U.S.DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

A STRATEGIC PLAN FOR A COASTAL FORECAST SYSTEM

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PREFACE

The few-hundred-mile-wide zone that contains coastal watersheds, bays, estuaries, and coastal oceans of the United States is one of the most important socioeconomic features of our Nation. This narrow coastal strip contains

- nearly half our population,
- many large urban areas,
- critical transportation hubs that link our Nation's commerce with the outside world,
- food harvests that rival those of the Nation's "breadbasket,"
- recreation for millions of people, and
- marine sanctuaries and protected species.

This concentration of people, resources, and commerce, combined with the special character of a land-water-air interface, presents a challenging set of environmental issues. The health and well-being of the human and living marine resources depend critically on their interaction with, and the quality of, the natural and anthropogenically perturbed environment. Our first line of defense against potential environmental calamities is our knowledge and understanding of the biogeochemical and physical processes and their interactions. Armed with this knowledge, we can better monitor our coastal regions and improve our ability to predict events in time to take preventive actions.

The few examples that follow demonstrate some of the current economic and societal reasons for having this coastal monitoring and prediction capability:

- Fish stock management is handicapped by lack of resolution in stock assessment. We need better measurement, assessment, and prediction of the size and condition of a given population and the likely impact of natural and anthropogenic fluctuations in the environment of the stocks.

- Large coastal populations are unnecessarily evacuated or alarmed because of the difficulty associated with predicting the land-fall location and intensity of hurricanes.

- Transportation and commerce are disrupted because we cannot predict accurately the location and severity of coastal storms and fog, the sea state, and the onset or trajectory of sea ice.

- Entire ecological systems, as well as human lives, are threatened by spills of oil and other toxic material. Prompt remedial action is often impossible because we are unable to predict accurately the controlling weather and sea conditions.

- Beaches are contaminated and fisheries threatened because we have only a poor idea of the current-driven trajectory of dumped material and effluent.

- Fisheries and ecosystems are endangered because we lack accurate predictions that would allow us to take cautionary measures before and during the buildup and movement of harmful algal blooms.

The growing concern about these critical problems, as well as many calls for action, have been well documented[1] in workshop reports and proposals over the past decade. Solving the complex issue of coastal forecasting will require the active participation of many groups, including Federal and State agencies, academia, and the private sector. NOAA's role in the creation and operation of a coastal forecast system is both central and very broad. Our mission includes monitoring and prediction of the atmosphere, the ocean, and biogeochemical aspects of coastal regions. In addition, NOAA is responsible for management of fisheries and marine sanctuaries, activities that are critically dependent on the best possible monitoring and forecasting. The combination of operational and research line organizations, providing biological, oceanic, atmospheric, and systems expertise, makes NOAA uniquely capable of playing its role in addressing and finding solutions for coastal forecasting issues.

To accomplish this mission, NOAA must coordinate and share capabilities with other agencies, work with regulatory officials, draw on research in academia, and seek cooperation with the private sector. This can only be done effectively within the context of a long-range strategy. NOAA's partners in this endeavor must be cognizant of our goals and understand the processes and mechanisms that we intend to use in accomplishing this important aspect of NOAA's mission. As a first step in meeting this challenge, NOAA must adopt a vision that focuses on the broad issue.

This NOAA vision is to create and maintain an effective coastal forecast system that meets today's requirements and that can be rapidly updated and enhanced as new requirements, knowledge, and technologies emerge.

This vision is buttressed by the long-range strategy presented here. It was drafted by the following NOAA team formed by the NOAA Coastal Ocean Office:

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A STRATEGIC PLAN FOR A COASTAL FORECAST SYSTEM

BACKGROUND

Daily operational activities, management decisions, long range planning, and regulation in the coastal zone typically require knowledge of the following:

- Weather: winds, precipitation, visibility, temperature.
- Water levels: tides, surges, seiches.
- Waves: height, period.
- Temperature and current fields: speeds, directions, dispersion characteristics.
- Chemical composition: salinity, presence of nutrients, pollutants.
- Biology: species (composition, abundance, distribution).

Increasing coastal population and economic activities have been accompanied by the expanded use of "environmentally sensitive" technology. Fog, bad weather, high seas, and ice can snarl local traffic and disrupt schedules in other parts of the national and global transportation network. In many cases the inconvenience and lost productivity are accompanied by the serious threat of injuries and death. Chemical spills, which many times result from inadequate forecasts, can have severe impacts on the local ecology, water supplies, and human health.

Once thought to be abundant, marine life no longer matches the demands of an increasing human population; the "endless supply" is a myth. What we have must be protected and wisely used. Major storms inflict enormous economic losses and human suffering. The sensitive connection between humans and nature has been made clear by empirical circumstance. In 1992 alone people in Florida, Louisiana, the Northeastern United States, Hawaii, and Guam were unwilling participants in this ongoing experiment. Coastal areas have reached a level of critical attention because of the severe pressures brought about by the addition of more than 30 million people to these regions since 1960. Current population projections add another 60 million to these regions by 2050. Protection of life and property, efficient and productive use of coastal resources, and maintenance of economic activities such as transportation, with minimal disruption, demand that we make major advances in our understanding and ability to foresee changes and events in the coastal environment.

A review of the current state of environmental prediction clearly shows that over the past 30 years major strides have been made in weather observing and prediction. We do not have an equivalent forecast system in place that translates the variations in weather to corresponding responses in the coastal ocean. We have almost no capability to link the weather-climate-coastal ocean condition to biological and ecological responses. Furthermore, because the entire system is linked and because our prediction capability of ocean characteristics is limited, we are unable to provide effective feedback from the ocean to the atmosphere and associated weather.

