

US Integrated Ocean Observing System (IOOS®): Delivering Benefits to Science and Society

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Abstract—

The United States Integrated Ocean Observing System (IOOS®) is a user-driven, coordinated network of people, organizations, and technology that generate and disseminate continuous data about our coastal waters, Great Lakes, and oceans supported by strong research and development activities. IOOS® is our Eyes on our Oceans, Coasts and Great Lakes that enable the United States to track, predict, manage, and adapt to changes in our marine environment and deliver critical information to decision makers to improve safety, enhance our economy and protect our environment. IOOS provides a major shift in the approach to ocean observing by drawing together the vast network of disparate federal and non-federal observing systems to produce a cohesive suite of data, information, and products on a sufficient geographic and temporal scale to support decision-making. Two interdependent components constitute the U.S. IOOS: (1) the global ocean component, and (2) the coastal component. The strength of IOOS is in its partnerships, starting with the federal agencies, the partnerships extend internationally for the global component and to the local level for the coastal component. The coastal component includes the national set of observations for the U.S. Ocean, Coasts and Great Lakes, a network of Regional Associations that are establishing Regional Coastal Ocean Observing Systems (RCOOS) and the Alliance for Coastal Technologies (ACT). The U.S. IOOS is our nation's contribution to the Global Ocean Observing System (GOOS) — the ocean component of the Global Earth Observation System of Systems (GEOSS).

Keywords-component; Integrated Ocean Observing System; Ocean Observing; Global Earth Observation System of Systems

I. INTRODUCTION

The U.S. Integrated Ocean Observing System (IOOS®) is a partnership serving lives and livelihoods. This partnership includes federal, regional, academic, Non Governmental Organization (NGOs) and industry parties that provide data and information to improve our understanding and management of our oceans, coasts, and Great Lakes. The last several years have seen some very positive progress within US IOOS including passage of the Integrated Coastal and Ocean Observing System (ICOOS) Act (March, 2009); the President's Ocean Policy, which puts priority on strengthening and integrating of ocean, coastal, and Great Lakes observations, mapping and infrastructure; the Global Climate Ocean Observing System reaching 61% completion; and the funding of the National Science Foundation's Ocean Observatory Initiative. The NOAA IOOS Program, initiated in 2007, now

represents the role of the US IOOS office and includes a member from the Army Corp of Engineers.

Also in 2010, the Integrated Ocean Observing Committee (IOOC) formed as called for in the ICOOS Act. Comprised of Federal representatives, they will oversee the implementation of procedural, technical, and scientific requirements to ensure full execution of the system. The IOOC released the "*U.S. Integrated Ocean Observing System: A Blueprint for Full Capability*" that defines activities and systems of IOOS.

II. A BLUEPRINT FOR FULL CAPABILITY

The U.S. IOOS program recently developed the "*U.S. Integrated Ocean Observing System: A Blueprint for Full Capability*" (*Blueprint*) to define the activities and systems that will make up the fully operational U.S. IOOS program and to guide the efforts of partners and the program office. As outlined in the *Blueprint*, U.S. IOOS activities fall into six distinct subsystems—three functional subsystems (observations, data management and communications, and modeling and analysis) to provide the technical capability to readily access Great Lakes and marine environment data and data products and three cross-cutting subsystems (governance and management, research and development, and training and education) that form the programmatic structure of U.S. IOOS to provide for sustainment and improvements to the system. Using a logical, structured approach as directed by the *Blueprint*, the U.S. IOOS program is leading the efforts to build on current observing capabilities with an initial focus on data integration, interoperability issues, and certification guidelines.

This document brings the concept of interdependency front and center. Fully implementing U.S. IOOS will take the combined efforts of all of the federal agencies in partnership with the non-federal entities. While the roles vary greatly, each partner shares a piece of the ocean observing community and all are needed to form a cohesive, functional U.S. IOOS. Reaching out to partners, both current and future, remains an essential component of U.S. IOOS program execution and will be further advanced with the planned FY2011 comprehensive U.S. partner assessment.

III. ADVANCES IN THE OBSERVING SUBSYSTEM?

Across US IOOS, we are advancing our observing capability. This paper will focus on three technologies: HF Radar, Wave measurements and gliders.

