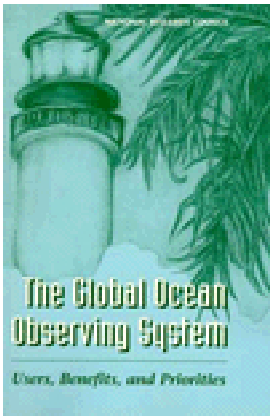


**The Global Ocean Observing System: Users, Benefits, and Priorities**

Committee on the Global Ocean Observing System, National Research Council

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# THE GLOBAL OCEAN OBSERVING SYSTEM

## USERS, BENEFITS, AND PRIORITIES

**Committee on the Global Ocean Observing System**
**Ocean Studies Board**
**Commission on Geosciences, Environment, and Resources**
**National Research Council**

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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# PREFACE

The first calls for coordinated observation of the world's oceans were raised nearly a decade ago. Since that time, the governments and scientists of the world have made some tentative steps toward developing a true global ocean observing system (commonly referred to as GOOS). The challenges to successful completion of a satisfactory observing system are numerous and complex. However, the value of such a system, if well designed, could be great. As stated in the 1992 report of the National Research Council's Ocean Studies Board, *Oceanography in the Next Decade: Building New Partnerships*, "Designing and deploying a GOOS will be among the most important and difficult tasks for physical oceanography and climate studies for the next decade."

The overall scope of GOOS includes important nonphysical issues such as the health of the ocean and living marine resources. Thus, the successful implementation of GOOS could result in improvements in a number of areas (e.g., coastal hazard prediction and warnings, navigational systems, fish stock assessments, prediction of algal blooms in coastal regions, climate forecasts, health warnings).

The present represents the efforts of the Ocean Studies Board's Committee on the Global Ocean Observing System to provide guidance and impetus to U.S. efforts toward implementing GOOS. With the assistance of the U.S. GOOS Project Office, the committee gathered information from numerous federal agencies involved in planning U.S. implementation of GOOS and solicited input from numerous nongovernmental entities.

This, the resulting report, outlines the nature and status of international plans toward development of GOOS. With these international plans as a context, the report (1) discusses U.S. efforts to implement GOOS and recommends specific actions to be taken by the U.S. GOOS community, (2) provides detailed discussion of potential benefits of GOOS to a variety of users, and (3) discusses the importance of developing support for GOOS across the entire marine community.

An effort as complex and important as GOOS represents a serious challenge for the ocean science community and for society as a whole. Every effort must be made to ensure that the goals are reasonable and the efforts well reasoned, because the costs of failing to meet this challenge would be enormous.

KENNETH BRINK, CHAIRMAN
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# TABLE OF CONTENTS

# EXECUTIVE SUMMARY

Dependence on the ocean is an ancient and complex part of human existence. As the population increases, society's need to understand the ocean and make sound decisions on a variety of related topics (e.g., nutrition, safety, economic activities, health, long-term security of the planet) also will increase. This need was recognized at the international level just within the past few decades and led to the Intergovernmental Oceanographic Commission's (IOC) call for initiation of a global ocean observing system (GOOS) in 1989. The IOC has since been joined by the World Meteorological Organization, the United Nations Environment Programme, and the International Council of Scientific Unions as cosponsors of GOOS.

During the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro (sometimes referred to as the Earth Summit), the United States and more than a hundred other nations recognized the important role that oceans play in human existence and forged an agreement to "pursue the protection and sustainable development of the marine and coastal environment and its resources." Among other actions agreed to during UNCED, specific provision was made to support "the collection, analysis and distribution of data and information... through the Global Ocean Observing System."

GOOS is therefore intended to provide a global framework, similar to the World Weather Watch, to coordinate global, long-term, systematic observations of the world's oceans and to provide mechanisms and infrastructure so that the data and information collected can be made available to institutions and nations around the world. These efforts are, in part, intended to help solve problems related to changes in regional and global environments on various timescales. Through training, capacity building, and collaboration, GOOS will enable all nations to benefit from this information (IOC, 1996a).

A major underlying principle behind this endeavor is that a global ocean observing system is too large for any one nation to undertake. However, if appropriate plans for a system can be generally agreed upon, many national contributions can be aggregated to constitute such a system. This observing system is therefore to be implemented by a community of nations, planned and coordinated through a formal GOOS structure.

In 1994 the National Research Council's (NRC) Ocean Studies Board (OSB) issued a report, *Review of U.S. Planning for the Global Ocean Observing System*, supporting the GOOS concept In the fall of 1994, M. G. Briscoe, then chairman of the U.S. GOOS Interagency *ad hoc* Working Group, requested that OSB conduct a follow-up study. The new study was intended to provide information and advice to federal agencies (the U.S. GOOS Interagency ad *hoc* Working Group) to help define and implement an effective, affordable, and customer-based U.S. contribution to GOOS. In particular, the committee was asked to provide advice to U.S. agencies regarding a practical concept for GOOS, identify potential applications and users of GOOS during the next 3 to 5 years and beyond, recommend appropriate roles for industry and academia in GOOS, and prioritize observational and infrastructure activities that should be undertaken or continued by the United States in its initial commitments to GOOS.

In response to its charge, the committee reviewed the status of GOOS planning and implementation at both the national and international levels, invited presentations by relevant federal agencies and members of the private sector, and examined the range of potential uses and benefits of products derived from information to be collected by GOOS. Finally, the committee drew upon this information and its own expertise to develop a number of recommendations intended to help move the implementation of GOOS forward.

## OVERARCHING THEMES

A functional GOOS has the potential to provide many benefits to decisionmakers, academic scientists, commercial entities, and consumers. In some cases, implementation of GOOS will result in improvement of existing environmental products, such as maps of sea surface temperature. For example, severe storm forecasters can use near-real-time maps of sea surface temperature as one key input for atmospheric models used to predict hurricane tracks. Improved sea surface temperature maps can then translate into improved storm forecasts. Improved forecasts would allow federal, state, and local officials to take timely and effective action to warn marine users of impending storms. Ship captains, fishermen, offshore drilling managers, and other marine users would then be able to take appropriate action to avoid or minimize storm damage. Minimizing storm damage would result in real savings to the insurance and reinsurance industries, which should result in an decreased burden on policyholders across the nation.

In other instances the observations will be combined with other data and with our understanding of the ocean and the ocean-land-atmosphere system to produce new forecast products (e.g., a prediction of the time and location of toxic algal blooms). In these cases the integration of data from multiple disciplines is necessary and may generate new hypotheses and increased understanding. Increased understanding of the variety of factors that lead to toxic algal blooms, for example, could lead to reliable predictions enabling state and local officials to intercede and possibly prevent economic loss associated with contaminated shellfish beds, fish kills, or increased public health problems. Consumers would ultimately benefit by gaining access to more widely available and safer seafood, reduced health insurance rates, or the improved standard of living associated with a stronger local economy.

Implementation of GOOS will be expensive, but it can begin with relatively modest steps. If society is to be convinced that GOOS is a worthwhile endeavor, efforts must be made to estimate the economic and societal benefits to be gained from the eventual system. **Cost-benefit analyses and other socioeconomic studies can provide guidance as to which GOOS efforts are worth pursuing, with what priority, with what objectives, and at what level**. Furthermore, careful socioeconomic studies of GOOS (e.g., the potential role of GOOS in mitigating El Niño and the Southern Oscillation (ENSO) effects on agribusiness or climate-related public health problems) are important tools for convincing decisionmakers that GOOS efforts should be funded.

To realize the potential benefits of GOOS, a community with diverse needs and talents must be brought together. **U.S. government agencies responsible for planning and implementing GOOS must make a serious commitment to international cooperation while taking a leadership role to encourage development of a GOOS that will address the nation's needs and priorities**. Maintaining such a leadership role will require the establishment of government/academia/private-sector partnerships. The GOOS infrastructure that presently exists in the United States will need to be strengthened. Independent and objective oversight of U.S. activities is needed to ensure that efforts to implement GOOS both domestically and abroad reflect the needs and priorities of government, academia, and the private sector. **The United States should provide financial support for international and national planning and implementation of GOOS commensurate with U.S. national interests and the value of GOOS benefits**.

To obtain optimal results, the design of any observing system must be based on accurate knowledge of the system to be observed. Research programs are contributing data, understanding, and mechanisms on which GOOS plans are being formulated. **To facilitate the transition of elements of observing systems from research programs to a functional GOOS, support should be continued for the full and orderly completion of ongoing research programs contributing to GOOS plans and implementation**.

The present report is designed to help decisionmakers, scientists, and the public understand the importance and implications of implementing a functional GOOS. Chapter 1 presents a historical overview of the development of GOOS and includes discussions of its structure. The remainder of the report is devoted to discussing five major aspects of GOOS: (1) International GOOS, (2) GOOS in the United States, (3) users and benefits of GOOS, (4) developing GOOS in the spirit of partnership, and (5) priorities for U.S. GOOS activities. (Specific findings and recommendations in each of these areas can be found in corresponding chapters of the report.)

## INTERNATIONAL GOOS

GOOS is intended to be a truly international effort. The needs and perspectives of the international community must be addressed if GOOS is to be truly global in scope and impact. Chapter 2 discusses a number of conclusions reached by the committee regarding the present status of international GOOS planning and implementation efforts that bear on U.S. activities and the overall effectiveness of GOOS. Framing of a fully developed GOOS strategy, decisive actions by international GOOS committees, and provision for adequate staff support for and action by a GOOS support office have not occurred.

The tendency of nations and small groups of nations to address their immediate problems, without adequate consideration of the global system, could lead to development of an ocean observing system that consists solely of a series of distinct and separate regional systems. Regionalization of GOOS in this manner poses a special problem in the case of fundamentally global modules, such as the climate module. Global cooperation is needed to learn how to make measurements and products and contributes to capacity building. **All nations must be encouraged to focus on the needs of the international community in developing global observations and models; in sharing methods, standards, instruments, data, and products; and in capacity building**.

## GOOS IN THE UNITED STATES

Chapter 3 discusses the present organization of U.S. GOOS programs and the status of planning and implementation of GOOS in the United States. It also includes a number of committee recommendations regarding present plans for implementing GOOS, interaction among U.S. agencies involved in implementing GOOS, and coordination of GOOS activities with efforts to develop a global observing strategy. **Bodies designed to foster cooperation among government agencies developing GOOS in the United States must be properly comprised to ensure that effective action can be taken by the widest number of relevant agencies. Furthermore, these bodies must have formal ties to international GOOS planning bodies and to bodies responsible for developing an integrated global observing strategy**.

## USERS AND BENEFITS OF GOOS

Chapter 4 discusses some potential GOOS products by tracing their evolution from GOOS observations to user benefits. Many of the phenomena that adversely impact humans and the environment occur as events. Thus, parts of GOOS must focus on monitoring events as emergent phenomena and subsequent rapid response using the warning time available. Initially, specific areas of potential GOOS benefits derived from observations of surface winds over the ocean and sea surface temperature are discussed in detail. Then, derivative products useful for coastal hazard predictions and warnings, improved navigational systems, improved fish stocks assessments, prediction of algal blooms in coastal regions, climate forecasts, and health warnings are examined in greater detail.

Balancing the costs of implementing various possible components of GOOS against the value of their potential benefits will be an ongoing challenge. Funding was not provided to allow the committee to undertake thorough cost-benefit studies on its own. Some examples of human and economic costs that could be mitigated with the kind of information GOOS should provide are offered in Chapter 4 as useful examples or potential candidates for further study (e.g., ENSO effects on agribusiness; amnesiac shell fish poisoning on Prince Edward Island, Canada, in 1987; or coastal weather forecasts).

## DEVELOPING GOOS IN THE SPIRIT OF PARTNERSHIP

The establishment of government/academia/private-sector partnerships will be critical for the development and long-term sustenance of GOOS. As discussed in the 1992 NRC report, *Oceanography in the Next Decade: Building New Partnerships*, our nation is faced with many pressing problems that would benefit from increased cooperation among federal agencies, nongovernmental scientists, and the private sector. Making successful policies in a number of areas will require an adequate understanding of the earth and its systems. Our efforts to address many of the challenges facing our nation and the world would be greatly enhanced by the type of partnerships discussed in Chapter 5.

## PRIORITIES FOR U.S. GOOS ACTIVITIES

Chapter 6 attempts to both review the present applicability of recommendations made in *Review of U.S. Planning for the Global Ocean Observing System* and present updated priorities for U.S. GOOS efforts. In many cases, ocean observations are in a state of transition. Because of the uncertain status of many observations, it is critical that GOOS move forward in a timely manner and that its priorities are established quickly. **In doing so, the United States not only should consider the potential benefits to users in this nation, but should also strive to maintain its leadership role in building a truly global observing system**. Chapter 6 includes a number of committee recommendations designed to help the United States maintain a leadership role in GOOS.

# 1

# INTRODUCTION

Our society is inextricably involved with the ocean. The ocean is a major part of the climate system and therefore influences our environment no matter where we live. Humanity uses vast quantities of marine organisms from plankton to fish, for needs ranging from food to pharmaceuticals. Marine recreation plays a vital part in renewing our bodies and spirits—and results in a highly profitable industry. Most international trade travels by sea and is often at the mercy of its state. Ocean waves reform our beaches and threaten property but also provide sport for suffers. The ocean determines to large measure the formation and tracks of dangerous cyclones. We pollute the ocean in a thousand ways but are coming to realize that such pollution is at a price.

Because of its close involvement with the ocean, society needs information about it in order to make sound decisions on a variety of topics. This requirement was realized at the international level sometime late in this century. Finally, in 1989 the Intergovernmental Oceanographic Commission (IOC) called for the initiation of a global ocean observing system (GOOS). The purpose of GOOS is to provide a global framework or system to ensure global, long-term, systematic observations of the world ocean. In addition, GOOS is intended to provide mechanisms and infrastructure for data and information to be made available to institutions and nations to help solve problems related to changes in regional and global environments on various timescales. Through training and capacity building and by encouraging collaboration, GOOS will enable all nations to benefit from this information (IOC, 1996a).

The IOC has since been joined by the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), and the International Council of Scientific Unions (ICSU) as cosponsors of GOOS. Formation of GOOS also was urged in 1990 by the Second World Climate Conference to provide ocean data needed as part of the Global Climate Observing System, the establishment of which was begun in 1992. In 1992 the United Nations Conference on Environment and Development (UNCED) also endorsed the concept of a system of global ocean observations to help understand and monitor environmental variability (UNCED, 1992). In addition, Chapter 17, Agenda 21, of the 1992 UNCED report calls for the developed nations to "provide the financing for further development and implementation of the Global Ocean Observing System."

## GOOS OBJECTIVES AND APPROACH

Implementation of GOOS is expected to be carried out by national agencies, organizations, and industries that will make the observations and produce the derived products and by national and international bodies that will archive and distribute the data and derived products and assist in their interpretation and use of the consequent information. Consequently, many intergovernmental and nongovernmental organizations are involved. For example, the IOC is an intergovernmental organizations whose actions must reflect some level of consensus among member nations, while the ICSU is nongovernmental and its actions are therefore nonbinding on participating nations. An underlying principle is that a global ocean observing system is too large for any one nation to undertake but that, if plans for a system can be generally agreed upon, national contributions can be aggregated to constitute such a system. This observing system is therefore to be implemented by a community of nations, planned and coordinated through a formal GOOS structure (Figure 1). Part of that GOOS structure will need to address mechanisms to ensure that adequate numbers of trained observers are available and develop the ability of various nations to contribute dam of uniform quality.

It has been agreed by the IOC that the observations which GOOS is designed to make should have certain characteristics. These characteristics are described as follows:

**Long-term**—They should continue indefinitely. The continuity should be in the measures and not in the method; so, if methods are changed, overlap should be planned to ensure continuity of series with undiminished quality.

**Relevant**—Quantities to be observed should be selected with end products in mind.

**Systematic**—The spatial and temporal scales and the precision and accuracy of sampling should address specific objectives.

**Cost-effective**—Where possible, observational methods that are economical and efficient should be selected.

**Routine**—Data acquisition, quality control, and production and dissemination of products should be carried out in an operational manner.

