Final Report for the Enhancement of the
Northwest Association of Networked Ocean Observing Systems (NANOOS)
Regional Coastal Ocean Observing System (RCOOS)
NA07NOS4730203

1) Award Information: Provided as a separate Cover Sheet.
Reporting period: 01 October 2007 – 30 September 2011

2) Project Summary

NANOOS is engaged, through this NOAA funding, in an active process to develop, implement, and integrate various in-water and land-based systems that will constitute a fully robust and user-driven Regional Coastal Ocean Observing System (RCOOS) for the Pacific Northwest (PNW). This includes all necessary sub-systems to provide PNW, west coast, and national stakeholders with the ocean data, tools, and knowledge they need to make responsive and responsible decisions appropriate to their individual and collective societal roles. Our ongoing knowledge of prioritized issues and user needs is gained through proactive NANOOS interactions with a wide range of PNW stakeholders.

To attain the goals of this project, with adjustments for funding realities, we are:

- **Maintaining existing surface current mapping capabilities and evaluating the use of additional HF radar sites in the PNW.** This tool is a fundamental foundation block for building an observing system for the coastal ocean and serves a multitude of disparate users.
- **Maintaining observation capabilities in PNW estuaries.** The NANOOS objective in this arena is a federated real-time observation network across Oregon and Washington estuaries to address PNW societal needs.
- **Strategically maintaining coverage and range of observations in the PNW shelf, in coordination with emerging national programs.** We have targeted the use of fixed (buoys) and mobile (glider) assets to provide advanced information on hypoxia/anoxia and Harmful Algal Blooms (HABs), which are major regional concerns affecting ecosystem and human health, fisheries, and coastal economies.
- **Maintaining core elements of existing beach and shoreline observing programs in Oregon and Washington.** This is improving coastal hazard mitigation by providing better decision support tools for coastal managers, planners, engineers, and coastal hazard mitigation decision makers.
- **Evaluating the creation of a federated system of numerical daily forecasts of PNW ocean circulation.** We are extending utility and availability of operational models from the head of tide of estuaries to the outer edges of the exclusive economic zone (EEZ).
- **Bolstering ongoing Data Management and Communications (DMAC) activities to support routine operational distribution of data and information.** Our DMAC design mandates a collaborative, dynamic distributed system of systems that provides a wide range of products, tools, and services to regional user communities while allowing unfettered access to the IOOS national backbone and national information infrastructure.
- **Building from and strengthening ongoing NANOOS education and outreach efforts.** We are conducting these in coordination with other regional efforts (e.g., NSF-funded

STC and COSEE projects), to foster ocean literacy and facilitate use of NANOOS products in the PNW by stakeholders, decision makers, and the general public.

We have delineated a specific NANOOS RCOOS focus on high-priority PNW user-driven applications of: **a) maritime operations; b) ecosystem impacts including hypoxia and harmful algal blooms; c) fisheries; and, d) mitigation of coastal hazards** as these issues represent applications having the greatest impact on PNW citizenry and ecosystems and, we believe, are amenable to being substantively improved with the development of a PNW RCOOS.

3) Final Technical Accomplishments
NANOOS reports in this section in the fashion it adopted in the original proposal; specifically, we divide our final technical report into the sections of our efforts for: a) observing systems (shelf, estuaries, shorelines, and currents); b) modeling (estuaries and shelves); c) Data management and Communications (DMAC); and, d) Education and Outreach.

a) **Observing System:** *NB: Data from all assets reported here are served via NANOOS NVS.*

- Shelf

1. Washington Buoy and Glider observing network operations: Led by M. Alford (University of Washington (UW)), efforts in years 1-3 focused on activities related to designing, fabricating and testing the surface buoy (Cha Ba) of the three-part Washington coast real-time moored array. In years 1 and 2 efforts focused on designing and purchasing equipment and instrumentation. Mechanical and electronics design were largely completed by the end of year 2, and most instrumentation (meteorological, water-column and buoy hardware) had been purchased.

In December 2008 work on this project and the purchase of additional equipment was temporarily suspended due to budget limitations, resuming when Y3 funding became available several months later.

Efforts in Y3 focused on finalizing the surface mooring design and equipment purchases to allow bench-top assembly of the instrumentation/communication framework by January 2010 and a full deployment of the system in Puget Sound in April 2010. To ensure both survivability and serviceability, extensive research was conducted regarding various mooring components including the sub-surface instrument cage and the buoy hull design.

In August, 2009 (Y3), we (Newton, Alford, Devol, Martin, UW) were informed that we were chosen as the recipients of the Murdock Charitable Trust Award, providing $450K for the purchase of equipment/instrumentation in support of this network. Additionally, in September 2009 we hired a field engineer to commit half of his time to assisting with mooring fabrication and maintenance.

2. Oregon Glider operations: The Oregon State University (OSU) glider group led by J. Barth and K. Shearman made nearly continuous measurements off Newport, Oregon, with autonomous underwater gliders using a combination of NANOOS, NSF, and private funding (Moore Foundation). The gliders measure vertical profiles of temperature, salinity, dissolved oxygen, chlorophyll fluorescence, colored dissolved organic matter fluorescence, and light backscatter from near the shore in about 20 m of water to approximately 300 km offshore. Near real-time, the glider reported position and returns a subset of data to shore every 6 hours. The Newport Hydrographic Line was sampled using two different gliders: a 200-m Teledyne Webb Research Slocum glider on the inshore side out to 45 nautical miles offshore; a 1000-m University of Washington Seaglider to sample the deeper waters. The two gliders overlapped over the continental slope to allow data comparison and inter-calibration. From October 2007 to September 2010, the OSU gliders on the Newport line accumulated the following statistics: ~1100 days of operation; 50 separate deployments; 316 cross-margin sections; about 72,000 vertical profiles; 23,150 km of track line.

Impact:
The glider data are useful for assessing changes in water column properties in support of studies of hypoxia, harmful algal blooms, coastal productivity, etc. For example, glider data were used to monitor the progress of the 2009-2010 El Niño. We also used the dissolved oxygen data from the gliders in a variety of ways to understand the increasing occurrence of hypoxia in Oregon shelf waters (e.g., Pierce et al., 2012).

We maintained a working web page to monitor the health and status of our at-sea gliders (http://gliderfs.coas.oregonstate.edu/gliderweb). The page also includes information about OSU glider group personnel and the goals of our project. We provided near real-time plots of glider data to the NANOOS Visualization System. We supplied quality-controlled glider data to our NANOOS colleague, Dr. Alexander Kurapov, for assimilation into his Oregon coastal ocean circulation model.

During each summer, an undergraduate student from outside OSU joined our glider research team as a Research Experiences for Undergraduates fellow: Rosalinda Fortier (University of Rhode Island, 2008); Meghan Flink (Linfield College, Oregon, 2009); Derrick Monroy (New Mexico State University, 2010).

J. Barth represented NANOOS at the North Pacific Marine Science Organization (PICES) Annual Meetings during 2007-2010.

Presentations acknowledging NANOOS support:

Shearman, R. K., J. A. Barth, A. Erofeev, L. Rubiano-Gomez, J. Brodersen and R. Fortier, 2007: Autonomous glider observations from the Oregon shelf, The new vagaries of fortune. AGU Fall Meeting, Invited Abstract OS31E-01.

Fortier, R., R. K. Shearman, J. A. Barth, A. Erofeev, L. Rubiano-Gomez and J. G. Brodersen, 2007: Subducting tongues of warm, high-chlorophyll water on the Oregon shelf. AGU Fall Meeting, REU session abstract, OS33C-1360.

Barth, J. A., F. Chan, S. D. Pierce, R. K. Shearman, A. Erofeev, L. Rubiano Gomez and J. Brodersen, 2007: Interanual variability and modeling of upwelling-driven hypoxia off the central Oregon coast. AGU Fall meeting, Abstract OS43C-1312.

Barth, R. K. Shearman, A. Y. Erofeev and T. Peery, 2008: Summertime hypoxia off central Oregon as observed using autonomous underwater gliders. Eos Trans. AGU, Ocean Sci. Meet. Suppl., Abstract.

Erofeev, A., J. A. Barth, R. K. Shearman, T. Peery, L. Rubiano-Gomez and J. Brodersen, 2008: Long-term glider observations off the Oregon coast. Eos Trans. AGU, Ocean Sci. Meet. Suppl., Abstract.

Barth, J. A., 2008: Physical processes of shelf-open ocean exchange and their influence on upwelling ecosystems. Eastern Boundary Upwelling Ecosystems Symposium: Integrative and Comparative Approaches, Las Palma, Gran Canaria, Spain, June 2008.

Barth, J. A., S. D. Pierce and F. Chan, 2008: The changing coastal ocean: Low-oxygen water off the Pacific Northwest. AGU Fall meeting, Abstract.

Barth, J. A., R. K. Shearman, F. Chan, S. D. Pierce, A. Y. Erofeev, J. Brodersen, M. D. Levine, K. Page-Albins, C. Risien, L. Rubiano-Gomez, and B. W. Waldorf, 2009: An expanding observatory to monitor hypoxia in the Northern California Current System. Presented at the Ocean Obs'09 Conference, September, 2009, Venice, Italy.

Barth, J. A., S. D. Pierce, F. Chan and Collaborators, 2010: Spatial and temporal variability in near-bottom hypoxia over the Pacific Northwest continental shelf, Presented at the Eastern Pacific Ocean Conference, September 2010.

Mazzini, P. L. F., J. A. Barth , R. K. Shearman, A. Y. Erofeev, J. Brodersen, L. Rubiano and K. Adams, 2010: Seasonal variation of fresh water content off the Oregon coast estimated from glider observations. Presented at the Eastern Pacific Ocean Conference, September 2010.

Adams, K., J. Barth, K. Shearman, A. Erofeev, F. Chan, R. Milston-Clements, K. Page-Albins, J. Brodersen, L. Rubiano-Gomez, 2010: Along-shelf variability of central Oregon oxygen minimum zone during 2009 upwelling season. Presented at the 2010 Ocean Sciences Meeting, Feb. 2010, Portland, OR.

Barth, J. A., S. D. Pierce, F. Chan, B. A. Menge, W. T. Peterson, J. Peterson, C. Morgan, R. K. Shearman, A. E. Erofeev, M. D. Levine, B. Crump, L. Herfort, R. Feely, B. Hales, S. Rumrill, and M. S. Brancato, 2010: Spatial and temporal variability in near-bottom hypoxia over the Pacific Northwest continental shelf. Presented at the 2010 Ocean Sciences Meeting, Feb. 2010, Portland, OR.

Erofeev, A., J. A. Barth, R. K. Shearman, L. Rubiano-Gomez, and J. Brodersen, 2010: Seasonal and interannual variability of hydrographic and bio-optical fields off central Oregon from glider observations. Presented at the 2010 Ocean Sciences Meeting, Feb. 2010, Portland, OR.

Outreach activities acknowledging NANOOS support:

Oregon Association of Environmental Professionals Forum, Portland, OR, October 25, 2007. (J. Barth).

Heceta Head Conference, Florence, OR, October 27, 2007. (R. K. Shearman).

High School Student Job Shadow, COAS, OSU, December 2007. (R. K. Shearman).

Interview about ``Northwest Dead Zone," National Public Radio's ``Living on Earth" with Steve Curwood, March 8, 2008. (J. Barth).

"Oregon's Dynamic Coastal Ocean: Climate Variability and Ocean Observing," Oregon Coast Aquarium Rockfish Society, Portland, OR, May 14, 2008. (J. Barth).

Glider display, HMSC SeaFest, Newport, OR, June 2008. (L. Rubiano-Gomez and R. K. Shearman).

Seminar and demonstration on autonomous underwater gliders, Oregon Institute of Biology, Charleston, OR, July 2008. (R. K. Shearman).

Hatfield Marine Science Camp Oceanography Science Camp tour of glider lab, COAS/OSU, July 30, 2008. (J. Barth)

"Dead Zones: Mysteries of Ocean Die-Offs Revealed," NSF Special Report multimedia, 10/8/2009, http://www.nsf.gov/news/special_reports/deadzones/ (J. Barth).

"Ocean Dead Zones," Canadian Broadcasting Corporation's "As It Happens" radio interview, 10/14/2009, http://www.cbc.ca/radioshows/AS_IT_HAPPENS/20091014.shtml (starts at 19:28 in Part III) (J. Barth).

"Dead Zones," Dr. Kiki's Science Hour, This Week in Technology podcast, 11/21/2009, http://wiki.twit.tv/wiki/Dr._Kiki%27s_Science_Hour_24 (J. Barth).

"Undersea Gliders May Help Oceanographers Understand 'Dead Zones'," NSF Science Nation video, 11/16/09, http://www.nsf.gov/news/special_reports/science_nation/deadzones.jsp (J. Barth).

"Dead Zone Update," Oregon Field Guide, Oregon Public Broadcasting, March 18, 2010, http://www.opb.org/programs/ofg/segments/view/1747 (J. Barth).

"The Changing Sea," Canadian Broadcasting Corporation documentary "One Ocean," March, 25, 2010, http://oneocean.cbc.ca/series/episodes/4-the-changing-sea and http://oneocean.cbc.ca/series/experts/jack-barth (J. Barth).

Publications acknowledging NANOOS support:

Pierce, S. D., J. A. Barth, R. K. Shearman and A. Y. Erofeev, 2012. Declining oxygen in the Northeast Pacific. J. Phys. Oceanogr., in press.

3. Oregon Buoy (mooring) operations*:* Led by M. Levine (OSU), a mooring about 10 miles off Newport, Oregon, at a site known as NH-10 was in operation from October 2007 through September 2010 as part of the NANOOS RCOOS. The result of this project has led to a remarkably near-continuous set of real-time observations, and the resulting archived data set will continue to be of value into the future.

About every six months the mooring was recovered, and a refurbished mooring was deployed. The buoy was operational over this three year period, except for a gap from December 2007 to April 2008, caused by a severe storm event that produced the first-ever hurricane-force wind warning for the Oregon coast. The mooring measured a combination of atmospheric and ocean parameters. Ocean sensors measured temperature, salinity, and water velocity at a number of depths. Occasionally, sensors measuring chlorophyll fluorescence, turbidity, dissolved oxygen and pCO_2 were also attached to the mooring. The meteorological package measured: wind velocity, air temperature, atmospheric pressure, and incoming solar radiation. The specific number of sensors on a given deployment depended upon availability, as most sensors were borrowed from other projects.

The mooring field work required the use of a medium-sized UNOLS vessel or equivalent for a minimum of 1 day, twice per year. Funding for ship time was primarily provided by NSF through the Science and Technology Center for Coastal Margin Observation and Prediction (CMOP).

Impact:

Some of the data were transmitted to shore in near-real time through a cellular phone modem and were available on the NANOOS Visualization System (http://www.nanoos.org/nvs/nvs.php). The data were also displayed by the National Data Buoy Center as station #46094 (http://www.ndbc.noaa.gov/station_page.php?station=46094). These data were used by numerous scientists and others for applications such as hypoxia, climate variability and change, ocean acidification, and coastal transport.

Presentations acknowledging NANOOS support:

Risien, C.M., J.A. Barth, P.M. Kosro, M.D. Levine, R.K. Shearman and W. Waldorf. 2008. Space/time evolution of low-salinity events along the Oregon coast. Eastern Pacific Ocean Congress (EPOC) meeting, Sept 2008.

Barth, J. A., S. D. Pierce, F. Chan, B. A. Menge, W. T. Peterson, J. Peterson, C. Morgan, R. K. Shearman, A. E. Erofeev, M. D. Levine, B. Crump, L. Herfort, R. Feely, B. Hales, S. Rumrill, and M. S. Brancato, 2010: Spatial and temporal variability in near-bottom hypoxia over the Pacific Northwest continental shelf. Presented at the 2010 Ocean Sciences Meeting, Feb. 2010, Portland, OR.

4. Northern Oregon to Central Washington shelf:

Glider: OHSU-CMOP operated a glider in the WA shelf and maintained two seasonal buoys in the OR shelf off the mouth of the Columbia River, with applications to ecosystem impacts and fisheries.

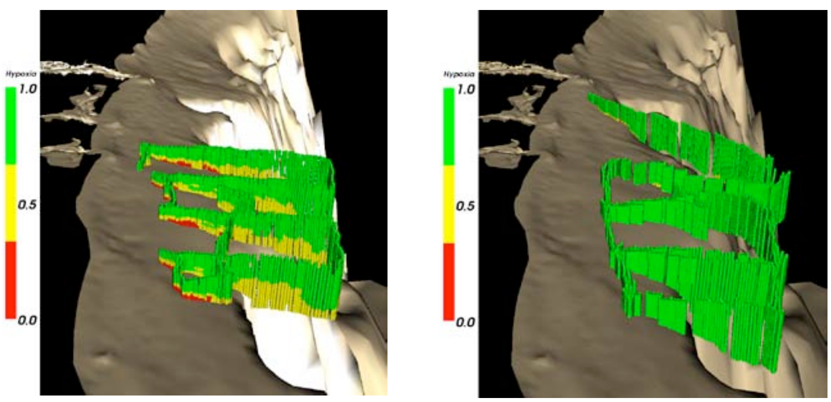

Fig. 1: Glider tracks for missions conducted (left) 2009-07-23 to 2009-08-21; and (right) 2010-07-08 to 2010-08-09. Views are from the North, with the continental slope off WA and OR visible in the right side of the images; and Grays Harbor, Willapa Bay and the Columbia River visible in the left side of the images. Colors represent the degree of oxygenation of the water: well oxygenated (green; DO > 1.4 ml/l), mild hypoxia (yellow; 0.5 ml/l < DO < 1.4 ml/l) and strong hypoxia (red; DO < 0.5 mg/l). Images are reflective of the higher oxygenation of the WA shelf observed in 2010 relative to 2009.

First deployed on 17 May 2009, the glider has since flown 351 days. The glider operation is seasonal (spring through early fall), and is conducted in collaboration with the Quinault Indian Nation (QIN) Department of Fisheries. Missions typically lasted 1-5 weeks and were flown in a modified radiator pattern (e.g., Fig. 1) across the WA shelf, from Grays Harbor to Quinault.

Impact:

The glider missions were designed to:

- Support QIN fisheries management, via the characterization of hypoxia in the WA shelf.
- Address a spatial gap (WA coast) in sustained observations of hypoxia and harmful algal blooms in the California Current system.
- Characterize changes in the ocean conditions (including but not limited to hypoxia) that affect the function of the Columbia River as an estuarine bioreactor.

- Support the definition of boundary conditions for emerging ecosystem models for the Columbia River coastal margin.

- Support a multi-purpose operational Oxygen Watch, geographically focused on the Columbia River coastal margin. The Watch is maintained by OHSU-CMOP, to address needs of three partner agencies (NOAA, QIN and Columbia River Inter-Tribal Fish Commission – CRITFC) with mandates on the management of fisheries resources, including the management of various ESA-listed salmon and steelhead stocks.

For the reporting period, we note in particular that the glider missions captured the sharp differences in the oxygenation levels for the WA shelf between 2009 (when hypoxia was pervasive) and 2010 (when waters were, with few exception, well oxygenated). Figs. 1 and 2 both illustrate these differences. These two years (2009 and 2010) represent the beginning of what we envision as a long-term time series of glider observations in the WA shelf, with similar spatial coverage.

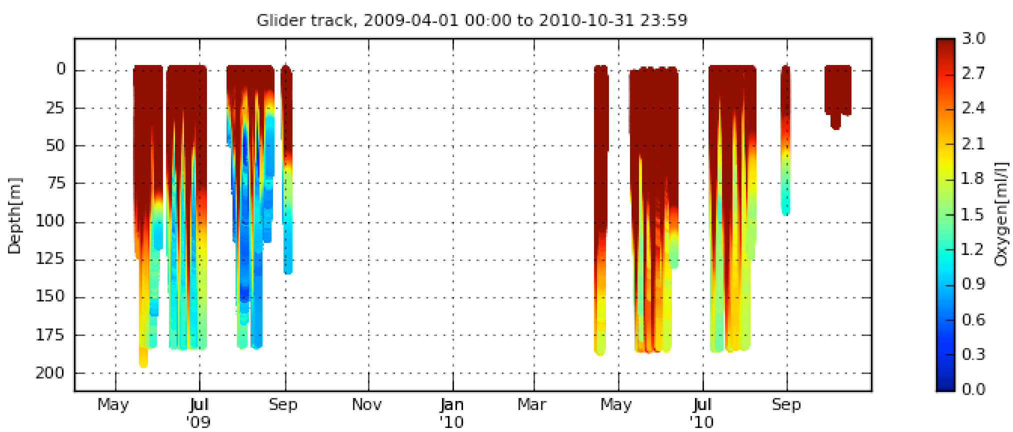

Figure 2: Temporal coverage by the OHSU-CMOP glider missions in 2009 and 2010. The graphs are truncated at 3 mg/l of DO, to better illustrate the difference in low oxygen conditions between the two years. Starting in 2012, we will seek to minimize gaps between missions by operating two gliders in temporal rotation, within the same mission plan. The goal is to achieve nearly continuous coverage from late April through early October, every year.

Operations have been conducted with a single Slocum Glider, manufactured by the Webb Research Corporation. Instrumentation include sensors for salinity, temperature, chlorophyll fluorescence, turbidity (via backscatter), color dissolved organic matter (CDOM) and dissolved oxygen (DO). Operational experience in 2009 and 2010 suggested the need for a second glider, with the same instrumentation package, to minimize data gaps associated with glider repair or routine maintenance. This second glider was acquired in late 2011, and is planned to start operations in 2012.

Buoys: Two seasonal buoys (OGI01 and SATURN-02) were deployed in the OR shelf off the mouth of the Columbia River. The stations were designed to operate from Spring to early Fall, with skeletal configurations over the winter; actual periods of deployment during 2007-2010 are shown in Fig. 3, via their recorded time series of temperature. Both stations are envisioned as inter-disciplinary multi-level endurance stations, but were operated only in very limited configurations during the reporting period, due to funding restrictions.

The SATURN-02 buoy is installed in the northern OR shelf, at ~40m depth, within the region of influence of the Columbia River ebb tides. It was designed to capture (e.g., Fig. 4) the vertical structure of the near-field freshwater plume, as well as the ocean sources into the estuary. The information is required to understand the variability of estuary-ocean exchanges, which is critical in order to understand (a) hypoxia in the river-to-ocean continuum in the PNW, a major interest of various stakeholders including NOAA, CRITFC and QIN; (b) the role of the estuary and the plume in salmon life cycle, which is subject to ESA-related biological opinions and is a target of multiple regional projects led by the NOAA Northwest Fisheries Science Center (some of which with the participation of OHSU-CMOP); and (c) the role of the estuary as a bioreactor that transforms biogeochemically the biogenic and anthropogenic river inputs, thus modulating water quality and ocean productivity in the OR and WA shelves near the Columbia River (a major scientific target of multi-institutional CMOP science initiatives).

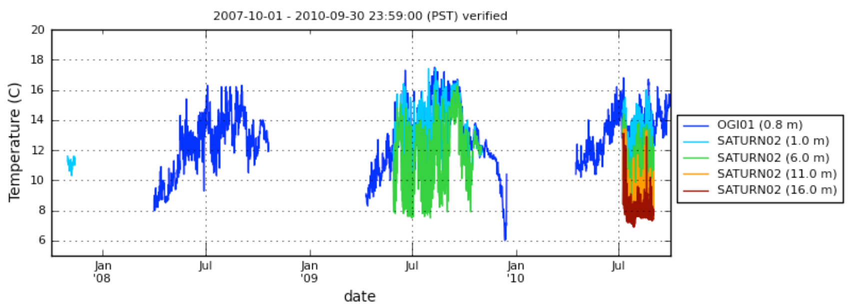

Figure 3: Time series of temperatures at OGI-01 and SATURN-02, for the reporting period.

In its present configuration (which started April 2011), SATURN-02 is a six-level buoy, with:

- at the surface: telemetry (spread spectrum radio); velocity profile via a downward-looking acoustic Doppler profiler (ADP); atmospheric data (winds, air temperature and humidity); and water properties: salinity, temperature, chlorophyll fluorescence, turbidity (via backscatter), CDOM, DO and nitrate.
- at 6, 11, 16 and 21 m below the surface: salinity and temperature;
- at 35 m below the surface: DO, salinity and temperature.

During the reporting period, however, only velocities, and salinity and temperature (at a maximum of four levels; Fig. 3) were recorded at SATURN-02. The complexity and variability of the vertical density structure is illustrated in Fig. 4, and a skilled representation of the observed stratification is a demanding challenge for numerical models (not shown), underscoring the need for these observations.

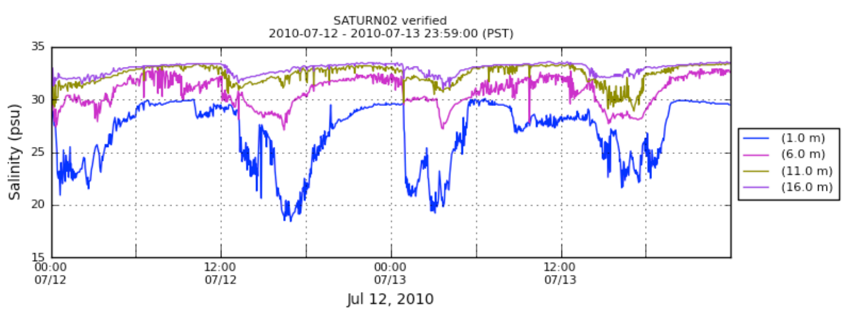

Figure 4: The vertical structure of salinity at SATURN-02 reflects multiple influences (tides, upwelling regime, and river discharge) and scales of variability. Here, the signature of ebb tides is clearly visible near the surface, and greatly diminished but still apparent 16 m below the surface. During sustained upwelling (not shown) the thickness of the freshwater plume is substantially reduced, often to 5m or less.

