THE COASTAL COMPONENT OF THE U.S. INTEGRATED OCEAN OBSERVING SYSTEM

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Abstract. The combined effects of human activities and natural variability present significant challenges to the goals of protecting, restoring, and sustaining coastal ecosystems. Meeting these challenges and resolving conflicts in an informed fashion will require (1) more timely detection and prediction of environmental changes and their consequences and (2) more timely access to relevant environmental information. The achievement of these goals depends on the development of a sustained and integrated coastal ocean observing system (ICOOS) that insures timely access to the data and information required to improve (1) climate predictions and the effects of changes in the weather on coastal populations; (2) efforts to sustain and restore healthy coastal marine ecosystems and living marine resources; and (3) compliance monitoring and evaluations of the efficacy of environmental policies. Although the responsible federal and state agencies all require similar environmental information, many separate programs have evolved for collecting, managing, and analyzing data for various purposes. Consequently, there is too much redundancy; access to diverse data from disparate sources is limited and time consuming; and individual programs are inevitably underfunded and too limited in scope. A system is needed that coordinates and integrates many of the elements of these programs to minimize redundancy, be more comprehensive, provide more timely access to data and information, and satisfy the information needs of a greater number of user groups in a more cost-effective fashion. This is the purpose of the ICOOS.

Keywords: integrated coastal ocean observing system, detecting and predicting environmental change, anthropogenic effects, sustained observations, coastal monitoring, ecosystem assessments

1. Introduction

Living resources are concentrated in coastal marine and estuarine systems and the number of people living in coastal drainage basins is increasing rapidly (Costanza et al., 1997; Daily et al., 2000; Hinrichsen, 1998). Consequently, the demands on these systems to provide goods and services will continue to grow (e.g., shipping and recreation; provide resources and living space; receive, process, and dilute the effluents of human society). At the same time, coastal ecosystems are experiencing unprecedented changes (Table 1). The phenomena of interest include a broad spectrum of variability from changes in sea state, coastal flooding, and harmful algal events to habitat loss (e.g., coral reefs, sea grass beds and tidal wetlands) and sea level rise associated with climate change. Together, these changes are making the coastal zone more susceptible to natural hazards, more costly to live in, and of less value to people and the national economy.

The purpose of this contribution is to describe a major effort that is underway to organize an integrated coastal observing system by coordinating, enhancing and supplementing existing programs that meet the design requirements of the system (see section 3). The goal is to develop an integrated, coastal ocean observing system (ICOOS) that will enable (1) more cost-effective use of infrastructure, knowledge and expertise; (2) more rapid access to environmental data and information; (3) more timely detection and prediction of changes and events; (4) broader applications of data and information; and (5) increases in the value of and funding for coastal marine and estuarine research and monitoring.

2. Rationale for an Integrated Approach

The nation's efforts to understand, detect and predict the changes occurring in coastal ecosystems suffers from the paradox of <u>too much</u> (redundancy), <u>too little</u> (not comprehensive in terms of both the measurements that are made and the data that reside in accessible data bases) and <u>too late</u> (the time required to acquire and analyze data is too long). A large number of state and federal agencies are currently engaged in and responsible for different but overlapping aspects of environmental change in

Table 1. Natural and anthropogenic forcings and associated changes in the phenomena of interest in coastal marine ecosystems where forcings refer to inputs of matter and energy from sources external to the system in question. No attempt has been made to distinguish between anthropogenic and natural forcings because, although some forcings are clearly of human origin (e.g., harvesting marine resources and chemical contamination), there are few if any "natural" forcings that do not have a human signature of some sort (e.g., climate change).

