Gulf of Mexico

The
Coastal Ocean Prediction Systems
Program:

Understanding and Managing
Our Coastal Ocean

Volume I: Strategic Summary

May 1990
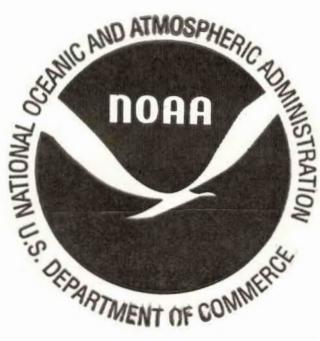
COASTAL OCEAN PREDICTION SYSTEMS

Report of a Planning Workshop
Held
31 October to 2 November 1989
at the
University of New Orleans

VOLUME I: STRATEGIC SUMMARY

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VOLUME I: STRATEGIC SUMMARY
TABLE OF CONTENTS

NOTE: "Master Reference" and "Acronym" listings for both Volumes I and II appear at the end of Volume II.
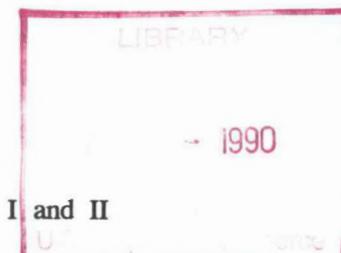
EXECUTIVE SUMMARY

Introduction to COPS

The proposed COPS (Coastal Ocean Prediction Systems) program is concerned with combining numerical models with observations (through data assimilation) to improve our predictive knowledge of the coastal ocean. It is oriented toward applied research and development and depends upon the continued pursuit of basic research in programs like CoOP (Coastal Ocean Processes); i.e., to a significant degree it is involved with "technology transfer" from basic knowledge to operational and management applications. (Here, the term 'prediction' is used in the broad sense to include modeling systems for simulations, hindcasts, nowcasts, and forecasts. Consequently, there is a special emphasis on data-assimilation schemes which benefit from real-time observing systems. Also, here, the term 'coastal ocean' means the entire EEZ plus estuaries and the Great Lakes.) This predictive knowledge is intended to address a variety of societal problems: (1) ship routing, (2) trajectories for search and rescue operations, (3) oil spill trajectory simulations, (4) pollution assessments, (5) fisheries management guidance, (6) simulation of the coastal ocean's response to climate variability, (7) calculation of sediment transport, (8) calculation of forces on structures, and so forth. The initial concern is with physical models and observations in order to provide a capability for the estimation of physical forces and transports in the coastal ocean. For all these applications, there are common needs for physical field estimates: waves, tides, currents, temperature, and salinity, including mixed layers, thermoclines, fronts, jets, etc. However, the intent is to work with biologists, chemists, and geologists in developing integrated multidisciplinary prediction systems as it becomes feasible to do so. From another perspective, by combining observations with models through data assimilation, a modern approach to monitoring is provided through whole-field estimation. These same predictive models can be used for process-oriented research.

The COPS Planning Workshop was held at the University of New Orleans on 30 October to 2 November 1989. The goal of the Workshop was to scope the system requirements, and necessary R&D, for establishing an initial operational coastal ocean prediction system by the turn of the century. Such an operational system will combine, as a minimum, "all" real-time physical data, through numerical models, to

provide well-defined data products on a regular schedule and grid for the coastal ocean, and will disseminate them to users. The Workshop was co-sponsored by the following agencies: NOAA, MMS, EPA, NASA, DOE, USCG, USGS, NSF, and ONR; the co-sponsoring agencies provided financial support. The NAS Ocean Studies Board was a sponsoring institution. The COE was a participating agency, while the NAE Marine Board was a participating institution. JOI was the managing entity. There were 80 participants: research scientists and engineers, plus program managers, from the academic, federal, and commercial sectors. While physical oceanography was the predominant field of the attendees, there were participants from biological oceanography, fisheries oceanography, ocean engineering, and meteorology. Similarly, while the participants were predominantly researchers, there were operational, applications, and management personnel present as well. They were all Americans; the invited Canadians were unable to attend.

The Workshop was structured in the following fashion: on the first day, there was a series of overview talks; on the second and third days, working group discussions and plenary sessions were interwoven for conceptual development and consensus-building. The overview talks included a summary of the recent Marine Board report on marine forecasting, and presentations on agency missions and programs, research and operational modeling systems, research and operational real-time observing and data management systems, ocean data assimilation, and process studies. The three separate working groups addressed issues of modeling, real-time observing systems, and implementation and infrastructure.

Workshop Results

The Workshop Report contains the overview talks, invited technical background papers, and the working group papers, plus descriptions of the motivation and prospects for COPS.

The Modeling Working Group concluded that advances in physical understanding, numerical modeling, computer hardware and software, and observational capabilities now make it possible to develop a useful coastal ocean prediction system. (N.B. The "advances in observational capabilities" noted here by the Modeling Working Group refer to the technological advances, while the "totally inadequate present observational situation" noted below by the Observing Systems Working Group refer to the

inadequacies of the operational observational network.) An operational modeling system is envisioned that has two levels: (1) a low-resolution model which runs continually and (2) a "rapid response," high-resolution model which can be activated for a particular area when it is needed. The prediction system envisioned would provide information on the Lagrangian dispersal of particles as well as encompass many dynamical phenomena, including oceanic fronts. Research on the sensitivity of the model to boundary conditions, numerical schemes, and completeness of model physics will be needed. Improvements in the understanding of certain processes (e.g., turbulent boundary layers, fronts, and ice mechanics) will be required. Highly technical research on data-assimilation methodology and data requirements of models are required for COPS. Realistic chemical (water quality/biogeochemical), biological (ecosystem), and geological (sediment transport and sediment interface flux) coordinate-models will need to be incorporated into the predictive models. To these ends, extensive numerical experiments, improved data bases, and real-time field tests of a predictive system will be essential efforts. The predictive model experiments should be done on both phenomenological and regional bases, be available to multiple investigators, and be coordinated with field studies conducted outside of the COPS arena.

The Observing Systems Working Group concluded that the present operational observational situation is totally inadequate for developing predictive coastal ocean models, let alone supporting an operational coastal ocean prediction system, although NOS maintains an array of coastal tide gages, NDBC maintains semi-permanent meteorological buoys in some regions, and NESDIS provides AVHRR imagery. (In some regions, there are coastal temperature, salinity, and meteorological stations provided by various non-federal entities. For only limited durations and domains, there are comprehensive current and mass field observations acquired by the R&D community.) Though real-time telemetry is an established technology, with the exception of NDBC buoys, coastal ocean data are only rarely provided in real-time. The technology and methodology exist for many of the elements of a real-time observing system, and it is time to begin to assemble such a system, building on existing capability (such as NDBC buoys) wherever possible. The COPS observing system should consist of (1) a coastal meteorological network, (2) moored ocean measurements, (3) synoptic surveys, (4) remote sensing (airborne (and coastal radars) as well as satellite) systems, (5) Lagrangian drifters, and (6) a data management system. An operational observing system is envisioned that has two levels: (1) sparse, long-term, telemetering arrays of moored instruments and (2) "rapid

response," limited-duration, dense arrays of moored, Lagrangian and survey observations which telemeter to a central Data Integration Center for model updating and forecasting. Additional recommendations include (1) increasing the density of NOAA's various arrays, (2) vigorously developing and employing airborne remote sensing techniques, (3) conducting a cost effectiveness study of the use of drifters for the coastal ocean, as part of the "rapid response," and (4) augmenting planned coastal ocean studies (e.g., the MMS study on the Louisiana/East Texas Shelf called LATEX), with a telemetry system and a real-time analysis component. Finally, it is recommended that biogeochemical time series and spatial mapping observing system technologies should be incorporated into the COPS observing system in order to support the development of the suite of predictive water quality, ecosystem, and sediment transport models for the coastal ocean.

The Implementation and Infrastructure Working Group recommended an implementation strategy. The societal importance of the coastal ocean and the need for a scientific base, such as COPS, for coastal ocean management were considered. The Working Group concluded that many of the requisite elements for COPS exist within the public, private, and academic sectors. It recommended that a strong but flexible management structure be developed to deal with system integration; TOGA and JOIDES were identified as possible models. Organizational elements are needed to facilitate technology transfer from the R&D community to the operational users (e.g., NOAA, MMS, EPA, USCG, COE, etc.) in areas of observing system networks, data management, routine operation of recommended models, and dissemination of prediction products. Multi-institutional, multi-agency mechanisms must be established to focus initiative and provide broad-based coordination on such COPS issues as long-term R&D strategies, major scientific facilities, technical standards, and human resources. These mechanisms must be able to: expand interagency coordination at the federal level, support a scientific steering committee drawn from the academic and private sectors, foster liaison between federal and scientific communities, and encourage participation of state and local entities. To promote and provide the best COPS services, these mechanisms should: orient research efforts to meet user needs, develop integrated programs for cost effectiveness, suggest additions or revisions to current and proposed projects in light of COPS goals and objectives, and identify organizational structures that promote continuity in development and coordination of interagency coastal oceanographic services.

Overall, the technical credibility and the broad awareness and acceptance of the predictive systems which COPS may develop are crucial to the ultimate success of COPS. Hence, it is vital that COPS be committed to intensive and extensive testing and evaluation of these predictive systems so that their capabilities and limitations can be documented in an open and fully professional fashion. Even in the R&D phases of COPS, modeling activities and field observations must be carried out interactively to ensure cost-effective, fruitful, and timely results. Data-assimilative modeling requires observations to establish initial interior and boundary conditions, to update interior and boundary fields, to validate model physics, and to verify model output fields. This class of modeling is very data dependent, because it closely relates numerical models to observed reality. On the other hand, such advanced models can be used to assess the accuracy of a given observational network, and to design an improved sampling strategy. In the long run, this is the only sound approach to an efficient and effective monitoring system, one which will minimize observational costs, quantify monitoring system errors, and maximize information recovered from the coastal ocean.

Status of COPS

At the conclusion of the Workshop, a COPS Interim Steering Group (ISG) was established; it consists of co-sponsoring agency representatives (plus Frank Eden, JOI and Chris Mooers, UNH, who serve *ex-officio*) and was charged with providing agency oversight to the production of the Workshop Report *per se* and the "Conspectus." A COPS Interim (Scientific) Planning Group (IPG) was also established; it consists of several academic scientists who played leadership roles in the Workshop (plus Frank Eden, JOI and Joe Huang, NOAA, who serve *ex-officio*) and was charged with providing R&D community oversight to the production of the Workshop report, defining initial follow-on activities, and offering expertise to the agencies. The possibility of providing commercial sector representation on the IPG is being explored by Chris Mooers and representatives of the commercial sector.

As agreed upon at the Workshop, NOAA is taking the lead in organizing an interagency group to discuss issues of common concern vis-a-vis COPS. NOAA is also developing improved communications among its line offices in this arena.

Overall, the expectation is that the federal agencies will further develop and coordinate their program plans, and organize their operational, applications, and R&D activities as necessary. Similarly, the R&D community will refine its plans and respond to opportunities as the federal agencies begin to define them. With proper communication and coordination, there is the potential to form a national COPS program--a program which will provide a modern, national, operational, coastal ocean monitoring (modeling plus observations) capability to both meet the common needs of several agencies and facilitate process-oriented research.

A programmatic structure for such a program has yet to be fully identified. However, the TOGA model of an international as well as national partnership among several agencies, researchers, and operational entities, and between observationalists and modelers, has considerable applicability to the COPS program as envisioned. Both programs have a similar focus on the development, evaluation, and utilization of numerical models and real-time observing systems to provide modern monitoring and prediction system(s). However, there are some differences, too, between COPS and TOGA. For example, in the COPS arena there are roles for the commercial sector, needs for regional approaches, and requirements for multidisciplinary aspects. Also, at this stage, COPS does not have a single, integrating scientific theme analogous to the coupled ocean-atmosphere dynamical system for ENSO which underpins TOGA. (N.B. In the next stage of scientific planning it is a goal to identify one or a few integrating scientific themes. See the Scientific Strategy section for the first steps in formulating a goal and objectives.) However, COPS and TOGA both require that the R&D community assist the federal and other agencies in evolving a modern operational monitoring system necessary to meet societal needs. Such a monitoring system will also be an important tool for the next generation of basic research in the global coastal ocean.

The Epilogue provides a vision of how COPS may unfold over the next decade. In the meantime, the IPG has outlined the steps needed, over the course of the next year, in the planning process: conduct a small multidisciplinary workshop; develop a formal science plan; and organize dedicated sessions at major scientific meetings. The IPG has also reformulated the COPS scientific goal and objectives statements, as described in the Scientific Strategy section.

PROLOGUE

The New Orleans Coastal Ocean Prediction Systems Planning Workshop was the culmination of nearly two years of planning. It was preceded by a series of scientific community workshops on coastal physical oceanography which began with the Annapolis Conference on Shelf Dynamics in 1974 and continued through the Mississippi Gulf Coast Workshop on Coastal Physical Oceanography in 1988. This series included discussions of the critical coastal ocean processes which limit our knowledge. A second series, the Monterey Ocean Prediction Workshop 1981 and Cambridge/Gulf Park Ocean Prediction Workshop 1986, addressed issues of mesoscale ocean prediction over a broad range of domains and regimes. These workshops included consideration of the numerical models, observing systems, and data assimilation schemes needed as components to ocean prediction. The ocean prediction series, with its special emphasis on naval, as well as civil, applications, set the stage for the small Preliminary COPS Workshop held in 1988. These series of workshops have provided periodic measures of the status of the science in coastal physical oceanography, and in the broader ocean prediction realm; its future prospects; and its foreseeable applications. The COPS Planning Workshop represented a convergence of these two streams of ocean science development. It helped to identify research and development imperatives and the operational requirements in coastal ocean prediction.

The COPS Workshop was timely and on target. The report of the National Research Council study on "Opportunities to Improve Marine Forecasting," which documented user requirements for ocean prediction schemes, appeared in 1989, and gave further impetus to the Workshop. Subsequently, the report of the National Research Council study on "The Adequacy of Environmental Information for Outer Continental Shelf Oil and Gas Decisions: Florida and California," which raised concerns about the roles played by models and observations in environmental impact studies, also appeared in 1989, and served to highlight the need for a coordinated, national, observational and model-based effort such as COPS. Fortuitously, the Workshop was held at a time when societal concerns about the quality of the coastal ocean environment, and governmental concerns about the adequacy of coastal ocean monitoring activities, were growing. It was, and continues to be, a time when fresh coastal ocean research, applications and operational program initiatives were, and are, being planned by federal agencies.

Thus, it was, and is, timely to consider how real-time observing systems and regional models might be carried forward jointly, through careful research and development, to be employed in operational predictions for the coastal ocean. It is clear that close cooperation between the research and the applications-and-operational communities is necessary to accomplish the "technology transfer" activities required to implement operational ocean prediction systems. And it is also important to develop interfaces with the other ocean science and engineering disciplines in this effort because of their need for appropriate physical information, and because of their societal relevance. Considering the related roles and technical capabilities of the several responsible federal agencies, it is furthermore clear that close coordination between these agencies is absolutely essential. All these considerations guided the development of the Coastal Ocean Prediction Systems Planning Workshop and this report, and continue to guide our thinking, planning, and action today.

INTRODUCTION

Over the past several decades, scientists, engineers, managers, and society at large have developed considerable awareness and understanding of the multiple and abundant resources of the coastal ocean. Society has developed the need and capability to use those resources; however, overexploitation or misexploitation has, in a number of instances, led to degradation of the environment, if not of the resource itself. Thus, there is a growing awareness of the need to manage the coastal ocean wisely. In a loosely-coupled fashion, scientific understanding of the coastal ocean has grown in parallel to societal utilization and concern. The environmental damage, or risks of damage, have helped to fuel the support for both basic and applied research. As societal awareness of the coastal ocean environment has grown, new programs, and even agencies, have been created to deal with the concerns. One approach has been to "monitor" the coastal ocean through routine observations. Another has been to model the coastal ocean, both with analytical and numerical models.

Though the scientific community is still constrained by the limits of its basic knowledge, of the capabilities of its observing systems and models, and of its human resources, it is time to plan to support humankind in its attempts to manage more wisely---both in utilization and preservation---the coastal ocean. The COPS Planning Workshop was convened to outline a program, following the lead of the operational meteorologists, to create a an operational capability for coastal ocean prediction in all its forms: simulation, hindcast, nowcast, and forecast. The central idea is to combine, through data assimilation, the inevitably sparse available observations with adequate but necessarily incomplete models to make best estimates of field variables in a systematic fashion. This provides a means of modern monitoring which goes well beyond observations alone.

The same concepts can be applied to the physics, chemistry, biology, and sediment dynamics of the coastal ocean. The state of coastal ocean physics permits it to proceed now with COPS; also, this is a time when the other ocean science disciplines are undergoing rapid development and, thus, soon will be able to participate in COPS as they pursue similar goals in real-time observations and modeling. Additionally, the other disciplines, of necessity, build upon the physical information, such as circulation, mass fields, tides, gravity waves, and mixing. Thus, proceeding with COPS will be a benefit to these disciplines when their observing and modeling techniques have further developed.

1

The COPS Planning Workshop was held after 22 months of preparation and at a time when reports abound of pollution throughout the U.S. coastal ocean and, indeed, including worldwide reports of "red tides," oil spills, medical waste pollution, and lethal beachings of marine mammals. This is also an era of concern for global climate change and the impacts of global change in various domains, including the coastal ocean. Thus, it can be anticipated that there may be links from COPS to similar international programs.

Because there are at least ten federal agencies significantly involved in the coastal ocean, broad agency sponsorship was sought and achieved for the Workshop. This was a vital part of beginning to develop a coordinated national effort in an environment where the academic community and the community of agency personnel were not well acquainted with each other nor even among themselves. It was judged important to include the commercial sector, too, because various private nonprofit and for-profit firms have come to play important roles in the coastal ocean.

The Workshop was designed by the Organizing Committee (see Appendix C). It was given strong focus and substantial structure, as outlined below. A broad geographic and functional representation of scientists and engineers, researchers and managers, academic, federal agency, and commercial sector personnel were invited. In all, more than 160 people were invited and 80 attended (see Appendix D). The analysis below summarizes the breadth and depth of representation:

ANALYSIS OF ATTENDEES

I. EMPLOYER		II. FUNCTION	
Federal	33	Research	45
For-profit	8	Operations	7
Academic	37	Management	26
	78		78

III. DISCIPLINE		IV. REGION	
Physical Oceanography	61	District of Columbia	20
Biological Oceanography	6	Northeast	21
Chemical Oceanography	0	Southeast	9
Geological Oceanography	3	Gulf	13
Meteorology	6	Southwest	6
Unknown	2	Northwest	9
	78	Alaska	0
		Hawaii	0
V. SEX		Great Lakes	0
Female	2		78
Male	76		
	78		

NOTES: (1) Ocean engineers are lumped with physical oceanographers.
(2) Two of the eighty attendees are not accounted for above.

The goal, objectives, and scope of the Workshop are outlined below:

Goal

The goal of the COPS Planning Workshop was to recommend a national R&D program for the development of a first-generation, operational prediction system for coastal ocean circulation. The Workshop focused on issues concerning:

- the U.S. coastal ocean (i.e., the entire EEZ plus estuaries and the Great Lakes);
- coastal ocean prediction (i.e., combined numerical models and real-time observations); and
- transient (days to years) coastal ocean circulation and property structure.

The Workshop assessed alternative approaches and estimated requirements to achieve an operational COPS within a decade.

Objectives

The Workshop participants were charged with the following mandates:

- Describe the status of and prospects for:
  1. numerical models of coastal ocean circulation, especially three-dimensional models;
  2. observing systems for the coastal ocean, especially real-time systems;
- Determine the elements of a first generation capability (including numerical and field experiments, data bases, and other R&D components) for:
  1. a numerical coastal ocean descriptive/predictive system;
  2. a real-time coastal ocean monitoring system.
- Outline the necessary infrastructure, resources, and management system for:
  1. identification of major, logical programmatic steps on a national scale, with regional aspects considered; and

3

2. incorporation of the commonality between the roles of various agencies and societal sectors which provide the mutually beneficial basis for cooperative approaches.

Scope

The outline below details the scope of the COPS Planning Workshop agenda:

- Modeling Systems
    1. numerical models
    2. data bases
    3. model evaluation
- Observing and Data Systems
    1. instrumentation systems
    2. data bases
    3. telecommunications
- Overall Descriptive/Predictive Systems
    1. numerical coastal ocean prediction (simulation, hindcasting, nowcasting, forecasting)
    2. data streams
    3. data assimilation schemes
    4. regional experiments
- Infrastructural, Research and Operational Requirements
    1. operational and applications requirements
    2. research requirements of other disciplines
    3. roles of various sectors
    4. interfaces to CoPO and other programs
    5. funding estimates
    6. personnel requirements
    7. measures of success
    8. institutional infrastructure needs
- Areas of Special Emphasis
    1. turbulent boundary layers of the coastal ocean
    2. air-sea interaction in the coastal ocean
    3. requirement of other disciplines for information on coastal ocean circulation

4

Of course, it was not possible to address adequately all important issues within the confines of a brief workshop.