A. High Frequency(HF) Radar

The Global Earth Observing (GEO) has been described as “Science without Borders” and brings together 87 Governments and the European Commission and 64 intergovernmental, international, and regional organizations to provide access to timely data, new analytical tools, and forecasts about emerging threats that will enable wise choices in an uncertain world.

During GEO-VIII Plenary the GEO 2012-2105 workplan was accepted that includes a focus on the importance of ocean observing under the *Blue Planet* Societal Benefit Area (SBA). One component of this SBA is the operational systems for monitoring of marine and coastal ecosystems. There are many systems ranging from buoys and gauges to autonomous underwater and surface vehicles to satellites and animal tagging that must work in a complementary fashion to provide the three dimensional observing needed to answer pressing questions such as: Can we efficiently and safely move commerce; how will we adapt to, and mitigate, a changing climate; is the water safe to swim in; will we continue to sustain the world’s need for food from the ocean?

Just as measuring winds in the atmosphere is fundamental to weather forecasting, ocean currents determine the movement of surface waters, providing critical information to support pollutant tracking, search and rescue, harmful algal bloom monitoring, navigation, and ecosystem based management and coastal and marine spatial planning. One system that has proven to effectively measure surface currents along the coast is the high frequency (HF) radar.

A number of countries have used HF radar operationally in the areas of navigation, oil spill monitoring, search and rescue and harmful algal bloom forecasting but in many cases this is done on a case by case basis. Within the United States, the Coast Guard uses this data in their operational Search and Rescue Program and have shown that the search area can be decreased by 66% in 96 hours and that means saving lives. HF radar information was used by the National Oceanic and Atmospheric Administration for oil track predictions during the Deepwater Horizon spill. Emerging uses include ecosystem-based studies, vessel tracking and most recently HF radar did pick up the signal from the March 2011 Pacific Tsunami – see Journal of Remote Sensing - <http://www.mdpi.com/2072-4292/3/8/1663/pdf>

The United States has been working many years to transition its HF radar network of over 100 radars to an operational system and has succeeded in moving from individual radars to clusters of radars to a comprehensive national network tied together through common data architecture, set of practices

and a national plan. Many other nations have begun to deploy HF radars and there is a tremendous amount of informal coordination and collaboration taking place. But to truly make a difference on a global scale we need to unite under a single worldwide network to make these critical measurements available into ocean and ecosystem modeling.

Therefore, under GEO we have set forth a bold task to develop a global HF radar network. The Global High Frequency Radar Initiative was launched during Oceanology International 2012. The meeting co-chairs included Jack Harlan, U.S. IOOS Program Office; Lucy Wyatt, Australia Integrated Marine Observing System; and Enrique Alvarez-Fanjul, Physical Oceanography Department, Puertos del Estado (Spain). About 40 people attended, representing 11 countries from Europe, Asia, and North America.

B. Wave Buoys

The waves entering and crossing the nation’s waters, whether generated by a distant Pacific storm, local sea breeze, or a Category 5 hurricane in the Gulf of Mexico, have a profound impact on navigation, recreation, safety and the economic vitality of the nation’s maritime and coastal communities. Requirements differ: commercial fisherman want the wave conditions at their fishing site, plus a forecast for the length of their trip; ship captains on the Columbia River want to know if they’ll be able to safely clear the waves breaking on the outer bar, before they leave port and head down the river; surfers look for large swell while recreational fisherman seek calm waters; lifeguards want to know if the rip currents of yesterday will be there today; Navy captains need wave information for efficient ship routing to reduce fuel usage; and modelers need boundary conditions to drive their models, or observations to validate their predictions.

US IOOS established a National Waves plan in 2008 and identified that we had 181 buoys in the network. Now in 2011 we have 227 platforms.

