Integrated Ocean Observing System
Report to Congress

Executive Summary

The Explanatory Statement accompanying the Consolidated Appropriations Act, 2008 (P.L. 110-161) referenced the Senate Appropriations Committee Report, 2008 (S. Rept. 110-124) that directed NOAA to provide a 5-year plan to implement a viable Integrated Ocean Observing System (IOOS). In addition, the Explanatory Statement accompanying the Omnibus Appropriations Act, 2009 (P.L. 111-8) directed NOAA to develop "a strategy for incorporating observations systems from estuaries, bays and other near shore waters as part of the IOOS regional network of observatories." This report to Congress addresses both of these requirements.

Current plans provide for the continued development of the 11 regional components of IOOS. The bulk of the IOOS Program's investments in observing platforms and systems will be through the regions. Each region will be overseen by associations, which today are in various stages of development. The associations serve as the primary point of contact for NOAA in the regions. They are required to maintain a governance body made up of governmental, academic, private sector and nongovernmental interests to ensure regional observing capabilities are built and designed to meet local priority needs. Data from the regions will in turn be made available through NOAA's Data Management and Communications (DMAC) subsystem, supporting national requirements and objectives, including long-term archiving and accessibility for future research and models. Federal funding for regional components will be subject to competitive processes, a rigid performance review process based on demonstrated outcomes, and relevance to national priorities, needs, and requirements. Since the establishment of the IOOS Program, NOAA has invested $10.7 million in the development and implementation of this fundamental, data sharing component of IOOS.

The NOAA IOOS program has targeted improvements in data management and communications in support of three priority NOAA mission areas:

- harmful algal bloom forecasting,
- coastal marine ecosystem assessments, and
- coastal inundation modeling, including flooding due to hurricanes, storm surge, tsunamis and sea level rise associated with climate change.

These areas were selected because they (1) span the entire U.S. coastal geography; (2) are relevant to more than one federal agency mission mandate; (3) are identified as a priority in most, if not all, regions; (4) directly impact our Nation's economy; and (5) can demonstrate measurable improvement based on access to IOOS coordinated data. In parallel, IOOS will continue to assess user needs and when warranted adjust current integration efforts to address these needs on a national scale.

The NOAA IOOS Program will also support associated research and development and education and outreach. It will continue to support cooperation across the Federal Government through existing institutions, such as the Interagency Working Group on Ocean Observations. Particular

attention will be given to the continued coordination of other agency assets with the NOAA-supported regional associations and systems and DMAC.

Through the IOOS Program, NOAA and its national, regional, and other partners will enable the sharing and application of data necessary to drive advanced models and predictive capabilities. IOOS will provide a markedly more robust and consistent data stream for scientists, emergency responders, natural resource managers, mariners, and the American public and enable them to make dramatically more informed decisions that produce economic, environmental, and societal benefits for the Nation.

The FY 2011 Budget requests $14.6 million for IOOS regional observations and $6.6 million to support activities conducted by the program office. The IOOS program and regional associations also receive support from other NOAA programs that utilize the IOOS network.

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1. Introduction

The national Integrated Ocean Observing System (IOOS) gathers physical, geological, chemical, and biological information of our oceans and coasts—conditions that affect, and are affected by, humans and their activities. This coordinated network of people and technology generates and disseminates continuous data, information, models, products, and services on our coastal waters, Greats Lakes, and oceans. NOAA has already initiated efforts to increase access to and compatibility of NOAA and non-NOAA ocean observing data through a data integration framework (DIF) in order to improve national applications, products, and services.

The U.S. Commission on Ocean Policy (USCOP) called for the implementation of an integrated ocean observing system to increase our knowledge of the ocean.[1] In response to the commission, the U.S. Ocean Action Plan (OAP) calls for the integration of U.S. ocean observations into Global Earth Observation System of Systems (GEOSS).[2] The First U.S. IOOS Development Plan—approved by the Interagency Committee on Ocean Science and Resource Management Integration—addresses many of the recommendations of the USCOP, as supported by the OAP. Key recommendations are to establish an IOOS with an emphasis on regional development, to develop the capacity for ecosystem-based management, and to link IOOS data and information to applications.[3]

IOOS will employ available assets, knowledge, and advances in technology to develop a unified, comprehensive, and cost-effective approach for providing the data and information that will serve the needs of multiple user groups and will lead to:

- improved understanding of climate change and its socioeconomic consequences,
- improved safety and efficiency of marine operations,
- more effectively mitigating the effects of natural hazards such as tropical storms,
- reduced public health risks,
- protecting and restoring of healthy marine ecosystems more effectively, and
- improved ecosystem-based management of natural resources.[4]

This report outlines NOAA's plans to implement the coastal (national) components of IOOS and to achieve measurable benefits for a defined set of national needs and challenges. Its content is focused primarily on current and planned NOAA IOOS efforts; however, the report does

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[1] U.S. Commission on Ocean Policy, *An Ocean Blueprint for the 21st Century*, Final Report, 2004.
[2] Council on Environmental Quality, *U.S. Ocean Action Plan: The Bush Administration's Response to the U.S. Commission on Ocean Policy*, December 17, 2007.
[3] Ocean.US, *The U.S. Integrated Ocean Observing System (IOOS) Development Plan*, January 2005, pp. 20–24. (http://www.ocean.us/documents/docs/IOOSDevPlan_low-res.pdf)
[4] *U.S. Ocean Action Plan*, p. 13.

recognize the important contributions of IOOS regional and other partners. Also, this report does not make future funding recommendations. Funding recommendations will be made on a year-by-year basis and provided annually in the President's annual budget submission to Congress.

2. National Needs, Challenges, and Benefits—Why IOOS?

Oceans are critically important to our society and affect the lives of all Americans regardless of whether they reside along the coasts. Oceans provide critical sources of dietary protein, and they generate services such as tourism, recreational opportunities, and employment. They are the birthplace of weather systems and modifiers of weather and climate; they are highways for marine commerce and a buffer for national security; and they are a major reservoir of natural resources, havens for recreation, and virtual schoolrooms for educators, and laboratories for science.

As a Nation, we have benefited enormously from our oceans, coasts, and Great Lakes. More than half of the U.S. population—153 million people—live in the 673 coastal counties[6]. We expect by 2025, approximately 75 percent of Americans will live in coastal areas. More than 78 percent of U.S. overseas trade by volume, and 38 percent by value, is waterborne—contributing $742 billion annually to the gross domestic product while employing 13 million Americans[6]. Coastal states earn 85 percent of all U.S. tourism revenues, with approximately 89.3 million people vacationing and recreating along U.S. coasts every year[6]. Offshore oil and gas development produces 22 percent of all domestically produced oil and 27 percent of natural gas.[5] Oceans are the home of the majority of the world's living organisms, and over the past two decades, thousands of marine biochemicals have been identified.

The ocean is a critical component of the Earth's climate system, second only to the sun in its impacts on seasonal variability and long-term climate change. It can store 1,000 times more heat than the atmosphere and 50 times more carbon.[6] Changes are occurring in the oceans that have profound effects on our society—from rising sea levels and coastal flooding to harmful algal blooms, dead zones, and fish kills. Our ability to understand the magnitude of ocean changes, including their causes and consequences, and to effectively manage impacts to marine ecosystems and living resources, depends on the ability to rapidly detect and predict changes in the ocean and coastal environments. Due to the disparate nature of our national observing capabilities, a comprehensive view of the ocean environment does not currently exist. Resource and emergency managers, land use planners, and others do not have access to sufficient, timely ocean information to support their decisions.

Historically, the United States has responded to these challenges individually and in an ad hoc, uncoordinated fashion. Hundreds of federal, state, and local programs collect information on our Nation's oceans and coasts. Many of these programs collect, distribute, and archive the *same* data (e.g., temperature and salinity) but in *different* ways. This disparity results in data that cannot be combined or analyzed together, are not easily accessible, and may never be known to exist. Consequently, time and resources are wasted converting disparate data and potentially duplicating data collections. Data from existing observing systems would be much more useful and timely if it were linked and presented in an integrated, standardized way.

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[5] NOAA, Office of the Chief NOAA Economist, *Economic Statistics for NOAA*, 5th ed., April 2006.

[6] NOAA, Office of Climate Observation, *Program Plan for Building a Sustained Ocean Observing System for Climate*, May 2007.

With IOOS, the Nation can more effectively monitor and address the increasing demands on our coasts and oceans. Improved capabilities could provide better predictions of hazardous events; allow more accurate measurement or prediction of risks of illness, injury, and death; route ships more cost effectively through U.S. waterways; and improve search, rescue, and emergency response efforts.

3. Envisioning the National Integrated Ocean Observing System—What Is IOOS?

The Nation's various observing systems are not well integrated. They operate largely independent of one another, and most were designed to support a single purpose, with limited data interoperability. Technically, the integration of massive volumes of data from disparate sources, and providing this information in formats and at rates that are useful for a broad array of applications, represents a major but fundamental challenge.

IOOS is a major shift in the approach to ocean observing, drawing together many networks of federal and nonfederal observing systems to produce data, information, and products needed to support decision making. As a collaboration of existing national and regional entities working together, IOOS will improve coordination of observation strategies and systems, identify gaps in the Nation's ocean observing capacity, and facilitate the exchange of information to help decision makers address pressing policy issues. By collecting and bringing together data in a way that ensures the information can be used with other data sets, IOOS will make a broader suite of data available to scientists, allowing them to develop a more complete characterization of our oceans and coasts.

3.1 IOOS Organization and Governance

In the broadest sense, IOOS has both national and global components. The national coastal component includes both federal and regional contributions to monitor and manage the Great Lakes and the entire U.S. ocean environment. The First U.S. IOOS Development plan defines "coastal" as the nation's Exclusive Economic Zone, Great Lakes, and estuaries, including includes all semi-enclosed bodies of water (e.g., bays, lagoons, fjords, tidal wetlands) that are connected to the ocean. IOOS is also a U.S. contribution to the Global Ocean Observing System (GOOS), an international ocean observing partnership that supports operational ocean services worldwide.

IOOS is a partnership of U.S. government agencies (federal and state), regional partners, private enterprise, academia and nongovernmental organizations. Each federal agency is a member of the Interagency Working Group on Ocean Observations (IWGOO). The IWGOO was established by the Joint Subcommittee on Ocean Science and Technology (JSOST) and is charged with advising and assisting the JSOST on matters related to ocean observations. The IWGOO's charter establishes NOAA as the lead federal agency for implementation of an integrated ocean observation system. NOAA chairs the IWGOO, and the Office of Naval Research (ONR), the National Science Foundation (NSF), and the National Aeronautics and Space Administration (NASA) are vice-chairs. In 2008, the IWGOO completed the "Integrated Ocean Observing System Strategic Plan"[7], which provides the interagency vision and direction for IOOS and characterizes the areas of highest priority for the U.S. contribution to the Global Earth

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[7] Joint Subcommittee for Ocean Science and Technology's Interagency Working Group on Ocean Observations, *Integrated Ocean Observing System Strategic Plan*, June 2008. http://www.oceanleadership.org/files/IWGOO-IOOS_Strategic_Plan-JSOST.pdf.

Observation System of Systems (GEOSS) over the next five years. Upon adoption of this strategic plan, an implementation plan with roles and responsibilities for each action will be developed to describe the details of the way forward, and will be led by the IWGOO.

The NOAA IOOS Program was established in February 2007 to support, manage, and coordinate IOOS implementation efforts distributed across the agency. The NOAA IOOS Program is responsible for developing the national framework for data integration across NOAA and IOOS regions that will then be extended nationwide. NOAA is the lead federal agency for the development and oversight of the Regional Associations (RAs) and their Regional Coastal Ocean Observing Systems (RCOOS), working to ensure federal and regional contributions develop in a consistent and complementary manner.

NOAA's IOOS implementation relies on the contributions of multiple programs across the agency, including observation systems, models, decision-support tools, and certain data management activities. The NOAA IOOS Program is responsible for coordinating these distributed capabilities to maximize NOAA's contributions to IOOS. The objective is to take advantage of existing technical capacity and to objectively identify opportunities for collaboration.

Ocean.US was established in 2000 to coordinate the planning activities of ten federal agencies as they worked together to design a roadmap for establishing IOOS as a national program. Ocean.US provided interagency coordination of IOOS and other ocean observing programs, such as National Science Foundation's Ocean Observatories Initiative and the National Oceanographic Partnership Program (NOPP). Ocean.US facilitated interagency partnership through coordination and communication of shared federal goals, themes and activities; provided Executive Secretariat to the IWGOO; provides insight into agency and other IOOS (or IOOS-related) activities; and oversaw and facilitated specific projects as assigned by IWGOO. Most recently, these efforts focused on DMAC-related advancements across the participating federal agencies, establishing a solid foundation upon which to implement IOOS.

Given the successful completion of the planning phase of IOOS, the IWGOO determined that Ocean.US activities were complete and that the office would sunset at the end of September, 2008. The ocean observing community is now focused on the transition to implementation and sustained operation of the IOOS, and Federal agencies remain committed to cooperating among themselves and with partners throughout the ocean community. Coordination among the federal agency partners will remain the responsibility of the IWGOO, along with NOAA as the designated lead federal agency for IOOS. The IWGOO will also serve as the lead coordinating group to oversee coordination of IOOS with other major ocean initiatives and will continue to coordinate with the Regional Associations, through the National Federation of Regional Associations (NFRA). The interagency IOOS Strategic Plan describes the current organizational structure and establishes priority goals and objectives for national IOOS development, including specific actions for the IWGOO.

The IOOS regions provide significant capacity to support federal mission areas implemented regionally and, in fact, many regions have established a number of working relationships with IOOS federal agencies at the regional and local levels. However, these connections are not always apparent at all levels. An improved understanding of regional capacity is critical to ensure agency representatives can insert requirements and guidance into future Federal Funding Announcements beyond those managed by the NOAA IOOS Program.

To achieve targeted improvements for a set of national applications, IOOS will address integration challenges across three areas:

- *Data*, integrated with common content characteristics and sufficient metadata attached to data sets to allow discovery and informed, appropriate use of the data by a wide variety of models and decision-support tools and public and private end users;
- *Products*, integrated end-to-end (observations, data management and communication, modeling, and decision-support tools) to support end-user-defined requirements while maintaining interoperable components;
- *Organization*, integrated across federal agencies and their regional partners to leverage distinctive missions and competencies and to minimize duplication of development efforts.