Organization

The Workshop began with a set of overview talks to establish the present status and direction of development of coastal ocean models, observing systems, monitoring schemes, operational data products, and federal agency programs. The main activity of the Workshop was the deliberations of the following Working Groups:

- Coastal Ocean Circulation Modeling Systems
  (Chair, Allan Robinson; Rapporteur, Kenneth Brink)
- Coastal Ocean Circulation Observing Systems
  (Chair, Clinton Winant; Rapporteur, Thomas Lee)
- Implementation of a National Coastal Ocean Prediction System
  (Chair, Larry Atkinson; Rapporteur, Evans Waddell)

Each of the Working Groups determined the elements in its arena required to achieve the COPS Planning Workshop goal; however, issues of needed climatologies, operational data streams, analyses, and data/model products were included in the deliberations of all the Working Groups.

It was judged that a participant total of between forty and eighty would provide adequate representation, on the one hand, and satisfy manageability and affordability requirements, on the other. To ensure the balance needed to achieve the objectives of the Workshop, attendance was by invitation only.

As noted earlier, the majority of the 80 attendees were physical ocean scientists and engineers. However, several meteorologists, as well as coastal ocean scientists from the biological, chemical, geological and fisheries disciplines participated and made essential contributions, especially in defining applications requiring coastal ocean circulation information.

WORKING GROUP I:

Coastal Ocean Circulation Modeling Systems Working Group

<u>Chair</u>: Allan Robinson

<u>Rapporteur</u>: Ken Brink

<u>Members</u>: John Allen, Jack Barth, Shenn-Yu Chao, Gabriel Csanady, Donald Denbo, Dale Haidvogel, Robert Haney, Hsiao-Ming Hsu, Joseph Huang, George Jackson, Walter Johnson, Robert LaBelle, Daniel Lynch, Jay McCreary, George Mellor, Harold Mofjeld, Donald Murphy, Theresa Paluszkiewicz, Alejandro Pares-Sierra, Richard Patchen, George Saunders, Craig Swanson, Leonard Walstad, Dong-Ping Wang, John Wang, Warren White

The Modeling Systems Working Group's Goals were to:

* Establish the status of (and prospects for) predictive coastal ocean models;

* Determine the necessary research elements for the development of a coastal ocean prediction system; and

* Define the sequence of prediction experiments required.

Several Sample Questions Regarding Predictive Coastal Ocean Models

1. What model physics need to be incorporated (e.g, surface, bottom, and coastal boundary layers; ice thermodynamics and dynamics; lateral mixing)?

2. What are the requirements for surface boundary conditions and atmospheric forcing prescription?

3. What lateral boundary conditions should be imposed or provided?

4. What phenomena and features must be incorporated (e.g., tides, waves, eddies, jets, fronts, capes, canyons, banks, basins)?

5. What are the domain-size and grid-resolution issues?

6. What are the issues with non-uniform gridding, embedding, and adaptive gridding?

7. What special coupled modeling problems arise when considering various applications (e.g., oil spill trajectories, sediment transport, coastal marine ecosystems, coastal air-sea interactions)?

8. What are the special opportunities and challenges for coastal ocean data assimilation?

9. What are the issues in coastal ocean model validation and predictive skill assessment?

10. What are the issues in implementing a COPS modeling system to ensure that it will have scientific credibility and societal utility?

Introduction

The goal of the COPS Planning Workshop overall is to recommend a national R&D effort to develop a first-generation predictive system for coastal ocean circulation. (The coastal ocean is here understood to mean the Exclusive Economic Zone (EEZ) for the entire United States, a definition which includes estuaries (and Great Lakes), the shelf, slope and adjoining deep ocean in many locations.) The predictive system would have to function for time scales of hours to days, or longer and be able to include the effects of (while not actually predicting) seasonal and interannual variability. "Prediction," for the purposes of this workshop, is taken to encompass the two broad areas of "forecasting" and "simulation." "Forecasting" means using existing information and a model to say what the state of the ocean system will be in the future. True forecasting means doing this in real-time. A second aspect of forecasting is "hindcasting," which means doing a forecast using historical data to predict some past state of the ocean. Hindcasting is used as a research tool, for doing simulations, and as a diagnostic tool for reconstructing past events. "Nowcasting" is a third aspect of forecasting, and implies using available information (both observational and model-related) to provide the best possible dynamical estimation of the ocean's present state. It is useful as a research tool in itself, for operational purposes, and it is needed for initiating a forecast. "Simulations" of the coastal ocean try to represent the important physical processes and oceanic statistics accurately. They would likely use realistic inputs, but may not use data assimilation as heavily as a forecast might. In many ways, simulations are similar to hindcasts. Thus we have used "prediction" in the broad sense: to predict the currents and water properties a few days into the future, to

7

predict the ensemble of surface particle paths, and to predict the most extreme currents in a given location.

Prediction is a particularly demanding activity. A good forecast requires appreciable accuracy in both phase and amplitude. Controlling phase error has been a particularly important and demanding task for scientists doing predictive research. An aspect of the problem is characterized by "predictability," which is the study of the flow's sensitivity to initial conditions and to the nonlinear growth of small-scale features to magnitudes sufficient to contaminate the forecast (Holloway and West, 1984). It is not sufficient simply to calculate the statistics or dominant physics correctly. The type of development required varies considerably with what variables need to be forecasted, on what spatial and temporal scales and over what space-time domain. It thus is worthwhile to spend some effort establishing what some of the important phenomena in the coastal ocean are, what the needs for different types of predictive models are, and how to mesh the two considerations. Following that, the more detailed objectives are defined, and specific findings summarized.

Definition of the Problem

<u>Phenomenology</u>

As a first attempt at defining the relevant physical processes, we tried to assemble a list of the various phenomena which might be important in the coastal ocean. The processes are listed in Table 1 and fall under the general headings of tides, fronts, waves, currents and eddies, turbulent boundary layers, surf zone effects and estuarine processes. In some cases, the group recognized that some predictive skill now exists. These examples include storm surges, barotropic tides and coastal-trapped waves (for alongshore currents and sea levels over the shelf). In many other cases, it is clear that some understanding exists, although it falls short of a predictive capability. Third, there is a category in which the underlying processes are not well enough known to begin to define what information is needed to carry out a successful prediction. Finally, in other cases, such as surf zone phenomena and estuaries, it was clear that important processes were involved, but the group did not feel well-qualified to go into detail.

Forcing Functions

There are numerous effects which could contribute to defining the characteristics of flow over the continental margin. These can be thought of, in general terms, as forcing functions and as boundary conditions which shape the flow. At the surface of the ocean, fluxes of momentum, heat, salinity (evaporation minus precipitation), and surface waves are all expected to be important. On the landward side, the runoff of fresh or brackish water would serve as a forcing function, while the irregularities of the coastline would provide important influences on the form of the flow. At the ocean's bottom, the roughness, topographic form and sediment composition all would provide important influences on the flow structure and amplitude. At the seaward boundary, the basin-scale tides and surface waves would provide important inputs, as would oceanic flow structures such as eddies and boundary currents. Finally, at the cross-shelf boundaries of the domain, the instantaneous state of the known current systems would influence the flow in the domain's interior through mechanisms involving the propagation of coastal-trapped waves.

These various effects could influence flow and water properties on time scales ranging from hours to years. It is thus possible that any of these influences could be important for a given prediction problem.

Applications for Predictive Models

To focus in on the issue of which scales and processes need to be accounted for in predictive models, we felt that it would be worthwhile to review the needs of various users. This in turn would help us to focus on the needed model attributes.

The National Oceanic and Atmospheric Administration (NOAA) is interested in developing the capability to forecast "ocean internal weather" for the entire EEZ. Such a system would be expected to forecast waves, winds, weather conditions, tides, ice conditions and the three-dimensional structure of velocity, temperature, and salinity for the entire coastal ocean. It is desirable to forecast conditions for about two days into the future on scales of about 10-30 km over the continental shelf. Finer resolution would be desirable closer to shore. The uses of such model results would include fisheries operations and management, coastal hazard warnings, pollution applications, and prediction of conditions for offshore activities (such as

9

oil platforms). Phenomena of particular interest include oceanic fronts, tides, surface waves (including tsunamis and storm surges), major coastal currents, upwelling, cross shelf transport, sediment transport in the nearshore ocean and air-sea exchanges. Forecasting capability for both estuaries and the open coastal waters is desirable. NOAA is also interested in simulation modeling, especially for the purposes of fisheries and ecosystem models.

The Minerals Management Service (MMS) uses models primarily to simulate trajectories of nearsurface particles in order to carry out oil spill risk assessments. In many cases, a regional general circulation ocean model provides the ocean currents for this simulation. Since oil can sink with time, the interest is not entirely confined to the surface waters of the coastal ocean. The model domains need to be large (typically 1000 km by 400 km), but to have fine enough spatial resolution to allow good estimates of the trajectories. A given trajectory would need to be calculated for at least 30 days, or until the trajectory encounters the coast, whichever happens first. Tidal and lower-frequency phenomena need to be modeled. It is not clear what the high-frequency cutoff of the model resolution should be. In fact, modeling trajectories is a difficult, partially stochastic process which calls for more model development and verification. Particular phenomena of interest to MMS include fronts, energetic currents, surface boundary layer processes, eddies, tides and ice physics.

The Department of Energy (DOE) has an interest in the fate of energy byproducts in the marine environment. Very often, this translates into a focus on particulate organic matter in the ocean. Further, DOE has recently taken a specific interest in the closely related problem of global carbon fluxes, in which the continental margins are expected to play an important role. DOE has a long history of sponsoring interdisciplinary observational studies of particle behavior over the U.S. continental shelf and slope. Traditionally, such DOE studies have taken place in a number of different locations around the United States mainland; these locations have generally been quite different in their dynamical geographies. As a part of this effort, interdisciplinary numerical models would be useful for the study of how particles over the continental shelf are formed, and how they are deposited, resuspended and removed from the shelf waters. Since such coupled physical/ biological applications will be sensitive to a variety of effects and would be applied in a number of different locations, there are very few phenomena that can be eliminated from consideration.

The Environmental Protection Agency (EPA) uses models to help in evaluation of applications for new discharge points (e.g., dump sites and sewage outfalls), enforcement of regulations, and enactment of pollution control strategies. The scientific issue involved is the transport, dispersion and ultimate fate of contaminants introduced into the environment. Most of EPA's present problems arise within estuaries, although there is also interest in the inner continental shelf. The demand is largely for simulations and hindcasts covering length scales of 1-100 km. Phenomena of primary interest include tides, mixing, surface and bottom boundary layer effects, and the transport of suspended sediments. Also of concern are cross-shore and alongshore exchange at greater distances offshore, for example at the 106-mile dump site off New York City.

The United States Coast Guard (USCG) is primarily interested in search and rescue operations. In addition, the USCG is interested in predicting oil spill trajectories once the spill has occurred to support its clean-up operations. The USCG would like a truly operational real-time nowcasting and forecasting system to trace the movement of floating and semisubmerged drifting objects. Such a model system would cover a domain size of about 200 km by 200 km, and would function for periods of up to about one week. It is desirable to obtain model updates about twice daily. Phenomena of interest include surface currents, tides, winds, surface gravity waves and water temperature.

The coastal ocean interests of the U.S. Navy overlap those of other agencies, but some are unique. Geographically, they include the coasts of the United States, but also extend to the coastal ocean in other parts of the world. In scale, the focus is on a few hundreds of km and about one week: the extent and duration of typical Navy operations. Acoustical and optical properties of the water column, nearshore bottom morphology, low-level winds and aerosol concentrations, surf characteristics and ice cover are examples of particular interests. The Navy would be a likely user of most coastal prediction systems that can be envisioned presently, and it has a long range goal of developing prediction systems for its own unique interests.

Finally, physical, chemical, biological and geological oceanographers would likely be serious users of prediction models for their own research. The full water column would have to be simulated accurately for many purposes, with special attention to the turbulent surface and bottom boundary layers. Nearly the entire

inventory of coastal phenomena would have to be considered in many applications. Attention would have to be put on the reality that particles and living things do not move in the same way as the water itself, so that specialized submodels would likely have to be included in a complete system. Forecasting models would be useful for guiding field sampling, and simulation models would be needed for understanding ecosystem behavior. Phenomena of interest include the bottom boundary layer, turbulence (particularly relevant for the formation of "marine snow"), upwelling, and various transport processes.

Specific COPS Goals

Given the above needs, the following refined goals for a coastal ocean prediction system were enumerated:

1) *To achieve the capability to nowcast and to forecast for a few days over the entire EEZ.*

2) *To develop the capability for simulations of the entire EEZ on time scales ranging from hours to interannual.* The simulations should include accurate representations of transport, sea level, and ecosystem behavior. This goal would call for properly forced numerical models and the use of data assimilation. The system should also be capable of predicting Lagrangian statistics.

3) *To research the basic processes relevant to development of a coastal model.* The most important processes need to be defined, and a plan developed for their study. The ensuing research should be carefully coordinated among the various agencies which would be the users of a predictive system.

To obtain specific findings and recommendations, the working group broke into three subgroups, each to address one of the above general COPS goals. The results of their deliberations are summarized in the following section.

Subgroup Findings

The first two subgroups were charged with addressing the following issues for their aspect of coastal ocean prediction:

- What is the present status of models with regard to the assigned goal?
- What are the research issues to be addressed? For example, what are the issues with regard to model physics, mathematical formulation, computational considerations, and data requirements?
- What methodological questions are involved with regard to data assimilation?
- What experiments or sequence of experiments are needed in order to validate the models? In this category, some consideration should also be given to the type of observational network that would be required.

The third subgroup (role of basic research) had a somewhat different set of questions to consider, since much of what it had to address dealt with how COPS relates to the broader field of coastal oceanography.

Forecasting Capability
Chair: Leonard Walstad
Members: J. Barth, D. Haidvogel, J. Huang, L. Kantha, H. Mofjeld, T. Paluszkiewicz, R. Patchen, W. White

The first issue to be addressed was "what shape would a coastal forecasting system have to take?" It was clear from the outset that a detailed, continuously operating prediction system for the entire U.S. EEZ might require unrealistic observational and computational resources under present conditions. The solution to this problem was seen to be a continuously running routine forecasting system which would cover the entire EEZ coarsely, and perhaps with limited accuracy. In special circumstances, such as for an oil spill or for a search and rescue mission, a "rapid response" forecasting system would come into play. Other applications for this model could involve fisheries (e.g., frontal locations) or mineral recovery (e.g., loop current rings approaching a drilling platform). This predictive system would

provide a much higher quality forecast within a limited area (roughly 200 km by 200 km), and would require substantially more observational resources for accurate operation.

The routine forecasting system should forecast the following variables with the preliminary prescribed accuracy:

Estuaries and near the coast:
1) sea level (10 cm accuracy)
2) currents (25 cm/sec, 20° accuracy)
3) surface waves (0.5 m accuracy)
4) ice (location and type)
5) surface temperature (for help in forecasting fog)

Continental shelf:
1) currents (10 cm/sec, 20° accuracy)
2) frontal existence and locations (5 km accuracy)
3) thermal structures
4) waves and swell (0.5 m accuracy)
5) ice location (10 km accuracy) and type
6) fog

Deep ocean (desired accuracies not immediately known):
1) currents
2) waves and swell
3) thermal structure including fronts

Our accuracy specification for the near coast recognizes the difficulties associated with complex topography. We expect that the accuracy would generally be better than these estimates, but that some areas would not be well forecast without special consideration. Among these, the important areas may be emphasized by a forecasting system resulting in improved accuracies.

The difficulty with forecasting frontal locations is substantial. A 2.5 cm/sec error in the velocity field advecting the front will result in a 5 km frontal location forecast error after 2 days. Fortunately, along-front velocities and velocity errors are expected to be largest and do not affect the position of the front. Conversely, errors in the frontal position or orientation may greatly contribute to velocity errors since fronts are often associated with highly sheared flows.

14

The rapid response model would be expected to predict currents to within 2 cm/sec and 10° accuracy. Further, the model would be expected to be able to predict the Lagrangian dispersive properties of the upper water column. A relatively simple model for Lagrangian dispersion is envisioned. This would make it possible for real-time forecasts of the dispersion distribution. Development of this capability will require a substantial effort with both oceanographic and particle tracer simulation models.

The issues raised by the development considerations for such a suite of models include the following:

- The model physics needed to meet these goals is, in itself, a major research topic. Particulars to be considered include surface and bottom boundary layers, nearshore wave processes, and internal dynamics of the water column.
- Application of lateral boundary conditions is not well understood. Particular topics include where the boundaries should be located, which types of conditions are required for which type of model physics, and whether persistence boundary conditions might be adequate. It is also not clear how the specification of the lateral boundary conditions will affect the physical model.
- The type and quality of surface flux information required by the model is not well understood. This question includes the issue of the spatial and temporal scales on which the fluxes must be provided.
- The types of data to be assimilated into the forecast models are not entirely clear, although certain types of information seem to be important. For the routine forecasting model, inputs to be used would include coastal and offshore winds, coastal and offshore sea level, hydrographic measurements (temperature, salinity and density), a few current measurements at key locations, wave data, ice location information and radar products. Producing rapid forecasts will require immediate deployment of surface current measuring devices. Surface drifters would be immediately deployed in large numbers. Some of these might have drag profiles similar to the search target or contaminant. Ships which participate in these operations might employ hull-mounted acoustic Doppler current profilers. Special considerations might have required other types of input such as ice data. The quantity and mix of data needed to satisfy the forecast accuracy requirements is an important area of study. Further, the propagation of error in a coastal prediction system is not well understood. In

15

any case, there is a very clear and pressing need for real-time availability of coastal ocean data.

- While accuracy is an important consideration in forecasting, a robust and efficient model is critical. Errors in measurements and the growth of instabilities are likely to dominate errors in the numerical calculation. Robustness will be particularly important to the rapid response component of the system. Embedded grids should be considered when addressing the open boundary problem. Higher order differencing schemes may prove more efficient if the required grid spacing is substantially coarser than that required by the lower order schemes.

- Data assimilation schemes for the coastal ocean are not well understood. The schemes chosen should be flexible, so as to be readily adaptable to improved or different basic models. There is a need to understand how the assimilation scheme relates to the given model physics. The data assimilation methodology must be developed and evaluated in a range of physical regimes. We anticipate that there will be different requirements and capabilities when the ocean is forced versus unforced. As the data volume is minimal, sophisticated data assimilation methods will be important to the production of accurate forecasts. Atmospheric scientists are developing a range of assimilation options which should be evaluated for their coastal oceanographic potential.

The issues which have been described are best addressed initially through simulated forecast experiments. In this type of experiment, a simulation model is used to produce an idealized "data" set. This "data" set is then sampled using proposed observing systems. The forecast system may then be evaluated by assimilating the sampled "data" and comparing the forecast to the simulated ocean. This permits isolation of the various error-producing mechanisms as well as evaluation of the predictability of the model fluid system, which is hoped to be similar to that of the real ocean.

The subgroup recommends the following sequence of studies designed to address the issues raised and culminate in a forecast system of known accuracy for routine forecasts and rapid response in the EEZ.

- Conduct a full suite of simulated forecast experiments (SFEs) using a model having realistically complete physics to provide the control "data" to address the issues described above.

- Identify and compile existing data sets that could be used for preliminary forecast experiments.
- Design a prototype forecast system based upon the results of the SFEs and evaluate this system through a suite of SFEs.
- Conduct a set of field experiments using the prototype forecast system, collect additional verification data and assess the skill of the system. It is only through the use of actual ocean observations that the model can be tested and improved for operational purposes.

Simulations
Chair: Robert Haney
Members: G. Csanady, D. Denbo, W. Johnson, D. Lynch,
G. Mellor, G. Saunders, C. Swanson, J. Wang

Simulation models for the coastal region are needed for better understanding of coastal ocean physical processes and to provide input for studies of risk assessment, fisheries applications, ecosystem models and pollutant dispersal. While some aspects of the coastal ocean are presently well-modeled (for example, storm surges, barotropic tides and coastal-trapped waves), coastal circulation models are in their infancy and their level of skill is unknown. A number of areas in which progress needs to be made were isolated, and the group also made some more general recommendations.

In the area of model physics, issues raised include the following:

- Is the hydrostatic approximation valid for all applications?
- Parameterizations of subgrid-scale processes are not well verified. For example, the use of lateral eddy viscosities and turbulence closure schemes need more development in the context of the actual coastal ocean physics.
- While primitive equation models, in principle, cover a broad range of physical phenomena, they tend to be expensive to run. Thus, intermediate models, which have simplified physics and generally cheaper costs, should be explored.
- Air-sea interaction deserves more attention, especially with regard to refining estimates of surface fluxes, and to the effect of the coastal ocean on the coastal atmosphere.