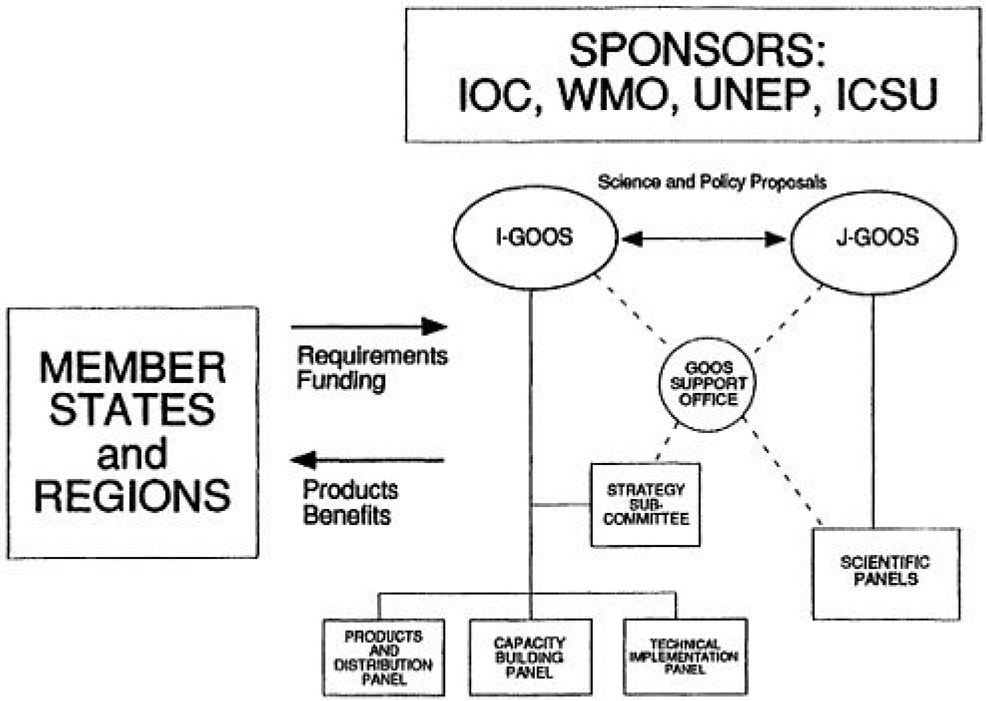


FIGURE 1
Relationship among various intergovernmental and nongovernmental entities responsible for planning and implementing GOOS internationally (after IOC, 1992).

**BOX 1 THE OVERALL OBJECTIVES OF GOOS**

1. To specify and detail in terms of space, time, quality, and other relevant factors the marine observational data needed on a continuing basis to meet the common and identifiable requirements of the world community of users of the oceanic environment.
2. To develop and implement an internationally coordinated strategy for the gathering or acquisition of these data.
3. To facilitate the development of uses and products of these data, and encourage and widen their application in use and protection of the marine environment.
4. To facilitate means by which less-developed. nations can increase their capacity to acquire and use marine data according to the GOOS
5. To coordinate the ongoing operation of GOOS and ensure its integration Within wider global observational and environmental management strategies.

Source: IOC(1996a).

The development of GOOS is considered a long-term activity beginning with identification of needs and scientific/technical planning. This development is being carried out using a modular approach. The objectives for the five modules are stated later in this chapter, and the status of their planning is described in Chapter 2. Overall development of COOS plans is the responsibility of the Joint Scientific and Technical Committee of GOOS (J-GOOS).

Implementation of GOOS is proceeding using a phased approach, as is implementation for the Global Climate Observing System (GCOS). Ongoing contributions are being identified and acknowledged. Enhancements to existing systems are being sought now. Together the ongoing contributions and enhancements will form the initial observing system. Longer-term desirable additions are being identified for future implementation. Research and development needed for future refinement of the system is encouraged. Implementation will take the form of contributions from various national agencies and the private sector. Overall responsibility for coordination of the implementation resides with the IOC-WMO-UNEP Committee for GOOS (I-GOOS). Continuing assessment of the system is considered essential. However, at this stage of development, responsibility for this phase is unclear.

In a sense, I-GOOS can be considered the "board of directors" for GOOS. Having general responsibility for international planning and coordination of GOOS, this body interacts with nations and sponsoring organizations. To date, I-GOOS has met formally every other year (1993 and 1995), with planning sessions in alternate years (1994 and 1996). I-GOOS has commissioned the preparation of a Data Management Plan and a Space Plan (modeled on the analogous plans prepared for GCOS) to articulate the needs of the system in these areas. A draft data management plan exists. Both plans are being developed jointly with GCOS and the Global Terrestrial Observing System (GTOS).

## THE GOOS MODULES

As a starting point GOOS has been envisioned as consisting of five "modules." These modules are organized according to likely user interest. This concept is useful when planning the observations and products necessary to address user needs (Figure 2 from IOC 1996c, is an example from the health of the ocean [HOTO] module). However, there is much overlap between the modules. As the system becomes operational, it is intended that facilities, observations, networks, and products will be shared by all classes of users.

The five modules are: (1) Climate Monitoring, Assessment, and Prediction; (2) Assessment and Prediction of the Health of the Ocean; (3) Monitoring and Assessment of Living Marine Resources; (4) Coastal Zone Management and Development; and (5) Marine Meteorological and Oceanographic Services. The scope and intent of each of the five modules described in the following subsections have been considered by the various GOOS bodies (IOC, 1996a). It is the responsibility of J-GOOS to oversee completion of the planning for these modules and to integrate and prioritize these plans.

### Climate Monitoring, Assessment, and Prediction

The global atmosphere and the world's oceans are an interactive system. The oceans store, transport, and exchange heat with the atmosphere. The oceans are both a source and a sink for carbon dioxide and other "greenhouse gases." The oceans also drive the global cycle of evaporation and rainfall. Predicting climate variations longer than a few weeks demands that ocean behavior be taken into account. The Climate Monitoring, Assessment, and Prediction module (commonly referred to simply as the climate module) will seek to reduce the uncertainty that now exists with regard to the ocean's role in climate variability.

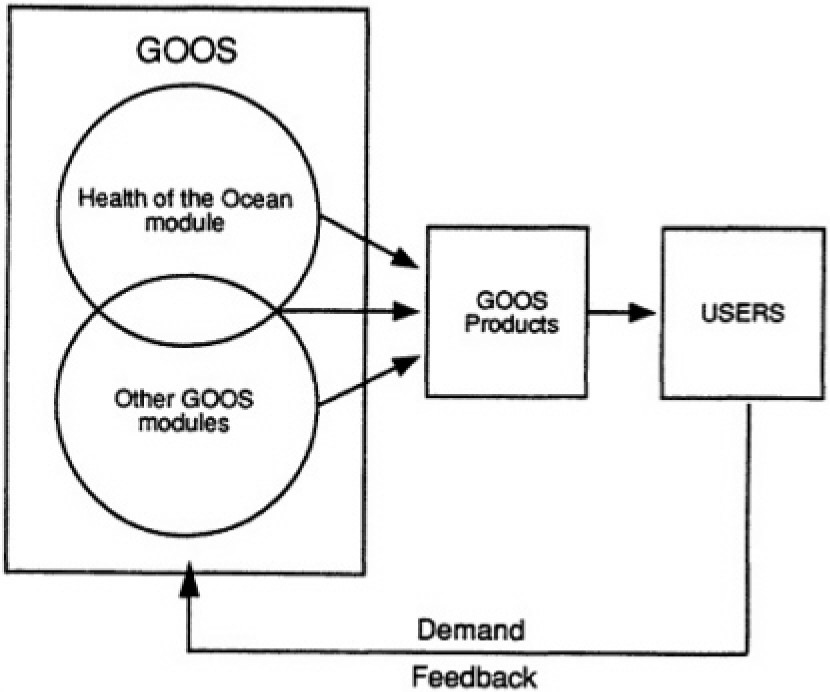


FIGURE 2
Conceptual illustration of potential GOOS delivery pathways for the Health of t he Ocean module (after IOC, 1996c).

The Global Climate Observing System (GCOS), to be developed jointly by WMO, IOC, ICSU, and UNEP, will provide comprehensive information on the total climate system. GCOS will involve a multidisciplinary range of physical, chemical, and biological variables and atmospheric, oceanic, hydraulic, cryospheric, and terrestrial processes. The GOOS climate module will constitute the oceanographic component of GCOS. It is being designed to monitor, describe, and understand the physical and biogeochemical processes in the ocean that determine ocean climate variability (particularly circulation) and their effects on seasonal and longer-term climate variability and to provide the observations needed for climate prediction. The scientific and technical design of the GOOS climate module is being developed with oversight of GOOS GCOS, and the World Climate Research Programme (WCRP). If the International Research Institute for Climate Prediction is successfully developed, it will provide great impetus for the GOOS climate module.

### Assessment and Prediction of the Health of the Ocean

The HOTO module aims to establish a framework for monitoring the levels and trends of pollution on global and regional scales and for assessments of the health of the ocean, in particular in the shelf and coastal areas. A primary objective of the HOTO module will be to monitor and assess contaminant loads in the marine environment (with particular emphasis on the state and response of marine ecosystems to both anthropogenic impact and natural change). Data collection and analysis are to be based on the use of commonly agreed to methods, standards, and techniques. The HOTO module will include regional components having specific observational networks geared to the problems of each region. The HOTO module must be closely related to the coastal and living marine resources modules.

### Monitoring and Assessment of Living Marine Resources

The ocean's living resources depend on their environment. Changes to the marine environment will inevitably change the composition and behavior of the living resources it contains. The living marine resources (LMR) module will include development of a system to monitor the physical, biological, and chemical variables needed to describe the structure and functioning of marine ecosystems as well as changes in marine ecosystems over various space and time scales. Sustainable development of living marine resources requires predictive capabilities. Predictions must take into account the effects of environmental change on the abundance and production of these resources. GOOS will improve the continuity and quality of data sets, allow access to related information, and provide products benefiting the sustainable use of marine living resources. The LMR module will provide both specification and a framework for an adequate package of observations and analysis to understand and forecast major changes in the abundance and/or production of critical living marine resources over time scales of years to decades arising from changes in the carrying capacity and/or health of the ocean. Thus, the LMR and HOTO modules are closely coupled.

## Coastal Zone Management and Development

The GOOS coastal module is intended to provide the infrastructure necessary to produce products needed for a wide range of coastal-area management issues, such as environmental protection, vessel traffic services, aquaculture, coastal engineering, sports fishing, and boating. Monitoring and documenting changes in coastal and near-shore areas require an interdisciplinary approach that integrates physical, chemical, biological, and geological observations with socioeconomic aspects of coastal-zone use. The GOOS coastal module is of high priority to many coastal nations because of the importance of coastal areas for development and the effects of coastal changes on economic development and human habitation. It is acknowledged that such responsibilities in many cases should belong, in part, to regional GOOS organizations.

## Marine Meteorological and Oceanographic Services

The fifth GOOS module is the marine meteorological and oceanographic services module. Extensive marine meteorological and oceanographic operational services are already available worldwide, in support of a large variety of user groups and applications, ranging from the safety of life and property at sea to major economic and commercial interests, such as offshore mining and industry, ship routing, fisheries, recreation, and tourism. These services are provided by both operational national agencies (e.g., national meteorological and/or oceanographic services) and private companies. The marine services module will seek to assist in enhancing the collection, exchange, and processing of oceanographic and meteorological data to support the improvement and expansion of existing services, as well as the development and implementation of new ones, in response to user requirements. Activities will be undertaken in collaboration with existing WMO and IOC activities, in particular the World Weather Watch, the WMO Marine Programme, and the Integrated Global Ocean Services System.

## U.S. GOOS

The U.S. GOOS Interagency *ad hoc* Working Group (U.S. GOOS IWG) was established in 1993 to help coordinate efforts among U.S. agencies involved in GOOS. U.S. GOOS IWG meets monthly or bimonthly and provides a forum for various agencies involved to exchange information about GOOS activities and find areas for cooperation and mutual benefit. Partially in response to the 1994 National Research Council (NRC) report, *Review of U.S. Planning for the*

*Global Ocean Observing System*, the U.S. GOOS Interagency Project Office was established to facilitate the design and implementation of U.S. components of GOOS. The lead agency for GOOS in the United States is the National Oceanic and Atmospheric Administration (NOAA), which is the site of the U.S. GOOS Interagency Project Office (U.S. GOOS Interagency Project Office, 1996).

**BOX 2 U.S. GOOS INTERAGENCY *AD HOC* WORKING GROUP TERMS OF REFERENCE**

A. The U.S. agencies interested in GOOS will cooperate in an Interagency *ad hoc* Working Group for U.S. GOOS (henceforth: U.S. GOOS IWG) with the following tasks:

1. Document activities and plans that constitute U.S. GOOS efforts, to result in publication of a U.S. National GOOS Report for presentation at IOC GOOS meetings and other events (e.g., WMO, ICSU, U.S. interagency meetings).
2. Formulate and agree to U.S. positions for IOC GOOS and other formal meetings.
3. Coordinate, *pro tem*, U.S. activities related to the international Global Ocean Observing System
4. Define, develop, and implement a mechanism for long term, formalized interagency coordination of U.S. GOOS.
5. Serve as an advocate for U.S. GOOS within and among agencies.

B. The U.S. GOOS Interagency *ad hoc* Working Group will be chaired by NOAA (National Ocean Service).

C. The U.S. GOOS Interagency *ad hoc* Working Group will provide periodic progress reports to the Ocean Studies Board, Marine Board, and Board on Atmospheric Science and Climate of the National Research Council, Subcommittee on U.S. Coastal Science of the Committee on Earth and Environmental Sciences, and other groups as appropriate.

Source: U.S. GOOS Interagency Project Office

Each year the U.S. GOOS Interagency Project Office produces a compendium of activities contributing to a U.S. GOOS by its membership (e.g., NOAA, National Science Foundation, National Aeronautics and Space Administration, Department of Energy, Department of the Navy, U.S. Coast Guard, Environmental Protection Agency, U.S. Geological Survey, Minerals Management Service, Department of State). These reports are a useful source of

**BOX 3 OBJECTIVES OF THE TASK FORCE ON OBSERVATIONS AND DATA MANAGEMENT (TFODM)**

- **Coordinate the development of an inventory** of Continuing global and regional operational and research environmental observations (especially those with long data records and observational persistence) and data and information management systems for all environmental and natural resources activities.
- **Coordinate research observation and data systems requirements**, both current and future. Assess the needs of the CENR subcommittees ranging from global to place-based and from long-term to snapshots so that existing and new observational and data technologies may best be used to address these requirements.
- **Identify overlaps and gaps in research observation and data management efforts**, and use this knowledge to recommend new initiatives or restructure current ones to make best use of research resources.
- **Promote the development of a more comprehensive system** of global and national observations that provide data types and resolutions (spatial and temporal) needed for research activities but presently not available.
- **Promote the development of a system to manage this extensive information**, integrate it with data and information from other sources, and make it widely available and easily used by the research community at international, national, state, and local levels.
- **Ensure that the data collected can be used to provide credible information** on the environment to meet CENR objectives. Collect feedback from the subcommittees on the availability, adequacy, and

information on the state of U.S. efforts in various aspects of GOOS (U.S. IWG 1993, U.S. GOOS Interagency Project Office 1995, 1996).

utility of environmental space-and Earth-based observational data.

- **Establish close working relationships with the environmental modeling community** to assist with four-dimensional data assimilation, and with the High Performance Computing and Communications Information Technology (HPCCIT) Subcommittee of the NSTC Committee on Information and Communications R&D (CIC) to link data and information systems research with high performance computing research.
- **Develop and test ways to improve the usefulness of observations and data** and derived information to national and international initiatives in such areas as global change; geographic information systems; national security; sustainable development, including: biodiversity conservation; ecosystem protection, restoration, and management; and improvement of human health and welfare.
- **Provide the U.S. Secretariat for the International Global Observing System** programs such as the Global Climate Observing System, the Global Ocean Observing System and the Global Terrestrial Observing System, and coordination of associated data management activities.
- **Promote the continuance and extension of the policy of full and open exchange of data for environmental research**. Promote the U.S. position in international global observing and data management system forums.

Source: Committee on Environment and Natural Resources (1996).

Aside from the U.S. GOOS IWG, a number of federal entities are involved in formulating and implementing observing systems. The Committee on Environment and Natural Resources (CENR) is one of eight R&D coordinating committees chartered under the President's National Science and Technology Council. The role of CENR is to improve coordination of all federal environmental and natural resources research activities, to establish a strong link between science and policy, and to develop and oversee policies and strategies that respond to national and international concerns and agreements.