	FORCINGS
Natural & Anthropogenic	✍ Global warming & sea level rise ✍ Storms & other extreme weather events ✍ Seismic events ✍ Ocean currents , waves, tides & storm surges ✍ River & ground water discharges ✍ Physical restructuring of the environment ✍ Alteration of the hydrological cycle ✍ Harvesting living & nonliving resources ✍ Alteration of nutrient cycles ✍ Sediment inputs ✍ Chemical contamination ✍ Inputs of human pathogens ✍ Introductions of non-native species
	PHENOMENA OF INTEREST
Marine Services & Public Safety	✍ Sea level ✍ Changes in sea state ✍ Changes in coastal circulation ✍ Coastal flooding ✍ Shoreline changes ✍ Changes in shallow water bathymetry
Public Health	✍ Seafood contamination ✍ Abundance of pathogens
Ecosystem Health	✍ Habitat modification & loss ✍ Changes in biodiversity ✍ Eutrophication ✍ Harmful algal events ✍ Invasive species ✍ Disease & mass mortalities of marine organisms
Living Resources	✍ Changes in the abundance of exploitable living marine resources ✍ Change in landings (plants and animals)

coastal ecosystems. At least 8 federal agencies are responsible for collecting environmental data from estuarine and coastal marine systems (Commerce, Navy, Interior, Transportation, Energy, National Science Foundation, National Aeronautics and Space Administration, and the Environmental Protection Agency), and agency budgets and programs are reviewed and approved by 47 different Congressional Committees (Weisberg et al., 2000). Agency missions range from forecasting the weather, enabling safer and more efficient marine operations, and predicting the effects of climate change to managing the health of coastal ecosystems and the resources they support, protecting public health, and mitigating the effects of natural disasters and human activities. In response to these needs and in a case-by-case fashion, individual agencies and departments within agencies (both federal and state) have developed separate systems for collecting, managing, analyzing and applying environmental data, e.g., compliance monitoring, resource management, coastal zone management, coastal engineering. This has led to much redundancy (from measurements to data management) and to inefficiencies in the detection and prediction of environmental changes and their consequences. At the same time, individual programs, by themselves, are inevitably underfunded, limited in scope, and target a limited number of user groups. Consequently, major gaps exist in our understanding of variability in coastal environments; our ability to assess the status of coastal ecosystems and predict future conditions is inadequate; and our capacity to mitigate the effects of environmental changes is rudimentary at best.

It is likely that, in the absence of an organized and integrated system for improved detection and prediction of environmental changes and their effects on the environment and people, conflicts between commerce, recreation, development, environmental protection, and the management of living resources will become increasingly contentious and politically charged, and the social and economic costs of uninformed decisions will become more expensive. Although, the challenges of developing such a system are significant, we are witnessing a convergence of societal needs and technical capabilities that suggest the time is right to develop an ICOOS. It is time to design and implement a coastal system that is (1) based on sound science and modern technologies; (2) provides more timely access to data and information on environmental change; (3) makes more effective use of existing resources, knowledge and expertise; and (4) develops in concert with the integrated ocean observing system for climate (Nowlin et al., 1996; Malone and Cole, 2000).

3. The Design of An End-to-End, Integrated and Sustained Observing System

3.1 ELEMENTS OF AN END-TO-END OBSERVING SYSTEM

Both detection and prediction depend on the development of an integrated (multidisciplinay, end-to-end) and sustained observing system that effectively links measurements and data analysis to the needs of government agencies for more timely access to data and environmental information. 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 monitoring 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 (data dissemination and access) 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).

The **monitoring subsystem** is the measurement end of the system. It consists of the national infrastructure required to measure the required variables and transmit data to the communications network and data management subsystem. The infrastructure consists of the mix of platforms, samplers, and sensors required to measure the common 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 monitoring elements: (1) coastal observing networks for the near shore; (2) fixed platforms, moorings and drifters; (3) research and survey vessels, ships of opportunity (SOOP) and voluntary observing ships (VOS); (4) remote sensing from satellites and aircraft; and (5) remote sensing from land-based platforms (e.g., high frequency radar).

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, regional and national organizations is envisioned to provide data, information and access to users at each level. **Regional Information Centers** (RICs) are needed that will provide processed products (e.g., assimilating data from remote and *in situ* sources for numerical model predictions and GIS applications that require 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 (Walstad and McGillicuddy, 2000).

