The NANOOS Visualization System (NVS): A Decade of Development and Progress Addressing Stakeholder Needs

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***Abstract*— Over the past few decades coastal regions have experienced considerable socio-economic change. Accompanying these socio-economic shifts are unprecedented environmental changes, which include variation in magnitude and frequency of extreme weather events, marine heatwaves, increased ocean acidification, expansion of dead zones, extreme harmful algal blooms, and accelerating sea level rise. To understand these emerging environmental shifts, the past two decades have witnessed increased capacity to monitor changing environmental conditions and predict with greater accuracy such variations and events. These observation and prediction systems produce ever increasing amounts of data. Ongoing efforts to deliver this information using standard data models, metadata, data access protocols, and community accepted data server applications have helped reduce the heterogeneity of these data and improved data distribution. However, delivering critical information to stakeholders in a user-friendly and accessible manner remains a challenge. Beginning in 2009, the Northwest Association of Networked Ocean Observing Systems (NANOOS), the U.S. Integrated Ocean Observing System (IOOS) regional association for the Pacific Northwest, began to address this challenge by developing the NANOOS Visualization System (NVS), a map-based platform that aggregated a multitude of diverse data sets and forecast model fields into one system with the goal of delivering a more seamless, one-stop-shopping experience for users of coastal, ocean and atmospheric data. Here we describe the early vision and development of NVS and how it evolved into a flexible, multi-application platform where customized web applications can be developed to meet the needs of specific stakeholder groups. We focus on three applications (Seacast, Shellfish Growers, and Tsunami Evacuation Zones) that were developed using more formal design processes in close coordination with commercial crab fishermen, shellfish growers, and state and local emergency managers. In addition, we briefly describe the Tuna Fishers application, which evolved out of informal discussions with recreational tuna fishers. In highlighting these applications, we demonstrate the flexibility of NVS to quickly spin up prototype applications using pre-existing NVS framework elements. Working closely with small groups of dedicated stakeholders, we are then able to refine and extend an application before releasing it to the broader audience. Such a capability has enabled NANOOS to truly meet stakeholder needs, while increasing user capacity to understand and better respond to ongoing regional environmental changes.**

***Keywords*— NVS; NANOOS; Product development; Data visualization; Stakeholder engagement**

I. Introduction

Over the past few decades coastal counties and communities have experienced considerable socio-economic change. While such regions account for only 23% of the contiguous U.S. land area, they account for approximately 50% of all land-cover change and 43% of all urbanization [1]. These changes are being driven in large part by substantial population increases; between 1970 and 2010, coastal populations increased by nearly 40%. This has resulted in population densities six times higher than in non-coastal areas [2]. Starting in the mid- to late 1980s Pacific Northwest coastal communities saw significant economic change as they shifted from resource-centric industries such as fishing and timber to more service-centric sectors such as tourism, retirement and health care [3]. Accompanying these socio-economic changes are extraordinary environmental changes [4]. Lubchenco and Karl [5] document shifts in the magnitude and frequency of extreme weather including one-day heavy precipitation events and heat waves. Ocean environments are experiencing the expansion of dead zones [6], increasing acidity [7], marine heatwaves [8], harmful algal blooms [9], accelerating sea level rise [10], and extreme storm events [11] all of which have important economic impacts on coastal communities.

To understand emerging environmental shifts, the past three decades have witnessed an ever increasing capacity to monitor changing environmental conditions, through in situ programs such as Argo [12], the Tropical Ocean Global Atmosphere (TOGA) [13] program, the Ocean Observatories Initiative (OOI) [14] and the U.S. Integrated Ocean Observing System (IOOS) [15], and predict with increasing accuracy such variations and events [16]. These observation and prediction systems produce ever increasing amounts of data and forecasts. Ongoing efforts to deliver this information using standard data models, metadata, data access protocols [17], and community accepted data server applications such as THREDDS [18] and ERDDAP [19] have helped reduce the heterogeneity of these data and improved data distribution. However, delivering critical information to stakeholders such as the United States Coast Guard, natural resource managers, educators, beachgoers, commercial fishermen and shellfish growers in a user-friendly and accessible manner remains a challenge.

