The NANOOS Visualization System: Aggregating, Displaying and Serving Data

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Abstract*- The Northwest Association of Networked Ocean Observing Systems (NANOOS) is one of eleven Regional Associations of the US Integrated Ocean Observing System (IOOS). NANOOS serves the Pacific Northwest from the US/Canada border to Cape Mendocino on the northern California coast. Its mission is to coordinate and support the development, implementation, and operations of a regional coastal ocean observing system (RCOOS) for the Pacific Northwest region, as part of IOOS. A key objective for NANOOS is to provide data and user-defined products regarding the coast, estuaries and ocean to a diverse group of end users in a timely fashion, and at spatial and temporal scales appropriate for their needs. To this end, NANOOS is developing a web mapping portal, the NANOOS Visualization System (NVS), that aggregates, displays and serves near real-time coastal, estuarine, oceanographic and meteorological data, derived from buoys, gliders, tide gauges, HF Radar, meteorological stations, satellites and shore based coastal stations, as well as model forecast information in such a way that it presents end users with a rich, informative and meaningful experience. NVS makes use of a variety of services, including the Google Maps service and a data translation and visualization service known as ERDDAP (Environmental Research Division's Data Access Program), compliant Open Geospatial Consortium (OGC) web standards such as the Sensor Observation Service (SOS), Web Map Service (WMS), and Keyhole Markup Language (KML), as well as the Open-source Project for a Network Data Access Protocol (OPeNDAP) as served and cataloged by the NANOOS THREDDS (Thematic Realtime Environmental Distributed Data Services) Data Server (TDS). These heterogeneous data streams are transformed on-the-fly to other formats or representations, which NVS makes available to the end user via a Google Maps interface. We will describe in detail the NVS development process and will demonstrate the ability of NVS to serve as a portal for one-stop access to near real-time regional data and forecast products, including NOAA's first seven "core variables" (ocean currents, temperature, salinity, water level, waves, chlorophyll and surface winds), by describing the data flows from NANOOS funded coastal and ocean observing and forecasting assets as well as Federal assets. In addition, we will describe future development plans that include greater functionality, iteratively improving NVS based on feedback received at planned training workshops and from identified stakeholders, and updating NVS to be compliant with future IOOS and OGC standards.

I. Introduction

The Northwest Association of Networked Ocean Observing Systems (NANOOS) is the Regional Association of the national Integrated Ocean Observing System (IOOS) for the Pacific Northwest (PNW) states of Oregon and Washington. The spatial domain of NANOOS extends from the US/Canada border in the north to Cape Mendocino in the south. Despite these political boundaries NANOOS maintains strong cross-boundary ties with observing programs in Alaska, British Columbia, and in central and northern California through our common purpose and because of the overlap of data and products. Established by charter in 2003, NANOOS now comprises over 40 entities, including tribal (e.g. Quileute Tribe, Northwest Indian Fisheries Commission), state, and local governments (e.g. OR Dept. of Land Conservation & Development, OR Dept of Geology and Mineral Industries (DOGAMI); OR Dept. State Lands; WA Dept. of Ecology (WADOE); Puget Sound Action Team), industries (e.g. The Boeing Company, Wet-Labs, Sea-Bird Electronics), non-governmental organizations (e.g. Hood Canal Salmon Enhancement Group, Council of American Master Mariners, Scientist and Fishermen Exchange, Ocean Inquiry Project, Surfrider Foundation) and academic institutions (e.g. University of Washington, including Washington Sea Grant, Oregon Health & Science University, Oregon State University, including Oregon Sea Grant), who have signed NANOOS' operational Memorandum of Agreement (MOA) and now form its Governing Council.

The primary mission of NANOOS is to coordinate and support the development, implementation, and operations of a Regional Coastal Ocean Observing System (RCOOS) that can provide PNW 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 goal is specifically focused on delivering products users need to address high-priority issues determined through existing NANOOS proactive interactions with the wide range of PNW stakeholders. To that end, NANOOS user members have identified several high priority areas for product development including maritime operations, regional fisheries, ecosystem assessment, and coastal hazards. To accomplish these goals, NANOOS members designed an RCOOS focused on several core observing capacities (Fig. 1) including HF radar nodes that map surface currents offshore the Oregon coast, in situ sensor observation capacity in several major estuaries (e.g. Puget Sound, Willapa Bay, lower Columbia River estuary, and Coos Bay), autonomous underwater vehicles (e.g. Newport, Oregon glider line) and in situ measurements of oceanographic variables on the continental shelf (e.g. NH-10 buoy), monitoring of PNW beach and shoreline morphodynamics (e.g. the northern Oregon and southwest Washington coast), short-wave monitoring using X-band radar (e.g. Newport), and the implementation of ocean circulation and estuarine modeling (e.g. Oregon shelf, lower Columbia River estuary and shelf, and the Puget Sound). In all cases, data must be measured at appropriate temporal and spatial scales and delivered in appropriate formats in order to meet identified societal needs.