The OGI01 buoy is installed in the northern OR shelf, at 100m depth. Instrumentation was limited during the reporting period to surface temperature (Fig. 3) and salinity. Expansion to an inter-disciplinary package of sensors will be done as funds allow.

Data from all the above platforms, and those from the Columbia River estuary (below), were publicly available. NANOOS NVS functions as the PNW-integration portal, displaying real-time data and allowing downloads of recent data; it also contains links to the CMOP SATURN website, which offers access to both the near real-time data and since-inception archival data, besides allowing interactive analysis of data within and across stations through the SATURN Data Explorer.

- **Estuaries**

1. Puget Sound, ORCA Buoy program: Led by A. Devol and J. Newton (UW), the ORCA (Oceanic Remote Chemical Analyzer) group maintained 4 buoys in operation in Hood Canal, and one in the main basin of Puget Sound. Buoys were maintained at Twanoh, Hoodsport, and Hansville throughout the project period. In May 2010, the Duckabush mooring was moved to Dabob Bay to help study the "oyster emergency" via funds from the Puget Sound Partnership, who along with the shellfish industry, are concerned with ocean acidification as a possible cause of the reduced shellfish hatchery larval set. Full buoy location details are available online (see http://orca.ocean.washington.edu via the NANOOS web portal). Each buoy measured vertical profiles of temperature, salinity, dissolved oxygen, chlorophyll fluorescence, and meteorological data. Additionally, some buoys also measured currents, nitrate, PAR (photosynthetically active radiation) and turbidity. All buoy data were continuously available in real time on the NANOOS website. These observations were leveraged with the Hood Canal Dissolved Oxygen Program and NSF funding.

During the project period several upgrades were performed on the buoys. One major upgrade was a redesigned power system, which included a wind generator and updated solar charger. The original buoy power system used only solar energy to charge the battery banks, allowing ample profiles (12 profiles/day) during the summer months, but limiting profiling capacity during the winter months to 1-2 profiles/day. The addition of wind generators allowed higher sampling frequency in the winter months when the storm activity was higher. The updated solar charger allowed better monitoring of the battery banks and more precise trouble-shooting of the power system. Another major upgrade was that of the weather station. Switching from a station with a mechanical anemometer to one with ultrasonic transducers eliminated moving parts, thereby adding a level of robustness to the system. In addition to the standard variables measured with the old weather stations (i.e., temperature, solar radiation, etc.) the new stations also more accurately measured barometric pressure and added the ability to log the buoy position via GPS. Upgrades to the sensor package included the integration of new sensors, namely the Satlantic ISUS nitrate sensor and the Nortek Aquadopp current profiler.

Through collaboration with NOAA PMEL (D. Feely and C. Sabine), we installed pCO_2 sensors on the Twanoh and Dabob Bay moorings in July 2009 and July 2010, respectively. Data from the pCO_2 sensors were available online through the NANOOS web portal. We also collaborated with the IOOS-funded Alliance for Coastal Technologies (ACT) during their project to field test several different pCO_2 sensors for comparison by mounting them on the Twanoh mooring for 30 days and assisting with the intensive nearly-daily sampling regime during the project.

Key Findings and Impact: Though we observed substantial inter-annual variability, the general seasonal cycles at the moorings were consistent during the study. Below we describe the seasonal cycles at each mooring site, with 2007 as an example year.

Twanoh: Temperature at depth was fairly consistent through-out the year. At the surface, the temperature ranged from below 5 degrees C in the winter months to over 20 degrees C in mid-summer. The strong pycnocline at 5-10 m coincided with a sharp salinity gradient resulting from high rainfall (~1500 cm annually). Large rain events, usually occurring in the winter months, decreased the surface salinity to below 16 psu for the duration of the event. Salinities in the deeper waters generally decreased during the first half of the year and then increased for the last half, with a sharp increase in October when high-salinity, relatively high-oxygen water from Pacific coastal upwelling flood into Hood Canal and displace the existing deep water (ventilation event). Dissolved oxygen in the bottom waters was low throughout the year, and in late summer of 2006 and 2010 some of the lowest concentrations observed at this site during the HCDOP study were recorded. Even so, the values generally increased through April and then decreased until the ventilation event; by September, hypoxic water (=< 2 mg/l; 64 µmol) was present up to the pycnocline. Surface oxygen concentrations generally co-varied with chlorophyll concentrations, and super-saturation often occurred with chlorophyll bloom events. The oxycline followed the depth of the chlorophyll max. Chlorophyll blooms typically started in February, and occurred sporadically throughout the spring. The main phytoplankton growing season began around April and continued through October, with peak chlorophyll concentrations greater than 45 mg/m^3. The early bloom typically occurred at the surface and nutrients were depleted rapidly; maximum chlorophyll concentrations were subsurface by March and remained sub-surface along the nitracline through-out the growing season. Nitrate was present in the surface during the winter months, after which the nitracline deepened until it reached its maximum in July. Nitrate concentrations at depth varied between 25 and 35 µmol through-out the year. Current meter data from Twanoh indicated that upwelling during the fall ventilation event may draw hypoxic water out of Lynch Cove. This mid-depth extrusion of hypoxic water may exacerbate the low oxygen conditions at Hoodsport at a time when it is most susceptible to fish-kills.

Hoodsport: The seasonal cycles at Hoodsport were similar to those observed at Twanoh. Hoodsport was generally less stratified with deeper mixing depths than Twanoh; temperatures at the surface were a few degrees warmer in the winter, and a few degrees cooler in the summer; water had less of a freshwater signature at the surface, though large rain events in the winter still resulted in salinities less than 20 psu. The oxycline, nitracline, and depth of the chlorophyll max all co-varied as they do at Twanoh with similar magnitudes, though the oxygen concentration below the oxycline was typically higher than that observed at Twanoh. At depth there was less variation observed. Temperature increased and salinity decreased gradually from January through the summer, then reversed sharply during the fall ventilation event. Oxygen at depth decreased steadily during the summer, with hypoxic water shoaling upward during the late summer/early fall. By late September this hypoxic water was near the pycnocline, and given the right atmospheric conditions could break through to the surface water and result in a fish kill, as happened in 2006 and 2010. The fall ventilation brought in relatively higher oxygen concentrations, which may influence the oxygen concentrations at depth the following year.

Nitrate concentrations at depth were generally over 20 µmol through-out the year, though the fall ventilation brought in water with relatively lower nitrate concentrations.

Duckabush: The seasonal cycles at the Duckabush mooring were nearly identical in pattern to those observed at Hoodsport, both in the surface layers and at depth, with values that were seemingly more tempered by oceanic input than those at Hoodsport. The temperatures at the surface and at depth were typically a few degrees colder than at Hoodsport, and salinities were generally higher, although the November rain event during 2007 was evident in the data with a pycnocline at the same depth as was observed at Hoodsport. Surface oxygen and chlorophyll co-varied, and though we did not have a nitrate sensor deployed at this site, we can infer from the Hoodsport data that they also followed the nitracline. Maximum chlorophyll concentrations were generally above 45 mg/m^3 during the peak of the growing season, similar to concentrations observed at Twanoh and Hoodsport. At depth, the Duckabush site was colder and more saline, with higher oxygen concentrations than at Hoodsport. The late summer shoaling of deep water up to the surface was observed at Duckabush as well, though the water that shoals was not as hypoxic, having mixed with higher oxygenated waters at this part of Hood Canal. The ventilation event was observed a few weeks earlier than at Hoodsport, with a less sharp increase in the first of three distinct salinity increases, but sharp increases in the next two.

Dabob Bay: The deployment at Dabob Bay in 2010 was not long enough to observe the full seasonal cycle. During the period of data collection from May through October 2010, a typical summer growth season was observed, similar to that at Duckabush and Hoodsport. Oxygen concentrations were typically high, with no deep water hypoxia.

North Buoy: The water column at the North Buoy was relatively well mixed through-out the year. Temperature increased from January through August, and then began decreasing again through December. Salinity gradually increased from January through late summer, then strongly increased during the fall ventilation event and began decreasing again in December. Oxygen concentrations were significantly higher than at the three southern mooring sites in Hood Canal, and increased at depth until mid-August. The ventilation event brought relatively lower oxygen water past the North buoy, and oxygen concentrations decreased starting in August, then began increasing again in December. Small chlorophyll blooms (~5 mg/m^3) occurred throughout the early spring and summer. Larger blooms occurred during the summer growing season, though the maximum concentrations were significantly lower than those observed at the southern moorings, and the blooms were never subsurface, suggesting there was no nitrate limitation at this site.

Pt Wells: The main basin of Puget Sound observed at the Point Wells mooring was similar to the North Buoy, with a well-mixed water column through most of the winter months. However, a strong seasonal growth was observed in the surface layers during the summer as well. Oxygen concentrations were generally high throughout the year, with no hypoxia observed at depth.

Fish Kill Events: It was only through the understanding of drivers of the variation in these various locations in Puget Sound that we were able to understand hypoxia in Hood Canal, and thus be able to advise the Washington State Dept of Fish and Wildlife, Dept of Ecology, and others re an increased understanding of natural and anthropogenic drivers of hypoxia. The seasonal and interannual variation in data from these buoys was instrumental in identifying a major stakeholder-driven objective: to investigate the frequency and forces involved in fish kills in southern Hood Canal. Observations from the Hoodsport ORCA mooring suggest some fish kills are caused by the combination of the gradual depletion of deep water oxygen, followed by shoaling of oxygen depleted deep water to just under the pycnocline, driven by the annual intrusion of high salinity water from the Pacific Ocean. Changes in the surface water column during a fish kill event typically occur rapidly, while low oxygen conditions in the deep layer develop over the summer. As the annual intrusion of dense ocean water travels down the canal, the low oxygen water shoals up near the surface, residing just below the mixed layer by early fall. A rapid sustained upwelling-favorable wind event from the south will then potentially push the surface water layer northwards and result in outcrops of low oxygen water at the surface. When the wind event dies down, the oxygen-rich surface returns and conditions stabilize quickly. Despite the quick recovery of the surface layer, the hypoxic water column during the event leaves little refuge for marine life and can result in a major fish kill event. One such event was observed in 2006, with oxygen concentrations in the surface layer decreasing by ~125 umol/kg (4mg/L) to values less than 20 umol/kg (~0.6 mg/L) over just 12 hours. The 24 hour wind event that precipitated the upwelling lasted just 24 hours and ended abruptly, with surface oxygen concentrations returning to pre-fish kill levels within 2-4 hours.

Presentations acknowledging NANOOS support:

Devol, A.H., J. Newton, M. Kawase. (2008) Hypoxia and Fish Kill Events in Hood Canal, Washington State. 2008 Ocean Sciences Meeting, March 2-7, Orlando, Florida.

Devol, A.H., J. Newton, M. Kawase. (2008) Understanding fish kill dynamics in Hood Canal. 55th annual Eastern Pacific Ocean Conference, September 23-26, Stanford Sierra Camp, California.

Ruef, W., A. Devol, C. Smith, J. Newton. (2007) Integrated Current Measurements from the ORCA Profiling Moorings in Hood Canal, WA. NortekUSA Training Symposium, May 9-11, Carmel, CA.

Ruef, W., A. Devol, C. Smith. (2008) In-situ profiling: What it takes to get a time series. School of Oceanography Seminar, University of Washington, February 12, Seattle, WA.

Devol, A., W. Ruef, J. Newton, J. Richey. (2008) Anthropogenic Contributions to Hypoxia in Lower Hood Canal, Washington State. AGU Fall Meeting, December 15-19, San Francisco, California.

Newton, J., Devol, A., W. Ruef. (2008) Insights into Hood Canal hypoxia from NANOOS real time data. 55th annual Eastern Pacific Ocean Conference, September 23-26, Stanford Sierra Camp, California.

Newton, J., A. Devol, M. Kawase, M. Alford, M. Warner, J. Mickett, W. Ruef, C. Bassin. (2008) Fish- Kill Dynamics in Hood Canal (Washington State, USA) as revealed by real-time data and integrated modeling. AGU Fall Meeting, December 15-19, San Francisco, California.

Ruef, W., A. Devol, J. Newton, C. Smith. (2008) Interannual Variability in Hood Canal Hypoxia. 2008 Ocean Sciences Meeting, March 2-7, Orlando, Florida.

Ruef, W., J. Mickett, A. Devol, J. Newton, M. Alford. (2008) Factors Affecting Inter-Annual Variability of Hypoxia in Hood Canal. AGU Fall Meeting, December 15-19, San Francisco, California.

Devol, A.H., Newton, J., Ruef, W. 2009. Sampling frequencies necessary for coastal ocean observatories. Ocean Obs 09 confrence, Venice, Itlay. 21-25 Sept 09.

Newton, J. and Martin, D. 2009. Development of a regional coastal ocean observing system for societal benefit through US IOOS: NANOOS. Ocean Obs 09 confrence, Venice, Itlay. 21-25 Sept 09.

Newton, J., A. Devol, J. Richey, M. Kawase, B. Simmonds, S. Parker-Stetter. (2009) Hood Canal Dissolved Oxygen Program's Integrated Assessment and Modeling Study: What we did, what we learned, and why it matters. 2009 Puget Sound Georgia Basin Ecosystem Conference, February 8-11, Seattle, Washington.

Newton, J., J. Richey, M. Kawase, A. Devol. (2009) Watershed and marine modeling used to assess hypoxia for the Hood Canal Dissolved Oxygen Program's Integrated Assessment and Modeling Study. 2009 Puget Sound Georgia Basin Ecosystem Conference, February 8-11, Seattle, Washington.

Newton, et al. 2009. Summary of findings from the Hood Canal Dissolved Oxygen Program Integrated Assessment and Modeling Study and Implications for Corrective Actions, presented to the Hood Canal Coordinating Council's Technical Advisory Committee, 1 Sept 09, Bremerton, WA.

Ruef, W., C. Bassin, A. Devol, J. Newton. (2009) Spatial Variability in Hood Canal. 2009 Puget Sound Georgia Basin Ecosystem Conference, February 8-11, Seattle, Washington.

Ruef, W., A. Devol, C. Bassin, J. Newton. (2009) High-frequency Variability in Water Properties in Estuaries and the Implications for Monitoring Programs. Coastal and Estuarine Federation Meeting, November 1-5, Portland, OR.

Publications acknowledging NANOOS support:

Devol, Allan H., Wendi Ruef, Steven Emerson, Jan Newton (2007). In Situ and Remote Monitoring of Water Quality in Puget Sound: the ORCA Time-Series. Environmental Research, Engineering and Management; No. 1(39), 19-23.

Parker-Stetter, Sandra L. and John K. Horne (2009). Nekton distribution and midwater hypoxia: A seasonal, diel prey refuge? Estuarine, Coastal and Shelf Science; 81:13-18.

Parker-Stetter, Sandra L., John K. Horne, and Mariko M. Langness (2009). The Influence of midwater hypoxia on nekton vertical migration. ICES Journal of Mar. Sci. Feb 2009.

Ruef, Wendi, Allan Devol (2007). Monitoring water quality with an autonomous moored profiler: the ORCA project. Marine Scientist; No. 20, 31-32.

2. Washington State estuarine monitoring: Coordinated by D. Mora, the WA State Department of Ecology (Ecology) maintained five Puget Sound mooring stations and one Willapa Bay station with partial NANOOS support. This report covers Ecology activity from October 2007 through September 2010. Ecology contributed to regional estuarine observations by maintaining moorings and evaluating data on a monthly basis. In Willapa Bay we monitored salinity, temperature, and chlorophyll fluorescence. In Puget Sound we monitored tidal height, salinity, temperature, chlorophyll fluorescence, and dissolved oxygen. These moorings produced valuable data on environmental conditions, as evidenced by Ecology findings as well as ongoing data requests from government, academic, tribal, and private entities for projects ranging from shellfish growing to fish migrations to hydrodynamic models. During this reporting period NANOOS funding helped maintain and advance monitoring efforts in the face of austere and uncertain state budgets.

During this reporting period we greatly improved the reliability and functionality of our telemetry system. Initially our system consisted of Free-wave™ radios that transmitted data to base stations that connected to an internet portal. This data was then retrieved, posted, and forwarded by a third party to NANOOS for internet broadcasts. We switched to a system using DIGI™ cellular modems, greatly increasing reliability. We also began directly harvesting data from instruments rather than relying on a third party.

We made significant advancements toward improving data quality. Among these were holding periodic data review sessions with our lead oceanographer, quality coding our data, switching from *in-situ* to control bath dissolved oxygen verification sampling, and the development of in-house data review tools. Placing a higher priority on data quality and budgetary constraints resulted in a reduction in the number of moorings deployed in Willapa Bay.

Impact:
Dissolved oxygen is an important ecological stress indicator that is useful toward understanding Puget Sound water quality dynamics. To increase the value of our monitoring efforts we placed moorings at key inter-basin exchange zones. The deployment at Budd Inlet was discontinued and exploratory moorings were placed at the Narrows, Admiralty Inlet, and Guemes Channel. The Budd Inlet mooring was redeployed to Possession Sound (Mukilteo). These locations complement the profiling buoys (Devol and Newton, reported above) that are located within major basins.

Below is a brief timeline of significant changes:
<u>Willapa Bay</u>:
October 2007-September 2008
- Maintained four mooring stations (began in 1997) monitoring near-surface water temperature, salinity, and chlorophyll fluorescence.
- Cut back to two stations due to budget cuts.
- Completed communication testing in the lab for floating moorings in Willapa Bay using Bluetooth wireless devices. Randy Fabro at UW/Oceanography designed a watertight housing and power source for Bluetooth transmitter. In August 2008 installation of real-time data delivery capability was completed, but failed after two weeks.

October 2008-September 2009
- Cut back to a single station at Bay Center station due budget shortfalls.
- Ecology received strong urging from UW to stay with the SeaBird sensor package and continued efforts to telemeter the surface-floating mooring.

Oct 2009-September 2010
- Mooring maintained but no telemetry solution implemented until after September 2010.

<u>Puget Sound</u>:
October 2007-September 2008
- Maintained three fixed mooring stations (began in 2006) monitoring nears-shore, near-bottom water temperature, salinity, and dissolved oxygen.
- Puget Sound stations telemetry established using the Free-wave™ system and partnership with CMOP OHSU for collecting and posting data.
- In November 2007, a second fixed near-surface sensor package was added to the Manchester pier site in Central Puget Sound (water temperature, salinity, chlorophyll fluorescence and turbidity). Paired with the near-bottom sensor, this mooring provided

information on water column stratification, of particular interest to our collaborator Vera Trainer and the Marine Biotoxins Group at NOAA and the investigation of harmful algal blooms.

- Mooring coordinator Stephanie Jaeger left Ecology and unable to immediately refill position due to WA state hiring freeze.
- Budd Inlet mooring was removed in September due to staffing shortage. The low environmental dynamic over the last three years in the harbor and its position at a strategic inferior site (little water exchange) guided us in our decision making.
- In August 2008, a second fixed sensor package was added to the Squaxin pier site in South Puget Sound to collect near-surface data (water temperature, salinity, chlorophyll fluorescence and turbidity). Paired with the near-bottom sensor, this mooring provided information on water column stratification.

October 2008-September 2009

- Despite hiring freezes and staff reductions Ecology was maintained mooring deployments in part with assistance from volunteers from Ecology's Manchester Lab and NOAA.
- David Mora hired as new mooring coordinator.
- Ecology began posting archived mooring data on their FTP site.
- Four new exploratory near-bottom moorings deployed at inter basin exchange zones with the objective of detecting low dissolved oxygen intrusion. Deployment locations at:
    - Possession Sound, Mukilteo with assistance from Everett Community College (ORCA) and the Port of Everett.
    - Tacoma Narrows
    - Guemes Channel, in partnership with the Shannon Point Marine Lab.
    - Admiralty Inlet, in partnership with University Washington APL.

Oct 2009-September 2010

- Hired a new technician, Ashley Carle, partially funded by NANOOS.
- Ecology experienced significant problems with existing telemetry system and explored alternatives and upgraded: 1) switching from radios to cellular modems for data transmissions, enabling two-way communication; and 2) capturing our own data transmissions instead of relying on CMOP for this service. These moves have improved reliability, decreased a burden on CMOP, and increased quality control capacity.
- Ecology began initial phases of implementing their new Marine Data Architecture Plan. Ecology designers worked with NANOOS to assure that data feeds were compatible with NANOOS web postings. See Continuous Real-time Marine Water Data from Monitoring Stations (Moorings) (http://www.ecy.wa.gov/programs/eap/mar_wat/moorings.html) for station locations and unique Ecology data displays.
- Ecology significantly improved quality of dissolved oxygen data through implementation of an improved sensor performance check program (using a control bath).
- Ecology improved the timeliness of quality control data evaluations, usually within 30 days, and is using GOMOOS QAQC codes as a tool for describing data quality.

Presentations acknowledging NANOOS support:

Jaeger S., et al, 2008. "Dissolved oxygen dynamics at two stations in South Puget Sound." Pacific Estuarine Research Society Annual Conference, Newport, OR and South Puget Sound Science Symposium, Shelton, WA.

Carle, A., Mora, D., Krembs, C., Albertson, S., 2010. "Transport of heat, salt, oxygen, and freshwater within the southernmost extent of Puget Sound: The year 2010 in review". 2010 South Sound Science Symposium Poster presented at the, Squaxin Island Tribal Center, Shelton, WA, October 2010.

Albertson, S., Krembs, C., Sackmann, B., Maloy, C., Mora, D., Carle, A, Bos, J., and Jones, M. "Tidal to subtidal timescales of variability for telemetered moorings in Puget Sound". 2010 Presented at the MTS/IEEE Oceans 2010 Conference, Seattle, WA, September 2010.

3. Columbia River estuarine monitoring: OHSU-CMOP continued to maintain an extensive network of endurance stations in the Columbia River estuary, including both physical and biogeochemical stations. Of note is the growth of the total counts of raw physical and biogeochemical observations since the program's inception in 1996 (Fig. 5). The counts represent sums over all sensors, so observations from instruments with multiple sensors are counted per sensor rather than per instrument. These counts do not include data from gliders, drifters, AUVs, and observations gathered during CMOP cruises from ship based instrumentation. Also excluded are radar observations.

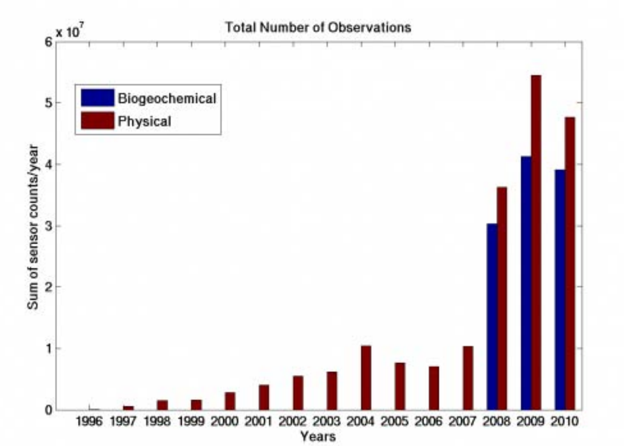

Figure 5: Total counts of raw physical and biogeochemical observations from SATURN endurance stations, from 1996 through 2009. The sums are over all sensors so observations from instruments with multiple sensors are counted per sensor rather than per instrument. These counts do not include data from mobile platforms.

Physical endurance stations: These stations were originally deployed as a part of an autonomous observation and prediction system (CORIE), one of the pioneer estuarine observatories in the US, now subsumed by the SATURN collaboratory. In most stations, measurements were at single level. Variables were salinity, temperature, water levels, and velocity profiles. Two former CORIE stations have been upgraded to become biogeochemical stations.

SATURN biogeochemical stations. Six biogeochemistry stations were deployed during the reporting period to characterize Columbia River river-to-shelf gradients.

SATURN-02 is in the near-field plume (and was described earlier); SATURN-01, 03 and 04 are in the estuary (in two channels and a low-salinity lateral bay); SATURN-05[1] is in the main stem of the Columbia River at river mile 53; and SATURN-06[1] is in the Willamette River (a major tributary that joins near Portland, OR). All stations experience tidal fluctuations.

- Each SATURN biogeochemical station consisted of a horizontally-fixed platform. River stations SATURN-05 and 06 monitored the water surface only, while estuary and plume stations were designed to capture the vertical structure of the water column (using either

[1] While most SATURN stations are partially supported by NANOOS, neither SATURN-05 nor SATURN-06 receives NANOOS funding. These two stations are operated under the direction of Dr. Joseph Needoba, with funding from NSF and the Bonneville Power Administration and in partnership with U.S. Geological Survey and WETLabs.

winch- and pump-based technologies). Most stations monitored the following variables: salinity, temperature, CDOM, turbidity, chlorophyll *a*, nitrate and dissolved oxygen.

- Salinity, temperature and water level data were quality controlled on a monthly basis, using documented procedures developed for physical endurance stations. Data were available through NANOOS NVS. Data, analyses tools, quality control procedures, and performance metrics were available through the CMOP web site. Quality control procedures for biogeochemical data are still under development.
- All stations were supported by the CMOP cyber team and the NANOOS DMAC team (which synergistically overlap). Sensor-to-user handling of information flow, including database and web interface, were the same as for physical data. SATURN-06 was also a USGS station, and reported as such via the USGS web site. SATURN-05 was also a LOBO station, and reported as such by the LOBO network. LOBO is an industry-led national biogeochemical network.

Impact:

Selected outcomes during the reporting period:

- To address important questions regarding the ecological function of the estuary, sensors for DO and Phycoerythrin (PE) were installed at SATURN-01 and SATURN-03.
- The new DO data (Fig. 6) show that the estuary incurred substantial, ocean-driven, oxygen depletion at levels of concern for salmon. An 'Oxygen Watch', covering both the estuary (SATURN-01 and SATURN-03 data) and the WA shelf (CMOP glider data) was developed.