Beginning in early 2009, the Northwest Association of Networked Ocean Observing Systems (NANOOS), the IOOS regional association for the Pacific Northwest, began to address this challenge by developing the NANOOS Visualization System (NVS) [20, 21]. NVS (Fig. 1) is a map-based platform that aggregates and distributes a multitude of diverse data sets from local (e.g. Washington King County, Washington Department of Health, and the Pacific Shellfish Institute), regional (e.g., OOI), national (e.g., the National Data Buoy Center, the U.S. Geological Survey) and Canadian (e.g., Environment and Climate Change Canada, Hakai Institute, Ocean Networks Canada) ocean observing partners. These data sets include data collected by High-Frequency (HF) Radar, ferries, moorings, benthic platforms, underwater gliders, profilers and shore stations. In addition, regional and global ocean and atmospheric forecast fields are accessible

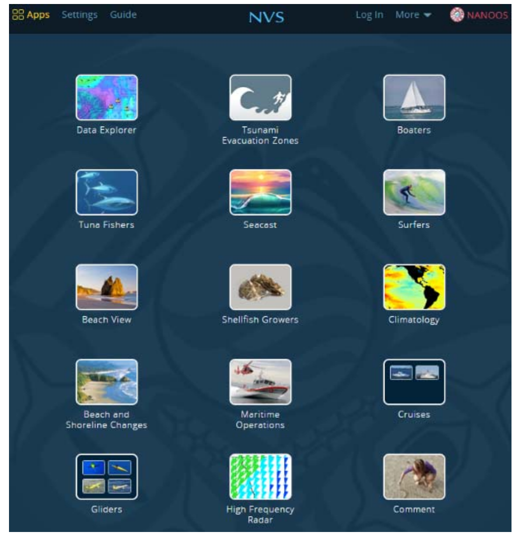

Fig. 1. The NANOOS Visualization System (v6.3) landing page showing available web applications. Available at http://nvs.nanoos.org/.

through NVS. The overall goal when development began on NVS in 2009, which remains true, was to deliver a rich and seamless, one-stop-shopping experience for users of coastal, ocean and atmospheric data.

This paper describes how NVS has evolved over the past decade (Table I) into a flexible, multi-application platform that allows developers to quickly spin up prototype applications using pre-existing NVS framework elements. Then, working closely with small groups of dedicated stakeholders, developers can refine and extend an application before releasing it to the broader audience. Section II describes how the NVS architecture has advanced over the past decade to include the above capabilities. Section III details the history and development of three NVS applications (Seacast, Shellfish Growers, and Tsunami Evacuation Zones) that were developed using a more formal design process, similar to the stakeholder-driven process outlined by Iwamoto et al [22], in close coordination and collaboration with commercial crab fishermen, shellfish growers, and state and local emergency managers. In addition, Section III briefly describes the Tuna Fishers application, which evolved out of informal discussions with recreational tuna fishers. Conclusions and final thoughts are summarized in Section IV.

II. The NANOOS Visualization System (NVS)

NVS was initially conceived as a tool to display a wide range of heterogeneous oceanographic and meteorological information via an intuitive and consistent user interface [20]. Various data products existed across numerous websites, requiring users to visit multiple disparate sites and create their own composite view of how different visualizations and data sets related to one another. Further compounding the problem, each product had its own map projection, time scale, variable names and units. The non-uniform way information was presented between various products made it difficult for stakeholders to perform comparisons and often led to errors. The NANOOS user products team realized that a single visualization tool that composited all the various products into

TABLE I. A HIGH-LEVEL VERSION HISTORY OF THE NANOOS VISUALIZATION SYSTEM. A MORE DETAILED VERSION HISTORY IS AVAILABLE AT HTTP://NVS.NANOOS.ORG/VERSIONHISTORY.

