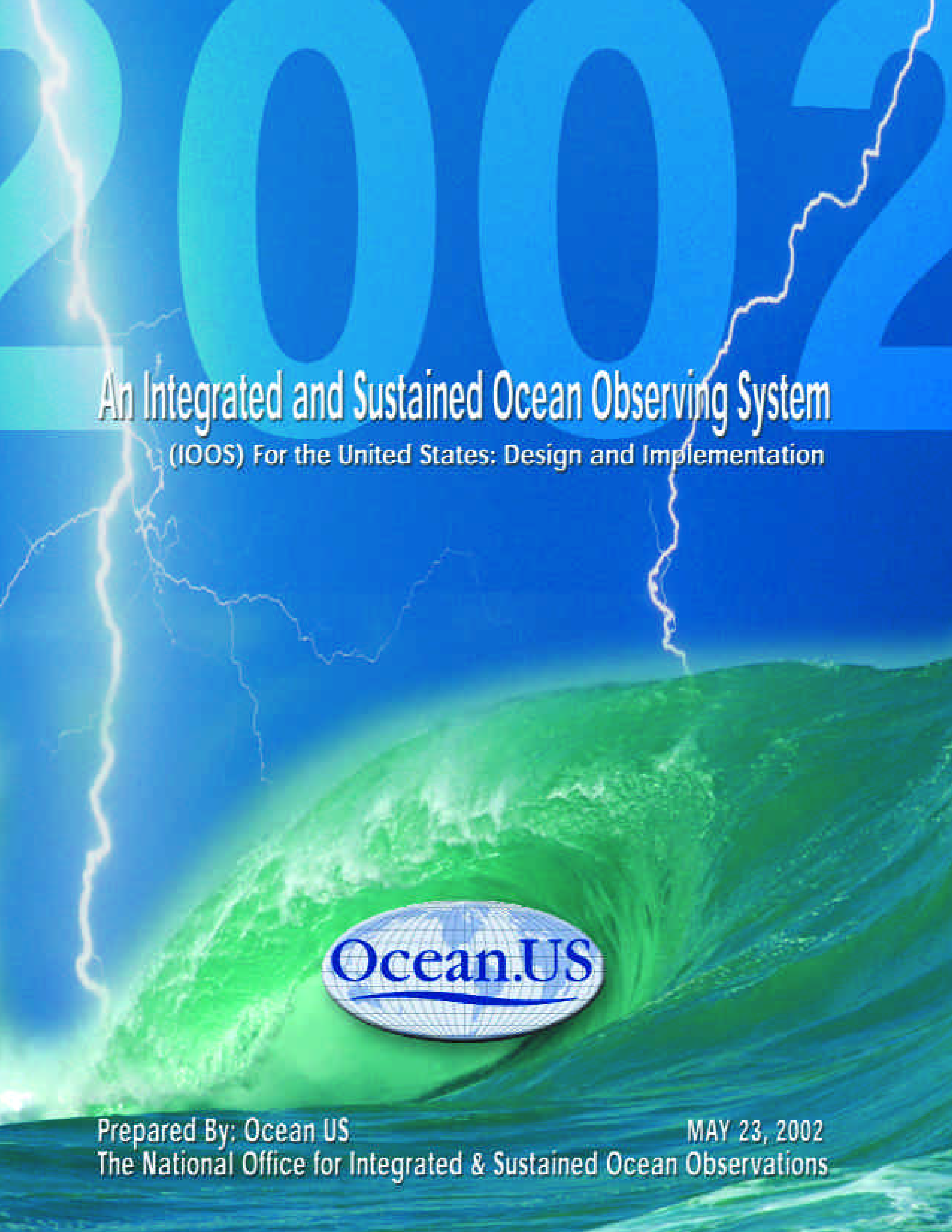

2002

An Integrated and Sustained Ocean Observing System

(IOOS) For the United States: Design and Implementation

Ocean.US

Prepared By: Ocean US
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The National Office for Integrated & Sustained Ocean Observations

WORKSHOP EXECUTIVE COMMITTEE

- **CAPT David Martin**, USN, Ph.D., Director, Ocean.US
- **Dr. Larry Atkinson**, Dept of Oceanography, Old Dominion University
- **Dr. Thomas Malone**, Center for Environmental Science, Univ. of Maryland
- **Dr. Worth Nowlin**, Dept of Oceanography, Texas A&M University

WORKSHOP SUPPORT STAFF

OCEAN.US

- **Ms. Rosalind Cohen**
- **Ms. Muriel Cole**
- **Mr. Patrick Dennis**
- **Dr. Stephen Piotrowicz**

NOAA

- **Ms. Judy Hickey**

NOPP PROGRAM OFFICE

- **Dr. William Fornes**
- **Ms. Shannon Gordon**
- **Mr. Robert Wagner**

Special thanks to **Ms. Shelby Walker**, Sea Grant Knauss Fellow, NSF

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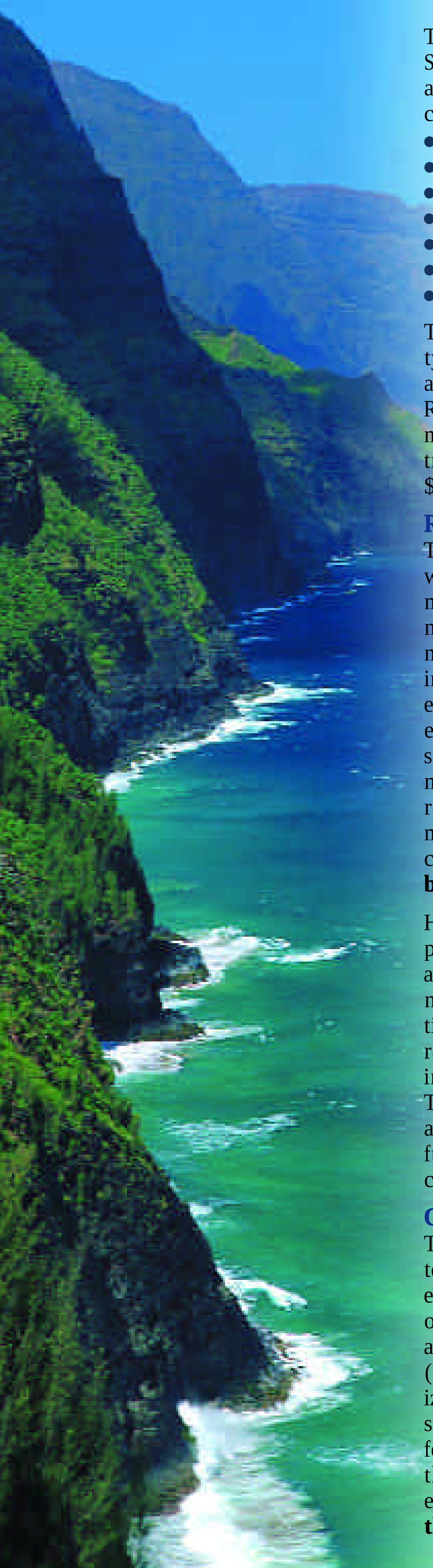
AN INTEGRATED AND SUSTAINED OCEAN OBSERVING SYSTEM (IOOS) FOR THE UNITED STATES: DESIGN AND IMPLEMENTATION



There is an immediate need for a sustained and Integrated Ocean Observing System (IOOS) that will make more effective use of existing resources, new knowledge, and advances in technology as the means to develop a unified, comprehensive, cost-effective approach for providing the data and information required to:

- improve the safety and efficiency of marine operations,
- more effectively mitigate the effects of natural hazards,
- improve predictions of climate change and its effects on coastal populations,
- improve national security,
- reduce public health risks,
- more effectively protect and restore healthy coastal marine ecosystems, and
- enable the sustained use of marine resources.

The development of such an integrated system will benefit those sectors of society that use or are influenced by the ocean from private enterprise and government agencies to the science and education communities, NGOs, and the public at large. Recent studies indicate that benefits will substantially exceed the required investment. For example, improved climate forecasts made possible by the El Niño tropical ocean observing system have been estimated to save the agriculture sector $300M/year. The system costs $10M/year to maintain and operate.