In July 1995 CENR requested that its Task Force on Observations and Data Management (TFODM) develop a plan for organizing U.S. civil earth observations in the context of an integrated global observing strategy (IGOS). TFODM developed a draft entitled *Concept for an Integrated Global Observation Strategy* in February 1996. The intent of the strategy is to promote communication and coordination among responsible federal agencies and help translate the recommendations of the Global Climate Observing System (GCOS), the Global Terrestrial Observing System (GTOS) and the GOOS into nationally funded activities within a common framework (U.S. GOOS Interagency Project Office, 1996).

## NRC COMMITTEE FOR THE GLOBAL OCEAN OBSERVING SYSTEM

In the fall of 1994, M. G. Briscoe, then chairman of U.S. GOOS IWG, requested that the NRC's Ocean Studies Board create a committee on the Global Ocean Observing System and conduct a follow-up to the 1994 NRC report, *Review of U.S. Planning for the Global Ocean Observing System* (see Appendix A). This new study was intended to provide information and advice to U.S. GOOS IWG to help define and implement an effective, affordable, and customer-based U.S. contribution to GOOS. In particular, the committee was charged with identifying priorities and cost-benefit tradeoffs where possible and with recommending additional efforts of this type, if needed.

Specific charges to the committee were to (1) provide advice to U.S. agencies regarding a practical concept for GOOS as a primarily operational activity with an emphasis on identifying potential applications and users of GOOS during the next 3 to 5 years and beyond; (2) recommend appropriate roles for industry and academia in GOOS to help ensure that user needs are addressed adequately; (3) prioritize (to the extent possible) observational and infrastructural activities that should be undertaken or continued by the United States in its initial commitments to GOOS, including pilot programs; and (4) update (as needed) the NRC report, *Review of U.S. Planning for the Global Ocean Observing System.*

To accomplish this task, three fundamental types of information developed by the committee are contained in this, the resulting report: (1) history, organization, and focus of GOOS (at both international and national scales); (2) discussion of the potential users and benefits of GOOS; and (3) recommendations for improving the function of the structure and facilitating the implementation of GOOS plans.

Many of these recommendations were originally put forward in the 1994 National Research Program (NRC) report, *Review of U.S. Planning for the Global Ocean Observing System.* In an effort to both update and expand upon that report, the committee chose to repeat and support specific recommendations from it that have yet to be adequately implemented. It is hoped that by providing an expanded discussion of the users and benefits of GOOS (Chapter 4), that this report will help provide impetus to the implementation of: those and other recommendations.

Although many readers may find the entire report of value, the broad nature of the committee's task has resulted in a report that deals with a broad range of topics. Readers interested in a general discussion of GOOS may find the organizational details of GOOS contained in Chapters 2 and 3 imposing and may wish to concentrate on Chapters 4 and 5. Readers interested in a comprehensive discussion of the origin and complexities associated with a global efforts of the type represented by GOOS should find Chapters 2 and 3 of value.

# 2

# INTERNATIONAL GOOS

The Global Ocean Observing System (GOOS) is intended to be a truly international effort. International panels are developing guidelines for participation in GOOS. The United States can provide leadership by developing implementation plans for its own agencies to follow. All countries, developed or developing, are encouraged to participate, even if only by expressing needs and allowing access for monitoring systems. The needs and perspectives of the international community must be addressed if GOOS is to be truly global in scope and impact.

Although the committee was formed largely to address aspects of GOOS efforts undertaken by U.S. government agencies, the committee recognizes that those same efforts will have profound influence on actions taken by the international community. Consequently, this chapter describes the present state of international GOOS efforts (as a context for U.S. actions) and recommends certain activities or actions that U.S. agencies may wish to implement or advocate.

## INTERNATIONAL INFRASTRUCTURE

The senior scientific/technical body advising the Intergovernmental Committee for GOOS (I-GOOS) is the Joint Scientific and Technical Committee for GOOS (J-GOOS) which has met annually since 1994 (Figure 1). Panels preparing plans for and overseeing the implementation of the various modules (e.g., the Ocean Observations Panel for Climate for the climate module) report to J-GOOS.

Following the 1994 meeting of I-GOOS, a Strategy Sub-Committee (SSC) to I-GOOS was established; it has met in 1995 and 1996. The rationale for the SSC was to have a nongovernmental group of experts provide advice to I-GOOS regarding the actions needed to make GOOS a reality. At its first meeting, the SSC focused on preparing an expanded outline of a strategic plan covering the range of activities needed by the various GOOS bodies, with time tables for action. Unfortunately, firm support for such a plan was not forthcoming from I-

GOOS, and work on the plan had not progressed by the time of the second SSC meeting.

These bodies (e.g., I-GOOS, J-GOOS, SSC) are, in principle, to receive staff support from a GOOS support office located within the Secretariat of the Intergovernmental Oceanographic Commission (IOC). Although in existence for several years, the office has only a minimal staff (most of whom have other primary responsibilities) and until recently lacked a permanent director. Thus, the fact that only limited progress has been made by the three aforementioned bodies toward establishing firm plans and mechanisms for implementation and coordination of GOOS is understandable. Committees such as I-GOOS, J-GOOS, and the SSC cannot be expected to complete the required work during their short annual sessions; an adequate staff working during intersessional periods is needed.

Full development of a GOOS strategy, decisive actions by international GOOS committees, and adequate staff support for and action by the GOOS support office have not occurred. **In order for the full benefits of GOOS to be realized, adequate support for an international GOOS support office is needed. Completion of a GOOS Strategic Plan and decisive actions to follow that plan are needed**.

## STATUS OF INTERNATIONAL PLANNING BY MODULE

The international plans for each module vary in maturity. Consequently, plans for the climate module are further developed than for other modules, followed by planning for the health of the ocean module.

### Climate Monitoring, Assessment, and Prediction

Under the auspices of the Committee for Climate Change and the Ocean and the Joint Steering Committee of the World Climate Research Programme (WCRP), an Ocean Observing System Development Panel (OOSDP) was commissioned in 1990 to begin design of the climate module. The panel's charge was "to formulate the conceptual design of a long-term systematic observing system to monitor, describe, and understand the physical and biogeochemical processes that determine ocean circulation and the effects of the ocean on seasonal to decadal climate changes and to provide the observations needed for climate predictions" (OOSDP, 1995). In 1995 the OOSDP submitted its plan to the IOC, the Joint Scientific Committee of WCRP, and the Joint Scientific and Technical Committee of GCOS. It was published as a report (OOSDP, 1995) and also placed on the World Wide Web (<http://www.ocean.tamu.edu/OOSDP/oosdp.html>). A comprehensive summary of the report appeared in the October 1996 issue of the *Bulletin of the American Meteorological Society* (Nowlin et al., 1996). Other views of the report are given by Smith et al. (1995).

As stated previously, the climate module of GOOS is intended to be the ocean component of the Global Climate Observing System (GCOS). The OOSDP design for the common module of GOOS and GCOS is based on four goals dealing with (1) observations needed to determine necessary ocean surface fields (including sea ice) and fluxes through the surface; (2) observations needed for deterministic prediction of the variability of the coupled ocean-atmosphere system on seasonal to interannual time scales and for the regular monitoring of climate variability at monthly to interannual scales; (3) measurements of the deep ocean essential for monitoring and understanding natural and anthropogenic ocean climate variability at long time scales with a focus mainly on monitoring, understanding, and validating model simulations rather than model initialization and prediction; and (4) provision of the infrastructure and techniques to ensure that these data are quality controlled and archived and that products are prepared and distributed. It is envisioned that this synthesis will be achieved in a variety of ways, including routine monitoring, analyses (typically at monthly intervals), preparation of improved climatologies, and through model data assimilation.

Eleven subgoals dealing with observations and three dealing with needed infrastructure were developed to support these goals. For each subgoal, contributing observations were weighted as to their impact on meeting the subgoal as well as their feasibility. Finally, the subgoals were prioritized, and the observations needed to meet them were ranked. Thus, there exists a design for the climate module that awaits implementation. However, few new observations have yet been added because of lack of financial support.

Following completion of its report, the OOSDP was dissolved. Recognizing the need for continued scientific oversight of the design and implementation of the climate module, J-GOOS, the Joint Scientific and Technical Committee of GCOS, and the Joint Steering Committee of the WCRP together formed the Ocean Observations Panel for Climate (OOPC). This panel is charged with evaluating, modifying, and updating the design for the common module of GOOS and GCOS and with preparing a procedural plan, with priorities, for the requirements consistent with that design.

The OOPC first met in 1996 and is scheduled to meet in February 1997. The panel has already begun to take needed steps to refine the design based on new technical developments and understanding, and it seems clear that this panel will take a proactive role in implementation of the climate module.

## Assessment and Prediction of the Health of the Ocean

A strategic plan for assessment and prediction of the Health of the Ocean (HOTO) module has been under development for several years by the HOTO panel. The plan has been considered by I-GOOS and J-GOOS and is available as a preliminary report from the IOC (HOTO Panel, 1996). The panel identified issues of current concern in a global sense when considering the health of the ocean, including biodiversity, endangered species, climate variability, human health, tourism, and eutrophication. Collectively, these health of the ocean issues were related by the panel to a range of contaminants or analytes: aquatic toxins, pesticides and herbicides, pathogens, oxygen, petroleum hydrocarbons, suspended particulate matter, phytoplankton pigments, artificial radionuclides, litter, nutrients, synthetic organic compounds, polycyclic aromatic hydrocarbons, trace metals, and pharmaceuticals. For each of these variables, the panel considered the socioeconomic impacts in coastal zones, the resulting stressrelated signals of harmful effects, capabilities for their measurement, and priorities among the world's marine areas. Quantitative ratings were associated with most comparisons. Consequently, the panel was able to rank each variable's impact on the health of the ocean versus its difficulty of measurement.

The HOTO module should be considered ready for implementation, although the degree of prioritization and ranking of measurements as related to specific goals are not yet nearly as complete as for the climate module. In 1995 the HOTO Panel recommended to the I-GOOS, via J-GOOS, a number of specific recommendations for implementation. These included the preparation of a global inventory of measurement capabilities and relevant programs, the completion of the ongoing International Mussel Watch Program, and numerous steps to initiate or improve measurement techniques and quality assurance procedures. Revised terms of reference for a reconstituted HOTO panel were formulated by J-GOOS in April 1996, and a request was made for nominations of new members (IOC, 1996b). The first meeting of the reconstituted HOTO panel is scheduled for spring of 1997.

## Monitoring and Assessment of Marine Living Resources

Changes in the marine environment may result in changes in the composition and behavior of living marine resources (IMP,). In turn, such changes can further impact the environment, including mankind. As stated in international plans, the LMR module will develop a system to monitor the physical, chemical, and biological variables needed to describe marine ecosystems and their variability.

The LMR module is intended to identify user requirements for oceanographic data on living marine resources and to give advice on design and implementation of the observing system. The scope of the module is dictated by the need to obtain data and make predictions about living resources of the ocean and coastal seas that meet the economic, social, and environmental needs of society.

An *ad hoc* panel to begin planning for the LMR module was held in Costa Rica in December 1993. Building on that groundwork the Scientific Committee on Oceanic Research (SCOR), at the request of the J-GOOS, convened a workshop in Dartmouth, Massachusetts during March 1996. Participants of that workshop made six recommendations to J-GOOS:

- Consider how the following issues should be addressed within the overall framework of GOOS: critical marine habitats, living marine resources in coastal waters (including issues of biodiversity and genetics), harmful algal blooms, diseases in relation to the health of humans and marine biota.
- Consult with sponsoring organizations on the establishment of mechanisms to ensure the appropriate involvement of other agencies.
- Facilitate the formation of close working relationships between LMR and existing bodies responsible for the collection of data at the higher trophic levels (e.g., fisheries agencies, environmental organizations). Their collaboration is needed both as contributors of the data they collect and as users of LMR products derived from observations made specifically as part of the LMR program. Formal structures to facilitate these relationships may need to be elaborated, and such bodies should be represented on the LMR panel so that it may contribute to the planning process.
- J-GOOS should undertake responsibility for issues of training and capacity building as an integrated GOOS-wide activity rather than it being addressed separately by each module.
- A formal LMR panel should be established to facilitate planning of the LMR module. Selected LMR panel members should be members, or corresponding members, of planning groups for related modules (e.g., HOTO, coastal).
- Earth observations from satellites and aircraft will be essential given the need to observe broad areas of the ocean on a regular basis. Workshop participants supported the J-GOOS recommendation to establish a panel on satellites, which should ensure consideration of the requirements and needs of the various GOOS modules.

The design of the LMR module is in progress. As a fundamental issue, there is not yet agreement on the proper balance between needed ecosystem research and more pragmatic operational data needs.

Entire ecosystems are complex. Thus, for various reasons (economy, lack of time or data, etc.), their investigators may choose to emphasize certain ecosystem constituents or properties to the exclusion or oversimplification of others. For example, studies of pelagic ecosystems may focus solely on lower trophic levels, excluding higher predators, such as fish, or relegating their effects to "closure terms" in the ecosystem balance. Conversely, fishery investigations often neglect crucial elements of ecosystem monitoring, concentrating on abundance and other characteristics of the various stages of fish populations alone. This is particularly true of studies that depend on data from commercial fish catches.

Neither ecosystem studies that pay only cursory attention to higher predators or fishery investigations that neglect other ecosystem influences (especially environmental) can be considered a satisfactory basis for the observing strategy of the GOOS LMR module. A more complete integration of fish populations into ecosystem/environmental monitoring is required.

As noted in the recommendations from the LMR workshop, there is the need for a formal GOOS panel to complete planning for the LMR module. Only then can implementation began. Meeting in April 1996, the J-GOOS approved terms of reference for an LMR panel and requested development of a potential membership (IOC, 1996b).

## Coastal Zone Management and Development

As mentioned previously, the coastal module is of high priority to many coastal nations. Monitoring and documenting changes in coastal and near-shore areas require integration of physical, chemical, biological, and geological observations with socioeconomic uses of the coastal zone. The coastal module should provide necessary infrastructure needed by service providers who provide products used in various areas of coastal management, including environmental protection, vessel traffic services, recreation and tourism, coastal engineering, or water management. Such products clearly will depend in large measure on coastal zone observations also needed for other modules, especially the HOTO and LMR modules. To date, there has been no enunciation at the intergovernmental level of specifics regarding a design for the coastal module.

It is internationally acknowledged that many responsibilities for the coastal module may be effectively carried out by regional organizations. Following that approach, nations in Europe and northeast Asia have been actively planning two consortia for several years, European GOOS (Euro GOOS) and Northeast Asia Regional GOOS (NEARGOOS). Discussion of the establishment of these two consortia appears in the report of the second meeting of I-GOOS (IOC, 1995).

The United States is proceeding with the development of an implementation plan in which the coastal module has three major themes: Sustain Healthy Coasts, Natural Hazard Mitigation, and Safe Marine Navigation (U.S. GOOS IWG 1996). For each of these themes, customers and beneficiaries as well as initial, specific objectives (in terms of observations and products) are being identified. For example, proposed special initiatives under the Sustain Healthy Coasts theme are to monitor coral reef ecosystem changes, land-based sources of pollution, and toxic contaminants in bivalves. Each of these themes has many U.S. programs in place. Initial discussions have begun between U.S. officials and their Canadian counterparts regarding cooperation in the coastal module.

### Marine Meteorological and Oceanographic Operational Services

A large range of marine meteorological and oceanographic services already is available worldwide. These services are provided by both national agencies and private companies. These services are utilized for economic operation of shipping, fisheries, tourism and recreation, improving the safety of life and property at sea, and seabed exploration.

The marine services module aims to enhance the collection and analysis of oceanographic and marine meteorological data required for improved short-and medium-term weather forecasting, improved warning of severe weather events, as well as specialized global and regional oceanographic and meteorological services. The enhancements will consist of improved methodologies, standards, data, data analysis, models, and predictions. It is anticipated that this module will encompass a training program for assistance in establishing operational services and in the use of products.

As a start toward a plan for this module, the I-GOOS established an *ad hoc* working group in 1995 to prepare a report on existing operational marine meteorological and oceanographic services, user requirements, perceived deficiencies and future trends, and suggestions as to how GOOS might enhance these services. The report is due in 1997. An interim report appears as Annex VI to the report of J-GOOS-III (IOC, 1996b).

