NOAA Science Advisory Board

Review of

National Center for Environmental Prediction
Ocean Modeling

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Honorable Conrad C. Lautenbacher, Jr., USN (Ret.)
Under Secretary for Oceans and Atmosphere
National Oceanic and Atmospheric Administration
Department of Commerce, Room 5128
14th and Constitution Avenue, NW
Washington, DC 20230

Dear Admiral Lautenbacher: Conrad

This is the letter of transmittal of the NOAA Science Advisory Board commissioned and approved final report of the National Center for Environmental Prediction Ocean Modeling Review Panel. The report is attached.

The Ocean Modeling Review Panel consisted of national experts in ocean modeling and was convened by the NOAA Science Advisory Board in July, 2003. The Board acted at the requests from the National Weather Service chain of command at that time, General John Kelly and Dr. John Hays via Dr. Louis Uccellini. The SAB was asked to evaluate NCEP's existing capability and capacity for "ocean modeling" and for recommendations on what could and should be done to ensure that NCEP's operational forecasts are optimal. The study was conducted in the late fall of 2003 and early spring of 2004. The University Corporation for Atmospheric Research facilitated the panel visit to NCEP headquarters and follow-up meetings. In July of 2004 the SAB approved the report with minor modifications; which were accepted at the November 2004 Board meeting.

The Review Panel was given the following two part charge:

1. To provide an assessment of the current ocean modeling activities at the National Centers for Environmental Prediction (NCEP)'s Environmental Modeling Center (EMC) including those that support global, regional and coastal applications for Climate, Weather and Marine forecasts.

2. To provide a review of, and specific recommendations for, EMC's future plans for the improvement of Ocean Models used operationally in NOAA, including the proposed approach for the next generation Modeling System based on the multi-agency Earth System Modeling Framework.

In meeting the Charge, the OMRP has reviewed NCEP forecast capabilities, resources, and aspirations. In its investigation and subsequent findings, the Panel made the following three recommendations:

1) In-situ and remote-sensing observations and models of air-sea interactions over a broad range of time and space scales dictate the need for the coupling of ocean, coastal ocean and Great Lakes models to atmospheric models. The coupled modeling will enhance the forecast capabilities for the atmosphere, the ocean, and coastal ocean and Great Lakes, in the context of a whole earth system model framework. Thus ocean, coastal ocean and Great Lakes modeling must be fully integrated into operational weather, climate, hydrologic and earth system forecasts.

2) NCEP is presently the major governmental provider of atmospheric forecast enabling capacity in the United States and thus delivers services of significant social and economic value to the Nation. To maintain this preeminence, particularly given the nation's growing needs in the ocean and coastal regions, NCEP must develop internal and external partners committed towards implementing two-way, interactively coupled ocean-coastal-atmosphere models for its operational forecasts, which will result in additional products and capabilities of social and economic value to the United States.

3) In order to move forward aggressively, and to most efficiently and effectively make accurate and comprehensive weather, climate, water and marine forecast forecasts and warnings, NCEP must develop a comprehensive strategy with the ocean community, including academia, private industry, and all appropriate federal entities, both external and internal, to capitalize on existing and developing ocean and coastal observations and models. Further NCEP must lead in the merging of models and data via data assimilation, and in the applications which ensue.

The SAB is confident that the findings and recommendations of the NCEP Ocean Modeling Panel could foster a future NCEP the value of whose services would be greatly enhanced by including operational ocean and coastal forecasting in its mission and routine responsibility. The SAB accepts the rationale that this inclusion will result in improved atmospheric forecasts, products and services and capabilities for the Nation and in addition will deliver a new suite of greatly needed global ocean, coastal ocean and Great Lakes forecast products above and beyond those produced at any of its peer organizations.

The SAB acknowledges the University Corporation for Atmospheric Research staff, Ms. Meg Austin and Ms. Susan Baltuch, who facilitated the review process. All travel and meeting arrangements for each and all panel members and communications and materials distributions were handled professionally and promptly.

The Board also acknowledges that NCEP Headquarters was responsive in providing any and all support material deemed necessary by the Panel to conduct this review. This included all NCEP presentation materials, strategic planning documents, and

access to staff and facilities, as well as detailed spending documents contained within the NCEP Technical Operating Plans. The Board and members of the Panel feel that an important signal about the professionalism of an organization being reviewed is the level of cooperation demonstrated by those being reviewed. NCEP management and personnel receive high marks for this.

With very best regards,

Leonard J. Pietrafesa, PhD

cc: DUS – J. Kelly	(DUS)
J. Hayes	(W/OST)
D. L. Johnson	(W)
R. Spinrad	(N)
L. Uccellini	(W/NP)
F. Aikman	(N/CS13)
R. Anthes	
M. Uhart	(R/SAB)

1.0 Executive Summary

In response to a request from the National Oceanic & Atmospheric Administration (NOAA) National Weather Service, an Ocean Model Review Panel (ORMP) was commissioned by the NOAA Science Advisory Board (SAB), to address the following two-part Charge:

1. To provide an assessment of the current ocean modeling activities at the National Centers for Environmental Prediction (NCEP)'s Environmental Modeling Center (EMC) including those that support global, regional and coastal applications for Climate, Weather and Marine forecasts.

2. To provide a review of, and specific recommendations for, EMC's future plans for the improvement of Ocean Models used operationally in NOAA, including the proposed approach for the next generation Modeling System based on the multi-agency Earth System Modeling Framework (ESMF).

In meeting the Charge, the OMRP has reviewed NCEP forecast capabilities, resources, and aspirations. In its investigation and subsequent findings, the OMRP makes the following three recommendations:

1) In-situ and remote-sensing observations and models of air-sea interactions over a broad range of time and space scales dictate the need for the coupling of ocean, coastal ocean and Great Lakes models to atmospheric models. The coupled modeling will enhance the forecast capabilities for the atmosphere, the ocean, and coastal ocean and Great Lakes, in the context of a whole earth system model framework. Thus ocean, coastal ocean and Great Lakes modeling must be fully integrated into operational weather, climate, hydrologic and earth system forecasts.

2) NCEP is presently the major governmental provider of atmospheric forecast enabling capacity in the United States and thus delivers services of significant social and economic value to the Nation. To maintain this preeminence, particularly given the nation's growing needs in the ocean and coastal regions, NCEP must develop internal and external partners committed towards implementing two-way, interactively coupled ocean-coastal-atmosphere models for its operational forecasts, which will result in additional products and capabilities of social and economic value to the United States.

3) In order to move forward aggressively, and to most efficiently and effectively make accurate and comprehensive weather, climate, water and marine forecast forecasts and warnings, NCEP must develop a comprehensive strategy with the ocean community, including academia, private industry, and all appropriate federal entities, both external and internal, to capitalize on existing and developing ocean and coastal

observations and models. Further NCEP must lead in the merging of models and data via data assimilation, and in the applications which ensue.

The OMRP is confident that its findings and recommendations could foster a future NCEP the value of whose services would be greatly enhanced by including operational ocean and coastal forecasting in its mission and routine responsibility. The OMRP reasons this inclusion will result in improved atmospheric forecasts, products and services and capabilities for the Nation and in addition will deliver a new suite of greatly needed global ocean, coastal ocean and Great Lakes forecast products above and beyond those produced at any of its peer organizations.

On behalf of The University Corporation for Atmospheric Research (UCAR), Ms. Meg Austin and Ms. Susan Baltuch facilitated the review process. All travel and meeting arrangements for each and all panel members and communications and materials distributions were handled professionally and promptly. UCAR and its two lead facilitators for this review are applauded by the Panel for making the entire experience rewarding for the Panel.

The Panel also notes that NCEP Headquarters was responsive in providing any and all support material deemed necessary by the Panel to conduct this review. This included all NCEP presentation materials, strategic planning documents, and access to staff and facilities, as well as detailed spending documents contained within the NCEP Technical Operating Plans (NTOPs). The Panel feels that an important signal about the professionalism of an organization being reviewed is the level of cooperation demonstrated by those being reviewed. NCEP management and personnel receive high marks for this.

This report is in keeping with the discussion from the Panel meetings and considerable communications between Panel members and represents the summary of the Review Panel's findings and recommendations and has been assessed for correctness by the Director of NCEP.

2. Introduction

The NCEP Ocean Modeling Review Panel (NCEP OMRP) was commissioned by the NOAA Science Advisory Board (SAB) in July 2003, to review the present ocean science and technology operational prediction capability and future capacity that exist within NCEP and to make recommendations regarding the appropriateness and strategy of NCEP to advance that capability. (Because of Panel member schedules, the first and second meetings of the entire group could not be held until mid-November and mid-January).The Charge was twofold:

1) To provide an assessment of the current ocean modeling activities at the NCEP Environmental Modeling Center (EMC) including those that support global, regional and coastal applications for Climate, Weather and Marine forecasts

2) To provide a review of, and specific recommendations for, EMC's future plans for the improvement of Ocean Models used operationally in NOAA, including the proposed approach for the next generation Modeling System based on the multi-agency Earth System Modeling Framework.

The OMRP met at NCEP headquarters and UCAR arranged locations for an evening and two full days (11-13 November 2003), with the first day spent gathering information about the varied activities across the distributed NCEP, as well as information about the work environment, attitudes particularly toward new ideas and approaches, and enabling capacity to deliver needed operational forecasts. The second day was spent in internal Panel discussions and analyses with communications with NCEP as necessary.