Given the complexity of modern life, we need to provide more specific and accurate predictions of the weather and ocean conditions. It is no longer sufficient simply to say that a large area will experience a bad storm; we need to specify accurately storm surge levels and wave heights, regions of unusually high winds, specific regions that must be evacuated, and highways and airports that must be closed. We need to predict where a chemical spill will move and/or dissipate, and even more importantly, where dangerous conditions that could abet such spills are probable so that they can be avoided.

We need a coastal forecast system that links the weather forecasts to the coastal ocean, that provides feedback to the weather, and that is ultimately coupled to biological-ecological models. Creating such a system is a major scientific and governmental enterprise because the dynamics and the biogeochemical make-up of the ocean are perhaps more complicated than those of the atmosphere (and less easy to observe). This development of a coastal forecast system is a long-term investment that must be an evolutionary process. It will take many years to put a full coastal observing and prediction system in place, just as it did for the atmosphere. As coastal predictions become available and increasingly reliable, the Nation, and especially the half of the U.S. population that lives in or near our coastal regions, will find them a necessary part of daily life.

LONG-RANGE GOAL

NOAA's coastal forecast system goal is to improve our ability to measure, understand, and predict coastal environmental phenomena that impact public safety and well-being, the national economy, and environmental management.

To achieve this goal, we must create a NOAA service system that is focused on the Nation's coasts. It will address the environment and resources of coastal waters and the air above, with emphasis on the unique set of conditions produced at the interfaces of water, air, and land.

In the marine-biosphere environment we will have more complete information on the size and distribution of fish stocks and protected species. Sophisticated fisheries models, coupled with forecasts of the physical environment and detailed resolution of current environmental and biological conditions, will provide essential guidance on the viability of commercial fish stocks, which will, in turn, help us to make sound long-term fisheries management decisions.

In the marine-atmosphere environment we will provide, in real time, a three-dimensional picture of the structure and motions of the coastal oceans and weather. Water contamination, the health of coastal habitats and wetlands, and salt water intrusion will be monitored so that better management decisions can be made. Prediction models will provide guidance far enough in advance to ensure that decisions by users such as transportation, fisheries, and waste managers are sensible and effective.

In the atmosphere-land environment we will be able to provide accurate site-specific forecasts of transportation-disrupting fog and life-threatening severe storms. Serious air pollution episodes in coastal cities can be mitigated, and the devastation caused by events such as coastal mountain brush fires will be reduced because of precise forecasts of coastal atmospheric conditions.

COMPONENTS OF THE STRATEGY

The overall strategy includes five major components: (1) environment, (2) regions, (3) conceptual elements, (4) development stages, and (5) responsibility. Each is treated separately in the following subsections.

Environment

The coastal ecosystem is distinctly different from other forecasting environments. The differences offer an interesting and complex challenge to forecasters and system developers. Atmospheric and oceanic predictions are profoundly influenced by exchanges at the air-sea interface, by the marked change in surface characteristics between sea and land, and by the topography at the ocean-land interface. In turn, living coastal resources are strongly influenced by their oceanic and atmospheric environments.

We have generated a considerable body of knowledge within each of the separate disciplines that make up the coastal environment. Similar progress in dealing with the coastal environment as a complete ecosystem is yet to come. Indeed, our tendency to think of the ecosystem as a collection of components is reflected in NOAA's organizational structure, which has separate Line Offices (LOs) dedicated to the ocean, the atmosphere, and fisheries. As the need for cross-cutting programs and stronger ties between disciplines and LOs grew, the Coastal Ocean Program (COP) Office was created to help foster better coordination on coastal topics.

While accepting the importance of interdisciplinary activities, we must also recognize that the levels of knowledge and capability in the separate areas may not be equal. For example, we have reasonably good operational models for the coastal atmosphere, but few if any coastal ocean or fish population models that are truly operational in scope. Similarly, our ability to observe the coastal atmosphere is fairly good, whereas the same cannot be said for the ocean or its biomass.

There is a primary need to develop sensors with resolution capabilities that are matched to concentrations and distributions of oceanic and biological phenomena.

NOAA's strategy with regard to the coastal environment includes the following:

- Recognizing the lag between our knowledge of different coastal ecosystem disciplines and directing a balanced effort toward reaching equal levels of understanding of all components of the coastal environment.
- Increasing the emphasis on interdisciplinary studies that deal with the total coastal ecosystem.
- Reaping the benefits from more fully integrated, interdisciplinary, prediction models, which will result from a more uniform knowledge base.

Regions

The United States has a remarkably long and diverse coast line. It is characterized by features ranging from pack ice on the northern shore of Alaska to tropical coral reefs near the shores of Florida and Hawaii (see Figure 1). The Alaska and California Currents off the West Coast and the Gulf Stream off the East Coast produce striking differences in the coastal ocean currents and the associated weather patterns. Each region has a different set of key processes and factors that dominate environmental variability. These differing physical conditions influence the habitat for a large variety of commercial fisheries and protected species.

