow during the high flow spring season on WSE is prominent at the upstream Vancouver station while the tidal variation is most prominent near the river mouth at Astoria.

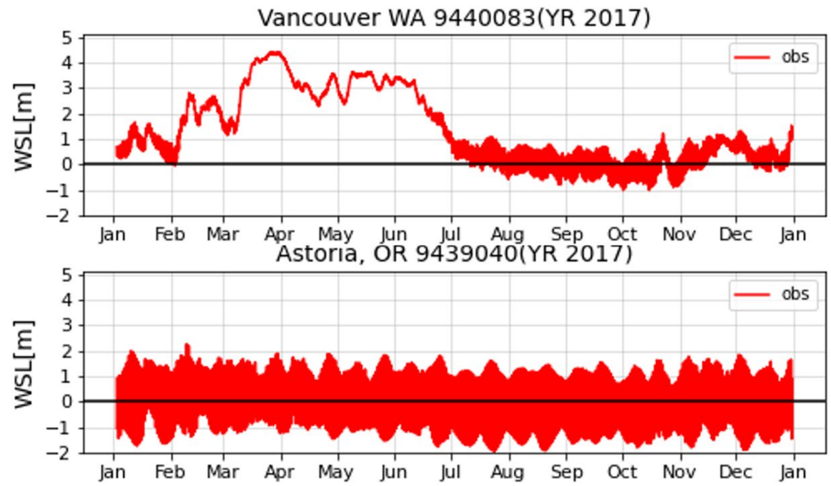


Figure 2(b): Year 2017 WSE time series from NOAA CO-OPS stations at Vancouver and Astoria respectively shown as examples of response to seasonal variations in river flow and tidal forcing.

The ability of the model to reproduce these changes in WSE modulated by tides and river flow and distance from the river mouth was made the primary target for calibration and skill assessment.

Task 2: Iterative Refinement of Columbia River Grid and Testing with SSCOFS

The Salish Sea Model (SSM) (Khangaonkar et al. 2018) has always included the Columbia River estuary as a sub-domain that allowed the freshwater flow released by the Bonneville Dam to reach the Pacific Ocean. However, the focus of SSM has always been the Puget Sound and the northwest straits within U.S. waters of the Salish Sea. As a result, all prior model calibration and testing efforts have focused on the inner Salish Sea regions using data from existing marine monitoring programs. The Columbia River region of the model has until this project been treated as a placeholder for future development.

Through this effort, we iteratively refined and incorporated the Columbia River region into a higher resolution version of SSM (SSM-OFS) previously developed in preparation for the Salish Sea Operational Forecast System. The requirement imposed was that the combined SSM-OFS and Columbia River grid must function in a stable manner using the same time step for deployment as a single FVCOM based model for the *Salish Sea Columbia River Operational Forecast System* (SSCOFS). This was accomplished through numerous tests of varying levels of grid refinement and smoothing to ensure the SSCOFS model version functioned effectively and efficiently as a single model of the Oregon-Washington continental shelf with Salish Sea, Columbia River, and Canadian waters surrounding Vancouver Island. Although this could have been accomplished with a nested grid approach, NOAA CO-OPS expressed a strong preference for a non-nested single model of the system. Relative to the baseline SSM, the SSCOFS model may be regarded as approximately 12-fold higher resolution Salish Sea Model with an embedded representation of the Lower Columbia River, also at compatible higher resolution.

Figure 3 shows the comparison of the original Columbia River grid from SSM, intermediate refined version, and the final version of Colombia River region of SSCOFS model grid. In parallel with grid refinement, the existing bathymetry (originally from Eastern North Pacific ADCIRC model grid) was also updated using a more detailed and updated bathymetry provided by NOAA from the Columbia River Estuary Operational Forecast System (CREOFS).

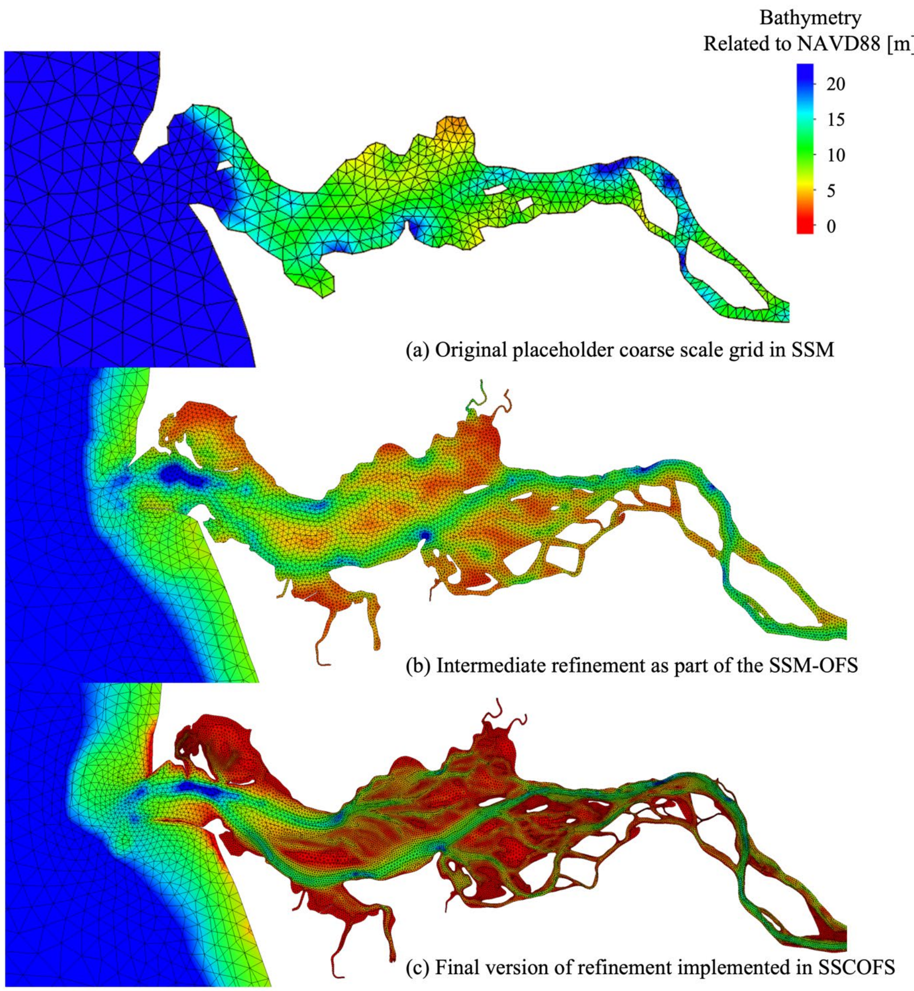


Figure 3: *Evolution of Columbia River estuary region of the Salish Sea Model (a) Original placeholder coarse scale grid in SSM, (b) Intermediate refinement as part of the SSM-OFS model version grid, and (c) Final version of refinement implemented in SSCOFS model.*

Task 3: Model setup and skill assessment– Columbia River Focus

As described in Task 1, the original intent was to conduct skill assessment using tides as well as currents data. However, data collection planned for the years 2020-2021 has been postponed to 2023-2024. In consultation with CO-OPS, the Task 3 effort focused on maximizing WSE prediction skill. Temperature and salinity data were used as a secondary model validation step.