RATIONALE FOR AN INTEGRATED SYSTEM

The oceans are critically important to our society. 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; they are a major reservoir of natural resources, havens for recreation, virtual schoolrooms for educators, and natural laboratories for science. Rapid growth in the number of people living in immediate proximity to the ocean is placing conflicting demands on coastal ecosystems that threaten their integrity and capacity to provide goods and services. This demographic trend is also placing an increasingly large segment of our society at risk to natural hazards. Improvements in the quality of life, effective management of the marine environment and sustained utilization of living resources depend on the ability to (1) rapidly detect changes in the status of marine ecosystems and living resources and to (2) provide timely predictions of changes and their consequences for the public good. **We do not have this capability today.**

Historically, the U.S. has responded to these challenges in an uncoordinated, piecemeal, ad hoc fashion. Consequently, when the programs of all government agencies with ocean related missions and goals are considered as a whole, they are not as cost-effective as they could be, and they do not provide data and information on the causes and consequences of human activities and natural variability rapidly enough to serve as a basis for timely and scientifically sound decision making - **the whole is less than the sum of its parts**. This need not be the case. Today, the rates at which data can be acquired, processed and analyzed are approaching the time scales on which our political, social and economic systems function. It is time to close the gap between scientifically sound analyses of changes in the oceans and the decision making process.

CONCEPTUAL DESIGN

The IOOS must be operational (in the same sense as the weather forecasting system), and it must evolve as a partnership of government agencies (state and federal), private enterprise, academia and non-governmental organizations. The ocean observing system is envisioned as a network that systematically acquires and disseminates data and information to serve the needs of many user groups (government agencies, industries, scientists, educators, non-governmental organizations, and the public). Achieving this goal depends on the development of a system that efficiently links ocean observations to data management and analysis for timely delivery of environmental data and information. This is the purpose of the IOOS, the implementation and evolution of which will selectively build on, enhance and supplement existing elements based on user group specifications - **the whole will be greater than the sum of its parts.**

AN INTEGRATED AND SUSTAINED OCEAN OBSERVING SYSTEM (IOOS) FOR THE UNITED STATES: DESIGN AND IMPLEMENTATION

The IOOS will develop as two interdependent components, a global oceanic component and a national coastal component. The **global component** of the IOOS is part of an international partnership to develop a global system (the Global Ocean Observing System, GOOS) designed to improve weather forecasts and climate predictions. The **coastal component** is a national effort concerned with the effects of the ocean-climate system and human activities on coastal ecosystems, living resources, and the quality of life in the coastal zone. This component is conceived as a federation of regional observing systems nested in a federally supported national backbone of observations, data management, and modeling. Regional observing systems would both contribute to and benefit from the national backbone and would enhance the national backbone based on regional priorities.

Emphasis here is on in situ observations. Although critical to the development of a fully integrated observing system, the recommendations here do not specifically address requirements for satellite-based remote sensing. Clearly, implementation of in situ elements of the system must be coordinated with and meet the requirements for the remote sensing elements of the system.

DEVELOPING THE INITIAL SYSTEM

The development of the IOOS requires the establishment of (1) a process for selectively incorporating, enhancing and supplementing existing programs; (2) an integrated data management subsystem; (3) procedures for selectively and systematically migrating new knowledge, technologies and models into the operational observing system; and (4) mechanisms for permanent and ongoing evaluations of system performance.

Development of the global component depends on:

- full implementation of Argo and the global ocean time series observatories,
- successful completion of the Global Ocean Data Assimilation Experiment (GODAE),
- optimizing the global network of observations, and
- enhancing the ocean time series observatories with key biological and chemical sensors.

Implementing the coastal component depends on:

- enhancing existing federal networks for in situ measurements from fixed platforms and tide gauges to improve spatial and temporal resolution and to expand the spectrum of measurements to include physical, chemical and biological variables; and
- building the National Federation by establishing regional observing systems as “proof of concept” projects with the goal of transitioning successful systems or elements of these systems into an operational mode as part of the IOOS.

Existing governance structures were not designed to implement, maintain, and improve a sustained and integrated observing system for coasts and oceans. Three approaches are described in this report that should be considered in the establishment of an effective governance mechanism.

FUNDING

Current Federal spending on ocean related research is approximately $600M, while spending for operational oceanography across all federal agencies and other stakeholders is roughly $1B. The additional annual cost of a fully implemented IOOS is estimated to be $500M in constant dollars. A phased, multi-year development of the IOOS is recommended to implement the system effectively and efficiently. To begin this effort, an initial investment of new money is required to (1) accelerate the implementation of the U.S. commitment to the global ocean observing system for climate change ($30M), (2) develop the data communications and management system required for the IOOS ($18M), (3) enhance and expand existing federal programs ($40M), and (4) develop regional observing systems ($50M). The total new investment needed to begin the phased implementation plan is estimated to be $138M.

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1. PURPOSE

This report, the first of three reports on the implementation of a national ocean observing system, summarizes (1) the rationale for an Integrated Ocean Observing System (The Problem), (2) the conceptual design of the System (Solving the Problem), (3) economic benefits of an integrated system, (4) first steps for implementation, and (5) the high priority actions and associated funding levels that should be implemented now (Conclusions). First steps and high priorities are based on the consensus that crystallized at the March 2002 Ocean.US workshop. The recommendations presented in this report build on the work of many national and international bodies and on two recent reports prepared under the auspices of the National Ocean Research Leadership Council (NORLC) of the National Ocean Partnership Program (NOPP): "Toward a U.S. Plan for an Integrated, Sustained Ocean Observing System" (submitted to Congress on 20 April, 1999) and "An Integrated Ocean Observing System: A Strategy for Implementing the First Steps of a U.S. Plan" completed in 2000.

Two reports will follow this one: (1) the Proceedings of the March 2002 Ocean.US workshop (to be completed by 1 June 2002) and (2) a multi-year, phased implementation plan with a time table and cost estimates (to be in Draft form by 1 September, 2002). The latter, which will be developed in partnership with the federal agencies of NOPP, is intended to be a strategic plan that charts the way forward based on current knowledge and technical capabilities. It is also intended that this plan be subject to annual review and updating as the number of users grows and their needs diversify, and as new knowledge and technologies become available.

2. THE PROBLEM

2.1 DETECTING AND PREDICTING CHANGE

The oceans surrounding the United States are our lifelines to national and international commerce and a tie to our historical roots. They are sources and modifiers of our weather and climate; they are buffers for national security; they are major reservoirs of living and non-living

NATURAL & ANTHROPOGENIC
CLIMATE, MARINE SERVICES, NATURAL HAZARDS, & NATIONAL SECURITY
PUBLIC HEALTH
ECOSYSTEM HEALTH
LIVING MARINE RESOURCES

TABLE 1. Natural and anthropogenic drivers of change and associated phenor

resources, are places of recreation, and subjects of scientific research aimed at understanding the "water planet" called Earth.

Ocean environments are undergoing profound changes as a consequence of two contemporary global patterns of great significance to the health, safety and well being of the U.S. population: (1) the increase in both the size of the human population and the proportion of that population living in the coastal zone and (2) climate change. As the number of people in the coastal zone continues to increase rapidly, the demands on coastal systems to provide commerce, recreation, and living space and to receive, process, and dilute the effluents of human society will continue to grow. Increasing coastal populations are placing a larger fraction of our society at risk from natural hazards. At the same time, coastal ecosystems are undergoing changes that are likely to affect their capacity to provide these services.

FORCINGS

- Global climate change
- Storms & other extreme weather events
- Seismic events
- Ocean currents, waves, tides & storm surges
- River & ground water discharges
- Physical restructuring of the environment
- Alteration of the hydrological cycle
- Harvesting living & nonliving resources
- Alteration of nutrient cycles
- Sediment inputs
- Chemical contamination
- Inputs of human pathogens
- Introductions of non-native species

PHENOMENA OF INTEREST

- Increasing heat content of the oceans
- Sea level rise
- Changes in sea state
- Changes in coastal circulation
- Coastal flooding
- Shoreline changes
- Change in shallow water bathymetry

- Chemical contamination of seafood
- Exposure to human pathogens

- Habitat modification & loss
- Changes in biodiversity
- Coastal eutrophication
- Harmful algal events
- Invasive species
- Biological affects of chemical contaminants
- Chemical contamination of the environment
- Disease & mass mortalities of marine organisms

- Changes in the abundance of exploitable living marine resources
- Capture fisheries: changes in landings (plants and animals)
- Aquaculture: changes in harvest

mena of interest in coastal marine ecosystems that are the subject of the IOOS.