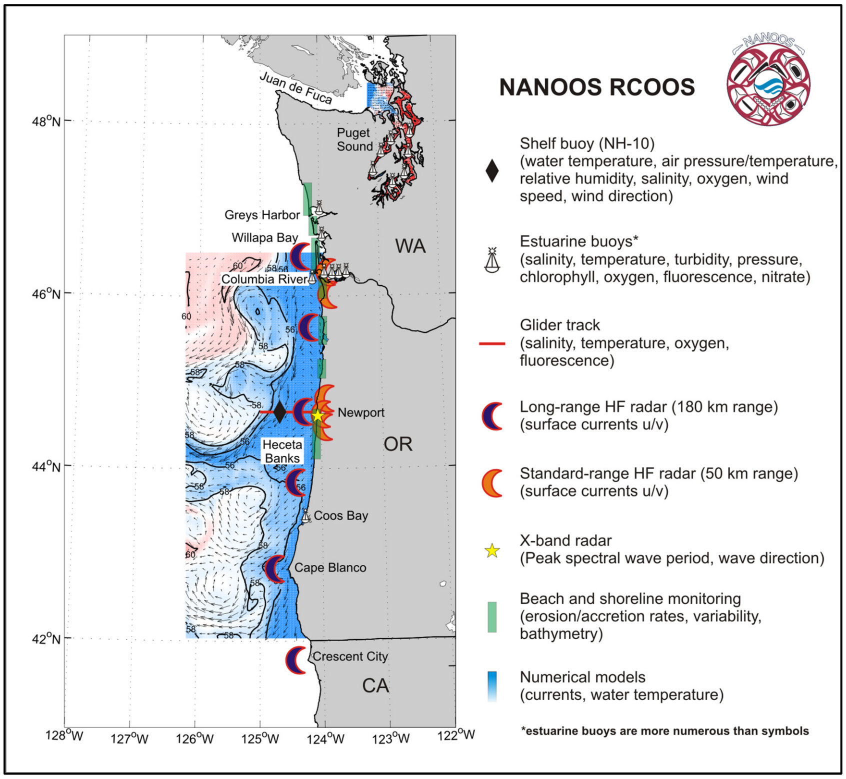

Fig. 1. The NANOOS Regional Coastal Ocean Observing System showing its various sensor and observation assets. Note: this map excludes the federal assets that exist within the NANOOS domain.

Over the past several years, NANOOS community members, comprised of information technology (IT) system architects, software engineers, ocean and coastal scientists, education and outreach experts, and user members spanning many disparate professions and interests, have met to strategize through visioning processes, the necessary data management and communication (DMAC) components that will ultimately comprise the NANOOS Visualization System (NVS). Critical to the success of the NVS and other products or tools, is enabling the seamless delivery of coastal, estuarine and ocean data to stakeholders within the NANOOS domain and to connect seamlessly with external partners, other RCOOS efforts, and national/international programs. The DMAC architecture that underpins the NVS (and other product tools) must therefore support the functions of observing, processing, archiving and dissemination through a set of recognized interoperability standards providing public access to an inventory of existing data, metadata, services and products. Thus, there are four primary requirements: 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) rich yet simple interfaces enabling decision making by end users on a routine, unassisted basis. This paper examines these various components as they relate to NVS, providing an insight into the strengths (and weaknesses) of the various components. In particular, Section II describes NANOOS DMAC efforts as they relate to the development of NVS. Section III describes NVS, including identified requirements, selected approach and functionality, innovations as well as the regional and federal observation and modeling assets that are currently aggregated. Conclusions and next steps are summarized in Section IV.