2009 Nov	**NVS 1.0.** First NVS release.
2010 Mar	Model forecasts at observation sites
2010 May	Asset visualization as map overlays (models, remote sensing, etc)
2010 Aug	**NVS 2.0.** Large usability enhancements. User-friendly observation-forecast comparison plots ("comparator"). Initial timeline interface for selecting time-dependent overlays.
2011 Mar	Login support to store preferences. Units switcher (metric vs US common). Time series y-axis range modes (global vs local). Asset status history information.
2011 Nov	Tsunami Evacuation Zones App.
2013 Mar	**NVS 3.0.** Generalized, unified NVS Apps presentation, with new Apps (Tuna Fishers, Maritime Operations, High Frequency Radar) and integrating previous NVS apps (Data Explorer, Tsunami Evacuation, Beach and Shorelines, cruises, gliders). Large usability enhancements. Map overlay time sequence player.
2013 Jun	Unified timeline control across all overlays. Shellfish Growers App now an NVS App. NOAA Navigation Charts. Asset offline-status map icons.
2014 Apr	Comprehensive NVS Help App. Boaters App. Backend database refactoring for more robust support of new capabilities.
2014 Oct	Climatology App, with timeline support for cyclical climatology overlays.
2015 Jul	**NVS 4.0.** Interactive time series plots integrated into timeline interface. Depth control for multi-depth overlays.
2015 Nov	Forecast and comparator plotting added to timeline.
2016 May	Generalized, interactive Glider App framework. Mobile platform data support.
2016 Sep	**NVS 5.0.** Depth profile section plots integrated into timeline. Current conditions map view.
2017 Jan	Interactive routes feature.
2018 May	**NVS 6.0.** Seacast App. Large usability enhancements.
2018 Jun	Beach View and Surfers Apps.
2019 Apr	Obtain overlay values by clicking on map.

a uniform, consistent application would improve data discovery and interpretation for our stakeholders.

The first step in the creation of NVS was to identify key data sources, both near real-time (NRT) observations and model forecasts, and develop a means for harvesting and storing the information in a common format [21]. Observation data was integrated and stored in a local relational database, while forecast field output and images were loaded into a customized tile server. In order to ensure that users could load data as quickly as possible, a lightweight database schema that favored fast data retrieval was developed. In addition, client-server data service responses were cached whenever possible.

Once the NVS database and tile server were in place, development of the data portal began. The initial version of the portal contained all observations and forecasts available in the NVS database and tile server. This “kitchen sink” approach allowed users to compare a multitude of platforms and forecasts in a single map-based interface. Users were able to view observational data for each platform at the same time they were viewing forecast fields. For each platform, static time series plots were available for each variable. Users were also able to select how units were viewed, either as “Scientific” (Celsius, meters, m/s, etc.) or “Common” (Fahrenheit, Feet, Knots, etc.).

A significant improvement to NVS was the addition of the timeline tool in June 2013 (Table I). The timeline is an interactive visual of time series data displayed below the map (Figs. 2 and 3). In the previous version of NVS, all time series plots were static images. With the advent of the timeline, all platform time series plots became interactive, allowing users to mouse over any point to view values at any available time. The timeline also allows users to zoom in and out of the data, making it easier to analyze small time scales with large rates of change. Finally, the timeline displayed the available forecast times for overlays in the same place as the time series plots, allowing users to easily see how forecast times correlated to observational values.

While NVS was proving to be a very useful tool for displaying a wide variety of observational data and model output simultaneously, some users were finding the multitude of platforms, overlays, markers, and other features rather complicated and overwhelming. The NANOOS education and outreach team started talking to individual stakeholder communities about how NVS could be improved to make it easier for them to use. From the stakeholder meetings it became clear that each community wanted a simpler version of NVS, with data and features tailored to their specific needs. As a result of this feedback, NVS was rebuilt using a modular framework that would replace the kitchen sink approach with multiple web applications, each tailored to a specific community stakeholder need. While each community needed specific and sometimes different information and data sets, there were many overlaps with regard to features and data sets each group desired. The NVS framework was rebuilt as a collection of modules, and an application was created for each community. Each application became a different view of the same underlying data and features, allowing developers to easily modify or create new prototype applications as needed. The development process behind four NVS applications, Seacast, Shellfish Growers, Tsunami Evacuation Zones, and the Tuna Fishers application, is described below.