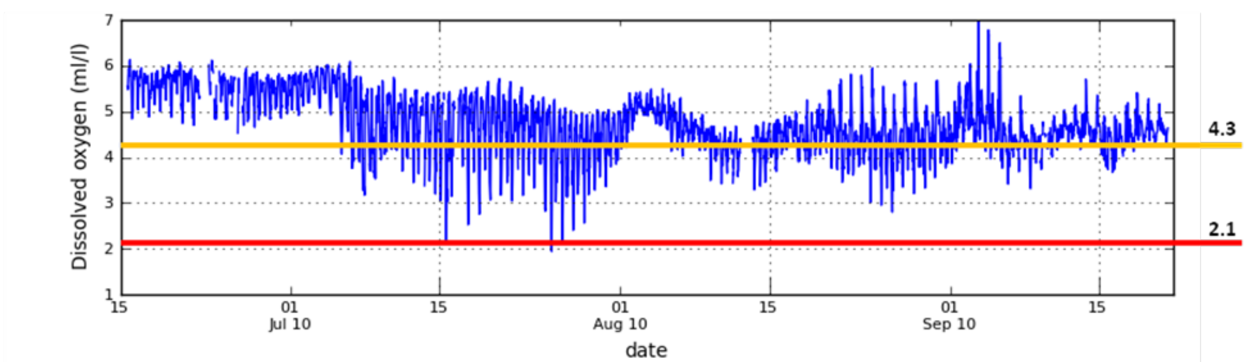

Figure 6: DO data showing levels of hypoxia for Oxygen Watch.

4. Oregon South Slough: Participation by the Oregon Department of State Lands (ODSL) in NANOOS activities was led by S. Rumrill (former Chief Scientist and Research Program Coordinator for ODSL, current Shellfish Program Leader for Oregon Department of Fish and Wildlife), and coordinated by A. Helms (Estuarine Monitoring Coordinator), and A. DeMarzo (Estuarine Monitoring Assistant) at the South Slough National Estuarine Research Reserve (NERR).

Staff members from the ODSL / South Slough NERR operated a series of moored observing stations within the South Slough estuary as part of the NERR/SWMP network of NANOOS anchor stations. The monitoring stations, equipped with a YSI-6600 multi-parameter datalogger located 50 cm above the bottom, were located at: 1) Oregon Institute of Marine Biology–Boat House (Coos Bay), 2) Charleston Pier, 3) Valino Island, 4) Winchester Arm, and 5) Sengstacken Arm along the estuarine gradient, providing continuous near real-time data from marine (euhaline), marine-dominated (polyhaline), mixing (mesohaline), and riverine (oligohaline) hydrographic regions of the South Slough estuary. A sub-set of the stations were equipped with Sutron SatLink2 data telemetry systems that transmit the digital datastreams via the Geostationary Operational Environmental Satellite (GOES) system.

The NERR-SWMP/NANOOS water monitoring stations in the South Slough estuary were in continuous operation throughout the period of 1 Oct 2007 to 30 Sept 2010, and the dataloggers were retrieved, downloaded, recalibrated, reprogrammed, and redeployed on a monthly basis. Time-series measurements generated by three of the monitoring stations are available in near real-time from several websites including NANOOS, the NOAA / Hydro-Meteorological Automated Data System, and via the NOAA/NERRS data access website operated by the NERRS Centralized Data Management Office.

Free-standing welded stainless-steel pipe towers were installed at the Sengstacken Arm (2008) and Winchester Creek (2009) stations to allow for the placement and operation of the Sutron SatLink2 / GOES telemetry equipment. The historic Sengstacken station was attached to an old log piling, and the site has become increasingly inoperable due to the accumulation of silt and mud. The historic Winchester station did not allow for line of site necessary to transmit to the GOES satellite due to tree canopy interference; the new Winchester station transmits real-time and was relocated directly in the channel.

In order to support and upgrade the NERR-SWMP/NANOOS anchor stations, South Slough purchased two YSI-6600 V2 dataloggers with sensor arrays and underwater field cables; a Sutron SatLink2 /GOES telemetry system, a Dell XFR-D630 rugged laptop field computer; two 12VDC AGM batteries, a 20 W solar panel, charge controller, and mounting hardware in July 2008.

The NERRS Centralized Data Management Office began supporting the chlorophyll data collected by the dataloggers in November 2008. This included incorporation of the chlorophyll variable into the three tiered data Quality Control/Quality Assurance methods, access by the oyster growers via the NANOOS real-time website, and fulfillment of one of the primary requests gleaned from the local oyster grower interviews/surveys.

Staff members from the South Slough NERR worked in the field during summers 2008 with representatives from the NOAA NGS to install and conduct GPS surveys for a series of elevation benchmarks located throughout the shoreline of the South Slough estuary. Additional field work was completed Summer 2009 and 2010 to tie these land-based elevation benchmarks to the free-standing towers in the estuarine tidal channels that are used as support platforms for the NERR-SWMP/NANOOS anchor stations. Water level measurements generated by the Valino and Winchester stations are now referenced to the US standards of Mean Sea Level (MSL) and the North American Vertical Datum (NAVD-88).

Adjustments to the Sutron SatLink2 set-up menu, YAGI antenna, and solar power system were completed in Spring and Summer 2010 in an effort to increase reliability of the transmissions of the near real-time datasets. All aluminum YAGI transmission antennae were replaced with stainless-steel versions or non-corrosive Stevens V4TH / helical design.

Impact:

Oyster Growers (2007-2010): Staff members provided site descriptions, additional metadata, and local reference water quality condition information by season for the initial development of the Real-Time Data Application for shellfish growers in Oct 2007 (Figure 7) and participated in conference calls for development and upgrades to the product.

Staff members from the South Slough NERR interacted directly with the four commercial oyster growers (Clausen's Silverpoint Oysters, North Bend Oyster Company, Coos Bay Oyster Co LLC, and Qualman Oyster Farms) in Coos Bay to provide introduction and subsequent technical assistance with access to water-quality data, including discussing real-time data issues and aiding with navigation and understanding of the NANOOS Data Product (Real-Time Water Quality Data for Shellfish Growers in the Pacific Northwest). In person interviews with oyster growers were conducted in March 2008 to contribute data to the shellfish grower surveys to inform changes to the Data Application product.

In order to help minimize anomalous or erroneous chlorophyll data and improve the datasets, staff worked with Mindfly Web Design in 2010 to place a data filter on transmitted chlorophyll data that excludes extremely high values or spikes. The time-series measurements of temperature, salinity, DO, pH, and fluorescence are of primary interest to the local oyster shellfish growers because they provide the essential information to characterize estuary water quality conditions for shellfish mariculture and an indicator of the concentration of phytoplankton available in the estuarine water column as food for filter-feeding oysters.

Estuary Atlas (2009): Datasets generated by operation of the monitoring stations were used to construct an atlas of variability in ambient water parameters. The project 'Estuary Atlas of the South Slough' was constructed with Surfer (ver. 8) software and provides a graphical illustration of seasonal and spatial changes in temperature and salinity of the tidal waters of the estuary. Below (Figure 8) are two images of the product for a representative month of salinity regimes at high and low tide (February 2007). This product has been used by staff members and graduate students from the University of Oregon Institute of Marine Biology.

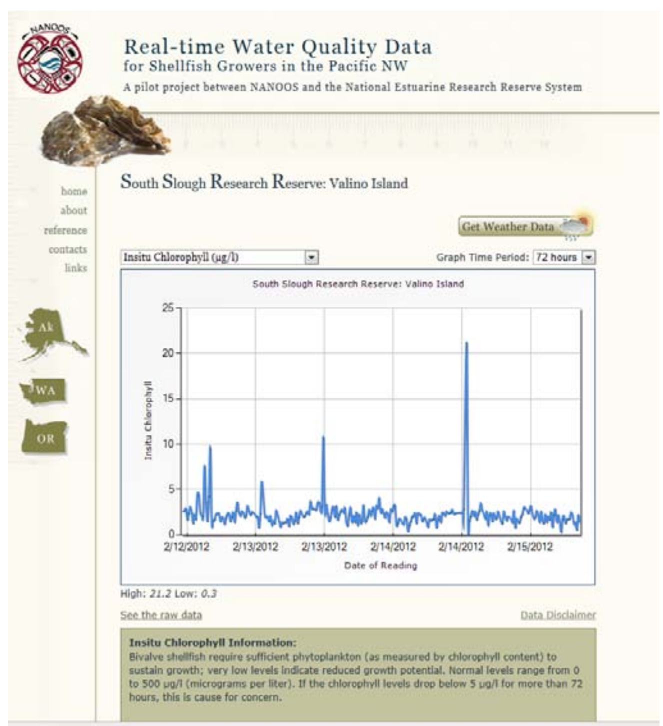

Figure 7. Shellfish Growers' web application on NANOOS web with South Slough NERRS data.

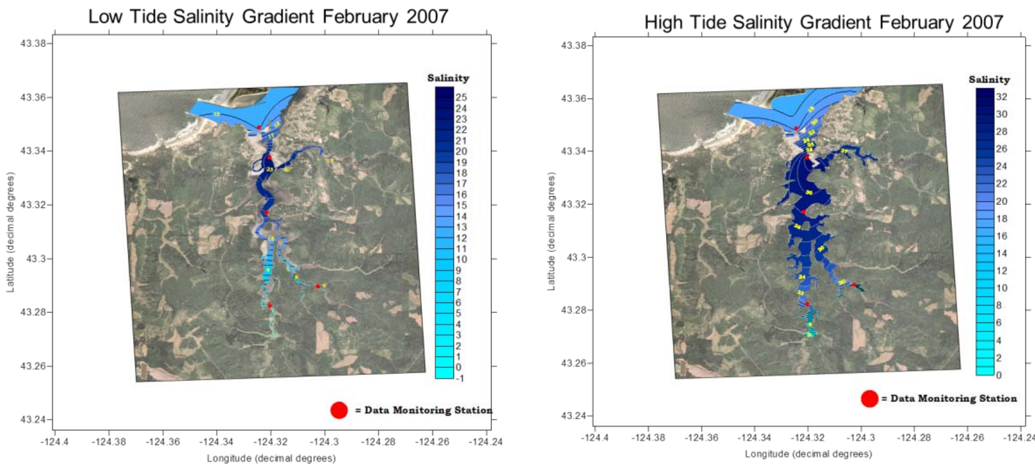

Figure 8. Estuary Atlas with South Slough NERRS data.

Estuary pH / ocean acidification (2010): Recent observations of elevated pCO_2 values in the nearshore ocean waters along the Pacific coast of North America (Feely et al., 2008) provide an opportunity to investigate the relationship between ocean acidification and variability in pH values in Pacific coast estuaries. Staff members from the South Slough NERR examined time-series measurements of water column parameters recorded at the NANOOS/SWMP stations (YSI-6600 EDS multi-parameter dataloggers equipped with a YSI 605091 pH/ORP sealed gel probe (resolution 0.01 pH unit; accuracy $\pm$ 0.2 pH unit)). The datasets that were analyzed (over the period of 2002-2009) recorded about 208,500 measurements of estuary pH values at one site (Charleston Bridge), which ranged between 7.7 and 8.3 throughout each day. A strong tidal signal as well as a diurnal cycle was observed with lowest pH values in mid-morning and highest pH values in mid-afternoon. The estuary pH at all monitoring stations (Charleston Bridge, Valino Island, Winchester, & Senstacken) showed a long term shift toward increased pH values (more alkaline) over time, which is unexpected and interesting because it is in the opposite direction of ocean measurements (more acidic). The daily pH cycle may be driven by photosynthesis and respiration of phytoplankton, macroalgae, and submerged aquatic vegetation within the estuary. This estuary pH shift data was included in the Oregon Climate Assessment Report December 2010 (see Figures 9-12; http://occri.net/ocar).

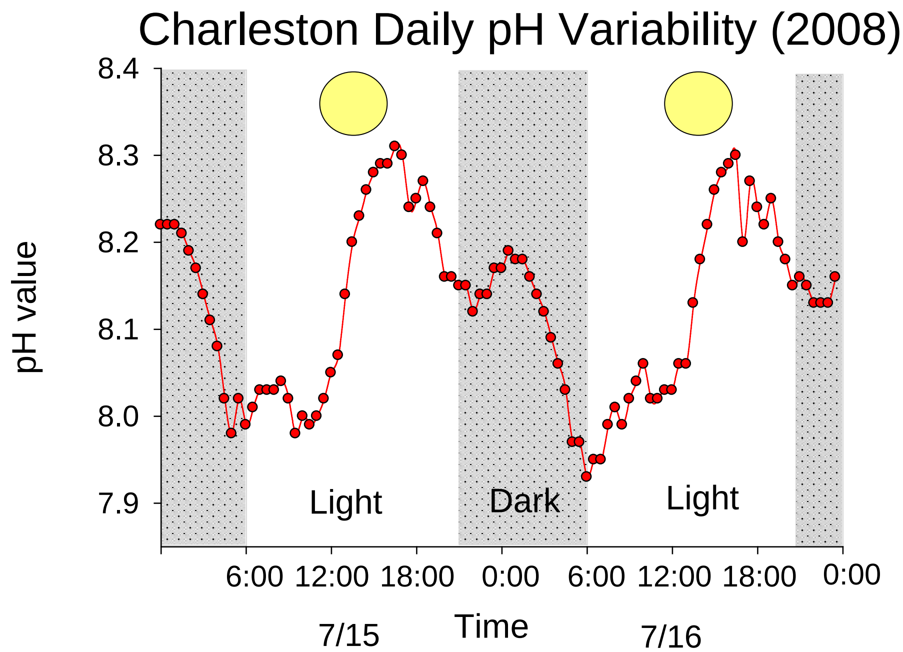

Figure 9. Diel cycle of daily changes in pH values measured within the South Slough estuary (Coos Bay, OR) over the period of 15-16 July, 2008, data from South Slough National Estuarine Research Reserve / System-Wide Monitoring Program.

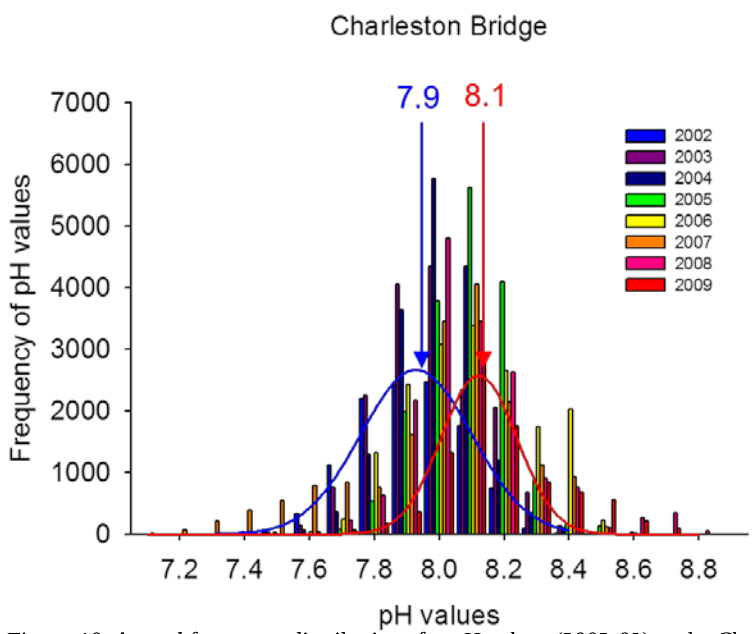

Figure 10. Annual frequency distributions for pH values (2002-09) at the Charleston SWMP station, South Slough estuary (Coos Bay, OR). Annual median values are shown for 2002 (blue) and 2009 (red); datasets from South Slough National Estuarine Research Reserve/System-Wide Monitoring Program.

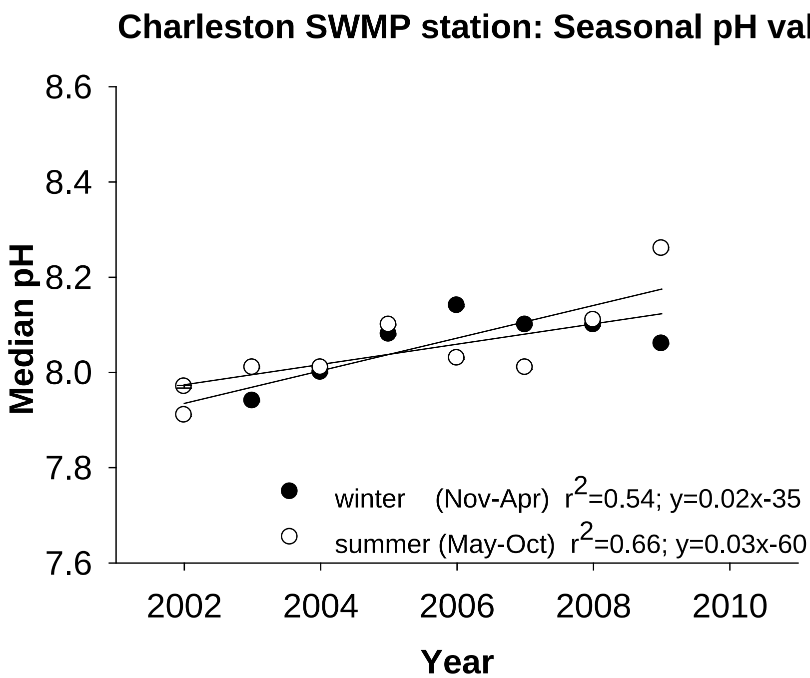

Figure 11. Median seasonal pH values at the Charleston SWMP Station (South Slough estuary (Coos Bay, OR) for Winter (Nov-Apr) and Summer (May-Oct). Datasets are from South Slough National Estuarine Research Reserve/System-Wide Monitoring Program.

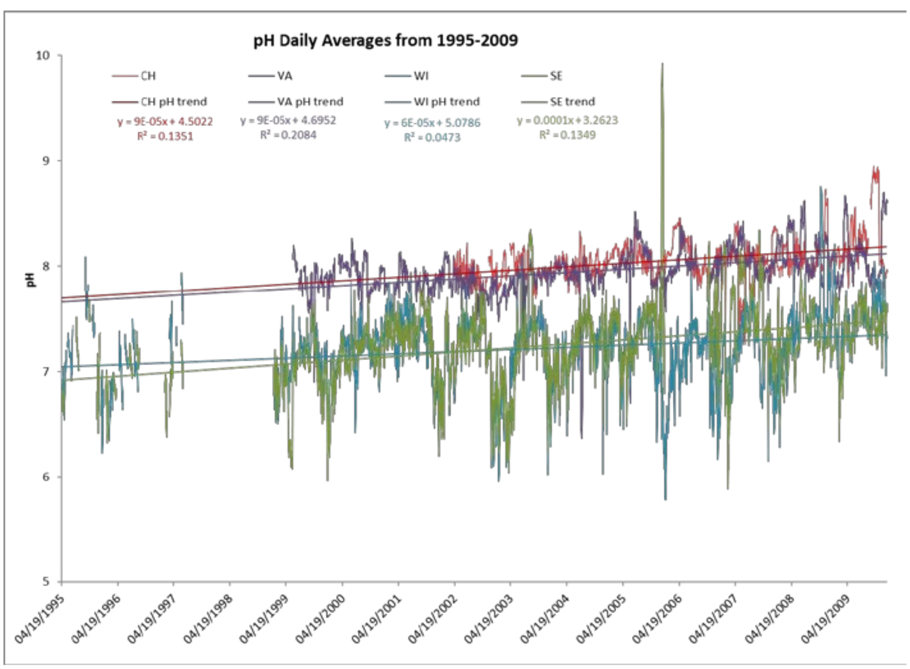

Figure 12. Longer-term shift in estuary pH values at four SWMP/NANOOS monitoring stations.

Native Oysters (2010): Datasets generated by the NANOOS/SWMP observation stations were also used to help guide local decisions over the summer about the optimum location in the estuary for the placement of experimental outplants of Olympia oysters (*Ostrea lurida*). In particular, time-series data from the Charleston and Valino Island monitoring stations were used to describe variability in summer and winter temperature and salinity regimes and to identify the region of the tidal channel that will be most conducive to survival and growth of juvenile oysters.

- **Shorelines**

1. Washington Shorelines:

During this 3-year period from October 1, 2007 to September 30, 2010, the Washington State Department of Ecology (Ecology) Coastal Monitoring & Analysis Program (CMAP) continued a beach and shoreline monitoring program in the Columbia River littoral cell (CRLC) and at the Elwha River delta. In the CRLC, quarterly beach profiles (46) beach surface maps (typically 14 in summer, 2 in fall and spring, and 5 in winter) were collected. At the Elwha River mouth, beach and nearshore profiles were collected semiannually in collaboration with the US Geological Survey (USGS). During each summer, Ecology collaborated with Oregon State University (OSU) to collect nearshore bathymetry in the CRLC with the Coastal Profiling System.

Impact: Monitoring data informs management decisions:

The data and information obtained from this monitoring program proved to be a critical component to ongoing work on regional sediment management at the mouth of the Columbia River. Results of the monitoring program were presented and discussed at several meetings hosted by the Lower Columbia Solutions Group (LCSG), convened by the Governors of Washington and Oregon, in their ongoing projects, including the Southwest Washington Littoral Drift Restoration (Benson Beach) Project, and the Oregon Nearshore Beneficial Use Project.

In 2008, the data from the monitoring program was used to guide the placement of 125,000 cubic yards of dredged material adjacent to the Columbia River North Jetty, in an effort to increase the resiliency of the jetty and reduce the impacts of coastal storms. After the placement of dredged material and the installation of sand fences, CMAP's quarterly beach monitoring program documented an increase in sand volume on the beach berm due to the sand fences. The fences trapped sand that would otherwise be blown into the Columbia River navigation channel. The accumulation of sand in the fenced area reduced the impacts of flooding as well as the rate of beach erosion.

By March 2010, quarterly beach surveys documented more sand-volume increase on the beach berm even after two years of large winter storms. The monitoring data thus revealed that the sand fences resulted in the accumulation of sand, which reduced erosion and inundation next to the jetty.

During summer 2010, the Southwest Washington Littoral Drift Restoration Project placed 367,000 yd^3 of dredged material on Benson Beach. To document the project, CMAP performed 7 surveys that include sixty 50-m spaced topographic profiles, 5 surveys that include a surface map, and 4 surveys in collaboration with OSU and the USGS that include bathymetry on approximately seventy-one 50-m spaced lines – roughly 1 million data points each survey when merged with topography.

Based on the shoreline change trends extracted from the beach monitoring data through 2008, CMAP provided technical advice to the Washington State Parks and Recreation Commission to help them decide where beach sand could or should not be taken from along the southwest Washington coast. WA State Parks has been under increasing pressure to allow sand extraction for use by cranberry farmers. CMAP recommended that WA State Parks do not permit beach sand mining where shoreline accretion rates are relatively low or where there is net erosion. CMAP provided WA State Parks with map products showing shoreline change rates based on beach profile data and historical shorelines. Data analysis and interpretation was performed to support specific recommendations on which areas of the coast were most appropriate to permit sand extraction.

Information from the beach morphology monitoring program were used in the 2008 review and comment on the draft Ocean Shores Critical Areas Ordinance (CAO), which is a local set of land-use regulations that must consider best available science. CMAP reviewed the erosion/geological hazards portion of the draft Ocean Shores CAO, and provided recommendations in light of beach response to coastal storms – particularly large El Niño events – and the state's Shoreline Master Program guidelines.

In early 2009, CMAP analyzed shoreline data to document a growth of an incipient beach plain near Moclips. The Grays Harbor County planning department requires new development to have appropriate setbacks from the defined land boundary. CMAP collected data on the current position of the land boundary and developed an elevation model of the beach immediately in front of a site proposed for development. CMAP validated observations of a seaward migration of the beach plain. These results were used by state shoreline planners to inform the County that larger beach-plain setbacks, rather than the smaller bluff-environment setbacks, should be applied to the development site.

In spring 2009, monitoring data was used in modeling to strengthen the City of Long Beach Critical Areas Ordinance. CMAP's monitoring data provided calibration for a model that Peter Ruggiero (OSU) used to predict shoreline change to 2020 along the Long Beach Peninsula. The City needed this information to comply with the Growth Management Act in assessing hazard areas and susceptibility to risk of erosion.

In summer 2009, monitoring data supported sustainable sand removal practices to benefit Cranberry Growers. CMAP's monitoring of the Long Beach Peninsula provided data to minimize the impact of sand removal on the environment, adjacent lands, and the public. CMAP used current and historical beach profile data to analyze shoreline change and identify optimal sand extraction locations and volume regulations. The information allowed State Parks to designate only highly accreting areas for sand removal for cranberry production.

In summer 2009, CMAP initiated a comparative assessment on beach profile change and razor clam population density to explore possible relationships to beach dynamics. A cursory review showed higher clam populations where the beach is highly accretional, and low populations in where the beach has been eroding. This information could be used by the Washington Department of Fish and Wildlife for siting and permitting dredged-material disposal sites along northwest Oregon and southwest Washington.

During summer to fall 2009, CMAP provided input to a number of government initiatives related to climate change including:

- A presentation to the West Coast Regional Coastal Managers Meeting on Washington's climate change adaptation activities.
- A scope of work for the Climate Change Action Coordination Team of the West Coast Governor's Agreement on Ocean Health.
- A coastal experts workshop, a joint effort between the Province of British Columbia's Ministry of Environment, Climate Change Branch and Washington State's Department of Ecology to bring together experts on sea level changes along the Pacific coast.
- A wave hazard and navigation safety workshop organized by the Lower Columbia Solutions Group.

