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A NOAA Perspective on a Coastal Ocean Forecast System

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Abstract

The elements involved in the establishment of a comprehensive Coastal Ocean Forecast System (COFS), the philosophy of approach towards achieving this goal, and the existing components of NOAA's coastal marine observational, analysis and forecast services are described. A COFS will enable NOAA to meet its requirements to issue timely warnings and forecasts to coastal communities to reduce loss of life and damage to property, as well as to provide the necessary information for management of coastal resources, the environment, and commercial and recreational activities. In this paper, the existing capabilities of NOAA in meeting several of these needs are presented, including a description of the operational components of its coastal marine observation network and of its marine forecasts and services. Also included are a summary of the NOAA vision and long-range strategy for development of a COFS, as well as a discussion of some near-term, on-going development activities.

Introduction

The coastal zone in the United States is under an ever increasing stress because of the mounting pressures brought about by the migration of population to coastal areas. The migration is of such magnitude that this narrow strip of land now contains nearly half of the U.S. population, with current projections adding another 60 million people to this region by the year 2050 (NRC, 1989). Protection of life and property, environmentally sensible and productive use of coastal resources, and maintenance of economic activities such as marine commerce demand major advances in our understanding of the coastal environment and in our ability to observe this environment and to predict its changes. Major storms, with the attendant high waves and storm surges,

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can inflict enormous economic loss and human suffering, hazardous material spills can have severe impacts on the local ecology and human health, and disruptions in local sea traffic due to bad weather, high seas, fog, or ice can now have an impact that can be felt at national and international levels in the transportation industry.

Coastal zone management and regulation, long-range planning, and daily operational activities require knowledge of the weather (pressure, winds, precipitation, visibility, temperature), water levels (tides, surges, seiches), waves (height, period), water temperatures and currents (dispersion), chemical composition (salinity, nutrients, pollutants), and biology (species composition, abundance and distribution) in the coastal domain (COPS, 1990). Major strides have been made in weather observation and prediction over the continental U.S. in the last 30 years, yet this does not translate to equivalent improvements in coastal weather observation or prediction, nor to corresponding capability in the coastal ocean. In addition, our ability to link the weather and the physical condition of the coastal ocean to biochemical and ecological responses is even more tenuous.

The ultimate Coastal Ocean Forecast System (COFS) required to serve the above needs will link the atmosphere and the coastal ocean in an interactive manner producing forecasts of physical variables to be used in coupled biochemical and ecological models. At NOAA we see the development of such a COFS as an evolutionary process, a long-term investment that will take many years to fulfill. A preliminary quantitative estimate of the benefits and costs of a COFS (Kite-Powell et al., 1994) suggests that a modest investment in this effort would generate annual benefits on the order of tens of millions of dollars in the commercial shipping and recreational boating and fishing sectors alone.

In fact, a number of operational activities do now exist within NOAA that constitute a rudimentary COFS. These include an observational network providing data from conventional platforms such as ships, buoys, coastal stations, water level gauges and radar, as well as remotely-sensed ocean surface data from operational satellites. Also available routinely are operational marine forecasts of sea level pressure, winds, air temperatures, precipitation, fog, visibility, surface waves, storm surge, and tidal heights and tidal currents. However, these are available on space and time scales that are too coarse for many coastal applications. Particularly lacking is any routine information on the state variables in the interior of the coastal ocean.

This chapter describes the NOAA perspective on a COFS. In Part 2 we summarize NOAA's long-range strategy for development of a COFS (NOAA, 1993), including what we consider to be the fundamental conceptual elements, the basic components, and the developmental evolution of a COFS. Part 3 describes the existing operational components of NOAA's coastal marine observation network and of its marine forecasts and services. And in Part 4 we summarize a number of research and development activities currently underway to enhance the existing operational system.

As increasingly reliable coastal predictions become available, the U.S. population that lives in or near our coastal zones, and the entire Nation, will find them a necessary part of daily life.

The Development of a Coastal Ocean Forecast System

The NOAA goal is "to create and maintain an effective COFS that meets today's requirements and that can be rapidly updated and enhanced as new requirements, knowledge, and technologies emerge" (NOAA, 1993). This goal is supported by a long range strategy that seeks to build upon existing oceanic, atmospheric, and biologica services that serve a wide range of coastal interests by improving existing services, fillin service gaps, and creating new services. This strategy includes what we consider to b the fundamental conceptual elements of any forecast system, the basic components of th system, and the developmental evolution of a COFS.

Conceptual Elements

The long-range goal is "to improve our ability to observe, understand, and predic coastal environmental phenomena that impact public safety and well-being, the nationa economy, and environmental management" (NOAA, 1993). This statement contains th three fundamental conceptual elements of any forecast system, namely *observations knowledge,* and *models*. Based on observations, we form hypotheses and develo models to predict the future evolution of the system. The skill of the predictions is measure of how well we understand the system and shortcomings in our ability t observe and describe the important properties of the system. The measurements knowledge, and models may be quite different for different disciplines (e.g. physical chemical, biological), yet all disciplines share these common elements. The interactio between the atmosphere, ocean, and living marine resources in the coastal environment i of paramount importance, but significant differences in time and space scales, as well a the basic laws of behavior, make the integration of these disciplines a considerabl challenge.

Thus, our strategy is to achieve and maintain a balance between the conceptua elements of a COFS, keeping in mind that there are large disciplinary differences i knowledge and by directing resources and attention at the weaker elements in each of th relevant disciplines. We must recognize and build on the existing separate data an knowledge bases within the disciplines represented in the coastal domain, and emphasiz interdisciplinary measurements, studies, and prediction modeling that deal with the tota coastal ecosystem.

System Components

Any forecast system has a natural flow of information beginning with fundamental observations and ending with decisions by users. Although a forecast system can be broken down into a large number of sub-components, the basic system has three broad generic components: *research and development, operations,* and *dissemination.* NOAA's present capabilities contain some of the elements of the desired system, but new thrusts will be needed to address the full range of system requirements. These basic system components, and some of the characteristics that are unique to operations in a COFS, are briefly expanded upon here.

Research and development is the underpinning of a technically sound operational system. At NOAA several ongoing research and development activities (see Section IV) promise to produce some of the required technology and understanding. New efforts are required, however, to support both current and future needs for: (a) system design - to determine COFS mission requirements and to define new observational and modeling technologies to meet those requirements; (b) observation system development - to design ew sensors and to develop and test instrument prototypes; and © model development o test and evaluate the hierarchy of coastal forecast models.

Operations basically include observations and prediction methods, as well as the ssociated sub-components of communications, data management and archival, and uman intervention. Conditions in the coastal zone are strongly influenced by global to ynoptic scale processes, thus a COFS must be properly configured within larger-scale bserving systems, such as the Global Ocean Observing System, the global radiosonde etwork, and global satellite networks. At regional and local scales there will be the eed for greater spatial and temporal resolution in the observational systems. bservations must include, in addition to the classical physical measurements, nformation on biochemical parameters as well as anthropogenic indicators such as ollution levels and discharges, algal blooms and eutrophication, and hazardous naterials spills.

Operational prediction methodology is almost always based on some form of model. urrently NOAA has operational models that provide forecasts of relevant neteorological fields and ocean surface waves mostly on scales larger than those equired for coastal problems. Storm surges associated with tropical hurricanes and esulting inundation considerations are dealt with on an individual basin case. Forecasts f storm surges associated with extra tropical storms are also generated operationally on daily basis for the East Coast of the U.S. Some details on these are given in Section 3. he National Centers for Environmental Prediction (NCEP) has been actively engaged in eveloping high resolution mesoscale Numerical Weather Prediction (NWP) models that an potentially give useful meteorological forecasts in the coastal areas. However, in the oastal ocean there is still a need to develop models on the relevant space and time cales for forecasting waves and the internal state of the ocean. In the future we envision hierarchy of operational forecast models to couple the physical forecasts with other isciplines and to aim towards prediction in the coastal environment as a complete ystem.

Dissemination entails the means of getting the required information to the user and he defining role of user requirements in the development of a coastal prediction system annot be overemphasized. It is these requirements that must drive the design, evelopment, implementation and evolution of the COFS.

Developmental Evolution

The U.S. has a diversity of coastal zones with differing temporal and spatial scales f coherence and variability, and a single forecast system may not be suitable for all egions. However, there are generic issues that can be addressed by a central capability edicated to system design, testing, validation, and demonstration. This generic apability would then be applied to more region-specific observational, modeling and issemination requirements, as shown in Figure 1. It is important to recognize regional ifferences and uniqueness and to build on local expertise and capabilities, while at the ame time employing optimum technologies and techniques where common equirements do exist.

NOAA has recently started a number of development efforts that support this trategy. The Great Lakes Forecast System, a prototype system that has been under evelopment for a number of years, is now being phased into operations, and is covered

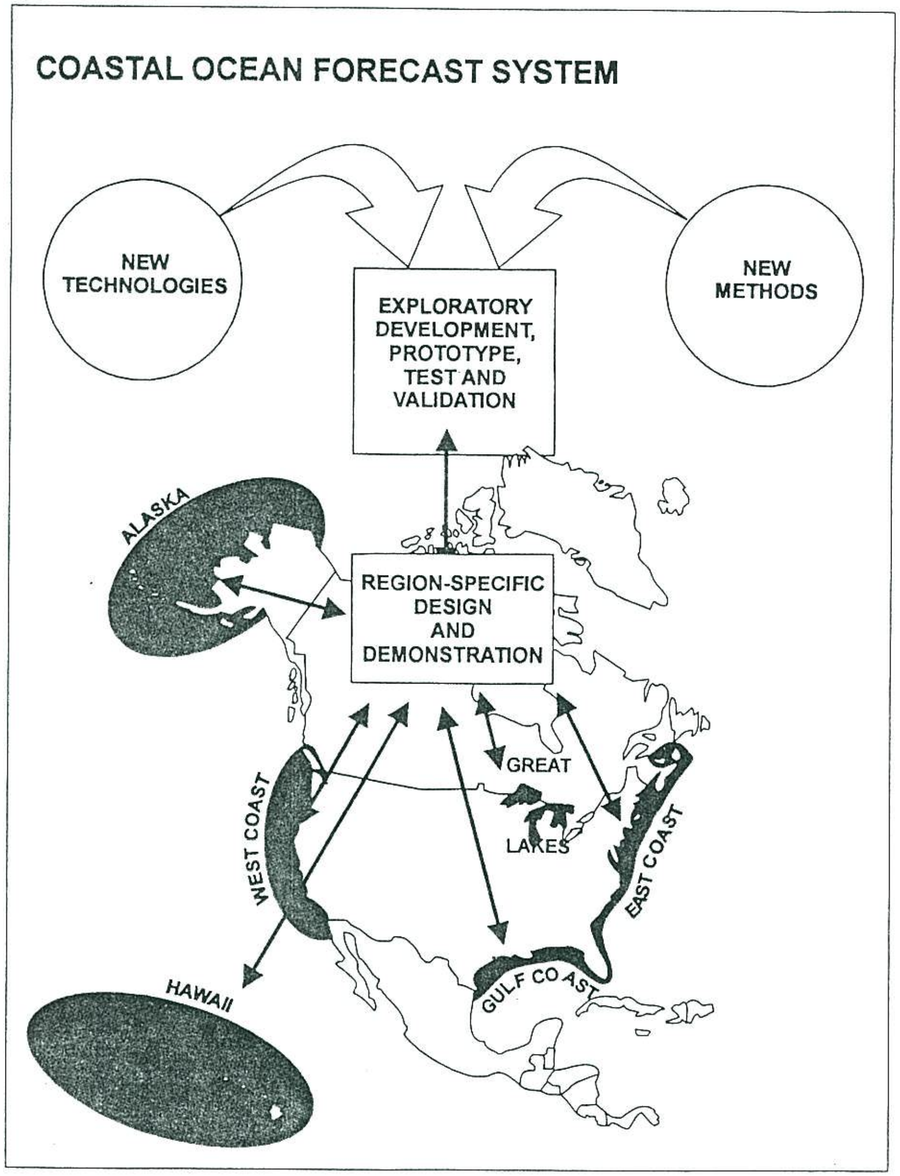


Figure 1. Concept of the development of a generic COFS capability and its subsequent application to region specific problems.