Because the diversity of our coastal zones is one of their defining features, no single forecast system may be suitable for all regions. For example, the temporal and spatial scales of coherence vary substantially with region, leading to the need for different observational schemes. Measurement of lateral wind curl off the West Coast may require a high-resolution network made up of closely spaced meteoro-

COASTAL REGIONS

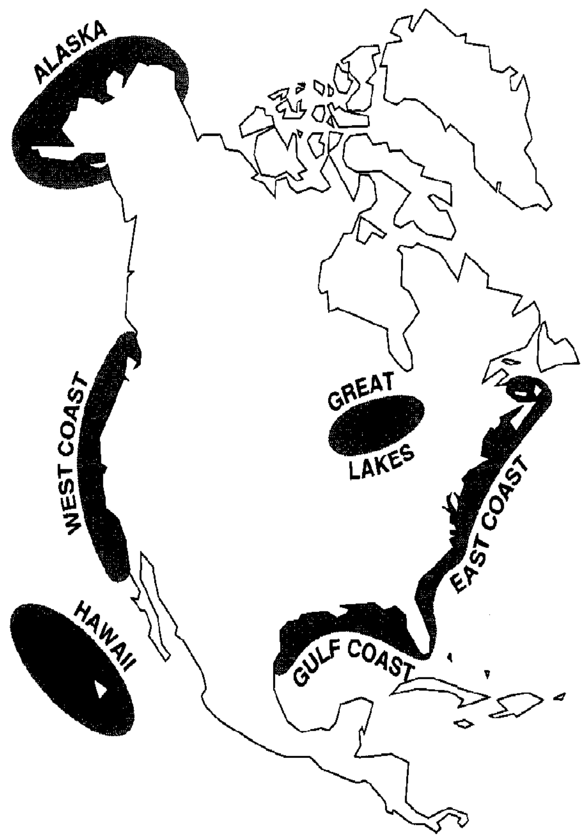


Figure 1. The U.S. coastal regions are extensive and diverse, ranging from pack ice to tropical waters.

logical buoys, whereas such measurements may not be critical off the East Coast.

An important aspect of this regional character is the local expertise and support that exist within each area. The universities, industries, and states associated within a particular region are the best sources of information on regional requirements, special features, and location-specific research and development. Although central coordination is desirable, an optimum strategy must not only recognize regional differences; it must also build on local strengths and expertise.

NOAA's strategy with respect to the coastal regions includes the following:

- Recognizing important regional differences and basing coastal forecast system designs on those requirements that are unique to a particular area.
- Building on existing local expertise and capability where possible and encouraging the continuation of region-specific research.
- Strengthening the coordination and exchange of ideas and techniques among regions to ensure a minimum of duplication and the selection of optimum technologies and techniques where common requirements do exist.

Conceptual Elements

The conceptual elements of any forecast system are ***observations, knowledge,*** and ***models*** (see Figure 2). Each is necessary, but alone, is not sufficient. They are intimately related in the creation of a forecast system, and in the forecast process itself.

To forecast an event we must know something about the initial conditions, the starting point. This requires that we observe the state of the phenomenon that we want to predict. We then must have a model of the behavior of the phenomenon with time. These models can range in complexity, from the experience of an individual forecaster to sophisticated, numerical calculations. No matter which model is used, it is nothing more than a manifestation of our knowledge or understanding of the process that is being predicted.

The interaction between the three conceptual elements of a forecast system forms an improvement cycle (see Figure 3) that starts with the observations of some feature or phenomenon of interest. On the basis of these observations, we form hypotheses and theories, and conduct

CONCEPTUAL ELEMENTS

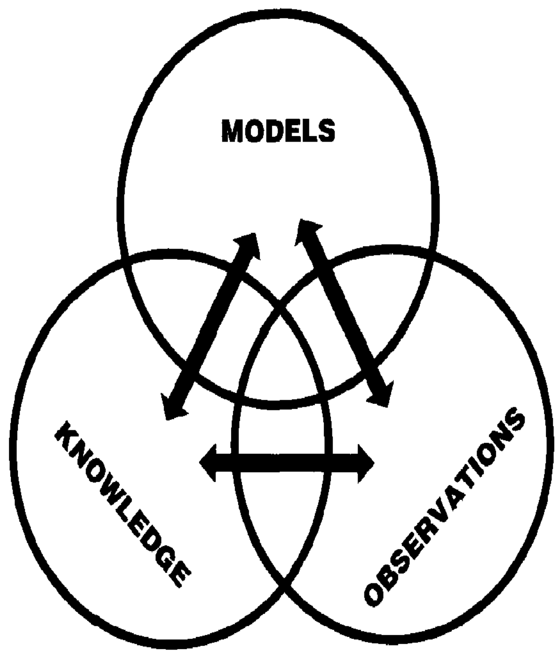


Figure 2. The operational interconnectivity of the necessary elements of a forecast system is depicted by the overlapping circles and double-headed arrows.

process studies that increase our understanding. This knowledge is then converted into a model that allows us to make predictions of the future state of the feature or phenomenon. The quality of the prediction is related to our level of knowledge and to our ability to observe at any given time. New observations and better understanding will then result in improved predictions, and so on into the future. These improvement cycles are dependent on our research and development capability, which when taken together with new requirements becomes the driver for our long-range strategy.

Although the data sets, knowledge base, and models may be very different for the disciplines of oceanography and meteorology, their associated prediction systems conform to these basic elements.

NOAA's strategy recognizes these disciplinary differences while stressing the potential benefits of stronger interdisciplinary activity. For example, air-sea interactions have a profound effect on both atmospheric and oceanic predictions. Less well understood, but perhaps of even greater importance, is the interaction between the ocean/atmosphere and living resources. Significantly different time scales, as well as laws of behavior, make the integration of these disciplines a challenge worthy of our best academic minds.

NOAA's strategy with regard to the conceptual elements of a coastal forecast system is the following:

- To achieve balance between the conceptual elements by focusing attention and resources on weak elements in each of the relevant disciplines.
- To recognize and build on the existing separate data and knowledge bases within the disciplines represented in the coastal zone while working to strengthen interdisciplinary activities.

