U.S. Commission on Ocean Policy

Part VII
Science-based Decisions: Advancing Our Understanding of the Oceans

CHAPTER 25: CREATING A NATIONAL STRATEGY FOR INCREASING SCIENTIFIC KNOWLEDGE

Ocean managers and policy makers need comprehensive scientific information about the ocean and its environment to make wise decisions. Increased knowledge can support sustainable resource use, economic development, and conservation of the ocean's biological diversity and natural beauty. A national strategy is needed to ensure the highest return on the nation's investment in ocean research, exploration, and marine operations. The strategy should coordinate and prioritize basic and applied research supported by federal agencies, increase partnerships with the academic and private sectors, promote enhanced ocean exploration, and coordinate federal marine operations to reduce redundancies. Significantly increased funding for research in ocean-related natural and social sciences and a renewed commitment to ocean exploration are keys to fostering a new era of ecosystem-based management supported by science.

FORTIFYING THE FOUNDATIONS OF OCEAN UNDERSTANDING

Ocean science and technology are integral parts of the overall U.S. research enterprise and contribute greatly to society. They are essential to understanding the Earth's environment and how it changes over time, managing marine resources wisely, finding beneficial new uses of ocean resources, and protecting national security. In addition, important technological advances have resulted from devices originally developed for ocean research and exploration, such as medical acoustic tools that grew out of sonar technologies.

Components of Ocean Science and Technology

For the purpose of this and the following three chapters of Part VII, ocean science and technology is defined as:

- the exploration of ocean environments, and the conduct of basic and applied research to increase understanding of (1) the biology, chemistry, physics, and geology of the oceans and coasts, (2) oceanic and coastal processes and interactions with terrestrial, hydrologic, and atmospheric systems, and (3) the impacts of oceans and coastal regions on society and of humans on these environments; and
- the development of methodologies and instruments to improve that understanding.

Knowledge about the oceans advanced remarkably during the 20th century due to significant financial investments, a host of multidisciplinary and interdisciplinary studies, new technologies, and an expanding community of dedicated experts. Despite this progress, the ocean remains one of the least explored and understood environments on the planet—a frontier for discoveries that could provide important benefits. A broader understanding of coastal waters and the deep ocean is essential to enable the practice of ecosystem-based, multi-use, and adaptive management and to conserve biodiversity. Ocean science and technology will play an increasingly central role in the multidisciplinary study and management of the whole-Earth system.

The chapters of Part VII focus on four building blocks of a renewed and restructured U.S. commitment to ocean science and technology:

1) a national strategy for conducting research, exploration, and marine operations at the federal level and in partnership with academia and private organizations (Chapter 25);
2) an integrated ocean observing system to better measure and predict ocean conditions and processes (Chapter 26);
3) the infrastructure and technology development needed to conduct and support ocean science (Chapter 27); and
4) data and information management to handle and manipulate research data and generate useful products for resource managers and the general public (Chapter 28).

Federal Leadership in Ocean Science and Technology

Since the mid-1900s, the U.S. government has assumed a leadership role in ocean science and technology. Today, fifteen federal agencies support or conduct diverse activities in ocean research, assessment, and management. The heads of these agencies direct the National Oceanographic Partnership Program (NOPP), which coordinates national oceanographic research and education. NOPP has provided a useful venue for agencies to support selected ocean science and technology projects, but it has not realized its full potential as an overarching mechanism for coordination among federal agencies or between federal activities and those of state, local, academic, and private entities.

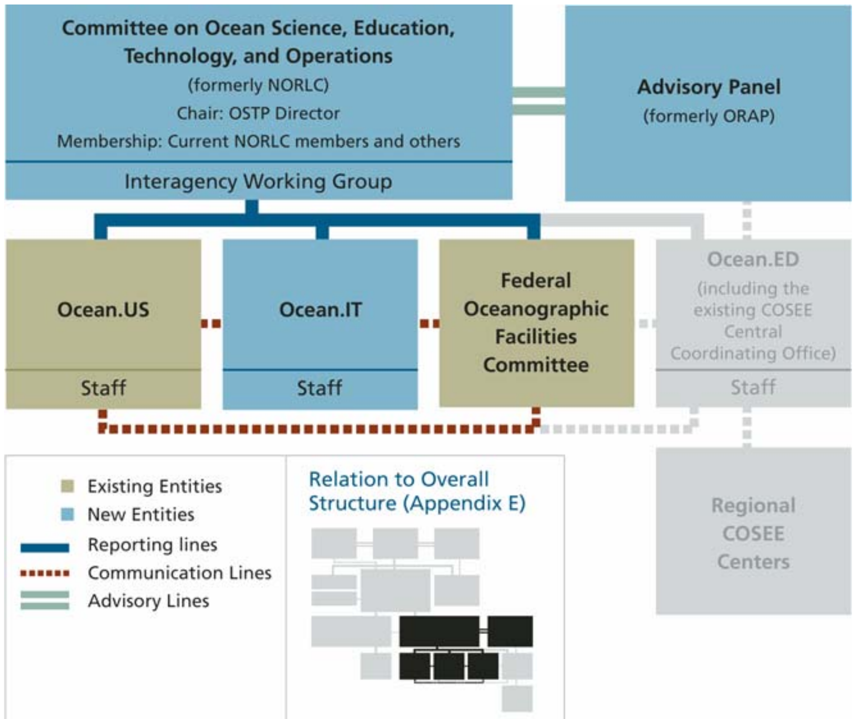
Under the new National Ocean Policy Framework proposed in Chapter 4, the National Ocean Council (NOC) will serve as the federal coordinating body for all ocean-related activities and the NOC's Committee on Ocean Science, Education, Technology, and Operations (COSETO) will assume leadership of NOPP. This new structure will allow for the design and implementation of a national strategy to promote ocean research, education, observation, exploration, and marine operations. NOPP's existing offices and committees will be incorporated within this structure (Figure 25.1). Ocean.US, the lead office for planning the Integrated Ocean Observing System (IOOS), and the Federal Oceanographic Facilities Committee, which provides advice related to oceanographic facilities, will both report to COSETO. An additional planning and coordinating body, Ocean.IT should be added to COSETO to provide stronger integration for information technology activities. (The creation of Ocean.IT is discussed in Chapter 28.)

ESTABLISHING A NATIONAL STRATEGY

The United States does not have a national strategy for ocean and coastal research, exploration, and marine operations that can integrate ongoing efforts, promote synergies among federal, state, and local governments, academia, and the private sector, translate scientific and technological advances into operational applications, and establish national goals and objectives for addressing high-priority issues. Instead, for the most part, each federal ocean agency independently addresses its own specific information needs.

A national strategy can help meet the ocean resource management challenges of the 21st century and ensure that useful products result from federal investments in ocean research. Moving toward ecosystem-based management approaches will require a new generation of scientific understanding. Specifically, more needs to be known about how marine ecosystems function on varying spatial scales, how human activities affect marine ecosystems and how, in turn, these changes affect human health.

Figure 25.1. Proposed Structure for the Coordination of Federal Ocean Research Activities



Shown here are the institutional components that should be established under the National Ocean Council's Committee on Ocean Science, Education, Technology, and Operations (COSETO) recommended in Chapter 4. COSETO's purpose is to improve federal leadership and coordination in ocean science, education, technology, and marine operations. This diagram also illustrates the organizational links between the new Ocean.IT and other existing and planned units under COSETO. Entities shaded in gray are discussed in Chapters 4 and 8.

Ecosystem-based management will also require a deeper understanding of biological, physical, chemical, and socioeconomic processes and interactions. For example, as coastal population growth feeds a demand for new construction, managers will need to know which activities may cause rapid erosion of the beach, increased turbidity that harms a coral reef, or economic disruption. In another example, fishery conservation can be promoted by protecting spawning grounds and other essential habitat; to make this possible, scientists and managers must understand the fundamental biology of the fish species.

Maintaining overall ecosystem health also requires an improved understanding of biological diversity on different levels, including genetic diversity (the variety of genetic traits within a single species), species diversity (the number of species within an ecosystem), and ecosystem diversity (the number of different ecosystems on Earth). The largest threats to maintaining diversity on all three scales are human activities, such as overfishing, pollution, habitat alteration, and introductions of non-native species. The extent of marine biological diversity, like so much about the ocean, remains unknown. But based on the rate at which new species are currently being discovered, continued exploration of the ocean is almost certain to result in the documentation of many additional species that can provide fresh insights into the origin of life and human biology.

A national strategy should promote the scientific and technological advances required to observe, monitor, assess, and predict environmental events and long-term trends. Foremost in this category is climate change. The role of the ocean in climate, although critical, remains poorly understood. The ocean has 1000 times the heat capacity of the freshwater lakes and rivers, ocean circulation drives the global heat balance, and ocean biochemistry plays a primary role in controlling the global carbon cycle.

The process of climate change should be examined both on geologic time scales, such as the transitions between ice ages, and over shorter periods of time. The buildup of greenhouse gases in the atmosphere will increase the melting of polar ice, introducing large quantities of fresh water into the North Atlantic. Many researchers now believe that could drastically change ocean circulation and weather patterns in the span of a couple of years.[1] In particular, the Gulf Stream could slow or stop, causing colder temperatures along the eastern seaboard of the United States and ramifications around the globe. It is in man's interests to learn more about the processes that lead to abrupt climate changes, as well as their potential ecological, economic, and social impacts.

Even as we try to comprehend the role of the ocean in climate change, we need also to understand the effects of climate change on ocean ecosystems. If temperatures around the globe continue to warm, sea level will continue to rise, putting many coastal residents at greater risk from storm surges and erosion. For individual ecosystems, even small changes in ocean temperature can put the health and lives of sea creatures and humans at risk. Ocean monitoring, through programs like the IOOS, will be essential for detecting and predicting changes more accurately, thereby improving prospects for minimizing harmful effects.

Some large initiatives, such as the U.S. Climate Change Science Program and the Census of Marine Life, have been launched in the last couple of years to study large-scale research topics. However, many of the issues most relevant to the needs of coastal managers do not occur on such global scales. Due to the regional nature of many ocean and coastal ecosystem processes, regional-scale research programs are also needed. Currently, insufficient emphasis is placed on this kind of research. The regional ocean information programs discussed in Chapter 5 are designed to close this gap and increase our understanding of ocean and coastal ecosystems by prioritizing, coordinating, and funding research that meets regional and local management needs.

At the state level, the National Oceanic and Atmospheric Administration's (NOAA's) National Sea Grant College Program can make essential contributions to achieving research goals. The state Sea Grant programs have the organization and infrastructure necessary to fund research and conduct educational activities that will expand understanding of ocean ecosystems up and down our coasts. Sea Grant's current strategic plan focuses on promoting ecosystem-based management and on involving constituencies from government, universities, the public and the private sector, all of whom are needed to strengthen the U.S. research enterprise.[2]

It is time for the United States to establish a national strategy for ocean research investments, and oversee implementation and funding of programs throughout the ocean science community. This plan should address issues at the global, regional, state, and local levels. It should emphasize ecosystem-based science to help resolve the current mismatch between the size and complexity of marine ecosystems and the fragmented nature of science and the federal structure. Better coordination and integration will help provide the information needed to sustain resources, protect human lives and property, identify and nurture new beneficial uses, and resolve issues that result from competing activities. A unified national approach to ocean research, exploration, and marine operations, structured around national investment priorities, will also result in wiser and more efficient use of resources.

ADVANCING OCEAN AND COASTAL RESEARCH

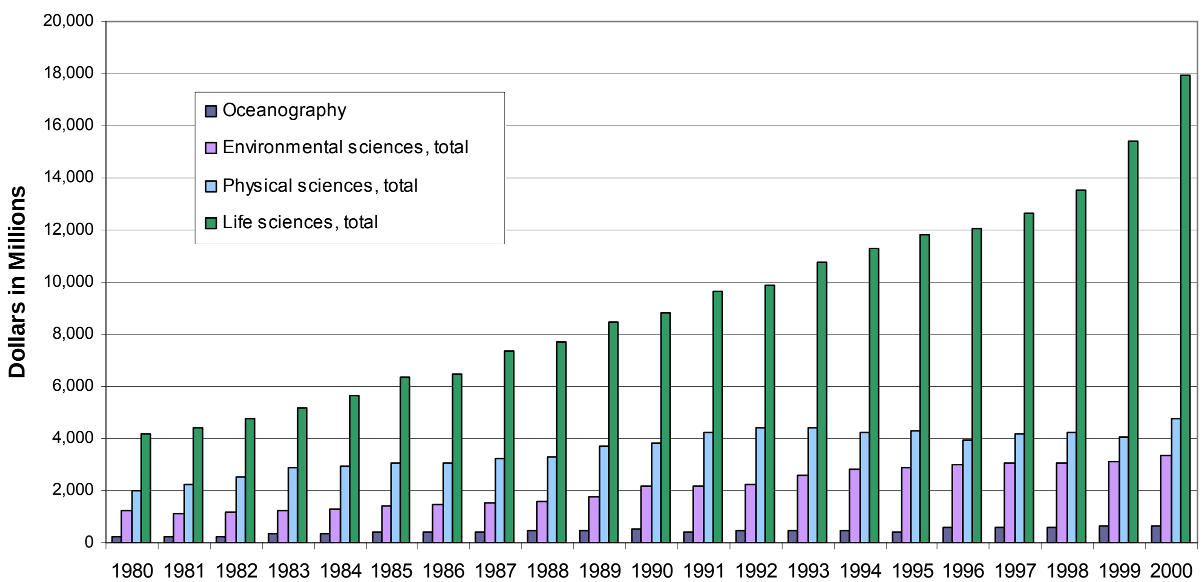
Better coordination of ocean and coastal research is needed at all levels and across all sectors. Increases in funding, changes in grant practices, and the establishment of new partnerships are all essential to maximize the national research enterprise. Advances in social science and economic research are particularly important to generate information needed for the wise management of ocean resources.

Reviving the Federal Investment

The United States has a wealth of ocean research expertise spread across a network of government and industry laboratories and world-class universities, colleges, and marine centers. With strong federal support, these institutions made the United States the world leader in oceanography during the 20th century. However, a leader cannot stand still. Ocean and coastal management issues continue to grow in number and complexity, new fields of study have emerged, new interdisciplinary approaches are being tried, and there is a growing need to understand the ocean on a global and regional scale. All this has created a corresponding demand for high-quality scientific information.

Federal investments during the cold war years of the 1960s and 1970s enabled scientists to help promote our national economy and security through research into the fundamental physical, chemical, biological, and geological properties of the oceans. During that period, ocean research funding constituted 7 percent of the federal research budget. However, the federal investment in ocean research began to stagnate in the early 1980s, while investments in other fields of science continued to grow (Figure 25.2).[3] As a result, ocean research investments comprise a meager 3.5 percent of today's federal portfolio.

Figure 25.2. Ocean Research Neglected as Part of the National Research Budget



Funding for oceanography has remained stagnant for twenty years while other scientific disciplines have experienced steady increases in research funding.
Source: National Science Foundation. *Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1951–2002*. <http://www.nsf.gov/sbe/srs/nsf03325/> (Accessed January, 2004).

The current annual federal investment of approximately $650 million in marine science is well below the level necessary to address adequately the nation's needs for coastal and ocean information. Unless funding increases sharply, the gap between requirements and resources will continue to grow and the United States will lose its position as the world's leader in ocean research.

Recommendation 25–1. Congress should double the federal ocean and coastal research budget over the next five years, from the 2004 level of approximately $650 million to $1.3 billion per year.

A portion of these new funds should be used to:

- *support regional research, directed by the regional ocean information programs discussed in Chapter 5.*
- *significantly enlarge the National Sea Grant College Program.*
- *support other high priority research areas, as outlined throughout this report.*

Coordination and Prioritization

To ensure that increased investments are used wisely and that important research activities continue, federal agencies will need to create long-term strategic plans and remedy structural problems in their grant mechanisms.

In creating long-term plans, a balance must be reached between funding basic, curiosity-driven research conducted mostly at universities and marine research centers and more applied research conducted largely at government laboratories to support operations, management, and monitoring activities. Over time, changes in national priorities may shift the balance slightly between basic and applied research but the enduring value, and often unexpected outcomes, of basic research should never be underestimated. Basic oceanographic research in the 1940s, 1950s, and 1960s increased our understanding of ocean currents, marine acoustics, seafloor geology, and robotics, and basic research supported by the U.S. Navy has led to many widely-used and versatile new technologies, such as the Global Positioning System. Improved cooperation between federal labs and academic institutions can combine the strengths of both, ensure that quality research is conducted, and achieve a balance between basic and applied science.

Problems in the current system for awarding federal research grants make it difficult to conduct the kind of interdisciplinary, ecosystem-based research required to understand the ocean environment. Short-term research grants of two- to five-years duration are now typical. This type of funding is useful for research on discrete topics of limited scope, and has the advantage of giving agencies the flexibility to adjust quickly to changing priorities. However, it is not adequate to acquire the continuous data sets that will be essential for examining environmental changes over time.

In addition, a variety of mechanisms are used by federal agencies to review proposed ocean research grants. Some of these mechanisms work better than others. Grant review systems that are not open to all applicants or that do not use an objective review process for ranking proposals are unlikely to produce the highest quality research. Systems that favor established researchers to the detriment of young scientists, whether intentionally or not, are also flawed, stifling diversity and limiting the infusion of new ideas. When all research proposals, including those from scientists working at federal labs, are subject to the same rigorous review process, tax dollars are more likely to support the best science. Streamlined grant application and review processes will also help get more good science done in a timely way.