in Chapter 8 (Schwab and Bedford, 1997) of this book. On the East Coast of the U.S. NOAA has initiated an experimental forecast system (Aikman et al., 1996). The approach has been to begin with the whole-coast domain (in this case the U.S. East Coast), which will eventually be coupled to regional high resolution model systems, such as presently under development at the National Ocean Service (NOS) for the Port of New

York and New Jersey and for the Chesapeake Bay. We will initially use the output from the whole-coast system to provide lateral (seaward) boundary conditions for the regional forecast systems. At the same time, the U.S. Navy has begun a similar development effort for the West Coast of the U.S. (Clancy et al., 1996).

Existing Components of a COFS

While the concept of a comprehensive coastal ocean forecast system is being developed, NOAA has to meet certain immediate operational requirements to deal with its responsibility to provide warnings and forecasts to the public in the coastal region for the protection of life, property, and the safety of maritime activity. To issue these warnings and forecasts, it is necessary to have a basic observing system in operation and a modeling capability for forecasting those environmental variables that can potentially create hazards. In general, these variables are winds, waves, storm surges, fog and visibility, tidal currents and tidal heights, and ice in high latitudes and in the Great Lakes during winter.

A brief description of the existing observational network and operational forecast and analysis products that are routinely produced to meet these important requirements is presented below.

Coastal Marine Observation Network

Fixed buoys

The primary sources of conventional measurements over the coastal and open oceans are ships, drifting and fixed buoys, and Coastal-Marine Automated Network (C-MAN) stations. In general, ships make only a very few observations in the coastal areas and the drifting buoys are mostly deployed in the open ocean. In terms of quality and dependability, the best available measurements in the coastal area are those taken from a network of fixed buoys and C-MAN stations maintained by the National Data Buoy Center (NDBC) of NOAA over the west and east coasts of the United States, in the Gulfs of Mexico and Alaska, around the Hawaii region, and in the Great Lakes. Similarly, the Atmospheric Data Acquisition (Ocean) Division (ADAD) of the Atmospheric Environmental Service, Canada, maintains a buoy network over the Canadian waters on their east and west coasts and the Great Lakes. Both the US and Canada remove the buoys in the Great Lakes during winter time. Figure 2 shows the network of buoys from U.S. sources around North American waters. More detailed and up-to-date information on the types of buoys, locations, etc. can be obtained directly from the NDBC homepage at http://www.ndbc.noaa.gov.

The routine measurements available from these buoys are: sea level pressure (SLP), wind speed and direction, air temperature, sea surface temperature (SST), and one-dimensional wave spectrum and significant wave height. The wind speed measurements are 8 minute averages. These buoy measurements are transmitted over the Geostationary Operational Environmental Satellite (GOES) telecommunications network. Due to differing user requirements, some of the NDBC buoys transmit their data twice per hour, some once per hour, and some once per three hours. The Canadian buoys

transmit their data on an hourly basis. Both on the U.S. and Canadian sides, the buoys involved in this network are of different types with anemometers located at different levels. The various types of buoys involved and their anemometer heights are:

Type of Buoy	Anemometer Height (m)
12- meter discus	10
10- meter discus	10
6- meter NOMAD	5
3- meter discus	5
LNB-USCG Large Navigational Buoy	13.8
ELB-USCG Exposed location Buoy	6.6

The performance of all the buoys is closely monitored on both the U.S. and Canadian sides. Problems encountered with any of the buoys or their sensors are regularly reported by both NDBC as well as ADAD through their regular periodic news letters and on their web sites. The buoys deployed in coastal areas may be classified into two categories. Buoys that are greater than 20 miles from the east coast and greater than 60 miles from the west coast may be considered offshore and the rest inshore. The number of buoys in both of these categories are shown below, including those on the Great Lakes.

Organization	Offshore	Inshore	Total
NDBC	27	38	65
ADAD	8	18	26
Great Lakes (NDBC)			8
Great Lakes (ADAD)			5

These numbers are representative of the available buoy network around the coastal waters of North America. The inshore buoys on the U.S. side are supported by various agencies such as the Corps of Engineers, the Minerals Management Service, the National Aeronautics and Space Administration, etc. The number of these inshore buoys is more likely to fluctuate and their locations are also likely to change depending on the changes in the requirements of each of the supporting organizations and funding support.

Coastal-marine automated network

In response to the need for more coastal observations, the National Weather Service (NWS) has established a network of 62 C-MAN stations. These sites are selected based on priorities established by the NWS for its coastal and marine forecasts, watches, and warnings. In addition to these 62 operational stations, the NWS has identified 84 more stations to be implemented when funding becomes available. As for NDBC buoys, more detailed and up-to-date information on the C-MAN network can be obtained directly from the NDBC homepage at http://www.ndbc.noaa.gov.

The locations of the existing C-MAN stations are shown in Figure 3. Six of these stations are installed on US Coast Guard navigational buoys off the Atlantic and Pacific Coasts. The remaining 56 are installed onshore in coastal areas or offshore on rigid structures. NDBC has selected the sites after surveying to obtain optimum sensor

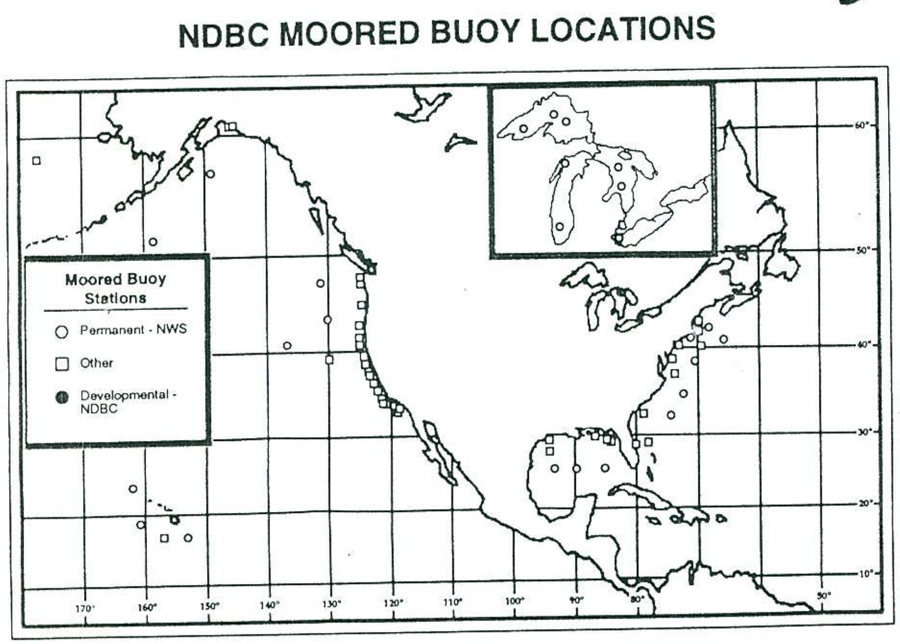


Figure 2. Locations of the U.S. buoy network off of the East and West Coasts of the North American continent, the Great Lakes and Hawaii.

exposure and to facilitate easy servicing of the equipment. Local topography, ground cover, and other relevant factors are taken into account to determine the extent of the wind boundary layer at each site. Anemometer heights are chosen based on these calculations and these heights are often greater than 10 m in order to measure representative conditions over the water. Basic parameters measured by the payloads on the C-MAN stations are wind speed and direction, wind gust, air temperature, and SLP. The wind speed measurements on C-MAN stations are two minute averages. Several of the C-MAN stations have a capability to measure SST and water level. The measurements from these stations are reported to NCEP at regular hourly intervals via GOES. The C-MAN station data are also monitored closely by NDBC to detect and correct problems that may arise with any of the sensors.

Satellite-borne sensors

It is now well recognized that satellite-borne sensors offer the most viable means to obtain routine and frequent measurements of ocean surface parameters both on a global and regional basis. Some of the sensors have had a long history of reliable operational performance, such as the Advanced Very High Resolution Radiometer (AVHRR) onboard the operational satellites of NOAA for measuring SST and the Special Sensor Microwave Imager (SSMI) on board the Defense Meteorological Satellite Program (DMSP) series to measure wind speeds. Other satellite-borne instruments have been successfully tested, primarily on research satellites, to derive additional ocean surface parameters. A summary of these sensors and their applications is shown in Figure 4