The OMRP (entire committee along with UCAR facilitators M. Austin and S. Baltuch and NCEP representatives, Dr. L. Uccellini, Dr. S. Lord and Dr. D. Johnson) met the morning of 13 January, 2004 during the American Meteorological Society annual meeting in Seattle, WA, to discuss the status of the Panel's findings and recommendations and to plan for completion of the panel report.

On March 17, the preliminary draft report was presented to the NOAA SAB and their comments have been incorporated into this final report. The principal concern was the relationship between NCEP and the National Ocean Service (NOS), especially between NCEP's modeling and NOS's emerging operational forecast enterprise. Another concern was incorporation of recommendations derived from the Draft of the U.S. Commission on Ocean Policy Report (COPR), which became available on 20 April, 2004. Finally, the SAB was concerned about the socio-economic based activities of NCEP. The panel has since obtained information on all NOS modeling activities and has summarized them briefly. The Panel has also assessed the findings and recommendations of the COPR and has incorporated recommendations of the (COPR), as appropriate, into this final report.

The OMRP has not considered the preliminary findings and recommendations of the NOAA Research Review Team Report because of the timing of the two reports.

Finally, the OMRP notes that the U.S. Department of Commerce (DOC), the parent department of NOAA, recently released the results of a DOC commissioned study entitled *Partners on a Mission: Federal Laboratory Practices Contributing to Economic Development*. The study focused on the viability and great value of federal laboratories as seed beds for the facilitation of technology transfer for innovation, entrepreneurship, and new industries. The DOC study reviewed the policies and protocols pertaining to nine case studies of technology transfer, all of which have become highly successful. Curiously, NOAA laboratories and centers are not included in the highlighted case studies. In fact, NOAA is not mentioned in the DOC document. Here the OMRP reasons that NCEP, together with its partners can become a progenitor for new economic development in the rapidly emerging industry of the commercialization of weather, climate, air and water quality and ecosystem information, product and service derivatives. NCEP and its partners hold potential for moving model data and information into the arena of products and services in keeping with the *Crossing the Valley of Death* and the

Fair Weather reports of the National Research Council (NRC) because its mission requires that it be timely, accurate, thorough and routine, and as such, is truly "operational".

3. Background

"The National Center for Environmental Prediction (NCEP) was re-named (in 1995*) after it was determined that NOAA required a unit with a name that was 'extensible' in keeping with its mission" (direct quote of Dr. R. McPherson, formerly the Director of NCEP and presently the Executive Director of the American Meteorological Society). (* It was formerly known as the National Meteorological Center or NMC).

NCEP's Mission Statement is to deliver national and global weather, water, climate and space weather guidance, forecasts, warnings and analyses to its Partners and External User Communities. These products and services respond to user needs to protect life and property, enhance the Nation's economy and support the Nation's need for growing environmental information (www.ncep.noaa.gov)

NCEP's vision is to serve as the Nation's 1st choice for global and national climate and weather analyses, forecasts and guidance; to be the Nation's source of 1st alert for all climate, weather and space weather hazards; and to be the preferred partner in developing numerical model and new weather, water, climate and space weather products and services. NCEP considers that its future is built on: improving its forecasts by employing and exploiting climate-weather-water linkages; producing a seamless suite of products through a collaborative approach; extending the predictability of weather and climate; improving forecasts of extreme events; creating a common model infrastructure; and addressing uncertainty in forecasts.

NCEP, which is located in the National Weather Service (NWS) line of NOAA, consists of a constellation and distributed network of eight Service Centers (refer to Figures 1, 2), with seven of the centers networked to the Environmental Modeling Center through Central Operations. These centers report to the NCEP Office of the Director. These centers are presently staffed by a total of 375 Full Time Equivalent permanent employees of the U.S. government (FTEs) and an additional 155 Contractors and Visitors (C/Vs). With the addition of the Space Environment Center on 10/04 the total number of FTEs will rise to 426 and C/Vs to 160. For perspective on location, function and relative size, a brief summary of each of these centers with numbers of personnel is:

- The Office of the Director (NDO, Camp Springs MD) directs, oversees and coordinates NCEP budgets, personnel and planning (9 FTEs and 1 C/V = 10)
- Central Operations (CO, Camp Springs MD) operates the central computing and information facilities, oversees data management, quality assessment and control, and product production (75 FTEs and 32 C/Vs = 107)

- The Aviation Weather Center (AWC, Kansas MO) provides aviation warnings and forecasts of hazardous flight conditions at all levels within domestic and international air space (54 FTEs and 10 C/Vs = 64)
- The Climate Prediction Center (CPC, Camp Springs, MD) monitors and forecasts short-term climate fluctuations and provides information on the possible effects on the Nation (50 FTEs and 30 C/Vs = 80)
- The Environmental Modeling Center (EMC, Camp Springs MD) is the center for operational model output and is really the hub of operational forecast model output production (47 FTEs and 75 C/Vs = 122)
- The Hydrometeorological Prediction Center (HPC, Camp Springs, MD) provides analysis and forecast products, focusing on quantitative precipitation out to five days, weather guidance out to seven days, real time weather model diagnostics discussions, and surface pressure and frontal analyses (43 FTEs and 1 C/V = 44)
- The Ocean Prediction Center (OPC, Camp Springs, MD) issues marine weather warnings out to five days in graphical text for the Atlantic and Pacific coasts north of 30N (24 FTEs and 0 C/Vs) = 24); but its title may be somewhat of a misnomer
- The Space Environment Center (SEC, Boulder, CO) provides space weather alerts and warnings of electro-magnetic and solar radiation disturbances (51 FTEs and 5 C/Vs) = 56)
- The Severe Storms Prediction Center (SPC, Norman, OK) provides thunderstorm, tornado and severe weather watches over land for the contiguous U.S. along with a suite of hazardous weather forecasts, mesoscale guidance products and a continuous watch on mesoscale atmospheric processes related to severe weather outbreaks, extreme winter weather and fire weather (32 FTEs and 4 C/Vs = 36)
- The Tropical Prediction Center (TPC, Miami, FL) provides forecasts of tropical weather systems, issue watches and warnings and marine forecasts for the U.S. and surrounding areas of the Tropical Pacific and Atlantic Oceans and Gulf of Mexico south of 30N (41 FTEs and 2 C/Vs = 43)

Diversity information is provided for the 363 positions of the 375 FTE positions (12 are open presently) across NCEP as a whole. The ratio of male to female is 297 to 66 or 82% to 18% (~ 4/1). The ethnicity of the permanent employee pool is: 299 are White (82.4%), 20 are African American (5.5%), 12 (3.3 %) are Hispanic, 31 are (8.5%) Asian Americans and or Pacific Islanders and 1 (.03%) are Native American. (NCEP contractors may have varying distributions but the Panel did not request this information).

NCEP provides numerical model guidance to support the Weather Forecast Offices (WFOs) and River Forecast Centers (RFCs) across the Nation including: severe storm outlooks, fire weather outlooks, weather forecasts out to Day 7, quantitative precipitation forecasts, marine weather discussions and model output discussions. NCEP produces a product line which includes: surface analyses, severe weather watches, hurricane watches and warnings, aviation forecasts and warnings, climate forecasts, marine high seas watches and warnings and space weather watches and warnings. NCEP also provides underlying development and operational support to global and regional models, data assimilation methodologies, ensemble forecast systems and computer and network operations.

NCEP's presently stated strategic goals and objectives include: a) the improvement of products and services by anticipating user needs and striving to exceed expectations in product development and delivery; b) the capitalization of scientific and technological advances by increasing collaboration with the world's leading scientists in development of improved products, services and numerical models; c) the exercising of global leadership by serving as a catalyst to reduce the impacts of weather related natural disasters world wide through applied partnerships, applied research, training and technology transfer; d) the focusing of the NCEP organizational culture by embracing change, valuing service and promoting teamwork with users, partners, and internally; and e) the management of NCEP resources more effectively by optimizing their use.

NCEP's outreach can be measured in multiple ways, for example by: its web site hit rate which is in the 10s of millions per month; its student programs typically with more than 20 student interns, many from minority serving institutions (e.g., Howard and Clark Atlanta Universities and the University of Puerto Rico-Mayaquez); its forecaster exchange program such as those in SPC and EMC; its hosting of the CPC Diagnostics and Prediction and SPC Severe Weather Workshops and Conferences; its Hurricane Awareness Tours such as recent TPC visits to Belize, Costa Rica, Mexico, Honduras, the Dominican Republic and Puerto Rico; and its International Desk Program in which training, tools, services are provided on-site in Camp Springs to visitors, continually in residence. However, there are no comparable programs for the ocean prediction aspects of NCEP.