The WSE response in the Columbia River is complex, affected by large river flow, river morphology that allows tidal effects to propagate well upstream of the estuary segment. Tidal amplitude diminishes with distance from the mouth, and flow reversals typically don't extend beyond the RM36, but the tidal modulation of the water surface is seen all the way up to the tailrace of Bonneville Dam during low flows. During high flow period, there is a sharp increase in WSE from Bonneville Dam up to St. Helens (RM86) that dominates over the tidal signature which increases as we move downstream towards the moth near Astoria.

Initially, we implemented a smoothing step to ensure compatibility with pressure gradient error criterion associated with the sigma coordinate system (Mellor et al., 1994). While this minimized excessive numerical mixing, the model could not reproduce the observed high WSE during high flows toward the upper reaches of the model domain. When attempts were made to enhance the response during high flow by reducing the river cross section, it muted the tidal signature and affected the model skill. WSE was also found to be particularly sensitive to bed friction. Over 110 model runs were conducted with varying levels of smoothing, and distribution of bed friction. The final configuration that yielded the best response consists of (1) use of raw bathymetry (ie. zero smoothing), and (b) spatially varying value of bed friction z0 from a background of 0.006 from the shelf to 0.014 up to St. Helens in the Columbia River.

The SSCOFS was set up for 2017 as that was the first year with NOAA operational products data (HRRR meteorological forcing and GRTOFS ocean boundary) available for testing. River flows were specified using the NOAA National Water Model (NWM). Tidal constituents for the SSCOFS model were obtained from ENPAC database and default values of river temperatures provided by Washington State Department of Ecology were used for specifying Columbia River and Willamette River temperatures. During testing we found that unlike the Salish Sea region where atmospheric heat exchange dominates over the influence of river temperatures, the Columbia River response is sensitive to river inflow temperatures. Improving temperature and salinity response will be addressed in future phases of the project using real-time measurements to specify inflow temperatures from Columbia River and Willamette River upstream boundaries.

As part of skill assessment, we compared predicted WSE with data from 7 NOAA CO-OPS stations, and predicted S and T with data from 8 CMOP stations. Figure 4 shows locations of the CMOP stations in blue and CO-OPS stations are shown in yellow. The skill assessment for WSE was conducted using NOAA procedures (Zhang et al. 2006).

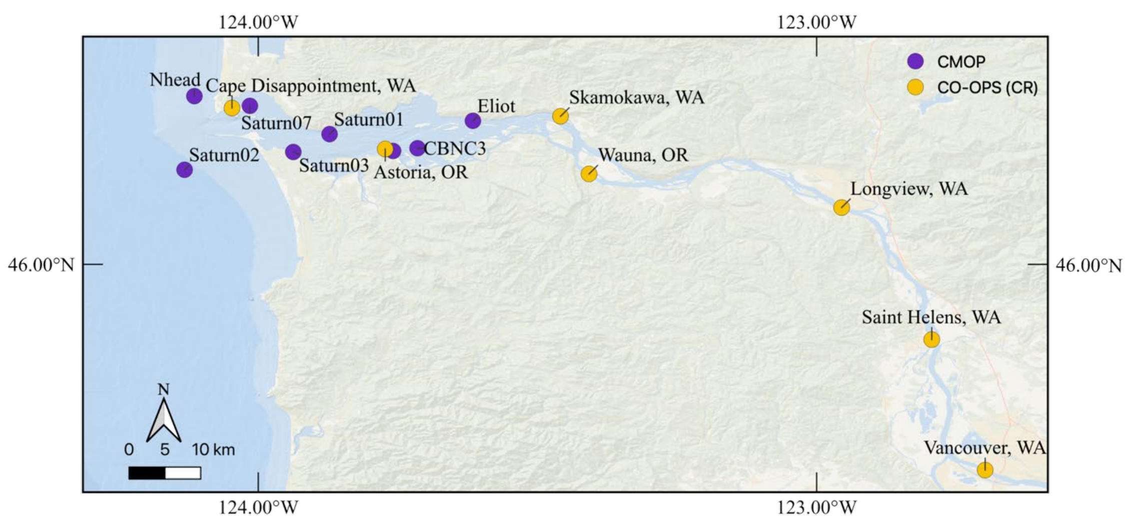


Figure 4: NOAA CO-OPS monitoring stations for WSE (7) and CMOP monitoring stations for salinity and temperature (8) used in Columbia River model performance and skill assessment.

a. *NOAA-SA for WSE:* The WSE skill assessment was conducted using NOAA-SA procedures, standards (Zhang et al. 2006), and associated software. The NOAA-SA standards specify requirements for numerous parameters including Series Mean (SM), Root Mean Square Error (RMSE), Central Frequency (CF), Negative and Positive Outlier Frequency (NOF and POF), Maximum Duration of Negative and Positive Outlier (MDNO and MDPO), and the Worst Outlier Frequency (WOF). In this report, we elected to focus on the requirement that central frequency (CF) for established error magnitude (X) be as close to 90% as possible. The expectation is that other parameters would be likely within acceptable limits if the CF value is achieved. The established error limit for WSE is 0.15m or 10% of the tidal range.

Table 5 provides NOAA-SA results for WSE comparison in the Columbia River region. The RMSE levels are below 0.15 m except for the Vancouver and Saint Heles. The CF levels are below the 90% standard. The stations located in the upper part of the Columbia River show high RMSE value and low CF value compared to the stations located at the estuary and lower part of the river. Improvement on bathymetry resolution upstream end, and in combination with spatial detailed of bed friction could improve the NOAA-SA metric.