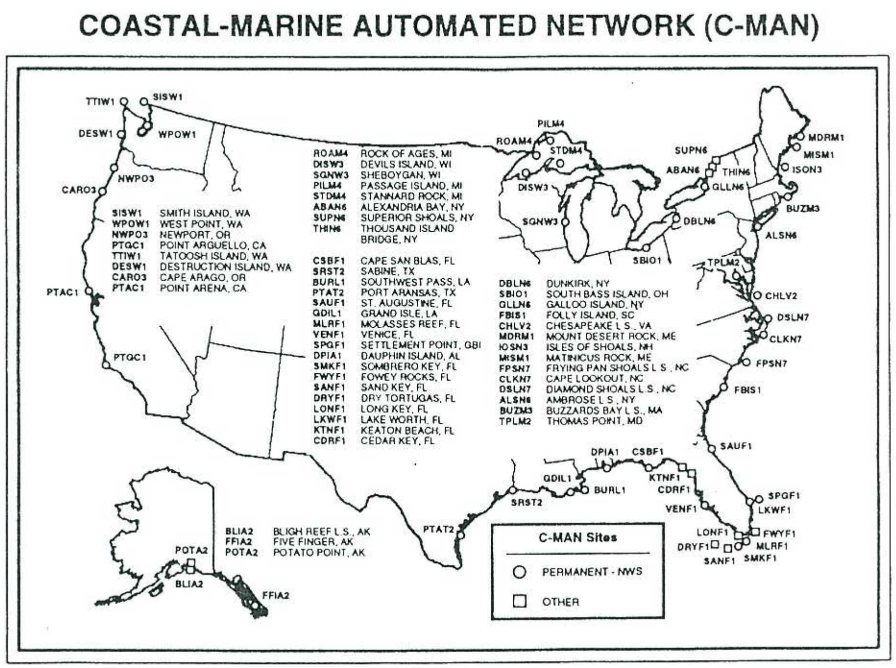
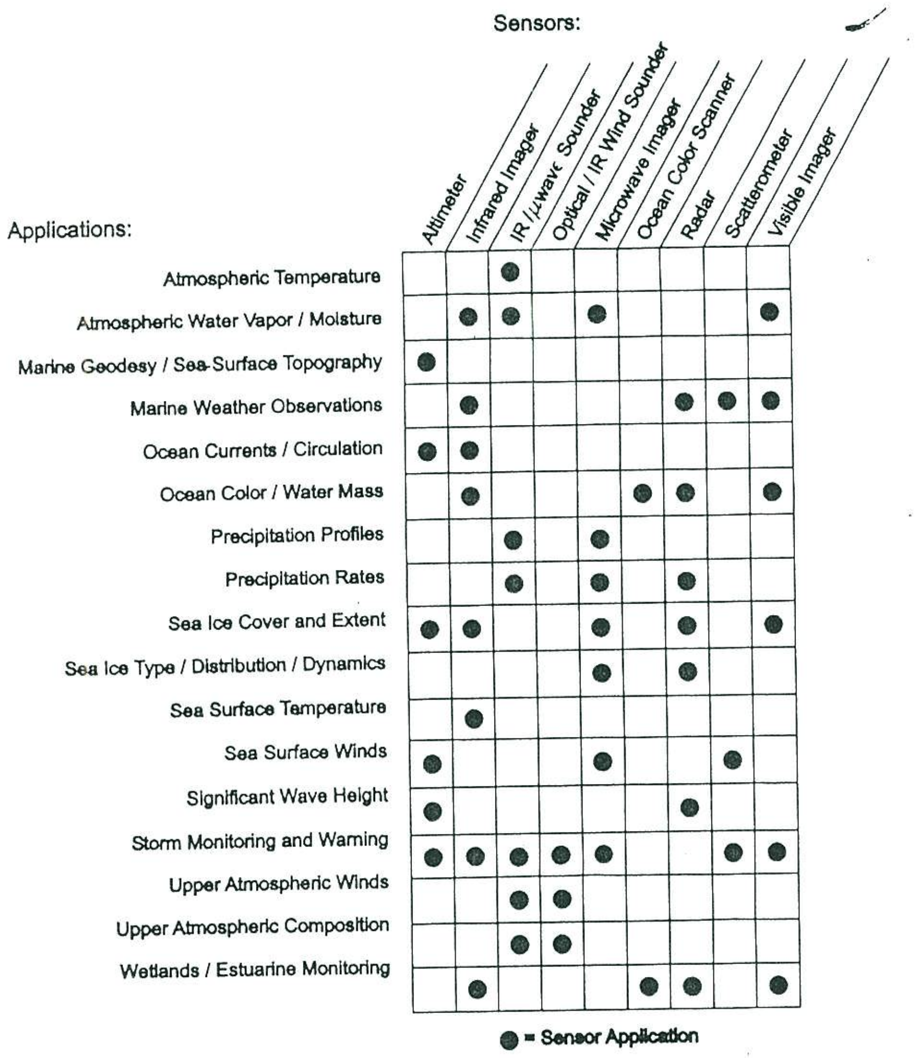


Figure 3. Coastal- Marine Automated Network (C-MAN) locations in North America.

(Sherman, 1993a). In addition to the existing operational satellites, several research satellite missions are planned for launch in the near future. These are shown in Figure 5 (Sherman, 1993b). If all of these satellite missions are launched as planned, the data coverage that can be realized over the coastal ocean areas will be very extensive. NOAA is also working closely with the Department of Defense and the National Aeronautical and Space Administration to converge the nation's separate civilian and military polar-orbiting weather satellite programs into one joint system. The National Polar-Orbiting Environmental Satellite System (NPOESS) is projected to save in excess of $1 billion over the life of the program.

An important issue with the satellite-borne sensor measurements is a careful validation of their geophysical retrievals because problems arise due to various causes. For example, SST retrievals can be seriously affected by cloud contamination in the field of view, due to problems created by aerosols and volcanic eruptions, and due to sensor degradation. The National Environmental Satellite, Data and Information Service (NESDIS) carefully monitors the retrievals on a continuous basis to take corrective actions as necessary to ensure that the product is of acceptable quality. The wind speed retrievals from the current operational algorithm for the DMSP/SSMI sensor are adversely effected by clouds, high humidity and rain conditions. A careful evaluation using co-located wind speed measurements from the NDBC buoy network showed that the currently used SSMI operational retrievals are found to be acceptable, in terms of their bias and RMS error statistics, for use in operational models, but only under clear sky conditions and moderate wind speeds (~20 m/s). A significantly improved algorithm, based on neural network techniques, has been developed (Krasnopolsky et al.,



Applications:	Altimeter	Infrared Imager	IR/μwave Sounder	Optical / IR Wind Sounder	Microwave Imager	Ocean Color Scanner	Radar	Scatterometer	Visible Imager
Atmospheric Temperature			●						
Atmospheric Water Vapor / Moisture		●	●		●				●
Marine Geodesy / Sea-Surface Topography	●								
Marine Weather Observations		●					●	●	●
Ocean Currents / Circulation	●	●							
Ocean Color / Water Mass		●				●	●		●
Precipitation Profiles			●		●				
Precipitation Rates			●		●		●		
Sea Ice Cover and Extent	●	●			●		●		●
Sea Ice Type / Distribution / Dynamics					●		●		
Sea Surface Temperature		●							
Sea Surface Winds	●				●			●	
Significant Wave Height	●						●		
Storm Monitoring and Warning	●	●	●	●	●			●	●
Upper Atmospheric Winds			●	●					
Upper Atmospheric Composition			●	●					
Wetlands / Estuarine Monitoring		●				●	●		●

● = Sensor Application

Data derived from satellite-borne sensors and their meteorological and oceanographic applications.

Figure 4. Data derived from satellite borne sensors and their meteorological and oceanographic applications.

1996) to retrieve geophysical parameters with acceptable accuracy over a wide range of wind speeds (~32 m/s) and moisture conditions. This algorithm also yields, in addition to wind speed, retrievals of columnar water vapor and liquid water with good accuracy.

On the other hand, the wind vector retrievals from the ERS-1 and -2 (European Research Satellite) scatterometer measurements received at NCEP in real time are found to have severe directional ambiguity problems. Hence, NCEP has embarked on an effort to reprocess the data directly from the radar back scatter measurements to rederive the wind vectors. These reprocessed vectors have much better directional retrieval

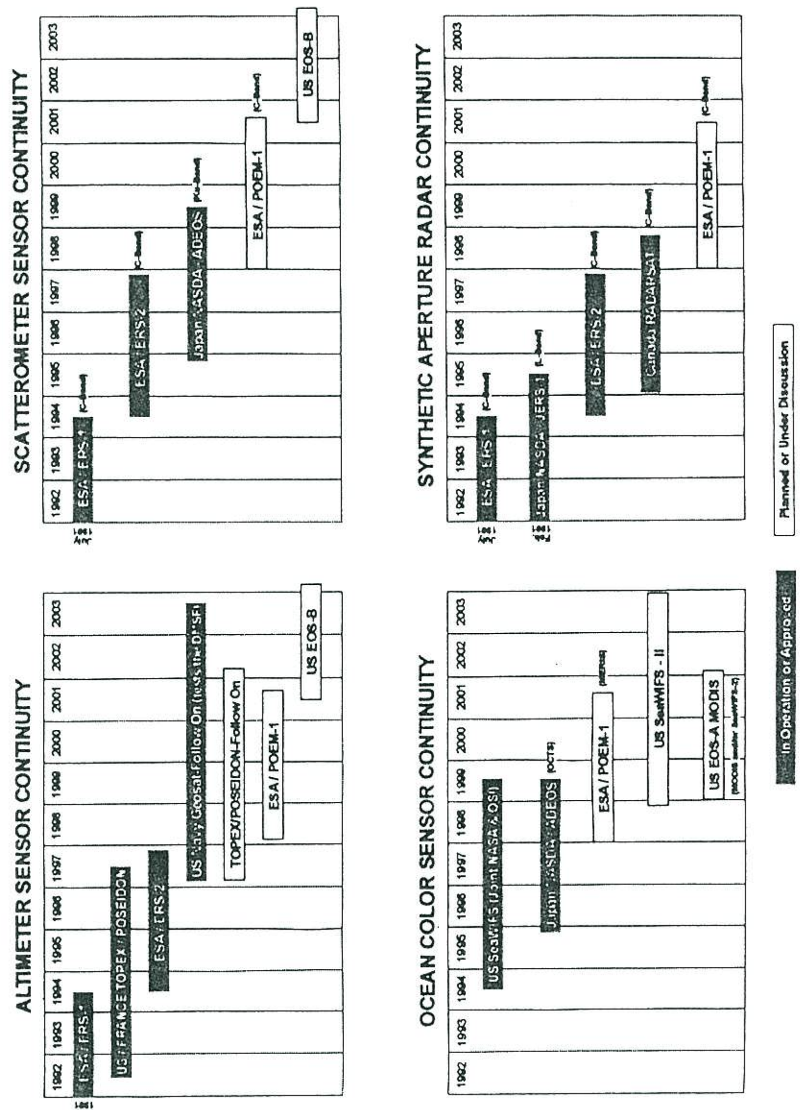


Figure 5. Currently operating (or approved) and planned (or under discussion) satellite borne sensors for oceanographic research and marine operations.

characteristics than the operational fast delivery product (Gemmill et al., 1994). Significant wave height and wind speed measurements from altimeters appear to be of acceptable quality to use them in wave forecast models. Real-time retrievals of sea surface topography need to be evaluated to determine their ability in providing information on sea level and surface currents for use in COFS models.

The possibility of using directional wave spectra from space-borne Synthetic Aperture Radars (SAR) in wave prediction models is still in a very early stage of development. The limited areas of coverage by SAR and its high data rate may make this sensor somewhat impractical for use in operational wave forecast models. Applications of the retrievals of other possible geophysical parameters from SAR and ocean color sensors in the COFS models need to be investigated. Real-time data from the DMSP/SSMI and ERS-2 scatterometers and altimeters are available on the world wide web homepage of NCEP's Ocean Modeling Branch (http://polar.wwb.noaa.gov). Analysis and forecast products dealing with ocean surface winds, waves and polar ice are also available on these pages.

Several of the satellite missions shown in Figure 5 are research satellites which tend to release carefully processed high quality data retrospectively. A very important factor in being able to use these data in operational models is that they be made available in real-time to an operational center. Real-time for meteorological models at NCEP is approximately 3 hours. For the COFS operations one may tolerate a slightly longer time delay, perhaps of the order of 12 hours. If the geophysical retrievals are carefully validated, and robust quality control procedures are put in place, the COFS system would then have access to a significant amount of data that would be useful for assimilation and validation purposes.