3.2 SCIENTIFIC FOUNDATIONS

Given the reality that the phenomena of interest are diverse and exhibit a broad spectrum of variability from hours to decades (cf. Powell, 1995; Steele, 1995), is it realistic to believe that an ICOOS can be developed that will provide the data and information required to detect and predict the causes and consequences of changes in the status of coastal ecosystems? Although this may seem to be an insurmountable goal, there is reason to believe that a cost-effective, sustained and integrated system is achievable. Many of the changes occurring in coastal ecosystems are local expressions of regional to global scale changes that are related through ecosystem dynamics. Marine ecosystems are structured by physical processes and changes in biological, chemical and geological properties are related through a hierarchy of physical-ecological interactions that can be represented by robust models of ecosystem dynamics (e.g., numerical models of physical processes and coupled physical-ecological models) (cf. Brink and Robinson, 1998; Robinson and Brink, 1998). This suggests that there is a relatively small set of common variables that, if measured with sufficient resolution for extended periods over sufficiently large areas, will serve many needs from forecasting the effects of tropical storms and harmful algal events on short time scales (hours to days) to predicting the environmental consequences of human activities and climate change on longer time scales (years to decades).

The phenomena to be addressed by the ICOOS fall into three general categories (Table 1): (1) coastal marine services and natural hazards, (2) ecosystem and public health, and (3) living marine resources. The data requirements of coastal marine services are, for the most part, common to all three categories (Figure 1). Safe and efficient coastal marine operations require accurate nowcasts and timely forecasts of storms, coastal flooding and precipitation; of coastal wind-, current-, wave-, and ice-fields; and of water depth, temperature and visibility. The set of variables that must be measured and assimilated in near real time include barometric pressure, winds, air and water temperature, sea level, and surface currents and waves. In addition to these variables, protecting, sustaining and restoring "ecosystem health" require timely information on measures of ecosystem status that are related to nutrient enrichment and habitat modification (including coastal erosion, oxygen depletion, loss of critical fish habitats such as submerged attached vegetation and coral reefs); harmful algal events and mass mortalities of marine organisms; chemical and bacterial contamination of habitats and organisms; and changes in the abundance and distribution of native and non-native species of benthic and pelagic organisms. The demands of protecting "living marine resources" and managing harvests (of wild and farmed stocks) in an ecosystem context require data on all of the above as well as timely information on population (stock) abundance, distribution, age (size)-structure, reproduction, year-class strength, migratory patterns, and mortality (including catch statistics). While all three categories must be addressed from the beginning, current capabilities dictate an emphasis on marine operations and natural hazards. The achievement of a comprehensive and integrated system that provides the full spectrum of data and information requires a system that is designed to adapt as new capabilities become available and a major investment in research and development (Figure 1).

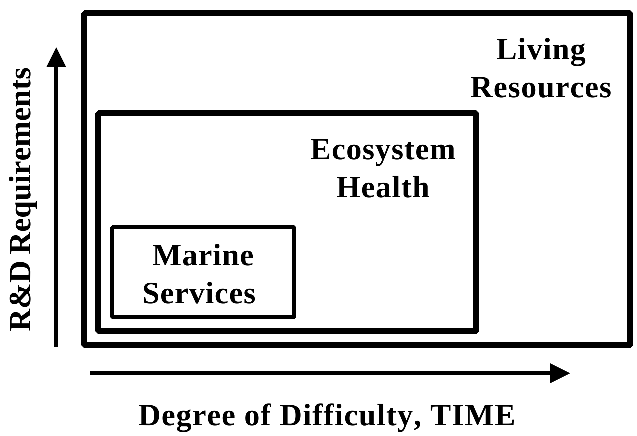

Figure 1. Time-dependent development of a fully integrated observing system. Most of the phenomena of interest require physical and meteorological data provided for the purpose of marine services and weather forecasting. Given current capabilities and the importance of physical processes to issues of ecosystem health and living marine resources, the initial backbone will emphasize those variables that are most useful to detecting and predicting the largest number of the phenomena of interest. As technologies for rapid measurements of biological and chemical variables are developed they will be incorporated into the system. Note that biological and chemical variables can and should be incorporated now as regional enhancements.