C. Gliders

For the atmosphere and terrestrial we can use satellites for a significant role in monitoring, but for 70% of our planet the ocean, but they are not effective to understand the ocean in three 3 dimensions. Therefore unmanned vehicles are important platforms to measure the entire water column. For example, during Deep Water Horizon, gliders, outfitted with fluorometer which excite in the presence of oil, were used to determine depths and extent of the sub-surface plume and importantly where it was not. This allowed the response teams to more effectively use more expensive ships with acoustic sensors to map the sub surface plume. Gliders are being used in understanding fisheries management. The California Cooperative Oceanic Fisheries Investigations (CalCOFI) are a unique partnership of the California Department of Fish and Game, NOAA Fisheries Service and Scripps Institution of Oceanography. The organization was formed in 1949 to study the ecological aspects of the

sardine population collapse off California. Today our focus has shifted to the study of the marine environment off the coast of California, the management of its living resources, and monitoring the indicators of El Nino and climate change. CalCOFI conducts quarterly cruises off southern & central California, collecting a suite of hydrographic and biological data on station and underway. The ships go out quarterly, but the gliders are able to occupy the lines continuously therefore we can get a more complete picture of what is going on in the ecosystem. We operate in the Arctic. The 2011 mission was the second year of studies on the hydrographic properties of Arctic waters, led by Dr. Peter Winsor at the University of Alaska Fairbanks and funded by the Bureau of Ocean Energy Management (BOEM), Conoco Phillips, and Shell Oil. The glider program is part of a larger project lead by Tom Weingartner at UAF, which includes land-based HF radars, drifters and moorings. The glider data provides detailed biochemical and physical ocean data that when combined with HF radar shows features and complexities previously unknown. The National Science Foundation's Long-term ecosystem research programs funds gliders in Antarctic. Antarctica is one of the fastest warming locations and we are seeing accelerated impacts on the phytoplankton and krill both sources of food and shifting in penguin population. In addition to collecting the ocean conditions the gliders are used in conjunction with penguins that carry tags to better understand the ecosystems. In 2011, the Rutgers University team, for the first time launched the glider from a zodiac, at US Palmer station flew it 400km as the crew flies all the way to the dock at the British station. This was significant because there significant savings in not having to use a research vessel.



Want to take a virtual ride in our oceans with an underwater robot, known as a glider? There is a new map for that. US IOOS launched, in March 2012, a new asset map that displays where partner gliders are currently patrolling and where they've been. That means users can get one-stop access to a current snapshot of where gliders are at sea. Once returned from a mission, users can scroll over visualizations of collected data. Additionally, users can retrieve an historical collection of data from previous missions, reaching back to 2005.

IV. ADVANCES IN DATA MANAGEMENT

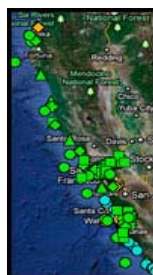
We continue to integrate numbers of data sets from national agencies, state, local and tribal governments, industry and academia.

A. Round Up from the US IOOS Regions

IOOS partners collect coastal and marine data — water temperature, water level, currents, winds, waves, and more — using satellites, buoys, tide gauges, radar stations, underwater vehicles, and a bunch of other high-tech tools. This ocean data is then turned into information that people can use, often in the form of forecasts and products designed to track, predict, manage, adapt, and respond to changes in our marine environment. **Here's what's new on IOOS websites representing regions around the United States:**



The [Alaska Ocean Observing System \(AOOS\)](#) recently released a new version of the AOOS [real-time sensor map](#). New capabilities include the ability to see the latest observations from multiple sensors housed on a single platform at the same time, bookmark a specific view to return to or send to a friend, and view wind vectors on the main map, showing wind direction and magnitude. AOOS will soon add wave vectors as well. Users can also view a visual representation of relative differences in temperature, precipitation, or other parameters of their choosing across stations.



New and improved ocean and coastal data is now available in California. The [Central and Northern California Ocean Observing System \(CeNCOOS\)](#) now offers a new version of their [data portal](#) with more than a dozen upgrades. Changes include locations and links to real-time data for 32 high-frequency radar stations that measure ocean surface currents from the shoreline, four new National Weather Service wind stations, and a link to the data portal's mobile iPhone app. An Android app will be released in the near future.



The [Southern California Regional Coastal Ocean Observing System \(SCCOOS\)](#) delivers fishermen, mariners, surfers, and decision makers real-time and archived ocean and coastal data collected within the Southern California Bight. Surface current mapping, wave conditions, wind and rain forecasts, and harmful algal bloom (HAB) monitoring are some of the products and services provided through the SCCOOS Observation Map.



