THE NAVY OCEAN MODELING AND PREDICTION PROGRAM

FROM RESEARCH TO OPERATIONS: AN OVERVIEW

By Robert A. Peloquin

"Develop a Global Ocean forecasting capability. . . ."
Rear Admiral J.R. Seesholtz, 1986

THE QUOTE, by the Oceanographer of the Navy, accurately conveys the theme of the articles that follow. Although the ultimate goal of this new capability is to meet Navy needs, there will be beneficial outflow to the marine community. The motivation for this development was originated in 1984 by John Lehman, then Secretary of the Navy, through his "Policy on Oceanography," which identified a number of initiatives ranging from scientific program enhancements to organizational changes. At the time, ocean modeling know-how and computer technology had progressed sufficiently to warrant a sizeable investment to achieve this forecasting capability.

. . . to produce three-dimensional environmental data fields for assessing and predicting the performance of operational systems . . .

The Oceanographer of the Navy and the Chief of Naval Research sponsored a comprehensive Ocean Prediction Workshop in 1986 (OPW86) to review progress in ocean modeling and to identify scientific and technological opportunities that facilitate the development of ocean prediction capabilities. The Oceanographer also initiated a supercomputer acquisition effort. The first of two Cray YMP computers is presently installed at the Naval Oceanographic Office (NAVOCEANO), Bay St. Louis, Mississippi, and through an agreement with the Chief of Naval Research is being used for model development as well as operational predictions. The second will be installed at the Fleet Numerical Oceanography Center (FNOC), Monterey, California, in 1992. In addition, the Navy is installing highly capable computer systems for environmental prediction aboard key ships and planes. Computer generated atmospheric and oceanic data fields transmitted from shore sites will be combined with measurements received from satellites, and observed on-site (Fig. 1). The objective is to produce three-dimensional environmental data fields for assessing and predicting the performance of operational systems (sonar, radar, weapons systems, etc.). Numerical products generated by FNOC and NAVOCEANO are transmitted to the Regional Ocean Centers and to Fleet Units. The Regional Ocean Centers, distributed globally, produce special-interest tactical products for specific areas.

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Navy Ocean Modeling and Prediction Program (NOMP)

NOMP was established by the Director of the Office of Naval Research jointly with the Director of the Office of Naval Technology and with the Technical Director to the Oceanographer of the Navy, as a mechanism to expedite models through research to an operational stage. The progression of this model development, as depicted in Figure 2, involves the assessment of model performance in the prototype development stage and extensive testing in both off-line (simulated operational conditions) and on-line operational environments before acceptance for use. FNOC is responsible for the final test and operational implementation of large-scale models (global, basin, and regional, including the Arctic), and NAVOCEANO is assigned the semi-enclosed sea and coastal models. Models destined for Fleet Units (Regional Ocean Centers, ships, etc.) are tested by the Oceanographic Office and upon acceptance for "Navy use" are provided to appropriate Naval activities. For instance, a shipboard model is presently being interfaced with acoustic models to predict the performance of anti-submarine sonar systems aboard aircraft carriers and cruisers.

The recommendations that emerged from OPW86 greatly influenced the structure and the evolution of Navy ocean modeling to date. The "Global Capability" involves a hierarchy of models of differing grid size, ranging from global to regional (including shipboard) scale (Fig. 3). As conceived, the larger scale provides internal fields and boundary conditions to the smaller scale models. For example, a global $\frac{1}{2}°$ ocean circulation model (now running operationally at FNOC) will provide boundary conditions and internal fields for a $\frac{1}{10}°$ regional model of the Northwest Atlantic (presently being evaluated for operational use).

Implicit to a forecast system is the ability to continuously assimilate data into a circulation or ocean prediction model. A forecast model of the Northwest Atlantic is expected in 1992, and a global capability will be available in 1996. The models will be eddy resolving, i.e., they will provide accurate depictions of fronts and eddies, including the subsurface density structure associated with these. The importance of this capability is illustrated in Figures 4 and 5, using model output data of the Gulf Stream region. Acoustic propagation loss for a 500-Hz signal was computed using oceanographic predictions obtained from a combination of the Harvard dynamic model (see Robinson, 1992, this issue) and the Navy Optimal Thermal Interpolation System (OTIS). The propagation-loss calculations were performed using the parabolic-equation formulation for two-dimensional propagation in vertical planes, chosen radially at 2° intervals. Propagation-loss, in decibels relative to one micropascal, is presented on a horizontal plane selected at 100 meters below the surface. Red and light yellow are synonymous with low loss, and indigo with high loss. A submarine target outside a red or yellow region probably would not be detected.