II. NANOOS Data Management and communication

At a National level, DMAC is critical to the success of NANOOS (and ultimately IOOS) in meeting its goals of delivering near real-time and archived observations and model output to a wide variety of users (de La Beaujardiere, 2008). At a local level, the DMAC subsystem is the bridge between data collection and management, data products and the end users of the data. The Pacific Northwest region has a wide variety of users that rely on data and data products from NANOOS – as well as federal – observing systems and forecast models. Many of these users, such as shellfish growers and commercial fishermen depend on the timely delivery of such data for their livelihood. Other users include recreational boaters, educators, local and state Government agencies. NANOOS DMAC must be responsive to the needs of these users as well as to IOOS interoperability requirements.

NANOOS DMAC is meeting these diverse requirements by focusing on three distinct functions:

1. *National data interoperability*. The IOOS program office is in the process of defining long-term data standards for the interchange of data between national assets (de La Beaujardiere, 2008). The IOOS Data Interchange Framework (DIF) is to be fully defined in fiscal year 2010. NANOOS has representatives on the DIF working group that is defining the DIF standards. Currently, data communication and interoperability with the national IOOS network is implemented using IOOS-supported standards such as Open Geospatial Consortium (OGC) Sensor Observation Service (SOS), Web Map Service (WMS) and Open-source Project for a Network Data Access Protocol (OPeNDAP).
2. *Data management and stewardship, including long-term archival*. Some of our larger partners such as state agencies have mandates and resources to perform this function for their own data holdings. However, many data providers are not in a position to play that role given limited resources and diverse interests. NANOOS DMAC has set up two Data Archives (as defined by de La Beaujardiere et al., 2009; and http://www.oostethys.org/System Architecture) for in situ observations, based at the Center for Coastal Margin Observation & Prediction – Oregon Health & Science University (CMOP, Oregon) and the Applied Physics Laboratory – University of Washington (APL-UW, Washington), to provide this service to regional data providers, as needed and as more partnerships are built (e.g. the Hood Canal Dissolved Oxygen Program, tidal and wave energy baseline assessment projects). Data management for ocean circulation models is currently handled in a more distributed fashion at CMOP, APL-UW, and Oregon State University (OSU, Oregon).
3. *Regional data aggregation and interoperability*. NANOOS DMAC is working closely with major regional data providers, such as WADOE and the Victoria Experimental Network Under the Sea (VENUS) cabled ocean observatory in British Columbia, Canada, to enable the implementation of IOOS-supported data distribution protocols on their own servers, or otherwise to aggregate their data and redistribute through NANOOS infrastructure via such protocols. These distributed or aggregated services together with those served through the NANOOS Data Archives will soon become a data-rich regional interoperable network that is integrated with the national IOOS network. NANOOS DMAC also maintains a catalog of regional data assets and a registry of regional web services. In effect, NANOOS is quickly evolving its capabilities as a distributed, regional Data Assembly Center (DAC; see de La Beaujardiere et al., 2009).

Data interoperability between individual data providers and NANOOS, and between regional and national efforts is being enabled by the emerging standards fostered and supported by IOOS. This interoperable network of regionally relevant data, from long-term baseline surveys and satellite products to near real-time in situ observations and model output will support unfettered access by users ranging from scientists to the general public. It will also support the development of online user applications such as NVS that provide user-friendly and consistent access to observation and modeling assets.

A. In situ data

For in situ observations such as those from buoys, platforms secured to moorings, and research vessels, NANOOS uses IOOS SOS, a proposed standard (currently under review by IOOS DMAC) based on OGC SOS to serve data encoded in Extensible Markup Language (XML). SOS defines a set of operations for software to request data or service metadata using Hypertext Transfer Protocol (HTTP). NANOOS data providers are implementing the SOS “core operations profile,” which comprises three basic functions:

1. *GetCapabilities* allows users to obtain service metadata including data provider contact information, list of sensors and measured phenomena, and valid operations and parameters that this service accepts
2. *DescribeSensor* returns the sensor metadata, including processes in an XML document that conforms to Transducer Markup Language (TML) or SensorML schema definition.
3. *GetObservation* allows users to retrieve data from the desired sensor(s) for a given time period.

In general SOS is too flexible and ambiguous for use without a-priori knowledge of the implementation. The client developer must have a deep understanding of the data formats and encodings that are in use by the SOS service provider. Such a lack of a concrete data-encoding standard has lead to several incompatible implementations of the SOS service. This fact has made it hard to achieve a consistent level of interoperability that is desired in a standard that is intended to facilitate the exchange of data between different entities. Adding to the complexity of the SOS standard is that SOS is not self-describing. The GetCapiblilities method does not return sufficient information about the format of the data to make it possible to construct a client program. Client developers must work closely with the service provider in order to successfully obtain data. This leads to client implementations that are brittle, hard to maintain, and error prone. OGC is actively working on the SOS standard to address issues in the initial release. IOOS is also working on a unified data model that will allow IOOS SOS implementations to be fully interoperable.