Improving the capacity to detect changes regionally and globally and predicting how global-scale drivers alter coastal ecosystems are major objectives of the observing system. Of primary concern are

- Basin scale processes such as El Niño, the Pacific Decadal Oscillation, and the North Atlantic Oscillation;
- Global climate change, and its effects on temperature, weather patterns, and sea level;
- Changes in inputs of water, sediments, nutrients and contaminants from coastal drainage basins;
- Exploitation of living marine resources;
- Seismic events, and
- Global movements of ships and cargo.

Coastal ecosystems are subject to focused impacts from land, sea and air. **This underscores the importance of continuing and improving observing systems designed to measure the influences of water and associated materials from the land to the sea.**

2.2 TOO MUCH, TOO LITTLE AND TOO LATE

Effective management and sustained utilization of the marine environment and its resources depend on our ability to detect and predict changes in the status of coastal ecosystems and living resources on local to national scales. **We do not have this capability today**. In the continued absence of a system for improved detection and prediction of global and coastal changes and their environmental and socio-economic effects, conflicts will increase between commerce, recreation, national security, development, conservation, and the management of living resources. The adverse social and economic costs of uninformed decisions will increase accordingly.

There is an immediate need for a sustained and integrated ocean observing system that will make more effective use of existing resources, new knowledge, and advances in technology as the means to:

- Improve predictions of climate change and its effects on coastal populations,
- Mitigate more effectively the effects of natural hazards,
- Improve the safety and efficiency of marine operations,
- Improve national security,
- Reduce public health risks,
- More effectively protect and restore healthy coastal marine ecosystems, and
- Sustain marine resources.

In the past, each of these seven goals (and often subsets of them) has been addressed through the development of independent programs that serve the specific purposes of a limited number of user groups for relatively short time periods. The federal, state, and private mechanisms established to fund and implement these programs were not designed to support a sustained, comprehensive and integrated approach to meeting these goals. Consequently, we suffer from the paradox of **too much** (redundant programs with little or no outside coordination or communication), **too little** (few if any programs are sufficiently comprehensive), and too late (current procedures for acquiring, processing, and analyzing data are too slow relative to the decision-making process). **We must broaden our concepts and develop mechanisms for sustaining an integrated system of observations, data management and analysis to provide timely responses to user requirements.**

2.3 WHY NOW?

The development and implementation of scientifically sound environmental policies for effective management and sustainable utilization of global and coastal environments and resources have been slow and limited in scope for two major reasons. First, the rate of data acquisition, processing and analysis for basic research is too slow to effectively aid the decision-making process. We must improve and streamline current mechanisms by which data are communicated, managed and analyzed. Second, the gap between scientific knowledge and public understanding of environmental issues is wide and growing wider. An observing system is needed that provides routine and rapid access to data and information to close these gaps.

Although the challenges are significant, we are witnessing a convergence of societal needs and technical capabilities that provide the motivation and means to begin the implementation of an integrated and sustained ocean observing system. The time is right to develop an observing system that (1) is based on sound science; (2) is responsive to the information needs of many user groups; (3) makes more effective use of existing resources, knowledge and expertise for the public good; (4) provides a direct window to the ocean environment for research and public education; and (5) provides a framework that will enable government agencies to achieve their missions and goals more effectively.

3.SOLVING THE PROBLEM

3.1 AN INTEGRATED AND SUSTAINED SYSTEM

The IOOS is envisioned as a national and international network that systematically acquires and disseminates data and products in response to the needs of government agencies (from resource management and land-use planning to emergency response and national defense), industries, scientists, educators, non-governmental organizations, and the public. Use of these data for both detection and prediction depends on the development of a system that effectively links ocean observations to data management and analysis

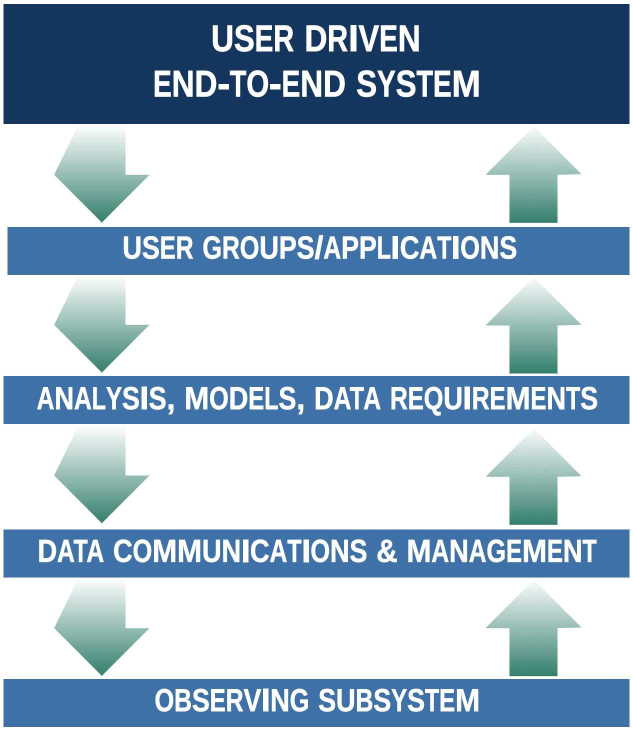
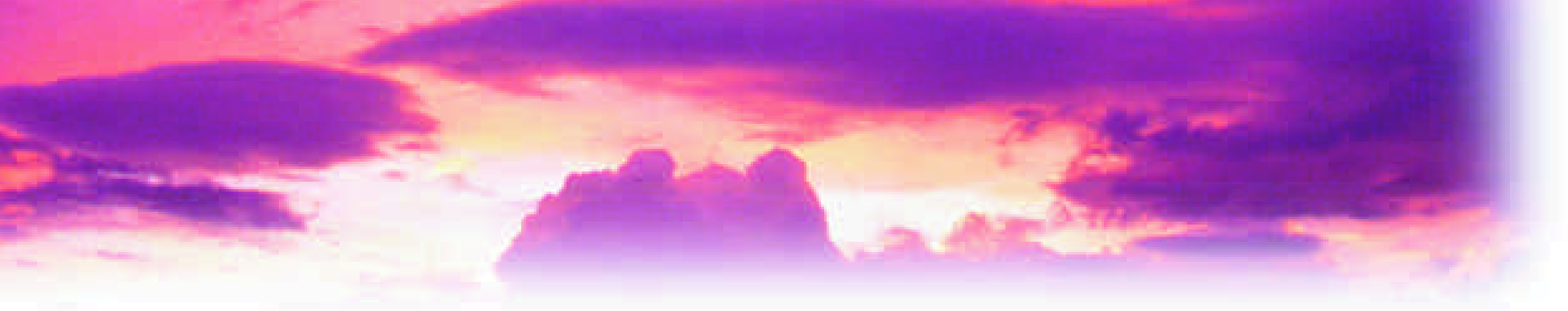


FIGURE 1. Linking user needs to measurements requires a managed, two-way flow of data and information among three essential subsystems: (1) observations (2) data communications and management, and (3) modeling and data analysis. The IOOS is "user-driven" in that the user needs determine what variables are measured, how data are managed and analyzed, and the speed with which quality data and data-products become available to users.

for more timely access to data and delivery of environmental information. Thus, the system will consist of three linked subsystems for data acquisition, management and analysis (Figure 1) that are designed, implemented, operated and evaluated in terms of user needs.

In some ways the National Weather Service provides a model for the development of IOOS. While the issues relevant to atmospheric observations and prediction are not as multi-dimensional as those required for the IOOS, the NWS maintains a system of observations, data management and analysis designed to provide weather forecasts and warnings for the public good. Today,



the NWS supplies meteorological data and products, in accordance with national standards, to private enterprise, scientists and educators who generate value-added products to meet specific needs. Timely delivery of data and products (e.g., weather nowcasts and forecasts) are made possible by linking real-time data streams to models via effective data management.

Unlike the NWS, ocean observing systems have been initiated and maintained by many different agencies, universities, industries, and other organizations. Consequently, the process for establishing an integrated ocean observing system can be compared to assembling a patchwork quilt. Some pieces of the quilt already are in place, others are ready to be installed, and others have yet to be designed or imagined. With time, some will be replaced as technology advances, understanding increases, and needs evolve.