Next generation weather radar

The NWS has launched an ambitious program to modernize its services. This involves new observational technology, new information and forecast systems, and a new organizational structure. A central part of the new observing system that is potentially of use to the COFS system is the WSR-88D Next Generation Weather Radar (NEXRAD). This system integrates advanced Doppler radar capabilities, real-time signal processing techniques, meteorological and hydrological algorithms, and automated product processing to generate several analysis products at very fine spatial and temporal resolution. In particular, radial wind velocity is provided out to a range of 230 km with a resolution of 1 km x 1 degree azimuthal resolution at 8 or 16 data levels (Klazura and Imy, 1993). These NEXRAD measurements are helpful in early detection of severe weather resulting in longer lead time to issue warnings and will also be beneficial for assimilation into the mesoscale operational NWP models, which provide the necessary surface forcing for the COFS model(s). The NEXRAD deployment plan is shown in Figure 6. Efforts are underway to investigate the possible applications of the NEXRAD measurements to derive environmental parameters on the ocean surface and in the marine atmospheric boundary layer.

National water level program

The NOS National Water Level Program provides unique tide, water level and ancillary data sets and information to users in support of navigation and positioning requirements, storm surge and tsunami warnings, climate research, dredging and safe commerce, marine construction, water resource management, marine boundary determinations, and coastal ocean research and modeling. The program is supported by the National Water Level Observation Network (NWLON) which currently consists of 140 primary or permanent coastal tidal stations and 49 Great Lakes water level stations (Figure 7). The long-term, continuously-operating stations in the NWLON (5 to 150 years operation) provide control for datum determination at secondary stations (1 to 5 years operation) and tertiary stations (1 to 12 months operation) that are installed for a variety of national and other user programs. The National Water Level Program provides the foundation for the tidal and Great Lakes vertical water level datum control for the

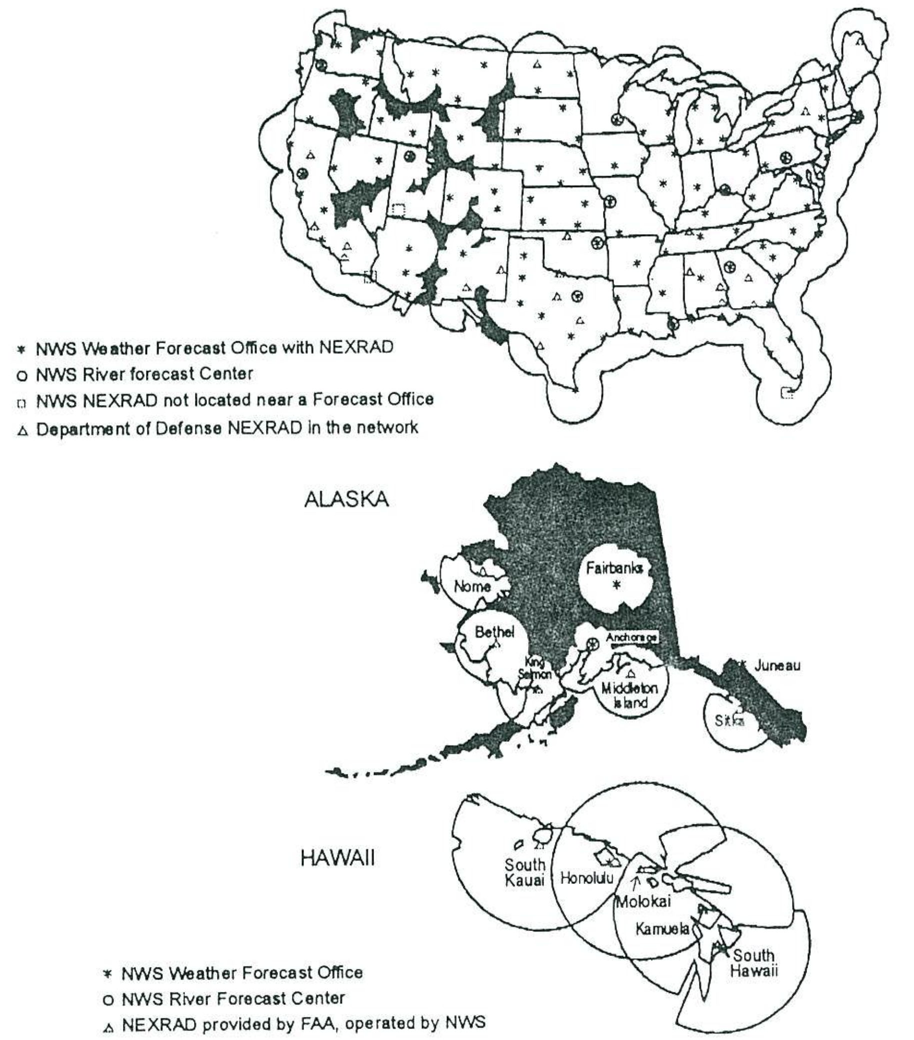


Figure 6. Locations of NEXRAD sites and total coverage (at 10,000 ft elevation above the level of the site). Shaded areas represent gaps in the coverage below 10,000 ft, mostly due to mountains.

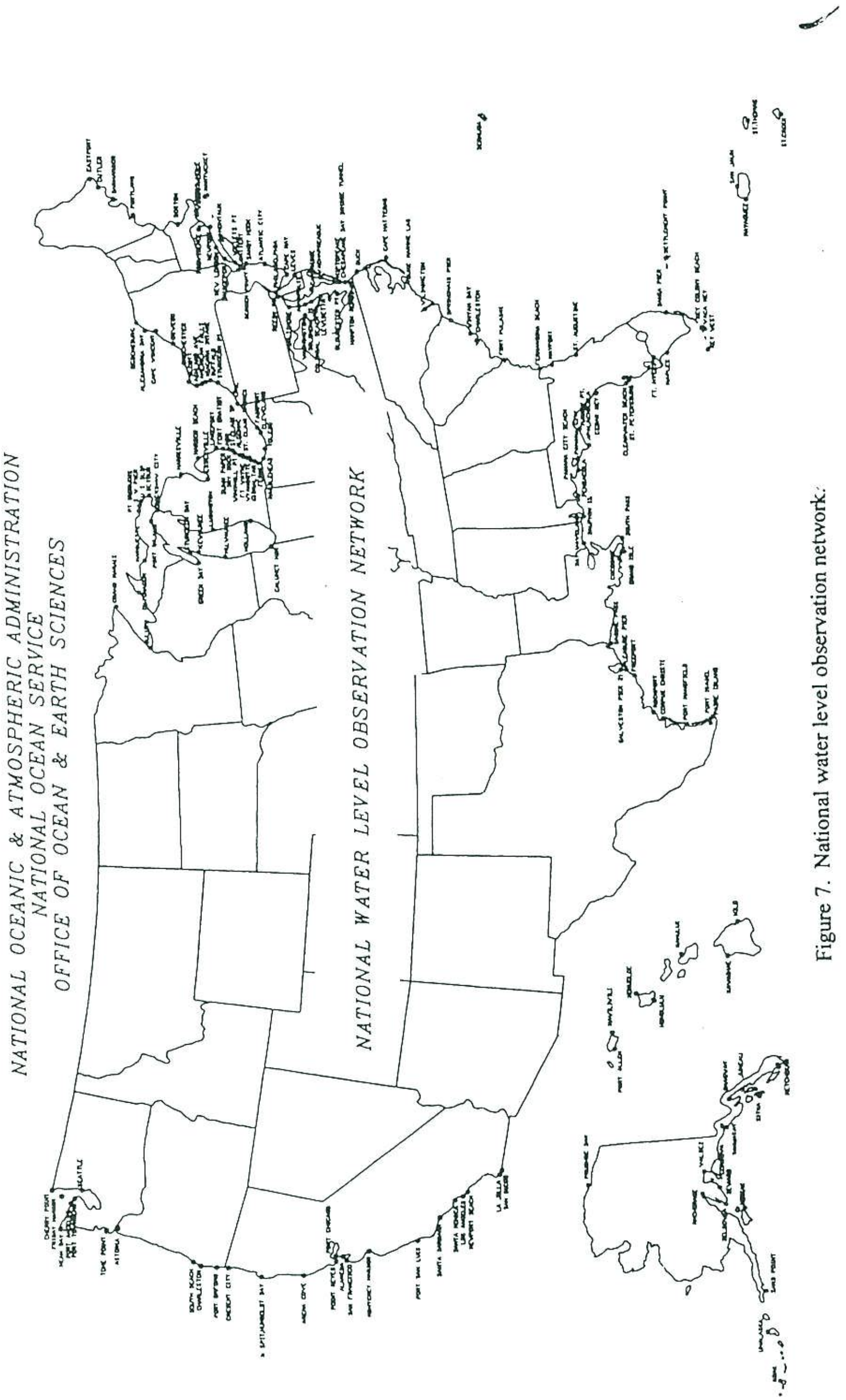


Figure 7. National water level observation network.

U.S. The datums are computed and monumented at each station using a local network of benchmarks. There are now several thousand historical locations throughout the U.S. coastal zone which must be tracked and their datums periodically updated.

Modernization of the NWLON began in 1987 with development of the Next Generation Water Level Measurement System (NGWLMS). The NGWLMS consists of microprocessor-based data collection and telephone/radio/satellite transmission field units and the development of a minicomputer relational database management system, called DPAS (Data Processing and Analysis System), to automate data acquisition, analysis, quality control, storage, processing, and dissemination of water level products. At the beginning of 1997 there were 119 locations at which NGWLMS field units were operating, 109 at tidal stations and 10 in the Great Lakes. In addition to water levels, meteorological packages have been installed at selected NGWLMS stations and provide information on wind speed and direction, SLP, and air temperature. Completion of the modernization is expected to be achieved by the end of 1999. Currently, there are several water level products that NOAA provides in near-real-time. Observed and predicted tidal data is directly accessible via telephone at six minute sampling intervals at selected stations, and is routinely accessed by the NWS for storm surge and tsunami events, as well as the Corps of Engineers, marine pilot associations, etc. For the Great Lakes region, hourly and daily water levels are compiled by NOAA via telephone interrogation of 26 stations. For COFS purposes, the NGWLMS data offers critical near-real-time water level data information that is essential for model nowcast and forecast skill assessment and eventually for assimilation into operational models. Through the DPAS, near-real-time and processed water level data is now available either via direct dissemination, through user telnet sessions, and via the web at http://www.olld.nos.noaa.gov.

Physical oceanographic real-time system

The NOS has developed a Physical Oceanographic Real-Time System (PORTS) and has begun the establishment of a national network (Frey, 1991). Experimental applications from 1983 to 1989, in first Delaware Bay and then Charleston Harbor, provided the technical experience for development of the nation's first system in which current, water level, and meteorological data are fully integrated into a data acquisition and dissemination system, including voice data response via telephone and availability through the web at http://www.olld.nos.noaa.gov. The Tampa Bay PORTS (Figure 8), forerunner of the national network, consists of two acoustic Doppler current profilers, a meteorological station, four water level gauges with anemometers, and a data collection and dissemination system (Appell et al., 1991; Bethem and Frey, 1991). The variety of parameters measured around the bay are reported at six minute intervals via a packet modem-controlled telemetry system. The types of data measured and disseminated by PORTS consist of: current speed and direction; water temperature and salinity; water level; wind speed and direction; and atmospheric pressure. In Tampa Bay the system has proven to be a valuable real-time asset to the local and regional marine community, providing information for safe navigation, real-time storm surge response, hazardous material and oil spill response, search and rescue, and recreational boating and fishing.