The ocean science community includes many scientists outside academic and federal labs. Although coordination among sectors has steadily improved, the process remains mainly ad hoc, without the backing of a national strategy and leadership. A clearer understanding of the respective strengths and roles of the different sectors could lead to productive new research partnerships, foster intellectual risk-taking, leverage funding, and encourage participation in large multi-sector research efforts valuable to the nation.

There is also a need to gain feedback from managers at state and federal levels and from the private sector that can guide new research directions and technology development. The regional ocean information programs recommended in Chapter 5 will provide an excellent mechanism for gaining input on user needs and regional research priorities.

A mechanism is required to coordinate federally funded ocean research (both basic and applied), support long-term projects, and create partnerships throughout all agencies and sectors. Transparent and comprehensive research plans would achieve these goals and ensure that research results can be translated into operational products in a timely manner.

Recommendation 25–2. The National Ocean Council should develop a national ocean research strategy that reflects a long-term vision, promotes advances in basic and applied ocean science and technology, and guides relevant agencies in developing ten-year science plans and budgets.

The national strategy should:

- *require agencies to provide multi-year (greater than 5 year) funding opportunities.*
- *reiterate the importance of balancing basic and applied research projects.*
- *promote the transition of basic research results to applied uses.*
- *require a system of independent review for all grant applications, including those from federal labs.*
- *recognize the different ocean science sectors (government, academic, commercial, and non-governmental), clarify their roles, and maximize the use of partnerships.*
- *incorporate the science needs and priorities of local, state, regional, and national managers, working through the regional ocean information programs described in Chapter 5.*

Each agency's first ten-year science plan should include a detailed strategy for how the proposed doubling of federal ocean research investments would be incorporated into new and ongoing activities.

The Need for Social and Economic Research

The ocean and coastal environment is rife with conflicts among competing users and between groups of people applying different sets of values to the same issues. To resolve these conflicts, information is needed not only about the natural environment but also about relevant social, cultural, and economic factors. The funding required to increase knowledge in these areas is modest when compared to the cost of the ships, labs, and instruments used in oceanographic research. Nevertheless, social and economic research related to our coasts and oceans has long been overlooked.

A Neglected Research Area

The National Sea Grant College Program does fund some studies that examine legal, political, economic, anthropological, and other human dimensions of ocean and coastal affairs. However, these projects often receive less than 10 percent of the program's overall research budget. In other research programs, social and economic science garners even less support, creating a situation where basic information is not available to support management and planning.

To meet specific programmatic requirements of the National Environmental Policy Act (NEPA) and other laws that require impact analyses, individual resource management agencies have had to pull together social science and economic information at various times. For example, NOAA's National Marine Fisheries Service hired anthropologists and economic researchers following enactment of the 1976 Magnuson–Stevens Fishery Conservation and Management Act. The Minerals Management Service instituted a socioeconomic research program in the 1970s to aid in developing five-year leasing plans that would meet NEPA standards. The U.S. Army Corps of Engineers has also funded research into marine cultural heritage to meet its NEPA obligations. And in the 1990s, NOAA's National Ocean Service created the Coastal Services Center to help generate information on coastal demographics. Although wide-ranging, these efforts remain ad hoc, uncoordinated, and related to specific issues that wax and wane in importance over time. Furthermore, the data developed on an agency-by-agency basis are often mutually incompatible and hard to access.

Recently, NOAA has begun to reassess its needs for social and economic information. In 2003, a panel of social scientists established by its Science Advisory Board concluded that NOAA's support for social sciences is not comparable to that of other agencies with similar environmental assessment and stewardship responsibilities and that this shortcoming has hindered the agency's ability to accomplish its mission.[4] NOAA's National Marine Protected Areas Center also issued a report identifying high-priority social science needs to support the planning, management, and evaluation of marine protected areas.[5]

Some existing and emerging ocean and coastal issues that will require better social and economic information include:

- multiple-use controversies in the coastal zone;
- novel offshore uses, such as the proposed introduction of offshore wind farms;
- consensus-based decision making involving stakeholders, watershed councils, public-private partnerships, and numerous nongovernmental organizations;
- changes in coastal communities due to shifts in fisheries policy, growth of the tourism industry, and redevelopment of ports and waterfronts;
- changes in coastal demographics; and
- varying perceptions of coastal environmental values.

Any decision affecting our oceans and coasts should take socioeconomic information into account, harnessing expertise from a wide range of specialties to deal with issues that demand a broad range of knowledge. This will require integrated assessments by teams of natural and social scientists working together with stakeholders and policy makers. Such an approach, which has been employed in the context of climate change, is especially well suited to emerging ocean issues that require a merger of natural and social sciences, technology, and policy.

The Coastal and Ocean Economy

Cost-benefit analyses to support ocean and coastal decisions require enhanced economic data. However, the major federal economic statistical agencies have neither the mandate nor the means to study the ocean and coastal economy.

NOAA undertakes some economic analyses in support of its various missions. For example, its Coastal and Ocean Resource Economics Program has assessed the economic impacts of fishery management plans and marine sanctuaries. NOAA has also worked with other federal agencies to conduct the first major examination of the economics of marine-related recreation.[6] But NOAA's economic analyses tend to be directed at very specific purposes associated with particular programs. NOAA has not supported sustained, consistent, and comprehensive data collection and analyses on the ocean and coastal economies.

To lay the groundwork for a broader program, NOAA and the U.S. Environmental Protection Agency are helping support the National Ocean Economics Project, a multi-year research initiative involving economists from several universities. While this effort is generating valuable information, including much of the economic data used in this report, it remains a research project. To be useful in understanding coastal and ocean economies and assessing the impacts of management policies on individuals, businesses and communities, a long-term, operational program is needed. Coordination between the federal government and other entities will be needed to generate the socioeconomic data required for operational activities (Table 25.3). NOAA, as the federal agency with principal responsibility for the oceans, should take the lead in bringing these parties together to provide the economic data needed for ocean and coastal decision making at the federal, state, regional, and local levels

Table 25.3. Organizations with Important Roles in Collecting and Distributing Socioeconomic Data on the Ocean and Coasts The organizations listed below will play key roles in creating an operational coastal and ocean economics program to support management activities.	
Entity	**Role**
National Oceanic and Atmospheric Administration	Current economic activities are performed by the National Marine Fisheries Service to help draft and defend Fishery Management Plans and by the Coastal and Ocean Resource Economics (CORE) Program, which conducts individual studies on issues of interest, such as economic valuations of beaches or coral reefs.
Bureau of Labor Statistics	In cooperation with the states, the Bureau collects the largest amount of basic employment and wage data on the U.S. economy. These data will continue to be the fundamental elements used for monitoring the coastal and ocean economies at national, regional, and local levels.
Bureau of the Census	The Census Bureau is the other major collector of primary data on the economy, including the tabulation of population, housing and major economic sectors.
U.S. Department of Agriculture	USDA has responsibility for the Census of Agriculture, which includes data on aquaculture.
Bureau of Economic Analysis	BEA uses inputs from the data-collecting agencies to maintain the most important measure of annual economic activity: the national income and product accounts, whose best-known element is the gross domestic product. Related measures, such as the gross state product, are key to understanding regional economies, as is the measurement of self-employment.
U.S. Environmental Protection Agency	EPA undertakes substantial economic research in the fields of land, water, and air pollution. EPA's economic research focuses particular attention on nonmarket values, and provides an important supplement to the National Oceanic and Atmospheric Administration's work in this area.
National Science Foundation	NSF supports much of the basic research in the sciences, including the social sciences. It has recently undertaken new initiatives to better integrate the natural and social sciences to improve management of the environment and natural resources.
Bureau of Transportation Statistics	BTS collects and analyzes data relative to maritime trade and transportation, such as tonnage of U.S. commerce shipped, and foreign vessel entries and departures at major U.S. ports.
Universities and Other Researchers	As with marine science in general, the majority of research on the coastal and ocean economies is a cooperative arrangement among the federal government and researchers in the nation's universities and private research organizations. The interaction among federal, academic, and private researchers benefits from the strengths of multiple perspectives and organizational missions.

Key functions of an operational program for ocean economic data should include:

- *Data Collection*—Standard measures of employment, income, and output for ocean and coastal economies must be developed. The National Ocean Economics Project provides a foundation for this work, but additional measures are needed to assess: the influence of oceans and coasts on land values; the role of the oceans in the tourism and recreation industries in terms of both market and non-market values; and the economic value of ecosystem services provided by the oceans and coasts.

- *Data Distribution*—Data must be easily accessible to policy makers to assist in management decisions and to scientists to facilitate further research. The availability of modern database and Internet delivery systems has made this function much easier and cheaper than in the past.

- *Data Analysis*—Data only become useful outside the academic realm when they are analyzed and transformed into information products. Data analyses should be tailored to federal, regional, state, and local needs. Socioeconomic trends should be analyzed and linked to environmental trends. Geographic Information Systems will facilitate the integration of socioeconomic and natural resource data.

- *Education and Research*— Additional research should focus on improving measurements of nonmarket values, developing ways to quantify the use of ocean and coastal resources, and standardizing measures such as employment and output. The field of ocean and coastal economics is relatively new and primarily confined to a small group of specialists. To accommodate the growing demand for expertise in this field, expanded training of scientists and policy specialists will be required.

Recommendation 25–3. The National Ocean Council should create a national program for social science and economic research to examine the human dimensions and economic value of the nation's oceans and coasts. All ocean research agencies should include socioeconomic research as part of their efforts.

Implementation of the national program should include:

- *designation of an operational socioeconomic research and assessment function within the National Oceanic and Atmospheric Administration (NOAA).*
- *creation of an interagency group, chaired by NOAA, and including the Bureau of Labor Statistics (BLS), Bureau of the Census, Bureau of Economic Analysis (BEA), U.S. Department of Agriculture, U.S. Environmental Protection Agency, and National Science Foundation.*
- *preparation of biennial reports by BLS and BEA on the employment, wages, and output associated with U.S. coasts and oceans.*
- *preparation of biennial reports by the Bureau of Transportation Statistics on intermodal access to U.S. ports and maritime facilities and assessments of relevant maritime system performance and economic data.*
- *support for periodic reports on such topics as coastal demographics, geographic patterns and trends of ocean and coastal use, economic contributions, attitudes and perceptions, functioning of governance arrangements, and public–private partnerships.*
- *coordination of efforts to take maximum advantage of the expertise resident within government agencies, universities, and the private sector.*
- *creation of formal mechanisms for interacting with the regional ocean information programs so that changes at regional, state, and local levels can be documented and analyzed.*

Funding for these efforts should be at least $8–$10 million a year. While this amount may seem substantial in a time of scarce budgetary resources, it is less than one-tenth the amount the federal government currently spends on economic research related to agriculture, although the ocean economy is 2.5 times larger than agriculture in terms of total production of goods and services (Appendix C).

BUILDING A NATIONAL OCEAN EXPLORATION PROGRAM

Ocean exploration missions conducted during the 19th and 20th centuries were the first attempts to document how deep the oceans are, to chart key bathymetric features, and to identify and study marine life. Previously, the oceans were viewed as mere highways for maritime commerce, void of life below 1,000 feet. But despite the important discoveries made during these missions, we still have only a cursory understanding of the deep ocean.

The Value of Ocean Exploration

About 95 percent of the ocean floor remains unexplored, much of it located in harsh environments such as the polar latitudes and the Southern Ocean. Experience teaches us, however, that these vast and remote regions teem with undiscovered species and resources. On virtually every expedition, oceanographers discover fascinating new creatures. Some, such as the giant squid, have never been seen alive and are known only from dead specimens washed ashore or snagged in fishing gear.

Advances in deep-sea technologies have also made it easier to locate shipwrecks and historical artifacts lost in the ocean depths, such as the stunning discovery of the *RMS Titanic* in 1985. The continued exploration of marine archaeological sites will help us to better understand human history and our global cultural heritage.

In addition, preliminary evidence indicates that immense new energy sources exist in the deep sea. The amount of carbon bound in frozen gas hydrates on the seafloor is conservatively estimated to be twice the total amount of carbon existing in all the other known fossil fuels on Earth.[7]

Ocean exploration also offers an unprecedented opportunity to engage the general public in marine science and conservation. Exploration missions to the depths of the ocean provide images of ancient human artifacts, amazing creatures, and never-before-seen ecosystems. These images fire the imagination of people of all ages and can be used in both formal and informal educational settings. This kind of popular excitement and support can be an enormous asset in sustaining exploration projects over the long term.

Given the importance of the ocean in human history and in regulating climate change, guaranteeing food security, providing energy resources, and enabling worldwide commerce, it is astounding that we still know so little about it. This is due primarily to the lack of a long-term, large-scale national commitment to ocean exploration. The ocean and its depths need to be systematically explored to serve the interests of the nation and humankind.

Growing Calls for a National Program

Although our dependence on healthy marine ecosystems continues to grow, ocean exploration remains a relatively minor component of U.S. ocean science and is a missing link in the national strategy to better understand Earth's environment. Comprehending the genetic diversity of ocean life, developing fisheries, discovering energy resources, and mapping the seafloor all require more extensive exploration. U.S. leadership in ocean exploration will increase what we know about all aspects of ocean life and resources and make it possible to reach management decisions based on more complete scientific information.

There have been many calls for a dedicated national ocean exploration program. The Stratton Commission recommended an international program on a global scale.[8] In response, the United States led the International Decade of Ocean Exploration (IDOE) in the 1970s. IDOE programs greatly improved ocean observation systems, and led to such important research programs as Geochemical Ocean Sections, the Joint Global Ocean Flux Study, the Ridge Interdisciplinary Global Experiments, and the World Ocean Circulation Experiment. These initiatives dramatically enhanced our understanding of the global climate system, geochemical cycling, ocean circulation, plate geodynamics, and life in extreme environments.

In 1983, President Reagan directed the U.S. Department of the Interior to take the lead role in exploring the waters of the newly-recognized U.S. exclusive economic zone (EEZ). Three years later, in a report to the President and Congress, the National Advisory Committee on Oceans and Atmosphere (NACOA) detailed the economic importance of the EEZ and emphasized the need to improve efforts to assess its resources.[9] The NACOA report recognized that federal science programs were making important contributions, but concluded that individual efforts based on separate agency missions were neither comprehensive nor making acceptable progress. In response, the U.S. Geological Survey (USGS) and NOAA were tasked with developing a ten-year exploration plan. Although reconnaissance surveys of much of the EEZ were completed through 1990, more detailed assessments were never pursued. During the late 1990s, efforts to explore the EEZ and beyond lagged due to budgetary constraints.

In 2000, however, the President's Panel on Ocean Exploration called for a robust national ocean exploration program propelled by the spirit of discovery. The panel proposed multidisciplinary expeditions and annual funding of $75 million.[10] These recommendations led to the establishment of the Office of Exploration within NOAA, at a modest funding level of $4 million in fiscal year 2001, and $14 million in each of fiscal years 2002 and 2003. This program is helping NOAA to fulfill its applied science, environmental assessment, and technology development responsibilities, although the program's small budget and agency-specific focus limit its effectiveness.

A 2003 National Research Council report reiterated the need for a comprehensive national ocean exploration program strongly linked to traditional research, with broad international partnerships, and a commitment to educational opportunities.[11] The report offered specific recommendations on exploration priorities, funding needs, management models, and technology and infrastructure requirements.

NOAA and the National Science Foundation (NSF), by virtue of their missions and mandates, are well positioned to lead a global U.S. ocean exploration effort. NOAA currently runs the Office of Ocean Exploration, but NSF's focus on basic research provides an excellent complement to NOAA's more applied mission. Working together, the two agencies have the capacity to systematically explore and conduct research in previously unexamined ocean environments. To succeed, coordination, joint funding, and interactions with academia and industry will be essential.

Recommendation 25–4. Congress should appropriate significant funding for an expanded national ocean exploration program. The National Oceanic and Atmospheric Administration and the National Science Foundation should be designated as the lead agencies, with additional involvement from the U.S. Geological Survey and the U.S. Navy's Office of Naval Research. Public outreach and education should be integral components of the program.

An expanded national ocean exploration program will require a budget of approximately $110 million annually, plus additional funds for required infrastructure (discussed in Chapter 27).

COORDINATING AND CONSOLIDATING MARINE OPERATIONS

The need for routine mapping, monitoring, and assessment of U.S. waters (referred to as marine operations) has grown significantly in the past two decades. Accurate, up-to-date maps and charts of harbors, coastlines, and the open ocean are necessary for many activities, including shipping, military operations, and scientific research. In addition, expanded regulatory regimes rely heavily on routine assessments of living and nonliving marine resources and water quality. However, the ocean environment is changing faster than can be documented by the current number and frequency of surveys.

Modern sensor technologies, which can detect new variables in greater detail in the water column and seafloor, have improved our ability to follow changing ocean and terrestrial dynamics. But as these new technologies are implemented, they need to be calibrated against previous methods, as well as with each other, to provide useful environmental characterizations and ensure the consistency of long-term statistical data sets.

Integrated National Maps and Assessments

At least ten federal agencies, almost all coastal states, and many local agencies, academic institutions, and private companies are involved in mapping, charting, and assessing living and nonliving resources in U.S. waters. However, different organizations use varying methods for collecting and presenting these data, leading to disparate products that contain gaps in the information they present.