Regional capabilities are essential to building and supporting a national IOOS. They provide increased observation density, distinctive knowledge, and technology competencies related to local environments (sea ice, coral reefs, Great Lakes), as well as support local user needs. The NOAA IOOS Program supports regional development across the spectrum of observations, data management, and modeling and analysis to support regional user needs while contributing to the national IOOS capability. The 11 Regional Associations (RAs) and their associated Regional Coastal Ocean Observing Systems (RCOOSs) and geographic coverage are shown in Table 3-1.

Table 3-1. IOOS Regional Associations and Geographic Coverage

Regional association	Primary geographic coverage
Great Lakes Observing System (GLOS)	The Great Lakes, its interconnecting waterways, and the St. Lawrence River
Northeast Regional Association of Coastal Ocean Observing Systems (NERACOOS)	Maine to Massachusetts, including the Canadian provinces of New Brunswick and Nova Scotia
Mid-Atlantic Coastal Ocean Observing Regional Association (MACOORA)	Cape Cod, MA, to Cape Hatteras, NC
Southeast Coastal Ocean Observing Regional Association (SECOORA)	North Carolina to the Atlantic coast of Florida
Caribbean Regional Association (CaRA)	Puerto Rico, U.S. Virgin Islands, and the island of Navassa
Gulf of Mexico Coastal Ocean Observing System (GCOOS)	Gulf Coast of Florida to Texas
Southern California Coastal Ocean Observing System (SCCOOS)	Southern California Bight
Central and Northern California Ocean Observing System (CeNCOOS)	Central and Northern California

Regional association	Primary geographic coverage
Northwest Association of Networked Ocean Observing Systems (NANOOS)	Washington, Oregon, and northern California
Alaska Ocean Observing System (AOOS)	Gulf of Alaska, Bering Sea and Aleutian Islands, and the Arctic
Pacific Islands Integrated Ocean Observing System (PacIOOS)	Hawaii, U.S. territories in the Pacific, and the Freely Associated States in the Pacific

3.2 IOOS System Design

The success of a national IOOS depends on the development of a consistent data management infrastructure that will link observations to the data and information needs of multiple users at the global, national, regional, and state levels. There are few commonly accepted and applied standards for data format and transport, except for some specific applications. Consequently, data are not easily assembled from numerous diverse sources to meet the geographic coverage, vertical and horizontal resolution, accuracy, timeliness, and data processing needs of multiple ocean models, assessments, or other end users. Effectively linking a societal need for environmental information to observations will require an efficiently managed, two-way flow of data and information among the three IOOS "subsystems:" observations, data management and communications (DMAC), and data analysis and modeling. These subsystems refer to necessary functions of IOOS, not organizational entities or physical components.

3.2.1 Observing Subsystem

The observing subsystem provides the foundation of IOOS and consists of two interdependent components: the global component and the coastal component, a national capability consisting of federal observing systems and RCOOSs. The regions contribute additional observing capacity to complement federal systems and enhance the IOOS coastal component, which extends to estuaries and includes all semi-enclosed bodies of water connected to the ocean. The observing subsystem will monitor changes on global, national, and regional scales and will employ both remote and *in situ* sensing. Remote sensing will include satellite-, aircraft-, and land-based sensors, power sources, and transmitters. *In situ* sensing will include fixed sensors, buoys, gliders (a type of autonomous underwater vehicle), and ships with their associated sampling devices and transmitters. The observing subsystem will use the Observing System Experiment (OSE) and Observing System Simulation Experiment (OSSE) process to identify the optimal placement of new observations to improve model accuracy.

The U.S. IOOS Development Plan identified an initial set of 20 core oceanographic variables required on a national scale.[8] These variables were identified as the most critical data sets, and are the driving force behind development of the observing subsystem. IOOS is building a national capacity to deliver these data and ensure their continuity and sustainability over the long

[8] *First U.S. Integrated Ocean Observing System (IOOS) Development Plan.* (http://www.csc.noaa.gov/cir/files/Core.Variables.from.IOOSPlan_FIN_low-res%2033.pdf)

term. Currently, these data are being measured by NOAA, the Navy, the U.S. Army Corp of Engineers (USACE), the U.S. Geological Survey (USGS), the Environmental Protection Agency (EPA), and the RCOOSs, primarily in standalone or vertically integrated systems, with limited data sharing.

The 11 RCOOSs provide localized data, information, and products on marine and estuarine systems to increase temporal and spatial resolution of the national observation capability. The marine and estuarine data collected in the regions represent an integral part of the system and will be incorporated, via DMAC, as part of the IOOS regional network of observations. Most RCOOSs comprise many smaller observing systems. NOAA maintains an IOOS Regional Observation Registry that documents the significant growth of the IOOS regional contribution. The registry now records data from 723 observation platforms from 9 of the 11 regions and is actively working to develop records for the less mature regions.

3.2.2 Data Management and Communications Subsystem

The presence of a DMAC subsystem capable of delivering real-time and non-real-time (delayed-mode) observations to a wide variety of users is central to the success of all the regional, national, and international ocean and coastal observing systems. The DMAC will provide data streams to modeling centers, model-generated forecasts to users, land and ecosystem planning and management tools to decision makers, and all forms of data to and from secure archive facilities, such as NOAA's data centers.

NOAA's development of Data Assembly Centers (DACs) at the National Data Buoy Center (NDBC) and the Center for Operational Oceanographic Products and Services (CO-OPS) is a first step towards establishing DMAC capabilities. The NDBC DAC increases availability of many NOAA and regional observations, delivering these data to the World Meteorological Organization (WMO) Global Telecommunication System (GTS). Since the establishment of NDBC's IOOS partnership in 2002, the number of IOOS observations processed has grown from 200,000 to 4.4 million annually in 2008. These observations include data sets that were previously not available, except to local system users. For example, in addition to the regional data, observations from NOAA's National Estuarine Research Reserve System (NERRS) were added in 2007. However, although transmission to the GTS has improved availability for real-time observations, a lack of uniform standards and cataloging procedures hampers access to and use of non-real-time data.

Data standards are an essential component of DMAC. Data standards, management, and quality control procedures are implemented at the individual system level but are not consistently applied from one system to another. The NOAA IOOS Program tested the interoperability of federal and nonfederal systems and determined that disparate formats and a number of other difficulties impede the integration of data from multiple providers, particularly for non-real-time data sources. To address these interoperability issues, the NOAA IOOS Program is addressing gaps in data accessibility and management for an initial set of IOOS core data variables. Once the inherent incompatibilities among existing NOAA and other data sets are addressed, improvements in model outputs, assessments, and products, as well as efficiencies in time and costs, can be achieved and measured.

DMAC development efforts are focused on the data integration framework—integrating a subset of oceanographic data for 5 of the 20 core IOOS variables (temperature, salinity, water level, currents, and ocean color) and distributing these data to selected NOAA decision-support models and tools. Data will be compiled from a variety of sources, including NOAA observing systems, the RCOOSs, and other federal agencies and partners. The intent is to achieve rapid and routine operational access and use by NOAA product developers and other end users. These sound and repeatable data integration methods will be applied to a broader suite of NOAA and non-NOAA data to support targeted national applications and improve existing products, such as Physical Oceanographic Real Time System (PORTS®), to further enhance safe navigation and maritime commerce. The NOAA IOOS Program continues to evaluate conceptual design studies prepared by industry, as well as work conducted internally within the agency, to determine the most appropriate and cost-effective system design and engineering approaches to advance the DMAC beyond these initial efforts.

NOAA's National Data Centers, as well as other federal data centers, will play an important role in long-term data archiving and stewardship. In addition to improvements in data delivery and management discussed above, data archiving, maintenance, and stewardship are also essential to ensure the vast IOOS data resources generated each day can be recovered easily to support ecosystem, climate, and other analyses requiring longer-term, historical data records.

3.2.3 Modeling and Analysis Subsystem

Models are the primary tools used to analyze large amounts of data to evaluate the current state of the ocean and coastal environments and to rapidly detect and predict changes to support informed decision making. The IOOS modeling and analysis subsystem will improve, develop, test, and validate operational models; produce accurate estimates of current states of marine systems; and develop data assimilating techniques to initialize and update models for more accurate forecasts. Global and coastal models differ in spatial and temporal scale resolutions, but the observational and developmental challenges associated with each are fundamentally similar. The global and coastal components must not be addressed independently, and NOAA is working to ensure collaboration not only between these two components but also with interagency partners through participation in the IWGOO.

As information on user needs continues to accumulate, NOAA's modeling, analysis, and decision-support tool requirements will evolve. The NOAA IOOS Program focuses on outcome based, user-defined needs to drive observation and data management development. This focus helps ensure that operational models will provide outputs in the time frame and format necessary for decision makers and other user groups and will better support the incorporation of uncertainty into models for more useful, probabilistic predictions to support risk- and ecosystem-based management approaches.

3.3 Interdependent Implementation Functions

The interdependent nature of the national, regional, and state IOOS components requires continued research and education to achieve the goals and objectives of IOOS. According to the First U.S. IOOS Development Plan, the objectives of IOOS are to:

- Enable data integration by implementing DMAC;
- Establish RAs to manage development of regional coastal ocean observing systems in support of maritime operations, natural hazards, public and ecosystem health, and living marine resources;
- Continue implementing the global ocean-climate component of the IOOS to address climate change, maritime operations, and natural hazards;
- Implement the coastal component to provide improved estimates of geophysical, biological and chemical states of pelagic and benthic environments;
- Establish linkages between IOOS development and the use of IOOS data and information for education, training and public outreach; and
- Improve positive feedbacks between the Earth sciences and the development of IOOS operational capabilities.

3.3.1 Research and Development

Research is providing the technologies and understanding required to build and improve a scientifically sound, operational observing system. While the IOOS community has already overcome many technical hurdles, additional research is needed to advance sensor technologies for biological observing and other applications, and to develop a robust technical infrastructure for national DMAC that can support the multiple data types and sources collected by federal and regional partners. Research projects selected for funding via the NOPP process, as well as by individual federal agencies, support national research priorities established to provide the scientific foundation to improve society's stewardship and use of, and interaction with, the ocean.[9]

New technology and scientific knowledge is required to meet IOOS user requirements, improve IOOS products and their interpretation, develop new IOOS applications to serve existing requirements, and provide new IOOS products for user requirements not currently anticipated. For example, continued research is needed to develop data assimilation techniques to extract the useful information from raw data streams and transform it into a data product that can be incorporated into models and end products. NOAA has already funded the Alliance for Coastal Technologies to conduct new sensor verification and validation tests and to support technology transfer efforts. Research communities from academia and industry to nongovernmental organizations and government agencies are needed to address these issues and, in addition, are important users of the data and information provided by IOOS. Therefore, it is critical to engage researchers and research agencies in the evolution of IOOS.

3.3.2 Education and Outreach

IOOS provides a capability to change the public perception of our oceans and motivate people to become stewards of the environment. The NOAA IOOS Program will work with NOAA, federal, regional, and other partners to develop a science- and technology-literate society and

[9] Joint Subcommittee on Ocean Science and Technology, National Science and Technology Council, *Charting the Course for Ocean Science for the United States for the Next Decade: An Ocean Research Priorities Plan and Implementation Strategy*, January 26, 2007.

workforce to create the breakthroughs needed to tackle the challenges involving our oceans and coasts, including global climate change and its effects on the ocean, coastal and Great Lakes environment.

3.4 IOOS Implementation and Development Approach

Consistent with the phased implementation approach presented in the IWGOO's IOOS Strategic Plan, IOOS is being implemented in stages. Phased implementation requires the prioritization of variables that are essential and common to more than one societal benefit and use both *in situ* and remote-sensing platforms to provide new, or improve existing, products by integrating data from more than one program, institution, or agency. Capitalizing on planned improvements in data quality, access, and compatibility, IOOS will deliver focused improvements in four national application areas: harmful algal bloom (HAB) forecasts; integrated ecosystem assessments (IEAs); coastal inundation predictions; and national surface current monitoring, as shown in Table 3-2.

Table 3-2. National Application Areas

Application	Current state	Future state
HAB forecasts	Operational HAB forecast in eastern Gulf Developmental forecast in western Gulf Ongoing research to develop sensors to detect HAB toxins	National HAB forecasting capability, including *in situ* and field-based bloom detection
IEAs	Single-sector assessments of fisheries, habitat, and other ecosystem components	Completed IEAs in priority Large Marine Ecosystems
Coastal inundation predictions	Textual storm surge forecasts that do not reflect additive effects of waves and coastal precipitation and do not easily communicate flood risk to local decision makers	Total maximum water level, or inundation, predictions (including winds, waves, surge, and precipitation) mapped to the street level in high-risk regions
National surface current monitoring	*In situ* currents monitoring; regional and state-operated high-frequency radar stations delivering near-real-time surface currents	National surface currents for oil spill tracking, search and rescue, and other applications (increasing observations from about 200/hour to more than 60,000/hour)

These national application areas were selected because they (1) span the entire U.S. coastal geography; (2) are relevant to more than one federal agency mission mandate; (3) are identified as a priority in most, if not all, regions; (4) directly impact our Nation's economy; and (5) can demonstrate measurable improvement based on access and use of core IOOS variables. In parallel with achieving these specific objectives, IOOS will continue to assess user needs and apply a systems engineering approach to the evolution of current integration efforts, including the potential acquisition of enhanced DMAC capabilities, in order to meet these needs.

4. Building an Integrated Ocean Observing System for the Nation

NOAA's efforts to build a truly integrated ocean observing system are focused on the DMAC subsystem, which provides the primary integration mechanism necessary to improve IOOS products and services. The NOAA IOOS Program initiated development of a data integration framework to incorporate various data sources and types, accommodate existing differences and incompatibilities, and to provide a foundation for a more comprehensive, national DMAC capability. The data integration framework (DIF) is being designed to identify common standards and protocols that will address data interoperability issues, achieve measurable improvements in models and decision-support tools, as well as the related data management processes for the four national application areas.

4.1 NOAA's IOOS Data Integration Framework

The DIF is specifically designed as a limited-scope, risk-reduction project to develop and implement a repeatable, extensible approach to data integration. The principal goal is to validate the premise that improved interoperability of selected data would enhance the performance of operational models in NOAA and improve related program efficiencies. Initiated in February 2007, the project is scheduled to conclude in 2010. At that time, the NOAA IOOS Program anticipates expanding the application of data integration principles established via the DIF project to a broader foundation for a national DMAC. This could include further development or expansion of the DIF, a major DMAC acquisition, or some other alternative yet to be defined.