Development Stages

We know that requirements, knowledge, and technology are not static; they change under pressure from evolving demographics, economic adjustments, new research results, advanced development, and the birth of new concepts. We must have the ability to respond to these changes by adopting new technologies and procedures so that the operational system remains at an effective state-of-the-art level at all times into the future.

NOAA now provides some level of oceanic, atmospheric, and biological services to a wide range of coastal interests. This collection of services can be thought of as a weakly connected "system." If we wish to strengthen the connections, create improved services, fill important

IMPROVEMENT CYCLES

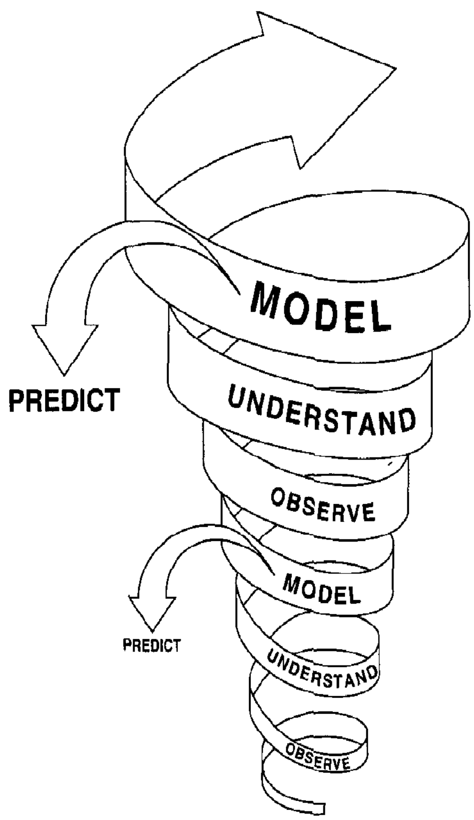
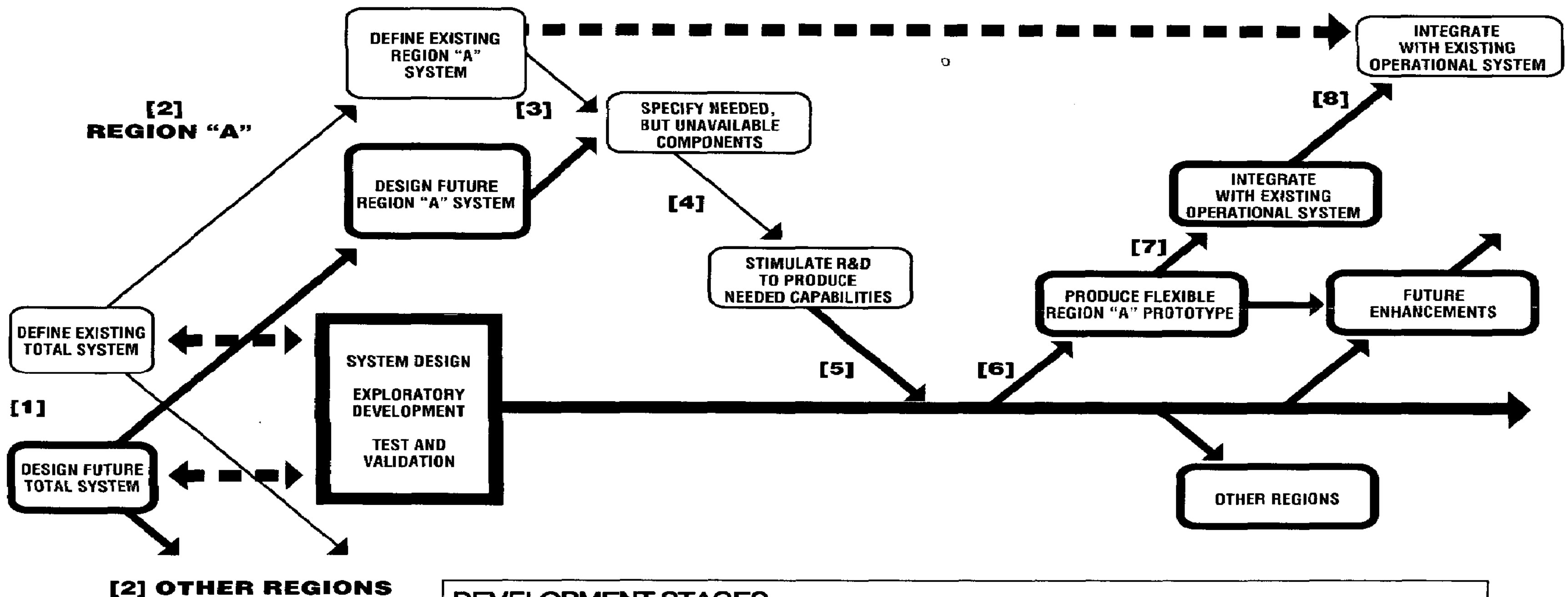


Figure 3. The improvement cycles show how observations lead to understanding, which in turn leads to models. The process is continuous and results in increased prediction capability at the completion of each cycle.

service gaps, and move toward more efficient operations, we must develop a controlled process that fosters the evolution from what we have now to what we wish to have in the future.