17

- Internal waves and tides are known to be important for some processes (such as the bottom boundary layer and the surface mixed layer), but they are generally not explicitly included in existing models. The acceptability of their neglect needs to be addressed with regard to the needed model products.
- Ice modeling in the coastal ocean is not well advanced. It, too, deserves more attention.

Mathematical and computational issues include the following:

- Coordinate transformations in both the horizontal and the vertical have several desirable properties, but we do not yet know how to control all of their potential negative side effects.
- It is not clear what the best way to handle open boundaries might be. Further, it is not clear over how large an area the influence of an open boundary will be felt.
- The use of adaptive grids should be considered. These would have considerable advantages for tracking high-gradient areas such as fronts.
- It would be very useful to identify standard test cases for verifying model formulations and boundary conditions.

In the category of data requirements, a number of problems need to be addressed:

- It seems that very highly resolved bottom topographies will need to be used. We still need to develop experience on the complications that this might entail.
- It is presently unknown at what spatial scale the surface wind stress needs to be provided for an accurate simulation.
- It appears that heat and salinity fluxes will need to be provided to the model at all surface, open and solid boundaries.
- Tidal data will be needed for model verification.
- Current and hydrographic data will be needed for testing how well the models reproduce the physical processes and statistical properties of the true flow.
- It would be useful to have a coastal climatology similar to that developed for the open ocean by Sid Levitus, GFDL.

In the category of data assimilation, a good deal is yet to be learned about which particular techniques (e.g., nudging) are optimal for a particular application.

18

Further, it is also not clear which types of physical data would be most effective in terms of the model's overall accuracy.

The overall recommendations of the simulation group are as follows:

1) Model simulations of the coastal ocean should be made on time scales of hours to years and compared quantitatively to observations.

2) Studies of model sensitivity skill to grid resolution, resolved physics, and forcing functions should be made.

3) Lagrangian dispersion studies should be made using model outputs, and the results should be compared to observations. As a corollary to this, field programs conducted in conjunction with modeling studies should make Lagrangian as well as Eulerian observations.

4) Parameterization of subgrid-scale processes needs further improvement. For example, large eddy numerical simulations could be used to help improve our understanding of oceanic turbulence.

5) Fine scale (less than 100m resolution) bottom topography and a climatology of the coastal ocean should be made readily accessible to researchers.

Basic Research and COPS
Chair: John Allen
Members: K. Brink, H.-M. Hsu, J. McCreary, A. Robinson, D.-P. Wang

The scientific and methodological basis exists for the development of a coastal ocean predictive system, but there are a number of issues which require further attention:

- Existing models for coastal ocean prediction need extensive development and testing.
- Critical physical processes for prediction need to be identified, studied and understood.
- Connections between the physical model and biological, chemical, geological, and other applications models need development.

To make the report more specific, the following findings and recommendations were advanced:

1) Research is needed on basic physical processes associated with transport, mixing, and fronts. Obvious examples include upper oceanic physics and air-sea interaction.

2) The COPS effort should include process-oriented prediction experiments with theoretical, modeling and field components.

3) Other process-oriented research will be necessary to the COPS effort.

4) Critical issues in numerical and computational methods important for the coastal domain need to be identified and researched.

5) Data assimilation methods for the coastal ocean require research, development and testing.

6) Research is required on the development and validation of physical model coupling with biological, chemical, geological and other models.

7) Models and submodels need to be rigorously tested and verified on a phenomenological and regional basis. This will necessarily be an iterative process. Testing procedures should include model availability to multiple users from the research community. Model use should be coordinated with field studies outside COPS.

Conclusions

For the first time, it now seems possible to develop a useful coastal ocean prediction system. This is so because of advances in our physical understanding, computer hardware and observational capabilities. Such predictive systems already exist for, of course, the atmosphere and, more recently, for some aspects of the open ocean, so we have a good deal of related experience to draw upon. Although such a model system can be envisioned, there is a good deal yet to be done before it can be realized, and the work will call for a coordinated effort among the various agencies which will be likely users of such a system.

We envision an operational forecasting system that has two levels: a low-resolution model which runs all of the time and a "rapid response," high-resolution model which can be activated for a particular area when it is needed for

20

management, operational or crisis purposes. To make such a system functional, research is needed in the following areas:

1) Sensitivity of the model system to:
   a) lateral and surface boundary conditions
   b) numerical schemes, including adaptive grids and multigrids
   c) degree of physical sophistication.
2) Propagation of errors:
   a) initial conditions
   b) boundary conditions
   c) updating observations
   d) geophysical noise
   e) numerical methods.
3) Critical physical processes, e.g.,
   a) turbulent boundary layers
   b) ice mechanics.
4) Data assimilation schemes, including type, quality and quantity of data required.
5) Model prediction of Lagrangian properties of the flow field.
6) Incorporating realistic submodels for chemical, biological and geological processes.

The development of simulation model systems will require the same sorts of effort, so that it would be artificial to separate forecasting from simulation systems.

Model system performance will need to be quantitatively evaluated. Toward the end of meeting this goal, it will be useful to carry out numerical experiments driven by assimilating the outputs of realistic ocean models. Further, existing data sets should be compiled in a convenient way, so that they, too, can be used to drive a prototype prediction system. Most importantly, there will be a need to carry out actual real-time field tests of a predictive system in a variety of settings. Such studies will allow the determination of which physical processes are most important and which need further concentrated study. Although there is much work to be done, it seems likely that a coastal ocean predictive system can be a reality within the foreseeable future.

Table 1

Phenomenology of the Coastal Ocean

Tides

    Barotropic
    Internal
    Overtides (harmonic generation)
    Secondary circulations

Fronts (including formation, instability and decay)

    Shelf break fronts
    Upwelling fronts
    Buoyancy fronts
    Fronts of deep ocean origin (e.g., at the edge of the Gulf Stream)
    Mixing fronts
    Topographic fronts

Waves

    Surface waves, including wind waves, swell, tsunamis, storm surges, solitary
        waves and rogue waves
    Stokes drift
    Internal-inertial waves
    Edge and infragravity waves
    Planetary waves
    Frontal-trapped and shear waves
    Coastal-trapped waves, including Kelvin and hybrid (shelf) waves

Currents and Eddies

    Coastal and shelf currents and jets,
        wind driven, buoyancy driven, and other mechanisms
    Squirts and filaments
    Eddies, both remotely and locally generated
    Offshore flows and pressure gradients of external origin
    Upper slope flows
    Boundary current meanders and rings
    Undercurrents
    Tidal rectification
    Gravity wave-related, such as rip currents
    Geometrically, topographically and coastline-related eddies

Table 1 (continued)

Turbulent Boundary Layers

    Surface

        Mixing layer
        Heat, momentum and salinity fluxes
        Ekman transport
        Stratification
        Breaking waves
        Langmuir circulation
        Entrainment
        Ice interactions
        Near-inertial waves
        Surface films and the microlayer

    Bottom

        Bottom shear stress
        Stratification or its absence
        Shear dispersion
        Roughness and topographic interactions
        Ekman transport
        Entrainment
        Tidal currents
        Near-inertial waves
        Gravity wave effects
        Sediment transport, suspended sediment interactions
        Organized motions of the Langmuir type
        Biological effects, such as bioturbation and bed armoring

    Free interior shear layers

Surf Zone Effects

    Sediment transport

    Rip currents

    Mean flow generation

    Storm surges

    Surf beat

Estuarine Processes

    Entrainment

    Layered circulations

    Salt wedges

    Tidal fronts

WORKING GROUP II:

Coastal Ocean Circulation Observing Systems Working Group

Chair: Clinton Winant

Rapporteur: Thomas Lee

Members: David Brooks, Murray Brown, Wendell Brown, Paul Falkowski, Glenn Flittner, Steve Haeger, Glenn Hamilton, James Herring, Barbara Hickey, Richard Legeckis, Tom Lee, M. Lewandowski, Bruce Magnell, David McGehee, Robin Muench, Stephen Rich, Ken Ruggles, Ted Strub, William Wiseman, James Yoder

The Observing Systems Working Group's goals were to:

* Establish the requirements of coastal/atmospheric observing systems which will satisfy the needs of future predictive models;
* Determine the inadequacies of the existing observing systems; and
* Make recommendations for future operational approaches.

The requirements for model development, initialization, forcing, updating, and verification will be considered. The means by which real-time observations and model results are integrated and disseminated will be examined.

Several Sample Questions Regarding Coastal Ocean Observing Systems

1. What physical variables must be observed?
2. What are the time/space sampling capabilities at present, and future criteria, for each variable?
3. What observational elements are presently available, and will be required, to provide information to models concerning:
    (a) open boundary conditions,
    (b) surface and bottom boundary conditions,
    (c) nearshore boundary conditions, and
    (d) interior update?
4. What are the present capabilities, and future requirements, for observing atmospheric fields in the coastal oceans?

5. What are present observational capabilities, (i.e., Lagrangian, Eulerian; remote sensing [spaceborne, shipborne, airborne, bottom-mounted & shore-based]; expendable or recoverable; telemetering or recording)?

6. How cost effective are these existing observing systems?

7. What observations will require new technical development?

8. What will be the future data dissemination requirements for both process-oriented research and operational data products (i.e., GTS-like system)?

9. What are the data base management requirements?

10. What are the problems in long term deployment in terms of navigation, safety, maintenance, vandalism and public involvement?

11. What information is needed from coastal ocean models in order to design an effective coastal ocean monitoring system?

12. What has been learned from coastal ocean monitoring experiments to date and what monitoring experiments need to be conducted?

13. What is the present federal role in acquiring operational observations?

14. How might the federal role change in the future?

15. What are the issues in implementing a COPS observing system that will have scientific credibility and societal utility?

Rationale

Presently, the coastal ocean is observed regularly with an array of coastal tide gages maintained by NOS. In some regions, there are also permanent and semi-permanent meteorological buoys maintained by NDBC. The COE has a nearshore, real-time wave gage network, which is expanding. Under cloud-free conditions, there is twice-daily IR imagery provided by NOAA satellites, which are operated by NESDIS. In some regions, there are coastal stations which sample temperature and salinity and/or coastal winds, air temperature, and air pressure; they are maintained by various federal, state and private sector entities. For finite durations and limited areas, there are current and mass field measurements on the continental shelf and slope; these are generally acquired by the R&D community. Despite the fact that the technology and methodology for real-time reporting of key ocean variables is available, only rarely are any of these observational stations, with the exception of the NDBC buoys, equipped with real-time data telemetry. The present situation with operational observations is totally unsatisfactory for fostering the development of predictive coastal ocean models, let alone for supporting an operational coastal ocean prediction system.

Numerical models of coastal ocean circulation (like all numerical models) require the specification of initial and boundary conditions, generally via observations. Data-assimilative models also utilize observations to update boundary conditions and model results in the interior of the model domain. Observations are also required for predictive model validations, evaluations, and verifications.

The coastal ocean is very responsive to atmospheric forcing. Thus, coastal ocean predictive schemes must include coupled atmosphere-ocean models and atmospheric observing systems to provide descriptions of this essential forcing agent. The coastal atmosphere has energetic structures with scales much smaller than are typical of atmospheric systems. Hence, higher spatial resolution is required in the coastal oceanic atmosphere than is the usual case for atmospheric observing systems and models.

The open boundary conditions at the lateral boundaries of the coastal ocean are difficult to specify. The seaward, alongshore open boundary is generally influenced by vigorous, open ocean mesoscale phenomena, such as cyclonic and anticyclonic eddies, meandering jets and fronts. Planetary Rossby wave radiation onshore and offshore must be taken into account, also. The cross-shore open boundary (which lies equatorward on west coasts and poleward on east coasts) is subject to inward radiation of coastally trapped waves.

While the coastal ocean is characterized by motions and processes on a broad spectrum of scales from global to microturbulent, most of the energy generally seems to be on the mesoscale (ca. 100 km) and regional scale (ca. 1000 km). Thus, there are scientific (as well as logistical and political) reasons why regional domains represent reasonable building blocks for constructing a national coastal ocean prediction capability: one can envision, for example, a "national quilt" constructed of (perhaps 30) "regional patches." It is also very important to acquire some long (decades) time series of key variables (sea level, temperature and salinity, and velocity) in each of the regional domains in order to: 1) provide a continuous stream of environmental data to validate and update ongoing routine regional model runs; and 2) for evaluation of global climate change effects.

With data available in real-time via telemetry, it is possible to assess the present state of the ocean both for operational and research purposes. Also, the development, evaluation and dissemination of data products are enabled, and the development of data-assimilative models is facilitated.

Discussion

There was a general discussion of the federal agencies' needs and requirements for coastal observing systems. It was felt that most agencies would significantly benefit from a real-time observing/reporting network covering U.S. coastal oceans on a regional basis. The consensus was that we have the technologies to begin real-time coastal observing networks by expanding and improving existing systems such as NDBC data buoys and satellite remote sensing, and that we should get on with it. One of the greatest challenges will be to develop a data management system that will be able to handle large volumes of different data types and, in near-real-time, conduct quality control, storage and dissemination to users.

Fisheries Management Needs

Glenn Flittner, NMFS, led a discussion of NOAA's concern for the coastal environment from a "fisheries perspective." A summary of the highlights of this presentation follows.

- The National Marine Fisheries Service has responsibility for management of all fisheries inside the 200 Nm Immediate Economic Coastal Zone (EEZ). There is a strong need to know more about the environment and fish stocks and their interactions. We need to know more than just SST; we need trends and variability of the important surface and subsurface fields.
- Involvement in disputes with other nations about fishing zones requires information on global coastal oceans.
- We need information on deep ocean and atmospheric forcing of coastal zone.
- We need a tiered system of information from global estuaries.
- The challenge is to extend forecasts for atmospheric and oceanic weather.
- We need to know when significant events take place and provide this information to the management and enforcement agencies via an information transfer system in near-real-time.
- We need to begin to start forecasting the coastal ocean now.
- The existing ocean data sets are inadequate; although 70% of planet is ocean, most observations are taken over land.
- Large time delays exist now in receiving ocean observations.
- Existing in situ reporting systems are labor intensive and outmoded.

- We need end-to-end data quality control at source, transmission, reception, data processing and archiving stages.
- A global ocean data exchange system must be developed, which includes the coastal ocean.
- Now most global data go to the NMC.
- Satellite observations can help fill the void in data for surface and derived deep fields of temperature, current, and transport.
- We need an improved CZCS for coastal waters.
- It takes several hours to transfer data to NMC which should to be improved to be useful for real-time forecasting.
- The GOES satellite has an existing communication system for real-time telemetry, which could be utilized for data transfer.
- Examples of real-time telemetry from coastal waters in use today are NDBC data buoys for atmospheric variables and limited oceanic variables, COE wave gage network, and the Brookhaven spar buoy that telemeters atmospheric/oceanic information as well as biovariables.

Specifics of a Real-Time Coastal Observing System

It was generally agreed that to be useful to an ongoing COPS, the observing components must function in real-time and be telemetered to a regional data management center. Methodology to be used in this observational approach must be:

1) real-time;
2) synoptic;
3) spatially integrating;
4) reliable;
5) relatively inexpensive; and
6) germane to the important time and space scales of the region.

The consensus was that a real-time observational system in a generic coastal ocean should consist of a judicious mix of the following elements:

1) coastal meteorological observing network;
2) moored ocean measurements;
3) synoptic surveys;
4) remote sensing;

5) Lagrangian drifters; and

6) system integration/data management network.

Summary of Conclusions and Recommendations

The general consensus of this working group is that a real-time coastal ocean predictions system requires the establishment of an observing system consisting of sparse, long-term arrays of moored instruments, to be augmented as required by limited-duration dense arrays of moored, Lagrangian and survey measurements that transmit real-time coastal ocean forecasting parameters to a central Data Integration Center for model updating and forecasting.

The implementation of this strategy will depend on the scope of the coastal area of interest and the time available to plan and deploy the system. One goal of this effort would be to provide long time-series observations of coastal circulation and its forcing.

Recommendations for the Near Future (ca. two years)

1) The density of the NDBC meteorological buoy network needs to be increased with additional buoys that also measure ocean currents and temperature. These should be used to augment the existing buoy network to resolve the dominant cross- and alongshore scales of ocean and atmospheric variability;

2) Vigorous development of airborne techniques for ocean measurement of water column conductivity (salinity) and velocity should be undertaken;

3) Standards for data quality and format should be determined;

4) NOAA/NESDIS should produce an operational SST product for coastal regions on 1km resolution every 12 hours;

5) The number of telemetering coastal sea level stations should be increased;

6) A cost effectiveness study of drifters for the coastal region should be conducted including data transmission, recovery, and dissemination as part of the "rapid response" effort;

7) The addition of a real-time component to future shelf studies should be attempted, for example the upcoming MMS study of the Florida/Texas shelf (LATEX);

29

Recommendations for Future Studies

To create an observational network to support the development and eventual implementation of operational coastal ocean prediction and continued scientific research, an R&D program should be established to:

1)   determine necessary observables for an observational network;

2)   determine their sampling attributes -- e.g., accuracy, precision, and space and time resolutions and correlation/ coherence scales;

3)   establish long time series, on a real-time basis, in strategic locations of each regional domain for input to continually running regional models and to evaluate climatic changes;

4)   deploy Lagrangian drifters to develop regional-seasonal statistics on turbulent surface dispersion;

5)   explore new observational technologies/methodologies to increase reliability and affordability;

6)   determine the sensitivity of alternative data-assimilative models to the quantity and quality characteristics of prototype observing systems;

7)   establish close working relationship between NOAA and other agencies and academia in defining and developing the human resources needed to develop, operate and manage coastal ocean observing systems;

8)   encourage cooperative ventures between NOAA (NOS, NDBC, etc.) and academia in developing and evaluating new coastal ocean observing systems, and between NOAA and both the private sector and academia in developing and operating them (for example, a coordinated, national, airborne coastal oceanography program, with dedicated aircraft);

9)   develop and deploy, in addition to common suites of physical oceanographic and meteorological sensors, operational (automatic) sensing systems for phytoplankton and zooplankton biomass, and other biogeochemical variables; and

10) link the U.S. coastal ocean observing system network into future global-coastal data systems, and provide for other involvement in international coastal ocean programs.

Subgroup reports on each of the elements of a real-time observational system for the coastal ocean follow.

Coastal Meteorology
Chair: Ted Strub, OSU
Member: Steve Rich, NOAA/NWS

Introduction

Observations of the surface conditions over the coastal ocean are necessary for two related purposes: (1) specification of surface boundary conditions for numerical models of the coastal circulation; and (2) analysis of the statistical relationships between surface forcing and the oceanic response, as measured by other components of the coastal ocean observing system. Both purposes relate to ocean prediction, since the statistical analysis in (2) can be used as the basis for stochastic prediction models of the coastal ocean, as opposed to the dynamical numerical models in (1). The primary surface fields needed include (a) surface momentum fluxes (wind stress components); and (b) surface heat and moisture fluxes. Additional surface fields needed for some applications include (c) sea level height (or subsurface pressure) fields, on time scales that resolve tidal and longer period variations; and (d) surface gravity wave statistics. Measurements of these surface fields need to represent accurately horizontal gradients in the surface wind stress field, so that the curl of the wind stress may be calculated on important spatial scales.

The radiation components (long and short wave) of the surface heat fluxes can be measured directly, although maintenance of radiation instruments in the marine environment is not easy. Surface fluxes of momentum and sensible and latent heat (the turbulent fluxes) are usually calculated from "bulk formulae" using wind speed and direction, air temperature and humidity, atmospheric pressure and surface water temperature and salinity. These bulk formulae have accuracies typically estimated as 10 to 20%. In many instances, the balance of terms which create the net surface heat flux is the small difference between large terms, resulting in an uncertainty in even the sign of the net heating, let alone the magnitude. Although this net heating may not greatly affect horizontal currents in many cases, it can exert a strong influence

on vertical mixing at the base of the mixed layer and determine whether or not nutrients are mixed upward into the euphotic zone. Possible improvements in the calculation of the turbulent surface fluxes are discussed below, as are possible measurements of absolute sea level height from buoys (see report on Remote Sensing, chaired by J. Yoder, this volume).

Below we consider observing systems for these surface conditions based on (1) ground level systems, (2) operational meteorological models, and (3) remote sensors.