There are currently three additional systems similar to the Tampa Bay PORTS that have been established for the Port of New York/New Jersey, in San Francisco Bay, and

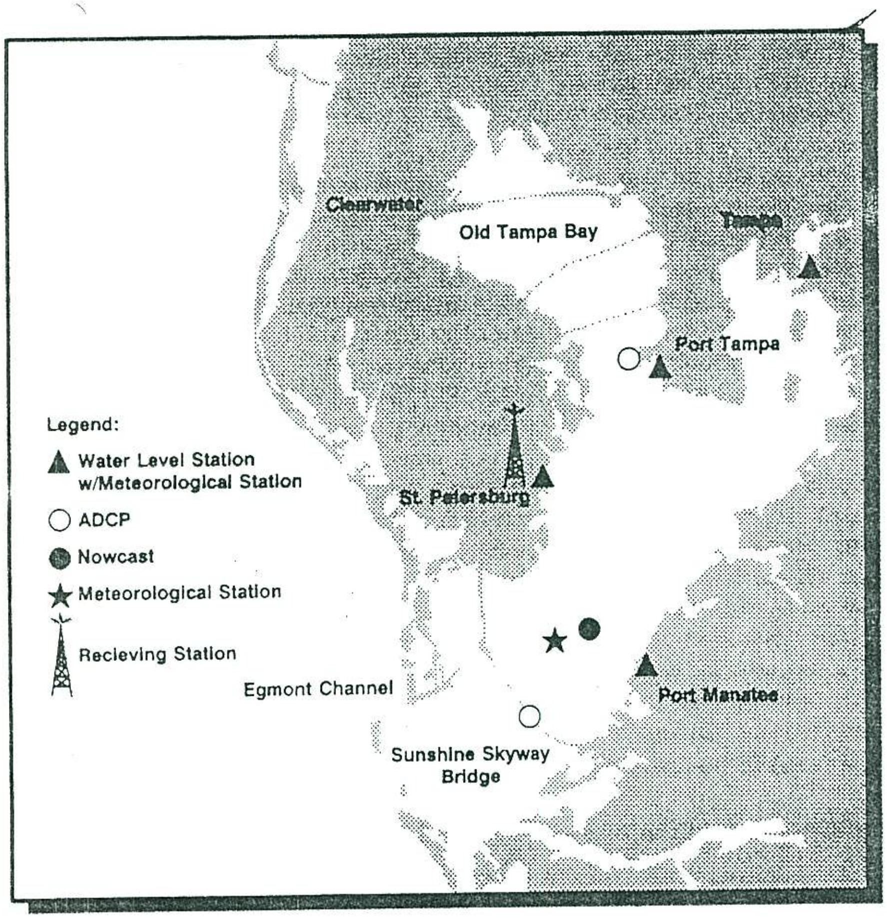


Figure 8. Tampa Bay PORTS deployment.

in Galveston Bay. The San Francisco Bay PORTS includes the real-time monitoring of salinity for assessing and eventually predicting the effects of fresh water withdrawal from the Sacramento and San Joaquin Rivers (for agricultural and municipal uses) on San Francisco Bay salinities (to identify times of high salinity intrusion) and ecosystems (for long-term assessment of habitat degradation). See the PORTS homepage at http://www.olld.nos.noaa.gov for up-to-date information.

A centralized system like PORTS also allows the incorporation of nowcast and forecast information from numerical hydrodynamic models, which themselves depend on the real-time data as input. Thus, the NOS is presently developing and testing nowcast and forecast systems and hydrodynamic models for the Port of New York and New Jersey, for Galveston Bay and the Houston Ship Channel, and for the Chesapeake Bay (where the NOS real-time water level and meteorological sensors have been incorporated into the Chesapeake Bay Observing System, operated by the University of Maryland, Old Dominion University and the Virginia Institute of Marine Sciences). In Tampa Bay the NOS is presently using a statistical approach (Zervas, 1996) to provide short-term (6

hour) forecasts of subtidal water levels, but is now working with the University of Sout Florida to develop a hydrodynamic model-based nowcast and forecast system for thi bay. In San Francisco Bay, the United State Geological Survey (Ralph Cheng, person communication) is presently developing a nowcast modeling capability with plans for a eventual forecast capability as well. All of these PORTS forecast systems will requir accurate forecast information on the water levels at their coastal entrances, thus th COFS development effort described in Section IV will be quite important. Up to dat information on the development of these regional nowcast and forecast systems i available on the web at http://www.ceob.nos.noaa.gov.

Operational Marine Forecasts and Services

NCEP routinely disseminates marine forecast guidance to NWS field offices o SLP, ocean surface winds, waves, fog and visibility over North American coastal water as well as storm surges associated with tropical hurricanes and extra tropical storms o the East and Gulf of Mexico Coasts of the U.S., from its suite of operational global an regional models. At NOS, tide and tidal current predictions are produced annually for a U.S. navigable waters using harmonic constants derived from observations. A bri discussion is presented below on each of these products.

Wind forecasts

NCEP operates a suite of global and regional NWP models to provide guidance t the NWS's field offices to issue forecasts and warnings to the public. These models ca provide wind forecasts over the coastal areas even though, at present, they may not mee the desired degree of spatial and temporal resolutions.

Ocean surface wind forecasts out to 72 hrs are produced twice daily from NCEP operational global NWP (aviation) model. This model's horizontal domain is represente in spectral space by spherical harmonics with a wave number truncation of (triangular 126 waves. The vertical coordinate is a sigma coordinate with 28 levels (Kanamits 1989). The lowest sigma layer is approximately 100 m thick so that the foreca variables in the model are available at a height of about 50 m above the ocean surface From this height, the wind fields are reduced to 10 m height using a simple logarithm profile for neutral stability. Even though the fields are available at 1 degre latitude/longitude resolution, they are disseminated to the field offices on 2.5 degree resolution due to the limitations of the currently available communication systems. These winds are also used in producing ocean surface wave forecasts.

NCEP has been operationally running a limited area mesoscale NWP model called the Eta model. In this model the conventional terrain following sigma coordinate in the vertical is replaced by the Eta coordinate which makes the coordinate surfaces quasi-horizontal. This feature allows the capability to resolve topographic effects better tha the sigma coordinate system (for details see Mesinger et al., 1988; Black, 1994) whil still retaining the simplicity of the sigma system. The current operational version has a 29 km horizontal resolution with 38 vertical layers. The ocean surface wind forecast from this model are under evaluation for use in the coastal fog and visibility foreca model as well as the regional ocean wave forecast models.

Sea level pressure

For mariners at sea, SLP is a very important parameter as an indicator of developing weather. It identifies storm locations, storm tracks, and changes of intensity. All other forecast variables are better interpreted in conjunction with the SLP field and its changes. The NWP models work with changes in surface pressure which over the sea is identical to SLP. SLP analysis and forecast fields are basic post-processed products from all operational models and are routinely disseminated to the users.

Fog and visibility forecasts

A coastal fog and visibility forecast guidance is available for the east coast of the US as an operational product (Alpert and Feit, 1990) twice daily. This model uses the initial conditions of moisture, air temperature and horizontal velocities from the global model over the domain of interest. The forecasted horizontal wind over the full domain and the forecasted temperature and moisture on the boundaries of the domain are also taken from the global model. These fields are interpolated to a high resolution vertical and horizontal grid covering the eastern seaboard. The changes in the temperature and moisture fields through advection and exchange of heat and moisture are computed over the area using the thermodynamic equation and the equation for the conservation of water substance. The moisture fields are used to compute liquid water content and prescribe droplet size distribution. Fog and visibility development is governed by droplet size distribution through empirical relationships and depletion of fog is based on droplet fallout.

Ocean surface wave forecasts

NCEP produces operational wave forecasts on a global domain and two regional domains. The global wave model is an adaptation of the third generation deep water spectral model, called the WAM (WAve Model), developed by the Max Planck Institute in Hamburg, Germany (see The WAMDI, 1988). The driving force for the forecasts is provided by the global aviation model surface winds mentioned above. This model produces wave forecasts out to 72 hours twice daily at 2.5 degree latitude/longitude resolution using 24 frequencies and 12 directional bands. The forecasts, in terms of significant wave heights, peak energy wave period, and its direction of propagation, are disseminated to the field forecast offices. In the hindcast cycle, the significant wave heights from the ERS-1 altimeter and buoys are assimilated into the model to generate new initial conditions for each forecast cycle.

There are two regional wave forecast models in operation. One is over the Gulf of Mexico and the other is over the Gulf of Alaska. Currently, these are second generation shallow water spectral wave models based on the formulation of Golding (1983). The models include dissipation of wave energy due to bottom friction. The Gulf of Mexico is treated as a closed water body and the wave forecasts are driven by the wind forecasts from the global model. Wave conditions in the Gulf of Alaska, however, are very much influenced by the wave trains propagating into the region from the Pacific Ocean as well by the local winds. Hence, the Gulf of Alaska model uses the wave forecasts from the lobal model as a boundary condition at the mouth and the ocean surface winds from the

global model (Chao, 1988 and 1993). The wave forecasts for both models are given c
to 48 hours on a grid of 30 nautical miles using 20 frequency and 12 directional banc
The model forecasts sent to the field offices for the Gulf of Mexico are the significa
wave height, peak energy and wave direction. For the Gulf of Alaska, however, mc
forecast wave parameters are sent to the field. These include total significant wa
height, peak period and its direction, significant wave height of swell (computed from t
energy contained in all spectral components outside of 90 degrees of the prevailing wi
direction at a grid point, as well as those components traveling faster than the local wi
at the grid point), mean period and direction of the swell, and mean period of the wi
sea. It is planned to replace both of these second generation models with an appropri
version of the third generation WAM model shortly.

Storm surge forecasts

The NWS has developed a model called SLOSH (Sea, Lake, and Overland Surg
from Hurricanes) to forecast surges produced by tropical cyclones. This is a dep
integrated, two-dimensional barotropic model which incorporates detailed bathyme
and terrain features (Jelesnianski et al., 1992). The model computes inland flooding a
water height over bays and estuaries. It also treats sub-grid scale flow through cu
between barrier islands and flow up rivers. The model can be applied to either a segme
of a coastline or an island. Model coverage of individual segments (basins) within th
continental US is shown in Figure 9. After the model is adapted to a particular basin,
is made available to the National Hurricane Center which conducts a comprehensi
study to determine areas of potential flooding. In these studies, several hundre
hypothetical hurricanes are simulated with various storm track directions, landfa
locations, intensities, forward speeds, and storm sizes. To reduce the massive outp
from these simulations, composites of the maximum flooding produced by storms of
given category and direction, regardless of the landfall location, are made. Loc
emergency managers find these composites to be useful tools in determining areas f
evacuation whenever a hurricane threatens.

An East Coast extra tropical storm surge model has been implemented f
operational forecasting along the U.S. Atlantic coast and is being tested for the Gu
coast. This model is based on the same dynamical system as the above SLOSH mode
However, unlike the SLOSH model, which has an imbedded parametric wind field, th
dynamical model uses forecast winds and pressure from the global aviation model
forcing. The aviation model has been relatively stable in NWS operations and produc
adequate input fields. As other atmospheric models improve in forecast skill in the ne
shore area and supplant the Aviation model, these newer models will be used to drive th
extra tropical storm surge model.

