Addressing ocean and coastal issues at the West Coast scale through regional ocean observing system collaboration

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The U.S. Integrated Ocean Observing System (U.S. IOOS®) is a network of eleven regional ocean observing systems coordinating observations of the nation's oceans, coasts, and Great Lakes. Three of these regional systems span the continental U.S. West Coast: the Southern California Coastal Ocean Observing System (SCCOOS), the Central and Northern California Ocean Observing System (CeNCOOS), and the Northwest Association of Networked Ocean Observing Systems (NANOOS) (Figure 1). Each regional coastal ocean observing system (RCOOS) provides key observations, data, and information products that meet unique place-based needs through collaborations between academic institutions, state, tribal and federal agencies, private industry, and non-profit organizations.

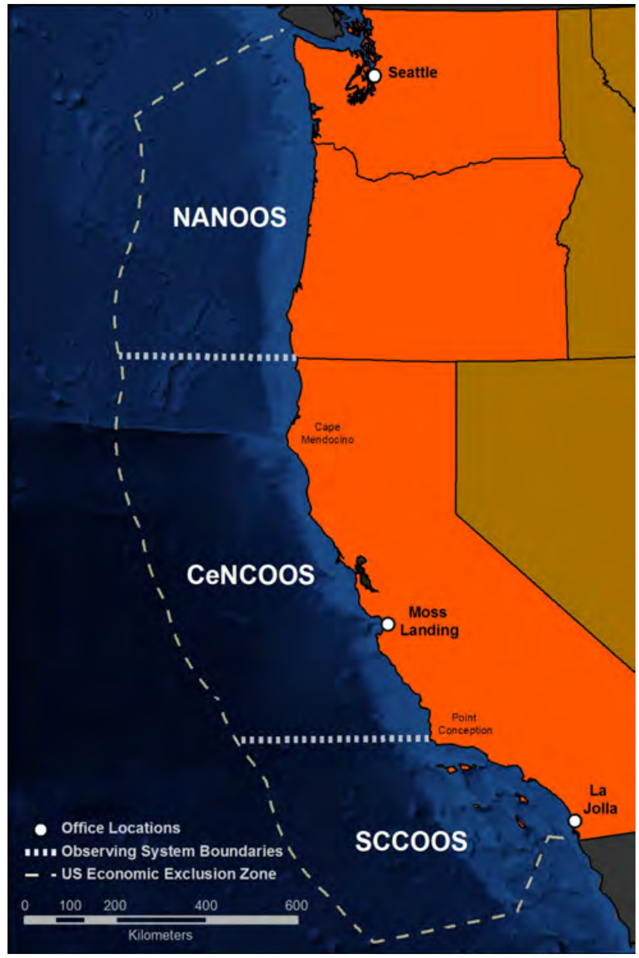

Figure 1. Map showing the geographic extent of the West Coast IOOS regional ocean observing systems. The northern, southern and seaward boundaries are defined by the U.S. EEZ.

Adding Value through Collaboration

While each of the regions has specific local user requirements for monitoring, the three systems share responsibility for observing larger scale ocean processes that span the West Coast. The three observing systems all lie within the California Current Large Marine Ecosystem (CCLME) which extends from Washington State to Baja California. The West Coast RCOOS recognize that in order to address certain issues most effectively, a collaborative approach is required - one that goes beyond the traditional regional organization structure of IOOS. These large-scale issues, including fisheries, and water quality, climate variability and change, and marine commerce and safety, transcend the boundaries of each individual system.

West Coast Ocean Observing Governance

To further the mission of U.S. IOOS by expanding and strengthening West Coast regional ocean observing collaboration the three regional systems, SCCOOS, CeNCOOS and NANOOS entered into a Memorandum of Understanding (MOU) in September 2011. The MOU affirms their commitment to jointly plan CCLME observations, share information that will mutually benefit each sub-region and the larger CCLME, and work cooperatively with governmental and non-governmental entities to inform scientific, economic and management activities that span the West Coast.