Ground Level Systems
In Situ Buoys

At present, NDBC buoys measure wind speed and direction, air and water temperature, atmospheric pressure, significant wave height and period, and humidity (recently added). They are mostly located over the continental shelf, with some in deeper water, and they telemeter their data directly for use in operational models. There are several ways this system can be improved immediately and several studies that should be undertaken now which will lead to improvements in the future. The spatial distribution of the buoys should be improved to establish a grid of buoys which better resolves the cross-shore and alongshore wind and heat flux variations. In the cross-shore direction we recommend at least three locations: (a) an overwater or shore location that represents conditions approximately 1 km offshore; (b) a location over the shelf approximately 10 km offshore; and (c) a location approximately 100 to 200 km offshore in deep water. (The exact distances offshore may vary with location.) This distribution is based on the observation that winds are often steered in the alongshore direction in the region within 1 to 20 km from shore and retarded by the greater friction over the land. In the alongshore direction, the decorrelation scales are greater over the water, suggesting separations of approximately 150 to 300 km in the alongshore direction. Over land, small-scale topographic features (like river drainage valleys) may cause wind variations over short distances, arguing in favor of locating the nearshore measurement site over water (1 km offshore), although this is logistically more difficult. Measurements over water will also allow the calculation of vertical fluxes of sensible and latent heat and radiation, which may change rapidly from land to water. If a shore station is used, an effort should be made to verify that it represents conditions over the water.

The suggested spatial distribution of buoys will provide measured winds with spatial resolution similar to the Limited-Area Fine Mesh (LFM) operational wind forecasts (approximately 190 km) over the large-scale coastal ocean. It will also include greater cross-shore resolution next to the coast, where spatial gradients caused by the land boundary are concentrated. This will allow a realistic representation of the dynamically important wind stress curl. This degree of coverage may already exist in some regions along the East Coast, but is definitely lacking in others, such as the West Coast. The effort should be made to provide uniform coverage everywhere. This requires no new technology, only a decision to use NOAA's resources in a manner that will resolve the important spatial scales in the coastal ocean's surface atmospheric fields.

The instrumentation on the buoys should be augmented to include long and shortwave radiation, and humidity where lacking. (Humidity sensors have been tested and added to the operational suite of sensors on some buoys.) Such measurements are necessary for the calculation of latent heat flux, the second largest of the heat flux terms. Radiation instruments have been deployed on buoys in research studies and should now be attempted on the operational buoys. Problems to be overcome include the environmental fouling of the globes surrounding the radiation sensors, and the maintenance of a level orientation for the instruments (when averaged over some period). It may be easier to deploy and maintain instruments to measure shortwave radiation than to measure longwave radiation, in which case the shortwave radiometers should be deployed first, since the shortwave radiation is often the largest of the heat flux terms. Additional instrumentation of interest to some of the users includes those needed for directional wave spectra. These directional wave spectra sensors should be added to the operational buoys when feasible.

Improved estimates of the turbulent surface fluxes (wind stress, sensible and latent heat) should be evaluated now and implemented when feasible. The method suggested at present is exemplified by the "dissipation method," which estimates the turbulent fluxes from the spectra of wind, temperature and specific humidity. The method requires fast response sensors, which are presently available for temperature and wind. The response of the capacitance sensor for humidity, which is added to the operational buoys, should be evaluated in terms of the dissipation method for latent heat flux. This method should be evaluated along with any others which provide comparable estimates of the turbulent fluxes over a wide range of environmental conditions.

33

Shore-Based Radar

Looking farther into the future, shore-based radar and laser systems may be available which provide greater resolution of the wind field over the coastal ocean. A study of the capabilities of these systems should be undertaken. CODAR or LIDAR systems may provide the needed coverage; the NEXRAD system should be investigated, but may not resolve the boundary layer winds well. Use of such a system might improve the spatial resolution of the fields of wind stress, as calculated by bulk formulae. It may also improve the spatial resolution of fields of latent and sensible heat flux, again using bulk formulae, although the optimal method of blending temperatures and humidities from the buoys with "radar" winds would need to be determined. Tradeoffs between using improved instruments and methods at the buoy locations as opposed to using the more dense sampling of "radar" winds (most likely less accurate than those measured at the buoys) with bulk formulae will also need to be evaluated. Even if such radar wind fields become available, maintenance of the NDBC buoys should be continued, since they will provide ground-truth measurements for the radar system, and platforms for other necessary oceanographic measurements.

Operational Model Fields of Wind and Heat Flux

If the NDBC buoys are deployed as recommended above, they will provide better spatial resolution and accuracy than are available from the operational products at present or in the near future. If the distribution of NDBC buoys remains in its present form, however, the only estimates of cross-shore gradients in many regions will come from the operational products.

An evaluation of three of the most commonly available operational wind fields (Fleet Numerical Oceanography Center (FNOC), Limited-Area Fine Mesh (LFM), Nested Grid Model (NGM)) was recently conducted by Strub and James (Volume II). The FNOC winds are objectively analyzed fields formed from all ship and buoy data available every six hours. LFM and NGM winds come from the NMC and are six-hour forecasts made every 12 hours, incorporating the same ship and buoy data as used for the FNOC fields. RMS differences between the operational wind fields and buoy winds range from approximately 2 m/s at buoys 500 km offshore to 3.5-5.0 m/s at buoys 10 km from shore. Although the LFM and NGM winds are calculated on finer grids (190 and 95km spacing respectively) than the FNOC (380km separation), none of the fields accurately resolves spatial differences in the buoy winds with scales less than 600 km. The LFM fields appear to represent more accurately the qualitative

effect of coastal alongshore steering, while FNOC and NGM fields are usually slightly better correlated with the buoys and have slightly lower RMS differences in comparison to the buoys.

Future NMC plans include the retirement of the LFM model in the early 1990s, the continued use of the NGM, and the development of a new regional model, to be operational in the mid-1990s. We assume that the FNOC product will continue to be available, although it is only supplied in real-time to Navy users. These fields should continue to be evaluated as improvements are made. The forecast models, however, are affected more strongly by the structure of the 3-D atmosphere, as specified by radiosonde and satellite sounders, than by surface measurements. Thus, it seems likely that even improved model forecasts will remain inferior to surface fields interpolated from a good grid of surface measurements. If the offshore buoys (150 to 300 km from shore) are not added to the system, winds from the operational products could be interpolated to the proposed offshore locations and used in combination with the shelf buoys and the land or 1km offshore measurements. Strub and James (Volume II) show that the operational products represent the offshore winds better than the nearshore winds. The combination of offshore operational winds with nearshore measured winds represents the measured cross-shore wind differences better than do the operational fields alone.

Remote Sensors
Satellite Infrared

The AVHRR imagers on polar-orbiting NOAA satellites will continue to provide measurements of SST with 1km resolution every 12 hours. Thus, when two satellites are in operation, fields are available four times each day. Experience has shown that clouds obscure much of the coastal ocean at any given time, making it desirable to collect as many passes as possible to composite the images over periods of 1 to 5 days. If accurate SST data become available from the geostationary satellites, with approximately 4km resolution very 1/2 hour, daily composites should be made from those data. If the absolute SST fields are accurate enough, such fields can be used in the calculation of latent and sensible heat flux (if wind speed, air temperature and humidity are also known), as well as upward longwave radiation. Estimates of cloud amount and height can also be made from the fields, which can then be used to estimate the downward short and longwave radiation. In many instances, patterns in the SST fields can be used to infer surface currents in the ocean. Thus, these passive IR sensors are very useful in investigating the surface atmospheric fields as

well as the surface ocean response. Production of the composites and the radiation estimates routinely requires the ability to detect clouds objectively in an automatic fashion. Cloud detection, radiation estimation, surface current estimation and absolute accuracy improvement are all subjects of ongoing research.

The primary obstacle in using present AVHRR data is the cost and difficulty in obtaining raw or processed data. For instance, one pass of raw data along the western coast of the USA (LAC, 1km resolution) can be ordered from the Scripps Satellite Oceanography Center. The data occupy over half of a 6250 bpi tape. The cheapest way to obtain the data is to purchase a simple tape copy for approximately $120. Thus, the cost of two passes per day for a year costs approximately $90,000. To obtain GAC (4km resolution) data from NOAA costs approximately the same, since they store the data sequentially, four orbits per tape, and the cheapest way to get the data is to buy a tape copy costing approximately $100. Making either raw or processed LAC data covering the coastal ocean surrounding the USA available over a fast electronic network would greatly facilitate the wider use of these valuable data. Before these data can be made available on an operational basis, a number of questions must be answered. Should the data be raw or processed? If raw, which channels should be provided, keeping in mind the need for cloud detection and multichannel atmospheric corrections. If processed, what cloud detection and atmospheric correction algorithms should be used? Would processing be done at regional NOAA centers, regional academic centers, or some central facility? Note that the NOAA satellite data center in Washington, DC can barely respond to requests over fairly long periods, and that service from institutions such as Scripps is very costly. Perhaps the electronic data transfer arrangement between the University of Miami and the University of Rhode Island would serve as a model, but the logistics of this processing and distribution would be non-trivial.

Satellite Microwave

Most of the passive and active microwave sensors cannot be used within some distance (20 to 200 km) of land, due both to their large footprint and to contamination from side-lobe effects. One of the more useful of these sensors may prove to be the altimeter, an active microwave radar which provides the time-variable sea level height field along crossing tracks that are approximately orthogonal. If certain tracks can be ground-truthed in some way, the absolute sea level height might be determined, allowing calculation of the geostrophic velocities. Resolution is

roughly 7 to 20 km alongtrack and 140 to 300 km between tracks. It also provides an estimate of wind speed and significant wave height. Several studies are in press which show that the altimeter can provide useful information on the statistical properties of the variable circulation in the large-scale coastal ocean (300 to 500 km offshore, 2000 km alongshore). It may also be useful in coastal data-assimilative models, and a number of studies are underway to evaluate this use. Another active microwave sensor is the scatterometer, which measures wind speed and direction. Its resolution is 25 to 50 km, with land contamination within 50 to 100 km of the coast. A passive, scanning multichannel microwave radiometer (SMMR) measures SST, wind speed and total water vapor content of the atmosphere. Resolution is coarse (50 to 100 km) and data within 100 km (or more) of the coast are unreliable. Research is underway on the efficacy of estimating latent and sensible heat fluxes from SMMR data. These microwave sensors are primarily intended for use in the deep ocean, where surface observations are not available. Given the availability of surface observations in the coastal ocean, the microwave sensors are less useful, except for the uses of the altimeter, noted above. If coastal ocean models are imbedded in larger-scale and coarser numerical models, the microwave sensors might be useful to drive the coarser model. Future improvements in microwave sensors may increase their resolution and their use near land. One such improvement has been realized with the synthetic aperture radar (SAR). This sensor achieves much finer-scale resolution by electronically simulating a larger antenna. In the coastal ocean context, it is most useful in characterizing the surface wave field. The SAR instrument on the European satellite ERS-1 will be used to improve the observational wave forecasts of the European weather agencies. The tremendous data rate involved in SAR analysis poses even greater data management problems than those encountered for the other satellite ocean sensors.

Aircraft

Although meteorological measurements can be made from aircraft, it seems unlikely that routine airplane surveys will ever be made over the large-scale coastal ocean, due to the cost. (N.B. If small aircraft are used with new, smaller instrumentation packages, this adverse cost projection could be reversed.) Specific surveys made in conjunction with coastal ocean field studies or emergency surveys in response to spills of hazardous materials or search and rescue missions would be possible. Before this could be done as an operational response to an emergency, the methodology of combining high-resolution aircraft data at some height above the surface with surface buoy and ship measurements should be investigated as a research

problem. This might be attempted in conjunction with the dedicated prediction experiment proposed by the modelers within the COPS framework.

Conclusions

We conclude that the best meteorological fields that can realistically be expected in the near future will be produced by objective analysis of surface measurements from an adequate grid of buoys, perhaps supplemented by ships-of-opportunity. This is the approach taken by the FNOC, although improved objective analysis schemes might be possible. Given the grid of NDBC buoys suggested above, a much finer coastal grid should be used in the analysis than the hemispheric grid with 380 km separation used by the FNOC. Based on the stronger gradients expected near the coast, a grid with finer resolution in the nearshore region should be investigated. This analysis might be undertaken as a combined NOAA/FNOC project, using facilities already in place. If so, the fields should be made available in real-time to civilian as well as Navy investigators and operators. Archiving could perhaps be done through NCAR, where a number of the operational products are stored.

In the future, a more dynamical interpolation of buoy and ship measurements might be made using mass-conserving boundary layer models, as done over land. However, these require observations of the vertical structure of winds and temperature in the lower atmosphere at a grid of locations. If automated, upward-looking vertical profilers could be located on moored buoys or could profile the atmosphere over the coastal ocean from land, they would provide the measurements necessary for boundary layer models of coastal winds. They would also improve the larger-scale 3-D regional models over the coastal ocean and land. Such a system should be the long-term goal for coastal meteorological measurements.

Recommendation

The single most important recommendation for immediate action with regard to improving the coastal meteorological observation system is the improvement of the spatial resolution of the NDBC buoys. The same recommendation has been made a number of times over the past decade. For example, in the "Recommendation for a California Coastal Circulation Field Program, Summary and Recommendations of a Workshop", held at Scripps Institution of Oceanography, June 16-17, 1982, chaired by Bernstein, Chelton, and Mooers, for the MMS Pacific Outer Continental Shelf Region, it states:

We therefore recommend that lines of buoys be placed in an offshore directed line at one or more locations. Since winds and wind stress curl are thought to be most intense between Point Conception and Cape Mendocino, this area should receive the highest priority. (Bernstein et al., 1982, p.12)

Similar statements were made at the MMS-sponsored "Workshop on Coastal Circulation along Washington and Oregon" held February 8-9, 1988, in Seattle, Washington (Environsphere Company, 1988). Although new buoys have been added to the system, along the West Coast only alongshore coverage has been added, in some cases close to existing buoys. It is time for NOAA, MMS and the other agencies to act upon the repeated recommendations for a well-considered grid of buoys which specifically provides resolution of the offshore gradients.

Moored Measurements

Chair: David McGehee, U.S. Army Corps of Engineers
Members: Barbara Hickey, University of Washington
Robin Muench, SAIC
Paul Falkowski, Brookhaven National Laboratories

Introduction

The suite of observed variables to be sampled on existing moored systems to meet COPS requirements, as well as the adequacy of those systems, were addressed. In addition, the logistical and fiscal constraints of alternative approaches were compared in order to arrive at a recommendation.

A moored observational network in the coastal ocean would have the primary function of providing real-time data to numerical models. The model uses include specification of initial and boundary conditions, updating results within the model domain by data-assimilative models, and calibration/verification of model output. Secondary benefits would include (1) establishment of a climatology from which the statistical properties of the observed variables could be calculated, and (2) transfer of real-time data on present conditions to operational users.

Requirements

Two categories of observed variables will be considered. Level I observations are those made using existing sensors and technology which have been proven reliable for long-term, as opposed to experimental or short-term, use. Measurements in this category have been obtained, more or less routinely, by academic and governmental organizations, though not necessarily integrated into a single platform. Level II observations are those measurable with sensors which already exist, but which may require engineering or analytical development before becoming practical for untended deployments of long duration. Table 1 lists these variables, the preferred sensor type, the platform required, and an estimate of the sensor acquisition cost for Level I variables.

The minimum spatial density of measurements cannot be estimated firmly at this time. During the model development phase, many measurements will be required to build confidence in the results; ideally, as verification proceeds, fewer measurements will be necessary. Also, different variables have different scales of variability, both horizontally and vertically so they will have different spatial density requirements. It is a certainty that fiscal constraints will always be reached before redundant data are acquired, thus, limiting the quality of the spatial resolution. Nevertheless, planning with available resources is required. Three approaches are possible: maximize extent of coverage at the expense of density by spreading observations on a national scale; maximize density within a limited region before measuring in another region; or a combination of relatively widely spaced, long-term "index" observational stations, enhanced by more closely spaced, short-term stations that operate long enough to provide model calibration/verification. The third approach is recommended as optimizing the productivity of a limited resource, assuming establishment of a nationwide program is the goal, while the second is preferable if accelerated model development is desired. A more quantitative specification must consider the specific requirements of a given numerical model and the actual budget, and is beyond the scope of this report.

In general, priority should be given to measuring the most important boundary conditions. For circulation and heat flux models, the critical boundaries are the open ocean (alongshore and cross-shore) and the air-sea surface. For water quality models, the shoreline/estuarine boundary is equally important. Temperature and salinity gradients are particularly important in driving circulation in the open ocean, so deep-water platforms should emphasize atmospheric factors, temperature and

salinity profiles and current profiles. In nearshore environments, wind and wave forces dominate the circulation process. At estuary entrances, tidal flows usually predominate. Shallower stations, therefore, should stress tide and wave measurements as well as currents.

Sampling intervals are less constrained by technology or budget; they are limited more by the ability of the data base management system to absorb the data than by the platform's ability to acquire it. On-board processing and memory buffers, packet transmission, low-power circuitry and renewable power sources are some of the techniques available to allow continuous sampling, if desired. A nominal target interval for most observations is hourly.

Data processing will comprise a considerable portion of the observational effort. Hourly sampling from a network of ~100 platforms will entail processing of ~100 megabytes of data daily. Automated systems must be developed to access, analyze, quality check and edit, disseminate and archive this data stream. Onboard analysis and reduction can lower the volume of data processed centrally, but increases the risk of spurious signals passing as valid measurements. Expert systems may prove helpful, but human judgement should be integrated as fully as practical into the process before the data are assimilated by the models.

Existing Networks

There are presently three agencies operating national-scale observational networks in the coastal ocean: The National Ocean Service (NOS) operates coastal tide stations; the National Data Buoy Center (NDBC) maintains a moored buoy network and the C-MAN (nearshore) weather station network; and the U.S. Army Corps of Engineers (COE) operates the Field Wave Gauging Program of coastal wave and surge gages.

- The NOS tide gages are focused on measuring sea level and are almost always located in estuaries or protected harbors. There are 48 reference stations, with additional short-term stations.
- The NDBC buoy and C-MAN networks provide atmospheric and wave data in deep ocean and intermediate-depth coastal waters. They do not provide salinity or currents and only a sea surface temperature. NDBC operates 54 moored buoys and 46 fixed C-MAN stations.

- The COE network obtains nearshore wave and water levels, and, in some locations, nearbottom currents. The COE also supports operation of additional NDBC directional wave buoys on the continental shelf. The network does not obtain current or any water chemistry/quality variables. Currently, 40 real-time reporting stations are operational, with a projected increase to 80 by 1994. Data are reported in monthly and annual reports; there is no existing or planned system for dissemination of the data in real-time.

The major deficiencies of the existing networks are the lack of adequate temperature, salinity, and current observations; the insufficient number of platforms to provide needed resolution; and the total lack of vertical profiles of any variable. Nevertheless, these networks have demonstrated the feasibility of a national observational program. Each has evolved through the accumulation of the talent and infrastructure that is essential to such a program. The hardware and software design capability, construction, logistical and maintenance support, and the data telemetry, processing and management capability are essential resources for a coastal observational system. Sensor acquisition represents a small fraction of the required costs.

Recommendations

1) Implement a coastal ocean circulation observing system by enhancing the capabilities and expanding the scope of the existing national networks. Efforts to duplicate this capability in order to acquire different types of data in the same region would be counterproductive.

2) Pursue the integration of the data bases of the three existing networks to allow single-source access, common formats and standardized analysis.

3) Adapt additional Level I sensors, mount them on existing platforms, and assimilate their signals into the platform's data telemetry scheme. Specifically:
   a) temperature/conductivity chains on the NDBC buoys moorings;
   b) bottom-mounted pressure transducers for the NDBC buoys;
   c) bottom- or hull-mounted acoustic Doppler current profilers for the NDBC buoys;
   d) temperature and conductivity sensors on the COE gages;
   e) acoustic Doppler current profilers on the COE gages.

4)   Continue development of Level II sensors for inclusion into the existing platforms, particularly those providing water quality measurements nearshore and radiation flux offshore.

Synoptic Surveying
<u>Chair</u>:   Bruce Magnell, EG&G
<u>Members</u>:   Wendell Brown, UNH
David Brooks, TAMU

Introduction

Synoptic surveys of the ocean provide three-dimensional "snapshots" of temperature, salinity, density, current velocity and biogeochemical variables. These snapshots are important in helping to define the pertinent spatial structure of these fields. Such synoptic snapshots are essential for initialization and updating of numerical model computations. Unfortunately, the synopticity of shipboard survey data is severely compromised in the coastal ocean, where significant variability on time scales of hours-to-days exists.

We find that the present methods for obtaining synoptic survey data are inadequate for the COPS goals in terms of timeliness, quantity, and synopticity. What follows are recommendations for the development of synoptic survey data-acquisition systems which can meet COPS goals. The emphasis of these recommendations is on improving synopticity with increasingly less expensive systems. We recommend that highest priority be given to improving the quantity and synopticity of physical variables (temperature, salinity, and velocity). This is based on the assumption that the description of water motion is the foundation upon which understanding of biogeochemical data rests. This recommended emphasis may be "orthogonal" to the need for improved description of biogeochemical variables, but such a separation may be inevitable due to fundamental differences in sensor speed, etc.