Primary Federal Agencies that Conduct Science-based Marine Operations

U.S. Environmental Protection Agency	U.S. Coast Guard
Minerals Management Service	U.S. Fish and Wildlife Service
National Geospatial-Intelligence Agency	U.S. Geological Survey
National Oceanic and Atmospheric Administration	U.S. Navy
U.S. Army Corps of Engineers	National Science Foundation

Ideally, a variety of information (e.g., bathymetry, topography, bottom type, habitat, salinity, vulnerability) should be integrated into maps using Global Positioning System coordinates and a common geodetic reference frame. In addition, these maps should include living marine resources, energy resources, and environmental data when available, to create complete ocean characterizations necessary for developing and implementing science-based ecosystem-based management approaches. Achieving this integration in the coastal zone is an extremely complex proposition.

By launching the Geospatial One-Stop Portal, the Office of Management and Budget has taken steps to curtail the collection of redundant data, facilitate information sharing, and plan for future integrated mapping and charting. This Web-based server will provide national base maps with administrative and political boundaries that can also incorporate information on agriculture, atmosphere and climate, ecology, economics, conservation, human health, inland water resources, oceans, estuaries, transportation networks, and utilities. In addition, the Federal Geographic Data Committee is developing the National Spatial Data Infrastructure in cooperation with organizations from state, local, and tribal governments, the academic community, and the private sector. This initiative includes policies, standards, and procedures for organizations to cooperatively produce and share geographically-linked data.

The relevant federal agencies must continue to integrate and share data in the quest to create readily accessible maps that track geological, physical, biological, and chemical resources in three dimensions. The fourth dimension—time—should be incorporated wherever possible so changes in ocean resources can be tracked over the short and long terms.

The National Research Council's 2003 study of national needs for coastal mapping and charting includes an examination of the major spatial information requirements of federal agencies and the principal user groups they support, identifies the highest priorities, and evaluates the potential for meeting those needs based on the current level of effort.[12]

Federal Mapping and Charting Activities

Maps of coastal land areas, and charts of nearshore and offshore areas, are essential for safe navigation and for defining boundaries, mitigating hazards, tracking environmental changes, and monitoring uses. Because so many federal agencies have mapping and charting responsibilities (Appendix 5), there are significant overlaps. This situation results in multiple entities within government, industry, and academia undertaking the expensive and time-consuming task of repeating surveys of the same area for different purposes. Furthermore, differences in scale, resolution, projection, and reference frames inhibit the integration of onshore and offshore data. It is impossible to merge most existing maps and charts to provide a continuous picture of the coastal zone. However, recent advances in the development of satellite positioning systems, mapping sensors, and the manipulation of data have created a new generation of geospatial data products that address some of the key challenges faced by ocean and coastal managers and policymakers.

The U.S. marine transportation system is in particular need of better charts. As this industry prepares for exponential growth over the next twenty years, a backlog of required surveys is developing. Approximately 35,000 square nautical miles of navigationally significant U.S. waters have been designated as critical areas requiring updated information on depth and obstructions.[13] New maps and charts of these waters and ports are essential to minimize shipping accidents and to support the national security missions of the U.S. Navy and U.S. Coast Guard.

Another significant issue is the need to conduct extensive multi-beam sonar mapping of the U.S. continental shelf, where a potential $1.3 trillion in resources (including oil, minerals, and sedentary species) could become available under United Nations Convention on the Law of the Sea (LOS Convention) provisions concerning extensions of the continental shelf. If the United States accedes to the LOS Convention, it would be able to present evidence to the United Nations Commission on the Limits of the Continental Shelf in support of U.S. jurisdictional claims to its continental shelf. The University of New Hampshire's Center for Coastal and Ocean Mapping/Joint Hydrographic Center, in conjunction with NOAA and USGS, has already identified regions in U.S. waters where the continental shelf is likely to extend beyond 200 nautical miles and is developing strategies for surveying these areas.[14] Bathymetric and seismic data will be required to establish and meet a range of other environmental, geologic, engineering, and resource needs.

Consolidation and coordination of the many existing federal mapping activities will increase efficiency and help ensure that all necessary surveys are conducted. NOAA, which has responsibility for collecting hydrographic and bathymetric data and creating navigational charts for safe and efficient maritime commerce, is the logical agency to lead the nation's coastal and ocean mapping and charting activities. Where consolidation is not feasible because of another agency's mission needs, clearer definitions of roles and responsibilities will be helpful. Drawing upon the mapping and charting abilities found in the private sector and academia will also be necessary to achieve the best results at the lowest cost.

Recommendation 25–5. The National Ocean Council (NOC) should coordinate federal resource assessment, mapping, and charting activities with the goal of creating standardized, easily accessible national maps that incorporate living and nonliving marine resource data along with bathymetry, topography, and other natural features.

In addition, the NOC should:

- *review and make recommendations on consolidation of appropriate federal, nonmilitary ocean mapping and charting activities within a strengthened National Oceanic and Atmospheric Administration.*
- *ensure that federal mapping and charting activities take full advantage of resources available in the academic and private sectors.*

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[2] National Sea Grant College Program. *NOAA Sea Grant Strategic Plan for FY 2003–2008 and Beyond: Science for Sustainability in the 21st Century*. Silver Spring, MD: National Oceanic and Atmospheric Administration, November 4, 2003.

[3] National Science Foundation. "Federal Funds for Research and Development, Detailed Historical Tables: Fiscal Years 1951–2002." <http://www.nsf.gov/sbe/srs/nsf03325/> Accessed January, 2004.

[4] Social Science Review Panel. *Social Science Research within NOAA: Review and Recommendations.* Washington, DC: National Oceanic and Atmospheric Administration, Science Advisory Board, 2003.

[5] National Marine Protected Areas Center. "Social Science Research Strategy for Marine Protected Areas." Internal draft. Silver Spring, MD, June 11, 2003.

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[8] U.S. Commission on Marine Science, Engineering and Resources. *Our Nation and the Sea: A Plan for National Action*. Washington, DC: U.S. Government Printing Office, 1969.

[9] National Advisory Committee on Oceans and Atmosphere. *The Need for a National Plan of Scientific Exploration for the Exclusive Economic Zone*. Washington, DC, 1986.

[10] President's Panel for Ocean Exploration. *Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration*. Washington, DC: National Oceanic and Atmospheric Administration, 2000.

[11] National Research Council. *Exploration of the Seas: Voyage into the Unknown*. Washington, DC: National Academy Press, 2003.

[12] National Research Council. *Interim Report—National Needs for Coastal Mapping and Charting*. Washington, DC: National Academy Press, 2003.

[13] Office of Coast Survey. *National Survey Plan*. Sliver Spring, MD: National Oceanic and Atmospheric Administration, November 2000.

[14] Center for Coastal and Ocean Mapping/Joint Hydrographic Center. *The Compilation and Analysis of Data Relevant to a U.S. Claim under United Nations Law of the Sea Article 76*. Durham, NH: University of New Hampshire, 2002.

CHAPTER 26: ACHIEVING A SUSTAINED, INTEGRATED OCEAN OBSERVING SYSTEM

Coastal and ocean observations provide critical information for protecting human lives and property from marine hazards, enhancing national and homeland security, predicting global climate change, improving ocean health, and providing for the protection, sustainable use, and enjoyment of ocean resources. While the technology currently exists to integrate data gathered from a variety of sensors deployed on buoys, gliders, ships, and satellites, the implementation of a sustained national Integrated Ocean Observation System (IOOS) is overdue and should begin immediately. Care should be taken to ensure that user needs are incorporated into planning and that the data collected by the IOOS are turned into information products and forecasts that benefit the nation. In addition, the IOOS should be coordinated with other national and international environmental observing systems to enhance our Earth observing capabilities and enable us to better understand and respond to the interactions among ocean, atmospheric, and terrestrial processes.

MAKING THE CASE FOR AN INTEGRATED OCEAN OBSERVING SYSTEM

About 150 years ago, this nation set out to create a comprehensive weather forecasting and warning network and today most people cannot imagine living without constantly updated weather reports. Virtually every segment of U.S. society depends on the weather observing network. Millions of citizens check reports each day to decide how to dress, whether to plan outdoor activities, and to determine if they need to prepare for severe weather. Commercial interests use daily and seasonal forecasts to plan business activities and to safeguard employees and infrastructure. Government agencies use forecasts to prepare for and respond to severe weather, issue warnings to the general public, and decide whether to activate emergency plans.

Recognizing the enormous national benefits that have accrued from the weather observing network, it is time to invest in a similar observational and forecasting capability for the oceans. This system would gather information on physical, geological, chemical, and biological parameters for the oceans and coasts, conditions that affect—and are affected by—humans and their activities. The United States currently has the scientific and technological capacity to develop a sustained, national Integrated Ocean Observing System (IOOS) that will support and enhance the nation's efforts for:

- improving the health of our coasts and oceans;
- protecting human lives and livelihoods from marine hazards;
- supporting national defense and homeland security efforts;
- understanding human-induced and naturally caused environmental changes and the interactions between them;
- measuring, explaining, and predicting environmental changes;
- providing for the sustainable use, protection, and enjoyment of ocean resources;
- providing a scientific basis for implementation and refinement of ecosystem-based management;

- educating the public about the role and importance of the oceans in daily life;
- tracking and understanding climate change and the ocean's role in it; and
- supplying important information to ocean-related businesses such as marine transportation, aquaculture, fisheries, and offshore energy production.

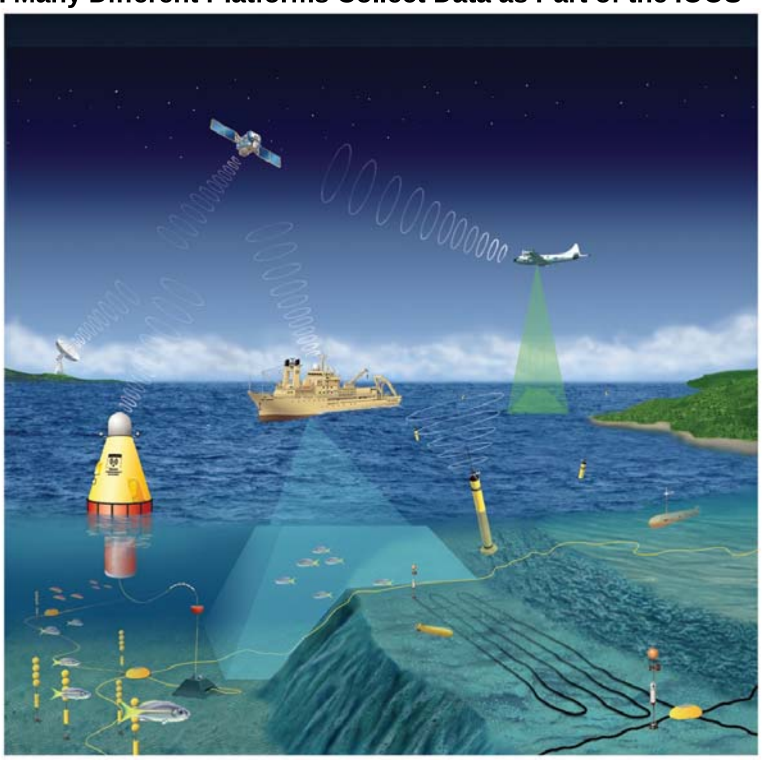
The United States simply cannot provide the economic, environmental, and security benefits listed above, achieve new levels of understanding and predictive capability, or generate the information needed by a wide range of users, without implementing the IOOS.

Components of an Integrated Ocean Observing System

The IOOS, an integrated and sustained ocean and coastal observing and prediction system, is a complex amalgam of many different land-, water-, air- and space-based facilities and technologies (Figure 26.1). Some broad categories of components are:

- *platforms,* such as ships, airplanes, satellites, buoys, and drifters, that are used for mounting or deploying instruments, sensors, and other components;
- *instruments and sensors* that sample, detect, and measure environmental variables;
- *telecommunication systems* that receive and transmit the data collected by the instruments and sensors; and
- *computer systems* that collect, store, assimilate, analyze, and model the environmental data and generate information products.

Figure 26.1. Many Different Platforms Collect Data as Part of the IOOS



This picture is an artist's rendering of the various water-, air-, and space-components of ocean observing systems. The data collected by each of these different sensors are transmitted via seafloor fiber optic cables and satellites to a central location on land.
Picture courtesy of the Marine Technology Society, Columbia, MD.

Assessing Existing Observing Systems

The United States has numerous research and operational observing systems that measure and monitor a wide range of terrestrial, atmospheric, and oceanic environmental variables (Appendix 5). For the most part, each system focuses on specific research objectives or limited operational applications. Among these are the U.S. Geological Survey's (USGS's) stream gage monitoring system that helps predict flooding and droughts, the National Weather Service's atmospheric observation system for weather, wind, and storm predictions and warnings, and the USGS/National Aeronautics and Space Administration (NASA) Landsat satellite system that characterizes landscape features and changes for land use planning. The technologies used run the gamut from simple on-the-ground human observations to highly sophisticated instruments, such as radar, radiometers, seismometers, magnetometers, and multispectral scanners.

Coastal and Ocean Observing Systems

Currently, the United States has more than forty coastal ocean observing systems, operated independently or jointly by various federal, state, industry, and academic entities (Appendix 5). The federal government also operates or participates in several large-scale, open-ocean observing systems. Examples include the National Oceanic and Atmospheric Administration's (NOAA's) Tropical Atmosphere Ocean program in the central Pacific Ocean that provides data to monitor and predict El Niño–La Niña conditions and the global-scale Argo float program for monitoring ocean climate.

There are several independent regional ocean and coastal observing systems. For the most part, they were built for different purposes and applications, measure different variables at different spatial and temporal scales, are not intercalibrated, and use different standards and protocols for collecting, archiving, and assimilating data. They also compete with each other for the limited funding available to support such efforts. As a result, despite considerable interest among stakeholders, and existence of required technology and scientific expertise, the United States has progressed very slowly in the design and implementation of a cohesive national ocean observing system.

An integrated ocean and coastal observing system that is regionally, nationally, and internationally coordinated and is relevant at local to global scales can serve a wide array of users, be more cost-effective, and provide greater national benefits relative to the investments made. Although the current regional systems are valuable assets that will be essential to the implementation of the IOOS, they are insufficiently integrated to realize a national vision.

Committing to Creation of the IOOS

The global ocean community has consistently articulated the need for a sustained ocean observing system to address the myriad challenges facing the world's oceans. In 1991, the United Nations Intergovernmental Oceanographic Commission proposed implementation of the Global Ocean Observing System (GOOS), and in 1992 participating nations at the United Nations Conference on Environment and Development (known as the Earth Summit) in Rio de Janeiro agreed to work toward establishment of this global system.

The U.S. National Ocean Research Leadership Council (NORLC), the leadership body for the National Oceanographic Partnership Program, has taken the lead in creating the IOOS, which will serve in part as the U.S. contribution to the GOOS. In response to congressional requests, the NORLC drafted two reports outlining the steps for creating a national system: *Toward a U.S. Plan for an Integrated, Sustained Ocean Observing System (1999)*, and *An Integrated Ocean Observing System: A Strategy for Implementing the First Steps of a U.S. Plan (2000)*. The second report provided a blueprint for the system's design and implementation. In October 2000, the NORLC established a federal interagency office called Ocean.US and charged it with coordinating development of the IOOS.

Ocean.US has made significant progress on a strategic plan for design and implementation. The plan is based on two distinct components: open ocean observations conducted in cooperation with the international GOOS and a national network of coastal observations conducted at the regional level. The coastal component will include the U.S. exclusive economic zone, the Great Lakes, and coastal and estuarine areas.

Developers of the IOOS must ensure that the global component is not minimized and that the connectivity with GOOS, including U.S. funding and leadership, remains strong and viable. GOOS data will be essential for assimilating environmental data that spans many spatial scales and for creating forecasts of national and regional impacts that may originate hundreds or thousands of miles away. Strong U.S. involvement in the GOOS will also demonstrate the nation's commitment to working toward an inclusive Earth observing system.

Although many individuals and agencies have spent countless hours creating plans for the IOOS, its successful realization will require high-level visibility and support within the administration, Congress, and the broad stakeholder community.

Recommendation 26–1. The National Ocean Council should make development and implementation of a sustained, national Integrated Ocean Observing System a central focus of its leadership and coordination role.

The support of a broad-based, multi-sector constituency is also critical to the success of the IOOS, particularly in light of the funding levels required to build, operate, and sustain such as system. As a first step, two national pilot projects and one or two international pilot projects should be implemented to link existing systems and produce operational applications relevant to national policy and a broad spectrum of users. The pilot projects will provide important visibility and demonstrate the potential economic and societal benefits of the full system, while advancing research and development of useful technologies and applications.

Creating a Governance Structure for the IOOS

National Planning

A strong national governance structure is required to establish policy and provide oversight for all components of the IOOS and to ensure strong integration among the regional, national, and global levels. Interagency coordination and consensus through the National Ocean Council and Ocean.US will be essential. While regional systems will retain a level of autonomy, achievement of the IOOS with nationwide benefits will require the regional systems to follow some national guidelines and standards. (Chapter 5 includes additional discussion of regional observing systems and their place within broader regional ocean information programs.) Regional observing systems can and should pursue needs outside the scope of the national system so long as these activities do not conflict with the smooth operation of the IOOS.