The dark wavy line through the center of Figures 4 and 5 represents the northern boundary of the Gulf Stream. The concentric circles are eddies that have pinched off from Gulf Stream meanders. To the north of the Gulf Stream are warm-core eddies, and to the south are cold-core eddies. Accurate knowledge about the location of these thermal features is of tactical significance for target detection and the deployment of forces. In Figure 4, the receiver is located within a warm-core eddy (at the center of the yellow patch), and a solid and widespread detection zone is prevalent in the immediate vicinity of the eddy. The receiver in Figure 5 is located 35 miles to the east, outside the eddy. Red bands indicative of acoustic-ray-path convergence zones present a significantly different picture. Noteworthy shadow zones, having Naval tactical implications, are created by the nearby eddy and along some sections of the Stream itself. These zones result from the refraction of acoustic rays as they pass through abrupt changes in the density structure. Ships conducting anti-submarine operations in similar regions would require constant updating about these features, to assure the proper positioning to provide optimum detection conditions.

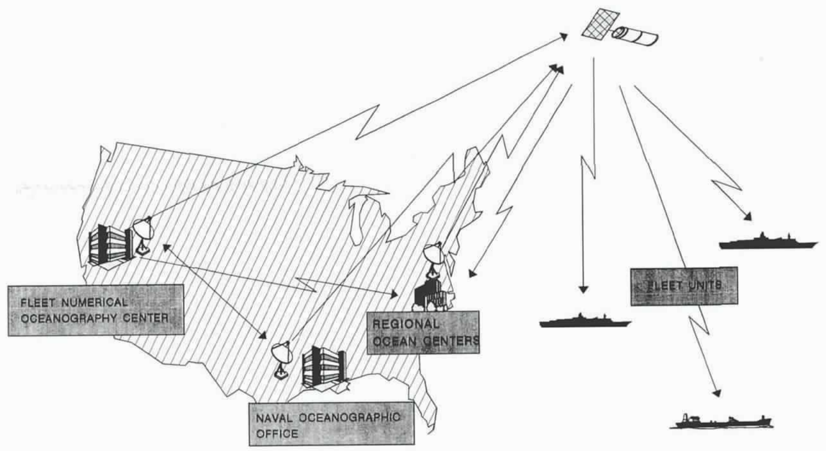

Fig. 1: Data and information flow from shore sites (large-scale computers) to fleet units at sea and ashore.

Although the program is ambitious, it is nevertheless attainable. Academic involvement is viewed as an essential element to success. As a result, the research base of the ocean-modeling program is closely tied to the Office of Naval Research, Research Programs Department, which supports university research. The Institute for Naval Oceanography, funded through the Navy Ocean Modeling and Prediction Program, has established a project for the comparative assessment of forecast models that have been developed through university research. This effort is expected to formulate recommendations for future model development. In this sense, the Institute provides a bridge between academic research and Navy applications. The Naval Research Laboratory (NRL) also is participating in this effort.

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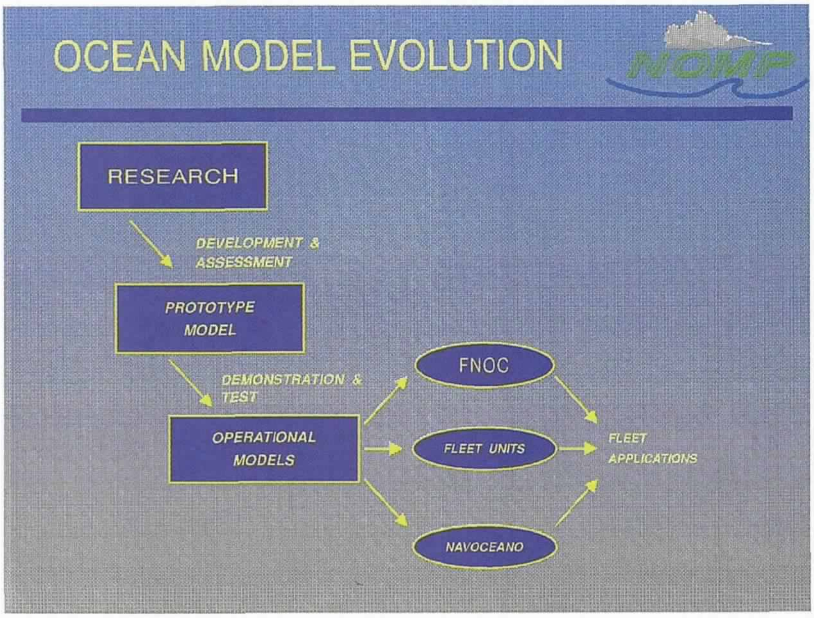