III. Examples of Focused, Stakeholder-Driven Web Applications

A. *Seacast*

Development of Seacast.org began in late 2013 as part of an Oregon State University (OSU) graduate project [23]. This project focused on the development of an online ocean condition forecasting tool tailored to the planning and safety needs of Oregon's commercial fishermen, one of the most dangerous employment sectors in the U.S. with a 2016 work-related fatality rate 23 times that of all U.S. workers [24]. Website development was done by a team of senior undergraduate Computer Science (CS) students as part of a Capstone Project using the results of interviews with Newport Dungeness crab fishermen [23].

An initial version of the Seacast.org website (Fig. 2, top), which allowed users to visualize OSU ROMS model [25] forecasts of surface ocean temperature, salinity and currents up to three days into the future via a simple, easy-to-use interface, was delivered in December 2014 in time for the commercial crab fishing season. Development on Seacast.org continued in 2015 as part of a new undergraduate CS Capstone Project. Two members of the 2015 CS team as well as another graduate student [26] worked to extend and improve the website in 2016 and 2017 through Oregon Sea Grant (OSG) and Space Grant funded work. Throughout this four-year period members of the Seacast.org development teams and project Principal Investigators (PIs) met regularly with Newport fishermen to obtain feedback on additions and changes that were made to the website and to get suggestions on what new features and forecast fields they would like to see included. These discussions led to wind and wave forecast information being added as well as efforts to extend the surface temperature, salinity and current fields beyond the three-day ROMS forecast fields to six-day forecasts using a lower spatial and temporal resolution HYCOM model. It is important to note that fishermen fully understand that as forecasts extend farther out into the future they become less and less reliable, but they find this information useful for planning purposes.

In late 2017 with the Seacast.org research project drawing to a close PIs began to discuss with NANOOS the possibility of creating an NVS application that contained the same information and functionality as Seacast.org but would be sustained beyond the life of the Seacast research project. Work began on NVS Seacast in early 2018 and it was released to users in June 2018 (Fig. 2, bottom). NVS Seacast includes all Seacast.org features, along with additional features (e.g. NOAA Nautical Charts and predefined bathymetric contours) and information (e.g. WaveWatch III wind wave forecasts) that were requested by fishermen but were not implemented on the pilot website due to lack of time or capabilities. Thus, Seacast.org transitioned to an improved, more stable, operational platform that will continue to serve fishermen into the future.

Since NVS Seacast was released it has been further enhanced to now include NRT salinity observations from Yaquina Bay, OR. This request was made during a November 2018 meeting between fishermen, OSU PIs and NVS developers. After NVS Seacast was presented to the fishermen they noted the importance of understanding salinity levels in Yaquina Bay, since water from the bay is used to replace salt water in the crab holding tanks on a periodic basis. If the water contains too much fresh water, the bay water could impact crab health. As a result, the fishermen requested a need for a salinity monitoring station to be deployed in Yaquina Bay, to help alert them to low salinity conditions that could possibly kill their catch. Given the impending start of crab season (normally December 1st), there was a need for immediate action if this was to be done for the 2018/2019 season. Using the last of the OSG funds, this was collaboratively accomplished by mid-January, shortly after the crab season started. These NRT salinity values, collected at 3, 7 and 11 feet, have proven to be exceptionally beneficial to fishermen, who sometimes return to port with as much as 100,000 pounds of crab, as the following email excerpt shows,

"*Yesterday was perhaps the best example of the value of the new salinity station. Lots of rain prior and a short weather window. Many boats blown off the ocean at the same time and (this resulted in) many boats had to wait (sometimes several hours) to unload. Price just went up ($4.75/lb.). ALL those that had to wait were deciding (whether to) re-circulate and/or provide aeration. When we crossed 2 hours after low water, the salinity was at 11, 12 and 13 [PSU] (beginning at 3' depth): all toxic numbers for crab. We shut off our pump and held the crab in good water until we could unload. 0 dead loss. 0 weak crab. Excellent!*"