3.3 DESIGN FRAMEWORK FOR AN OPERATIONS SYSTEM

Given the interdependence of the physical and ecological processes that govern the status of estuarine and marine ecosystems and the reality that priorities vary regionally and among countries, **the coastal ocean observing system is conceived as a national network (the backbone) for the measurement of common variables that is regionally and locally enhanced (e.g., more variables, greater resolution, additional products) to detect and predict state changes that are of greatest concern to participating entities (State agencies, industry, academic institutions)**. ICOOS will initially develop through the establishment of regional pilot projects (proof of concept) that incorporate existing programs and new initiatives into a coordinated and integrated end-to-end system that is consistent with the ICOOS design principles (see below).

An operational observing system requires that measurements be routine, long-term (sustained into the foreseeable future), and systematic (stable delivery of data and information with sufficient precision and accuracy on appropriate time and space scales). As discussed above, many of the measurements and models required for a comprehensive, fully integrated, multi-disciplinary observing system are not operational. In addition, much work is needed to identify and develop those products that are most useful and to build capacity at the state level. To these ends, the design will be guided by the following principles:

1. The observing system will provide the data and information on changes in the status of coastal ecosystems that require regional to national approaches (e.g., local expressions of larger scale changes). It will produce data-products that address a broad spectrum of user needs.

2. The development of ICOOS 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. ICOOS will build a national backbone of common observations that will be regionally enhanced to address regional and local priorities as determined by the participating users in the region. The system will develop by incorporating, enhancing and supplementing existing programs as appropriate. It will become 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.

3. ICOOS 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 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. 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.

To date, few, if any, programs are both integrated and sustained. A sustained commitment will be required of ICOOS partners to establish, maintain, validate, make accessible, and distribute high quality data that meet nationally 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 a nationally accepted design; national and state commitments of assets and funds; and partnerships among states, institutions, data providers and users.

4. Implementation

Detecting, assessing, predicting and mitigating the effects of natural variability and human activities on coastal ecosystems requires a regional perspective that transcends political boundaries and provides the means to evaluate local changes in marine ecosystems in terms of larger scale changes in climate, ocean circulation, fishing pressure and land-use practices. Regional approaches also provide a practical framework to coordinate the efforts of local, state, and federal programs, involve stakeholders, and enable the timely analysis of data. A nation-wide network can thus be built by coordinating the development and linking of regional observing systems that measure a common set of core variables and are regionally and locally enhanced (additional variables, greater resolution in time and space, data management and synthesis centers) to address those issues that are of greatest interest to user groups in the region.

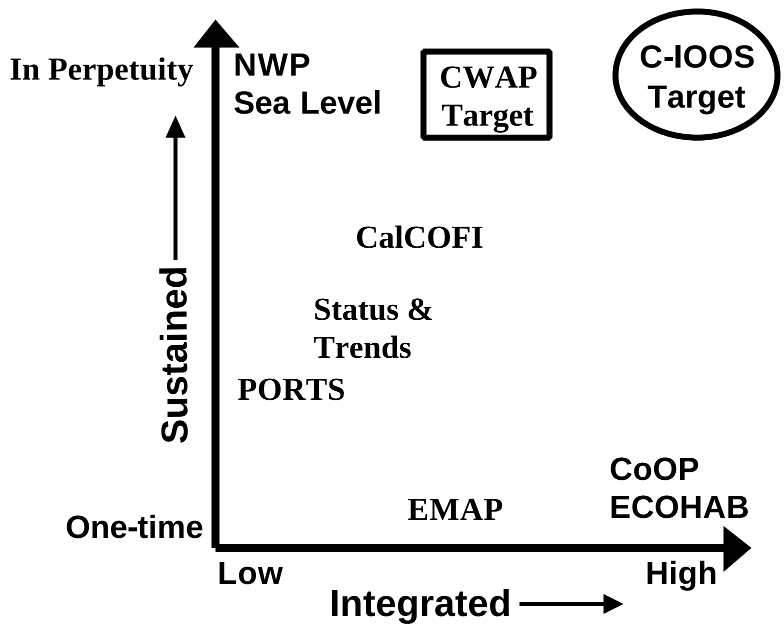

Figure 2. Some programs are sustained (Numerical Weather Predictions and Sea Level networks) and some are integrated (research programs such as the Coastal Ocean Program and the Ecology and Oceanography of Harmful Algal Blooms). Other programs such as NOAA's Status and Trends, EPA's EMAP, and the NOAA's PORTS (Physical Oceanography Real-Time System) are intermediate along one of the axes. The monitoring program proposed as part of the Clean Water Action Plan (www.cleanwater.gov) is intended to be sustained but it does not achieve the level of integration that is the target of the ICOOS.

