Global Ocean Observing System

Intergovernmental Oceanographic Commission

Strategic Design Plan for the Coastal Component of the Global Ocean Observing System (GOOS)

October 2000

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Purpose

The coastal zone is a unique environment in that it is the only place on the globe where terrestrial, oceanic, atmospheric, and human inputs of energy and matter all converge. It also supports the greatest concentration of living resources and people on the planet. As the number of people living, working and playing in coastal ecosystems increases, the demands on these systems to provide commerce, recreation, and resources and to receive, process, and dilute the effluents of human society will increase. Likewise, the risk that natural hazards pose society also increases. Thus, it should come as no surprise that coastal ecosystems are experiencing unprecedented changes from habitat loss (tidal wetlands, sea grass beds, coral reefs), oxygen depletion, harmful algal blooms, fish kills, and declining fish stocks to beach closures, coastal erosion and flooding. The resulting conflicts between commerce, recreation, development, the utilization of natural resources, and conservation will become increasingly contentious, politically charged, and expensive.

Resolving these conflicts in an informed, timely and cost-effective fashion requires a significant **increase in our ability to detect and predict the changes that are occurring coastal ecosystems**. This is the purpose of the coastal component of the Global Ocean Observing System. The goal is to **build on, enhance and supplement existing observing programs to develop a sustained and integrated observing system** that provides the data and knowledge required to:

- manage and restore healthy coastal ecosystems and living resources;
- enable safer and more cost-effective marine operations;
- forecast and mitigate the effects of storms;
- detect and predict the effects of climate change; and
- protect public health.

To address these needs, the observing system must ultimately provide information on a broad spectrum of environmental changes that reflect interactions between natural variability and human activities in a complex environmental setting. The system is intended to serve the needs of many user groups including industries (shipping, oil and gas, compliance monitoring, fishing, aquaculture, agriculture, and recreation), government agencies and ministries (management of resource and the environment, land-use and economic development plans), teaching institutions, and the community of research scientists.

This report describes the initial design for the coastal component of the Global Ocean Observing System (C-GOOS). The development of C-GOOS will take place in the context of the Integrated Global Observing Strategy through coordination and collaboration with the GOOS modules (Ocean Observations Panel for Climate, Health of the Oceans, and Living Marine Resources), the Global Climate Observing System (GCOS) and the Global Terrestrial Observing System (GTOS). The plan proposed herein is intended to be the first step in the development of an internationally accepted and supported design plan for C-GOOS.

A Global System for the Coastal Environment

C-GOOS is primarily concerned with the coastal marine and estuarine environments of the coastal zone. These are complex environments composed of a diverse mosaic of ecosystems from intertidal beaches, rocky shores and tidal wetlands to lagoons, coral reefs, estuaries, bays, fjords, sounds and the open waters of the EEZ. Since most of the changes the observing system is intended to detect and predict (from changes in the weather and sea state to harmful algal events and oxygen depletion) are local to regional in scale, it is reasonable to ask why a global observing system for coastal ecosystems is needed in the first place? A global system is needed for three reasons: (1) local changes are often related to or caused by changes occurring on larger scales in the ocean, on land or in the atmosphere (the propagation of variability from large to small scales); (2) marine ecosystems are highly undersampled and the actual scale of changes are often larger than is perceived; and (3) marine ecosystems are complex and the development of a predictive understanding of the changes occurring in them will require a comparative analysis of many systems (local changes that are globally ubiquitous). Differentiating the effects of human activities from the effects of natural processes requires knowledge of the coherence of changes that are occurring locally on global scales and comparative analysis of such changes in the context of larger scale forcings (the propagation of variability from large to small scales). Furthermore, the problem of undersampling, which severely limits our ability to detect and predict change, cannot be solved by any one nation by itself. Although many changes are local to regional in scale, their boundaries rarely, if ever, correspond to political boundaries. Consideration of larger scales and the development of appropriate technologies will require the sharing of knowledge, data, infrastructure and expertise among nations; capacity building to enable all nations to participate and benefit; and financial commitment on the part of the industrialized world. Clearly, this will require an unprecedented level of coordination and collaboration among nations with coastal interests.

Design Considerations

Three general observations form the basis for the design of the observing system: (1) most of the changes occurring in coastal ecosystems are local in scale and are globally ubiquitous; (2) physical processes structure the pelagic environment and are of fundamental importance to changes in the physical, biological and chemical characteristics of coastal ecosystems; and (3) changes in these characteristics are related through a hierarchy of interactions that can be represented by robust models of ecosystems dynamics (e.g., numerical models of physical processes and coupled physical-biological models). Thus, it is likely that there is a relatively small set of core variables that, if measured with sufficient resolution, for extended periods over large scales, will provide the data and information required to detect and predict changes in coastal ecosystems that benefit a broad spectrum of user groups.

Both detection and prediction depend on the development of an integrated and sustained observing system that provides effective linkages between measurements and data analysis for more timely access to data and delivery of environmental information. The system must be integrated to provide multi-disciplinary (physical, chemical and biological) data and information to many user groups. This is the "value-added" aspect of C-GOOS. The system must also be sustained to capture the scales of variability that characterize the changes of interest and to provide continuity in the data streams and resulting data products. **There are no systems that are integrated (multi-disciplinary observations servicing the needs of many user groups), sustained and global in scope**.

C-GOOS will come into being by selectively enhancing, networking and supplementing existing programs. It must also be recognized at the onset that many of the measurements and models required for a comprehensive, fully integrated, multi-disciplinary observing system are not operational, that much work is needed to develop and determine those products that are most useful, and that capabilities and resources vary enormously among nations. These realities underscore the importance and need for enabling research and capacity building. In addition to becoming integrated and sustained, the observing system must achieve the following as it grows and matures:

- produce information that meets the needs of a broad spectrum of user groups;
- provide a more cost-effective means of obtaining and applying environmental data;
- enable a constructive and timely synergy between the detection of changes and the hypothesis-driven research required to understand and predict such changes;
- promote the development of new technologies and models required for a fully integrated, multi-disciplinary system; and
- develop mechanisms to evaluate the functioning of the system and the value of the information it produces, to incorporate new technologies, and to increase the diversity of user groups it serves.

Design Framework

The observing system is conceived as a **global network for the measurement and analysis of a common set of key (core) variables that is regionally and locally customized (e.g., more variables, greater resolution, additional products) to address those issues that are of greatest concern to participating countries**. The global network is the focus of the C-GOOS design strategy. Linking user needs to measurements to form an end-to-end, user-driven system requires a managed, two-way flow of data and information among three essential subsystems:

- the observing subsystem (detection);
- the communications network and data management subsystem (integration); and
- the modeling (prediction) and applications subsystem.

The **observing subsystem** is the measurement end of the system. It consists of the global infrastructure required to measure core variables and transmit data to the communications network and data management subsystem. Recommended core variables are surface winds, air pressure and temperature, precipitation, sea level, bathymetry, temperature, salinity, surface currents and waves, turbidity, sediment type, dissolved nutrients, phytoplankton pigments, and water clarity. The infrastructure must incorporate the mix of platforms, samplers, and sensors required to measure core variables with sufficient spatial and temporal resolution to capture important scales of variability in 4 dimensions. This will require the synthesis of data from remote sensing and *in situ* measurements involving six interrelated categories of observing elements: (1) coastal observing networks for the near shore (CONNS); (2) global network of coastal tide gauges (GLOSS); (3) fixed platforms, moorings and drifters; (4) ships of opportunity (SOOP) and voluntary observing ships (VOS); (5) remote sensing from satellites and aircraft; and (6) remote sensing from land-based platforms.

Data communications and management link measurements to applications. The objective is to develop a system for both real-time and delayed mode data that allows users to exploit multiple data sets from disparate sources in a timely fashion. A hierarchical system of local, national and supra-national organizations is envisioned to provide data, information, and access to users at each level. Some national and supranational organizations will be developed into synthesis centers that will provide highly processed products (e.g., assimilating data from remote and *in situ* sources for numerical model predictions requiring substantial computing power). The development of this component of the system should be of the highest priority.

Data assimilation and modeling are critical components of the observing system. Real-time data from remote and *in situ* sensors will be particularly valuable in that data telemetered from these sources can be assimilated to (1) produce more accurate estimates of the distributions of state variables, (2) develop, test and validate models, and (3) initialize and update models for improved forecasts of coastal environmental conditions and, ultimately, changes in ecosystem health and living resources. A variety of modeling approaches (statistical, empirical, theoretical) will be required. The challenge of developing a cost-effective observing system underscores the importance of the interaction between measurements and modeling. Due to the complexity of coastal ecosystems and the cost of observing them, Observation System Simulation Experiments (OSSEs) will become increasing valuable as tool for assessing the efficacy of different sampling schemes and the usefulness of measuring different variables.

Building C-GOOS

Programs that are relevant to the development of C-GOOS are divided into 3 categories: (i) **operational programs**, (ii) **pre-operational pilot projects**, and (iii) **enabling research**. Operational programs provide products to user groups that are in demand and are made possible by sustained data streams and data management systems that guarantee data quality. Pilot projects and enabling research are organized, planned sets of activities with focused objectives, a defined schedule, and a finite life time that are expected to produce results that significantly benefit the global ocean observing system in general and C-GOOS in particular. An important function of pilot projects is to demonstrate the utility of the GOOS "end-to-end, user-driven" approach. Enabling research develops the technologies and knowledge (e.g., sensor and models) required to detect and predict changes.

It is expected that C-GOOS will develop along two tracks: (1) the building of an initial global network through the incorporation of existing operational elements that meet GOOS design requirements and (2) the implementation of pre-operational pilot projects that demonstrate the utility and cost-effectiveness of the "end-to-end, user-driven" approach and contribute to the development of the global network and regional enhancements. Pilot projects will also be an important vehicle for the incorporation of new scientific knowledge and technologies into the observing system (transformation from research applications to operational modes). Both pilot projects and enabling research programs will be essential to capacity building and the scientific advances required to grow the system into a fully integrated and operational observing system. In this regard, mechanisms are needed to enable the exchange of information and technologies among pilot projects so that they may learn from each others successes and failures and to insure the incorporation of GOOS design principles and the development of common techniques, models, and data processing strategies. This is particularly important for the data management subsystem if data and data products are to be exchanged in a timely fashion on regional to global scales.

The successful development of C-GOOS depends on broad-based international support and ongoing sponsorship by nations and private institutions. The annual operating cost of the World Weather Watch in 1992 was about $2 billion U.S. The annual cost of a GOOS at that time was also about $2 billion U.S., most of which was for satellites. Although a cost analysis has yet to be performed for C-GOOS, these figures provide an order of magnitude estimate of the investment that will be required to initiate the core network proposed here. Although government funding will be essential, especially for large capital-intensive components of the observing system such as satellites, funding from the private sector will be required in the long term. In these regards, **the importance of National and Regional GOOS Programs cannot be overemphasized**. These programs are vehicles for implementation. They provide an important means for facilitating the user input required to implement and enhance the core program and for institutionalizing mechanisms for sustainable funding.

Collaboration with key research programs will provide the scientific basis for continued development toward a fully integrated system. The first step is to coordinate and integrate existing efforts to insure continuity and to achieve larger scale regional and global perspectives, minimize redundancy, improve access to data, and produce timely analyses that benefit a broader spectrum of user groups. By building on existing capabilities and infrastructure, and by using a phased implementation approach, work can start immediately to achieve the vision. New technologies, past investments, evolving scientific understanding, advances in data communications and processing, and the will to address pressing societal needs combine to provide the opportunity to initiate an integrated observing system for coastal ecosystems. The major pieces missing are an internationally accepted global design; national and international commitments of assets and funds; and an unprecedented level of collaboration among nations, institutions, data providers and users.

PROLOGUE

The Integrated Global Observing Strategy (IGOS) is based on the development of three related systems: the Global Climate Observing System (GCOS), the Global Terrestrial Observing System (GTOS), and the Global Ocean Observing System (GOOS). GOOS includes the ocean component of GCOS and the coastal marine and estuarine component of GTOS. The concept of GOOS is that of an integrated global network that systematically acquires and disseminates data and data products in response to the information needs of government, industry, science and the public to address marine-related issues and problems in a timely fashion.

There are many multilateral agreements that are relevant to GOOS (Keckes, 1997). Three of the most relevant are (1) the 1982 UN Convention on the Law of the Sea, (2) the Second World Climate Conference in 1990, and (3) two conventions and a program of action signed at the 1992 UN Conference on Environment and Development (UNCED) in Rio de Janeiro (the Framework Convention on Climate Change, Convention on Biodiversity and Program of Action for Sustainable Development, and the Program of Action for Sustainable Development or *Agenda 21*). The Law of the Sea Convention provides the legal basis for implementing GOOS by defining jurisdictions in the form of territorial seas and the EEZ; the Climate Conference recommended establishing an observing system, including a global ocean observing system, to monitor climate variability and change more effectively; and ***Agenda 21*** **calls for the establishment of a global ocean observing system that will enable effective and sustainable management and utilization of the marine environment and its natural resources**.

The IOC envisioned a global ocean observing system in 1989 as a means to:

- improve weather forecasts, climate predictions and the mitigation of natural hazards;
- assess the state and health of marine ecosystems and the resources they support; and
- enable the development and implementation of scientifically sound environmental policies that take into account natural and anthropogenic changes in marine ecosystems and the effects of these changes on people.

GOOS is conceived as an “end-to-end, user-driven” system, the operational objective of which is to develop a locally relevant, global scale observing system for multiple uses that is sustained and integrated.

The effort to design the system and make the transition from concept to reality is being led by the GOOS Steering Committee (GSC). An Intergovernmental Committee (I-GOOS) assists in gaining government approval of and support for implementation. Sponsors include the Intergovernmental Oceanographic Commission (IOC), the United Nations Environment Program (UNEP), the World Meteorological Organization (WMO), and the International Council for Science (ICSU).

Panels have been established to formulate recommendations for the design and implementation of GOOS in four modules: (1) climate change - Ocean Observations Panel for Climate (OOPC), (2) chemical and biological contamination - Health Of The Oceans (HOTO) Panel, (3) sustainability of living marine resources - Living Marine Resources (LMR) Panel, and

(4) environmental change in coastal marine and estuarine ecosystems - Coastal (C-GOOS) Panel. The panels report to the GSC and are working to:

- specify the measurement programs and information required on a continuing basis to meet user group needs on local to global scales;
- design and promote the implementation of an internationally coordinated strategy for the timely acquisition, dissemination, analysis and archiving of data (including data that have been or are being collected);
- identify existing programs that should be incorporated into the observing system to minimize redundancy and optimize shared use capabilities;
- enable all nations to participate in and benefit from GOOS;
- identify research and development priorities required to achieve the goals of GOOS; and
- coordinate with the OOPC, GCOS and GTOS to insure the full integration of environmental data and information.

Given the concentration of living resources in coastal waters and the rapid increase in the number of people living, working and playing in coastal watersheds, the health of coastal ecosystems and their capacity to support living marine resources are of primary concern to most countries. Consequently, **the HOTO, LMR and C-GOOS modules will be merged for the development of an integrated implementation plan for the coastal component of GOOS**. The GOOS will then develop through two related and convergent components: (1) a basin scale component concerned primarily with the role of the ocean in the earth's climate system (OOPC) and (2) a coastal component concerned primarily (but not exclusively) with environmental changes in coastal marine and estuarine ecosystems and their impacts on people (Coastal Ocean Observations Panel, COOP).

Here, we present the design plan for the coastal component of GOOS. The report begins with a discussion of the goals and benefits of a fully integrated and operational observing system and of the challenges that must be overcome to implement it. A brief summary of the development of the observing systems for the atmosphere and the open ocean provides a historical perspective helped to guide the formulation of the design for C-GOOS. We note the 300 year history of the observing system for climate and the reality that design and implementation of C-GOOS must address a much more complex set of issues from the multi-disciplinary spectrum of measurements that must be made to the diversity of user groups that must be served. The general framework for the design is set forth in section 4 with details of the major components of an end-to-end system being described in sections 5 (observing subsystem), 6 (linking measurements and models) and 7 (data communications and management). Following a section on pilot projects that illustrate the kinds of "proof of concept" projects that will be needed to implement the design, we conclude with a discussion that underscores two important considerations that must be taken into account in the development of C-GOOS. First, many elements of the system are in place and must be incorporated into a global system. Second, the scientific basis for C-GOOS is in its formative stages of development, and enabling research will be critical to the successful development of a fully integrated, operational observing system for coastal marine and estuarine systems.

Finally, there are, in effect two bibliographies: the standard list of literature that was used in the preparation of this report and a listing of URLs (Annex II) which served a similar purpose. In addition, the URLs listed in the annex provide an entree to many of the programs and planning activities that are relevant to the development of C-GOOS.

The report reflects the hard work of many people. Conversations with and guidance from Worth Nowlin, Neville Smith, Ron Wilson and Neil Anderson were invaluable. In addition to the Panel, invited experts, the IOC Secretariat (Annex I) and an anonymous reviewer, we also wish to thank the following individuals whose timely and constructive reviews of an earlier draft resulted in significant improvements: Willem Behrens, Lou Codispoti, Chris Crossland, John Cullen, Lewis Incze, John Marra, Phil Mundy, John Parslow, Nadia Pinardi, David Prandle, John Rees, Shubha Sathyendranath, Don Scavia, Stephanie Turner, Frank van der Meulen, and Stan Wilson.

1. INTRODUCTION

*"**It is a capital mistake to theorize before one has data. Insensibly, one begins to twist facts to suit theories, instead of theories to suit facts.**"*
Holmes to Watson (Sir Arthur Conan Doyle. 1892. *The Adventures of Sherlock Holmes*)

"Nature is possessed of a surprising perfection, and this is the result of the sum of its limits...If you understand the limits, you understand how the mechanism works...And so now I have come to the sea. The sea. The sea ends too, like everything else, but you see, here too, it is a little like sunsets, ***the hard thing is to isolate the idea...to condense miles and miles of cliffs, shores, and beaches into a single image, into a concept that is the end of the sea...****"*
Professor Bartleboom to Ann Deverià in Alessandro Baricco's *Ocean Sea*, 1993.

1.1 PURPOSE

The successful implementation of the coastal component of GOOS is critical to meeting the goals set forth in *Agenda 21*. Living resources are concentrated in coastal marine and estuarine systems (Table 1) and the number of people living along their shorelines is increasing rapidly. The demands on these systems to provide commerce, recreation, and living space and to receive, process, and dilute the effluents of human society will continue to grow. At the same time, coastal ecosystems are experiencing unprecedented changes that affect their capacity to provide these services and support valuable resources, e.g., habitat loss (coral reefs, sea grass beds, tidal wetlands), oxygen depletion, harmful algal blooms, fish kills, declining fish stocks, beach closures, coastal erosion and flooding. They indicate profound changes in the capacity of coastal ecosystems to support living resources; and they are making the coastal zone more susceptible to natural hazards, more costly to live in, and of less value to national economies. The resulting conflicts between commerce, recreation, development, and conservation will become increasingly contentious, politically charged, and expensive.

The changes occurring in these systems on daily to decadal time scales reflect both the character of the ecosystems themselves and changing inputs of energy (storms, tides, solar radiation, etc.) and materials (water, sediments, nutrients, chemical contaminants, nonindigenous species, etc.) from terrestrial, atmospheric and oceanic sources, e.g., land-based sources account for about 80% of the annual input of contaminants to the oceans (UNEP, 1995). Thus, the broad goal of the coastal component of GOOS to detect and predict the effects of changes in these inputs on coastal marine and estuarine ecosystems and the human populations that live, work and recreate in coastal environments. Although, the challenges are significant, we are witnessing a convergence of societal needs and technical capabilities that provide the motivation and means to design and implement such a system. The time is right to develop the coastal component of GOOS that is (1) based on sound science, (2) responsive to the information needs of many user groups, (3) more cost-effective (shared-use of existing infrastructure, build on and supplement existing programs), and (4) is both sustained and integrated.

Table 1. Ecosystem services provided by coastal aquatic ecosystems in rank order of estimated value (adapted from Costanza *et al*., 1997). A recent analysis of "ecosystem goods and services" concluded that their global value is on the order of $30 trillion U.S. or nearly twice the cumulative global GNP (Costanza *et al*., 1997). Services provided by coastal aquatic ecosystems were valued at $11.4 x 10^{12} with terrestrial ($11.1 x 10^{12}) and oceanic ($7.5 x 10^{12}) ecosystems accounting for the rest. Although such analyses of ecosystem services are controversial, they underscore the importance and urgency of achieving a more holistic, predictive understanding of the responses of coastal ecosystems to inputs from terrestrial, atmospheric, oceanic, and human sources.

Rank	Ecosystem Service	Ecosystem Functions	Examples
1	Nutrient Cycling	Nutrient storage & processing	N fixation, nutrient cycles
2	Waste Treatment	Removal, breakdown of excess nutrients & contaminants	Pollution control, detoxification
3	Disturbance Regulation	Buffer impact of climatic disturbances	Storm protection, flood control, drought recovery
4	Recreation	None	Boating, sport fishing, swimming, etc.
5	Food Production	Portion of PP extractable as food	Fish harvest
6	Refugia	Habitat, biodiversity	Nurseries, resting stages, migratory species
7	Cultural	None	Aesthetic, artistic, spiritual, research
8	Biological Control	Trophic dynamics, biodiversity	Keystone predator, pest control
9	Raw materials	Portion of PP extractable as raw materials	Lumber & fuel
10	Gas Regulation	Chemical composition of the atmosphere	CO_2, O_3, SO_x

This report describes the initial design for the coastal component of the global ocean observing system. It is not an implementation plan, but a blue-print for how the community of nations can more effectively address environmental issues and problems of mutual concern. We also emphasize that a distinction must be made between an observing system that is operational and hypothesis driven research. The purpose of the observing system is to detect and predict patterns of change over a broad range of time and scales. The determination of what to measure on what time and space scales is driven by societal needs to detect and predict environmental changes and their consequences to society. Measurements and the resulting data streams are expected to be sustained in perpetuity. The purpose of environmental research is to test hypotheses concerning patterns of change that have been defined by observations. The variables to be measured are selected because they must be measured to test the hypothesis. Consequently, the measurement program is expected to be of a specified, finite duration. Clearly, the two are mutually dependent, and the design of the observing system must insure a timely, positive feedback between them. Of course, this is not to say that data provided by the observing system cannot and should not be used to test hypotheses. This must be encouraged and be enabled by the system.

Clearly, close coordination with the OOPC, GTOS and GCOS will be required to achieve this ambitious goal. The "vision" is to develop the detection and predictive capabilities required to make informed and timely decisions for the prevention, control and mitigation of these effects. If this is to be achieved, individuals, institutions, and governments must be confident that they have access to data and information on the causes and consequences of environmental variability and change in coastal ecosystems that are reliable and relevant to their needs.

1.2 BENEFITS

An integrated ocean observing system is needed for coastal waters as the means to address the following societal needs:

X detect and forecast the effects of climate change on coastal ecosystems and their human inhabitants;
X protect and restore healthy coastal ecosystems and manage natural resources for sustainable use;
X forecast and mitigate the effects of natural hazards;
X enable safer and more efficient marine operations; and
X protect public health.

In order to meet this challenge, C-GOOS must ultimately address a broad spectrum of local changes that are related to the interaction between natural variability and human activities (Table 2) in a complex environmental setting (U.S. National Research Council, 1994; Malone and Cole, 2000). Although local in scale, many of these changes are occurring in coastal ecosystems world-wide. Such a pattern suggest that these are either local expressions of global scale environmental changes (e.g., climate change) or of anthropogenic effects that are also local in scale but globally ubiquitous (e.g., nutrient loading) or both. To the extent that the changes occurring in coastal ecosystems are a consequence of human activities, the development of a predictive understanding of the effects of human activities is essential to the realization of these benefits.

Table 2. Natural and anthropogenic forcings and associated variables and indicators of change that are occurring in coastal marine ecosystems (U.S. NRC, 1994). Although most indicators of change occur on local to regional scales, they are occurring in coastal ecosystems throughout the world.

FORCINGS: Natural & Anthropogenic	• Air pressure & surface wind stress • Tides, ocean currents & waves • Atmospheric deposition • Utilization of natural resources • Physical restructuring of habitats • Incident solar radiation & heat flux • Introductions of nonindigenous species • Inputs of freshwater, nutrients, sediments, & contaminants
INDICATORS OF CHANGE: Ecosystem Health & Living Marine Resources	• Accumulations of organic matter & carbon storage (algae, sediment organic content, etc.) • Harmful algal events & their consequences • (aerosols, fish kills, public health) • Mass mortalities (e.g., fish, birds, & mammals) • Diseases & biological effects of chemical contaminants • Changes in species composition & abundance • Declines in living resources • Oxygen depletion • Temperature increase & changes in salinity • Growth of nonindigenous species • Habitat modification & loss
INDICATORS OF CHANGE: Coastal Hazards & Safe, Efficient Marine Operations	• Flooding & coastal erosion • Salt water intrusion • Changes in sea state & sea ice • Changes in shallow water bathymetry • Increases in susceptibility to natural hazards

The potential economic and social benefits of C-GOOS are difficult to quantify with certainty. However, the benefits could be large, both in terms of developing a more cost-effective observing system and applications of the knowledge gained for the public good. There are clear and compelling indications that improved environmental information on coastal ecosystems is likely to yield cost-benefit ratios on the order of 1:4 to 1:10 (EuroGOOS, 1996; IOC, 1998). Analyses and activities such as these suggest that the vision of GOOS is well founded and investment in specific elements of the end-to-end system is a sensible strategy. They also underscore the importance of *ex post facto* cost-benefit analysis as means of developing the tools and techniques to measure the true value of environmental data and the products derived from them and, therefore, of improving the cost-effectiveness of the observing system as a whole. As in the case of weather and climate services, strong public-private partnerships will improve opportunities for economic development, enable governments to serve the public more effectively, and lead to a more informed citizenry.

Integrated Coastal Area Management (ICAM) programs are potential users of C-GOOS data and products. A recent agreement between the IOC and the IGU to collaborate in the development of ICAM is of particular significance to the design of C-GOOS. "Oceans 21: Science for Sustainable Use of the Ocean and Coastal Zones" targets five project areas for development:

- Interdisciplinary Approaches to an ICAM Science Plan (recommend approaches to coastal management; identify priority research problems);
- Marine Scientific and Technological Information System for ICAM (ICAM and the International Oceanographic Data and Information Exchange (IODE) serve as a clearing house of information and data);
- Methodology Development in Support of ICAM (develop methods for translating scientific knowledge into information products that will guide the management process)
- Coastal and Deep Ocean Monitoring System for ICAM (identify and strengthen the environmental and socioeconomic monitoring systems required to effect the management program);
- Training, Education and Mutual Assistance (TEMA) in Marine Science (promote and improve training and education in coastal and ocean management at all levels).

Successful development of C-GOOS will depend on and **benefit a broad spectrum of industries and government services including offshore oil and gas production, recreational and commercial fisheries, aquaculture, resource management and integrated coastal area management programs, agriculture, coastal tourism, recreational boating and commercial shipping, coastal science and engineering, science education, weather forecasting, habitat restoration, and search and rescue** (Glenn *et al.*, 2000a, 2000b). Specific benefits of C-GOOS must be recognized by the users themselves. There are international and regional user constituencies who can speak on behalf of their representative industrial or political members (e.g., National and Regional GOOS programs), and the development of C-GOOS must reflect their evolving needs. User scenarios, such as those below, illustrate examples of C-GOOS benefits:

"Industries and services are subject to uncertainty, loss of efficiency, and direct costs and damages caused by unpredictable forces of the marine environment such as storms, sea level surges, waves, erosion, transport of pollutants, shifts in fish stock migration, and harmful algal blooms.... Improvement of short- and medium-term prediction services for maritime conditions would improve the value of maritime industries and services by a few percent. If we accept 1% as a most conservative estimate, the value added to the GNP of the EU by a prediction system is of the order of $1.4 - $2.3 billion/yr" (Woods *et al.*, 1996). The newly formed European Oceanographic Industry Association (EOIA) is but one indication of the potential value of C-GOOS. EOIA was established to represent and promote companies in the commercial marine information products and services sector. EOIA's goal is to develop a network of over 500 companies to achieve the following:

- Influence decisions in national governments and the European Commission;
- Ensure marine R&D programs reflect the needs of industry;
- Oppose unfair competition; and
- Provide a forum to discuss common industry issues.

Full information on the aims and proposed activities of EOIA may be obtained from their web site (Annex 11.2) or from eoia@eoia.demon.co.uk.

> A major user of C-GOOS data will be government agencies and NGOs that require data-products to assess changes in the status of the world's ecosystems, e.g., the Millennium Ecosystem Assessment, http://www.ma-secretariat.org. In 1972, the United Nations Conference on the Human Environment called for reports on the status of the environment. Today, state of the environment reports are being produced by governments and non-governmental organizations on local to global scales (cf., Parris, 2000; Linden, 2000). All of these reports suffer from a lack of common methodology for assessing ecosystem condition, from a lack of quantitative data that are routinely available, and from a lack of continuity in terms of periodic reporting. Recent efforts to develop indicators (such as economic indicators of performance used by governments, private enterprise, and the public for a variety of purposes from managing national economies to investment strategies) of the status of coastal and oceanic ecosystems have revealed major gaps in the data and information required to define, calculate, and apply indicators in an operational mode (cf., O'Malley and Wing. 2000). The development of routine and sustained data-streams that are required to produce periodic status reports in a timely fashion depends on the establishment of C-GOOS.

- Storm surge warnings provided by a service agency can potentially save thousands of lives in the world's lowlands exposed to surges and flooding. Such agencies benefit in turn from C-GOOS data input and infrastructure to improve their professional performance.

- Predictions of the effects of land-use practices on the export of nutrients to coastal waters and the effects of such exports on water quality (e.g., coastal eutrophication) and living resources provide the scientific basis for the economically and ecologically sound development of coastal drainage basins.

- Coastal navigation becomes safer and oil spill hazards less likely by provision of local coastal monitoring/forecast of current and waves. C-GOOS provides boundary values to models and supports technical advances and training.

- Property damage and changes in habitat due to coastal erosion can be better understood and mitigated from modeling studies of coastal processes. C-GOOS provides input data to such studies as well as experience gained from other locations.

- The effects of harmful algae events may be mitigated based on predictions that rely on more effective monitoring of the time-space dimensions of HABs.

- Habitat loss, its causes and its consequences (including oxygen depletion and increasing susceptibility to coastal erosion and flooding) will be detected and assessed earlier for more effective mitigation and restoration.

- Finally, the benefits of C-GOOS will also be expressed through capacity building and improved public awareness and science education at all levels.

1.3 WHY NOW?

We are witnessing a convergence of societal needs and technical capabilities that provide both the motivation and means for major advances in our abilities to evaluate, prevent, control and mitigate the effects of human activities and natural variability (Glenn *et al.*, 2000b). These include:

- increasing population density and diversity of human activity in coastal ecosystems,
- effects of large scale climatic events and climate change,

- emerging technologies from instrumentation for *in situ* and remote sensing to fiber optics, communication satellites, and the Internet for rapid data transmission and dissemination, rapidly increasing computing power for more efficient data assimilation and analysis, and
- the development of a critical mass of human resources and scientific knowledge on marine environments.

Until recently, most of our understanding of marine ecosystems is based on shipboard sampling that is limited to a sequence of measurements made at single locations in time and space and to data management and analytical capabilities that are inefficient and time consuming. Improved sensor technologies and high speed computers are providing the tools to overcome these limitations. Shipboard measurements that require the collection of water samples for subsequent analysis are gradually being augmented by continuous measurements from *in situ* sensors mounted on a diversity of platforms (towed instrument packages, fixed moorings, drifters, autonomous underwater and remotely operated vehicles) and remote sensors mounted on aircraft, satellites and land-based platforms. As the volume and diversity of data transmitted in real-time increase, data assimilation techniques improve, and more powerful models are developed, applications of environmental data in response to user needs will expand rapidly leading to near real-time, 3-dimensional, time-dependent visualizations of environmental change in marine systems (circulation patterns, the evolution of hypoxia, harmful algal events, etc.), rapid detection of trends (from changing sea state and shallow water bathymetry to habitat loss and climate change), and timely and reliable predictions of environmental changes that directly or indirectly affect the quality of life.

1.4 DESIGN PRINCIPLES

The development of C-GOOS will be guided by the GOOS design principles (Table 3; IOC, 1998). As C-GOOS grows and matures, it must become more than the sum of its parts. The system will not be an opportunistic assembly of whatever might be available. It will develop by selectively incorporating, enhancing and supplementing existing programs consistent with the goals of GOOS and participating nations. To these ends, the design of C-GOOS will be guided by the following design principles:

(1) The observing system will produce data-products that address a broad spectrum of user needs.[1]

- Observation will be designed to address specific problems that occur in the coastal zone and affect human activities at several different levels. The design plan must identify observations required to achieve defined objectives and should, where possible, describe how they will be applied to the needs of users.

[1] The products of C-GOOS will depend on the level of data analysis required by user groups ranging from Araw@ (unprocessed) data and calibrated data for scientists to near-real time predictions and more highly processed data for education and commercial use. At the present time, it is not clear where in the continuum from data to products the non-commercial role of GOOS ends and the commercial development of products begins.

- The users of the data and data-products will interact with both technical experts and scientists to drive the process of designing, operating and improving the system in response to the evolving needs of user groups.

Table 3. The GOOS Design Principles

1.	GOOS is based on a plan designed to meet defined objectives based on user needs.
2.	The design assumes that contributions to GOOS are long term and systematic.
3.	The design will be reviewed regularly and adapt as needed.
4.	Methods of measurement may differ provided there are adequate standards.
5.	The problems addressed must benefit from global observations, i.e., be global in scale or globally ubiquitous in distribution.
6.	The design encompasses the entire system from data capture to end products and services.
7.	The management, processing and distribution of data will follow a specific data policy that includes timely dissemination of and access to data.
8.	The design takes into account systems outside of GOOS that can contribute to or benefit from GOOS.
9.	The design incorporates procedures for quality assurance.

(2) The development of C-GOOS must involve a more cost-effective use of existing data, expertise and infrastructure than is currently realized, i.e., the entire process from measurements to products will be cost-effective.

- C-GOOS will incorporate, enhance and supplement existing programs as appropriate. It will develop a comprehensive system of observations through shared use of infrastructure from measurement systems and platforms to communication networks, data management systems, assimilation techniques, and modeling.
- Measurements will be routine (uninterrupted flow of data of known quality) and data will be assimilated, analyzed and transformed into products in a timely fashion.
- Products will ensure social and economic benefits that will largely compensate the operational costs of the observation system.

(3) Hypothesis-driven, environmental research that results in new knowledge, improved technologies, and more powerful models is of critical importance to the development of C-GOOS.

- C-GOOS will enable a constructive and timely synergy between hypothesis-driven research, the detection of patterns of variability, and the generation of information in response to user needs.

(4) The observing system must be both integrated and sustained (Figure 1). The successful achievement of the goals of C-GOOS requires that it be designed to capture the spectrum of environmental responses (the temporal and spatial dimensions of variability) to external forcings that are relevant to the indicators given in Table 2.

- Observations will be sustained in perpetuity to capture episodic events and long-term trends (document both high and low frequency variability), enhance scientific analysis, and support model predictions.[2]
- The observing system will be integrated from measurements (synoptic measurements of physical, biological and chemical properties over a broad range of time and space scales) to data management (multiple data types from disparate sources) and analyses that are responsive to the needs of multiple end-users, i.e., it will be a user-driven, end-to-end system.
- C-GOOS will be designed and implemented as a component of GOOS and in collaboration with GCOS and GTOS.

To date, few, if any, programs are both integrated and sustained (Figure 1). A sustained commitment will be required of C-GOOS partners to establish, maintain, validate, make accessible, and distribute high quality data that meet internationally agreed upon standards. By building on existing activities, capabilities, and infrastructure, and by using a phased implementation approach, work can start immediately to achieve the vision. New technologies, past investments, evolving scientific understanding, advances in communications and data processing, and pressing societal needs combine to provide the opportunity to initiate an integrated observing system for coastal waters immediately. The major pieces missing are an internationally accepted global design; international commitments of assets and funds; and partnerships among nations, institutions, data providers and users.

[2] For the purposes of C-GOOS, **prediction** is defined in its broadest sense to include forecasting future events as well as estimating (interpolating, extrapolating) quantities or distributions that are not directly observed.