The DIF will establish technical infrastructure, identify standards, and provide guidelines to improve delivery of at least 5 of the 20 IOOS core oceanographic variables defined in the First U.S. IOOS Development Plan. Initial integration efforts focus on temperature, salinity, water level, currents, and ocean color to improve NOAA's efforts to model and forecast HABs, predict coastal inundation, conduct IEAs, and monitor coastal surface currents. Since NOAA operates a large portion of the Nation's coastal and ocean observing data and distribution infrastructure, it is necessary to develop an internal core capacity to collect, share, and access NOAA and regional data first, to ensure these data sets are archived and accessible for future use. Once established, these capabilities will be extensible to other federal, state, and local data.

Another function of the DIF is to increase data interoperability from multiple, disparate NOAA observing systems by standardizing the content of data records, as well as the quality control, data documentation (metadata), and transport procedures. Each data provider records and transmits data in a variety of ways that, while satisfactory for its own purpose, are often not consistent in content or format with other providers of the same data. The interoperability of data among diverse systems can be greatly improved by standardizing the structure of the data record and prescribing the minimum content of the data record.

The NOAA IOOS Program is also addressing known data consistency and interoperability challenges through an interagency standards review process, established in October 2007 in accordance with the Ocean.US DMAC Plan. This process will identify appropriate standards, best practices, and other protocols to establish a common foundation for integration. While initial efforts to design and build the DIF are limited in scope, the use of existing community standards and common data sharing infrastructure will facilitate extensibility to additional variables, data sources, and systems, as well as the larger IOOS community to build toward a national DMAC structure. Basing the infrastructure on international standards, where feasible, also positions IOOS to be interoperable with the international community, GOOS, and GEOSS.

A preliminary data content standard for ocean surface currents has been implemented at the CO-OPS and NDBC. This standard will provide greater interoperability among 10 ocean current observing systems across the nation.[10] The resulting data content standard and implementation method will be extended to additional core variables, with simultaneous efforts to expand the number of NOAA and non-NOAA data providers implementing the data content standard. NOAA will work with the data management and communication representatives of the 11 IOOS RAs to implement data content standards for their respective observing systems.

Figure 4-1 provides the sequence of IOOS data integration efforts.

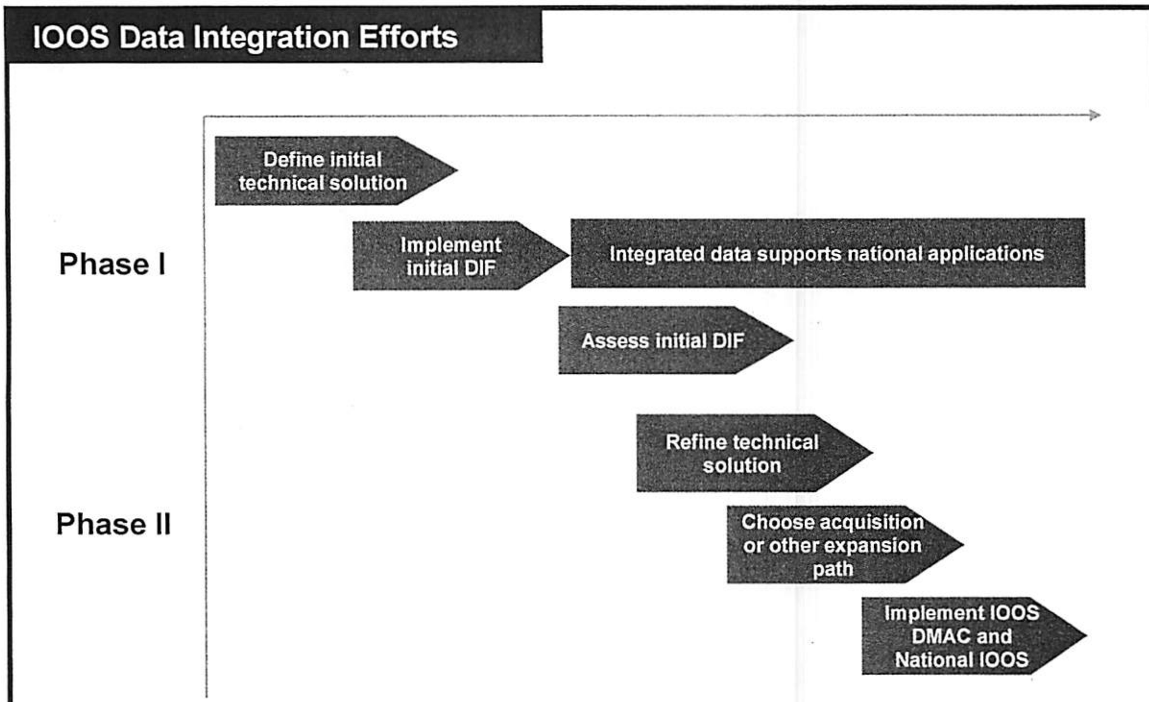
Why Standards Matter

Models and environmental analyses are often based on numerical calculations which require consistent inputs to produce meaningful results. A numerical temperature input of 32 degrees can have a very different effect if reported inconsistently in degrees Celsius and degrees Fahrenheit. Similarly, geographic position may be expressed in degrees, minutes, and seconds of latitude and longitude or decimal degrees. Date may be expressed in year-month-day, day-month-year, days since the observing system came on-line, or a myriad of other ways. Time may be expressed in local, Greenwich mean time, or seconds since a fixed point in time.

Analysts can develop algorithms to accommodate for such incompatibilities. Every modeler or researcher must devote resources to address the same data inconsistency issues, either through manual data conversions or automated processes. This is inefficient, costly, and potentially hazardous if improperly performed.

[10] The observing systems are (1) NDBC Acoustic Doppler Current Profile (ADCP), 24 stations; (2) NOAA CO-OPS PORTS, 30 stations; (3) Department of Interior Minerals Management Service ADCP, 40 stations; (4) State of Texas Automated Buoy System (TABS), 5 stations; (5) Coastal Ocean Research and Monitoring Program (CORMP), 2 stations; (6) HFR systems, 90+ stations; (7) Gulf of Maine Ocean Observing System (GOMOOS), 9 stations; (8) Carolinas Coastal Ocean Observing and Prediction System (Caro-COOPS), 5 stations; (9) Southern California Coastal Ocean Observing System (SCCOOS), 1 station; and (10) Marine Energy, 1 station. These systems have a total of 117 interoperable reporting stations.

Figure 4-1. Schedule for IOOS Data Integration Efforts



IOOS Data Integration

Current State	Future State
• Interoperability challenges faced by IOOS • DMAC standards collection process underway • Determination and integration of at least 5 IOOS core variables of key importance to ocean science and modeling	• Implementation of initial IOOS DMAC and National IOOS that meets end users' needs • Integration of data from diverse sources • Requirements met for geographic coverage, resolution, accuracy, and timeliness of multiple NOAA ocean models, assessments, or product owners • Integrated data incorporated into national applications: HAB forecasting, IEA development, total water level inundation prediction, and national surface current capability (high frequency radar) • Improved performance of models and decision-support tools

NOAA's DIF effort will have broad utility across the ocean observing community. In addition to enhancing data integration, the NOAA IOOS Program is working with other NOAA programs and the modeling, analysis, and decision-support communities in support of product-level integration, leveraging DIF efforts to achieve benchmarked improvements for specific national applications identified based on end-user needs.[11] While integration efforts are targeted toward four national application areas, they will have broad applicability and benefit for a number of other user communities, including marine navigation and commerce, fisheries management, public health, and ocean and coastal resource management.

For example, the collection of real-time oceanographic information, including IOOS data, in New York Harbor is absolutely critical to support safe and efficient marine commerce, given the shallow coast and highly variable ocean conditions. The high turbidity (mixing), strong currents, fog, high vessel traffic, and limited shoreline access underscore the need for such an observing system. There is no tolerance for error, and the New York Port Authority relies on strategically placed, continually operating observations in the area to provide real-time conditions to high-resolution circulation models. Resulting information is used by the Port Authority to make decisions and ensure safe and efficient movement of commercial, recreational, and ferry traffic.

The Pacific Fisheries Management Council (PFMC) recently reported unexpectedly low chinook salmon returns to California in 2007.[12] Adult returns to the Sacramento River failed to meet resource management goals for the first time in 15 years. Ocean conditions are believed to be a major cause of the decline. Typically, commercial catch statistics would serve as a primary data resource to monitor the fish stock. However, because this and other local salmon species are endangered and not commercially traded, they are more difficult to manage. IOOS data are needed to understand how valuable marine living resources, such as salmon, respond to the changing ocean and coastal environment, and to improve our ability to predict impacts of local changes.

It is important to recognize the broader applicability and benefit of IOOS in the context of NOAA's efforts to advance the four national application areas. Sections 4.2–4.5 focus on integration efforts for HAB forecasting, IEAs, coastal inundation products, and national surface current monitoring.

4.2 Harmful Algal Bloom Forecasts

HABs are a naturally occurring phenomenon whereby certain species of microscopic phytoplankton and cyanobacteria, many producing highly potent toxins, form dense and harmful aggregations, or "blooms." Toxins can kill or sicken fish, birds, and mammals, including humans, by contact with or ingestion of affected marine organisms or by direct contact with the

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[11] The end-to-end (observation to model/tool output) system performance will be monitored to document expected improvements in processing time (e.g., from days to hours to minutes), reduced machine manipulation to achieve interoperable data, increased resolution due to increased data density, and reduced manpower support requirements.

[12] R.B. MacFarlane, S. Hayes, B. Wells, *Coho and Chinook Salmon Decline in California during the Spawning Seasons of 2007/08*. Technical Report from NOAA's Southwest Fisheries Science Center, February 2008.

bloom and its toxins (e.g., through inhalation of airborne toxins). Recent work by the Centers for Disease Control and Prevention (CDC) and by Oceans and Human Health (OHH) researchers found significant increases in reported respiratory symptoms among recreational beachgoers in Florida after a red tide (*Karenia spp.*) exposure. Another study showed emergency room visits related to respiratory diagnoses rose 54 percent in years when red tides occurred in coastal Florida. HABs also result in substantial economic losses to coastal communities and commercial fisheries due to fish kills, beach closures, and closed shellfish beds. Although probably significantly underestimated, the overall economic effects of HABs in the U.S. (not including freshwater outbreaks) are at least $82 million per year, with public health costs of illness accounting for 45 percent of the total, commercial fisheries impacts accounting for 46 percent, local recreation and tourism impacts accounting for 5 percent, and costs of coastal monitoring and management accounting for 4 percent.[13]

NOAA has been a national leader in responding to HABs for over a decade. In response to a severe HAB event in the southeast in 1988, NOAA started the CoastWatch program—the first national capability to provide near-real-time satellite imagery to state and federal managers. In 1998, Congress passed the Harmful Algal Bloom and Hypoxia Control Act (HABHRCA), authorizing NOAA to initiate two applied national research programs—Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) and Monitoring and Event Response for Harmful Algal Blooms (MERHAB). These programs award grants competitively to develop tools and techniques to help managers identify causes of the bloom and provide detection and early warning. NOAA scientists complement this competitive funding with in-house expertise, including transition of ECOHAB, MERHAB, and the Oceans and Human Health Initiative (OHHI) products to operational status (e.g., HAB forecast system for the eastern Gulf of Mexico).

NOAA will capitalize on the demonstration operational HAB forecast product in the eastern Gulf of Mexico by improving and expanding this capability to the western Gulf of Mexico, Great Lakes (Erie and Huron), Gulf of Maine, Pacific Northwest, Coastal California, and the Chesapeake Bay. NOAA's efforts will improve the efficiency in generating and the quality of HAB forecasts by facilitating the input of ocean data, including new sources of surface current measurement, while leveraging the expertise of regional IOOS partners to address locally specific aspects.

4.2.1 HAB Forecast Development

A national HAB forecasting effort that targets regionally specific HAB species and mechanisms will provide the advanced warning needed by managers at all levels to implement appropriate fisheries and coastal management measures (such as harvesting and beach closures) and to mitigate impacts to coastal residents and visitors. Local decision makers need reliable forecasts of the presence, extent, toxicity, and movement of a HAB event to target mitigation measures.

[13] P. Sandifer, C. Sotka, D. Garrison, and V. Fay, *Interagency Oceans and Human Health Research Implementation Plan: A Prescription for the Future* (Washington, DC: Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology, 2007).

Due to existing data limitations, today's HAB forecasts provide a fairly coarse and conservative estimation of bloom location and extent. Given the economic impact of reduced tourism and closed shellfish beds, it is beneficial to refine the forecast and provide more geographically specific and precise predictions. NOAA is developing this capability through its HABHRCA-related programs and in support of OHHI, established by Congress in 2003 to focus NOAA activities on the connection between the oceans and human health.

HAB forecasting involves the integration of a diverse suite of data types, formats, and time scales provided by a number of NOAA, state, and regional partners. Forecasts of HAB location and movement are based on processed satellite and aerial imagery, *in situ* and field/lab-based observations at a variety of temporal and spatial scales, and forecasted conditions from wind and ocean circulation model outputs. Due to a lack of accessibility and compatibility among these data, HAB modelers must manually compile and convert the various data inputs to standard formats prior to each forecast. This is both time consuming and inefficient (about 4 hours per forecast) and impedes development of a national HAB forecasting capability, requiring modelers to devote a significant amount of time managing data rather than improving models. Expanding delivery of such a time- and labor-intensive process to multiple regions is not practical or sustainable.

NOAA has established a cross-program effort to develop a HAB forecasting system that supplies information on the location, extent, and potential for development or movement of HABs.[14] The forecasting system that has been operational in the eastern part of the Gulf of Mexico since September 2004[15] remains in demonstration status in the western Gulf in part due to an inability to integrate the observations needed to model HAB transport (e.g., winds and currents). The operational forecasting system routinely generates a bulletin for managers and other interested parties describing HAB conditions in the eastern Gulf of Mexico. Bulletins are generated on a schedule and in a format preferred by managers and include information on wind conditions, chlorophyll levels, and potential or actual bloom events.

NOAA plans to transition HAB forecasting into a nationwide network of regionally specific forecasting systems. This network will be modeled after the operational system in the eastern Gulf of Mexico, though improvements will be made to increase the quality, including species specificity of forecasts, by integrating additional variables. The eastern Gulf prototype system has produced over 200 bulletins, over 90 percent of which have been used by authorities as a basis for planning and for issuing public advisories. The demonstrational western Gulf HAB forecasting system has been under development since 2006, and strong demand for its preliminary bulletins has already been expressed, even though it is not yet operational.