### Overall Status of Module Planning at the International Level

Planning for the climate module is well advanced and refinement is continuing. Planning for the HOTO module is well under way but still lacks certain dimensions (e.g., impacts on human health and the health of various marine species). To date, plans for the coastal module have been formulated only on regional or national bases. Plans are in progress for the LMR and marine services modules. The division in emphasis between fisheries and research on major ecosystems has yet to be addressed as part of the development of the LMR module.

Planning must be initiated and/or continued for each module at a level adequate to produce plans that can be the basis for implementation. Scientific and technical panels may be required to guide the planning for each module. As discussed in the 1994 NRC report, *Review of U.S. Planning for the Global Ocean Observing System*,

> It is essential for the United States to provide leadership internationally and to set firm directions nationally. Adequate financial support should be devoted to international planning and coordination by the United States and other nations participating in GOOS. **Without the resources required to provide sufficient international staff and support to J-GOOS and I-GOOS activities, it is unlikely that GOOS will be able to carry out the international functions that are critical to its success**. (emphasis added)

**The United States, through U.S. GOOS IWG and the U.S. GOOS Interagency Project Office, should provide financial support for this effort commensurate with national interests**.

Plans are being developed for the implementation of much of GOOS as purely regional initiatives (e.g., Euro GOOS, NEARGOOS) based on local concerns and interests. Although regional operational oceanography may be important for initiating GOOS support and demonstrating its potentials, there is risk that such initial division will impede the ultimate development of a global operational system.

Regionalization poses a special problem in the case of the fundamentally global modules such as the climate module. Global cooperation is needed to learn how to make measurements and products, and so contributes to capacity building. **All nations are encouraged to focus on the needs of the international community in developing global observations and models; in sharing methods, standards, instruments, data, and products; and in capacity building**.

## Importance of Time Series

Ocean observations taken during research programs are often collected intensively but for brief times, whether as individual long hydrographic lines or three-dimensional process studies. GOOS can interact productively with such programs by extending the time axis at individual time-series sites or lines. New drifter and mooring technologies can be a part of this monitoring scheme, as can the rich suite of satellite measurements.

**Currently occupied time series should be cataloged and their priority for GOOS established through an evaluation of their relative costs and potential benefits or some other similar systematic approach. For high-priority stations, steps should be taken as needed to preserve and make available the data. Where future continuity is in jeopardy, international planning should focus on maintaining the observations and introducing new technology to effect cost savings as possible**.

## RELATIONSHIP OF RESEARCH PROGRAMS TO GOOS

The design of a successful observing system for the oceans is predicated on the designers having an informed understanding of the ocean and associated phenomena. Consequently, the design for GOOS is based on the results of innumerable research efforts around the world, such as the World Ocean Circulation Experiment (WOCE), the Global Ocean Ecosystem Dynamics Program (GLOBEC), the Global Energy and Water Cycle Experiment (GEWEX), the Joint Global Ocean Flux Study (JGOFS), and the Programme on the Variability of the Coupled Ocean-Atmosphere System and Climate Prediction (CLIVAR), to name a few. Research programs, such as those organized under WCRP or International Biosphere-Geosphere Programme (IBGP), are contributing data, understanding, and mechanisms on which GOOS plans axe being formulated. To obtain optimal results, the design of any observing plan should be based on as complete and accurate an understanding of the system to be observed as possible. **Support should be continued for the full and orderly completion of ongoing research programs contributing to GOOS plans and implementation**.

GOOS data, in addition to providing the basis for products used by national and local governments and the private sector, will be used by researchers. CLIVAR is one program being planned by the international community (under WRCP auspices) that anticipates using GOOS data. The results of such research programs undoubtedly will further the methods, instrumentation, and conceptual development of GOOS.

Close liaisons should be developed between the research programs and GOOS, formalized by the mutual involvement of planning and steering groups. **The goals of this effort should be to address (1) the needs of the research programs for GOOS data, (2) the transition of elements of observing systems from research programs to GOOS, and (3) the evolution of the existing GOOS to new technologies and/or modified sampling schemes driven by experience and knowledge gained in the research programs**.

# 3

# GOOS IN THE UNITED STATES

The Global Ocean Observing System's (GOOS) contributions are intended to be encouraged and coordinated by international mechanisms, but implementation must stem from contributions of national agencies and companies. As a major potential contributor, U.S. plans and actions for GOOS are of great interest and importance to other countries. The United States, because of its strong ocean science legacy, is in a unique position to shape International GOOS structure and implementation.

## U.S. GOOS INFRASTRUCTURE

As discussed in Chapter 1, most U.S. efforts to develop and implement GOOS involve unilateral agency decisions to fund specific monitoring efforts or joint activities organized through the U.S. GOOS Interagency *ad hoc* Working Group (U.S. GOOS IWG). Although the U.S. GOOS Interagency Project Office is intended to provide a formal mechanism to implement U.S. GOOS IWG initiatives, discussions with the director of the project office suggest that financial support for the office is provided by a very small subset of agencies participating in the U.S. GOOS IWG (oral communication, E. Lindstrom, 1996).

### U.S. GOOS Interagency ad Hoc Working Group

The U.S. GOOS contribution is (still) being coordinated by an *ad hoc* working group (i.e., U.S. GOOS IWG). Membership may not include all potential agency contributors (e.g., U.S. National Park Service or U.S. Army Corps of Engineers).

Annual reports of U.S. GOOS IWG provide summaries of U.S. contributions and activities (U.S. GOOS IWG, 1993; U.S. GOOS Interagency Project Office, 1995, 1996). Based on these reports, U.S. GOOS IWG is more reactive than proactive. Consequently, there is no specific set of priority activities agreed on by U.S. GOOS IWG. Considering the potential magnitude and impact of GOOS, it is not clear that representatives on U.S. GOOS IWG are sufficiently well positioned within their agencies to represent agency opinion or plans. A strong connection between U.S. GOOS IWG and the research community is required to ensure that scientific input is incorporated into GOOS planning and implementation. As stated in *Review of U.S. Planning for the Global Ocean Observing System*,

> Research and development efforts must be coupled and interactive. Instrument requirements will be driven by scientific and technical communities. The interaction must be systematic, not occasional.... It is clear, therefore, that the next stages of development of U.S. GOOS will require ... a clear overall strategy document and specific plans for implementing specific aspects of GOOS, a coordinated budget process for the cooperating agencies, and a strong reporting mechanism into the National Science and Technology Council (NSTC) Process.

In recognition of these and other factors, the NRC report, *Review of U.S. Planning for the Global Ocean Observing System*, included a range of recommendations intended to strengthen U.S. capabilities to support, plan, and implement GOOS in the United States and abroad. Although many of the recommendations were implemented, many others were not. To fully realize the benefits of GOOS, participating U.S. agencies should reexamine and strengthen some aspects of the U.S. GOOS administrative infrastructure to reflect a concerted commitment to the agreements made during the Earth Summit held in 1992 in Rio de Janeiro (UNCED, 1992). **As a first step, U.S. GOOS IWG should be made permanent and its status raised. This includes raising the level of agency representatives to assure that they reflect agency views to the maximum feasible extent. Membership should be reviewed to include relevant agencies**.

**U.S. GOOS IWG should develop and adopt procedures for (1) regularly reviewing international GOOS priorities, (2) ensuring that potential contributions from the United States are relevant to GOOS, and (3) setting priorities for future U.S. contributions. The U.S. GOOS IWG should work with agencies to select a small number (say a half dozen) of major contributions of the highest priority for implementation**.

## U.S. GOOS Interagency Project Office

A GOOS Interagency Project Office has been established within the National Oceanic and Atmospheric Administration (NOAA) to provide support for U.S. GOOS IWG and for other activities to effect GOOS development as directed by U.S. GOOS IWG. As stated in the 1994 NRC report, *Review of U.S. Planning for the Global Ocean Observing System*, the GOOS Interagency Project Office must be organized and staffed adequately to allow multiagency interests to be met and programs coordinated. The NRC report **recommended that all U.S. agencies involved in GOOS should share in providing financial and staff support for the U.S. GOOS Interagency Project Office so that the office represents a coordinated interagency view. Furthermore, the U.S. GOOS Interagency Project Office should help support international planning for GOOS, in particular to expedite the development of interim designs for the GOOS modules**.

### Relationship to the Integrated Global Observing Strategy

The recently proposed Integrated Global Observing Strategy (IGOS) has the function of coordinating U.S. activities related to GOOS, the Global Climate Observing System (GCOS), and the Global Terrestrial Observing System (GTOS), at the executive level in the National Science and Technology Council (NSTC) structure. There does not appear to be a formal connection between U.S. GOOS IWG and IGOS. **Again, as recommended in the NRC report, *Review of U.S. Planning for the Global Ocean Observing System*, U.S. GOOS IWG should report to the highest appropriate level in the NSTC structure. Furthermore, a formal connection to IGOS should be established to ensure that GOOS needs are adequately reflected in IGOS planning**.

A draft IGOS document (CENR, 1996) is being considered by the Task Force on Observations and Data Management. The discussion of physical mechanisms in that draft document is primarily focused on the upper ocean. While the ocean's immediate influence on the atmosphere is transmitted principally through sea surface temperature (SST), many other oceanic fields affect climate over longer times. Mixed-layer salinity and temperature profiles control the heat storage available to the atmosphere. The deeper density structure and advection by ocean gyres and zonal current systems are known to change over years-to-centuries. Thus, mechanisms in the interior ocean are of importance to global climate and its variability. Consideration in the IGOS draft document of the observational needs for GOOS modules other than climate (e.g., HOTO or LMR) are even more limited than are those for the climate module. **The plans for IGOS should adequately reflect the scope of GOOS**.

### Relationship to International GOOS

**As stated in *Review of U.S. Planning for the Global Ocean Observing System*, functional relationships between U.S. GOOS IWG and international bodies planning GOOS [e.g., the Global Climate Observing System (GCOS), the IOC-WOCE-UNEP Committee for GOOS (I-GOOS), and the Joint Scientific and Technical Committee for GOOS (J-GOOS)] need to be either clarified or established**.

### Review and Advice

*Review of U.S. Planning for the Global Ocean Observing System* pointed out that although implementation of GOOS will require a significant research and development effort, many activities already under way through single-agency or multiagency activities need only modest expansion to begin to realize their potential benefits. Cooperation among academic, government, and commercial entities may provide the impetus and resources needed to make these activities operational components of GOOS. Furthermore, the potential benefits of GOOS should be distributed across many sectors of our society. For this to take place, academic and commercial sectors, and state and local agencies, should be given an opportunity to provide advice and support on an ongoing basis.

As stated in *Review of U.S. Planning for the Global Ocean Observing System*, the U.S. GOOS IWG does not have a formal mechanism for obtaining such advice from the academic or commercial sectors or from state and local governments. The need for an ongoing and independent advisory body to U.S. GOOS IWG has not changed. **The U.S. GOOS IWG should form a committee (U.S. GOOS Committee) (1) to provide independent oversight of U.S. COOS efforts; (2) to provide scientific and technical/commercial real-time advice; (3) to act on its behalf in relationships with the U.S. and international scientific community and others; and (4) to function as an information exchange medium as needed, including the preparation of reports and other documents. The U.S. GOOS Committee should be funded through the U.S. GOOS Interagency Project Office**.

**Furthermore, in an effort to increase and formalize its interactions with the private sector, the U.S. GOOS Committee should include representation from industry and commercial business**.

## U.S. PLANS FOR IMPLEMENTATION

U.S. GOOS IWG proposes to initially implement the U.S. contributions to GOOS in three modules: climate, LMR, and coastal. Three themes are proposed for the coastal module: Sustain Healthy Coasts, Coastal Hazards, and Safe Marine Navigation (Figure 3). NOAA's National Ocean Service (NOS) has prepared and offered to the U.S. GOOS community a draft plan for the coastal module as the basis for a U.S. implementation for that module. A U.S. Coastal GOOS technical workshop was held December 10-12, 1996, in Bethesda, Maryland. The 43 invited participants included senior scientists from universities, managers from state government agencies, and representatives of federal agencies. Recommendations were made regarding parameters to be

| *International GOOS* | *Initial U.S. GOOS* | *Initial U.S. GOOS Themes* | *U.S. GOOS Specific Initial Goals* | *Ultimate Customers Beneficiaries* |
|---|---|---|---|---|
| **Climate** | **Climate** | Seasonal - to - Interannual Climate Prediction | • Continue Post-TOGA Pacific Ocean Observing System for ENSO Prediction | • Agriculture<br>• Water Resources<br>• Energy Distribution |
| | | Decadal - to - Centennial Climate Monitoring | • Monitor Global<br>• Absolute Sea Level | • Coastal Planners/Managers<br>• Construction |
| **Living Marine Resources** | **Fisheries** | Sustainable Fisheries | • Monitor Large-scale Ecosystems Regime Shifts | • Fishermen<br>• Fisheries Managers |
| **Health of the Ocean** | **Coasts** | Sustain Healthy Coasts (Land Use, Water Quality, Habitat) | • Monitor Coral Reef Ecosystem Changes<br>• Monitor Land-based Sources of Pollution<br>Monitor Toxic Contaminants in Bivalves | • Recreation<br>• Tourism<br>• Fisheries Managers<br>• Human Health |
| **Coastal** | | Coastal Hazards | • Predict Toxic Algal Blooms | • Human Health<br>• Recreation<br>• Tourism |
| | | | • Monitor Sea Level for Tsunami Warning<br>• Forecast Coastal Erosion | • General Public<br>• Insurance Industry<br>• Coastal Planners/Managers<br>• Construction |
| **Marine Services** | | Safe Marine Navigation | • Improve Observational Networks | • Marine Navigation<br>• Insurance Industry<br>• Recreation |
| | **Open Ocean** | | • Deliver Open Ocean/Coastal Data Products | |
| | | | • Improve Modeling of Iceberg Distribution<br>• Predict Ice Conditions | |

FIGURE 3
Chart summarizing relationships among International and U.S. GOOS initiatives (from U.S. GOOS Project Office).

measured to address priority problems facing coastal areas. The discussion focused on the United States, but the conclusions were intended to be applicable to international deliberations as well. A presentation of the results of the workshop will be given at an international Coastal GOOS workshop being held in Miami, February 24-28, 1997. NOS is to be commended for taking the initiative in this matter. However, the committee has a few concerns regarding the extent of interaction between the coastal module and other GOOS modules and among the proposed coastal themes as described by NOS (Figure 3) including:

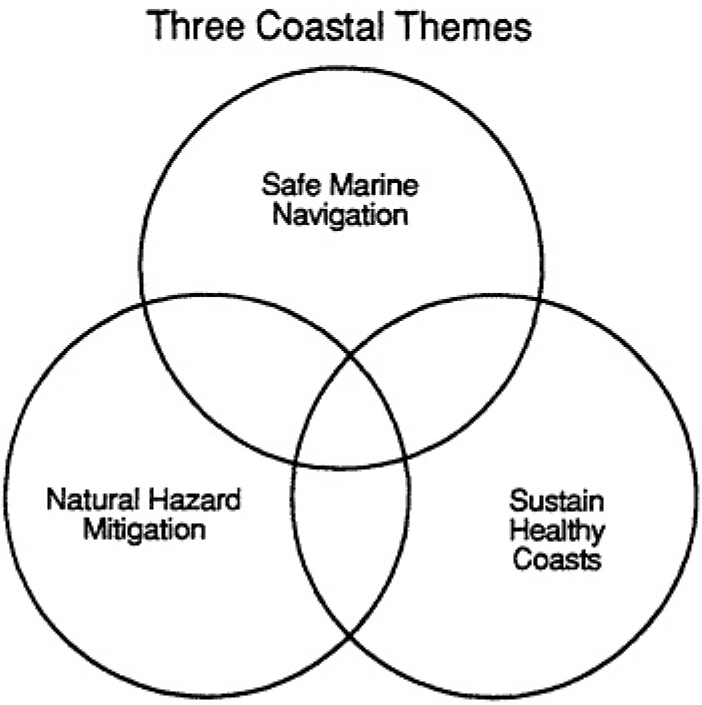


FIGURE 4
Conceptual relationships among the Coastal GOOS themes emphasizing the overlapping nature of each themes mission (provided by the U.S. GOOS Interagency Project Office).