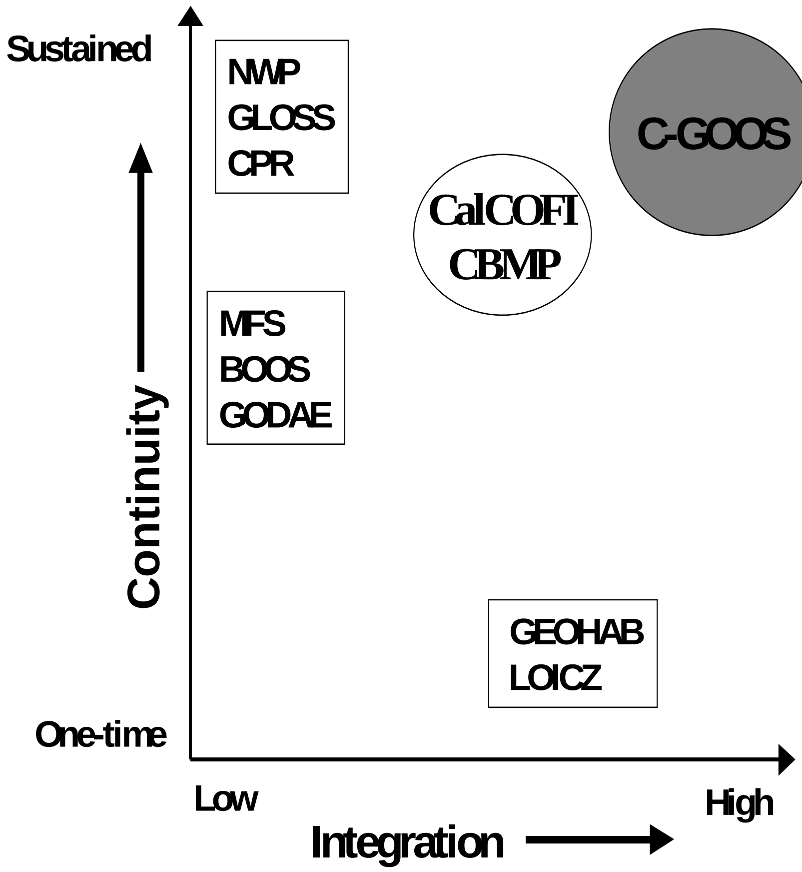


Figure 1. The extent to which programs are sustained and integrated. "Sustained" is the assurance that observations will be continued in perpetuity. An observing system is "integrated" to the extent that the measurement program is multi-disciplinary (physical, chemical and biological variables measured synoptically in time and space) and the observing system is designed to address the needs of multiple user groups. Most programs are either sustained or integrated. Very few are both. For example, Numerical Weather Predictions (NWP), the Global Sea Level Observing System (GLOSS), and the Continuous Plankton Recorder (CPR) survey are sustained, but not integrated. Likewise, programs such as the Land-Ocean Interactions in the Coastal Zone (LOICZ) Program and the Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) Program are integrated but not sustained. Of the examples given here, the California Cooperative Fisheries Investigation (CalCOFI) and the Chesapeake Bay Monitoring Program (CBMP) come closest to the vision of C-GOOS in terms of being multi-disciplinary and sustained (MFS - Mediterranean Forecasting System, BOOS - Baltic Operational Observing System, GODAE - Global Data Assimilation Experiment).

2. CHALLENGES

There are many challenges to the design and implementation of an integrated coastal ocean observing system. Some of these, the complex nature of the ecosystems that constitute the coastal environment, deficiencies in our current capacity to detect and predict changes, social and political barriers, and the need for capacity building, are briefly discussed here.

2.1 HETEROGENEITY OF THE COASTAL ENVIRONMENT

Coastal marine and estuarine environments are the focus of the C-GOOS design. These constitute a mosaic of complex, interacting ecosystems that include intertidal beaches and rocky shores, tidal wetlands, lagoons, coral reefs, estuaries, bays, fjords, sounds and the open waters of the continental shelf, including the EEZ. In the context of this heterogeneity, the design of C-GOOS must take into consideration four important aspects of coastal ecosystems (e.g., Chelton *et al*., 1982; Steele, 1985; Powell, 1989; NRC, 1994; Cloern, 1996):

- They are constrained by irregular coastlines and a shallow, highly variable bathymetry. In this context, the interaction between intertidal, benthic and pelagic communities enhances nutrient cycles and the capacity of coastal ecosystems to support living resources.

- They are subject to convergent inputs of materials and energy from terrestrial, atmospheric, oceanic and anthropogenic sources that vary over a broad range of time-space scales. In addition to the combined effects of solar radiation, tides, winds, atmospheric deposition, freshwater flows from land, and ocean currents, the effects of human activities converge on coastal ecosystem.

- Physical and biological processes resonate over shorter time scales (higher frequencies) and over a broader spectrum of variability relative to terrestrial and oceanic systems. Consequently, populations and processes in coastal ecosystems are more variable on smaller space and shorter time scales than are typical of either the open ocean or terrestrial ecosystems.

- Coastal regions of the world are experiencing explosive increases in population density through growth and changing demographics. Perhaps as a consequence of the concentration of resources in the coastal zone (Table 1), it is projected that by the year 2025, 75% of the world's population will live within 120 miles of the coast. The pressures on shallow marine ecosystems to provide commerce, recreation, and resources and to receive, process, disperse, and dilute the effluents of a complex modern human society will continue to increase. The resulting conflicts between commerce, recreation, development, the utilization of resources, and conservation are contentious, politically sensitive, and expensive.

The challenges of detecting variability and predicting change in such heterogeneous and complex systems require substantial advances in our basic understanding of (1) relationships between habitat, biodiversity and living marine resources and (2) how larger scale changes are expressed within and propagated among coastal ecosystems, i.e., how changes in the indicators of environmental change are quantitatively related to natural and anthropogenic sources of variability (Table 2).

Biodiversity is a case in point. The estimated global rate of species loss (extinction) is currently 100 to 1,000 times higher than it was prior to the evolution of the human species. It is suspected that the principal cause of this high rate of extinction is the degradation and destruction of habitats by people. In coastal ecosystems, it is well known that (1) the loss of critical habitats (e.g., tidal wetlands, submerged grasses, and coral reefs) is related to the combination of current land-use (including diversions of freshwater) and fishing practices. There is also strong evidence that (2) habitat loss is affecting the carrying capacity of coastal ecosystems for biodiversity in general and living marine resources in particular. However, the causal linkages between human activities, changes in habitat, and biodiversity are poorly understood.

2.2 TOWARD A PREDICTIVE UNDERSTANDING: TECHNICAL CHALLENGES

The problem of establishing and quantifying causal linkages between human activities and indicators of change is compounded by the effects of natural variability. Changes occurring in local ecosystems cannot be understood and predicted unless they explicitly include the influences of larger scale changes in ocean circulation, climate, and land-use practices. For example, the 1992 ENSO event caused the thermocline and nitracline to deepen in the Monterey Bay upwelling system resulting in a four-fold decline in new production (that fraction of total phytoplankton production available for export and fish production) (Kudela and Chavez, 2000), and occurrences of bottom water oxygen depletion are clearly related to accumulations of organic matter caused by excessive inputs of anthropogenic nutrients from coastal watersheds (e.g., Malone *et al*., 1999). The former is an example of the local effect of a larger-scale change in the ocean-climate system while the latter reflects the effects of larger scale changes in land-use practices. Likewise, fluctuations in living marine resources are difficult to understand without long-term time series of observations that capture significant scales of environmental variability and provide the kinds of data required to resolve short-term variability from longer term trends or cycles (e.g., Figure 2). Thus, **although many of the changes occurring in coastal ecosystems are thought to be related to human activities, causal linkages between them are difficult to establish in the absence of observations that describe local changes in the context of larger scale patterns of change.**

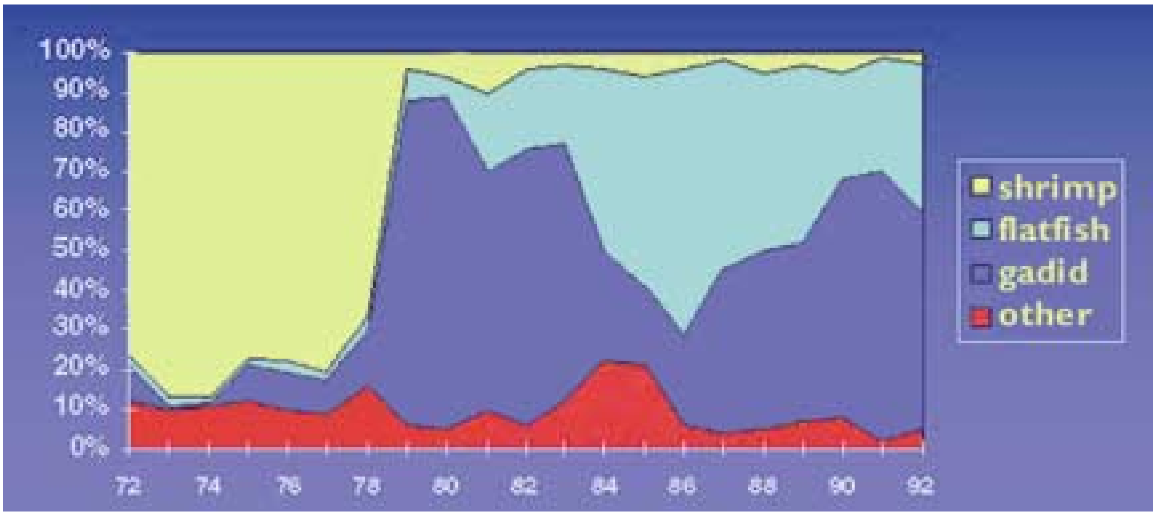
It is clear that substantial advances in understanding and predictive capabilities cannot be achieved in the absence of regional, long-term observations where “regional” refers to the next larger scale of variability that must be observed to understand the local scale of interest (Nixon, 1996) and “long-term” refers to the length of time required to capture the full spectrum of variability that characterizes the indicators of change in coastal ecosystems. Indicators of change must be considered in the context of larger-scale changes in ocean circulation, climate, and land-use practices in coastal drainage basins. Differentiating the effects of anthropogenic activities from the effects of natural processes will require comparative analysis of coastal ecosystems in the context of sustained observations on local to global scales. Thus, from a technical view point, the design and implementation of the coastal component of GOOS must address six major challenges to the development of a predictive understanding of environmental variability and change:

- address the problem of undersampling by making observations of sufficient duration, spatial extent, and resolution to capture patterns of change;
- make synoptic (simultaneous in time and space) measurements of key physical, geological, chemical and biological attributes of coastal ecosystems for the purposes of prediction;
- increase the volume of data on key variables that is transmitted and assimilated in real-time for improved nowcasts and forecasts;

- integrate data from *in situ* measurements and remote sensing to provide 4-dimensional representations of change;
- implement integrated data management systems that captures the diversity of data types and enables timely access to disparate data sets; and
- develop a robust theory of ecosystem dynamics and of coupled physical-ecosystem models that can be used to predict changes and their consequences.

These challenges are especially daunting for the biological and chemical aspects of a fully integrated, sustained system and for developing nations where resources, expertise and infrastructure are in short supply.

(a)



(b)

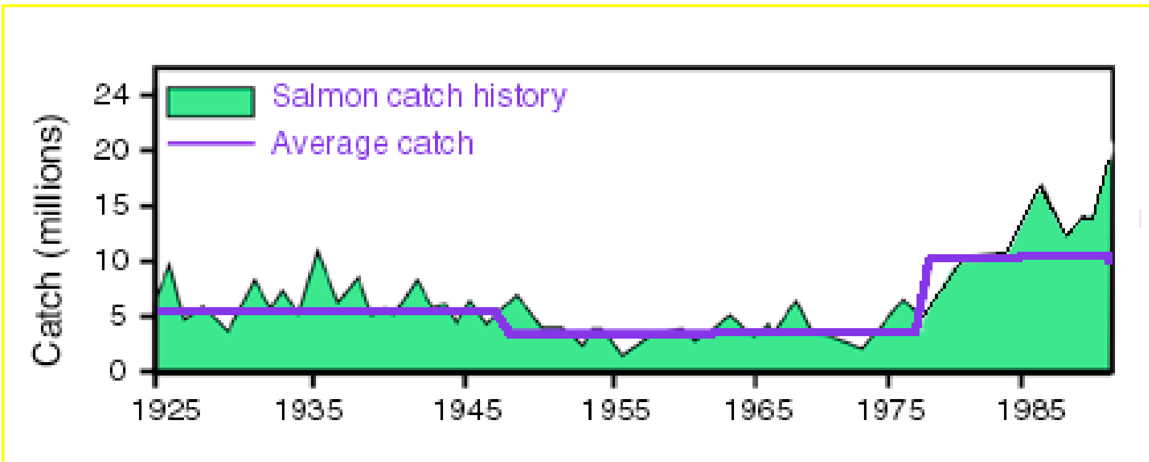


Figure 2. Two examples illustrating the importance of long-term times series observations. In both cases, rapid changes in the relative abundance of species were correlated with the north Pacific Decadal Oscillation (PDO) index. (a) Landings of shrimp, flatfish and gadids in the Gulf of Alaska from 1972 to 1992. (b) Landings of salmon in the Pacific northeast from 1925 to 1995.

2.3 TOWARD A PREDICTIVE UNDERSTANDING: SOCIO-POLITICAL CHALLENGES

The development of predictive capabilities and of effective policies for environmental and resource management depend on recognizing and understanding "the system as a whole" in a regional to global context. When the decision making process does not consider the largest scale (in time and space) required to capture the variance of factors relevant to the local scale of interest, it is likely that the loss of natural resources will persist until the full scale of the problem is appreciated. As discussed by Lee (1993), this is largely a consequence of targeting apparent or proximate causes to manage when the real problem lies elsewhere. Consideration of larger scales requires the sharing of data, infrastructure, and expertise among nations.

The successful implementation of C-GOOS will depend a great deal on constructive collaborations among nations and among data-providers and users to (1) overcome parochial attitudes and approaches, (2) make more effective use of collective resources, (3) establish a stable funding base, (4) exchange data and information in more timely and effective ways, and (5) respond to new demands and expectations. Mechanisms will be needed to provide the means for defining and solving environmental problems on regional to global scales that go beyond national boundaries and the missions of individual government agencies. The first steps are to coordinate and integrate existing efforts to minimize redundancy, increase standardization, improve access to data, and produce timely analyses that are useful to a broader spectrum of society. Implementation will require an unprecedented level of international coordination and collaboration among nations with coastal interests.

Thus, in addition to the technical challenges of designing and implementing coastal observing systems, there are political and social barriers to the coordinated use of resources and integration of data across programmatic and geopolitical boundaries. Politically, there are major conflicts related to traditional attitudes of national security and to the mismatch between political boundaries and scales of environmental change in coastal waters. Socially, the scientific community is both too fragmented (e.g., oceanographers, terrestrial ecologists, meteorologists) and isolated (from decision makers, resource managers, industry, the public). Clearly, the flows of data and information across these boundaries must be enhanced to make more effective use of data, information and the collective resources of participating nations for the common good. By improving the international coordination of data collection, dissemination and management, an integrated ocean observing system will provide more complete information on coastal indicators for a broader range of users.

2.4 CAPACITY BUILDING

The purpose of capacity building is to make it possible for all nations to contribute to and benefit from GOOS. Given the extensive shorelines and coastal waters of developing nations, this is of particular importance to C-GOOS. Coastal nations in the developing world often have the greatest need for data and information products but lack the financial resources, infrastructure, and technical expertise to participate in C-GOOS. As a minimum, capacity building must involve (1) developing and maintaining the basic technical expertise and infrastructure (human resources, measurement systems, communications networks, data management systems) required to participate in GOOS and (2) educating the public and governments concerning the benefits of investing in GOOS (public relations). Funding for capacity building is expected to come from industrialized nations in a sustained and reliable manner.

A draft of "Principles of GOOS Capacity Building" (April, 1999) prepared for the GSC (http//ioc.unesco.org/goos/Cap_Build_Principles.pdf) emphasizes the following:

- Capacity building can be thought of as occurring in three stages beginning with an initial stage (research capabilities are quite limited; planning and policy functions are non-existent or fragmented), developing into a transitional stage, and concluding with a developed stage (planning, management, research system and the research community are dynamic, well linked to society and the economy, and self-sustaining);

- Capacity building must involve a long-term commitment and partnership of governments, foundations, scientific and international organizations to training, technology transfer, and sustained international interactions among providers and user groups;

- GOOS capacity building should be built through the parallel development of nested observing systems at national, regional and global scales; and

- The IOC, in collaboration with the GOOS sponsors, should play a lead role in implementing capacity building activities and raising the awareness of GOOS requirements, benefits, and costs.

A GOOS Capacity Building Panel has been formed and charged with the following: (1) initiate, plan and oversee the implementation of GOOS capacity building through the development of key demonstration projects using the GOOS implementation process; (2) submit a plan to donor organizations to obtain funding; (3) create an awareness of GOOS capacity building activities; (4) develop standardized mechanisms and tools to be used in GOOS capacity building; and (5) initiate and assist in the development of multi-year regional plans for capacity building including partnerships with developed regional activities.

A key ingredient of capacity building in C-GOOS is the development of international communication networks that enable exchanges of data and information and promote cooperation among nations. Such a network must effectively address problems of intellectual isolation and inadequate resources as well as the establishment of regional partnerships as a means of achieving the critical mass of talent and resources required to participate in C-GOOS.

3. HISTORICAL PERSPECTIVE

3.1 THE OBSERVING SYSTEM FOR THE ATMOSPHERE

Although observations of the atmosphere, land and ocean environments have been made for centuries, it is only during the past few decades that the possibility of systematic, global observing systems has been realized. This is due in part to the advent of autonomous *in situ* and satellite-borne sensors that have allowed an increasing number of environmental variables to be measured on a global scale. At the same time, the need for *in situ* observations has never been clearer. The first international and intergovernmental observing systems were developed for the atmosphere and a review of their history provides important lessons for C-GOOS.

The seeds of the modern global meteorological observing system were planted over 300 years ago with the commencement of regular meteorological observations (Daley, 1991). The first national weather service with a permanent observing network was established in France in the mid 1800s. The International Meteorological Conference of Vienna in 1873 established a permanent international committee to standardize meteorological observations. By the early 1900s a real-time global observing system was in place. It was primarily a land-based, surface network of unevenly spaced observing stations. An upper air network was established in the mid 1900s and by the late 1960s satellite-borne radiometers began providing uniform global coverage including surface properties of the oceans which, to that point, had been much more poorly sampled than they are today.

Today, the global meteorological observing system, the World Weather Watch (WWW), has three components that are fundamental to any observing system:

- The global observing network of sensors and platforms (surface and radiosonde networks, aircraft and satellite systems for the measurement of wind speed and direction; air temperature, pressure, and moisture content from the earth's surface to the top of the troposphere);

- The Global Telecommunications System (GTS) used to transmit and process observations; and

- The global data processing system, a network of national and international meteorological centers that collect, process, archive and disseminate observations in near real-time (a complete set of global observations is usually available several hours after the time of observation).

The World Weather Watch is a mature system built on decades of international cooperation. Since its main purpose is to provide the data required to initialize models for forecasting weather, rapid communication is paramount. The system is made up of many types of instruments controlled by many nations. Thus, there is great variation in coverage and data quality. It is interesting to note that formal procedures for network design, based on sensitivity studies using forecast models, have generally not been used to develop the global meteorological observing system. Indeed the location of upper atmosphere stations has been as dictated as much by past requirements for meteorological observations and predictions around airports as by any consideration of the requirements for global climate prediction. WWW coverage in developing nations remains unsatisfactory in general.

3.2 THE OBSERVING SYSTEM FOR THE OPEN OCEAN

During the 1980s two important ocean programs were initiated under the auspices of the World Climate Research Program: (1) the Tropical Ocean and Global Atmosphere (TOGA) Experiment to develop a predictive understanding of ENSO events, and (2) the World Ocean Circulation Experiment (WOCE) to provide the first global description of ocean basin scale current patterns. The success of these programs, and the recognition that climate change and related environmental effects may be occurring as a consequence of increasing greenhouse gases, underscored the need for long-term global observations of the ocean.

The Second World Climate Conference in 1990 recommended that systematic, global observations of the components of the climate system (including a global ocean observing system) should be developed to monitor climate variably and change more effectively. This was reinforced by the subsequent Framework Convention on Climate Change and its Conferences of the Parties, most recently at Kyoto and Buenos Aires. GCOS was established in 1992 to meet these needs. It is expected to lead to earlier detection and more reliable prediction of climate change through research and the development of an enhanced operational observing system for climate. It is anticipated that the benefits of GCOS are likely to be much larger than the costs of implementation.

Although marine research programs provided sporadic observations of the global ocean, an operational observing system did not exist when GOOS and GCOS were formed. This provided an opportunity to develop a global strategy for the design of GOOS based on information needs rather than the convenience of measurement or the specialized requirements of a small number of user groups. The original design of an ocean observing system for climate was completed by the Ocean Observing System Development Panel (OOSDP) in 1994 (OOSDP, 1995), and endorsed by both GCOS and GOOS soon afterwards. The task of the OOSDP was to provide 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."

The OOSDP set priorities for the elements of the observing system on the basis of their contribution to achieving subgoals for the surface of the ocean, the upper ocean and the deep ocean. Highest priority was given to observations needed for the determination of the global sea surface temperature (SST) and the global surface wind and wind stress, the observations needed for the initialization of ENSO prediction models and verification of their results, and to those needed for the determination of the global change in sea-level (Nowlin *et al*., 1996). In the process, the OOSDP realized that it was not possible to separate the requirements of the observing elements into different, non-redundant, and unique climate problems or signals. Some variables provide input to a number of fundamental climate signals. For example, SST is not only important as an indicator of global warming; it is also required to initialize and verify ENSO predictions and to estimate surface heat flux on local to global scales.

3.3 THE OCEAN-CLIMATE SYSTEM AND COASTAL ECOSYSTEMS

Observing systems for the atmosphere, the open ocean, and coastal ecosystems must overcome similar problems: (1) irregular distributions of observing sites, many established for non-scientific purposes and without regard for the scales or patterns of variability of the phenomena being observed; (2) measurements in different units and of different quality; (3) the need for rapid data collection, quality control and dissemination; and (4) the need for predictions in forms that satisfy a wide range of end users. It is also clear that data assimilation and numerical models will play an increasingly important role in sampling design and the synthesis and interpretation of data (e.g., Glenn *et al*., 2000b).

The observing system for weather forecasting and climate predictions differs from the coastal component of GOOS in the diversity issues to be addressed (Table 2) and, therefore, the number of variables that must ultimately be measured. The coastal observing system must monitor a much wider range of variables; many of the measurements cannot be made and transmitted operationally; and the fundamental principles of ecosystem dynamics have yet to be fully elucidated. Consequently, patterns of variability in the coastal indicators of change have not been well documented and ecological events in coastal ecosystems cannot be predicted with confidence. However, it is to be expected that rapid advances will be made as new technologies for observing marine ecosystems are developed (e.g., remote sensing of surface salinity, waves, currents, and ocean color; *in situ* sensing of nutrients, optical properties, plankton, and fish), advances are made in the understanding of physical processes and physical-biological interactions, and computers become ever more powerful.

A significant investment has already been made in observing infrastructure for the coastal ocean, at least in some regions. In regions such as North America and Europe, more variables are measured in coastal ecosystems for more purposes (e.g., weather and sea state forecasts, compliance monitoring, and the management of living resources and water quality) than in oceanic systems. Some measurements, such as sea level, have been made for more than two centuries and there is presently a global distribution of tide gauges that report sea level in near real time. Clearly, the coastal observing system of the future must be built on the extensive infrastructure already in place, a process that can only occur through extensive collaboration and coordination among agencies and nations. In this sense, the development of the coastal ocean observing will be more similar to that for the atmosphere than that for the ocean basins.

4. DESIGN FRAMEWORK

The purpose of the coastal ocean observing system is to detect and predict the causes and consequences of changes in coastal ecosystems. Although this may seem to be an insurmountable goal, it is important to note that most of the indicators of change in Table 2 are related through ecosystem dynamics. Marine ecosystems are structured by physical processes and variations in biological and chemical properties are related through a hierarchy of physical-chemical-biological interactions that govern their status and effect changes (cf. Mooers, 1999). This underscores the importance of modeling (section 6) and suggests that there is a common set of core variables that, if measured with sufficient resolution over long enough periods and large enough areas, will serve many needs e.g., from forecasting changes in water depth and sea state on short time scales to predicting the environmental consequences of human activities and climate change on longer time scales. Given the interdependence of these processes and the reality that priorities vary regionally and among countries, **the coastal ocean observing system is conceived as a global network for the measurement of a common set of core variables that is regionally and locally enhanced to address those issues that are of greatest concern of participating countries**.

Both detection and prediction depend on effective linkages between measurement, data communication, and analysis. Using the WWW as a model, this will require a managed end-to-end system with the following elements:

- the observing subsystem (networks of platforms, sensors, sampling devices, and measurement techniques) to measure the required variables on the required time and space scales to detect and predict changes in coastal indicators;

- the communications network and data management subsystem (telemetry, protocols and standards for quality assurance and control, data dissemination and exchange, archival, user access); and

- The modeling and applications subsystem (data assimilation, synthesis and analysis; procedures for translating data into products).

An **operational observing system requires that measurements are routine, long-term (sustained into the foreseeable future), and systematic (with sufficient precision and accuracy on appropriate time and space scales)**. In these regards, the initial coastal ocean observing system should develop to meet the following requirements:

- Coordinate the development of observing subsystems among nations to minimize duplication and costs, and maximize data availability and temporal-spatial resolution;

- Integrate data from remote sensing (aircraft, satellites, land based) and *in situ* sensors (moored instruments, drifters, AUVs, ships) to capture the full temporal and spatial dimensions of change in the coastal environment;

- Provide quality controlled and quality assured data to drive operational models;

- Develop an integrated information management system that ensures continuous data-streams, adequate quality assurance, and timely delivery of data and information in response to user needs; and

- Develop a process that ensures periodic review of the observing system from measurements to data management and adaptation to new and changing user requirements for ocean data and products

It also must be recognized that most of the biological and chemical observations required for a fully integrated observing system are not operational and that much work is needed to determine those products that are most useful to user groups. Thus, the coastal component of GOOS will evolve along two tracks: (1) **the building of an initial global network of existing operational programs** and (2) **the implementation of pilot projects** (see section 8) that demonstrate the utility and cost-effectiveness of the GOOS end-to-end, user-driven approach and contribute to the regional development of the global network (including regional enhancements). Pilot projects will also be important as a vehicle for incorporating new scientific knowledge and technologies (new sensor technologies and platforms, telemetry, data assimilation techniques, model, products, etc.) and for transforming research into operational modes.

5. THE INITIAL OBSERVING SUBSYSTEM

5.1 DEFINING THE CORE VARIABLES

It is clear from the above discussion that the design of the observing system for the coastal ocean will be more complex and involve more compromises than for the ocean observing system for climate. For example, many end users want immediate answers to pressing problems, often in the form of predictions. At the same time, our understanding of underlying principles and scales of variability is so rudimentary that more research is needed before predictive models are developed. The observing subsystem must help serve the needs of both groups. Another challenge is the choice of variables to monitor. At this time, the easiest variables to measure and predict are physical (e.g. sea level and temperature) in contrast to biological and chemical variables that are needed to detect and predict changes in the status of coastal ecosystems and their ability to support living marine resources. Thus, the selection of core variables will involve compromises in terms of what is most straightforward to measure and model in the short term and what will ultimately be the most useful in terms of both the cost of detecting changes and the reliability of the resulting predictions. **The goal is to identify the minimum number of state variables that must be measured to detect and predict changes in a maximum number of the indicators (Table 2) that will benefit the maximum number of user groups.**

The procedure by which core variables were selected, a tentative list of core variables, and a discussion of the observing elements required for an integrated system are described below. The procedure is explained in greater detail in Annex III. It is recognized at the onset that there are other approaches that could be used to define core variables. The procedure used here is intended to provide a systematic means to identify the minimum number of variables that should be incorporated into the global network. (It would be straightforward to extend the present approach to allow for different weights to be given to the various user groups, the value of the predictions and so on.) Clearly, the initial design must evolve in response to increasing input from user groups (including scientists) as the system comes into being. The main goal here is to stimulate dialogue among the providers and users of the data as a means to develop a truly end-to-end, user-driven system.

5.1.1 Identifying the Variables to Detect and Predict Change

Panel members and invited experts (Annex I) were asked to independently identify those state variables that should be monitored to detect and quantify changes and in the coastal indicators listed in Table 2. (Note: This process did not begin with a list of variables. Variables were identified based on their relevance to each indicator of change listed in Table 2.) They were also asked to identify user groups that would benefit from information on each indicator. The variables were then ranked based on the number of indicators and user groups they are relevant to. This led to a list of variables required to **detect** change in coastal ecosystems.

The next step was to select a subset of indicators to represent a cross section of the full list given in Table 2. User groups were identified that could benefit from timely predictions of quantities related to these indicators. The panel then identified the form of the prediction, the type of predictive models to be used, and the input variables required to drive them. This led to a list of variables required to **predict** change in coastal ecosystems. Given the lists of users, indicators and input variables, the next steps followed those used to identify variables required to detect change. Input variables were ranked in terms of the number of predictions and user groups they are relevant to.

5.1.2 Selecting the Core Variables

The final step was to identify the core variables. Variables required to detect and predict change were ranked in terms of the number of indicators, models, and user groups they are relevant to. Based on these rankings (a measure of impact), and on the feasibility of measurement (Annex IV), the minimum set of core variables that satisfy the maximum number of user needs were identified (Table 4).

Although the identification of variables required to detect and predict change is strongly dependent on the choice of indicators and data products required by user groups, these results compare remarkably well to the results of an independent survey conducted recently for EuroGOOS (Fischer and Flemming, 1999). Of the 17 variables in greatest demand by user groups, all but freshwater runoff are listed in Table 4 (see Annex III). Even so, the set of core variables identified here should be considered a “first cut” in an ongoing process that must involve more user groups (in addition to scientists) in the selection process and that will incorporate additional biological and chemical attributes as they are needed and measurements become feasible and operational. We note, for example, that river runoff and basic meteorological variables such as humidity and solar radiation did not make this list.

Table 4. Preliminary list of core variables to be measured as part of the global network. See Annex III for a full explanation of how these were selected.

TYPE	VARIABLE
Meteorological	Surface Wind, Air pressure and Temperature, Precipitation
Physical	Sea level, Bathymetry & Geomorphology Temperature & Salinity Surface Currents & Waves Turbidity/Total Suspended Solids Sediment Type & Grain Size
Chemical	Dissolved Inorganic Nitrogen, Phosphorus, & Silicon Dissolved Oxygen
Biological	Chlorophyll-*a*, Phytoplankton Pigments, & Ocean Color Species Composition (including HABs and nonindigenous species) Attenuation of Photosynthetically Active Radiation

At the phytoplankton level, species groups (see section 5.2.7) can be identified through the measurement of accessory pigments. At the community level (all of the species in an ecosystem), the species and groups of species that should be monitored vary from region to region. Consequently, measurements of species abundance and distribution should be incorporated as regional enhancements.

5.2 THE CORE VARIABLES

A brief description of the core variables and their significance to the indicators of change follows. It must be recognized that **measuring only the core variables will not allow the detection and prediction of all indicators of change in all coastal ecosystems**. To do this, additional measurements will need to be made at local and regional levels as determined by national and regional priorities (regional enhancements). Although details concerning methods of measurement were considered to be beyond the scope of this report, methods are described in Annex IV. The related issues of standardization and the feasibility of measurement (e.g., cost-benefit analysis) are important and must receive high priority in the formulation of the implementation plan for C-GOOS.

Likewise, a rigorous treatment of the time and space scales of measurement has not been attempted here. The question of how many tide gauges C-GOOS needs illustrates one of the many difficulties that must be addressed. In the case of sea level, the spatial scale of variability is a strong function of frequency. For example, consider the sea level measured by 3 neighboring gauges on the west coast of the U.S. and Central America separated by about 30 degrees of latitude: San Francisco, San Diego and Balboa. The linear trends in sea level at these gauges are similar and range from 1.4 to 2.1 mm/y. However, the similarity decreases with increasing frequency. In the 2-10 day band for example, the average coherence has dropped below 0.5. Although the coherences are significantly different from zero at the 1% level, they are not of much practical significance, and we conclude that these gauges are too far apart to map out the structure of sea level variability in the 2-10 day band. As discussed in section 6.4, one approach to the problem of defining the required temporal and spatial scales of resolution for a large number variables and indicators of change is through the use of simulation model experiments.

5.2.1 Wind, Air Pressure, Temperature and Precipitation

Wind, air pressure, temperature and precipitation influence coastal circulation. Precipitation also contributes to inputs of particulate matter, nutrients and freshwater:

- Accurate fields of wind stress over continental shelves are a primary input to hydrodynamic models and are required to predict a number of important physical variables including sea level, sea state, vertical stratification and mixed layer depth, surface currents, the distribution of sea ice, and the trajectories of river and effluent plumes, oil spills and icebergs. Wind is also an important variable in its own right through its effect on the safety of offshore operations and marine navigation.

- Air pressure is important through its effect on shelf circulation and also through its influence on sea level variability (inverse barometer effect).

- Accurate information on precipitation intensity, type and amount is also required to predict a number of important state variables including sea level, sea state, vertical stratification and surface currents. Precipitation is also important through its effect on coastal flooding, coastal erosion, and freshwater runoff; associated inputs of buoyancy, sediments, nutrients and contaminants; and the safety of offshore operations and marine navigation.

5.2.2 Sea Level and Bathymetry

Water depth (bathymetry + sea level) and geomorphology affect, directly or indirectly, virtually every indicator of change in coastal ecosystems (Mann, 1976; Petersen *et al.*, 1997). Responses of marine ecosystems to meteorological forcings and associated inputs of water, sediments, nutrients and contaminants are, to a great extent, governed by depth (proximity of the benthos to the air-sea interface) and geomorphology. Sea level is an important input variable for numerical models of circulation in coastal ecosystems, and sea level measurements can be a cost-effective way to monitor variations in the surface flow, transport through straits and exchange between coastal embayments and the coastal ocean. On longer time scales, sea level is also an indirect measure of vertical crustal movement, subsidence, global warming of the world's ocean, melting of Antarctic ice sheets, and deep sea circulation.

5.2.3 Temperature and Salinity

Water temperature and salinity in coastal ecosystems are important indicators of large scale changes in the ocean-climate system (e.g., ENSO, the N. Pacific and N. Atlantic decadal oscillations) and of inputs from coastal drainage basins (e.g., salinity can be used as a tracer of river plumes and, where concentrations in the freshwater end member are know, as a surrogate for nutrient and sediment loading). They are important parameters of circulation and mixing; of the distributions of marine, estuarine, and anadromous species; and of the development of harmful algal blooms. Temperature is also an important parameter of biological and chemical rate processes and of habitat loss or modification, e.g., coral reef bleaching.

5.2.4 Surface Currents

This is one of the basic state variables of the coastal ocean. Along with the wind, currents control the transport and distribution of water masses, nutrients, plankton, suspended sediments, point source discharges, river plumes, life rafts, oil slicks, sea ice and icebergs, etc. Current patterns are important for navigation; the location and design of bridges, piers, offshore platforms and mariculture operations; and the development and location of fronts, eddies, and multi-layered circulation patterns that influence the abundance and distribution of marine organisms through their effects on reproduction, feeding, and recruitment (Powell, 1989; Levin, 1992; Hood *et al.*, 1999).

5.2.5 Surface Waves

Ocean surface waves are one of the most important mechanisms for two-way coupling of the atmosphere and ocean. Without waves, atmospheric momentum would pass directly into ocean currents. With waves, some momentum is transferred to waves and radiated away from the generation area. Coastal flooding is often the result of a combination of high tide, surge and waves. The importance of waves to safe navigation is undeniable and reflected in the operational wave forecasting systems that are run by meteorological centers in many nations. Storm tracks and concomitant waves often follow major coastlines. In the North Atlantic for example, hurricanes tend to be generated in the tropics and track northeast along the USA coastline, across the Canadian Maritime provinces towards Greenland. The largest waves ever recorded were measured by operational buoys on the continental shelf off Nova Scotia in the 1990s. They reached heights of 30 m, the maximum the buoys could record. Waves are also responsible for a feedback of the ocean surface to the atmosphere through their modifications of the wind stress that drives them.

In terms of local ecosystems, waves and associated turbulence have significant effects on a wide range of processes from coastal erosion and sediment transport to species succession, HABs, habitat loss or modification, and the dispersal of oil slicks. They are a major determinant of beach erosion and geomorphology and can generate infragavity waves and mean alongshore currents. From the intertidal to the continental shelf, waves influence the distribution and species composition of flora and fauna as well as accumulations of organic matter and the occurrence of anoxia.

5.2.6 Attenuation of Photosynthetically Active Radiation (PAR) and Turbidity

Underwater light is an important parameter of photosynthesis, habitat type (e.g., coral reefs, benthic macrophytes) and vision. Photosynthesis supports most biological production in the ocean; habitats such as coral reefs, kelp beds, and sea grasses are important habitats for living resources and biodiversity; and vision is an important parameter of trophic interactions (and, therefore the transfer of phytoplankton production to higher trophic levels, including commercially important fisheries) and reproduction. Attenuation coefficients for irradiance (spectrally resolved or integrated over the PAR domain) are used in biological models to compute water-column and benthic primary production and can be used to estimate the electromagnetic and heat budgets of the water column.