We discuss a suite of observing systems whose development can be implemented on three different time horizons, namely the: (1) <u>present</u>, using existing instrumentation, (2) <u>short</u> term (within a few years), using new configurations of existing technology, and (3) <u>long</u> term (five to ten years), using instrumentation

which must be developed. We distinguish observing system technologies required to make (a) larger mesoscale (of the order of an internal Rossby radius) measurements from those for measuring on frontal spatial scales (smaller mesoscale), and observing systems to be used (b) in the region of the seaward boundary from those to be used in the interior.

Hydrography

In general, both temperature (T) and salinity (S) must be measured in the coastal ocean to determine the density and water mass distributions. These T/S surveys can be augmented by T-only surveys if locally-stable T-S relations can be determined.

Present
Mesoscale

The synopticity of present CTD surveys could be improved by employing more ships and/or boats to improve simultaneous coverage of a given region. The cost of this improved synopticity could be substantially reduced by employing technicians to use presently available internally recording CTD instrumentation and automatic onboard data acquisition, checking, and processing systems from small boats. The requirements for conducting-wire winch systems severely limits our present options, and increases cost.

Frontal-scale

The spatial resolution of such mesoscale surveys could be refined "as necessary" in frontal regions by using underway XBT observations. Recently developed automatic, multiple-shot XBT launchers could be used to augment the efforts of the modest-sized technical groups envisioned for this type of effort.

Seaward "Boundary"

In the near term, we must continue to rely on larger ships to survey the seaward edge of a regional coastal domain. Costs might be minimized by using the internally recording CTD instrumentation on less expensive non-research vessels.

Short Term

Evolutionary improvements in hydrographic sampling techniques should permit routine underway density profiling over the shelf and upper slope. Underway profiling will provide major improvements in synopticity, horizontal resolution, and/or cost, and will also enhance the value of other underway data, including Doppler acoustic log current profiles.

The free-fall profilers and the To-Yo discussed next will provide quantum leaps in the quantity and usefulness of hydrographic data for the synoptic description of mesoscale and frontal-scale hydrographic fields required for model initialization.

Mesoscale

Another approach would be to develop a free-fall underway profiler, a modern BT. Based on available small-diameter CTDs, such as the Ocean Sensors, Inc., unit, this technique would involve the use of a heavy streamlined fish which sails rapidly through the water column as wire is unreeled freely from the moving ship. Data would be recorded internally on solid-state instrumentation, retrieved and plotted immediately upon recovery of the fish. While this technique would not be amenable to the addition of bulky biogeochemical sensors, it is potentially much cheaper than the To-Yo and could be installed and routinely operated aboard literally hundreds of coastal vessels to provide an extensive data base of detailed T/S profiles in the upper few hundred meters of the ocean. This would be particularly valuable for real-time data input for reinitialization and/or verification of models.

The primary technological development required for the free-fall profilers would be the design of an improved winch, as the WWII-vintage mechanical BT winch would probably prove inadequate. Acoustic telemetry of data from the fish might also be valuable as it would permit continuous profiling and active experimental design.

Frontal Scale

One approach is the Bat Fish, or "To-Yo," involving a towed CTD package on an actively controlled fish which "flies" up and down through the water column. Presently available devices of this type, such as the Guildline Bat Fish, are large and expensive, but the use of modern, moderate-sized CTD's (such as the Sea Bird) should allow for the development of a much smaller and less expensive towed fish.

45

In principle, a To-Yo could be equipped with biogeochemical sensors also. The To-Yo is probably best suited to observing small-scale processes such as fronts, where the real-time data provided from the towed fish will allow immediate fine-tuning of the experiment.

Long Term

Ultimately, observing systems capable of more nearly synoptic hydrographic measurements over wide areas at acceptable cost will be needed to achieve COPS goals. This implies aircraft-based sampling. Fixed-wing aircraft provide a relatively inexpensive and readily available platform for coastal ocean sampling. Their usefulness, however, depends on the development of a suite of expendable sensors. Helicopters, VSTOL aircraft, and airships (blimps) all offer various advantages due to their ability to hover. These platforms may be most cost-effectively utilized with recoverable sensor packages.

The single most important technical development for COPS would be that of a useful AXCTD. A significant reduction in the present unit probe cost will have to occur if the full benefit of its further development is to be achieved.

Currents
Present
Mesoscale, Frontal Scale

In the short run, hull-mounted Doppler acoustic log systems will continue to be the most practical method for surveying the 3-D velocity field. However, few ships are equipped for this important measurement. Thus, these data will be restricted primarily to research operations.

Seaward "Boundary"

When current observations are required along the seaward boundary of a particular domain, deep current profile methods must be employed to complement the depth limitation of the shipboard Doppler log. The Pegasus current profilers and expendable electric field current profilers (Sanford XCP) represent two options.

The Pegasus profiler is a recoverable instrument whose lateral displacement profile is tracked by a pair of acoustic transponders prelocated on the bottom. The

advantage of this system is that a large number of profiles can be obtained over the several-year lifetime of the bottom transponders (@ $2000 each), using non-research boats and ships. The disadvantages include (a) the fact that the station locations are fixed for the lifetime of the transponders, and (b) the time it takes (a couple of hours) to obtain a deep profile.

The Sanford XCP current profiler would permit more synopticity. It's principal disadvantage is a unit cost of about $1000 each.

Short Term
Mesoscale

An improvement (called POGO) on the old Richardson transport measurement concept has recently been suggested by Prof. H.T. Rossby. The Richardson transport measurement consists of determining the lateral surface displacement of a probe which has been released at the surface, fallen to the bottom and returned to the surface. The water column transport can be related to the measured displacement. By adding LORAN or GPS positioning and retransmitting capability to a Richardson float, the time-consuming process of determining the surface location of the returned float could be eliminated. This would permit ships to deploy many more probes than presently possible, especially if aircraft could be used for data recovery. The usefulness of this technique to deep water applications and accuracy requirements needs to be investigated.

Frontal Scale

The development of a towed Doppler current profiling system would lead to wider use by non-research ships and boats and, perhaps as important, a less noisy product. The system would also have application to mesoscale surveys.

Seaward "Boundary"

The POGO technology would be applicable to this deeper ocean domain as well. There is probably no other short-term development which could improve the options for deep current profiling beyond the presently available XCP and Pegasus.

Long Term

An air-deployable version of the POGO transport system (called AXPOGO by Rossby) would offer significantly improved synopticity over wide ocean areas. The addition of an XCTD to the AXPOGO probe would make possible the collection of simultaneous water column structure information. A lower cost AXCP would provide synoptic current profile information over entire regional domains.

Long-term technological development for POGO or AXPOGO would focus on producing low-cost navigation receivers and retransmitters.

Biogeochemical Variables

Recommendation

Technological development has traditionally been difficult to fund under the present proposal review systems. Yet it is clear that the major improvements in data acquisition capability which are needed to support COPS cannot be sustained solely on present-day technology. We recommend that funding agencies recognize the need to support future technological development.

Remote Sensing
Chair: Jim Yoder, URI
Members: Richard Legeckis, NOAA
Tom Lee, UM
David Johnson, MMS

Present Practices

NOAA recently (1989) started a new Coastal Ocean Program. Coast-Watch, one component of this program, is aimed at improving the timely delivery of near-real-time satellite AVHRR remapped images to "operational" NOAA users. The first user was NOAA's Fisheries Laboratory at Beaufort, NC. The driving force for this data stream was the apparent influence of the Gulf Stream, and subsequent spin-off eddies

(or "shingles"), in transporting "red tide" organisms from the Gulf of Mexico to the shores of North Carolina.

The NOAA system for the electronic delivery of the remapped AVHRR images consists of the following three components. A NESDIS mainframe computer at Suitland, MD, is used to process and remap the AVHRR images (visible and sea surface temperature) each day. The remapped images are sent to a MicroVax computer at the Ocean Products Center in the World Weather Building in Camp Springs, MD, where they are stored on disk. The Fisheries Lab transfers the images via phone line to an IBM-PC which is equipped with a Number-9 board. The images are then evaluated at the PC workstation. The software for processing, transfer, and display of the images is unique and was developed at NESDIS.

Future plans call for the expansion of the image distribution system by NESDIS NOS, the Ocean Products Center at Camp Springs and the new NOAA Center for Ocean Analysis and Prediction (COAP) in Monterey, CA. A NOAA communications networ is being implemented by NOS to tie together the different components of the Coast-Watch system. Eventually images of the entire coastal zone of the United States should be available in near-real-time.

Plans are being made by COAP to acquire the digital AVHRR data stream from a new Navy satellite receiving station in Monterey. The AVHRR data would be sent to NESDIS for archiving and processing. This would provide an alternate source of West Coast AVHRR data.

Deficiencies

The present NOAA effort in the Coast-Watch program is aimed at meeting NOAA's needs for near-real-time AVHRR data by NOAA users. This may not meet the expectations of COPS, which is proposing the availability of satellite data to a wide range of users who may require data in different stages of processing (raw data to finished products). Furthermore, the present NESDIS remapped image formats are tailored for use on an IBM-PC (with a Number-9 board) and requires that the NESDIS software be used. A potential user with a different computer system will be forced to adjust to this constraint.

Recommendations

1) The principal recommendation of the remote sensing subgroup is for COPS to distribute an AVHRR-derived SST field for the U.S. EEZ at 6- to 12-hour intervals with 1km grid spacing within six hours of data collection.

   Specifics:
   a) A central facility is needed which distributes the product for the entire U.S. EEZ.
   b) Since the initial product is based only on satellite data, some areas of the EEZ will be cloud-covered.
   c) A 1km-gridded SST coverage of the continental U.S. EEZ amounts to ca. 2-3 mbytes of data, so files can be distributed over electronic networks.

2) Following successful implementation of recommendation (1), at some later date, the AVHRR-derived SST data should be merged with model results or other information to provide an SST field for the EEZ, including areas covered by clouds.

3) In the near future (2 to 4 years) a new geostationary satellite (GOES-I) will allow SST estimates at 4km resolution and 30-min intervals, using split window IR channels to make atmospheric corrections. Once recommendations (1) and (2) are implemented successfully, the new GOES data could be used to observe the formation and dissipation of features, such as tidal fronts, which are too short-lived to observe with the 12-hour SST product.

4) An operational system is needed for determining coastal and offshore wind vectors. This could be a combination of coastal radars for nearshore winds plus satellite scatterometers or buoys for offshore winds.

5) The visible and near-IR channels on the AVHRR instrument and the new Sea-WiFS ocean color scanner planned for mid-1990s launch can be used to locate sediment plumes, phytoplankton blooms and other visible-band features which closely track coastal circulation patterns. The ocean color instruments become critical in the coastal zone since water color can be used to identify water mass boundaries when they are not apparent in the thermal images. For example, during the summer the Loop Current and the Gulf Stream "disappear" in infrared images while they can still be detected by water color measurements. Therefore, a strong endorsement is made for the Sea-WiFS instrument proposed by NASA.

6) Operational sea level height measurements are presently made at a number of coastal locations. Some of these instruments telemeter their data in real-time. These should be continued and augmented with additional stations which are representative of sea level heights over the ocean a short distance from shore, since many of the shore-based tide gauges are located inside estuaries and bays where freshwater discharge may affect the measurements.

7) The feasibility of using Global Positioning System (GPS) sensors on moored buoys to measure absolute sea level height to accuracies of 2-3 cm is presently being evaluated by George Born (University of Colorado). If this proves possible, these instruments should be added to all NDBC buoys. This would be another reason to locate the measurements nearest to shore over water (1 km from shore) rather than onshore. The measurement of sea level height at both an onshore tide gauge and a buoy 1 km offshore at a few locations would be advisable, allowing a check on the consistency of the two types of measurements. If the addition of such sensors makes absolute sea level measurable over water, this would allow calculation of the absolute geostrophic velocities in a manner previously impossible. It would also provide an additional boundary condition for the models. Although such a capability would appear to provide a motivation to coordinate the location of NDBC buoys with altimeter tracks, this should only be considered if the same orbits are maintained by a number of satellites over a long period (many years), which seems unlikely. The primary consideration for the permanent NDBC network should be the maintenance of the buoy absolute sea level height measurements at fixed locations for long periods to determine the interannual variations in geostrophic velocities, which would not be possible if the buoy locations shifted. A more important consideration (than coordination with altimeter tracks) for the location of the NDBC buoys would be the proximity to repeated shipping routes where ship-of-opportunity sections of XBT, and eventually XCTD, data would provide the baroclinic component of the geostrophic transport over many years, with perhaps weekly resolution.

Lagrangian Drifters
Chair: William Wiseman, LSU
Members: Murray Brown, MMS New Orleans
M. Lewandowski, U.S. Coast Guard

Discussion

The important socio-economic problems of transport in the coastal ocean are often Lagrangian in character, not Eulerian. These include search and rescue mission planning, oil spill trajectory forecasting, larva recruitment predictions and sediment transport predictions, among others. The strength of the spatial and temporal variability of the Eulerian flow field in the coastal ocean imply the possibility of Lagrangian residual currents which are significantly different from the mean Eulerian flow field.

Surface drifters with subsurface drogues are probably the most common technology used to assess the variability of the Lagrangian flow field. Significant recent effort has been devoted to the design of these instruments to eliminate slippage between the drogue and the water, to eliminate wind drift, and to improve tracking capabilities, both by radio receiver and by satellite. Despite these efforts, other problems remain. Due to frontal convergence, there appears to be a preference for drifters to over-sample high-shear regions of the ocean. If the field of horizontal shear is weak, this may not be a serious problem. In most coastal situations, though, strong shear is often associated with the many frontal boundaries and topographic variations over the shelf.

Water parcels tend to move along surfaces of constant density, yet these drogued drifters tag fixed depth levels beneath the sea surface. Because of this fact, they do not follow a truly Lagrangian path. Nevertheless, they may be extremely appropriate for particular practical problems. A man overboard wearing a life jacket behaves more like a drogued drifter than like a Lagrangian parcel. Similarly, an oil slick does not follow surfaces of constant density.

One final problem with present day technology is the cost. The beauty of a satellite-tracked buoy is the fact that it can be left unattended for long periods. In the coastal ocean, though, large numbers of drifters will be required to determine

accurately the statistics of the Lagrangian flow field and the drifters will rapidly depart from the region of interest. The drifters must either be considered expendable or they must be retrieved and redeployed, which requires the use of expensive boat time, or an automated system for self-propulsion, navigation, and control.

Neutrally-buoyant floats might eliminate some of these problems. They more closely follow a constant density surface, but they still require tracking from a boat and are expensive to treat as expendable. Furthermore, it is not clear how they respond to a strong shear or how one might effectively seed a shallow water region.

Natural tracers are rarely much simpler to use. The chemical analysis necessary to determine the tracer concentration is often time-consuming. Adequate sampling involves extensive boat time. The simplest tracer to use in the coastal ocean is fresh water. Even this tracer's use is confounded by multiple sources, some at the coastline and others, precipitation, distributed in space. Instantaneous, point source releases are rarely available so the tracer field that is observed represents the convolution of the source function with a system function in which we are interested. The deconvolution process is not straightforward.

Introduced tracers, such as chemical dyes, involve their own problems. Sampling and analysis difficulties still remain a concern. Additional problems arise because of the interactions of the tracers with suspended sediment, biological uptake or contamination of the analysis, and photodegradation of the tracer.

Thus, while Lagrangian data is important to the resolution of practical problems in the coastal ocean, the measurement of this data remains a difficult and expensive undertaking.

Recommendations

Lagrangian measurements have two fundamental roles to play in a coastal ocean prediction system program. Small numbers of drifters may be used to verify model flow predictions. Larger numbers of drifters will be needed to determine the Lagrangian statistics of the flow field. In light of the problems mentioned above, a number of immediate studies should be started:

1) An immediate cost-effectiveness study should be undertaken to evaluate different drogue designs, deployment schemes and telemetry techniques for coastal areas. This should be supplemented with field and laboratory studies of drogue response in strong shear and density gradients.

2) Natural tracers useful for the study of coastal water movement should be identified and long-lived dyes should be developed for the same purpose.

3) An evaluation of neutrally-buoyant floats in coastal waters should be undertaken. Efforts should simultaneously begin to incorporate additional sensors in these floats, e.g. fluorometers, salinometers.

System Integration

Chair: Jim Herring, Dynalysis of Princeton
Members: Steve Haeger, Naval Oceanographic Office
Glenn Flittner, NOAA
Glenn Hamilton, NOAA
Ken Ruggles, Systems West

Data Management

The data systems capable of handling the acquisition, reduction, and processing of data for real-time ocean prediction systems do not now exist. What does exist is a well-structured meteorological data system, some special data centers operated by institutions such as the COE and the USCG, and individual-experimenter data systems.

A structure must be emplaced to interface these existing data systems and to integrate the new baseline observing sensor data and systems required by COPS. Because of the magnitude and uniqueness of the data, it was felt that most of the data do not interface well into existing networks, and would require a new network.

Based on an assumed regional/national modeling center structure, we see the establishment of a regional data center within each coastal region, most likely with a forecast facility, which would acquire data in real-time, reduce the data to common formats, archive the data and interchange the data with regional users, including the

modeling activity. The possible structure of such a system was considered for the sake of illustration in Figure 1.

The regional data centers would provide for gross error checking of the data, and the organization of the data into a local archive for application. Raw sensor data and other real-time or non-real-time data from experimenters or other sources would be routinely fed into the data center. To the extent the data center required satellite and radar data, that data would be provided for processing into manageable and useful data sets of high-resolution coastal weather and ocean variables.

The regional data center must have staff to support actively an outreach program in the coastal region to recruit potential raw data suppliers and to arrange for efficient data acquisition and interchange. The regional data center would maintain real-time communication with a national data center. Data required for national-level modeling activities, national archives, and other regional data centers will be passed to the national data center. The regional data center would also receive data from the national data center about its region, developed by federal agencies such as NWS, NODC, and by other regional data centers. Finally, the regional data center would provide an electronic pathway for the distribution of coastal ocean prediction products and the associated raw data to users of the system.

The National Coastal Ocean Data Center would receive local data from each regional data center, from existing national data centers such as NDBC and COE, and from the National Weather Data Centers. These data would be preformatted into the standard COPS format as required and provided to the National Modeling Center. The National Modeling Center would perform large-scale calculations of coastal and near-coastal regions in real-time and transmit the results back to the National Coastal Ocean Data Center. These real-time predictions would be formatted in standard COPS format, and relevant portions of the large-scale forecasts would be provided to the Regional Ocean Data Centers to be used as boundary conditions for each of the regional models.

The long-term archiving responsibility for both observational data and model predictions would rest with the National Coastal Ocean Data Center. There the high-resolution regional model results would be combined with the large-scale results and, standard data products of non-real-time interest such as climatology would be prepared and archived.

For initial demonstration purposes, the organizational structure is such that a single regional complex could be established as a pilot feasibility study. In this case, the Regional Data Center would obtain data directly from the National Weather Centers, and the Regional Modeling Center would perform large-scale predictions as well as the regional predictions.

Data Structures

Management of real-time and forecast data sets across a broad range/ population of users will require a set of standard data structures for each report type. This standard structure must be flexible enough to support the insertion of information such as calibration or expected measurement error data, but must have sufficient rigidity in structure to allow machine readability of the encoded reports. The development and publication of standard reporting formats must be a primary task of a committee organized for that purpose. In addition to standards for reports, standards for the data center products, such as report collections, must be established.

Data Relay

The relay of raw sensor data from the observing site to the regional data center would use all available communication paths; however, the GOES Data Collection System (DCS) is likely to be heavily used because of the inherent economy of the system. We are concerned that the GOES DCS system may not have the necessary capacity to support this new requirement. Planning should begin now in government to assure the availability of adequate DCS capability to support this program.

Data Quality

To provide good model predictions, the initial environmental analysis must be as accurate as possible. This means that gross-error data quality control (QC) functions must be performed at the regional and national data centers in real-time. Additional near-real-time QC checks are needed for subsequent analyses, and non-real-time QC is needed for archive sets used for research purposes.

At present this type of QC is maintained by NDBC on approximately 150 marine platforms. NDBC develops and maintains software to process and QC the data processed at the National Weather Service Telecommunications Gateway (NWSTG) in Suitland,

MD, and which is disseminated in real-time. More stringent near-real-time QC is performed at NDBC to detect more subtle errors such as sensor drift. Algorithms flag suspicious data, and a man-machine mix using computer graphics is utilized to identify bad data. QC cannot be fully automated. Data biases are applied to data subsequently processed and disseminated at NWSTG. Bad data that cannot be corrected are withheld from release at NWSTG. Once a month, cleaned-up data sets of valid data are archived at NCDC and NODC. Approximately nine people are involved in the QC effort at NDBC. This effort is expensive, but considered vitally important in ensuring that only the best quality data are made available. At the present time, the world meteorological centers, such as the European Center for Medium Range Weather Forecasts and NMC, consider that bad data entered into the models are the biggest hindrance to improving forecasts.