NOAA's role as the nation's civilian oceanic and atmospheric agency, and its mission to describe and predict changes in the Earth's environment and to conserve and manage the nation's coastal and marine resources, make it the logical federal agency to implement and operate the national IOOS.

Recommendation 26–2. Ocean.US, with National Ocean Council (NOC) oversight, should be responsible for planning the national Integrated Ocean Observing System (IOOS). The National Oceanic and Atmospheric Administration should be the lead federal agency for implementing and operating the IOOS, with extensive interagency coordination and subject to NOC approval.

Ocean.US

A memorandum of agreement (MOA) among ten federal agencies created Ocean.US as an interagency ocean observation office, supported by annual contributions from the signatories. The fundamental problem with the current arrangement is that Ocean.US has a number of responsibilities without any real authority or control over budgets. Its ephemeral existence under the MOA, its dependence on personnel detailed from the member agencies, and its lack of a dedicated budget severely detract from its stature within the ocean community and its ability to carry out its responsibilities.

Signatories to the Ocean.US Memorandum of Agreement	
U.S. Navy	Minerals Management Service
National Oceanic and Atmospheric Administration	U.S. Department of Energy
National Science Foundation	U.S. Coast Guard
National Aeronautics and Space Administration	U.S. Army Corps of Engineers
U.S. Geological Survey	U.S. Environmental Protection Agency

A more formal establishment of the Ocean.US office is needed for it to advise the National Ocean Council and achieve its coordination and planning mandates. The office requires consistent funding and dedicated full-time staff with the expertise and skills needed to ensure professional credibility. In addition, outside experts on rotational appointments could help Ocean.US meet its responsibilities.

Recommendation 26–3. Congress should amend the National Oceanographic Partnership Act to formally establish Ocean.US, with a budget appropriate to carry out its mission. Ocean.US should report to the National Ocean Council's (NOC's) Committee on Ocean Science, Education, Technology, and Operations (COSETO).

Congress should:

- *make the Ocean.US budget a line item within the National Oceanic and Atmospheric Administration's budget, to be spent subject to NOC approval.*
- *give Ocean.US authority to bring in outside experts on rotational appointments when needed.*

Regional Structure

Ocean.US envisions the creation of a nationwide network of regional ocean observing systems that will form the backbone of coastal observations for the IOOS. Although Ocean.US proposes creation of regional associations for coastal observing, coordinated through a national federation, [1,2] this concept is unnecessarily narrow. To fully address the needs of coastal managers, ocean observations need to be integrated into other information gathering activities such as regionally-focused research, outreach and education, and regional ecosystem assessments. Thus, as recommended in Chapter 5, the regional ocean information programs should be in charge of the development and implementation of regional ocean observing systems, along with their broader responsibilities. Regular meetings among all the regional ocean information programs and Ocean.US will be important for providing regional and local input into the development of the national IOOS.

Reaching Out to the User Community

To fulfill its mission, the IOOS must meet the needs of a broad suite of users, including the general public. However, at this early stage many people do not even know what the national IOOS is, nor do they grasp the potential utility and value of the information it will generate. This has slowed progress in its implementation.

Some important stakeholders outside of the federal agency and ocean research communities have not been sufficiently integrated into the initial planning process. Some of those who were consulted believe they were brought into the process after important design and other decisions had already been made. While Congress and the administration have both expressed support for the concept of a national integrated ocean observing system, there has been insufficient constituent demand to compel appropriation of significant public funds. Clearer communication about the benefits of the IOOS and broader participation in planning activities are necessary to help create a groundswell of support.

To get the most out of the IOOS, resource managers at federal, state, regional, territorial, tribal, and local levels will need to supply input about their information needs and operational requirements and provide guidance on what output would be most useful. Other users, including educators, ocean and coastal industries, fishermen, and coastal citizens, must also have a visible avenue for providing input. Ocean.US and the regional ocean information programs will need to devote significant time and thought to proactively approaching users and promoting public awareness of the enormous potential of the IOOS.

One obvious application of the observing system will be to monitor potential terrorist threats to the United States, including the possible use of commercial and recreational vessels to introduce nuclear, chemical, or biological weapons through the nation's ports to attack large metropolitan areas or critical marine infrastructure. Thus, it is important that homeland security personnel be actively engaged in defining their needs as part of the IOOS design process.

Recommendation 26–4. Ocean.US should proactively seek input from coastal and ocean communities to build cross-sector support for the national Integrated Ocean Observing System (IOOS) and develop consensus about operational requirements.

Specifically, Ocean.US should seek input from:

- *state, local, territorial, and tribal management agencies, industry, academia, nongovernmental organizations, and the public in the design and implementation of regional ocean observing systems and their integration into the national IOOS.*
- *Homeland security agencies in the design of the national IOOS, including planning for future research and development efforts to improve and enhance the system.*

Assembling the Elements of a Successful IOOS

The success of the IOOS will depend on several design elements: measuring the right set of environmental variables to meet regional, national, and global information requirements; transitioning research accomplishments into operational applications; and developing technologies to improve all aspects of the system, especially the timeliness and accuracy of its predictive models and the usefulness of its information products.

Critical Environmental Variables

To establish a uniform national system, a consistent core of environmental variables must be measured by all of the system's components. This core must strike a balance, remaining manageable and affordable while including enough parameters to address watershed, atmosphere, and ocean interconnections and support resource management, research, and practical use by many stakeholders. Measurements should include natural variables as well as human influences.

Based on an evaluation of more than one hundred possible environmental variables, Ocean.US identified an initial priority set of physical, chemical, and biological parameters for measurement by the IOOS (Table 26.2). It also created a supplemental list of meteorological, terrestrial, and human variables that are related to ocean conditions (Table 26.3).[3]

Table 26.2. Proposed Core Variables for the IOOS
Participants at an Ocean.US workshop recognized the following variables as important measurements to be made by the national IOOS.

Physical	Chemical	Biological
Salinity	Contaminants: Water	Fish Species
Water Temperature	Dissolved Nutrients	Fish Abundance/Biomass
Bathymetry	Dissolved Oxygen	Zooplankton Species
Sea Level	Carbon: Total Organic	Optical Properties
Directional Wave Spectra	Contaminants: Sediments	Ocean Color
Vector Currents	Suspended Sediments	Pathogens: Water
Ice Concentration	pCO_2	Phytoplankton Species
Surface Heat Flux	Carbon: Total Inorganic	Zooplankton Abundance
Bottom Characteristics	Total Nitrogen: Water	Benthic Abundance
Seafloor Seismicity		Benthic Species
Ice Thickness		Mammals: Abundance
Sea-surface Height		Mammals: Mortality Events
		Bacterial Biomass
		Chlorophyll-a
		Non-native Species
		Phytoplankton Abundance
		Phytoplankton Productivity
		Wetlands: Spatial Extent
		Bioacoustics

Source: National Ocean Research Leadership Council. *Building Consensus: Toward an Integrated and Sustained Ocean Observing System*. Proceedings of an Ocean.US workshop. Arlington, VA, March, 2002.

Table 26.3: Proposed Supplemental IOOS Variables
In addition to the ocean specific variables listed above, the participants at the Ocean.US workshop highlighted a number of other variables that affect ocean and coastal environments.

Meteorological	Terrestrial	Human Health & Use
Wind Vector	River Discharge	Seafood Contaminants
Air Temperature	Groundwater Discharge	Pathogens: Seafood
Atmospheric Pressure		Fish Catch and Effort
Precipitation (dry and wet)		Seafood Consumption
Humidity		Beach Usage
Aerosol Type		
Ambient Noise		
Atmospheric Visibility		
Cloud Cover		

Source: National Ocean Research Leadership Council. *Building Consensus: Toward an Integrated and Sustained Ocean Observing System*. Proceedings of an Ocean.US workshop. Arlington, VA, March, 2002.

While these lists provide a starting point for further discussion, many of the items included are actually broad categories rather than specific variables to be measured. The lists do not specify which variables can be measured with current technologies, which particular contaminants and pathogens should be observed, or which sets of observations can be assimilated to predict potentially hazardous environmental conditions, such as harmful algal blooms. Surprisingly, several important variables, such as inputs of air- and river-borne pollutants, are not included at all.

These lists will require further refinement and review by potential users of the system and a mechanism must be established to solicit additional feedback. Regional observation needs, such as fish stock assessments, assessments of sensitive and critical habitats, or monitoring for invasive species, are best understood by those in the regions affected. Therefore, input from local and regional groups, organized through the regional ocean information programs, will be essential for determining which variables should be included as national priorities.

Variables should be prioritized based on their value in resolving specific issues or questions, their application across issues, and the cost of measuring them. Priorities should also be assigned based on the variable's application to global, national, regional, state, and local information needs. Future deliberations will also need to identify variables for which current observation capabilities are sufficient and those that require new technologies.

Recommendation 26–5. Ocean.US, with National Ocean Council oversight, should develop a set of core variables to be collected by all components of the national Integrated Ocean Observing System.

This set of core variables should:
- *include appropriate biological, chemical, geological, and physical variables.*
- *be agreed on by the regional ocean information programs.*

Space-based Mission Priorities

Space-borne sensors can provide comprehensive, real-time, widespread coverage of ocean conditions and features and will be an integral part of the national IOOS. A growing international constellation of satellites allows extensive observation of ocean-surface conditions as well as the ability to extrapolate measurements from *in situ* sensors. Satellites can also provide baseline measurements at local, regional, national, and global scales that can be used to assess long-term environmental changes and the impacts of catastrophic events.

However, implementing sustained observations from space requires intense planning with long lead times. Given the cost, the time frame for constructing and launching satellites, and the inability to modify satellites once in orbit, five- to ten-year plans are required to ensure that satellite observations will be available on a continuous basis and employ the most useful and modern sensors. NOAA, as the lead federal agency for implementing and operating the IOOS, must ensure that ongoing satellite operations are fully integrated into the national IOOS.

Common needs for space-based observations should be identified and prioritized by a diverse group of users, in a manner similar to that recommended for determining IOOS environmental variables. Coordination with international satellite organizations will also be necessary to integrate the national IOOS with the GOOS and to accelerate development of new satellite-based sensor technologies.

Recommendation 26–6. Ocean.US should recommend priorities and long-term plans for space-based missions as an essential component of the national Integrated Ocean Observing System.

Ocean.US should:
- *work closely with the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, the user community, and the space industry to identify the most important space-based ocean observation needs.*
- *work with the international community on technical requirements for the Global Ocean Observing System in developing a plan for satellite remote sensing.*

Converting Research into Operational Capabilities

Research Observatories

A number of research observatories now in operation were created primarily by academic institutions to develop new observation technologies. Rutgers University's Long-term Ecosystem Observatory and the Monterey Bay Aquarium Research Institute's Ocean Observing System are two examples of programs that have made significant advances in developing observation technologies and the data management systems needed to support them. These observatories provide valuable scientific and engineering information that will be essential in building the IOOS. However, they can not be easily integrated into an operational, national IOOS, which will need to be based on stable, proven technologies and structured to deliver long-term observations.

The national IOOS will also have significant synergies with the NSF Ocean Observatories Initiative, which is being designed to address the ocean research community's needs for long-term, *in situ* measurements of biological, chemical, geological, and physical variables over a variety of scales. The NSF observatories will be used to examine the processes that drive atmospheric, oceanic, and terrestrial systems, and will serve as an incubator for new technologies to monitor these processes. While the IOOS and the NSF observatories have thus far been planned independently, the basic research and technology development from the NSF Observatories and the information generated by the IOOS are in reality interdependent, with each program supplying ingredients essential to the other. Close coordination and cooperation between NOAA and NSF will be necessary to capitalize on these benefits.

To ensure that the best available science and technology are continuously integrated into the national IOOS, mechanisms are needed for transitioning findings from research settings to routine operational applications. A new NOAA Office of Technology, recommended in Chapter 27, would be instrumental in making this transfer proceed smoothly. It would oversee coordination between NOAA, NSF, the U.S. Navy (including the Office of Naval Research, Naval Research Laboratory, Naval Oceanographic Office, Fleet Numerical Meteorology and Oceanography Center, and National Ice Center), NASA, other pertinent federal agencies, academia, and the private sector, all of which are essential in creating the bridge from research to operations.

New Sensor Technology

One area where additional capabilities are critically needed is in sensor technologies. Currently, the ability to continuously observe and measure physical variables (such as water temperature, current speed, and wave height) far surpasses the ability to measure chemical and biological parameters. With a few exceptions, most chemical and biological measurements are still obtained mainly by direct sampling and analysis. This shortcoming seriously hampers real-time observations of a broad range of biological parameters and populations of special interest, such as corals, marine mammals, and fish stocks. To realize the full promise of the IOOS, accelerated research into biological and chemical sensing techniques will be needed, with rapid transitions to operational use. NOAA, NSF, the Navy, and NASA should fund the development, and subsequent integration, of biological and chemical sensors for the IOOS as high priorities. Sensor development is discussed in more detail in Chapter 27.

Recommendation 26–7. The National Oceanic and Atmospheric Administration, the National Science Foundation (NSF), the U.S. Navy, and the National Aeronautics and Space Administration should require investigators who receive federal funding related to ocean research observatories, including the NSF Ocean Observatories Initiative, to develop plans for transferring new technologies to an operational mode in the Integrated Ocean Observing System.

Consolidating Civilian Satellite Observations

Both NOAA and NASA currently operate civilian, space-based, Earth observing programs that measure terrestrial, atmospheric, and oceanic variables (Appendix 5). NOAA's primary mission in this area is to provide sustained, operational observations for monitoring and predicting environmental conditions and long-term changes, with a focus on weather and climate. In contrast, NASA's mission is to advance research efforts and sensor development. A NASA project can last from a few days to a few years, and NASA has repeatedly asserted that it is not in the business of providing data continuity. In many instances, the lifetime of a NASA satellite, and its continued ability to collect and transmit data, outlasts its funding, resulting in premature termination at odds with the pressing demands for data in the operational context.

Benefits of Consolidation

While NASA-led research missions have greatly advanced our understanding of the oceans, they are developed without regard to ongoing, operational observing needs beyond the planned one- to ten-year life of the individual mission. Thus NASA's efforts have not, and will not, result in the sustained capabilities needed for the national IOOS. NASA also does not have the extensive atmospheric, land, and ocean ground-truthing infrastructure needed to verify remote observations for operational purposes.

The integration of space-based Earth environmental observing into one agency will greatly ease the implementation of a functional national system. Development of a multi-decadal record of observations requires space missions with sufficient overlap to avoid gaps in data collection and allow intercalibration of successive generations of sensors. Lack of such coordination can result in crippling information gaps, such as occurred during an eleven-year hiatus in the collection of ocean color data between the Coastal Zone Color Scanner and SeaWiFS missions. By consolidating Earth, and particularly ocean, observing satellite missions, more seamless, long term planning will be possible, resulting in a smooth concept-to-operations data collection process.

Recommendation 26–8. Congress should transfer National Aeronautics and Space Administration's (NASA's) Earth environmental observing satellites, along with associated resources, to the National Oceanic and Atmospheric Administration (NOAA) to achieve continued operations. NOAA and NASA should work together to ensure the smooth transition of each Earth environmental observing satellite after its launch.

Specifically, NOAA should:

- *work with NASA to define requirements for research-oriented Earth observing missions.*
- *ensure that satellite-derived ocean databases are integrated with traditional ocean and coastal databases.*
- *implement phased satellite missions and equipment replacement to maintain consistent data acquisition, based on Ocean.US plans.*
- *establish a long-term archive that includes historical satellite data to safeguard records, particularly those related to climate trends.*
- *prepare budget submissions that reflect the cost of transitioning satellite research missions into sustained operation.*

Because of its expertise and capabilities, NASA should maintain research, engineering, and development responsibility for Earth observing satellites. However, operational control of these satellites should be turned over to NOAA after the integrity of the satellite is confirmed in orbit (usually within approximately twenty days). This handoff has been demonstrated with the National Polar-orbiting Operational Environmental Satellite System.

Planning for Satellite Consolidation

A number of infrastructure and organizational changes will be needed at NOAA to ensure seamless assimilation of all Earth environmental observing satellites. Enhanced science, technology, and management coordination should occur within NOAA and among NOAA, other agencies, and the private and academic sectors. In addition, NOAA should initiate a review of its past successes and challenges in remote-sensing activities, satellite hardware procurement, satellite data collection and processing, and data distribution and archival strategies and programs. It is essential that NOAA be able to deliver raw data as well as analytical products to the public on an ongoing basis, and archive data in readily accessible formats for future assessments of environmental change.

NOAA's data and information management practices should be flexible, address customer needs, allow for continuous feedback and improvement, and be based on partnerships with industry and academia when appropriate. Further recommendations for improved data management and information product development within NOAA are found in Chapter 28. NOAA will also need to plan for continued calibration of all its observing satellites, using academic and private sector partners to form calibration and validation teams.

Developing Useful End Products Based on IOOS Data

To justify large federal investments in the IOOS, the system must result in tangible benefits for a broad and diverse user community, including the general public, scientists, resource managers, emergency responders, policy makers, private industry, educators, and officials responsible for homeland security. The IOOS cannot be developed as a narrow system useful only for research or federal government applications. The longtime partnership between the National Weather Service (NWS) and the private sector, which results in both general and tailored weather forecast and warning products that are widely acknowledged as valuable, is a good model upon which to build the IOOS.