The West Coast RCOOS recognize that collaborating and leveraging human and financial resources will benefit planning and decision-making at both sub-regional and West Coast scales.

Several important ocean governance and management initiatives operate on the West Coast scale, including the West Coast Governors Alliance on Ocean Health (WCGA) and the designation of the West Coast as a single regional planning area for Coastal and Marine Spatial Planning (CMSP) under the National Ocean Policy (NOP). The WCGA has established Action Coordination Teams (ACTs) focused on themes such as marine debris, pollution, and others. Working under their 2011 MOU, the West Coast RCOOS are coordinating their interactions with these management efforts and associated entities, speaking with a single, unified voice that allows for effective lines of communication and identification and delivery of relevant data, information products, and expertise.

The WCGA Executive Committee, SCCOOS, CeNCOOS and NANOOS have proposed an MOU between the WCGA and the West Coast regional ocean observing systems. This MOU will enhance West Coast-wide coordination on ocean observing and management related issues in the context of dynamic ocean conditions and complex governance and management structures. In particular, it will enable increased efficiency by providing the framework for linking the West Coast regional ocean observing systems and the WCGA to facilitate and promote the sharing of information to the appropriate people, at the appropriate times, and in the appropriate formats. It will provide increased effectiveness of each organization by providing a platform for the planning of future work in shared priority areas along the West Coast as a whole, as well as within state or local areas. It will also enable increased competitiveness for the West Coast on a national scale by demonstrating the West Coast's advanced efforts to align shared goals and activities.

WCGA Regional Data Framework

In the fall of 2010, the West Coast regional ocean observing systems joined forces to respond to the NOAA Regional Ocean Partnership Funding Program (ROPP) for advancing regional coastal and ocean management. In collaboration with the governmental, non-profit and academic groups that had previously coalesced as an informal West Coast Coastal Atlas community (http://ican.science.oregonstate.edu/westcoast/), the RCOOS presented to the WCGA a common, broad-community vision for data coordination and management on the West Coast. This vision became one of the main components of the grant awarded to the WCGA. The West Coast RCOOS have been closely engaged in all subsequent work planning steps along with the wider partnership. They delivered a joint presentation on IOOS and regional association data management and interoperability efforts at a planning workshop in December 2011 and helped compose the recently drafted Work Plan, select a contractor, Ecotrust, to carry out the first phase of this plan, and write a successful proposal to NOAA that will fund the second phase of the plan. The NANOOS data team lead is also the coordinator of the IT working group and SCCOOS staff members are engaged in outreach and general coordination efforts. In addition, the NANOOS Executive Director and data team lead are members of the newly created WCGA Regional Data Framework Action Coordination Team. More information about the RDF ACT is available online at http://www.westcoastoceans.org.

The WCGA RDF effort strives to address the data needs of a wide range of partners, including CMSP data efforts occurring on the West Coast. Initial prioritization is based on needs already highlighted in reports from the thematic WCGA ACT, where state agencies have played a prominent role, and a data-needs survey of these ACTs conducted by Ecotrust under the RDF contract. This survey revealed a strong interest across all ACTs in oceanographic data of all types and at all temporal scales.

The RDF ACT Work Plan places a strong emphasis on facilitating access to geospatial data via a data registry and catalog system built on interoperable catalog services, supported by an open "human network" of diverse partners. Specific RDF ACT goals include: 1) Improving access to regionally relevant coastal and marine geospatial data and information products; 2) Promoting the interoperability of web services and applications that support coastal and marine management; and 3) Supporting a resourceful and informed community of practice among West Coast data providers, data users, and GIS practitioners. The West Coast regional ocean observing systems will continue to play a leading role in guiding the execution of the RDF ACT Work Plan, leveraging their expertise in regional and national data interoperability and ensuring that the system that is developed is consistent with IOOS recommendations. In turn, their collaboration with this effort will help inform IOOS on best practices regarding geospatial data catalogs and data access.