Figure 1

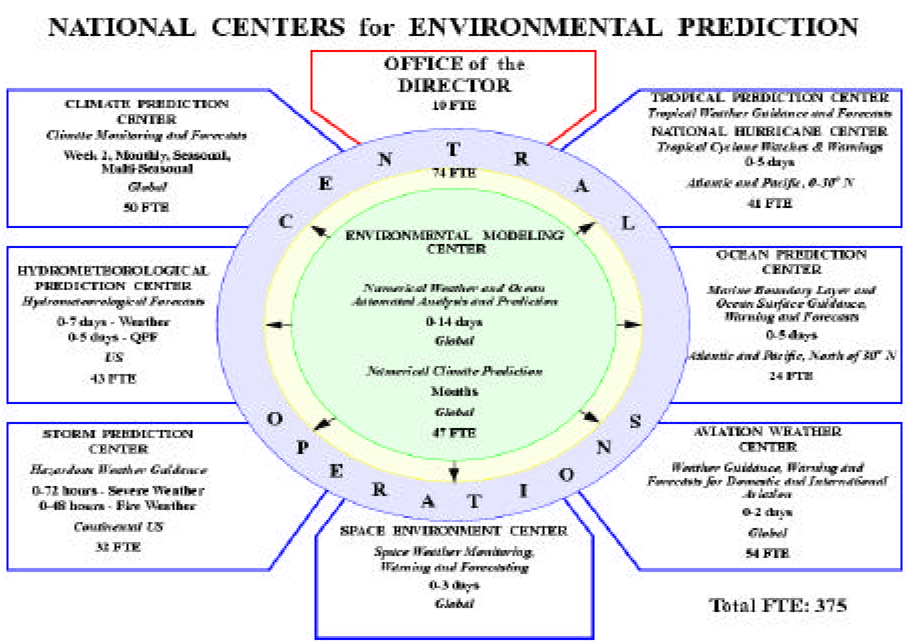
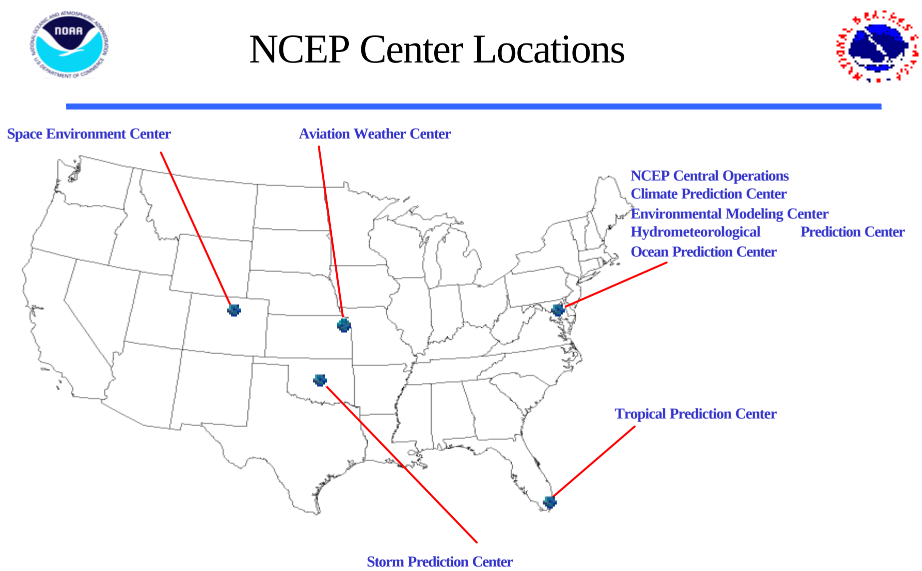


Figure 2



4.0 Findings of the OMRP

The OMRP received information and data from NCEP during this review. It also made an effort to ask the question: What social and economic value would be added NCEP's ability to conduct state of the science forecasts in the ocean, coastal ocean zones and Great Lakes regions of the Nation? The overview and information are summarized in the sections to follow and form the basis for the findings of the OMRP. These findings are organized in four sections to follow, covering:

1. Rationale for why an improved capability for ocean, coastal ocean and Great Lakes predictions are important
2. State of the Science of Atmosphere, Ocean and Coastal Zone Observation and Prediction
3. State of NCEP's Predictive Capabilities
4. State of NCEP's Relation to the Ocean Science Community

4.1 Rationale for Importance of an Improved Forecast Capability or "Why Bother?"

NCEP's mission ("To deliver national and global weather, water, climate and space weather guidance, forecasts, warnings and analyses to its Partners and External User Communities. That these products and services respond to user needs to protect life and property, enhance the Nation's economy and support the Nation's growing need for environmental information") begs the question: Are there compelling reasons for improved forecasts in and over the oceans, and in and over the coastal ocean, estuary and Great Lakes regions of the Nation?

The following estimates, comments and recommendations derived from the Report of the Commission on Ocean Policy.

- Marine commerce contributes nearly $0.75 Trillion in annual revenues to the U.S. economy
- 13 million U.S. workers are employed in the Marine Commerce industry
- More than 60 % of the Nation's population lives in the coastal zone, including the continental U.S. coastlines, Alaska, Hawaii and the Great Lakes; in fact in some coastal regions population growth over the past century has been exponential
- While only 15 % of the Nation's coastal areas are presently developed, that figure is projected to rise to 25 % within the next two decades; in fact in some coastal areas the value of housing (adjusted to the Nation's Consumer Price Index) has grown exponentially over the past half-century
- Between 70-75% of all weather related losses over the past two decades have occurred in the coastal zones
- Projected sea level rise may greatly exacerbate future weather related impacts in the coastal ocean regions
- Projected shifts in climate will greatly impact the economies of coastal communities
- Coastal communities have expressed great need for integrated oceans, coasts, and estuary centric products, services and delivery mechanisms for weather and climate related impacts
- Ocean-Land-Atmosphere Connections: "the oceans, land and atmosphere are inextricably intertwined
- NOAA and the NAVY should establish a joint ocean and coastal management and communications program to generate information products relevant to national, regional, state and local needs on an operational basis
- There is only sparse in-situ data presently available in and over the global ocean, coastal ocean, Great Lakes and estuary environs. This include marine buoy, coastal water level, Coastal- Marine Automated Network (CMAN), ocean, coastal and estuary mooring system based data
- National Weather Systems (NWS) verifications (the NWS national weather forecast verification program) of forecast accuracy indicates that weather forecasts over land are far more accurate than are forecasts along the coasts
- There are many boating deaths and drowning of swimmers that are directly attributable to the lack of accurate coastal zone forecasts of sea state and currents. It is noteworthy that "rip currents" are responsible for the second largest number of fatalities ascribed to "weather"
- In 2003 the NWS determined that the addition of several new meteorological buoys with wave spectra led to a dramatic improvement of significant wave height forecast capability lending credence to the assumption that more data in coastal ocean areas will improve forecasts
- Coastal ocean and estuary academic community-developed coupled models of storm induced surge and flooding have proven to be very accurate and demonstrate that an advanced systems modeling approach, both deterministic and probabilistic, will significantly improve forecast accuracy

- Coastal watersheds are integrated systems, stretching from heads of rivers to the coastal zone and coupled to the atmosphere and must be modeled as such
- The Integrated Ocean Observing System (IOOS) should be supported by Congress and managed by NOAA
- There should be a doubling of Ocean centric research (~$650M)

The OMRP finds that:

- The spectrum of facts, needs success stories and COP Report recommendations that are compelling for addressing the question "why bother", stretching from need to opportunity.

(The OMRP notes that the brief discourse above does not address the issue of whether or not building capacity in the oceans and the coastal zones, including estuaries, intertidal regions, and rivers to head of tides and the Great Lakes areas will also improve forecasts over land. That question will be addressed later).

4.2 State of the Science of Atmosphere, Ocean and Coastal Ocean and Great Lakes Observations and Prediction

a. Over and In the Ocean, Coastal Ocean, Estuaries and Great Lakes State Variable Observations

Ocean, coastal ocean, estuary and Great Lakes state variable estimation applies to a broad range of spatial scales downscaled from the global oceans to coastal oceans to estuaries and around the Great Lakes. Real-time global ocean observing has its basis in satellites, ship reports, ocean weather stations and buoys, Volunteer Observing Ships (VOS), surface drifters, the newly emergent Array for Real-time Geostrophic Oceanography (ARGO) program of profiling floats, and specialized observing systems such as the Tropical Atmosphere-Ocean (TAO) array of current meters in the equatorial Pacific Ocean and the Pilot Research Moored array in the Tropical Atlantic (PIRATA) array in the equatorial Atlantic Ocean (a counterpart to TAO) presently undergoing construction. It must be stated that satellite remote sensing of the global ocean is an indispensable element of NCEP's capacity to monitor ocean state variables (e.g., sea surface height, surface winds, surface wave heights and directional wave spectra, sea surface temperature, sea surface color (a proxy for chlorophyll, etc.), and (potentially) sea surface salinity and currents. The National Environmental & Data Information Service (NESDIS) of NOAA oversees the collection and data access to much of the satellite information utilized by NCEP. The availability and use of these global ocean data sets and their linkages are much farther along in maturity than are the equivalent observational resources for the coastal oceans and estuaries, in general, with Great Lakes coverage marginal.

The coastal oceans, estuaries and Great Lakes are regional in nature. Forced locally by winds, heat, evaporation, and precipitation and river fresh water fluxes, impacted by deep-ocean boundary currents and the astronomical tides, and constrained by bottom topography, each coastal region has its own physical characteristics requiring focused regional attention. Estuaries and the Great Lakes are even more unique. Real- time coastal ocean and Great Lakes observing presently is based on the NOS/National Water Level Observational Network (NWLON) of stations primarily along shorelines and the NWS/National Data Buoy Center (NDBC) meteorological buoys offshore and Coastal-Marine Automated Network (C-MAN) along the coast, but these are primarily for water level, coastal water surface temperatures and winds with very few other ocean, coastal and estuary state variable measurements, especially subsurface, presently being collected in-situ. The coverage is as follows.