Figure 4-2 provides a schedule for the HAB forecasting capability, as well as a comparison of the current and future state of HAB forecasting.

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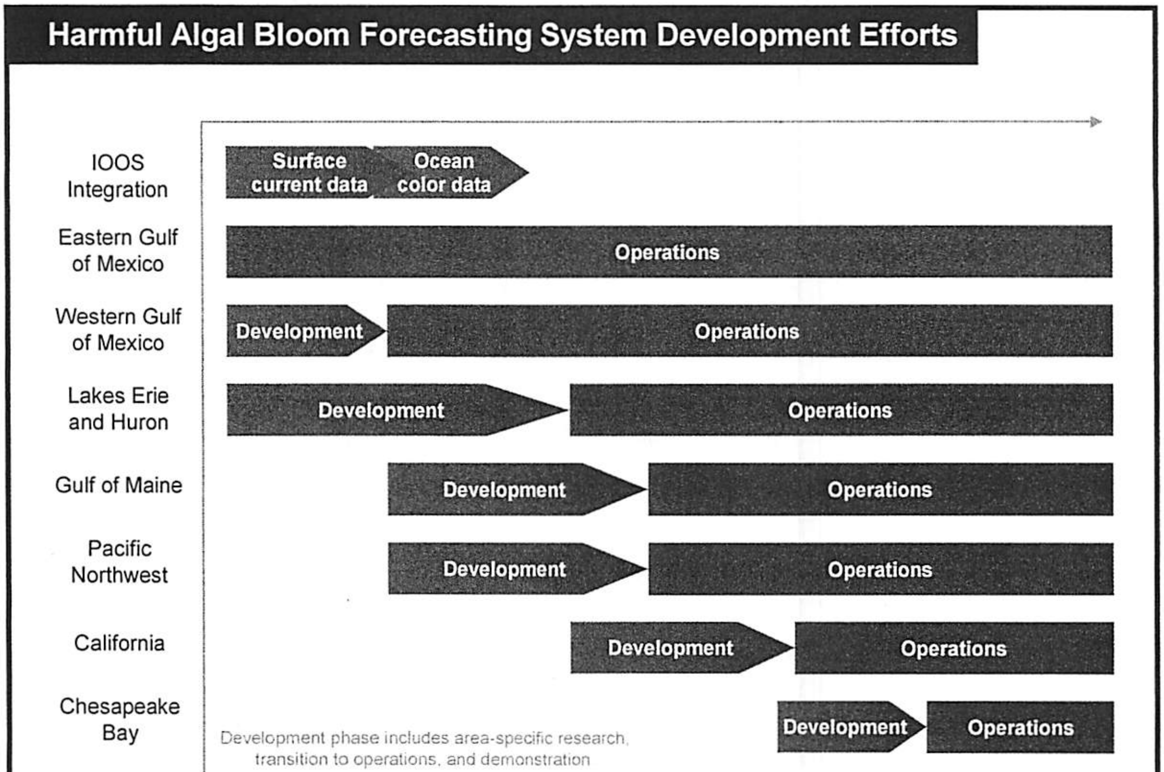
[14] National Ocean Service (National Centers for Coastal and Ocean Science, Coastal Services Center, and CO-OPS); National Environmental Satellite Data and Information Service (CoastWatch Program and National Coastal Data Development Center); and National Weather Service (National Data Buoy Center).

[15] See http://www.csc.noaa.gov/crs/habf/.

Figure 4-2. Schedule for Developing Harmful Algal Bloom Forecasting Capability



HAB Forecasting System Development

Current State	Future State
• HAB reports based on local water-quality monitoring, winds, and human interpretation of satellite ocean color • No access to critical surface and sub-surface currents • Capability to produce localized nowcasts, but not forecasts • Preliminary HAB forecasting system operational in the eastern Gulf of Mexico • Development of pilot HAB forecasting system in the western Gulf of Mexico • Development time per forecast of about 4 hours • Preliminary version of HAB bulletins online (at http://coastwatch.noaa.gov/hab/bulletins_ns.htm)	• Operational HAB forecasting system based on integrated data • Increased access to currents and other required data • HAB forecasting capability at the local level • HAB forecasting processes and impact Information shared among regions • HAB bulletins produced and distributed as needed, including electronic distribution on demand • Reduced time and human involvement to produce HAB forecast; development time per forecast reduced by 30-50%

4.2.2 The Role of IOOS in HAB Forecast Development

The NOAA IOOS Program will support the integration of data generated by *in situ* sensors and remote sources (e.g., satellites) required to provide a HAB forecast. Addressing data inconsistencies and providing automated delivery of data in the formats and time scales required by forecasters will reduce the manpower required to incorporate and convert the many different types and sources of data to common formats, expediting model development, improving forecast accuracy, and reducing the cost to develop forecasts on a nationwide scale. Improving forecast timeliness and accuracy will enhance the opportunity for local decision makers to take action to mitigate the HAB effects. Each of the efforts described below will achieve measurable improvements in the existing Gulf of Mexico HAB forecast system.

The NOAA IOOS Program will address HAB forecast challenges by doing the following:

- Delivering a comprehensive suite of standard ocean currents data and forecasts, including surface, bottom, and (depth) profile observations from *in situ* Acoustic Doppler Current Profilers (ADCPs), and surface currents from high-frequency radar. Currently, HAB forecasters do not have access to these data, impeding the ability to forecast movement. Incorporation of these disparate ocean current measurements in a standard manner into the eastern Gulf of Mexico HAB forecast model will improve 24- to 48-hour bloom trajectory predictions.[16]

- Delivering standardized ocean color data from satellite imagery—a key remote indicator of a HAB.

- Improving access to sensor-detected presence of harmful microorganisms. Developmental HAB sensors and volunteer efforts to monitor phytoplankton blooms provide quick detection of HAB species and human pathogens at lower concentrations than can be observed from satellites. These sensor development and field data collection efforts, and incorporation of resulting data into IOOS, represent important enhancements to increase warning time for developing blooms and improve HAB forecasting capability over time. IOOS, through the integration and delivery of these new observations, will work with developers to transition successful research efforts to an operational status.[17]

In addition, the NOAA IOOS Program is sponsoring cooperative agreements with regional partners to support locally specific needs to predict and mitigate HAB events. To date, IOOS RAs have successfully delivered data and information that complement and expand federal

[16] HAB modelers do not presently have access to near-real-time currents to predict movement of the identified bloom. In situ and forecasted winds are used as a substitute. As a result, a trajectory forecast cannot be issued during periods of low winds or in the absence of a local wind forecasting capability (e.g., in the western Gulf).

[17] Standard collection, quality control, and reporting procedures have already been implemented to support NOAA's Phytoplankton Monitoring Network, which relies on volunteer effort to collect significant amounts of field data on the presence and concentration of harmful (and unharmful) algal species. This network consists of 103 sampling sites in the southeast United States, Hawaii, and U.S. Virgin Islands. The network is expanding to the Chesapeake Bay region in 2008.

observational coverage. For example, the Northwest Association of Networked Ocean Observing Systems (NANOOS) is implementing fixed buoys and gliders to provide advanced information on HABs, while the Northeast Regional Association will complete observing system simulation experiments to determine the most critical placement of additional observations to support HAB monitoring and prediction. Data and lessons learned from these and other IOOS regional activities inform NOAA's expanded HAB forecasting capability.

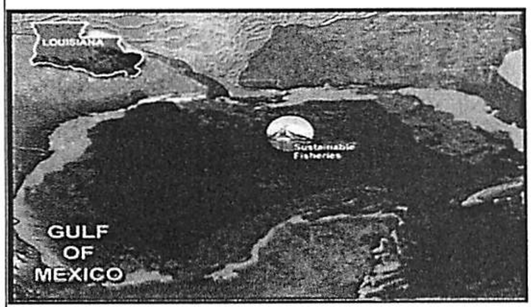
In the future, IOOS regional partners will continue to provide ocean and coastal observations needed to support NOAA's HAB models and to ensure national applications produce data at a relevant scale to inform local decision-making. In addition, the academic institutions involved in each RCOOS provide considerable expertise to support applied research and development to address HAB detection and modeling challenges as this capability is transitioned to other regions. Due to the differences in HAB species found around the country, it is ineffective to monitor and forecast a bloom in exactly the same way in every region. NOAA must modify its observation and modeling techniques accordingly to maintain a consistent level of quality and accuracy. Regional partners are working with NOAA to develop and refine *in situ* sensors to detect the presence of harmful species and may assist with the development of local circulation models to support trajectory forecasts. IOOS regional partnerships will continue to play an important role in these and other areas as NOAA expands its HAB forecasting capability.

4.3 Integrated Ecosystem Assessments

Ecosystem-based management provides a comprehensive framework for ocean, coastal, and Great Lakes resource decision-making. In contrast to individual species or single-sector management, an ecosystems approach affects a wider range of relevant ecological, environmental, and human factors (as shown in Figure 4-3). NOAA is developing IEAs as one key tool for implementing ecosystem-based management, enabling managers to understand the complexity of an ecosystem by including interactions among physical, biological, chemical, and human processes. They provide a fuller examination of economic tradeoffs and enable decision makers to explore optimal management scenarios that may not be evident with single species assessments. IEAs will enable NOAA to meet a variety of statutory responsibilities (e.g., the Magnuson-Stevens Fishery Conservation and Management Act, Coastal Zone Management Act, Endangered Species Act, etc.) and are supported by a variety of policy documents and oceanic stakeholders, including the U.S. Ocean Commission Report, the Ocean Research Priorities Plan, the West Coast Governors' Agreement on Ocean Health, and NOAA's Science Advisory Board.

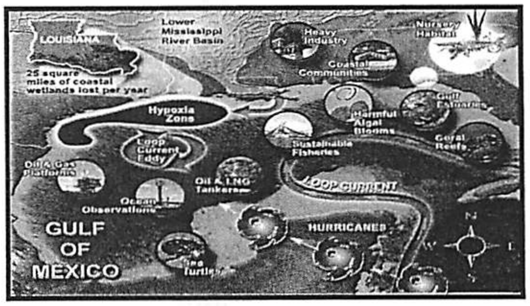
Figure 4-3. Comparison of Single-Sector and Integrated Ecosystem Assessments

Single-Sector Assessment



- Assesses individual species and groups.
- Sector-specific perspective and varying spatial scales.
- Short-term and equilibrium focus for science and management.
- Human impacts considered primarily in relation to sector outcomes.
- Science supports current sector-by-sector management.
- Many uncoordinated observations.

Integrated Ecosystem Assessment (IEA)



- Provides a "big picture" of an ecosystem.
- Broad perspective and multiple time and spatial scales.
- Long-term strategic balance among competing uses of ecosystems.
- Human impacts and effects of communities considered in tradeoff analyses.
- Supports adaptive and integrated management across sectors.
- Shared and standardized observations.

Source: NOAA Ecosystem Goal Team

4.3.1 Integrated Ecosystem Assessment Development

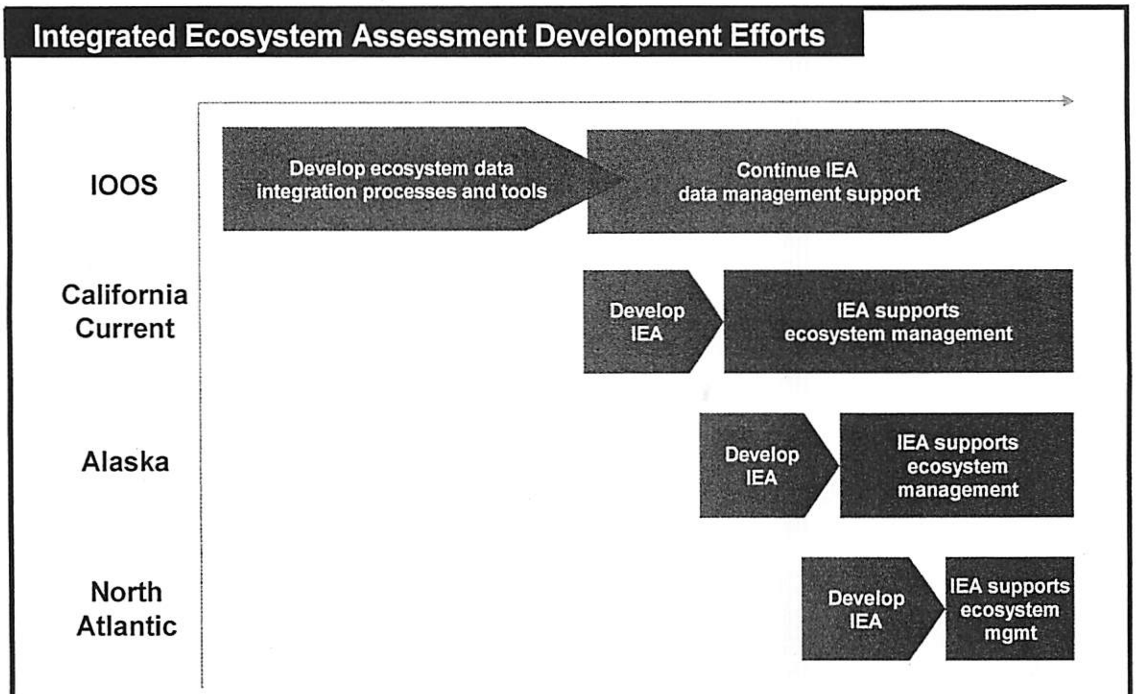
IEA data integration requirements differ from forecasts of weather or water events. IEAs require data on a wide range of time (months, seasons, and years) and spatial (estuaries, bays, and large marine ecosystems) scales, entail the mining of significant amounts of historic data from disparate sources, and—in addition to physical and chemical ocean observations—involve ecological and biological observations, which are typically less well integrated than physical and chemical oceanographic data. IEAs require near-real-time and historical data, as well as model outputs and socioeconomic analyses, from a variety of federal, regional, state, and academic sources and observing systems—for example, marine sanctuaries, satellites, weather buoys, climate forecasts, and fish stock assessments.

IEAs focus on integrating multiple data sets to conduct more comprehensive assessments and to develop decision-support tools. Data standards are critical to the success of this integration activity. Real-time data providers can implement required improvements to ensure that all future data meet desired standards. Historical data integration may also require improvements to identify, access, or convert data for use in models and tools supporting an IEA. By linking IOOS and IEA standards development and data management infrastructure early in development, NOAA can ensure that the data, products, and services are mutually compatible and transferable, supporting not only ecosystem assessments but also a number of other national and regional applications, maximizing efficiency and effectiveness of development efforts.