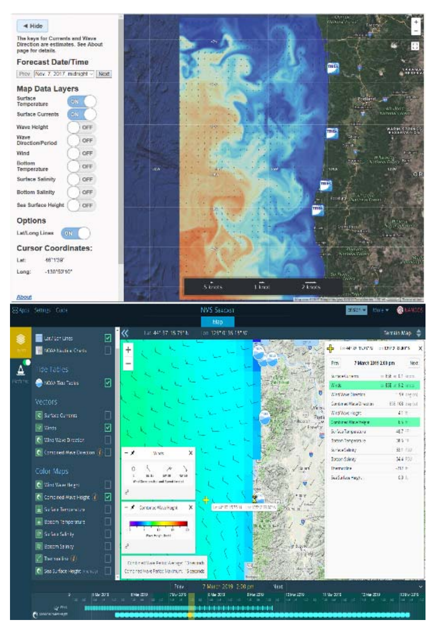

Fig. 2. The original Seacast.org website (top) developed by OSU faculty, graduate students, and senior undergraduate computer science students working closely Newport Dungeness crab fishermen. NVS Seacast (bottom), with new features including NOAA Nautical Charts, thermocline and wind wave forecast fields, and the capability to show information at a location for all available forecast models.

B. *Shellfish Growers*

The Pacific Northwest Coast is the largest producer of farmed shellfish in the nation. With recent concerns about ocean acidification and other environmental changes associated with rapid climate change, shellfish growers in the NANOOS region are increasingly in need of high quality real time information on water quality in order to make operational decisions about when to seed a particular estuary site or to fill tanks with seawater. Specific types of needed information include water temperature, chlorophyll levels, salinity, turbidity, and dissolved oxygen. To address this need, three National Estuarine Research Reserves (NERR) in Alaska, Washington, and Oregon partnered with NANOOS as part of pilot effort in 2004 to develop a website to share real time water quality data with shellfish growers. The project was coordinated by the Padilla Bay National Estuarine Research Reserve in Washington, which is part of the Washington State Department of Ecology. The resulting website was strongly guided by the growers regarding how to best present the water quality data, such as temperature in degrees Fahrenheit and different temporal views (e.g., 24 hours, 3 days, 14 days) to visualize particular conditions, patterns or trends.

As the Shellfish Growers website was transitioned to NVS in 2013, a meeting was held that included a small focus group of 6-8 growers, the lead NVS software developer, outreach staff, and the NANOOS director. The objective of the meeting was to identify specific features and information needs that would best assist the growers, which would be included in the NVS Shellfish Growers application (Fig. 3) and to demonstrate NVS functionality. This meeting resulted in NANOOS staff learning, for example, that regional airport rainfall data is important to growers because non-point storm water runoff can carry bacteria to shorelines, which in turn can result in hatchery closures. With the increasing awareness of the impacts ocean acidification is having on shellfish growers, NRT data from buoys and moorings from a host of partners and forecasts from a University of Washington developed LiveOcean ROMS model were also incorporated. Adding the forecast information to the Shellfish Growers application resulted in a more complex user experience. Growers therefore requested guidance on features they may not have discovered on their own. This resulted in a slideshow guide that pops up on first use of the application and then can be consulted thereafter or turned off. Being flexible, listening to user feedback, and a willingness to change original designs resulted in an improved application that specifically meets shellfish grower needs. The Pacific Coast Shellfish Growers Association Executive Director explains,

"This current generation of shellfish farmer is reliant upon data and services from NANOOS. Checking the NANOOS app before seeding a beach or filling a settling tank has become standard practice."

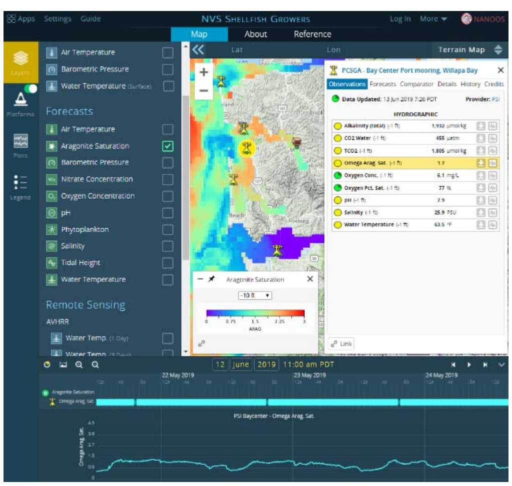

Fig. 3. The Shellfish Growers application showing aragonite saturation at the Bay Center Port water quality station in Willapa Bay, Washington, as well as a aragonite saturation forecast derived from the University of Washington developed LiveOcean ROMS model.