Table 5: Model skill assessment for WSE using data for NOAA stations in the Columbia River region. Only SM (m), RMSE (m), and CF (%) values are presented for simplicity.

Station	SM (m)	RMSE (m)	CF (%)	Datum Conversion MSL to NAVD88 (m)
Vancouver, WA	0.22	0.29	31.2	-2.27
Saint Helens, OR	-0.03	0.18	61.7	-2.33
Longview, WA	0.01	0.14	74.0	-2.13
Wauna, OR	0.03	0.12	84.6	-1.62
Skamokawa, WA	-0.01	0.13	87.2	1.55
Astoria, OR	-0.06	0.13	89.9	1.44
Cape Disappointment, WA	0.07	0.14	83.0	1.20
Average	0.03	0.16	73.1	

In column 5 of Table 5 we have provided the datum conversion from MSL to NAVD88. The conversion values were based on VDATUM software. It is possible that the datum conversion at Vancouver is in error and that model performance metrics could be improved with a datum adjustment if determined appropriate.

While the SM and RMSE metrics, in general, look good/reasonable the CF at most stations varies between 80-90% and is lower at Longview, St. Helens, and Vancouver. Based on our discussions with the NOAA CO-OPS team we understand that this performance is comparable to the existing CREOFS. Clearly there is room for further improvement, but it may require further model refinement and may come at the cost of computational efficiency.

Figure 5 below shows the comparison between the predicted WSE (blue) and observation data (red). Results show that the estuary and lower parts of the Columbia River domain have higher model skills compared to the upper reaches. In addition, the model simulates high flow better compared to low flow. The reason could be that a high friction coefficient was needed to achieve the high flow WSE peak which also tends to retain water in the channel slowing the drainage. We expect fine-tuning the bathymetric resolution and spatial variation of bed friction could be used to improve the SA results.

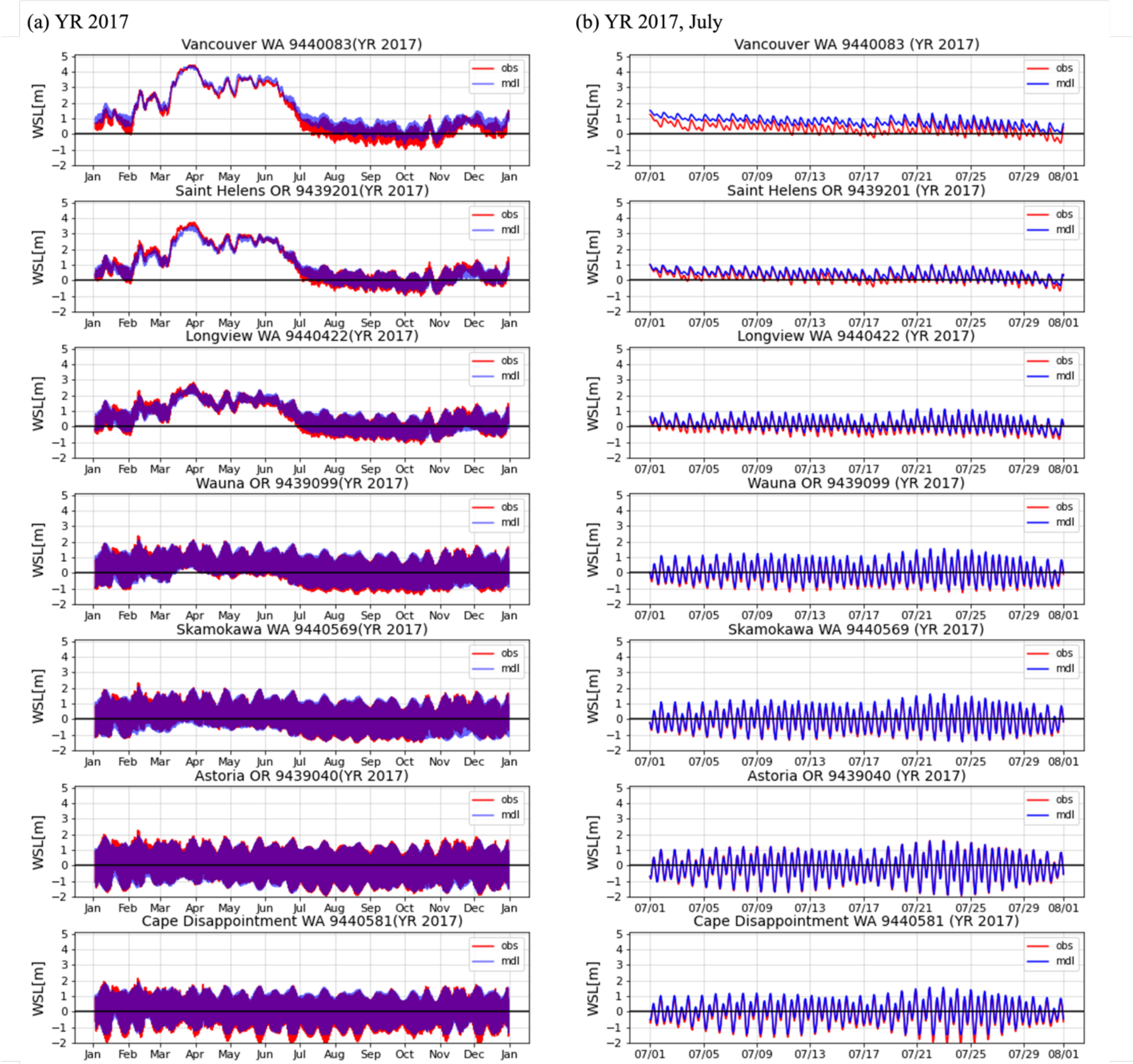


Figure 5: The comparison of predicted WSE (blue) and measured data (red)from the NOAA CO-OPS stations in the Columbia River region of SSCOFS. The left panel (a) shows the timeseries for the full year 2017, and the right panel (b) shows example month July of the year 2017.

b. *Skill assessment for S and T:* As mentioned previously, we have conducted this modeling using raw bathymetry in the Columbia River using a grid resolution restricted to no lower than » 50-100m, and 10 vertical layers. This was done deliberately for consistency with the Salish Sea region of SSCOFS. As a result, in this phase of the project we expect that the estuary will be impacted by the pressure gradient error and will have more mixing than observed. We expect that salinity intrusion will be reduced, more vertical mixing of the surface and bottom layers.