Fig. 2: Research and development process for ocean models.

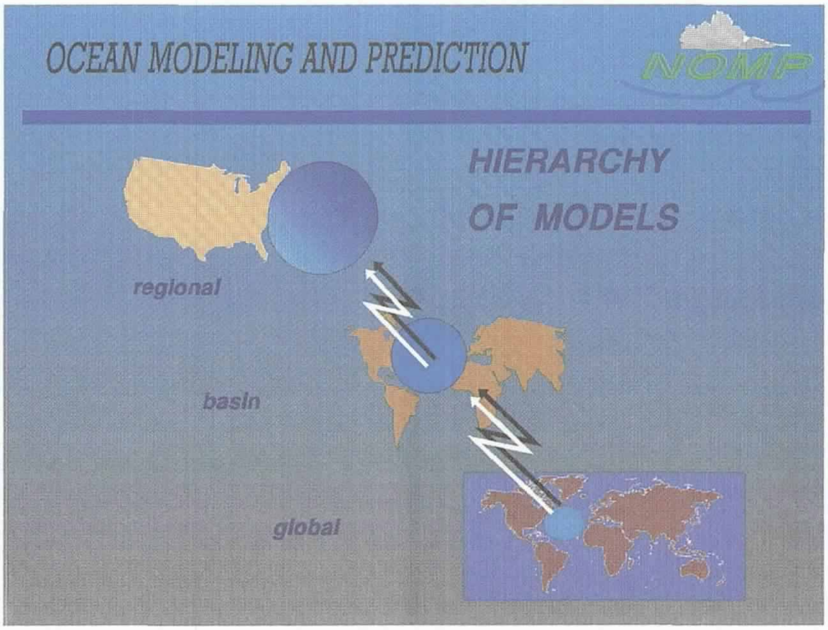

Fig. 3: Model development, i.e., global- to basin- to regional-scale.

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NRL is involved in another essential element, namely, the establishment of prototype models. This assures compatibility within the Navy operational environment and the evaluation of the models using the best available data sets in an offline quasi-operational mode. To achieve this objective, NRL works closely with NAVOCEANO and FNOC to assure the smooth transition of prototype models to operational use. With regard to data, the daily and even weekly volume of oceanographic data available for model input is very sparse. For that reason, the accuracy of oceanographic forecasts are expected to be dependent on the methods used for the assimilation of available data into the models.

A Description of the Modeling and Prediction Capabilities

NOMP was established to assure full consideration of modeling research and to accelerate the establishment of research results as operational models. The articles appearing in this issue of *Oceanography* were specifically selected to convey the scientific and technical content of the program.

The model development within the program has clearly emphasized the large-scale models, i.e., global, basin, and regional. The Navy is committed to the implementation of an operational forecast system by 1996. Hurlburt *et al.* (1992, this issue) discuss some aspects of the global effort in their large-scale modeling paper. One highlight of the article is the comparison of geodetic Earth-orbiting satellite (GEOSAT) sea-surface-height measurements with sea-surface heights computed using the $\frac{1}{2}°$ resolution model now running at FNOC. This work suggests that the assimilation of satellite measurements of sea-surface height into global models may soon be feasible. Equally sig-