B. Gridded data

NANOOS uses OPeNDAP for serving gridded data, particularly model outputs but also including satellite data and surface currents from high-frequency radar. OPeNDAP has been widely adopted in the oceanographic and atmospheric communities, and has a proven record of supporting community needs for multi-dimensional, continuous data, (Hankin et al., 2009; Signell et al. 2008), including unstructured grids (Nativi et al., 2008; Signell et al. 2008). To provide a more unified and consistent presentation of diverse gridded assets, NANOOS has started to use the THREDDS Data Server (TDS). TDS presents users with aggregations of subdatasets into more consistent datasets also accessible via OPeNDaP, provides catalogs of datasets that may be distributed across servers, and facilitates the addition of CF (Climate and Forecast) compliance on gridded data (Signell et al., 2008). TDS also provides access via OGC WCS; however, we believe that OPeNDAP is serving the data-access need of the oceanographic community well. As WCS does not currently offer clear, additional advantages, we have no plans to support it in the near future.

With respect to satellite data, NANOOS is not producing its own regionally-generated products at this time. Instead, we will primarily consume existing regional, national and global products representing current or recent conditions. For such client mapping applications, we will rely mainly on access through WMS (see below), though this may be enhanced with OPeNDAP access for greater flexibility and access to the data, as needed.

C. Distributed access to individual data map visualization via OGC WMS

WMS provides access to map visualizations of individual or aggregated datasets that may be based on dynamic, time-varying data. These visualizations are served as simple, pre-styled, georeferenced images. WMS is perhaps the most mature and widespread of the OGC web services, and is relatively simple to implement both as a server and client, as a variety of open source and commercial software support it. We are using the open-source GeoServer software (http://geoserver.org) to serve GIS data through WMS for consumption by NVS and other NANOOS and non-NANOOS users. For multi-dimensional gridded data such as 4-dimensional ocean model output (which include depth and time), we are currently exploring NVS access to geographic visualizations via ncWMS (Blower et al., 2009) as implemented by TDS.

III. THE NANOOS VISUALIZATION SYSTEM (NVS)

The web mapping and visualization system that NANOOS is developing, NVS, aggregates, displays and serves near real-time coastal, estuarine, oceanographic and meteorological data, derived from buoys, gliders, tide gauges, HF Radar, meteorological stations, shore based coastal stations and satellites, as well as model forecast fields and eventually archived information. This functionality will be accomplished in such a way that it provides a rich, informative and meaningful experience to a diverse group of end users, thus directly addressing the IOOS mandate to "provide the data and information needed to improve safety, enhance our economy, and protect our marine environment". Here we describe the requirements and priorities identified for the NVS, including the selection of functionality and technical approaches, aggregation of federal and regionally maintained observation and modeling assets, and current status of NVS. We highlight aspects of NVS that we believe represent significant innovations, particularly when implemented as coupled components of an integrated visualization platform.

A. Selection of NVS user functionality and supporting technical framework

Users of ocean and coastal information need the capability to query and display data from existing observing platforms, models, and remote sensing data, typically for three distinct time windows:

- current conditions (what is occurring now and in the last few days);
- forecasts (what can be expected over the next 24 hours to several days); and,
- historical archives (what has occurred in the past).

Furthermore, because of the diverse range of needs and experience of users interested in querying, manipulating and viewing oceanographic and coastal data, it is necessary to design an interface capable of meeting such a diverse range of needs and perspectives. The core components of the NVS must therefore be capable of generating the following: 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. Thus, a comprehensive visualization application encompasses the capability to interactively select one or more variables, locations, spatial domains, depth interval, and time periods and seamlessly display and deliver the appropriate information. These needs and objectives represent a substantial challenge to the community of ocean observing systems in terms of both technical complexities involved and the ability to deliver rich yet simple interfaces that enable decision making by end users on a routine, unassisted basis.

The development of NVS has been guided by an emphasis on an intuitive, coherent and interactive user experience. For the first public version of NVS (NVS-1), considerable internal discussion among core NANOOS members led to a focus on discovery and access to near real-time marine data assets via geographic and tag or data-characteristic selection, coupled with consistent presentation and visualization of recent, dynamic observations and forecasts independent of the data provider.