Good research looks for answers over a very broad spectrum. Not all answers that emerge from research are relevant to a particular operational need. Thus, we must have a process that examines new answers, validates them, relates them to operational requirements, and integrates them into the operational system. This process is contained



DEVELOPMENT STAGES

Figure 4. The flow chart contrasts the existing process (light lines) with the proposed process (light plus heavy lines). The required ongoing systems support is shown in the square box and by the long, solid, heavy arrow. The long, dashed arrow represents ongoing operations. The dashed, double-headed arrows represent the interactions between the existing systems, future designs and the development capability. The bracketed numbers relate to the description found in the text.

in the development stages, which are (1) ***research,*** the expansion of our understanding and technological capability; (2) ***exploratory development,*** the refinement and validation of new concepts; (3) ***prototype/demonstration,*** the integration that removes barriers between related yet separate components and disciplines; and (4) ***operational implementation,*** phased introduction of proven new subsystems and procedures. The strategic challenge is to design and implement a process, the supporting organizational structure, external interfaces, and facilities that are dedicated to producing the desired improvements to operational services.

This technology/science transfer process should have the following characteristics:

- It should stimulate relevant research through effective feedback of operational requirements.
- It should have the capability to evaluate new research products, create and test working models of relevant subsystems, and examine the interfaces between the new subsystems and the operational system.
- It should allow for developing, fielding, and validating functional prototypes, pilot projects, and/or demonstration systems as a final risk-reduction measure before full operational implementation.
- It should be strongly influenced by system design principles that ensure interface compatibility, practicality, and operability.
- It should result in operational service systems that are tolerant of change and easily modified as new requirements, technologies, and methods emerge.

NOAA's strategy includes the institutionalization of this technology/science transfer process. The flow chart in Figure 4 shows this process beginning after requirements for a national coastal forecast system have been collected and validated.

The requirements are used to generate a total (or national) system design (see area [1] in Figure 4). Regional differences in coastal environments make it necessary to divide the total design into region-specific subsystems [2]. By comparing the existing and proposed systems, we can identify components and knowledge that are lacking [3].

This identification of operational system requirements is an important first step that will result in more focused research [4]. New research results enter the next phase of the transfer process, exploratory development [5], where the results are tested, validated, and applied by independent groups. Those concepts that pass the early validation phase are then ready for prototype development [6] and integration as quasi-operational systems. Their value as a new component is then tested in a final validation and demonstration step [7], before the full procurement and integration with the existing operational system [8].

The foundation for this process is an adherence to systems principles, depicted by the items in the square box in Figure 4. Good systems design is essential for the matching of technology, models, or procedures to a given set of requirements, and for the selection of components to achieve the optimum system balance. This capability has been developed for NOAA's atmospheric forecasting mission and has become a key support activity for the NWS modernization effort. Despite differences in time and motion scales, much of the approach used for atmospheric systems can be extended to the development of oceanic and biological forecast systems.

The long-term success of NOAA's coastal forecast system strategy is tied to the implementation of an effective ongoing evolutionary process. The central focus of this process is a working prototype that is periodically updated to include technologies and methods that are more advanced than, and intended for implementation in, the operational system. This working prototype is the final test-bed used to validate changes and improvements. Properly used, it will greatly reduce the risk associated with major procurement, ensure that new requirements are met rapidly with optimum technology and methods, and act as a feedback conduit for stimulating needed research.

Because coastal forecasting issues vary from region to region, a single prototype location may not be optimum. On the other hand many issues are more generic and common to all regions. This suggests the need to separate some of the prototype functions. For example, one option (see Figure 5) would be to create a central capability dedicated to system design, subcomponent testing and validation, and program oversight, and more region-specific pilot projects to address unique observational, modeling, and dissemination requirements. This would help to ensure a level of commonality that is necessary for operational logistics while still accommodating recognized regional differences.

NOAA's strategy with regard to the development stages of a coastal forecast system includes these items:

- Expand our present system design, testing, validation, and demonstration capability to include oceanic and biological forecast systems.
- Use this expanded capability to make the technology/science transfer process more effective and efficient.
- Continually update and validate the requirements for coastal forecasting.
- Use these requirements to generate updated system designs that will provide a standard for assessing operational capability, and for stimulating new and more focused research and development activities.