Photosynthetically Active Radiation (PAR) is operationally defined as irradiance (flux per unit area) in the electromagnetic spectrum from 400 to 700 nm. PAR declines exponentially with depth due to **absorption** and **scattering**. Both absorption and scattering increase as the concentration of suspended particles increases, i.e., as turbidity increases. Suspended solids not only affect light attenuation, they are indicative of coastal erosion and can be an important sources or sinks of nutrients (phosphorus in particular) and chemical contaminants. The suspended load transported to coastal ecosystems by rivers is kept in suspension by turbulent mixing (caused by waves and turbulent flows) which also resuspends bottom sediments. Thus, in addition to being an important parameter of downwelling irradiance, turbidity is an important tracer of sediment transport, coastal erosion, extent of buoyant plumes and effluent discharges, nutrient supply, the environmental mobility of inorganic and organic pollutants via adsorption processes and sedimentation, and detritus and living particulate matter.

5.2.7 Phytoplankton Pigments and Ocean Color

Three kinds of ocean color variables are recommended for the observing system: (1) chlorophyll-*a* (Chl-a), a measure of phytoplankton biomass and biological production; (2) accessory pigments, bioindicators of the presence and biomass of different floristic groups of phytoplankton (related to biodiversity, the fate of phytoplankton production, and trophic dynamics); and (3) ocean leaving radiance (passive remote sensing) which utilizes naturally reflected visible and near infrared wavelengths and naturally emitted longer wavelength infrared and microwave radiation (fluorescence) to provide information on ocean color (as well as surface temperature; ice cover; surface roughness due to winds, waves, and currents; cloud type and extent; and the water vapor content of the atmosphere).

Chl-a is among the most widely measured biological variables in coastal research and monitoring programs around the world, and there is a significant amount of historical data for coastal ecosystems. Of the plant pigments found in phytoplankton, Chl-a (or its variant di-vinyl chlorophyll *a*) is the only one that is present in all species of phytoplankton. It plays a central role in photosynthesis and is the most easily measured biomass property of phytoplankton. In regard to the latter, it must be emphasized that the relationship between Chl-a and biomass (measure in terms of carbon or dry weight) can vary by over an order of magnitude due to changes in species composition and physiological state. The concentration of Chl-a has a dynamic range of more the 4 orders of magnitude (< 0.1 µg liter^{-1} to > 100 µg liter^{-1}). It is a proxy for phytoplankton biomass and is a fundamental parameter of primary productivity and of light attenuation in aquatic ecosystems (see section 5.2.6). As such, it is widely used in predictive models of phytoplankton productivity and as a key biological variable in coupled physical/biological models. Variations in its concentration reflect changes in the balance between primary production and heterotrophic consumption in the euphotic zone of marine and estuarine ecosystems. Patterns in the distribution of Chl-a provide information on the carrying capacity of ecosystems for living resources and on the amount of organic matter that may be exported from the euphotic zone (resulting in carbon storage, oxygen depletion, or deep-sea food webs).

While Chl-a can be used as an index of bulk phytoplankton biomass, the presence and relative abundance of other algal pigments provide insights into the floristic composition of the community. Some pigments are commonly distributed among several algal groups, while others are unique to specific algal classes or species. For example, the following pigments can be used to indicate the presence and biomass of specific classes of algae (in parentheses):

- alloxanthin (Cryptophytes);
- peridinin (Dinoflagellates);
- prasinoxanthin, 19-hexanoyl fucoxanthin (Prasinophytes);
- divinyl chlorophyll *a* (Prochlorophytes).

As analytical methods become more refined and new pigments are identified, pigment analysis as a tool for characterizing variability in dominant species groups will become increasingly powerful. For example, the pigment gyroxanthin-diester only occurs in a small number of dinoflagellate species and may be used to detect the presence and biomass of *Gymnodinium breve*, an important species of harmful algae.

5.2.8 Dissolved Inorganic Nutrients

Nutrient inputs (inorganic and organic) often govern primary production, and the concentrations of nutrients provide information on the trophic status (oligotrophic to euptrophic) of coastal ecosystems. Nutrients of interest are nitrogen, phosphorus and silica. The concentrations and ratios of dissolved inorganic nutrients in coastal ecosystems reflect the combined actions of (1) inputs from terrestrial, deep ocean and atmospheric sources; (2) remineralization within the water column, (3) benthic remineralization and release from benthic sediments; (4) consumption by primary producers and bacterial communities; and (5) exports. Variations in concentrations depend on a dynamic balance between the physical, chemical and biological processes that govern each of these pathways of input, uptake, recycling and export. In concert with measurements of related environmental variables (temperature, salinity, dissolved oxygen) and phytoplankton biomass, long term measurement of nutrient concentration are important to the detection of secular trends in the effects of anthropogenic nutrient loading on water quality and living marine resources. For example, changes in the ratios of major nutrients (N:Si:P) can have profound consequences in terms of species succession and the occurrence of HABs.

5.2.9 Dissolved Oxygen

Dissolved oxygen (DO) is an important habitat parameter for both aerobic and anaerobic organisms. The distribution of dissolved oxygen is an integrative measure of the dynamic balance between primary production, heterotrophic consumption, chemical oxygen demand, physical transport and exchange processes, and exchange across the air-sea interface. Changes in dissolved oxygen (1) provide a means to assess trophic status (oligotrophic to eutrophic) and the extent to which coastal ecosystems are sources or sinks of organic carbon and (2) can alter habitats (e.g., development of anoxia) and the biogeochemical cycles of biologically important elements including nitrogen, phosphorus, and iron. Thus, changes in dissolved oxygen are related to many indicators of environmental change including accumulations of organic matter, HABs, carbon storage and export, habitat loss, changes in biodiversity, and sustainable fisheries. Long-term measurements of DO (together with related variables such as temperature, salinity, nutrients and phytoplankton biomass) are needed to detect and predict changes in coastal ecosystems that are caused by natural variability and anthropogenic activities (nutrient inputs and exploitation of living resources).

5.2.10 Sediment Type and Grain Size

Bottom sediment type and composition (including grain size distribution) are major factors governing the distribution of benthic organisms, sediment transport and bottom friction. The horizontal divergence of sediment transport has a direct effect on the bathymetry of coastal regions, including relatively rapid changes in coastline associated with the in filling of jetties, beach loss, and migration of manmade and natural channels. Other bathymetric effects include the migration and growth of sand ridges (with length scales on the order of a tidal excursion), wave energy refraction, reflection and dissipation over sand bars, and the evolution and growth of ebb-tidal deltas. Bottom sediment type and composition exert strong control over local sediment resuspension. High concentrations of suspended sediment can generate sediment size-dependent, apparent density stratification near the bed. This stratification feeds back into the estimation of bottom shear stress and friction.

Accurate estimates of bottom friction are critical when calculating the dynamic response of the overlying fluid in coastal and continental shelf environments. Estimating bottom friction is complicated by the non-linear coupling of different frequency components in the flow so that, for example, the apparent bottom roughness felt by the mean current depends on the magnitude and direction of near-bottom orbital motions induced by surface gravity waves (Grant and Madsen, 1986), and further complicated in the case of mobile bottom sediments by the dynamical adjustment of the bed itself. Sediment size and composition are important variables in controlling the size and shape of the bedforms generated by the variety of waves and currents encountered in coastal regions. The dynamical adjustment of bedforms to the flow results in time-varying, flow-dependent changes in the physical roughness of the bed, which, for example, appear to explain for unexpectedly high observed rates of energy dissipation of swell propagating across the shelf (Young and Gorman, 1995).

5.3 THE OBSERVING ELEMENTS

The observing subsystem will incorporate the mix of approaches that can be categorized in one of three categories: discrete *in situ* sampling followed by measurements (e.g., a water sample is collected and taken to a laboratory where measurements are made); autonomous *in situ* sensing (the sensor is in the environment where the measurement is made); and remote sensing (from satellites, aircraft, and land-based sensors). *In situ* measurements may be made from docks, small boats, ships, fixed platforms, moorings, drifters, remotely operated vehicles, and autonomous underwater vehicles. Coastal observatories for *in situ* and remote sensing are expected to become especially important components of the observing subsystem as the technologies for these platforms and associated sensors develop (Glenn *et al.*, 2000b).

Six general, interrelated categories of observing elements are considered critical to the design plan: (1) the near shore observing network; (2) the global network of coastal tide gauges; (3) fixed platforms, moorings and drifters; (4) ships of opportunity and voluntary observing ships; (5) remote sensing from satellites and aircraft; and (6) remote sensing from land-based platforms.

5.3.1 Coastal Observing Network for the Near Shore (CONNS)

The near shore is where the human population has the greatest interaction with the marine environment and where the indicators of environmental change are most clearly expressed. It is also the area of the ocean where public awareness and interest are greatest and where most marine research laboratories are located. Coastal laboratories provide access to local marine and estuarine ecosystems, and they provide the facilities required to support most of the three elements of the observing system described above. Consequently, regional networks of these laboratories will form the backbone of the global observing subsystem, and CONNS will provide the means to address a broad range of issues that are critical to the successful implementation of C-GOOS as follows:

- <u>Monitor terrestrial inputs</u>. The near shore is directly affected by diffuse and point source inputs of freshwater, nutrients, sediments, and contaminants from coastal drainage basins (surface runoff, ground water discharge, coastal erosion). Near-shore sites located near rivers and other sources are, therefore, the obvious location at which to monitor exports from terrestrial ecosystems and their effects on estuarine and marine ecosystem. Although this aspect was not captured by the process by which core variables were defined, it is expected that this will become an integral part of the observing system.

- <u>Document temporal variability</u>. High resolution, synoptic measurements of many biological and chemical variables are most feasible and cost-effective in local ecosystems that are near laboratory facilities. These capabilities are critical to the successful development of index sites (see below), coastal observatories, ocean color algorithms for case 2 waters, calibration and maintenance of *in situ* sensors, and land-based remote sensing.

- <u>Support the development of "test beds"</u>. The development of *in situ* sensor and communications technologies are critical to the evolution of a fully implemented, multidisciplinary observing system that includes the measurement of key biological and chemical properties and real-time telemetry of data for timely forecasts.

- <u>Facilitate the participation of all coastal countries</u>. Implementing C-GOOS on a global scale will be a major challenge, and the network of coastal laboratories will not only provide the infrastructure for capacity building, it will provide the opportunity for all interested countries to contribute and participate in a meaningful way.

- Promote public awareness and support. Coastal laboratories provide direct communication links to local communities, and networks of laboratories provide the infrastructure and resources required to translate and communicate scientific knowledge for the public good.

CONNS is envisioned as a hierarchical network of institutions that will provide the means to understand local changes in the context of regional and global scales of variability. It has been designed to interface directly with the C-GOOS Data Flows and Management scheme (section 7.3.2, Figure 4). Participating institutions would include coastal research laboratories, government agencies, industries, environmental NGOs, and schools. Three levels of participation with two-way data and information flows among each level are envisioned:

(1) Level 1 institutions would require the most assistance from C-GOOS and regional hubs to participate (e.g., concerned citizens, environmental groups, and high schools). At the measurement end of the system, participants at this level would be trained and provided with the means (e.g., instruments, supplies, kits) for sampling, making measurements (in some cases), and recording results (data and meta-data; see section 7.4). Data would be communicated (electronically or otherwise) to a level 2 participant capable of storing and transmitting data electronically. Application of the principles of capacity building will be most important here.

(2) Level 2 institutions would have the resources and expertise to routinely collect samples, to measure the required variables (in some cases), and to store and transmit data in electronic formats in a timely fashion (e.g., industries, hydrographic services, coastal administrations, universities, and navies). Training and the development of common protocols for measurements, meta-data, and data exchange will also be important at this level (see section 7.3 and 7.4). Participants at this level directly or indirectly involve the greatest diversity of user groups. One important advantage of Level 2 participation will be access to the vast amount of data that are collected routinely in the near shore region but are not generally available outside the region (e.g. compliance monitoring).

(3) Level 3 institutions will function as **regional hubs** providing general guidance, training and advice to level 1 and level 2 participants. They will link schools, environmental groups, industry, and operational agencies in a given region. Hubs will be linked to form a global network that may also function as the communication network for the global system (section 7.3.2). They will have all of the capabilities of level 1 and 2 participants, but with a broader spectrum of expertise and resources to design and implement measurement programs and to store and analyze diverse data types from many sources (e.g., major research institutions and operational agencies). The organizations in Level 3 may also add to CONNS by (i) providing analytical services to level 1 and level 2 providers; (ii) setting standards for data quality; and (iii) providing an interdisciplinary or larger time-space context for more robust interpretations of data.

In addition, level 2 and 3 participants may provide the support base for index sites. **Index sites** are ecosystems that are intensely monitored and where experiments are conducted on scales required to develop a predictive understanding of the processes controlling ecosystem change. The unique and critical aspects of index sites are as follows:

- Multiple variables and rate processes are measured on the time and space scales required to determine and model the causes and consequences of environmental variability and change;

- Baseline or reference conditions are established as a means to resolve long term change from short term variability;

- Procedures are developed to integrate diverse data from different sources collected on different time and space scales to visualize change in 4 dimensions;

- Provide incubators (test beds) to accelerate the development of new sensor technologies and dynamic models to test hypotheses and predict changes; and

- Transform technologies and models from research to operational modes to improve the capacity of the observing system to serve the needs of a broader mix of users.

Index sites provide a critical link between large-scale survey and monitoring programs and the basic research required to understand causal relationships and predict change in coastal waters. They may incorporate observatories or test beds. Some index sites may also function as **regional synthesis centers**. Index sites, such as coastal sites that are a part of the Long Term Ecosystem Research network (LTER), should be strategically located to determine how external forcings (e.g., inputs of water, sediments, nutrients, and contaminants from coastal drainage basins; changes in large scale ocean circulation patterns and wave spectra; atmospheric deposition) are propagated through and among coastal ecosystems and thereby cause change.

5.3.2 Global Network of Coastal Tide Gauges

The 1997 Implementation Plan for the Global Sea Level Observing System (GLOSS) called for the establishment of a global core network (GCN) of approximately 270 stations with a roughly even global distribution and of which approximately two thirds are in operation. The plan also defined sets of gauges for altimeter calibration, for the monitoring of long term trends in sea level and ocean circulation. The plan calls for data collection with delays of between 1-12 months and recognizes the importance of the global network to the calibration of satellite measurements. Many GLOSS stations are on islands in the deep ocean and it could be argued that they are not relevant to C-GOOS. Note however that sea level from island stations will feed into the deep ocean GOOS observing system and could, therefore, be useful in providing offshore boundary conditions for coastal models. In addition, many GLOSS stations are located on continental coastlines and provide a baseline global network around which denser local networks are constructed.

GLOSS has agreed in principle to measure selected C-GOOS core variables at gauged sea level sites. The most straightforward variables to monitor are air pressure, salinity and water temperature. Air pressure is particularly import in the analysis of sea level data because of the inverse relationship between air pressure and sea level, i.e., a 1 mb increase in air pressure is associated with a 1 cm decrease in sea level. (It should be noted that there has been a reduction in air pressure measurements by meteorological agencies for several years in the tropics, and the addition of the proposed new tide gauge sites might help to rectify this problem.) In some cases it may be possible to equip GLOSS stations with an observing kit (e.g., level 1 kits described above in the Coastal Observing Network for the Near Shore) which would include not only sensors for air pressure, salinity and temperature but also wind, waves, current, Chl-a, nutrient concentrations and optical properties. The advantages of such enhancements are obvious, and the approach is consistent with the GOOS design philosophy of building on existing infrastructure.

This collaboration with GLOSS will need an immediate follow-up from the GOOS Project Office in order to maintain momentum.

In addition to GLOSS there are a number of other groups undertaking work on sea level that is relevant to C-GOOS. For example, the International GPS Service for Geodynamics (IGS) is beginning to add continuous GPS to tens of tide gauges around the world. One goal is to define the absolute vertical position of the tide gauges to within a few cm in order to calibrate and validate measurements of sea-level by satellite-borne altimeters. Another goal is to measure the vertical velocity of the tide gauges on time scales of decades. If accuracies of better than 1mm/year over a 10-year period could be achieved it may be possible to separate the effects of vertical crustal movement from oceanic effects and allow for better predictions of sea level rise.

5.3.3 Fixed Platforms, Moorings and Drifters

There have been significant improvements over the last decade in the instrumentation for measuring water properties from fixed platforms, moorings, vertical profilers, remotely operated vehicles (ROVs), autonomous underwater vehicles (AUV), gliders and drifting buoys (Dickey *et al*., 1998; Glenn *et al*., 2000b). Routine measurements can now be made of position (using GPS) and of meteorological (wind, air pressure, temperature, humidity, incident solar radiation) and physical variables (water temperature and salinity, currents). *In situ* sensors are used in a research mode for fluorescence, transmittance, dissolved oxygen, turbidity, nutrients, and a variety of optical properties. Although many of these sensors are commercially available, they are not generally operational in the sense of being routine and providing guaranteed data streams. There have also been developments in telemetry that allow users to communicate with remote platforms to download data and change sampling strategy (e.g. Chavez *et. al.* 1999). The range is of order 100 km and so such technology is well suited to applications in coastal ecosystems.

There are several benefits of enhancing the distribution of, and instrumentation on, offshore moored buoys and fixed platforms. They include:

- Better predictions of extreme marine weather;
- Data on vertical distributions below the surface;
- Improved nowcasts and forecasts of wind and air pressure fields that can be used to drive hydrodynamic models;
- More rigorous calibration and validation of satellite remote sensing (e.g. winds, surface temperature, currents, sea level, ocean color) and continuity of data on cloudy days;
- An expanded data base of ocean variability which will improve our understanding of how the coastal ocean works, including ecosystem dynamics, and accelerate the development and validation of predictive models.

One group of offshore platforms that could carry additional sensors is the moored meteorological buoys used by the World Weather Watch to monitor atmospheric variability over the ocean (programs of the IOC-WMO Data Buoy Cooperation Panel). Another set of offshore platforms is the rigs used for hydrocarbon exploitation. EuroGOOS has already developed a monitoring network based on fixed structures in the North Sea. The objective of SeaNet is to establish a homogenous distribution of fixed monitoring sites, along with the online exchange of standardized and validated data, as a contribution to an integrated European marine monitoring and forecasting system. It appears that the SeaNet idea could be usefully extended to other regions.

Many research institutes, water authorities, oil and gas exploration companies maintain lines of quasi-permanent stations on critical sections along which hydrographic and biological variables are monitored. These data would also be usefully combined with the above measurements to provide estimates of integral fluxes of quantities like mass and nutrients along the shelves. Such fluxes, in combination with data from other sources, could be most useful in providing boundary conditions or limited area models of the shelf. Cross-shelf transects ("corridors") will also be needed to determine environmental trends and cross-shelf gradients between land and the open ocean.

Biofouling and rust problems are common in the ocean environment, and affect the quality of measurements taken above and below the ocean surface. In addition to frequent maintenance a few steps can be taken to minimize the problem. For example the use of anti-rust material can be helpful, as can the use of PVC films covering underwater instruments. Anti-fouling and anti-rust inks are common in the marine/naval industry, but the use of chemical products is not generally recommended for environmental or quality assurance reasons. Several new technology instruments, based on sound or electromagnetic field generation (e.g. ADCP, electromagnetic and acoustic current meters, conductivity sensors) are a more appropriate way to minimize both kind of problems, and are to be recommended. Copper has been found to be an excellent anti-fouling material, and is now being used, for example, to make shutters that protect optical sensors in the intervals between measurements. Another problem of unattended instrumentation is related with vandalism, which has been recognized as a major threat to observational systems by the international community. Both of these problems, vandalism and biofouling, may be solved to some extent through the use of bottom mounted profiling packages that spend a significant amount of time below biological active surface layers.

5.3.4 Ships of Opportunity and Voluntary Observing Ships

Ships of Opportunity (e.g., SOOP) and Voluntary Observing Ships (VOS) provide valuable oceanographic and meteorological data on a global scale. These ships make important contributions to the World Weather Watch and hence weather forecasting. To give an idea of the amount of data collected, the Shipboard Environmental Data Acquisition System (SEAS) program of the National Oceanic and Atmospheric Administration provides meteorological and oceanographic data in real time from ships at sea. SEAS equipped vessels provide as many as 80,000 observations per year. Most of NOAA's ships submit at least one SEAS report a day and some report as often as every 3 hours. The OOPC has included Ships of Opportunity and Voluntary Observing Ships as an important part of their observing strategy for the global ocean.

Turning to coastal ecosystems, two examples of how existing ships can be used to make cost-effective observations are the “Ferry Box” project of EuroGOOS and the Seakeepers Program. The former will take advantage of the more than 800 ferries operating in European coastal waters to monitor marine conditions along critical sections using an operational, autonomous instrument package (the so called “Ferry Box”). When fully developed, underway measurements will be made of sea surface temperature, salinity, oxygen, nitrate, sound velocity, fluorescence, light attenuation and light scattering. The International Seakeepers Society has been established as a non-profit organization to develop and deploy on private yachts, cruise ships, and other vessels an autonomous ocean sensing and weather monitoring module that will collect data on the marine environment and make it available in real time. The present module is advertised to monitor meteorological conditions, sea surface temperature and salinity, oxygen and redox levels, pH, C-DOM, turbidity, and chlorophyll. The module has gone through field testing aboard about 20 vessels during the boreal winter of 1999-2000. It is planned to install up to 500 fully developed monitoring modules by 2001. These approaches could be usefully extended to other regions to provide measurements that would complement those from fixed and moored platforms. Assuming that the problem of calibration can be properly addressed, routine measurement of conditions along critical corridors, sounds and straits would be particularly valuable to C-GOOS.

5.3.5 Remote Sensing from Satellites and Aircraft

A suite of satellites and satellite technologies is available for remote sensing of the marine environment. Active and passive sensors are able to detect visible (0.4 - 0.7 μm), infrared (0.7 - 10 μm), and microwave (0.3 - 30 cm) portions of the electromagnetic spectrum. Data from these ranges of the spectrum are used to detect four basic properties of the ocean: ocean color, temperature, height and roughness. Such measurements are used to measure surface distributions of core variables as follows:

- Ocean-color sensors monitor the spectral properties of water-leaving radiance in the visible domain to obtain information on the concentration of Chl-a in the surface layer of the ocean.
- Both infrared (IR) and microwave sensors are used to monitor sea surface temperature (SST). As for ocean-color, infrared sensors cannot see through clouds. Passive microwave sensors can measure SST through clouds but with less accuracy and spatial resolution.
- Microwave sensors can be used to detect sea surface height (ocean topography, altimetry), surface waves (altimeters and synthetic aperture radar, SAR), winds at the sea surface (ocean vector winds, scatterometry) and sea ice (SAR). Microwave radiometry may also provide the means to measure sea surface salinity.

In 1999, the IGOS Partnership established a thematic approach to the implementation of the Integrated Global Observing Strategy. The "Oceans Theme" was selected to initiate the process with remote sensing as the primary focus. The first report, “An Ocean Theme for the IGOS Partnership”, addresses remote sensing capabilities in two categories: (1) those for which the challenge is to sustain a long-term commitment to continued measurements and (2) those for which the challenge is to improve knowledge of ocean processes and remote sensing technologies. Ocean topography, ocean vector winds, ocean-color, sea ice, and sea surface temperature and salinity fall into the first category. The “knowledge” or research challenge encompasses a diverse range of problems that include developing the technology to measure surface salinity remotely and the algorithms required to calculate with known precision and accuracy phytoplankton pigments and productivity in coastal (case 2) waters (IOCCG, 2000).

In addition to temperature and salinity, remote sensing of ocean color (Table 5) and surface roughness are of particular importance to the development of C-GOOS. Ocean color can be used to estimate phytoplankton Chl-a. In turn, the concentration of Chl-a, in conjunction with data on incident PAR, can be used in models of light penetration and photosynthesis to estimate primary production. Ocean-color data can also be used in the study of some harmful algal blooms, plumes caused by point source inputs of pollutants, suspended solids, circulation features and the distribution and health of submerged attached vegetation and coral reefs to a limited extent. The European Union has established directives that require monitoring water quality indicators in coastal waters including transparency, color, and suspended solids. Ocean color sensors offer the potential of standard, cost-effective means to monitor compliance. Thus, ocean color provides data required to (1) quantify carbon flux, (2) couple physical and ecosystem models of the surface layer, and (3) manage water quality and fisheries. In the long run, a multi-decadal time series of biological and chemical properties in coastal waters is needed to provide the observational basis for understanding and predicting change in coastal ecosystems.

Table 5. Example application areas of coastal ocean-color data, requirements for spatial resolution and extent, temporal resolution, and examples of current or planned platforms and sensors meeting those requirements. From IOCCG Report No. 3. Additional details about the instruments can be found in IOCCG (1998, 1999).

Applications / Issues	**Spatial Resolution x Extent**	**Temporal Resolution**	**Examples of suitable platforms or sensors**
River plumes outfalls	(30 m - 1 km) x (300 m - 100 km)	Hours - weeks	GLI, MERIS, MODIS, NEMO, SeaWiFS
Tidal plumes, jets, frontal dynamics	(100 m - 1 km) x (1 km - 10 km)	Hours	Airborne, SEI
Harmful algal blooms, aquaculture, coastal water quality	(100 m - 1 km) x (1 km - 100 km)	Days - weeks	GLI, MERIS, MODIS, NEMO, SeaWiFS
Bathymetry and shallow benthic habitat: distribution, status	(1 m - 30 m) x (1 km - 100 km)	Weeks - months	Airborne platforms, ARIES, NEMO
Maritime operations: navigation, visibility	(30 m - 1 km) x (30 km - 100 km)	Hours - days	MERIS, MODIS, NEMO SeaWiFS
Oil spills	(100 m - 1 km) x (1 km - 100 km)	Hours - days	Airborne, MERIS, MODIS, NEMO, SEI
Operational fisheries oceanography	1 km x 1000 km	Days	GLI, MERIS, MODIS, SeaWiFS
Integrated regional management	(30 m - 300 m) x (30 km - 300 km)	Days	MERIS, NEMO

If the remote sensing of ocean color is to become an operational component of C-GOOS, two major challenges must be over come.

(1) The requirements for high spectral resolution, high spatial resolution (0.1 - 0.5 km), and high temporal resolution (< 5 days) must be met; and

(2) New algorithms must be developed for the more optically complex case 2 coastal waters (IOCCG, 1998, 2000).

In the 2000-2005 period, MODIS, MERIS and GLI will provide major advances in coastal water imaging and will meet many of the spectral and spatial requirements for case 2 waters. These sensors will also enable the development of new algorithms that are not possible from SeaWiFS. In these regards, the collection of *in situ* data to establish and validate robust case 2 algorithms will be critical to realizing the full potential of remote sensing in C-GOOS. The observational requirements for ocean color measurements in coastal ecosystems (submitted by the IOCCG to the CEOS/WMO Meta Data Base in 2000) are summarized in Table 6.

In addition, there is considerable uncertainty concerning the sustainability of an uninterrupted flow of ocean-color data into the indefinite future. At present, ocean-color data for coastal applications are not secure beyond the year 2005 (IOCCG 1999). Although the costs of sensors, satellite deployment, and algorithm development are high, the marginal costs of remotely-sensed products are low, and many global and regional products are distributed virtually free. Ultimately, it is expected that remotely-sensed products will be cost-effective for environmental monitoring. This will be especially important for developing countries.

Table 6. IOCCG observational requirements for the coastal ocean: horizontal resolution (Spatial), accuracy, observing cycle (Freq), and delay of availability (Lag) are all expressed as optimum/threshold values.

Geophysical Parameter	**Unit of Measure**	**Spatial**	**Accuracy**	**Freq**	**Lag**
Top of atmosphere radiance	W m^{-2} sr^{-1} μm^{-1}	0.05/0.5 km	% max=1% % max=2%	1 h/2 d	1 h/2 weeks
Water-leaving radiance	W m^{-2} sr^{-1} μm^{-1}	0.05/0.5 km	% max=1% % max=2%	1 h/2 d	1 h/2 weeks
PAR	W m^{-2}	0.05/0.5 km	3% 10%	1 h/1 d	1 h/2 d
Yellow substance absorbance (412 nm)	m^{-1}	0.05/0.5 km	10% 20%	1 h/2 d	1 h/2 d
Suspended sediment	g m^{-3}	0.05/0.5 km	10% 20%	1 h/2 d	1 h/2 d
Chlorophyll	mg m^{-3}	0.05/0.5 km	10% 30%	1 h/2 d	1 h/2 weeks

Remote sensing of surface roughness is also expected to become a key measurement for C-GOOS. Synthetic Aperture Radar (SAR) provides an all weather, high resolution (10 m to 100 m), wide swath (50 km to 500 km) capability to measure the physical roughness distribution of the ocean's surface. Any oceanic or atmospheric process that modulates the ocean surface roughness at the Bragg scale, a few cm for C-band SAR, can be imaged. This allows the following types of phenomena and processes to be monitored:

- Surface wind fields and wind effects;
- Ocean waves;
- Surface currents;
- Advection of natural surfactants;
- Shear and convergence zones.

There are a number of proven operational applications of SAR data including sea ice surveillance, vessel and iceberg detection, and detection of the location and extent of oil spills.

Unfortunately, the characteristic signatures of these processes may be ambiguously combined, with the dominant effect being the wind speed, especially for higher wind speeds (above 10 m/s as a rule of thumb).

There has been progress towards deriving quantitative information from SAR data. These include km-scale radial currents from Doppler frequency analysis of the backscattered signal and ocean surface wind fields from analysis of the radar cross section (providing wind speeds that are accurate to about 2 m/s, if the derived wind direction is good). Qualitative information from SAR data includes the location of oceanic and atmospheric fronts, storm effects (e.g. precipitation, storm center) and the state and downwind evolution of the marine planetary boundary layer.

Several problems arise in using SAR data for coastal surveillance. These include the large data volume for these high resolution, wide swath images and limited flexibility in acquisition tasking and possible long delays for repeat coverage (especially for an exact repeat). Certain applications suffer from specific problems. For example, non-linearity of ocean wave imaging means that inversion to the actual wave conditions is difficult. Finally, it is important to bear in mind that higher wind conditions could mask the ocean phenomena of interest.

Future missions include ESA's ENVISAT (launch expected in mid-2001), which will carry a wide swath C-band SAR as well as an optical instrument that has a swath that overlaps that of the SAR. This will present new data fusion opportunities for coastal zone surveillance. NASDA's ALOS (launch expected in 2003) will offer similar opportunities at L-band. RADARSAT-2, the follow-on to the RADARSAT-1 mission that is currently in operation, is currently being built and is scheduled for launch in 2003. RADARSAT-2 will offer all of the acquisition modes of RADARSAT-1, plus some new and important capabilities. For example, the polarization can be selected for any acquisition mode and some modes are fully polarimetric. Furthermore, some new ultra-high resolution modes (3 m with a 30 km swath) will be available. RADARSAT-2 will broaden the observation space for coastal applications and allow more optimal selection of imaging modes for this wide dynamic range environment.

5.3.6 Remote Sensing from Land-Based Platforms

Coastal monitoring systems using high frequency radars have been in development since the 1960s. These radars operate between 5 and 50 Mhz, and their measurement principle lies in analyzing the radar signal beams reflected from the ocean surface. The most developed systems use the so-called ground wave system, also referred to as CODAR, with a typical range of 30 - 40 km (up to 80 km), while the less developed sky wave system potentially can have a range of hundreds of kilometers. CODARS or similar systems thus have the capacity to cover fairly extensive areas and provide current and wave data with a spatial resolution of order 0.5 km. The range and resolution, however, depends on the radar working frequency and the bandwidth. In recent years, the high frequency (HF) radar data processing has improved greatly, enabling real time monitoring with a delay of less than 20 minutes. Typical output results are maps of areas surrounding for example a major port, showing current vectors and wave height/directions to customers within traffic management and search and rescue organizations.

From the early 1990s it also became clear that X-band radars could in some cases replace moored buoy systems in the coastal zone or close to platforms, provided no subsurface measurements were required. (HF radar estimates of currents should be interpreted as valid for the upper 1 meter of the water.) The measurement principle of the X-band wave radar is the digitization of the sea clutter image and a subsequent Fourier analysis in space and time. The system provides an area averaged directional/frequency wave energy spectrum and a corresponding estimate of the surface current vector.

Both HF and X-band radars have proven their potential in coastal oceanographic monitoring. There is a clear advantage to have the systems on land, which gives easier access in case of maintenance and repair actions. The major advantage, however, is the ability to cover fairly extensive areas, such as port approaches where accurate navigation of supertankers requires high quality current measurements, not only for a few locations, but in the form of a map, so shipmasters can read the variation of current over some distance and over some time along their route. The current map information also comes into play in cases of oil spill mitigation where relevant countermeasures are planned in order to protect certain vulnerable areas.

ADCP sensors, mentioned above, can also be considered a remote sensing technology that provides vertical and horizontal current profiles and wave energy as a function of time. Land-based radiometers can also be used to map out surface temperature over a range of a few kilometers. Finally, video cameras with time lapse capability can also be used to monitor variations in sea state averaged over several wave periods. This has allowed for example spatial patterns in beach morphology to be monitored and related to eternal forcing functions such as incident wave energy.

5.4 INTEGRATION OF THE OBSERVING ELEMENTS

As indicated above, it is envisaged that remote sensing, *in situ* observations and modeling will be closely related and interactive components of an integrated approach to detecting and predicting changes in the coastal environment. It is also recognized that the components, when judiciously merged, will complement each other in such a way as to provide a more comprehensive picture of the environment than would be possible otherwise. This is an important value added aspect of the observing system.

The time-space scales intrinsic to remote sensing differ significantly from those of *in situ* observations. Remote sensing provides the primary means to observe the ocean's surface at large synoptic spatial scales. *In situ* sensing provides the primary means to observe the vertical distribution of properties synoptically in time and space and is essential for calibrating remote sensors and for continuity. In general, time-series observations are more highly resolved by *in situ* than by remote sensing. Also, the number of required variables that can be estimated from remote sensing is small compared to the number that can be estimated from *in situ* sensing or from measurements made on samples collected *in situ*. These contributions of *in situ* measurements are especially important in coastal ecosystems which are characterized by significant variability at relatively high frequencies. **The integration of remote sensing and *in situ* measurements provides a powerful approach to accurately capturing variability in all 4 dimensions through inter-calibration, validation, and modeling**.

It must be emphasized that while remote sensing is the only tool by which truly global coverage can be obtained using the same instrument, there are limitations. Visible and infra-red sensors cannot see through clouds to the ocean surface. Only microwave sensors can do this. Simply masking out the clouded areas in thermal or ocean-color images can lead to serious biases in estimated quantities which increases the reliance on *in situ* observations or to low-flying aircraft to fill in the gaps in data.

An example of a coastal problem that clearly requires an integrated approach is the monitoring of HAB's. There is no simple relationship between ocean color and HABs. Although some types of HABs have the potential to be detected remotely (e.g. cyanobacteria in the Baltic Sea or *G. breve* along the U.S. coast), many harmful species cause problems at low concentrations, lack pigmentation (no optical signature), or develop in subsurface layers where they cannot be detected by remote sensors. Although the ability to distinguish between groups of phytoplankton by remote sensing is expected to improve with technology, these realities emphasize the importance of the integrated approach advocated by GOOS.

Merging disparate, discontinuous observations that are often mismatched in time and space is not a trivial task. This problem merits further investigation and it is proposed that the development of index sites will provide an important means to improve techniques for integrating the observing elements and for developing a predictive understanding of change. Remote and *in situ* sensing must also be closely allied with modeling. Data telemetered from these sources can be used (1) to initialize models of the marine environment, (2) for assimilation and, thereby, provide more accurate estimates of surface properties, and (3) to test and validate models. A hierarchy of models (statistical, theoretical, empirical) is envisioned as the means to address difficulties that emerge when observations made on different time and space scales are merged to provide a single, multi-dimensional view of change, e.g., combining precise, local, and vertically-resolved *in situ* observations with spatially-extensive, less precise, surface observations made by remote sensing.

6. COMBINING OBSERVATIONS AND MODELS

Observing and modeling coastal ecosystems are complementary activities that will require strong interactions among instrument developers, observationalists, modelers, assimilators and users if C-GOOS is to realize its full potential. Effective operational models depend on a steady flow of data that are both quality controlled and quality assured where quality control ensures that data meet certain standards and quality assurance refers to the documentation of quality control. The problem of data management is discussed in detail in section 7. The main point to make here is that **operational modes are critically dependent on routine access to reliable observations in a timely fashion**. Challenges that must be faced when developing operational models are discussed below in section 6.1. The following illustrate the benefits of synergy between observations and modeling:

- A storm surge model for the South China Sea running operationally giving 72-hour forecasts of total water level;

Forecasts are compared to emergency thresholds, and when exceeded, warnings are passed to emergency control centers that make decisions concerning the evacuation of people or other mitigation actions. A successful forecast may save hundreds or possibly thousands of lives. The evacuation and mitigation authorities contribute actively to the warning system by coordination of emergency procedures and facilitation of communication aids.

- A circulation model for a busy port and its approaches, providing routine hourly forecasts of surface flow one day into the future with a horizontal resolution of order 100 m;

The port model is nested within a larger shelf model that provides open boundary conditions in real time. The port model also refines its flow fields locally by assimilating hourly current vector data from an HF radar system. The model output is in the form of a current map provided to Vessel Traffic Central, which in turn gives navigational advice to supertankers trafficking the area. Accurate maps of currents are used to route ships and help prepare ship masters for sudden changes in currents, especially during passage through narrow entrances, and thereby avoid grounding with consequent oil spills and environmental damages.