- The international HOTO module includes monitoring the health of, and adverse effects on, marine flora and fauna (e.g., seagrass wasting; coral diseases and bleaching; fish, seabird, and sea mammal mortality) as well as society. **Such activities should he included in the Sustain Healthy**

**Coasts theme of the U.S. coastal module and thus should be coordinated with the HOTO module**.

- The joint NOAA/Environmental Protection Agency (EPA) Coastal Monitoring Task Force did a rational job of making preliminary site selections for the Sustain Healthy Coasts theme. However, all of the potential sites selected represent estuaries, bays, or other largely sheltered water bodies. Although these may be reasonable initial choices, some problems (such as along-shore transport of toxic algal blooms) may well require measurements in "open" coastal waters. **Future planning exercises, while dealing with the most important perceived areas, should not be constrained to deal only with sheltered waters**.
- Figure 3 appears to imply that the prediction of toxic algal blooms will be addressed only under the theme of Coastal Hazards. **The prediction of toxic algal blooms is properly a part of the Sustain Healthy Coasts theme as well. Efforts should be made to encourage coordination across these two areas as depicted in Figure 4**.
- The committee noted that open-ocean products (from the marine services module) are now included under the Safe Marine Navigation theme of the U.S. coastal module. These include marine surface conditions, currents, and prediction of iceberg and ice conditions. **Care should be taken that activities taken under the Safe Marine Navigation theme of the coastal module complement and are coordinated to the greatest extent possible with activities taken under the marine services module**.
- The Safe Marine Navigation theme of the U.S. coastal module includes observations/products needed in response to oil and hazardous material spills. This will require monitoring/modeling of offshore currents, especially in areas where lightering takes place. **Care should be taken that activities taken under the Safe Marine Navigation theme of the coastal module compliment, and are coordinated to the greatest extent possible with, activities taken under the marine services module**.

## EDUCATION

As discussed in *Review of U.S. Planning for the Global Ocean Observing System*, GOOS is a new type of system. It is global in nature and combines substantial scientific and engineering content but is intended as being driven by user needs. Perhaps the closest analog is the World Weather Watch. It is likely that implementation of GOOS, in the United States and internationally, will require a variety of educational activities. The primary needs at this time are to inform the public and policymakers about the importance of GOOS and to impart relevant needs and skills to U.S. and foreign scientists, engineers, and technicians.

U.S. GOOS efforts should include public education and information activities designed to promote understanding of the GOOS concept and its purpose, including publication of information brochures and presentations at relevant regional, national, and international events. U.S. GOOS should include an attempt to improve communication among federal agencies, state and local governments, academic scientists, commercial interests, and the public. This effort should employ traditional means such as newsletters as well as newer methods such as electronic bulletin boards and open file servers. Similar efforts in other science fields can serve as instructive models in this area (e.g., work by the National Weather Service to provide educational Internet-based meteorological observations to schools). Agencies responsible for GOOS in the United States should consider expanding present postdoctoral programs to offer training in federal agencies or the private sector in support of the development of GOOS to a larger number of qualified applicants.

As stated in *Review of U.S. Planning for the Global Ocean Observing System*, U.S. GOOS efforts should include a provision for the mining of foreign scientists and engineers in U.S. laboratories for future implementation of GOOS in their countries. **Provision should be made for U.S. scientists and engineers to offer training and assistance in foreign countries**.

# 4

# USERS AND BENEFITS OF GOOS

In some cases, products to be distributed to users will be derived directly from Global Ocean Observing System (GOOS) observations (e.g., maps of sea surface temperature or sea surface winds). In other instances, the observations will be combined with non-GOOS data and interpreted based on our understanding of the ocean and the ocean-land-atmosphere system to produce a forecast product (e.g., a prediction of the time and location of algal blooms) that will be distributed to users. For these cases the integration of data from multiple disciplines is necessary and may generate new hypotheses and increased understanding.

Many of the phenomena that adversely impact society and the environment occur as events. Thus, parts of GOOS must be focused on monitoring events as emergent phenomena and subsequent rapid response using the warning time available.

## EXAMPLES OF POTENTIAL GOOS APPLICATIONS

A fully realized GOOS should involve the collection of data, the development of products from those data, and the users of those products and should focus the benefits and beneficiaries. Several end-to-end examples (from data to ultimate users) are given here to facilitate better understanding of the potential for GOOS. For each example the pertinent data to come from GOOS, the initial users, the benefits, and the ultimate users are identified.

Examples of fundamentally different natures were selected for this discussion. Some examples illustrate the many different products, users, and benefits produced directly from one type of data (e.g., sea surface winds and sea surface temperature; see Figure 5). Others are organized to address specific challenges (e.g., safe navigation or coastal hazards) and to illustrate the use of multiple data sets (GOOS with non-GOOS) within existing operational systems to produce multiple benefits. Consequently, the organization of the examples provided below is slightly different for these two groups.

Before predictive capability is proven and operational, researchers will be the users of GOOS data—working to develop models, predictive capabilities,

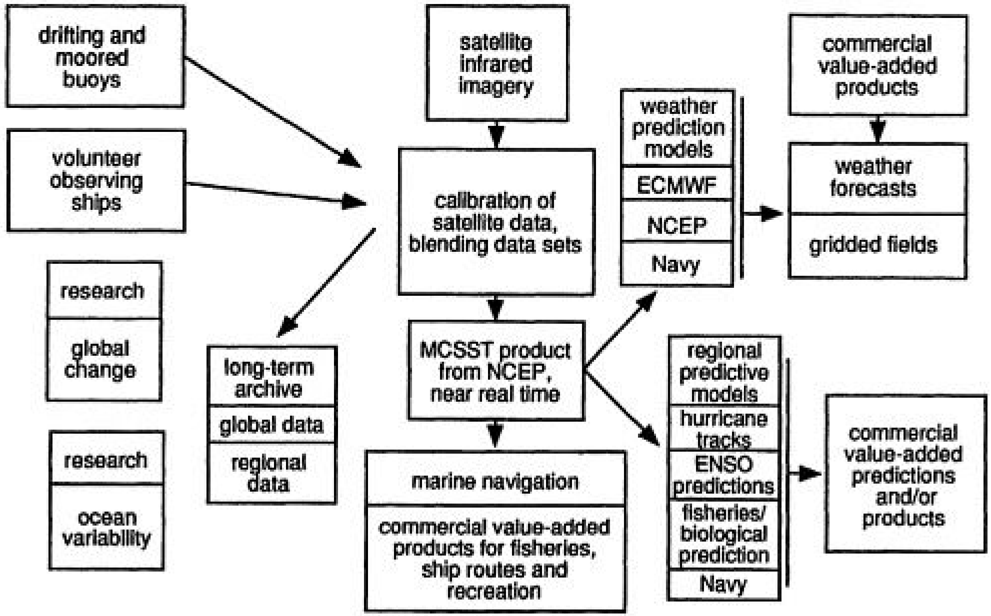


FIGURE 5 Wiring diagram illustrating the relationships and interactions among entities responsible for collection, assimilation, archiving and dissemination of GOOS information related to sea surface temperature and various potential user groups.

and operational products. For example, the capability to predict pollock populations in the northeast Pacific based on ocean temperature, salinities, currents, and predation has been under development and will soon provide fisheries managers with an operational product (Traynor et al., 1990: Traynor and Williams, 1983). In some cases, the research is not yet complete, and the immediate product sought from the use of GOOS data is increased understanding. GOOS data will be used by researchers to develop the analysis methods and models that would add new products and benefits in the future. An example is provided by the need to monitor algal blooms. Improved forecasts of where hurricanes make landfall or alerts of high probability of cholera outbreaks linked to the El Niño/Southern Oscillation phenomenon (ENSO) variability are other examples of products that could be anticipated.

## Surface Winds Over the Ocean

Although this first in the series of end-to-end (data-to-user) examples of GOOS products and benefits may be the most straightforward, sea surface wind (SSW) data represent a very important component of many climate applications. The following example may be the simplest as it describes the development of important products derived directly from GOOS observations.

### Data Users, Products, and Benefits

Examples of the benefits that result from an ocean observing system that provides maps of surface wind speed are provided in Table 1. Each row illustrates an example of the immediate user of SSW data, the nature of the SSW product, the benefits that arise from using the product, and the ultimate beneficiaries.

### Strategy for Improving System

The Volunteer Observing Ship system (VOS) and a limited subset of the moored and drifting buoys provide direct observations of wind. These *in situ* observations can be blended with global observations of wind by satellites, using either active microwave sensors known as scatterometers that look at radiation scattered back from the sea surface or passive microwave sensors.

Commitment to operational continuity of coverage by satellite wind sensors, such as that provided for sea surface temperature by the continuing series of polar orbiting satellites, is needed to ensure ongoing global coverage.

Research will continue to ensure that remotely sensed wind speed is being properly interpreted and accurately converted from the raw observable to wind speed. This requires more accurate direct observations of wind speed. Attention

TABLE 1- Surface Winds Over the Ocean: Data Users, Benefits, and Ultimate Users

| DATA USERS | PRODUCTS | BENEFITS | ULTIMATE USERS |
|---|---|---|---|
| Forecast meteorologists | Regional and global, near real-time reports of direct observations of surface winds by ships and buoys | *In situ* surface wind observations assimilated into numerical weather models, improving their accuracy. Also, they serve as a check on the accuracy of the models, which may miss or underestimate the severity of localized wind events, and provide the basis for warnings to mariners | Users of weather forecasts, particularly those using the sea for transport, fishing, and recreation. |
| Forecast oceanographers | Regional and global, near real-time surface wind fields | Used in conjunction with ocean models and surface wave models, tropical Pacific wind data provide forecasts of surface wave heights, directions, and periods and of surface currents; used in El Niño-Southern Oscillation (ENSO) forecasts. Local winds used for prediction of storm surges, surface currents, and wind waves | Those involved in navigation, fishing, recreation at sea. Those producing maritime safety warnings, alerts of coastal erosion and flooding, maps of surface currents for search and rescue or mitigation of environmental disasters at sea |
| Research meteorologists | Global, near real-time reports of surface winds from ships, buoys, and satellites | Assimilated into global numerical weather models, improving their accuracy | Users of weather forecasts and those using the gridded fields of surface variables and air-sea fluxes produced by weather models |

| DATA USERS | PRODUCTS | BENEFITS | ULTIMATE USERS |
|---|---|---|---|
| Research oceanographers | Many years of sequential, daily tropical Pacific surface wind speed maps available in a data base | Used as the basis for research on the development of improved El Nine-Southern Oscillation (ENSO) predictions and study of how anomalous winds trigger such events, these maps thus lead to improved regional forecasts of weather and climates anomalies, such as those in air temperature and rainfall | Farmers, governments, investors, and managers whose planning would benefit from accurate prediction of temperature and rainfall anomalies up to one year in advance |
| Research oceanographers | Regional and global maps of surface wind, available from a data base, gridded in space and evenly spaced in time | Allows research oceanographers to investigate how the upper ocean is forced by the wind, to compute the wind stress and wind speed dependent heat fluxes (latent and sensible), and work toward modeling and prediction of how the vertical profiles of temperature, velocity, and other properties in the ocean evolve with time | Better understanding of the coupling of the atmosphere and ocean will lead to improved models of atmospheric variability on time scales from days to centuries, benefiting a broad range of users of weather and climate forecasts |
| Research climatologists | Data base of sequential, over tens to hundreds of years, regional and global maps of surface wind speed based on careful analyses of the raw data to remove biases and errors and produce the best possible accuracy and precision | With the ocean covering 70% of the earth's surface and some spatial variability in the global signature of climate change, these maps are needed to look for change in the atmospheric forcing of the ocean and in the air-sea exchanges of beat and moisture in order to understand the ocean's role in global change | Government and private sector planners and managers who need to be aware of long-term change in climate |

should be paid to the quality of VOS wind observations and to developing a broader capability of making wind speed measurements from drifting buoys. One possibility for the latter is through the use of hydrophones to measure ambient noise and the development of algorithms to parameterize wind speed in terms of ambient noise.

## Sea Surface Temperature

One of the most fundamental and useful ocean observations is sea surface temperature (SST). This variable is presently being measured and used in many products for a variety of purposes. Such measurements must be continued and improved as part of GOOS. Following this discussion, other examples that build on SST and SSW (e.g., fish stock assessments, algal bloom predictions, climate-related human health warnings) are discussed to help demonstrate the importance of SST observations as pan of GOOS.

### Data Users, Products, and Benefits

Examples of the benefits that result from an ocean observing system that provides maps of sea surface temperature are provided in Table 2. Each row provides an example of the immediate user of SST data, the nature of the specific SST product, the benefits that arise from using the product, and the ultimate beneficiaries.

### Strategy for Improving System

The present system relies on a mix of direct and remote measurements. Drifting and moored buoys together with volunteer observing ships provide ocean temperatures at or near the sea surface. Polar orbiting satellites collect infrared images (Advanced Very High Resolution Radiometer or AIR) of the temperature of the sea surface, sampling the globe twice a day. The direct buoy and ship observations are used to provide calibration points for the satellite SST measurements, which can be erroneous due to aerosols (e.g., dust from forest fires or ash from volcanic eruptions). In addition, infrared sensors cannot see the ocean surface through clouds, and direct observations become critical in cloudy regions. The present operational SST product uses nighttime satellite data together with direct measurements. Polar orbiting satellites cannot, by sampling only twice a day, adequately sample the diurnal cycle in SST that results from heating of the upper several meters of the ocean by sunlight.

These SST products can be improved by upgrading the accuracy of the direct measurements and by having more such measurements reported from regions that at present are sparsely sampled by ships and buoys. The present

VOS sea surface temperature sensors are less accurate than those on buoys. Upgrades, in the form of the more accurate hull-contact sensors, should be fitted to the VOS. More buoys should be deployed in data-sparse regions. Efforts should also be made to ensure that all platforms (ships and buoys) report their observations. In addition, improvements to the data telemetry hardware and systems are needed.

A major advance over the present observing system would be the development of a system that would sample the SST field many times a day (e.g., every 3 hours). Not only would this resolve the diurnal cycle, but the more frequent views of each location would greatly improve the ability to minimize blockage associated with cloud cover. This could be done by bringing in data from geostationary satellites. Two GOES satellites and GMS5, for example, provide almost global coverage (missing the Indian Ocean) of sea surface temperature every 3 hours, reported to 0.1 deuce C, accurate to approximately 0.5 degree C, at 10 or 30 km spatial resolution.

Further refinements to satellite sensors and methods (e.g., improved ability to deal with atmospheric effects and combination of infrared data with data from microwave sensors that can see through clouds) also are possible. However, because of the potential importance of the diurnal cycle in SST to atmosphere-ocean coupling, improvements to the temporal sampling of SST by the operational system should come first.

Examples in the following sections involve multiple data sets, including SSW or SST, described above. The following discussions are organized to include (1) an overview of the challenge or issue to be addressed with GOOS data and products; (2) a table of related data, data users, and products; (3) the ultimate users and benefits to be derived from GOOS products; and (4) ways to improve or implement the system.

## Coastal Hazard Prediction and Warnings

The population of U.S. coastal zones in 2010 is expected to approach 127 million, a projected increase of 15 million since 1990 (Department of Commerce, 1990). Although recent improvements in hurricane and severe coastal storm forecasting have sharply reduced loss of life, this ongoing shift in U.S. population toward the coastlines will result in increased in risk to property from coastal storms and other geological and marine processes characteristic of coastal settings. Estimates of the present total value of insured property at risk range from $2 trillion (National Research Council, 1994a) to $3.15 trillion (Lewis and Murdock, in press; Institute for Property Loss Reduction and Insurance Research Council, 1995). In addition, millions of people worldwide will remain at risk from rapid-onset events, such as tsunami, where present and future forecasting capabilities may be less effective.