A NEW APPROACH

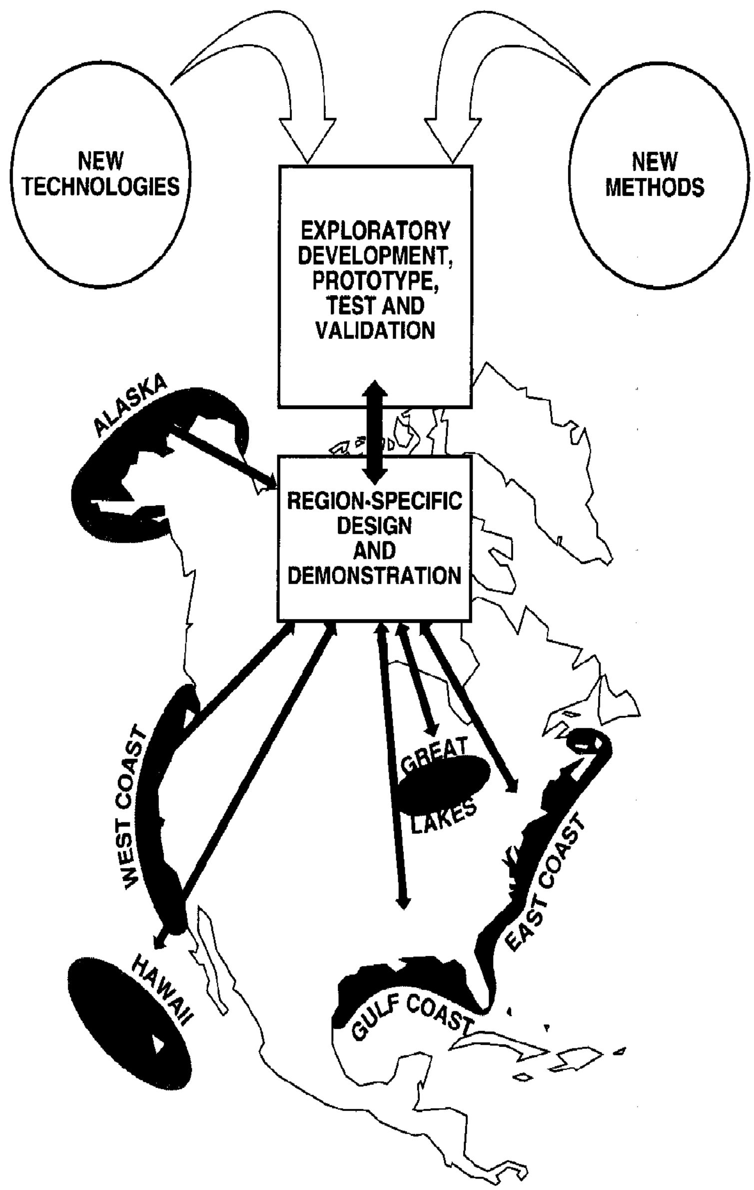


Figure 5. A new approach for research and development, and implementation related to a coastal forecast system would include exploratory development and region-specific design and demonstrations.

Responsibility

The strategy for a coastal forecast system covers its design and upgrade, its operation, and its maintenance as a state-of-the-art system. It relates to activities at universities, other agencies, and the private sector. Within NOAA it spans operational, research, and program coordination groups, including the Coastal Ocean Program (COP), the Systems Program Office (SPO), and the five major LOs — National Ocean Service (NOS), National Weather Service (NWS), National Marine Fisheries Service (NMFS), National Environmental Satellite, Data, and Information Service (NESDIS), and Office of Oceanic and Atmospheric Research (OAR).

The very nature of the problem (the interfaces of land, water, and living resources) makes this a somewhat special organizational challenge. The five LOs, COP, and SPO will each have important responsibilities. Because of the diversity of activities it is necessary to clearly define the overall management responsibility, the role and expected interactions, of each group. The following paragraphs outline these:

- ***COP:*** Overall program coordination between LOs during the development stages. Once a system is determined to be operational, full responsibility will shift to the proper LO. COP will continue to serve as coordinator to ensure effective feedback for the other stages. The Assistant Administrators (AAs) from all five LOs will oversee COP's role. COP will be responsible for raising issues to the AAs through the existing Program Development Board (PDB) and for coordinating the implementation of decisions made by this group.
- ***SPO:*** Overall systems support including requirements analysis, design studies, validation and assessment, formulation of operational logistics, procurement, and system integration.
- ***NOS:*** Physical oceanographic and estuarine research and operations, including data acquisition, processing, and assimilation;

model development, testing, and evaluation; and product development and dissemination.

- *NWS:* All aspects of atmospheric operations and special research topics. The NWS National Data Buoy Center (NDBC) will be responsible for deployment and operation of ocean buoys. The National Meteorological Center (NMC) of NWS in conjunction with other LOs will be responsible for testing new models and for running operational models including those that integrate elements of the atmosphere, ocean, and biosphere.
- *NMFS:* All aspects of the biological operations including data delivery and special research in areas of direct concern to its mission.
- *NESDIS:* Satellite data collection, product generation, data archiving, and distribution.
- *OAR:* NOAA's technical arm during all development stages, providing systems capability and conducting tests, validations, and demonstrations in conjunction with other LOs and SPO. In addition, OAR would conduct research and provide the interface with external (to OAR) scientists and engineers working on topics relevant to the coastal forecast system.

An important aspect of responsibility is the maintenance of strong interfaces with other agencies and groups that have vested interests in coastal forecasting. For example, coastal issues are high on the agendas of the Navy, Department of Interior (Mineral Management Service [MMS] and the U.S. Geological Survey [USGS]), the Environmental Protection Agency, many states, and universities. Where possible, NOAA will join with these parallel activities to share observations, knowledge, and models. The programs of the Navy and MMS involving process studies, coastal data management, and observations are of particular relevance. Each LO, COP, and SPO will have the responsibility for monitoring these external programs, seeking and developing joint programs, and sharing resources in their specific areas of responsibility.

The breadth of the coastal forecast system is such that it will have interfaces with other programs such as the Global Ocean Observing System (GOOS), CoastWatch, and Climate and Global Change. It will be a primary responsibility of COP, SPO, and OAR to ensure that effective crosscut analyses are made between these programs and the coastal forecast system. Each LO will also monitor these interactions to ensure strong symbiotic relationships.

The overlap with GOOS is particularly important. Although GOOS is global in scope, it does not address other components of a prediction system. On the other hand, the more limited geographic scope of the coastal forecast system does consider all elements of an end-to-end prediction system. The point of commonality (coastal observations) provides a significant opportunity for interprogram cooperation and rapid progress for both activities.

NOAA's strategy with regard to responsibility includes the following:

- Using NOAA's existing organizational structure, coordination mechanisms, and management lines where possible to ensure central responsibility for policy approval, priority setting, issue resolution, and resource allocation.
- Employing COP as the coordinator for the development stages.
- Building on existing OAR and SPO capability to implement a centralized capability for system design, testing, and demonstration to foster the technology/science transfer process.
- Retaining existing operational LO responsibilities for assessment, product delivery, and policy setting.
- Making NMC responsible for operational model runs for the separate disciplines and future integrated models.
- Establishing and strengthening symbiotic relationships with other agencies, universities, and the private sector in order to foster joint projects and services.