There are presently 77 NDBC meteorological buoys and 56 NDBC C-MAN stations and 41 NOS NWLON (tidal current reference water level) stations for all the ocean and coastal zone waters of the 50 states of the Nation (including the Great Lakes). According to Bosart and Sprigg (1997), Rotunno et al (1998) and the Integrated Ocean Observing Systems (IOOS), Global Ocean Observing Systems (GOOS) and Coastal GOOS (CGOOS) documents, much more data are needed, even for the fundamental suite of basic, core variables such as currents, waves, temperature, salinity, sea and water levels, nutrients and measures of primary and higher order productivity. A concern for the lack of NOAA attention to a more ambitious and robust in-situ monitoring program has been brought to the attention of NOAA by the NOAA SAB repeatedly over a several year period, to no avail. NOAA upper management chose not to prioritize the importance of seeking funding to modernize its monitoring networks over and in the global ocean, coastal ocean, estuary and Great Lakes.

Noteworthy is that IOOS, as coordinated by the National Office for Integrated and Sustained Ocean Observations (Ocean. US) is envisioned as a cooperative international, global (downscaled to the national coastal ocean scale) network of observations, metadata and modeling. The coastal ocean observing component of IOOS is seen as a national backbone operated by the federal government plus a densification and extension by approximately 10 emerging regional observing systems, all designed, to greater or lessor extent, to assess and predict ocean currents and stratification, improve predictions of weather and climate, and their effects on marine operations, emergency management, and environmental management for marine living resources. Here NOS and NWS have an opportunity to capitalize on this emerging observing network, to enhance NOAA's undercapitalized existing network and to provide context to the optimal sittings of the elements of the arrays.

Over the past several years, given the lack of an aggressive NOAA-based program to dramatically increase the coverage and scope of in-situ observing networks, academic institutions in concert with local, state and private entities have begun to develop their own observing networks, suited to local and regional needs. Arising out of necessity, these emergent observing networks provide NOAA an opportunity for support and expansion. Scientific design and regional densification are well within the purview of the academic community. By furthering its contributions to the national backbone (NWLON, NDBC buoys, and CMAN stations) capabilities, NOAA can greatly assist the overall observing system effort through operational data distribution, field support and QA/QC standardization and by providing guidance and oversight and to ensure that precious capital is not wasted on local, parochial interests..

Noteworthy is that NWS/NDBC and NESDIS/NCDDC have extensive projects to QA/QC all coastal data and to store these data centrally, whatever the source of the data. So there is more overlap between NOS, NESDIS, NWS on coastal observations than implied here. Further since some of the emerging observing systems are funded through NOS, NWS has an opportunity to work directly with the NOS, to help facilitate and coordinate further developments by the government, academic and private sectors in ocean and coastal zone observations, thereby assuring a more direct coupling of all relevant data with NCEP. Here the NWS and NOS can assume leadership roles to ensure that the observing systems being developed meet NOAA's monitoring needs for operational forecasting.

Here, linking the limited set of in-situ and remote (satellite) measurements to measurements now being made regionally by consortia of academic, state and local governments, and private sector scientists and environmental managers is essential toward developing an ocean and coastal ocean observing system. This capability, while not robust, is at least a start towards building needed capacity that can be supportive of ocean, coastal ocean, and lake and estuary state variable estimation and for providing essential input in to atmospheric models over ocean, coastal and estuary environments, including the Great Lakes.

The OMRP finds that:

- NOAA's ocean, coastal ocean, Great Lakes and estuary observing networks per se are lacking and could be enhanced by incorporating data being collected by other groups and agencies; some of whom are supported by NOAA
- NOAA has undervalued ocean, coastal ocean, Great Lakes and estuary observations
- NWS could partner within NOAA with NOS and Coastal Ocean Technology Services (COTS)- type programs to provide oversight and guidance to maintain and further develop the national observing network that is emerging

b. The Need for Coupled Models

Two-way, interactively coupled ocean, coastal ocean and Great Lakes and atmospheric models will improve existing atmospheric forecasts, as air and water are interactively coupled in the real world. However, the deep ocean, coastal ocean areas and Great Lakes do not comprise the entire environmental system that must be considered in improving capacity to deliver better and timelier forecasts. To do so, a systems approach which links and interactively couples the components of the atmosphere, ocean, coastal and land elements need to be developed and implemented.

The maturation of the ocean and coastal components of numerical modeling parallels that of the supporting observations. On the ocean side, the development of seasonal to inter-annual predictions based on global ocean circulation models coupled with atmospheric models received major emphasis following the 1982/83 El Nino, and the past 20 years has seen major improvements with data assimilated from the TAO array and satellites. Coastal ocean, estuary and Great Lakes modeling and prediction has not had the same emphasis. Given the regionalism of the coastal ocean, estuary and Great Lakes processes (the physics are the same, but the relative importance of diverse local versus deep-ocean forcing (for coastal ocean and estuary regions) and the control by local topography differs widely, as do the specific regional environmental and ecological issues) a distributed approach to modeling is needed.

Moreover, since modeling and observations are dependent on one another to maximize their joint forecast utility, coordinated programs of observations and models are required regionally and locally. In coastal ocean, estuary and Great Lakes areas, as well as across the global ocean, succinctly stated, there is insufficient data coverage to validate let alone drive models. NCEP produces forecasts of phenomena in these areas but lacks critical observations. Additionally, couplings to hydrologic systems, both atmospheric and land-based, are necessary both from monitoring and modeling perspectives. These are all feasible and in some cases, discussed below, are being accomplished both within and outside of NOAA. Thus there are opportunities that do exist to develop the integrated approach required.

While our emphasis is on coupling ocean and atmospheric models to improve atmospheric forecasts, as well as ocean forecasts, recognition must also be given to the land (and ice) elements of the entire environmental system. Thus, improving the capacity for delivering better and timelier forecasts must include the development of a complete Earth System Modeling Framework (ESMF).

Given the regionalism of coastal ocean and estuarine processes a distributed and downscaled approach to modeling may be useful. Moreover, since modeling and observations are dependent on one another to maximize their joint forecast utility, coordinated programs of observations and models are required regionally.

The OMRP finds that:

- A prerequisite for advancing earth system prediction is achieving excellence in global ocean and coastal ocean and Great Lakes forecasting.
- By conducting ESMF, atmospheric forecasts, per se, will be improved.

4.3 State of NOAA NCEP Predictive Capabilities

NCEP is one of the leading atmospheric prediction centers in the world providing both national and international products focused principally on safety of life and property. For example, it is one of two World Area Forecast Centers with the responsibility to provide data and forecasts to the global aviation community. Its national centers provide specialized products for the early detection of tornadoes; for the prediction of the track and intensity of hurricanes; for climate prediction; for marine prediction; for river flood prediction and water resource management; and for the detection of solar storms that affect Planet Earth.

The "atmospheric forecast machinery", that is, the people, hardware and software at NCEP, functions effectively. The NCEP meteorological team understands how to handle massive quantities of data, how to use that data in prediction systems, how to run the systems in an operational environment, how to create and disseminate model data products, and how to archive results for future use. There is no doubt that the forecast community has a tremendous amount of respect for how NCEP conducts its business. The move to ocean and coastal ocean systems forecasting is a natural one in part because of the dependence of accurate weather forecasts on the global ocean, coastal ocean, estuary and Great Lakes environments.

NCEP's prediction capabilities depend largely on its in-house environmental modeling group, which supports data assimilation of observations, numerical weather prediction (NWP), advanced hydrological prediction, wave forecasting, and climate prediction. The Environmental Modeling Center (EMC) has increasingly supplemented its own expertise through collaborative research efforts with other agencies and with the university research community. This approach has led to the recent development, with the National Center for Atmospheric Research (NCAR), of the Weather Research and Forecasting (WRF) model, which is planned to replace NCEP's mesoscale ETA model operationally by the Fall of 2004.

NCEP provides its atmospheric forecast model output to the National Climatic Data Center (NCDC) for storage and access to the general public via its web site. This relationship with NCDC is admired by the OMRP because the availability of these model runs facilitates many kinds of statistical and data driven experiments that are conducted by NCEP and its university community partners. Such observation simulation and data infusion experiments for the ocean would lead to a better understanding and capability for improving NCEP forecasts across its entire suite.

Similarly, NCEP is partnering with other agencies to advance data assimilation, via the Joint Center for Satellite Data Assimilation, leveraging its resources with those of NASA and others to increase the utilization of satellite data in NWP. It is working closely with its partners on an ESMF, which will increase interoperability in weather, climate and ocean models. A similar approach would be needed if NCEP were to fully engage the oceanographic research community and other agencies to assist in the development of operational ocean and coastal forecasting. Here, NCEP is in a potentially excellent position to engage and provide purpose to the global ocean, coastal ocean, and Great Lakes observing community. However, NCEP's global ocean, coastal ocean, estuary and Great Lakes prediction activities are not explicitly reflected in the NCEP mission statement and are not visible within the NWS at large.