IEAs will support the needs of a wide variety of end users including resource managers (for example, fisheries management councils and sanctuary managers), academics, conservation groups, and the public who are interested in coastal ecosystem health and sustainability. With further development, dynamic IEAs may become feasible, allowing marine and coastal managers to conduct Internet-based interactive assessments to evaluate impacts of ecosystem stressors and related management options. Dynamic IEAs are different from standard, static reports in that they provide a Web-based capability to manipulate available data to produce customized IEA products and scenarios by regions and at a variety of spatial scales on-demand.

Figure 4-4 provides a sequence of activities for IEA development, as well as a comparison of the current and future state of ecosystem assessment processes and capabilities.

Figure 4-4. Schedule for Developing Integrated Ecosystem Assessment Capability



IEA Development

Current State	Future State
• Single-sector ecosystem assessments that look at individual species and components of the ecosystem • Limited integration of data on physical, chemical, ecological, and human processes • Assessments use single-use observations • Ecosystem is viewed independently of human interaction • Existing ecosystem assessments not well-integrated, user-friendly, or sufficient to support management decision-making	• Assessments using multi-purpose and standardized observations • Consideration of human interaction with the ecosystem • Comprehensive assessment of ecosystem and its health • IEAs provide the foundation for an ecosystem approach to management of marine and coastal resources

4.3.2 The Role of IOOS in Integrated Ecosystem Assessment Implementation

In 2007, the NOAA IOOS Program began funding an effort across the NOAA line offices to address data integration and access challenges associated with the production of an IEA.

In support of IEA development, the NOAA IOOS Program will focus on data management activities to provide the following:

- Current and historical, ecologically relevant data on ecosystem-appropriate time and space scales needed to evaluate ecosystem change over time.
- Integrated data on a variety of ecosystem characteristics, which use clearly defined formats based on the community's agreed-upon standards to be conveniently used by researchers and ecosystem managers.

The NOAA IOOS Program is supporting a data integration project with partners in NOAA Fisheries and the Office of National Marine Sanctuaries for the pilot California Current IEA. The project is coordinated by the Pacific Coast Ocean Observing System (PaCOOS), a consortium of multiple NOAA programs, West Coast IOOS RAs, state partners, and public institutions and foundations. With NOAA IOOS Program support, the multiple partners associated with this IEA have already begun to apply IOOS standards and data protocols, ensuring greater synergy as the effort matures. NOAA's work has demonstrated significant capacity for improved access, integration, and use of a wide variety of disparate biological, physical, and chemical oceanographic data. As a result of these efforts, a fisheries habitat portal became operational in 2008 and provides access to more than 30 years of data (www.pacoos.org). In addition, the IOOS DIF efforts will support integration of the 5 IOOS core variables for IEAs, primarily through the process of setting standards for data content and transport. Standardized ocean current data will be available to the California Current IEA, with the other variables to follow shortly thereafter.

NOAA's IEA development efforts also rely on the integration of data from other federal, regional, state, and local governments and other parties whose missions involve ocean, coastal, and Great Lakes management. NOAA has begun development of a regional Ecosystem Data Management Framework to achieve seamless data integration among local, regional, and national levels to support IEAs. Through the IWGOO, the NOAA IOOS Program will engage other federal agencies such as the USGS and the Environmental Protection Agency (EPA) to integrate the National Water Quality Monitoring Network effort, which will provide information on coastal and inland water quality information for incorporation into ecosystems assessments.

The IOOS RAs and participating institutions, as well as NOAA regional collaboration teams, are key contributors to the national expansion of IEA capabilities through scientific collaborations. Regional IOOS partners contribute subject matter expertise and knowledge of present and historical data sets maintained within the regions. The IOOS RAs in southern and central California and in the Pacific Northwest are already contributing data to support IEA development. IOOS funding to the regions supports development of web-based "gateways" to the NOAA National Marine Fisheries Services' Science Centers and to regional IOOS data archives, products, and services. The gateways and underlying technical code will be documented and made freely available to expedite IEA development in other regions.

In the future, IOOS regional partners will continue to play an important role in IEA development, providing ocean and coastal observations needed to support the ecological analyses contributing to an IEA. Regional, state and local marine and environmental resource managers are primary consumers of NOAA IEA information. NOAA requires regional-to-local scale data to make effective integrated baseline assessments of regional ecosystems and to measure changes in these ecosystems over time. While ecosystem assessments can be conducted at a variety of geographic and temporal scales, state and local decision-makers often require finer scale, area-specific information to ensure the best decision for their region and constituents. IOOS regional partners provide important near-real time observations within a given area to validate the current state and, when paired with the comprehensive, longer-term analyses, provide an added level of confidence in a particular management action.

The NOAA IOOS Program will support the transfer of lessons learned and successful technical approaches demonstrated from the California Current IEA development to other pilot regions. Transferring standard approaches and guidelines from region to region ensures consistency and compatibility of data when addressing trans-boundary ecosystem challenges and ensures that the data can be used to support multiple IOOS application areas. The IOOS role and its underlying integration efforts will advance development of IEA's and related ecological assessments. As the California IEA development matures, NOAA expects to realize a number of benefits for the fisheries, coastal, and marine protected areas management communities.

4.4 Coastal Inundation Prediction

Coastal inundation is the flooding of coastal lands, including wave action, usually resulting from riverine flooding, spring tides, severe storms, or seismic activity (tsunami).[18] Coastal communities are inherently susceptible to inundation due to storm surge, waves, and precipitation runoff, particularly when nature acts to combine these effects. The deadly Gulf Coast hurricanes of 2005, Katrina and Rita, demonstrated the significant loss of life, property, industrial damage, and ecological strain that can result from coastal inundation. Since 1900, more than 200 tsunami events were observed or have affected U.S. coasts and its territories. These events have caused more than 500 deaths and $186 million in damage.[19] Coastal decision makers require high-quality inundation predictions that are easily accessed and understood to develop land-use plans, emergency response planning, community evacuation, and disaster response after an inundation event.

NOAA will focus on improving predictions of coastal inundation by including data and product-level integration from various sources: hurricane intensity and track; associated storm surge, wind, and wave effects; precipitation-induced runoff; and the coupling of these effects in coastal environments, to visualize local impacts and support informed decision making. The NOAA IOOS Program not only contributes data integration, but also coordination of efforts across NOAA and its interagency and regional partners, to ensure consistency among the vast expertise and resources within the larger IOOS community.

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[18] National Science and Technology Council, *Grand Challenges for Disaster Reduction Implementation Plan: Coastal Inundation. A Report of the Subcommittee on Disaster Resilience*, 2008.

[19] NOAA, *Economic Statistics for NOAA*, 5th Edition, April 2006, p. 17.

4.4.1 Coastal Inundation Prediction Improvement

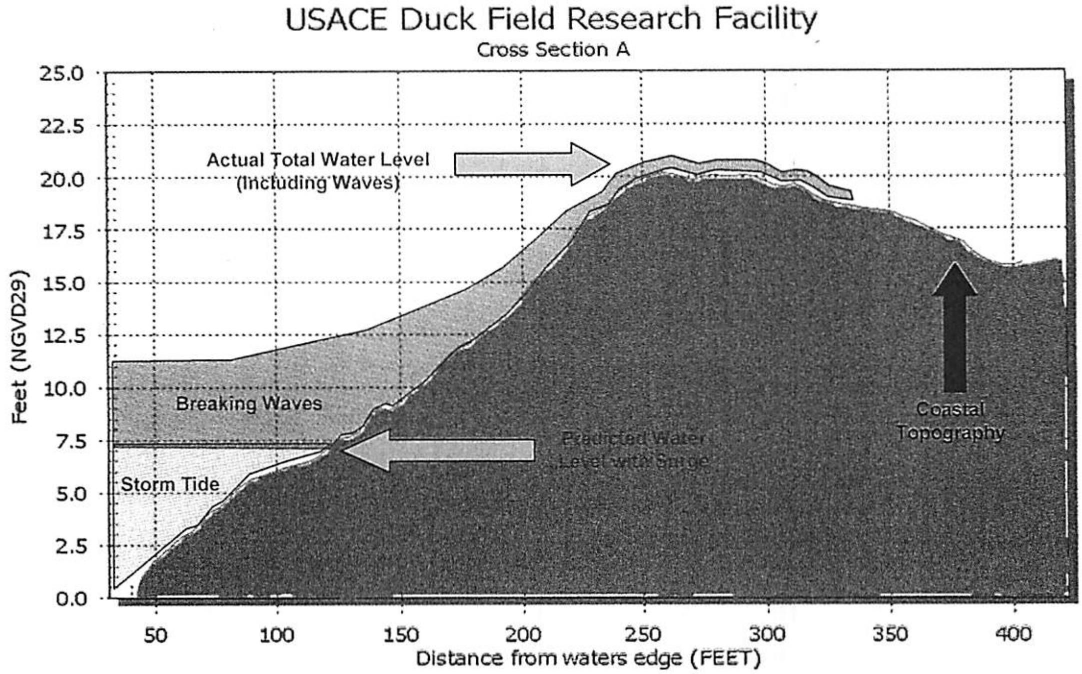
Inundation predictions are closely coupled with hurricane intensity and landfall predictions to identify the location and severity of floods. As a result, NOAA's efforts related to coastal inundation will be closely linked with the NOAA Hurricane Forecast Improvement Project (HFIP), which oversees NOAA's multipronged hurricane forecasting undertakings to increase the overall accuracy of hurricane track and intensity forecasts, to develop probabilistic hurricane forecasts, and to improve storm surge forecasts.

Predicting coastal inundation is a complex integration challenge, given inherent incompatibilities associated with land-based and ocean/coastal data and the variety of scientific disciplines (oceanography, meteorology, hydrology, etc.) involved. For example, wave, tide, and water level data are collected by NOAA, USACE, and USGS; however, these total data holdings are not readily used to address coastal inundation due to varying baselines, quality control procedures, and data formats.

The importance of integrating wave, coastal precipitation runoff, and water-level information can be seen in Figures 4-5 and 4-6, which illustrate the differences in observed total water level and predicted water level based on storm surge alone. These diagrams also illustrate the importance of storm-survivable water-level instrumentation because without continuous water-level data, it is not possible to validate inundation model predictions. As well, these figures highlight the need to provide decision makers with total water level inundation predictions so they can be more responsive to their constituents.

Figure 4-5 shows the difference between a storm surge prediction and the actual high water level during Hurricane Isabel at the USACE Field Research Facility in Duck, NC. The predicted water level with storm surge was 6.9 feet, which was somewhat higher than the 6 feet observed at a water-level station offshore but was significantly lower than the 21-foot height that the water reached at the shore. The difference is attributed to the added influence of breaking waves.

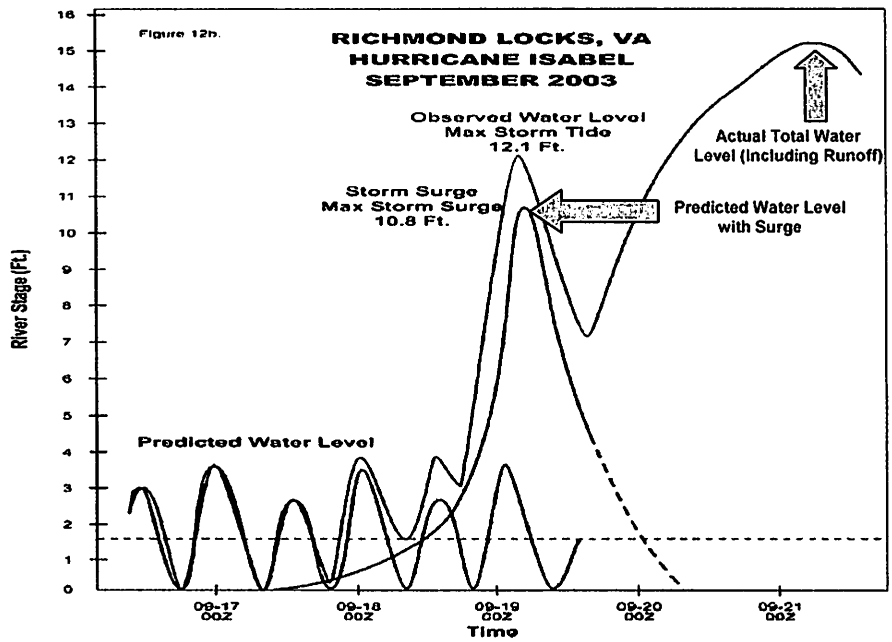
Figure 4-5. Predicted and Observed Water Level at Duck, NC, during Hurricane Isabel



Source: Jarvinen, Brian, SLOSH Modeling for the NWS, Interdepartmental Hurricane Conference, March 2004, Charleston, SC, slide 8. Annotation added.

Similarly, Figure 4-6 provides an example from Hurricane Isabel of the difference between the storm surge prediction and the actual total flooding high water level due to freshwater runoff. The storm surge model provided a relatively accurate prediction of the maximum water level at the time of the storm, but the highest total water level was roughly 50 percent higher and occurred almost 48 hours later—a key difference to emergency planners and local citizens.