Coastal Scale Events and Processes

The CCLME exists within the eastern boundary current region of the North Pacific Gyre. The near surface waters off the U.S. West Coast originate in large part from the eastward-flowing North Pacific Current (the northern limb of the North Pacific Gyre), which advects biota and debris towards the West Coast, and serves as a source for the water properties of the California Current System. While the specifics of the coastal circulation vary somewhat along the coast, all three regions are connected by the equatorward-flowing California Current in the upper ocean, and the poleward-flowing subsurface California Undercurrent.

To monitor these large scale events and processes, the RCOOS employ a variety of in situ and remote sensing technologies to measure physical, chemical, biological and geological parameters. The major measurement platforms operated by all three West Coast RCOOS include: wave buoys, autonomous profiling gliders, automated shore stations, and high frequency radars. All three also use additional data collected from moorings, ships, and satellites.

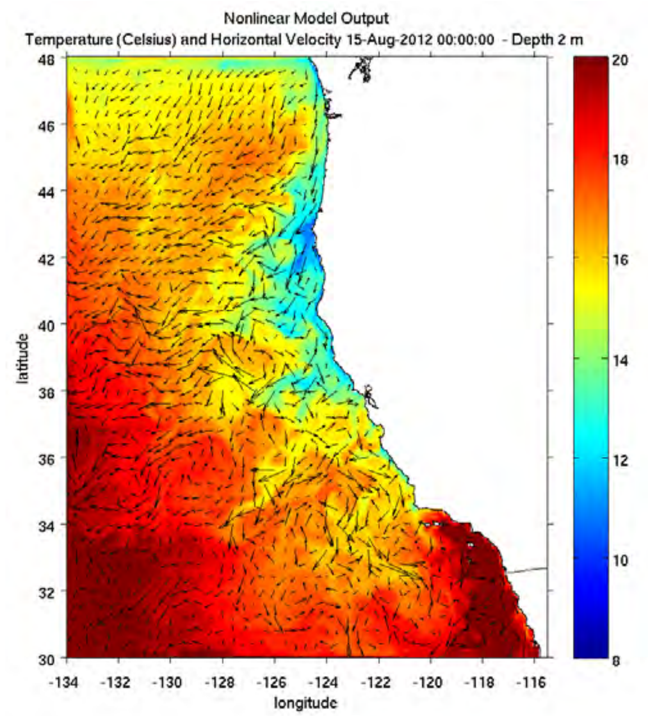

Figure 2. West Coast ROMS model output. Color indicates water temperature in °C. Arrows indicate horizontal current velocity with longer arrows representing higher current speeds.

In addition to observations, each of the West Coast regional ocean observing systems also support the operation of numerical ocean models to fill in measurement gaps and provide forecasts of future conditions. These models are based on observations of the past and present state of the ocean as well as scientific knowledge of how these physical and ecological ocean systems work together. The models produce information on ocean conditions for places, times, and variables that we are unable to measure, and forecast how these conditions will change over time. Currently, in addition to smaller-scale local models run by each of the regional associations, CeNCOOS is supporting a West Coast-wide implementation of the Regional Ocean Modeling System (ROMS; Figure 2).

Surface Currents

As part of the national IOOS program to monitor coastal surface currents throughout the U.S., the West Coast RCOOS collectively operate an array of more than 50 high-frequency (HF) radars to measure and map ocean surface currents in near real-time. These measurements span the west coast from Mexico to Canada and have spatial resolutions ranging between 500m, 2km, and 6 km; and extending 100 to 150 km from the coast (Figure 3). Higher spatial resolution measurements are made over areas along the coast to increase support of marine operations, oil spill response, and coastal water quality. Examples include areas such as San Francisco Bay, Monterey Bay, the Port of Los Angeles, Point Conception, the Channel Islands, and San Diego Bay. The development of this network can be attributed to large investments by science agencies (NSF, ONR, NOAA and MMS), the State of California and the U.S. IOOS program.