TABLE 2- Sea Surface Temperature: Data Users, Products, Benefits and Ultimate Users

| DATA USERS | PRODUCTS | BENEFITS | ULTIMATE USERS |
|---|---|---|---|
| Forecast meteorologists | Global gridded, 6-hourly sea surface temperature maps available in near real time | Used to initialize numerical weather prediction models, these maps improve the predictions made by these models | Users of weather forecasts |
| Forecast oceanographers | Regional and global, near real-time maps of sea surface temperature | Forecast oceanographers interpret the maps to infer tile location of strong currents, eddies, ocean fronts, and other features and to provide guidance to the fishing industry | Marine transportation users that seek tile most economical ship routes, fisherman, recreational users |
| Research meteorologists and oceanographers | Many years of sequential, daily tropical and mid-latitude Pacific sea surface temperature maps available in a data base | Used as the basis for research on the development of improved El Niño-Southern Oscillation (ENSO) predictions, these maps thus lead to improved regional forecasts of weather and climates anomalies, such as those in air temperature and rainfall | Farmers, governments, investors, and managers whose planning would benefit from accurate prediction of temperature and rainfall anomalies up to one year in advance |

| DATA USERS | PRODUCTS | BENEFITS | ULTIMATE USERS |
|---|---|---|---|
| Research oceanographers | Several months of daily maps of local and regional sea surface temperature fields with sufficient spatial resolution to reveal oceanic features such as coastal currents, eddies, and sea surface temperature fronts, available in near real time and later as a data base | These maps allow research oceanographers to describe, identify, and track the evolution of oceanic features and processes. Of interest are not only physical features such as boundary currents and eddies, but also biological features, such as algal blooms, coral reefs, and biodiversity that depend on upper ocean temperatures | Oceanographers and other scientists interested in the impact of oceanic variability; those studying biological and chemical processes that are impacted by shifts in tile location of currents and regional changes in sea surface temperatures |
| Research climatologists | Data base of sequential, over tens to hundreds of years, regional and global maps of sea surface temperature based on careful analyses of the raw data to remove biases and errors and produce the best possible accuracy and precision | With the ocean covering 70% of the earth's surface and some spatial variability in the global signature of climate change, these maps are needed for assessments of global and regional warming and cooling with improved confidence. In addition, they are used to look for links or teleconnections between sea surface temperature variability and weather arid climate variability at remote locations on land | Government and private sector planners and managers who need to be aware of long-term change in climate. Those interested in predictors of weather and climate variability due to ocean variability other than ENSO |
| Severe storm forecasters | Near real-lime regional maps of sea surface temperature | These maps are needed as the surface boundary condition for atmospheric models used in efforts to improve predictions of cyclogenesis and of cyclone and hurricane tracks | Inhabitants and property owners at risk due to storms and hurricanes, especially those in or near the storm tracks |

Due in part to the costs associated with storm and wave damage, and in pan to the question of who pays and who benefits, the pressure to reduce financial losses caused by natural processes that operate in coastal settings is mounting. The U.S. government is concerned about growing expenditures associated with relief and recovery from coastal disasters (e.g., hurricanes, tsunami, long-term coastal erosion). Momentum is gaining to implement measures that reduce the impact of these processes and that shift a greater amount of the costs of recovery to those individuals and communities who most benefit from development of high-risk coastal areas (e.g., via a restructuring of insurance or other mechanisms).

### Data, Users, and Products

The data needed for effective coastal hazard prediction are diverse. GOOS observations such as wind and sea-level data (for storm surge prediction) will be combined with seismic information (for tsunami prediction) and accurate shoreline characterization to develop accurate predictions and coastal warnings. Historical data will be required for model verification and improvement. Finally, information on land usage (e.g., buildings, roads, power lines, population distributions) will be required to make risk assessments and damage predictions. Depending on the location or problem, data concerning stream flow, sea ice, or ocean currents, for example, also could be required.

| DATA | USERS | PRODUCTS |
|---|---|---|
| • Gridded fields and point measurements of SSW (from GOOS) | • Forecasters | • Costal erosion risk maps |
| | • Coastal and architectural engineers | • Storm surge susceptibility maps |
| • Sea level measurements (from GOOS) | • Modelers | • Coastal flooding risk maps |
| • Sesmic information | | • Public health alerts (e.g., impact of storm surge on local water supplies) |
| • Shoreline sediment characteristics | | |
| • Land usage information | | |

### Ultimate Users and Benefits

The SSW and sea-level data give near-real-time information on sea state (elevation and wave characteristics). When these data are used in a forward model, they provide forecasts of sea state. If combined with non-GOOS data (e.g., distribution of community infrastructure, topographic and bathymetric data) and modeled, a number of valuable derivative products could be made available to a range of user communities:

- **state and local** officials could receive and broadcast advance and real-time warnings of dangers (e.g., flooding, tsunami, severe erosion)
- **coastal managers**, through the use of improved hazard maps derived from modeling GOOS data, could help reduce risk exposure for coastal development
- The **insurance industry** could create more realistic actuarial models by incorporating realistic hazard index maps
- **financial institutions** could encourage sensible coastal development by, for example, basing mortgage rates on risk exposure
- **residents and business owners** could enjoy improved quality of life and long-term financial stability by avoiding high-risk coastal areas.

### Implementation Strategy

First, existing historical knowledge (e.g., surf zone conditions, hurricane probabilities, seismic data, ice data) should be used to assess the sorts of coastal hazards likely to occur along given coastal segments. For each segment, bathymetric charts and land topographic charts should be reviewed, made consistent, digitized, and improved. Further, land-usage patterns should be characterized and ocean and atmospheric data requirements assessed, both in terms of sufficiency for local characterization and adequacy for modeling. Coastal hazards (e.g., flooding, ice damage, erosion) models then must be tested, improved, and made operational. The model predictions and observations must then be made readily available and easy to interpret. Finally, continued system performance evaluation and system improvements are essential.

## Improved Navigational Systems

In 1991 the National Oceanic and Atmospheric Administration (NOAA) introduced its first physical oceanographic real-time system (PORTS) applied to a U.S. seaport. This system is intended to acquire data, make analyses and predictions, and disseminate information regarding water level, currents, and other selected oceanographic and meteorological data in real tune to maritime users. Expanding these systems would provide important navigational data and forecasts, greatly reducing transportation costs and improving safety.

### Data, Users, and Products

Unlike some other GOOS data sets, data for improving navigational systems would be tied to specific coastal, harbor, or marine installations.

| DATA | USERS | PRODUCTS |
| --- | --- | --- |
| • SSW fields | • Operational ocean forecasters | • Real-time water level and currents |
| • Tide gauge heights | | |
| • Current velocities | | • Forecasts of water level and currents |

These data and derived products are combined with highly accurate electronic navigation charts (where available) to develop the overall navigation system.

### Ultimate Users and Benefits

Providing easy access to these products could result in a number of benefits for **ship captains and owners, harbor pilots**, and **port authorities**:

- increased access to more precise bathymetric and water-level data
- decreased likelihood of grounding
- decreased need for unnecessary lightering, increased competitiveness of deep draft vessels, and increased transportation efficiency

By decreasing the likelihood of ship grounding, deep draft vessels can take on greater loads and become more competitive. **Transportation brokers** can schedule ship time more effectively. By increasing the pool of competitive cargo vessels, transportation costs can be lowered, resulting in decreased costs to consumers. In addition, resource extraction and manufacturing in some areas is limited by access to worldwide trade by lack of adequate ports. Improved tide information may make marginal ports more accessible.

### Strategies for Improving the System

PORTS has been successful in the limited number of harbors in which it has been installed. This experience suggests that the system could be improved and its capabilities expanded by including (1) widely distributed acoustic Doppler profilers and anemometers (coupled with packet radio transmitters), (2) a data acquisition system, (3) improved models, and (4) an information dissemination system. To obtain the maximum benefit from this system, similar systems would need to be installed worldwide in shipping centers with limited harbor access.

## Improved Fish Stock Assessments

The techniques of fishery stock assessment are well developed (e.g., Hilborn and Walters, 1992). One can conceptually summarize the procedure as following a cohort of newly spawned larval fish as they mature, taking into account the losses that such a cohort experiences through predation and advection away from areas conducive to maturation. GOOS activities should be expected to collect the hydrographic and biological abundance data.

### Data, Users, and Products

Although these techniques would not be truly new or unique to GOOS, the collation of data collected over relatively short time periods from around the world would provide a useful data set for improving global stock assessments.

| DATA | USERS | PRODUCTS |
|---|---|---|
| • Standard hydrographic data (e.g., SST, current velocities)<br>• Biological information regarding the abundance of the larval stages of the fish populations<br>• Biological information regarding abundance of the predators on these same larval stages | • Fishery scientists and managers | • Indices of advective losses from the population<br><br>• Expected range of fish abundance |

### Benefits and Ultimate Users

Using validated circulation models, hydrographic information collected in spawning areas can be assimilated into the models, and indices of advective losses from the population can be obtained. Once such indices are available, they can be used with standard stock assessment techniques plus estimates of mortality due to predation on the larval stages to determine the expected range of fish abundance from the newly spawned larvae. Such a system could have specific benefits:

- better knowledge of year-class abundance will allow **fishery managers** to make better-informed stock management decisions—an important and necessary step in sustaining most fish populations
- by improving the management of fish stocks, **consumers** will benefit directly by gaining access to better quality and a great variety of seafood
- greater variety and product quality should lead to increased market competition and savings for **consumers**

### Strategy for Improving System

Though space does not permit a complete enumeration of the details of stock assessment techniques, the general notions cited above are now used operationally to manage the important wail-eyed pollock stock found in the western Gulf of Alaska (Traynor et al., 1990; Traynor and Williams, 1983). Currently, the indices of advection are only *qualitative* (e.g., "large," "medium," or "small"). Longer data series, coupled with more thoroughly tested transport models, will allow the incorporation of *quantitative* estimates of advection and, accordingly, better abundance estimates. Equally important are measurements of the larval-stage abundance. A thoughtfully focused LMR module will aim to collect such larval data. Long and reliable data series of larval stage abundance —hopefully a product from GOOS activities—could prove invaluable to many fishery stock assessments.

## Prediction of Algal Blooms in Coastal Regions

Several locations in the coastal United States are subject to sporadic blooms of harmful or "nuisance" algae. These blooms can (a) introduce toxins into the marine food chain, (b) overwhelm "normal" ecosystem structures through hypoxic conditions, and (c) form a reservoir for bacteria such as cholera (Colwell, 1991; Epstein, 1993). There are indications that the frequency of such events is increasing globally in response to increased coastal development and changes in nutrient supply and climate. However, in most cases our understanding of the factors that initiate such blooms is limited and insufficient to allow prediction or the rational design of mitigation strategies. Remote sensing of ocean color as part of GOOS could help target sampling for noxious species, red tides, and other algal blooms.

One case study is the brown tide bloom that occurs in the bays of Eastern Long Island, which has had major impacts on seagrass beds and the scallop industry on Long Island. In this case a 10-year time series of water quality observations coupled with other long time-series data sets is now revealing the factors leading to bloom initiation. On the basis of these data, it appears that brown tide blooms may be predicted with lead times of several months—sufficient time to guide the decisionmaking management process.

### Data, Users, and Products

Many of these parameters important for algal bloom prediction can be measured routinely by *in situ* automated systems and are appropriate for immediate implementation. Others require labor-intensive sampling and analyses (for these cases, improved technology should be sought). Data requirements for bloom prediction will vary somewhat from region to region. Note that the requirements are site specific; other regions and algal blooms may require a different set of measurements (e.g., remote sensing and information on coastal advection).

| DATA | USERS | PRODUCTS |
|---|---|---|
| • S ST (from GOOS) | • State and local government officials | Improved understanding |
| • Salinity (from GOOS) | | |
| • Dissolved oxygen (from GOOS) | | • Predictions of algal blooms |
| • Chlorophyll fluorescence (from GOOS) | • Academic community | |
| • Inorganic nutrients (N, P, Si) (from GOOS) | | |
| • Organic nutrients (N, P) (from GOOS) | | |
| • Algal species composition | | |
| • Cell counts | | |
| • Meteorological parameters | | |
| • Groundwater flow and associated nutrient loading | | |
| • Point-source nutrient inputs | | |

Related non-GOOS parameters are normally collected and archived under existing federal and local programs, separate from GOOS. As in the case discussing the role of GOOS data in coastal hazard predictions, they must be integrated with GOOS data to derive the desired products and maximum benefit.

The initial product of time-series monitoring will normally be the establishment of scientific understanding concerning the factors associated with algal bloom initiation. Such information will usually need to be supplemented by non-GOOS research aimed at providing mechanistic understanding. Bloom initiation as a result of environmental factors should be predictable in many cases, and such predictions are an ultimate "product" of a coastal GOOS observing system.

### Ultimate Users and Benefits

In the Long Island bays, significant cost and effort are expended on reseeding of juvenile scallops. Such effort has been rendered ineffective on several occasions as a result of subsequent brown tide occurrences. Predictive ability would permit decisions to be made concerning the likely success of such efforts. In addition, such a complex use of GOOS data would have other benefits to ultimate users:

- improved **local community** water quality
- enhanced **tourism and recreation industry**
- enhanced **commercial and recreational fishing**

## Climate Forecasts and Health Warnings

Dengue ("breakbone") fever (DF) is caused by a virus (in the yellow fever family) transmitted by the mosquito *Aedes aegypti*. The illness is severe and can last up to 2 weeks; most eases are not fatal. Two severe and potentially fatal forms, dengue hemmoragic fever (DHF) and dengue shock syndrome (DSS), may result when individuals are infected sequentially by more than one of the few virus strains.

Dengue fever occurs in poor, periurban populations (i.e., populations in and adjacent to cities) with inadequate sanitation and ubiquitous small receptacles where mosquitoes can breed. Large epidemics are often precipitated by extreme weather events, especially involving warm, wet, overcast conditions. However, in some situations, drought is a precipitating factor when streams cease to flow and form pools.

Dengue fever epidemics can involve large health costs but can also affect productivity and tourism. Early warning of meteorological conditions conducive to outbreaks can permit timely intervention of preventive public health measures.

El Niño/Southern Oscillation phenomenon (ENSO) conditions are closely correlated with DF outbreaks in Central America, the Caribbean, Brazil, and Southeast Asia.

## Data, Users, and Products

| DATA | USERS | PRODUCTS |
| --- | --- | --- |
| • SST | • Forecasters | • Long-term weather predictions (seasonal) |
| • Water column temperature | • Modelers (dynamic and statistical) | • Early warning of weather conditions favoring increased mosquito breeding and reproduction |
| • SSW | | |
| • Sea-level data | | |

## Ultimate Users and Benefits

Understanding of ENSO has reached the level of maturity at which prediction of El Niño or La Niña some 6 months in advance is possible with some skill. Improvements in that predictive skill and in the ability to forecast resulting long-term weather patterns globally are needed. The GOOS observing system has this as a specific objective.

Products would be used by public health authorities and services; the ultimate beneficiaries are populations. Public health warnings may be issued centrally and distributed to national ministries of health through the preventive health divisions of the U.S. Centers for Disease Control and Prevention (CDC), the World Health Organization (WHO), and the Pan American Health Organization (PAHO).

In addition, international relief, development, agricultural and health organizations could benefit from climate forecasts and function as partners (e.g., the International Red Cross, United Nations High Commission on Refugees, World Bank, Global Environmental Faculty, and the Food and Agriculture Organizations).

Improved forecasting of seasonal or interannual climate variations would greatly benefit local health and government officials in preparation for potential outbreaks of dengue fever. Specifically, improved predictions would facilitate timely efforts to:

- clean up of peridomestic breeding sites (nonbiodegradable containers)
- introduce carnivorous fish to ponds

- apply larvicidal bacteria (*Bacillus thuringiensis isrealiensis*—BTI), innocuous to humans, to breeding sites
- target use of chemical larvicides and pesticides

By enabling government officials to take the timely efforts listed above, GOOS will result in a number of ultimate benefits, including:

- improved health warnings that allow time for mitigation of negative effects
- improved public health and decreased mortality
- enhanced quality of life
- decreased costs for relief efforts
- enhanced productivity due to reduced incidences of illness

## COST-BENEFIT STUDIES

Implementation of GOOS will be expensive. As discussed earlier in this chapter, its aim is to provide products that benefit society. If society is to be convinced that GOOS is a worthwhile endeavor, efforts must be made to estimate the economic and societal benefits to be had from the eventual system. Cost-benefit analyses can provide guidance as to which efforts are worth pursuing, with what priority, with what objectives, and at what level. Furthermore, careful cost-benefit studies are important tools for convincing decisionmakers that GOOS efforts should be funded.