The [Great Lakes Observing System \(GLOS\)](#) recently launched a new [website](#) to improve access to Great Lakes data, products, tools, and the latest GLOS projects. The site features a new design and user interface, product launch pages, relevant news and events, and access to the new Great Lakes

Data Catalog. The site makes it easier for users to find real-time and historic Great Lakes data and access tools that process data in a meaningful way for decision makers.



A new [website](#) provides one-stop information requested by boaters and fishermen in U.S. Gulf of Mexico waters. The [Gulf of Mexico Coastal Ocean Observing System \(GCOOS\)](#) recently repackaged real-time data into a website that includes seven-day oceanographic and meteorological conditions and forecasts. Information offered includes near real-time weather radar, satellite cloud coverage, sea surface and air temperature, wind speed and direction, surface current speed and direction, and water depth. Users can select map layers to show nautical charts, marine hazard warnings, and habitat maps such as Essential Fish Habitat and Marine Protected Areas.



The [Pacific Islands Ocean Observing System \(PACIOOS\)](#) Hawaii Data Explorer Map provides ocean and meteorological data and information. Information provided includes surface currents, bathymetric, nautical charts, and ocean, tide, surf, and weather forecasts. Recent data and information on various types of natural hazards, such as earthquakes, volcanic eruptions, and drought are provided as well as the locations of emergency shelters, tsunami evacuation zones, and other hazard-related information.



The [Northwest Association of Networked Ocean Observing Systems \(NANOOS\)](#) released version 2.6 of the NANOOS Visual System (NVS). NVS gathers data across a wide range of assets such as buoys, shore stations, and coastal land-based stations. Visualizations of data are provided in a consistent format. You can access plots and data for almost all in-situ assets for the previous 30-day period. New features include places, markers, and tsunami evacuation maps for the coastlines of Oregon and Washington.ⁱ

V. DELIVERING THE BENEFITS

A. US IOOS Modeling Test Bed

In 2010, with funding included in the FY2010 appropriations, U.S. IOOS initiated a project under the Southeastern Universities Research Association (SURA) to evaluate the readiness of marine forecasts along the Atlantic and Gulf of Mexico coasts and improve them for operational use. This project creates an objective environment to compare the latest models for improved forecasting of chronic issues of high relevance in the Atlantic and Gulf regions such as flooding from storm surge and seasonal depletion of oxygen in shallow waters. Through this project, methods will also be explored for

effectively delivering model results to regional centers, scientists, and managers relying on U.S. IOOS.

From the start this project was envisioned as an effort that would be a Federal/non-Federal partnership that would singularly modeling testbed effort to support ocean, coastal, Great Lakes, ecosystem modeling. By bringing together a tiger team made up of Federal and non-Federal partners to write a white paper on what a modeling test bed that used as a foundation work done by the US IOOS Modeling and Analysis Steering Team (MAST). Equally important was the understanding by SURA that for this to be successful as a foundation for all of US IOOS that it needed to be closely linked to the operational modeling centers within the Federal Agencies and be responsive to the needs of the IOOS Regional Associations. Finally the focus of the modeling testbed was to set up processes for the transition of models to an operational status vice development of new models. In the first year there have been a number of successes which is the subject of other papers, but these successes have cemented support for moving this effort from a prototype into a truly operational US IOOS Modeling Testbed. In this case it will be truly interdependent as we expect that this test bed will be operated by a non-Federal consortium, serve both the Federal and non-Federal partners, anchored at an operational modeling center and resourced by more than one Federal agency

B. Water Quality

The responsibility for issuing water quality warnings are the State and Local Health agencies, but they are dependent on Federal, State and Academia observing. There is also the issue that current methodologies of testing require a 24 hour incubation period and therefore decisions are made to post or lift advisories based on the previous day's sample. So by using a combination of observing assets we can improve advisory decision making. US IOOS partners have developed a Web-based view of the predictions for the water quality conditions at beaches on the South Carolina coast. The tool depicts the high, medium, low or no prediction scale represented by color-coded icons identify the bacterial water quality conditions based on the South Carolina predictive model used per the Environmental Protection Agency criteria for safe swimming conditions. The model outputs will benefit the public by providing more timely delivery of swimming advisories or other relevant beach water quality information to decision makers (i.e. public health officials) to disseminate advisories or through real-time notification systems.