3.2 THE TWO COMPONENTS OF IOOS

The IOOS will develop as two related and linked components: (1) a global, oceanic component, and (2) a national coastal component. The global component is part of an international collaboration that will provide the means to improve nowcasts and forecasts of weather, surface wave and current patterns, and general circulation, and predictions of climate trends on a global scale, as well as boundary and initial conditions for higher-resolution applications in the coastal zone. It is of primary interest to users in the climate, defense, maritime commerce, research, and education sectors. The coastal component encompasses the U.S. EEZ, estuaries, and the Great Lakes (Figure 2). It is envisioned as a collaboration among state and federal agencies, industry, non-governmental organizations (NGOs), and academia. It is primarily concerned with the effects of weather, cli-

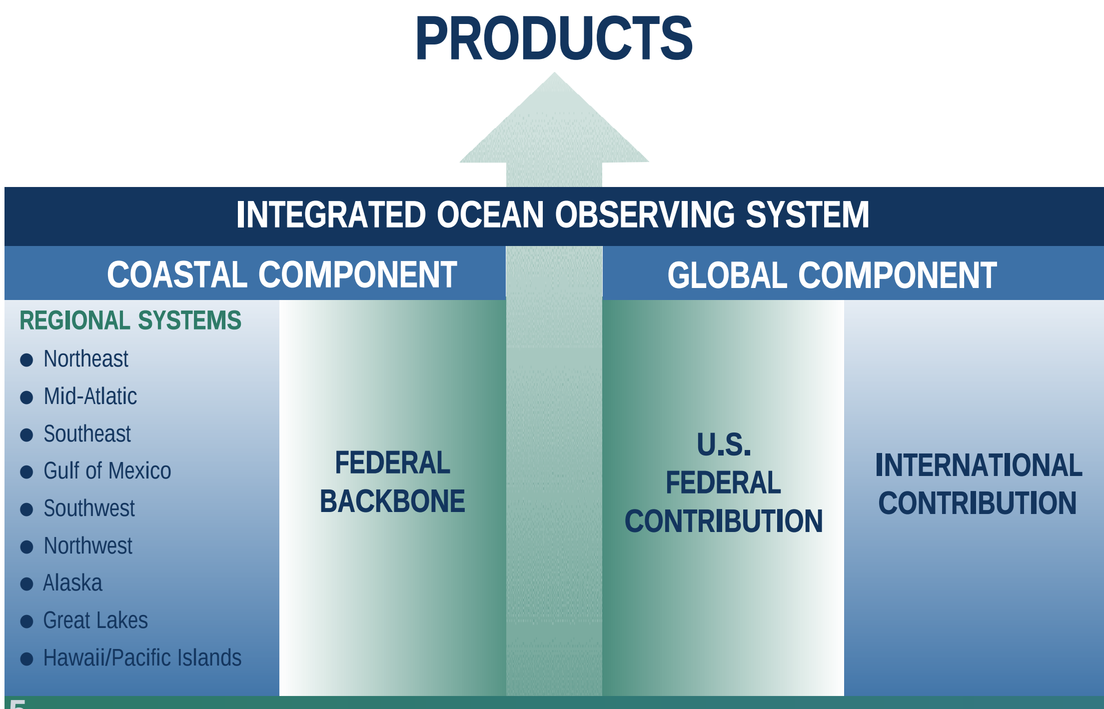


FIGURE 2. A schematic of the IOOS illustrating the relationships between the Federal contributions to the national coastal and the global ocean components. The global component is being developed as an international collaboration. The coastal component will develop as a national federation of regional systems in which regional systems contribute to and benefit from a federally supported national backbone of observations and data management (section 3.4).

mate, and human activities on coastal ecosystems, living resources, and people who live, work and play in the coastal zone.

3.3 THE GLOBAL COMPONENT

The global component of the IOOS is part of an international effort to significantly improve our ability to detect and predict changes in the ocean-climate system on a global scale. Representatives from the international oceanographic (GOOS) and climate (GCOS) communities reached consensus on the next steps for the global module. The plan calls for an internationally sponsored and maintained global system of observations based on:

- Continued deployment of ocean observing satellites;
- Enhanced global observations of coastal sea level;
- Systematic observations of the ocean surface with modern techniques;
- An integrated upper ocean observing system for temperature (heat) and salinity (freshwater);
- A global suite of fixed time series stations; and
- Repeat surveys of ocean carbon and water column conditions.

Implementation is underway, but not complete. Elements of the observing system currently being implemented include (1) the Argo array of drifting, profiling floats designed to provide high quality oceanic data for global modeling; (2) the TAO/TRITON (tropical atmosphere ocean/triangle trans ocean fixed buoy network) array of data buoys in the equatorial Pacific Ocean for improved detection and prediction of El Niño and La Niña events; and (3) the Global Ocean Data Assimilation Experiment (GODAE). Support of national research programs is required to develop technology for the evolution of the global module and to evaluate and improve its effectiveness. The global module also calls for the use of cutting-edge technology to assimilate all available ocean data into products that can be used to evaluate changes in the state of the global ocean for a wide variety of applications, to increase our understanding of the roles of the ocean in global climate variability, and to improve forecasts of future climate. The U.S. global component will fulfill the national contribution to the global module as well as provide initiative for the development of technology for national and international interests.

3.4 THE COASTAL COMPONENT

The design and implementation of the coastal component has lagged behind the global component. Impediments to the development of the coastal module include:

- The challenge of designing and implementing a system to detect and predict changes in a region as complex as the coastal zone;

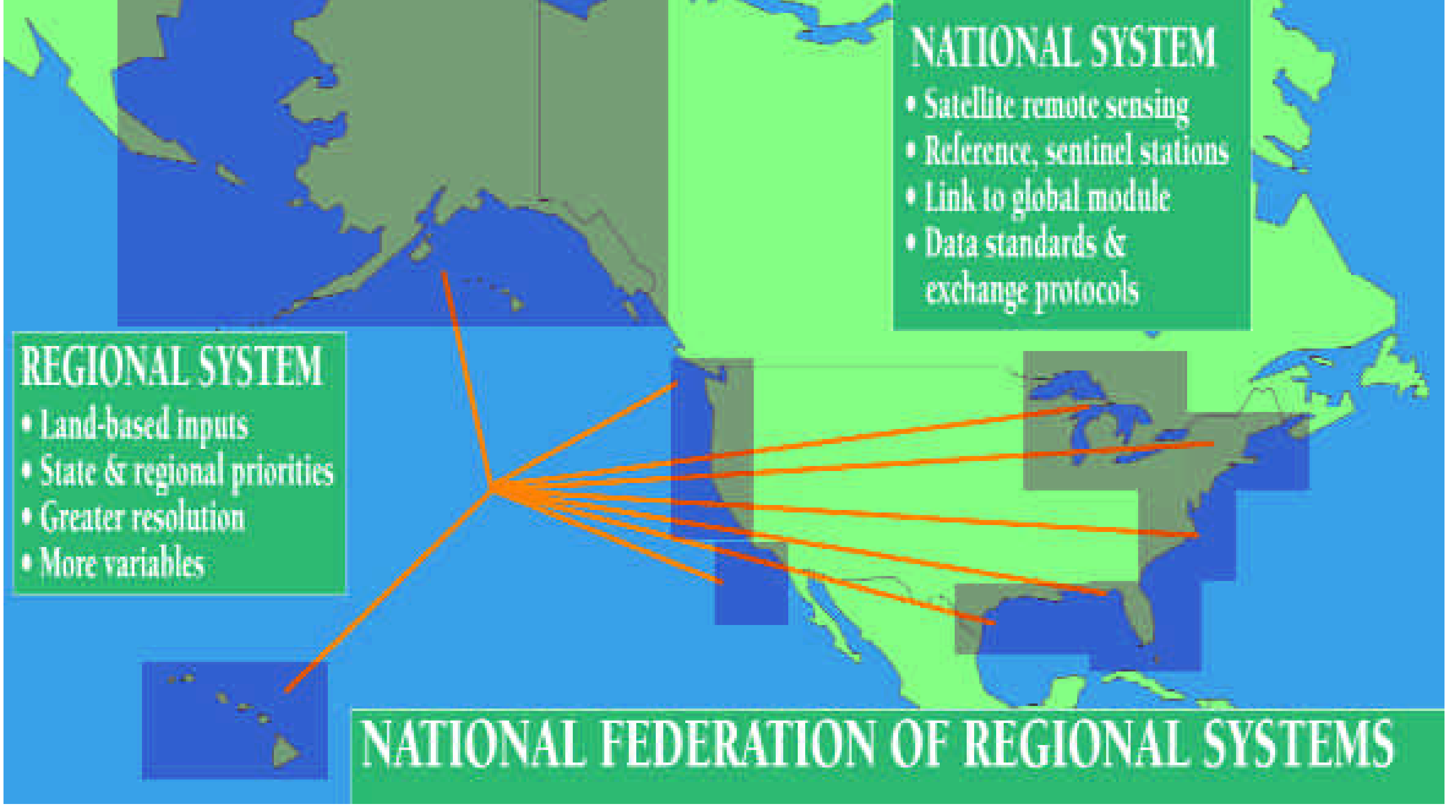


Figure 3. The coastal component of the IOOS will be a national federation of regional observing systems. Regional boundaries are shown for conceptual purposes only. Although there may be a rough correspondence to the regions listed in Figure 2, in actual practice, boundaries will be determined by regional priorities.