The predicted solution was compared with the 8 CMOP stations. All these stations are located in the estuary region of the Columbia River (RM0 to RM36). Among these 8 stations (Figure 4), the Saturn03 station has data from 3 water depths and most continuous record and is presented in Figure 6 as an example. The reported depth was relative to the NGVD29. We therefore selected a that best matched the measurement depth level considering the datum change. Figure 6 shows that the match with near surface salinity is reasonable. However, the predicted salinity in deeper layers is lower than observed to due to excessive vertical mixing.

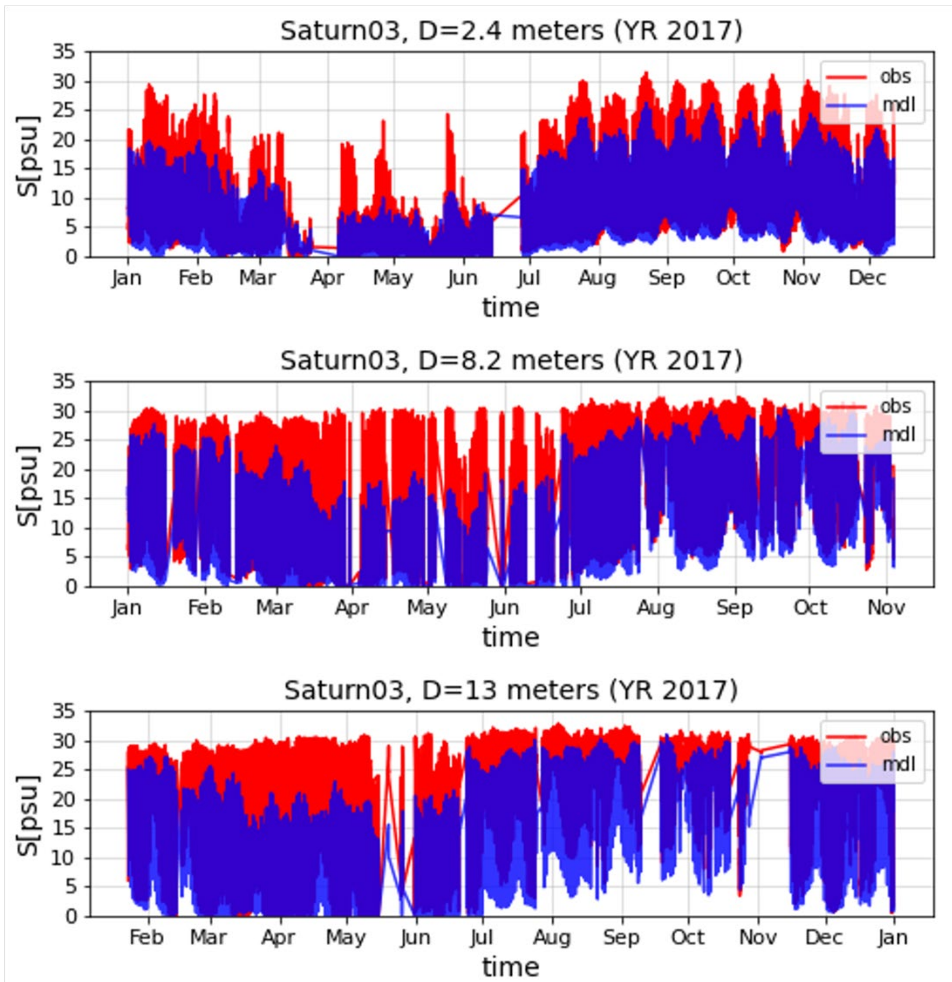


Figure 6: The time series comparison of predicted salinity and observed data from Saturn3 located near the mouth of Columbia River estuary in the Year 2017. The comparison represents 3 different depths relative to the NGVD29 datum from surface to bottom of the water column.

The effect of excessive vertical mixing is also noticeable in predicted temperature but inverted in depth. The near bed temperatures appear to match better than the surface layer. The vertical mixing results in cooler than observed temperatures particularly in the upper layers of the water column as shown in Figure 7**.**