The extra tropical storm surge model was first tested on the Halloween Northeast
of 1991, with encouraging results. Since the beginning of 1994, the model has been ru
twice daily and verification of these heights has shown that the dynamical model
significantly better than the statistical procedure. The 20-year old statistical techniq
relates storm surge heights to model forecasts of pressure in a "perfect prognos
statistical formulation.

The model starts from a state of rest with zero water level elevation and undergoes
spinup of 48 hours using analyzed forcing fields, followed by a forecast that is issued o

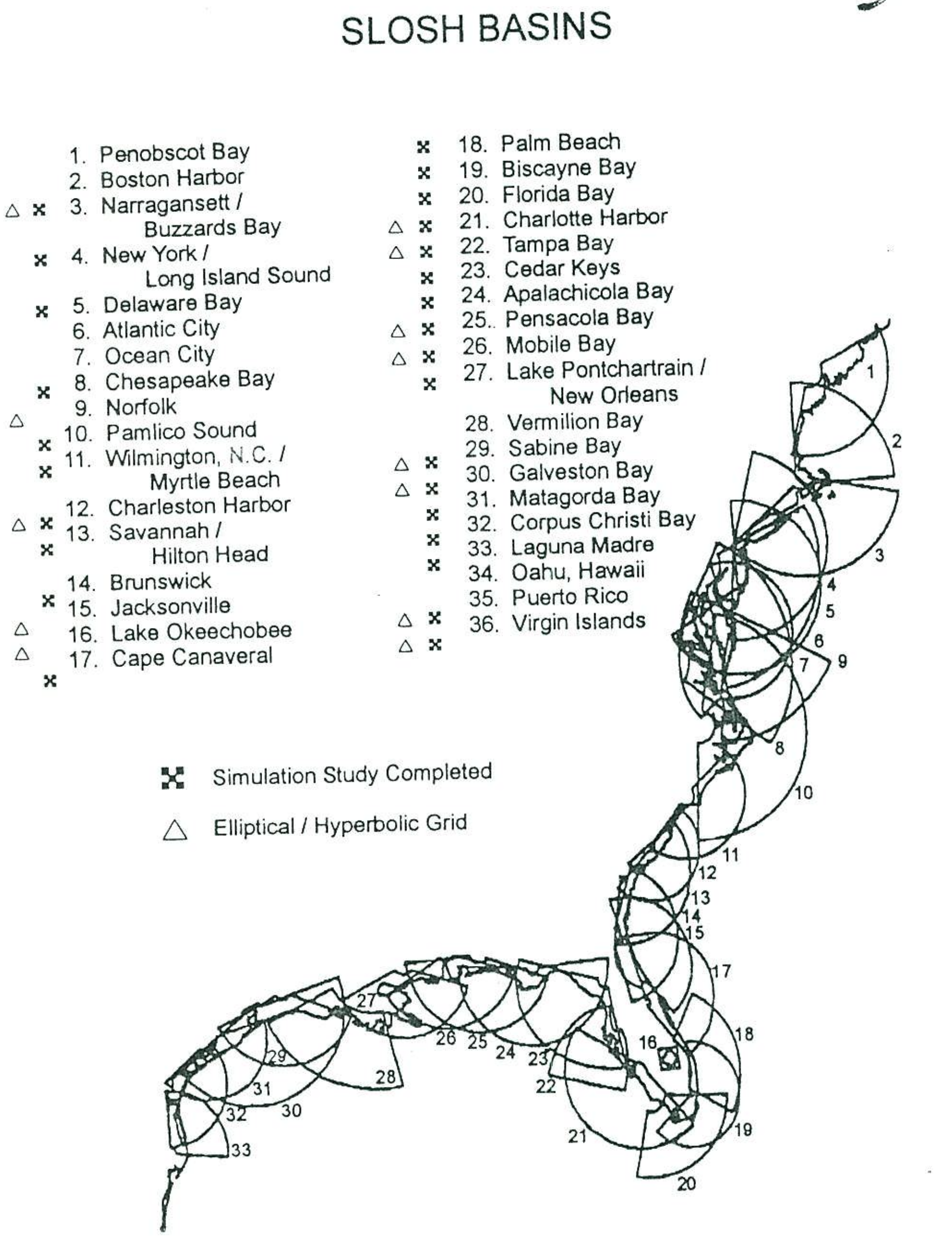


Figure 9. SLOSH basin coverage on the East Coast of U.S.A. Basins for which simulation studies have been completed are indicated by an asterisk.

to 36 hours. The domain of integration covers three main oceanographic regions on the U. S. East Coast - the Gulf of Maine, the Middle Atlantic Bight, and the South Atlantic Bight - and includes the Long Island Sound, the Delaware Bay, and the Chesapeake Bay (see Kim et al., 1996 for details).

Sea surface temperature analyses

Even though these are not products of forecast models, satellite-only SST analyses with different horizontal resolutions have been operationally produced by NOAA and distributed in chart form through the National Climate Data Center for the last several years. SST's are widely used for prescribing the bottom boundary condition in NWP models, for diagnostic marine boundary layer calculations that take into account stability effects, for Gulf Stream and Loop Current analyses, for inferring occurrence of fog, for fisheries applications, etc. This product would, probably, constitute the most reliable and routinely available oceanographic product for validation of SST forecasts produced by any hydrodynamic model adopted for COFS purposes.

These analyses are produced using MCSST (Multi-Channel SST) techniques that use measurements from infrared (IR), near-IR, and visible bands on the AVHRR aboard the Television Infrared Operational Satellite (TIROS) satellites of NOAA. Combinations of channel sums, differences, and ratios are used to screen for clouds and calculate SST's by means of algorithms described by McClain (1980) and McClain et al (1985). More recently, nonlinear MCSST equations have been derived which further improve the accuracy of the SST retrievals (Walton, 1993). Several different equations are used to process MCSST calculations depending on such variables as day/night, cloud cover, atmospheric moisture, etc. Different night and day time equations are applied to the sensors in order to derive the SST's. Approximately 75,000 daytime and 25,000 night time SST observations are calculated daily at a resolution of 8 km. Observations are located every 8 km (high density) along coastal areas of the U.S., every 15 km (medium density) in the Eastern North Pacific and Western North Atlantic, and every 25 km elsewhere (low density), as shown in Figure 10a.

Satellite SST observations are objectively analyzed at a number of spatial and temporal resolutions to produce gridded SST fields. A global analysis (100 km grid spacing) is produced daily, five regional analyses (50 km grid spacing) are produced weekly, and nine coastal analyses (14 km grid spacing) are produced twice a week. Figure 10b shows the locations of these various regions (including the Hawaii region, which also has a 14 km resolution product).

Tide and tidal current predictions

The NOS Tide and Tidal Current Tables and Charts are the main source of "water level" and "current" predictions in the United States. Published annually, these tables include the predicted times and heights of high and low waters for every day in the year for a number of reference stations and differences for obtaining similar predictions for numerous subordinate stations. All of the predictions are derived from observations. For tidal heights, historical water level observations have been made at six minute intervals at approximately 3400 locations and water level measurements continue to be made at approximately 190 locations in the NWLON. The duration of observations varies but control stations are typically maintained for at least a tidal epoch (19 years), with many reference stations having record histories many decades long. Measurements are typically taken at subordinate stations for a month.

Current measurements have been taken at varying durations for tidal current predictions (e.g. from hourly pole observations to 15-minute current meter observations

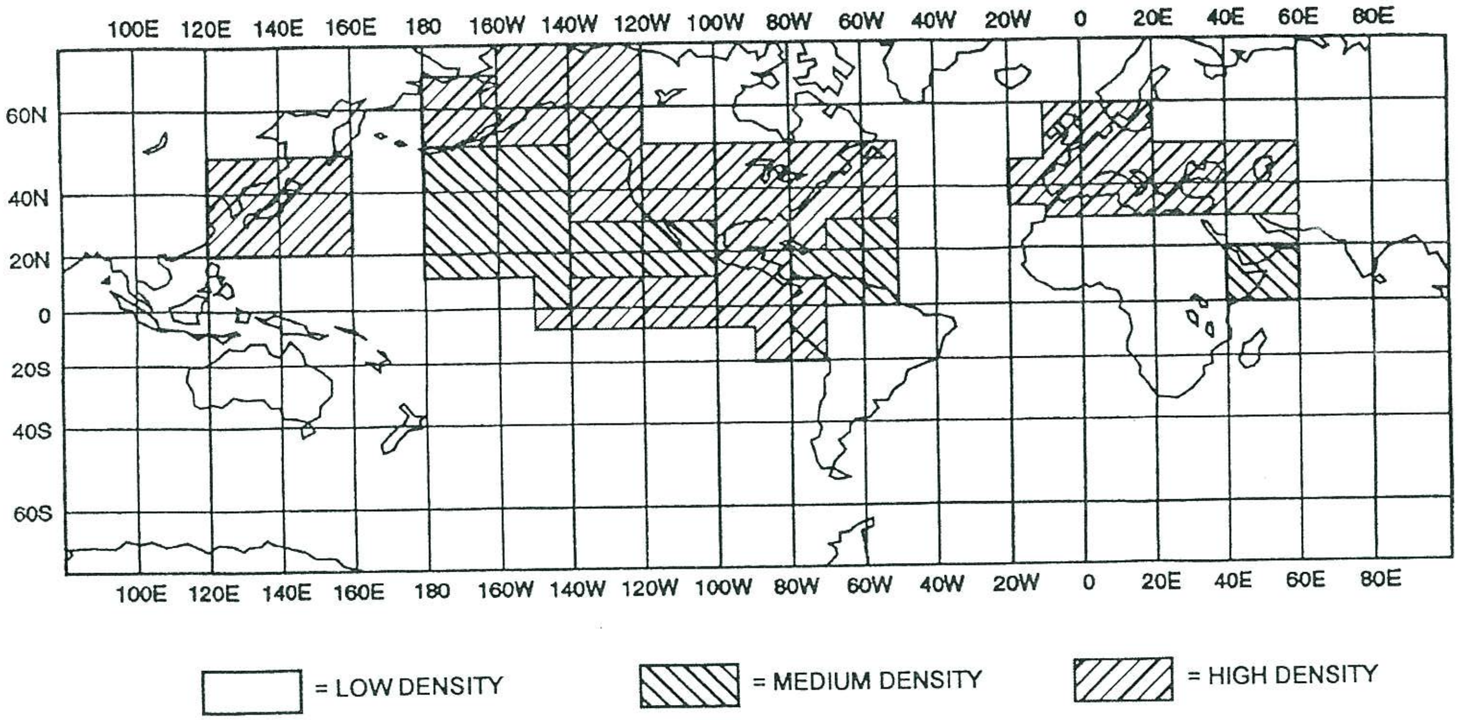


Figure 10a. Geographical regions with associated SST observation sample densities.