The National Weather Service: An Investment That Paid Off

Billions of dollars have been invested over the last century to create a robust weather-related observing system. Continued operation of the National Weather Service (NWS) costs every U.S. citizen $4-$5 a year. For this investment, the NWS issues more than 734,000 weather forecasts and 850,000 river and flood forecasts annually, along with 45,000–50,000 potentially life-saving severe weather warnings. These forecasts and warnings have the potential to save millions to billions of dollars. For example, during a typical hurricane season, the savings realized based on timely warnings add up to an estimated $2.5 billion.[4] Geomagnetic storm forecasts are estimated to save the North American electric generating industry upwards of $150 million per year.[5]

NWS and commercial meteorological products have applications ranging from scientific research to human safety, transportation, agriculture, and simple daily forecasts. Similarly, IOOS products should be wide-ranging and based on the needs of regional and local organizations and communities, as well as national needs. The regional ocean information programs described in Chapter 5 will help produce information products of benefit to regional, state, and local managers and organizations. These regional programs will also provide important feedback to national planners about ways to make national IOOS products more useful. In addition, close coordination with Ocean.IT (a new data management office recommended in Chapter 28) will help in developing new forecast models of coastal and open-ocean conditions.

NOAA–Navy Partnership

Both NOAA and the Navy have the computer infrastructure and human capital needed to produce data and information products at varying spatial and temporal scales, and have experience tailoring products to the requirements of stakeholders in different regions and for different purposes. A joint NOAA–Navy ocean and coastal information management and communications program can help ensure high-quality end products from the national IOOS. Working together, these agencies will be able to produce routine operational ocean condition reports, forecasts, and warning products based on data from the IOOS. The NOAA–Navy program should work closely with nonfederal organizations, such as state and local governments, the regional ocean information programs, educators, nongovernmental organizations, and the private sector, to ensure that IOOS information products are useful to a broad user community. Specific recommendations about a NOAA–Navy ocean and coastal information management and communications program are included in Chapter 28.

Table 26.4. Proposed Annual Costs for Implementation

Assuming startup in fiscal year 2006, this table shows the IOOS cost estimates for each year until 2010. These figures do not include the costs for some essential components, such as satellite observations, which could add another $50-100 million per year.

Fiscal Year	Cost
2006	$138 million (start-up costs)
2007	$260 million
2008	$385 million
2009	$480 million
2010	$500 million (fully operational system)
Total for first five years	$1.7 billion
Out Years	$500 million/yr (to keep system operational, not accounting for inflation)

Data courtesy of Ocean.US., Arlington, VA.

Funding the National IOOS

The existing IOOS implementation plan calls for a distributed funding structure under which funds for implementation and operation of the national IOOS would be appropriated to many individual ocean agencies to support their respective contributions to the system.[6] This approach is not conducive to timely and seamless implementation of the national IOOS. The differences in missions and priorities among the ocean agencies could slow the implementation of key components of the IOOS. Additionally, the federal ocean agencies answer to different congressional committees and subcommittees for authorizations and appropriations, which could result in inconsistent and incomplete funding of the national system. Furthermore, in times of tight budgets, federal agencies may be tempted to tap into their IOOS budgets to support other shortfalls or unfunded initiatives. Only by consolidating the IOOS budget within one agency, with input and agreement on spending from the other agencies, can full implementation be assured.

System Cost Estimates

Ocean.US has provided estimates of the costs of implementing, operating, maintaining, and enhancing a national IOOS. The plan for the system involves a four-year ramp-up of funding, from a $138 million start-up cost in fiscal year 2006 to $500 million annually starting in fiscal year 2010 (Table 26.4). Details of the $138 million start-up cost are provided in Table 26.5.[7] The cumulative cost over the first five years is estimated at $1.7 billion.

Table 26.5: Breakdown of Proposed IOOS Start-up Costs

In fiscal year 2006, the start-up cost of $138 million is based on expenditures for four distinct components.

Activity	Cost to Perform
Accelerate the implementation of the U.S. commitment to the Global Ocean Observing System	$30M
Develop data communications and data management systems for the national IOOS	$18M
Enhance and expand existing federal observing programs	$40M
Develop regional observing systems	$50M
Total	**$138M**

Source: Ocean.US. *An Integrated and Sustained Ocean Observing System (IOOS) for the United States: Design and Implementation*. Arlington, VA, May 2002.

However, these cost estimates are not complete. They do not include all requirements for building, operating, and maintaining the system, such as costs associated with dedicated satellite sensors, space-borne platforms, and data stream collection and assimilation. Considering these additional system elements, rough estimates suggest that total funding for the national IOOS over the first five years may be closer to $2 billion.

Continuous improvements to IOOS observation and prediction capabilities will require sustained investments in technology development. Considering the costs of sensor development, telecommunications, computer systems, and improvements in modeling and prediction capabilities, an additional annual investment of about $100–$150 million will most likely be needed. Thus, the eventual ongoing costs for operating, maintaining, and upgrading the national IOOS could approach $650–$750 million a year.

Given the importance of the IOOS as an element in an integrated Earth observing system, these costs are in line with federal expenditures for other elements, including atmospheric, hydrologic, and pollution-related monitoring. For example, the ongoing cost of operating NWS is a comparable $700 million a year.

To fulfill its potential, the IOOS will require stable funding over the long haul. The lack of long-term funding for existing regional ocean observing systems has contributed to their isolation and piecemeal implementation. Consistent funding will help ensure that the American public receives the greatest return for its investment in the form of useful information, reliable forecasts, and timely warnings.

Recommendation 26–9. Congress should fund the Integrated Ocean Observing System (IOOS) as a line item in the National Oceanic and Atmospheric Administration (NOAA) budget, to be spent subject to National Ocean Council direction and approval. IOOS funds should be appropriated without fiscal year limitation. NOAA should develop a streamlined process for distributing IOOS funds to other federal and nonfederal partners.

An Investment with Big Returns: The Economic Value of Ocean Observations

While it is impossible to predict all the economic benefits that would flow from a national Integrated Ocean Observing System, its potential can be estimated by looking at a few systems currently in operation.

For example, the Tropical Global Ocean Atmosphere (TOGA) observing system in the Pacific Ocean provides enhanced El Niño forecasting. The economic benefits of these forecasts to U.S. agriculture have been estimated at $300 million per year.[8] Advanced El Niño forecasts allow fishery managers to adjust harvest levels and hatchery production 12 to 16 months in advance. For one small northwestern Coho salmon fishery, the net benefits of these forecasts have been estimated to exceed $1 million per year.[9] When summed over all economic sectors, the estimated value of improved El Niño forecasts reaches $1 billion a year.[10]

Improved wind and wave models based on ocean observations make weather-based vessel routing possible. Today, at least half of all commercial ocean transits take advantage of this, saving $300 million in transportation costs annually.[11] Search and rescue efforts by the U.S. Coast Guard also benefit from ocean observations. Small improvements in search efficiency can generate life and property savings in excess of $100 million per year.[12] Although more difficult to quantify, marine tourism, recreation, and resource management also benefit greatly from integrated observations and the improved forecasts they allow.

Finally, scientists estimate that reductions in greenhouse gas emissions now, compared to 20 years in the future, could result in world-wide benefits of $80 billion, with the United States' share approaching $20 billion.[13] Such emissions reductions will only be undertaken when policy makers feel fairly certain about their likelihood of success. Improved ocean observations and models will be critical to filling these knowledge gaps to support appropriate action.

Strengthening Earth Observations through National and International Partnerships

Other U.S. Operational Observing Systems

Atmospheric, terrestrial, and oceanic conditions and processes are inextricably intertwined. Progress in managing and protecting global resources will depend on understanding how those systems interact and what their impacts are on all scales, from local to global, over minutes or decades. Understanding such interactions is essential for accurately forecasting global climate change (long-term or abrupt), seasonal to decadal oscillations (like El Niño–La Niña, the North Atlantic Oscillation, or the Pacific Decadal Oscillation), and short and long-term ecosystem responses to environmental change.

The IOOS cannot exist as a stand-alone system, developed without considering associated observations. Rather, it should be integrated with other environmental observing systems to link weather, climate, terrestrial, biological, watershed, and ocean observations into a unified Earth Observing System. Such a system would improve understanding of environmental changes, processes, and interactions, making ecosystem-based management possible.

Integration of the IOOS with NWS's ground-, water-, space-, and atmosphere-based observations, with USGS's stream gage, water quality monitoring, and landscape observations, and with EPA's pollution monitoring, should be essential steps in implementation of the IOOS. The IOOS should also be linked with the broad national water quality monitoring network recommended in Chapter 15. Credible data gathered through other agencies and mechanisms, such as the Coral Reef and Invasive Species task forces, should all be considered in creating a coordinated Earth Observing System.

Recommendation 26–10. The National Ocean Council should oversee coordination of the Integrated Ocean Observing System with other existing and planned terrestrial, watershed, atmospheric, and biological observation and information collection systems, with the ultimate goal of developing a national Earth Observing System.

Enhancing Global Cooperation

The United States should continue to participate in the international Global Ocean Observing System to gain a better understanding of global ocean circulation patterns and biological processes, and answer pressing policy questions about global climate change and resource availability. In July 2003, the Earth Observation Summit was held in Washington, D.C. to focus on building an integrated global observation system over the next ten years. Thirty-four nations, the European Commission, and twenty international organizations joined the United States in adopting a declaration that affirmed the need for timely, high-quality, long-term global Earth observations as a basis for sound decision making. The ad hoc Group on Earth Observations has been formed to implement the declaration, co-chaired by the United States, the European Commission, Japan, and South Africa, and an implementation plan is scheduled to be completed by late 2004.

A recurring limitation of international scientific agreements and programs is the growing divide between scientific capacity and resources in developed and developing nations. Global programs function most effectively when all partners can participate fully. In addition to expanding scientific knowledge and stimulating technological development, capacity-building programs serve U.S. interests by creating goodwill and strengthening ties with other countries. Examples of capacity-building techniques include: providing access to U.S. scientific and technological expertise on a continuing basis; establishing education and training programs; securing funding for travel grants to allow scientists from less developed countries to participate in symposia, conferences, and research cruises; and funding international student fellowships.

High-level U.S. participation in international global observing planning meetings is essential, particularly by top-level NASA and NOAA officials. Furthermore, the United States should be strongly involved in international Earth Observation satellite missions. This includes supporting U.S. scientists to participate in foreign satellite mission planning and execution activities, such as planning for enhanced data management and access protocols.

Compatibility and accessibility of data collected by all participants in the GOOS will be needed to make the whole worth more than the sum of its parts. Although the United States has always supported full and open access to oceanographic data, this policy has met with resistance in some nations, especially where basic data collection and management activities have been outsourced to private companies. The U.S. should encourage foreign entities to engage in a policy of reciprocity, with a commitment to mutual sharing of data.

Recommendation 26–11. The National Ocean Council (NOC) should promote international coordination and capacity building in the field of global ocean observations.

The NOC should:

- *lead the interagency implementation of the 2003 Declaration on Earth Observing.*
- *encourage and support developing nations' participation in the Global Ocean Observing System.*
- *continue to advocate full, open, and meaningful data access policies and contribute technological expertise to ensure such access by all participants.*

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[1] Ocean.US. Implementation of the Initial U.S. Integrated Ocean Observing System. Part 1: Structure and Governance. Arlington, VA, June 2003.

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[3] National Ocean Research Leadership Council. *Building Consensus: Toward an Integrated and Sustained Ocean Observing System*. Arlington, VA: Ocean.US, March 2002.

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[7] Ibid.

[8] Solow, A.R., et al. "The Value of Improved ENSO prediction to US Agriculture." *Climate Change* 39 (1998):47-60.

[9] Adams, R.M., et al. "The Value of El Niño Forecasts in the Management of Salomon: A Stochastic Dynamics Approach." *American Journal of Agricultural Economics* 80 (1998): 765–77.

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[11] Kite-Powell, H.L. "NPOESS Benefits to Commercial Shipping." Silver Spring, MD, May 2000.

[12] Kite-Powell, H.L., S. Farrow, and P. Sassone. *Quantitative Estimation of Benefits and Costs of a Proposed Coastal Forecast System*. Woods Hole, MA: Woods Hole Oceanographic Institution, Marine Policy Center, 1994.

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Chapter 27:
Enhancing Ocean Infrastructure and Technology Development

The future success of ocean and coastal research in the United States will depend on the availability of modern ships, undersea vehicles, aircraft, laboratories, and observing systems, as well as the continuous development and integration of new technologies into these facilities. Significant interagency coordination, guided by a national strategy, is needed to plan the acquisition and operation of expensive, large-scale assets. A renewed commitment to funding the purchase, maintenance, and operation of these facilities will be essential. Technology development activities would be further aided by creating virtual centers of marine technology with coordinated federal activities to help transition new technologies into operational use.

Advancing Ocean and Coastal Science with Modern Tools

A robust infrastructure with cutting-edge technology forms the backbone of modern ocean science. It supports scientific discovery and facilitates application of those discoveries to the management of ocean resources. The nation has long relied on technological innovation, including satellites, early-warning systems, broadband telecommunications, and pollution control devices to advance economic prosperity, protect life and property, and conserve natural resources. Ocean research, exploration, mapping, and assessment activities will continue to rely on modern facilities and new technologies to acquire data in the open ocean, along the coasts, in challenging polar regions, on the seafloor, and even from space.

The three major components of the nation's scientific infrastructure for oceans and coasts are:

- *Facilities*—land-based laboratories and ocean platforms, including ships, airplanes, satellites, and submersibles, where research and observations are conducted;
- *Hardware*—research equipment, instrumentation, sensors, and information technology systems used in the facilities; and
- *Technical Support*—the expert human resources needed to operate and maintain the facilities and hardware as well as participating in data collection, assimilation, analysis, modeling, and dissemination.

This chapter does not attempt to provide a comprehensive review of all marine-related infrastructure and technology needs. Rather, it highlights several key areas where improvements in federal planning, coordination, and investment will be essential to support an enhanced ocean science enterprise.

Improving Infrastructure and Technology

Gaps in Infrastructure

Periodic surveys have attempted to assess various aspects of academic, private-sector, and federal ocean infrastructure, but many of these attempts have been incomplete, particularly regarding private and academic assets. The last official inventory of marine facilities, undertaken in 1981 by the Congressional Office of Technology Assessment, did not include information related to maritime commerce, marine safety, or education.[1]

As one of its early tasks, the U.S. Commission on Ocean Policy, as required by the Oceans Act of 2000, authorized an extensive assessment of the infrastructure associated with ocean and coastal activities (Appendix 5). This inventory documents the U.S. infrastructure for maritime commerce and transportation, ocean and coastal safety and protection, research, exploration, and monitoring, and marine education and outreach. The number and types of assets included are extensive and cover a wide range of federal, state, academic, institutional, and private-sector entities. Together, they represent a substantial public and private investment that has made possible great strides in modern oceanography over the last fifty years. But the assessment also revealed that significant components of the U.S. ocean infrastructure are aged or obsolete and that, in some cases, current capacity is insufficient to meet the needs of the ocean science and operational community.

Thirteen federal agencies with activities in ocean and coastal science develop, build, and operate infrastructure components to support their science missions, often in partnership with academic institutions. For very expensive or unique assets, federal organizations can develop shared resources, such as supercomputers and data centers.

The National Science Foundation (NSF) is the lead federal agency for supporting science and engineering infrastructure for academia, and is also the major supporter of basic science. However, NSF's share of support for ocean infrastructure has declined over the recent past as priorities have shifted to other science sectors. NSF funds large research facilities (those costing hundreds of millions of dollars) through its Major Research Equipment and Facilities Construction account. Small infrastructure projects (costing millions of dollars or less) have generally been funded through its regular disciplinary science programs. In 1997, NSF launched the Major Research Instrumentation program to provide additional support for instrumentation ranging in cost from $100,000 to $2 million, but the funding for this program falls far short of the needs and opportunities in the academic community. There is currently no NSF program dedicated to funding mid-size facilities (costing millions to tens of millions of dollars), although the disciplinary research programs would be very hard pressed to support such investments.

In 2003, the National Science Board (NSB), the governing board of the NSF, concluded that academic research infrastructure has not kept pace with rapidly changing technology, expanding opportunities, and increasing numbers of users.[2] New technologies allow researchers to be remotely connected to a sophisticated array of facilities, instruments, and databases; however these technologies are not readily available to the majority of scientists. NSB concluded that additional federal investments would be needed to provide scientists access to the latest and best infrastructure and technologies.

Gaps in Technology Development

In both the federal and academic arenas, it is difficult to incorporate rapidly changing technology into ongoing activities. However, to provide the public with useful information and products, the science community must learn how to rapidly transition marine technologies from the research and development stages to sustained applications. A prime example is the difficulty involved in transitioning the National Aeronautics and Space Administration's (NASA's) research-oriented ocean observing sensors into operational use at the National Oceanic and Atmospheric Administration (NOAA). Better planning and new funding will be needed to bridge this gap, allowing new technologies to revolutionize ocean science and management.