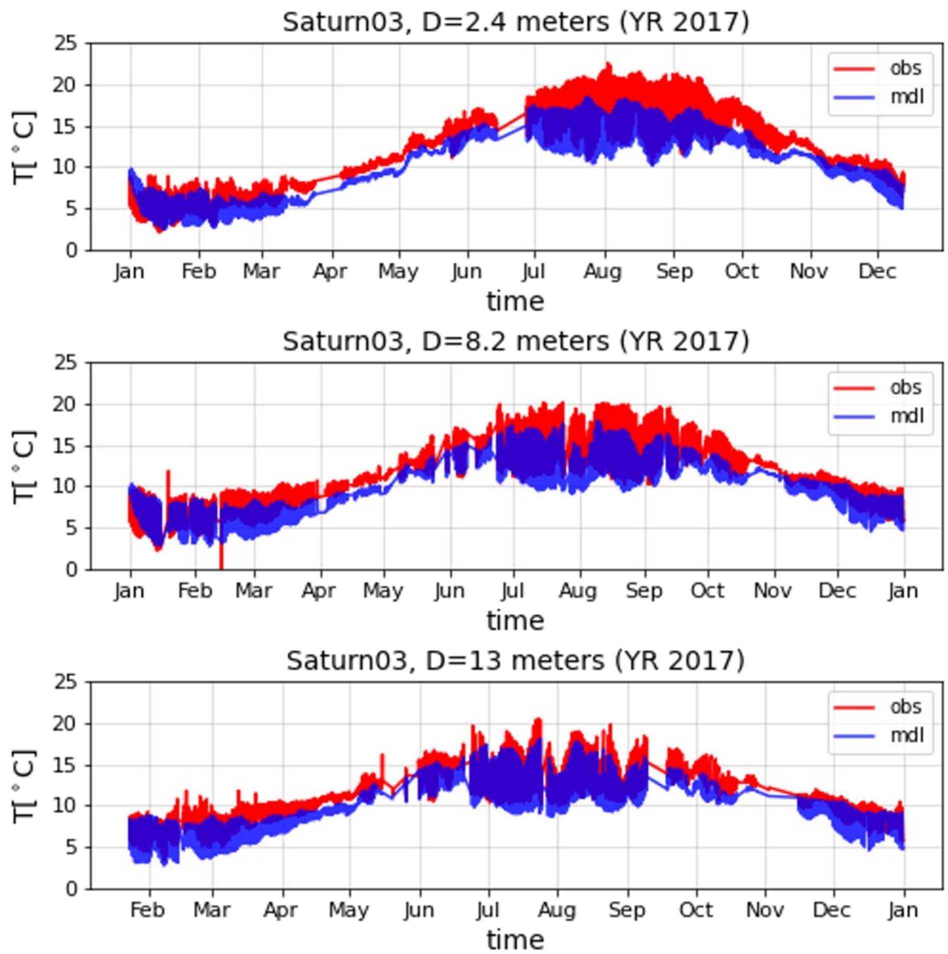


Figure 7: The time series comparison of predicted temperature and observed data from Saturn3 located near the mouth of Columbia River estuary in the Year 2017. The comparison represents 3 different depths relative to the NGVD29 datum from surface to bottom of the water column.

Error analysis of results for temperature and salinity at all available stations from the Columbia River estuary has been completed. However, there is much room for improvement. The average RMSE of Salinity is 2.30 ppt, and the water temperature's RMSE is 1.94 ℃. These errors are higher than our expectation, 1-2 ppt for RMSE of salinity, and < 1 °C for water temperature's RMSE.

Note: While the performance may be acceptable for navigational support, we present these results with full acknowledgement that a detailed temperature and salinity calibration step is needed to improve the model performance to a level that would be suitable for application to water quality simulations.

c. *Skill assessment for currents (u,v):* Due to lack of currents data from 2017, a currents SA is not presented. However, contour plots of current magnitudes during peak flood and ebb periods are presented in Figure 8 for illustration purposes. Figure 8 shows the ebb tide at 4:00 PST and flood tide at 13:00 PST on July 9th, 2017. As the water moves from the Columbia River toward the ocean (Figure 8-a surface currents), the freshwater with a salinity level of 0 ppt moves out at the mouth of the Columbia River (Figure 8-c salinity) at 4:00 PST. On the other hand, the water moves in from the ocean toward the mouth of the Columbia River (Figure 8-b currents). The seawater with a salinity range between 10 ppt to 20 ppt comes from the Columbia River (Figure 8-d).

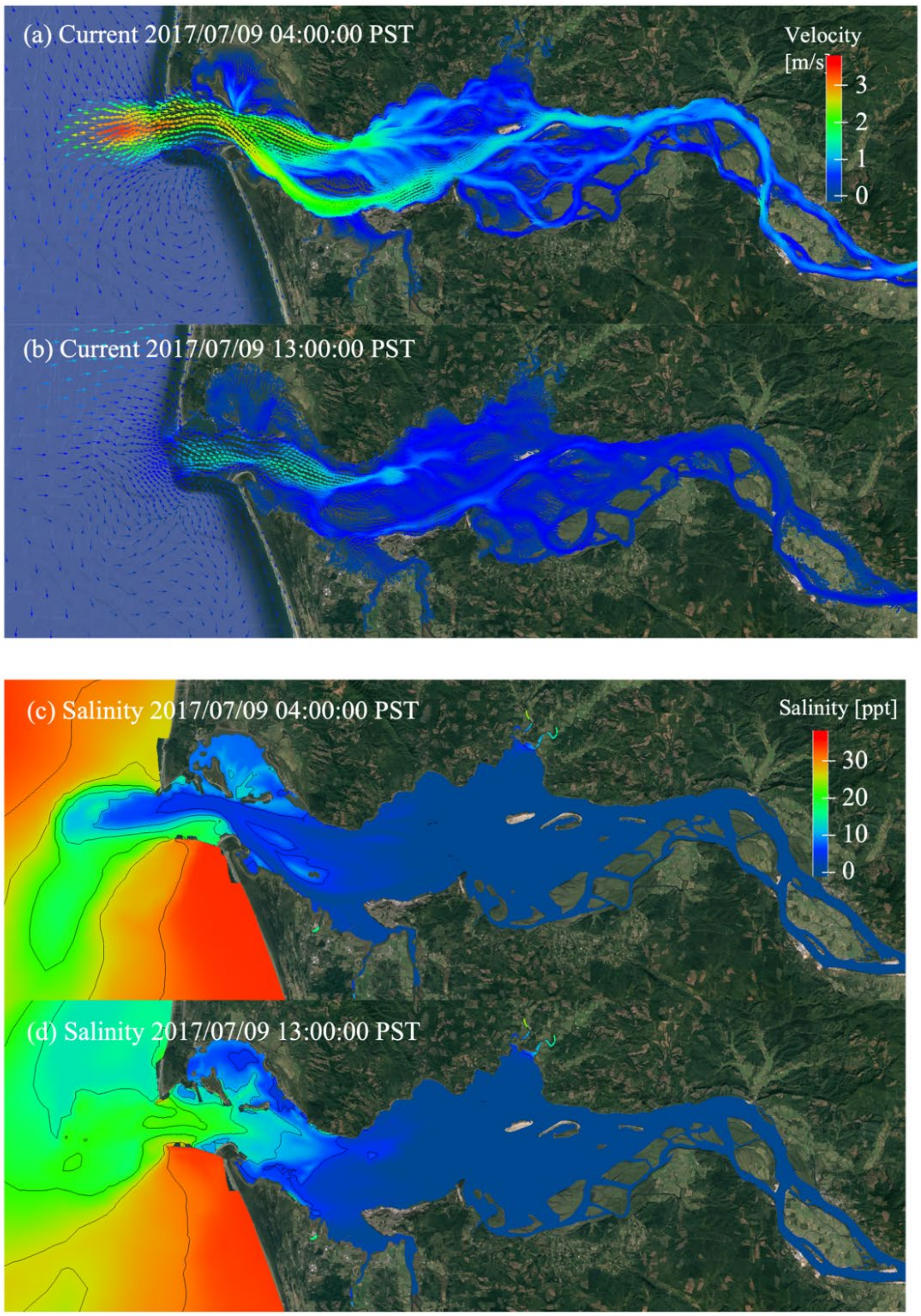


Figure 8: Predicted surface layer currents and salinity in Columbia River estuary region from year 2017 SSCOFS simulation. Results from July 9 of 2017 are show. The upper panels of current (a) and

salinity (c) are snap shots at 4:00 PST, and the lower figures of current (b) and salinity (d) correspond to 13:00 PST.