- A coupled air-sea model forecasting seasonal and interannual variations rainfall patterns on continental to global scales based on oceanographic and meteorological data from the equatorial Pacific Ocean including *in situ* (TAO array) and remote (AVHRR; Topex/Poseidon) measurements of temperature and surface currents;

The value of such a system is illustrated by the onset of the 1997-98 El Niño event, which was detected in April 1997. Maps of the Pacific Ocean showed the progression of El Niño to its peak in November by which time unusually warm water had spread as far north as the Gulf of Alaska. Model runs during the early stages of the event forecast drought in Australia and Indonesia and excessive rainfall in the western regions of the Americas. Forecasts for the United States indicated a mild winter with greater than average rainfall in the southwest and west coast. Consequently, $2.2 billion U.S. less was spent on oil and gas, and agriculture production was disrupted at a cost of about $3 billion U.S.. Economists estimate the annual value of improved ENSO forecasts to the U.S. agriculture alone could be on the order of $250 million U.S. assuming that farmers change crops accordingly.

- A coupled drainage basin-estuary model that is used to predict the effects of a range of land-use scenarios on water quality, habitat loss and fisheries in the estuary.

Nutrient inputs to coastal ecosystems are increasing as a consequence of increases in the number of people living in coastal drainage basins and changes in land use. This is causing excessive accumulations of organic matter (often in the form of phytoplankton as indicated by Chl-a concentration), bottom water anoxia, and, possibly, harmful algal events and fish kills. Using LandSat imagery, areal photography, and Doppler radar, the spatial distribution of land cover, land uses, and rainfall are mapped. Using airborne LIDAR and *in situ* measurements of nutrients, changes in the distributions of nutrients and Chl-a in the receiving waters are mapped. This information is used by scientists to link land-use practices to changes in water quality and by coastal zone planners and decision makers to develop and implement a comprehensive plan for sustainable economic development of coastal drainage basins, clean water and the harvesting of living marine resources.

6.1 THE ONGOING DEVELOPMENT AND COUPLING OF NUMERICAL MODELS

Numerical modeling of the coastal ocean has matured to the point that there are now a number of operational systems that provide useful products to a large range of users (e.g. see examples above and Annex III). Most operational models currently in use forecast physical state variables such as sea surface height, waves, and currents. However, rapid advances are being made in modeling chemical and biological variables. It is important to emphasize that much work remains to be done to improve these models, particularly in the parameterization of processes for coupled physical-biological and physical-atmospheric models. In this regard, the development of robust models that can be applied to many ecosystems in different locations (global models for local ecosystems) will be facilitated by implementing mechanisms that enable modeling groups to compare the skill of different models, to share results and code, and to exchange personnel. This will be a particularly important component of capacity building in those countries that have yet to develop the required expertise.

Two approaches are commonly used in coastal modeling to increase resolution in areas of greatest interest: finite element modeling and nesting of finite difference models. A number of issues must be faced when using either approach, e.g., computational efficiency for finite element models and two-way interaction with nested, finite difference models. It is to be expected that these issues will become increasingly important as more comprehensive models of interactive physical-chemical-biological processes are developed. On the positive side, the ability to increase resolution in areas of special interest will eventually blur the distinction between "coastal" and "deep ocean" modeling. This will accelerate the integration of the deep ocean and coastal components of the observing system.

The advantage of "modularity" when coupling models of various types has long been recognized by the atmospheric community (e.g. for coupled atmosphere-wave-ice-ocean modeling). Considerable effort has been expended in the development of "couplers" that allow models to communicate with each other at different times (asynchronously). It is to be expected that modularity will also be an important feature of comprehensive coastal models that realistically simulate interactions among physical and ecological systems and among terrestrial and marine systems (e.g., linking drainage basin hydrology and nutrient transport to changes in water quality receiving waters; linking storm surge forecasts to land-cover in the coastal zone that modulates the extent of flooding). Couplers will allow various models to be added and removed from the system in order to assess their effectiveness and allow the observing system to improve in an orderly way. Expertise in the development and use of couplers should be made broadly available to accelerate the development of coupled coastal models.

6.2 THE IMPORTANCE OF DATA ASSIMILATION

Most operational coastal models require some form of data assimilation to ensure they do not drift too far from reality. The assimilation techniques presently being used range from simple data insertion and "nudging" based on multivariate statistical interpolation to more sophisticated techniques such as the "adjoint method" and "Ensemble Kalman filtering" (cf., Walstad and McGillicuddy, 2000).

Data assimilation is still a relatively new activity for oceanographers and a number of important problems remain to be solved. These include the following:

- The more sophisticated assimilation schemes require the typical magnitude and time-space scales of the observation and model errors to be specified. This is extremely difficult to do for complex, non-linear models.

- There is much to be gained by taking into account the time-history of oceanographic observations (e.g., sequences of satellite images) when assimilating data into ocean models. This approach however is computationally expensive and oceanographers are working hard to develop practical schemes in which the accuracy of the fitted model may be sacrificed for a much-needed increase in computational efficiency.

- Providing reliable statistics on errors for estimated fields is difficult for highly non-linear models. One solution is to use an ensemble of forecasts to determine the sensitivity of estimated quantities to initial conditions, boundary forcing or internal model dynamics (Robinson and Glenn, 1999). However, this approach is computationally intensive.

- Multiple data sets must be simultaneously assimilated into models with due consideration of their respective error structures and the multivariate aspects of assimilation. The development of multivariate assimilation tools is progressing rapidly in the open ocean where the number of variables is small. However, this will be especially challenging for coastal models where data from both *in situ* and remote sensing must be integrated.

- Data assimilation techniques are not yet used to help nest a hierarchy of models of different resolution. Although it has been shown that accounting for coarse model errors eliminates spurious numerical adjustments when higher resolution coastal models are initialized, such errors are rarely taken into account. More work is needed.

In addition to these challenges, assimilation requires knowledge of coastal ocean processes, statistics and numerical modeling. At the present time there is a shortage of highly trained personnel in most parts of the world (including North America and Europe). This is a serious impediment to the development of operational coastal oceanography, particularly for those indicators that require models of ecosystem processes.

6.3 DEVELOPMENT OF NUMERICAL MODELS FOR THE PREDICTION OF ECOLOGICAL PROCESSES

Numerical models of ecosystem dynamics have been developed and calibrated for several coastal ecosystems around the world (cf., Cerco and Cole, 1993; Franks, 1997; Robinson, 1999; Kudela and Chavez, 2000). They typically contain explicit representations of trophic interactions between nutrients, primary producers, bacteria and zooplankton. They can consider both benthic and pelagic subsystems and their interactions (e.g., Cerco and Cole, 1993). Most ecosystem models have been used in a hindcast mode to predict the response of phytoplankton and other components of marine ecosystems (e.g., HABs, zooplankton, benthic macrophytes, dissolved oxygen) to variations in nutrient inputs, PAR, and mixed layer dynamics. Limited experiences exist in assimilation of satellite color data and initialization with measured nutrients and phytoplankton biomass concentrations (e.g., Robinson, 1999). More extensive experience has been gained in the calibration of parameters of ecological processes using simple biochemical models and adjoint techniques. Such models should be interfaced with near real time data acquisition systems as discussed in the observing subsystem section of this volume and experimental forecasting should be initiated. Some relevant experience already exist for one dimensional physical models (models with the time and vertical space dimension only) interfaced to operational atmospheric analyses to compute fluxes at the air-sea interface.

6.4 THE DESIGN OF EFFECTIVE OBSERVING SYSTEMS

Effective operational models depend on a steady flow of data that are both quality controlled (ensures that the data meet certain standards) and quality assured (documentation of the quality control). The permissible delay in the provision of data is model-dependent. For the above port model a delay of more than a few hours would significantly degrade the value of the HF radar data in the forecasting surface currents. On the other hand a delay of tens of days would not seriously affect the value of subsurface hydrographic observations when providing seasonal forecasts of rainfall patterns using a coupled model. There are other reasons for making observations available in near real-time. For example, breakdowns in the observing system become rapidly apparent thereby allowing the problem to be fixed and long, almost continuous data records to be archived. Such records are most valuable for defining background variability and statistics for observation and model errors. They are also useful in processes studies that ultimately lead to better predictive models. Another reason for making data available in near real-time is that it will allow groups not directly involved in data collection to develop and test new systems that could add value to GOOS data (e.g., HAB forecast systems).

A validated assimilation scheme can be most useful in optimizing the design of the observing subsystem upon which it depends. This underscores the mutual dependence of observing and modeling the ocean, i.e., observations should not be conducted independently of modeling and vice versa. For example the so-called “adjoint method” of assimilation can be used to gauge the sensitivity of model controls (e.g., open boundary and initial conditions, mixing parameters) to the addition or deletion of observations at arbitrary locations within the model domain. In this regard, Observation System Simulation Experiments (OSSEs) are becoming increasingly popular in oceanography as way of assessing various sampling strategies. The model is first run with realistic forcing and model parameters. The output is then subsampled at times and locations at which the observations were sampled. These simulated observations are then assimilated into the model and the inferred field compared against the original field from which the “observations” were taken. This allows the efficacy of the assimilation scheme and sampling strategy to be evaluated (at least to the extent that the model is believed to be a reasonable representation of reality).

Although OSSEs and related techniques have not been used extensively in designing the atmospheric observing system, it is to be expected that, due to the cost of observing marine ecosystems, they will become increasingly important in improving the initial C-GOOS observing subsystem design. For example, it is now possible to use surge models to determine the optimal locations of tide gauges in order to maximize skill in forecasting sea level at critical locations. As coupled physical-biological-chemical models and data assimilation techniques are developed and proven, it will be possible to use them to determine (1) optimal combinations of variables to measure and (2) the optimal time and space scales for the measurements to be made. Given the diversity of variables of interest (sea level to phytoplankton pigments) and sampling constraints, this will not be a trivial exercise but one with a huge potential pay off.

6.5 ASSESSING THE SKILL OF MODELS

As coastal oceanography becomes more operational it is essential that a common system be developed for the quantitative assessment of models. This is fairly straightforward for variables such as sea level where the standard deviation of the difference between observation and prediction, perhaps scaled by the standard deviation of the observation, is the natural measure of skill. It is more problematic for variables such as sea surface temperature. Consider for example a model that predicts perfectly a surface temperature distribution except for a slight error in the location of a strong thermal front. Clearly, the standard deviation of the difference between observation and prediction will be large which suggests no skill even though the model has correctly predicted the existence of the front and perhaps its orientation. We can expect the problem of skill assessment to become more complex with the addition of biological and chemical variables to the observing system. It is therefore essential that the issue of skill assessment be addressed if models are to reach their full potential and be used to optimize the design of the observing subsystem.

Skill indices have been developed in the past 30 years for numerical weather prediction (NWP) models, and they should be applied to the assessment of ocean forecasts much more than they have been to date. It is important to consider anomaly RMS and correlation indices rather than full signal indices since models estimate the variability well but produce climatological means that are not consistent with observations. The development and study of skill scores such as tendency RMS and correlation scores and persistence versus forecast scores are important considerations in the quantitative assessment of model forecasts and intercomparisons.

7. COMMUNICATIONS NETWORK AND DATA MANAGEMENT SUBSYSTEM

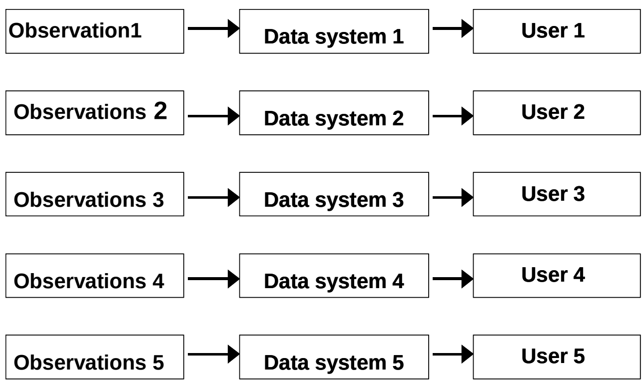
C-GOOS is intended to serve a wide range of users of environmental data products, and many applications will require timely access to and integration of data from a diversity of sources. The observing subsystem must capture the spectra of variability that characterize coastal indicators (Table 2) and the core variables required to measure them (Table 4). Thus, the observing subsystem will be multidisciplinary and multidimensional. As such, the data streams will include physical, biological, chemical and geological data that are input from *in situ* and remote sensors and from laboratory analyses of samples collected from fixed platforms, drifters and ships. Some applications will require real time or near real time inputs.

7.1 OBJECTIVES

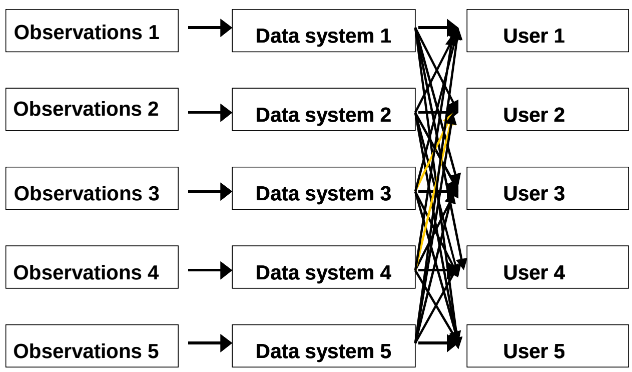
In the past, programs of environmental research and monitoring were developed independently, case-by-case by different groups to address specific issues and mission based goals (Figure 3a). Consequently, there are a plethora of programs in coastal ecosystems that employ different platforms and methods, make measurements on different time and space scales, and use different data management schemes designed for the purposes of a particular agency, institution, or program. As the multi-disciplinary nature of most environmental issues became clear, efforts to collate and integrate data from a variety of disparate sources have increased (Figure 3b). Under present conditions, this is an expensive and time consuming process that inhibits the timely analysis of data and severely limits the development of a predictive understanding of change in coastal ecosystems. The objective is an integrated system that allows users to exploit multiple data sets from a variety of disparate sources through one stop shopping (Figure 3c).

Figure 3 . End-to-end data management:

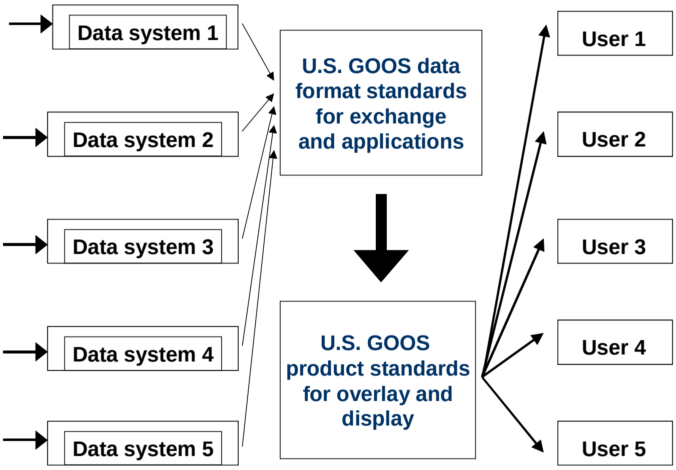
(a) Historically, programs were developed independently by different groups to address specific issues and mission based goals;



(b) As the interdisciplinary and multidimensional nature of environmental indicators (Table 2) became clear, efforts to collate and synthesize diverse data from disparate sources have increased. Under current conditions, this is an expensive and time consuming process that inhibits the timely analysis of data and severely limits the development of predictive capabilities.;



(c) The objective is an integrated system that allows users to exploit multiple data sets from many different sources through "one stop shopping." The linkages between measurements and data integration are internal to the observing system and transparent to users



A well planned and coordinated approach to data management is vital if coastal GOOS is to achieve its goals. The magnitude of the challenge of developing an integrated data management system is indicated by the number and diversity of currently functioning national and international data management programs. Thus, the development of a comprehensive data management plan will be a formidable task. This is not the purpose of this exercise. Rather, the objectives are to:

- Raise awareness of generic data management issues;
- Formulate guidelines for the development of an overall framework for C-GOOS data management and data flow;
- Describe the scope of C-GOOS data types and initial possible variable datasets;
- Recommend mechanism for maintenance and assessment of the observing system;
- Provide guidelines for capability building in data management.

7.2 DATA POLICY

A basic premise of C-GOOS is that data on regional to global scale environmental variability are locally relevant to decision makers, e.g., neighboring countries have more to gain by freely exchanging data than they do by restricting access. Free exchange of meteorological data (at the cost of retrieval only) is encouraged by the WMO through the World Weather Watch and WMO Resolution 40 and by the IOC (IOC, 2000). The same requirements exist for the exchange of oceanographic data, e.g., in support of the Safety of Life At Sea (SOLAS) Convention and the United Nations Framework Convention on Climate Change (UNFCCC), and the Programme of Action for Sustainable Development (*Agenda 21* of UNCED, 1992).

Free and timely access to data on the marine environment is just as important to the success of C-GOOS.

The management, processing and distribution of C-GOOS data will be based on guidelines that are in accordance with the GOOS Design Principles (see Section 1.4). In particular, GOOS Design Principle D6 states that:

"In concert with the policies of IODE, IGOSS and GCOS, and following the data management plan for the World Weather Watch of the WMO, commitment is required by GOOS participants to establishing, maintaining, validating, making accessible and distributing high quality, long term data meeting internationally agreed standards. Preservation of GOOS data is required in suitable archives following appropriate procedures and criteria for data acquisition and retention, and should include information about data holdings. Data should be processed to a level which is generally suitable for the generation of operational products and for research, and described in internationally accessible on-line computerized directories that can also be made available by other means. GOOS contributors are responsible for full, open and timely sharing and exchange of GOOS-relevant data and products for non-commercial activities. Exchange implies that donation by individual nations gains access to data from others as well as products derived using all available data, such that the benefit of cooperation exceeds the cost."

Accordingly, the C-GOOS data and information management plan will be based on the following guidelines:

- Full and open sharing and exchange of C-GOOS relevant data and products for all C-GOOS users is a fundamental objective. Data should be provided in a timely manner and at the lowest possible cost (i.e., cost of providing or retrieving data; data are not to be sold for profit).
- Preservation of all data collected by C-GOOS is required. Suitable archive facilities should be ensured for all C-GOOS data sets. As part of the end-to-end information framework, all C-GOOS data sets should have one or more designated data custodians, who have the capacity and responsibility for long-term data storage and access.
- Procedures and criteria for setting methods for data acquisition, retention, and purging should be developed and implemented by participating nations. An international clearinghouse process should be established to prevent the purging and loss of important data.
- All data-sets should be subject to comprehensive and well documented quality control and quality assurance procedures. Descriptions of the quality level of each data set should form part of the meta-data associated with those data.
- To the maximum extent possible, data archives must include easily accessible information about the data holdings (meta-data), including quality assessments, supporting ancillary information, and guidance and aids for locating and obtaining the data.
- Internationally agreed standard protocols should be developed for the acquisition, processing, archiving, and distribution of both data and associated meta-data.

- As appropriate, all C-GOOS data should be processed to a level which is generally useful to users without a detailed knowledge of the observing instrument. However, for data from those instruments that utilize sophisticated algorithms for this processing, archives must be adequately maintained to permit recalculation of the geophysical and bio-optical data as improved information or methods become available.
- All data and products pertinent to C-GOOS should be described in internationally accessible, on-line computerized directories which conform to agreed standards. C-GOOS data centers or institutions which are unable to host such directory services should provide detailed, standard descriptions of their C-GOOS data sets (and preferably the data sets themselves) to centers which do have such an ability.
- Users of C-GOOS data must acknowledge the source(s) of data and information in an appropriate manner. Data management centers will maintain data bases of end users, applications, derived products, and publications.
- Data streams will be monitored to ensure that they are routine and reliable. Users will be encouraged to provide feedback on the quality and timeliness of data product and provide suggestions for improvements and for new products.
- Data communication and management networks will be harmonized between all elements of GOOS on national, regional and global scales to allow for local variation in data management practices.

7.3 INFRASTRUCTURE

7.3.1 Overview

The goal is to establish a multinational data and information management system that ensures timely dissemination of quality data and data-products in response to user demand on local, regional and global scales. It must be true to the GOOS design principles (e.g., free and open access to data) and it must (1) consider the needs of end users in the initial design; (2) incorporate appropriate meta-data standards (including quality assurance); and (3) develop mechanisms for monitoring and assessing the reliability of data flows and the usefulness of data-products. In practice, the initial data management system will grow in an incremental way by linking and integrating existing national and international communications networks and data management programs that collect and manage the data types (Table 4) required to quantify and predict variations in coastal indicators (Table 2). Several end-to-end systems may develop, each contributing one or more data types and providing data to other parts of the global system as required. Each of these systems is likely to involve several organizations with varying expertise and emphasis in operational data assimilation, modeling, data dissemination, meta-data standards, archival, and product development and distribution. The challenge will be to develop an integrated network that can adapt to accommodate development of new requirements and capabilities as the full end-to-end system evolves.

C-GOOS data management and communication mechanisms must recognize the multiplicity of data sources and data types, the multiplicity of users and their varying needs, and the overarching concerns of quality assurance, timeliness, and ease of access to data and data products. For a significant range of data sets related to the fields of meteorology and physical oceanography, the World Weather Watch (WWW) of the WMO, and the Committee on

International Oceanographic Data and Information Exchange (IODE) of the IOC represent existing communication and data management structures that should be adapted to manage all meteorological and physical data from coastal ecosystems. However, international (and often national) mechanisms are generally lacking for many types of geological, chemical, biological and ecological data. There is a clear need for many of the existing data management programs to increase their capabilities in these areas not only to collate and integrate existing data, but also to accommodate increases in the volume of data and the number of data types as user needs become better defined and the diversity of data products increases. This is likely to be a long term process.

7.3.2 Levels of Data Management

The data communications and management structure is envisaged as a hierarchy consisting of three levels: local, national, and supra-national (Figure 4). Data and information are disseminated laterally within levels and vertically among levels. In some cases, Level III data management and **synthesis centers** may perform the functions of level II institutions, e.g., in those cases where individual nations do not have the capability to establish NODCs or Responsible Local Data Centers (RLDCs).

C-GOOS Data Flows & Management

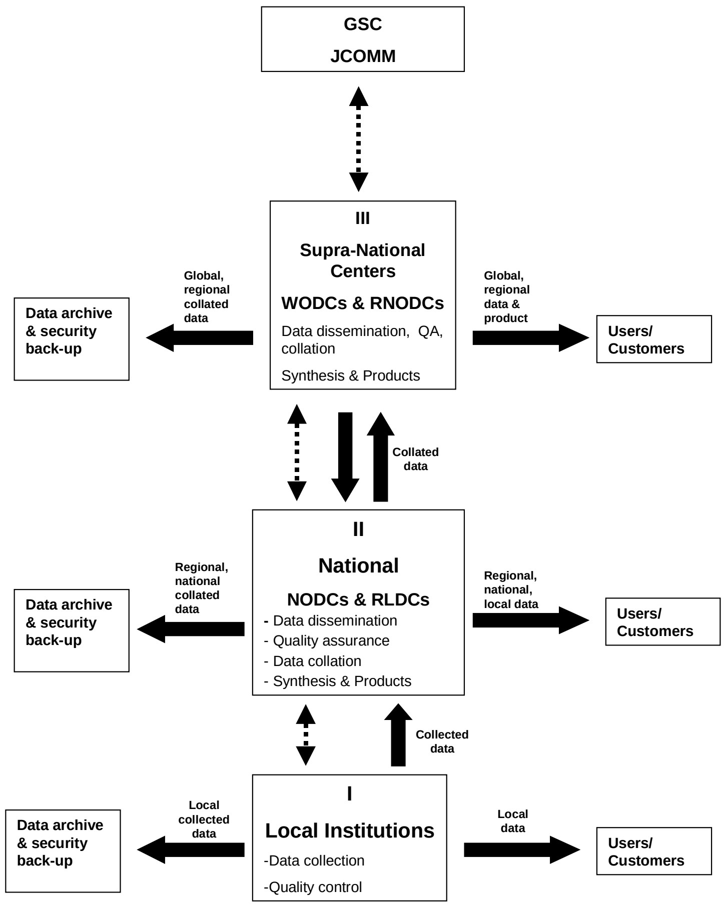


Figure 4. Schematic of the communications network and data management subsystem of C-GOOS. Data and meta-data streams are indicated by the solid, one-way arrows; system maintenance and assessments by the two-way, dotted line arrows (JCOMM - Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology, WODC - World Oceanographic Data Center, RNODC - Responsible National Oceanographic Data Center, NODC - National Oceanographic Data Center, RLDC - Responsible Local Data Center).

7.3.2.1 Level I: Local

This level consists of those organizations that collect, process, and provide quality control of the data. Organizations that are a part of the C-GOOS network will also be responsible for data dissemination and, in some cases archival. This network will provide the infrastructure for distributed environmental data bases located at participating organizations to provide data and data products via the web. In the coastal context, there are a very large number of such organizations, with widely differing capacities. The functions performed by an organization participating in the C-GOOS network need to include:

- Sustained collection of data on one or more core variables (Table 4) and variables measured as a part of regional enhancements.
- Quality control of the data.
- Provision of network access to data sets in a time frame that is appropriate to the application.
- Provision of network access to comprehensive meta-data for all data sets collected by participating organizations.
- Timely delivery of data sets, and associated meta-data, to higher levels in the data management structure.

> LABNET, an initiative of the U.S. National Association of Marine Laboratories (> 120 coastal research institutions), is an example of a Level I data management system. It is a distributed data management system that links data bases at participating coastal laboratories to provide visually integrated environmental data on temporal and geospatial scales via the World Wide Web. The purpose of LABNET is to provide the means to access, exchange and integrate data residing at individual coastal laboratories to analyze and visualize data to address specific problems, i.e., **the intent is not to manage all data from coastal monitoring and research programs but to serve data required to address a problem or issue defined by end users**. The infrastructure consists of 4 layers:
>
> - The data source layer where data reside and are accessible via the Internet;
> - The meta-data layer required to retrieve data (uses a robust data description standard, the FGDC meta-data format) using standard means (http, Z39.50 retrieval protocol to query meta-data and data);
> - The integration layer that contains a data base of known data sources that comprise a LABNET integrated data set and provides the means to (i) locate and communicate with the meta-data layer, (ii) to query and extract relevant data from the data source, (iii) to normalize different data sources according to the information provided by the meta-data layer, and (iv) to process data into a form that can be used by the output layer; and
> - The output layer which processes and presents data in a form that can be used by the end user (e.g., time-series or frequency distribution, numerical model output, GIS output).
>
> Participating laboratories will have different capabilities and become a part of LABNET at one of 4 levels:
>
> - Level 1 suppliers - Laboratories and organizations that have data they wish to make available but are unable to serve the data from their own facility;
> - Level 2 suppliers (data server) - Have data and the means to disseminate them to levels 3 and 4;
> - Level 3 suppliers (data and index server) - In addition to level 2 capabilities, provides the indexing and meta-data tools required to locate and integrate diverse data from disparate sources; and
> - Level 4 suppliers (regional nodes) - In addition to level 3 capabilities, a small number of institutions (currently located in the northeast, southeast and southwest sectors of the U.S. coastal zone) lead the design and evolution of LABNET.
>
> Level 1 suppliers will collaborate with a level 2 or higher supplier to make their data available to LABNET. The resources required to index, locate and integrate data from a level 2 supplier will typically be provided by level 3 or level 4 institutions. Level 4 institutions provide training services to institutions in levels 2 and 3.

There may be cases where an organization is collecting C-GOOS data sets, but is not able to perform some of the functions outlined above. In such cases, mechanisms should be identified that will enable participation, e.g., through capacity building or by providing the means to communicate data to a site that has the above capabilities. The importance of quality control being the responsibility of data providers cannot be overemphasized.

7.3.2.2 Level II: National

This is the first level in which diverse data types from many different sources are collated and quality assurance occurs (including certification of *in situ* and remote sensors to guarantee the level of reliability of data). For the most part, level II data centers will not be responsible for the development of data-products. However, the data management system must be designed to be responsive to user needs. Clearly, this will be an evolving process in which experience and new knowledge results in more and better products. The primary function of a Level II Center is to:

- actively seek and acquire quality controlled data from national sources;
- develop and implement quality assurance procedures based on international standards;
- effect the timely exchange of data of known quality among Level II Centers;
- inventory and archive quality assured data in accordance with international standards and protocols; and
- communicate data and information vertically to other levels as appropriate.

For those countries that do not have NODCs, a national coordinator for C-GOOS data management should be designated to develop procedures for performing these functions (e.g., identify Responsible Local Centers, work with existing NODCs or with Supra-National Centers to perform these functions). One center at this level may be designated as a “lead center” that is responsible for reporting chronic data quality problems to the Global Steering Committee as the first step in resolving problems of quality assurance. This function may also be performed by a Level III Center.

7.3.2.3 Level III: Supra-National

Supra-National Data Management and Synthesis Centers are needed for global scale observations, to serve key regions, or to address key issues. Level III Centers would:

- collate data from Level II Centers and directly from marine and coastal science organizations and individual scientist;
- establish international data standards and exchange protocols;
- monitor the performance of the international data exchange system and report their findings to the Global Steering Committee and the IOC Secretariat;
- establish global data bases;
- enable problem-specific data synthesis;
- establish online services to provide data and data-products to users; and
- provide an information directory of products and services.

Such centers would become the building blocks of a global network of data management and synthesis centers, the functions of which would be coordinated by a Global Steering Committee. The World Oceanographic Data Centers (WODCs) established by ICSU provide one model that could be used to guide the development of infrastructure, policies and procedures for the dissemination and management of C-GOOS data. The possibility that the WODCs could incorporate the C-GOOS Level III data management system cannot be ruled out at this time.

The Global Telecommunications System (GTS) was established for international exchange of atmospheric data among national weather centers for numerical weather predictions. It operates in broadcast mode and is also used to transmit gridded analyses and model fields to other centers. The data and fields are inserted and distributed with regional or global headers that determine the extent of the circulation. The weather centers know what is being transmitted and are programmed to copy data for the headers of interest. Access to GTS is restricted to national weather centers and a few commercial enterprises that produce weather forecasts and engage in ship routing. The user interfaces vary from country to country. Data types include surface meteorological and upper atmosphere data, sea surface and some subsurface physical data, and sea level. Data may also be transmitted via GOES or communications such as INMARSAT to land-based sites that could provide data to the appropriate C-GOOS center via the GTS or the Internet. For data that are not required for weather forecasts and warnings, dissemination via the Internet may be more efficient.

7.3.3 Data Streams

The nature and types of data sets needed in each coastal setting will depend on the requirements of both the global network and on regional enhancements of the network (see section 5.1). Thus, the range of data types that will be collected and applied to the coastal zone is large (Table 4, Annex III), and data may need to be acquired from a large number of the different data sources depending on the application. Both data providers and users will need to have access to the C-GOOS network at any of the levels described above (Figure 4).

Timely access to data and data-products at each level require that data flows efficiently from measurements to end users and, concurrently, into distributed archives for retrospective analysis. If this ambitious goal is to be achieved, standard interface and meta-data formats must be defined (where “format” refers to the digital arrangement of the information). Meta-data formats are those that specify the information (e.g., source, methods, instrument calibration, data quality, where and when the data were collected) that must accompany data to render it useful. Interface formats include exchange formats (to extract data from existing data bases and format them into an integrated data base for application purposes) and product formats (that allow data from application centers to be overlaid, merged, and jointly visualized or used to make a prediction). Geographical information systems (GIS) and numerical models are powerful tools for the latter.

It is beyond the scope of this document to discuss the many ways in which institutions may transfer data from measurement sites or instruments to their home institutions or data centers. However, for certain types of platforms, internationally accepted methods exist that should be explored as possible models and building blocks for developing the fully integrated data management subsystem. For example, meteorological and physical data from moored platforms and drifters are commonly transferred to several of centers via the ARGOS network (a CNES-NASA-NOAA satellite based system for data collection and platform location). The data collected by ARGOS can be transferred directly to the Global Telecommunications System (GTS) if it is a data-type for which a GTS format exists and data processing via ARGOS for that data-type includes the GTS formatting routines.

Although C-GOOS must explore the incorporation of existing frameworks for the transfer and archival of environmental data, GTS is only one option. It is not an integrated system, and it may be most effective to restrict the use of GTS for data required to make weather forecasts and issue warnings. In addition, Level I institutions and users of data at this level will most likely be linked via the Internet. It is highly unlikely that every organization will choose to use the same data base software to manage their data, so standard protocols for data exchange will be needed which can be overlaid on both existing and future software packages. Where existing standards exist, they should be used if possible.

One possible way forward is for each participating organization to identify a technical contact who will be responsible for installing and supporting a package of appropriate technologies to enable their laboratory to store and access specific environmental data. Because organizations have a wide array of technological infrastructure and personnel support, a variety of options for the submission and maintenance of the environmental data must be developed, e.g., all data providers and users may not have access to the Internet and other mean of communication may have to be used. A system must be designed that will allow cooperating organizations to easily measure, maintain, and submit targeted environmental data, both "real time" and historic data sets, to a system which can then collate those data and make them available on the web.

7.3.4 Examples of Hierarchical Management Schemes

Programs that exhibit some aspects of this 3-tiered approach to data management include the CEOS and GBIF meta-data systems (global scale), BOOS and NEAR-GOOS (regional scale), and the GCRMN (key issue). These are summarized below.

(1) The Committee on Earth Observation Satellites (CEOS) has established a meta-data base as means of linking data providers and users. Information in the data base include the following: (i) summaries of user requirements; (ii) summaries of potential performance capabilities of satellite instruments; (iii) instrument and missions descriptions in sufficient detail to support performance evaluations; and (iv) programmatic information to permit assessments of continuity of observations the degree to which data-streams are routine. Data are categorized according to standard meteorological conventions as follows:

- Level 0 - Unprocessed instrument data at the original time-space resolution in chronological sequence with duplicate packets removed;
- Level 1 - Level 0 data that have been reformatted with geolocation data and radiances or irradiances calculated using the appropriate calibration algorithms;
- Level 2 - Geophysical parameters or environmental observations retrieved from Level 1 data by application of parameter algorithms at standard projection;
- Level 3 - Earth gridded geophysical parameter data that have been averaged, gridded or otherwise rectified or composited in time and space;
- Level 4 - Geophysical parameters that have been derived from Level 3 products, usually involving complex model calculations.

The CEOS has requested that users and providers give their requirements and performances in terms of Level 2 products where ever possible.

(2) The Global Biodiversity Information Facility (GBIF) was established in 1999 by the science ministers of 29 nations. The development of a system that enables access to existing data on species distributions and abundances and into which data collected in the future is a high priority. The working group report of the Organization for Economic Cooperation and Development (OECD), identified 3 major areas to be addressed:

- coordination of new software development that link data bases which embrace the full range of biodiversity information (including geographical, ecological, genetic and molecular data);
- digitization of all biodiversity information; and
- compilation of definitive lists of species.

The Sloan Foundation and the U.S. National Oceanographic Partnership Program wish to participate in the marine component of the GBIF by forming the Ocean Biogeographical Information Systems (OBIS).

(3) The Baltic Operational Oceanographic System (BOOS) is a collaboration between national government agencies of the nine countries surrounding the Baltic Sea that are responsible for observations, modeling and the production of forecasts, services and information for the marine industry, public and other end users. BOOS was initiated by the EuroGOOS Baltic Task Team. The development of a common Prototype Ocean Data Analysis System (PRODAS) for exchanging, managing and analyzing data is the highest priority for 1999 - 2003 (Buch and Dahlin, 2000). PRODAS is an example of a Level III data management effort. The data exchange component is addressing two problems:

- Clarification of the legal issues that constrain the free and timely exchange of data- and
- Design and implementation of technical solutions.

A BOOS Information System (InfoBOOS) is being developed for timely data and information exchange. InfoBOOS consists of two interfaces: (i) a user layer that interfaces between users that require specific oceanographic services and the agencies responsible for providing these services and (ii) the provider layer which consists of a network of servers distributed among different agencies that employ models to translate data into useful applications in response to user needs. Universal data-algorithm transfer protocols are being developed to link provider and user layers. Interagency (multilateral) data exchange has been initiated via the Internet using a system of ftp-boxes into which participating institutions enter data to be exchanged among the partners (the system is protected by user names and passwords).

(4) The Global Coral Reef Monitoring Network (GCRMN) is an example of a Level I monitoring system. Coral reef ecosystems are important to millions of people as habitats that support the production of high quality protein and pharmaceuticals, protect fragile shorelines from storm damage and erosion, provide the raw materials for building and maintaining white sand beaches that support the tourist industry, and support a rich diversity of marine organisms. Coral reefs are in serious decline throughout the tropics and subtropics due, in part, to human activities. Effective mitigation of this trend can only come through the involvement of user groups and through greater public knowledge of the status of reefs and the factors responsible for the loss of coral reef habitat. To these ends, the GCRMN was established in 1997 as a global network of local institutions that have taken on the responsibility of monitoring coral reefs and related socioeconomic activity in their respective regions. Data from local institutions are distributed laterally to each other and vertically to the International Center for Living Aquatic Resources Management (ICLARM) in Manila that functions as a Level III data management center. The initial product of this program is an annual assessment of the status of coral reefs, the first of which was issued in 1998 (Wilkinson, 1998).