Furthermore, a decline in U.S. leadership in marine technology development will result in increasing reliance on foreign capabilities. Japan, the European Community, India, and China are all making great strides in technology development and have the potential to out compete the United States in the near future. Changes in the policies and priorities of foreign nations, and potential reluctance to freely share technology and environmental information with the United States, may put the nation's ocean research and observation activities at risk.

In 2001, the U.S. Commission on National Security/21st Century reported that federal investment in non-defense technology development has remained flat since 1989 and that the United States is losing its technological edge in many scientific fields.[3]

Maximizing Resources through Collaboration

Ocean science has become a highly interdisciplinary field, requiring close collaborations among natural, physical, and social scientists, engineers, and information technology experts. Because few organizations possess the facilities and expertise to support all major fields of investigation, ocean projects frequently depend on partnerships among federal, state, academic, and private institutions, both U.S.- and foreign-based.

An overarching message from the Inventory of U.S. Coastal and Ocean Facilities (Appendix 5) is the need for continued partnerships among public and private entities to reduce costs, leverage resources, and encourage information sharing. Many successful collaborations have formed across the nation and around the world in recent decades. Ocean and coastal laboratories are frequently focal points for these efforts, drawing additional resources and new facilities supported by government, private, or academic institutions to advance the science capabilities of a region.

For example, Narragansett, Rhode Island is home to a strong coalition of diverse research organizations, including the Atlantic Ecology Division of the U.S. Environmental Protection Agency's (EPA's) National Health and Environmental Effects Research Laboratory, NOAA's Northeast Fisheries Science Center Narragansett Laboratory, and the University of Rhode Island's Graduate School of Oceanography. Similarly, at the Hollings Marine Laboratory in Charleston, South Carolina, NOAA's National Ocean Service and the National Institute of Standards and Technology have partnered with the South Carolina Department of Natural Resources, the College of Charleston, and the Medical University of South Carolina to construct and operate a state-of-the-art marine laboratory dedicated solely to collaborative, interdisciplinary research.

Consortia and joint programs, with facilities that support several institutions, create marine science communities that interact closely, share knowledge, enhance career pathways, and promote collaboration among government, academic, and private sectors. The most cost-effective means of making infrastructure available to the largest number of scientists is to emphasize partnering among many institutions from all sectors.

Back in 1969, the Stratton Commission already recognized that the technological and scientific demands of global ocean research would overtax the means of any single nation, stressing the need for international partnerships.[4] Realizing the expense involved in building and maintaining infrastructure and developing new technologies, nations have joined together in extremely successful ways. Current examples of such shared resources include satellite-based sensors, Argo profiling floats that measure meteorological and ocean variables as part of the Global Ocean Observing System, the Global Climate Observing System, and the Integrated Ocean Drilling Program. The United States should continue to pursue partnerships with foreign nations for high-cost technology development activities with worldwide applications, while ensuring that foreign efforts are complementary to those in the United States, not replacements for them.

A National Strategy

Despite the growing need to improve ocean observing, forecasting, and management, the federal government has yet to develop a long-range strategy to support the civilian infrastructure and technology needed for both research and operational purposes. Although federal agencies have made efforts to improve their coordination through the National Oceanographic Partnership Program and other mechanisms, infrastructure and technology planning is still not conducted in an integrated fashion that reflects regional, national, and international priorities.

Although some facilities are operated with joint funding, interagency budgeting for shared facilities has had limited success due to differences in Congressional oversight and financial and project approval processes. As a result, facilities are typically constructed or modernized in a piecemeal fashion, often through earmarked congressional funding. A unified national strategy can help achieve and maintain an appropriate mix of federally supported, modern ocean facilities that meet the nation's needs for quality resource management, science, and assessment. Federal coordination could also focus support on developing and transferring technologies that numerous agencies desire for operational activities.

Recommendation 27–1. The National Ocean Council's Committee on Ocean Science, Education, Technology, and Operations should develop a national ocean and coastal infrastructure and technology strategy, including funding and implementation requirements.

The strategy should include:

- *consideration of the existing capabilities of academic, state, and private entities.*
- *identification of emerging technologies that should be incorporated into agency operations.*
- *mechanisms for establishing international partnerships.*
- *guidelines for incorporating the strategy into agency plans for technology development and facilities construction and consolidation.*
- *specific priorities for acquiring and upgrading ocean research infrastructure, including vessels, facilities, instrumentation, and equipment.*

The development of needed ocean technologies—whether identified by the national strategy or through interagency communication—requires directed funding and coordination. Federal agency programs will benefit by having a centralized office responsible for accelerating the transition of technological advances made by federal and academic laboratories into routine operations. NOAA, by virtue of its mission, is the logical agency for this role.

Recommendation 27–2. The National Oceanic and Atmospheric Administration should create, and Congress should fund, an Office of Technology to expedite the transition of experimental technologies into operational applications. This office should work closely with academic institutions, the regional ocean information programs, the National Science Foundation, the U.S. Navy, the National Aeronautics and Space Administration, and other relevant agencies to achieve its mission.

Periodic Reviews and Assessments

In conducting its inventory of U.S. coastal and ocean facilities, the Commission discovered few long-term plans for maintaining, replacing, or modernizing facilities (Appendix 5). As the first such assessment conducted in twenty-two years, the need for periodic future infrastructure assessments became obvious. A meaningful accounting of national assets, facilities, and human resources requires regular updates to ensure that the national strategy is based on an up-to-date understanding of capacity, capabilities, and trends.

Developing a national facilities database would help plan for asset replacement or refurbishment. Furthermore, organizing such a database along regional lines would help identify the facility needs of each region and improve the prospects for resource sharing. State and private-sector capabilities should be included in the inventory to alert scientists to the existence and potential availability of these assets.

Recommendation 27–3. The National Ocean Council should update the assessment of U.S. ocean and coastal infrastructure and technology, including federal, state, academic, and private assets, every five years.

The assessment should include information on:

- *the location, ownership, availability, remaining service life, and replacement cost for a wide range of ocean infrastructure assets.*
- *maintenance and operational costs associated with these assets.*
- *associated human resource needs.*
- *the outcomes of past federal investments in ocean technology and infrastructure, with recommendations for improvements.*

Funding the Modernization of Critically Needed Assets

Too often, federal and state agencies have had to delay, reduce, or cancel infrastructure upgrades at government facilities during the past decade due to budgetary constraints or changing agency priorities. Similar challenges arise within the academic community which must balance the cost of expensive facilities with other institutional priorities.

Recent state fiscal crises have exacerbated the problem at public universities, and a significant decline in the value of many endowment funds during the same period has delayed modernization and expansion activities at many private institutions. Funds dedicated for operations and maintenance of existing equipment have also declined. As a result, significant parts of the ocean and coastal infrastructure are outmoded, limiting the progress of ocean research and hindering the prospects for using science to improve management practices.

Essential Infrastructure and Technology Components

The following discussion provides a summary of the condition of several major ocean science infrastructure categories, highlighting those most in need of coordinated planning and increased investment.

Surface Vessels

Despite the increasing availability of moored instruments, drifters, gliders, and satellites to collect ocean data, the need will remain for traditional ships to conduct research, exploration, operations, and education. But insufficient vessel capacity, vessel deterioration, and outdated shipboard equipment and technology hinder the conduct of vessel-based science and operations. In some cases, these conditions also present safety issues and increase the cost of routine maintenance and operation.

The nation's existing 400-plus surface vessels for research and operations are spread across federal and state agencies, universities, private research institutions, and private industry. The five largest U.S. fleet operators conducting global, coastal, and near shore research and mission operations are NOAA, the U.S. Navy, the U.S. Environmental Protection Agency, the U.S. Geological Survey, and the U.S. Department of the Interior, which together own and operate the forty-one primary vessels of the federal fleet associated with ocean science and operations. In addition, fifty-four academic institutions and five federal agencies (NSF, the Office of Naval Research (ONR), NOAA, USGS, and the U.S. Coast Guard) operate and use the twenty-nine vessels in the University National Oceanographic Laboratory System (UNOLS) fleet. Most coastal states also own and operate vessels of various sizes and mission capabilities to satisfy state needs. A significant and growing number of privately-owned research and operations vessels are also being used by federal and state agencies and academic institutions through contract or lease arrangements, particularly for highly specialized work.

The Navy survey fleet is relatively new and generally maintained at a level adequate to meet defense mission requirements. The Coast Guard operates three icebreakers, which provide polar research capabilities. This fleet was recently updated with a new vessel specifically designed for research. NOAA has enlarged its fleet by refitting surplus Navy vessels and launching a ten-year plan to build four specialized fishery research ships at $52 million per vessel.[5] Two of the ships are under construction, but funding has not been finalized for the remaining two. USGS and EPA need new vessels to satisfy basic mission mandates, but currently have no funding or plans to acquire these resources.

While all of the agency fleets would benefit from upgrades, the UNOLS fleet is *in extremis*. Twelve of the seventeen largest UNOLS ships will reach the end of their service life over the next fifteen years, and almost all UNOLS ships need immediate and significant enhancements.[6]

The development of the Integrated Ocean Observing System (IOOS, discussed in Chapter 26) will intensify the demand for ship support to install and maintain system components. This capacity is not available in the research fleet today, nor is it foreseen in the near future. With the start of the international Integrated Ocean Drilling Program, the United States has pledged to provide a modernized non-riser drilling vessel with enhanced coring and drilling capabilities at an estimated cost of $100 million.[7]

Modern research ships are designed as flexible multi-mission platforms that can accept different instrument systems to suit particular projects. However, the instrumentation that is built in (such as sonars, mapping systems, or computer labs) must be considered part of the vessel. These onboard technologies typically require much more frequent maintenance and upgrades than the vessels themselves. Thus, fleet planning strategies need to consider the costs of maintaining existing instrumentation and integrating emerging technologies.

The National Ocean Partnership Program established the Federal Oceanographic Facilities Committee to oversee oceanographic vessel use, upgrades, and investments. The committee's 2001 plan for recapitalization of the academic research fleet is an excellent example of successful interagency planning at the national level.[8] Unfortunately, the plan has not yet been funded or implemented.

Undersea Vehicles

Scientists working in the deep ocean have made fundamental contributions to understanding ocean and planetary processes and the nature of life itself. Further scientific breakthroughs are likely if more regular access to the ocean depths can be provided. Ninety-seven percent of the ocean floor can be accessed by existing undersea vehicles with depth capabilities of around 20,000 feet. The remaining three percent—an additional 16,000 feet of ocean depth—remains largely inaccessible, although it includes most of the deep ocean trenches and comprises an area the size of the continental United States, Alaska, and about half of Mexico combined.

Human-occupied deep submersible vehicles came into operation in the late 1950s, followed by tethered remotely operated vehicles, and later by autonomous underwater vehicles. All three types of vessels are still used, and this variety allows researchers to choose the best tool for their needs, based on factors such as task, complexity, cost, and risks.

Today French, Russian, and Japanese human-occupied submersibles regularly work at depths of 20,000 feet or more. The last such vehicle in the United States was the *Sea Cliff*, which was retired in 1998 and not replaced. U.S. capability today is limited to the *Alvin*, built in 1964, which can only descend to 15,000 feet and stay submerged for short periods. For missions of long duration, the United States relies on the Navy's NR-1 nuclear research submarine, which can stay submerged for thirty days but has a maximum depth of only 3,000 feet. The NR-1 was constructed in 1969, and its service life will end in 2012.

The United States has a well-developed remotely operated vehicle (ROV) industry, and ROVs are readily available for academic and industrial purposes. The last twenty-five years have witnessed extraordinary advances in the field of sub-sea robotics, developed mainly for the oil and gas industry, and there is a wide array of ROVs available with working depths of 9,800 feet. Current U.S. ROV capabilities are led by *Jason II*, with a maximum operating depth of 21,325 feet, but it is the only vehicle in the federal fleet capable of reaching this depth. Federal funding has expedited the development of ROVs that can dive to 23,000 feet and deeper, but a concerted effort will be needed to make deep-water capabilities more economical and accessible. All submersibles in the federal fleet, including *Alvin* and *Jason II*, are currently housed at the National Deep Submergence Facility at the Woods Hole Oceanographic Institution. The facility is funded through a partnership among NSF, ONR, and NOAA.

The U.S. autonomous underwater vehicle (AUV) industry has just begun to emerge from the research, development, and prototype phase. Over the past decade, close to sixty development programs have been initiated throughout the world, and approximately 175 prototypes have been developed. About twenty of these programs remain active, with at least eight in the United States. While the primary financial drivers of AUV development in the United States have been the U.S. military and the oil industry, significant programs are in place at a few academic institutions and private institutes.

A 2003 report by the National Research Council found that the scientific demand for deep-diving vehicles is not being met.[9] The report supports a mix of vehicles to support current and future research needs. Recommendations include: (1) setting aside funds at the National Deep Submergence Facility to gain access to vehicles outside the federal fleet for specific missions; (2) acquiring a second ROV to join *Jason II* by 2005, at a cost of approximately $5 million; and (3) initiating an engineering study to evaluate various options for replacing *Alvin*, with a goal of providing submergence capability up to 21,000 feet, at a cost of approximately $20 million. The report noted that in time and with a higher level of funding, additional platforms with greater capabilities could be profitably added to the fleet.

Dedicated Ocean Exploration Platforms

The success of a robust national ocean exploration program (described in Chapter 25) will depend on the availability of sufficient vessel support, particularly ships and submersibles. Given that the existing suite of platforms requires upgrading just to meet current demands—not to mention the additional needs of the IOOS—implementation of a robust, national ocean exploration program will require additional support facilities. These assets should provide dedicated support for exploration missions and the flexibility to investigate many ocean areas and environments.

In 2003, the National Research Council recommended U.S. participation in an international exploration effort and discussed the benefits of providing a $70 million modern flagship and modernized underwater vehicles and platforms.[10] Such assets should be included in the national strategy for ocean infrastructure and technology.

Airborne Ocean Science Platforms

Piloted and autonomous aircraft are an integral part of modern ocean research and operations. They are needed for precise airborne observation and measurements of the ocean, air–sea interface, and atmosphere. Many multidisciplinary, ocean–atmosphere field projects require a mix of observational platforms, particularly aircraft teamed with ships and satellites. Research aircraft are also instrumental in developing new satellite and airborne sensors. The national airborne fleet is operated by a partnership of federal agencies and academia. Private aircraft are often used for specialty and operational projects such as aerial mapping, marine mammal surveys, and supply missions.

The future of airborne ocean science and monitoring rests on the increased availability of autonomous or remotely-piloted aircraft. These research platforms are being developed with a greater range, duration, and ceiling than conventional aircraft, and present less risk when operating in hazardous environments. The research community has suggested the need for a worldwide fleet of autonomous aircraft for ocean and atmospheric observation by 2005.[11] NASA, ONR, and NSF currently have active autonomous airborne ocean research programs, and are working to develop additional resources.

The Interagency Coordinating Committee for Airborne Geoscience Research and Applications, which is composed of federal agencies and academic institutions that operate research aircraft programs, works to improve cooperation, foster awareness, and facilitate communication among its members, and serves as a resource to senior managers. In an effort to coordinate ocean research aircraft, UNOLS has recently designated certain assets as National Oceanographic Aircraft Facilities.

The demand for these assets is increasing, particularly as collaborative ocean-atmosphere projects become more common. Demand currently exceeds availability. Inadequate funding for research flight time is exacerbating the problem. Furthermore, as with surface vessels, emerging technologies and updated safety and personnel requirements will require significant funding that must be included in planning.

In 2003, NOAA drafted a ten-year plan for airborne platforms that provides an extensive analysis of agency requirements. The plan included an examination of historical flight requests, allocations, and budgets, and delineated future requirements, contracts for service, and a recapitalization schedule and cost.[12]

Laboratories and Instrumentation

Maintaining academic laboratory space and instrumentation over the past decade has been challenging due to increased construction of new facilities to meet rising student and faculty needs and increased upkeep needs for aging facilities. This problem is aggravated by the prohibition against academic institutions setting aside adequate federal funds for ongoing maintenance and replacement. A recent RAND study estimated that the true cost of providing facilities and administration to support research projects is about 31 percent of the grant amount.[13] However, federal regulations limit the share that can be covered with federal funds to between 24 and 28 percent, leaving the difference to be covered by the institutions.

In 2002, the Consortium for Oceanographic Research and Education surveyed eighty-six non-UNOLS academic ocean programs to examine facility age and replacement plans (Appendix 4). Relatively few institutions had replacement plans for their facilities, and a number of institutions noted that lack of available funds was the primary factor preventing planning and upgrades. Yet increases in both lab space and instrumentation capacity will be essential for the continued conduct of cutting-edge ocean research.

Many federal facilities are deteriorating due to growing budget pressures and new mandates related to safety, homeland security, and environmental health compliance. NOAA characterizes its need for improvements to equipment and labs as a major impediment to future science capabilities. In a 2002 Performance Review Report, NOAA showed holdings of 800 buildings at 500 installations, representing 6 million square feet of space.[14] Approximately 50 percent of the properties were over 30 years old, and there was a backlog of 316 maintenance and repair projects. Of the estimated $65 million in costs needed to remedy this backlog, $25 million was required just to address health and safety problems. If the fiscal year 2002 facility funding level of $3.2 million is maintained over the next few years, 60 percent of this backlog will remain in 2010. In its Strategic Plan for 2003-2008, NOAA presented a strategy for improving infrastructure development, construction, consolidation, and maintenance, but additional funding will be needed to implement the plan.[15]

Advanced Telecommunications Technology and Broadband Capabilities

Federal satellite communications infrastructure is needed to provide affordable, global broadband coverage to support ocean observations and exploration. Current coverage does not provide links to important polar regions or portions of the Southern Ocean. Advanced communication capabilities are also required for scientists to remotely operate ocean exploration vehicles, similar to the highly successful use of space probes. These telecommunication technologies also provide excellent educational opportunities for the general public, allowing them to participate in virtual voyages to deep and inaccessible parts of the ocean. Telepresence— the transmission of real-time, high-quality video, audio, and other digital data from undersea exploration sites over the Internet—will demand modern broadband data transfer capabilities.