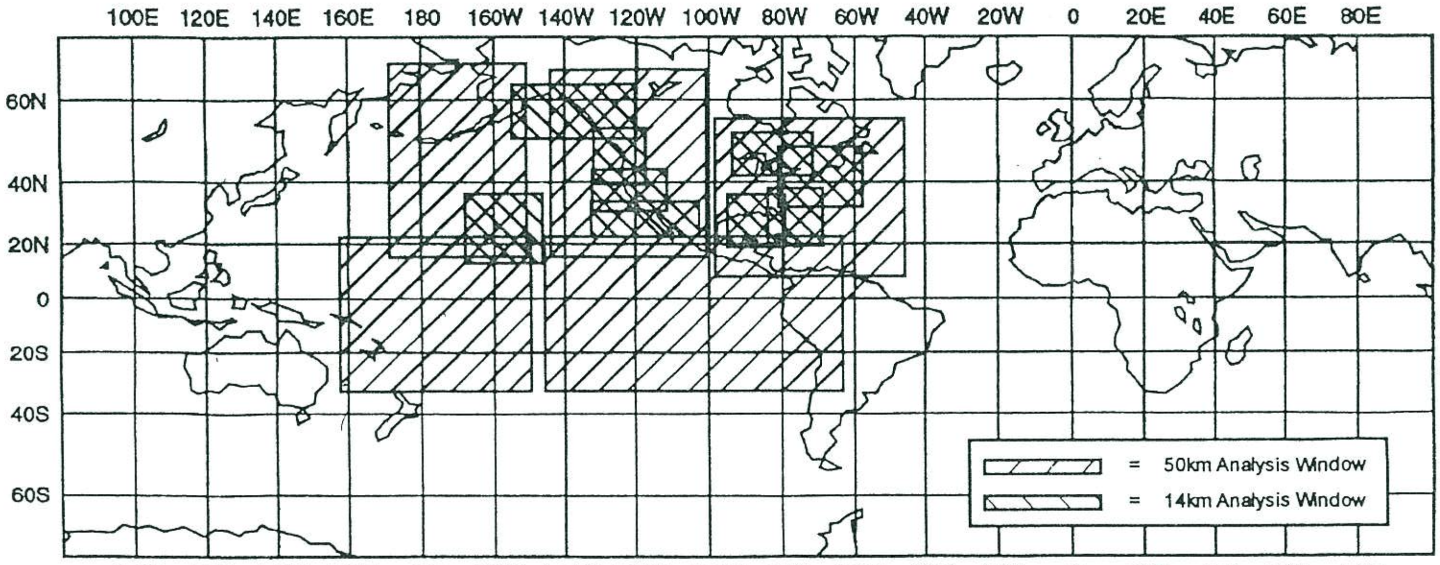


Figure 10b. Domains of 50 km and 14 km satellite only SST analyses.

to monthly current meter deployments) at approximately 2800 locations. The duration of historical observations are typically a month for reference stations and a few days for subordinate stations. Ongoing current measurement programs presently exist at the four NOS PORTS sites in Tampa Bay, the Port of New York/New Jersey, San Francisco Bay, and Galveston Bay (see Section III.A.6). Up to date information on tide and tidal current measurements and predictions are available on the web at http://www.olld.noa.noaa.gov.

Each reference station's observed time series is harmonically analyzed to derive the tidal constituent amplitudes and phases for that location. Tidal height predictions are made from the constituents and compared with observations. In particular, the predicted tidal heights are compared with accepted values for observed mean high and mean lower low water datums, and the constituents are adjusted (usually less than a 3% adjustment) to reproduce those legal datums. Tidal current predictions are made from the constituents, compared with observations, and accepted for use without adjustment as there are no legally accepted "datums" for currents. For subordinate stations, the times of current or water level phases are referred either to the corresponding phases at a reference station, or both reference and subordinate station predictions are referred to the times of the moon's transit. From these analyses time differences for the subordinate stations relative to the reference station are derived for each tidal cycle event.

To satisfy the needs of the principal users in the marine community, the objective of NOS predictions is to reproduce the astronomically induced extreme values of water level and current speed. Predictions attempt to match the timing and amplitude of events such as high and low water, maximum flood and ebb, and minimum before flood and ebb. However, there are constraints inherent to the hard copy format of the Tide and Tidal Current Tables and Charts, thus NOS has embarked on the development of digital tidal prediction products. A totally harmonic, graphics-based tide and tidal current prediction product has been designed for the personal computer. This can eventually be combined with future electronic charts and the first application will be produced for San Francisco Bay.

Future Plans for COFS

It is clear that even though a comprehensive COFS, as discussed in Section 2, is not yet established, there do currently exist various activities, in different parts of NOAA, to meet the needs of the users to a certain extent. These efforts need to be expanded, integrated, and coupled in a multi-disciplinary manner in the future to produce the COFS envisioned in Section 2. Since it is difficult to make precise projections on how effectively and how fast these efforts would progress, we limit ourselves to presenting a brief outline of some of the activity currently underway at NOAA and of the actions on which emphasis would be placed in the near future.

Experimental COFS for the U.S. East Coast

A cooperative effort is underway between NOS, NCEP, Princeton University, NOAA's Geophysical Fluid Dynamics Laboratory and Coastal Ocean Program Office, and the U.S. Navy, to develop an operational forecast system for the U.S. East Coast (Aikman et al., 1996; Kelley et al., 1997). The objective of this effort is to develop short-term synoptic forecast capability of the physical state of the coastal ocean environment.

A model system has been implemented operationally at NCEP wherein 24-hour foreca surface momentum, heat and moisture fluxes are derived from NCEP's operation mesoscale Eta atmospheric model (see Section III.B.1) to drive a 24-hour forecast of a dimensional numerical hydrodynamic model (Blumberg and Mellor, 1987) for the enti U.S. East Coast. The ocean model output includes 3-dimensional currents, temperature and salinities, and surface elevations, that respond to the atmospheric forcing, ocean forcing through conditions specified on the open boundaries of the model domain, riv runoff, and tides. Presently, available near-real-time data streams, including coast water level gauge data from NOS's NGWLMS (see Section III.A.5), MCSST data fro NESDIS (see Section III.B.6) and in-situ SST data from fixed and drifting buoys ar ships of opportunity, and TOPEX/Poseidon and ERS-2 altimetry data, are being us operationally in the East Coast COFS. Initially, these data sets are being used f evaluation purposes, but SST data assimilation has begun, and eventually all three da types will be assimilated into the operational ocean model.

Originally, the strategy in the East Coast COFS was to establish some level operational predictability without data assimilation, and thus feasibility, and this has be done (Aikman et al., 1996). Following that, the strategy is to complete the developme of data assimilative capability, to couple the "whole coast" forecast system to region forecast systems, such as the NOS systems under development in the Port of NY/NJ ar in the Chesapeake Bay (see Section III.A.6), and to establish the means of disseminati of useful nowcast and forecast information to users. An overview of the East Coa COFS results to date are summarized below.

Evaluation

A thorough evaluation of two years (September 1993 to October 1995) of foreca output on subtidal coastal water levels and SST is nearing completion (Schultz a Aikman, 1996). Comparisons of the 24-hour forecast subtidal water level at the model shoreward boundary to observations along the coast are encouraging (Aikman et a 1996). The observed and forecasted water levels exhibit a meridional average correlati coefficient of 0.75 and an average RMS difference of ~11 cm. The ratio of the forecas to-observed standard deviations also indicates that the ocean model under-represents t subtidal variability, on average, by less than 5% (see Table 1). A comparison of foreca SST with MCSST and buoy data indicates that the worse errors in the forecast a associated with the mesoscale variability of the Gulf Stream. The RMS error at fi buoy locations averages 1.2 degrees Celsius and the correlations suggests that t forecast is highly correlated with the observations at seasonal time scales but less so shorter time scales or in dynamic regimes where the mesoscale variability dominates.

These results provide a benchmark of model performance with which to measure th success of present and future efforts that include the inclusion of tides as a physic process, the assimilation of SST and altimeter sea surface height data, and th establishment of a nowcast cycle to reinitialize the model before each forecast cycle.

Tidal model

A least squares technique has been developed and tested to solve for the op boundary tidal amplitude and phase such that tidal errors at the coast are minimize

Table 1. Root Mean Square (RMS) differences, correlation coefficients, and the ratio of the model-to-observed standard deviations from two years (October 1993 to September 1995) of 24-hour simulated and observed subtidal water levels. Only the ten NOS coastal water level gauges that retained two years of continuous data were used in these calculations.

Coastal Station	RMS Difference (meter)	Correlation Coefficient	Ratio Model: Obser Standard Deviation
Portland, ME	.099	.667	1.073
Newport, RI	.099	.721	1.082
Sandy Hook, NJ	.108	.809	1.058
Atlantic City, NJ	.112	.798	.978
Lewis, DE	.110	.801	0.969
Chesapeake Bay Bridge Tunnel	.126	.725	0.963
Duck, NC	.114	.731	0.862
Springmaid Pier, SC	.121	.700	0.935
Fort Pulaski, GA	.120	.788	0.792
Saint Augustine, FL	.120	.728	0.792
Average	.113	.747	0.961

(Chen & Mellor, 1997; see Chapter 14). The method reduces the RMS error by 20% for the M_2 tide and 30% for the K_1 tide, relative to the results using Schwiderski's (1980) global ocean tide model as boundary forcing. The technique has been tested for the East Coast COFS ocean model and was implemented operationally in November 1996. In the tidal model the 3-dimensional ocean model code has been modified to include celestial body forces in the momentum equations, as well as the specification of the amplitude and phase of the elevation, or the vertically averaged velocity, of each tidal constituent at each point on the open boundary. While forcing the open boundaries with the tidal oscillations, it is essential to maintain the mean inflows and outflows so that, for example, the Gulf Stream is simulated correctly. Although this problem has been addressed in the methodology implemented in the East Coast COFS, research continues on this open boundary specification problem.

Data assimilation

The East Coast COFS systematic errors described above are, to some degree, the result of the one-way coupling with the Eta atmospheric model and/or ocean model deficiencies. SST, SSH (sea surface height) data from altimetry and surface current data assimilation are likely to provide substantial improvements to model forecast skill and eliminate some of these problems.

SST data assimilation is being operationally tested now in a parallel run at NCEP. The system is based on two data assimilation schemes (Kelley and Behringer, 1997). First, observed temperatures are assimilated into the model's top layer following the method of Derber and Rosati (1989). A correction field is applied to the model temperature field at each model time step. The correction field is determined by an optimum interpolation scheme framed as an equivalent variational problem (Behringer, 1994). The functional has two terms: one is a measure of the fit of the corrected temperature field to the model temperature field and the other is a measure of the fit of the corrected temperature field to the observations. The solution is a correction field which balances information from the observations and the model. Next, surface temperature corrections are projected into the mixed layer following the method Chalikov et al. (1996).

The experimental assimilative version now being tested at NCEP assimilat real-time *in situ* and remotely sensed SST observations. An example of the COI domain SST and 1 meter current simulation for 0000 UTC on January 31, 1997 is shov in Figure 11. This version of the model includes SST data assimilation and tides, as w as surface forcing derived from the NCEP 29-km Eta atmospheric forecast model. The *situ* observations include reports from drifting and moored buoys and the remote sensed observations consist of MCSST retrievals. The number of retrievals in the Ea Coast COFS domain on a particular day varies from approximately 1000 to 60(observations. In the future, the data used for assimilation will also include subsurfa temperatures (i.e. expendable bathythermographs). The data assimilation system w form the basis of an East Coast COFS nowcast/assimilation cycle to generate a dai three-dimensional nowcast. The nowcast will reestablish the initial conditions for tl daily 24-hour forecast.