C. *Tsunami Evacuation Zones*

Low-lying areas along the coasts of Oregon, Washington, and northern California are exposed to considerable risk from tsunamis generated locally due to magnitude ~8-9 (Mw) earthquakes on the Cascadia subduction zone [27], as well as from distant tsunamis produced elsewhere in the Pacific basin such as the 2011 Tōhoku Japan tsunami [28]. Of these, the greatest hazard to coastal communities is the local Cascadia tsunami which will arrive at the shore in 10-20 minutes, inundating entire communities in about 30-40 minutes. To reduce the risk of tsunamis, the Oregon Department of Geology and Mineral Industries (DOGAMI), Oregon's Emergency Management (OEM), Washington Military Department (WMD) and Washington Geological Survey (WGS) have undertaken numerical modeling of tsunamis in order to produce tsunami evacuation brochures for their respective coasts. To ensure unfettered access to the lifesaving tsunami evacuation information, a pilot effort was initiated in 2009 between DOGAMI and OSU to stand up a simple web site that depicted the evacuation zones. A more collaborative effort between NANOOS DMAC/User Products/Education & Outreach and DOGAMI/ WMD staff was initiated in 2011 to build an entirely new and feature rich NVS Tsunami Evacuation Zones application (http://nvs.nanoos.org/TsunamiEvac).

The application, which was completed in November 2011, allows residents, planners, emergency responders, and others to see the extent of areas affected by both local and distant evacuation zones. Information contained in the overlays include access to various critical and essential facilities, and two recent additions that reflect spot elevations along the coast as well as detailed arrows that highlight key evacuation routes where available. Users can search by address and a pop-up is displayed telling the user if the location is either in a tsunami zone or outside. Although the overall concept of the application was developed within NANOOS, with considerable input from state experts, periodic refinements have been included as a result of local stakeholder input. For example, updates to the JSON file that maintains the locations of assembly areas is revisited a few times per year based on new sites identified by local or county emergency responders.

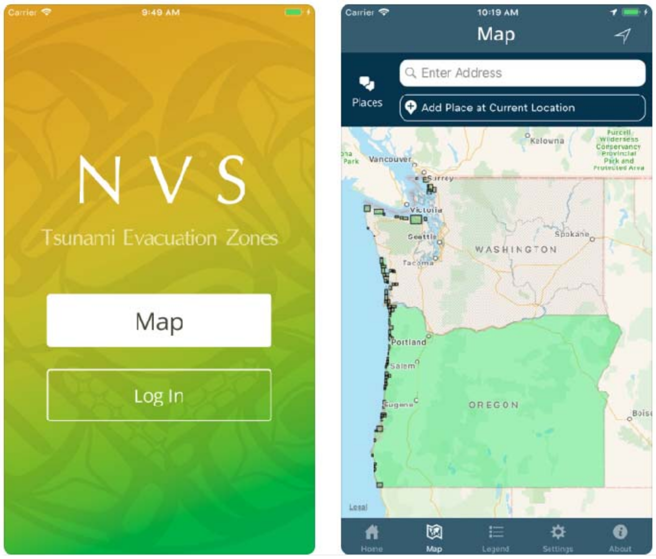

Fig. 4. The tsunami smartphone application that provides at-a-glance views of where the tsunami hazard zones are located along the Oregon and Washington coasts. It allows users to map whether, for example, their home, place of work, or school is located in a tsunami evacuation zone or not. The tsunami application is avaiable from the Apple and Google stores at https://apps.apple.com/us/app/nvs-tsunami-evacuation/id478984841 and https://play.google.com/store/apps/details?id=tsunamievac.nvs.nanoos.org.nvs_tsunami_android, respectively.