Table 1

Measured Variables	Sensor	*Platform	COST $K
Level I			
Surface winds	Anemometer	F,R	3
Surface atmospheric pressure	Barometer	F,R	2
Single point current	Electromagnetic current meter	F,R,B	10
Current profile	Current meter string (5)	F,R	25
	Acoustic Doppler current profiler	R,B	75
Single point temperature	Thermistor	F,R,B	1
Temperature profile	Thermistor chain	F,R	5
Salinity profile	Conductivity chain	F,R,B	2
1-D wave spectra	Accelerometer	F	10
	Wave staff	R	10
	Pressure transducer	B	5
2-D wave spectra	Pitch/roll/heave (hippy)	F	15
	Pressure/current (Puv)	R,B	25
	Slope array	R,B	25
Surface elevation	Float/stilling-well	R	10
	Pressure transducer	R,B	5
Level II			
Relative humidity	Several under development	F,R	
Precipitation	Rain gage/acoustic sounder	F,R	
Visibility	Spectrometer	F,R	
Insolation	Photocell	F,R	
Wind profile	Doppler radar	F,R	
Dissolved oxygen	Pulsed electrode	F,R,B	
Fluorescence	Fluorometer	F,R,B	
Chlorophyll	Fluorometer	F,R,B	
Hydrocarbons	Fluorometer	F,R,B	
Suspended sediment	Transmissometer/optical backscatter	R,B	
Bed-load transport	Acoustic Doppler	B	
Light attenuation	Photocell	F,R	

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*F - floating (buoy); R - rigid (tower, jacket); B - bottom-mounted

DATA MANAGEMENT OVERVIEW
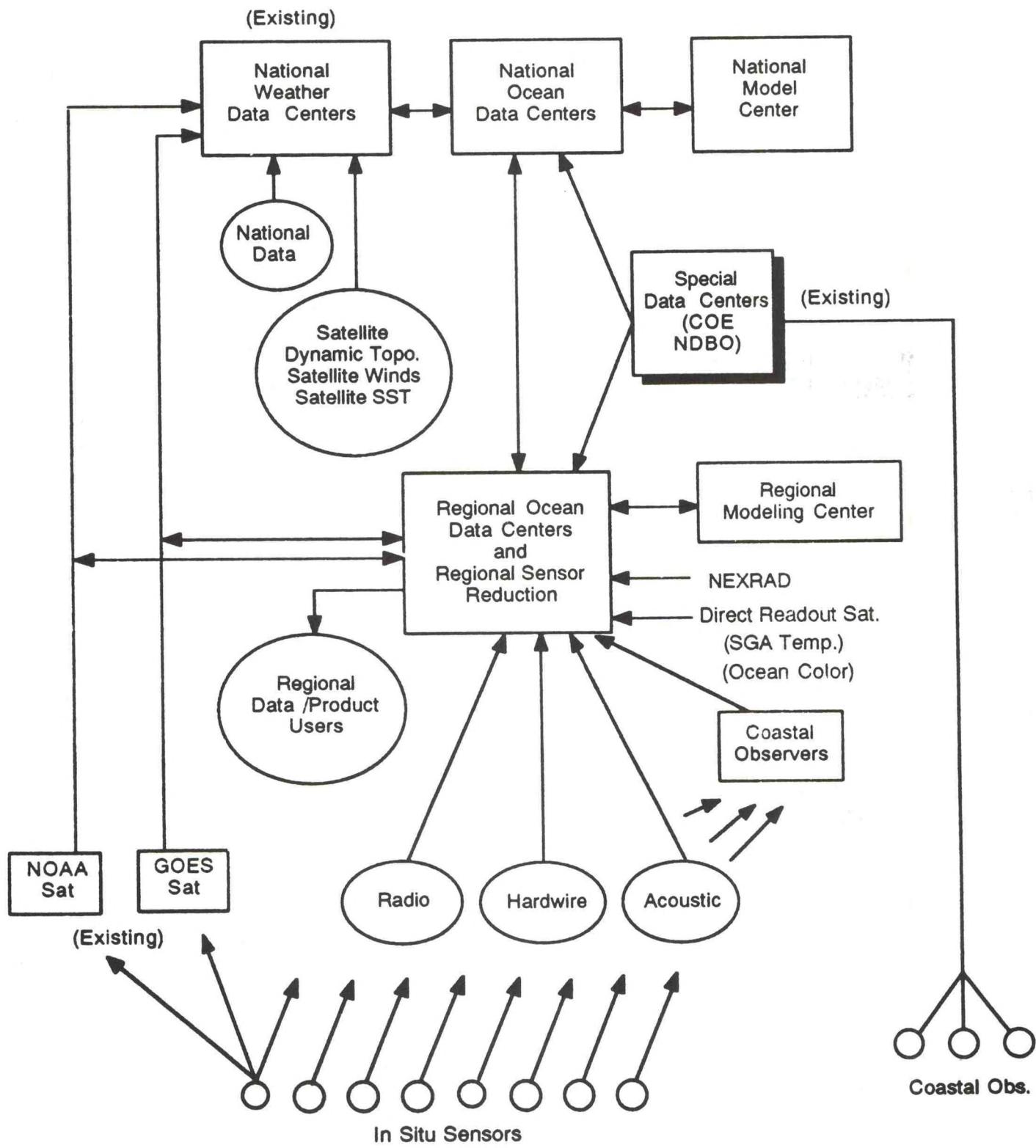

Figure 1.

WORKING GROUP III:

Implementation of a National
Coastal Ocean Prediction System Working Group

Chair: Larry Atkinson

Rapporteur: Van Waddell

Members: Larry Atkinson, Ledolph Baer, Bill Boicourt, Frank Eden, Glenn Flittner, Steve Hager, Walter Hanson, Tom Kinder, Richard Legeckis, Curt Mason, John Morrison, David Paskausky, John Paul, D.B. Rao, Eric Schneider, Ron Schlitz, Bill Schramm, Van Waddell

The Implementation Working Group's goals were to:

* Identify the infrastructural, sectorial roles, resource, and related aspects of a national effort to provide an operational COPS;

* Consider applications and motivations for such a system; management issues; regionalization; interagency sponsorship and overview; roles of public, private, and academic sectors; and

* Estimate infrastructural, personnel, and financial needs, and a nominal programmatic scenario.

Several Sample Questions Regarding National COPS Needs and Implementation

1. What are the current and future national needs for coastal ocean prediction? Who are the user groups -- industry, pollution management, maritime, recreation, fisheries management, coastal development, national security, scientific research? What prediction capabilities do they need?

2. What coastal ocean prediction systems exist at present? Which agencies are involved?

3. How might technical recommendations from other working groups be implemented? Regional vs. National? Roles of public, private, and academic sectors? What roles can state and local agencies play?

4. How can we take advantage of current agency programs to implement working group recommendations?

5. How can voids in the present national effort be filled? How can inter-agency interfaces be improved? How can effective "teamwork" between public, private, and academic sectors be engendered, enhanced, and maintained?

6. How can the coastal physical oceanographic community contribute to the scientific and practical goals of other disciplinary communities? How can the physical oceanographers take advantage of work in the other communities? How can the physical oceanographers join with other communities to address joint issues?

7. What resources are required to build and implement a national coastal ocean prediction system or systems?

8. What steps must be taken by the federal agencies in developing an operational COPS? How can the R & D community assist?

9. What follow-up is required after this workshop? Standing Committee? Writing assignments? Other specific actions?

10. What are logical steps in creating a national program for developing, evaluating and implementing a COPS of high scientific calibre and societal utility?

Overview

The coastal ocean is increasingly recognized as a regime with resources which are crucial to meeting societal needs. Due to expanding human impacts and to concern about the effects of global climate on the coastal ocean, a coordinated and coherent national effort is needed which will lead to science-based management and utilization of the coastal ocean by federal and other agencies. Prediction systems (i.e., numerical models and real-time observing systems) should play a key role in these management activities, scientific research, and other critical issues as they arise in the future.

Many requisite elements of such an undertaking already exist. For example, research investigators in and out of the government are engaged in scientific studies which support or lead to enhanced coastal ocean prediction. The private sector has significant technical capability and scientific management expertise in these areas

as well. Several federal agencies have complementary and shared responsibilities in coastal ocean prediction.

Expertise and basic technical capabilities for coastal ocean prediction are or will soon be sufficiently mature to consider implementation of a Coastal Ocean Prediction System. To move closer to realizing this goal of functional predictions of coastal ocean conditions, a multi-year, multi-disciplinary cooperative R&D effort with strong links to operational units is needed. The key role of a strong yet flexible management structure to foster integration among the participants in such an undertaking is apparent and recognized. There are examples of such structures that have proved successful in programs dealing with problems of similar complexity, for example, TOGA and JOIDES, as noted below.

The Tropical Ocean and Global Atmosphere program (TOGA), which is aimed at understanding and predicting interannual variability in the tropical Pacific, involves several agencies and the academic community in a major ten-year observation and modeling program. Now at its halfway mark, TOGA is providing the basis for operational prediction of environmental variability, including the El Nino and the Southern Oscillation. TOGA provides examples of successful coordination and advisory mechanisms that link the scientific community to federal management of a large program which is also multidisciplinary, relates focused research and improved operations, and integrates improved understanding, observing systems, and models.

The Joint Oceanographic Institutions Deep Earth Sampling (JOIDES) project has been effective for over two decades in planning, advising and coordinating the ocean drilling program and its predecessor programs. It involves several federal agencies, many academic institutions, several nations, and industry. JOIDES provides technical management and coordination to large scale, long term goal-oriented basic research.

As opportunities arise for transfer of technology from the R&D sector to operational entities, organizational elements must be identified that will address:

- Observing, acquiring, and exchanging environmental information needed by the forecasting community and other users;
- Employing and routinely operating those predictive models recommended by the scientific community for use; and
- Disseminating the information and predictions as a service to the public and private sectors.

Discussion

Mechanisms are needed for promoting and focusing initiative and innovation, for broad-based planning and coordination, for improving communications and visibility, and for establishing a professional consensus on many coastal ocean prediction issues such as:

- long-term research strategies and development;
- major scientific facilities;
- technical standards; and
- human resources.

Since the academic, private, and public sectors will have important roles in the development of a coastal ocean prediction system, mechanisms must be multi-institutional and multi-agency in scope. Such mechanisms will provide opportunities for the coastal ocean community to promote, develop, and establish a coastal physical oceanography capability with applications to operational users. These opportunities could range from graduate education to R&D to monitoring and would involve various partnerships. Overall, there is a serious need to transfer results obtained from research to modern operational monitoring, i.e., the combination of observing systems and numerical models.

Several scientific management issues should be considered. For example, regionally specific approaches may be needed within the context of a national program. Provisions are needed for coordinating with other disciplinary programs in coastal biogeochemistry, ocean engineering, and meteorology. In particular, COPS will need to draw upon fundamental understanding of the coastal ocean which is being developed in basic research efforts such as the NSF-sponsored Coastal Physical Oceanography (CoPO) initiative.

Recommendations

Several mechanisms can be established to foster innovation, initiative planning, coordination and communication in the development and implementation of coastal ocean prediction systems on a continuing basis. These mechanisms should address the following principal functions:

63

- Expand and enhance active interagency coordination at the federal level;
- Support a scientific steering committee drawn from the ranks of academia and private industry to further the planning process and encourage innovation;
- Foster active liaison between the federal and scientific communities, thereby ensuring and maintaining open lines of communication between them;
- Encourage participation of interested regional, state, and local entities, both public and private, in augmenting an observational network as well as utilizing the information products and services of the coastal ocean prediction system.

To promote and provide the best combination of coastal ocean prediction services that will meet anticipated national needs, the following issues should be addressed in future years:

- Directing research efforts toward meeting user requirements with particular focus on development of a coastal ocean prediction capability;
- Developing integrated (observational and modeling; multidisciplinary) programs for improved cost effectiveness;
- Suggesting additions or revisions to current and proposed programs in light of overall program activities; and
- Identifying structures, standards, and projects that promote continuity in development and coordination of interagency coastal oceanographic services, including plans, procedures, and operations and the requisite supporting research.

Summary

The societal needs and the scientific and technological prospects exist for the development of a COPS capability over the course of the next decade. Effective cooperation between the several federal agencies, and several levels of government, involved is essential. The needed cooperation extends to the academic and private sectors and across disciplines. It is time to proceed with the next level of scientific planning.

SUMMARY

The Workshop's major findings and recommendations are summarized below, as well as a revamped scientific strategy consisting of goal and objective statements plus a diagram of major program elements.

A. Findings

1. The feasibility of establishing a coastal ocean prediction system (COPS) was considered, and it was concluded that, for the first time, it is now possible to develop a useful coastal ocean prediction system, due to the advances in:

    - physical understanding
    - computer hardware and software
    - observational capabilities
    - numerical methods
    - model formulation
    - model evaluation
    - data assimilation schemes
    - ocean prediction community maturity

2. Several essential elements of a coastal ocean predictive system have been identified. A logical approach to an operational forecast system envisions two levels of observation:

    a. low-resolution, continuous observation (for the entire U.S. EEZ), and
    b. high-resolution, rapid-response observation (as needed for limited domains and durations)

and two (complementary) levels of models:

    a. low-resolution, large regional scale, and
    b. high-resolution, subregional scale.

65

In particular, a sparse, long-term, large-scale moored array is needed to develop a statistical coastal ocean climatology, as well as provide real-time information for prediction. It should be possible to augment the long-term array with limited-duration, dense arrays of moored, Lagrangian, and survey data to support the localized, short-term needs of search-and-rescue operations, oil spill trajectory predictions, fisheries operations, and other such operational activities.

3. The pathway to modern, efficient, and effective coastal ocean monitoring is through utilization of data-assimilative numerical models which make best use of real-time observations and statistical and dynamical models.

4. Several essential modeling activities have been identified. However, much R&D remains to be accomplished, particularly in the following areas:

- tests of sensitivity to BCs and ICs, numerics, and physical sophistication of parameterizations of subgrid scale processes
- critical processes; e.g., turbulent boundary layers and ice mechanics
- data-assimilation schemes, including type, quality, and quantity of data required
- model prediction of Lagrangian properties
- methods for incorporating realistic models of chemical, biological, and geological processes
- telemetering observing systems for chemical, biological, and geological fields
- innovative methods in airborne remote sensing

5. Prediction system performance must be evaluated quantitatively. It is important to compile existing data to facilitate prediction system development and evaluation.

6. Several vital aspects of the needed infrastructure have been identified. For example, an entire infrastructure for operational coastal ocean prediction remains to be created. Considering their complementary and overlapping roles, and the magnitude of the effort required and the value

to be achieved, agencies involved in the coastal ocean must join in a coordinated national effort. Partnerships are also needed between:

a.   federal, regional, state, and local agencies
b.   governmental, academic, and private sectors
c.   physical, chemical, biological, geological, and fisheries ocean science disciplines, and coastal meteorology
c.   coastal science and engineering.

B. Recommendations

Development Issues

1.   It would be beneficial to develop and evaluate simulation models together with prediction systems because the same type of effort is required.

2.   Complementary suites of physical and biological sensors should be developed and deployed on common elements in observing system networks.

3.   Physical coastal ocean modelers and observationalists should develop an outreach to the ecosystems, water quality, and sediment transport modelers to foster interfacing to their models and observations over a long period.

System Requirements

1.   A strategy of regionalization for coastal ocean prediction should be adopted in recognition of the nature and scale of many coastal ocean natural and societal phenomena. Of course, the regional systems must be under federal scrutiny and stewardship, as well as linked through various national centers. It is absolutely essential that such developments proceed only with high national standards and under national peer review.

2.   A network of national and regional data and modeling centers should be evolved.

67

3. The large-scale NDBC coastal meteorological buoy network should be enhanced, both quantitatively and qualitatively; and high priority should be given to augmenting the network with ocean sensors and cross-shore array elements.

4. The resolution and accuracy of coastal ocean atmospheric observations and models should be improved.

5. Satellite observations (IR, color, and SAR imagers plus altimetry and scatterometry) are needed on a continuing basis.

6. Regional, state, local, and private entities should be encouraged to participate in augmenting the coastal ocean observational network and utilizing its informational products.

7. The U.S. coastal ocean observing system should be linked into any prospective global-coastal network established for global change studies.

8. A coastal ocean climatology should be established; it should include current meter, sea level, etc. data as well as hydrographic data.

Essential Activities

1. An R&D effort should be established for the design of a real-time coastal ocean observing system network.

2. Real-time elements should be added to future shelf studies; e.g., the new MMS program called LATEX and the new EPA program called Massachusetts Bays Program, in order to facilitate the evolution of prototype operational data products and predictive models.

3. Real-time airborne observing systems for the coastal ocean, including remote sensors and deployable sensors--both biological and physical, should be vigorously utilized and further developed.

4. Observational and modeling studies should be planned and accomplished together to facilitate the development of predictive systems in particular, and to maximize synergistic benefits in general.

5. Field tests of candidate and alternative coastal ocean predictive systems should be carried out, and in a variety of settings.

6. Lagrangian drifters and Eulerian moorings should be deployed to develop regional-seasonal statistics.

7. Standards for data quality, database management, and data dissemination must be established at a high level by the community of coastal ocean scientists and engineers.

Needed Infrastructure

1. A national program for coastal ocean prediction should be modeled along the lines of TOGA and JOIDES, taking into account the multi-regional, multi-agency, multi-disciplinary nature of the topic area.

2. Possibly under the auspices of CES (Committee on Earth Sciences), NOAA should take the lead in developing a national program for coastal ocean prediction, allowing for the leadership roles of other agencies.

3. The academic scientific community should work with NOAA and other agencies to scope, and plan to meet, the human resource requirements for the coastal ocean prediction arena.

4. Active liaison should be fostered between the federal, academic, and research communities.

5. Support should be provided to a scientific steering committee drawn from the ranks of academia, with representation from federal institutions and private industry; this committee should be charged with developing a Science Plan for COPS and otherwise providing technical oversight to the COPS Program.

6. A partnership should be established between federal and other governmental levels, on the one hand, and the academic and private sectors, on the other, for the development of a national coastal ocean prediction system.

7. The present active interagency coordination at the federal level should be expanded and enhanced.

8. Infrastructural development for coastal ocean prediction should be promoted by all the partners, and through regular communication in professional society meetings and journals, and in periodic workshops.

9. Professional collaboration should be fostered between coastal ocean scientists and engineers.

C. Scientific Strategy

Scientific Goal

To develop and validate a predictive system for the U.S. coastal ocean, including the capability of forecasting the EEZ for several days and of simulating it for several years.

Scientific Objectives

1. To determine to what extent the coastal oceans are predictable on time scales of hours to days and to understand the processes that relate to this predictability.

2. To develop a set of efficient hindcast, nowcast, and forecast systems with observational network, dynamical model, and data assimilation components suitable for continual large scale regional use and with intensive, highly accurate subregional forecasts.

3. To couple the physical predictive system to biological, chemical, and geological components in order to advance interdisciplinary ocean science, to facilitate the management and utilization of coastal marine resources, and to enable simulations of the coastal ocean's response to various global change scenarios. The multidisciplinary coastal ocean prediction system should be structured so that it is available for the solution of real-time environmental problems, the study of ecosystem processes, and the management of coastal resources and environmental quality.