Data assimilation experiments (Ezer and Mellor, 1997) indicate that the assimilatic of SST and SSH together yields smaller errors at all depths than the assimilation of ea data type alone. In the upper layers surface temperature is a more effective source data, while in the deep ocean surface elevation is a more effective source of data. NOA has recently obtained access to near-real-time TOPEX/Poseidon and ERS-2 altimetry ar SSH data assimilation experiments are getting underway. It is expected that the additic of SSH assimilation will have the largest impact in the Gulf Stream region, where SS gradients are largest. It is precisely in this region of large mesoscale variability that tl predictability of the ocean model is lowest (Sheinin and Mellor, 1995) and, thus, whe the ocean model needs the most correction (Schultz and Aikman, 1996).

Once the data assimilation system is tested and ready to be made operational, tl East Coast COFS will introduce a nowcast system such that a 24 to 48 hour nowcast wi be run using analyzed winds from the Eta model data assimilation system. This wi insure that the daily forecasts will begin from the "best" initial state available (i.e. nowcast; presently the East Coast COFS runs a series of forecast cycles and the ocea model is never reinitialized or updated with data). The nowcast/forecast cycle will b implemented after the data assimilation cycle in place.

Product development and information dissemination

NWS and NOS are currently engaged in an outreach effort to inform commercial government and recreational marine users, educators, and the general public about th East Coast COFS products. The outreach will involve a national workshop, continue development of a web site (see below), and an on-line archive of model output. Digita output will be available on-line for approximately three months via NOAA's Nationa Oceanographic Data Center server. The output will be stored in the Worl Meteorological Organization's GRIdded Binary (GRIB) format on both sigma model layers and at many standard and supplemental depths. Software and instructions fo decoding GRIB files will be available from the World Wide Web site. After the dat assimilation cycle is implemented in the East Coast COFS, the output will be mad available to NWS Weather Forecast Offices and NCEP's Marine Prediction Center fo evaluation. Eventually, the output will be accessible via the NWS Family of Service

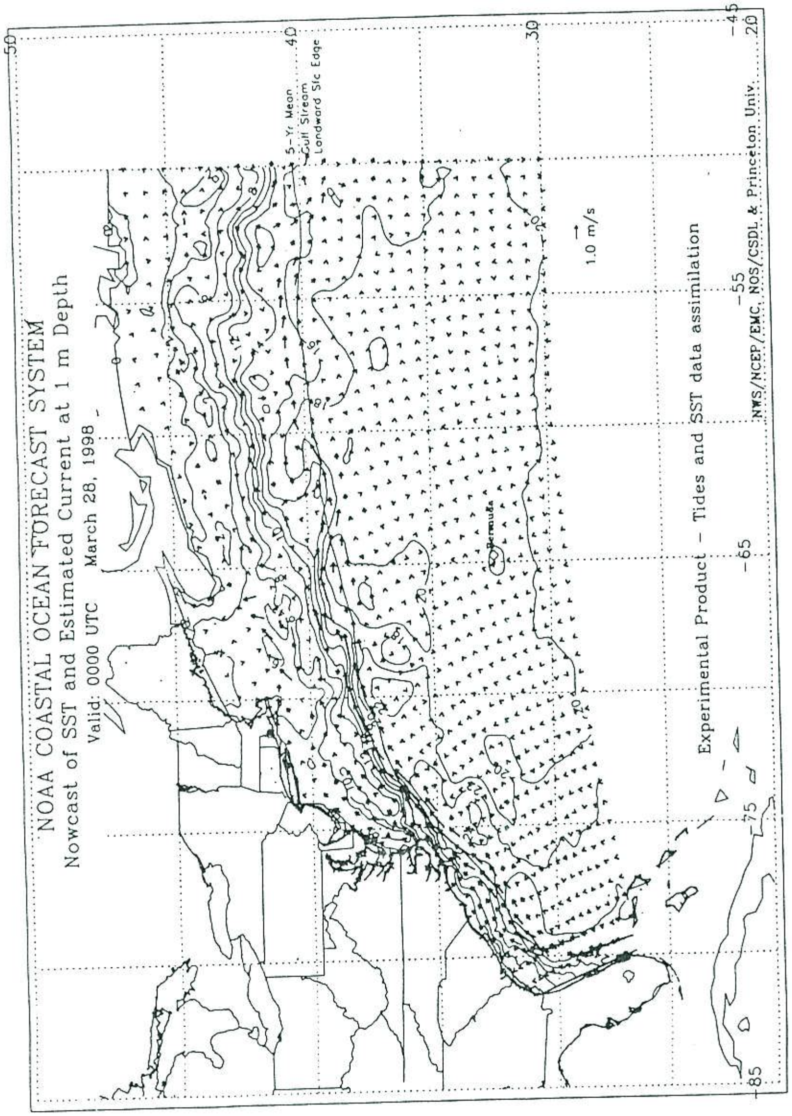


Figure 11. An example of the COFS domain SST and 1 meter current simulation for 0000 UTC on January 31, 1997. This version of the model includes SST data assimilation and tides, as well as surface forcing derived from the NCEP 29-km Eta atmospheric forecast model.

distribution network. See the COFS web site homepage under development http://polar.wwb.noaa.gov/develop/cfs/cfs.html.

Winds

Since winds are the primary driving force for waves, storm surges, and coastal ocea circulation, wind fields with high horizontal and vertical resolution in the marin boundary layer are needed over this domain. NCEP implemented a 29 km/38 laye resolution version of the Eta model in 1996 and future plans call for the implementatio of even higher resolution (e.g. 10 km) models for handling the small scale local effects i a better manner. As these higher resolution models are being implemented, thei forecasts of SLP, winds, temperatures, and moisture fields would be evaluated on continuing basis to further improve their performance with specific attention being pai to the physics of the marine boundary layer, its sensitivity to high resolution sea surfac temperatures, the impact of assimilating ocean surface wind data from satellites, and other aspects of the model physics. If the high resolution Eta model(s) succeed in meeting the desired requirements for meteorological fields, it would be immediately possible to exploit them for several different purposes.

Waves

Even though, at present, the WAM model is considered to be the leading third generation wave forecast model, there is still room for improvement in its numerics, physics, and model structure. In particular, the physics parameterizations in WAM need improvements in shallow water domains of the coastal areas as well as under fetch limited conditions. An important consideration with waves is to eventually couple the wave model to the coastal ocean model as well as the Eta model. The sea state and wave age influence the fluxes across the air-sea interface (Chalikov and Belevich, 1993). Also, wave fields carry momentum acquired in far away regions into the shallow areas of the coastal ocean and release the momentum when they break. This constitutes an important driving force for currents near the coasts and they also contribute to an increased water level on the beach effecting inundation considerations. The operational coupling of an atmospheric model, coastal ocean hydrodynamic model, and wave model would constitute the first truly integrated physical component of a COFS.

Ocean Surface Currents From Feature Tracking

Ocean surface currents can be estimated using sequential imagery to determine the displacements of selected ocean features over the time interval between the images. Initially, the thermal IR imagery from the AVHRR on board NOAA's polar orbiting satellites has been used to conduct the tracking. Ocean color, when it becomes available, would prove to be another, perhaps more valuable, source. The technique is particularly suitable for coastal areas since navigation errors in earth-locating the features can be handled very accurately. The technique, in concept, is the same as that used in meteorology to estimate cloud track winds from geostationary satellites. This technique (Breaker et al., 1994) offers the potential for acquiring synoptic scale coverage of the surface circulation in coastal areas on a quasi-continuous basis due to limitations imposed by cloud cover.

Outlook

Focusing the attention in the near future on the forecasts of the physical variables in the atmospheric and oceanic components of the COFS, it should be noted that the spectrum of user activities in the coastal areas spans a wide range. It involves people engaged in commercial activities to exploit living and non-living resources as well as recreational activities. It involves structures of differing sizes and navigation by ships and boats of widely varying sizes. In order to protect this investment of humans and resources, it is essential to provide reliable forecasts under all weather and ocean conditions, since the threshold of dangerous meteorological or oceanographic conditions depends on the activity and this threshold varies over a large range. Hence, in the coastal area accuracy and space-time resolution requirements are more stringent for forecast fields as compared to an open ocean domain which is primarily traversed by large ships.

The improvements in the performance of the models depend on factors such as improving various aspects of a model's physics, parameterizations, and numerics, as well as on the availability of high quality data with the necessary temporal and spatial resolutions for assimilation into the models to improve the initial conditions. These data also serve the purpose of evaluating the model performance and isolating problems in the model formulations. Deployment of conventional *in situ* observing sensors at the required resolutions to satisfy the data needs of COFS would be prohibitively expensive. The alternative is to exploit the advantages of remotely-sensed measurements from various satellite-borne sensors. In view of the problems associated with geophysical retrievals from satellite sensor measurements, more emphasis should be placed on developing robust methods for developing high quality geophysical parameter values by exploiting new techniques, such as the neural networks. Since most of the satellite measurements reflect only the ocean surface parameters, it is necessary to develop innovative data assimilation techniques that would project the surface properties into the internal dynamics of the ocean model.

The physical state of the coastal ocean plays a dominant role in governing the internal dynamics of the food chain in the ecosystem. To understand and predict marine productivity, it is necessary to develop an improved capability to model the coupling of the physical oceanographic processes with those of the marine food web. We do not yet have a clear understanding of the interaction between physical, chemical and biological processes in the water column and their space-time scales. However, we first need to develop reliable coupled atmosphere-ocean circulation-ocean wave forecast models before proceeding to couple other disciplines to the system. Accomplishment of even this limited objective in the near future, within the overall goal of a comprehensive COFS, would certainly prove to be beneficial in its own right. It offers a valuable tool to coastal communities, with the desired temporal and spatial resolutions, to get more accurate and timely warnings which would permit them to take preventive actions to reduce loss of life and property damage, as well as to respond quickly to cases of toxic spills and search and rescue missions.

Some of the most important activities that need to be pursued to fully utilize the benefits of a COFS, and to advance our understanding of inter-disciplinary coupling, are to vigorously interact with the user community in learning their needs, to educate them on the utility and limitations of the COFS-produced products, and to ensure that the products are delivered in a timely and readily useable form. Perhaps most importantly, it is necessary to get regular feedback from the users on how these physical model-base products have been of use and in developing, with their assistance, a data base for th eventual coupling with non-physical (e.g. water quality, ecosystem, biological an chemical) models and coastal concerns.

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http://polar.wwb.noaa.gov:	Analysis and forecast products dealing with ocean surface winds, waves and polar ice.
http://www.olld.nos.noaa.gov:	National Water Level Network data; PORTS; tide and tidal curren predictions.
http://www.ceob.nos.noaa.gov:	Regional (PORTS) nowcast and forecast systems.
http://polar.wwb.noaa.gov/cfs/cfsprod.html:	East Coast COFS.