Task 4: Skill Assessment – Salish Sea regional Focus

While the project objective was an incorporation of the Columbia River into SSM-OFS, it also presented an opportunity to revisit the model performance based on lessons learned. Independent SA conducted by NOAA CO-OPS using the latest SSCOFS results showed that previously completed WSE and currents skill could be further improved with certain compromises on pressure gradient induced limitations and specification of bed friction. The primary challenge was the predicted amplitudes within the Salish Sea. M2 tidal component was noticeably higher than observed at most stations. The direction provided by NOAA CO-OPS was to focus on maximizing the performance for WSE metric while retaining sufficient stratification in most of the Salish Sea through (a) Reduction in smoothing and vertical distortion relative to prior versions, (b) further improving the performance through adjustment (increase) in spatially varying bed friction, and (c) Implementing a boundary adjustment of incident tidal amplitude as a correction to potential error in estimates from ENPAC database.

Using the updated Columbia River grid embedded, SSCOFS was updated as follows.

- Bathymetric smoothing approach to manage sigma-coordinate pressure gradient error was modified. Each sub-basin was smoothed only up to 5% volumetric error. No depth-distortion was implemented to eliminate this volume error. This allowed the tides to propagate into the Salish Sea without alteration of the natural phase.

- Background bed friction was increased from z0 of 0.001 m to 0.006 m providing some loss of tidal energy helping reduce the tidal amplitude.

- Ocean boundary tidal amplitudes obtained from ENPAC were reduced by 5% across all frequencies after a qualitative examination showed that ENPAC constituents were in general higher than those provided by alternate sources such as TPXO.

- Implementation of higher bed friction at selected short reaches such as (a) Entrance to the Strait of Juan De Fuca (b) Passages through the San Juan Islands, and (c) Johnstone Straits

As a result of these modifications, SSCOFS performance for WSE improved significantly nearing CF of 90%. As anticipated, in some sub-basins (eg. Hood Canal, Saratoga Passage), the loss of smoothing affected stratification. However, the change did not appear to impact SA relative to currents significantly.

We compared WSE with data from 7 NOAA CO-OPS stations, currents predictions with NOAA-NCOP Acoustic Doppler Current Profile (ADCP) data from 46 stations from 2017, and salinity (S) and temperature (T) with data from Ecology's 23 monthly monitoring stations. Locations of these monitoring stations are shown in Figure 9 below.

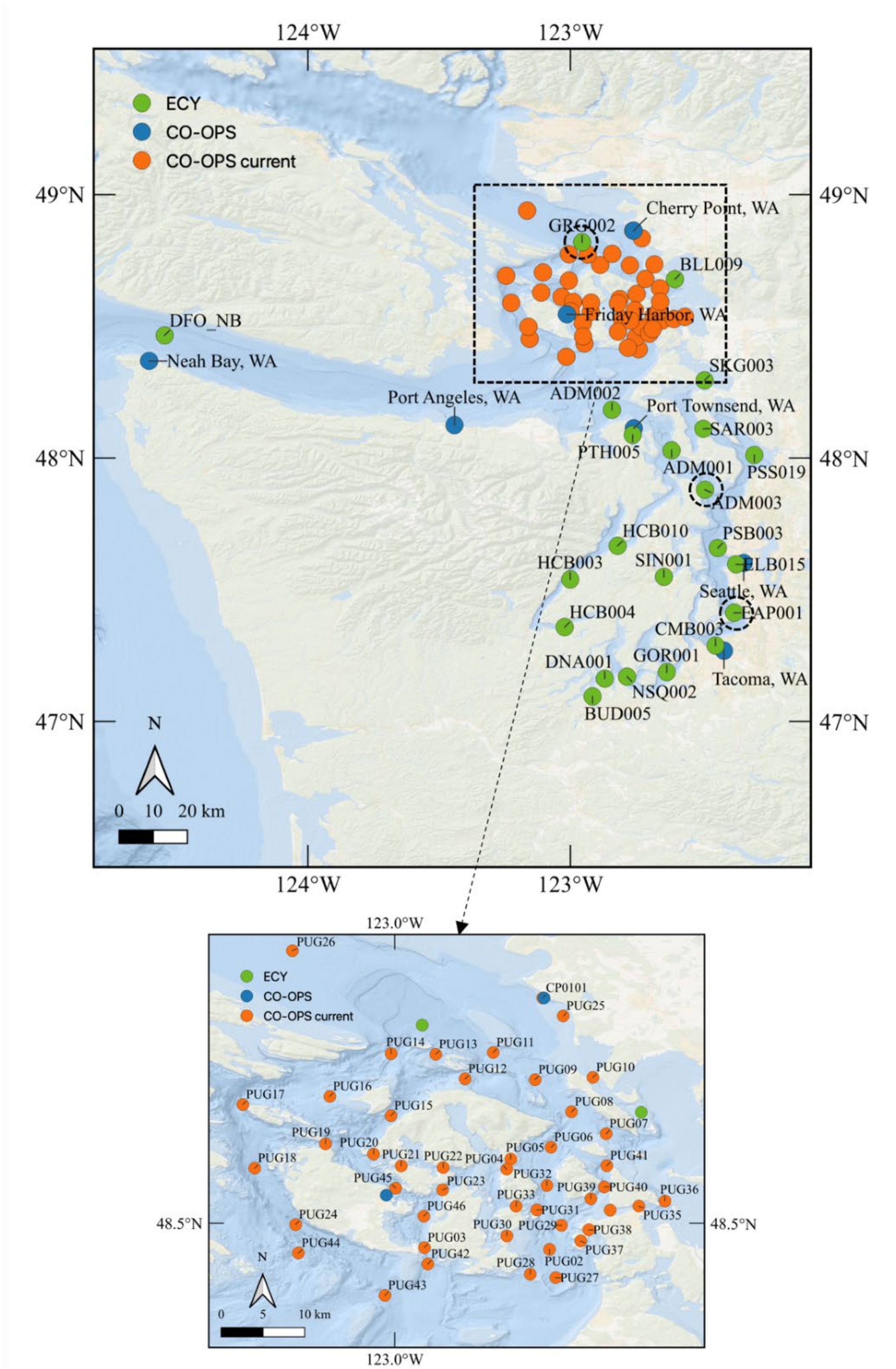


Figure 9: Monthly salinity and temperature monitoring stations from the Washington State Department of Ecology (23 stations ECY, green) and WSE stations from NOAA CO-OPS, (7 stations, blue), and currents from the CO-OPS survey (46, orange) are shown. The ECY stations (GRG002, ADM001, and EAP001) circled with a black dotted line were used as examples of comparison between predicted salinity and temperature and

observed data. The bottom map shows a close-up of the CO-OPS current stations available from the San Juan Island region in 2017.

a. *NOAA- Skill Assessment (NOAA-SA) for WSE:* This analysis was conducted using the same methods as use for the Columbia River region. Table 6 provides skill assessment results for WSE using the NOAA-SA standard. While RMSE levels are < »0.15-0.20 m, the CF levels obtained through comparison to NOAA gage data were closer to the 90% standard relative to past efforts. The model performance improved significantly relative to prior versions at the maximum of 89.7 % at Tacoma, WA station and average of 81.3 %.