Regional Priorities and the National Backbone: For example, tracking the movement of lobster larvae to improve forecasts of recruitment may be a priority in the Gulf of Maine; movements of the Loop Current that endanger offshore drilling operations might be a high priority in the Gulf of Mexico; the effects of an El Niño event on the distribution of fish stocks might be a high priority off California; while tracking coastal currents that are migratory pathways for whales, sea lions, and salmon may be a priority in the Gulf of Alaska. Observations of coastal circulation, temperature and salinity are required for all of these regional priorities, but because applications differ, the observing systems for each region will differ in terms of when and where measurements are made, the kinds of measurements made, the kinds of models used, etc.

- Inefficient and ineffective data communications and management of diverse data from many sources;
- The challenge of developing and maintaining technologies for sensing biological and chemical changes in near real-time;
- Lack of an accepted process for selectively transitioning new technologies and knowledge into an operational mode; and
- The challenges of developing partnerships between all stakeholders.

The Ocean.US workshop specifically addressed these challenges and determined that the time has come to implement the coastal component.

The coastal component is conceived as a federation of regional observing systems nested in a federally supported national backbone of observations. Regional observing systems will contribute to and benefit from the national backbone (Figure 3). This construct reflects two important realities: (1) environmental priorities vary among regions and states, and (2) there are common requirements for data and data processing that transcend state and regional boundaries and provide a basis for achieving economies of scale.

The purpose of the national backbone is to maintain and operate the observing and data management infrastructure that will benefit the nation and regional observing systems in several important ways:

- establish a network of reference stations (to provide baseline data required to assess the significance of local variability) and sentinel stations (to provide early warning indicators, i.e., advanced warnings of events and trends and to allow adaptive monitoring for improved detections and predictions);
- establish standards and protocols for measurements, data exchange and management (for rapid access to diverse data from disparate sources);
- link the global component to regional observing systems (to detect and predict the effects of global scale weather and climate patterns on coastal ecosystems);
- enable comparative ecosystem analysis

(required to develop operational models of ecological change);

- provide economies of scale that will improve the cost-effectiveness of regional observing systems by investing in a national system that minimizes redundancy and optimizes data and information exchange (the IOOS will be more than the sum of its parts); and
- facilitate capacity building within regions (to ensure that all states and regions can contribute to and benefit from the IOOS).

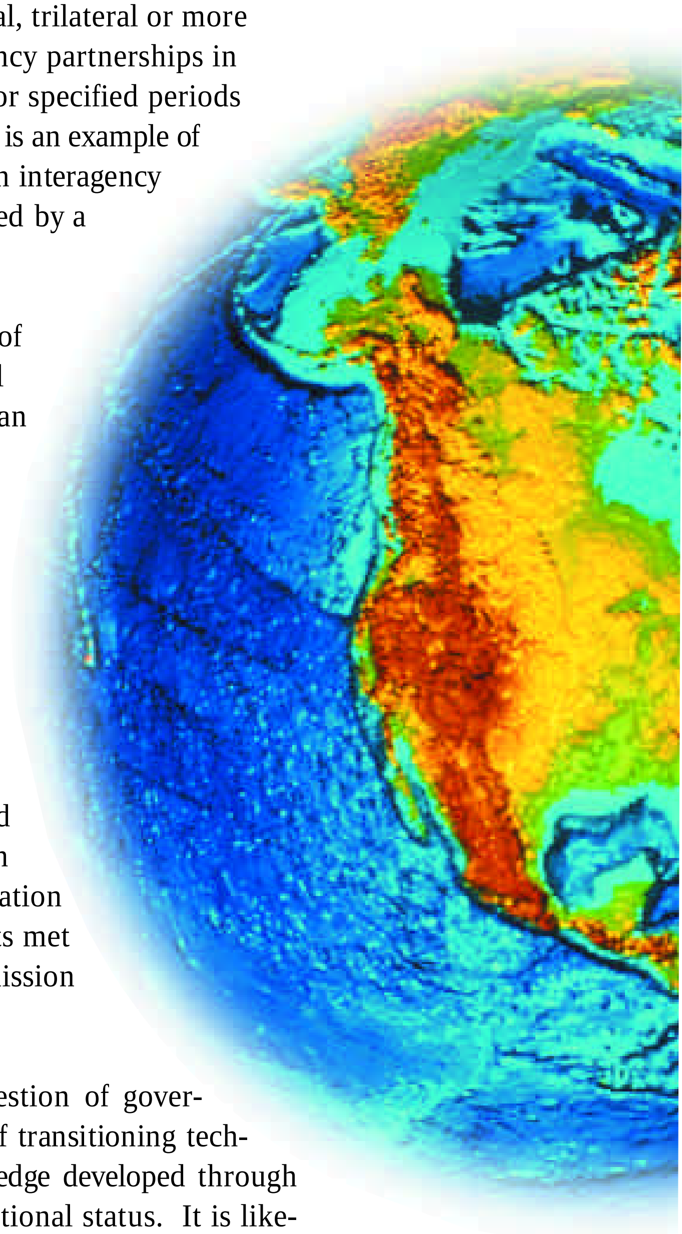
Specifically, the national backbone will measure and manage a set of core variables required to detect and predict most of the phenomena of interest associated with the seven goals (to achieve economies of scale). However, it is important to emphasize that **measurement of the core variables will not, by themselves, provide all of the data required to detect and predict changes in or the occurrence of all of the phenomena of interest**. For instance, in the areas of public health, ecosystem health and living marine resources, it is likely that more variables will have to be measured with greater resolution on regional scales.

3.5 GOVERNANCE CONSIDERATIONS

The IOOS must be nationally coordinated and regionally relevant, and it must enable government agencies and other user groups to fulfill their missions and achieve their goals more effectively. At present, there is no coherent governance structure that provides an efficient mechanism to achieve these goals. New approaches to governance will be needed for the development of both the national backbone and regional observing systems. We focus here on the federal level where several governance options could provide the basis for achieving a coordinated approach to implementing, developing and operating the IOOS. Options include:

- The establishment of an interagency ocean observing Integrated Program Office (IPO) that would administer and control funding for the observing system similar in nature to the IPO established for the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Program. Such a program would require individual federal agencies to establish identified program lines within their budgets for the interagency ocean observing program.
- The establishment, through interagency Memoranda or Agreements, or similar documents, of mechanisms that would coordinate bilateral, trilateral or more inclusive interagency partnerships in ocean observing for specified periods of time. Ocean.US is an example of a program based on interagency cooperation codified by a Memorandum of Agreement.
- The continuation of the present federal governance of ocean observing that is agency-specific with no explicit identification of funding dedicated to an interagency, integrated ocean observing effort.

These efforts could be funded based on agencies' determination of how such efforts met their individual mission requirements.



Inherent in the question of governance is the issue of transitioning technologies and knowledge developed through research to an operational status. It is likely that the governance structures for the research and operational arms of the IOOS will be quite different since the goals and programmatic time scales differ markedly between research and operations. An effective governance structure leading to national leadership and coordination is required to enable and promote:

- cooperation and collaboration among federal and state agencies to enable the nation-wide development and implementation of economically and ecologically sound environmental policies;
- efficiencies in the design and implementation of regional programs and the timely incorporation of new technologies, models and products;
- capacity building through training programs and infrastructure development;
- measurement of core variables by all regional observing systems using nationally accepted methods and quality assurance/quality control (QA/QC) standards;
- dissemination and management of data for the benefit of all;
- development of the IOOS in the inter national framework of GOOS; and
- sustained, predictable and performance-based funding to insure uninterrupted data streams and routine provision of data-products.