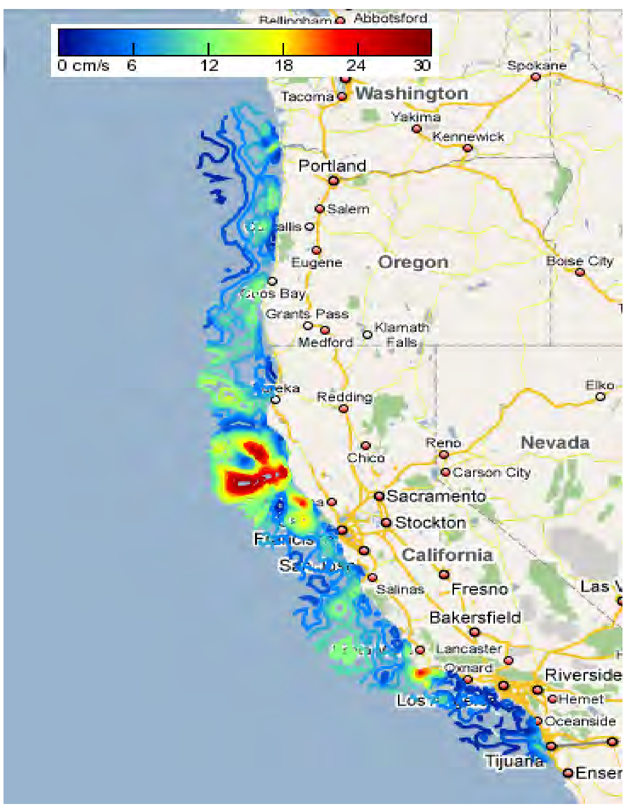

Figure 3. Surface current streamlines derived from two-year averaged HF radar observations along the west coast. Red lines indicate areas with higher average current speeds.[2]

Surface current data are collected and quality assured and controlled within each RCOOS, and region specific products including surface current maps are made available at the regional level. In addition, all west coast HF data are forwarded to the national HF data centers at UCSD and at NDBC, where they are combined into region-spanning maps.

The IOOS program has also supported a distributed data system, the HF Radar Network (HFRNet), that provides a reliable, common source and means of obtaining surface current data.[1] The Coastal Observing Research and Development Center (CORDC) leads the development and administration of the HFRNet for distribution of HF radar derived surface currents. This network is characterized by a tiered structure that extends from the individual field installations of HF radar equipment (site), a local regional operations center that maintains multiple sites (site aggregator), and centralized locations that compile data from multiple regions (node). This data system focuses on maintaining robust site aggregator to node communications with centralized data repositories that are updated in near real-time. Central repository nodes have been deployed and are maintained at three locations, the National Data Buoy Center (NDBC) on the gulf coast, Scripps Institution of Oceanography (SIO) on the west coast, and Rutgers University on the east coast, to demonstrate an end to end distributed data system which links multiple regions to a central repository of data. Site aggregators are currently deployed at eleven partners throughout the U.S., including seven institutions throughout Oregon and California.

Data are also made available via common data access methods from the node centers in custom formats to the US Coast Guard for use in search & rescue, and to the NOAA Office of Response and Restoration (ORR) for use in oil spill and pollution response. These access methods enable near real-time surface current data to be ingested by tactical decision aids, such as those used by the U.S. Coast Guard for search-and-rescue, and NOAA for oil spill tracking and abatement. The Cosco Busan oil spill in San

Francisco Bay in November 2007 helped provide impetus for these efforts, which proved so useful in the Deepwater Horizon spill in the Gulf of Mexico during 2010.

The surface current data benefits a wide variety of users including local, state and federal agencies, resource managers, industry, policy makers, educators, scientists and the general public. These data are used in applications including but not limited to ship navigation and safety for maritime and port operations, improving efforts to restore endangered salmon and steelhead populations, and plotting routes for recreational sailing and boating. On the West Coast, regional IOOS researchers assimilate surface current measurements into ocean circulation models, the measurements provide correction to the models and improve the accuracy of subsurface current information. The combination of surface current measurement and forecasting of currents with ocean models contributes to the research and awareness of ocean conditions that relate to ecosystem dynamics and Harmful Algal Bloom (HAB) events, including the transport of larvae and contaminants. Long term time series measurements of coastal surface currents will ultimately contribute to improving our ability to monitor climate change, assess the impacts of sea level rise on coastal habitats, and increase precision in weather and climate forecasts.