Funding was not provided to allow the committee to undertake cost-benefit studies on its own. Below are some examples of human and economic costs that could be mitigated with the kind of information GOOS could provide.

### Enso Effects On Agribusiness

Climate and decisions based on expectations about climate, affect the economies of the world (Sassone, 1997). Understanding the ways in which climate affects agribusiness, and subsequently the economy, should be a priority. Agriculture in the United States is becoming an increasingly sophisticated industry, relying heavily on technology. Though they differ from more traditional types of agricultural technologies, climate research and forecasting programs are becoming socially and economically beneficial.

The occurrence of the ENSO phenomenon can result in substantial economic and social losses for agricultural businesses in the United States and worldwide. Through the Tropical Oceans and Global Atmosphere (TOGA) program, a 10-year international study established to understand ENSO, scientists have learned to predict ENSO events as much as a year in advance with modest success. Climate prediction of this sort relies on models based on scientific understanding of atmosphere and ocean dynamics and interactions and on an extensive data-gathering system. These models are developed through research involving detailed and long-term *in situ* measurements of climate variables (e.g., sea surface temperature, sea surface winds, subsurface temperature and currents, sea-level measurement) and through modeling. The data-gathering system involves air, water, and land-based instruments, reaching across much of the globe. Both the development of the climate module and their subsequent operation involve significant costs (Sassone, 1997).

The economic and social value of this type of climate forecasting depends on the accuracy of predictions and the rate of forecast acceptance by farmers and other business owners. Cost-benefit analyses (Adams et al., 1995) of TOGA and the ENSO forecasting system predicted an annual economic return on investment (commonly referred to as the Internal Rate of Return [IRR]) for agribusiness that ranged from 13 to 26 percent of the annual cost (in 1995 U.S. dollars, this translates to an annual estimated return of $96 to $145 million for the southeastern United States, and $240 to $266 million for the entire U.S. agricultural sector). Based on a farmer acceptance of 50 percent that grows to 95 percent over a six-year period, these rates are substantially higher than the federal government's recommended internal rate of return of 7 percent (the Office of Management and Budget recommends that projects demonstrate an IRR greater than 7 percent to be considered cost-effective (oral communication, R. Weiher, Chief Economist, NOAA). If the cost-benefit analysis is modified to reflect a lower rate of acceptance than those of the scenarios presented above, the actual annual return is about 7 percent. This analysis suggests that improving ENSO forecasts is economically worthwhile, though greater participation (i.e., acceptance) by farmers translates into greater savings.

This example also points out that evaluation of the benefits of GOOS observations and derivative products must take into account both the quality of the observations or products *and the* acceptance and rate of use of those products. To realize full benefit, society would need to incorporate GOOS products/results into decisionmaking processes. By using GOOS products to determine whether the next growing season will be wetter or drier or warmer or cooler than average, farmers will be able to adjust their planting strategy to take advantage of this information (Sassone, 1997). In return, consistently accurate forecasts will encourage widespread societal implementation of GOOS products.

### Amnesiac Shellfish Poisoning: Prince Edward Island, Canada, 1987

The year 1987 was an El Niño year, and there was an associated series of adverse events in marine fauna and flora along the U.S. Atlantic Coast, including

(1) extensive coral bleaching in the Caribbean; (2) a large die-off of seagrass off Florida; (3) movement of *Gymnodinium breve* (causing Neurological Shellfish Poisoning) from the Gulf of Mexico to Cape Hatteras, North Carolina; (4) dolphin and whale die-offs off Cape Cod and in the North Sea in 1988; and (5) the appearance of amnesiac shellfish poisoning (a "new disease") in Prince Edward Island.

The outbreak in Prince Edward Island was the first outbreak of shellfish poisoning due to a diatom-related biotoxin recorded in Canada, The episodes of amnesiac shellfish poisoning were attributed to consumption of cultured mussels from Prince Edward Island. Domoic acid originating from *Nitschia pungens f. mutiseries* was responsible for at least 145 cases of short-term amnesia, and some permanent amnesia, and three deaths. Prior to this event, warm Gulf Stream rings were found close to shore (resulting in elevated sea surface temperatures), and intense rains increased runoff, which elevated nutrient levels near Prince Edward Island.

**BOX 4 COST ESTIMATE OF THE OUTBREAK OF AMNESIAC SHELLFISH POISONING, PRINCE EDWARD ISLAND, 1987**

| | |
|---|---|
| A. Human Toll | |
| 145 cases | |
| 3 deaths | |
| B. Economic Costs (Cambella & Todd, 1993) | In thousands of $ |
| I. Health-related | |
| a Health: medical care & hospitalization | 2,012 |
| b Deaths: valued at (@ 300,000 each) | 900 |
| c Lost productivity, leisure time | 87 |
| II. Market research | |
| a Research, recall and investigation | 1,600 |
| b Seafood industry | 4,364 |
| Total | $8,363 |
| Subsequent monitoring costs: | $1,360 |

Source: Cambella and Todd (1993).

Although the precise role that extreme weather and elevated sea surface temperatures played in generating this series of adverse events is unclear and costs for initial outbreaks tend to be unusually high, forecasting of similar changes could help target surveillance and improve readiness. In addition, such observations could address questions regarding the overall role of ocean warming and its potential consequences in terms of adverse events related to the marine environment. An observing system for adverse events could better inform policymakers on (a) choosing sentinel coastal sites to monitor, (b) evaluating the ecological and global contributions to impacts and consequences, and (c) determining measures with which to better analyze costs of global change.

## Coastal Forecasts

Kite-Powell et al. (1994) examined the potential benefits of improved coastal forecasts. As envisioned in their study, an improved system would make better use of wind, current, sea level, and remote sensing information (of the type expected from GOOS) to derive real-time and forecast models of winds and currents over the continental shelf. The system would include a physical oceanographic real-time system (PORTS) as implemented by NOAA (discussed earlier in this chapter). A number of potential beneficiaries were identified, ranging from small, localized organizations in the recreational boating and fishing industry to large commercial shipping and offshore drilling companies. The commercial fishing industry also was identified as a major beneficiary of coastal forecast dam, as were the military and local marine search and rescue operations.

Kite-Powell, et al. also reviewed the potential value of improved coastal forecasts to this range of possible beneficiaries. A series of cases was examined in which each case represented an alternate outcome associated with a particular decision. The calculations were made to reflect likely outcomes based on decisions made in response to coastal forecasts. These potential responses and their likely outcomes were then aggregated to determine the overall value of coastal forecasts.

For example, the Kite-Powell, et al. study suggests that the value of improved coastal forecasts to the commercial fishing fleet (just one subset of possible beneficiaries) would be considerable. Figure 6 illustrates the approach used to estimate the value of more accurate forecasts to a subset of the fishing fleet by comparing the value of payoff determined for a baseline scenario to one in which the accuracy of forecasts was improved. Comparison of the two cases suggested chat improved coastal forecasts could result in an increased payoff of $1.6 million a year. By aggregating similar estimates for many beneficiary groups, the report indicates that improving the coastal forecast system could result in a savings of tens of millions of dollars a year as the result of an

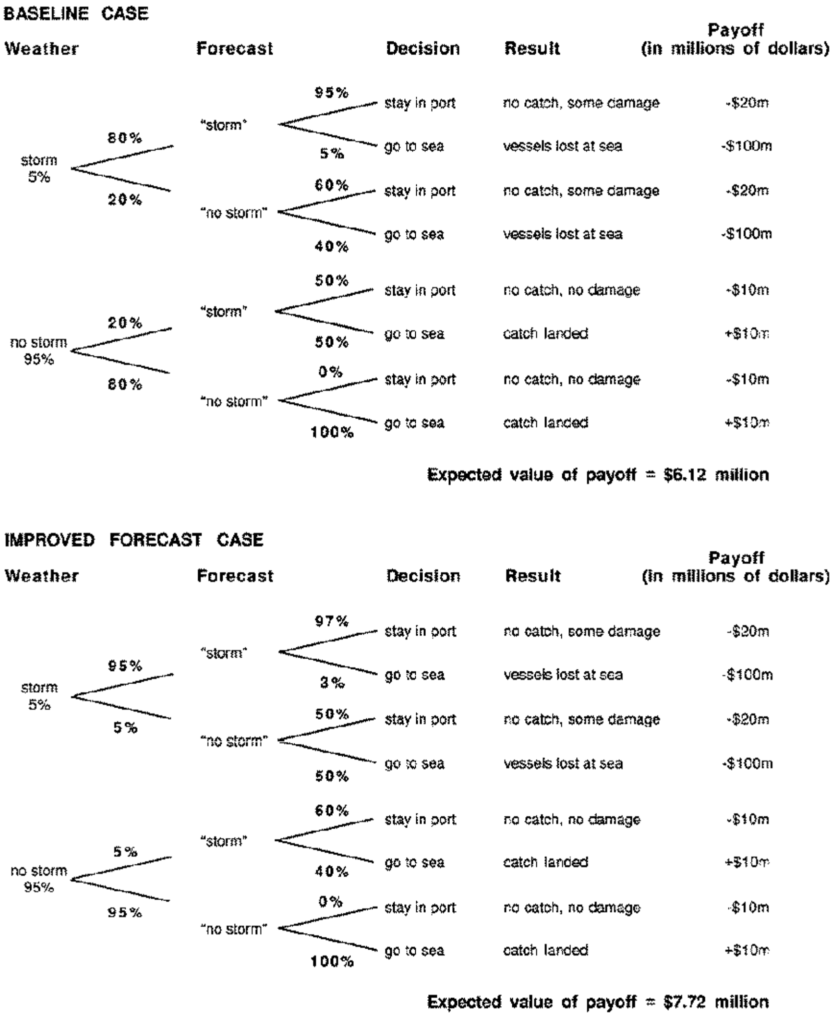


FIGURE 6
Logic diagram for two scenarios used in cost-benefit analysis of improved coastal weather forecasts and their value to the fishing industry by Kite-Powell et al. (1994).

investment of about $4 million a year. It thus seems likely that a coastal forecast system could represent a worthwhile GOOS-related effort.

# 5

# DEVELOPING GOOS IN THE SPIRIT OF PARTNERSHIP

The establishment of government/research/private-sector partnerships will be critical for the development and long-term success of the Global Ocean Observing System (GOOS). There are useful examples of active partnerships of this nature in other fields (e.g., the establishment and maintenance of a global monitoring network for atmospheric chlorofluorocarbons by the Chemical Manufacturers Association).

An ongoing effort is required to identify the users and potential customers for GOOS products and services and to educate them about the benefits that could accrue. For the Marine Navigation and Coastal Hazards themes of coastal GOOS in the United States, considerable progress has already been made, which should be translated to the other themes of U.S. GOOS.

## THE CONCEPT

As discussed in the 1992 National Research Council (NRC) report, *Oceanography in the Next Decade: Building New Partnerships, the* United States is faced with many pressing problems that would benefit from increased cooperation among government agencies, academia, and the private sector. The most commonly cited example of such a cross-cutting problem is global climate change. Successful policymaking regarding global change will be based on an adequate understanding of the earth and its systems. That understanding will be provided by collective and cooperative efforts among government agencies, academia, and the private sector. Many other challenges facing our nation and the world would benefit greatly by the type of partnerships being developed to address global climate change. A few of these successful partnerships are discussed below and are organized to reflect their ties to GOOS observations or challenges discussed in Chapter 4—Users and Benefits of GOOS.

## EXAMPLES

### Surface Winds

As discussed in Chapter 4, sea surface wind (SSW) products are produced from data collected from both private and government sources. Presently, basic products come from government centers, in the form of maps of SSW and digital data. An additional set of products is produced by companies in the private sector in an attempt to meet the needs of specific users.

Direct observations of wind and barometric pressure (the spatial gradients of surface pressure can be used to estimate the surface and wind) come from buoys and ships; additional remote measurements come from satellite sensors. The government maintains buoys along the coasts and some drifting buoys in the open ocean, while research programs deploy the majority of the open-ocean moored and drifting buoys. Commercial shipping participates in the Volunteer Observing Ship (VOS) system, where weather observations are collected at sea. In recent years active and passive microwave sensors on satellites launched by the United States, Japan, and other countries have provided the ability to remotely measure the surface roughness of the ocean, which is then used to estimate the surface wind.

The majority of direct wind and pressure observations and, recently, satellite wind estimates are sent in near real time via government-funded communications links to forecast centers and then are used to produce maps to the present wind field and predictions of future wind fields. Short-range forecast maps are produced, for example, for 12, 24, 36, and 72 hours into the future by some centers. Private, government, and research users use these maps to produce further products. Typically, additional interpretation and analysis are done by commercial firms to address a customer's specific needs. For example, Ocean Routes, Inc., uses wind fields to estimate wave heights and those wave heights, and winds are used to determine optimum rates for commercial shipping. Surface winds in the tropical Pacific provide another example; they are one of the key inputs to ENSO prediction models whose products, as discussed in Chapter 4, would benefit public and private sectors.

### Physical Oceanographic Real-Time Systems (Ports)

In 1991 the National Oceanic and Atmospheric Administration (NOAA) introduced its first physical oceanographic real-time system (PORTS). As discussed in Chapter 4, PORTS is a data acquisition and dissemination system that provides analyses of water level, currents and other selected oceanographic and meteorological data as well as forecasts on a real-time basis to maritime users.

The system not only enhances safety but also provides information to increase the economic benefits to ports, shippers, and carriers by providing current, accurate information on channel depths and currents. Using real-time information, carriers can time their arrivals and departures to maximize their loads and efficiently utilize port facilities.

From a safety perspective, the real-time information gives ships' officers and pilots exact information about tides, currents, and wind which can be factored into the decisionmaking process when navigating a vessel through a harbor. Prior to PORTS, the information was gathered by word of mouth, historical information, or exploration.

PORTS was developed and continues to be improved through partnerships. These partnerships are composed of NOAA, port authorities, and various pilot organizations. The partnerships have been successful because NOAA had a need to improve its discovery of the data, and industry needed more timely and accurate information for both safety and economic progress.

PORTS is now installed in four port complexes: Tampa Bay, Houston-Galveston, New York and New Jersey, and San Francisco Bay. This system is an excellent example of how oceanographic data can be applied to practical uses for the safety. of ship navigation and the economic benefit of shippers.

### The California Cooperative Fisheries Investigations

The University of California Cooperative Fisheries Investigations (CalCOFI) program is a consortium of state and federal agencies (including the University of California at San Diego) that supports the efforts of scientists who conduct integrated oceanographic research of the California Current. A unique aspect of the program is that it is partially funded by ultimate users (i.e., through state taxes on commercial fishery products). In addition, non-CalCOFI scientists conducting research sponsored by the Office of Naval Research and the National Science Foundation may participate in CalCOFI cruises. The data collected by these additional scientists while conducting their independent research supplements the standard CalCOFI data set. Consequently, ship resources are maximized to produce a detailed and robust description of the CalCOFI study area.

The CalCOFI program was established in 1949 to investigate factors causing the collapse of the sardine fishery off California, but over the years the scope of its research has broadened. The CalCOFI effort has produced a long-term picture of the oceanography of a 250,000-square-mile area of the Pacific Ocean off California and Baja California. The CalCOFI program has produced one of the best long-term examples of oceanographic data sets and the study area in the California Current. This is one of the few regions for which there is a long time series of archived plankton and larval fish samples. The CalCOFI program sponsors quarterly surveys of 68 stations south of 35ºN. The current sampling pattern has been used since 1985; however, prior to 1985, a larger region was sampled.

## Algal Blooms

The establishment of routine, long-term, geographically widespread systems designed to help prediction of harmful or "nuisance" algal blooms will require a broad spectrum of partners acting as data providers, data users, and customers. In contrast with some other GOOS activities (e.g., development and production of climate-related products), non-GOOS as well as GOOS data streams will be required to produce useful products, such as bloom predictions considered.

The nature of partnerships involved in this problem is illustrated in Figure 7. In the case of the Long Island brown tide, partnerships are being established to address the problem. The motivation for tackling this problem was rooted in a request from the local community and local business organizations to identify and mitigate the factors causing brown tide blooms. The local county government established a biweekly water quality monitoring program in the affected areas that has been operating now for 11 years. Various more specialized research activities have been supported at regional universities in order to gain understanding of the conditions and organisms responsible for the blooms. These studies have been supported variously by local, state, and federal agencies.