MAJOR PROGRAM ELEMENTS
FOR COPS

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┌─────────────────┐
│ Societal Needs and │
│    Scientific    │
│   Opportunities  │
└─────────────────┘
         ┊
┌─────────────────┐
│ Scientific Goal and │
│    Objectives    │
└─────────────────┘


                                                    ┌─────────────────┐
                                                    │ Basic Research  │
                                                    │ Programs; e.g., │
                                                    │ COOP, GLOBEC, ... │
                                                    └─────────────────┘

┌──────────┐  ┌──────────────┐  ┌──────────┐  ┌──────────────┐
│ Observing │  │ Data Management │  │          │  │              │
│  Systems  │  │      and      │  │ Modeling │  │ Process Studies │
│ and Networks │  │ Communication  │  │          │  │              │
└──────────┘  └──────────────┘  └──────────┘  └──────────────┘


                 ┌─────────────────┐
                 │     System      │
                 │  Development    │
                 │ and Validation  │
                 └─────────────────┘
                          ┊
                 ┌─────────────────┐
                 │   Operations    │
                 │      and        │
                 │  Applications   │
                 └─────────────────┘
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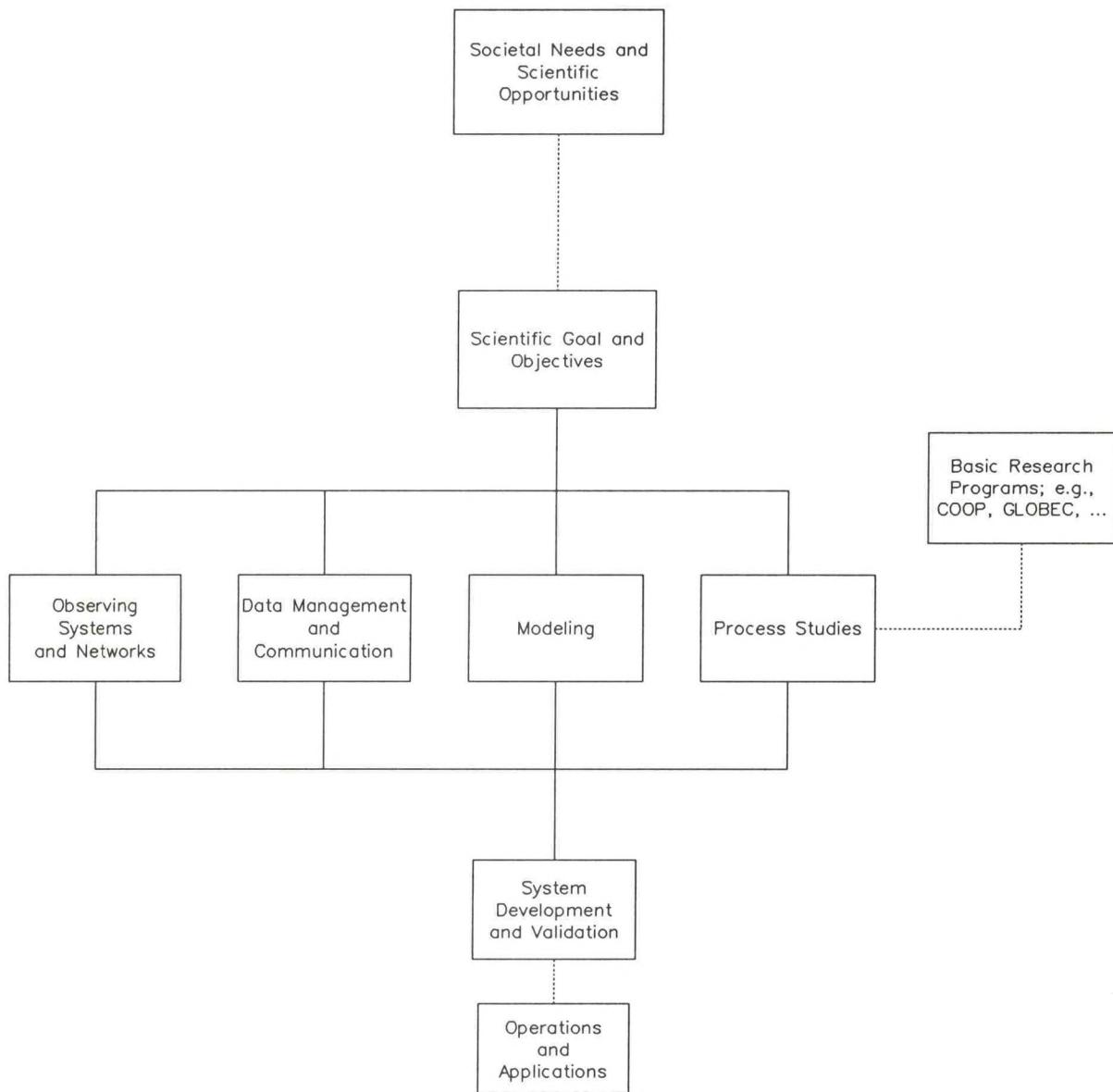
EPILOGUE

Background

Today the Nation's environmental managers make, and will continue to make in the foreseeable future, decisions impacting the coastal ocean environment and commerce without the information which could be made available to them, and which is necessary for higher quality decisions. Our information derives from data, models, and understanding. However, there will never be enough data or understanding; the models will never be perfect. Yet, the combined use of observations and models can greatly improve upon the present situation.

Based on the COPS Planning Workshop's recommendations, an operational coastal ocean prediction system will have two major components:

1.   a coarse-grid model and observing system which will be functioning continually throughout the U.S. coastal ocean; and
2.   a fine-grid, deployable model and observing system which will function when and where required.

Such a system will provide an optimal capability for coastal ocean technical management--one which is designed to meet societal needs, including monitoring, since it combines routinely available observations and numerical models through data assimilation. It, in turn, is combined with fine-resolution observations and numerical models which are specially deployed to address specific environmental events or issues.

The operational observing system, provided by NOAA, presently available in the coastal ocean consists of meteorological buoys (which report in real-time) for wind and SST data, coastal tide gages (the majority of which do not report in real-time) for sea level data, AVHRR images for SST maps, and real-time XBT and meteorological reports from the voluntary ship program, which is being extended to include coastal ships. The COE has a surface gravity wave (expanding) network on the nearshore of the continental shelf, which, in principle, could contribute to a national coastal ocean observing system. Other than a few qualitative SST analyses, there are no data products available on a regular basis for the coastal ocean, let alone ones which are based on the dynamical constraints that only a

numerical model can provide. (Full-resolution AVHRR-derived SST fields could be useful for the coastal ocean, but they are not broadly available on a regular, near-real-time basis.) Some numerical models are run for simulations or special operational/applications purposes; some are available to NOAA; others are available to other agencies; still others reside only in academia.

The *in situ* and remote sensing technologies and telecommunications systems for the observing systems needed are in hand or in sight. Similarly, the numerical modeling methodologies, and computational systems, are in hand or in sight for the needed predictive modeling systems. What is missing includes an expanded network of observations, consisting of those sensors that presently exist and those that observe additional ocean variables; e.g., bottom pressure; temperature, salinity, and currents in the water column; and particle drift and dispersal, -- across the coastal ocean. These should all report in real-time. The designs for the coarse and fine grids, and their observing systems, are yet to be determined.

Similarly, the predictive modeling systems need to be fostered through an extensive program of development, testing, and evaluation, both on a regional and a national basis.

To facilitate the design and development of both the observing and modeling systems, the existing data bases for the coastal ocean need to be organized in a convenient form. These data bases would also support the study of climatic variations in the coastal ocean.

The initial focus in COPS will be on physical observing and modeling systems for three reasons:

1. there is enough capability in the coastal physical oceanographic community to proceed soon;
2. there are numerous direct applications for predictions of the physical variability, physical transports, and physical forces; and
3. the physical predictive capability is needed to characterize physical transports which are essential to describing biogeochemical (NOTE: this term is used here to mean any chemical, biological, or geological quantity; e.g., nutrient, zooplankton biomass, or suspended sediment concentration.) variability and transports.

74

However, our colleagues in the other disciplines are making accelerated progress, in some cases, with developments of real-time observing systems and numerical models. Overall, the strategy to be pursued would foster the development, testing, and evaluation of biogeochemical observing systems and predictive models, side-by-side with their physical counterparts, as they become ready. Hence, it is now time to begin extensive multidisciplinary collaborations in the COPS arena.

Though relatively sparse, when data telemetry is implemented in regions of major field studies, there would be enough data available of various types in near-real-time to begin to organize and disseminate data products/displays on a regular basis. With the stimulus of feedback from contributors and users, the demand for, and capability of, these data products would expand. (In this arena of societal interfaces for COPS, the National Sea Grant and Coastal Zone Management programs may be helpful.) Such activity will help stimulate the evolution of the infrastructure needed to support an operational predictive modeling system. For example, so-called "management decision aids" can be anticipated as an applications requirement; some of these need to be of a real-time nature, others of a statistical character.

A central point here is that a national capability must be developed -- presumably one which is under NOAA's leadership. It is anticipated that mission-oriented, operational agencies; such as, EPA, MMS, COE, and USCG, as well as NOAA, will be playing major roles in implementing certain observing systems, developing special applications models, conducting certain field studies, and so forth. It is also anticipated that the goal-oriented R&D needed for creating a national capability will be underpinned by a robust basic research program led by NSF, ONR, DOE, USGS, and NASA. In many instances the goal-oriented R&D and the basic research programs can mutually beneficially utilize common assets; e.g., numerical models, observing systems, computers, telemetry systems, data bases, research vessels and aircraft and satellites.

NOAA and other federal agencies have a national responsibility in the coastal ocean; hence, they need a national capability. However, the scales of variability are so small in the coastal ocean that a single predictive modeling system for the Nation would demand excessive observational and computational resources. Moreover, the coastal circulation and marine ecosystems are regional in character; i.e., not all regional coastal ocean regimes are strongly coupled

to one another. Thus, together with the fact that each regional regime has unique features which must be either dealt with or exploited, there are compelling technical reasons for adopting a regional approach blended into a national panorama.

To carry out the national (and regional) program, the combined efforts and relative strengths of the academic, private, and public sectors will be needed. The attributes of each include:

public sector -	national interest
	operations
	continuity
	standardization
	objectivity
	oversight
	management of national assets
private sector -	technical innovation
	service
	development
	technology transfer
	responsiveness
	good technical and project management
	competitiveness
	adaptability
	timeliness
academic sector -	scientific innovation
	research
	scholarship
	peer review quality control
	human resource development
	flexibility
	long term commitment

It is important that all of the cooperating, participating federal agencies have readily recognizable leadership roles in COPS; for example, the following leadership roles are conceivable:

Agency	Leadership Role
NOAA* (operational monitoring-oriented)	• overall system development, integration, and operation • large-regional data base and model development and evaluation • ocean observing system network management • applications to fisheries oceanography management • applications to coastal ecosystem monitoring • operational oil spill trajectory models • circulation data and models • tidal data and models • ice data and models • gravity wave data and models • storm surge models • beach erosion models
MMS (EIS-oriented)	• large-regional data base and circulation model development and evaluation for long durations • Lagrangian data base and model development • applications to stochastic oil spill trajectory modeling for the purpose of oil spill risk assessment • applications to site-specific monitoring
EPA (response-oriented)	• development of biogeochemical instrumentation and observing systems • data base development through long time series of physical and biogeochemical variables • numerical simulations of the coastal ocean response to climate change scenarios • water quality models for applications to coastal ocean response to pollution • applications to coastal water quality monitoring

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* Implicit here is that NOAA serves to interface the civil community to the Navy's operational observational and modeling products.

COE (technical planning-oriented)	- nearshore observing systems and process models - sediment transport observing systems and models - gravity wave data - estuarine circulation and water quality models
USCG (operations-oriented)	- deployment of observing systems - operation of rapidly deployable observing systems - development and evaluation of high-resolution, limited-area models - ice observations

Recognizing that it is more difficult to delineate unique, individual roles in the basic research arena, an attempt is made, however, to characterize salient features:

<u>Agency</u>	<u>Leadership Role</u>
NSF	- basic process studies - marine ecosystem studies - model development - observing system development
ONR	- basic process studies - special regional studies - multidisciplinary studies - applications of acoustic methodology
DOE	- assessment of the transport and fate of energy-related materials - regional studies - multidisciplinary studies
USGS	- sediment transport studies - coastal erosion - historical record of sediment transport processes - indentification of sediment sinks
NASA	development and validation of remote sensing applications

Discussion

Given the main attributes of a coastal ocean prediction system, as described above, it is appropriate now to envision an operational system and the R&D program needed to achieve it. The operational system will have national and regional components. For the sake of discussion, let us adopt the goal of having functional a first-generation coastal ocean prediction system by 2001. (NOTE: in the interim, there will be benefits accrued to ocean monitoring as the system is developed, tested, and deployed. Also, simple models; e.g., the first order wave equation for coastally-trapped waves which can be used to estimate sea level and alongshore velocity variations given good wind estimates, could be used in early phases. Pre-existing numerical models with more complete dynamics can begin to be used and evaluated in a very preliminary fashion, too.) This system will be a fully functional physical observing and modeling system. Maps of currents, sea level, temperature, and salinity will be available at least daily at the surface and several subsurface levels throughout the EEZ plus major estuaries. It will be useful for near-real-time nowcasting, hindcasting, and short-range forecasting; it will also be useful for off-line simulations. There will be complementary biogeochemical observing system elements and water quality, marine ecosystem, and sediment transport model components running in a demonstration and evaluation mode; they will be a central part of the next generation operational prediction system to be on line in ca. 2005.

On the national scale, a real-time, coarse array will be deployed throughout the EEZ on a continuing basis. For the sake of discussion, consider that there will be ca. 30 cross-shore moored arrays, one every ca. 300 km alongshore over the ca. 10,000 km of U.S. coastal ocean. Assume each cross-shore array will have nearshore, mid-shelf, shelfbreak, continental slope, and deepwater elements. Altogether, there will be ca. 150 mooring stations where temperature, salinity, and horizontal velocity profiles, plus bottom pressure and sea level, are available continually, in addition to surface atmospheric observations. There will be four-times-daily satellite IR, OCI, and SAR images for all U.S. coastal regions. There will be weekly coverage of the coastal ocean by satellite altimeters and scatterometers. These systems will be supported by shorebased radars (e.g., CODAR and NEXRAD) for surface currents and winds, temperature, and humidity in the marine boundary layer. Unexpected developments in ocean acoustic remote sensing and drifting buoy technology may be playing a role, too.

The associated data streams will flow into national, operational computational/communications centers (NMC, OPC, COAP, etc.) for processing, quality control, and product preparation. These centers will be running data assimilative coastal ocean models which are provided with open boundary condition estimates derived from analyses performed with NOAA's global, marginally-eddy-resolving model and the operational data sets. The coastal ocean models run at the national centers will have ca. 10 km grids and cover the following large-regional domains: Atlantic Coast, Gulf Coast (actually, entire Gulf of Mexico), Pacific Coast, Alaskan Coast, and Hawaiian-plus-Oceania-Coast. They will be multi-level, primitive equation models capable of treating density stratification, the sea surface, bottom topography, atmospheric forcing, and tides. The output fields from the models of large-regional domains will be transferred to the regional centers, where they will be enhanced by regional data sets and provided to fine-resolution (ca. 1 km) regional models. The products from these regional centers can be expected to be useful for real-time environmental management.

It is assumed that the Navy, through FNOC and NAVOCEANO, will continue to have access to, and control of, the most comprehensive oceanic data sets, especially ships-of-opportunity and classified data. Hence, it will remain important for NOAA to maintain close liaison with operational Naval Oceanography Command activities. COAP is in an ideal position to provide such liaison; it has a major role to play in organizing, analyzing, and adapting Navy data sets and model products, and in providing them to other NOAA national centers and the regional centers.

For the sake of discussion, assume the organizational structure described below. There will be about 10 regional centers, plus about 20 to 30 subregional centers. In contrast to the national centers, which will be presumably in-house federal (NOAA) entities, the regional centers could be GOCO (government-owned, contractor-operated) entities. The regional centers will be coupled to other national centers by high-speed data links*, have their own computational

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*NOAA's emerging National Ocean Communication Network (NOCN) is a candidate, if it has sufficient data rate capacity, can be used in a two-way mode, and can meet the needs of researchers and other agencies.

resources for regional models and data sets, and may serve as the data centers for the permanent and deployable regional observing systems. They will also operate and manage the deployable, fine-resolution observing systems in collaboration with federal agencies. Consortia of regional institutions (state and local governments and academic institutions) will manage the regional centers, which will be operated by contractors. These consortia will, among other things, help ensure that regional priorities for coastal ocean management are addressed. Federal agencies will provide management oversight on a national scale to the regional centers, and they will participate as users and supporters of the centers. The regional centers will be operated under contract to the federal government, possibly in association with state governments or regional governmental entities. (Under federal management, elements of the national observing system, as well as the regional observing system, may be developed and operated under contract, too.)

To create the system described above, an R&D program is needed for the development and operation of the:

1. large-regional models
2. smaller-regional models
3. permanent, moored arrays
4. deployable arrays of moorings and drifters
5. Lagrangian data base
6. airborne remote sensing systems
7. data management and communications center(s) (COAP, OPC)
8. test and evaluation program.

It is assumed that NOAA will establish a global (or at least North Atlantic and North Pacific) operational analysis model(s) which can provide some of the needed open boundary conditions for the large-regional models.

It is also assumed that NOAA will provide coastal meteorological models with the greatly enhanced spatial resolution needed for coastal ocean prediction.

The development of large-regional models and several of the smaller-regional models should be undertaken as soon as possible, while the observing systems are being enhanced and expanded. A program of field testing and evaluation of alternative research predictive systems should be undertaken within two years.

With ten-years' lead time, it will be possible to establish the needed infrastructure, educate and train the needed human resources, and garner the needed financial resources. As the observing and modeling systems are gradually deployed and tested, there will be benefits even before the full system is in place.

It is essential that the COPS program begin immediately to organize on a regional basis, putting together investigations on both the large and small regional predictive systems tasks. There will be a significant amount of cross-cutting on a national scale, with "common denominator" items and activities clearly delineated.

The most challenging aspects of this program will involve managing the technology transfer in a fully credible and professional fashion. For example, a well-conceived test and evaluation program aimed at evaluating alternative approaches is essential for making system-selection decisions. In other words, "third-party," open evaluation mechanisms will be needed at critical junctures. As another example, it is essential to minimize the number of links (or "handoffs") in the transition process. Hence, researchers, developers, and operators/applications people should work in a well-phased, overlapping fashion for considerable periods of time - preferably, for the duration of the R&D program.

For the overall technical management and oversight of a program as complex and important as COPS, it is necessary to have an advisory and steering committee apparatus similar to that used by TOGA or JOIDES.

Recommendation

A goal-oriented R&D program is needed to develop, test, evaluate, and implement a coastal ocean prediction system. To have an initial system in place by 2001, a system development schedule of the following nature would be appropriate:

'90/'91 Program planning
* multidisciplinary workshop
* science plan retreat
System design
Infrastructure development

'92/'94 Enhanced and expanded -
* observing systems
* modeling systems
* data bases
* data products
* coastal ocean climatology

'95/'97 Demonstrate and evaluate a prototype system
Analyze user feedback
Refine environmental managers' requirements

'96/'98 Systems design and procurement

'99/'00 System implementation and evaluation
Commence development of second-generation system

Of course, this process is more continuous than the above programmatic time-horizons might suggest. For example, an active research program is needed on a continuing basis, while there would be operational benefits from even early efforts to expand and enhance the present observing system and data products.

APPENDIX A

COPS PLANNING WORKSHOP AGENDA

31 October to 2 November 1989
University of New Orleans (UNO)
(Agenda As Realized)

DAY ONE

0800 - Registration

0830 - Welcoming Remarks — UNO Chancellor Gregory O'Brien

0835 - Introductory Remarks — JOI Representative Frank Eden

0840 - Opening Remarks: — Convenor Christopher N.K. Mooers
    1. Discussion of the Objectives
       & Organization of the Workshop
    2. Review of Agenda

OVERVIEW TALKS I — Chair: Warren B. White

0855 - NRC Report on Marine Forecasting — Kenneth Ruggles

0910 - Agency Missions/Needs/Programs — William C. Boicourt

1010 - Coffee

1030 - Operational & Applications Models — Christopher N.K. Mooers

1120 - Research Models — John S. Allen

1220 - Lunch

OVERVIEW TALKS II — Chair: George L. Mellor

1320 - Operational Observing & Data Systems
    (archival) — James H. Herring
    (real-time) — Henry Frey

1420 - Research Observing & Data Systems — Wendell S. Brown

1520 - Coffee

1540 - Oceanic & Atmospheric Data Assimilation — Dale B. Haidvogel

1640 - Coastal Physical Processes:
    Areas of Understanding & Ignorance — Gabriel T. Csanady
    vis-a-vis COPS Goal

1740 - Closing Remarks for the Day — Christopher N.K. Mooers

1800 - Recess/Social Hour

1900 - Adjourn to Patou's Restaurant

1930 - Dinner

2030 - Remarks by the NOAA Administrator and — John A. Knauss
    the MMS Deputy Director — Ed Cassidy

DAY TWO

0830 - Working Group (WG) Discussions

1000 - Coffee

1030 - WG Discussions

1200 - Lunch
(WG Chairs & Rapporteurs Converse with Steering Group (SG))

1330 - WG Discussions

1530 - Coffee

1600 - Plenary
(WGs Progress Reports)

1730 - Recess/Social Hour (WG Chairs & Rapporteurs Caucus with SG)

DAY THREE

0830 - WG Discussions

1000 - Coffee

1030 - WG Writing Session

1200 - Lunch (WG Chairs & Rapporteurs Converse with SG)

1330 - WGs Final Revision Session
SG Preparations for Final Plenary Session

1430 - Plenary
1. WGs: Report Revisions
2. SG: Conclusions & Recommendations

1600 - Adjourn

APPENDIX B
ORGANIZING COMMITTEE

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Ken Brink, WHOI

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APPENDIX C

COASTAL OCEAN PREDICTION SYSTEMS WORKSHOP
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Duration: ca. 6 to 12 mos.