At NCEP the coastal ocean and Great Lakes prediction program is presently regional (except for a broader surface wave coverage) with a more general system under development. Other coastal ocean modeling activities, including applications to specific estuaries, storm surge and land based hydrologic systems modeling, are distributed among various NOAA directorates (primarily but not solely NOS) and locations seemingly without clear or adequate coordination. Here, NCEP, as an established organization with experience and expertise in providing NWP products using advanced computational capabilities, is well positioned to extend that capability to foster the creation of a truly comprehensive ESMF encompassing the atmosphere, ocean, land, and ecosystem elements of environmental and ecological prediction.

NCEP now possesses many of the essential elements to begin developing a strategy for implementing a coupled ESMM, which takes into account the various forcing and feedbacks across the atmosphere, ocean, land, and ecosystem components. As has been documented in the case of ocean-atmosphere coupling, not only has this enabled new seasonal to inter-annual climate products and the concept of climate services, but it has also improved atmospheric forecasts unto themselves. Such a strategy would not only support the NWS with the provision of improved atmospheric forecasts, but it would satisfy some of the predictive needs of other line organizations in NOAA. Be it forecasting of marine ecosystems, the global water cycle, or the global carbon cycle, an Earth system modeling strategy is required to develop such a predictive capability. Here, NOS has embarked on a marine ecosystem component and should be engaged by NCEP.

The NCEP EMC clearly identified several ocean prediction capabilities to be developed or expanded for global, regional, and coastal ocean applications on daily to inter-annual time scales for climate, weather and marine forecasts. However, NCEP human and computational resources are largely committed to the maintenance and improvement of the existing forecast capability, which is primarily atmospheric. Nonetheless, the capabilities that are needed by the greater community and which could be developed within NCEP include (but are not limited to) addressing the following issues and needs:

- Ocean modeling presently requires the provision of a "coarse" ocean model of at least 1°, progressing to 1/3° or finer, such as the Naval Oceanographic Office (NAVOCEANO), presently modeling at 1/8°, resolution global model for coupled ocean-atmosphere short-term climate diagnostics and prognostics. (Note, "coarse" can mean 2° or 3° in some climate studies. For seasonal to inter-annual prediction, higher resolution can be used whereas centennial prediction will necessitate lower resolution.)
- Ocean modeling presently requires the provision of mesoscale-admitting (at least 1/10°) resolution global models for coupling to the global NWP model in support of improved operational weather forecasting
- The future expectation is that the two coupled global ocean-atmosphere prediction systems (preceding bullet) may use the same underlying oceanic and atmospheric models and model grids
- There is a need for regional coupled ocean-atmosphere forecast systems for the Exclusive Economic Zone (EEZ) of the Atlantic and Pacific coastal oceans. They will necessarily have to be nested in the coupled global models
- There is a need for the nesting of coastal ocean, estuary and Great Lakes forecast systems into the aforementioned coupled regional models.
- There is a need for integrated storm surge, tides and wave modeling. As an interim capability three approaches, two immediate and the third, in relatively short order, could be taken: immediately, two-dimensional (2-D), vertically integrated forecasts that interactively combine tidal, storm surge, and 2-D wave

models, which are now treated separately within NOAA (specifically the Meteorology Development Laboratory (MDL) of the NWS, NOS and NCEP); could be provided; immediately, three-dimensional (3-D) forecasts that combine storm surge, tides and 2-D wave models; and within a relatively short time, 3-dimensional forecasts that combine interactively coupled tidal, storm surge and 2-D waves. All of the above is possible via the development of academic partnerships jointly with NOS and NWS or directly with NCEP.

Balancing needs against resources, it appears that:

- NCEP presently has insufficient resources, both computational and personnel, to advance global ocean, coastal ocean, estuary and Great Lakes prediction, let alone addressing the interactive coupling issues. For advancing operational ocean modeling, senior scientist leadership is required. However, a potential lack of internal senior guidance hinders the process. University and inter and intra federal agency partnering is the key here. Leveraging existing capabilities of NCEP via partnering will help ensure NCEP meeting its goals
- NOAA through NCEP is well situated to eventually conduct Earth System prediction through modeling the coupled ocean, atmosphere, land, and ecosystems, but this must be done in a coordinated manner. Again, as documented by NCEP in a summary of current resource utilization, the addition of ocean prediction capabilities on an operational basis could not be accomplished by simply integrating the new applications into or onto the existing atmospheric forecast infrastructure, or by simply redeploying existing resources to these new tasks at the expense of existing functions. University and inter and intra federal agency partnering is the key here. Leveraging existing capabilities via partnering outside of NCEP will help ensure NCEP meeting its goals

Thus, the evidence reviewed by the OMRP supports these findings:

- NCEP presently has insufficient and inadequate resources as a sole entity to take on ocean prediction without partners
- Future environmental prediction should not be disjoint, but should encompass the total earth system
- NCEP is well positioned culturally to eventually participate in ESM

4.4 State of NCEP's Relation to the Ocean Science Community

Currently several ocean models (Modular Ocean Model (MOM), Princeton Ocean Model (POM), Hybrid Coordinate Model (HYCOM)) are being used or tested at NCEP for climate (seasonal to inter-annual), daily ocean state, coastal and hurricane prediction needs. Very limited in-house assessment of these models by NCEP has taken place and a clear strategy for their selection has not been developed. Assessment of the skill of the ocean modeling products also is largely lacking.

At the present time, water level forecasts involving storm surge, tidal and wave modeling are not integrated. This is scientifically incorrect and a coupled, unified approach must be taken. The OMRP feels that this is an issue of very high priority. The reason for this may well be that NCEP was not charged to do so and that the capability has simply languished within NOAA. However, the academic and private industry communities have developed capabilities that would be of great benefit to NCEP forecasting of surge and inundation.

NCEP is not presently well situated to assess the relative merits of all these and other models and would benefit from stronger partnering and collaboration with other NOAA laboratories such as Geophysical Forecast Dynamics Laboratory (GFDL), Pacific Marine Environmental Laboratory (PMEL), and Atlantic Oceanographic and Meteorological Laboratory (AOML) who are in some activities well partnered with NCEP and in others at best only weakly integrated with NCEP. For example, NCEP has had a very successful partnership with GFDL as NCEP's Global Forecast System (GFS) was merged with GFDL's MOM 3 and with Forecast Systems Laboratory (FSL) in their production of the Rapid Update Cycle Model (RUC), which was then implemented at NCEP.

Further strengthening of such ties would address some of the current deficits in NCEP's ocean prediction program. GFDL has significant experience in both ocean modeling code development and data assimilation and has the expertise to evaluate the relative merits of various ocean codes. PMEL and AOML also have extensive experience with all phases of data collection, processing, and analysis and could contribute to skill assessments of the ocean products. NCEP does not have an ocean forecast support system in place to deliver products; however, NWS does have a network in place for atmospheric prediction, so this could be expanded to include ocean products.

Within the NOAA family, though across traditional lines, NOS should be entrained as a closer partner for NCEP as NOS has implemented community estuary models and generated model products that would benefit from better open boundary conditions from NCEP.

Forecast modeling is a component of NOS's Global Leader in Integrated Management of the Ocean (GLIMO) theme, for which NOS will soon release a strategic framework. This strategic framework may provide a basis upon which a group similar to the OMRP can convene to help assess the interactions between the NWS (through NCEP) and the NOS in advancing coastal ocean prediction.

For example, NOS has a 24/7 QC'd operational (standardized and modularized) estuarine nowcast/forecast model system in place. Further NOS is in the process of transitioning the Great Lakes Forecast System into this system, working with GLERL and a university partner. These nowcast/forecast systems: have documented skill criteria for certifying them as usable in the operational environment and documented procedures for transition of validated research models to the operational environment and make use of recognized standardized exchange formats; are already integrated into and make use of NOS operational oceanographic observation systems, such as Physical Oceanographic Real-time System (PORTS) and NWLON, which include information distribution systems; and make use of NCEP weather forecast model outputs, as well as river forecast outputs

Additionally, NOS has developed some connections with the coastal and estuary user communities. The products and services that NOS produces using oceanographic forecast models are building on previous products and services that previously were based on data only or on classical tide and tidal current predictions. The NOS has two major modeling efforts. One includes hazardous material trajectory models, which are national in scope of application, and are being used for ecosystem applications. Finally, NOS conducts geospatial modeling, an important underlying component of prognostic modeling.

NCEP is beginning to work with the broad atmospheric and ocean research community to develop new mechanisms to increase the interaction between operations and research, including the establishment of community partnership test-beds focused on the rapid transition of research ideas into operational solutions through the use of operational data streams and models. Here, community-derived numerical predictions of global ocean, marine atmospheric, coastal ocean, and estuary events could be stored at NCDC and be jointly accessed by NCEP and the model developers to conduct ensemble and probabilistic forecasts.

One of the critical questions for linking NCEP to other components within NOAA is whether or not the research and development pursued and developed in other intra-agency entities is managed in a proper way to ensure transitioning to a routine operational mode, which is the charge of a contemporary NOAA-wide research review under the auspices of the SAB. It is of note that several NOAA NWS NCEP links do exist and should be mentioned.

The Meteorology Development Laboratory (MDL) does not appear to occupy a significant resource presence at NCEP. In the context of global ocean and coastal ocean modeling, MDL's highly valued WFO guidance Model Output Statistics (MOS) product suggests that MDL and NCEP might be able to create similar ocean forecast products. This assumes that MDL's development of competency to conduct MOS in the ocean would align with its outstanding competency for MOS in the atmosphere, and that NCEP would adopt and adapt MOS for the ocean and coastal environments.