More recently, the local county government has entered into a partnership with a nearby federal laboratory (Brookhaven National Laboratory). This partnership allows expertise and technologies developed by the Department of Energy, to be applied to this regional problem. For example, an *in situ* observing system designed to collect and transmit continuous measurements of T, S, 02 and chlorophyll back to shore has been deployed. Plans to have the county maintain and operate the system are under discussion. NOAA is now sponsoring a concerted research effort by the academic community into brown tide causation, and brown tide research is supported as part of the Peconice Estuary Program (a pan of the Environmental Protection Agency's National Estuary Program).

The challenges associated with brown tide have resulted in the emergence of a partnership that has increased understanding, which can be translated into productive capability. Coastal GOOS could play an important role in stimulating partnerships tackling similar problems in other regions nationwide and worldwide.

These examples of partnerships also demonstrate the need to develop coordinated observation systems within GOOS and GTOS to monitor the consequences of human activities and natural variability. One aspect of this

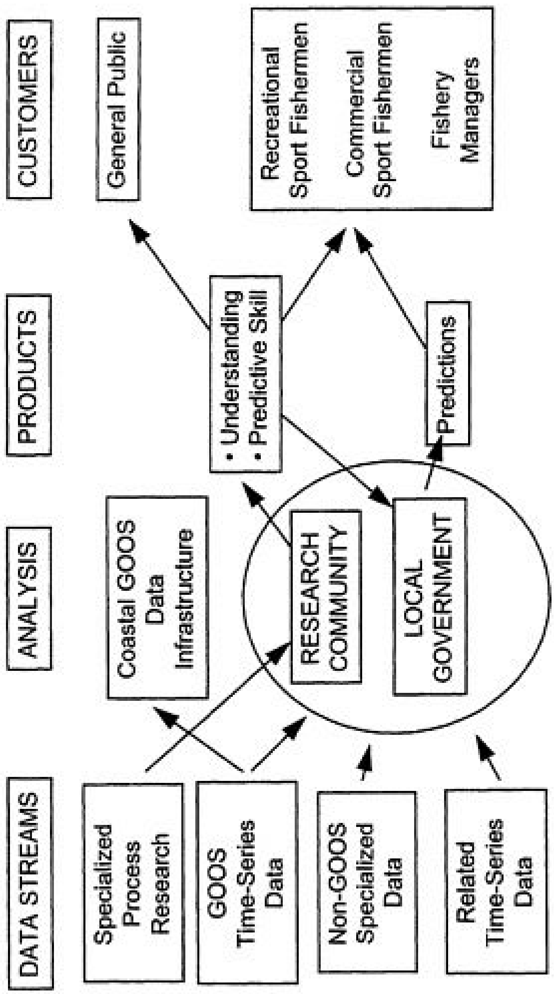


FIGURE 7
Wiring diagram illustrating the relationships and interactions among entities responsible for the collection, assimilation, archiving, dissemination of GOOS information and various users of predictions of algal blooms.

could include mapping of adverse and disease events in coastal zones and their impacts on floral and faunal taxa (e.g., algae, seagrass, shellfish, finfish, invertebrates, coral reefs, sea birds, sea mammals). An observing system for adverse events could be beneficial in (a) determining local ecological causes (eutrophication) and global factors (warm sea surface temperatures); (b) identifying spatial "hotspots" and temporal signals (e.g., El Niño/Southern Oscillation); and (c) helping derive economic damages ("costs") of change in global and regional systems.

# 6

# PRIORITIES FOR U.S. GOOS ACTIVITIES

Many ocean observations are in a state of transition. Investments in repeat expendable bathythermograph (XBT) sections by the U.S. Navy have been reevaluated and shifted to the National Oceanic and Atmospheric Administration (NOAA). Long-running research programs (e.g., the World Oceans Circulation Experiment [WOCE], Tropical Oceans and Global Atmosphere [TOGA], and Joint Global Ocean Flux Study [JGOFS]) are finishing, and operational funding for continuing some of their observations as part of the Global Ocean Observing System (GOOS) has not been forthcoming. In some cases, long-running time-series stations are threatened by lack of support in the near future. Because of the uncertain status of many observations, it is critical that GOOS move forward in a timely manner and act wisely to establish its priorities. In doing so, the United States should act in consideration not only of users and benefits in this nation but also its potential leadership role in building a truly global observing system.

## PRIORITIES FOR OBSERVATIONS

Planning for the climate module is well advanced, and initial prioritization of GOOS activities has been made. The Health of the Ocean (HOTO) module also has advanced to the point that several activities of high priority to GOOS are identified. **As recommended in Chapter 3, the U.S. GOOS Interagency *ad hoc* Working Group (U.S. GOOS IWG), in concert with the agencies, should select a small number of major efforts of highest priority for immediate implementation**.

As discussed earlier, some potential U.S. GOOS activities are already under way through single or multiagency efforts and need only modest expansion plus national identification as a high-priority component of U.S. GOOS. These efforts have been thoroughly reviewed and are generally anticipated to become part of U.S. and international GOOS at some time.

Successful and useful predictions depend on adequate monitoring. **The committee agrees with the 1994 National Research Council (NRC) report, *Review of U.S. Planning for the Global Ocean Observing System*, and repeats**

**its recommendation that the United States take a leadership role in GOOS by**:

- **Converting relevant parts of the TOGA research observing system to operational status**
- **Maintaining and improving global measurements of absolute and relative sea level, surface wind stress, sea ice extent and concentration, and continuation of satellite altimetry missions**
- **Maintaining and improving the monitoring of global sea surface temperatures and salinities, upper-ocean thermal and salinity structure, and temperature and salinity structure at select deep-ocean sites**
- **Identifying and committing resources to a selected set of time-series stations and programs, as "permanent" sections, stations, and moored and drifting instrument deployments to be repeated over the long term both in and out of the tropics**
- **Fully implementing the International Mussel Watch**
- **Supporting ongoing efforts to determine the health of coral reefs worldwide such as the United Nations sponsored Global Coral Reef Monitoring Network (GMRMZN**)
- **Proceeding with site selection and establishment of initial estuarine and coastal index sites for coastal U.S. GOOS implementation**
- **Supporting the acquisition and processing of satellite ocean color data**

A key goal of GOOS is to compile, assess, and utilize long records of high quality. It is critical that adequate provision be made for the quality control and archiving of GOOS data. Moreover, many of the products produced from these data sets have long-term value and likewise should be archived.

In its initial phase GOOS will draw from existing observational networks that already have the necessary infrastructure for quality control and data management. **Attention should focus initially on making data readily and reliably available to users. As GOOS continues to grow (i.e., as new observations are added), attention should be paid to archiving and ensuring the availability of the data**.

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# APPENDIXES

# APPENDIX A
## Letter of Request

**UNITED STATES DEPARTMENT OF COMMERCE National Oceario and Atmospheric Administratreton NATIONAL OCEAN SERVICE Office of Ocean and Earth Soarces Siver Sorre Meryenc 20810**

September 28, 1994

Dr. Robert White
Vice-Chairman.
National Research Council
2101 Constitution Ave. NW Washington, D.C. 20418

Dear Dr. White:

The U.S. GOOS interagency *ad hoc* Working Group is very. pleased with the report of the recent NAS/NRC Committee :o Review Plans for a Global Ocean Observing System (GOOS;. We particularly appreciate :he timeliness of the report:, which allows us :o begin quickly :o address the *recommendations*.

The Working Group has considered the recommendation for a mechanism to provide review and advice in the further development and implementation of GOOS and for the need to formalize Interactions with the industrial/ commercial sector. we also are particularly interested in assistance in further articulating the operational concept of GOOS and the products, services, and mechanisms for data and product dissemination to accomplish these objectives. We wash to consider a follow on to the earlier multi-Board Committee established at the request of Under Secretary Baker to provide advice explicitly to the agencies involved (including NSF, NASA, Navy, EPA, DOE, USGS, MMS, ARPA, and State, as well as NOAA). We seek continuing input. advice, review, and help on all aspects of GOOS, but are not clear on the NRC's role in defining the industrial and operational aspects.

We would appreciate receiving a proposal and budget for FY95 for a onetime project, perhaps led by the Ocean Studies Board, but composed of NAS/NRC representatives of all relevant Board who can provide both scientific advice and the requisite linkage with industry and operations and users. Financial support would be available in FY95 for the work of this multi-Board Committee. One aspect of this effort, which should be completed by June 30, 1995, is to help us define the mechanism for continued broad advice and review.

Priority areas for U.S. GOOS in FY95 are listed below. Your proposal should describe approaches to be followed and anticipated products to be provided which reflect a focus on these activities.

- Formulating a GOOS operational concept and its relationship to existing institutions and their current and planned ocean activities
- From the *NAS/NRC* list of proposed activities recommended for implementation. selecting a feasible subset for immediate attention
- Developing Industry and Academic roles in GOOS, including priorities for research, technology development, and advocacy

I look forward to hearing from you soon.

Sincerely.

M.G. Briscoe
Chairman.
Interagency ad hoc Working Group for GOOS

# APPENDIX B

# Committee Roster

**Worth D. Nowlin** received his Ph.D. in physical oceanography from Texas A&M University in 1966 and has since held positions with the Office of Naval Research, National Science Foundation, and Texas A&M University. Dr. Nowlin is currently vice president of the Texas Institute of Oceanography, director of the Texas Center for Climate Studies, and a distinguished professor. His research interests include mesoscale and large-scale oceanic distributions of properties, dynamics of ocean circulation, shelf oceanography, systematic observations for climate studies, and research planning and management.

**Jerry Aspland** received an M.B.A. from California State University, Long Beach, in 1971 and holds an Unlimited Master's License from the U.S. Merchant Marine. Mr. Aspland recently retired as president of ARCO Marine, Inc. (AMI), a subsidiary of the Atlantic Richfield Company (ARCO). As president, he was responsible for AMI's tanker fleet and for the effective transportation of ARCO crude oil worldwide. Mr. Aspland was recently named president of the California Maritime Academy.

**Kenneth Brink** earned a Ph.D. in geology and geophysics in 1977 from Yale University. Dr. Brink has been a scientist at the Woods Hole Oceanographic Institution since 1980. He is presently on the editorial board of a number of journals related to physical oceanography. Dr. Brink also serves as chairman of the Ocean Studies Board. His research interests include coastal trapped waves, shelf dynamics, and coastal upwelling.

**Paul Epstein** earned an M.D. from Albert Einstein College of Medicine in 1969 and an M.P.H. in tropical public health from the Harvard School of Public Health in 1983. Dr. Epstein is presently on the staff of the Harvard School of Public Health. His professional interests include the role of the marine environment and the potential impact of global change on public health.

**John Flipse** holds deuces from New York University and the Massachusetts Institute of Technology. Mr. Flipse recently retired from his position as director of the Offshore Technology and Research Center at Texas A&M University, and is presently professor emeritus. He is a member of the National Academy of Engineering, a fellow of the Marine Technology Society and the Society of Naval Architects and Marine Engineers, a past chairman of the National

Research Council's Marine Board, and a past member of the Ocean Studies Board.

**David Keeley** earned a master's of geography and land use planning from Arizona State University in 1977. Mr. Keeley has been director of the Maine Coastal Program since 1981. He was a member of the Ocean Studies Board's Committee on Science Policy and the Coastal Ocean. He has over 12 years of experience in environmental management, policy development, and planning, with particular emphasis on coastal and estuarine issues related to water quality, land use, and public outreach at the local, state, and regional levels.

**Thomas Powell** earned his Ph.D. in physics from the University of California, Berkeley, in 1970. Dr. Powell is now a professor at the University of California, Berkeley and is also a member of the Ocean Studies Board's Committee on Ecosystem Management for Sustainable Marine Fisheries. His areas of expertise are the impact of physical processes (such as currents, waves, and mixing) on the ecology of plankton in lakes, estuaries, and the coastal ocean and measurement and modeling of physical and biological processes.

**Peter Rhines** received his Ph.D. from Trinity College, Cambridge University, in 1967. He is interested in geophysical fluid dynamics, ocean circulation, and computer modeling. Dr. Rhines is professor of oceanography and atmospheric sciences at the University of Washington. He is a member of the National Academy of Sciences, a fellow of both the American Geophysical Union and the American Meteorological Society, and a former member of the National Research Council's Ocean Studies Board.

**Brian Rothschild** earned a Ph.D. in vertebrate zoology from Cornell University in 1962. Dr. Rothschild serves on the faculty of the University of Massachusetts, Dartmouth. His main research interests are in the fields of ecology of fishes, marine ecology, population dynamics, and resource policy. He is a former member of the Ocean Studies Board and served on both the board's Committee on Fisheries and the committee that produced the 1994 National Research Council report, *Review of U.S. Planning for the Global Ocean Observing System.*

**Douglas Wallace** received his Ph.D. in chemical oceanography from Dalhousie University in 1985 and is presently a scientist at the Brookhaven National Laboratory. His research interests include oceanic uptake of fossil fuel carbon dioxide, oceanic distribution of anthropogenic tracers and natural halogens, and cycling of carbon dioxide and oxygen on continental shelves.

**Robert Weller** received his Ph.D. in oceanography from the Scripps Institution of Oceanography at the University of California, San Diego. Dr. Weller is currently senior scientist with tenure at the Woods Hole Oceanographic Institution. His research interests include experimental work in observing and understanding the response of the upper ocean to atmospheric forcing.

**Herbert Windom** received his Ph.D. in earth science from the University of California, San Diego, in 1968. Dr. Windom is presently director of the Skidaway Institute of Oceanography, of the Georgia Institute of Technology. His research interests include marine environmental quality, chemical oceanography, marine biochemistry of trace elements, and environmental effects of dredging.

# APPENDIX C

## Acronyms

| | |
|---|---|
| CalCOFI | University of California Cooperative Fisheries Investigations Program |
| CENR | Committee on Environment and Natural Resources |
| CLIVAR | The Programme on the Variability of the Coupled Ocean-Atmosphere System and Climate Prediction (WCRP) |
| ECMWF | European Centre for Medium Range Forecasts |
| ENSO | El Niño and the Southern Oscillation |
| Euro GOOS | European GOOS |
| FAO | Food and Agriculture Organization of the United Nations |
| GCOS | Global Climate Observing System (WMO-ICSU-IOC-UNEP) |
| GEWEX | Global Energy, and Water Cycle Experiment |
| GLOBEC | Global Ocean Ecosystem Dynamics Program |
| GOOS | Global Ocean Observing System (IOC-WMO-UNEP-ICSU) |
| GTOS | Global Terrestrial Observing System |
| HOTO | Health of the Oceans Module |
| ICSU | International Council of Scientific Unions |
| I-GOOS | Committee for the Global Ocean Observing System |
| ICC-WMO-UNEP | |
| IGOSS | Integrated Global Ocean Services System |
| IOC | Intergovernmental Oceanographic Commission (UNESCO) |
| IRR | Internal Rate of Return |
| JGOFS | Joint Global Ocean Flux Study (IGBP) |
| J-GOOS | Joint Scientific and Technical Committee (IOC-WMO-ICSU) of GOOS |
| LMR | Living Marine Resources Module |
| MCSST | Multi-Channel Sea Surface Temperature |
| NCEP | National Centers for Environmental Protection |
| NEARGOOS | Neareast Asia Regional GOOS |
| NOAA | National Oceanic and Atmospheric Administration (USA) |
| NOS | National Ocean Service (NOAA) |
| NRC | National Research Council |
| NSTC | National Science and Technology Council |
| OOPC | Ocean Observations Panel for Climate |
| OOSDP | Ocean Observing System Development Panel |

| | |
|---|---|
| OSB | Ocean Studies Board (NRC) |
| PORTS | Physical Oceanographic Real-Time System |
| SCOR | Scientific Committee on Oceanic Research |
| SSC | Strategy Sub-Committee (I-GOOS) |
| SST | sea surface temperature |
| SSW | sea surface wind |
| TFODM | Task Force on Observations and Data Management |
| TOGA | Tropical Oceans and Global Atmosphere program (WCRP) |
| UNCED | United Nations Conference on Environment and Development |
| UNEP | United Nations Environment Programme |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| U.S. GOOS IWG U.S. GOOS | Interagency *ad hoc* Working Group |
| VOS Volunteer | Observing Ship |
| WCRP | World Climate Research Programme |
| WMO | World Meteorological Organization |
| WOCE | World Ocean Circulation Experiment |