In early 2010, CMAP's monitoring data helped state shoreline planners convey shoreline change risks to city planners. After an El-Niño-like winter, Ocean Shores has experienced a significant amount of erosion similar to that experienced during the 1997/1998 El Niño. CMAP provided interpretive data products to convey the vulnerability of this area to these kinds of events. The data show large fluctuations in the state of the dune have occurred within a short period. With the knowledge of the temporal variability of shoreline position, shoreline planners are grappling with the problem of basing building setbacks solely on the location of the vegetation line at the time construction is proposed.

Impact: <u>Monitoring data provides educational outreach:</u>
In early 2008, CMAP provided information from our beach monitoring program to the Seattle Times for a news article on North Cove erosion and the impacts of storm events. We also provided information for an Oregon and Washington public radio feature story on climate change and coastal erosion.

During late spring 2008, CMAP provided information on beach profile changes at 3 sites we monitor just north of North Head at the request of a reporter at the Chinook Observer newspaper. At the most southern site, the dune has retreated over 2 m landward since last summer, probably most of which happened during an early December 2007 storm. This information resulted in a feature article on erosion of the Seaview dunes and the ongoing erosion of the southern Long Beach Peninsula. The article also reported on the wasting of sand by the U.S. Army Corps of Engineers and the need to pump dredged material onto Benson Beach. The article prompted a request from the City of Long Beach for more information on erosion rates and locations of survey sites within the city limits.

CMAP also provided information from the beach monitoring program through an interview with a public radio correspondent on coastal erosion. During the 2007-2008 winter most of the monitored beaches along the southwest Washington coast experienced beach lowering of approximately 30 cm compared to last year; substantial dune retreat has also occurred in Westport, Washaway Beach, and Cape Disappointment State Park.

In June 2008, CMAP provided educational outreach and information on beach erosion to several high school students working on similar class projects. CMAP gave six lectures on coastal processes and dune ecology to grade school and high school students in Ilwaco and Long Beach.

During the winter of 2009-2010, CMAP documented extraordinarily large shoreline retreat along the entrance to Willapa Bay and southern Grayland Plains, which captured the attention of several media outlets and the general public. Within 6 months, 200 m of shoreline retreat was recorded along the Warrenton Cannery Road in North Cove, whereas typical erosion rates in area have been on the order of 15 m per year over the past 2 decades. Erosion destroyed 14 structures including seven houses, six sheds, and a State Parks restroom facility. A geodetic control survey monument was also lost. Immediately to the north of the erosion area is a dramatically widened beach that has temporarily enhanced snowy plover habitat. A National Public Radio news report followed a co-authored journal paper on the trend of increasing wave height and beach erosion in the Pacific Northwest, and the connection to climate change.

Presentations acknowledging NANOOS support:

Guthrie, C., Ruggiero, P., and Kaminsky, G., 2009. Dune face erosion and winter wave climate in the Columbia River littoral cell, Pacific Estuarine Research Society Conference, Bellingham, WA, April 2009.

Kaminsky, G.M., 2008. Coastal erosion: Recent trends and patterns on Washington's coast, State Ocean Caucus outreach meeting, Ocean Shores, WA.

Kaminsky, G.M., 2009. The Columbia River littoral cell, 2009 Geological Society of America Annual Meeting Field Trip on Coastal Geomorphology, Hazards, and Management Issues along the Pacific Northwest Coast of Oregon and Washington, Ilwaco, WA.

Kaminsky, G. and Johnson, S.Y., 2008. Overview of the Southwest Washington Coastal Erosion Study and the segue to RSM-related activities around the mouth of the Columbia River, 85th Meeting of the Coastal Engineering Research Board, September 24, 2008, Portland, Oregon.

Kaminsky, G., Allan, J.C., and Ruggiero, P., 2010. PNW coastal morphology monitoring and observation network, *Eos Trans. AGU*, *91*(26), Ocean Sci. Meet. Suppl., Abstract IT25L-12.

Kaminsky, G., Ruggiero, P., Buijsman, M.C., McCandless, D. and Gelfenbaum, G., 2009. Human-induced coastal evolution of the Columbia River littoral cell, 2009 Geological Society of America Annual Meeting, Portland, OR.

Osborne, P. and Kaminsky, G. 2010. Coastal Erosion in Southwest Washington and the Benson Beach Littoral Drift Restoration Project, Pacific County Marine Resources Committee 2010 Coastal Summit, Long Beach, WA.

Ruggiero, P., Kaminsky, G., and Gelfenbaum, G., 2008. Morphodynamics of high energy dissipative beaches: A decade of observations in the US Pacific Northwest. Ocean Sciences Meeting 2008, Orlando, FL.

Ruggiero, P., Maddux, T., Kaminsky, G., Palmsten, M., Holman, R.A., Cox, D., Dec. 2007. Field and Laboratory Investigations of Coastal Dune Morphodynamics, American Geophysical Union Fall 2007 Meeting, San Francisco, CA.

Publications acknowledging NANOOS support:

Gelfenbaum, G., and Kaminsky, G.M., 2010. Large-scale coastal change in the Columbia River littoral cell: An overview, Marine Geology, 273, 1–10.

Kaminsky, G.M., Ruggiero, P., Buijsman, M., McCandless, D., and Gelfenbaum, G., 2010, Historical evolution of the Columbia River littoral cell, Marine Geology, 273, 96–126.

Ruggiero, P, Buijsman, M., Kaminsky, G., and Gelfenbaum, G., 2010, Modeling the effects of wave climate and sediment supply variability on large-scale shoreline change, Marine

Geology, 273, 127–140.
Warrick, J.A., George, D.A., Gelfenbaum, G., Ruggiero, P., Kaminsky, G. M., and Beirne, M., 2009. Beach morphology and change along the mixed grain-size delta of the dammed Elwha River, Washington. Geomorphology, doi:10.1016/j.geomorph.2009.04.012.

2. Oregon Shorelines:

Leveraging NANOOS, the Oregon Beach and Shoreline mapping Analysis Program (OBSMAP) efforts were led by J. Allan and V. McConnell of the Oregon Department of Geology and Mineral Industries (DOGAMI). As part of DOGAMI's commitment to NANOOS, the OBSMAP network was sustained for the study period (1 Oct 2007 to 30 Sep 2011) and in some cases enhanced with the addition of new observation sites.

Aside from beach and shoreline monitoring, PI Allan also provided equipment support for PI Ruggiero (OSU) in order to assist Ruggiero with the collection of nearshore bathymetry (Mean Higher High Water (MHHW) out to a depth of approximately 20 m (~65 ft)) using personal water crafts in the Rockaway littoral cell. These latter surveys occurred in late summer at the same time as our regular beach monitoring to provide overlap and quality control checks of the land-based and bathymetry data.

Beach and shoreline monitoring were initially undertaken at 46 sites on the northern Oregon coast; 6 sites along the Clatsop Plains, 25 sites in the Rockaway cell, and 15 sites in the Neskowin cell (Figure 13). However, leveraging funding from other sources, the OBSMAP network further expanded to include an additional 73 sites on the central Oregon coast (Newport/Beverly Beach cells). All of these sites were monitored either on a seasonal[2] or biannual basis[3]. To date, we have completed a total of 1,576 individual

Figure 13: Map showing the OBSMAP beach and shoreline monitoring network as well as other non-NANOOS beach observation programs.

[2] Summer (~August/September), Fall (~December/January), Winter (~March/April), Spring (~May/June).
[3] Summer (~August/September), Spring (~May/June).

measurements of the OBSMAP network that were directly funded by NANOOS.

With the help of airborne Light Detection and Ranging topographic data (lidar) collected by the USGS/NASA/NOAA in 1997 (summer), 1998 (winter, post El Niño), and 2002 (summer), we were able to extend the time series of coastal change back to at least 1997. Combined, the lidar and GPS data now provide ~14 years of observations of coastal change. As a result, NANOOS has provided critical funding that enabled the establishment of a permanent, beach and shoreline observation network at 119 sites on the central to northern Oregon coast (Figure 13) that has provided critical information on the state of Oregon's beaches, their response to storms, El Niños, and over the long term, effects associated with climate change and variability.

Through technology transfers and by leveraging funding from other sources, similar observation networks were established at another 300+ sites along the length of the Oregon coast. For example, in 2010/2011 the OBSMAP network was expanded to include 24 sites in the Netarts cell and another 35 sites on the southern Oregon coast (Gold Beach/Nesika Beach cells) in order to document erosion hazards and coastal changes in those areas. Of importance, however, these latter sites are presently not supported by NANOOS, and are thus observed on an *ad hoc* basis, or as and when funding becomes available. As part of continued efforts to improve on and sustain the OBSMAP network, we are exploring ways in which some of these important monitoring sites may be able to be sustained through ongoing NANOOS funding.

The OBSMAP network has been able to be observed, sustained, and adapted to other local sites as and when the need arises due to its dependence on Real Time Kinematic Differential Global Positioning System (RTK-DGPS) surveying technology developed for beach monitoring (Ruggiero et al., 2003; Barnard et al., 2011). Around the globe, RTK-DGPS has effectively become the standard for undertaking rapid and highly accurate surveys of coastal change on beaches, bluffs and in the surfzone, due to its high degree of accuracy (both horizontal and vertical positioning), ease of use, and because it enables larger areas to be monitored at significantly lower costs (Figure 14) on the Oregon coast are described in Allan and Hart (2007; 2008).

Figure 14: *Beach profile surveys being undertaken using a Trimble R8 GPS rover mounted on a backpack.*

Impact: While collecting and processing the GPS data are now routine, disseminating the information to non-technical audiences remains a challenge. As a result, significant effort over the reporting period was directed at developing products that are useful to State resource managers (e.g. the Oregon Parks and Recreation Department (OPRD) who manages the public beach, and the Department of Land Conservation and Development Ocean Coastal Management Program (DLCD-OCMP)), Geotechnical consultants and the public for assessing coastal change, stability and erosion/flood hazard risk. After considerable discussion with stakeholders, we settled on two key products that have been disseminated via NANOOS and through DOGAMI. These include *beach profile* and *contour change* plots (Figure 15).

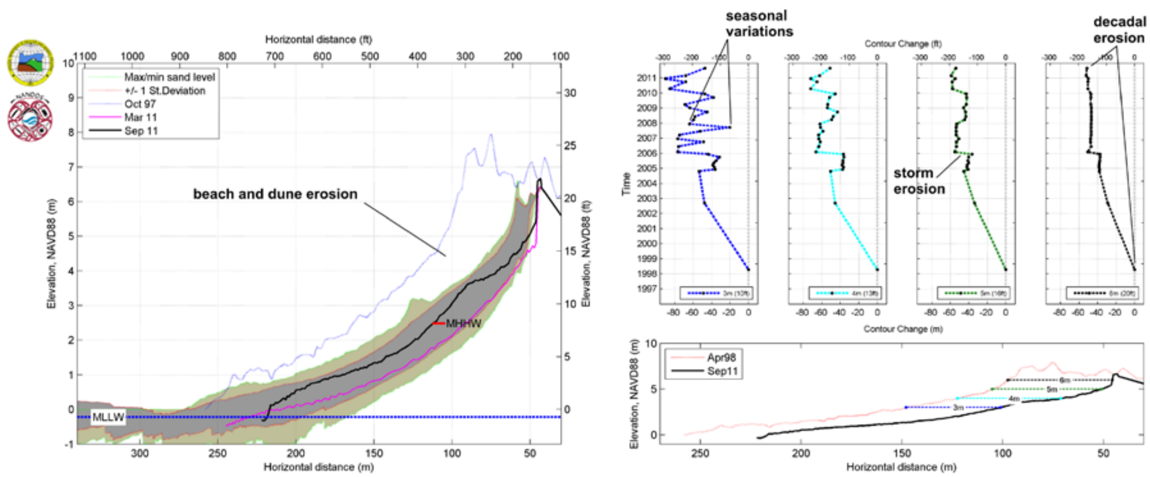

Figure 15: Left, Beach profile plot example at the Rck1 site in the Rockaway littoral cell. Right, Contour change plots showing the complete time series of observed changes at different elevations across the beach.

Figure 15 (*left*) provides an example beach profile plot from the Rockaway (Rck1 site) littoral cell. The plot identifies the initial survey of the site derived from lidar in 1997 (blue line) and the most recent survey (black line). Importantly, the plot includes shading that defines the 'typical' range of variability (i.e. ±68% (1σ) about the mean profile (dark shading) and the maximum/minimum beach elevation changes (light grey shading) determined for the period 2004 to 2011 (i.e. based only on the GPS surveys). This product is useful since coastal resource managers and other stakeholders can quickly assess the condition of the beach identified by the most recent survey, relative to some 'normal' range of expected responses.

In order to understand changes that may be occurring at the seasonal to interannual time scale, we have developed contour change plots (Figure 15, *right*). These latter plots provide a time stack of changes occurring at four different elevations down the beach face. These include changes occurring near the dune toe (e.g. the 6.0 m and 5.0 m contour) and lower down the beach face near the MHHW mark (e.g. the 3.0 m contour). The former describe changes that tend to be more event-based (i.e. the product of major storms), while the latter characterize the seasonal variability. In all cases, the orientation of the lines provides an important indication of any prevailing trends. For example, lines that deviate to the left of the zero line as shown in Figure 15 (*right*) indicate erosion; based on the Rck1 example it can be seen that the dune face has eroded by about 50 m (164 ft) since 1997 with no sign of recovery. Ultimately, these data are made available to NANOOS stakeholders via the OBSMAP[4] and NANOOS[5] websites.

Besides the transects, shoreline variability continued to be also measured, involving re-measurement of the Mean High Higher Water (MHHW) contour located at an elevation of ~2.3 m above MLLW, a tidally-based proxy for the position of shorelines along each of the littoral cells. These data are important since they provide greater insights and hence understanding of the spatial and temporal variability of the beaches, and in particular can be used to identify the locations of rip embayments, which may be used to define potential 'hotspots' of erosion.

Key findings: During the winters of 1997-98 (an El Niño) and 1998-99, the PNW coast experienced an unprecedented number of extreme storms. The cumulative effect of these storms has resulted in lasting changes to the morphology of many Pacific Northwest beaches and dunes, while also causing considerable damage to properties and infrastructure along the PNW coast, requiring expensive engineering in order to mitigate many of the erosion problems. Examination of the lidar data revealed that in the communities of Neskowin and Rockaway, the dunes eroded by 10-30 m between 1997 and 2002 (Figure 16). Data shown in Figure 16 reflects measured changes at the 6 m contour elevation. Baseline data from which all comparisons have been made is the position of the beach in 1997 prior to the 1997–1998 El Niño.

Since the lidar data was flown, our GPS monitoring indicates that in both communities the erosion has continued to the present (Figure 16); at Neskowin and Rockaway the dunes eroded 20 - 50 m, much of which can be attributed to major winter storms. In response, residents have spent several million dollars in expensive remediation in order to mitigate the hazard and safeguard their properties and infrastructure from further erosion. Nevertheless, despite erosion dominating most of these beaches, it can be seen in Figure 16 that a few areas of the coast (e.g. Bayocean Spit and mid-way along Nehalem Spit) have been accreting.

In summary our findings reinforce two important points concerning Oregon beach morphodynamics: 1) high ocean waves exert a primary control on beach and shoreline responses; 2) several of the littoral cells (e.g., Neskowin and Rockaway) remain in a state of sediment deficit due to the volume of sand removed from the beaches and dunes over the past decade. As a result, many of these beaches and the communities that back them are now even more vulnerable to storm damage and wave inundation due to the loss of significant buffering capacity provided by the beaches previously.

[4] http://www.oregongeology.org/sub/Nanoos1/index.htm
[5] http://www.nanoos.org/nvs/nvs.php?section=NVS-Products-Beaches-Mapping

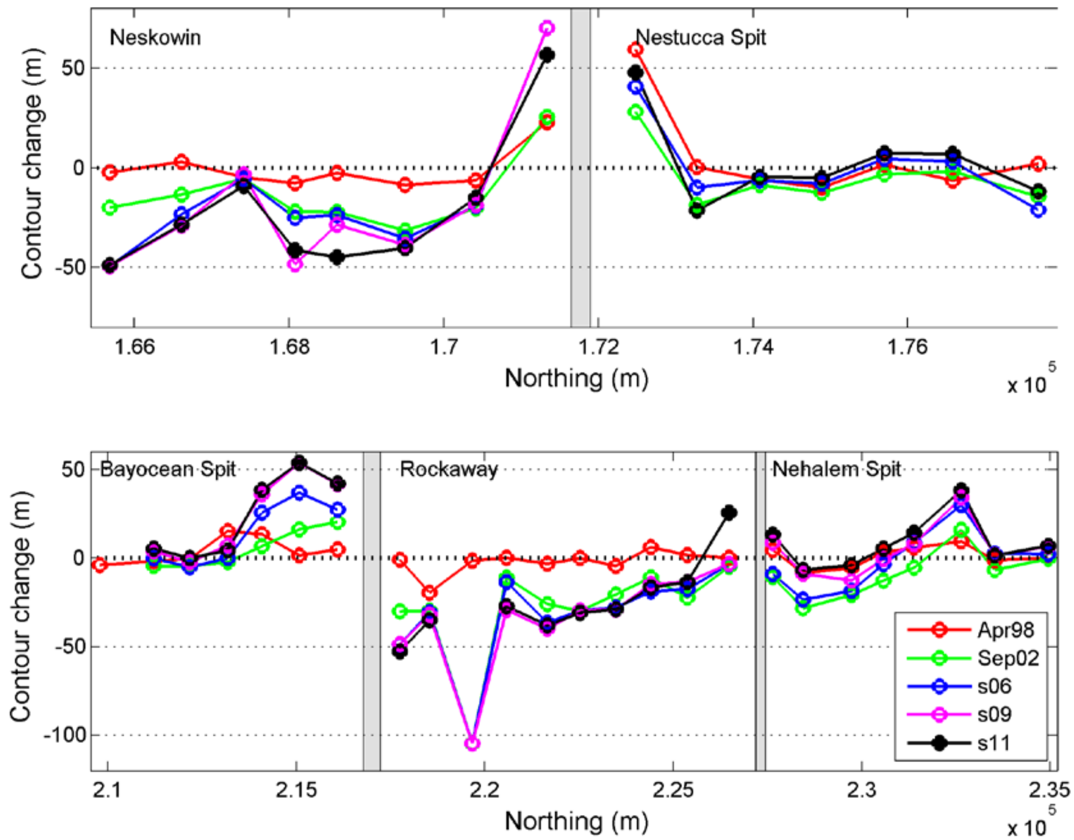

Figure 16: Alongshore variability in the response of the dune face determined at the 6 m contour elevation in the Neskowin (Top,) and Rockaway (Bottom) littoral cells. Shaded bands indicate the locations of estuaries mouths; jetties further constrain the estuaries in the Rockaway littoral cell.

Stakeholders:

- Oregon State Parks and Recreation Department (OPRD) used the OBSMAP data to assist with beach management, including the permitting of engineering structures. This has included the development of “hotspot” hazard maps for selected communities preceding a winter season;
- Beach surveys have been used in the community of Rockaway to assess ongoing problems relating to the loss of sand from the beach system and the increased incidence of damage to engineering structures, including overtopping by ocean waves and inundation of backshore properties;
- Beach change data measured adjacent to the mouth of Tillamook Bay have been used to evaluate the potential effects of wave energy development offshore from Tillamook Bay.
- Beach surveys were and continue to be used in the community of Neskowin to assess ongoing problems relating to the loss of sand from the beach system and the increased incidence of damage to engineering structures, including overtopping by ocean waves and inundation of backshore properties;
- Beach change data adjacent to the Columbia River south jetty were used by the USACE to monitor the erosion of the dunes adjacent to the jetty, which exhibits signs that it may breach in the not too distant future;
- The combined beach observation dataset now available for Tillamook and Clatsop Counties were used to assess 1% (100-year) coastal flood and erosion risk along the shorelines of both counties for the purposes of developing FEMA flood insurance rate maps;
- Other stakeholders include the Coastal Hazards Processes Working Group (an ad hoc group of planners, geotechs, engineers, agencies, and environmental groups that periodically met to discuss coastal hazard issues), practicing geotechnical consultants, planners, and the public at large.

Presentations acknowledging NANOOS support:

Allan, J. C., and Hart, R., 2007, Assessing the temporal and spatial variability of coastal change in the Neskowin littoral cell: Developing a comprehensive monitoring program for Oregon beaches Oregon Department of Geology and Mineral Industries, Open-file-report O-07-01.

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Barnard, P. L., Allan, J. C., Hansen, J. E., Kaminsky, G. M., Ruggiero, P., and Doria, A., 2011, The impact of the 2009-10 El Niño Modoki on U.S. West Coast Beaches: Geophysical Research Letters, v. 38.

Ruggiero, P., Kaminsky, G. M., Gelfenbaum, G., and Voight, B., 2005, Seasonal to interannual morphodynamics along a high-energy dissipative littoral cell: Journal of Coastal Research, v. 21, no. 3, p. 553-578.

3. Nearshore Bathymetry: PI Ruggiero’s group, with support from NANOOS, successfully developed a 4th generation Coastal Profiling System (CPS, Figure 17), a platform for a physical/biological sampling system for the nearshore ocean. The platform essentially consists of a pair of personal watercrafts (PWCs) outfitted with fixed sampling equipment for high-resolution surveying of sea bottom topography and for physical and ecological sampling in the previously inaccessible surf zone. The Coastal Profiling System is a unique asset that has supported emerging research into nearshore ocean processes in the PNW.

Figure 17. 4th generation Coastal Profiling System collecting nearshore bathymetric data.

In each of summers 2008, 2009, and 2010 Peter Ruggiero's group at OSU successfully completed the collection of nearshore bathymetry along the Columbia River littoral cell (CRLC) in close collaboration with the Washington State Department of Ecology and the US Geological Survey. Each summer, over 200 individual cross-shore profiles were collected in the cell extending from the lower inter-tidal to approximately 12 m of water depth (~2000 m from the shoreline). Approximately 400 kilometers of nearshore mapping took place within 12 days of field data collection. In all cases these nearshore bathymetry measurements were combined with topographic measurement collected by Ecology to develop complete maps of the nearshore planform. These data have been processed from their raw format into deliverable text files and have passed a rigorous quality assurance process. As of the end of summer 2010, 12 years of nearshore bathymetric profiles have been collected along the CRLC.

In summers 2008 and 2009, Ruggiero's group, in close collaboration with DOGAMI and Ecology, planned and executed the first nearshore bathymetric data collection within the Rockaway littoral cell in Oregon. Over 70 individual cross-shore beach profiles were collected from the lower intertidal to approximately 20 m of water depth (~1500 m from the shoreline). These data have been combined with topographic data collected synoptically by DOGAMI, and are processed from their raw format into deliverable text files after passing a rigorous quality assurance process.

In summer 2009 this tool was used for the first time along a rocky coastline (Cape Foulweather, OR) in support of OSU's PISCO group. The nearshore bathymetric data collected during this NANOOS supported effort will be used in studies of nearshore larvae transport.

In summer 2010, Ruggiero's group completed the collection of nearshore bathymetry data in south Clatsop County, Oregon in close collaboration with the Oregon Department of Geology and Mineral Industries. Over 100 individual cross-shore profiles were collected in 5 days of field collection. These data have been combined with topographic data collected synoptically by DOGAMI, and have been processed from their raw format into deliverable text files and have passed a rigorous quality assurance process. This is the first time that nearshore bathymetry data has been collected in this region of the Oregon coast. This data will be used extensively in DOGAMIs planned flood studies of Clatsop County.

Impact:
In 2009 PI Ruggiero delivered nearshore bathymetry data from the Clatsop Plains in Oregon to researchers at the O.H. Hinsdale Wave Research Laboratory who used the data to aid in developing physical scale models of Seaside, OR for tsunami inundation research.

The data and information obtained from the monitoring efforts supported by NANOOS was a critical component in ongoing work on regional sediment management at the mouth of the Columbia River (MCR). Results of the monitoring program have been presented and discussed at several meetings hosted by the Lower Columbia Solutions Group (LCSG), convened by the Governors of Washington and Oregon, in their ongoing projects, including the Oregon Nearshore Beneficial Use Project. With partial support from NANOOS, Ruggiero's group has participated in The Southwest Washington Littoral Drift Restoration (SW LDR) project at the MCR. The aim of this project was to assess the long-term viability of placing dredged material from the mouth of the Columbia River (MCR) directly on Benson Beach to supplement the littoral sediment budget. Approximately 300,000 m^3 of dredged material from the MCR was placed along the intertidal area of Benson Beach during the summer of 2010. An extensive monitoring effort is underway to evaluate the effectiveness of the SW LDR project. One component of the monitoring program is to track the morphological response of the beach and nearshore areas during and after the SW LDR sand emplacement. Oregon State University, the Washington State Department of Ecology and the US Geological Survey are collaborating on collecting morphological change data to address these questions and completed 4 nearshore survey of the region in summer 2010 (Figure 2, Andrew Stevens, personal communication).

- PI Ruggiero used NANOOS supported data and knowledge in his Coastal Geomorphology and Coastal Hazards classes taught at Oregon State University. NANOOS efforts were highlighted during guest lectures and in advising students.
- In October 2009 Ruggiero and PI Allan led a field trip along the coasts of Oregon and Washington (25 participants from several countries) associated with the Geological Society of America's annual meeting. The focus of the field trip was coastal hazards and morphodynamics and NANOOS efforts were highlighted.
- With partial support from NANOOS, Ruggiero's group also collected nearshore bathymetry data along the coast near Reedsport, Oregon in summer 2010. The overarching objective of this study is to understand if wave energy conversion devices cause changes in the surf zone circulation patterns and alter the shoreline configuration. This project extended a field-based beach monitoring program begun in spring 2009 to document changes to the beach and nearshore bars, and enables comparisons of the measured changes with the natural envelope of variability determined for the Reedsport site and elsewhere.