As the geographical framework represents the most user-visible aspect of the application, considerable internal discussions centered on selecting the most appropriate one. Contrasting options that were considered included: 1) Existing, powerful web-based, multi-dimensional, on-demand visualization applications that include a geographical interface (e.g., Live Access Server, http://ferret.pmel.noaa.gov/Ferret/LAS/home/; Godiva2, Blower et al., 2009); 2) Interactive geographical navigation via a conventional, rich toolset coupled with an extensive, customized selection of individual geographical data layers, analogous to desktop GIS software; and 3) Simplified set of navigation tools with a responsive interface and simplified selection of layers, an example of which is the Google Maps service. Applications of the first type are typically oriented towards oceanographers and have fairly complex interfaces, limited functionality on the geographical interface, and a relatively small user and developer base. The second type of application can deliver rich geographical user interactions but may often produce a cluttered interface. The Google Maps service commonly starts out with a minimal interface that may be built upon for additional functionality. In addition, the Google Maps API (Application Programming Interface) provides some additional functional advantages, including a set of optimized, default background layers (satellite, terrain, and conventional cartographic backgrounds), a small but sufficient set of map navigation functionality (draggable map and zooming), and an overall interface experience (including clickable site markers with rich pop-up information bubbles) that has become widely familiar to a large and diverse user base.

Based on this assessment, we chose Google Maps as the geographical interface framework for NVS, focusing on consistent, integrated access to dynamic marine information while minimizing the inclusion of many, heterogeneous, static GIS layers that is characteristic of Coastal Atlas applications. The large developer and user base centered on Google Maps provides a diversity of component tools and developer documentation that may be adapted for NVS. Nevertheless, this starting base was greatly extended by substantial customization and coupling of linked custom tools using PHP (an open-source server-side language), an extension of the AJAX (asynchronous JavaScript and XML) client-server data transfer framework used by Google Maps, and communication with a NANOOS custom-built MySQL database (the NVS Assets Database or Catalog) holding information about observational and modeling assets as well as the latest observations from these assets.

NVS-1 encompasses much more than the geographical discovery and visualization of marine assets. Two fundamental and distinctive components are the tag-based discovery and selection of assets and asset data using controlled vocabularies, and consistent, intuitive access to displays of current and forecast conditions, particularly for in situ observational assets. These components are integrated to provide a seamless user experience independent of data source, while clearly identifying the asset provider. Fig. 2 shows a screenshot of the current development version of NVS-1.

The NVS Assets Catalog includes controlled vocabularies for platform type (e.g. buoy), provider, measurement type (Hydrographic vs. Atmospheric), measurement variables, regions, and other categories. These controlled vocabularies provide for tag-based asset selection ("Asset Filters" bar in Fig. 2, shown in collapsed mode) that dynamically filters the set of assets shown on the "Assets" layers block (Fig. 2, left side); they also correspond to labels shown on the information-rich asset pop-up bubble (Fig. 2, inset). For measurement data variables, they incorporate data variables prioritized by IOOS, including the initial IOOS-DIF seven core variables (Table I). The controlled vocabularies are also consistent with the NANOOS Products selection application (http://www.nanoos.org/data/products/products.php). In effect, we have implemented mappings of category and measurement variable name between heterogeneous original data sources and the NVS Catalog vocabularies, and this lightweight semantic mediation (see Beran & Piasecki, 2009; the Marine Metadata Interoperability project, http://www.marinemetadata.org/; and OOSTethys, http://www.oostethys.org/) provides a foundation for the integrated interactions among NVS components.