Waves

Energetic ocean waves travel along the length of the West Coast, impacting large sections of coastline that span the geographical boundaries of each RCOOS. The Coastal Data Information Program (CDIP), which is hosted at Scripps Institution of Oceanography and funded by the US Army Corps of Engineers and the California Department of Boating and Waterways, is a contributing program to IOOS and operates 30 directional wave buoys throughout the West Coast. CDIP works in close cooperation with the West Coast RCOOS, allowing for a leveraged and symbiotic relationship that includes services in kind, leveraged data dissemination, and assistance through vessels, logistics, and personnel.

The West Coast wave buoy network monitors storms in near real time as they move north or south, enabling accurate predictions of dangerous wave conditions both offshore and at harbor entrances. This information is highly valuable to the West Coast maritime community for their navigational safety and efficiency. Commercial transportation and fishing fleets benefit by being able to track the offshore wave climate and approaching wave events. For example, marine transportation and towing companies routinely operate between several locations in Washington, Oregon and California. These transits require a West Coast perspective of present and forecast offshore wave conditions.

At the same time, near-shore wave observations at harbor entrances throughout the West Coast inform the operations of bar pilots and the navigation of commercial and recreational boaters as they leave and approach port. CDIP operates wave buoys located at or just offshore from Grays Harbor, WA; the mouth of the Columbia River at the WA/OR border; Coos Bay, OR; and the ports of Humboldt, San Francisco, Los Angeles/Long Beach, and San Diego. Wave observations from these buoys and the information products they enable directly enhance the safety of maritime operations on the West Coast.

CDIP wave data are also integrated into the NOAA PORTS (Physical Oceanographic Real-Time System) decision support tools on the West Coast for the Lower Columbia River, San Francisco Bay, and Los Angeles/Long Beach—an example of increased inter-agency collaboration within the IOOS framework. In addition, the West Coast RCOOS provide customized, integrated products to inform marine operations that overlay observations of waves, surface currents and winds with shipping lanes and nautical charts. The economic importance of safe, efficient, and free-flowing commercial maritime traffic is significant with the cost of holding a vessel offshore of the Los Angeles and Columbia River ports ranging from $75,000-$200,000. These real-time products, derived from ocean data collected by the regional RCOOS, directly support safe and efficient maritime traffic on the West Coast.

CDIP's long-term wave observations also assist in assessing the potential for wave energy development on the West Coast.

Harmful Algal Blooms and Hypoxia

As the physical oceanographic linkages of currents and waves span across RCOOS boundaries certain ecosystem and water quality issues are also shared throughout the coast. Harmful algal blooms (HABs) and hypoxia events are examples of ecosystem/water quality events that can occur on larger scales. The West Coast RCOOS monitor critical water quality indicators such as dissolved oxygen, pH, chlorophyll, and the presence of potentially harmful algae species. These indicators are of great interest to regional stakeholders such as shellfish growers and harvesters, natural resource managers, and desalination and wastewater treatment plants.

The California Harmful Algal Bloom Monitoring and Alert Program (HABMAP) is an example of a collaborative effort between the California RCOOS, NOAA, the California Ocean Science Trust, the Southern California Coastal Water Research Project, State agencies, non-profit groups (such as the Marine Mammal Center), and numerous academic partners. The goal of HABMAP is to implement a proactive HAB alert network that will provide information on current algal blooms and facilitate information exchange among HAB researchers, managers and the general public throughout the state of California. Crucial decisions on how to respond to HAB events, how to mitigate their impacts, how to predict them and potentially how to prevent them require knowledge of their behavior and impacts. The program consists of routine HAB sampling at 12 locations in California and Baja, which the RCOOS contribute to by supporting HABs sampling at eight sites. A representative from each RCOOS also sits on the HABMAP steering committee.