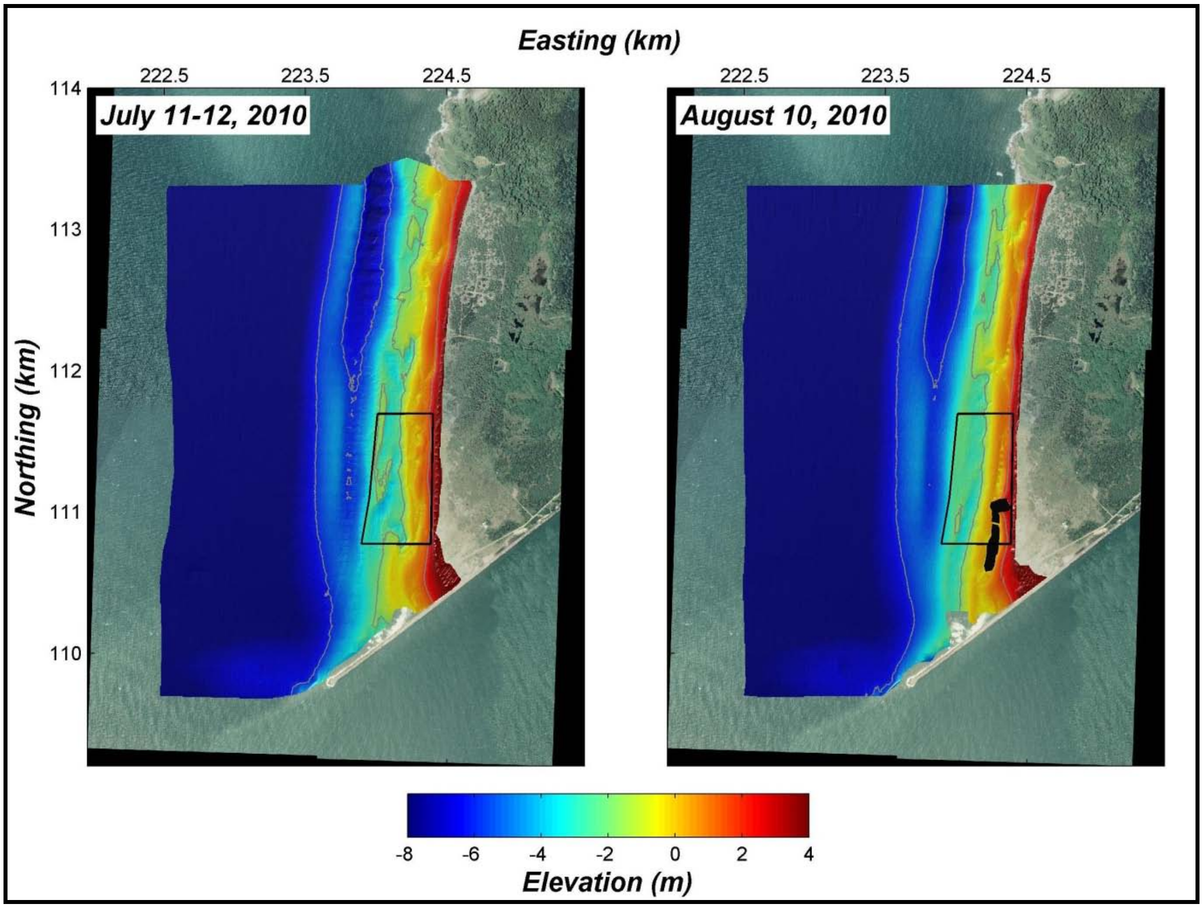


Figure 18. Maps showing interpolated bathymetric and topographic surfaces of Benson Beach derived from data obtained on July 11-12 (left) and August 10 (right). Elevation measurements were interpolated using linear (triangular) interpolation. Grid resolution is 5 m. The black box indicates the Littoral Drift Restoration permit area. The filled black area in the right panel denotes the gap in data coverage in the August 10 survey.

- Understanding sandbar dynamics and variability is integral to developing a predictive capacity for nearshore flows, sediment transport, morphological change, and ultimately for determining coastline exposure to damaging storm waves. Unfortunately, the large scale behavior of nearshore morphology is still poorly understood, partially because of the difficulty, expense, and danger of collecting data in this highly dynamic region. The time series of nearshore bathymetry along the CRLC is being used in fundamental studies of sandbar dynamics and PI Ruggiero collaborates with numerous scientists on these issues while partially supported by NANOOS.

Presentations acknowledging NANOOS support:

Ruggiero, P., "Morphological trends and flood probability of Empire Spit: Willapa Bay, Washington," US Army Corps of Engineers, Coastal Engineering Research Board Fall meeting, Portland, OR, September 2008.

Ruggiero, P., "Morphodynamics of Pacific Northwest Beaches: A Decade of Observations along the Columbia River littoral cell," OSU Geography Seminar Series, Corvallis, OR, October 2008.

Ruggiero, P., “Bathymetry survey assessment methodologies,” Wave amplification/safe navigation at the Mouth of the Columbia River workshop, Ilwaco, WA, April 2009.

Ruggiero, P., Maddux, T., Kaminsky, G., Palmsten, M., Holman, R.A., Cox, D., Dec. 2007. Field and Laboratory Investigations of Coastal Dune Morphodynamics, American Geophysical Union Fall 2007 Meeting, San Francisco, CA.

Ruggiero, P., Kaminsky, G., and Gelfenbaum, G., 2008. Morphodynamics of high energy dissipative beaches: A decade of observations in the US Pacific Northwest. Ocean Sciences Meeting 2008, Orlando, FL.

Guthrie, C., Ruggiero, P., and Kaminsky, G., 2009. Wave climate and dune face erosion in the Columbia River littoral cell, Proceedings of the Pacific Estuarine Research 2009 Meeting, Bellingham, WA, April 2009.

Kaminsky, G., Ruggiero, P., Buijsman, M.C., McCandless, D. and Gelfenbaum, G., 2009. Human-induced coastal evolution of the Columbia River littoral cell, 2009 Geological Society of America Annual Meeting, Portland, OR.

Kaminsky, G., Allan, J.C., and Ruggiero, P., 2010. PNW coastal morphology monitoring and observation network, *Eos Trans. AGU, 91*(26), Ocean Sci. Meet. Suppl., Abstract IT25L-12.

Publications acknowledging NANOOS support:

Ruggiero, P., Walstra, D.J., Gelfenbaum, G., and Ormont, M.V., 2009. Seasonal scale nearshore morphological evolution: Field observations and modeling, *Coastal Engineering, (56) 1153-1172, DOI:10.1016/j.coastaleng.2009.09.003.*

Allan, J.C., Witter, R.C., Ruggiero, P., and Hawkes, A.D., 2009. Coastal Geomorphology, hazards, and management issues along the Pacific Northwest coast of Oregon and Washington, in O’Connor, J.E., Dorsey, R.J., and Madin, I.P., eds., Volcanoes to Vineyards: Geologic Field Trips through the dynamic landscape of the Pacific Northwest: *Geological Society of America Field Guide 15*, p. 495-519, doi: 10.1130/2009.fld015(24).

Ruggiero, P., Holman, R., and Allan, J., 2010. Baseline Observations and Characterization of Sediment Transport Processes for the Reedsport Wave Energy Site Report to the Oregon Wave Energy Trust.

Allan, J.C. and Ruggiero, P., 2010. Coastal Flood Insurance Study, Coos County, Oregon, Oregon Department of Geology and Mineral Industries Report to the Federal Emergency Management Agency, Portland, Oregon.

Ozkan-Haller, T., J.C. Allan, J.A. Barth, M.C. Haller, R.A. Holman, and P. Ruggiero, 2009, Baseline Observations and Modeling for the Reedsport Wave Energy Site, Report to the Oregon Wave Energy Trust.

- **Currents**

1. Coastal Currents: The HF surface current mapping program at Oregon State University (PI: Mike Kosro; RAs Anne Dorkins, David Langner, and Walt Waldorf) provided near-real-time maps of ocean surface currents along the coasts of Oregon, southern Washington, and northern California, to the public via the web (http://currents.coas.oregonstate.edu, plus links to this page from the NANOOS web site), as well as downloadable text files containing the data values, during the full reporting period. The array included eleven land-based coastal stations, operated full-time and year-round, with coastal data acquisition infrastructure, high-speed data communications from the coastal sites to an analysis center at OSU, where data are quality-controlled, processed, archived, displayed and distributed. These data were also provided in near-real-time to NOAA/NDBC via the national HFR-net, and were used to evaluate numerical circulation models as well as provide for assimilation into NANOOS circulation forecast models.

During the grant period, infrastructure maintenance included repairs from the hurricane-strength winter storm of Dec 2007, lightening strikes, erosion, and numerous other weather, age, and human-related events. We upgraded the archive system to all disk-based and migrated from computing from Sun workstations to Mac-based systems. Real-time monitoring tools also were improved.

Kosro participated as a member of the first IOOS HF Radar National Steering Team. He participated in their first meeting on July 28, 2010 at the Consortium for Ocean Leadership office in Washington D.C. He also attended a meeting of the Eastern Pacific Ocean Prediction Forum (ePOPf) during 20-22 September 2010 in Portland, and gave a presentation on surface-current mapping on the west coast and its relation to ocean modeling. Alexander Kurapov and John Osborne of NANOOS also presented results using the NANOOS surface current data for to improve modeling of the offshore circulation and for understanding the tides, respectively. At the end of September 2010, Kosro participated in the 10th International Radiowave Oceanography Workshop, held at Mt. Hood. Kosro also worked with NANOOS modelers on assimilation of HF data into circulation models.

During summer 2008, antenna pattern measurements were performed over the ocean at three sites to update calibration of the direction-finding capability of the HFs there. Computers were upgraded at about half the field sites, allowing data acquisition and operating system software to be updated. The web site was transitioned to a new computer architecture (Mac from Sun). An improved hard drive-based data backup system was put in place. Site diagnostics available to operators have been improved. High-speed data access was installed using a backhaul system between the site in Crescent City, CA and an ISP in Brookings, OR in Oct 2008, and SWOP-radio data systems were installed at Yaquina Head in spring; these latter systems also serve to expand the range of wireless data availability to coastal vessels, including Wecoma. The group participated in a planning workshop for a coordinated national HF system, in August 2008, and in a Data Quality/Data Assurance workshop for west-coast HF providers in September 2008.

A lightening strike at the Point St. George site on Dec 25, 2008 resulted in significant damage, with repairs required to site electronics, cables and communications equipment, and computer replacements. Replacement electronics were borrowed from CSU Humboldt, during their operational hiatus. We also contributed to the IOOS plan for a National HF Radar system through work on the draft plan, and by providing a requested report to IOOS HQ on our experience with staffing needs. We prepared a special data set for J. Moriarity, a U. Chicago student interested in ocean currents and sedimentation from the Umpqua River. On Feb 23, 2009 we met with CODAR at their headquarters to review data extraction algorithms and to renew the collaboration on effects of high currents and strong horizontal shear on data resolution.

We developed a new capability for dual-processing at our Columbia River sites, to allow production of both standard and expanded first-order limit output in real-time, with the goal of improving our resolution of the strong ebb-flow currents there. To improve QA/QC and outage detection, we implemented a heads-up site status display for the web. A pamphlet was prepared for the visitor center at Cape Blanco for public outreach. Incidents of large ionospheric noise in July were investigated, and a report sent to the ROW-G mailing list (techs from other HF operators). Remote sites have been upgraded to MacOS 10.5.8; we plan to hold off on 10.6 until it stabilizes.

We are rolling in CODAR updates to the data acquisition software (SS10R6), with about half of sites updated. Three new computers have been installed. In a major operation, we moved our two Columbia River sites STV and SEA to address issues of erosion and neighbor relations, respectively. In the former case, the move required construction of a new shelter, trenching of a new cable set and electric-power feed, and moving the electronics, computers, and communications equipment, as well as installing new security fences and alarms. The moves also required a major effort to collect new antenna pattern measurements over the water. We conducted tests at Cape Blanco to diagnose low returns, solved false-alarm problems from our security system at Loomis Lake, WA, reduced interference by adjusting GPS timing delays at Point St. George, CA, and added an Internet-enabled power switch to our Winchester Bay site, to provide more reliable remote on- off capability. We are worked with the NSF-sponsored Ocean Observing Initiative to allow them to test ocean-to-shore data transmission through our established wireless communications channels for HF radar data.

In late October 2009, our northernmost site at Loomis Lake, WA, stopped working. Onsite troubleshooting indicated that the electronics needed factory repair, so the system was returned to CODAR Ocean Sensors; in December 2009, CODAR provided a repair estimate of $4990 for essential repairs; the unit was returned in late February 2010.

During winter 2010 we also experienced periods of reduced areal coverage at our oldest HF site, on Cape Blanco (CBL1). This was an intermittent but recurring problem at this site, which is central to our chain and important. In mid-March 2010, we repaired/upgraded CBL1 by replacing all exterior cables, at a cost of approx. $6K; at the same time, we moved the receive antenna electronics and the repaired transmitter/receiver from Loomis Lake to Cape Blanco. This was wildly successful, with CBL now extending reliably to its maximum range. On April 8 2010, we installed the CBL electronics and receive antenna box at LOO. Electronics at our standard-range site at Washburn (WSH1) have failed, and it was sent to CODAR for analysis and repair estimate. Due to NOAA program cuts, budgeted funds for repairs had to be eliminated.

We discovered interference from a long-range site in California was degrading our measurements at Point St. George; coordination with CODAR and the COCMP investigators produced a cooperative solution that spread time-delays for transmission so that regional sites could operate without interference. For the future, we anticipate the need to upgrade two of our older sites to allow GPS timebased operation, at an approximate cost of $60K, presently unbudgeted. We exchanged electronics between WIN and CBL to move GPS capability where it's most needed, and are installing GPS timing antennas at each site. Renewals of our five-year FCC secondary permits proceeded favorably. To increase site resilience, we installed Web Power Switches at each of our 11 sites; these allow individual plugs in a power strip to be power cycled remotely through a web interface, often averting the need for an in-person site visit. Wireless communications to YHS were upgraded with installation of a new 10dbi SWOP antenna. At LOO, a lightning strike took out the computer and monitor on 4/19/10. Service to the site was restored on 7/27/10, after repairs to the site transmitter/receiver electronics were completed at CODAR. A receive antenna cable at WLD was found above ground and severed; one of the pre-buried spares was swapped in to replace it. The aging site computer at YHL was replaced with a new Mac mini.

Impact:

Presentations using the HF data from this system were made by numerous authors at the IEEE Oceans ’09 Meeting in October 2009 (Barletto et al.; Risien et al.), the Coastal and Estuarine Research Foundation (CERF) meeting in Portland in November 2009 (Kosro et al.), and at the Ocean Sciences Meeting in Portland in February 2010 (Osborne, et al.; Kim et al.; Yu et al.; Levine et al.; Cho et al.). In addition, two invited talks at the Meeting of the Americas, scheduled for Aug 2010, have been solicited (Zelenke and Kosro; Kurapov et al.). The paper by Barletto, Kosro and Harlan (2009) at the Oceans ’09 conference provided a vision for cooperation with the OOI to leverage their offshore technology and our onshore array, substantially extending the region of mapped HF coverage through the use of bistatic techniques with a transmitter mounted on the planned OOI surface infrastructure far offshore.

Presentations acknowledging NANOOS support:

Zelenke, B., and P.M. Kosro. “Short-term Current Forecasts from an Empirical Statistical Model”. (Invited Presentation), Meeting of the Americas, Foz do Iguassu, Brazil, 8-13 Aug 2010, Session OS02. 20

Kurapov, A., P. Yu, G. Egbert, P. M. Kosro. “Variational assimilation of high-frequency (HF) radar surface current observations in the coastal ocean model off Oregon” (Invited Presentation), Meeting of the Americas, Foz do Iguassu, Brazil, 8-13 Aug 2010, Session OS02.

Osborne J., A. L. Kurapov, G. D. Egbert, M. Kosro. “Modeling Interactions of M2 Internal Tide with Wind-Driven Circulation on the Oregon Shelf.” Ocean Sciences Meeting, Portland, OR, Paper PO31A-02. Feb 24, 2010.

Kim C., S. Lee, H. Moon, M. Kosro. “Surface Current Response to Wind Force during winter in the Coastal Sea off the Keum River Estuary (South Korea)”. Ocean Sciences Meeting, Portland, OR, Paper PO35E-15. Feb 24, 2010.

Yu P., A. L. Kurapov, G. D. Egbert, J. S. Allen, M. Kosro. “Variational Assimilation of HF Radar Surface Currents in the Coastal Ocean Circulation Model off Oregon”. Ocean Sciences Meeting, Portland, OR, Paper PO41E-09. Feb 25, 2010.

Levine M. D., S. D. Pierce, L. F. Kilcher, M. Kosro, A. M. Baptista, B. C. Crump. “Challenges in Tracking Dye in the Columbia River Plume”. Ocean Sciences Meeting, Portland, OR, Paper PO45J-10. Feb 25, 2010.

Cho K., A. M. Baptista, Y. J. Zhang, C. L. McNeil, M. P. Wilkin, K. Rathmel, M. Kosro, Y. H. Spitz, B. C. Crump, M. D. Levine, S. D. Pierce, T. D. Peterson, C. Wingard, “Subtidal circulation in the Columbia River estuary-plume-shelf system in spring and summer 2009”. Ocean Sciences Meeting, Portland, OR, Paper IT25H-05. Feb 23, 2010.

Kosro, M., J. Newton, and D. Martin, “NANOOS: Building coastal ocean observing within a historical context”. Coastal and Estuarine Research Foundation (CERF) Meeting, Portland, Oregon, Nov 2-6, 2009.

Barletto, P., P.M. Kosro, and J. Harlan, “Next Generation Use of High Power and Bandwidth in the NE Pacific - A Component of the NSF Ocean Observing Initiative”. Oceans 2009 MTS/IEEE Meeting, Biloxi Mississippi, 26-29 Oct 2009.

Risien, C., J. Allan, R. Blair, A. Jaramillo, D. Jones, P.M. Kosro, D. Martin, E. Mayorga, J. Newton, T. Tanner, S. Uczekai, “The NANOOS Visualization System: Aggregating, Displaying and Serving Data". Oceans 2009 MTS/IEEE Meeting, Biloxi, MS, 26-29 Oct 2009.

Publications acknowledging NANOOS support:

Kudela, R. M., A. R. Horner-Devine, N. S. Banas, B. M. Hickey, T. D. Peterson, R. M. McCabe, E. J. Lessard, E. Frame, K. W. Bruland, D. A. Jay, J. O. Peterson, W. T. Peterson, P. M. Kosro, S. L. Palacios, M. C. Lohan, and E. P. Dever (2010), Multiple trophic levels fueled by recirculation in the Columbia River plume, Geophys. Res. Lett., 37(L18607), 1-7, doi:10.1029/2010GL044342.

Yamada, Sylvia Behrens, and P. Michael Kosro, 2010. Can ocean conditions predict recruitment strength of the invasive European green crab, *Carcinus maenas*? Biological Invasions, 12(6): 1791-1804, doi:10.1007/s10530-009-9589-y.

Hickey, B.M, R.M. Kudela, J.D. Nash, K.W. Bruland, W.T. Peterson, P. MacCready, E.J. Lessard, D.A. Jay, N.S. Banas, A.M. Baptista, E.P. Dever, P.M. Kosro, L.K. Kilcher, A.R. Horner- Devine, E.D. Zaron, R.M. McCabe, J.O. Peterson, P.M. Orton, J. Pan and M.C. Lohan, 2010. River Influences on Shelf Ecosystems: Introduction and Synthesis. Journal of Geophysical Research, 115, C00B17, doi:10.1029/2009JC005452.

Kim, S.Y., E. Terrill, B. Cornuelle, B. Jones, L. Washburn, M. Moline, J. Paduan, N. Garfield, J.L. Largier, G. Crawford, P.M. Kosro, 2010. Observations of high-resolution coastal surface circulation on the U.S. West Coast. Submitted to Journal of Geophysical Research.

Hickey, B.M., V.L. Trainer, P.M. Kosro, N.G. Adams, T.P. Connolly, N.B. Kachel and S.L. Geier, 2010. Seasonal differences in sources of toxic *Pseudo-nitzschia* cells on Washington's razor clam beaches. Submitted to Journal of Geophysical Research.

2. Port X-band Radar: Funding for this topic began in Year 2 and continued through Year 3. During this time a real-time marine radar wave observation system was installed on the South Jetty at the entrance to Yaquina Bay (May 2009, Newport, Oregon). The radar antenna was mounted on an existing tower, which was reinforced with guy wires to reduce vibrations. A custom Pelican case was assembled for weather-proofing the data acquisition system and installed in existing "block house" structure. This site provided good views of waves both around the mouth of Yaquina Bay and along the beaches to the north and south. Working with Toby Martin at ShipOps (Hatfield Marine Science Center) data access to the outside world was provided through the existing local radio link with the Hatfield Marine Science Center. Although bandwidth of the link is not large, it has been large enough to support real-time throughput of short image sequences. If and when funding is available, there is a plan for improving the efficiency of the data transfer. The system collects short image sequences, on the hour, and uploads them to our web database server on the OSU campus. Individual images are also made available in real-time through the NANOOS Visualization System.

In early October 2009 the data acquisition suffered a motherboard failure and needed replacement. By April 2010, the data acquisition system was rebuilt and switched over to a Windows XP operating system and image collection resumed through the end of Yr 3 (and beyond).

Impacts:

In addition to establishing the real-time station, associated accomplishments through leveraged funds were as follows:

1) Through student support from the US Navy, radar data analysis demonstrated changes in the wind wave spectrum caused by strong winds between the offshore NDBC wave buoy (46050) and the shoreline. The work also demonstrated a clear correlation between tide stage and wave breaking conditions in the navigational channel.
2) Through leveraged funds from the USACE in support of regional sediment management at the Columbia River, the wave radar system was temporally installed on our mobile trailer at Clatsop Spit. These data serve as a pilot study for a potential new permanent station at the MCR. In this effort we generated high-resolution wave direction maps and bathymetry estimates using our radar observations and compared these data to outputs of local wave predictions from the SWAN model.
3) A PhD student (David Honegger, funded through US DOE) was awarded a student grant from CODAR (well-known HF radar vendor) in order to deploy a UHF radar current observation system (RiverSonde) at our Newport South Jetty wave radar site. The purpose was to map the surface currents through the jetties in order to better characterize the influence of opposing currents on the wave breaking conditions on the Yaquina Bar (as imaged by the marine radar). The system was operational from 10/13/2010-01/23/2011. This data is potentially available in real time in future years.

Publications acknowledging NANOOS support:

Honegger, D.A., S. Meskill, and M.C. Haller, X-band radar observations of waves near a tidal inlet and comparisons to the SWAN model, *AGU Ocean Sciences Meeting*, Portland, OR, Feb. 2010.

Honegger, D.A., M.C. Haller, J.A. Lerczak, and P. McEnaney, Concurrent remote and in situ wave and current observations at a tidal inlet, *AGU Fall Meeting*, San Francisco, CA, 2010.

Meskill, S., “Applications of Marine Radar Wave Observation Systems”, MS Project Report in partial fulfillment of the requirements for Masters of Science Degree, Oregon State University, Dec. 2009.

Presentations acknowledging NANOOS support:

INVITED: “Wave observations and modeling at Newport, OR”, Hatfield Marine Science Center, Newport, OR, November 12, 2009.

INVITED: “Wave measurement methods and data requirements for model validation”, *Wave Amplification / Save Navigation Workshop*, Lower Columbia Solutions Group, Ilwaco, WA, April 27-28, 2009.

b) Modeling efforts

- **Shelf:**

A. Kurapov's group at OSU has developed a real-time coastal ocean forecast model, which produces daily updates of 3-day forecasts of ocean conditions, including currents, temperatures and salinities through the water column (at 3-km horizontal resolution). Maps of the nowcasts and forecasts are posted daily through the NANOOS Visualization System (NVS) (Figure 19).

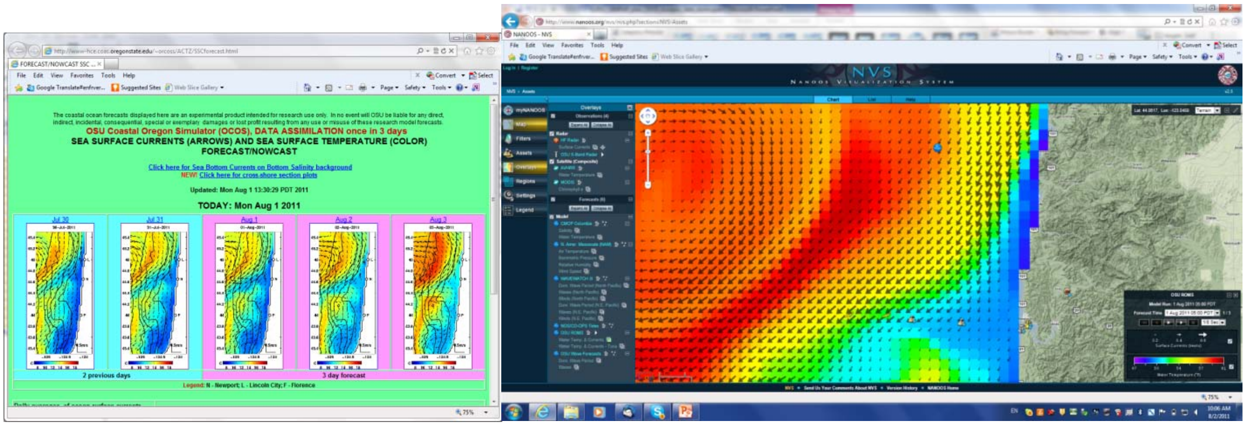


Figure 19. Maps of forecasts of SST and surface currents are provided to the public online via the OSU modeling group site (S. Erofeeva, www-hce.coas.oregonstate.edu/~orcoss/ACTZ/SSCforecast.html) (shown on the left), and the NANOOS visualization system (www.nanoos.org) (shown on the right).