C. Hurricane Irene

Hurricane Irene moved through the Caribbean and along the East Coast of the United States in August 2011 the non-Federal partners of US IOOS augmented NOAA's observing and forecasting capabilities. NOAA used the Caribbean Regional Association (CARA), the four buoys - in San Juan, Ponce, Rincon, and the U.S. Virgin Islands. From there the Southeast Coastal Ocean Observing Regional Association (SECOORA) tracked the Hurricane. Wind and wave data from the SECOORA assets were used to initialize models and to verify forecasts. Data from the buoys off the North

Carolina coast were featured on commercial and television coverage of Hurricane Irene. Local forecasting produced by Dr. Rick Luettich, University of North Carolina, were used by the U.S. Coast Guard to assist with decision making for positioning their boats along the East Coast and by the National Hurricane Center as part of their ensemble suite of models. As Irene progressed up the East Coast the Mid-Atlantic Regional Association of Coastal Ocean Observing Systems (MARACOOS) collected and distributed a dedicated hurricane blog - <http://maracoos.org/irene/> - with updates on the storm, especially with regard to high frequency radar data, glider routes and the phytoplankton bloom monitoring. Nearly all MARACOOS high frequency radar systems remained running to collect data on surface currents within the hurricane's footprint. The MARACOOS site also delivered new forecasts to the New Jersey Board of Public Utilities. Underwater glider RU-16 collected data during the hurricane. The RU16 glider which was deployed by the U.S. Environmental Protection Agency, the N.J Department of Environmental Protection, and Rutgers was directed offshore to survive the hurricane. It rode out the storm in deeper waters and collected an unprecedented dataset from Irene will inform forecast model development well into the future. Finally as the storm hit the US northeast coast, the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS), provided 50% of the real-time coastal ocean observing platforms in the region and excess of 90% of the subsurface variables for the region. In Long Island Sound all of the real-time buoy observations were supported by NERACOOS and its partners. John Cannon of the National Weather Service wrote "Buoy 'A' and 'B' were our focus at the NWS (WFO) Gray, Maine for this storm due to their unique positioning along and just upstream the Seacoast of NH and Southwestern populated beaches in Maine to determine the extent for the potential of coastal flooding...splash-over and beach erosion in real time with Irene. With south southeasterly winds...the buoy waves held below 20 feet as Irene approached due to the short fetch in the region as Cape Cod acted as a buffer. We have a very limited climatology of tropical systems creating winds from this direction so the real time information was crucial for our needs. Short Term Forecasts (STFs) were lowered to account for the ongoing situation during Irene's approach. The observation of limited wave action was a critical benchmark which caused our office to (accurately) limit our forecast and warnings for coastal flooding to 'minor'. This indeed verified to be the case. Higher waves (over 20 feet) were anticipated and reported at Buoy 'E' and 'I' in the more exposed wave situation along the Midcoast Region and our concern shifted to that area. The Maine Geological Survey visited Popham Beach after the storm and confirmed up to 10 feet of beach erosion in that area."

VI. SUMMARY

Resources for U.S. IOOS come from Federal, state, and private funding. Effective leveraging of these resources continues to yield positive results. And though a multi-sector

approach is a hallmark of IOOS, it also adds complexity to the challenges of maintaining existing capacity across the network. The value of an integrated approach to ocean observing is already evident based on early success stories, with more to come as the program continues to develop and mature. The future of IOOS lies in the ongoing efforts of its partners to collaboratively provide integrated data and information to its users, and helping them make more informed decisions that produce economic, societal, and environmental benefits for the nation.

The value of an interdependent approach to ocean observing is already evident based on early success stories, with more to come as the program matures. The future of U.S. IOOS lies in the continuing efforts of its partners to collaboratively provide integrated data and information to its users, helping them make more informed decisions that produce economic, societal, and environmental benefits for the Nation.

VII. ACKNOWLEDEMENTS

Information for this paper was compiled from weekly and monthly reports, as well as powerpoint presentations developed by the US IOOS program office and across the eleven US IOOS Regions.

i

<http://oceanservice.noaa.gov/news/weeklynews/jan12/ioos.html>