As documented in the WCGA Harmful Algal Bloom Summit[3], there is an increasing need for effective exchange of information on HAB ecology and impacts across regions. The RCOOS have also supported multiple research projects coordinated by

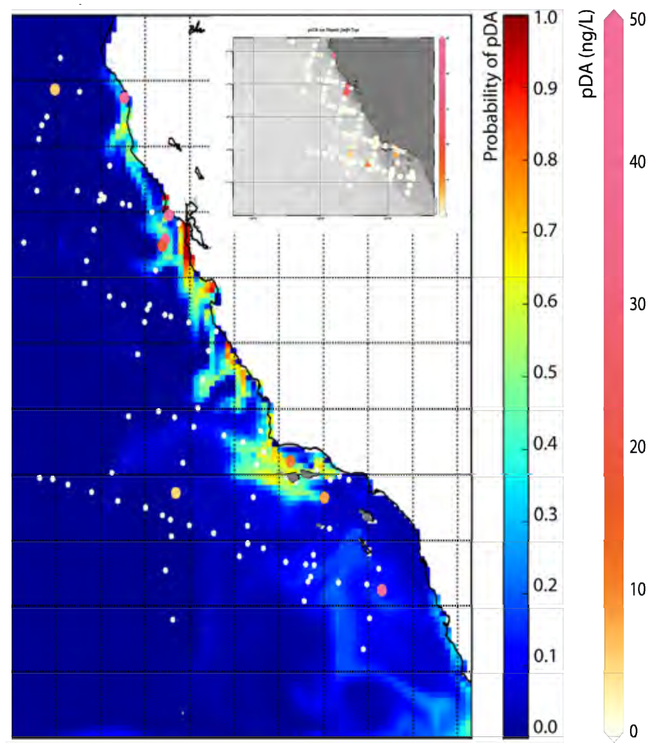

Figure 4. Data collected as part of a large-scale NOAA marine mammal survey along the US west coast were used to help validate predictive models of domoic acid produced by the HAB diatom *Pseudo-nitzschia*. The model (background) showed good qualitative agreement with discrete samples (colored circles). The model uses satellite data and ROMS numerical outputs to provide a probability of toxin concentration.

the NOAA ECOHAB and MERHAB offices, Sea Grant, and State agencies in Washington, Oregon, and California. These have led to advances in predictive modeling of HAB events for both the Washington and California coasts (Figure 4). Washington established an HAB Alert system based on the highly successful HAB Operational Forecast System (HAB-OFS) operated in the Gulf of Mexico; there are plans to add a similar California operational forecast in the near future. SCCOOS, CeNCOOS, and NANOOS are critical partners in the ongoing research efforts that provide the scientific basis for these operational systems.

Ocean Acidification

The Pacific Ocean is showing signs of ocean acidification (OA) from long-term atmospheric increases in CO_2 being partially absorbed by the world's oceans. Because the CCLME is also subject to acidification from upwelled, carbon-rich waters, OA has become a growing concern in the region for scientists, industry, and policy makers alike. The RCOOS have worked to provide platforms for OA observation and to serve data from regional partners who are monitoring pH and related carbon and physical variables. Throughout much of the West Coast, sensors provide measurements of pCO_2 while periodic vessel surveys provide measurements of total CO_2 or alkalinity.

All three West Coast RCOOS are working with the California Current Acidification Network (C-CAN), a collaborative effort between the West Coast shellfish industry and scientists to explore what is causing shellfish losses, the role of ocean acidification, and how to adapt to these changes in order to sustain shellfish resources. As part of this effort, NANOOS, CeNCOOS and SCCOOS are creating an inventory of monitoring stations along the West Coast that can contribute data relevant to ocean acidification (Figure 5). The data streams shown in this preliminary inventory are those that the RCOOS currently serve or link to, which may or may not be maintained by the RCOOS.