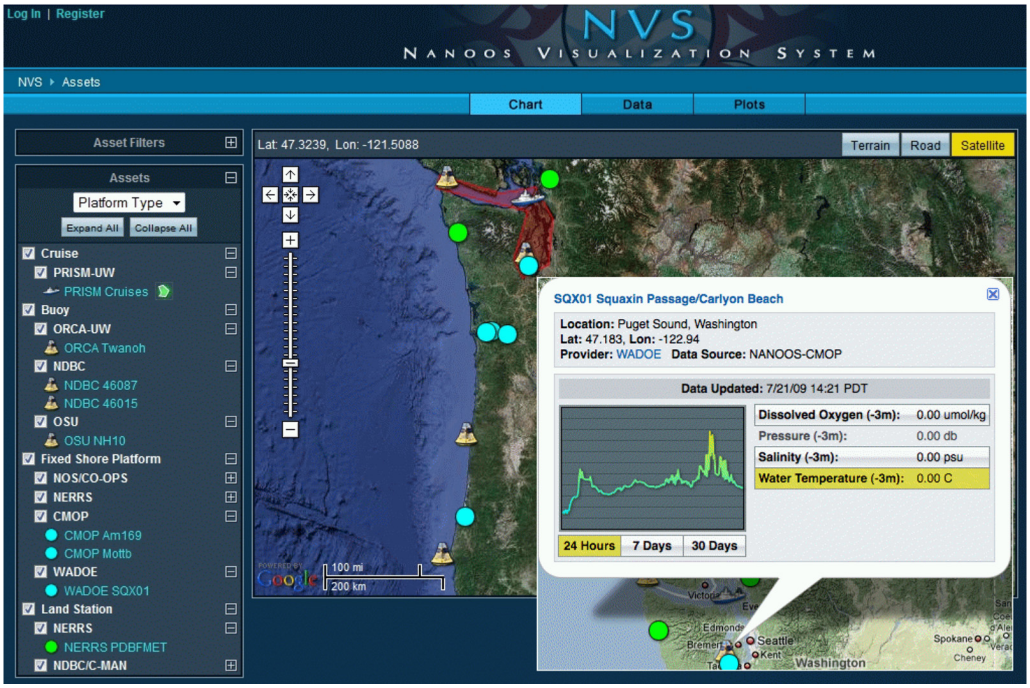

Fig. 2. The NANOOS Visualization System (NVS), displaying only a small subset of existing Pacific Northwest assets. Inset shows pop-up bubble for an in situ observation asset, providing asset background (name, location, data provider and data source) and latest observations, including values and plots by variable.

Table I. Pacific Northwest data variables targeted for inclusion in NVS-1. Additional variables will be addressed in future versions of NVS. Variables in bold correspond to the 7 core variables prioritized by IOOS DIF (http://ioos.gov/dif/overview .html). Variables marked with an asterisk (*) are more specific observations corresponding to the broader "ocean color" IOOS DIF variable.

OCEANS AND ESTUARIES	COAST	ATMOSPHERE
• **Water Temperature** • **Salinity** • Density • **Currents** • **Water Level** • **Wave Height, Direction and Frequency** • ***Turbidity** • ***Chl a Fluorescence** • Light transmission and availability • Dissolved Oxygen • Nitrate	• Coastal change (cross-sections and contour trends) • Shorelines • Bathymetry • **Water level** • **Wave Direction and Frequency**	• **Wind Speed and Direction** • Barometric Pressure • Air Temperature • Relative Humidity • Precipitation • Solar Radiation

B. Specific functionality included in NVS-1

After discussing broad objectives and fundamental, distinctive components of NVS-1, we present a more detailed listing of NVS-1 functionality by major category; many of these descriptions refer to functionality visible in Fig. 2. The implementation status as of this writing will be listed next to each major feature or group of features, and will be described as: **[1]** Completed Implementation, **[2]** Partial Implementation, **[3]** Early Development, or **[4]** Unclear and lower-priority NVS-1 Inclusion. Functions that we consider to be innovative are underlined. With some exceptions, components already discussed above will not be repeated here.

General: i) [**2**] Focus on integrated, consistent access to latest data and recent data plots independent of data provider or data source. ii) **[3]** User customizability via optional accounts and login that may include development of user-group profiles (e.g., fisheries, harmful algal blooms) that can be created by some users and re-used by others. iii) **[2]** Assets grouped into major, common types: in situ observations, satellite observations, surface currents from HF radar, and circulation model output, including forecasts.

Map Interface: i) **[1]** Uses Google Maps API with standard Google Maps navigation and map background widgets: zooming and panning, draggable panning, three default map backgrounds (terrain, satellite and cartographic), taking advantage of built-in labeling of cities, towns and significant features. ii) **[2]** Minimal set of application tools whose behavior may not be intuitive a priori; we rely instead on the common user expectations established over the last few years by Google Maps and similar applications, where map markers are clickable and information is accessible by following visual cues or clicking on links. iii) **[2]** Intuitive, graphical markers representing platform types for in situ observational assets.