In 2007-2011, the development of the model has progressed from a configuration featuring idealized boundary conditions and simplified atmospheric forcing implementation, to a model with more realistic boundary conditions, provided by climatology from the Navy regional model (NCOM-CCS, I. Shulman, NRL), and spatially variable atmospheric forcing from the 12-km resolution NOAA NAM. Most importantly, in August 2011 we have started routine assimilation of observations in the real-time regime, which significantly improved accuracy of the sea surface temperature, currents, and SSH. Assimilated data have included daily maps of high-frequency (HF) radar currents (provided by P. M. Kosro, OSU) (Figure 20), RADS alongtrack altimetry (provided by L. Miller, NOAA-STAR), and hourly GOES SST (provided by D. Foley, NOAA-Coastwatch). Assimilation proceeds using the advanced variational method (Kurapov et al. 2009, 2011, Yu et al., 2012) in a series of 3-day time windows, which allows synthesis of the sparse and noisy data from different platforms. This method may be viewed as space- and time-interpolation of sparse and noisy observations using dynamically based interpolation (covariance) functions implied by the model.

Impacts:
These forecasts have become a hot topic of fishermen's blogs (http://www.ifish.net/board/showthread.php?t=369346), indicating that the forecasts are useful. The owner of one of the boat charter companies has even made (and posted on their site) a tutorial video of how to use our forecasts via the NVS system (http://amigocharters.com/?page_id=58).

We have established collaboration with Dr. Amy MacFadyen (NOAA, the Office of Response and Restoration (ORR) lab, Seattle) who has run tests of their GNOME oil spill software using our surface velocity forecast fields. Dr. P. Yu, the research associate in charge of the real-time assimilation model, has set up an OpenDAP server that is used to provide fields to ORR immediately in case of emergency.

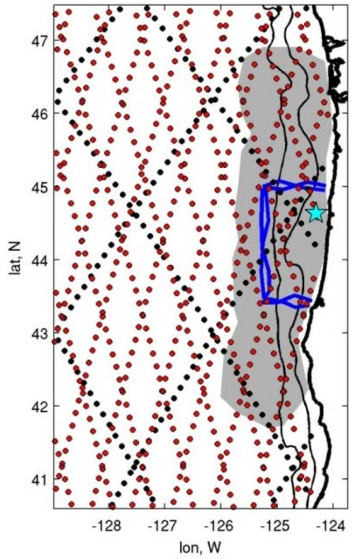


Figure 20. The present forecast model area and locations of some of observations used for assimilation and model verification: (gray) HF radar currents, (dots) Jason-2 and Envisat along-track altimetry, (blue) glider hydrographic sections, (star) NH-10 mooring (velocity profiler).

To better understand the impact of different data sources on the coastal ocean prediction, we have run and compared different hindcast cases (the free-run model and cases assimilating SST alone, HF radar currents alone, SST and currents, and SST, currents, and SSH in combination). These studies not only guide further development of this product, but also let us obtain new knowledge about regional ocean dynamics and identify challenging areas, for instance, enhanced diurnal tides around capes, the effect the Columbia River plume on SST, and interior-coastal ocean connectivity in winter.

Future short-term plans have included incorporation of the Columbia River discharge, extension of the domain to include North California and Washington coasts, and adding new data streams to the pool of assimilated data (most importantly, glider sections of temperature and salinity, NANOOS mooring time series data, satellite microwave radiometry, etc.), to further improve quality of the forecasts and to extend the user base.

Publications acknowledging NANOOS support:

Kurapov, A. L., G. D. Egbert, J. S. Allen, and R. N. Miller, 2009: Representer-based analyses in the coastal upwelling system, Dynamics of Atmospheres and Oceans, 48(1-3), 198-218, doi:10.1016/j.dynatmoce.2008.09.002.

Koch, A. O., A. L. Kurapov, and J. S. Allen, 2010: Near-surface dynamics of a separated jet in the coastal transition zone off Oregon, J. Geophys. Res., 115, C08020, doi:10.1029/2009JC005704.

Kurapov, A. L., D. Foley, P. T. Strub, G. D. Egbert, and J. S. Allen, 2011: Variational assimilation of satellite observations in a coastal ocean model off Oregon, J. Geophys. Res., 116, C05006, doi:10.1029/2010JC006909

Yu, P., A. L. Kurapov, G. D. Egbert, J. S. Allen, P. M. Kosro, 2012: Variational assimilation of HF radar surface currents in a coastal ocean model off Oregon, Oc. Mod., submitted.

- **Estuaries**

1. Puget Sound:

a. Puget Sound Princeton Ocean Model (PS_POM): Overseen by D. Jones, APL-UW, NANOOS/IOOS funding allowed APL-UW to maintain an operational hindcast model of the Puget Sound (PS-POM). PS-POM was originally developed the School of Oceanography, University of Washington and the code was transitioned to APL-UW. The PS-POM was set up as a semi-operational system. Changes to tidal forcing at the boundary were monitored and resulted in better performance than when the model was running prior to the NANOOS funding. Changes were made to the code-base to allow the model to more gracefully accommodate intermittent initialization data provided by outside resources.

APL-UW created a new interface for retrieving graphics products, matching the style of the NANOOS website, and allowing users to search through available dates to select dates of interest. Development on this part of the system is ongoing, and input from modelers and laypeople are being used in the process.

PS-POM data has been available via an OPeNDAP server, and as KML-formatted files viewable via Google Earth. PS-POM has a grid resolution of 295 grid points with 540 meter grid spacing in the North-South direction and 199 grid points with 360 meter grid spacing in the East-West direction. There are 14 sigma levels used to discretize the vertical axis. The model is run in a hindcast mode. The output for the previous day is made available daily at 4am PST. The output from one run is used as the initial conditions for the next day's hindcast.

The PS-POM files use the naming convention pom-YYYY-MM-DD.cdf.bz2. A user may use this to quickly retrieve information on a data set. For example, to download ASCII data from a PS-POM output file from the October 1st, 2007 you can enter this line in a browser and fill out the form: http://metoc2.apl.washington.edu/pydap/pom-2007-10-01.cdf.bz2.html

APL-UW has stored the PSPOM output locally in a compressed format. It may take some time (a minute or two) for the machine to uncompress the file and display the desired output. Once the file has been uncompressed it is cached, so subsequent viewing/data retrievals should not take as long. The page above also explains how to get access to the data in the PS-POM file using a number of other OPeNDAP clients. This OPeNDAP server provides PS-POM model output from May 4th, 2007 through the present. The OPeNDAP server used is pydap and is open source code that runs python in the Apache web server. Nicholas Lederer at APL-UW modified this code to serve compressed files.

There has also been effort to establish verification of the model with observations taken in Puget Sound. Some rudimentary visualizations of this can be found http://metoc1.apl.washington.edu/Visualizations/tide_verification/. Data for these plots is taken from http://www.co-ops.nos.noaa.gov/. See Figure 21.

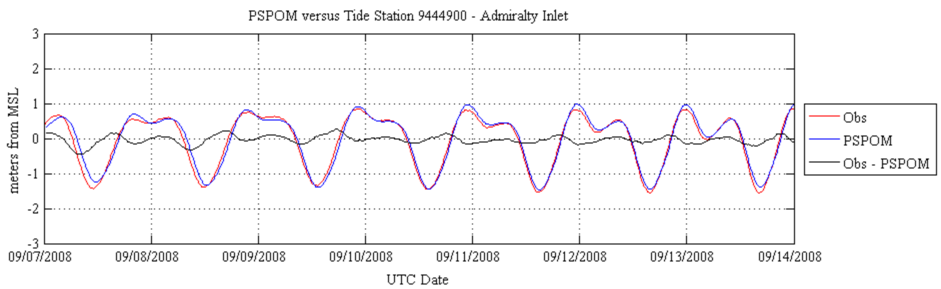


Figure 21. A comparison of the PS-POM tide prediction compared to the observation at Admiralty Inlet Tide Station 9444900.

b. Salish Sea ROMS Model: The Model of the Salish Sea (MoSSea) http://faculty.washington.edu/pmacc/MoSSea/ is based on the ROMS general circulation model (Figure 22). MoSSea is lead by Parker MacCready and the lead developer is Dave Sutherland, both in the School of Oceanography at the University of Washington. APL-UW provided software development guidance to the MoSSea developers. APL-UW worked to develop a visualization system for the ROMS model written in Python called ROMPY. Source code with example images and movies made with ROMPY can be found: http://metoc1.apl.washington.edu/~lederer/rompy/.

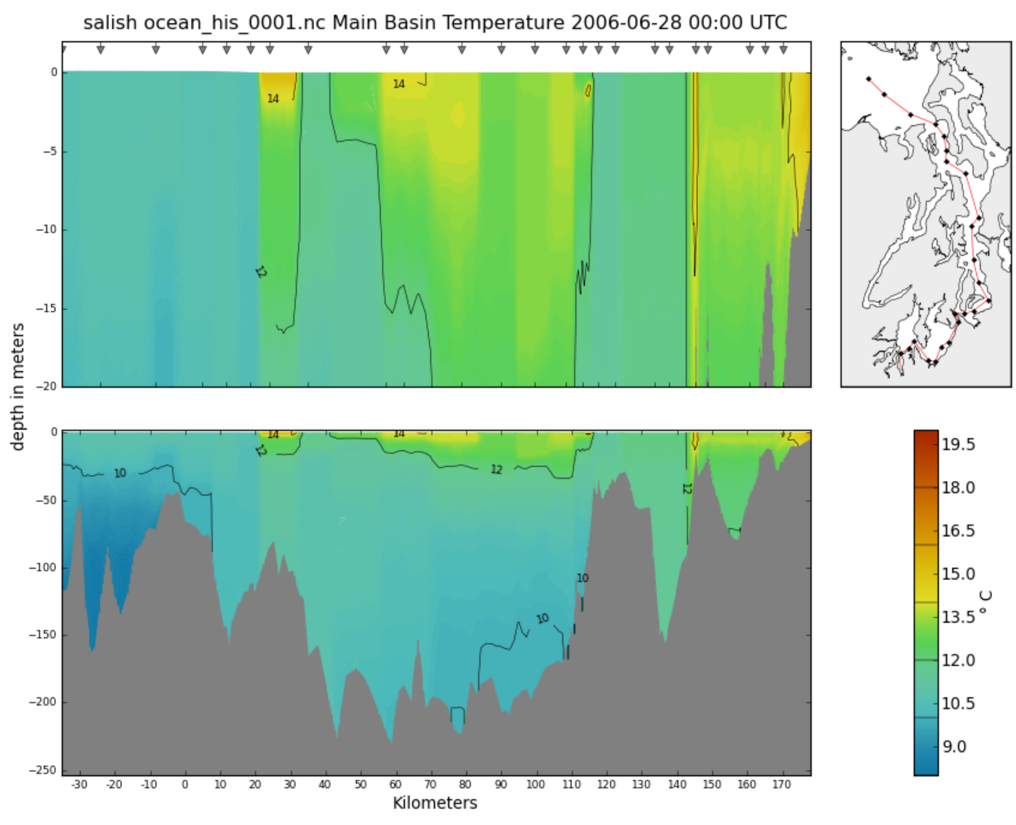


Figure 22. An example of the Salish Sea ROMS output for temperature on June 28, 2006.

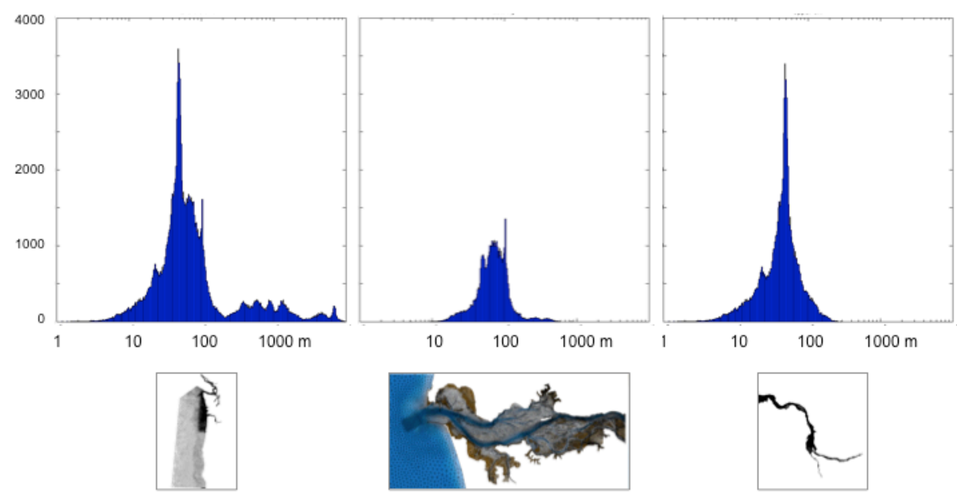
c. Additional modeling efforts by UW: With NANOOS/IOOS support and also support from U.S. Department of Energy, we implemented and evaluated the Stanford SUNTANS model for Puget Sound and the eastern Strait of Juan de Fuca. It would need considerable further work before it could be usable on an operational basis. There is a paper coming out on this model (Kawase and Thyng, 2010, IET Renewable Power Generation, in press).

Neil Banas and Nicholas Lederer (both at APL-UW) developed the software package named *Particulator*. The software package uses java to calculate particle trajectories from circulation model output and display particle paths graphically. The code now reads in output from the GETM and ROMS models, and plans are being made to add support for POM and SUNTANS output.

Banas and Lederer also developed a system using the General Estuarine Transport Model (GETM) to model synthetic oscillating/curving channels in an estuarine setting. These models are used to analyze the sensitivity of various estuarine features to changes in bathymetry. This work is motivated by an interesting feature in Willapa Bay, where there exists two regions in the bay that have vastly differing turnover time scales.

2. Columbia River coastal margin: OHSU-CMOP has maintained an extensive modeling system for the river-to-shelf circulation of the Columbia River. Regional stakeholders include the Bonneville Power Administration (BPA), NOAA, U.S. Army Corps of Engineers (USACE), Lower Columbia River Estuary Partnership (LCREP), and Columbia River Inter-Tribal Fish Commission (CRITFC).

The modeling system is integral to the SATURN collaboratory, and is informed by SATURN and other NANOOS observation networks. It is envisioned as a “virtual Columbia River,” with an array of products readily available for the use by a broad community of scientists, educators, and managers. Virtual Columbia River products include daily circulation forecasts (partially available through NANOOS NVS), decade-long hindcast simulation databases of circulation, a Climatological Atlas, and scenario simulations. Grids are 3D, horizontally unstructured, and extend across river-to-ocean domains (Fig. 23).



	# elements	# nodes
Total:	142689	74061
Estuary:	47531	24535
Ocean:	22014	11574
Tidal freshwater:	90220	46838

Figure 23: Extent and resolution of the grid for a recent simulation database of the Virtual Columbia River. The y-axes in the histograms are number of elements. The x-axes are equivalent diameters of the elements.

During the reporting period we continued the systematic enhancement of the modeling skill of circulation in the Virtual Columbia River. Activities included: (a) continued optimization of the spatial refinement of the underlying (unstructured) numerical grid; as in the past, particular care was placed in incorporating regions and scales of interest for salmon recovery projects; (b) sensitivity studies to various model parameters, with emphasis on turbulence closure schemes; and (b) characterization of coastal storms.

In 2010 we also extended the modeling domain of the Virtual Columbia River upstream of Beaver Army, to include the tidal freshwater in the Columbia River through Bonneville Dam and in Willamette River through Willamette Falls. The changes permit a more effective use of the simulations to support: climate impact studies; salmon and ecosystem restoration projects; flood protection studies; and hydropower and navigation management.

Impact:
We have continued applications of the Virtual Columbia River to multiple issues of regional significance, typically in partnership:

(a) Studies associated with the revision of the Columbia River Treaty between the US and Canada; these studies have been conducted in partnership with CRITFC and an increasing number of federal agencies.
(b) Studies of the influence of the Columbia River plume on salmon survival; these studies have been conducted in partnership with NOAA and with funding from BPA.
(c) Studies of the variability and contemporary evolution of salmon habitat opportunity in the Columbia River estuary and tidal freshwater; these studies have been conducted in partnership with NOAA and with funding from USACE.
(d) Studies of habitat suitability in the Columbia River estuary and tidal freshwater, funded by LCREP and conducted in collaboration with the Pacific Northwest National Laboratory.
(e) Creation of maps of coastal storm inundation in the Columbia River estuary and Pacific County, funded by FEMA and conducted in collaboration with a consulting company (PBS&J) and DOGAMI.

Presentations acknowledging NANOOS support:

Bandolin, N. (2010) Towards Long-Term Time Series of Sediment Concentrations in the Columbia River Estuary. Pacific University Student Poster Sessions, November 16, Forest Grove, Ore.

Baptista, A. M. (2010). Virtual Columbia River. Eastern Pacific Ocean Prediction Forum, September 20-22, Portland, Ore.

Baptista, A. M., C. Seaton, J. Needoba, M. Wilkin, K.Rathmell, P. Turner, S. Riseman, C. Roegner (2010). The Columbia River estuary as an ocean sentinel: temperature, hypoxia and other tales. EPOC 2010, September 22-25, Mt. Hood, Ore.

Baptista, A. M., E. V. Armbrust, B. C. Crump, L. Herfort; B. M. Howe, M. D. Levine, D. Maier, C. L. McNeil, J. Needoba, T. D. Peterson, F. G. Prahl, T. B. Sanford, H. M. Simon, M. Smit, Y. H. Spitz, B. M. Tebo, P. Zuber (2010). Coastal margin collaboratories: from reactive to anticipatory science (Invited). AGU Ocean Sciences Meeting, February 21-26, Portland, Ore.

Baptista, A. M. (2010). Coastal Margin Science in the Era of Collaboratories. AGU Ocean Sciences Meeting, February 21-26, Portland, Ore.

Baptista, A. M. (2010). An Advanced Observation and Prediction System for the Columbia River. 2010 Coastal Summit, May 21, Long Beach, Wa.

Cho, K., A. M. Baptista, Y. J. Zhang, C. L. McNeil, M. P. Wilkin, K. Rathmel, M. Kosro, Y. H. Spitz, B. C. Crump, M. D. Levine, S. D. Pierce, T. D. Peterson, C. Wingard (2010). Sub-tidal circulation in the Columbia River estuary-plume-shelf system in spring and summer 2009. AGU Ocean Sciences Meeting, February 21-26, Portland, Ore.

Law. G., A. M. Baptista (2010) The Virtual Estuary: From Modeling to Climatologies. November 16, Forest Grove, Ore.

Law, C. G., A. M. Baptista, C. Seaton, S. Frolov, Y. J. Zhang, K. Cho, Y. H. Spitz, S. M. Durski, N. Hyde (2010). Data-informed circulation simulations in the river-to-shelf Columbia River system. AGU Ocean Sciences Meeting, February 21-26, Portland, Ore.

Seaton C., A. M. Baptista, P. Turner, A. Jaramillo, D. Hansen, D. Maier, E. Van Matre, A. Johnson, J. Oltmann (2010) Lessons learned from the cyber infrastructure of the SATURN coastal margin “collaboratory” (Invited), Eos Trans. AGU, 91(26), Ocean Sci. Meet. Suppl., Abstract IT21C-03

Bandolin, N., M. Wilkin, K. J. Rathmell and A. M. Baptista (2009). Towards long-term time series of sediment concentrations in the Columbia River. Coastal and Estuarine Research Federation 20th Biennial Conference, Portland, OR.

Green, V. L. and A. M. Baptista (2009). Research Undergraduate Experiences in Coastal Margins: An experiment in bi-directional mentoring. Coastal and Estuarine Research Federation 20th Bienniel Conference, Portland, OR.

Hansen, D. M., C. M. Seaton, A. V. Jaramillo, P. J. Turner, J. Schilling, D. Maier, J. Freire, C. T. Silva and A. Baptista (2009). From Observatories to Collaboratories: The SATURN Cyber-Infrastructure. Coastal and Estuarine Research Federation 20th Biennial Conference, Portland, OR.

Hyde, N., P. J. Turner, C. G. Law, Y. J. Zhang and A. M. Baptista (2009). A Virtual Estuary: Columbia River climatology and anomalies. Coastal and Estuarine Research Federation 20th Bienniel Conference, Portland, OR.

Law, C. G. and A. M. Baptista (2009). A Virtual Estuary: Columbia River estuary and plume response to large-scale environmental change. Coastal and Estuarine Research Federation 20th Biennial Conference, Portland, OR.

Seaton, C. M., M. Wilkin, K. J. Rathmell, N. Hyde, Y. J. Zhang, T. D. Peterson, F. G. Prahl, J. A. Needoba and A. M. Baptista (2009). Salinity Intrusion in Estuaries: Lessons learned from a vertical profiler. Coastal and Estuarine Research Federation 20th Biennial Conference, Portland, OR.

Wilkin, M., K. J. Rathmell, C. M. Seaton, P. J. Turner, J. A. Needoba, T. D. Peterson and A. M. Baptista (2009). Towards long-term time series of biogeochemical vertical profiles in the Columbia River estuary. Coastal and Estuarine Research Federation 20th Biennial Conference, Portland, OR.

Bandolin, N., A.M. Baptista (2008). The Current State of Coastal Observation Networks. SACNAS International Polar Year: Global Change in Our Communities, October 9-12, 2008, Salt Lake City, UT.

Zhang, Y., A. Baptista, et al. (2008). A 3D hydrostatic model for coastal and oceanic applications. Seventh International Workshop on Unstructured Grid Numerical Modeling of Coastal, Shelf and Ocean Flows, Bedford Institute of Oceanography.

Frolov, S., A. M. Baptista, et al. (2007). Data Assimilation with a Reduced-Dimensionality Model in a Coastal Observatory. Workshop on Data Assimilation in Support of Coastal Ocean Observing Systems, Corvallis, OR.

Myers, E, Zhang A, Aikman F, Zhang Y, Baptista A, Turner P, Seaton C. 2007. Evaluation and Transition of a Columbia River Nowcast/Forecast Circulation Model to NOAA's National Ocean Service. Coastal Zone '07.

Zhang, Y. L., A. M. Baptista (2007). A 3D unstructured grid hydrostatic model for scales from O(10km) to O(1m) (poster). Gordon Research Conference, New London, NH.

Zhang, Y. L., A. M. Baptista (2007). Towards a 3D higher-order estuarine and coastal model based on unstructured grids. Estuarine and Coastal Modeling, Newport, RI.

Publications acknowledging NANOOS support:

Burla, M, Baptista A, Zhang Y, Frolov S. 2010. Seasonal and interannual variability of the Columbia River plume: A perspective enabled by multiyear simulation databases. Journal of Geophysical Research. 115(C00B16).

Burla, M, Baptista A, Casillas E, Williams JG, Marsh DM. 2010. The influence of the Columbia River plume on the survival of steelhead (Oncorhynchus mykiss) and Chinook salmon (Oncorhynchus tshawytscha): a numerical exploration. Canadian Journal of Fisheries & Aquatic Sciences. 67(10):1671-1684.

Baptista, A, Howe B, Freire J, Maier D, Silva CT. 2008. Scientific Exploration in the Era of Ocean Observatories. Computing in Science & Engineering. 10(3):53-58.

c) Data Management and Communications Committee (DMAC)

1. Managerial*:* Chaired by Stephen Uczekaj (Boeing Research and Technology) this committee is composed of members from APL-UW, OHSU-CMOP, OSU, members of NANOOS User Products Committee (UPC), Education & Outreach (E&O) Committee, and Web Portal team. Steve Uczekaj is a member of the NANOOS Governing council and responsible for coordination of DMAC activities and reporting. Boeing hosts a NANOOS DMAC weekly developers 'tag-up' conference call to facilitate open dialog, common vision, synergy of efforts, and consistent progress across a diverse team of university and industry participants. DMAC committee members also participate in cross regional coastal ocean observing activities and national workshops. Activities for this Y1-Y3 period included: 1) yearly kickoff meeting to plan out prioritized list of goals and activities, 2) weekly NANOOS DMAC teleconferences; 3) annual IOOS DMAC workshops, 4) annual meeting of NANOOS tri-committees including DMAC, UPC and E&O, 5) annual NANOOS PI meeting, 6) annual NANOOS Governing Council meeting, 7) progress reporting including bi-annual regional RCOOS and RA progress report.

2. Purpose of Committee*:* The purpose of NANOOS DMAC is to coordinate the development and maturation of a Northwest region Data Management and Communications computing system architecture and services for open access and delivery of ocean observing sensor data and models to Northwest regional and IOOS national stakeholders. NANOOS is one of 11 regional projects supporting the overall vision of the IOOS DMAC including:

1) Delivering accurate and timely ocean observations and model outputs to a diverse range of consumers including government, academic, private sector users, and the general public utilizing specification common across all providers,

2) Deploying information system solutions supporting life-cycle management of observations from collection to product creation to public delivery, system documentation, and archiving,

3) Ensuring robust data exchange that is responsive to variable customer requirements and routing feedback and not tightly bound to a specific application of the data or particular end-user decision support tool.

3. Achievements:

DMAC Architecture: DMAC focus during the RCOOS Y1-Y3 period was on activities supporting the development and implementation of an interoperable open service oriented architecture for collection and dissemination of ocean observing data. Specific activities included:

1) Developing a framework and process for collection and integration of Northwest Data Providers of ocean observing data for core variables identified in DMAC national workshops.

2) Sensor observation service interfaces for programmatic access to ocean observing data in near-real-time using open interoperable standards compliant with Open Geospatial Consortium (OGC) standards and IOOS guidelines.

3) Development of an asset list and metadata repository of NANOOS and Federal and non-Federal data sources.

4) Integration of DMAC services with Web-based portal for online data search and retrieval.

5) Mobile App interfaces and Services for mobile access and display.