Many of the elements of an integrated coastal ocean observing system (ICOOS) are already in place or in development, and the NOAA Coastal Services Center has established a web site that identifies and provides links to them (http://www.csc.noaa.gov/cts/coos/). In this regard, it is clear that a more cost-effective approach must be found that coordinates and integrates many of the elements of these systems. As ICOOS develops, it must become more than the sum of its parts. By formulating and implementing a plan for regional (often interstate) observing systems that are nationally coordinated and locally relevant, a wider array of users will be more effectively served with relatively modest increases in costs relative to the additional benefits. If this is to be achieved, 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 ICOOS design principles described above.

4.1 GOVERNANCE CONSIDERATIONS

The ICOOS must be nationally coordinated and locally relevant, and it must enable government agencies and other user groups to fulfill their respective missions and goals more effectively. At present, there is no coherent governance structure that provides an efficient mechanism to achieve these goals. National leadership and coordination is required to enable and promote

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

Given these goals, and the reality that the boundaries of most environmental issues of local importance are not confined to legal jurisdictions or to the missions of any one government agency, new mechanisms are needed that enable federal and multi-state collaboration in the allocation and management of funds and the periodic assessment of each regional system. To be successful, the governance of regional programs must harmonize "bottom-up" programmatic development through regional organizations of stakeholders (data providers and users) with "top-down" coordination by federal agencies and national organizations. The success of this approach will depend on the development of programs that are comprehensive in design and enjoy continuity of support that is not susceptible to short term political decisions and the annual funding cycles of state and federal governments.

4.2 A NATIONAL FEDERATION OF REGIONAL SYSTEMS

The goal is to develop a national federation of regional coastal ocean observing systems, each of which meets national performance standards for data quality and dissemination, is responsive to user needs, enjoys strong public support, and improves as new technologies become available and new needs emerge. Clearly, no single government agency is capable of planning and supporting such systems. Thus, in addition to providing the mechanism for building and managing observing systems that ensure ongoing, constructive feedback between data providers and users, the governance structure must clearly define and harmonize the roles of federal, state, and local agencies.

It has been proposed that the National Ocean Research Leadership Council (NORLC) should oversee the coordinated implementation of an ICOOS that conforms to the ICOOS design principles described above. In this capacity the NORLC would approve standards and protocols for the administration of the system including (1) the establishment of a common set of observations that would form the basis of the national backbone and be nationally distributed according to accepted protocols; (2) quality control and assurance; (3) the development and application of models for nowcasting and forecasting the status of coastal marine and estuarine ecosystems; and (4) data management for timely access to and archival.

The federation of regional observing systems would include, for example, 7 regions: northeast, southeast, Gulf of Mexico, West Coast, Hawaii, Alaska and the Great Lakes. Regional governing bodies would be established to provide leadership, management and accountability. The governing body would consist of representatives from user groups in the regions (e.g., the shipping, fishing, tourist, and construction industries; state and federal agencies; environmental research institutions; indigenous populations; and NGOs) and would be responsible for

- developing sustained state, regional, and federal financial support;
- overseeing the design, implementation and management of the observing system;
- ensuring that the system is driven by local priorities and begins by incorporating existing programs, expertise and infrastructure; and
- engaging stakeholders at all stages, from the establishment of priorities and planning to implementation, program evaluation, and product development.

Mechanisms for the management of funds, technical operations, research, data (including QAQC), product development, system review and evaluation, and public outreach will have to be established.

Acknowledgments

This paper reflects the thinking of many people including members of the U.S. Global Ocean Observing System (GOOS) Steering Committee (especially Worth Nowlin, Evan Richert, and Steve Weisberg) and the Intergovernmental Oceanographic Commission Coastal GOOS Panel (especially Keith Thompson and Julie Hall). Funding for this and related efforts was provided by NOAA, NSF, NASA and EPA.

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