User Interface Behavior: i) **[1]** Each user-interface component block can be minimized (e.g., asset filters, assets layers). ii) **[2]** Marine data assets will be grouped into broad asset types (listed above) and platform types rather than by data provider; this approach enhances usability for comprehensive regional assessments while preserving the acknowledgment of individual data providers, as these will be clearly stated and linked to. iii) **[2]** Different asset types will be grouped into separate asset blocks. iv) **[1]** Assets in each asset block can be sorted or grouped by platform type, data provider, or region. v) **[1]** Combination of selection by tags (controlled vocabularies) and by map layers provides a powerful and user-friendly mechanism to identify assets of interest.

Pop-up information bubble and time-series plots: i) **[1]** Rich bubble content generated through custom PHP code rather than built-in marker bubble tags. ii) **[2]** Bubble with basic asset information, latest observations, and plots for 3 time intervals (previous 24 hours, 7 days and 30 days) selectable by measurement variable; also, visual cues and simple disabling of plots when a measurement variable from an asset is unavailable. iii) **[2]** 3 types of time series plots, depending on the platform asset type (1, unique measurement occurring at a single depth or elevation: use simple single-curve time series plot; 2, platform has identical sensors at a small number of depths/elevations: use plots with each curve representing the individual depth/ elevation; and 3, for depth profilers where a sensor makes measurements at multiple depths: use fill plots of depth versus time where measurement variable values are represented by colormapped colors). iv) **[2]** Bubble displays the time when measurements were last taken or the data source last accessed, and the depth/elevation they correspond to; for multi-depth measurements, a drop-down form will let users select the depth for the latest-measurements listing. v) **[3]** Bubble provides access to near real-time (current) and future/forecast conditions through a tabbed interface. vi) **[4]** Historical data, including coastal monitoring and cruise data, will be deployed in a way that's consistent with near-real-time and forecast data. vii) **[2]** For in situ assets, plots will be pre-generated at regular intervals using Matlab in the backend, to maintain good user responsiveness of NVS. viii) **[2]** For latest measurement data, Python code is used to harvest the data and populate the NVS Assets Database at regular intervals (about 30 minutes).

C. Data aggregation

NVS-1 aggregates observation and modeling data from multiple providers and data sources (Fig. 1 and Table II) in order to deliver a comprehensive view of the Pacific Northwest marine environment. These data originate in different asset types (in situ observations, satellite observations, surface currents from HF radar, and circulation model output, including forecasts) as well as different platform types (e.g. for in situ observations, buoys vs. fixed shore platforms), as described in sections II and III.B. As discussed earlier, providers (asset managers or data product developers) range from federal to regional and local entities, with different capabilities for data management and distribution; at the same time, some entities such as NDBC have traditionally served as aggregators and re-distributors of data in common forms from multiple providers, providing valuable support for regionally focused ocean observing communities such as NANOOS.

IOOS DMAC is striving to identify and orient data access protocols that can enable scalable, machine-to-machine marine data interoperability. However, heterogeneity of data sources, geometry, and semantics remain significant challenges. For example, the apparent success of the OpenIOOS mapping application integrating national in situ observations (http://www.openioos.org/real_time_data/gm_sos.html) belies a substantial diversity in OGC SOS implementations and semantic representations that is only partially resolved through complex code handling many unique cases (E. Bridger, pers. comm.). For gridded data, the combination of NetCDF, CF conventions and OPeNDAP have demonstrated a significant degree of success at achieving interoperability (e.g. Signell et al., 2008; Hankin et al., 2009). We expect to be able to utilize these proven community standards with THREDDS Data Servers to integrate 4-dimensional circulation model output and possibly HF radar data into NVS-1. While satellite products are also gridded data, the reduced dimensionality (no depth dimension and time aggregations that lead to a limited set of time products for recent conditions) strongly argue for the use of OGC WMS as a mapping visualization integration service, while OPeNDAP may be used for direct, flexible access to data subsets.

To mitigate immaturity of the SOS standard for in situ assets, NVS-1 relies on simplified data harvesting and aggregation schemes for in situ assets, relying on data redistributors such as NDBC whenever possible. To expedite the implementation of NVS-1, NANOOS DMAC opted to sidestep the complexities and inconsistencies of SOS and access data in the simplest forms available, including ASCII tables and relatively straightforward XML files accessed via ftp or http from the smallest possible number of data distributors, including key NANOOS DMAC partners such as CMOP. Although the NVS Assets Database is manually maintained at this time, it's already providing clear benefits in supporting data aggregation, cataloguing, and functionality integration for NVS. While this traditional, idiosyncratic data harvesting approach has significant scalability limitations, it has served other regional ocean observing communities well (e.g. the Carolinas RCOOS application, http://carolinasrcoos.org/intmap.php?tab=4). Nevertheless, NVS is designed to be able to take advantage of emerging standards as they mature. NANOOS already makes its regional in situ observational assets available via IOOS SOS for data exchange at regional and national level; as IOOS SOS matures, we will regularly reassess the technical advantages of the current data aggregation approach.