Figure 4-6. Predicted and Observed Water Level at Richmond Locks, VA, during Hurricane Isabel



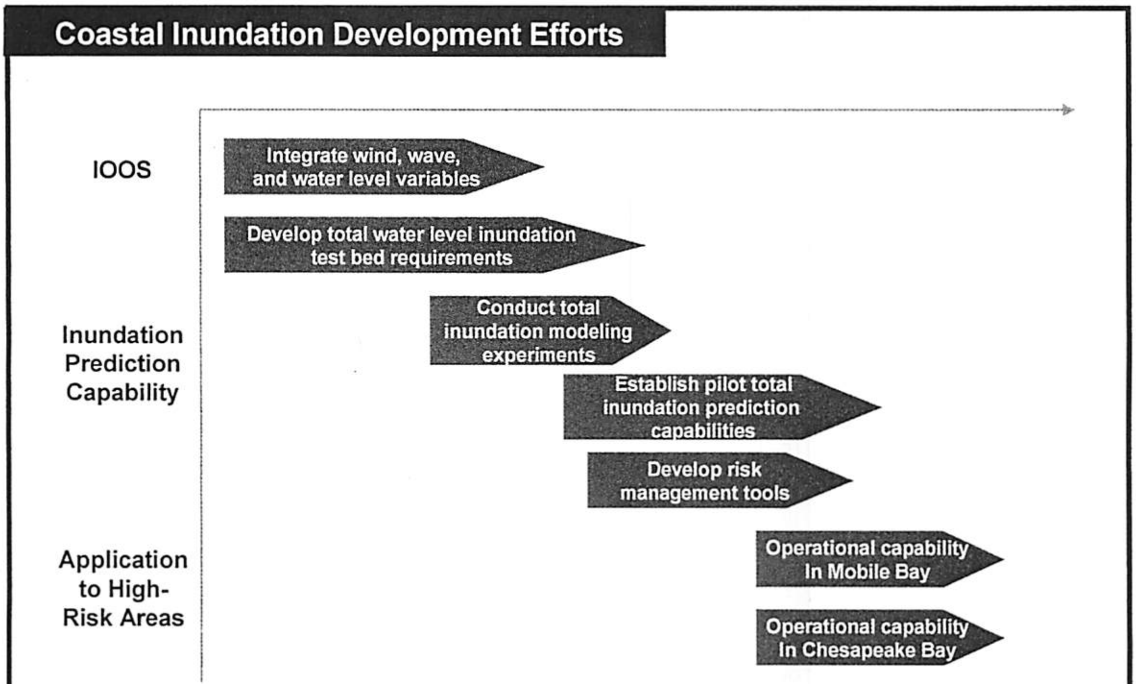
Source: Post, Buckley, Schuh, and Jernigan, Hurricane Isabel Assessment, U.S. Army Corps of Engineers and FEMA, March 2005, p. B-42.

Coastal inundation models must incorporate the effects of all of the contributors to total water level and provide detailed three-dimensional geography, including accurate land elevation and water depth with consistent elevation benchmarks, which do not currently exist for all areas of concern. Coastal shelves, levees, and interstate highways or railways all affect the flow of water and resultant inundation. To model the horizontal and vertical movement of water through the flooding area, scientists must be able to generate a seamless representation of the earth's surface, extending from near-shore coastal environment onto land. In addition, because of differences in vertical datum, there is no baseline or "zero" point from which to compare the data from multiple tide and stream gauge stations. These issues must also be addressed in order to achieve an accurate representation of coastal inundation.

NOAA's coastal inundation efforts are addressing the range of users who operate on different time scales and require different levels of resolution—long-time-scale climate-related effects for land-use planning, pre-event planning for emergency response, pre-event forecasting for evacuation decisions, and post-event for first responders. To support these users, NOAA is developing appropriate decision-support and risk management tools, including visualization aids, in addition to the inundation prediction modeling capability. For example, the official National Weather Service (NWS) surge forecast is provided as a text-based product, which may not be the most effective mechanism to communicate risk. To ensure maximum utility from improved inundation prediction capabilities, NOAA will work with Federal Emergency Management Agency (FEMA), USACE, local emergency managers, and others to determine the most effective tools to communicate risk and provide street-level visualization of the maximum inundation predicted for a given area.

Figure 4-7 provides a schedule of activities for improving coastal inundation prediction capability, as well as a comparison of the current and future state of coastal inundation prediction.

Figure 4-7. Schedule for Developing Coastal Inundation Prediction Capability



Coastal Inundation Product Development

Current State	Future State
• Coastal communities not prepared for inundation events and in need of assistance in building resilience to such events • Local decision-makers require total water level inundation forecasting products to make informed decisions on land use, zoning, emergency management, evacuations, real-time response, and post-event recovery • Current models run independently and, therefore, do not predict total water level inundation effects from storm surge, wind, waves, coastal precipitation, and runoff	• Delivery of total water level inundation products to support improved risk management and hazard resilience • Establish open-source, community modeling approach to total water level inundation forecasting • Develop extensible total water level inundation system prediction processes for planning and forecasting purposes, containing modeling, probabilistic, and visualization components • Enhanced ability to test, evaluate, and transition experimental systems and street-level total water level inundation predictions

4.4.2 The Role of IOOS in Coastal Inundation Prediction Improvement

IOOS will support the integration, of wind, wave, tide, storm surge, and hydrologic models to produce comprehensive, high-resolution predictions of total water level for inundation events from coastal storms, hurricanes, or tsunamis. These models can be used in a predictive mode to identify likely scenarios and impacts for land use and emergency response planning, as well as in a forecast mode to support evacuations, real-time response, and recovery from inundation events. In predictive mode, scientists run thousands of model runs to generate maximum storm surge heights in a particular location for a given hurricane category and storm track. They can further composite these data to represent the maximum surge at a location regardless of storm track or direction. Managers use these values for coastal development decision-making and evacuation planning. In forecast mode, scientists use near real-time data to determine expected inundation impacts based on an approaching storm or existing weather pattern.

Ocean observations are also useful to validate the outputs of these predictive models and to provide decision-makers with the patterns and trends needed to assess immediate threats and support long-term planning. For example, in the Pacific, these and other ocean observing data provide coastal and emergency managers with an understanding of how climate variability resulting from the El Niño Southern Oscillation influences water levels and storm patterns and, therefore, potential for storm surge in the winter season.

To improve coastal inundation prediction, the NOAA IOOS Program will do the following:

- Continue to work with partners to resolve data standards, transport, metadata, and quality control issues to ensure that data are consistent, compatible, and in formats capable of serving multiple applications and end users. Through the DIF effort, IOOS will implement data interoperability enhancements for coastal inundation and hurricane intensity models by February 2010.

- Increase the number of water level observations available to support coastal inundation and other multiagency efforts by making the water level data compatible and to a consistent level of quality across agencies. In the Gulf region alone, incorporation of USACE tide stations would nearly double the number of water level observations used by NOAA to support inundation prediction, navigation, and other purposes.

Water-level and waves data are required inputs for the National Hurricane Center's (NHC's) Sea, Lake, and Overland Surges from Hurricanes (SLOSH) and other inundation models. In addition, these observations, from survivable instruments, are used in post-event analysis to validate the outputs of predictive models and enhance model refinement. NOAA IOOS efforts will support integration of water-level data—from the CO-OPS National Water Level Observation Network (NWLON), the USGS National Water Information Service (NWIS), USACE, and, where feasible, regional, state, local, or private-sector instruments—to deliver more complete data coverage to the models, including runoff of overland precipitation. The NOAA IOOS Program is already engaged with the USACE on "An IOOS Operational Wave Observation Plan" and has supported this plan through a cooperative agreement with the Alliance for Coastal Technologies.

This effort will provide essential integrated wave data to support total maximum inundation predictions.

The integrated wave and water level data will result in a number of benefits to NOAA, as well as other federal, regional, state, local, and industry partners. These data are useful not only during periods of severe storms, but also to support every day decisions related to marine commerce, coastal engineering and construction (e.g., bridges), flood mitigation, habitat restoration, etc. While the primary intent of these activities is to improve coastal inundation predictions, proposed IOOS activities will produce benefits for the broader coastal and ocean user communities.

IOOS efforts across NOAA will also support the development of a coastal inundation modeling test bed to integrate disparate models to develop more meaningful forecasts that reflect the additive impact of winds, waves, tides, storm surge, and coastal precipitation, for a total maximum water level or inundation prediction. To maximize the capability of this test bed, IOOS supports the following:

- Enhancement in the current SLOSH model, including the incorporation of wave inputs.

- Investigation and incorporation of other higher-resolution models, such as the Advanced Circulation Model (ADCIRC),[20] which produce more detailed outputs for coastal and inshore inundation-prone areas but require longer run times to achieve the higher resolution.

- Increased technical discussions among surge modelers to identify the most critical data and model interoperability issues that need to be addressed to provide more automated, timely transport of required data inputs. For example, modelers currently review tide predictions and manually enter values into one storm surge model.

- Documentation of benchmarked model and process improvements and best practices and tools to support data integration, data management, and data transport for incorporation into other complex data integration and modeling efforts.[21]

To support the near-real-time needs of community managers, IOOS will support the development of decision-support and risk management tools, including the following:

- Near-real-time delivery of total inundation-level forecasts developed using various data, including projected hurricane intensity and track, associated storm surge, wind and wave effects, and precipitation-induced runoff.

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[20] ADCIRC is an advanced hydrodynamic model for coastal oceans, inlets, rivers, and floodplains sponsored by the U.S. Army Corps of Engineers, NOAA, NSF, U.S. Navy, Louisiana State University Hurricane Center, and Texas Water Development Board.

[21] The NOAA Tropical Prediction Center (TPC) has detailed benchmarking and performance measurement processes to track forecast precision; these processes can be expanded to track the effects of IOOS improvements.

- A mapping component that allows the user to visualize the prediction at the street level, providing policy and decision makers with an accurate and easy-to-understand description of expected coastal flooding impacts at local levels.

The NOAA IOOS Program will coordinate coastal inundation prediction and response efforts across NOAA and its interagency and regional partners. The IOOS Regional Associations represent a partnership of marine and estuarine data providers, including participation from state and federal agencies, private industry, non-governmental institutions and academia. University and industry participants, in particular, can provide a testbed environment to evaluate emerging models and tools that might be appropriate to transition to operations in the future and enhance the system. Research supported with IOOS regional funding successfully demonstrated improvements to address known coastal flooding data and modeling gaps. For example, wind fields are an important input to models that predict wave height and water level during a hurricane. Wind measurements are also important for issuing and verifying coastal marine forecasts. The Southeastern Universities Research Association (SURA) Coastal Ocean Observing and Prediction (SCOOP) Program integrated wind field data from multiple sources to predict the worst-case scenario for surge and flood levels based on a variety of storm tracks. IOOS also funded development of high-resolution, operational wave forecasts for the Gulf of Mexico and northeastern coasts, using NOAA models.

In the mid-Atlantic region, IOOS is supporting an RCOOS partnership with industry, academia, NWS, USGS, and state emergency managers and hydrologists to develop simulations of street-level inundation caused by storm events, using a high-resolution circulation model to predict inundation in the Washington, D.C., metropolitan area and the tidal Potomac River. The Chesapeake Inundation Prediction System provides a flood forecast prototype, both for immediate storm response and advanced mitigation planning and decision making. Based on preliminary results, the tool has great potential to enhance the capability of NWS Weather Forecast Offices (WFOs) to deliver more specific and timely inundation forecasts to individual localities.

There is an obvious role for IOOS regional partners to provide oceanographic and meteorological observations in support of coastal inundation forecasting efforts. In addition, the RCOOSs include a number of academic institutions capable of providing modeling and analytical expertise to complement NOAA's activities associated with coastal inundation. IOOS regional partners provide considerable capacity to conduct targeted research and development needed to produce high-resolution, locally-specific models and value-added products for decision-makers. These efforts, when coupled with the applied research and modeling efforts ongoing within NOAA offices and laboratories, will contribute useful information and lessons-learned to support NOAA's operational responsibility to issue storm surge and other inundation forecasts.

4.5 National Surface Current Monitoring

Just as the winds in the atmosphere provide information about where and when weather systems occur, ocean currents determine where and when oceanic "weather" occurs. These two dynamic flows are also used to determine where pollutants, man-made or natural, will travel. Modern weather "nowcasts" and forecasts generated by the NWS depend on the thousands of critical wind measurements collected worldwide each hour. However, ocean current measurements are not as readily available. Due to the expense and difficulty of measuring *in situ* ocean currents in many locations, these observations are outnumbered by wind measurements by more than a 1,000-to-1 ratio.

The NOAA IOOS Program will support development of a coastal surface current monitoring capability with high-density, near-real-time, round-the-clock coverage of the Nation's coastal waters, provided by a national network of high frequency radars (HFRs). The network will complement the existing network of *in situ* observations, providing timely monitoring and distribution of coastal current data to federal, state, and local governments, as well as to the general public. HFR is recognized nationally as an important technology to provide real-time currents to support safe navigation of vessels, search and rescue (SAR) activities, monitoring of oil spills, sewage outfalls and bacterial contamination, HABs, rip current forecasts, and other environmental hazards. A number of federal agencies, including NOAA, the US Coast Guard, Minerals Management Service, US Fish and Wildlife Service, and the US Geological Survey, use HFR radar to address federal mission responsibilities related to these and other issues. Also, given local health and safety implications, 8 of the 11 IOOS regions highlighted HFR as a high, near-term priority. The three remaining regions listed HFR as a medium priority due to technical implementation and logistical challenges, as well as other competing requirements, but recognized its importance and utility for a number of applications.

Existing HFR capacity was developed largely at the state and regional levels to address targeted local needs. As a result, these data were not readily accessible on a national scale or delivered according to consistent data quality standards. NOAA's objective is to ensure sustained, quality-controlled delivery of this critical data resource to federal and regional partners, as well as many other state, local, and industry users, to maximize the value of this ocean observing investment. As demonstrated in section 4.5.1, HFR provides a unique combination of increased surface current observations, wide geographic coverage, fine-scale data resolution, and low data uncertainty. While NOAA does not own and operate these HFR systems as federal assets, NOAA will support regional efforts to maintain these systems and expedite national data delivery and integration for a sustained, national surface current monitoring capability that addresses the needs of a range of users nationwide.

4.5.1 National Surface Current Monitoring Development

NOAA will support a national capability to deliver near-real-time surface currents, dramatically increasing the number of observations and their ability to support multiple coastal and ocean priorities. This critical data resource benefits HAB forecasting and IEA development and will greatly expand the number of observations available to oil spill/pollutant-tracking and SAR operations. The tens of thousands of HFR-derived current observations each hour from such a network would provide the data required to develop fine-scale resolution nowcast and forecast maps of currents in coastal waters, as well as large bays. Archived data will be delivered to coastal ecosystem managers and others needing long-term data sets for planning and decision making.

Sparsely located measurements provide a partial, less detailed description of the speed and direction of coastal currents, information that is essential for oil spill and point-source pollution tracking and prediction, SAR, marine navigation, HAB forecasts, marine protected area and ecosystem management, effects of climate change on coastal ecosystems, and coastal zone management. As an example, the U.S. Coast Guard, which currently ingests surface data currents from HFR sites into its SAR operations center for the mid-Atlantic coast, estimated that access to HFR data in all U.S. coastal waters would save 26 to 45 more lives annually and reduce the $30 million per year currently spent on rescue flights[22].