New mechanisms are needed that enable federal and multi-state collaboration in the allocation and management of funds and the periodic assessment of each regional system. To be successful, the governance of regional programs must harmonize "bottom-up" programmatic development through regional organizations of stakeholders (data providers and users) with "top-down" coordination by federal agencies and national organizations. The success of this approach will depend on the development of programs that are comprehensive in design and enjoy continuity of support.

3.6 RESEARCH AND THE DEVELOPMENT OF THE IOOS

The Nation's investment in oceanographic research and development provides the foundation for the design and implementation of the IOOS. Continued investment will be required to develop, operate, and maintain a fully integrated observing system. Research is essential for the evolution of the IOOS in at least two ways:

- Scientific knowledge, technologies, scientists, and engineers provide the continuing foundation for the design, implementation, and development of the IOOS;
- Long-term observations made for the purposes of science significantly contribute to the multiple use capacity of the IOOS.

Today, we are unable to adequately address many of the seven goals given above (section 2.2) for three reasons:

- Lack of mechanisms for

efficiently sharing observations and data throughout the research community;

- Inability to rapidly sense changes in the biology and chemistry of the oceans; and
- The knowledge required to construct models that can be used to predict changes in the capacity of ecosystems to provide goods and services is insufficient.

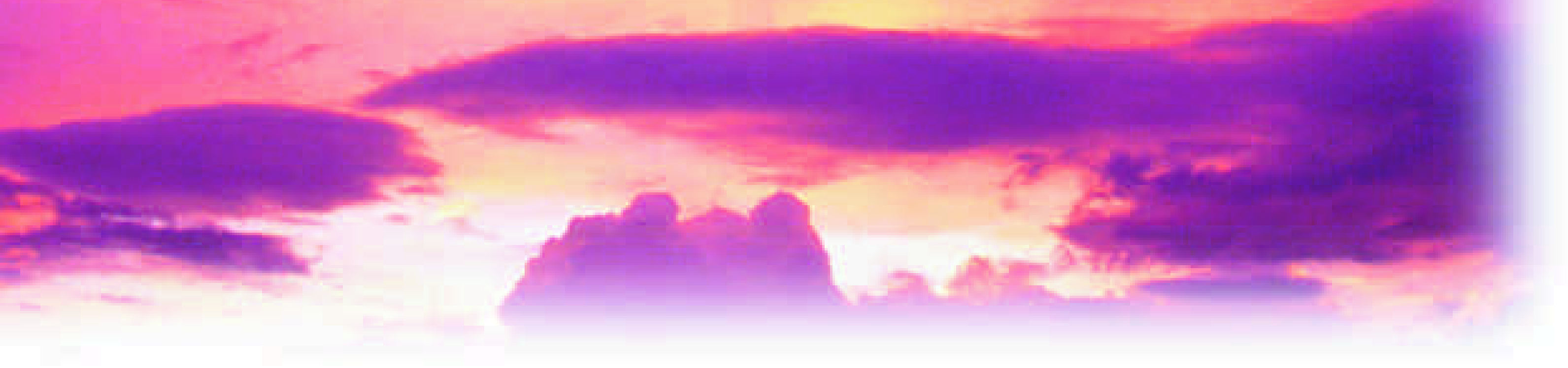
Realization of the full potential of the observing system will require (1) advances in technology to improve our ability to detect changes in the marine environment, especially biological and chemical properties and processes; (2) advances in understanding and related development of operational models that can predict change with known certainty; and (3) improved outreach activities (e.g., education, training and marketing) to ensure the most effective uses of environmental data and information (multiple use).

Government agencies, academia, and other stakeholders are responding to these needs by expanding our ocean knowledge base through research and development initiatives. For example, fixed point observatories could function as test beds and incubator sites for the development of new technologies (sensors, power sources, data telemetry) and modeling capabilities essential to the evolution of the IOOS.

Moreover, access to multidisciplinary, sustained observations provided by the IOOS will be invaluable to the research community and science educators, and as a result, will increase the impact of the Nation's investment in the sciences. The data streams and information provided by the observing system will stimulate the advancement of science by contributing to the development of more comprehensive and accurate representations of how and why the oceans and coastal ecosystems are changing in both time and space. Such a synergy between science and the evolution of the IOOS must be cultivated and sustained to achieve the full benefits of both.

4. BENEFITS

Substantial economic benefits are expected from the IOOS, both in its capacity for improved and expanded ocean observations as well as its integrated nature. Recent studies demonstrate that the economic benefits of investing in ocean observations to improve weather and climate forecasts can be substantial. For example, improved forecasts of El Niño events have led to adaptations in agricultural planning as well as hydroelectric power generation. In the case of the 1997 El Niño event, economists estimate that



the agriculture industry saved \$300M. The tropical ocean observing system costs \$10M/year to operate. Weather and climate predictions can be substantially improved with improved ocean measurements of other basin scale processes (e.g., the North Atlantic Oscillation and the North Pacific Decadal Oscillation). With improved predictions come enhanced economic benefits, not only for agriculture and power generation, but also for mitigating the effects of natural hazards, environmental protection, sustaining living resources, and coastal zone management. On a regional scale, a recent study of the Gulf of Maine illustrated the economic benefits of an integrated observing system for search and rescue, mitigation of oil spills, commercial fisheries, recreation and maritime transportation. A conservative analysis of the value of an ocean observing system for this region and for these sectors alone concludes that benefits will exceed the investment by a factor of ten.

The cost of not implementing the IOOS, of not improving and expanding our current ocean observational capacity, can be equally, if not more, substantial. The occurrence of biological phenomena presents a potential threat to public and marine health as well as to local and national economies. Enhancements to coastal observing systems could improve our response to episodic, deleterious events, such as harmful algal blooms of Florida red tide, toxic diatoms in California, and Pfiesteria in the Mid-Atlantic region. These events can pose risks to humans and marine life, and public concerns regarding recreation and seafood consumption can cause substantive economic impacts even if the risks are not realized. A robust, integrated observing system would allow advance preparation where the risks are real and reduce costly overreaction where they are not.

To determine the exact cost-benefit of the IOOS, it is necessary to conduct user sector studies on how IOOS data and products will differ from those currently available, their incremental costs, how the information is used in decision-making, and how that information improves outcomes in economic activities. The implementation of the IOOS includes this cost-benefit economic analysis, which will help in prioritizing areas of expansion as well as evaluate the effectiveness of the system. To develop useful economic characterizations of the IOOS products and ultimately develop a complete assessment of the cost-benefit of the IOOS, economists have already provided specific recommendations that will allow robust economic analyses for all regions to be conducted.

Public awareness of the value of the IOOS is critical to the success of the system and its continued support, and economic evaluation is key to demonstrating that value. The potential for an operational system (e.g., real-time visualization of underwater "weather" and the activities of marine organisms) for the purposes of science education and the development of an environmentally literate public is enormous and will be capitalized on.

5. IMPLEMENTING THE IOOS

5.1 SETTING PRIORITIES

The Ocean.US-2002 Workshop, convened in partnership with the U.S. GOOS Steering Committee, provided the information required to formulate a phased implementation plan for the IOOS. The workshop also achieved a consensus on (1) a prioritized list of variables that should be measured, (2) the techniques for providing the required data streams, (3) guidelines for the formulation of a phased implementation plan based on both feasibility and need, and (4) the immediate need to design and implement an integrated approach to data communications and management. The workshop proceedings will be published in a separate document, and a working group has been established to formulate an action plan for implementing the integrated data management subsystem for the IOOS.

Prior to the workshop, teams of experts were formed to draft subgoals and provisional products for each of the seven national goals to be addressed by an integrated system (section 2). Once reviewed and agreed to by workshop participants, the subgoals and products were used to develop full lists of environmental variables and potential techniques. Variables were then ranked based on the number of subgoals to which they are relevant. The highest ranked variables were recommended for incorporation into the national backbone of observations. Potential techniques (platforms, sensors, methods) were then evaluated based on their feasibility and their importance to providing the data required to detect and predict changes in the phenomena of interest (Table 1). These procedures and results will be described in more detail in the Proceedings of the Ocean.US-2002 Workshop. The impact-feasibility analysis and the ranking of variables provided the basis for achieving a consensus on high priority actions needed to develop an IOOS for the Nation. The actions recommended below are intended to significantly improve the ability of government agencies to achieve their missions and the goals articulated in section 2.