Similarly, as new evacuation zones are produced by state programs, these are included on the NVS application. To further enhance user access to these products, a smartphone application (Fig. 4) based on the tsunami web application was built and is now widely used along the coast. Importantly, the mobile application allows users to locate themselves in the tsunami zone, making it easier to identify potential escape routes to high ground. These data are especially critical for visitors who are largely unaware of the risk posed by local tsunamis.

The NVS Tsunami application remains one of the most widely used products, averaging about 30,000 pageviews per year. The application has proven its success from that response and from feedback such as this from the coordinator of Oregon's Geologic Hazards Program:

> *"The Oregon Office of Emergency Management appreciates the tools that NANOOS provides. The online tsunami evacuation route viewer is especially useful in helping coastal residents and visitors understand and respond to the tsunami hazards."*

D. Tuna Fishers

In August 2008, NANOOS received an email from a recreational albacore tuna (Thunnus alalunga) fisherman living in Coos Bay OR, after he was unable to download OSU ROMS model [25] derived sea surface temperature (SST) nowcast and forecast plots. Once the plot availability issue had been resolved NANOOS was able to capitalize on this fortuitous feedback by working with the user to tailor the SST forecast fields to better suit the needs of the commercial and recreational tuna fishing fleets. In particular, the dynamic range of the data was reduced from 44-62°F to 53-63°F to better highlight the 58-62°F water that tuna prefer. The color map was changed from a rainbow palette to a more culturally meaningful blue through red color palette [29] and 56, 58, 60, and 62°F isotherms were added all of which facilitate the interpretation of SST data.

NANOOS was once again fortuitously contacted via email in July 2009 by members of Oregon's recreational fishing community who used the OSU ROMS forecast fields, described above, and were interested in NRT chlorophyll and SST data. Based on input from these stakeholders such as the following text from an email received on July 7, 2009,

"*Very seldom have we ever caught tuna with a chlorophyll content greater than 1. The "Transition Zone" is defined as .2 chlorophyll content, where the tuna spend the majority of their time… Albacore voraciously feed from .4 to .6 on the chlorophyll chart, seldom much higher, when in relation to 58 to 62 degree water*",

NANOOS developed a tuna-oriented webpage that showed in addition to the forecast fields, 8-day composite plots of MODIS chlorophyll and AVHRR SST that were specifically tailored to meet the needs of this community (Fig. 5). In particular, the MODIS SST plots were created to have the exact same dynamic range and color palette as the ROMS SST forecast fields described above and the chlorophyll plots explicitly highlighted the 0.4 - 0.6 mg/m^3 zone where albacore tuna feed. As a result of several NANOOS outreach and engagement efforts, which included participating in Scientist and Fishermen Exchange (SAFE) and ProjectCROOS (Collaborative Research on Oregon Ocean Salmon) meetings as well as online discussion boards such as ifish.net (e.g. http://www.ifish.net/board/showthread.php?p=2639973), the number of first time and returning visitors to the tuna-oriented webpage increased significantly. As NVS evolved to include stakeholder specific applications the Tuna Fishers application was released as part of NVS 3.0 in March 2013. This application included the static figures described above as well as figures showing 1, 3 and 8-day mean MODIS SST and chlorophyll fields. In addition, the Tuna Fishers application included SST forecast fields overlaid on a Google map thus allowing users to ability to zoom into and explore regions of interest. Since its release in 2013 this application has proven to be very popular with fishermen with an average of more than 17,000 pageviews annually between 2013 and 2018, and approximately 30,000 pageviews in 2018 alone.

IV. Conclusions

The past three decades have witnessed a significant increase in local, regional and national ocean observing programs as well as forecast systems that are able to more accurately predict events and environmental changes at a range of spatial and temporal scales. These efforts now produce growing amounts of, at times, heterogenous information that is disseminated to a wide variety of stakeholder groups. While the use of standard data models, metadata and data server applications have helped reduce the heterogeneity and improved the distribution of these data, delivering information to meet stakeholder needs in common, consistent formats via intuitive interfaces remains an ongoing challenge.