In order for coastal forecasting to achieve the effectiveness and timeliness of weather forecasting and nowcasting, NOAA and other scientists require access to more densely distributed, near-real-time current measurements. HFR provides a solution to augment the existing system of *in situ* measurements and extend its geographic coverage. Recognizing the value of this technology, state, regional, and academic partners have already invested significant resources to purchase radar systems for their regions ($14 million in California alone). If data from these existing radars were integrated and made available to the public, the total number of surface current measurements would increase from about 100 to 200 per hour from *in situ* methods, such as moored buoys, to about 60,000 HFR observations per hour. IOOS will maximize the benefit of these investments and develop a national, near-real-time surface current capability by supporting the compilation, integration, and distribution of data from 95 existing HFR stations around the U.S. This increased capacity would cost in excess of $10 billion if monitored using only moored buoys[23].

Conventional in-situ methods provide sparse single-point measurements, at a great distance from one another along the U.S. coast, while HFR provides two-dimensional maps of oceanic flow over a much larger area. Each pair of HFRs can produce a current measurement coverage area of 6,000 square miles, equivalent to a square of about 77 miles on each side. Maps produced from these existing HFR observations cover a significant percentage of the Atlantic, Pacific, and Gulf coasts—more than 50 percent of the U.S. Exclusive Economic Zone (EEZ)—but these outputs are not yet fully integrated.

In addition to the expanded geographic coverage, HFR has the capacity to observe surface currents at a very fine (1km) resolution for short-range stations and 3km for long-range stations. An independent study conducted by the U.S. Coast Guard demonstrated that HFR had the lowest uncertainty of any source currently in use for predicted currents[23]. The USCG uses these data primarily for search and rescue purposes; however, reducing uncertainty when analyzing where and how quickly an oil spill will travel (as well as bacteria, sewage effluents, HABs, etc) is just as important.

Figure 4-8 provides a schedule of activities for the development of a national surface current capability, as well as a comparison of the current and future state of the national HFR capability.

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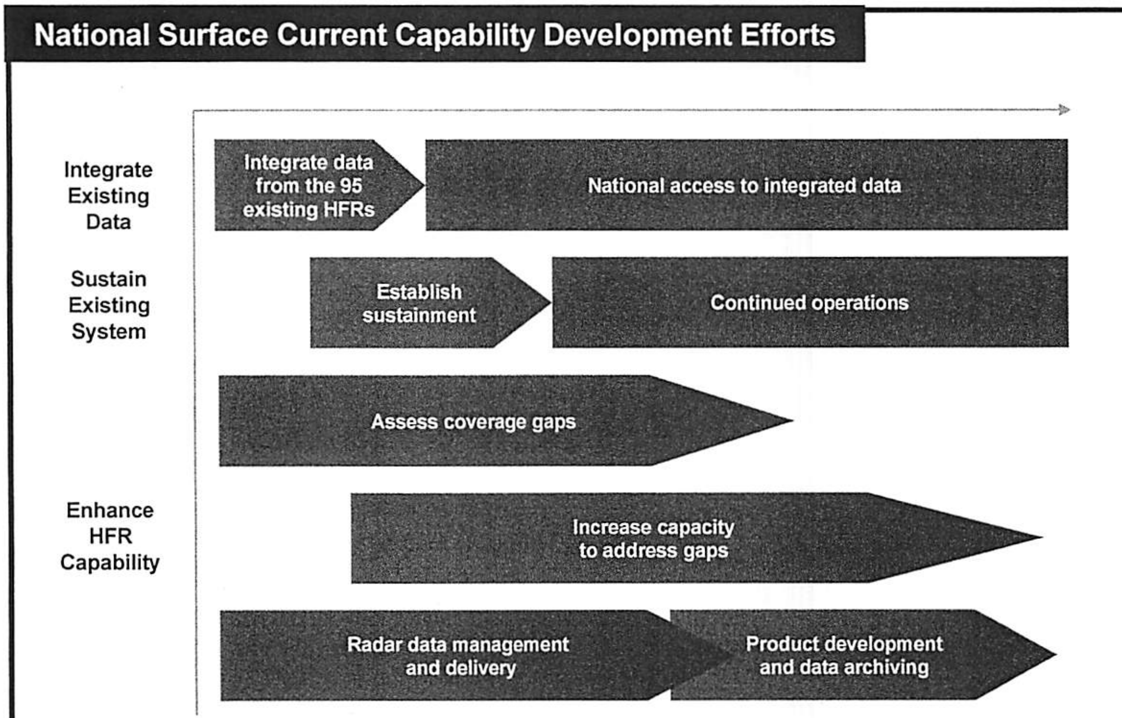
[22] Allen, A. (2006) *U.S. Coast Guard Search and Rescue Optimal Planning System (SAROPS): Environmental Data Sources and Their Uncertainties*. <http://ioos.noaa.gov/library/sarops_data_sources_uncert_nov2006.pdf>

Figure 4-8. Schedule for Developing National Surface Current Capability



National Surface Current Capability Development

Current State	Future State
• 95 existing high-frequency radars • Scalable server architecture for HFR system • Established process tools, including: – HFR data/metadata standards – Standard operating procedures – Quality control methods • Redundant nationally distributed servers (3 total) for failover capability • 4 regional data portal servers	• National HFR capability serving search and rescue, oil spill response, and other real-time emergency applications • Delivery of near-real-time surface currents with continuously available, round-the-clock (24/7) operations • Expansion in the number of observations and surface current forecasts available to support multiple coastal and ocean priorities, including: – Harmful algal bloom forecasting – Fisheries management – Maritime transportation – Coastal water quality management • Development of fine-scale resolution nowcast and forecast maps of currents in coastal waters and large bays

4.5.2 The Role of IOOS in National Surface Current Monitoring

Over the past three years, the NOAA IOOS Program has made significant progress in developing a national HFR data server to provide access to these vast surface current data resources. The server architecture is scaleable to accept data from additional HFRs at minimal additional server cost. To ensure data from the radar systems around the country are high quality, compatible, and able to be integrated, the NOAA IOOS Program has funded efforts to develop HFR data/metadata standards, as well as standard operating procedures and quality control methods. In addition, backup systems were implemented to ensure continuity in the event of a server failure or other problem. A national HFR capability serving SAR, oil-spill response, and other real-time emergency applications must be reliable and available for round-the-clock operations. NOAA's first priority is to advance the development of a national current-measuring capability is to integrate the data from the 95 existing HFRs and to work with the IOOS regional partners to sustain these systems.

To achieve a more comprehensive network, such as the network that exists for weather forecasting, the system must be augmented with more HFRs to fill gaps that exist in economically and ecologically important coastal areas. The NOAA IOOS Program will support regional efforts to fill gaps in areas where there is presently no HFR coverage or where even higher density observations are needed to fulfill a specific mission.

The NOAA IOOS Program is already engaging RCOOS partners to identify the greatest needs for increased surface current observations. All of the regions' conceptual designs contain requirements for HFR capability. Requirements vary by region depending on existing capacity and monitoring priorities. Some regions require long-range HFRs that provide 6,000 square miles of ocean coverage with data points every 3.5 miles, while others that already have access to long-range HFRs may need finer resolution from standard-range HFRs.

IOOS regional partners will continue to manage HFR platforms and work in partnership with NOAA to develop a cohesive national capability to deliver high-resolution, near real time surface currents. While many of these systems were funded by state or other federal sources to address a particular issue or research need, they can provide considerable value and utility to a number of users around the country if the data outputs were assembled in a consistent manner to deliver high-quality, easily accessible data at a variety of spatial scales. Regional partners will apply their understanding of local needs to ensure future investments are directed toward highest priority needs for oil spill, SAR, HABs, and other application areas. NOAA will work with regional partners to implement recommended data standards and ensure development of a cohesive, national surface current monitoring network that delivers continuous, high quality, easily accessible data that produces the greatest benefit for NOAA and its partners.

Reliable, quality-controlled delivery of surface-current forecasts and the associated HFR data require round-the-clock, real-time support, such as that provided by NOAA's many data centers. These efforts will build upon recent NOAA IOOS DIF efforts to provide standards for surface-current measurements and to make these measurements available to national applications, starting with HAB forecasting. NOAA will collaborate with programs whose missions intersect with the needs of the HFR network to identify specific product requirements for current forecasting, including HAB forecasting, maritime commerce, SAR, oil spill trajectory prediction, and ecosystem monitoring and assessment.

4.6 Summary

Building IOOS is a complex undertaking that will take many years. To ensure that the Nation receives optimal benefit from its investment in this system, focus must be maintained on the "I" in IOOS—Integrated. The NOAA IOOS Program is maintaining this focus, starting at the data level with the DIF driven by the data requirements of national applications such as HAB forecasting, integrated ecosystem assessments, coastal inundation prediction, and a national surface current measurement that support a wide variety of NOAA and national end users.

These steps represent the beginning of a national IOOS, and the lessons learned will support development of the DMAC subsystem and the modeling and analysis subsystem of IOOS. As IOOS end-user requirements are better understood, and the data management and modeling and analysis capabilities are refined to meet these user needs, IOOS will coherently expand its observation subsystem through NOAA and its federal, regional, and other partners. Developing and maintaining the linkages from observation to data management to modeling and analysis to end-user needs across this spectrum of partners requires a different type of integration—organizational integration—which is discussed in the following section.

5. Organizational Integration and Observations

Achieving an effective IOOS requires organizational integration as well as the data and product integration addressed in the DIF and the application areas. To achieve the full potential of IOOS, the NOAA IOOS Program will conduct national leadership efforts, support the development of regional capabilities, and ensure that the IOOS observation subsystem has a sufficient foundation of observation capabilities.

5.1 National Leadership Efforts

To implement IOOS, 17 federal agencies and 11 RAs have formed a national partnership and are sharing responsibility for the design, operation, and improvement of both the national and coastal network of observations. This partnership of U.S. government agencies (federal and state), private enterprise, academia, and nongovernmental organizations is governed by the policies and procedures by which design, implementation, operation, and improvement of IOOS is shared among entities at international, national, and regional levels. Federal agencies fund and implement the global component and the coastal contribution to the national system in collaboration with other partners. This implementation effort will be consistent with the GEOSS framework and the Strategic Plan for the U.S. Integrated Earth Observation System. [23]

The IWGOO is assigned the responsibility of managing the interagency coordination of an ocean observing system for the nation. NOAA is assigned as lead federal agency for planning and coordination of IOOS.[24] The NOAA IOOS Program will work with the IWGOO agencies, as well as other regional IOOS partners to achieve a national system.

Some recent achievements of interagency collaboration include the development of an interagency IOOS Strategic Plan, a white paper detailing connections between the national IOOS infrastructure, the NSF's Ocean Observatories Initiative[25], and NOAA and USACE partnership to develop "A National Operational Wave Observation Plan[26]." The wave observation plan identifies critical gaps in spatial coverage and identifies an approach to incrementally field a wave measurement capability that supports a range of IOOS goals and objectives, including coastal inundation prediction, by leveraging cross-agency and regional interests, funding, and capabilities. In addition, interagency collaborative efforts are underway to enhance integration of water level and quality, and biological data, including discussions among the NOAA IOOS Program, USGS, and the Environmental Protection Agency (EPA) regarding the incorporation of

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[23] Interagency Working Group on Earth Observations, National Science and Technology Council (2005). *Strategic Plan for the U.S. Integrated Earth Observation System.* .http://usgeo.gov/docs/EOCStrategic_Plan.pdf.

[24] Joint Subcommittee on Ocean Science and Technology, National Science and Technology Council, *Charter of the Interagency Working Group on Ocean Observations*, December 19, 2006. The charter also states that "using the resources available at Ocean.US, if needed, the IWGOO will: manage the interagency coordination of IOOS."

[25] NOAA, Integrated Ocean Observing System Program. *Linking IOOS to the Ocean Observatories Initiative.* A white paper to describe the connections between these two ocean observing efforts. February 2009. <http://ioos.noaa.gov/library/ioos-ooi_final.pdf>

[26] Joint Subcommittee on Ocean Science and Technology's, Interagency Working Group on Ocean Observations, *A National Observational Wave Observation Plan*, March 2009. <http://ioos.noaa.gov/program/wavesplan.html>

National Water Information System (NWIS) water-level data and National Water Quality Network (NWQN) data within IOOS. The NOAA IOOS Program is also working with USGS on biological data integration via the U.S. Ocean Biogeographic Information System (OBIS-USA). OBIS-USA is the information component of the Census of Marine Life that serves marine species data for the U.S. and its oceans.

The national IOOS partnership provides credibility to regional IOOS participants as they interface with state and local governments and the private sector. The national relationships also enhance the ability to transition IOOS regional efforts to operational applications. For example, Rutgers University was funded by the Public Service Electric and Gas (PSE&G) company in New Jersey (both partners in the Mid-Atlantic Coastal Ocean Observing Regional Association [MACOORA]), to deliver tailored operational weather forecasts, improved by oceanographic data, and severe weather alerts. The information allows PSE&G to more effectively manage energy requirements and potential impacts to the grid.27 Recognizing the importance of the data to the other partners in the Mid-Atlantic region, PSE&G allowed Rutgers to share the improved model and forecasting capability within MACOORA. The model has also been transitioned to operational use at the NWS WFO in Mt. Holly, New Jersey. The organizational relationships developed under the auspices of IOOS national leadership efforts were essential to the rapid transition of this capability to operations and the resultant benefit to public safety and economic activity.

5.2 Regional IOOS Contributions

A regional approach was chosen by the IOOS community to encompass coastal areas linked by common circulation systems and corresponding ecosystems. The role of Regional Associations (RA) in IOOS is to provide oversight in development and operation of the Regional Coastal Ocean Observing System (RCOOS). Regional efforts are intended to determine the appropriate resolution at which variables are measured, supplement the variables measured by the federal agencies, provide data and information tailored to the requirements of stakeholders in the region, and to implement programs to improve public awareness and education.

Prior to 2007, Congressionally directed funds were allocated to support a collection of regional projects (Appendix A). This resulted in valuable localized observation capability; however, with limited ability to insert regional or national direction, these investments yielded limited regional or national cohesiveness. Also, this approach provided no consistent means to fund operations and maintenance activities to sustain these capabilities over time.

Regional Associations represent a partnership of marine and estuarine data providers with users from state and federal agencies, private industry, non-governmental institutions and academia that provide connection to and understanding of local IOOS user needs, as well as oversight of

[27] From October 2004 through December 2006, these forecasts accurately predicted 82.9 percent of the 602 severe weather events, primarily due to incorporation of real-time sea surface temperature data and improved physics modeling in the forecast process. PSE&G uses the information to pre-position trucks in advance of a storm to limit the duration of power outages and to reduce economic impact.

the development and operation of the RCOOS. The RAs are responsible for managing system development within the region and working with stakeholders to prioritize observations, products, and services that are most important, given available resources. Each has an established governance structure guided by a Memorandum of Understanding, Memorandum of Agreement, or non-profit organization (i.e., Internal Revenue Code (26 U.S.C. § 501(c)(3)) to formalize relationships among the many partners involved in the region.