Using relationships developed by scientists at Scripps Institution of Oceanography, NOAA Pacific Marine Environmental Laboratory, Universidad Autonoma de Baja California, and University of Washington, data from gliders, such as those operated by the regional ocean observing systems, have been used to estimate pH and aragonite saturation. Aragonite is important to organisms that form shells, as saturation levels below one may lead to dissolution of the shells.

In addition, the RCOOS support a number of regional and state-level research projects related to ocean acidification. For instance, California's ocean observing systems are measuring pH with Durafet sensors, and are collecting weekly water samples, at six of their water quality stations, as part of a State Water Resources Control Board pilot project to develop methods to monitor state waters for acifidication paramters. The State is funding high-quality laboratory analyses of these water samples. This pilot project began in late summer 2012 and will last 9 months.

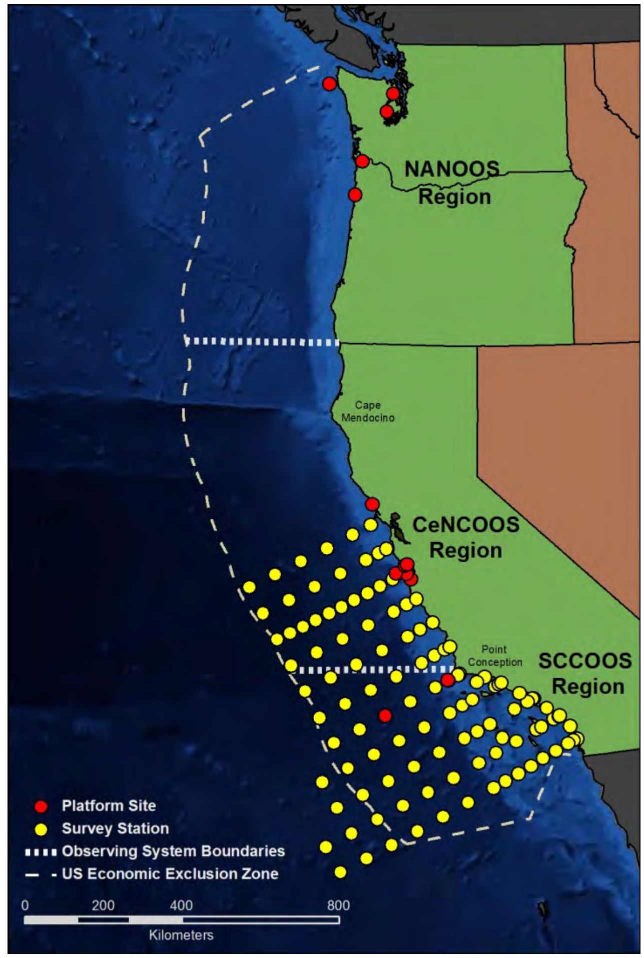

Figure 5. Preliminary inventory of pCO_2, total CO_2 and alkalinity measurements compiled by the RCOOS for C-CAN.

The power of the IOOS regional association design is that it affords the ability to leverage federal and non-federal resources and provides data on regional, CCLME, and national scales. Two NANOOS-supported coastal ocean buoys (Newport, OR, and La Push, WA) are also partially supported by the NOAA Ocean Acidification Program to measure pH and pCO_2, operated by OSU and UW in partnership with NOAA PMEL. In the Pacific NW, the status of OA in estuaries and near-shore areas is of high concern to the shellfish industry. NANOOS has worked with the Pacific Coast Shellfish Growers Association to host their OA data streams on the NANOOS Visualization System (NVS). These include data from the Whiskey

Creek, Taylor Shellfish Dabob Bay, and Lummi Indian Nation hatcheries and Pacific Shellfish Institute's sensors in Willapa Bay. These examples show the value added from the NANOOS infrastructure to leverage and link resources and information; the data from all of these assets are then relayed to C-CAN, IOOS, and are available to a global network.

Summary

It is the intent of the West Coast RCOOS to continue to collaborate, on observations, data management and information products as funding will allow. This partnership will provide the baseline for critical information in future years.

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