7.4 DATA AND INFORMATION TYPES

7.4.1 Meta-Data

Of extreme importance is the establishment of a standard meta-data system that provides the documentation required to make numerical data useful to end users. A distinction is made between “directory level” meta-data and “archive level” meta-data. Archive level meta-data provides the detailed, technical information needed to understand the precise characteristics of the data and to assess their adequacy for a particular application. This level of meta-data includes a description of the project or program (spatial and temporal extent and resolution), a description of the variable, units of measure; the name, type and location of the station at which data were collected; period(s) of observation; instrument(s) and platform used; measurement procedures; algorithms used to convert raw data; the frequency of calibration; level of processing (raw, interpolated, converted, averaged, model output, etc.); type and level of quality control; codes and formats used; availability of the data; and responsible institution or person. Directory level meta-data is a subset of archive level meta-data and provides the general descriptive information needed by a prospective user to identify the data set in a high-level catalog or listing of C-GOOS data sets. This would include information such as the specific variables and geographic area observed the time and frequency of observations, and the duration of the observation periods. It should also provide information on location, contacts, and access procedures/constraints. Individual institutions participating in the observing system must be responsible for compiling the meta-data that will be collated into the “global” meta-data system for the entire network.

7.4.2 Numerical Model Data

Management of numerical model data is not a new experience for meteorological and oceanographic agencies. Meteorological centers have been exchanging model output data for decade on GTS and some oceanographic centers have been dealing with gridded data sets for a number of years. For C-GOOS, numerical model data will eventually have to flow in an operational mode from modeling centers to various users and other analysis centers. Some modeling data will be appropriate for long term archival for future users. As well, some archived results will from time to time be made redundant by re-analysis projects. Decisions will have to be made as to whether the old version in fact has been replaced by new or if both should be retained. Formats need to be designed and meta-data standards developed to ensure that model results that are archived will be usable into the future.

7.4.3 Real-time and Delayed Mode Data

The data management subsystem must be amenable to differences in modes of data transmission, assimilation, analysis and use. For example, the climate research community needs very high quality data without urgency, whereas the operational forecasting community needs data immediately following its measurement, and may be willing to sacrifice some quality in exchange for timeliness. When several communities require the same data on the same variable (e.g., sea surface temperature), the data management system must be able to accommodate the constraints of both real-time and delayed mode access. This can be achieved if users have access to all levels of data management (Figure 4), e.g., Level I for real-time applications and Level III for high quality, delayed mode applications.

7.4.4 Quality Assurance and Quality Control (QAQC)

C-GOOS data will be generated by measurements made by different laboratories, programs, and governments, and QAQC procedures must be developed that ensure data are comparable irrespective of where and when measurements were made and that they are sufficiently precise and accurate to detect changes in coastal indicators (Table 2). Quality control refers to the procedures employed by a laboratory to ensure that data meet quality standards. Quality assurance is the documentation of quality control. In most cases, quality control will occur at the source (the responsible individual or institution) while quality assurance may take place at Levels II and III in the data management hierarchy. As discussed above, the level of quality control may be time-dependent or may occur at higher levels in the data management system, e.g., data that are accepted or rejected based on their fit when assimilated into numerical models. Thus, there will be multiple levels of quality control depending on the application.

The development of QAQC procedures for C-GOOS must meet the following requirements:

- Measurements are made by well trained and motivated personnel who understand how the data are to be used;
- The sampling program is designed to provide data that are representative of the populations sampled (in both time and space) and to ensure that the appropriate meta-data accompany each sample;
- Instruments are routinely calibrated against reference standards; and
- Calibrations are derived from authentic standards.

Meta-data should include information on the environmental conditions under which samples were collected and measurements made that are needed to interpret the data. In order to maintain confidence in the reliability of data, those responsible for making measurements must regularly participate in intercalibration and intercomparison exercises and should be willing to subject its sampling and measurements procedures to external vetting.

A QAQC plan should be developed for each variable measured as part of C-GOOS. These plans should specify standards for short-term accuracy and long-term stability. Although manuals that describe materials and methods should be routinely published, it should not be necessarily prescribe the precise method of measurement. This should make it possible for more countries to participate, and it encourages the development of improved methods. QAQC plans should include intercalibration and intercomparison exercises for each variable as well as procedures for validation and verification. In this regard, numerical modeling can be an effective tool for quality control by providing the means to test for internal consistency of complex systems (e.g., mass balance of material flows among ecosystem components and pool size of each component). Differences between first estimate predictions and observation made at several intervals over time can also provide a sensitive test for biases, calibration drift and outliers.

7.5 PROVISION AND EVALUATION OF DATA SERVICES

Two important aspects of the data management subsystem are timely access to and analysis of data in response to user needs. Data management must be maintained and upgraded to ensure continuity of the data streams and the routine provision of high quality data and data-products. Performance must be monitored and evaluated in these terms. Procedures to monitor the quality of the data must occur as close to the source of the data as possible to ensure precision and accuracy. The continuity of data streams and access to data must also be monitored regularly. Evaluation, maintenance and enhancements should occur at all levels in the data management system, and procedures must be developed to ensure that information on quality and data flow is exchanged between each level of the data management hierarchy. Finally, as the observing system develops and matures, mechanisms should be established by which end users are able to provide critical feedback on the timeliness and quality of the data and analyses provided by the system.

8. PILOT PROJECTS

Pilot projects are organized, planned sets of activities with focused objectives, a defined schedule, and a finite life time that are expected to produce results that significantly benefit the global ocean observing system in general and C-GOOS in particular. The purpose of this section is to illustrate the kinds of pilot projects that will be needed to begin the development of the coastal component of GOOS in terms of both the global network and regional enhancements that are responsive to regional needs and capabilities. More detailed accounts may be found in Annex V. It should be emphasized that **mechanisms have yet to be established for the identification of projects as GOOS pilot projects, for international coordination of pilot projects, and for insuring that such projects develop according to GOOS principles and internationally accepted standards**.

8.1 VIETNAMESE FORECASTING SYSTEM

Between about 400 - 800 people/year are killed by storm-surge flooding caused by surges in Vietnam. This project aims to establish a forecasting system for storm surges caused by typhoons in the South China Sea (SCS). The project has been initiated with the deployment of 4 moored buoys instrumented to measure meteorological variables (wind speed and direction, air pressure and temperature) and waves (height and direction) along the coast of Vietnam. A circulation/surge numerical model and 4 modern tidal gauges have been selected among several qualified providers in the commercial domain. Recent capacity building activities have built up skills in surge and wave forecasting. Six staff from the Hydrometeorological Service have been trained in “end-to-end” management of a modern forecasting service, and there will be continuous institutional cooperation between the Norwegian Meteorological Institute (DNMI) and the Hydrometeorological Service of Vietnam (HMS) in the near future. Routine forecasts are now available to government agencies and other relevant users.

The HMS is the primary user of the system. The products will be storm surge warnings delivered to the coastal population of Vietnam in order to mitigate or prepare for the incident of storm surges in connection with typhoons. The present typhoon forecasting is based on conventional methods and has not been very successful due to low predictability of typhoon development and propagation. However, the closer the typhoon is to the coast the higher the probability of improved forecast for surge and waves. The challenge is to establish the best possible surge/tide/wave forecast with a 24 - 48 hour lead time.

If successful, the project will contribute to the building of the global network. It will encourage and stimulate regional cooperation concerning ocean data exchange, the sharing of infrastructure, and the exchange of knowledge regarding monitoring technology and numerical models. Further, the project will foster closer cooperation in providing meteorological input and boundary values to a number of countries around the South China Sea through coordination with NEAR-GOOS.

The Tropical Cyclone Program (TCP) of WMO's World Weather Watch Department is an important catalyst in proving a common framework and intellectual development support to the project. In particular, TCP will aim for a common infrastructure as a basis for surge and wave forecasting in the area.

8.2 COASTAL OBSERVING SYSTEM FOR THE EASTERN SOUTH PACIFIC OCEAN (COSESPO)

The eastern South Pacific (ESP) region (Colombia, Ecuador, Peru and Chile) depends strongly on marine activities (e.g., fisheries, aquaculture, tourism, marine transportation) for its economical development. These activities are all sensitive to conditions in the ocean either directly for ocean-based activities or indirectly via the role of the ocean in influencing regional climate. This is particularly true for the ESP region, which often has suffered large inter-annual changes in oceanographic and atmospheric conditions associated with the El Niño/Southern Oscillation phenomenon. Furthermore, with industrial growth and increases in material consumption, coastal pollution has become a serious problem.

Recent studies of circulation patterns off Chile using long-term, direct current observations over the slope (at 30° S), as well as other observations from the coast of Peru and Chile and from the Equatorial Pacific Ocean, have revealed the occurrence of large current fluctuations with periods of 10 - 70 days. These intra-seasonal fluctuations propagate poleward as coastal trapped Kelvin waves (CTW) along the South-American coast, and the lower-frequency ones dominate the current-meter records. The CTWs have been shown to be remotely forced by winds in the Equatorial Pacific Ocean, to be uncorrelated with local winds, and to modulate coastal sea surface temperature variability. These properties imply that useful forecasts of such low-frequency variability off the western coast of South America may be possible with up to two months lead time (depending on the latitude), and hence with the possibility of many practical applications.

The users of the proposed observing system include meteorological and hydrographic services, local authorities (e.g., harbor authorities), government agencies (e.g., environmental agencies), coastal managers and industry. The products of COSESPO will include nowcasts and forecasts of the circulation patterns on the shelf and in bays and harbors in each of the coastal region participating. The information generated can be used in practical applications such as dispersion of pollutants.

It is expected that the observing system developed (COSESPO) in this pilot project will become a part of the C-GOOS Global Network. Furthermore, it will be an extension of the Tropical Atmosphere Ocean (TAO) array and an integral part of the eastern South Pacific Ocean Array being proposed for the region.

8.3 SW ATLANTIC NETWORK: QUICKLY INTEGRATED JOINT OBSERVING TEAM (QUIJOTE)

The goal of QUIJOTE is to monitor and predict changes in the coastal zone of the south western Atlantic Ocean by linking coastal institutions and improving the capability of national agencies and regional institutions. The operational categories to be addressed by the system include preserving healthy coastal ecosystems, promoting the sustainable use of coastal resources, mitigating coastal hazards, and safe and efficient marine operations. QUIJOTE is organized into 5 Modules that incorporate current projects and programs relevant to the coastal indicators of change (Table 2):

- The Near Shore Data Observing Network (DON);
- Storm Surge Forecast System (SSF);
- RedSur Network (RSN);
- Estuarine Dynamics (EDY);
- Beach Dynamics (BDY).

Each module addresses different aspects of the C-GOOS observing system (Tables V.3.1 and V.3.2). Each is based on existing activities that are at different stages of development, and it is anticipated that QUIJOTE will enable them to grow into operational programs. Participants are members of several institutions from Argentina, Brazil and Uruguay.

The SSF will provide storm surge forecasts in the south western Atlantic Ocean (SWAO region) for Argentina and Brazil. An important product of BDY will be maps of erosion risk that will provide information for decision-makers concerned with, for example, the management of land use in the coastal zone and the implementation of erosion control measures along the coastline. A common problem is the lack of coastal rules or policy, or the existing indifference to them. These maps would be based on detailed satellite images, specifically processed (NDVI products, unsupervised and supervised classifications, thematic maps).

EDY will provide understanding of interactions between estuaries, coastal drainage basins, and the adjacent sea based on observations that relate coastal oceanography to the life cycle of ecologically and commercially important plant and animal populations in estuarine habitats. This information will be of fundamental importance for the formulation and implementation of environmental policies for the management and mitigation of critical habitats (e.g., tidal wetlands such as mangrove swamps), fisheries, and water quality, especially in rapidly developing areas in the region of urban centers.

QUIJOTE is directly related to the development of the Coastal Observing Network for the Near Shore (CONNS) element of C-GOOS. Intergovernmental Oceanographic Commission workshops involving representatives from Argentina, Brazil and Uruguay led to the conclusion that one of the most important problems in the coastal zone is erosion of the shoreline caused by episodic storms (dominantly from the S and SE).

8.4 PHYTONET: THE PHYTOPLANKTON NETWORK

The term 'Harmful Algal Bloom' (HAB) covers a heterogeneous set of events which differ considerably in terms of species and floristic groups involved, the conditions under which they occur, and their effects on people and ecosystem processes (Zingone and Enevoldsen, 2000). Harmful algal events may be caused by photosynthetic, heterotrophic or mixotrophic microorganisms; they may occur at low or high cell densities; and their occurrence is often determined based more on their effects than on changes in their abundance or toxicity *per se*. In recent decades, HABs and related events have been observed more frequently and in more places. This trend may reflect the intensity of observations or a real trend in the frequency of occurrence in time and space that may or may not be related to human activities. The lack of systematic, routine observations of the abundance, distribution and toxicity of harmful species make it impossible to determine which of these possible explanations is true (Wyatt, 1995).

The recently established IOC-SCOR Science Program GEOHAB (Global Ecology of Harmful Algal Blooms) and the EUROHAB Science Plan have identified fundamental gaps in the knowledge of causes and consequences of HABs that hinder substantial improvements in capabilities for management and mitigation of the phenomenon. These programs highlight the need for long-term monitoring programs in representative ecosystems that are linked to detect regional and global trends and develop a predictive understanding of HABs (GEOHAB, 1998; EUROHAB Science Plan, 1998). They also emphasize the importance of studies that consider harmful algal species in an ecosystem context, including their relationship to the abundance and distribution of phytoplankton species as a whole. This is important because HABs are an integral part of phytoplankton species succession and because the direct effects of HABs on other organisms (e.g., fish kills, human health) and the environment (e.g., oxygen depletion, the release of noxious chemicals) also have indirect effects on an array of ecosystem processes including (1) the fate of primary production and fish production (Legendre, 1990); (2) biogeochemical cycles involving C and N (Arrigo *et al*., 1999; Karl *et al*., 1997); (3) the flux of DMS to the atmosphere (e.g. Matrai *et al*., 1995); and (4) biodiversity.

Data on the distribution and abundance of HAB species, and in some cases phytoplankton species as a whole, are collected at many coastal sites, though observation systems differ in terms of aims, methodology, quality assurance, coordination with similar efforts elsewhere, and dissemination of results. A monitoring network of laboratories (PhytoNet) is proposed to coordinate observations of HABs in the context of changes in the abundance of phytoplankton species in general to develop a sampling program that is representative and to improve the quality and availability of data on HABs, the environmental conditions under which they occur, and their effects. LABNET may be a model for the development of this network.

The network will begin by involving scientific institutions and monitoring agencies in Europe where data are most available and where the resources exist to achieve this ambitious goal. A high priority of the network will be a retrospective analysis of existing data bases with the aim of tracking compositional trends in relation to climatic and/or anthropogenic changes. The goal is to detect trends and to develop analytical tools and models required to predict, mitigate and control HABs. PhytoNet in Europe will be a test-bed for networking of on-going observation programs that can be expanded to include other regions connected to the C-GOOS global network.

The benefits of the proposed network are greater and more time by access to data on HABs, phytoplankton species composition, and related environmental variables; improved inter-calibration and quality control; earlier detection of trends; and the development of a predictive understanding of HABs. Potential users groups include:

- aquaculturists: to take timely decisions on management of aquaculture activities;
- health authorities: to optimize human health protection;
- scientists: who are both contributors and users of the data sets for scientific purposes;
- monitoring authorities: to produce data in a more timely way and reduce the cost/benefit ratio;
- resident populations: to diminish the risk of accidents caused by ingestion or exposure to algal toxins;
- tourist industry: to protect tourists from exposure and to mitigate the effect of HABs;
- decision-makers: to plan a safe and effective use of the coastal zone;
- regulatory bodies: to lay down common regulations for monitoring operations.

Products expected from PhytoNet include:

- guidelines for monitoring, data management and dissemination;
- easily accessible and illustrated species check-lists and data bases;
- standardized procedures for data quality assessment and control;
- regional and European meta-data centers;
- training and intercalibration on sampling, analysis and data management;
- identification of methodological, technological and scientific needs; and
- diversified, user-friendly data dissemination tools.

PhytoNet exploits existing monitoring systems which will improve the initial observing system as follows:

- provide high quality data on phytoplankton diversity and distribution in conjunction with data on relevant physical and chemical variables;
- provide a forum for conducting intercalibration exercises;
- increase the utility of satellite imagery of ocean color by providing data on floristic composition that may be resolved from water leaving radiance spectra; and

- help to identify biological and environmental variables and associated scales of variability that influence species succession, biodiversity, and HABs and contribute to the development of theory required to detect and predict HABs.

PhytoNet will also be a user of C-GOOS data: physical and chemical data gathered by the Global Network will be invaluable to the development of a predictive understanding of HABs. Timely information on the scales of variability of environmental factors such as wind stress, coastal circulation, vertical mixing, temperature, salinity and nutrient concentrations are essential to understand mechanisms underlying biological variability, including the development of blooms and the occurrence of harmful events. This will significantly improve predictive capability for HABs and their effects.

In addition to C-GOOS, PhytoNet will contribute to the success of several research programs including GEOHAB, IBOY, and I-LTER, and to the development of regional GOOS programs including BOOS and the Mediterranean Forecasting System (MFS).

8.5 THE COORDINATED ADRIATIC OBSERVING SYSTEM (CAOS)

The Adriatic Sea is a semi-enclosed body of water with densely populated coastal watersheds with a long history of land-use. Surrounding countries belong to the industrially developed and developing world with established or growing economies. The region is characterized by intensive land-based and sea-based activities including urban growth and development, agriculture, commercial and recreational fisheries, tourism, and multinational maritime commerce. Like many coastal environments throughout the world, land-use practices and population growth have led to increases in nutrient loading and changes in freshwater flow patterns to coastal waters that have been especially pronounced over the last 100 years. There is reason to believe that these changes are causing profound alterations of coastal waters as indicated by mucilage events, oxygen depletion of bottom water, harmful algal events, outbreaks of gelatinous zooplankton, invasions of nonindigenous species and loss of habitat (Malone *et al*., 1999). Individually, these phenomena may not be cause for concern. As a group, they may be indicative of a pattern of environmental degradation that threatens the health of coastal ecosystems of the northern Adriatic (NA).

The Po River is the largest single source of freshwater and nutrients (nitrogen and phosphorus) to the NA. However, about half of the nutrient load to the northern Adriatic enters the system north of the Po River discharge, and the importance of atmospheric deposition is unknown. Under most circumstances, nutrients delivered by the Po River have a short residence time in the northern Adriatic relative to nutrient inputs to the north and east (e.g., the Gulf of Trieste) of the Po. The latter are more likely to be retained and recycled within the northern Adriatic before being lost to the atmosphere (denitrification), buried in the sediments (particulate N and P), or transported into the southern reaches of the Adriatic. Thus, the effects of inputs north of the Po on the health of the northern Adriatic may be greater than for nutrients delivered by the Po. This underscores the importance of detecting and predicting changes in the circulation regime of the NA on time scales of days to months and space scales of 1-100 km.

Nutrient enrichment of the NA may be related to several indicators of environmental change that affect shipping, tourism, fisheries, and ecosystem health. These include (1) habitat loss (changes in attached macrophyte communities, loss of tidal wetlands); (2) phytoplankton blooms and subsequent episodes of bottom water hypoxia; (3) episodic mucilage events ("mare sporco") and mass mortalities of benthic organisms, (4) diarrhetic shellfish poisoning and the closure of mussel beds, (5) outbreaks of jellyfish, and (6) invasions of the exotic species. Given these problems, the observing system must be designed to detect and predict ecosystem responses to episodic and seasonal scale variations in freshwater inputs and nutrient loading that vary on interannual time scales.

In the beginning, users of CAOS products will be scientists concerned with documenting and predicting variability, change, and the causes and consequences of change; government agencies responsible for resource and environmental management; environmental conservation groups; and the tourist, shipping and fishing industries. Products will include periodic assessments of the status of the NA ecosystem, documentation of the scales of variability that characterize indicators of change, and nowcasts and forecasts of sea state and surface currents. Status of the NA (e.g., the Northern Adriatic Environmental Report) will be documented in terms of the following measures:

(1) Recreational use (beach use, boating, fishing; number of people or user days per year);
(2) Commercial landings of fish and shellfish (kg/yr);
(3) Mucilage events (duration and area affected) (time-area integral/yr);
(4) Bottom water hypoxic events (duration and area affected) (time-area integral/yr);
(5) Shellfish bed closures (cause, duration, area impacted)(no. organisms affected/yr);
(6) Harmful algal blooms (duration, area impacted)(number/yr);
(7) Phytoplankton biomass and light penetration (seasonal maximum for Po River Plume, Gulf of Trieste, Emilia Romagna, < 25 m along the Istrian coast); and
(8) Biodiversity of native species of marsh grass, submerged vascular plants, macroalgae, fish, shellfish, mammals, and birds.

It is envisioned that CAOS will contribute to the development of the Mediterranean Forecasting System (MFS) and become a component of the C-GOOS global network. MFS, a pilot project of EuroGOOS and MedGOOS, has been funded by the EC. The broad goal of the MFS is to nowcast and predict marine ecosystem variability (SST, surface currents and waves, primary productivity) from basin scale to the coastal-shelf areas on time scales of weeks-months. This requires the development and implementation of an automated monitoring-nowcasting-forecasting observation system with a modeling component that connects measurements (monitoring) to products (e.g., predictions, visualizations). The achievement of this ambitious goal will depend on the design and implementation of a hierarchy of nested observation systems from the scale of the Mediterranean (MFS) to the local and regional scale of continental shelves and seas. CAOS will contribute to the development of the higher resolution local-regional scale components of the MFS.

Research programs that provide the scientific foundation of CAOS include LOICZ (ELOISE), GLOBEC, COLORS and the international LTER program. The quantification of fluxes of water and nutrients coastal drainage basins to estuaries and the coastal ocean (ELOISE, LTER) and of trophic dynamics (GLOBEC) are of particular importance.

9. CONCLUSIONS AND RECOMMENDATIONS

The coastal component of GOOS is designed to detect and predict the effects of changing inputs of energy and matter from terrestrial, atmospheric, oceanic, and anthropogenic sources on coastal marine and estuarine ecosystems and the human populations that live, work and recreate in coastal environments. The time scales for prediction range from near real-time (weather, sea state) and hours-days (storms) to weeks-years (effects of land use) and decades (global climate change). In order to meet this challenge, the observing system must ultimately provide data and information on environmental changes (Table 2) that are occurring on a broad range of time and space scales in a complex environmental setting (the coastal zone).

The problem of detecting and predicting the effects of human activities on coastal ecosystems and the living resources they support is compounded by the effects of natural sources of variability and change. Differentiating the effects of human activities from the effects of natural processes requires an observing system that provides the data needed to (1) understand and quantify the effects of large scale changes on local ecosystems, and (2) comparative analysis of coastal ecosystems in the context of sustained observations, i.e., substantial advances in understanding and predictive capabilities cannot be made in the absence of systematic, regional, long-term observations of environmental variability and change. Thus, the system must be both sustained and integrated (Figure 1).

The first step is to coordinate and integrate existing efforts to insure continuity, achieve larger scale regional and global perspectives, minimize redundancy, improve access to data, and produce timely analyses that benefit a broader spectrum of user groups. As this proceeds, it will become necessary to address the problem of undersampling in terms of both the temporal and spatial resolution of observations and the interdisciplinary character of natural system (i.e., the measurement and analysis of the biological and chemical dimensions of coastal ecosystems). By building on existing capabilities and infrastructure, and by using a phased implementation approach, work can start immediately to achieve the vision. New technologies, past investments, evolving scientific understanding, advances in data communications and processing, and pressing societal needs combine to provide the opportunity to initiate an integrated observing system for coastal ecosystems. The major pieces missing are an internationally accepted global design; national commitments of assets and funding coordination; and collaboration among nations, institutions, data providers, and data users.

9.1 THE C-GOOS DESIGN

9.1.1 Conceptual Basis

The strategy for the design of C-GOOS is based on two basic concepts that are related to the structure and function of estuarine and marine ecosystems:

- Physical processes structure the pelagic environment and are of fundamental importance to most, if not all, of the indicators of change.
- Indicators of change are not independent but related through a hierarchy of interactions that can be represented by robust models of ecosystem dynamics.

This suggests the likelihood that there is a common set of key physical, chemical and biological properties that, if measured with sufficient resolution over long enough periods and large enough areas, will serve many needs (e.g., from forecasting changes in water depth, sea state, and currents on short time scales to predicting the environmental consequences of human activities and climate change on longer time scales).

Having said this, it is clearly unrealistic to expect that measurements of a single set of core variables will provide the comprehensive data base required to detect and predict all indicators of change in all coastal ecosystems. Greater resolution and additional measurements will be needed based on national and regional priorities. Consistent with this reality is the fact that, although many indicators of change are globally ubiquitous, their significance varies between nations and regions, (because of differences in environmental conditions, national priorities, or both). Thus, **the observing system is conceived as a global network for the measurement of a common set of core variables that is regionally and locally customized to address those issues that are of greatest concern to participating countries**.

9.1.2 Elements of an End-to-End System

Linking user needs to measurements for the purposes of detecting and predicting changes in coastal ecosystems requires a managed, two-way flow of data and information among three essential subsystems: (1) the **observing subsystem**, (2) the **communications network and data management subsystem**, and (3) the **modeling and applications subsystem**. It must be recognized at the onset that many of the measurements required for a fully integrated, multi-disciplinary observing system are not operational, that much work is needed to determine those products that are most useful, and that capabilities and resources vary enormously among nations. These realities underscore the need for enabling research and capacity building, and it is expected that the coastal component of GOOS will develop along two tracks:

- the building of an initial global network through the incorporation of existing operational elements; and
- the implementation of pilot projects that (i) demonstrate the utility and cost-effectiveness of the GOOS end-to-end, user-driven approach and (ii) contribute to the development of the global network and regional enhancements.

Pilot projects will also be an important vehicle for **capacity building**, **enabling research** and the incorporation of new scientific knowledge and technologies into the observing system (transformation from research applications to operational modes). It must be emphasized that there has been little coordination among the pilot projects discussed here. This is a serious deficiency that must be addressed. For example, the South China Sea, SE Pacific, and SW Atlantic projects have many elements in common and **mechanisms are needed to enable the exchange of information and technologies among pilot projects for the development of**

common techniques, models, and data processing strategies. This is particularly important for the data management subsystem if data and data products are to be exchanged in a timely fashion on regional to global scales.

The Observing Subsystem

This is the measurement end of the end-to-end, user-driven observing system. It consists of the global infrastructure required to measure core variables and transmit data to the communications network and data management subsystem. An objective procedure was used to identify the minimum number of variables required to detect changes in a maximum number of indicators and that satisfy a maximum number of user needs (section 5.1; Annex III). Although the set of core variables identified by this procedure (Table 4) are consistent with the results of the EuroGOOS survey of user groups (Fischer and Flemming, 1999) and represents a reasonable first cut, a more rigorous analysis is needed that involves a broader mix of user groups, models and products than was possible for this exercise.

Measurements of core variables in four dimensions are required for both detection and prediction. To these ends, the observing subsystem will consist of an integrated mix of samplers, sensors and platforms required to measure core variables with sufficient spatial coverage and temporal resolution to detect changes in 4 dimensions and to communicate data in a timely fashion. Thus, emphasis is placed on methods that provide high resolution, synoptic time series measurements (autonomous *in situ* sensing of multiple variables simultaneously and continuously in the vertical dimension), spatially synoptic measurements (remote sensing of surface distributions of a limited set of variables simultaneously over large areas), and near real time data telemetry (from sensors that make instantaneous measurements and generate electronic or acoustic signals). The observing sub system is organized into 6 related and mutually dependent categories:

- Coastal Observing Network for the Near Shore (CONNS);
- the Global Network of Coastal Tide Gauges;
- Fixed Platforms, Moorings and Drifters;
- Ships of Opportunity and Voluntary Observing Ships;
- Remote Sensing from Satellites and Aircraft; and
- Remote Sensing from Land-based Platforms.

These elements of the observing subsystem provide a hierarchy of measurements of multiple variables that must be judiciously merged in such a way as to provide more comprehensive and timely detection and prediction of environment changes than would otherwise be possible. Successful integration of these elements is an important aspect of the value added nature of the observing system.

Problems of immediate concern that must be solved if the full potential of the observing system is to be realized include the following:

- how to identify and coordinate national and regional observing systems into the global network;

- the undersampling of core variables;
- the development of sensor technologies (remote and *in situ*) for the detection of changes in the biological and chemical properties of marine and estuarine ecosystems;
- how to transition enabling research projects into pre-operational and operational modes; and
- the development of long-term, sustainable funding for capacity building and the completion of the global network.

Government agencies and ministries must be convinced that the benefits there citizens will realize are worth the investment. A significant investment in research will be needed to develop the required technologies and analytical tools. Governments will need to develop mechanisms by which new knowledge and technologies can be used to improve the observing system in a timely fashion. Existing observing systems (e.g., GLOSS, GCRMN, the global network of meteorological buoys, SOOP, VOS) will require enhancements to measure more oceanographic properties at additional locations and at higher frequencies. In general, the frequency and spatial resolution of observations must increase with decreasing distance from the coastline and with decreasing depth, especially in the proximity of urban centers and major river discharges.

The challenge of developing cost-effective sampling schemes underscores the importance of the interaction between measurements and modeling. Due to the complexity of marine ecosystems and the cost of observing them, OSSEs (Observation System Simulation Experiments) will become increasingly important as a means to assess different sampling strategies and improve the initial C-GOOS observing subsystem design. As coupled physical-biological-chemical models and data assimilation techniques are developed and become more effective, it will be possible to use them to determine (1) optimal combinations of variables to measure and (2) the optimal time and space scales for measurements to be made.

Finally, it is important to emphasize that all aspects of the observing subsystem cannot be based solely on autonomous *in situ* and remote sensing. For the purposes of continuity and integration, the initial system must incorporate variables that cannot be measured and communicated in real time. Autonomous *in situ* sensors have been developed for some core variables (e.g., dissolved inorganic nutrients, phytoplankton pigments, and dissolved oxygen), and it is likely that some of these will soon be operational (routine, guaranteed data stream). Of the biological and chemical properties in Table 4, Chl-a is the only variable that can be measured by both remote and *in situ* sensors and is most likely to become operational in the near future. Perhaps the greatest challenge is the detection of the full spectrum of biological species that inhabit coastal ecosystems. Changes in species composition, distribution and abundance are of fundamental importance to water quality, living resources, and the aesthetic beauty of coastal ecosystems; and regional enhancements of the observing system are likely to incorporate such measurements. Current methods of identification for most species (the exceptions being birds, marine mammals, turtles, and gelatinous zooplankton) rely on *in situ* sampling and subsequent laboratory analyses that can be laborious and time consuming. Although the use of molecular probes for sensing microbial species *in situ* is on the horizon, and acoustic techniques are being used to monitor some fish populations remotely, observing systems such as PhytoNet will rely on sampling and microscopic analysis for the foreseeable future.

The Communications Network and Data Management Subsystem

An international data and information management system must be established that ensures timely access to meta-data, quality data and data-products in response to user demand on local, regional and global scales. The subsystem must be designed for free and timely access to data. It must consider the needs of end users in the initial design; incorporate appropriate meta-data standards (including quality assurance); and develop mechanisms for monitoring the reliability of data streams and the usefulness of data-products. In addition, the subsystem must be designed to allow cooperating organizations to easily measure, maintain, and submit targeted environmental data in both "real time" and delayed modes.

The data communications and management structure is envisaged as a hierarchy of local, national, and supra-national levels in which data and information are disseminated to users at all levels (Figure 4). Data and information are disseminated laterally within levels and vertically among levels. In some cases, level III data management and synthesis centers may perform the functions of level II institutions, e.g., in those cases where individual nations do not have the capability to establish NODCs or Responsible Local Data Centers (RLDCs). Consideration should also be given to co-locating data centers with index sites where logistical and cost considerations warrant.

The observing subsystem will be multi-disciplinary and multidimensional. As such, the data streams will include physical, biological, chemical and geological data that are input from *in situ* and remote sensors and from laboratory analyses of samples collected from fixed platforms, drifters and ships. The continuity of data streams and access to data should be systematically monitored. Evaluation, maintenance and enhancements should occur at all levels in the data management system, and procedures should be developed to ensure that information on data quality and flow is exchanged between each level of the data management hierarchy. Clearly, procedures for merging multiple data-types from different sources collected on different time and space scales by different methods will be a major challenge that must be developed early on.

The initial data management subsystem should grow in an incremental way by linking and integrating existing national and international communications networks and data management programs that collect and manage the required diversity of data types. In this regard, there is a clear and immediate need for most existing data management systems to increase their capabilities to accommodate increases in the volume of data, the number of data types, and the need to collate and integrate data in response to user demand. Finally, as the observing system develops and matures, mechanisms should be established by which end users are able to provide critical feedback on the timeliness and quality of the data and data-products provided by the system.

The Modeling and Applications Subsystem

Data assimilation and modeling are critical components of the observing system, and observing and modeling coastal ecosystems must be treated as mutually dependent, complementary processes. Real-time data from remote and *in situ* sensors will be particularly valuable in this regard. Data telemetered from these sources can be used:

- for assimilation and more accurate estimates of the distributions of state variables;
- to develop, test and validate models; and
- to initialize models for improved forecasts of coastal environmental conditions and, ultimately, changes in ecosystem health and living resources.

A mix of modeling approaches (statistical, theoretical, empirical) will be required to produce realistic, multi-dimensional views of change based on data from multiple sources. Two approaches are commonly used in coastal modeling to increase resolution in areas of greatest interest and to address the problem of scale-dependent variability: finite element modeling and nesting of finite difference models. A number of issues must be faced when using either approach (e.g., computational efficiency for finite element models and allowing for true two-way interaction with nested, finite difference models), and these issues will become increasingly difficult as more comprehensive ecosystem (coupled physical-chemical-biological) models are developed. As these problems are solved, the distinction between the coastal and basin scale components of GOOS will blur.

Modeling the physics and meteorology of coastal ecosystems has matured to the point that there are now a number of operational systems that provide useful forecasts of state variables such as water depth (sea level), waves, and currents. Although advances are being made in modeling ecosystem processes related to ecosystem health and the sustainability of living resources, much improvement must be made before such models are useful for making predictions for the purposes of environmental science let alone being of use for operational forecasting.

Another problem of immediate concern is the development and application of data assimilation techniques that require knowledge of coastal marine and estuarine processes, statistics and numerical modeling. Currently, there is a global shortage of individuals with this combination of expertise in oceanography and ecology that must be addressed as this is a serious impediment to the development of operational coastal oceanography, particularly for those indicators that require ecosystem models to predict.

9.1.3 C-GOOS in the Context of IGOS

The Integrated Global Observing Strategy (IGOS) is based on the development of three related systems: GTOS, GCOS, and GOOS. GOOS includes the ocean component of GCOS (OOPC) and the coastal marine and estuarine component of GTOS (C-GOOS). Clearly, the development of these systems must be coordinated to ensure convergence toward an integrated system. The immediate link between GCOS and C-GOOS is provided by the OOPC which is primarily concerned with the effects of ocean-atmosphere interactions on global weather patterns and climate. The OOPC has taken the lead in the development of a pilot project which is particularly relevant to C-GOOS, the Global Ocean Data Assimilation Experiment (GODAE). The goal of GODAE is to demonstrate that useful and timely nowcasts of the global ocean circulation can be produced through global modeling and the assimilation of data from both remote and *in situ* (direct) sources. GODAE is an experiment to test the cost-effectiveness of this approach as a means to deliver useful products (Table 7).

From the perspective of C-GOOS, GODAE not only provides a model for the transition of research programs into an operational mode, it provides a global framework for linking, and ultimately merging, the coastal and basin scale components of GOOS. For example, coastal models will be able to use the global model to provide outer boundary conditions. The vision for GOOS involves the operation of global data assimilation systems within which will be embedded coastal model subsystems (with greater spatial resolution) of coupled physical-chemical-biological sub-models.

Table 7. Selection of sub-objectives, the related drivers and needs, and expected character of the associated products from GODAE.

Objective	Driver/Needs	Output Characteristics
Extend predictability of coastal and regional sub-systems.	Coastal forecast systems; regional monitoring, prediction	scale ~ week, 100 km fields: T, u, SL
Provide several, 20-day high-resolution, upper open-ocean forecasts and nowcasts	ship routing, transport, safety at sea, naval applications	rapid delivery, scales ~ 10km. Fields: u, SL, u (surface), $T(z_{upper})$
Integrated analyses for research and development. Re-analysis	CLIVAR, GLOBEC, etc. Hypothesis testing, process studies	~ 10 day, 150-100 km resolution, but high quality; delayed delivery OK; full depth, 10 v. modes; T, S, SL, u
Initial conditions for climate forecasts, e.g. Kuroshio, NAO, ENSO	Western boundary current prediction; seasonal prediction; climate change	~ 10 days, 100-200 km; SST, SL, heat content, high quality
Sustain and design for a permanent global ocean observing system, including remote and direct.	GOOS, GCOS, operational oceanography, multi-purpose applications	Managed data streams. QC systems. Efficiency. Guided evolution.