A variety of other research activities require upgrades in the current data transmission infrastructure, such as the fiber optics needed for cabled sensor systems. The IOOS will require transmission of large amounts of coastal, oceanic, and atmospheric data in real and near-real time, demanding advanced telecommunications technology and infrastructure. Active partnerships between ocean scientists and the private telecommunications industry will be crucial to ensure that the United States has the capability to transmit and assimilate the data streams of the future.

Environmental Sensors

Development of new environmental sensors—an essential component of the IOOS—will require a substantial federal investment. Sensors for measuring basic oceanographic parameters such as currents, temperature, and salinity are already widely available, but sensors that illuminate the chemistry and biology of the ocean are just emerging. The new generation of sensors will be able to measure such parameters as carbon dioxide, acidity, alkalinity, dissolved oxygen, nitrates, photosynthetically active radiation, spectral radiance and irradiance, back-scattered light, and stimulated fluorescence. Some of the innovative biological technologies currently being investigated include acoustic monitoring and optical scanning systems for identifying and tracking marine life, DNA probes for identifying harmful algal blooms, and nanotechnology sensors for monitoring potentially harmful pathogens. Although prototypes exist, many sensors still need considerable development before they can be expected to operate unattended for long periods of time in the harsh ocean environment. Federal support and multisector partnerships will be necessary to turn innovative environmental sensors into operational components of the national IOOS.

A Federal Modernization Fund

Coordinated federal support for ocean research infrastructure could be achieved through the establishment of a modernization fund. Such a fund would be used to build or upgrade critical facilities and acquire related instrumentation and equipment. It would also provide a mechanism to coordinate similar equipment purchases across agencies, where feasible, creating significant economies of scale.

Recommendation 27–4. Congress should establish a modernization fund for critical ocean infrastructure and technology needs. Spending priorities should be based on the National Ocean Council's ocean and coastal infrastructure and technology strategy.

High-priority areas for funding include the following:

- *the renewal of the University National Oceanographic Laboratory System ocean and air fleets, including the Integrated Ocean Drilling Program ship, and deep-submergence vehicles.*
- *the completion of the third and fourth dedicated fishery research vessels.*
- *the acquisition of vessels and infrastructure needed for an expanded national ocean exploration program.*
- *ongoing operations, maintenance, and modernization of existing assets, including laboratory facilities.*

Creating Virtual Marine Technology Centers

Fundamental oceanographic questions require the best scientific and engineering talent working cooperatively to obtain answers. Interdisciplinary oceanographic research programs typically require large numbers of platforms and sensors operating in a coordinated manner. While new technologies are enabling the creation of more powerful sensors, robotic platforms, and ocean observing systems, it would be extremely difficult for any individual research group to acquire all these technologies and master increasingly complex instrumentation. By sharing expensive technologies, infrastructure, and expertise, more investigators will have greater access to these assets.

Virtual centers will require a smaller federal investment than if numerous institutions all attempt to acquire the same essential instrumentation. By electronically linking existing academic, government, and private-sector capabilities and instrumentation, virtual centers for ocean and coastal technology could maximize the use of the excellent capabilities and facilities already present in the United States. These interdisciplinary virtual centers could take advantage of submersibles in one location, ocean observations halfway around the globe, and socioeconomic studies coordinated at another location. Infrastructure components available through the center could be used for small-scale, pilot projects that would normally not have access to such facilities. Investigators could apply for grants to join an ongoing team linked by computers, not geography. The multipurpose focus of each center also lends itself to the development of new approaches to education and public outreach.

The centers will also serve as incubators for infrastructure innovations and new technologies necessary to achieve and sustain national competitiveness in ocean science and engineering research. A strengthened NOAA, as the lead ocean observation, operations, and management agency, is the logical organization to provide funding for these virtual marine technology centers.

Recommendation 27–5. The National Oceanic and Atmospheric Administration should establish, and Congress should fund, national virtual marine technology centers to provide coordinated access, through electronic means, to cutting-edge, large-scale research technologies.

[1] Office of Technology Assessment, Science, Information and Natural Resources Division. *Technology and Oceanography: An Assessment of Federal Technologies for Oceanographic Research and Monitoring*. Washington, DC, 1981.
[2] National Science Board Task Force on Science and Engineering Infrastructure. *Science and Engineering Infrastructure for the 21st Century: The Role of the National Science Foundation*. Arlington, VA: National Science Foundation, April 2003.
[3] U.S. Commission on National Security/21st Century. *Road Map for National Security: Imperative for Change*. Washington, DC, 2001.
[4] U.S. Commission on Marine Science, Engineering, and Resources. *Panel Reports of the Commission on Marine Science, Engineering, and Resources*. Washington, DC: U.S. Government Printing Office, 1969.
[5] National Oceanic and Atmospheric Administration. *Report of NOAA's Ship Platform Requirements: FY 2003–2012*. Silver Spring, MD, March 2003.
[6] Office of Naval Research. *Report to Congress—Requirements and Plans for UNOLS Fleet Renewal*. Washington, DC: U.S. Navy, February 2003.
[7] U.S. Science Advisory Committee. *The Non-riser Drilling Vessel for the IODP: A Report from the Conceptual Design Committee*. Washington, DC: Integrated Ocean Drilling Program, March 2000.
[8] Federal Oceanographic Facilities Committee. *Charting the Future for the National Academic Research Fleet—A Long-Range Plan for Renewal*. Washington, DC: National Oceanographic Partnership Program, December 2001.
[9] National Research Council. *Future Needs in Deep Submergence Science: Occupied and Unoccupied Vehicles in Basic Ocean Research*. Washington, DC: National Academy Press, 2003.
[10] National Research Council. *Exploration of the Seas: Voyage into the Unknown*. Washington, DC: National Academy Press, 2003.
[11] National Oceanic and Atmospheric Administration. *Report of NOAA's Airborne Platform Requirements for the Ten-Year Period FY 2003–FY 2012*. Silver Spring, MD, February 2003.
[12] Ibid.
[13] Goldman, C.A., and T. Williams. *Paying for University Research Facilities and Administration*. Santa Monica, CA: RAND Corporation, 2000.
[14] National Oceanic and Atmospheric Administration. *NOAA Program Review*. Silver Spring, MD, June 2003.
[15] National Oceanic and Atmospheric Administration. *New Priorities and Beyond—NOAA's Strategic Plan for FY 2003–FY 2008 and Beyond*. Silver Spring, MD, March 2003.

Chapter 28:
Modernizing Ocean Data and Information Systems

Ocean and coastal research and observational activities are generating new data at ever-increasing rates—data that must eventually be analyzed, distributed, and stored. The nation's ocean and coastal data management systems should be modernized and integrated to promote interdisciplinary studies and provide useful information products for policy makers, resource managers, and the general public. Better interagency planning is needed to coordinate federal data management. An information management and communications program will help produce operational ocean and coastal forecasts and disseminate information products relevant to national, regional, and local needs. Ultimately, the goal should be to transition all environmental data archiving, assimilation, modeling, and information systems, which are currently divided by environmental sectors, into a fully integrated Earth environmental data system.

Turning Oceans of Data into Useful Products

Ocean and coastal data are essential for understanding marine processes and resources. They are the foundation for the science-based information on which resource managers depend. Previous chapters have provided ample evidence of the importance of data from ocean, coastal, and watershed observations; but processing these data, and converting them into information products useful to a broad community of end users, remains a huge challenge.

For the purpose of this discussion, *data* are defined as direct measurements collected during scientific research, observing, monitoring, exploration, or other marine operations. *Information*, on the other hand, includes both *synthesized products* developed through analyses of original data using statistical methods, interpolations, extrapolations, and model simulations, and *interpreted products* developed through incorporation of data and synthesized products with additional information that provides spatial, temporal, or issue-based context.

There are two major challenges facing data managers today: the exponentially growing volume of data, which continually strains data ingestion, storage, and assimilation capabilities; and the need for timely accessibility of these data to the user community in a variety of useful formats. Meeting these challenges will require a concerted effort to integrate and modernize the current management system. The ultimate goal of improved data management should be to effectively store, access, integrate, and utilize a wide and disparate range of data needed to better understand the environment and to translate and deliver scientific results and information products in a timely way.

Reviewing the Data Management Structure

Data centers throughout the nation collect and analyze environmental data and information. Because these centers often operate in isolation, users who need to gather and integrate data from multiple sources can face an inefficient and lengthy process.

Types of Data Centers

National Civilian Data Centers

The national data centers that archive and distribute environmental data have been evolving since the late 1950s. Federal science agencies maintain ten national data centers, some with regional extensions (Table 28.1). These centers collect, archive, and provide access to an assortment of publicly available data sets streaming in from local, regional, and global environmental observing systems. Nine of the centers are run by federal agencies, including the National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), National Aeronautics and Space Administration (NASA), and U.S. Department of Energy. The remaining center is housed at Columbia University and is sponsored by twenty-two federal and nonfederal organizations.

Each federal data center collects and archives complementary data and information sets. Yet for the most part, these centers are disconnected from each other, and attempting to gather and integrate data from several centers can be a time-consuming and sometimes impossible task due to differences in storage formats and computer software. Ever-increasing amounts of incoming data will only exacerbate this untenable situation, impeding the creation and dissemination of critical information products.

Stages in Data and Information Management

- *Collection*—gathering data from a range of sources, including observing systems and field research investigations.
- *Ingestion*—receiving data at data centers and processing it for entry into the archives.
- *Quality control*—determining the reliability of data received.
- *Archiving and maintenance*—standardizing formats, and establishing databases and security at repository centers.
- *Rescue and conversion*—identifying and reformatting historical data for placement into the archives.
- *Access and Distribution*—making data and information products available to end users.
- *Modeling*—using data in numerical computer models to describe systems, theories, and phenomena related to natural processes.
- *Assimilation and Data Fusion*—assembling and blending data, and combining them with models in optimal ways for operational and research purposes.

Useful Terms

- *Metadata*—information about the origin and attributes of data that allows users to find, understand, process, and reuse data and data products.
- *Visualization tools*—methods of visually displaying data, such as visualization theaters, computer displays, and maps and charts.
- *Communication networks*—telecommunications infrastructure that transfers data from observing systems to data centers, and from these centers to end users.

Distributed Active Archive Centers

NASA operates eight Distributed Active Archive Centers (DAACs) that are separate from the civilian data centers. The primary objectives of these DAACs are to focus on data from specific missions and experiments, not long-term stewardship of data. Implementation of the DAACs has been costly, and they have not yet fulfilled their potential.

NASA is now trying to organize the DAACs into a federation of databases managed by academia and industry, possibly transitioning away from the structure of the current centers. As part of this new organizational structure, and in an attempt to achieve long-term data storage and coordination, NASA data are supposed to be transferred to NOAA or USGS within fifteen years after their collection.

Table 28.1. Current National Civilian and Military Data Centers
Listed below are the existing federal data centers along with their sponsoring agencies and scientific specialties.

Center	Agency	Specialty
National Data Centers		
Carbon Dioxide Information Analysis Center (CDIAC)	U.S. Department of Energy	Atmospheric trace gases, global carbon cycle, solar and atmospheric radiation
Center for International Earth Science Information Network (CIESIN)	Columbia University (supported by contracts from 22 nonfederal and federal agencies)	Agriculture, biodiversity, ecosystems, world resources, population, environmental assessment and health, land use and land cover change
Earth Resources Observation Systems (EROS) Data Center (EDC)	U.S. Geological Survey (USGS)	Cartographic and land remote-sensing data products
National Earthquake Information Center (NEIC)	USGS	Earthquake information, seismograms
National Climatic Data Center (NCDC)	National Oceanic and Atmospheric Administration (NOAA)	Climate, meteorology, alpine environments, ocean–atmosphere interactions, vegetation, paleoclimatology
National Geophysical Data Center (NGDC)	NOAA	Bathymetry, topography, geomagnetism, habitat, hazards, marine geophysics
National Oceanographic Data Center (NODC)	NOAA	Physical, chemical, and biological oceanographic data
National Snow and Ice Data Center (NSIDC)	NOAA	Snow, land ice, sea ice, atmosphere, biosphere, hydrosphere
National Coastal Data Development Center	University of Colorado (under cooperative agreement with NOAA)	Data relevant to coastal managers
National Space Science Data Center (NSSDC)	National Aeronautics and Space Administration (NASA)	Astronomy, astrophysics, solar and space physics, lunar and planetary science
Distributed Active Archive Centers (DAACs)		
Oak Ridge National Laboratory (ORNL) DAAC	NASA	Terrestrial biogeochemistry, ecosystem dynamics
Socioeconomic Data and Applications Center (SEDAC)	NASA	Population and administrative boundaries
Land Processes (EDC) DAAC	NASA	Land remote-sensing imagery, elevation, land cover
National Snow and Ice Data Center (NSIDC) DAAC	NASA	Sea ice, snow cover, ice sheet data, brightness, temperature, polar atmosphere
Goddard Space Flight Center (GSFC) DAAC	NASA	Ocean color, hydrology and precipitation, land biosphere, atmospheric dynamics, and chemistry
Langley Research Center (LaRC) DAAC	NASA	Radiation budget, clouds, aerosols, and tropospheric chemistry
Physical Oceanography (PO) DAAC	NASA	Atmospheric moisture, climatology, heat flux, ice, ocean wind, sea surface height, temperature
Alaska Synthetic Aperture Radar (SAR) Facility DAAC	NASA	Sea ice, polar processes
Military Data Centers of Particular Importance to Ocean-related Issues		
Naval Oceanographic Office	U.S. Navy	Bathymetry, hydrography, oceanography
Fleet Numerical Meteorology and Oceanography Center	U.S. Navy	Atmosphere and oceans

Source (except military centers): National Research Council. *Government Data Centers: Meeting Increasing Demand*. Washington, DC: National Academy Press, 2003.

Military Data Centers

Several military data centers exist in addition to the civilian centers. Of particular importance are the U.S. Department of Defense assets at the Naval Oceanographic Office and the U.S. Navy's centers for ocean observation and prediction, which include the Fleet Numerical Meteorology and Oceanography Center, the Naval Oceanographic Office, and the Naval Ice Center. These centers are integrated with the civilian sector's national data centers through memoranda of agreement, primarily with NOAA, NASA, the Department of Energy, and the National Science Foundation (NSF). The purpose is to incorporate certain classified data into civilian research and operational products while retaining their confidentiality.

Other Specialized Data Centers

Fifteen discipline-based World Data Centers exist in the United States that collect and archive data related to atmospheric trace gases, glaciology, human interactions in the environment, marine geology and geophysics, meteorology, oceanography, paleoclimatology, remotely sensed land data, seismology, and solar-terrestrial physics. Individual states also operate data centers associated with certain state environmental offices, such as weather or geological offices. Independent specialized data collections have also been assembled by interagency groups, university and research centers, and consortia in various fields of science.

Ocean and Coastal Data

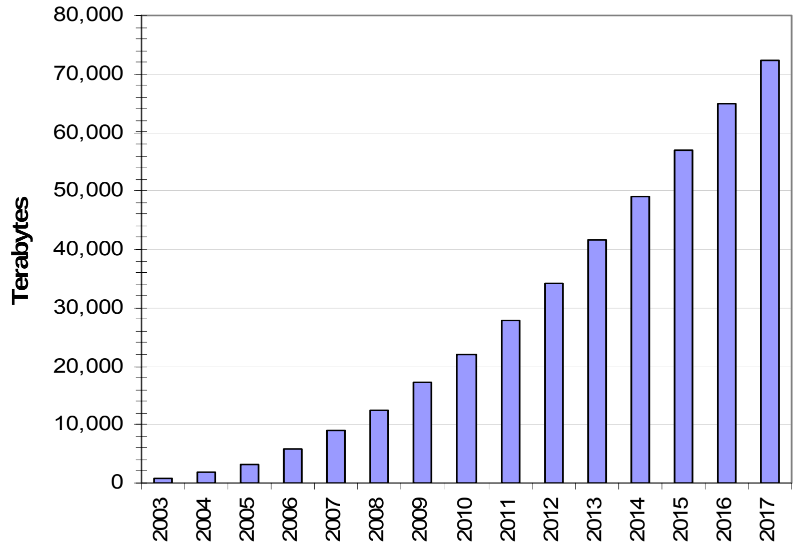
Ocean, coastal, and watershed data are primarily located in NOAA, NASA, USGS, the U.S. Environmental Protection Agency, and the Navy. NOAA has the unique mission of archiving environmental data, with a special focus on ocean and coastal data, and making it accessible to support management and economic decisions and ecosystem-based research. NOAA carries out this mission through its national data centers (five of the ten listed above), which jointly manage large collections of atmospheric, oceanographic, and geophysical data. Despite the fact that these five centers are co-located within NOAA, they function independently of each other, and it remains difficult for users to acquire and integrate data in a seamless manner. Other agencies are also experiencing problems with incorporating, storing, and distributing large amounts of environmental data. For example, USGS has struggled with the large volumes of Landsat satellite data which have historically been very helpful in ocean and coastal research and management activities.