99

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APPENDIX F

Remarks by
The Under Secretary of Commerce for Oceans and Atmosphere
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John A. Knauss

At The Dinner During the Meeting Of
Coastal Ocean Prediction Systems (COPS)
New Orleans, LA
October 31, 1989

The first order of business for me tonight is to thank Chris Mooers for calling this meeting. It is not clear to me, as I suspect it is not clear to many of you, that we have the proper tools to begin a significant assault on the very difficult problems of coastal ocean predictions. But I do believe it is high time that we take a serious look at this issue. And I expect that this workshop will do that very thing.

Most of us are environmental scientists of one kind or another and these certainly are exciting times to be an environmental scientist. The environment has reached center stage in the view of both the public and our political leaders. One measure of that fact is the communique that came out of the economic summit in Paris this past July. Fully one-third of that communique addressed environmental issues. The year before, the environment received one paragraph.

I'm actually on my way to the Netherlands this week to take part in a ministerial conference called to look at what national responses should be to changes in our global environment that have been caused by greenhouse gases. The issue in the United States delegation, in preparing for this conference, has not been whether to be concerned about such anthropogenically driven changes in our environment, but rather the degree of that concern.

For those of you who are a part of NOAA and for those who have been NOAA watchers of long standing, I am pleased to report that our Secretary of Commerce, Bob Mosbacher, is a confirmed environmentalist. When he first interviewed me and was trying to decide whether he wanted me to be the Administrator of NOAA (and as I was trying to decide whether I was interested in the job) his main concern was the coastal ocean and coastal ocean pollution. I believe I can assure you that NOAA is appreciated within the Department of Commerce and within the Administration, although I guess I'll have a better sense of that when I know a little better what next year's budget will be. [Editor's note: Since these remarks were delivered, the NOAA budget has been proposed. It includes an increase overall of some 35% and a 54% increase for coastal ocean programs.]

NOAA is no longer on the sidelines. I know you are going to hear tomorrow from Joe Huang, Curt Mason, and Glenn Flittner about aspects of NOAA's interest in the topics of this workshop.

There is renewed interest in monitoring the ocean, understanding the ocean, and forecasting the ocean and ocean circulation on a number of scales. Much of it, of course, is related to our weather. Like all of you, I know that the ocean and the atmosphere are part of a single complex system. We have long known that in the abstract, but I must confess I have sometimes wondered whether I would live long enough to see us sufficiently understand those interactions so that we could, in any useful way, project changes in our atmospheric patterns that are driven by changes in the ocean.

But our understanding of at least one component of this system has increased dramatically in recent years as we have learned more about the so-called Southern Oscillation in the tropical Pacific and its role in establishing El Nino conditions along the west coast of North and South America. And there is hope that our ability to predict ocean circulation changes will continue to increase. The Harvard group, under Allan Robinson, is attacking that very difficult task of attempting to understand the meandering pattern of the Gulf Stream, the spin-off of Gulf Stream rings, and ring-Gulf Stream interactions.

Those concerned about global change are finding that the ocean plays a very critical role in determining what the long-term atmospheric changes will be. There is considerable uncertainty in models at present. One can get estimates of

greenhouse gases causing an average temperature change world-wide of anywhere from about one to five degrees Celsius. If the change is only going to be one degree, we can probably grit our teeth and live with it. But if is going to be five degrees, perhaps we should be immediately declaring a state of emergency as we prepare for extraordinary changes in our environment and in our life styles.

Clouds may play the most important role in this uncertainty at present. But ocean circulation must be a close second, and the ocean circulation and the heat exchange are critically important in determining the distribution of these temperature changes on the earth. This phenomenon may best be seen by comparing two of the better models.

A United Kingdom model shows that the temperature rise is relatively small in the tropics and then increases poleward. But the increase is more or less symmetrical around the equator. The ocean in this model is very primitive--the ocean boundary condition is not much more than a heat sponge.

The other model is a recent one by Suko Manabe and his colleagues at NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), who have coupled their atmospheric model to a three-dimensional ocean model. It may not seem like a very realistic ocean to those of us who are oceanographers, but it is certainly a lot more realistic than anything done before. What this model shows is that, again, there is relatively little heating in the tropics; the heating increases as one goes poleward, but--and this is the key--essentially all of the atmospheric heating takes place in the Northern Hemisphere. The Antarctic Circumpolar Current essentially absorbs all the heat in the Southern Hemisphere.

You are here this week not to think about the global ocean but rather to think about the coastal ocean--how well we understand it and how well we can predict it. Coastal oceanography has a long and honorable tradition. One could make a case that modern physical oceanography began, as coastal oceanography began, with the International Council for the Exploration of the Sea (ICES), whose original efforts were concentrated on the hydrography of the North Sea.

There is a perhaps cautionary tale for those of you who are about to develop an onslaught on the coastal ocean. I had an opportunity two years ago to spend some time as an amateur historian of marine policy, looking at how marine

fisheries policy developed during its period of explosive growth a century ago. In the process I learned a bit about the early days of ICES.

Although Great Britain had by far the biggest fisheries in the North Sea, ICES was essentially a Scandinavian idea. Its originator was Otto Petterson, who proposed the program at the International Geographical Congress back in 1895. His goal was to attempt to explain the fluctuations in the large fisheries--the herring fishery and the cod fishery, for example--by relating them to changes in the circulation patterns in the North Sea. ICES studied the life histories of these fish and their environmental requirements and related those requirements to the ever-changing physical and chemical environment of the North Sea. That was an honorable pursuit, and it has been the goal of a number of fisheries programs ever since, including the California Cooperative Fisheries Investigation (CalCOFI), which celebrated its 40th birthday this past week.

ICES was a great success right from the beginning but, and this is the point I want to emphasize, not in its original mission. In retrospect its greatest success in its first few years was establishing the standards of modern physical oceanography. It succeeded through a short-lived International Hydrographic Bureau in Oslo, under the leadership of Fridjof Nansen, that remarkable explorer, scientist and statesman. It was there that Knudsen invented "standard sea water" which allowed technicians to measure salinity to five significant places in their cramped laboratories and small research vessels. It improved on the development of deep-sea reversing thermometers so that they could be trusted to give accurate readings of temperatures at depth to a few hundredths of a degree.

It was through the Hydrographic Bureau that Eckman developed his equation of state of sea water which allowed determination of density of sea water to a few parts in a million if one knew the temperature, the salinity and the depth at which the water was taken; and which, in turn, of course, made possible the calculation of geostrophic currents. And of course there was the Nansen bottle, which allowed not only the capture of uncontaminated water at depth but also the ability to string a dozen or more such bottles on a wire at one time and thus collect many samples almost simultaneously.

All of this was developed by ICES in its first few years, mostly before 1910. These were still the techniques of physical oceanography when I began after World War II, and they continued to be the techniques of physical

oceanographers up until the last 25 years, when replaced by Niskin bottles, the salinometer, CTDs and, most recently, slight changes in Eckman's equation of state.

ICES had much less success in its original goal of relating the physical environment to the abundance and distribution of fisheries, however. Although originally proposed in 1895, the multinational organization did not really begin its work until 1904, and at that time it was conceived as a five-year experiment. In 1909, at the end of its first five years, when its original budget was up for renewal and many, including the fishing industry in Great Britain, were questioning the success of its original goal of relating fisheries to the environment, Johan Hjort wrote, "We hope consequently that the results now obtained will facilitate to a substantial extent further investigation in this difficult but yet so important appeal of inquiry."

Although written 80 years ago, those words have a familiar ring to those of us (and I expect there are few in this room besides Allan Robinson and myself) who at one time or another have had a large experiment not quite live up to our hopes. Many of us have had to go, hat in hand, to the National Science Foundation or the Office of Naval Research or to our Director to admit that we might have been a bit optimistic in our original proposal, but assert that we are getting close and please don't cut off our funding now.

But the problem of relating fisheries to hydrography was and is an extraordinarily difficult one. Listen to one of the best fisheries biologists of the last generation, Michael Graham, writing in his excellent book *Sea Fisheries* almost 50 years after Hjort: "Future editions of this book would certainly include more on the relations between fisheries and hydrographic conditions. But at the present time they are imperfectly understood."

We are now, finally, almost a century after Otto Petterson's original ideas, beginning truly to understand the relationship between fisheries and hydrography. But it continues to be an extraordinarily difficult challenge, and there is still much we have to learn. I do not expect any rapid breakthroughs in our ability to forecast changes in the coastal oceans either. But I do expect, or at least hope, that the goals of this workshop will be somewhat easier to realize than the goals of ICES.

At the very least, it is time for all of us to think hard about the issues, and it might well be time to get started. We may now have sufficient computer power. We probably can develop the necessary observing system, if there is strong enough economic reason to do so. We think we understand enough of the physics. It may indeed be a time to begin a fundamental assault on this issue. The economic importance of the coastal ocean is certainly sufficient, and we should at least give it serious consideration.

But if we are to attack this problem, let us be sure we do it right. Let's attack the fundamental issues. If, God forbid, it takes us 60 years to begin to make real progress toward our original goal, let's at least be sure we learn something important about how the ocean works during the interim. Let us leave a proud scientific legacy behind, even if the problem is not the one we originally attempted to solve.

I am looking forward to reviewing the results of your deliberations. Thank you for inviting me to be with you this evening.

APPENDIX G

Remarks by
The Deputy Director
of the Minerals Management Service

Edward Cassidy

At The Dinner During the Meeting Of
Coastal Ocean Prediction Systems (COPS)
New Orleans, LA
October 31, 1989

It's a pleasure to be here with all of you tonight, and with Secretary Knauss, Dr. Mooers, and Bob LaBelle, chief of our Branch of Environmental Modeling. Not only have you assembled an unusually distinguished group of attendees for this workshop, but I have to commend you on your choice of location and especially this date! Call it the "Luck of the Irish," but this is the third year in a row that I've managed to get scheduled out of town on Halloween.

Actually, I wanted very much to join you tonight, for the best of all reasons: because your subject is critically important to the nation, and because the group you have gathered together for this conference is uniquely qualified to help chart the right course in this important area.

From a purely "selfish" standpoint, I should acknowledge up front that your success at establishing a COPS system can also have profoundly positive consequences for MMS. I'll have more to say about that in a moment, but first, let me outline briefly the Minerals Management Service--who we are, and what we do.

We are one of nine bureaus at the Department of Interior, less well-known than most of the others (such as the National Park Service, the Bureau of Land Management, and the Bureau of Indian Affairs, for example), and smaller than

most. We have about 2,000 employees, and two primary missions. First of all, we run the nation's offshore oil and gas program on the outer continental shelf (OCS); and, in addition, we collect (through our Royalty Management Program) all royalties due on coal, oil and gas, and other minerals taken from federal lands onshore as well as offshore.

The Minerals Management Service contributes much to the nation. Roughly an eighth of our oil and a quarter of our natural gas are produced on the OCS; and, in terms of proven reserves, experts estimate that fully one-third of our remaining oil and gas in this country is located offshore. From a revenue standpoint, we deposit roughly $4 billion into the U.S. Treasury each year, ranking MMS behind only the Internal Revenue Service and the Customs Service in that category. All told, OCS operations have generated nearly $90 billion to the Treasury since leasing and drilling began on the Outer Continental Shelf.

Our offshore program is operated through four regional offices that serve the Atlantic, the Pacific, the Gulf of Mexico, and Alaska, and the nature of our operations differs greatly from region to region. In Alaska, some very challenging and exciting exploration is underway, but as yet, no production has taken place. Off California, we have production from more than 20 platforms, but exploration activity is down for a number of reasons. In the Atlantic, we have neither exploration nor production at this point, but we're hopeful that before too much longer, we'll be in a position to approve or deny an exploration permit to Mobil for an exploratory well in 3,000 feet of water off Cape Hatteras in North Carolina. Here in the Gulf is where the lion's share of the action is on the OCS: lease sales are being held; drilling is taking place; industry is moving into ever deeper water; some 3,800 production platforms are operating; and the industry is so mature that MMS is being called upon to deal with questions of well abandonment and rig removal as leases reach the end of their productive lives.

However, all is not well on the outer continental shelf from a political standpoint. As most of you know, in recent years we have been faced with increasingly restrictive congressional moratoria on every significant portion of the OCS except the central and western Gulf of Mexico.

The single most significant factor driving the limitations on our OCS program is public concern about the potential impact on the environment of offshore drilling. And while environmental concerns associated with offshore operations fall into several categories, clearly the most powerful tool in the hands of our critics is public concern about oil spills.

That's where COPS comes in--and, from our perspective, not a moment too soon. You see, while it's true we were fighting congressional moratoria before the tanker spill in Prince William Sound, now we're in danger of being completely overwhelmed by them thanks to the Exxon Valdez.

All of us here tonight, I suspect, understand very well the significant differences between the oil spill risks associated with tanker traffic and those associated with offshore operations. But the public doesn't.

And most of us also have a pretty good feel for the actual spill record on the OCS. According to the National Academy of Sciences, 45 percent of the oil introduced into the world's oceans comes from tankers; while only 2 percent results from OCS operations. Moreover, there has never been an oil spill resulting from the blowout of an exploratory well on the OCS. In fact, seven of the eight largest spills in U.S. history (those over 100,000 barrels) were from tankers; and the single OCS spill in that group occurred in 1967, was the result of a pipeline rupture, and happened before many of today's stringent safety regulations were in place. Finally, of the ten largest spills on the OCS during the past twenty years, none is known to have reached shore or to have caused significant environmental damage.

But the public doesn't know any of that.

In addition, the public doesn't--for the most part--understand the significant advantages those responsible for anticipating and responding to oil spills on the OCS have over those called on to deal with tanker spills. For example, all our OCS drilling and production facilities are in known, fixed positions, for which likely spill trajectories have been plotted; that's not the case with tankers, which are in constant motion along infinitely variable paths. Each of those locations has a pre-approved contingency plan for responding to possible oil spills. In addition, many OCS wells produce natural gas, which doesn't spill; and many OCS oil wells require artificial

109

lift just to get any oil to the surface, making it possible to shut off the flow of oil on a moment's notice in the event of a spill.

Therefore, given these factors and considering the much smaller volumes of oil likely to spill from an OCS facility than from a tanker, I think you can see why we believe that critics of the OCS program are shooting at the wrong target. In a very real sense, their efforts will ultimately prove counterproductive. After all, every barrel of oil we don't produce on the OCS is a barrel we'll have to import by tanker from overseas--at far greater risk to our sensitive coastal areas.

And make no mistake about it, the owners of the tankers are licking their chops at the prospect of ever more restrictive OCS moratoria. Just this week, the *Oil and Gas Journal* reported, "The London tanker market is buzzing with talk of a substantial tanker building program by Kuwait Oil Tanker Company that would continue the miniboom in new buildings seen in the first half of this year."

At MMS, we recognize that we'll have to do more than point out these kinds of facts if we're going to reverse our fortunes. President Bush and Secretary Lujan have made clear their personal commitments not to permit the drilling of any well offshore of our coastal states unless and until we determine we can do so in an environmentally responsible fashion.

At MMS, we're very proud of our record; we're proud of our people; and we're proud of our programs. We have an inspection and enforcement program that is stringent and getting more so. We have an environmental studies program of which we are exceptionally proud. The results of our environmental studies are essential to our decision-making process; and at the heart of our environmental studies program is our physical observations and modeling effort. Of the $500 million we have spent on environmental studies, more than $100 million has been spent in this area.

Of late, I've been deeply involved in negotiations between Mobil and the State of North Carolina, and one of the most contentious issues has been physical oceanography. That's why Bob LaBelle has heard me say more than once that we could have used COPS years ago!

All of you are the reason why COPS is moving ahead and showing real promise. This group is an excellent example of the kind of federal-state and federal-interagency partnerships that are so often necessary for projects of this type to succeed. For those of us at MMS who are absolutely convinced of the need for the kind of capability that would be embodied in COPS, this workshop is a very positive sign.

We're convinced that no single agency could, or should be expected to, develop a COPS system alone. We have worked with most, if not all of you, in the past. The nation has benefitted from those partnerships; and we're confident that the nation will benefit again from the type of joint effort you've come together to discuss today and tomorrow.

We thank you all for coming. We encourage you to continue working creatively and cooperatively to add to our knowledge and understanding of the ocean and its currents. And we pledge our full support and participation wherever possible in developing an effective COPS system.

Finally, we look forward to meeting here again next year; let's make it the same time and same place!

APPENDIX H

REGIONAL DATA SETS WHICH FACILITATE
OCEAN MODELING RESEARCH

Gulf of Maine:

Various Canadian and U.S. hydrographic and current meter studies; mainly single-investigator efforts except

1. MMS/Raytheon study of Georges Bank in late '70s
2. NSF/WHOI New England shelf study at Nantucket Shoals
3. MMS/MASAR experiment

Middle Atlantic Bight:

1. NOAA NY Bight Study of mid '70s with hydrography and current meter arrays
2. DOE/SEEP experiment on shelfbreak exchange in mid-to-late '80s with hydrography and current meter arrays

South Atlantic Bight:

1. DOE/MMS/ONR/NSF studies of shelf and Gulf Stream circulation and interaction
2. GABEX was most complete current meter array
3. MMS/Blake Plateau experiment

Florida Straits:

1. NOAA/STACS Program in '80s study of seasonal and interannual variability with comprehensive current measurements
2. Various shelf studies with current meter arrays and hydrographic transects

West Florida Shelf:

1.   NSF current meter arrays and hydrographic transects in early '70s centered at 26N

2.   MMS Gulf of Mexico physical oceanography field experiments, SAIC, 1983-1985

Northern Gulf Shelf:

1.   NSF Texas shelf--various hydrographic and current meter studies

2.   MMS/LATEX program planned for Louisiana and east Texas shelves

Southern California Bight:

1.   DOE/California Basins Study (CABS) off Los Angeles with comprehensive multidisciplinary stations and current meter arrays--ongoing

2.   MMS/Santa Barbara Channel with Dynalysis and SAIC/first coordinated modeling and current meter mooring and hydrographic program in early '80s

California Shelf:

1.   MMS/Raytheon/Central California Coastal Circulation Study--current meters, drifters, hydrography, AVHRR, etc., in mid '80s

2.   MMS/EG&G and Scripps/Northern California Coastal Circulation Study--current meters, drifters, hydrography, AVHRR, etc., in late '80s

3.   NSF/CODE study off northern California in early '80s with comprehensive current meters, drifters, and hydrography

4.   ONR/OPTOMA study off northern California in mid '80s with dense XBT and CTD grids

5.   ONR and NSF/CTZ study off northern California in late '80s with specialized, multidisciplinary data sets

6.   CalCOFI hydrographic data sets have been acquired offshore since the '50s

Oregon and Washington Shelves:

1. NSF/CUEA studies in early '70s off Oregon with current meter arrays, hydrography, nutrients, and biology
2. DOE/multidisciplinary studies off Washington in late '70s and early '80s

Alaskan Shelf:

1. MMS/NOAA/Gulf of Alaska studies in '70s
2. NSF/Alaskan Coastal Current studies
3. NOAA/FOCI multidisciplinary fisheries/oceanography studies-- ongoing
4. MMS/NOAA studies in the Bering Sea
5. NSF/PROBES in the Bering Sea
6. NSF/ISHTAR in the Bering/Chukchi Seas
7. MMS/NOAA studies in the Chukchi/Beaufort Seas

APPENDIX I

REGIONAL COASTAL OCEAN GROUPS

Several regional groups exist which foster scientific communications and coordination regarding the coastal ocean. They are generally informal and meet annually, and have 50 to 100 attendees. Several are listed below as examples:

- EPOC, Eastern Pacific Oceanic Conference formed about 35 years ago

- MABPOM, Middle Atlantic Bight Physical Oceanography and Meteorology formed about 17 years ago

- Gulf of Maine Conferences, held biennially in late '70s and early '80s; may resume

- Friends of the Gulf of Mexico, has begun to emerge in the past few years

These regional groups are entities which can be used for fostering the development of the COPS program. They are especially useful for focusing regional scientific issues and bringing forth regional data sets.

ACKNOWLEDGEMENTS

Front Cover
(clockwise)

Biological Productivity in Gulf of Mexico (from Nimbus-7) - Courtesy of NASA
Fish Harvest - Courtesy of NOAA
Deploying Data Buoy - Courtesy of MMS
Offshore Oil Platform - Courtesy of MMS

Back Cover

U.S. Exclusive Economic Zone (illustration) - Courtesy of DOS

ARCTIC
OCEAN

ALASKA

Aleutian Islands

Bering
Sea

60

180

150

Midway
Islands

NORTH PACIFIC OCEAN

120

UNITED
STATES

90

30

HAWAII

Puerto Rico and
the Virgin Islands

Caribbean
Sea

0

ALASKA

Bering
Sea

Aleutian Islands

60

UNITED
STATES

30

Midway
Islands

Northern
Mariana Islands

HAWAII

120

Guam

Wake
Island

Johnston
Atoll

Kingman Reef and
Palmyra Atoll

150

NORTH PACIFIC OCEAN

180

150

0

Howland
and
Baker
Islands

Jarvis
Island

SOUTH PACIFIC OCEAN

American
Samoa