In 2009 NANOOS began to address this challenge by developing the NANOOS Visualization System (NVS). NVS is a map-based platform that aggregates a multitude of diverse data sets and forecast model fields into one system with the goal of delivering a more seamless, one-stop-shopping experience for regional stakeholders. Over the past decade NVS has evolved from a single platform that was considered by some users to be overwhelmingly complex to one that is more flexible, consisting of specifically tailored applications that are developed in close collaboration with targeted stakeholders. The current, more modular NVS framework allows developers to quickly deploy, refine and extend applications based on stakeholder feedback. Such capabilities have enabled NANOOS to develop, for example, the four highly successful applications described above that truly meet stakeholder needs, while increasing user capacity to understand and better respond to regional environmental changes and events.

Our vision for the future of NVS remains unchanged from what was proposed in 2009 [20]. That is a feature rich platform that pushes the envelope of ocean-atmospheric visualizations, with ever increasing access to model and observational platforms and datasets, through the adoption of more sophisticated and interactive, user-driven plotting capabilities and needs. This last point remains the success story of NANOOS to date, that is enhanced capabilities driven by targeted stakeholder needs and feedback, as demonstrated throughout this paper. Future enhancements are already being explored, planned, and in some cases implemented. For example, new capabilities to access and visualize long-term datasets and climatologies are already underway that will serve to improve our awareness of basin-wide climate and ocean related changes occurring throughout the NANOOS region. In time we anticipate being able to offer greater access to climatologies at the local level as future remote sensing technologies are developed and improvements in ocean modeling are implemented yielding higher resolution datasets. Future improvements to NVS will also include capabilities to track particles (at different spatial/temporal scales and with different particle densities), in order to assist emergency responders with search and rescue, as well as oil spill response planning important for select state and federal agencies. Such needs are inevitably being driven by an increasingly data discerning and knowledgeable population, who strive for improved access to real (and long term) time information, in order to make informed decisions. Finally, with the continued expected expansion of smartphone technologies in our day-to-day lives and business operations, it is inevitable that NANOOS NVS will probably see further expansion into the world of dedicated smartphone applications that serve needed ocean/atmospheric information in real time to assist with decision making. Such requests have already been identified by NANOOS shellfish growers. Similarly, in the tsunami hazard world, there is a recognized need to be able to provide on-the-fly information on evacuation routes, similar to google maps. We anticipate being able to incorporate such capabilities in the ensuing five years.

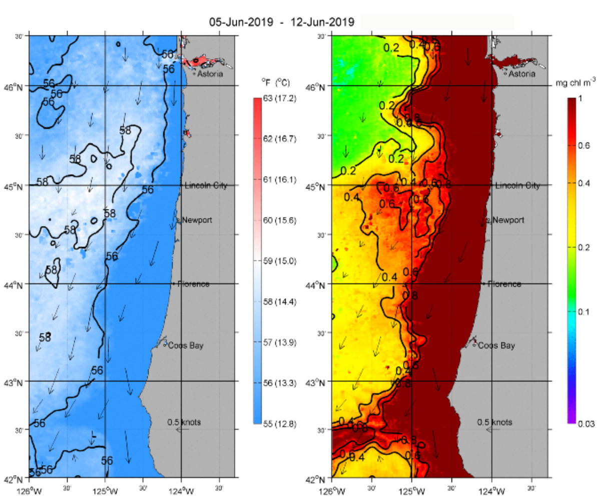

Fig. 5. 8-day mean (5-12 June 2019) MODIS SST (left) and CHLA (right) fields, which use more intuitive colormaps and dynamic ranges to help users interpret these data, provided by NOAA CoastWatch, and identify regions that may contain tuna. Overlaid vectors depict 8-day mean current velocities derived from HF Radar measurements..

ACKNOWLEDGMENT

We thank the many stakeholder partners, including Oregon Sea Grant, Padilla Bay National Estuarine Research Reserve, Pacific Coast Shellfish Growers Association, Surfrider Foundation, commercial and recreational fishermen, and the many tribes, agencies, non-governmental organizations and industry representatives who have and continue to help define, review, and improve NANOOS products. NANOOS data products, outreach, and the NANOOS Visualization System have been funded through NOAA IOOS awards NA10NOS4730018, NA11NOS0120036, and NA16NOS0120019. The statements and conclusions expressed here are those of the authors and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration or the U.S. Department of Commerce.

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