During the Y1-Y3 effort (2007-2010) NANOOS supported development of a DMAC architecture supporting standard recommendations from the IOOS program pilot project called Data Integration Framework (DIF). NANOOS developed standard programmatic interfaces for query and download of 7 DIF recommended core variables plus additional variables. In early 2010, NANOOS was invited by the IOOS national program office to submit recommendations on DMAC implementation priorities in support of the DIF pilot project. The NANOOS DMAC team submitted an input and was subsequently invited to Silver Springs, MD in June 2010 to present to IOOS DMAC national technical team on the definition and prioritization of 12 key areas of interest. These areas included security, alerts, archiving, standardization, registration, visualization, data integration, catalog, system monitoring, format conversion, metadata, quality control and assurance. The national IOOS program office incorporated many of these ideas into a requirements document tilted "Data Management and Communications (DMAC) Implementation Plan" in 2011. A current version of the paper can be downloaded from the following web link - http://www.ioos.gov/data/dmac/welcome.html .

In 2009-2010, the DMAC team worked closely with UPC and Web team members to develop a multi-tier service-oriented architecture for collection, management and dissemination of Northwest region data. Central to this architecture is a real-time data integrator and web-portal application called the NANOOS Visualization System (NVS, http://nvs.nanoos.org) first released as version 1.0 in November 2009 and reaching version 2.0.1 by September 2010 (see the UPC section for more details about NVS). The DMAC system architecture includes NVS specific elements for internal asset meta-data storage, automatic data harvesting and storage of regional and federal data provider information for portal access and display, as well as external services and interfaces for collection and dissemination of regional data. Figures 24 and 25 give a graphic portrayal of the NANOOS DMAC and NVS System Architecture.

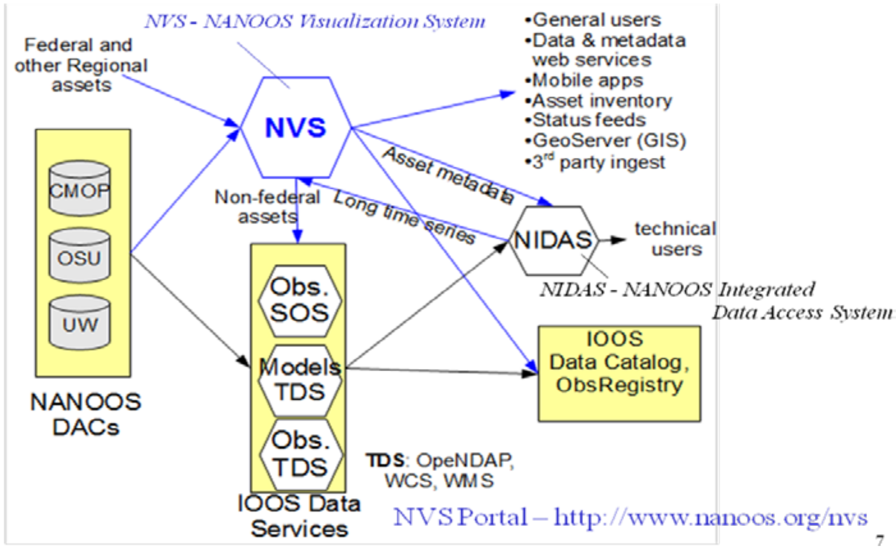


Figure 24 - NANOOS DMAC System Architecture

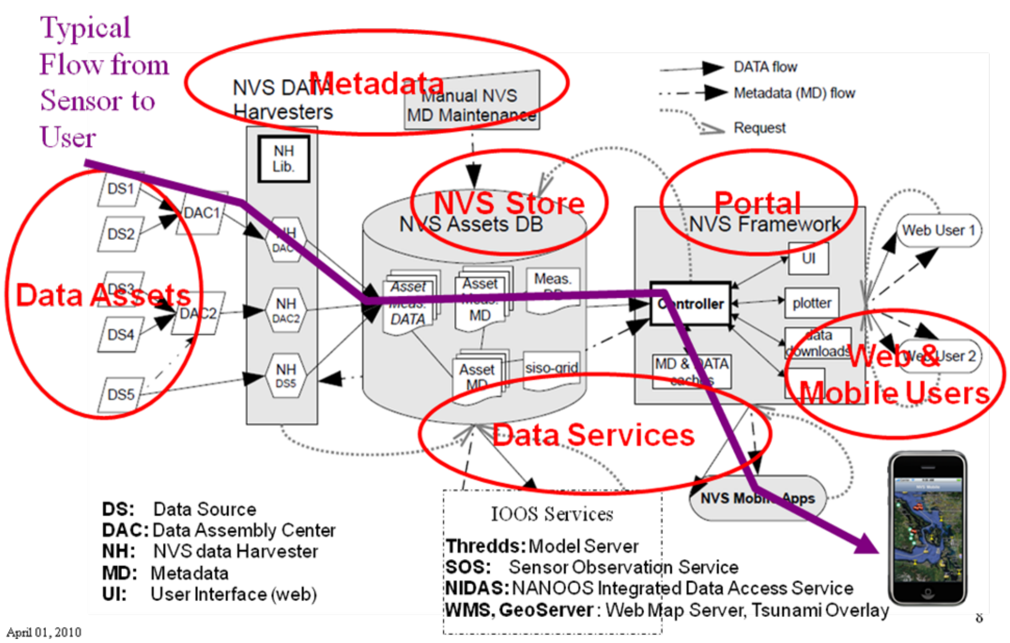


Figure 25 NVS/DMAC Architecture (from Mayorga et al., 2010).

DMAC Data Services*:* NANOOS DMAC data services were developed during Y1-Y3 to support both regional Northwest stakeholder interests and national IOOS program stakeholder interests.

Regional activities focused on providing reliable interfaces for access to Northwest region ocean observing data as well as working closely with the UPC, E&O and WEB teams on Web-based products and data management system. A NANOOS data management system for ingesting regional Datasets using a Data Provider meta-data profile was developed. With this approach any in-situ observation Dataset can be integrated and made available for access and dissemination through the NVS portal and standardized interoperable service interfaces including Sensor Observation Service (SOS). Gridded data from models and remote sensing systems were also integrated into NVS using tile services and OGC WMS. In addition, NANOOS model data distribution services were deployed in 2009 and 2010 using OGC Web Mapping Service (WMS), Unidata THREDDS and OPeNDAP.

National activities focused on development of interoperable observation data access services using OGC compliant standard interfaces. In 2008, NANOOS deployed an early SOS server at OHSU-CMOP providing access to data from 40 platforms across 5 observation networks around the Northwest and millions of observations. In 2010 this SOS server was replaced with an upgraded version adhering to the IOOS SOS GML 0.6.1 profile, and was linked to the IOOS Catalog soon after the release of the Catalog. Also, in 2010 a mobile device web service interface was developed as an extension of NVS light-weight web services to allow simplified smart phone access to NVS asset data and time series plots. In 2010, the open-source GeoServer software was deployed to provide Oregon Tsunami inundation hazard map via OGC WMS (see UPC section and Martin et al., 2011); GeoServer also provides interoperable access to geospatial data via other OGC standards, including KML and Web Feature Service (WFS).

DMAC Data Aggregation: Since its first release, NVS has continuously been updated to support new data streams as they became available (including a wide range of asset providers and platform types), and enhanced to deliver new functionality and data types. By August 2010, NVS ingested data from up to 112 in-situ and gridded assets, and 27 providers including academic, industry, county, state, federal and Canadian providers (Mayorga et al., 2010).

In 2009 and 2010, NANOOS DMAC worked closely with Web Portal and UPC members to develop a universal data aggregation service called NANOOS Integrated Data Access System (NIDAS) that is based on the Environmental Research Division's Data Access Program (ERDDAP). NIDAS, while not yet fully operational, will enable stakeholders to utilize a consistent, interoperable interface for access and display of a multitude of data types offered by NANOOS including long time-series sensed observation data, flexible access to model data in gridded and non-gridded form, and archival access to historical data including oceanographic data, and meteorological data. While NIDAS is not intended as a simple user interface and rapid response for new, local assets, NANOOS is adapting it to integrate seamlessly with NANOOS NVS/DMAC environment.

DMAC Mobile Data Access: In 2009-2010, Boeing took the lead on obtaining licenses, development and release of a Mobile APP version of NVS for the iPhone and Android smart phone devices (Figure 26). DMAC, UPC and Web Portal team members worked closely to build a light weight mobile interface to the Web-based NVS system and a streamlined graphical interface for viewing NANOOS assets and data as real-time plots in 24hour, 7 day and 30day time periods.

Figure 26. NVS Mobile App for iPhone

Presentations and Publications acknowledging NANOOS support:

Martin, D.L., J.C. Allan, J. Newton, D.W. Jones, S. Mikulak, E. Mayorga, T. Tanner, N. Lederer, A. Sprenger, R. Blair and S.A. Uczekaj. Using Web-based and Social Networking Technologies to Disseminate Coastal Hazard Mitigation Information within the Pacific Northwest Component of the Integrated Ocean Observing System (IOOS). *Proceedings of the MTS/IEEE Oceans 2011*, Kona, HI, Sept 19-22, 2011.

Mayorga, E., Tanner, T., Blair, R., Jaramillo, A.V., Lederer, N., Risien, C.M., Seaton, C., The NANOOS Visualization System (NVS): lessons learned in data aggregation, management and reuse, for a user application. *Proceedings of the MTS/IEEE Oceans 2010*, Seattle, WA, 20-23 Sept 2010

Risien, C., J. Allan, R. Blair, A. Jaramillo, D. Jones, P, Kosro, D. Martin, E. Mayorga, J. Newton, T. Tanner, and S. Uczekaj. The NANOOS Visualization System: Aggregating, Displaying and Serving Data. *Proceedings of the MTS/IEEE Oceans 2009*, Biloxi, MS, Oct 26-29, 2009.

d) NANOOS User Products Committee (UPC)

***1. Managerial**:* Chaired by Jonathan Allan (Oregon Department of Geology and Mineral Industries) this committee is composed of members from Boeing, OHSU-CMOP, APL-UW, OSU, OR Sea Grant, and NOAA. NANOOS UPC chair Allan participates in weekly "tag-up" calls with a smaller sub-group comprised of members from Data Management and Communication (DMAC), UPC, (Education & Outreach) E&O and Web development in order to facilitate consistent work efforts, synergy across the committees, and improvements to product development and enhancements. Activities for this Y1-3 period included: 1) weekly NANOOS DMAC and UPC teleconferences; 2) annual meetings of a core sub-group of NANOOS DMAC-UPC-WEB staff; and, 3) annual meetings of the full NANOOS DMAC-UPC -E&O Tri-committee members.

2. Purpose of Committee: The core focus of the NANOOS UPC is to guide the conceptual development of the data/analysis products (i.e. observations, time series, models, applications, etc.) identified by NANOOS stakeholders, and develop the appropriate graphical formats and lines of communications for product dissemination. Critical to this process has been the recognition that the UPC works closely with other NANOOS committees, most importantly the DMAC and E&O teams to ensure product concepts are effectively developed and tested prior to their release.

3. Achievements:

Website: Efforts by the UPC and WEB teams have focused on two important goals in the development of a regional RCOOS during Y1-3. These included:

1. Developing the overall conceptual look and design of the NANOOS website. Integral to this process was the identification of **existing** web-based products that met the core thematic areas (i.e. Maritime Ops, Ecosystem Impacts, Marine Fisheries, and Coastal Hazards) adopted by the NANOOS Governing Council, which could be integrated into the NANOOS website. Having identified these product links, NANOOS released version 1 of the website in June 2008, which was later substantially enhanced and updated early in 2009.

2. Identifying **new** important web-based products that could be designed and built by NANOOS, which would ultimately integrate and disseminate complex information such as oceanographic data from a wide and disparate group of data providers, in forms that could be easily accessed and interpreted by PNW stakeholders.

Over the course of Y1-3, we successfully fulfilled both goals and in many respects exceeded our initial expectations. Currently, NANOOS provides links to 40 products, of which 18 are custom built to meet the needs of NANOOS stakeholders. Several of these products are discussed in more detail in the sections below.

The development and iterative improvement of a web portal for NANOOS was commenced during RCOOS funding years Y1-Y3. The portal was seen as one of the primary mechanisms for meeting important goals of NANOOS, particularly in the areas of DMAC, user-centered products, and education and outreach. This effort also included the development of data-access web application tools such as NVS, and a wide range of new web content. Prior to start of the RCOOS project NANOOS had a relatively modest homepage with links to websites that hosted regional ocean observations. In addition to these external links, the homepage was used as a means of spreading the word about the nascent IOOS regional organization. Figure 27 is an example of the NANOOS homepage prior to the start of the RCOOS funding.

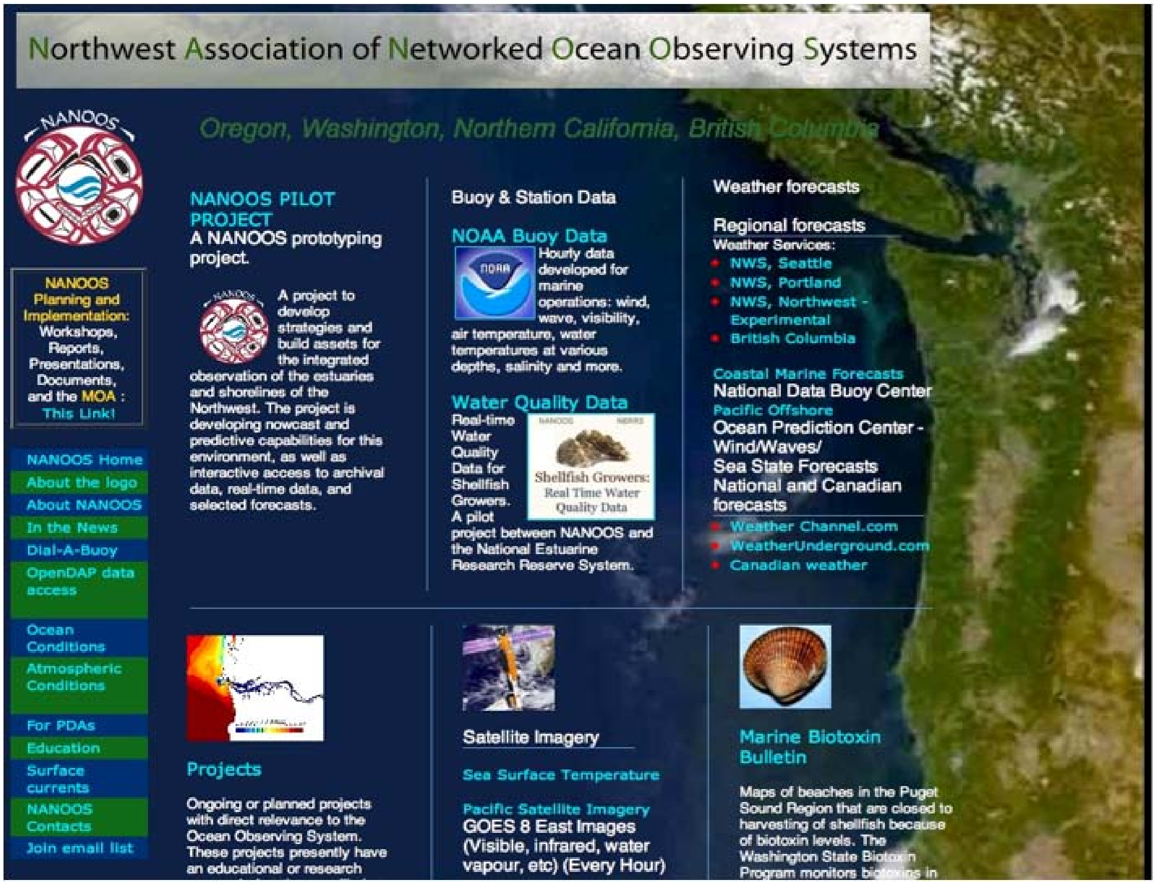


Figure 27. The original NANOOS Homepage prior to redesign.

With stable funding from NANOOS and the designation of APL-UW as lead developer, the NANOOS management team envisioned a more ambitious web portal. The goal was to not only become a focal point for environmental observations and forecasts in the Pacific Northwest region, but to also facilitate community building and education.

The key design features of the new NANOOS web portal were:

- Create an interface that was both visually appealing and intuitive to navigate
- Enhance data discovery and visualization of ocean observations
- Create a commons area where NANOOS members could share information and data
- Provide a communication pathway for education and outreach

The initial portal design was completed in the first six months of Y1 and was presented to the NANOOS Tri-Committees (UPC, DMAC and E&O). Following the tri-committee review, minor changes were made to the design and a prototype was operational by the summer of 2008. Figure 28 is an example of the new portal interface.

Figure 28. The updated NANOOS portal interface.

A comparison between the two interfaces reveals some of the design decisions for the new portal. The updated NANOOS interface has a sharper, cleaner look. Part of the reason is that the new typesets have a higher resolution, as does the background map. The navigation column on the left side has been simplified. There is less distracting background color being used, and user feedback has been added by creating a background highlight when the mouse pointer passes on top of a navigation links. Also, a subtle framing around each image makes the graphics standout more prominently; in the same way paintings look better in frames.

The organization of information on the homepage and in the other sections of the portal was also changed. In order to keep important information prominent, like the *Noteworthy* section or the primary navigation links, less important links like the *News* or *People* links were subordinated and placed at the bottom of the page. There was also an explicit decision to keep text to the minimum, especially on the homepage because it can be distracting to new users. Finally, because the portal was planned to be an iterative process, future capabilities such as a section for *Education and Outreach* (see figure 2), were given stubs on the interface but faded in color making it clear to the user that those links were still under construction. With the completion of the initial NANOOS portal, the next focus of the web portal team was to build out the content and create user tools. Some of this new content is described in other areas of this report; for example, lesson plans for educators, theme pages tailored to specific topics/users, and data visualizations.

Collection of user statistics commenced in early July 2008 by utilizing the free application called *Google Analytics*. Figure 29 shows NANOOS web visits for the period June 1, 2008 (before information collection started) to October 1, 2010. The graph shows the growth in usage, from tens of users in 2008, growing to days when over a hundred users visited the web portal in 2010. The figure also shows unusual spikes in visitors. Without additional data these can't be explained, however, data from other environmental sites developed by APL-UW show distinct increases in web visits when unusual weather events happen. This could be the explanation for apparently random spikes seen in visitors.

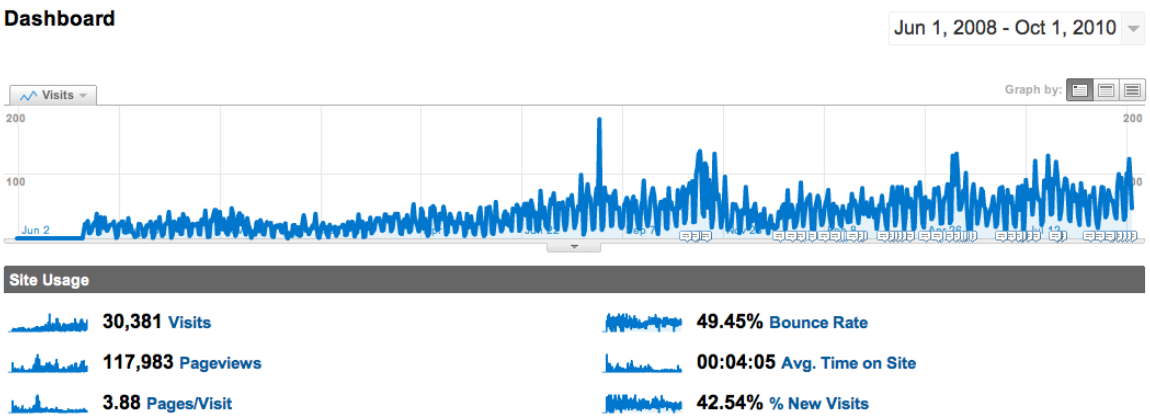


Figure 29. Web Portal visitor statistics available via Google Analytics.

NVS: The backbone of the NANOOS RCOOS is the NANOOS Visualization System (NVS, http://nvs.nanoos.org) that currently distributes data from a myriad of regional and federal assets. While it is recognized that a single visualization tool is unable to meet all user needs throughout the NANOOS region, such a tool can still provide the necessary framework on which additional applications are based and subsequently developed that meet specific user needs. It is this latter approach, which now forms the basis for future enhancements to application development within the NVS platform.

Early in 2008 NANOOS UPC/DMAC/E&O committee members and APL-UW web development team met to strategize through visioning processes, the necessary data management and communication (DMAC) components that ultimately would comprise the NVS. To facilitate the application and web development process, a core team developed a white paper, with significant input from NANOOS committee members. The NVS platform had four primary requirements (Risien et al. 2009):

1. Interoperability with national-scale applications;
2. Reliable, efficient ingest of data from observational assets;
3. Access to models, application tools and information products; and,
4. A rich yet simple interface enabling decision making by end users on a routine, unassisted basis.

To meet these requirements and ultimately the end user, NVS was designed in such a way that it provides a suite of interfaces that included: map views of observational asset locations and model domains, comparison of multiple variables, changes in variables over time, changes in variables with depth, geographical map views of parameter values, cross-sectional map views that include comparisons of depth with distance along transect(s) or comparisons of depth versus time changes at a range of geographic locations and spatial scales. Access to the asset data (Mayorga et al., 2010) is accomplished by clicking on specific icons, where the user is presented with a variety of distinct time windows and plots contained in a 'tabbed' interface that provide access to *current conditions, forecasts* and a *comparator* tool that enables access to both observations and modeled results at the same location. In time we anticipate adding additional tabbed views, most important of which is providing access to long-term and eventually archived datasets.

With these concepts in mind, NVS version 1 (Table 1) was developed over a period of several months between May (completion of the NVS white paper) and 2 November, 2009, when it was publicly released. At the time of its initial release, NVS provided all the necessary capabilities to aggregate, display and serve near real-time coastal, estuarine, oceanographic and meteorological data, derived from a suite of assets including buoys, tide gauges, meteorological stations, and shore based coastal stations. With the release of NVS v1.5 in March 2010, the capabilities of NVS were expanded to include several new enhancements, including an improved user interface, the inclusion of forecast capabilities at selected asset locations, and the incorporation of glider and cruise assets into the NVS platform. Version 1.6 released shortly after in May 2010, further extended the capabilities of NVS, enabling users to access map image overlays derived from a suite of products including HF Radar plots, model overlays, and satellite imagery. Version 2.0, released in August 2010, represented a large overhaul and improvement to usability and the user interface, including interface tools, informational tabs, region zooming, comparator observation-model comparison plots, and many other elements (see Table 1).

NVS integrates Google Map functionality along with tailored visualizations such as observing asset icons. The user is given the capability to select an observing asset by clicking its icon on the map. The user can also refine the search by first filtering the assets using the column to the left of the map. Figures 30 and 31 highlight some of the capabilities of NVS. In Figure 30 a user has selected an observing buoy off of Tillamook, OR. On one tab NVS displays a time series from the buoy's sensor; on the other tab Wave Watch III forecast data is displayed for the nearest grid point (see the line plot inside the call-out window of Figure 30). Figure 31 shows a different capability of NVS. Pre-rendered ocean observation data from the University of Washington's PRISM cruises is viewable through an easy to use interface. (Note: PRISM was a University of Washington funded program for cross-disciplinary study of the Puget Sound).

NVS continued to be refined in a spiral development process during Y2 and Y3. Table 1 shows the history of the NVS versions and demonstrates the significant additions that were made to NVS.

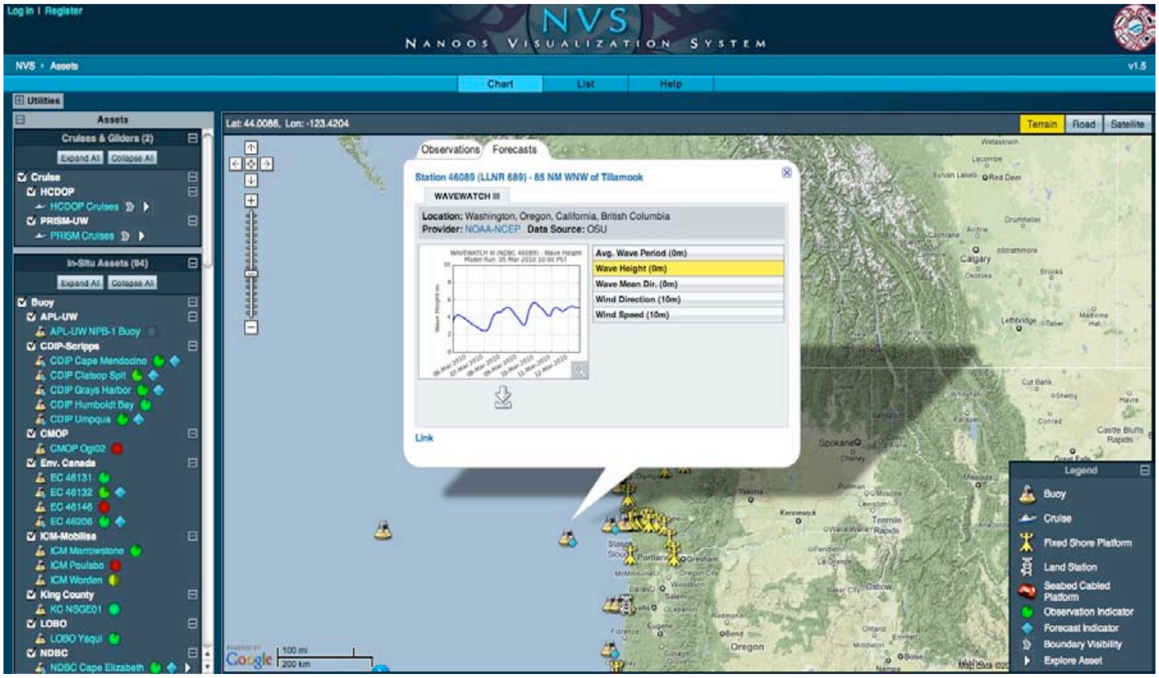


Figure 30. NVS interface (v. 1.5) with a data callout window for a buoy of the Oregon coast.