On the landside, GTOS was initiated in 1996 to improve the data and information required to improve the understanding of environmental change in terrestrial ecosystems and, therefore, the environmental policies and decision making. The major issues to be addressed by GTOS are changes in land quality, availability of freshwater resources, loss of biodiversity, climate change, and impacts of chemical contaminants. Clearly, many of the changes occurring in terrestrial ecosystems of coastal drainage basins have important impacts on coastal marine and estuarine ecosystems and are, therefore, of interest to C-GOOS. Of particular importance are changes in land-cover and land-use that influence flows of freshwater and associated nutrients, sediments and contaminants from land to the sea. Alterations in these inputs can lead to habitat loss or modification (from changes in salinity regimes to the loss of submerged attached macrophytes), coastal eutrophication (increased turbidity, oxygen depletion), fish kills, harmful algal events, coastal erosion, etc. These examples underscore the importance of developing an observing system that will provide the data and information required to document, quantify and predict the propagation of changes in terrestrial ecosystems to marine and estuarine ecosystems of the coastal zone. This will require close coordination and collaboration between GOOS and GTOS through the development of joint pilot projects that catalyze the transition of research programs such as LOICZ (see below) to operational observing systems for the coastal zone from drainage basins to the continental shelf. One example is the emerging collaboration of GTOS with the C-GOOS pilot project (section 8.5). Likewise, C-GOOS could collaborate with GTOS in a pilot project to estimate the net primary productivity of terrestrial, estuarine and marine ecosystems (GTOS Biennial Report, 1998-1999).

9.2 BUILDING AN OPERATIONAL SYSTEM

Collaboration with National and Regional GOOS Programs will provide the user input required to drive the formulation of an implementation plan and the development of the system. A cornerstone of the C-GOOS design is that it must build on existing programs in order to minimize redundancy and optimize shared used opportunities for all aspects of the system from measurements to data-products. Thus, the initial system will be implemented through the incorporation of existing programs and pilot projects that meet C-GOOS goals and design requirements. Collaboration with key research programs will provide the scientific basis for continued development toward a fully integrated (interdisciplinary, multidimensional, end-to-end) system.

The initial development of the observing system must take into consideration two contrasting realities:

- capabilities and resources vary enormously among nations and coastal monitoring and data management systems in the developing world are insufficient; and
- coastal ecosystems of most industrialized nations are intensely monitored (in terms of both the number of variables measured and the frequency and duration of measurement) for a variety of purposes including weather forecasting, shipping (commerce and recreation), environmental regulation (compliance monitoring), management (coastal area management, the management of living resources), and environmental research.

At the same time, It must also be recognized that many of the measurements and models required for a comprehensive, multi-disciplinary, fully integrated observing system are not operational and that much work is needed to develop and determine those products that are most useful. These realities underscore the need for capacity building to address problems of undersampling; the need for coordination and collaboration among government agencies and nations to make more effective use of existing infrastructure, data streams, and expertise; and the need for enabling research to develop sensor technologies for improved detection and models for improved prediction. In this context, **the following priorities are recommended for the initial development of the C-GOOS infrastructure** (see sections 4 and 5):

- Establish procedures to identify, solicit and approve the initial operational components of the coastal observing system;
- Enhance or establish data synthesis and application centers to provide more timely analyses, predictions and data products that meet the needs of end users;
- Improve and expand the data management and communication infrastructure necessary for routine monitoring, analysis, and prediction of the coastal ecosystems on required time and space scales;
- Begin the development of an integrated observing subsystem that incorporates routine and sustained measurements of the meteorological, physical, chemical, and biological variables required to detect and predict indicators of change in coastal ecosystems;
- Enhance and expand enabling research programs such as LOICZ, GLOBEC, and GEOHAB to develop new technologies and models;
- Develop capacity building programs to insure the participation of developing countries in the global network; and
- Establish formal mechanisms to insure coordination and collaborations with programs that are important to the full development of the observing system (e.g., OOPC, GTOS).

As suggested above, programs that are relevant to the development of C-GOOS can be divided into 3 categories: (1) **operational programs**, (2) **pre-operational pilot projects**, and (3) **enabling research**. Pilot projects and research have finite lifetimes. Examples of those that are relevant to C-GOOS are listed in Table 8. As this table indicates, many elements of the coastal observing system are in place, and an important initial task will be to develop an effective data management system and to network these elements in this context. Examples of programs that are critical to the successful implementation of C-GOOS are discussed below.

Table 8. Summary of selected projects and programs that provide the scientific basis for GOOS (enabling research), are pre-operational pilot projects (see section 9.2.2), and operational programs that are potential building blocks of the initial coastal ocean observing system. See Annex VI for the list of acronyms. The URLs for most of these programs are listed in Annex II.

Category	**Program**
Enabling Research	LOICZ, CLIVAR, IGAC, GEOHAB, GLOBEC, SIMBIOS, COLORS, GIWA, WCRP
Pre-Operational Pilot Project	BOOS/COMBINE, MFS, PhytoNet, CAOS, SEASS, COSESPO, QUIJOTE, ICAM, NEAR-GOOS
Operational	GLOSS, DBCP, CGMS, GIPME, GCRMN, IPHAB, ITSU, GPA/LBA, CalCOFI, IBTS, UNEP Regional Seas Programs, CPR (N. Sea)

9.2.1 Sustained Observing Systems

In addition to GLOSS which is an integral part of the C-GOOS design (see section 5.3.2), two programs are highlighted here because they represent two related approaches to operational systems that emphasize the biological components of marine ecosystems: (1) the California Cooperative Fishery Investigation (CalCOFI), an example of a regional program; and (2) the Global Coral Reef Monitoring Network (GCRMN), an example of a global program. Both observing systems are considered to be critical building blocks of C-GOOS.

The CalCOFI is a regional program that was established by the United States in 1950 in response to the collapse of the California sardine fishery. Its goal is to document long-term ecological changes in the marine environment (temperature, salinity, nutrient concentrations, and the biomass and taxonomic composition of phytoplankton, zooplankton, and forage fish) that influence the capacity of the California Current system to support marine fisheries. It is a collaboration between academic institutions and government agencies (University of California, U.S. National Marine Fisheries Service, and the California Department of Fish and Game). The initial program extended from northern California to mid-Baja California with a large array of stations (> 600 stations along 36 inshore-offshore transects roughly normal to the California Current) sampled at monthly intervals (hydrocasts, plankton tows). Although the program was reduced in scope in 1984, (< 70 stations sampled are quarterly intervals along transects between San Diego and San Luis Obispo), it is among the longest continuous, systematic, multi-disciplinary monitoring programs of an open coastal ecosystem in the world which measures many of the core variables identified above (temperature, salinity, nutrients, attenuation coefficient, turbidity, phytoplankton biomass and floristic composition).

The GCRMN is an international program that was established in 1997 in response to a global scale degradation of coral reefs in the tropics from East Africa and Southeast Asia to the Caribbean. It is sponsored by the IOC, UNEP and IUCN. The goals of the GCRMN are to: (1) improve the conservation, management and sustainable use of coral reefs and related coastal ecosystems by providing data and information on the trends in biophysical status and social, cultural and economic values of these ecosystems; and (2) provide individuals, organizations and governments with the capacity to assess the resources of coral reefs and related ecosystems and collaborate within a global network to document and disseminate data and information on their status and trends. The collection of data and information on reef status and trends began in 1997. Regional nodes have been created within participating countries to coordinate training, monitoring, and data management in regions based on the UNEP Regional Seas Program: Middle East, western Indian Ocean and east Africa, south Asia, east Asia, the Pacific, and the Caribbean and tropical Americas. The first report on the status of coral reefs was published in 1998 (Wilkinson, 1998). There are at least two important features of the GCRMN that are relevant to C-GOOS beyond the degradation of coral reefs and the living resources and recreational activities they support: (1) its emphasis on community awareness through the involvement of all users in the collection of data on status and trends and (2) the significance of coral reef bleaching as an early warning and potential effects of global climate change (Wilkinson *et al*., 1999).

9.2.2 Pre-Operational Pilot Projects

In addition to the pilot projects discussed in section 8, four projects are highlighted here that are particularly relevant to the development of C-GOOS: the Baltic Operational Oceanographic System (BOOS), Mediterranean Forecasting System (MFS), The North-East Asian Region GOOS (NEAR-GOOS) Pilot Project, and GODAE. GODAE was discussed above.

BOOS is a collaboration between government agencies of the countries surrounding the Baltic Sea (Germany, Poland, Lithuania, Latvia, Estonia, Russia, Finland, Sweden, and Denmark) that are responsible for monitoring and modeling the Baltic and for providing marine forecasts and other services for the marine industry, environmental organizations, and other end users. Through the shared use of infrastructure, expertise and data, the goals of BOOS are to:

- Improve services to meet the requirements of environmental and maritime user groups;
- Increase the cost-effectiveness of investments in ocean observations;
- Further develop the market for operational oceanographic products by identify new customers;
- Provide high quality data and long time series required to advance the scientific understanding of the Baltic Sea; and
- Provide data and forecasts to protect the marine environment, conserve biodiversity, and monitor climate change and variability.

In accordance with GOOS design principles, BOOS is developing by incorporating existing systems into an international network that will provide timely access to data and data-products. BOOS is working to coordinate activities, develop operational routines, improve elements of the observing system and harmonize products based on user requirements. Achieving these goals will require additional investments by participating nations and institutions in environmental research and technical development with an emphasis on the rapid delivery of data, model performance, data exchange, and user friendly product dissemination. During 1999-2003, the highest priority will be the establishment of an efficient system for data exchange that addresses both the legal issues of data exchange and the technical aspects of developing a prototype data analysis system for the Baltic Sea that will focus initially on physical conditions (water level, waves, sea ice, temperature and salinity, and currents). The system will be expanded to address problems of nutrient enrichment and hazardous substances. It is likely that C-GOOS will evolve in a similar fashion.

The MFS is a collaboration between environmental agencies of Cyprus, Egypt, France, Greece, Italy, Israel, Malta, Spain, Norway and the United Kingdom. Its primary goal is the prediction of marine ecosystem variability from sea surface temperature and salinity and currents to primary production on time scales of days to months. The scientific rationale for the system is based on the hypothesis that coastal hydrodynamics and ecosystem fluctuations are intimately connected to the large scale general circulation. A major goal of the pilot project is to demonstrate the utility of near real time (NRT) forecasts of basin scale currents. The project is based on (1) NRT data delivery from networks of voluntary observing ships (SST, SSS), a multisensor moored array system (temperature, salinity, dissolved oxygen, turbidity, chlorophyll, currents, PAR), and satellites (sea surface height, SST, and ocean color); (2) data assimilation techniques to assimilate multivariate parameters for 3-, 5- and 10-day forecasts for 3 month periods for the entire basin; (3) techniques to scale down basin scale hydrodynamics to smaller coastal regions using nested models; and (4) methods for assimilating nutrient, chlorophyll and PAR data into predictive ecosystem models and for validating such models. In this context, the Coordinated Adriatic Observing System (CAOS) is a logical extension of the MFS.

The NEAR-GOOS pilot project is a regional collaboration between China, Japan, the Republic of Korea and the Russian Federation. It was organized under the auspices of the IOC Sub-Commission for the Western Pacific (WESTPAC) to establish a data communications system based on the Internet to enable timely, free access to data on coastal marine systems. The goal is to (1) improve marine services including the prediction and mitigation of natural disasters caused by waves, storm surges and sea ice and (2) improve fisheries and water quality management for more efficient fisheries, aquaculture development, and recreation.

BOOS, GODAE, MFS, and NEAR-GOOS are important experiments that will test two key aspects of the C-GOOS design strategy: (1) building on existing observing elements with an initial emphasis on data communications and management (BOOS, GODAE, NEAR-GOOS) and (2) developing an integrated, multidisciplinary system from one that focuses initially on physical features to one that gradually incorporated chemical and biological sensors (BOOS, MFS). These programs, together with existing operational systems (e.g., Table 8) and the pilot projects described in section 8, provide the makings of an initial global observing system for the coastal ocean.

9.2.3 Enabling Research

Achieving the goals of C-GOOS will depend to a great extent on a synergy between C-GOOS and hypothesis driven research programs (Table 8), and every attempt must be made to insure that the observing system is closely linked to enabling research activities. The knowledge and technologies generated by these programs will improve the observing system through:

- the development of a more comprehensive quantitative understanding of the causes and consequences of environmental change;
- more effective and less expensive technologies for real time monitoring and data telemetry;
- improved capabilities to visualize and analyze change in near real-time; and
- the development of models for improved prediction of current conditions, future events and environmental changes.

C-GOOS will provide the spatial and temporal framework of observations required to understand the global and long-term significance of results from research on targeted ecosystems.

The recommended sequence of events that lead from research to operational observing systems can be described as follows:

- Research to develop the technology, knowledge and analytical tools required to enable the observing system to achieve the design principles (the science base);

- Community approval of these advances through pre-operational pilot projects that are likely to effect the transition from research to operational status; and
- Incorporation of methods, infrastructure, programs and data into an operational framework of sustained observations, data management and analysis in support of societal needs.

A high priority will be coordination and collaboration among related programs to enable timely access to and analysis of the diverse data required to detect changes in coastal indicators (Table 2) and to develop predictive capabilities.

9.2.3.1 Land Ocean Interactions in the Coastal Zone (LOICZ)

This program provides much of the scientific foundation of C-GOOS, and collaboration is required to facilitate information exchange; the development of joint projects; coordination between C-GOOS, GTOS, and the international LTER program; and to enable the transition of appropriate aspects of LOICZ from a research to an operational mode. The broad goal of LOICZ is to determine the fluxes of materials (emphasis on water, sediments, and carbon, nitrogen, and phosphorus compounds) into, within, and from coastal ecosystems. LOICZ activities are organized into four focus areas:

- The effects of changes in external forcings on coastal fluxes;
- Coastal biogeochemistry and global change;
- Carbon fluxes and trace gas emissions; and
- Economic and social impacts of global change in coastal systems.

Two major goals to be achieved by the end of this 10-year program are global estimates of C, N and P budgets for the coastal ocean and an assessment of specific data and techniques needed to improve and track changes in these budgets in local ecosystems and on regional to global scales. The knowledge and techniques developed by LOICZ will be of critical importance to the development of C-GOOS.

Recognizing that LOICZ has a finite "life" (1992-2002, subject to current negotiations in IGBP), mechanism are needed to ensure that the data, knowledge, tools, and networks developed by LOICZ are incorporated in C-GOOS as appropriate. It is expected that C-GOOS will encourage the development of sustained observing systems required to document and predict the consequences of changes in biogeochemical cycles and fluxes to, within and from coastal ecosystems. C-GOOS will promote the use of new knowledge and technological advances (sensors, models, data management) generated by LOICZ for applied purposes and provide the framework of observations required to extrapolate research results to coastal systems that have not been the subject of an in depth LOICZ study (Figure 5).

The work of the joint JGOFS/LOICZ Continental Margins Task Team also provides a scientific foundation for C-GOOS. The major goal of the task team is to determine the role of the continental margins in the fluxes of carbon, nitrogen and phosphorus. Close collaboration between this effort and future development of C-GOOS will be required to enable C-GOOS to effectively utilize the scientific knowledge generated by the continental margins studies. This will enable research results from the programs to be extrapolated to the continental margins on a global scale using data from the C-GOOS program.

Currently there are three areas where collaboration between C-GOOS and LOICZ could begin immediately:

Data Management

LOICZ is developing a global data base on material fluxes, biogeochemical processes, and socio-economic factors for a network of LOICZ projects, coastal zone researchers and agencies. The LOICZ data bases are linked to coastal zone information services and the data bases of government agencies concerned with environmental issues in the coastal zone. Data and metadata in the LOICZ data base are public domain, and the Executive Committee is discussing mechanisms for creating access to the data base which includes analyses of parameters of coastal typology, river discharge, and biogeochemical budgets for C, N and P in coastal seas and estuaries. The data management component of the design and implementation plans for C-GOOS should consider the data management systems developed for LOICZ. In this regard, LOICZ is keen to link with the initiatives of C-GOOS for resolving its data and information transfer questions.

Development of a Coastal Typology

The development of a coastal typology is intended to address issues of spatial scaling (Figure 5). A data base of physical, biological and socio-economic parameters (109 variables) has been established for the global coastal zone (50 m elevation) at one degree pixel scale (9600 pixels). It is likely that more than one typological approach will be required to meet the LOICZ needs for “scaling up” models for local ecosystems to regional and global scales. Current work includes: development of “cluster” methodologies, tools for aggregating coastal descriptions, expanding and rationalizing indicator parameters in the data base, ways of linking to existing global data models, and seeking ways to link coastal with catchment typologies (which are being developed in IGBP and elsewhere).

Formulation of Design and Implementation Plans for C-GOOS

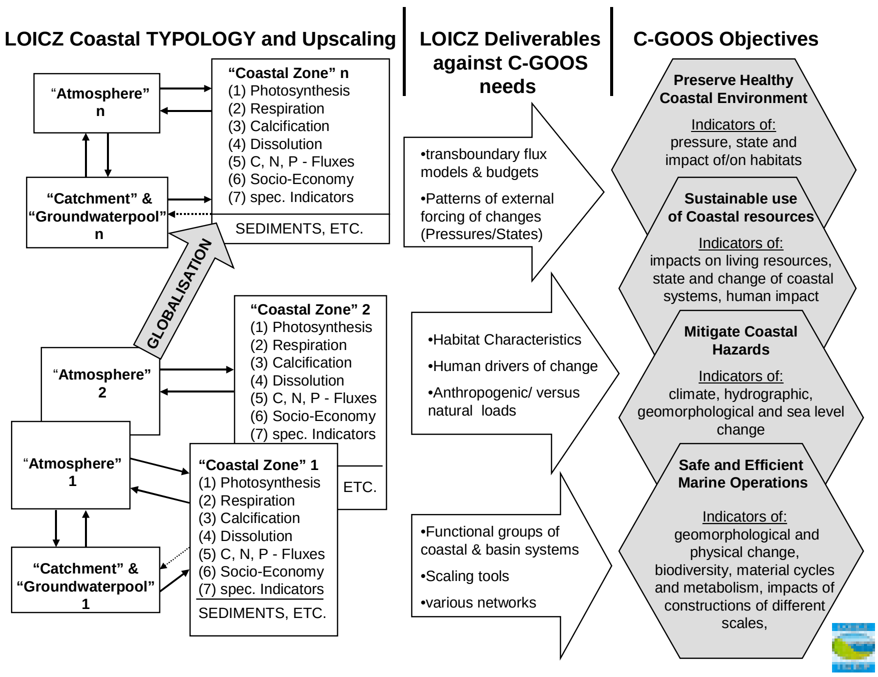
LOICZ organizes much of its activities on a regional scale and depends on the work of national agencies and scientists to bring together regional groups of experts to integrate relevant science and, where possible, to assist in capacity building. LOICZ has some history of working with IGBP-START and IOC in regional enterprise, and is actively seeking to expand these associations in carrying forward its work. Potential joint activities include capacity building and information transfer and the development of integrated research and monitoring activities. **To these ends, the existing MOU between LOICZ and IOC should be updated to provide the framework for incorporating the legacy of LOICZ as a part of C-GOOS.**

9.2.3.2 International Long Term Ecological Research (I-LTER) Programs

The concept of Coastal Index Sites, which are an integral part of the observing subsystem (section 5.3), is based on the LTER model. The effort to establish an international LTER network began in 1993, and interest is growing to establish international programs and networks for ecological research over long temporal and large spatial scales. As of December, 1999, 19 nations have established formal programs and joined the I-LTER network. The goals of the I-LTER are to:

- improve the understanding of long-term ecological phenomena across national and regional boundaries;
- facilitate interactions among scientists across disciplines and promote comparative analysis and synthesis across sites;
- enhance training and education in comparative long-term ecological research and its relevant technologies;
- contribute to the scientific basis for ecosystem management; and
- facilitate the development of such programs where they currently do not exist.

Figure 5. LOICZ coastal typology and the scientific foundations of C-GOOS.



It is anticipated that coastal LTERs will benefit the development of C-GOOS and that they will be incorporated into the design of the near shore component of the global network (section 5.3).

9.2.3.3 Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB)

Harmful algal blooms (HABs) have been identified as important indicators of the status of coastal marine and estuarine ecosystems (Table 2). HABs generally fall into one of two groups: toxin producers that contaminate seafood or kill fish and high biomass producers that cause anoxia and indiscriminate mass mortalities of marine life. Some species have both characteristics. The GEOHAB project was established in 1998 (sponsored by SCOR and the IOC) to provide a framework for research designed to improve the prediction of harmful algal events by determining the mechanisms underlying their population dynamics through interdisciplinary research, modeling, and an enhanced observational network. Three major questions will be addressed:

- What are the environmental factors that determine the changing distribution of HAB species, their genetic variability and the biodiversity of associated communities?
- What are the unique adaptations of HAB species that determine when and where they occur and the extent to which they produce harmful effects?
- What are the effects of human activities (e.g., nutrient enrichment) on the occurrence of HABs?
- How do HAB species, their population dynamics and community interactions respond to changes in their environment?

GEOHAB will foster scientific advancement in the understanding of HABs by encouraging and coordinating basic research. International cooperation to conduct research in comparable ecosystems is encouraged. Improved global observing systems will be required to resolve influences of natural environmental factors and anthropogenic effects on distributions and trends in HAB occurrence. This will be greatly facilitated through strong links between GEOHAB and C-GOOS.

9.2.3.4 SIMBIOS

The Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) Program was initiated by NASA in 1994 to foster information exchange and collaboration between satellite missions for the remote sensing of ocean color. Ongoing and projected ocean-color missions are highly complementary in many important respects, but the sensors employed differs in design and capabilities. The goal is to develop methods to combine data on ocean color from an array of independent satellite systems (e.g., SeaWiFS, MOS, MODIS, OCTS, POLDER) to ensure consistency and provide data products based on accurate and integrated spatial and temporal patterns of ocean color. The strategy to achieve this targets three goals: (1) quantify the relative accuracies of products from international ocean-color missions; (2) improve the compatibility among products; and (3) develop methods for generating merged global products for more comprehensive and detailed spatial and temporal coverage. Of particular importance to C-GOOS will be the development of hyperspectral algorithms for case 2 waters. The successful achievement of these goals is critical to the success of C-GOOS, especially in regard to issues of ecosystem health and living marine resources (sections 1.2, 4.2, 4.3).

9.3 IMPLEMENTING AND SUSTAINING C-GOOS

9.3.1 National and Regional GOOS Programs

Successful development of C-GOOS will depend on and benefit from a broad spectrum of end-users from industries and government services to NGOs, the public at large, science and science education. Although the challenges are great, a convergence of societal needs and technical capabilities provides both the means and motivation for major advances in the ability to evaluate, prevent, control and mitigate the effects of human activities and natural variability. Since most of the environmental changes to be addressed by the coastal component of GOOS are local in scale, implementation of the global network and of regional enhancements will ultimately be the responsibility of participating nations via regional and national GOOS programs. The role of C-GOOS in this regard is to develop design and implementation plans that benefit these programs in terms of both the development of an observing systems that serves the needs of many user groups and international coordination for the collective benefit of all nations.

9.3.2 Capacity Building

Given the reality that many nations do not have the resources, technologies or expertise to develop local or regional observing systems or to contribute to the global network without some assistance, capacity building must be an early priority. This is perhaps the greatest challenge to the implementation of C-GOOS on a global scale.

The goal of capacity building is to enable all nations to contribute to and benefit from the observing system. Achieving this goal will require partnerships between donors and recipients. Capacity building will generally involve a mix of activities from technology transfer (observing, communications network and data management, and modeling and product development subsystems), and training, to public outreach activities intended to educate the public, donor organizations, government agencies, and other user groups on the problems that should be addressed and best practices as articulated in the strategic design of C-GOOS. Approaches must be tailored to regional needs and cultures and should include active community participation and awareness building (from government agencies and private enterprise to NGOs and volunteers) as practiced, for example, by the GCRMN. Above all, a sustained commitment will be required by the community of industrialized nations. Participating nations and donor organizations must recognize the need to maintain capacity once it has been built.

Short term priorities include the following:

- increase public and political awareness of environmental problems and the benefits of detecting and predicting changes in coastal ecosystems;
- entrain stakeholders in the design and development of the observing system on local to regional scales;
- enlist academic institutions, environmental research laboratories and government agencies to provide facilities and expertise;
- incorporate existing capabilities, supporting and improving them according to the guidelines provided by the C-GOOS design plan;

- make use of computer-assisted and distance learning activities via the world wide web and interactive video networks; and
- develop the infrastructure for the communications network and provide the required training for data and information dissemination, QAQC, and archiving.

In the long-term, national plans for building the integrated system will need to be formulated. Such plans should include mechanisms for ensuring continuity of training and involvement of both data providers and users; building and maintaining the infrastructure for each of the three major elements of the observing system; and public awareness campaigns.

There are many capacity building programs that C-GOOS should work with to achieve the goals of capacity building. These include TEMA (IOC); START (IGBP); Train-Sea-Coast (UN); the IOC-EU South American oceanographic network; and training activities such as those organized by the IAEA Marine Environment Laboratory, NEAR-GOOS, and the International Center for Theoretical Physics. **Of particular importance to C-GOOS are the training courses of the E & T Program of the WMO, IOCCG, GLOSS, and the HAB Program**. The creation of National GOOS Coordinating Committees will help stimulate this process. Initially, increasing public and political awareness in developing countries will be particularly important. In many cases, these countries will have to be convinced that more and better information on the marine environment will benefit their economies and the well being of their citizens. The focus should be on the value of information on marine ecosystems and the value-added aspect of investing in an international system.

9.3.3 Implementing Mechanisms

9.3.3.1 Sustainable Financing for Coastal GOOS

The success of C-GOOS will depend entirely on broad-based international support and ongoing sponsorship by nations and private institutions. Preparatory documents for the 1992 UNCED Conference in Rio de Janeiro suggested that the annual operating cost of GOOS when fully implemented would be on the order of $2 billion US per year, most of which (about $1.3 billion) would be for eight oceanographic satellites. Most of the remaining $700 million will be required for open ocean monitoring. The annual operating budget for the World Weather Watch is also about $2 billion. Although a cost analysis has yet to be performed for C-GOOS, these figures provide an order of magnitude estimate of the investment that will be required to initiate the core network proposed here.

At least in the near term, the current trend to reduce governmental spending means that little or no additional public funding may be available until the value added aspects of the system begin to be realized by making more effective use of existing resources and infrastructure to produce useful information. This highlights the growing importance of the private sector as a potential ally. An examination of various options and opportunities for ensuring the sustainability of an international observing system on regional to global scales indicates that it is unlikely that a singular mechanism or arrangement will meet the needs of all countries. While national governments, particularly in the more developed world, will continue to be the primary source of funding for coastal observing systems, they need not be the only source.

The private sector provides nearly $260 billion US per year in investments and loans to developing countries. Development banks provide about $50 billion US per year in loans, and the GEF provides less than $1 billion US per year. However, since approximately 90% of private funding has been flowing to only 12 countries undergoing fast-paced economic development, private sector funds alone will not suffice. This increases the importance of making more efficient use of financing available from the domestic budgets of all governments, overseas development assistance, and multilateral development funds.

In order to develop a coastal observing capacity, most governments will have to strengthen their institutional arrangements for monitoring as well as the infrastructure and technical expertise that form the foundation of any observing system. It is here that national governments, NGOs, donor agencies, and international organizations can play a significant role. Some time-honored rules for dealing with uncertainty apply to the choice of financing instruments for coastal observations. These include (1) "looking before you leap," i.e., making informed decisions; (2) "not putting all your eggs in one basket," i.e., diversifying financing options; (3) not committing too much funding at once, i.e., step-wise implementation that provides the opportunity to build on experience; and (4) "securing political support," i.e., investment awareness building.

Within the framework of the C-GOOS strategic plan, and assuming that national governments continue to support large capital-intensive observing systems such as remote sensing, institutional financing could occur through the following actions:

(1) National Governments and Non-State Entities

- Prepare plans of action that target coastal observing systems on a national and regional basis and use public funding and private endowments to implement those plans.
- Build the costs of observations into statutory responsibilities and activities of governing bodies.
- Publicize achievements to potential funding sources.
- Develop national coastal observing systems aimed at providing local governments with the capabilities to manage local coastal areas by establishing new financial initiatives to support coastal observations on a long-term and self-reliant basis.
- Develop and support national and regional information infrastructures.
- Develop technical assistance and financial incentive programs for the establishment of a sustainable national and regional coastal observing capacity.
- Charge "user fees" for provision of "valued" services, i.e., monitoring, but realize that personnel and a system for collection of fees would be required. This will probably require legislation or regulations both to create the system and to ensure that fees are returned to the implementing agency or agencies and not the general fund.

(2) Local Governments

- Incorporate coastal observations and practices into local planning, economic development, land management, social and environmental services and fiscal policies.
- Develop partnerships with the private sector, both formal and informal, through contractual

arrangements, joint ventures, or similar schemes, by generating proposals that are technically and financially sound, implementing competitive bidding procedures, clearly identifying procedures and requirements of government in project development and implementation, and serving as the focal point between project proponents and the public sector (e.g., integrate compliance monitoring into the observing system).

- Enhance observing capabilities in marine and coastal areas and strengthen regulatory and economic instruments at the local level by forming partnerships and voluntary agreements with the private sector, NGOs, and the general public.

(3) The Global Environment Facility (GEF), Donor Agencies, and Multilateral Banking Institutions.

- Provide financial support to national and local governments, academic institutions and the private sector, within the framework of national economic programs and policies, to establish, develop, and extend coastal observations programs to individual countries, and regionally, through capacity building initiatives, pre-investment studies, research, and case studies.

(4) The Private Sector

- Work at the local, national and international level, develop and implement policies and procedures that combine good business with sound environmental management, including observations.
- Develop capabilities and capacities to provide infrastructure and related technical, scientific, and management services essential to the development and sustainability of coastal observing systems.

(5) Non-Governmental Organizations

- Implement community-based action programs that involve the public in those aspects of the observing system that are related to the protection and conservation of coastal marine and estuarine resources and ecosystem health.

9.3.3.2 Implementation Mechanisms

The Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) was established in 1999 to oversee the implementation of the physical observations required by the OOPC (and CLIVAR). JCOMM was established through the merger of the Commission for Marine Meteorology (CMM) and the Integrated Global Ocean Services System (IGOSS). It is the reporting and coordinating mechanism for all other existing bodies of WMO and IOC concerned with ocean observations and data management for weather and climate. Although JCOMM reports to the Executive Councils of the WMO and the IOC, it is expected to coordinate closely with the GSC and I-GOOS (responsible for the development and implementation of GOOS).

For the present, JCOMM has the responsibility for the physical observations required by GOOS. The current Action Plan for JCOMM calls for subsidiary working groups that will oversee the implementation of GOOS physical observations in three categories: (1) surface ocean and its atmospheric and oceanic boundary layers; (2) upper ocean; and (3) sea surface elevation. In the future it may be necessary to institute additional mechanisms to deal with deep sea hydrography, perhaps using systems similar to those developed by WOCE. When the requirements for C-GOOS observations have been further developed and accepted by the GSC, the JCOMM Action Plan will be modified to accommodate them. It remains unclear whether the biological and chemical observations required by C-GOOS should be coordinated by JCOMM. What is clear, is that there presently do not exist operational mechanisms for coordinating and implementing biological and chemical observations that are equivalent to such programs as the DBCP and GLOSS for physical observations. An option would be to constitute a parallel commission for coastal services and marine health.

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ANNEX II

URLs of Programs and Projects relevant to C-GOOS

Data Management
DataBloom - http://www.dundee.ac.uk/dcczr/abdmap/abdmap.htm
IODE - http://ioc.unesco.org/iode/
IOC - http://ioc.unesco.org/iocpub

GOOS Panels
CGOOS - http://ioc.unesco.org/goos/cozo.htm
HOTO - http://ioc.unesco.org/goos/hoto.htm
LMR - http://ioc.unesco.org/goos/lmr.htm
OOPC - http://ioc.unesco.org/goos/oopc.pdf

Integrated Global Observing Systems
GCOS - http://193.135.216.2/web/gcos/gcoshome.html
GOOS - http://ioc.unesco.org/goos/status.htm
GTOS - http://www.fao.org/gtos

National GOOS Programs
GOOS Brazil - http://www.labmet.io.usp.br/~goos-br
U.S. GOOS, Toward a U.S. Plan - http://core.cast.msstate.edu/NOPPobsplan.html
U.S. C-GOOS Workshop - http://www.hpl.umces.edu/projects/wrkrpt.pdf

Observing Systems
BOOS - http://www.soc.soton.ac.uk/OTHERS/EUROGOOS/eurogoosindex.html
CalCOFI - http://www-mlrg.ucsd.edu/calcofi.html
Chesapeake Bay Monitoring Program-
http://www.dnr.state.md.us/bay/monitoring/index.html

Pilot Projects
GODAE - http://www.bom.gov.au/bmrc/mrlr/nrs/oopc/godae/homepage.html
MFS - http://www.cineca.it/~mfspp000
QUIJOTE - http://www.cem.ufpr.br/fisica/quijote.htm

Regional GOOS Programs
EuroGOOS - http://www.soc.ac.uk/OTHERS/EUROGOOS/eurogoosindex.html
NEAR-GOOS -http://ioc.unesco.org/goos/NEAR-GOOS.htm

Research Programs
GEOHAB -http://www.phys.ocean.dal.ca/~jhurst/SCOR/GEOHAB/GEOHAB.html
GLOBEC - http://www1.npm.ac.uk/globec/
LOICZ - http://www.nioz.nl/loicz/welcome.html;http://www.nioz.nl/loicz/modelnod.htm
LTER - http://www.ilternet.edu/
SIMBIOS - http://simbios.gsfc.nasa.gov

User Groups and Programs

GIWA -	http://www.baltic-region.net/actors/giwa.htm
IBOY -	http://www.im.ac.cn/DIVERSITAS/Iboy/index.html

State of the Environment Reports

GEO 2000 -	http://www.unep.org/unep/eia/geo2000/
World Resources -	http://www.wri.org/wr-96-97/96tocful.html
	http://www.wri.org/wt-98-99/wr98-toc.htm
State of the Coast -	http://state-of-coast.noaa.gov/
State of the Nation's Ecosystems -	http://www.us-ecosystems.org/
Chesapeake Bay -	http://www.chesapeakebay.net/pubs/sob/index.html
Gulf of Finland -	http://www.baltic-region.net/baltfact/gof96.htm
Puget Sound -	http://www.wa.gov./puget_sound
Wadden Sea -	http://cwss.www.de/TMAP/QSR.html

ANNEX III

Selection of Core Variables

The process used to identify the core variables reflects the dual purpose of the observing system: the detection and prediction of change. To define the variables for detection the panel, with the help of invited experts, made a list of users groups (Table III.1) and determined which of the indicators of change (Table III.2) each user group was interested in. The panel and experts then listed the variables required to quantify changes in each of the indicators. It was then straightforward to count the number of user groups interested in each of the variables as a way of detecting change. (The idea is illustrated in the Figure III.1.) The variables were then ranked in terms of the number of user groups interested in them.

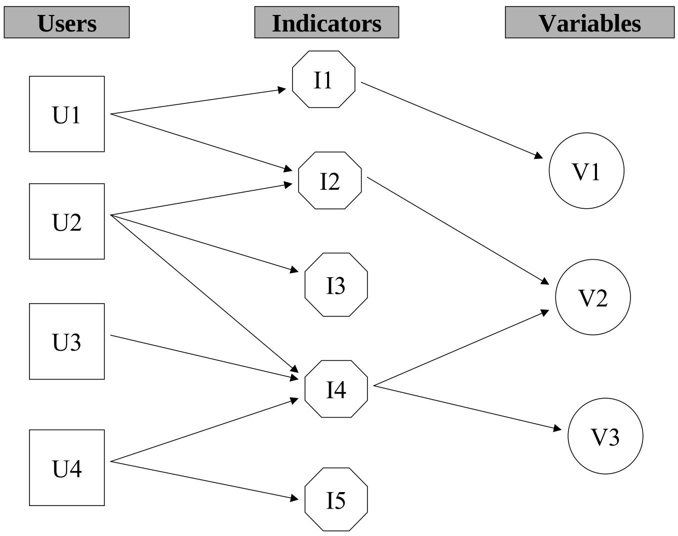
Table III.1. User groups and their respective codes (U1-U16)

Code	User Group
U1	Resource Managers (Managers of biological, geological, physical coastal resources)
U2	Aquaculturists (shellfish, crustacean and fin fish farmers)
U3	General public with any interest in the coastal environment
U4	Fishers (commercial and recreational fishers)
U5	Scientists
U6	Health authorities
U7	Insurance industry
U8	Local authorities (coastal development)
U9	Shipping Industry (commercial ocean transport)
U10	Oil and Gas industry (Platforms and pipelines)
U11	Port authorities
U12	Coast guard (including search and rescue)
U13	Environmental regulatory agencies
U14	Tourism (all elements of the tourism industry, as well as the tourists)
U15	Coastal engineers
U16	Seafood Processors

Table III.2 Indicators of change and their respective codes.