Alternatively, the storm surge predictions being made by MDL are outmoded. They do not directly, let alone interactively, include the tides, gravity waves, and physically correct lateral inundation and retreat schemes. Because they are only 2-D they are thus by definition, limited in application. Finally they are not interactive with either state-of-the-science oceanic or estuary models. Thus NCEP's potential engagement in providing prediction output of ensuing surge and flooding associated with individual storms is not only compromised by a lack of real interaction with MDL but also by a lack of core capability within NOAA to produce better model forecasts of surge and flood.

NCEP presently invokes Wave Watch III to forecast ocean waves. This model, developed within NOAA is extremely computationally efficient. However, the model does not consider depth induced wave breaking and dissipation and should be suspect in application in shallow waters, such as those less deep than 30 meters. Meanwhile the Navy has an operational model called Simulating Waves Nearshore (SWAN). This model, while computationally demanding, should yield much more accurate wave forecasts in waters between 30 to 5 meters in depth. Shoreward of that, the physics of wave models is sorely lacking.

Using contemporary modeling capabilities which exist at several key institutions within the academic community, NCEP has the opportunity to partner with universities which have developed this capability and to begin delivering more timely and accurate forecasts with little investment. Thus NCEP would have access to models that contain advanced and better fluid physics within, have produced predictions used by local WFOs, and have been shown to be accurate.

NCEP is developing core capacity to improve forecasts of the intensities of tropical cyclones and is working with GFDL and the Hurricane Research Division (HRD) to make further improvements.

The Air Resources Laboratory (ARL) began using NCEP model output for research and in diagnosing the model forecast vs. what actually occurred. They have improved forecasts from 6 to 10 to 14 days.

The Environmental Technology Laboratory (ETL) has embraced the NOAA Science and Technology Infusion Plan (STIP) approach, and will assume the responsibility of cold season quantitative precipitation forecasts which would be of benefit to NCEP.

The National Severe Storms Laboratory (NSSL) has a close partnership with NCEP and the application of coastal radar information by NSSL in forming quantitative precipitation estimates could be an important flow of information in modeling the hydraulics of coastal watersheds.

NCEP could partner with NAVOCEANO and therein adopt the Navy's operational ocean forecast system to obtain an immediate global ocean prediction capability. NCEP could simply utilize NAVOOCEANO fields that could then be assessed and evaluated for meeting the needs and adequacy of NCEP applications. NAVOCEANO expects to complete the OPTEST of Global-Navy Coastal Ocean Model (Global-NCOM), and declare it officially operational, by autumn 2004. Several years later, NAVOCEANO will be considering the possible adoption of HYCOM. Presently, NCEP has some core personnel working with the HYCOM group via National Oceanographic Partnership Program (NOPP) to help advance NCEP capabilities.

At the present time, there is not a complete set of operational ocean prediction products in the civil sector other than the Regional Ocean Forecast System (ROFS) for the East Coast. ROFS is the result of technology transfer of POM from Princeton University/GFDL and some collaboration with NOS. It has not been facilitated by an appropriate observing system. ROFS was the centerpiece of the successful (award-winning) Coastal Marine Prediction Demonstration Project briefly sponsored by NOPP for Chesapeake Bay but there was inadequate follow through. Even though ROFS is a meritorious and pioneering effort whose output is archived at the National Oceanographic

Data Center (NODC), it does not have links to either a user-base nor does it have scientific community wide acceptance as credible due to disconnects with both the user and research communities and programs.

NCEP did not act to aggressively upgrade ROFS. Today, ROFS is little known and little used by the oceanographic community and societal users. Meanwhile, the Navy has moved ahead with global operational ocean models at both NAVOCEANO and Fleet Numerical Meteorology and Oceanography Center (FNMOC), and several regional models at NAVOCEANO and the Naval Research Laboratory (NRL); however, their output fields have not generally been available to the civilian community. Recently, NAVOCEANO has agreed to transfer Global-NCOM fields to the National Coastal Data Development Center (NCDDC) for civil use. The Navy's achievements are due to a clearer sense of mission, an order(s) of magnitude greater investment in ocean prediction research and development, operations, and stronger connections to the ocean research community, than is the case for NOAA/NCEP.

Within NOAA, but external to NCEP, there are significant resources being devoted to the creation of ocean products. NOS, for example has had a long history of providing dependable ocean products that have saved millions of lives and billions of dollars in property and natural resources. The Center for Operational Oceanographic Products and Services (CO-OPS) is the point of distribution. CO-OPS relies to a large extent on ocean models from the Coast Survey Development Laboratory (CSDL), which are then linked to the Physical Oceanographic Real-Time System (PORTS) program where Great Lakes, estuarine and coastal ocean model forecasting systems are implemented. The PORTS focus is directed at safe and efficient navigation in ports and harbors; i.e., estuaries. Forecast systems are in place for about 12 estuaries throughout the continental US and Alaska.

While the PORTS observational data is of good quality, confidence in the PORTS model products however, unlike that for NCEP atmospheric products, has not been firmly established. The academic community, for example, has not embraced PORTS model products as being truly credible. Additionally, the delivery of PORTS forecasts through CO-OPS misses the entire network of WFOs, which is expert in forecast product delivery.

Another example of an NOS forecast program outside of NCEP is the one for ecosystem forecasts. While this program does not appear to be as dependent on forecast machinery so well developed at NCEP, it could be in the future as the science and models mature.

The Great Lakes forecasting system developed at GLERL is the last example to be considered here. The GLERL forecast system has been in and out of NWS operational status several times. While the system developers have put together an apparently workable system, it has not made it into the mainstream. The GLERL system would benefit from a closer collaboration with NCEP.

Given the present state of NOAA resources, plus any realistic projection of near term improvements to these, it follows that nurturing external links is a NOAA imperative. The external links have a three-fold role:

1) improving the quantity and quality of in-situ and remote_sensing data needed to support the ocean component of ESMF
2) improving the regional modeling capabilities, including the merging of in-situ and remote sensing data with model results through data assimilation
3) facilitating the dissemination of merged observational/model products to a broad user group.

Observational, modeling, and outreach links are all interrelated. NOAA needs a mechanism to facilitate this on a region-by-region basis. The multi-agency activities of Ocean. US and the emergence of coastal observational consortia or Regional Associations (RAs) provide such a mechanism. RAs are being tasked by the national community of concerned users and providers with goals that are complementary to the observing needs and prediction responsibilities of NCEP. By combining the talents and resource capabilities of NOAA with those of academia, state and local government, and private sector scientists and environmental managers, the linkages necessary to satisfy these parallel goals of ESMF in the coastal ocean and estuaries can be established.

Forecasting, as a continuous 24/7/365 activity with attendant liability, is a NOAA responsibility (NOTE: This is a NOAA responsibility, but one that will fail if the emergent IOOS is not embraced and nurtured as stated below). Research linkages within NOAA can accelerate the maturation of and improve the outcomes of global ocean, coastal ocean, estuary and Great Lakes forecasting. Such linkages will result in increased data flow, an evolving set of models, improved understanding of processes (resulting in more effective monitoring), and improved product dissemination to satisfy a broad-based user group. Engagement with and nurturing of emergent IOOS Regional Associations (RAs) and their regional coastal ocean observing systems is therefore an NCEP imperative. Coordination between NOAA and the regional observational activities at the local level can be achieved through existing WFOs; particularly those collocated on university campuses. Agency recognition is needed that ocean state variable prediction is required along with atmosphere state variable prediction, and that improvements of prediction in one medium will beneficially impact the other.

In review of information on NCEP research linkages, the OMRP finds that:

- NCEP presently has competent in-house capability for selection of global ocean, coastal ocean and Great Lakes models, but this capability could be enhanced by better linkages with the larger ocean science community
- NCEP links to users of ocean services and products are weak
- NCEP has developed a few effective partnerships within the ocean research modeling community but more partnerships would expand capacity and capability
- NCEP does not lead in ocean model development; rather, it most effectively transitions models from research to the operational environment
- NCEP has existing links to ocean observing system efforts (eg. COTS, IOOS and Ocean.US) but these are presently insufficient and should be expanded

- Ocean prediction within NCEP is weakly integrated to other NOAA ocean facilities such as PMEL, AOML, and GFDL
- Analysis and evaluation of ocean modeling is not adequate within NCEP specifically or NOAA in general
- NWS does not have an ocean forecast support system, as on the atmospheric side, to provide observations and deliver products
- There are initiatives within the broader community (NOPP, Hybrid Ocean Model Environment (HOME), WRF, COTS, Ocean.US, IOOS) that suggest this is an opportune time to move models from the research to the operational environment
- Contrary to NCEP's goals and objectives for "increasing collaboration with the world's leading scientists in development of improved products, services and numerical models" in meteorology, NCEP has no formal means (e.g., announcements of opportunity) for interacting with the external ocean modeling community
- NCEP's ocean modeling program is almost invisible to the ocean science community

The Review Panel thinks there is a national need for NCEP to become fully integrated into the U.S. national ocean science community, to take advantage of the division of labor to develop and rapidly move new ocean modeling capabilities from research into operations. This activity would require dedicated human resource as well, but would likely result in new, cost effective capabilities being deployed at NCEP far more rapidly than if NCEP were to try to develop similar capabilities completely in-house**.**

With NCEP playing a central role, NOAA needs to develop an across-line office strategy, particularly with NOS, possibly with the help of the Office of Science and Budget (OSB) & the Board on Atmospheric Sciences and Climate (BASC) of the National Academy of Sciences (NAS), for a total ocean prediction system (i.e., from requirements to observing systems, modeling systems, information products, delivery systems, and performance measures) in collaboration with the Navy, academic and private sectors where needed expertise and human resources reside.