Table 6: Model skill assessment for WSE using data for NOAA stations. Only SM (m), RMSE (m), and CF (%) values at Salish Sea stations are presented for simplicity.

Station	SM (m)	RMSE (m)	CF (%)	Datum Conversion MSL to NAVD88 (m)
Neah Bay, WA	0.00	0.13	82.6	-1.23[a]
Port Angeles, WA	0.03	0.14	70.3	-1.17
Friday Harbor, WA	-0.05	0.14	76.2	-1.27
Cherry Point, WA	-0.02	0.14	81.0	-1.32
Port Townsend, WA	-0.02	0.13	80.9	-1.19
Seattle, WA	-0.07	0.15	88.8	-1.31
Tacoma, WA	-0.08	0.15	89.7	-1.33
Average	-0.03	0.14	81.3	

[a] The datum conversion of 1.23 used at Neah Bay was back calculated to provide a SM of 0 as it appeared o be off by 0.11 and appeared to be an outlier relative to nearby stations. All other datum conversions re based on VDATUM software.

b. *NOAA- Skill Assessment for currents:* The current skill assessment results for 2017 were reproduced as a quality assurance step to ensure that the process of improving WSE skill did not result in loss of skill for currents. For simplicity and the purpose of this progress report, we are only representing the RMSE and CF results using an acceptable error limit of 0.26m/s as the target. The results are plotted as bar charts in Figure 10 from all the stations. Table 7 shows the averaged value of RMSE and CF for depth-averaged and surface currents of previous and the new SSSCOFS grids. The RMSE difference is 0 m/s (depth-averaged current) and 0.01 m/s (surface current), and the CF difference is 2.51% (depth-averaged current) and 0.15% (surface currents). The model performance shows the maximum CF at cp0101 as 99 % (surface currents) and 100% (depth-averaged currents). The averaged CF is 64% (surface currents) and 77% (depth-averaged currents). The model performance of currents is comparable to the previous grid.

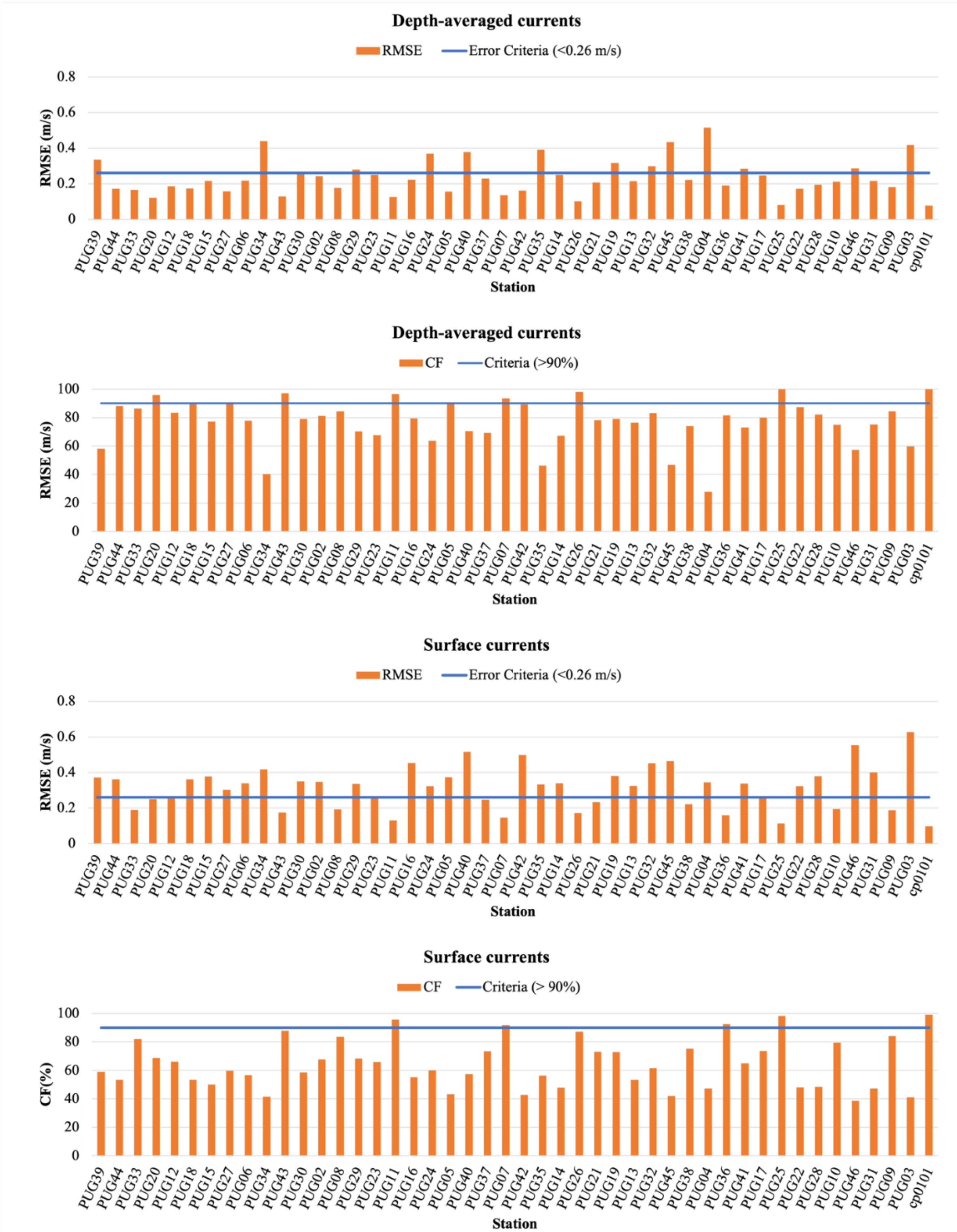


Figure 10: Skill assessment results using NOAA-SA procedures for the Year 2017 dataset. Skill assessment for currents was conducted separately for surface currents and depth-averaged currents. NOAA-SA software produces many metrics. Only the (a) RMSE and (b) CF are presented.