Category	Indicators of Change
Ecosystem Health & Living Marine Resources	I1 Accumulations of organic matter I2 HABs I3 Biodiversity I4 Growth of nonindigenous species I5 Benthic habitat modification, loss I6 Pelagic habitat modification, loss
Coastal Hazards & Safe-Efficient Marine Operations	I7 Coastal erosion I8 Salt water intrusion I9 Sea state I10 Sea ice I11 Bathymetry I12 Susceptibility to natural hazards I13 Public health

Figure III.1. Schematic of the process used to rank core variables. The middle column shows five indicators. The arrows connecting users (U) to indicators (I) boxes reflect the interest of users in each of the indicators. Here, user-1 desires information on indicators 1 and 2 and so on. The arrows connecting the indicator and variable (V) boxes show the variables required to quantify changes in each of the indicators. The ranking of variables is based on the number of indicators and user groups that each variable is relevant to. For example, V1 is required to measure 1 indicator and is relevant to only 1 user group. However, V2 is required to measure 2 indicators and is relevant to the needs of 4 user groups. Thus, V1 has a score of 2 (1 + 1) while V2 has a score of 6 (2 + 4)and so on.



A similar procedure was used to identify variables for prediction. A cross-section of indicators of change was selected and the form of the required prediction was specified. The models required to make each prediction were identified. These include not only operational forecast models but also models that can be used, for example, to predict changes in the occurrence of extreme events (such as flooding and HABs) under different climate scenarios. The variables need to drive the models were determined along with the user groups interested in the predictions.

The same approach as above was then used to count the number of user groups interested in each variable in terms of predicting change. (The idea is illustrated in Figure III.1 but with the middle column of indicators replaced by models.) The variables were then ranked as above. The final step was to chose a set of core variables from the two lists of ranked variables, taking into account their rankings and the feasibility of measuring them. The subsections that follow provide further details on the selection process.

III.1 Identifying Variables for the Detection of Change

Working individually, panel members and invited experts each constructed a matrix of user groups (rows U1 to U16) and indicators of change (columns I1 to I13) by placing a 1 in each cell (*i*, *j*) if the *j*th indicator was thought to be of interest to the *i*th user group (Table III.3). Blank cells were set to zero. The matrices were then collated into a single matrix with entries equal to 0 or 1.

The next step was to fill out a matrix of indicators and the variables required to quantify > "change in each" indicator (Table III.4). In contrast to the previous table, the rows (variables) were determined by the person filling out the table. If it was thought that the *i*th variable was needed to quantify changes in the *j*th indicator, a 1 was placed in cell (*i*, *j*) of the table. Otherwise it was set to zero. The results were collated into a single table with entries equal to 0 or 1. (After collation the table had 30 rows as shown in Table III.4.)

Table III.3. User groups (rows) and indicators of change in coastal ecosystems (columns).

USERS/INDICATORS	**I1**	**I2**	**I3**	**I4**	**I5**	**I6**	**I7**	**I8**	**I9**	**I10**	**I11**	**I12**	**I13**
U1													
U2													
U3													
U4													
U5													
U6													
U7													
U8													
U9													
U10													
U11													
U12													
U13													
U14													
U15													
U16													

Table III.4. Each panel member filled in this table by adding 1 in position (i, j) if they thought the jth variable could be used to quantify changes in the ith indicator.

VARIABLES/INDICATORS	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13
Bathymetry													
Turbidity													
Dissolved oxygen													
Salinity													
Temperature													
PAR attenuation coefficient													
Coastline													
Species composition													
Waves													
Currents													
Phytoplankton pigments													
Chlorophyll a													
Nutrients													
PCO2													
POC, N													
DOC, N													
Trophic levels													
Flood plain													
Flooding													
HAB toxins													
Insurance rates													
DOM													
Sediment type													
Sea level													
Ice cover													
Areal extent of habitat													
Number of habitats													
Enteric bacteria													
Vibrio													
Ocean color													

The next step was to post multiply the variable/indicator matrix by the transpose of the user/indicator variable. The result was a 30 by 16 variable/user matrix. The row sums of this matrix provide the user-based ranking of the variables (Table III.5).

Table III.5. Number of ways in which each variable is of interest to the 16 user groups in terms of detecting change. Turbidity obtained the highest ranking because it was thought to be useful in quantifying change in many of the indicators. The highest possible score is 208.

RANKED VARIABLE FOR DETECTIONS	RANKING BASED ON ROW SUM
Turbidity	104
Currents	83
Ocean color	74
Species composition	68
Bathymetry	66
PAR attenuation coefficient	65
Waves	60
Nutrients	49
Sea level	47
Phytoplankton pigments	39
Dissolved oxygen	38
Chlorophyll a	35
Coastline	31
Temperature	28
Salinity	24
Floodplain	21
Flooding	21
HAB toxins	21
Sediment type	21
Ice cover	21
DOC/DON	20
Trophic levels	17
Enteric bacteria	16
Vibrio	16
Insurance rates	11
PCO2	7
POC/DON	7

III.2 Identifying Variables for the Prediction of Change

The ranking of variables required for prediction began by selecting a representative cross section of indicators and determining a final prediction for each that was considered to be valued by the appropriate user groups. The type of model to be used and the required input variables were identified. A total of 21 models and associated inputs were evaluated. Of these, 5 examples are shown in Table III.6.

Table III.6: Predictive models for the coastal ecosystem and the input variables needed to drive them. It is recognized that most end users do not want predictions in the form of model output, e.g., an alert may be all that is required. Columns 3 and 4 respectively list the lead time for forecasts and the type of model that can be used for prediction. Models can range from rules of thumb, through statistical models to sophisticated coupled atmosphere-ocean models based on first principles. The last column lists the observations required to drive models.

Problem	**Final Prediction**	**Lead Time**	**Model Type**	**Input Variables**
Coastal Flooding	Alert	hours, days	mesoscales storm, hydrodynamic, wave & inundation	air pressure, winds, sea level, currents, precipitation, track
Extreme Weather	Alert	hours, days	limited area meteorological forecast	Global forecast model output; assimilation of local meteorological conditions, SST
Coastal Erosion	Criteria for coastal development or beach nourishment rate	months, years	morphodynamic & empirical	near shore development, bathymetry, grain size, intertidal & submerged vegetation, wave climate, sea level, winds, sedimentation rate
Shellfish Carrying Capacity	Maximum sustainable stock	years	Coupled hydrodynamic-trophic dynamics	Chl-a, nutrients, sediment load, algal species composition, PAR
Hypoxia	Benthic area impacted	days, weeks	Coupled hydrodynamic-water quality model	hydrodynamic model output; assimilation of Chl-a, nutrients, temperature, PAR

As before the results of this exercise were tabulated in a variable/ model matrix with 52 rows and 21 columns similar to Table III.4. A second matrix of users (16 rows) and models (21 columns) was constructed, transposed and pre-multiplied by the variable/model matrix to obtain the variable/user matrix as before. Again, the row sums of this matrix provide a user-based ranking of the variables, but in this case for the purposes of prediction (Table III.7).

III.3 Selecting the core variables

The final step was to choose a small set of core variables from the variables in Table III.5 and III.7. Based on the rankings of variables and the fiscal and technical feasibility of measurement (a somewhat subjective call by panel members), the panel arrived at the list of core variables given in Table 4. The list of variables and their rankings in Table III.7 clearly reflect the choice of indicators, models, and the opinions of panel members. It is not possible, nor desirable, to perform this exercise for all issues with all possible models. However, the indicators chosen and the models used for the exercise do cover a broad spectrum of issues and the ranking of variables is a reasonable first cut.

In this regard, it is useful to compare the results of this exercise with that employed by EuroGOOS to identify those variables most important for their users (Fischer and Flemming, 1999). There are two important differences. First, unlike this procedure where variables were defined based on their relevance to a particular indicator of change, the EuroGOOS survey began with a list of variables and asked potential user groups which ones are most important to them. The variables were ranked by the number of times they were requested by the respondents to the questionnaire. Second, the EuroGOOS ranking was based on responses from a wide user community across 6 countries in Europe. Bearing in mind these differences, it is useful to compare the results (Table III.7 and Table III.8).

All 17 of the variables identified by the EuroGOOS survey are found in the top 22 variables identified in Table III.7. Some variables in the C-GOOS top 22 are somewhat redundant, i.e., ocean color and chlorophyll, surface roughness and waves, retrospective analysis of algal species and phytoplankton species. Eliminating these redundancies results in a nearly perfect match in terms of the group of variables identified by the two procedures (the exception being “fish behavior”). Differences in the rankings of variables, which undoubtedly reflect the different procedures used, are not considered to be significant. What is important is that two very different procedures identified the same set of core variables.

Table III.7. Number of ways in which each variable is of interest to the 16 user groups in terms of predicting change.

RANKED VARIABLES FOR PREDICTION	RANKING BASED ON ROW SUM
Wind	147
Bathymetry	124
Currents	95
Water temperature	87
Salinity	80
Sea level	72
Nutrients	59
Turbidity	56
PAR attenuation coefficient	51
Chlorophyll a	40
Air pressure	40
Sediment type/grain size	35
Precipitation	30
Ocean color	29
Surface roughness	29
Phytoplankton species	28
Waves	23
Geomorphology	23
Retro algal species abundance	21
Runoff	18
Fish behavior	16
Dissolved oxygen	15
Color DOM	14
Photosynthesis	14
Climate statistics	13
Climate forecasts	13
Seismic activity	12
Cyst beds	11
Input from GCM	10
Grazing	8
Sinking	8
Fish species	8
Fish physiology	8
Primary Production	7
Fish pathogens	7
Ice cover	4
Air temperature	4

Table III.8. The ranking of variables derived from Table 3.2 in Fischer and Flemming (1999). All of the rankings for the subsets of each variable were averaged and reordered accordingly.

Variable	**Ranking**	**Variable**	**Ranking**
Waves	75	Sea level	38
Wind	71	Precipitation	35
Currents	61	Runoff	34
Water temperature	55	Phytoplankton	34
Salinity	48	Turbidity	34
Bathymetry	47	Chlorophyll	33
Sediment	42	Air pressure	31
Geomorphology	42	Oxygen	31
		Nutrients	30

ANNEX IV

Measuring the Core Variables

IV.1 Wind, air pressure and precipitation

Direct measurements of wind and air pressure can be readily made at coastal stations, or on ships and moored buoys using commercially available instrumentation. Space-borne scatterometers and passive microwave sensors also provide remotely-sensed estimates of wind fields in the coastal ocean.

There are a large number of coastal stations that record air pressure, wind speed and direction. Variations in air pressure are generally of larger spatial scale than the wind which is affected strongly, for example, by coastal orography and the change in surface roughness as the air passes from land to water. The result is that coastal measurements of wind may not give an adequate representation of the wind field over the coastal ocean. For certain applications (e.g., computing Ekman pumping) the quantity of interest is the curl of the wind stress, rather than wind at the site. Therefore, information on wind stress is required at both off-shore and near-shore locations. Basic meteorological measurements are made routinely from offshore buoys, fixed platforms and ships of opportunity. Some of this information is made available in near real-time on the GTS and assimilated into operational atmospheric forecast models. The present generation of atmospheric forecast models have a horizontal resolution of about 30 km which is too coarse for many coastal applications. In many locations atmospheric forecasts even at this resolution are not routinely available and estimation of wind forcing must be based on measurements from a small number of land stations and offshore buoys. Undersampling of the wind field over the coastal ocean must be recognized as a major problem to be faced by C-GOOS.

Precipitation can be estimated using a combination of rain and snow gauges, radars and satellite sensors. Direct measurements of precipitation are made using commercially available gauges (e.g. funnel and calibrated vessel) placed on fixed platforms, ships of opportunity and in the nearshore. For details see EMEP (1996). In populated coastal areas with few resources, recycled metal or plastic containers calibrated to 5 or 10% accuracy can be used to augment a network at little or no cost. Surface gauge networks exist in a number of places (e.g. OSPARCOM in the North Sea, HELCOM in the Baltic Sea and some in North America). These are used to augment radar systems. Land-based radar measurements are particularly useful within 200 km of the coastline, though the information is degraded in mountainous areas near the coast. Standard precipitation radar systems (e.g. the WSR 88D) can provide temporal and spatial information about particular precipitation events using rainfall-reflectivity relationships. This information, combined with direct measurements, can provide an excellent picture of both the short term rainfall intensity and the total amount of precipitation from the storm with a horizontal resolution of order 2 km. Radar information can be used alone, but comparisons with gauged measurements (e.g. Klazura *et al*., 1999) indicate that rainfall totals must be treated as rough estimates only. Radars, however, can do quite well in predicting flash floods in regions of complex terrain (e.g. Warner *et al*., 2000). Satellite measurements of precipitation are possible, but they are still in the early stages of development. However, the TRMM (Tropical Rainfall Measurement Mission) system (launched in November 1997) is designed to measure precipitation in remote areas such as the tropical oceans (between latitudes 30°N and 30°S). These measurements sample intermittently and over a region about 20 km across (Ha and North, 1999), making comparisons with surface gauges difficult, particularly at very high and low rain rates (Martin, 1999). However, they offer a storm-wide view of precipitation that is not possible from either radar or gauge systems. This is particularly important when tropical storms approach coastal regions which have no local radar, a rather common situation in the tropics. Similar satellite measurements for higher latitudes are possible, though their impact on coastal regions will be less important because many of the populated coastal areas are currently well covered by radar. Snowfall rates during individual storms are usually not of direct interest to coastal regions. Snow measurements (of both depth and total water content) are mainly important during the melting season in the watersheds of the rivers flowing through the coastal regions. These measurements are generally taken by direct sampling of the snow by tourism, hydroelectricity or transportation authorities. Predictions of the seasonal water flow from the existing snow pack involves estimation of melting and runoff, usually by regional meteorological authorities using techniques developed for individual areas (e.g. Scandinavia, north-east Asia or western North America).

IV.2 Sea level and bathymetry

Two methods are generally employed to measure changes in sea level. The simplest way is with coastal tide gauges or bottom pressure gauges. Networks of tide gauges have been operated by most maritime nations for many decades. Accuracies of several cm are routinely achieved for hourly heights. With long records stretching back several decades it is possible to identify trends on the order of millimeters per year. Altimeters carried by satellites provide all-weather, global coverage and spot measurements of sea level by the Topex/Poseidon mission are accurate to better that 10 cm. One of the problems with the altimetric data is the relatively slow repeat time which introduces the problem of tidal aliasing, particularly in coastal ecosystems where tidal variations are large. However it is possible to de-tide such records and obtain useful information on the coastal ocean (e.g. Foreman *et al.*, 1998).

Accurate water depths with respect to mean sea level (i.e. bathymetry) are critical inputs for dynamic models of the coastal ocean. For many coastal applications bathymetry is the most important determinant of both the circulation and vertical stratification of the water column. Bathymetry is also required for coupled physical-ecological models used to predict accumulations of organic matter, HABs, and habitat loss (including oxygen depletion). Changes in bathymetry are related to many indicators of change including coastal erosion/sediment transport/deposition and of habitat loss/modification due to changes in PAR incident on the bottom, sedimentation, dredging, bottom trawling, and sea level rise. Unfortunately for many parts of the world the available bathymetric data are inadequate for dynamically-based models with a resolution of better than 10 km.

Historically, water depth has been measured by direct soundings. More recently multi-beam techniques have become popular as a way of providing high resolution, three dimensional maps of the seafloor. LIDAR is now being used to map bathymetry in shallow water with vertical and horizontal resolution at the sub meter level.

IV.3 Temperature and salinity

In situ measurements of water temperature and salinity are made routinely from offshore buoys, fixed platforms and ships of opportunity using commercially available instrumentation. Many government and academic institutions, water authorities, and oil and gas exploration companies have long term observation programs on both the shelf and in the nearshore zone. Some of the shelf data are transmitted in near real time on the GTS and used in operational atmospheric forecast models. It is also possible to measure sea-surface temperature from space borne-sensors although clouds are a persistent problem in many areas. At present there are satellites providing sea-surface temperature data on a global scale. The horizontal resolution is typically 1 km, and the repeat time is twice a day.

There have been some interesting developments recently in the mapping of surface coastal salinity using Scanning Low Frequency Microwave Radiometers (SLFMR) carried by light aircraft. Accuracies better that 0.3 part per thousand have been reported. There are plans to measure salinity from a satellite borne sensor (e.g. http://www.esr.org/ssiwg-2/ssiwg_2.html). Advances have also been made recently in the design of profiling moorings (http://www.brooke-ocean.com/s_horse1.html) and autonomous underwater vehicles which can provide profiles of temperature and salinity at locations chosen by the controller of the vehicle. Although this type of instrumentation is extremely expensive at present it may become economical as the design improves and more units are built, particularly if the cost is compared against that of making measurements from a ship.

IV.4 Surface Currents

Current has traditionally been measured using rotor-vane meters attached to a mooring line. More recently electromagnetic sensors and bottom mounted Acoustic Doppler Current Profilers (ADCP) have become more popular. The accuracy of hourly means is about 1 cm/s. It is also possible to measure current profiles from a moving ship although particular care has to be taken in coastal waters to avoid aliasing of strong tidal streams with significant spatial variability. More recently reliable HF radar systems with ranges of up to 80 km have become commercially available (Glenn *et al*., 2000a).

Some regions have advanced systems for monitoring flow and many bays and ports now have operational systems based on routine current measurements (cf. Buch and Dahlin, 2000; Glenn *et al*., 2000a). There are also some regular observing programs based on ADCP carried by ferries. Overall, however, the infrastructure for long-term monitoring of coastal currents on a global scale is limited at the present time. As with coastal winds, the only way that the small number of coastal current observations can be transformed into time-varying fields is through their assimilation into dynamically-based models.

IV.5 Surface waves

Waves are presently measured using both remote and *in situ* techniques. Remote sensing methods include satellite and air-borne sensors, such as SAR (synthetic aperture radar) or various configurations of altimeters, and HF radars installed on fixed platforms. SAR measurements give two-dimensional wave spectra and are generally limited to rather long wavelengths, for example 200 m. Satellite-borne altimeters can give accurate wave heights (although the swath width is quite narrow). Airborne-altimeters such as the NASA scanning radar altimeter (SRA) give highly accurate topographic maps of the waves on the ocean surface, down to 100 m wavelengths, in swaths of about 1.2 km wide. Offshore structures, including hydrocarbon exploitation platforms (North Sea, Baltic, North and South America) are being used more frequently as observation platforms. Shore-based instrumentation, such as HF radar (CODAR), is being used to obtain surface current and wave data in some coastal regions. *In situ* techniques range from wave rider buoys, using accelerometers, to bottom pressure sensors and current meters, as well as ADCP, among others. Digital images and image analysis procedures are also used to study the wave fields.

IV.6 Attenuation of Photosynthetically Active Radiation (PAR) and Turbidity

Absorption, the conversion of light energy to chemical and heat energy, is a function of the concentrations of water, phytoplankton biomass, suspended particulate matter, and the colored components of dissolved organic matter (CDOM). Light attenuation also occurs as a consequence of scattering, changes in direction of electromagnetic radiation caused by multiple reflections by suspended particles. Thus, the rate of PAR attenuation with depth (Kpar) is a function of attenuation due to water (Kw), phytoplankton (Kph), the colored component of dissolved organic matter (Kcdom), and turbidity (Kss) (i.e., Kpar = Kw + Kph + Kcdom + Kss). Coastal waters tend to be particularly turbid and often have high concentrations of CDOM. Increases in turbidity have a proportionately greater effect on directional than on diffuse attenuation coefficients so that the ratio directional/diffuse attenuation can increase from < 3 in case 1 oceanic waters to > 10 in case 2 coastal waters.

Instruments used to measure underwater PAR and turbidity fall into three categories:

- Irradiance meters (e.g., spectroradiometers) measure light energy arriving from all directions (total irradiance or spectrally resolved irradiance). The diffuse attenuation coefficient for downwelling irradiance can be computed from measurements made at different depths. Spectral irradiance measurements can also be used to measure ocean color (see section on ocean color IV.7).

- Beam transmissometers and turbidity meters measure the attenuation rate of parallel (collimated) light beams from a source of known intensity over a fixed distance. The attenuation coefficient for directional light can be calculated from the source and receiver light intensities.

- Nephelometers measure scattering directly and provide a direct and quantitative measure of turbidity or the concentration of suspended particulate matter.

Algorithms are also available for calculating attenuation coefficients at individual wavelengths or wave bands from remotely sensed data on ocean color. However, these algorithms were developed for case 1 (oceanic) waters where concentrations of CDOM and suspended sediments are low relative to many coastal environments. Consequently, current optical models and algorithms are not valid for many coastal ecosystems, and new algorithms are under development. Successful development will require systematic *in situ* measurements to test, validate and calibrate models for case 2 waters (high concentrations of CDOM and/or turbidity).

If irradiance meters are not available, measurements can be made with a Secchi disc. This is a white circular disk (23 -30 cm in diameter) that is lowered from a platform above the water until it disappears. The depth at which the Secchi disc disappears (Secchi disc depth) is related to the exponential decrease in the intensity of downwelling irradiance such that Kpar = 1.5/Zs where Zs = Secchi disc depth. Secchi discs are inexpensive and easily made, and they have been used for over a century as a rapid, cost-effective means to assess water clarity.

IV.7 Phytoplankton pigments and ocean color

Traditionally, Chl-a concentration has been measured in solvent extracts of filters using spectrophotometric or fluorometric techniques following the filtration of water samples. The development of flow-through fluorometers has enabled the continuous measurement of *in vivo*, Chl-a fluorescence in a continuous mode. This approach is amenable to both shipboard and *in situ* measurements (moored, towed and profiling instruments), but requires frequent calibration against techniques that use solvent extraction. Light absorption by phytoplankton pigments modify the color of oceans sufficiently to be detectable by sensors in space, and algorithms are available at present to estimate Chl-a concentration by remote sensing. However, these algorithms have been developed primarily with a view to application in open-ocean waters, and the use of remote sensing of ocean color in coastal waters will require more advanced algorithms (see section on ocean color, IV.7). The analysis of the total algal pigment composition is most commonly performed by filtering seawater samples, extracting the filter with organic solvent (usually acetone or methanol) and analyzing the extract using chromatographic methods such as high performance liquid chromatography (HPLC). However, these methods do not detect water soluble pigments (phycobiliproteins) common to Cryptophytes and Cyanophytes.

The diversity of algal pigments is also reflected in the spectral characteristics of algal fluorescence. By measuring the red fluorescence emitted by Chl-a when excited by a spectrum of wavelengths, influences of different accessory pigments can be detected, along with some aspects of the physiological state of the phytoplankton. Spectral signatures of phytoplankton are measured in the laboratory by using spectrofluorometers. Instrumentation for *in situ* spectral fluorescence measurements at fixed wavelengths is also available, but to date the spectral resolution is not adequate for pattern-recognition algorithms. Fluorescence does not distinguish between chlorophyll *a* and divinyl chlorophyll *a*.

In most of the world ocean, phytoplankton is the primary source of variation in optical properties of the surface ocean. Consequently, remote sensing of ocean color is developing into a valuable tool for synoptic estimates of phytoplankton pigment concentration (mainly Chl-a, an index of phytoplankton biomass) at large spatial scales. Ocean color is the spectrally resolved ratio of the upwelling light leaving the sea surface to the downwelling incident light at the ocean surface (water leaving radiance). It is an optical property that can be measured directly by *in situ* optical sensors (see section 5.2.6). This optical property is of particular importance, because it can be measured from sensors carried on board aircraft and satellites. To a first approximation, its magnitude depends on the concentration of Chl-a and accessory pigments in case 1 waters. Thus, in addition to estimating Chl-a, it is also possible, in principle, to retrieve information from ocean color on the biomass of specific classes of phytoplankton. However, in case 2 coastal waters, CDOM and turbidity can also significantly affect the optical properties of seawater. Here, sensors with higher spectral resolution and sensitivity and more advanced algorithms (currently under development) are required to estimate Chl-a (and possible some accessory pigments), CDOM and turbidity from ocean color measurements.

Present technology also allows for *in situ* optical sensors to be deployed on moored buoys, profilers, drifters and AUVs and for measurements to be transmitted in real or near real time by telemetry. Such measurements (in conjunction with concurrent measurements of Chl-a, pigment concentration, turbidity, and phytoplankton species composition) are not only important for long term time-series observations, they are required to develop, validate and calibrate improved algorithms for applications of ocean color data to the detection and prediction of change in coastal ecosystems.

IV.8 Dissolved inorganic nutrients

Most nutrients measurements in the past have been analyzed in the laboratory (land or ship based) using colorimetric methods for water samples collected with bottles. Sampling methods are now available, using pumps or automatic samplers, to obtain serial samples that may be analyzed on line or preserved for several months in moored instrumentation for laboratory analyses. More recent technologies provide the means to measure nitrate concentrations using moored instrumentation and real time or near real time data telemetry. Similar technologies are being developed for other forms of nitrogen and for phosphorus and silicon.

IV.9 Dissolved oxygen

The concentration of dissolved oxygen in seawater has been commonly measured on water samples using colorimetric methods (particularly the Winkler method) and electronic sensors that can provide sensitive *in situ* measurements, continuous vertical profiles, and high resolution time series with real time telemetry.

IV.10 Sediment type and grain size

Direct measurement of sediment type and size is made by sampling followed by laboratory analysis. These procedures are generally tedious and time consuming, but a necessary component of the data base for any given shelf region. In many areas the nature of the bottom sediments on the large (10-100 km) scale may change so slowly as to be considered essentially constant for modeling purposes, and re-sampling may only be needed on decadal or century time scales. At smaller spatial scales, however, changes in surficial sediment properties, including grain size and bedform scale, occur much more quickly as mobile sediments are moved about in response to storms. Predicting these changes reliably is beyond the scope of our present understanding of fluid-sediment interactions on the shelf. Thus *in situ* observation systems at selected locations are needed to monitor local adjustment of mobile sediments during storms, augmented by repeated broad-scale surveys using acoustic and optical remote sensing technologies to map the redistribution of sediment types and the geometry and extent of large- and medium-scale bedforms (e.g. dunes, sand waves, sand ridges). Implementation of such sediment observation systems has been made feasible by the recent and continuing development of technologies for *in situ* sediment dynamics and remote sediment-type distribution measurements. Long-term observations are needed to test model skill over a range of conditions and particularly to capture the severest storm events, which are likely to induce the most pronounced sediment response, and the most critical tests of the models.

ANNEX V

Pilot Projects

V.1 Vietnamese Forecasting System

Coordination: Johannes Guddal, Project Manager, Co-President of JCOMM (IOC/WMO Joint Technical Commission for Oceanography and Marine Meteorology).

Issues and Significance: Between about 400 - 800 people/year are killed by storm-surge flooding caused by surges in Vietnam. This project aims to establish a forecasting system for storm surges caused by typhoons in the South China Sea (SCS). The project has been initiated with the deployment of 4 moored buoys instrumented to measure meteorological variables (wind speed and direction, air pressure and temperature) and waves (height and direction) along the coast of Vietnam. A circulation/surge numerical model and 4 modern tidal gauges have been selected among several qualified providers in the commercial domain. Recent capacity building activities have built up skills in surge and wave forecasting. Six staff from the Hydrometeorological Service have been trained in “end-to-end” management of a modern forecasting service, and there will be continuous institutional cooperation between DNMI and HMS in the near future. Routine forecasts are now available to government agencies and other relevant users. The next step is to consolidate the current infrastructure into professional operational forecasting system in close cooperation with other countries surrounding the South China Sea. One has been careful to include the needs of the society in different sectors of the coastal and marine activities. This is a foreign aid funded project, but the funding will cease in 2002 and then only regional cooperation will keep the project alive.

Users and products: The Hydrometeorological Service of Vietnam is the primary user of the system. The products will be storm surge warnings delivered to the coastal population of Vietnam in order to mitigate or prepare for the incident of storm surges in connection with typhoons. The present typhoon forecasting is based on conventional methods and has not been very successful due to low predictability of typhoon development and propagation. However, the closer the typhoon is to the coast the higher the probability of improved forecast for surge and waves. The challenge is to establish the best possible surge/tide/wave forecast with a 24 - 48 hour lead time.

Relationship to the C-GOOS Global Network and Other Programs: If successful, the project will contribute to the building of the global network. It will encourage and stimulate regional cooperation concerning ocean data exchange, the sharing of infrastructure, and the exchange of knowledge regarding monitoring technology and numerical models. Further, the project will foster closer cooperation in providing meteorological input and boundary values to a number of countries around the South China Sea through coordination with NEAR-GOOS. The Tropical Cyclone Program (TCP) of WMO’s World Weather Watch Department is an important catalyst in proving a common framework and intellectual development support to the project. In particular, TCP will aim for a common infrastructure as a basis for surge and wave forecasting in the area.

Project design

Issues to be addressed

The main issue will be to qualify HMS for long-term operation of an autonomous marine forecasting system, with emphasis on wind, waves, tides and storm surges during the typhoon season (natural hazards, safe and efficient marine operations). Forecasts are to be made at 2 - 3 day intervals with a lead time of 6 - 8 hours. Well documented numerical models are used for waves and surge/tide. The initial priority is to establish the infrastructure required to improve the meteorological input to the ocean models. These data from moored instrumentation and tidal gauges will be used to verify and initialize forecasts of waves and storm surges. A quality assurance procedure will be implemented following the chronology of the forecast process.

Regional cooperation will be initiated to address a variety of issues including joint model development, data exchange and standardization, measurement network development, testing new technology, etc. The project will be closely coordinated with the WMO/IOC Tropical Cyclone Program (TCP) which also has a comprehensive action for improving surge forecasting. The work plan addresses the following major tasks:

- Bring together SCS countries to demonstrate the benefits of regional cooperation in marine forecasting, of exploiting TCP, and discussion of common activities. The first step will be a TCP surge forecasting workshop in Thailand November 2000.

- Improve the provision of meteorological input data to ocean models by (i) means of large scale models fields and (ii) by assessing potential fine scale tropical atmospheric models. The first step will involve negotiation with ECMWF for a temporary test period during which their wind and air pressure fields will be applied.

- Establish capacity building programs in the areas of modeling, monitoring networks, and the management of services. The first step will be to identify and bring together existing expertise in ocean observations and numerical models in the area.

- Carrying out joint experiments to compare model outputs. The first step will be to establish HMS procedures for forecast validation and service QA.

- Establish new systems for disseminating information and early warnings to the public and other user groups. This will include the use of the Internet.

- Assess current products, improve them, and supplement them with additions products, e.g., oil spill predictions, flood plain maps with areas likely to be flooded for predicted magnitudes of storm surge height, erosion monitoring, and high resolution bathymetry.

Capacity building

This project includes staff training both in buoy operation, end-to-end management, model operation, practical forecasting and interaction with the users in the society. As such it addresses all elements in the production chain leading to the end product. Learning how to operate and plan a professional forecasting service is the overall goal for HMS. The TCP program is seen as a catalyst for the achievement of this goal. Particular emphasis will be put on management skill to ensure the relevant international connections and the ability to operate within budgetary constraints.

Participants

Hydrometeorological Service of Vietnam has the role as the primary user of the project outcome, being qualified to operate an autonomous ocean forecasting system. The Norwegian Meteorological Institute is the project coordinator and responsible for strategical advice. The WMO acts as a catalyst in terms of providing infrastructure advice, expert assistance, and, potentially, support for development.

V.2 Coastal Observing System for the Eastern South Pacific Ocean (COSESPO)

Coordination: Osvaldo Ulloa (Programa Regional de Oceanografía Física y Clima (PROFC), Universidad de Concepción, Concepción - Chile).

Issues and Significance: The eastern South Pacific (ESP) region (Colombia, Ecuador, Peru and Chile) depends strongly on marine activities (e.g., fisheries, aquaculture, tourism, and marine transportation) for its economical development. These activities are all sensitive to conditions in the ocean either directly for ocean-based activities or indirectly via the role of the ocean in influencing regional climate. This is particularly true for the ESP region, which often has suffered large inter-annual changes in oceanographic and atmospheric conditions associated with the El Niño/Southern Oscillation phenomenon. Furthermore, with industrial growth and increases in material consumption, coastal pollution has become a serious problem.

Recent studies of circulation patterns off Chile using long-term, direct current observations over the slope (at 30°S), as well as other observations from the coast of Peru and Chile and from the Equatorial Pacific Ocean, have revealed the occurrence of large current fluctuations with periods of 10 - 70 days. These intra-seasonal fluctuations propagate poleward as coastal trapped Kelvin waves (CTW) along the South-American coast, and the lower-frequency ones dominate the current-meter records. The CTWs have been shown to be remotely forced by winds in the Equatorial Pacific Ocean, to be uncorrelated with local winds, and to modulate coastal sea surface temperature variability. These properties imply that useful forecasts of such low-frequency variability off the western coast of South America may be possible with up to two months lead time (depending on the latitude), and hence with the possibility of many practical applications.

Users and Products: The users of the proposed observing system include meteorological and hydrographic services, local authorities (e.g., harbor authorities), government agencies (e.g., environmental agencies), coastal managers and industry. The products of COSESPO will include nowcasts and forecasts of the circulation patterns on the shelf and in bays and harbors in each of the coastal region participating. The information generated can be used in practical applications such as dispersion of pollutants.

Relationships to the C-GOOS Global Network: It is expected that the observing system developed (COSESPO) in this pilot project will become a part of the C-GOOS Global Network. Furthermore, it will be an extension of the TAO array and an integral part of the eastern South Pacific Ocean Array being proposed for the region.

Project Design

Issues to be addressed

The project will serve two main C-GOOS categories: preserving healthy coasts and safe and efficient marine operations. It will address several C-GOOS issues, including toxic contamination, nutrient over-enrichment, spills of hazardous materials, etc.

Final prediction and lead time

Sea level and current and temperature fields could be predicted hours - 2 months (depending on latitude) in advance. The lead time should be in the order of hours.

Models to be used, model variables and outputs

The models to be used will be 3-D, time dependent circulation models implemented and run in each of the four areas. The boundary conditions for running each of the local models will come from a regional numerical ocean model to be run at one place. The regional model could be a version of the Princeton Ocean Model (POM). Data from the Southeast Pacific Ocean Array (SEPOA) and the TAO array and from remote sensing will be assimilated in the regional model. The output of the models will be time dependent temperature, salinity and velocity fields.

Elements of the Observing System

In each of the four locations, the observing system will consist of:

- a meteorological/oceanographic buoy;
- a tide gauge;
- remote-sensing observations (sea surface temperature, winds, altimetry);
- 3-D, time-dependent circulation model.

Feasibility: The project is technologically feasible, given appropriate funding. There will be a need for capacity building (see below).

Research and Development Needs:

- Measurements: Digital integration of several sensors and the development of electronic sensors (especially for chemical and biological variables) to be incorporated in the buoy;
- An efficient and low-cost system for transmitting data from the meteorological/oceanographic buoy will be required. An information system that integrates and displays the data from the different components of the observing system will also be necessary;
- Development of time-dependent, coastal numerical models.

Data and Information Management: Information from each of the four sites will be stored locally and made freely available to the international community.

Capacity Building: Training will be coordinated at the regional level and done through workshops and courses. Collaboration with institutions and agencies outside the region with the proper experience in the areas of interest will be sought. Priorities are as follows:

- Technical capacity to implement and maintain buoys and automatic tide gauges;
- Capacity for data acquisition, management and distribution;
- Capacity for implementation and use of circulation models.

V.3 SW Atlantic Network: Quickly Integrated Joint Observing Team (QUIJOTE)

Coordination: Eduardo Marone (Brazil), Ricardo Camargo (Brazil), Ernesto Forbes (Uruguay), Carlos Lasta (Argentina), Federico Isla (Argentina).

Issues and Significance: The goal of QUIJOTE is to monitor and predict changes in the coastal zone of the south western Atlantic Ocean by linking coastal institutions and improving the capability of national agencies and regional institutions. The operational categories to be addressed by the system include preserving healthy coastal ecosystems, promoting the sustainable use of coastal resources, mitigating coastal hazards, and safe and efficient marine operations. QUIJOTE is organized into 5 Modules that incorporate current projects and programs relevant to the coastal indicators of change (Table 2):

- The Near Shore Data Observing Network (DON);
- Storm Surge Forecast System (SSF);
- RedSur Network (RSN);
- Estuarine Dynamics (EDY);
- Beach Dynamics (BDY).

Each module addresses different aspects of the C-GOOS observing system (Tables V.3.1 and V.3.2). Each is based on existing activities that are at different stages of development, and it is anticipated that QUIJOTE will enable them to grow into operational programs. Participants are members of several institutions from Argentina, Brazil and Uruguay. For more information on all of the modules see (www.cem.ufpr.br/fisica/quijote.htm).

Users and Products: The SSF will provide storm surge forecasts in the south western Atlantic Ocean (SWAO region) for Argentina and Brazil. An important product of BDY will be maps of erosion risk that will provide information for decision-makers concerned with, for example, the management of land use in the coastal zone and the implementation of erosion control measures along the coastline. A common problem is the lack of coastal rules or policy, or the existing indifference to them. These maps would be based on detailed satellite images, specifically processed (NDVI products, unsupervised and supervised classifications, thematic maps).