There is urgency in these matters; for example, the coastal ocean observing system components of IOOS depends upon a partnership between regional observing systems and networks and the "national backbone" to be provided by federal agencies (primarily NOAA). However, the design of the "backbone", which should accord NCEP a central role, is a missing part of the architecture for IOOS, which includes the concept of a Joint Operations Center involving the Navy and NOAA, and is now limiting progress with the local to regional observing systems and networks. This would move the coastal observing systems to morph into coastal prediction systems and thus provide the intellectual rationale for a national network of these systems.

4.5 Summary of the Findings

The OMRP, through discussion and review of information made available from NCEP, finds that in regard to ocean and coastal modeling:

- By conducting ESM, atmospheric forecasts will be improved

- A prerequisite for the development of an earth prediction system is achieving excellence in global ocean and coastal ocean forecasting, too.

In review of the current operations and plans at NCEP, it finds that:

- NCEP presently has insufficient and inadequate resources as a sole entity to take on global ocean and coastal ocean and Great Lakes prediction in-house
- If NCEP was to take on operational global ocean and coastal ocean and Great Lakes modeling, partnering with the external community (including Navy and NASA) and NOS would be the most expeditious route to achieve this capability
- NOAA and NCEP are well situated to eventually perform ESM. Environmental prediction should not be disjoint, but should encompass the total earth system.

As a corollary to the above, since NCEP does not have a global ocean and coastal ocean forecast support system, as on the atmospheric side, to deliver products, the OMRP suggests that:

- The NWS WFOs in place across the Nation, particularly those in coastal zone locales, could perform the forecast function with retraining of existing line forecasters or the hiring of a new breed of global ocean and coastal ocean marine forecaster
- NCEP via NWS, UCAR, and the appropriate professional societies should work with the Nation's academic institutions to develop ocean/coastal/marine forecasters

Thus, while NCEP has credible and valuable operational atmospheric forecast capability, there is significant additional value to be realized from enhancing the NCEP mission to include operational global ocean, coastal ocean and Great Lakes forecasting. First, and foremost, inclusion of an ocean forecast capability will improve the NCEP atmospheric forecast capability. Second, a global ocean and coastal ocean forecast capability, through active participation in IOOS, will increase the quantity and quality of forecast products delivered to the U.S. citizenry.

In addition, given NCEP's demonstrated ability to implement and manage the complexities and resources of operational atmospheric forecasting, it is logical to propose that NCEP also serve the mission of operational ocean forecasting.

Finally, given the broad spectrum of global ocean and coastal ocean research modeling capability across the United States, it is reasonable to suggest that NCEP not develop a redundant global ocean, coastal ocean, estuary, and Great Lakes operational modeling capability, but rather that it partner with NAVOCEANO and NOS and lead the Nation's ocean and atmospheric communities to develop those applications and accelerate their transfer to NCEP as the basis for a credible operational global ocean and coastal ocean forecast capability.

5.0 Recommendations of the OMRP

Based on the findings in its review of atmospheric and ocean prediction capabilities, the OMRP makes three broad recommendations:

1. In-situ and remote-sensing observations and models of air-sea interactions over a broad range of time and space scales dictate the need for the coupling of ocean, coastal ocean and Great Lakes models to atmospheric models. The coupled modeling will enhance the forecast capabilities for the atmosphere, the ocean, and coastal ocean and Great Lakes, in the context of a whole earth system model framework. Thus ocean, coastal ocean and Great Lakes modeling must be fully integrated into operational weather, climate, hydrologic and earth system forecasts.

2. NCEP is presently the major governmental provider of atmospheric forecast products and services in the United States. To maintain this preeminence, particularly given the nation's growing needs in the ocean and coastal regions, NCEP must develop internal and external partners, collectively committed towards implementing two-way, and interactively coupled ocean-coastal-atmosphere models for its operational forecasts.

3. In order to move forward aggressively, and to most efficiently and effectively make accurate and comprehensive weather, climate, water and marine forecast forecasts and warnings, NCEP must develop a comprehensive strategy with the ocean community, including academia, private industry, and all appropriate federal entities, both external and internal, to capitalize on existing and developing ocean and coastal observations and models. Further NCEP must lead in the merging of models and data via data assimilation, and in the applications which ensue.

NCEP may be the logical place for NOAA's global ocean, coastal ocean, estuary, Great Lakes environment forecasting. However NOS, the Navy, industry, and the academic community have also developed core capabilities. In fact NOS is conducting operational forecasting of water environment state variables in selected estuaries, the Great Lakes and is planning on conducting ecological forecasting. The NOS capability developed should be utilized by NCEP. Here, since NCEP communicates its operational forecasting tools to the WFOs, NCEP could and should take a leadership broker and facilitating role, partner with these other groups and expand the collective effort and capability to include the entire hydrologic cycle, from the land to the inland waters to regional and ocean basin systems. This can happen either through true partnerships or via structural changes within NOAA. The counter is also true, NOS must partner with NWS. The NWS WFOs must enhance their capacity to deliver the forecasts. To under-gird the proposed improvements to and extension of its mission, NCEP must leverage these other communities to take advantage of the necessary human, computer, and administrative resources so that the global ocean and coastal ocean components of NCEP can function as well as the atmospheric component presently does.

The OMRP expresses its gratitude to the management and scientists of NCEP for participating in this review and continuing to provide additional requested information.

In addition, the OMRP would like to commend NCEP for its excellence in providing to the United States a credible and highly valuable operational forecast capability.

6. NOAA Science Advisory Board Themes for Dealing with NOAA Science Reviews

The National Oceanic and Atmospheric Administration (NOAA) is a mission-oriented agency. It is responsible for monitoring, understanding, and predicting changes in the Earth's environment as part of its Environmental Assessment and Prediction Mission and for managing coastal ocean and marine resources as part of its Environmental Stewardship Mission. NOAA has an obligation to provide accurate and timely scientific information to policy makers, and it also has an obligation for operational implementation of its science results. The NOAA Science Advisory Board (SAB) believes that successful research and development programs have certain characteristics or themes.

The SAB thinks that the following themes are important parameters to consider relative to the review of NOAA science projects and programs. The themes are not listed in order of priority and the programs mentioned are not intended to be exclusive of other NOAA programs and activities.

- Quality, Creativity, and Credibility**:** NOAA science must be top quality. In general, NOAA is known for and should continue to strive for science that is acknowledged as being credible, reliable, and respected. Therefore, NOAA science needs to be screened and evaluated through appropriate peer review as being of high quality and relevant in terms of informing policy decision-making. The SAB could help by reviewing and agreeing on some general standards of what should be included in all peer reviews. The SAB should go on record as supporting the importance of NOAA science that the "outside" world sees as relevant, important and credible.

  The OMRP thinks that NCEP demonstrates a deep commitment to improving the quality and credibility of its operational forecasts and the request to have this review conducted is a strong indicator that NCEP aims to become more creative in its delivery of improved forecasts and information.

- Timeliness, Scale and Scope: NOAA science should be timely in the sense that it will be conducted and completed in a timeframe that is useful to decision-makers. It must also be at a scale *and scope* that is useful.

  The OMRP thinks that NCEP is the "poster child" for this theme. Routine operational forecasting by definition requires timeliness. Scale and scope are in continual transformation and improvement.

- Science Connected to the Formulation, Application and Operational Implementation of Policy: NOAA science should be directly linked to policy decision-making. NOAA science should be designed and conducted with the understanding that it is intended to inform and improve decision-making relative to coastal ocean and global ocean stewardship responsibilities.

The OMRP thinks that improved capability to deliver interactively coupled, ocean-atmospheric model output will lead to and ensure the linking of sound science to sound decision-making in a truly operational mode. This could be further advanced if NCEP were to be the provider of global ocean, coastal ocean and estuary forecasts, more broadly defined and authorized in the context of IOOS.

- Capacity-Building: NOAA has multiple environmental monitoring and stewardship responsibilities which collectively provide the foundation and constitute the Nation's ability to assess and address environmental issues. Among these is to assist its partners (including federal, state, and local governments, universities, private firms, non-profits, international affiliates, etc.) to build capacity to address scientific and technical questions related to atmospheric, global ocean, coastal ocean and hydrologic weather and climate prediction and assessment efforts. There are many ways NOAA can promote this agenda. One is to ensure this question is asked relative to NOAA science.

  NCEP's activities are at the core of this theme in that the systems approach that NCEP utilizes improves its forecasts and necessarily builds capacity for NOAA and for the coastal states and coastal communities and marine interests of the Nation.

- Education: Protecting and restoring our environment for the benefit of current and future generations requires far-reaching public education initiatives, public support and public involvement. Collaborative stewardship is what is expected by the public and stakeholders and is a fiscal and political reality. NOAA also needs to inform the environmental scientists and practitioners of the future. Therefore, a public outreach component of NOAA science should be encouraged.