Table 7: Currents skill assessment comparison between previous SSM-OFS grid and updated SSCOFS grid using data from all NOAA ADCP survey stations. Only RMSE and CF values are presented for simplicity

	Depth Averaged Currents		**Surface Currents**	
	RMSE (m/s)	**CF (%)**	**RMSE (m/s)**	**CF (%)**
SSM-OFS grid	0.23	79.68	0.32	64.79
SSCOFS updated grid	0.23	77.17	0.31	64.64

c. *Skill assessment for S and T: Error analysis of T and S is conducted with the comparison* of Ecology's 26 stations. The expected values of RMSE are 1-2 ppt for salinity, and < 1 °C for water temperature. Figure 11 shows an example comparison between predicted salinity and temperature from stations in Georgia Basin and Puget Sound regions of the Salish Sea respectively.

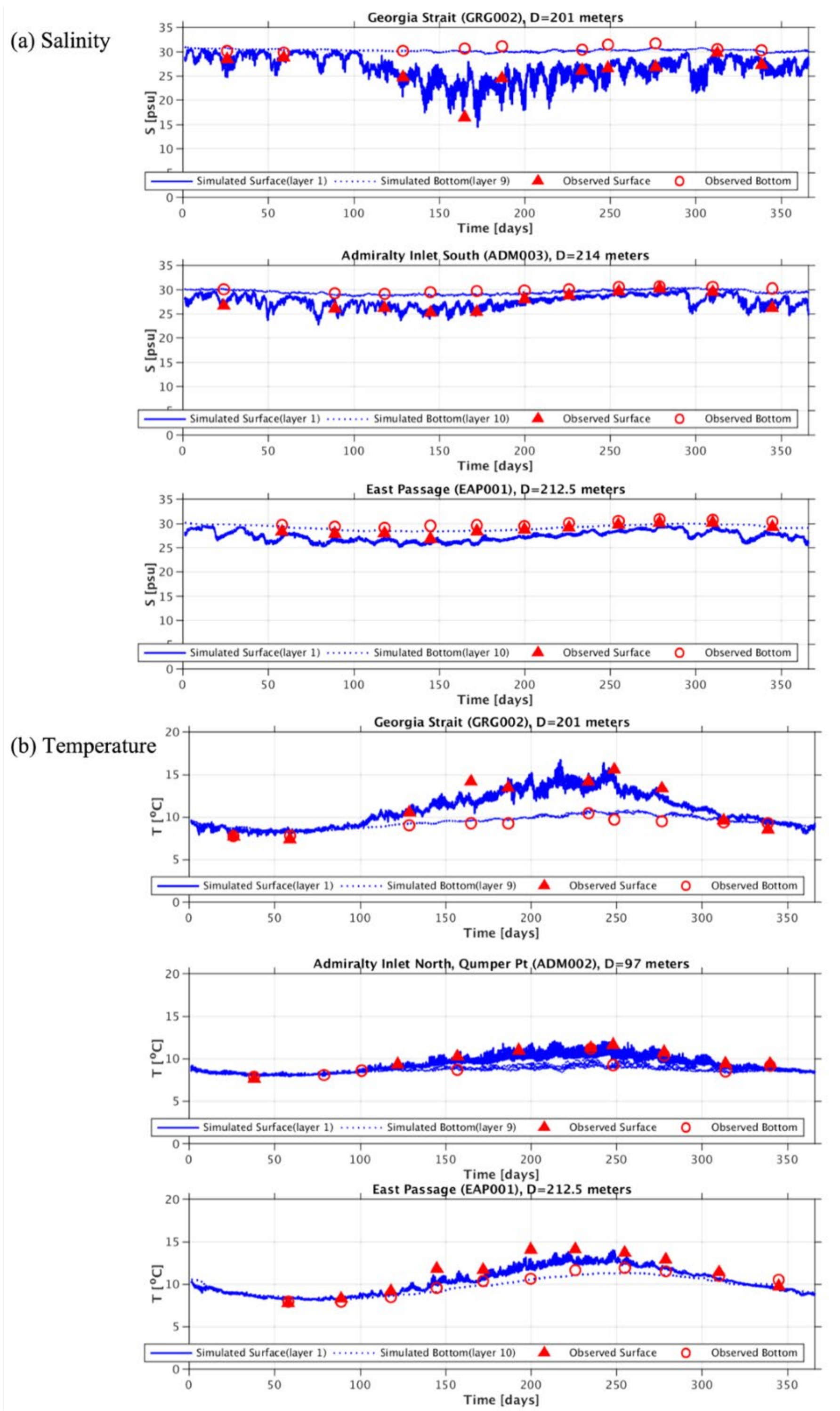


Figure 11. Example comparison of predicted S and T with measured data from Georgia Strait, Admiralty Inlet North, and East Passage. The top panel (a) shows S and the bottom panel (b) shows T with both surface and bottom layer.

As expected, the overall skill in reproducing T and S is acceptable but lower than prior versions with the standard application of bathymetric smoothing. Loss in stratification is noticeable in sub-basins where typically the stratification is strong. These are fjord-like sub-basins of Hood Canal and Saratoga passage. While this may not be an issue for SSCOFS with navigation support as the primary mission, it could impact the ability to simulate water quality in some of the sub-basins. This is not a concern as it implies that a prior fully smoothed version will be needed for studies where water quality is the primary focus.

Conclusion

Based on the improved performance of SSCOFS model, considering the challenges of using sigma-coordinate based model with fjord-like deep estuary, and the fact that performance in the Columbia River has matched CREOFS skill, we conclude that SSCOFS has reached the readiness level for transition to NOS CO-OPS for deployment. Further improvement in model skill is possible through future phases involving (a) further grid refinement, (b) addition of more model layers, and (c) improving bed friction and wind effect through machine learning techniques.