EDY will provide understanding of interactions between estuaries, coastal drainage basins, and the adjacent sea based on observations that relate coastal oceanography to the life cycle of ecologically and commercially important plant and animal populations in estuarine habitats. This information will be of fundamental importance for the formulation and implementation of environmental policies for the management and mitigation of critical habitats (e.g., tidal wetlands such as mangrove swamps), fisheries, and water quality, especially in rapidly developing areas in the region of urban centers.

Relationship to the C-GOOS Global Network and other programs: QUIJOTE is directly related to the development of the Coastal Observing Network for the Near Shore (CONNS) element of C-GOOS. Intergovernmental Oceanographic Commission workshops involving representatives from Argentina, Brazil and Uruguay led to the conclusion that one of the most important problems in the coastal zone is erosion of the shoreline caused by episodic storms (dominantly from the S and SE).

Project Design

Issues to be addressed

The initial focus of the observing system will be on coastal circulation (DON), erosion (BDY), habitat loss (EDY), forecasting natural hazards and associated storm surges (SSY), and capacity building (RSN).

Final prediction and lead time

The goal of the SSF is to provide storm surge forecasts in the south western Atlantic Ocean (SWAO region) for Argentina and Brazil with lead times of hours to days.

Models to be used, model variables and outputs

SSF will present the outputs (sea surface height, current over the shelf, winds) of a coupled Regional Atmospheric Model and an Ocean Numerical Model (Princeton Ocean Model) on the Internet. It will provide the circulation and sea level patterns for all the other projects and users. From a initial simulation phase, this module will evolve to a fully operational one, producing storm surge forecasts by using atmospheric and ocean circulation models, publishing the results on the Internet.

Mesoscale meteorological forecasts for the study area can be supplied by operational runs of the Regional Atmospheric Modelling System (RAMS) at the Department of Atmospheric Sciences of University of São Paulo. The model assimilates large scale analyzed and a predicted wind fields provided by global models (normally NCEP and CPTEC, and occasionally ECMWF) and improves the forecast considering regional aspects in a 32 km grid. The oceanic part of the proposed system is based on the Princeton Ocean Model (POM) simulations for the SWAO area with approximately 10 km resolution, which will be forced by predicted wind fields provided by RAMS as described above. The use of mesoscale wind fields in previous hindcasting simulations improves the results in comparison to wind fields directly from global models.

It will be necessary to understand the interaction between estuaries, coastal drainage basins, and the adjacent sea. EDY will employ a multidisciplinary approach to relate the coastal oceanography to the life cycle of fish and crabs based on conceptual models and a hierarchy of models that allow interactions among these systems to be explored.

Elements of the Observing System

DON is the regional near shore observing network that will formulate standards, develop common protocols for data exchange, integrate existing data, and identify and fill gaps in the observing system required to detect and forecast storm events and their effects on the coastal environment. Initial variables observed are meteorological (wind speed and direction, air pressure and temperature, humidity), oceanographic (salinity, temperature, sea level, turbidity, currents, and waves height, direction), and river runoff. The set of variables measured currently varies from place to place depending on local capabilities. The collected data are being graphically presented on-line, using the Internet. These data could be presented in an almost-real time or in a delayed mode (see http://www.cem.ufpr.br/fisica/don.htm).

Table V.3.1. Operational categories (Table 2) which will be addressed by each module. Issues to be addressed, users of the data and products, types of predictions or monitoring of changes and model types, inputs and outputs, are also presented.

Operational Category	**DON**- preserve healthy coastal environments; promote sustainable use of coastal resources; mitigate coastal hazards and safe and efficient marine operations **SSF** - mitigate coastal hazards; preserve healthy coastal environments **RSN** - public awareness, capacity building and networking of capabilities **BDY** - mitigate coastal hazards; promote sustainable use of coastal resources **EDY** - preserve healthy coastal environments; promote sustainable use of coastal resources
Issue	**DON** - Nearshore Observing Element; monitoring of change **SSF** - storm surges **RSN** - coastal information networking on all the GOOS operational categories **BDY** - promote sustainable use of coastal resources **EDY** - flooding, storm surges, erosion, sea level rise
Users	**DON** - scientists, decision-makers, fishery industry, harbors administration; universities, general public **SSF** - decision makers, fishery industry, harbors administration; universities **RSN** - scientific, technical and administrators community **BDY** - decision makers, fisheries management, universities, ONGs **EDY** - decision makers, coastal and harbor administrations; universities, governmental and non-governmental organizations
Prediction	**DON** - this module will not be predicting, but monitoring changes **SSF** - meteorological influence in coastal region, sea level and currents **RSN** - it will serve to predict regional needs, state of coastal zone studies, alert on problems and solutions **BDY** - fishing closed area, recruitment forecasting, ecological sensitivity charts, coastal hazard aids **EDY** - erosion and meteorological influence in the coastal region, risk maps
Model Type	**DON** - coastal observation network of laboratories using metocean stations **SSF** - atmospheric (RAMS) coupled to ocean 2D/3D (POM) numerical model **RSN** - communication network **BDY** - Conceptual, descriptive **EDY** - morphological models with the aid of a 2-3D ocean circulation model
Model Inputs	**DON** - direct data observation with QC procedures **SSF** - predicted wind fields from mesoscale models, tidal forcing **RSN** - individual, organization, agencies, governmental information **BDY** - WMF data, metocean stations, regular fishery/oceanographic cruises **EDY** - beach profiles, frequency and intensity of meteorological fronts, waves, sea level disturbances and shelf currents driven by winds
Model Output	**DON** - graphic data display on Internet; data reports **SSF** - sea level disturbances and shelf currents driven by winds **RSN** - information, up to date news on coastal zone issues **BDY** - prediction on living marine resources and health of the coastal zone **EDY** - erosion dynamics, alert system, risk maps

Table V.3.2. The types of variables that will be monitoring, their respective scales, the feasibility of each module as well as the technology that is being used or will be used to gather the data and to yield and deliver the products.

Variable	**DON** - wind, air temperature and pressure, rain, water temperature, salinity and height, coastal currents and waves, among others **SSF** - sea level along the coast; coastal winds and also winds over the open ocean **RSN** - does not apply **BDY** - beach profiles, waves, coastal currents, coastal sea level; coastal and oceanic winds **EDY** - water temperature & salinity, transparency, nutrients, species composition, among others
Scales	**DON** - from local to global **SSF** - from local to regional **RSN** - from local to regional **BDY** - from local to regional **EDY** - from local to regional
Feasibility	**DON** - already working at a basic stage, needs investment in equipment and up-grades **SSF** - at initial stage (simulation); few measuring problems in coastal stations; many operational problems with moored buoys; computer systems will need to be expanded **RSN** - already in place **BDY** - already working at a basic stage, needs investment in equipment and grades beach profilers need to be constructed and distributed among participants **EDY** - already working at a basic stage, needs investment in equipment and grades and for ocean cruises
Technology	**DON** coastal metocean automatic stations, Internet **SSF** numerical modeling using mid size computers, Internet **RSN** - Internet **BDY** CTD, coastal metocean stations, remote sensing, marine biology sampling devices, ships (which need resources to operate) **EDY** few problems in coastal stations for all variables, few meteo-station on the coastal zone; lack of wave records, but operational wave model is running

Feasibility and R&D needs: Initially, the main challenges involve the regional integration of existing systems and the development of an information network that capitalizes on the expertise and capabilities that are currently distributed among the participating nations and institutions.

Data and Information Management: A distributed system of data management will be employed using LABNET as a model.

Capacity Building: There is a need to develop capacity at all levels from the observing subsystem and data communications to data management, analysis and product development. The initial priority is to improve the flow of information and data among participating institutions and countries. Locally, the combined expertise required to design and implement QUIJOTE does not exist. However, when viewed as a whole, large regions of South America do have the required “critical mass” of marine scientists and oceanographers. Thus, the successful development of QUIJOTE will depend to a great extent on increasing the capacity to exchange knowledge among individuals and institutions on regional scales (e.g., the east coast of South America). The RedSur initiative is intended to develop the communication networks required to enable more effective sharing of ideas and information on the coastal ocean and the adjacent terrestrial environments that it impinges on. A second goal of the information network will be to create public access to data and information on coastal environments to increase awareness, understanding, and decision making. For more information see http://redsur.listbot.com.

V.4 Phytonet : The Phytoplankton Network

Coordination: Adriana Zingone, Stazione Zoologica ’A. Dohrn’, Napoli, Italy

Issues Addressed and Their Significance: The term 'Harmful Algal Bloom' (HAB) covers a heterogeneous set of events which differ considerably in terms of species and floristic groups involved, the conditions under which they occur, and their effects on people and ecosystem processes (Zingone and Enevoldsen, 2000). Harmful algal events may be caused by photosynthetic, heterotrophic or mixotrophic microorganisms; they may occur at low or high cell densities; and their occurrence is often determined based more on their effects than on changes in their abundance or toxicity *per se*. In recent decades, HABs and related events have been observed more frequently and in more places. This trend may reflect the intensity of observations or a real trend in the frequency of occurrence in time and space that may or may not be related to human activities. The lack of systematic, routine observations of the abundance, distribution and toxicity of harmful species make it impossible to determine which of these possible explanations is true (Wyatt, 1995).

The recently established IOC-SCOR Science Program GEOHAB (Global Ecology of Harmful Algal Blooms) and the EUROHAB Science Plan have identified fundamental gaps in the knowledge of causes and consequences of HABs that hinder substantial improvements in capabilities for management and mitigation of the phenomenon. These programs highlight the need for long-term monitoring programs in representative ecosystems that are linked to detect regional and global trends and develop a predictive understanding of HABs (GEOHAB, 1998; EUROHAB Science Plan, 1998). They also emphasize the importance of studies that consider harmful algal species in an ecosystem context, including their relationship to the abundance and distribution of phytoplankton species as a whole. This is important because HABs are an integral part of phytoplankton species succession and because the direct effects of HABs on other organisms (e.g., fish kills, human health) and the environment (e.g., oxygen depletion, the release of noxious chemicals) also have indirect effects on an array of ecosystem processes including (i) the fate of primary production and fish production (Legendre, 1990); (ii) biogeochemical cycles involving C and N (Arrigo *et al*. 1999; Karl *et al*. 1997); (iii) the flux of DMS to the atmosphere (e.g. Matrai *et al*. 1995); and (iv) biodiversity.

Data on the distribution and abundance of HAB species, and in some cases phytoplankton species as a whole, are collected at many coastal sites, though observation systems differ in terms of aims, methodology, quality assurance, coordination with similar efforts elsewhere, and dissemination of results. A monitoring network of laboratories (PhytoNet) is proposed to coordinate observations of HABs in the context of changes in the abundance of phytoplankton species in general to develop a sampling program that is representative and to improve the quality and availability of data on HABs, the environmental conditions under which they occur, and their effects. LABNET may be a model for the development of this network.

The network will begin by involving scientific institutions and monitoring agencies in Europe where data are most available and where the resources exist to achieve this ambitious goal. A high priority of the network will be a retrospective analysis of existing data bases with the aim of tracking compositional trends in relation to climatic and/or anthropogenic changes. The goal is to detect trends and to develop analytical tools and models required to predict, mitigate and control HABs. PhytoNet in Europe will be a test-bed for networking of on-going observation programs that can be expanded to include other regions connected to the C-GOOS global network.

Users and Products of the Observing System: The benefits of the proposed network are greater and more time by access to data on HABs, phytoplankton species composition, and related environmental variables; improved inter-calibration and quality control; earlier detection of trends; and the development of a predictive understanding of HABs. Potential users groups include:

- aquaculturists: to take timely decisions on management of aquaculture activities;
- health authorities: to optimize human health protection;
- scientists: who are both contributors and users of the data sets for scientific purposes;
- monitoring authorities: to produce data in a more timely way and reduce the cost/benefit ratio;
- resident populations: to diminish the risk of accidents caused by ingestion or exposure to algal toxins;
- tourist industry: to protect tourists from exposure and to mitigate the effect of HABs;
- decision-makers: to plan a safe and effective use of the coastal zone;
- regulatory bodies: to lay down common regulations for monitoring operations.

Products expected from PhytoNet include:

- guidelines for monitoring, data management and dissemination;
- easily accessible and illustrated species check-lists and data bases;
- standardized procedures for data quality assessment and control;
- regional and European meta-data centers;
- training and intercalibration on sampling, analysis and data management;
- identification of methodological, technological and scientific needs; and
- diversified, user-friendly data dissemination tools.

Relationship to the C-GOOS Global Network and Related Programs: PhytoNet exploits existing monitoring systems which will improve the initial observing system as follows:

- provide high quality data on phytoplankton diversity and distribution in conjunction with data on relevant physical and chemical variables;
- provide a forum for conducting intercalibration exercises;
- increase the utility of satellite imagery of ocean color by providing data on floristic composition that may be resolved from water leaving radiance spectra; and
- help to identify biological and environmental variables and associated scales of variability that influence species succession, biodiversity, and HABs and contribute to the development of theory required to detect and predict HABs.

PhytoNet will also be a user of C-GOOS data: physical and chemical data gathered by the Global Network will be invaluable to the development of a predictive understanding of HABs. Timely information on the scales of variability of environmental factors such as wind stress, coastal circulation, vertical mixing, temperature, salinity and nutrient concentrations are essential to understand mechanisms underlying biological variability, including the development of blooms and the occurrence of harmful events. This will significantly improve predictive capability for HABs and their effects.

In addition to C-GOOS, PhytoNet will contribute to the success of several research programs including GEOHAB, IBOY, and I-LTER, and to the development of regional GOOS programs including BOOS and the MFS.

Project Design

Issues to be addressed.

PhytoNet will provide data and information required to preserve and restore healthy ecosystems, to manage resources for sustainable use, and to mitigate coastal hazards. Although the network is primarily intended to address the problem of HABs, it will provide data on variables required to detect and predict changes in biodiversity, the proliferation of nonindigenous species, and fish stocks.

Final Prediction and Lead Time

Predicting the occurrence of nuisance and harmful species at specific sites is the primary goal of PhytoNet. A warning system is already in the scope of local and going monitoring activities. But alerts are usually given after HABs have developed, and, in most cases, too late to mitigate consequences. The probability of occurrence needs to be predicted with sufficient lead time to prevent or control the event and to mitigate consequences. In the case of responsible government agencies and the aquaculture industry, lead times should be on the order of days-weeks to achieve these ends. Predictions of locations that are likely to experience HABs might be made with much longer lead-times (years) to facilitate decisions by coastal managers concerning the use of coastal areas.

Model to be used, Model Variables and Outputs

Model predictions of phytoplankton succession in general and HABs in particular are difficult to make with confidence due to the numerous non-linear relationships between the biological, chemical and physical variables that govern changes in the abundance of species in plankton communities. In the absence of a robust theory of species succession, statistical approaches that require quantitative knowledge of historical time-space patterns of variability to make predictions based on probabilities are most realistic.

Feasibility and Cost-Benefit Analysis: PhytoNet focuses on phytoplankton abundance and species composition. For these variables, automated systems for sampling and identification are being developed but are not operational at this time. From this point of view, the feasibility of a phytoplankton network would be low. However, the initial PhytoNet will be established by incorporating and linking existing monitoring operations.

Variables that influence the growth of phytoplankton should be measured in conjunction with measurements of the abundance of phytoplankton species. These include temperature, salinity, nutrients and meteorological variables for which automated measurements are feasible. In many cases, these variables are included in routine phytoplankton monitoring operations. The biggest effort is in the intercalibration and harmonization of these data to make them comparable regardless the source of the data.

R&D needs: Extensive research will be required to develop a predictive understanding of HABs and their effects. The questions that must be addressed to develop an operational system include the following:

- Under what environmental conditions are HAB events most likely to occur?

HAB species exhibit a high interspecific and often intraspecific diversity in terms of ecophysiological requirements and bloom dynamics. Comparison among different species, areas and bloom dynamics are necessary in order to find commonalities and recurrent patterns. Research in this direction is fundamental to the prediction of HAB events based on hydrographic conditions as detected through real-time telemetered data and satellite imagery.

- Are patterns in the occurrence of HABs correlated with trends in anthropogenic inputs to and activities in coastal ecosystems or with large scale changes in climate or both?

This knowledge is essential for risk assessment and to formulate predictions that can assist politicians and managers in decisions concerning human uses of coastal ecosystems. This requires a retrospective analysis of available phytoplankton data and relevant environmental variables. First results obtained at selected sites indicate that it is possible to trace a relationship of long term trends for phytoplankton species, including harmful species, to human impacts or to large-scale meteorological oscillations (Cadée, 1986; Radach *et al*., 1990; Belgrano *et al*. 1999).

- On what scales in time and space must ecosystems be monitored to develop a predictive understanding of HABs based on variations in the environmental parameters of HABs?

This must be addressed in order to design an optimized sampling and data analysis strategy and reduce the cost-to-benefit ratio. Analogous questions on environmental forcings, trends and scales of variability must be answered when addressing the issues of biodiversity loss and community shifts in relation to the assessment of environmental quality and food availability for living marine resources.

The answers to these questions, and the development of analytical and predictive models, are among the aims of GEOHAB.

Data and Information Management: Data and information management are among the main issues of this project and will be addressed by specific working groups. The primary data expected from network activities are phytoplankton species abundances, with particular attention to toxic or potentially toxic and nuisance species. Complementary data concerning physical and chemical variables, as well as other biological variables monitored synchronously with phytoplankton will also be important. First steps will be the harmonization of different data bases, built on agreed taxonomic lists of species and common procedures for data archives.

A problem to tackle is the recovery of data gathered with old sampling techniques in the transition towards new and improved ones, in order not to interrupt or distort existing data-series. Statistical methods such as post-calibration techniques will be explored in cases of changing data quality and data gaps.

Another critical aspect is the translation of data into useful and clear information tailored for the distinct categories of customers that have been identified. Different communication channels and methodologies will be investigated in relation to possible uses of the information.

GOOS Policies for data exchange and data management will be adhered to. Participants in PhytoNet will address this issue in more detail during the early stages in planning.

Capacity Building: For most of the European community there is a need for capacity enhancement rather than capacity building. A large number of institutions have developed phytoplankton monitoring programs throughout Europe. The time devoted to sample analysis and species identification does not vary notably among laboratories, but data quality probably varies widely depending on the skill and experience of those who identify and count organisms as well as on the availability and quality of instruments (e.g., microscopes, image analyzers) and information (literature, text-books). A priority of this project is to provide the necessary training and equipment to ensure quality data from all laboratories. Increasing the reliability of species identification is a high priority in this regard. In addition, capabilities for data communications and management will need to be enhanced. Training courses and intercalibration exercises are planned, with thorough exchange of expertise and facilities within the network. Regional-based, intercalibrated species lists will be compiled, regularly updated and made available in electronic and paper support, as well on the web.

V.5 The Coordinated Adriatic Observing System (CAOS)

Coordination: Serena Fonda-Umani (Italy), Alenka Malej (Slovenia), Nenad Smodlaka (Croatia), and Tom Malone (USA)

Issues and Significance: The Adriatic Sea is a semi-enclosed body of water with densely populated coastal watersheds with a long history of land-use. Surrounding countries belong to the industrially developed and developing world with established or growing economies. The region is characterized by intensive land-based and sea-based activities including urban growth and development, agriculture, commercial and recreational fisheries, tourism, and multinational maritime commerce. Like many coastal environments throughout the world, land-use practices and population growth have led to increases in nutrient loading and changes in freshwater flow patterns to coastal waters that have been especially pronounced over the last 100 years. There is reason to believe that these changes are causing profound alterations of coastal waters as indicated by mucilage events, oxygen depletion of bottom water, harmful algal events, outbreaks of gelatinous zooplankton, invasions of nonindigenous species and loss of habitat (Malone *et al*., 1999). Individually, these phenomena may not be cause for concern. As a group, they may be indicative of a pattern of environmental degradation that threatens the health of coastal ecosystems of the Northern Adriatic (NA).

The Po River is the largest single source of freshwater and nutrients (nitrogen and phosphorus) to the NA. However, about half of the nutrient load to the northern Adriatic enters the system north of the Po River discharge, and the importance of atmospheric deposition is unknown. Under most circumstances, nutrients delivered by the Po River have a short residence time in the northern Adriatic relative to nutrient inputs to the north and east (e.g., the Gulf of Trieste) of the Po. The latter are more likely to be retained and recycled within the northern Adriatic before being lost to the atmosphere (denitrification), buried in the sediments (particulate N and P), or transported into the southern reaches of the Adriatic. Thus, the effects of inputs north of the Po on the health of the northern Adriatic may be greater than for nutrients delivered by the Po. This underscores the importance of detecting and predicting changes in the circulation regime of the NA on time scales of days to months and space scales of 1-100 km.

Users and Products of the Observing System: Nutrient enrichment of the NA may be related to several indicators of environmental change that affect shipping, tourism, fisheries, and ecosystem health. These include (1) habitat loss (changes in attached macrophyte communities, loss of tidal wetlands); (2) phytoplankton blooms and subsequent episodes of bottom water hypoxia; (3) episodic mucilage events (“mare sporco”) and mass mortalities of benthic organisms, (4) diarrhetic shellfish poisoning and the closure of mussel beds, (5) outbreaks of jellyfish, and (6) invasions of the exotic species. Given these problems, the observing system must be designed to detect and predict ecosystem responses to episodic and seasonal scale variations in freshwater inputs and nutrient loading that vary on interannual time scales.

In the beginning, users of CAOS products will be scientists concerned with documenting and predicting variability, change, and the causes and consequences of change; government agencies responsible for resource and environmental management; environmental conservation groups; and the tourist, shipping and fishing industries. Products will include periodic assessments of the status of the NA ecosystem, documentation of the scales of variability that characterize indicators of change, and nowcasts and forecasts of sea state and surface currents. Status of the NA (e.g., the Northern Adriatic Environmental Report) will be documented in terms of the following measures:

(1) Recreational use (beach use, boating, fishing; number of people or user days per year);
(2) Commercial landings of fish and shellfish (kg/yr);
(3) Mucilage events (duration and area affected) (time-area integral/yr);
(4) Bottom water hypoxic events (duration and area affected) (time-area integral/yr);
(5) Shellfish bed closures (cause, duration, area impacted)(no. organisms affected/yr);
(6) Harmful algal blooms (duration, area impacted)(number/yr);
(7) Phytoplankton biomass and light penetration (seasonal maximum for Po River Plume, Gulf of Trieste, Emilia Romagna, < 25 m along the Istrian coast); and
(8) Biodiversity of native species of marsh grass, submerged vascular plants, macroalgae, fish, shellfish, mammals, and birds.

Relationship to the C-GOOS Global Network and Related Programs: It is envisioned that CAOS will contribute to the development of the Mediterranean Forecasting System (MFS) and become a component of the C-GOOS global network. MFS, a pilot project of EuroGOOS and MedGOOS, has been funded by the EC. The broad goal of the MFS is to nowcast and predict marine ecosystem variability (SST, surface currents and waves, primary productivity) from basin scale to the coastal-shelf areas on time scales of weeks-months. This requires the development and implementation of an automated monitoring-nowcasting-forecasting observation system with a modeling component that connects measurements (monitoring) to products (e.g., predictions, visualizations). The achievement of this ambitious goal will depend on the design and implementation of a hierarchy of nested observation systems from the scale of the Mediterranean (MFS) to the local and regional scale of continental shelves and seas. CAOS will contribute to the development of the higher resolution local-regional scale components of the MFS.

Research programs that provide the scientific foundation of CAOS include LOICZ (ELOISE), GLOBEC, COLORS and the international LTER program. The quantification of fluxes of nutrients and water from coastal drainage basins to estuaries and the coastal ocean and of nutrient (ELOISE, LTER) and of trophic dynamics (GLOBEC) are of particular importance.

Project Design

Issues to be addressed

This pilot project is conceived as a component of the proposed Coordinated Adriatic Observing System (CAOS). In addition to changes in sea state, indicators of change (Table 2) to be addressed include all of those listed under the category of ecosystem health and living marine resources.

Final Prediction and Lead Time

As causal relationships between land-use, water quality and fisheries are established and parameterized, user groups will expand to include government agencies responsible for land-use planning and the agriculture industry. Products will expand to include forecasts, beginning with alerts for the development of HABs, bottom water hypoxia and mucilage events and developing into forecasts of probabilities of occurrence, areal and temporal extent, movement, and impacts. Lead times for predictions should range from days-weeks for tourist and mariculture industries to months-years for resource managers and land-use decisions.

Models to be Used, Model Variables and Outputs

The assimilation of data from *in situ* and remote sensing and improvements in coupled, 3-dimensional, time-dependent biological-physical models will be required to transform measurements into products in a timely fashion (e.g., predictions of environmental change, analysis of the efficacy of management actions mitigating coastal eutrophication). Advances in both modeling and remote sensing will require (1) more intelligent algorithms for coastal waters; (2) improved spatial and temporal resolution to resolve space scales of order 100 m associated with important physical and biological features in coastal waters on diurnal and semi-diurnal scales; and (3) integration of *in situ* time series measurements with remote observations for more accurate documentation of time-dependent changes in spatial distributions.

Given these considerations and the requirements of both detecting and predicting patterns of change, the observing system will consist of five key elements: (1) remote sensing (from aircraft, satellites, and fixed platforms, e.g. high frequency radar) to capture the spatial and temporal dimensions of change in surface properties; (2) *in situ* measurements to capture the temporal and spatial dimensions of change with depth (moored instruments, drifters, AUVs, ships); (3) research to develop the models required to link observations to products in the form of predictions and early warnings; (4) real time telemetry and data assimilation for timely access to and applications of environmental data; and (5) an effective data management system (including quality assurance and control) that accommodates the disparate sources of data and scales of measurement.

Feasibility: Measurements of many of these properties will be essential for periodic updates of the Northern Adriatic Environmental Report on the health of NA ecosystems. However, with the important exception of Chl-a, most of the important biological properties cannot be measured by either remote or *in situ* sensing technologies, i.e., measurements are time consuming and/or labor intensive. High priority should be given to the development of technologies that provide cost-effective methods for measuring biological and chemical properties for more timely dissemination of data.

Research and Development: Emphasis during the early phases of CAOS will be on data exchange, monitoring, and analysis to reveal time-space (4-D) patterns in the current field and related distributions of key properties (T, S, nutrients, chlorophyll, dissolved oxygen, turbidity) and research to quantify the causes and consequences of the observed patterns, model development. As measurements, data dissemination, assimilation modeling, and the production of products become routine, the observing system will become increasingly operational (Research monitoring => Operational monitoring).

There are fundamental questions that must be answered through research and monitoring before an operational system can be implemented. These include the following: (1) Do historical data bases and sediment records reveal past trends that can be related to anthropogenic activities and aid in the design of CAOS? (2) How does the NA respond to nutrient loading (nitrogen, phosphorus and silicon) in terms of variations in primary productivity and biomass, trophic dynamics, (microbial and metazoan food webs), and nutrient cycling? (3) How are these responses related to the development and magnitude of mucilage events; oxygen depletion; and the population dynamics of harmful algae, gelatinous zooplankton and living resources (indicators of ecosystem health)? (4) Are such indicators of the health of coastal ecosystems related to particular land-use practices or patterns of land-use? (5) How do changes in ecosystem health impact on the economies of the surrounding States in terms of fisheries (including mariculture), shipping and tourism?

The development of meaningful answers to these questions will require:

- a data communications network and distributed management system for the Adriatic;
- a network of high resolution observations in the NA nested in the larger scale observations of the MFS; and
- research programs that employ a combination of observation, experiments and modeling to determine the causes and effects of environmental phenomena revealed by the monitoring network.

The physical setting of the Adriatic Sea as a whole is of fundamental importance to the design of a sampling program that will provide meaningful answers to the environmental questions posed above. A quantitative understanding of the mean circulation, deviations from the mean (especially lateral west-east transport and advective exchanges between the shallow northern region and the deeper southern region), and of the processes responsible for these deviations will be required. Major forcings (e.g., river flows, wind stress, solar radiation, atmospheric deposition, tides) must be monitored on a regular basis. This, and the monitoring of changes in water quality parameters (e.g., nutrient loading, temperature, incident radiation, water column stratification, phytoplankton and zooplankton biomass) and indices (e.g., dissolved oxygen, turbidity, mucilage, HAB species, mass mortalities of macrobenthic organisms and fish) are key components of the proposed Coordinated Adriatic Observing System (CAOS).

Data and Information Management: The goals of data management are (1) data comparability, (2) validation of methods and measurements, (3) agreement on data and metadata formats and archival, and (4) timely access to data and information. Data management will include QAQC, dissemination of data, archival of data, and the generation of data products. The data management strategy must recognize the multiplicity of data sources and types, the diversity of users and products, and the overarching concerns of quality assurance, timeliness, and accessibility of data and data products. The basic requirements are (1) integration of existing systems, (2) design to meet user needs, (3) quality assurance, (4) appropriate metadata, and (5) free and open access. To the extent possible, data management will rely upon existing national and international programs, and will work with the MFS and the Joint Data and Information Management Panel (JDIMP) to develop an integrated management plan for the Adriatic.

Capacity Building: Recognizing that many coastal states lack the capabilities in marine science required to fully participate in, contribute to, and benefit from the effective planning, establishment and coordination of an operational ocean observing system, the IOC/GOOS has developed principles and is developing a program to develop national capabilities in marine sciences and services. A high priority for the Adriatic is capacity building for the purposes of data communications and management.

ANNEX VI

Acronyms

ADCP	Acoustic Doppler Current Profiler
ALOS	Advanced Land Observing Satellite
ARIES	Australian Resource Information and Environment Satellite
AUV	Autonomous Underwater Vehicle
AVHRR	Advanced Very High Resolution Radiometer
BDY	Beach DYnamics
BOOS	Baltic Operational Oceanographic System
CalCOFI	California Cooperative Fisheries Investigation
CAOS	Co-ordinated Adriatic Observing System
CBMP	Chesapeake Bay Monitoring Program
CDOM	Colored Dissolved Organic Matter
CEOS	Committee on Earth Observation Satellites
CGMS	WMO's Co-ordination Group for Meteorological Satellites
C-GOOS	Coastal Panel of GOOS
Chl	Chlorophyll
CLIVAR	Climate Variability and Predictability
CMM	Commission for Marine Meteorology (of WMO)
CNES	Centre National d'Etudes Spatiales (French space agency)
CODAR	High Frequency Coastal Radar
COLORS	COastal region LOng-term measurements for color Remote Sensing development and validation
COMBINE	COoperative Monitoring in the Baltic Marine Environment
CONNS	Coastal Observing Network for the Near Shore
COOP	Coastal Ocean Observations Panel
COSESPO	Coastal Observing System for the Eastern South Pacific Ocean
CPR	Continuous Plankton Recorder
CPTEC	Center for Weather Forecasts and Climate Studies (Brazil)
CTW	Coastal Trapped Wave
CZCS	Coastal Zone Colour Scanner
DBCP	Data Buoy Cooperation Panel
DMS	Dimethylsulphide
DNMI	Norwegian Meteorological Institute (Det norske meteorologiske institutt)
DO	Dissolved Oxygen
DON QUIJOTE	Data Observing Network for the QUIJOTE
EC	European Community
ECMWF	European Center for Medium Range Weather Forecasting
EDY	Estuarine DYnamics
EEZ	Exclusive Economic Zone
ELOISE	European Land-Ocean Interaction Studies
ENSO	El Niño Southern Oscillation
EOIA	European Oceanographic Industry Association

ESP	Eastern South Pacific
EU	European Union
EuroGOOS	European GOOS
EuroHAB	European Harmful Algae Bloom
GBIF	Global Biodiversity Information Facility
GCN	Global Core Network
GCOS	Global Climate Observing System
GCRMN	Global Coral Reef Monitoring Network
GEF	Global Environment Facility
GEOHAB	Global Ecology of Harmful Algal Blooms
GIPME	Global Investigation of Pollution in the Marine Environment (IOC)
GIS	Geographic Information System
GIWA	Global International Water Assessment
GLI	Global Imager
GLOBEC	Global Ocean Ecosystem Dynamics
GLOSS	Global Sea Level Observing System
GNP	Gross National Product
GODAE	Global Ocean Data Assimilation Experiment
GPA/LBA	Global Program of Action for the Protection of the Marine Environment from Land-Based Activities
GPO	GOOS Project Office
GPS	Global Positioning System
GSC	GOOS Steering Committee
GTOS	Global Terrestrial Observing System
GTS	Global Telecommunications System
HAB	Harmful Algal Bloom
HELCOM	Helsinki Commission -Baltic Marine Environment Protection Commission
HMS	Hydrometeorological Service (Vietnam)
HOTO	Health of the Oceans (IOC)
HPLC	High Performance Liquid Chromatography
IAEA	International Atomic Energy Agency
IBOY	International Biodiversity Observation Year
IBTS	The International Bottom Trawl Survey of the North Sea
ICAM	Integrated Coastal Area Management
ICES	International Council for the Exploitation of the Sea
ICLARM	International Center for Living Aquatic Resources Management
ICM	Integrated Coastal Management
ICSU	International Council for Science
IGAC	International Global Atmospheric Chemistry Project
IGBP	International Geosphere - Biosphere Program
I-GOOS	IOC-WMO-UNEP Intergovernmental Committee for the Global Ocean Observing System
IGOS	Integrated Global Observing Strategy
IGOSS	Integrated Global Ocean Services System
IGS	International GPS Service for Geodynamics
IGU	International Geographic Union

I-LTER	International LTER
InfoBOOS	BOOS Information System
IOC	Intergovernmental Oceanographic Commission (of UNESCO)
IOCCG	International Ocean-Colour Coordinating Group
IODE	International Ocean Data and Information Exchange program
IPHAB	Intergovernmental Panel on HABs
ITSU	International co-ordination group for the TSUnami Warning System in the Pacific (IOC)
IUCN	International Union for the Conservation of Nature (and Natural Resources)
JCOMM	Joint Technical Commission for Oceanography and Marine Meteorology
JDIMP	Joint Data and Information Management Panel
JGOFS	Joint Global Ocean Flux Study
LIDAR	Light Detection and Ranging
LMR	Living Marine Resources
LOICZ	Land-Ocean Interactions in the Coastal Zone
LTER	Long Term Ecosystem Research network
MERIS	Medium Resolution Imaging Spectrometer
MFS	Mediterranean Forecasting System
MODIS	Moderate Resolution Imaging Spectroradiometer
MOS	Modular Optoelectronic Scanner
NA	Northern Adriatic
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration (USA)
NASDA	National Space Agency of Japan
NCEP	National Centers for Environmental Protection
NDBC	National Data Buoy Center
NDVI	Normalized Difference Vegetation Index
NEAR-GOOS	North East Asian GOOS
NEMO	Naval Earth Map Observer
NGO	Non-governmental Organization
NOAA	National Oceanic and Atmospheric Administration (USA)
NODC	National Oceanographic Data Center
NWP	Numerical Weather Prediction
NRT	Near Real Time
OBIS	Ocean Biogeographical Information Systems
OCTS	Ocean Color and Temperature Scanner
OECD	Organization for Economic Co-operation and Development
OOPC	Ocean Observations Panel for Climate
OOSDP	Ocean Observing System Development Panel
OSNLR	Ocean Science in Relation to Non-Living Resources
OSPARCOM	Convention for the Protection of the Marine Environment of the North-East Atlantic
OSSE	Observation System Simulation Experiments
PAR	Phosynthetically Active Radiation
PDO	Pacific Decadal Oscillation

POLDER	Polarization and Directionality of the Earth's Reflectances
POM	Princeton Ocean Model
PRODAS	Prototype Ocean Data Analysis System
PROFC	Programa Regional de Oceanografía Física y Clima
QUIJOTE	QUickly Integrated Joint Observing TEam
QAQC	Quality Assurance and Quality Control
RAMS	Regional Atmospheric Modelling System
RLDC	Responsible Local Data Center
RNODC	Responsible National Oceanographic Data Center
ROV	Remotely Operated Vehicle
RSN	RedSur Network
SAR	Synthetic Aperture Radar
SCS	South China Sea
SEAS	Shipboard Environmental Data Acquisition System
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SEI	Special Events Imager
SEPOA	Southeast Pacific Ocean Array
SIMBIOS	Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies
SLFMR	Scanning Low Frequency Microwave Radiometers
SOLAS	Safety of Life At Sea
SOOP	Ship Of Opportunity Program
SSF	Storm Surge Forecast System
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
START	Global Change System for Analysis, Research and Training
SWAO	South western Atlantic Ocean
TAO	Tropical Atmosphere Ocean (buoy array)
TCP	Tropical Cyclone Program
TEMA	Training, Education and Mutual Assistance (IOC)
TOGA	Tropical Ocean and Global Atmosphere
TRMM	Tropical Rainfall Measurement Mission
UNCED	The United Nations Conference on Environment and Development
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
VOS	Voluntary Observing Ships
WAM	WAve Model
WCRP	World Climate Research Program
WESTPAC	IOC Sub-Commission for the Western Pacific
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WODC	World Oceanographic Data Center
WWW	World Weather Watch