A CONCEPTUAL SYSTEM

The strategic components described in the previous section must be used to mold a forecast service system that meets our Nation's coastal requirements with an optimum mix of observing methods, understanding, and automation.

The coastal forecast system will consist of all those components required to observe and predict atmospheric, oceanic, and biological conditions that impact the ecosystem and human well-being at or near the coastal boundary.

NOAA's present research, observation, and prediction capabilities comprise at least some of the elements of the desired system. Although several ongoing research and development (R&D) activities promise to produce some of the required technology and understanding, new R&D thrusts will be needed to address the full range of present and future requirements.

A forecast system has a natural flow of information starting with basic observations and ending with decisions by users. This end-to-end system contains several major components, each of which requires special design considerations (see Figure 6). These generic components, and some characteristics of the components that are unique to coastal forecast systems, are as follows:

- *Observations:* Global-, synoptic-, regional-, and local-scale observations must all be considered in the design. The larger scales are important because conditions within the coastal zone are strongly influenced by global and synoptic processes. The coastal forecast system must be properly nested within larger scale models, forecast services, and observing systems such as the global radiosonde and satellite networks. On the regional and local scales, there will be a need for observations with greater spatial and temporal resolution. The data set must also include information on biological and chemical parameters, as well as measure-

MAJOR SYSTEM COMPONENTS

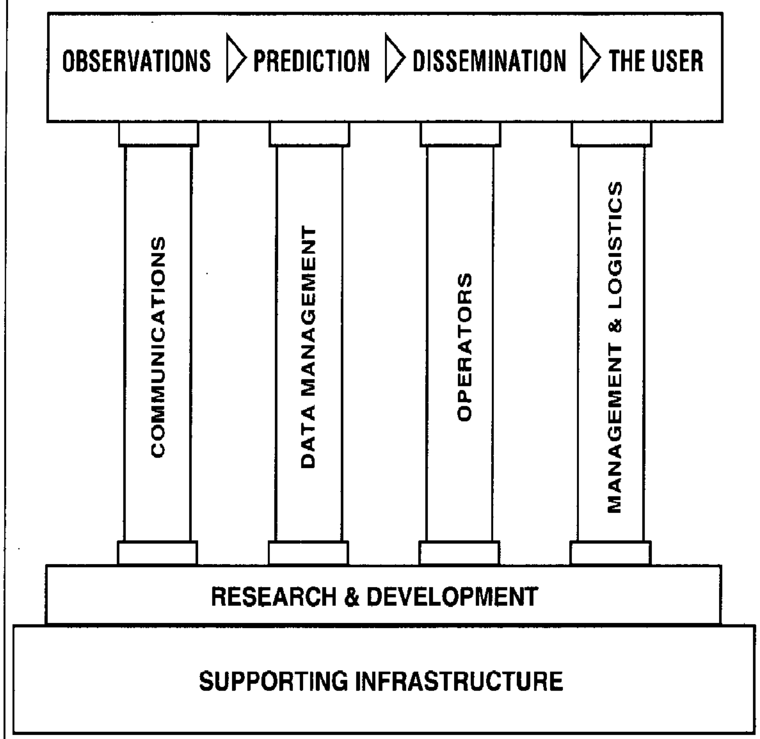


Figure 6. The major forecast system components are divided into "in-line" activities (observations, etc.) and "supporting" activities (communications, etc.) that are all dependent on a research and development capability.

ments of such anthropogenic features as oil slicks, pollution levels, and effluent discharge.

- *Prediction:* Nearly all prediction methods are based on some form of model. In the near term there is a need to stress coupled coastal oceanic-atmospheric circulations. Ultimately, a coastal forecast system will require a hierarchy of models consisting of those that (1) focus on separate disciplines, (2) depend on the interactions between two disciplines, and (3) fully integrate all relevant cross-disciplines. An important goal will be a model that deals with the coastal environments as complete ecosystems.

- *Dissemination:* Information must be available in a period of time that will allow the user to take beneficial action. The designer of a coastal forecast system must be cognizant of the users' requirements for timeliness and specificity. Because NOAA's operational control ends with the issuance of an analysis or forecast, it has little influence over the dissemination system. It can, however, monitor the development of dissemination techniques and ensure that there is a smooth handoff of forecast products to those who are responsible for dissemination.

- *The Users:* There are potentially five types of coastal forecast system users: (1) the in-house NOAA user (such as a fisheries manager), (2) all other government groups that might use the information to make an internal decision or to relay the information to one of their constituents, (3) all those in the private sector, including the general public, who require the information to make economic or personal decisions, (4) policymakers, and (5) the research community.

These in-line elements must be firmly embedded in a supporting infrastructure. The most critical elements of this infrastructure are the following:

- *Communications:* This is the glue that binds the system together. The mix of observing instruments and forecast products associated with oceanic and atmospheric environments presents an interesting challenge for communication subsystem design. Widely different data rates and the differing needs of real-time and retrospective data users all deserve special consideration.

- *Data Management:* Like communications, management of data is a ubiquitous element of forecast systems. It includes such diverse activities as processing by individual instruments, quality control, data integration and assimilation, long-term storage, and distribution of data directly to users. Again, the oceanic, atmospheric, and biological mix will pose special challenges. Data from each of these disciplines will have different characteristics, temporal and spatial domains, and parameters. Yet, their interrelationships must be understood before prediction techniques can be developed. The natural evolution to more advanced prediction models will place similar demands on the data management subsystem.