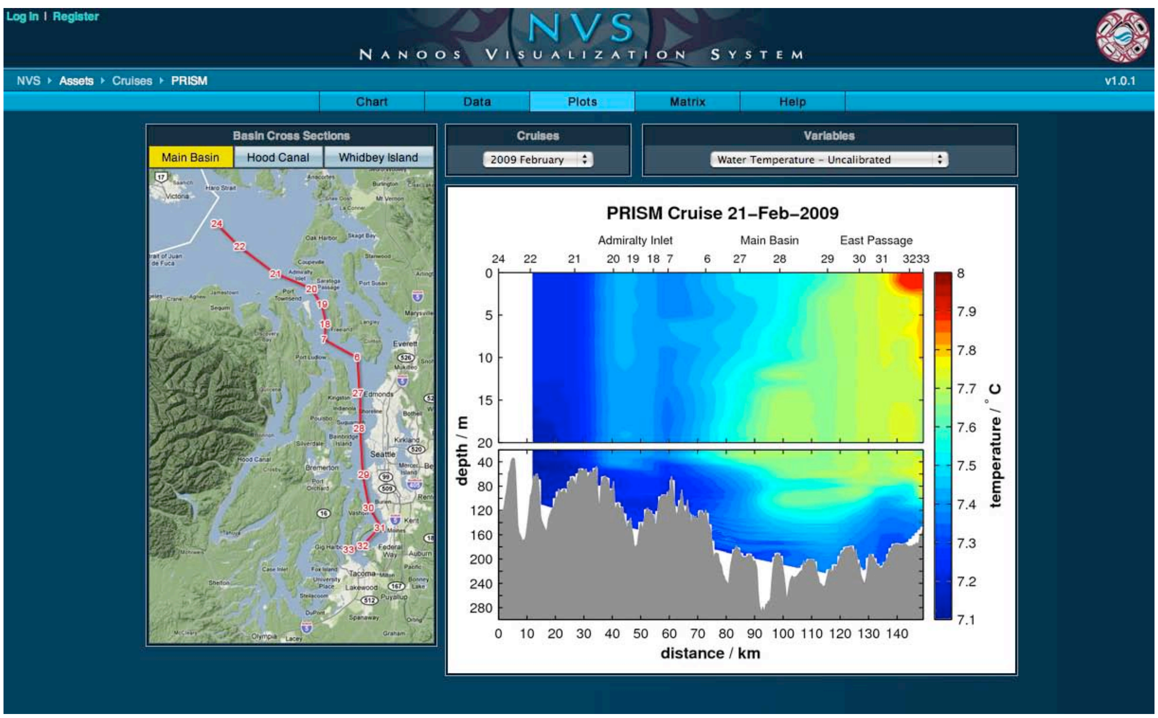


Figure 31. University of Washington PRISM transect data viewed via NVS (v. 1.0.1).

Mobile Applications: Early in 2010, the NANOOS UPC/DMAC sub-working group obtained an Apple Developers License, which enabled NANOOS software engineers to create and distribute an iPhone version of NVS. The NVS iPhone application, first released in Spring of 2010, allows for the browsing of all NANOOS in-situ observing assets on an iPhone or iPod Touch. The App provides easy access to the most recent data from these assets as well as a plot of the last 1, 7 and

30 days of data. The DMAC/UPC teams released a similar Android version of the mobile NVS app in September 2010.

Oregon Coast Tsunami Hazards portal: Many communities located in exposed, low-lying areas along the PNW coasts of Oregon, Washington, and northern California face the risk of tsunami inundation. The hazard originates from two main sources: distant tsunamis (e.g., Tōhoku, Japan) that cross the expanse of the Pacific Ocean, and local tsunamis spawned by a great subduction earthquake on the CSZ and accompanying giant tsunamis. Of these, local Cascadia tsunamis pose the greatest hazard to people living along the PNW coast. To reduce the risk associated with such events, the Oregon Department of Geology and Mineral Industries (DOGAMI) and the Washington Department of Natural Resources (WADNR) began developing tsunami evacuation zones for their respective coastlines. These first generation maps were completed in the mid 1990s. Considerable outreach was performed at the time, and continues to this day, involving the provision of tsunami evacuation maps, community presentations, tsunami evacuation drills, and local community efforts.

To provide easier access to the tsunami evacuation maps, a collaborative effort between NANOOS DMAC/UPC/E&O and DOGAMI staff was initiated to begin development of an online tsunami hazards Google-map portal (Martin et al. 2011). This tool allows residents, planners, emergency responders, and others to see the extent of areas affected by both local (CSZ) and distant (outside of the immediate Pacific Northwest region) earthquakes and tsunamis. DOGAMI staff synthesized the suite of evacuation maps developed over the years for the Oregon coast into a Geographical Information System (GIS), differentiating between those areas where maps are presently available from those where no maps had been produced. In addition, DOGAMI acquired a tsunami hazard web template originally developed by NOAA for Hawaii emergency services. Working with NANOOS DMAC, the template was modified and made operational in June 2009 to include the synthesized Oregon coast tsunami evacuation maps. The interactive map features a search-by-address (by street or coastal area) option, as well as the usual drag and zoom functions typical of Google-map portals. In addition to these, the tsunami portal contains considerable information about earthquake and tsunami preparedness, information on the warnings issued by WCATWC, and the capability to print a user defined tsunami evacuation map.

Table 1. NANOOS Visualization System (NVS) Version History; the complete version history is available at http://www.nanoos.org/nvs/information/version_history.php

Ver. #	Release Date	Feature Additions
1.0	11/2/2009	Re-hosted the NANOOS Website (www.nanoos.org). New interface included following capabilities: In-Situ Assets Menu (Washington, Oregon, Northern California, British Columbia) - Display of assets with icon and data age icon - Data age updates automatically for each asset/measurement Utility buttons (PRISM Cruises - Display Filters: Can filter assets by Region, Type, and Variable Info Windows - Meta Data (Name, Provider, Platform Type, Location, etc.) - Recent Measurements (Name, Depth, Units, and Value for previous 30-day period)

		- Data Freshness (Icons providing age of data for each measurement) - Plots (24-hour, 7-day, and 30-day plots for each measurement) - Data Downloads (24-hour, 7-day, and 30-day CSV data for each measurement) Info Window Link (URL for each asset info window - can copy and send to others) In-Situ Assets: List of all in-situ assets and most meta data grouped by provider and sorted alphabetically PRISM Cruise Data (Salish Sea area): Data for each cruise available in CSV format and various pre-rendered plots
1.0.1	11/10/2009	Modified Info Windows to change size based on map dimensions Added Station Info Windows for PRISM cruises
1.5	3/2/2010	Added forecast information, updated data flow, and reworked user-interface to improved ability to discover in-situ assets Added forecast information for selected assets (e.g., NDBC buoys) Added new utilities and asset columns in the data discovery section Added map legend with information about chart, menu and column icons
1.5.1	3/9/2010	Added visibility controls for asset panels - Can be used to hide / show entire contents of panel with one control
1.6	5/6/2010	This version added overlays for some assets, modified filter controls and changed plotting to be a “on-demand” feature. New features included: *Map Image Overlays* -Some assets have tiled image overlays that can be viewed on the map *Map Controls* -Region: shows general region covered by asset - Show / Hide Overlay: toggles the visibility of the asset's image overlay on and off - Map Click Control: toggles control of clicking the map. When on, map clicks drive asset overlay features -Image Overlay Legend: legend for the visible image overlay is displayed over the map *Map Panel* - Button area added below chart *Observation Plots* - Observation plots are now created on demand - Forecast plots are now created on demand *Info Windows* - Added "More Info" link to info windows *OSU Gliders* - Asset page added for OSU Gliders - Shows most recent information *X-Band Radar*

		- Asset page added for X-Band radar
2.0	8/4/2010	This is a major upgrade. It improved the interface, added loading notices, updated plotter and map tile maker, and added a forecast-versus- observation comparison tool called "the comparator" New features included: *Dock* - Dock added to left of interface - Controls display of columns - Can be hidden - Dock hide / show button located above dock *Comparator* - Added to in-situ asset info windows - Only available if asset has forecasts - Provides comparison between observation data and model forecasts across several model runs *Regions* - New column providing easy zooming to pre-defined areas - Accessible via the Dock - Initial NVS map view is set to the "NANOOS" region *Overlay Column* - New column created - Accessible via the Dock - Observations and Forecasts moved to their own panels - New "In-Situ Asset Forecast Location" button *Forecast Overlays* - Wave Watch III time series overlays now available *Details Tab - Info Window* - Added to info windows - Displays detailed asset information, if available *Credits Tab - Info Window* - Added to info windows - Displays detailed asset credits, if available *Message Bar* - Message bar added to top of interface *Map Controls* - Moved to floating panel over map - Background map controls converted to pull-down menu - Minimize button added - Controls size of Map Panel - Maximize Map button added - Toggles map size between "Maximum" and "Normal" *Overlay Legend* - Asset name and variable moved to legend title - Close and minimize buttons added - Overlay date information added - Time controls added for time series overlays *Filters* - Added keyword searching - Added categories (Observation, Model / Forecast, Has Forecasts) - Accessible via the Dock *Interface* - Initial NVS map view zooms to contain NANOOS region - Redesign layout with columns controlled by dock

		- Map area enlarged Filters Updated help information

Presentations and Publications acknowledging NANOOS support:

Jones, D and J. Olsonbaker. Developing Best Practices for IOOS Web Portals. *Proceedings of the MTS/IEEE Oceans 2009*, Biloxi, MS, Oct 26-29, 2009.

Martin, D.L., J.C. Allan, J. Newton, D.W. Jones, S. Mikulak, E. Mayorga, T. Tanner, N. Lederer, A. Sprenger, R. Blair and S.A. Uczekaj. Using Web-based and Social Networking Technologies to Disseminate Coastal Hazard Mitigation Information within the Pacific Northwest Component of the Integrated Ocean Observing System (IOOS). *Proceedings of the MTS/IEEE Oceans 2011*, Kona, HI, Sept 19-22, 2011.

Mayorga, E., Tanner, T., Blair, R., Jaramillo, A.V., Lederer, N., Risien, C.M., Seaton, C., The NANOOS Visualization System (NVS): lessons learned in data aggregation, management and reuse, for a user application. *Proceedings of the MTS/IEEE Oceans 2010*, Seattle, WA, 20-23 Sept 2010.

Risien, C., J. Allan, R. Blair, A. Jaramillo, D. Jones, P, Kosro, D. Martin, E. Mayorga, J. Newton, T. Tanner, and S. Uczekaj. The NANOOS Visualization System: Aggregating, Displaying and Serving Data. *Proceedings of the MTS/IEEE Oceans 2009*, Biloxi, MS, Oct 26-29, 2009.

e) <u>Education and Outreach</u>

1. Managerial: Over the course of the three years of this grant, NANOOS Education and Outreach (E&O) personnel capabilities have grown considerably. Throughout this time period NANOOS has had an active Education and Outreach committee. The committee has grown to include representatives from OR and WA Sea Grants, South Slough and Padilla Bay NERRs, the two NSF-funded Centers for Ocean Science Education Excellence (COSEEs) in the Northwest - COSEE Pacific Partnerships (COSEE PP) and COSEE Ocean Learning Communities (COSEE OLC), CMOP, Olympic Coast National Marine Sanctuary, Ocean Inquiry Project, Hood Canal Salmon Enhancement Group, OSU COAS and APL-UW. Mike Kosro chaired the E&O committee since its inception through the majority of this grant period until June of 2010. At that time, Kosro stepped down and the committee voted Nancee Hunter, the Director of Education for Oregon Sea Grant, as the new committee chair.

In mid October of 2007 Amy Sprenger (M.Ed.) began working at APL-UW part-time as a NANOOS Education and Outreach Specialist. In 2008/2009 Sarah Mikulak, a graduate student at OSU, was supported in her research through NANOOS funds, and in early 2010 joined APL-UW as an Informal Education Specialist based in Portland, Oregon.

The NANOOS EOC has held regular conference calls on a monthly to bi-monthly basis and EOC members have been active participants in the NANOOS tri-committee meetings in 2009 and 2010. Amy Sprenger and Mike Kosro presented on NANOOS EOC efforts to each of the NANOOS Governing Council meetings in 2008, 2009 and 2010.

In terms of national collaboration with the other RAs, Sprenger and Mikulak have been active members of the NFRA Education and Outreach Committee since its inception in 2008 and have supported NFRA EOC and IOOS E&O efforts including partnering with NFRA EOC members to present at national meetings and collaborating on a NFRA EOC grant submission.

2. Summary of Education Accomplishments:

NANOOS education efforts focus on promoting ocean literacy for both for formal K-12 and informal education providers and audiences. We worked with multiple partners including NANOOS members to provide content and resources for educators to use information about and coming from ocean observing systems in the northwest to promote understanding of the ocean and regional ocean issues.

K12 education

Over the duration of this grant, NANOOS reached over 150 educators through direct presentations and a few hundred more through networking, tabling, and exhibit opportunities. Presentations to teachers focused on providing information on ocean observing systems, the technology used to acquire ocean observing data, and examples of research and ocean processes which ocean observing helps us understand. We also demonstrated how to access to data as well as examples and demonstrations on how ocean observing data could be brought into classroom activities. The majority of the contact with teachers was through presentations at national, regional and local conferences for educators. Nationally, NANOOS partnered with the other RAs to present on ocean observing system resources for educators at the 2009 and 2010 National Marine Educators Association annual conferences. Regionally, the Northwest Aquatic and Marine Educators (NAME), a NANOOS member, held annual summer conferences at which NANOOS was a featured presenter in 2008, 2009 and 2010. More locally focused presentations on bringing ocean data into the classroom were presented at Oregon and Washington Science Teachers Association meetings, Hatfield Marine Science Center teacher workshops, and Environmental Education Association of Washington and the Puget Sound based Storming the Sound educator events.

In order to provide educators opportunities to gain familiarity and direct experience obtaining and using ocean data and data products themselves, NANOOS and NANOOS member Ocean Inquiry Project (OIP), a marine science education non-profit in Puget Sound, teamed up with two other education programs, Edmonds Community College's Learn and Serve Anthropology Field School (LEAF) and Service, Education and Adventure (SEA) to engage teachers in collecting and using ocean data to support authentic learning about the ocean. Through funding from the NOAA Bay Watershed Education and Training program (NOAA BWET), the LEAF School and SEA administered two weekend-long teacher workshops, one in Port Townsend and one in Anacortes in 2010. The workshops focused on helping teachers bring meaningful watershed educational experiences into their classrooms. The weekend included a day-long research/education cruise on marine waters. Throughout the day, Ocean Inquiry Project and NANOOS staff engaged teachers in collecting and analyzing various types of ocean observing data. Similar data collected by the teachers is available via the NANOOS Visualization System (NVS). NANOOS and OIP instructors led teachers through inquiry style activities to derive meaning from the data collected onboard. The second day of the workshop included presentations from community organizations, NOAA staff and/or NOAA education staff who have resources available to aid educators in linking local marine and watersheds into their classroom. On the boat or during the second day of presentations NANOOS staff demonstrated the NANOOS web portal, and presented products and lesson plans available for teachers to bring locally focused ocean data into their classrooms.

Over the course of the three years, the NANOOS Education area of the NANOOS web-portal was greatly improved to provide eight ocean observing curriculum pieces for classroom educators to modify and use for their own classrooms. The lesson plans include introductory activities to help students learn about ocean observing, simple data explorations to help students learn to interact with the NANOOS web portal to acquire data, and more involved activities for students to develop their own questions about water conditions and to use data available via the NANOOS web portal to answer these. Most of these lessons have been demonstrated to educators during the various presentations completed over the course of these three years of the grant period. In addition, a resource guide for educators on using real time data was adapted by the NFRA education committee, including Sprenger, and is available via the NANOOS web portal as are many other links to resources to help educators incorporate authentic ocean data into their classrooms.

Informal education

Over the duration of this grant, NANOOS supported the development and installation of an interactive computer exhibit featuring regional ocean observing data and the prototype and partial development of a second exhibit still in progress. In 2008/2009, NANOOS supported an OSU graduate student, Sarah Mikulak, in the development of an interactive exhibit at the Newport Marine Science Center. Sarah Mikulak worked with Jack Barth, Mike Kosro and Craig Risien (OSU) as well as Nancee Hunter (Oregon Sea Grant Director of Education) and Shawn Rowe (Hatfield Marine Science Center). Mikulak develop an interactive computer exhibit focused on building understanding and appreciation for real-time measurements, using data from the LOBO (Land/Ocean Biological Observatory) mooring in Yaquina Bay (http://yaquina.loboviz.com/). The LOBO mooring is owned and operated by NANOOS member WetLabs of Philomath, Oregon. Mikulak presented this work at the 2008 Ocean Sciences Meeting in Orlando, FL. In June 2009 Mikulak graduated from OSU with her Masters Degree and continued to work with NANOOS on developing educational material for the NANOOS web portal. In late 2009/early 2010, the exhibit Mikulak developed was converted to Flash and made available on the NANOOS web portal. In addition, Mikulak developed a theme page on hypoxia in the PNW which was incorporated into the NANOOS portal during the winter of 2010.

In early 2010 Mikulak, Newton and Sprenger met with members of the Port Townsend Marine Science Center (PTMSC) and Intellicheck Mobilisa to begin designs on an interactive display using real-time data (RTD) to be installed and field-tested at the PTMSC. This modular exhibit will look at seasonal trends of physical and chemical water properties in Puget Sound. It is anticipated that once this exhibit has been field tested at PTMSC it will be relatively easily modified to be appropriate for installation at other informal learning centers in the region.

In April 2009 Sprenger presented on the value of baseline data and NANOOS efforts to over 30 marine volunteers attending the WA Sea Grant, COSEE OLC and PTMSC organized Citizen Science Workshop. As a result of conversations and relationships developed during this workshop and other education events, Sprenger and Kate Litle (WA Sea Grant) worked with Emilio

Mayorga as PI and Nancee Hunter as co-PI to apply for a NOAA Environmental Literacy Grant in Informal Education to develop NANOOS capabilities for citizen science data . Though the grant was not awarded, the reviews were very encouraging and NANOOS is continuing to look for ways and funds to be able to accommodate this need on behalf of citizen science, volunteer, education and smaller-scale observing programs in this region.

3. Summary of Outreach Accomplishments:
NANOOS reached out to a variety of audiences over the span of this RCOOS period. Groups in particular that NANOOS engaged with included fishers, shellfish growers, scientists, and resource managers.

Efforts to reach out to fishers resulted in over 150 fishers attending presentations on NANOOS. Events included NANOOS EO chair Mike Kosro presented at meeting of the Scientists and Fishermen"s Exchange (SAFE) in both Feb. 2008 and 2009. In 2008 Kosro spoke about NANOOS and Marine Reserves and in 2009 Kosro gave a presentation on the physical aspects of the spring transition to upwelling; others addressed the biological aspects. The presentations produced a lively and respectful exchange of information with the fishers. Also in Feb. 2009 Amy Sprenger and Jon Allan attended and had a display at the Salty Dog Convention in Newport, where they interacted with about 50 tuna and halibut fishers and received feedback on NANOOS products.

In March 2010 NANOOS DMAC/UPC and E&O member C. Risien put up a NANOOS display at the Oregon Coalition for Educating ANglers meeting. Risien presented on NANOOS history, mission, goals and organizational structure. In addition, the presentation described in detail the products currently provided that are of interest to members of the recreational and commercial fishing communities. These include SST and surface current forecast information for Oregon, plots of satellite derived SST and CHLA and the NANOOS Visualization System. Approximately 70 people were present for this presentation.

Other events of note during this grant time period were the Tribal Habitat Conference and the R/V Bold visit to Puget Sound. Quinault Indian Nation, a NANOOS member, invited NANOOS to post an exhibit that Amy Sprenger presented at the May 2008 Tribal Habitat Conference in Quinault, WA. In the summer of 2008 several NANOOS investigators participated on a cruise in Puget Sound and the Strait of Juan de Fuca held by EPA on the R/V Bold. Following the cruise, an Open House was held on R/V Bold at Pier 66 on the Seattle waterfront on August 19-20, 2008. Jan Newton and Amy Sprenger put together a NANOOS exhibit for the event. The ship was open to the public for one day and to dignitaries and other guests on the second day. Attending were EPA Administrator Steven Johnson, EPA Regional Administrator Elin Miller, Congressman Jay Inslee, Nisqually Tribal Chairman Billy Frank Jr., several local and state agency heads and staff, and the media.

NANOOS worked to meet the needs of shellfish growers primarily through supporting and promoting the NANOOS-NERRS Pilot Project on real-time data for shellfish growers. This project, which was started before this grant period, continued via the efforts of Cathy Angell (NERRS) working with Jan Newton and Amy Sprenger. NERRS provided funds for updates and revision of the data products available on the web and inclusion of 3 new real-time sites from the Washington State Dept of Ecology. In 2009 NANOOS representative Amy Sprenger presented a poster on the data product at the Shellfish Growers Meeting organized through Washington Sea Grant. NANOOS reached about 70 attendees through this event.

NANOOS reached out to scientists and resource managers through a variety of events. In 2009, NANOOS displayed an exhibit at the Puget Sound Georgia Basin Research Conference in Seattle, WA and at the Coastal and Estuarine Research Federation (CERF) meeting in Portland, OR. Information given to attendees included resources on NANOOS, NOAA IOOS, NFRA and other regional associations. Mikulak and Sprenger had approximately 150 direct conversations with conference attendees over the 7 days of conference events, with many more attendees stopping by to pick up information. Sprenger also represented NANOOS at the West Coast Marine Spatial Planning Workshop conference organized by the Nature Conservancy, held in Seattle, WA in October 2009.

In 2010 Mikulak and Risien put up a NANOOS display at OSU's COAS 50th Anniversary celebration. Mikulak also presented her work on the development of the interactive date exhibit during this event. Sprenger had an informational exhibit on educational opportunities with NANOOS at COSEE OLC's Education and Public Outreach for research scientists workshop held at the University of Washington in January, 2010. NANOOS also put together and staffed an IOOS display at the International Marine Renewable Energy conference in Seattle that year.

During this grant period the first edition of the "NANOOS Observer" (N.O.) was released on the NANOOS web in late October 2009. It is the NANOOS community's update for new products, news items, and ocean-related issues affecting the NANOOS region of the Integrated Ocean Observing System. Janet Olsonbaker, Amy Sprenger, and Eric Shulenberger contributed to this first edition. The second edition of the "N.O." was released in April, 2010. The archived editions of N.O. are available here: http://www.nanoos.org/about_nanoos/documents.php

Presentations acknowledging NANOOS support:

Newton, J.A. Recent research on hypoxia and ocean acidification in Puget Sound. Keynote Speaker, Murdock Partners in Science Workshop, 13 August, 2010. Portland, OR.

Mikulak, S. and A. Sprenger. Hypoxia in Oregon and Washington: Using Data to Understand the "Dead Zones". Northwest Aquatic Marine Educators Conference. July 2010, Florence, OR.

Simoniello, C., L. Spence, S. Mikulak, S. Stewart, and J. Dorton. The U.S. Integrated Ocean Observing System: Eyes on the Ocean, Hands-On Learning. National Marine Educators Association Conference. July 2010. Gatlinburg, TN.

Newton, J.A. Washington's newest buoy: Part of the IOOS-NANOOS system, Olympic Coast National Marine Sanctuary Advisory Council, 16 July, 2010, La Push, WA

Carlin-Morgan, K., N. Hunter, and A. Sprenger. Using the Ocean to Teach STEM. Northwest Aquatic and Marine Educators Conference. July 2010, Florence, OR.

Newton, J.A. Oceans, Health, and Estuaries. Oceans Health Symposium, 18 June, 2010, APLUW, Seattle, WA.

Sprenger, A. Eyes on Washington Waters, Bringing Ocean Observing Data Into the Classroom. Washington Watershed Education Teacher Training Program, Port Townsend, WA April 10-11 2010; Anacortes, WA June 12-13 2010.

Newton, J.A. NANOOS: The Northwest Association of Networked Ocean Observing Systems. Keynote Speaker. NORTEK Symposium, 21 May 2010, Seattle, WA

Sprenger, A. Eyes on Washington Waters: Bringing Authentic Ocean Data into the Classroom. Washington Science Teachers Association, Everett WA March 2010.

Mikulak, S., S. Rowe, N. Hunter, and C. Orrico. 2010. Ocean Observing Data and Science Center Visitors: Creating Motivation and Relevance. *Eos Trans. AGU*, *91*(26), Ocean Sciences Meeting Suppl., Abstract ED45C-03. February 2010, Portland, OR.

Mikulak, S., C. Orrico, S. Rowe, and N. Hunter. 2009. A Partnership Model of How to Develop an Interactive Exhibit to Present Real-Time, Estuarine Water Quality Data to the Public in an Informal Education Setting. *Coastal and Estuarine Research Federation Conference*, Portland, OR, November 1-5, 2009.

McDonnell, J.; Deans, N.; Grabowski, M.; Sprenger, A.; Cline, A.; Dillon, A.; Kerkering, H. and Parsons, C. “Real Time Data Resources from Ocean Observing Systems”. National Marine Educators Association conference, July 2009 Monterey CA

Mikulak, S and Risien, C. Using real time data in the classroom Hatfield Marine Science Center teacher workshop, March, 2009 Newport, OR.

Sprenger, A. 2008. Using Ocean Observing Data in the Classroom. NW Aquatic and Marine Educators conference in Friday Harbor, WA July 2008.