5.2 THE OBSERVING SYSTEM AS A WHOLE

Two overarching recommendations focused on (1) the need for an integrated approach to data dissemination and management and (2) the establishment of government processes to build and sustain an operational observing system for coastal and oceanic environments. These are described below.

5.2.1 DATA COMMUNICATIONS AND MANAGEMENT

The development of an integrated data management system for rapid access to diverse data from disparate sources is the highest priority for implementation. The interface

with the IOOS for most users will occur through the Data management and Communications subsystem (DAC). The DAC will knit together the global and coastal components of the IOOS and will link every part of the observing system from the instruments to the users, and will contribute to defining the quality of the end products. The DAC subsystem is required to transmit multidisciplinary, multi-media observations from a broad range of platforms, and transmit them (in real-time, near-real-time, and delayed modes) directly to users for processing into maps, plots, forecasts, and other useful forms of information. The goal is to link data from buoys, autonomous drifters and vehicles, ships, aircraft, satellites, observatories, and other platforms to models (e.g., GIS, numerical models, statistical models) for rapid analysis and product delivery, while ensuring data quality and usability.

The DAC subsystem consists of data transport and quality control; data assembly and metadata management; data archeology, discovery, archival, and product development; and associated administrative functions. Two general actions are recommended:

- Design and implement an enhanced, distributed data and information management system that links all observational and data management systems (across agencies and programs) to all data users.
- Improve data management infrastructure.

More specifically, nation-wide standards, protocols and formats should be developed as follows:

- Assess oceanographic middleware protocols for data acquisition and modify as needed to accommodate multi-disciplinary data streams (meteorological, physical, geological, chemical and biological data);
- UseFederal standards for semantic metadata descriptions of the data;
- Use HTTP as the network data transport protocol for data discovery; and
- Designate GODAE as a primary integrator for real-time data assembly.

5.2.2 BUILDING THE SYSTEM

Involving all major stakeholders (data providers and users) in the development of the observing system early on in the process is essential to the evolution of an effective system that can be sustained in perpetuity. To these ends, Federal processes should be established for

- selectively incorporating (linking), enhancing, and supplementing existing operational programs;
- selectively and systematically migrating new knowledge, technologies and models into the operational observing system; and
- permanent and ongoing evaluations by stakeholders of system performance in terms of continuity and timeliness in the provision of data streams and products, product development and expanding the user-base, science education, public outreach (including environmental education K-gray), and the cost-effectiveness of the observing system.

5.3 THE GLOBAL COMPONENT

The global component of the IOOS will fulfill and optimize the national contribution to the global module (section 3.3). An internationally coordinated effort is leading to the development of a Global Ocean Observing System (GOOS, to which the U.S. global component contributes) that will significantly improve our understanding of changes in the global ocean-climate system and our ability to rapidly detect changes and predict their consequence. The specific actions that should be taken now to ensure successful implementation of the U.S. global component are as follows:

- Increase the temporal and spatial resolution of ocean observations by fully implementing Argo and the global ocean time series observatories and by enhancing the ship of opportunity and volunteer observing ships programs (SOOP and VOS);
- Contribute to the successful completion of the Global Ocean Data Assimilation Experiment (GODAE) as the first step toward the development of an integrated data management and assimilation system for ocean observations;
- Enhance oceanic time series stations with biological and chemical sensors (bio-optics, nutrients, dissolved oxygen, pCO_2);
- Develop and implement quantitative observing system design methodology to optimize the global network of observations for climate (e.g., Observing System Simulation Experiments or OSSEs); and
- Transition remote sensing capabilities from research to operational modes for sustained observations of ocean topography, ocean vector winds, and ocean color.

5.4 THE COASTAL COMPONENT

5.4.1 IMPLEMENTATION STRATEGY

The coastal component of IOOS will address an exceptionally broad spectrum of phenomena (Table 1). While it is not reasonable for the national backbone to comprehensively characterize all of these changes, it is feasible to develop a framework that will enable regional observing systems to provide the data and information required for rapid detection and

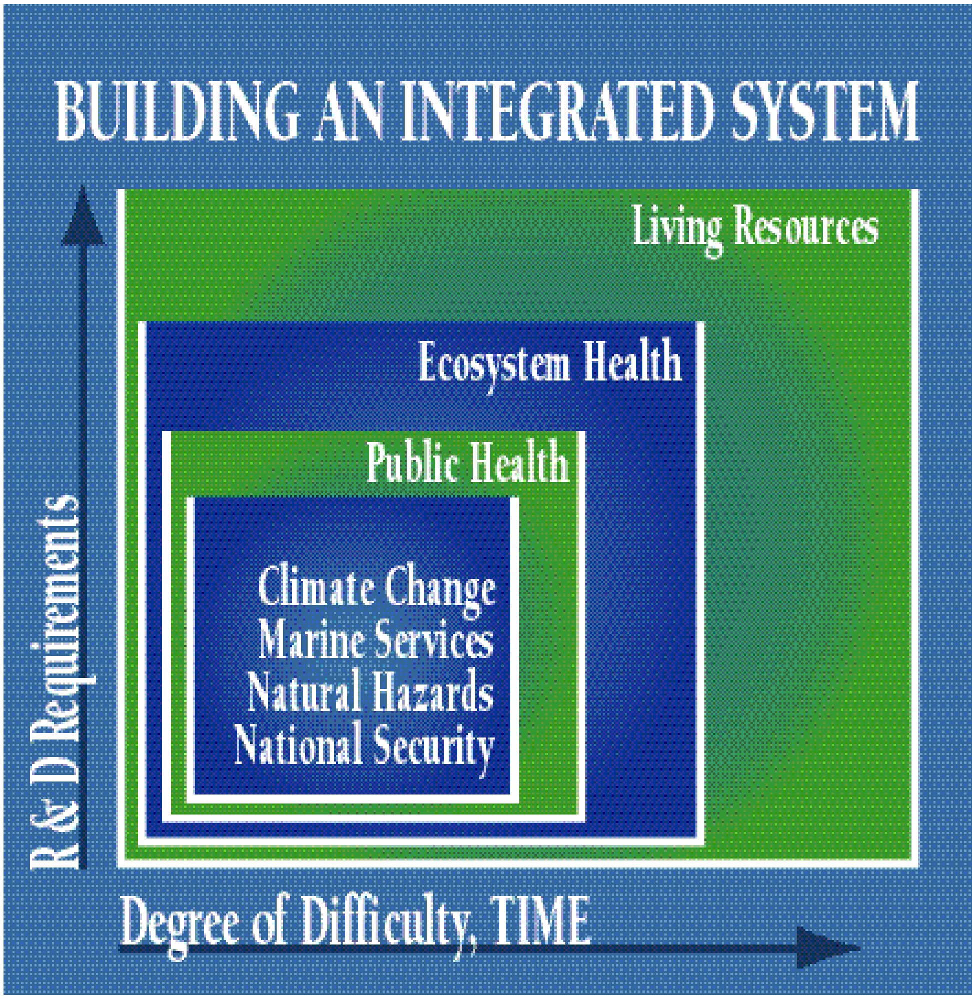
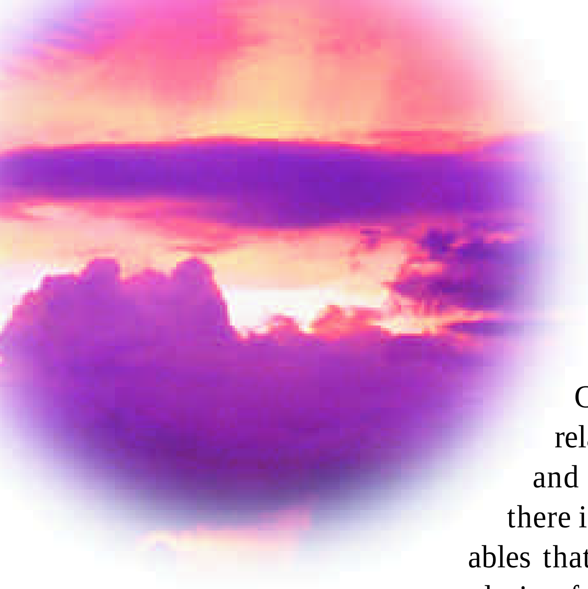


Figure 4. Time-dependent development of the IOOS.



prediction based on national and regional priorities.