Due to differences in historic funding levels, RCOOS capacity and level of maturity is not consistent across the 11 regions. However, RCOOSs generally provide 5 complementary contributions to the national IOOS:

(1) Identification of needs at the regional and local levels for, but not limited to, the following end users: coastal zone, resource, and emergency managers; commercial and recreational fishermen; state and local health officials; federal, state, local, and private port operators; oil and gas industry; and ocean energy industry;
(2) *in situ* observing capability to deliver comprehensive, real-time, quality-controlled measurements of oceanic, atmospheric, and watershed properties;
(3) remotely sensed measurements (e.g, HF radar) to deliver quality controlled, synoptic, two-dimensional fields of ocean surface currents;
(4) data management and communication to enable rapid access and/or delivery of data and products to a broad variety of users;
(5) modeling/ analytical capability to assimilate *in situ* and remotely sensed measurements and produce three-dimensional hindcasts, nowcasts, and forecasts of physical, biogeochemical, and biological oceanic processes.

The regional RA/RCOOS DMAC infrastructure will transmit data seamlessly from the *in situ* or remote sensor to the product developer through the implementation of a national DMAC capability, allowing easy access to marine and estuarine data and products for all end-users. IOOS as designed will incorporate observations from estuaries, bays, etc. from its regional network of observations. This is a fundamental component of IOOS as reflected throughout this report. The partnerships established via the RA provide access to not only IOOS-funded observing assets and data, but also state, local and private sector data. By supporting regional implementation of standards and protocols applied at the national level, IOOS regional partners greatly expand the consistency and interoperability of these and other ocean and coastal data and products nationwide.

5.2.1 Regional IOOS Development

The NOAA IOOS Program is the lead Federal Agency for the development and oversight of IOOS regional contributions. The NOAA IOOS Program works with the National Federation of Regional Associations (NFRA) and its RA partners to establish a core set of capabilities that meet both national IOOS requirements and regional end-user needs.

In December 2007, the 11 RAs submitted initial conceptual designs for the development of their respective RCOOSs. These initial designs identified regional priorities and a wide range of regional capabilities, services, and needs for enhancements (Appendix A). The NOAA IOOS

Program will work with NFRA and the RAs to refine this information, identify common functions and services, and align national and regional priorities. This analysis will strengthen IOOS regional planning and enable a more focused, effective partnership to complement national needs for observing infrastructure, improved data management, as well as models and information products that will support both regional and national needs.

In addition to observing, data management, and product development capabilities, RAs provide a broad network to support regional and local IOOS outreach and education. The RAs already work closely with educational partners, such as Sea Grant and the National Science Foundation's Center for Oceanographic Science and Education Excellence (COSEE) program, to identify needs and resources to encourage broad application of IOOS products and services.

5.2.2 The Federal-Regional IOOS Connection

In FY2007, the NOAA IOOS Program transitioned the regional IOOS funding from Congressionally-directed efforts to a merit-based system of cooperative agreements. The merit-based process allows NOAA to guide existing capacity and future regional IOOS development toward common goals, standards, and services that will advance a nationally integrated system.

The NOAA IOOS Program developed a regional business model[28] for the sustained operation of IOOS regional capabilities. This analysis will be used to structure an effective business model that supports the long term development of a national network of regional observing systems, including DMAC, data product development, and other program elements. This effort will result in effective funding processes, enhanced regional accountability and performance measurement, and increased knowledge sharing and lessons learned among the regional IOOS partners and with NOAA. The business model findings call for strong technical leadership from the NOAA IOOS Program to ensure capability developed by the regions is consistent with federal data standards and protocols and effectively integrated into NOAA and other federal programs. For example, the NOAA IOOS Program is leading the effort to integrate high resolution two-dimensional hydrodynamic models developed by the Great Lakes Observing System (GLOS) and the Mid-Atlantic Coastal Ocean Observing System (MARCOOS) into the operational NOAA PORTS®.

The NOAA IOOS Program is working closely with NFRA to provide guidance to the regions regarding national objectives, standards, and programmatic direction, as well as solicit feedback from the IOOS regions on a variety of issues. NFRA includes representation from each of the 11 regions and, therefore, provides a useful conduit to and "single voice" for the IOOS regional perspective. The NOAA IOOS Program is publishing national data standards that will be adopted by each of the regions, providing access to and increased compatibility among additional data streams from across the regions. The NOAA IOOS Program and NFRA provide cross-regional coordination and facilitate information-sharing among the regions, NOAA, and other

[28] NOAA. *The Business Case for Improving NOAA's Management and Integration of Ocean and Coastal Data,* January 2009. < http://ioos.noaa.gov/library/ioos_bus_case_final_jan2009.pdf>

federal IOOS partners to mitigate for the logistical challenges associated with managing and communicating regularly with 11 distinct regions.

Over 60 partners across 10 federal agencies are actively engaged with the 11 RAs to use regional IOOS data, provide data, collaborate on specific projects, participate in governing and advisory boards, and work collaboratively to meet identified stakeholder and user needs. IOOS federal and regional partners engage in a two-way exchange of information to meet shared national and regional objectives, including support for regionally-based initiatives, such as the Gulf of Mexico Alliance, Northeast Regional Ocean Council, Great Lakes Commission and the West Coast Governor's Agreement on Ocean Health. RCOOSs also support national objectives, as articulated in the National Water Quality Monitoring Network, Interagency Oceans and Human Health Research Implementation Plan, National Marine Protected Area Framework, and Fishery Management Plans. The Interagency Program Coordinating Office will play a key role in strengthening connections between the other IWGOO agencies and the RA/RCOOS partners to address these shared objectives.

5.3 Observing Systems

Consistent with IOOS's evolution to a system based on meeting end-user requirements, the NOAA IOOS Program will focus enhancement efforts on those observations most necessary to improve performance of the defined models and decision-support tools. The NOAA IOOS Program, in conjunction with other NOAA programs, will assess the state of the current observing systems relative to these customer requirements and identify observation shortfalls. These shortfalls will be further analyzed through Observing System Simulation Experiments to determine which additional observations are likely to translate to sufficient improvements in model or decision-support tool accuracy or performance to warrant observing system investment.

The NOAA IOOS Program will use the results of these analyses to propose observing system capacity and capability enhancements. Pending this analysis, the NOAA IOOS Program will focus on sustaining existing observing systems and meeting specific enhancement requirements that are clearly linked to well-defined national or regional end-user requirements.

6. Conclusion

As a coordinated network of people and technology working together to generate and disseminate useful data on our coasts, Great Lakes, and oceans, the U.S. IOOS will link ocean observations to data analysis and the relevant environmental information in a manner that is designed, implemented, operated, and evaluated to meet user needs. The U.S. IOOS will also be integrated with the GOOS to support the achievement of broader benefits associated with a truly global system.

NOAA IOOS is leading efforts to design, operate, and improve both the national and regional networks of ocean observations in partnership with 17 federal agencies, 11 RAs, and many NOAA offices and programs. The integration resulting from these partnerships will increase our knowledge of complex environmental phenomena and support better and smarter coastal and ocean-related management decisions. This integration will be multidimensional, including existing diverse efforts in three areas:

- *Data*, integrated with common content characteristics and sufficient metadata attached to data sets to allow discovery and informed, appropriate use of the data by a wide variety of models and decision-support tools and public and private end users,

- *Product*, integrated end-to-end (observations, data management and communication, modeling, and decision-support tools) to support end-user-defined requirements while maintaining interoperable components,

- *Organization*, integrated across federal agencies and their regional partners to leverage distinctive missions and competencies and minimize duplication of development efforts.

IOOS will build on the current observing system infrastructure with an initial focus on addressing data integration and interoperability issues. The NOAA IOOS Program efforts will achieve improvements in specific application areas including forecasts of harmful algal blooms, integrated ecosystem assessments, coastal inundation predictions, and national surface current monitoring. The NOAA IOOS Program is specifically addressing gaps in data management to improve model outputs, assessments, and products, as well as efficiencies in time and costs.

Through the development of a truly integrated ocean observing system, NOAA, with its national, regional, and other partners, will provide enhanced capabilities to allow scientists, mariners, farmers, teachers, emergency responders, environmental resource managers, and the American public at-large to rapidly access comprehensive information on demand and in formats that are useful for making everyday decisions and that can ultimately save lives.

Appendix A. IOOS Regional Contribution

A.1 Initial Analysis of Regional Conceptual Design Studies

Each IOOS Regional Association recently completed a conceptual design study for its associated RCOOS. Copies of these studies were provided to the NOAA IOOS Program in late December 2007. The NOAA IOOS Program has not yet had an opportunity to fully evaluate these designs (to look at regional capacity, system growth, and cost levels) NOAA will work with the National Federation of Regional Associations (NFRA) to refine the information contained within the conceptual design studies to develop a sound approach and associated cost estimates needed to achieve a cohesive, regional contribution to the national IOOS.

In addition to cost information, the conceptual designs also included priority issues and development activities within the region. Table A-1 represents a subjective assessment of need/ priority for each national application area based on an initial analysis of the regional conceptual design studies. These designs validated that HAB forecasting, IEAs, coastal inundation, and HFR for delivery of near-real-time currents are priorities not only on a national level, but also for the regions. A score of "Low," for example, indicates the topic was mentioned with little emphasis or explanation.

Nearly all conceptual designs made reference to the 4 national application areas and capabilities. The consistently "High" ranking for IEAs represents an interpretation, based on priorities placed on habitat, population dynamics, larval dispersion, and ecosystem-based management. Not all regions mentioned IEAs explicitly.

Other priority themes included in most reports include:

- water quality (particularly for drinking water in the Great Lakes),
- search and rescue and marine safety,
- oil and hazardous material spill response,
- climate variability, and
- marine transportation support.

Table A-1. Importance of National Application Areas to IOOS Regions

Regional Association	Priority level for the region			
	HABs	IEA	CI	HFR
Alaska Ocean Observing System (AOOS)	Low	High	Medium	Medium
Caribbean Regional Association (CaRA)	Low	Low	High	High
Central and Northern California Coastal Ocean Observing System (CeNCOOS)	High	High	Medium	High
Gulf of Mexico GCOOS	High	Medium	High	High
Great Lakes Observing System (GLOS)	Low	High	Medium	Medium
Mid-Atlantic Coastal Ocean Observing Regional Association (MACOORA)	Medium	High	High	High
Northeast Regional Association of Coastal Ocean Observing Systems (NERACOOS)	Medium	High	High	Medium
Northwest Association of Networked Ocean Observing Systems Northwest (NaNOOS)	Medium	High	Medium (erosion)	High
Pacific Islands Integrated Ocean Observing System (PacIOOS)	Low	High	High	High
Southeast Coastal Ocean Observing Regional Association (SECOORA)	Medium	High	High	High
Southern California Coastal Ocean Observing System (SCCOOS)	High	High	Medium	High

A.2 Historic Regional Investments

Prior to FY 2007, investment in regional IOOS capability was funded through congressionally directed projects that were administered primarily by NOAA, although some additional funding was provided through the Office of Naval Research. In FY 2007, NOAA implemented a competitive merit-based review process. Beginning in FY 2007, regional investments have been made by NOAA via cooperative agreement awards. Regional investments were made using this process in FY 2007 ($21.6M), FY 2008 ($20.4M) and FY 2009 ($20.9M). In FY2010, $28M is expected to be awarded using the same process.

Appendix B. List of Acronyms

ACT	Alliance for Coastal Technologies
ADCIRC	Advanced Circulation Model
ADCP	Acoustic Doppler Current Profile
Caro-COOPS	Carolinas Coastal Ocean Observing and Prediction System
CDC	Centers for Disease Control and Prevention
CI	Coastal Inundation
CO-OPS	Center for Operational Oceanographic Products and Services
COMPS	Coastal Ocean Monitoring and Prediction System
CORMP	Coastal Ocean Research and Monitoring Program
DAC	Data Assembly Center
DIF	data integration framework
DMAC	data management and communication
ECOHAB	Ecology and Oceanography of Harmful Algal Blooms
EEZ	Exclusive Economic Zone
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
HAB	Harmful Algal Bloom
HABHRCA	Harmful Algal Bloom and Hypoxia Control Act
HFIP	Hurricane Forecast Improvement Project
HFR	high-frequency radar
GEOSS	Global Earth Observation Systems of Systems
GOMOOS	Gulf of Maine Ocean Observing System
GOOS	Global Ocean Observing System
GTS	Global Telecommunication System
IEA	Integrated Ecosystem Assessment
IOOS	Integrated Ocean Observing System
IWGOO	Interagency Working Group on Ocean Observations
JSOST	Joint Subcommittee on Ocean Science and Technology
MACOORA	Mid-Atlantic Coastal Ocean Observing Regional Association
MERHAB	Monitoring and Event Response for Harmful Algal Blooms
NANOOS	Northwest Association of Networked Ocean Observing Systems
NASA	National Aeronautics and Space Administration
NDBC	National Data Buoy Center
NFRA	National Federation of Regional Associations

NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
NOEP	National Ocean Economics Project
NOPP	National Oceanographic Partnership Program
NSF	National Science Foundation
NWIS	National Water Information System
NWLON	National Water Level Observation Network
NWQN	National Water Quality Network
NWS	National Weather Service
OAP	United States Ocean Action Plan
OBIS-USA	United States Ocean Biogeographic Information System
OHHI	Oceans and Human Health Initiative
ONR	Office of Naval Research
OSE	Observing System Experiment
OSSE	Observing System Simulation Experiment
PaCOOS	Pacific Coast Ocean Observing System
PFMC	Pacific Fisheries Management Council
PORTS®	Physical Oceanographic Real Time System
PSE&G	Public Service Electric and Gas (New Jersey)
RA	Regional Association
RCOOS	Regional Coastal Ocean Observing System
SAR	search and rescue
SCCOOS	Southern California Coastal Ocean Observing System
SCOOP	SURA Coastal Ocean Observing and Prediction
SLOSH	NHC Sea, Lake, Overland, Surge from Hurricanes
SURA	Southeastern Universities Research Association
TABS	State of Texas Automated Buoy System
TPC	NOAA Tropical Prediction Center
USACE	United States Army Corps of Engineers
USCOP	United States Commission on Ocean Policy
USGS	United States Geological Survey
WFO	NWS Weather Forecast Office
WMO	World Meteorological Organization