- ***The Operators:*** Too often, a forecast system is thought of as a collection of instruments, communications, computers, and models; the role of the human operator is overlooked or relegated to a subservient position. The complexity of the coastal environment is such that we must not make this mistake. The person-machine interface, the special knowledge and experience of forecasters, not to mention the vagaries of the human mind, are essential aspects of an environmental forecast system design.

- ***Management and Logistics:*** Management structure, logistics, and regional differences are all important facets of the design. Because separate NOAA operational LOs serve each of the three disciplines that are relevant to the coastal forecast system, inter-LO agreements will be required to ensure efficient logistics and properly delegated responsibility. Different coastal regions may require different system components. This variation is an important consideration in determining commonality of spare parts and central versus distributed logistical support.

IMPLEMENTATION

The requirements behind the thrust for a greatly improved coastal forecast system are alluded to in the Background section of this document and covered more explicitly in the references listed in reference 1 of the Preface. These broad requirements must be refined and analyzed in detail before they are used to drive the system design process.

In parallel, we must carefully document existing coastal monitoring and forecast capabilities, their interfaces, their strengths, and their weaknesses. A detailed crosscut analysis of the validated requirements and the present capabilities will sharpen the focus on specific future program directions.

The results from these preliminary steps must be correlated with an assessment of relevant research work. Then, using the guidelines in the previous sections, we will develop the details of a conceptual coastal forecast system design. Finally, we must find a way to deal more effectively with the critical need to integrate oceanic, atmospheric, and biological disciplines. Briefly, the coastal forecasting system design of the future will

- be built on existing capabilities,
- integrate oceanic, atmospheric, and biological observations, knowledge, and models where appropriate,
- depend on continued R&D for many critical components, and
- be flexible enough to accept proven new technologies and methods with little or no disruption to ongoing services.

Buildup Phase

After the existing activities have been defined and coordinated, and the missing components identified, we will proceed with the buildup phase,

CORE ELEMENT OF BUILD UP PHASE

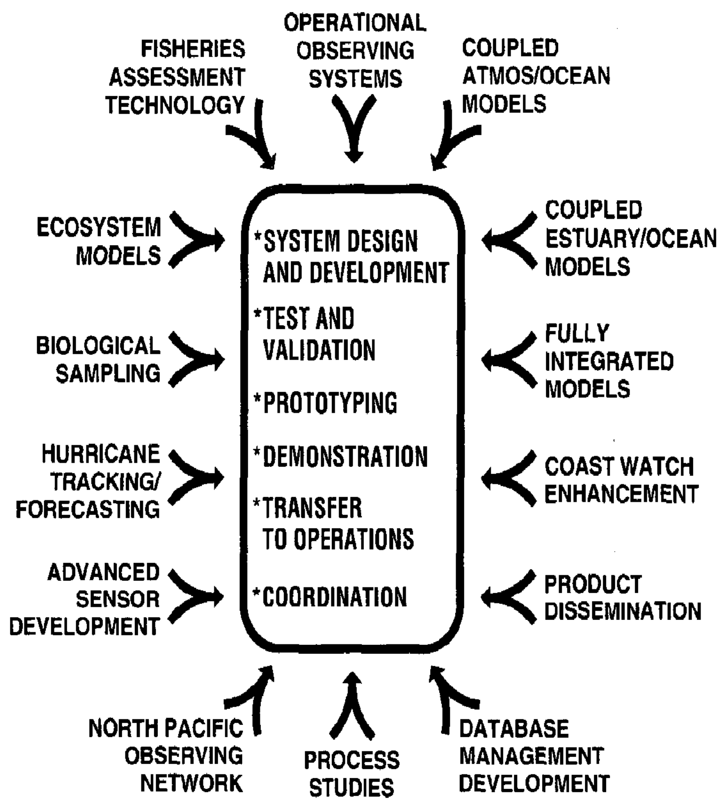


Figure 7. The buildup phase of implementation will require a core activity, which consists of the systems process. This core serves to prioritize and coordinate all other activities.

the first phase of the coastal forecast system strategy. An initiative dedicated to this phase will consist of three main elements:

1. Introducing previously identified upgrades to the existing operational system by procuring and installing critical operational system components needed to address urgent near-term requirements.

2. Stimulating and accelerating R&D that will provide the necessary long-term solutions, with special emphasis on those disciplines for

which the knowledge base is seriously lagging behind other coastal disciplines.

3. Institutionalizing the evolutionary development process (technology/science transfer) by building on existing capability and by implementing the necessary system design, testing, validation, and demonstration infrastructure.

The core of this initiative will be the third element, the expansion of the system design and coordination capabilities (see Figure 7). Urgent operational upgrades and critical research projects will complete this first initiative. The core activity, which will help to ensure that the other two critical elements are effective and part of a general improvement process, will include the following:

- Establish the facilities and infrastructure necessary to evaluate research products, assemble and test subsystems, and validate new methods.
- Integrate new subsystems with existing capabilities to provide a working prototype and demonstration of future operational coastal forecast systems.
- Implement a region-specific capability that addresses local problems and conducts pilot projects at several different locations.

Mature Phase

Once the desired improvement process has been established, changing requirements and capabilities will be continually reviewed. New research, development, demonstrations, and operational implementation will take place in response to evolving requirements. New initiatives will be generated as required by the process.

Enhancement of the operational system will occur in parallel with the creation of this enhanced NOAA development capability. During the first phases we must continue to address urgent operational requirements without the full benefit of the more structured testing and validation embodied in the new process. However, as the new systems capability is being established, further operational improvements will be made with less risk of major design flaws and with the benefit of the latest technologies and methods.

After the full systems development capability is implemented, there will be continued support of the research, development, and demonstration cycle that is essential for all future operational enhancements.

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