Current understanding of the relationships between physical and ecological processes suggest there is a relatively small set of variables that, if measured with sufficient resolution for extended periods over sufficiently large areas, will serve many needs from forecasting the effects of tropical storms and harmful algal events on short time scales (hours to days) to predicting the environmental consequences of human activities and climate change on longer time scales (years to decades). These are the "core" variables.

The data requirements for improved coastal marine services are, for the most part, common to all of the themes to be addressed by the coastal module (Figure 4). Safe and efficient coastal marine operations, national security activities, and the mitigation of natural hazards require accurate nowcasts and timely forecasts of storms and coastal flooding; of coastal current, wave-, and ice-fields; and of water depth, temperature and visibility. In addition to these data, minimizing public health risks, and protecting and restoring healthy ecosystems require timely data on environmental variables needed to detect and predict changes in habitats and in biological, chemical and geological properties and processes. Mitigating the effects of natural hazards and reducing public health risks also require a predictive understanding of the effects of habitat loss and modification (barrier islands, tidal wetlands, sea grass beds, etc.) on the susceptibility of coastal ecosystems and human populations to natural hazards. The demands of sustaining living marine resources and managing harvests (of wild and farmed stocks) in an ecosystem context require data on most of the above as well as timely information on population (stock) abundance, distribution, age- (size) structure, fecundity, year-class strength, migratory patterns, and mortality rates (including catch statistics). Figure 4 provides a conceptual framework for the phased implementation of the coastal component that recognizes two important realities: (1) all seven major goals can and must be addressed from the beginning and (2) current capabilities dictate an initial operational emphasis on physical variables relevant to all seven national goals. This provides the basis for the efficient, step-wise implementation of a national system that will supply the data and information needed to detect and predict changes in or the occurrence of most of the phenomena of interest.

5.4.2 INCORPORATE, ENHANCE AND SUPPLEMENT EXISTING FEDERAL CONTRIBUTIONS TO THE NATIONAL BACKBONE

The Federal contributions to the national backbone include time series observations at reference and sentinel stations and cross-shelf transects and satellite remote sensing. This will be developed through both federal programs and federally funded regional initiatives as appropriate. An important goal is the development of procedures for integrating data from remote and in situ sensing to routinely provide three-dimensional, time-dependent visualizations of change. Achieving this will require the following initial steps:

- Enhance the existing federal network

of instrumented moorings in the U.S. EEZ to improve forecasts of coastal weather, surface waves, and currents and to quantify related changes in bio-optical properties. This should include increases in both the number of moorings by at least a factor of five and in sensing capabilities by incorporating physical, biological and chemical sensors; increasing the number of depths sampled; and developing standardized instrument packages.

- Enhance the existing federal networks to improve nowcasts and forecasts of water depth, currents, and both relative and absolute sea level rise. This should include increases in the number of water-level measuring sites by a factor of five and sensing capabilities (including an increase in the number of geo-referenced gauges, incorporation of additional sensors, and the development of standardized instrument packages).
- Develop and deploy new satellite sensors to improve resolution (to 300 m) of ocean color, surface currents and waves in coastal waters.
- Enhance aircraft remote sensing for ecosystem assessments for more timely detection of coastal erosion and changes in ocean color and shallow water bathymetry.
- Enhance national program of ship-based cross-shelf surveys to establish reference and sentinel transects of multidisciplinary observations (assess the effects of land-based sources of pollution and to improve stock assessments of exploitable fish stocks).
- Periodically produce digital maps (e.g., five-year intervals) of marine habitats of the areal extent of coral reefs, sea grass beds, kelp beds, mangrove forests, marsh grasses, soft and hard bottom substrates, and shallow water bathymetry.
- Enhance shore-based measurements in near-shore waters of human pathogens, harmful algae, biotoxins, and chemical contaminants.
- Develop standardized sensor packages and deploy them on research vessels, voluntary observing ships and ships of opportunity.
- Develop glider platforms for synoptic, autonomous, in situ sensing of both physical and biological variables.

5.4.3 ESTABLISH A NATIONAL FEDERATION OF REGIONAL OBSERVING SYSTEMS.

The federation should include the development of a federally funded backbone as described above and in section 3. The backbone should be regionally enhanced based on state and regional priorities. Regional observing systems provide the primary interface with user groups outside the federal agencies. The regional scale also provides a focal point for data analysis and product development that will have local, regional and national applications. Thus, the development of regional systems must be considered a high priority as follows:

- Establish mechanisms that enable accountable transfers of funding from the Federal government to consortia of appropriate stakeholders (including both data providers and major user groups) charged with establishing, maintaining, and improving regional observing systems.
- Fund regional observing systems as proof of concept projects. These systems must include all three subsystems (data acquisition, management and

analysis) and must contribute to and benefit from the national backbone.

- Establish a process to transition successful projects into sustained, regional observing systems where success is defined in terms of benefits to user groups and the cost-effectiveness of the observing system (from measurements to data products).
- Ensure that products are developed to address regional and national goals and that such products are readily available to the public and other users. This will place a high priority on the development of data assimilation techniques and predictive models.
- Develop and implement quantitative observing design methodology to optimize coastal observations for detection and prediction of regional expressions of basin scale changes in the oceans and of changes related to land-use practices in coastal drainage.
- Implement networks of high frequency radar as part of regional observing systems for coastal currents and waves.

5.5 LONGER TERM, HIGH PRIORITY EFFORTS

Important aspects of the system will take longer to develop and implement. With this in mind, continued research should be fostered in the following areas:

- Develop operational, coupled physical-ecological and physical-chemical models and data assimilation techniques for now casting and forecasting changes in the condition of ecosystems (sediment and chemical transport, habitat loss, oxygen depletion, harmful algal blooms, diseases and mass mortalities in marine organisms, etc.) and the living resources they support.
- Develop aircraft remote sensing techniques for ecosystem assessments based on the changes in the distribution and physiological state of biologically structured habitats, sea surface salinity, and turbidity.
- Develop improved techniques for rapid sensing of biological and chemical variables, especially human pathogens, harmful algal species, and biotoxins.

Federal support for developing, capitalizing and maintaining the national contributions to the global and regional coastal components of the IOOS will be substantial. The global component is entirely a federal effort. Federal funding will be required in three categories to initiate the coastal IOOS as follows: (1) link and enhance federal elements of the national backbone (including observations and data management), (2) implement and link regional observing systems that will contribute to and benefit from the national backbone, and (3) enhance the regional systems in response to state and regional needs. While continued federal support is necessary for the first two initiatives of the coastal component, initial federal funding is required for regional enhancements with the expectation that successful investment in enhancing regional systems must eventually result in an increase over time in the proportion of funding derived from state and regional sources. Based on the priorities established above and the cost-effectiveness of a systematic and step-wise approach to implementation, the following actions should be taken now:

- Accelerate the implementation of the U.S. commitment to the global ocean observing system for global climate change. Resources required now: $30M
- Initiate a Data Communications and Management system for the IOOS. Resources required now: $18M
- Enhance/expand existing Federal Elements (buoys, water level sites, etc.). Resources required now: $40M
- Initiate Regional Observing Systems as Proof of Concept trials. Resources required now: $50M

The total new investment required to initiate a sustainable path to full implementation of the IOOS is $138M. The estimated annual cost of a fully-realized, integrated and sustained coastal and open ocean observing system in constant dollars is $500M. This level of investment will be approached over a multi-year period to ensure efficient use of resources and to allow sufficient time for capacity building to enable successful attainment of the project's goals. Emphasis here is on in situ observations. Although critical to the development of a fully integrated observing system, the recommendations here do not specifically address requirements for the satellite-based remote sensing.

Existing governance structures were not designed to implement, maintain, and improve a sustained IOOS such as that described here. Three approaches are suggested (section 3.5) for consideration as mechanisms to address three critical issues: (1) the establishment of the IOOS through coordinated development of the global and coastal components and, within the coastal component, a federal backbone and regional observing systems; (2) the timely and selective migration of new capabilities (knowledge, technologies, models) from research to the federal backbone and regional systems with appropriate levels of sustained funding based on performance; and (3) routine and regular performance evaluations by stakeholders based on the provision of uninterrupted data streams and products and the evolution of new capacities in response to improved definition of user needs and an expanding user base.