Coping with the Flood of Incoming Data

Throughout the 1990s and into this century, all of the national military and civilian data centers have experienced tremendous growth in the inflow and archiving of data. This growth is expected to continue; NOAA data holdings are projected to grow by a factor of 100 between 2002 and 2017 (Figure 28.2).[1] This projection may actually be an underestimate if currently envisioned automated data collection systems come on-line. The civilian data centers make data available to support operational products and forecasts and to fill specific requests. During the 1990s, NOAA's on-line data requests grew to 4 million a year (an average of 11,000 per day), while off-line requests doubled to a quarter of a million (Figure 28.3). Although many users increasingly rely on electronic access, only 4 percent of NOAA's digital data archive is currently available on-line and many of NOAA's historical data sets have yet to be converted to digital form.[2]

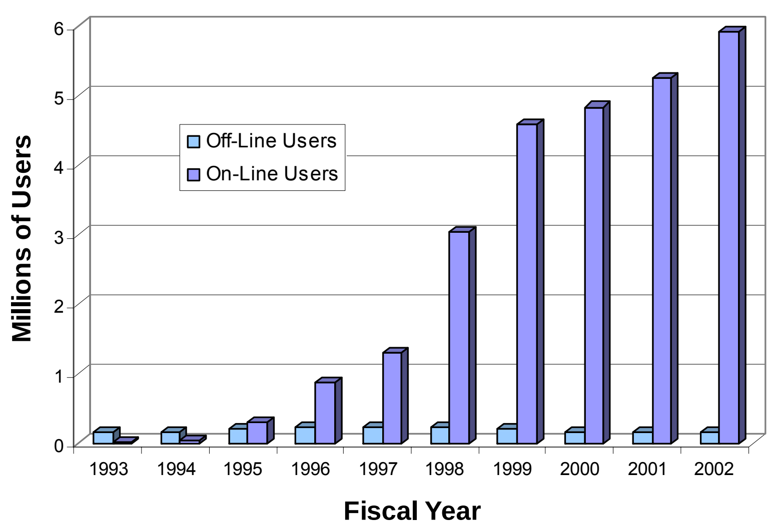
Ongoing improvements to ocean databases have substantially increased the amount of available data and have dramatically improved accessibility. However, data collection and information needs continue to outpace archiving and assimilation capabilities.

Figure 28.2. The Flood of Ocean and Coastal Data into NOAA



Between 2002 and 2017, NOAA's data holdings are expected to grow by a factor of 100, to a value of 74 million gigabytes. (One gigabyte roughly equals one billion bytes; one terabyte equals about one thousand gigabytes.)
Source: National Oceanic and Atmospheric Administration. *The Nation's Environmental Data: Treasures at Risk: A Report to Congress on the Status and Challenges for NOAA's Environmental Data Systems*. Washington, DC: U.S. Department of Commerce, 2001.

Figure 28.3. The Growing Demand for Ocean Data



On-line users are requesting increasing amounts of environmental data and information from NOAA each year. Improved data handling practices are needed to address the growing volume of requests.
Source: National Oceanic and Atmospheric Administration. *The Nation's Environmental Data: Treasures at Risk: A Report to Congress on the Status and Challenges for NOAA's Environmental Data Systems.* Washington, DC: U.S. Department of Commerce, 2001.

Reinventing Data and Information Management

Several improvements can help make the national system for storing and distributing ocean and coastal data more effective. Agencies tasked with collecting, archiving, assimilating, and disseminating data need to increase their cooperation and coordination and provide faster, easier, and more unified access to raw and processed data. In return, scientists and other data generators need to feed valuable, high quality data into the national system in a timely way.

Interagency Planning

Growing observational capabilities, improved numerical models of the world, and formal methods for linking data and models now permit scientists to study ecosystems with an unprecedented degree of realism. The impact of these developments on the understanding of oceanic processes pervades all disciplines and fuels cross-disciplinary links between physical, biological, and chemical oceanography, marine geology and geophysics, and atmospheric sciences.

Nevertheless, inadequate information technology infrastructure inhibits progress. Continuing efforts to establish modeling and data assimilation nodes within the National Ocean Partnership Program agencies provide just one example of a high-priority activity where infrastructure limitations are acute. Topics of particular concern include:

Data Incorporation—Scientists and managers need to combine data from disparate sources to produce information products, often in real time. As computer software and hardware technologies evolve, data stored in older formats need to be upgraded. In particular, enormous archives of historical data exist only in nondigital formats. Differences in data protocols also remain among scientific fields; physical and biological variables are measured using very different parameters. New methods are needed to incorporate biological data into ocean and coastal information products.

Computer Hardware—Ocean scientists are expected to require 10 to 1,000 times the current hardware capacity over the next five to ten years, with the most critical bottlenecks occurring in the availability of computer processing power, memory and mass-storage capacity, and communications network bandwidth. [3] Many oceanographic models have grown in computational size to the point that they require dedicated, long-term computing that exceeds the time available on computers currently used for most medium- and large-scale ocean projects.

Software and Modeling—Software challenges include the need to redesign models and methods to assimilate new data sources and improve visualization techniques to deal effectively with increasing volumes of observations and model outputs. There is a need throughout the ocean science community for well-designed, documented, and tested models of all types. Models of living systems lag significantly behind those related to physical variables; the capacity to run simulations of organisms, populations, and ultimately ecosystems, is currently not available.

Human Resources—In the early days of collecting and storing environmental data in digital formats, many of the technical staff were environmental scientists who gained experience through on-the-job training and trial and error. By the mid-1980s, this type of education was wholly inadequate to meet the ever-increasing complexity of computer hardware and software systems, and the volumes of digitized data being collected and archived. As technical requirements grew, the federal government fell far behind academia and the private sector in attracting and retaining highly trained experts, particularly because government pay scales for information technology specialists were well below those of the private sector. This scenario continues today. A strategy is needed for attracting and retaining highly trained technical staff in the federal government.

Meeting User Needs—Data and information must be available to a wide range of users, from scientists looking for raw data, to the individual interested in forecasts and other easily understandable information products. User needs should be determined at national, regional, and local levels. The regional ocean information programs, discussed in Chapter 5, will be an essential link to user communities when deciding on priorities.

An interagency group, dedicated to ocean data and information planning, is needed to enhance coordination, effectively use existing resources for joint projects, schedule future software and hardware acquisitions and upgrades, and oversee strategic funding. Most importantly, this entity will create and oversee implementation of an interagency plan to improve access to data at the national data centers, DAACs, and other discipline-based centers. The plan will need to be appropriately integrated with other national and international data management plans, including those for the Integrated Ocean Observing System (IOOS) and Global Ocean Observing System.

This coordination must extend beyond ocean data. The ocean community needs to take a leading role in broader environmental data planning efforts, such as the federal cyber infrastructure initiative. An interagency planning group could also coordinate the development of a viable, long-term strategy for partnering with the private sector to enhance environmental data and information management capabilities. This organization should not have an operational role, but instead should be responsible solely for interagency planning and coordination, similar to the role of Ocean.US for the IOOS.

Recommendation 28–1. Congress should amend the National Oceanographic Partnership Act to establish and fund Ocean.IT as the lead federal interagency planning organization for ocean and coastal data and information management. Ocean.IT should consist of representatives from all federal agencies involved in ocean data and information management, be supported by a small office, and report to the National Ocean Council's Committee on Ocean Science, Education, Technology, and Operations.

Ocean.IT should:

- *create an interagency plan to improve coordination between the existing data centers and integrate ocean and coastal data from different agencies and from the academic and private sectors.*
- *set priorities for archiving historical and nondigital data.*
- *coordinate shared resources and the acquisition of new hardware for use by the ocean sciences community.*
- *work with existing supercomputer centers to articulate and negotiate for ocean science needs.*
- *assess federal agency software needs and initiate interagency programs to create high-priority applications, such as new modeling programs.*
- *coordinate federal agency efforts to attract information technology expertise into the ocean sciences community.*
- *communicate with regional, state, and local organizations, including the regional ocean information programs, to determine user needs and feed this information back into agency activities.*

Access to Data and Information

There are two distinct types of data sought by users. Scientists are generally interested in calibrated, long-term time series of basic data that can be used to study topics such as atmospheric composition, ecosystem change, carbon cycles in the environment, the human dimensions of climate change, and the global water cycle. At the other end of the spectrum, the general public is most often interested in outcomes based on data analysis, such as forecasts and models, and do not wish to see the original data. Users seeking information products include commercial users, policy makers, and educators seeking information to develop curricula and class materials.

Information Products and Forecasts

Compared to a few decades ago, an impressive array of data and information products for forecasting ocean and coastal conditions is now available from a wide range of sources. A mechanism is now needed to bring these data together, including the enormous amounts of information that will be generated by the national IOOS, and use them to generate and disseminate products beneficial to large and diverse audiences.

At the national level, civilian operational ocean products and forecasts are produced mainly by NOAA's National Weather Service and National Ocean Service. The National Weather Service routinely issues marine and coastal information and forecasts related to meteorological conditions and issues marine warnings, forecasts, and guidance for maritime users. The National Ocean Service's Center for Operational Oceanographic Products and Services also collects and distributes oceanographic observations and predictions related to water levels, tides, and currents.

Military ocean informational products are produced mainly by two offices. The Fleet Numerical Meteorology and Oceanography Center provides weather and oceanographic products, data, and services to the operating and support forces of the Department of Defense. The Naval Oceanographic Office supplies global oceanographic products and generates strategic, operational, and tactical oceanographic and geospatial products to guarantee safe navigation and weapon/sensor performance.

While each of these offices possesses unique resources, infrastructure, and data, a partnership between them could lead to a new generation of ocean and coastal information and forecasts. A national ocean and coastal information management and communications program that builds on the Navy's model for operational oceanography would take advantage of the strengths of both agencies, reduce duplication, and more effectively meet the nation's information needs. This partnership would also allow for the prompt incorporation of classified military data into informational products without publicly releasing the raw data. A NOAA-Navy joint program would rapidly advance U.S. coastal and ocean analyses and forecasting capabilities using all available physical, biological, chemical, and socioeconomic data.

Private-sector involvement in creating ocean analyses and forecast products has matured over the last thirty years through highly successful public–private partnerships. Interactions between private companies and the national ocean and coastal information management and communications program could lead to the production of a wide range of general and tailored forecast and warning products. An interface between national forecasters at the NOAA–Navy program and the regional ocean information programs would also help identify ocean and coastal informational products of particular value at the regional and local levels.

Recommendation 28–2. The National Oceanic and Atmospheric Administration and the U.S. Navy should establish a joint ocean and coastal information management and communications program to generate information products relevant to national, regional, state, and local needs on an operational basis.

This new joint ocean and coastal information management and communications program should:

- *prioritize products and forecasts based on input from the regional ocean information programs, Ocean.IT, Ocean.US, and the National Ocean Council.*
- *base products and forecasts on all available data sources, including satellite and in situ data, and socioeconomic and biological data where applicable.*
- *create a research and development component of the program to generate new models and forecasts in collaboration with Ocean.IT, taking full advantage of the expertise found in academia and the private sector.*
- *develop a variety of dissemination techniques and educate users about access mechanisms, available products, and applications.*

Raw Data

Although many paths exist to access data, there is currently no focal point where users can go to gain access to all available ocean data and information. As a result, the process can be tedious, and the risk of missing key databases high. Interdisciplinary users face even greater challenges when attempting to integrate data sets from different centers. The varied data standards, formats, and metadata that have evolved over time make data exchange complex and unwieldy. Other problems arise when important data sets are kept by individual scientists or institutions, rather than being integrated into national databases.

One area of critical concern, particularly for coastal resource managers, is the integration of coastal data, including maps, charts, and living and non-living resource assessments. The user community is frustrated by the difficulties in accessing coastal geospatial data. Serious concerns continue regarding the timeliness, accuracy, and descriptions associated with coastal data, and the difficulties of integrating data sets from various sources. Coastal managers and researchers still lack a seamless bathymetric/topographic base map and database for the U.S. coast—an essential underpinning for improved understanding of the processes that occur across the land–sea interface. (The integration of maps and charts is also discussed in Chapter 25.)

Several innovative and highly promising interagency efforts to increase data accessibility are underway. The National Virtual Ocean Data System project is a primary example. Funded by the National Ocean Partnership Program, it facilitates seamless access to oceanographic data and data products via the Internet, regardless of data type, location of the storage site, the format in which the data are stored, or the user's visualization tools and level of expertise. The National Virtual Ocean Data System uses OPeNDAP technology that provides machine-to-machine interoperability within a highly distributed environment of heterogeneous data sets. This is similar to other successful Internet-based file sharing systems that allow users to access data (typically music files!) that reside on another individual's computer. The Ocean.US data management plan envisions that the National Virtual Ocean Data System will be implemented to allow access to IOOS data.

Recommendation 28–3. Ocean.IT should work with developers of the National Virtual Ocean Data System and other innovative data management systems to implement a federally-supported system for accessing ocean and coastal data both within and outside the national data centers.

Incorporating Data into the National Data Centers

Academic Research Data

The discussion of the IOOS in Chapter 26 points to the importance of collecting data from stable, long-term, calibrated *in situ* and satellite sensors. However, there is also value in capturing more ephemeral observational data, typically collected as a part of research projects. Recipients of federal research grants and contracts are required by law to submit their data to the appropriate national data center within a specified time period. Most oceanographic data must be submitted to the National Oceanographic Data Center or the National Geophysical Data Center. Oceanographic data arising from international programs must also be submitted, according to policies established by the Intergovernmental Oceanographic Data Exchange program. However, there are wide variations among agencies in their enforcement of these requirements and their tracking of compliance. Research data are often not submitted to national databases for years after a project ends, if ever. Strengthened procedures, both domestically and internationally, are urgently needed to provide for the timely inclusion of all ocean data into data centers, and to ensure full and open access to data collected at taxpayers' expense.

Recommendation 28–4. The Committee on Ocean Science, Education, Technology, and Operations (COSETO) should establish and enforce common requirements and deadlines for investigators to submit data acquired during federally funded ocean research projects.

In establishing these requirements, COSETO should:

- *provide incentives to ensure more timely submission of investigator data to the national centers.*

- *require that a certification of data deposit be supplied to investigators who comply with the new regulations and that this certificate be presented before subsequent federal funding is provided.*

Reviewing Classified Data

A significant proportion of all oceanographic data is collected and archived by the Navy. However, these data are generally classified and not available for access by the larger oceanographic community. In 1995, the MEDEA Special Task Force was created to determine the potential for important environmental research based on classified Navy databases, and to prioritize data for declassification. Opportunities were identified for mutually beneficial collaborations between the civilian and naval ocean sciences communities, and approaches were suggested to realize broader national benefits from public investments in data collection and modeling by the Navy.[4] Increased access to data declassified as a result of the one-time MEDEA initiative has been very useful to the oceanographic community. Both scientists and managers can continue to benefit from ongoing declassification of Navy data, particularly bathymetric data critical to improved ocean modeling.

Recommendation 28–5. The U.S. Navy should periodically review and declassify appropriate naval oceanographic data for access by the civilian science community.

MEETING THE CHALLENGES OF A NEW CENTURY

Looking beyond the data management needs for ocean sciences, the environmental challenges of the 21st century will require access to the full spectrum of environmental data. As a robust ocean observing system is created, and as the nation moves toward integrating ocean, climate, atmospheric, and terrestrial monitoring systems within a comprehensive Earth Observing System, both the volume of data and the need to integrate widely varied datasets will continue to grow. At the same time, historical environmental data must continually be preserved to enable long time-series analyses of natural processes that occur over decades, centuries, and millennia. Revolutionary discoveries about the Earth's environment and the ability to better predict its dynamics will result from the use of diverse, long-term, integrated data sets.

Critical improvements in the environmental data management infrastructure at the federal level must be made today and sustained into the future to realize the full benefits of an integrated system. Numerous valuable studies, pilot projects, recommendations, and strategies for improved management of environmental data have been produced over the years. However, the integration of existing environmental data is continually impeded by the lack of a unified interagency strategy and a national financial commitment to a modern, integrated data management system.

Recommendation 28–6. The President should convene an interagency task force to plan for modernizing the national environmental data archiving, assimilation, modeling, and distribution system with the goal of designing an integrated Earth environmental data and information system.

The task force should:

- *be comprised of all federal agencies with environmental data collection responsibilities.*
- *create an environmental data management plan that includes specific cost estimates and phasing requirements to ensure timely implementation and appropriate funding.*

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[1] National Oceanic and Atmospheric Administration. *The Nation's Environmental Data: Treasures at Risk*. A Report to Congress on the Status and Challenges for NOAA's Environmental Data Systems. Washington, DC: U.S. Department of Commerce, 2001.

[2] Ibid.

[3] Office of Naval Research and National Science Foundation. *An Information Technology Infrastructure Plan to Advance Ocean Sciences*. Washington, DC, January 2002.

[4] MEDEA. *Special Task Force Report: Scientific Utility of Naval Environmental Data*. McLean, VA: Mitre Corporation, 1995.