  The OMRP thinks that NCEP has done an admirable job of outreach and training on the atmospheric side, but not on the ocean side, via the engagement of international professionals, students, particularly minorities and women, by way of internships, and the public through workshops and visitations. Additionally, the atmospheric academic enterprise has a rich tradition and history of providing training to the next generation of forecasters and future employees in the weather services field. The same is not true for the ocean sciences community and affords the university community the opportunity to expand its educational programs to create a new type of forecaster and service provider, an ocean, marine sciences forecaster.

  Also, the NWS WFOs coupled with the NOAA Oceanic and Atmospheric Research (OAR) Sea Grant offices in the coastal ocean of the U.S., may provide significant numbers of potential public information and outreach links.

  - Efficiency: NOAA must effectively coordinate and integrate its scientific and technical capabilities to maximize efficiency, minimize redundancy and counter-productive overlap. Unnecessary programs or program elements must be eliminated.

There needs to be a greater effort to share expertise, and this drive for efficiency must be made known to Congress in order to maintain funding and programmatic support.

The OMRP thinks that NCEP is efficiently and effectively run, but the links to the ocean science community are too weak.

- Social Science Integration: There are important human dimensions to the use of environmental predictions (weather and climate forecasting) and to management of the Nation's coastal and ocean resources. Understanding complex environmental systems requires the integration of the social and economic sciences with the biological and physical sciences. Successful integration occurs in problem formulation at the beginning rather than at the end of the research pipeline.

While not yet on NCEP's "radar screen" but in the context of an ESMF, NCEP could become the core provider of information products and services via an end-to-end system that encompasses the physical, biological and human sciences network that embraces and integrates the social sciences in a quantitative way.

- Diversity: There is a need to expand involvement of people not historically involved or represented in NOAA science programs. NOAA should take explicit and tangible steps to achieve greater diversity in its science programs, projects, and activities. NOAA systems, policies and practices should encourage diversity and support all employees as they work to reach organizational and professional goals.

NCEP is engaging underrepresented groups, minorities and women, in its student outreach programs and in the view of the OMRP has made every effort to hire FTEs from these groups thereby increasing the diversity of its workforce. NOTE: in the ocean modeling arena, they may have the opposite problem.

APPENDIX A. Information on Members of the OMRP

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Consortium for Oceanographic Research and Education (CORE), and author of numerous publications on measurements and modeling of air-sea coupling and interaction, coastal meteorology and storms, coastal and estuary oceanography, hurricane climatology, coastal inland flooding due to Tropical and Extra-Tropical Cylclones, and abiotic influences on marine and human systems.

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Sales & Marketing Executive with International Business Machines (IBM). Member of the American Meteorological Society (AMS) Council and Chair of AMS Development Committee. Member of NOAA Science Advisory Board (SAB). History of world-wide sales & marketing leadership in high performance computing (HPC) for IBM, Cray Research, and Control Data.

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George Meade Bond Professor of Ocean Engineering in the Schaefer School of Engineering and Deputy Director of The Center for Maritime Systems at the Stevens Institute of Technology. The main focus of Dr. Blumberg's research is in environmental and geophysical fluid dynamics involving the application of fluid mechanics principles to the analysis of flow and transport processes operating in rivers, lakes, estuaries and the coastal ocean. He is the recipient of the 2001 American Society of Civil Engineers (ASCE) Karl Emil Hilgard Hydraulic Prize. In addition he is on the organizing committee of ASCE's prestigious biannual Estuarine and Coastal Modeling Conference and is an associate editor of two leading journals, The *Journal of Hydraulics Engineering* and *Estuaries*.

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Professor and Director, Earth System Science Interdisciplinary Center, University of Maryland, with research interests in climate variability and prediction, tropical ocean modeling and remote sensing. Present service as Chair of the National Research Council (NRC) Climate Research Committee, member of the NRC Committee on Earth Studies, Co-Chair of the Scientific Steering Group for the World Climate Variability and Predictability, Member-at-Large Section Committee on Atmospheric and Hydrospheric Science of the American Association for the Advancement of Science, and member of the American Geophysical Union Council on Public Affairs.

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Professor of Applied Marine Physics and Director of Ocean Prediction Experimental Laboratory (OPEL), Rosenstiel School of Marine and Atmospheric Sciences (RSMAS), University of Miami; 40 years of experience in observational, theoretical, and numerical studies of mainly the coastal ocean; author of numerous publications pertaining to coastal ocean circulation dynamics, mesoscale oceanography, coastal ocean modeling, and experimental forecasting; and a principal investigator in the Southeast Atlantic- Coastal Ocean Observing System (SEA-COOS).

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Professor of Physical Oceanography engaged in ocean circulation and ocean-atmosphere interaction studies in the tropics, on continental shelves, and in estuaries. As director of the USF Ocean Circulation Group and co-director of the USF Coastal Ocean Modeling and Prediction System, Dr. Weisberg's research presently emphasizes real-time in-situ measurements, analyses, and models of the West Florida Shelf circulation and the interactions between the shelf and the estuaries. He is a Southeast Atlantic Coastal Ocean Observing System (SEACOOS) principal investigator.

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Appendix B. Acronyms Used in the Text

Air Resources Laboratory	ARL
American Meteorological Society	AMS
American Society of Civil Engineers	ASCE
Applied Marine Physics	AMP
Array for Real-time Geostrophic Oceanography	ARGO
Atlantic Oceanographic and Meteorological Laboratory	AOML
Aviation Weather Center	AWC
Board on Atmospheric Sciences and Climate	BASC
Center for Operational Oceanographic Products	CO-OPS
Climate Prediction Center	CPC
Coast Survey Development Laboratory	CSDL
Coastal Global Ocean Observing Systems	CGOOS
Coastal-Marine Automated Network	CMAN
U.S. Commission on Ocean Policy Report	COPR
Commercial Ocean Technology Services	COTS
Contractors and Visitors	CV
Consortium for Oceanographic Research and Education	CORE
Department of Commerce	DOC
Earth System Modeling Framework	ESMF
	ESMM
Earth System Science Interdisciplinary Center	ESSIC
Environmental Modeling Center	EMC
Environmental Technology Laboratory	ETL
Exclusive Economic Zone	EEZ
Fleet Numerical Meteorology and Oceanography Center	FNMOC
Forecast Systems Laboratory	FSL
Full-time Equivalent	FTE
Geophysical Forecast Dynamics Laboratory	GFDL
Global Forecast System	GFS
Global Leader in Integrated Management of the Ocean	GLIMO
Global Ocean Observing System	GOOS
	GLOBAL
Global-Navy Coastal Ocean Model	NCOM
Great Lakes Environmental Research Laboratory	GLERL
Hurricane Research Division	HRD
Hybrid Coordinate Model	HYCOM
Hybrid Ocean Model Environment	HOME
Hydrometeorological Prediction Center	HPC
Integrated Ocean Observing System	IOOS
International Business Machines	IBM
Meteorology Development Laboratory	MDL
Model Output Statistics	MOS
Modular Ocean Model (GFDL)	MOM

National Academy of Sciences	NAS
National Aeronautics and Space Administration	NASA
National Center for Atmospheric Research	NCAR
National Centers for Environmental Prediction	NCEP
National Climatic Data Center	NCDC
National Coastal Data Development Center	NCDDC
National Data Buoy Center	NDBC
National Environmental & Data Information Service	NESDIS
National Meteorological Center	NMC
National Ocean Service	NOS
National Oceanic and Atmospheric Administration	NOAA
National Oceanographic Data Center	NODC
National Oceanographic Partnership Program	NOPP
National Office for Integrated and Sustained Ocean Observations	OCEAN. US
National Research Council	NRC
National Severe Storms Laboratory	NSSL
National Water Level Observational Network	NWLON
National Weather Service	NWS
Naval Oceanographic Office	NAVOCEANO
Naval Postgraduate School	NPS
Naval Research Laboratory	NRL
NCEP Directors Office	NDO
North Carolina State University	NCSU
Numerical Weather Prediction	NWP
Ocean Modeling Review Panel	ORMP
Ocean Prediction Center	OPC
Ocean Prediction Experimental Laboratory	OPEL
Oceanic and Atmospheric Research	OAR
Office of Science and Budget	OSB
Pacific Marine Environmental Laboratory	PMEL
Physical Oceanographic Real-time System	PORTS
Pilot Research Moored Array in the Tropical Atlantic	PIRATA
Princeton Ocean Model	POM
Rapid Update Cycle Model	RUC
Regional Association	Ras
Regional Ocean Forecast System	ROFS
River Forecast Centers	RFC
Rosenstiel School of Marine and Atmospheric Sciences	RSMAS
Science Advisory Board	SAB
Science and Technology Infusion Plan	STIP
Science Applications International Corporation	SAIC
Simulating Waves Nearshore	SWAN
Southeast Atlantic- Coastal Ocean Observing System	SEA-COOS
Space Environment Center	SEC
Stevens Institute of Technology	SIT
Storm Prediction Center	SPC

Technical Operating Plans	TOP
Tropical Atmosphere-Ocean	TAO
Tropical Prediction Center	TPC
University Corporation for Atmospheric Research	UCAR
University of Maryland	UMD
University of Miami	UM
University of South Florida	USF
Visiting Scientist Programs (UCAR)	VSP
Volunteer Observing Ships	VOS
Weather Forecast Offices	WFO
Weather Research and Forecasting Model	WRF
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