Table II. Pacific Northwest data sources. Data provider acronyms have been defined previously in the text. Asterisk (*) indicates datasets that may not be integrated into NVS-1.

Regional Providers and Data Sources
OSU: NH-10 Buoy, *Gliders, HF and X-band Radar, bathymetry, ROMS circulation model **CMOP:** Buoys, *Gliders, SATURN Observation Network, *Cruises, Columbia River Estuary circulation model **UW:** ORCA Profiling Buoys, *NPB Profiling Buoy, *PRISM Cruises, *Hood Canal Dissolved Oxygen Program, PSPOM circulation model, MM5 atmospheric model **DOGAMI:** Coastal shorelands (beach profiles, shorelines) **Oregon Department of State Lands, South Slough National Estuarine Research Reserve System (NERRS) Reserve:** Buoys, Fixed water monitoring shore stations, weather stations **WADOE:** Fixed water monitoring shore stations, coastal shorelands (beach profiles), bathymetry **Padilla Bay NERRS Reserve:** Fixed water monitoring shore stations, weather stations
National Providers and Data Sources
National Data Buoy Center (NDBC): buoys (wave, DART and CDIP), C-MAN coastal weather stations **National Ocean Service, Center for Operational Oceanographic Products and Services (NOS/CO-OPS):** tide gauges, coastal weather stations ***National Weather Service (NWS):** weather stations and information, weather forecasts **National Estuarine Research Reserve System (NERRS): See above, under Regional Providers** ***National Centers for Environmental Prediction (NCEP): weather forecasts** **National Environmental Satellite Data and Information Service, CoastWatch program:** Satellite products (sea surface temperature, chlorophyll, ocean currents), homogenized access to data from multiple sources ***United States Geological Service (USGS):** discharge and water quality at river mouths

IV. CONCLUSIONS AND NEXT STEPS

The Northwest Association of Networked Ocean Observing Systems (NANOOS) is coordinating and supporting the development of a Pacific Northwest regional coastal ocean observing system that will provide stakeholders with data, tools and information they need to make decisions related to their particular needs. As part of this effort NANOOS is developing a web mapping and visualization system, the NANOOS visualization system (NVS), that aggregates, displays and serves near real-time coastal, estuarine, oceanographic and meteorological data, derived from buoys, gliders, tide gauges, HF Radar, meteorological stations, shore based coastal stations and satellites, as well as model forecast information.

The development of NVS has been guided by an emphasis on an intuitive, consistent and interactive user experience. The first publicly available version of NVS, presented here, focuses on discovery and access to near real-time marine data and forecast information. Data and information are aggregated and presented using consistent data formats that are independent of the data provider, a standard vocabulary for platform types and data providers, as well as measurement types and variables and a unique tag-based data discovery system. These components are integrated to provide a seamless and rich web mapping and visualization system.

Future development of NVS functionality will, in large part, be driven by targeted stakeholder feedback, which will be collected during several planned training workshops. Such functionality will include the ability to access and download archived data, including research cruise data, and model output based on user selections. In addition, we anticipate that future versions of NVS will include more sophisticated visualization types (e.g. parameter-parameter plots) and more interactive, user-driven plotting capabilities. NANOOS is currently running an ERDDAP server as a data aggregation service and common front end to heterogeneous datasets from diverse sources. While our implementation is still undergoing extensive testing and development, we believe ERDDAP may provide convenient, integrated access to data and visualizations, particularly for more advanced users. ERDDAP can access data from a variety of other services including SOS, THREDDS, OPeNDAP, and other ERDDAP servers. Datasets can then be defined and made available via a URL in many formats including KML, CSV, HTML, JSON, and PNG plots. One use of ERDDAP with which we are experimenting is for creating the time series plots shown in the NVS information bubbles (Fig. 2). An embedded URL to the ERDDAP server in each bubble will return the requested data. The data is accessed via the appropriate service (e.g. THREDDS or SOS), aggregated into a defined dataset and transformed into the requested output format. It is hoped that this approach will free NVS from needing to be updated as the IOOS and OGC standards emerge and mature.

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