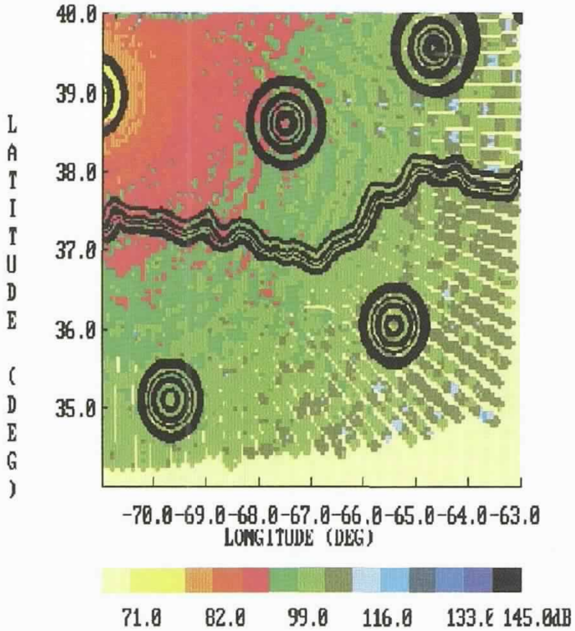

Fig. 4: Transmission loss pattern for a receiver (center of yellow patch) located in a warm-core eddy North of the Gulf Stream. Red and yellow imply regions having high submarine-detection probability.

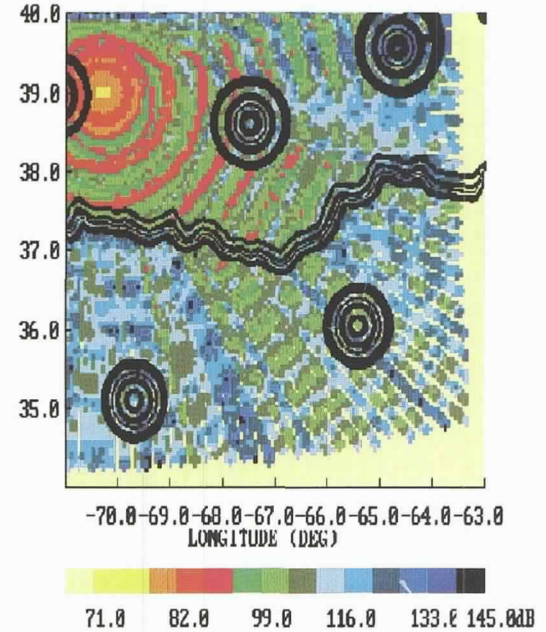

Fig. 5: Conditions same as in Figure 4, except that the receiver (center of yellow patch) is moved 35 miles east, outside the warm-core eddy. Note shadow zones produced by the Gulf Stream and the eddy to the east.

nificant is the modeling of the North Pacific at a resolution of $\frac{1}{8}°$. This is a first step toward a global $\frac{1}{8}°$ eddy-resolving model. The coupling of ocean and atmospheric models will be essential to future forecast systems. Ghil and Mechoso (1992, this issue) are presently developing techniques for the assimilation of oceanic and atmospheric data into coupled systems and for the assessment of predictability in such systems. Rosmond (1992, this issue) is approaching the ocean-atmosphere coupling through operational models. He is presently coupling the Navy global weather forecast model to the Navy ocean mixed-layer model, both of which are presently used operationally.

The Fleet Numerical Oceanographic Center is the major Navy operational facility for global, basin and regional predictions. Clancy (1992, this issue) provides an overview of the major oceanographic products at the Center. The developmental process leading to a high-resolution ($\frac{1}{8}°$ or 10–14 km) global prediction model has involved years of painstaking work in small regions. Thompson *et al.* (1992, this issue) discuss results of their work in the North Atlantic Ocean. Models, such as these that encompass large geographic areas, will, in the hierarchy concept, provide boundary conditions and model-initialization data fields to the smaller-scale local and shipboard models. Robinson (1992, this issue) gives a vivid account of what can be done aboard ship. The article relates well to current events, because the Navy is presently installing very capable computers aboard its ships specifically for this purpose.

Forecasting oceanic events will not be possible without a capability to assimilate observations, from satellites or through direct ocean measurements. Fox *et al.* (1992, this issue) have made notable progress toward assimilating data into a model of the Northwest Atlantic. The methods are being advanced for use in basin- and global-scale models developed by Hurlburt (1992, this issue) and Thompson (1992, this issue). Assessment of data assimilation methods is underway through the efforts of the Institute for Naval Oceanography. The Northwest Atlantic has been selected as the test region for a number of forecast systems, i.e., integrated ocean-prediction and data-assimilation models. The model assessment effort will be greatly facilitated by the Experimental Center for Mesoscale Ocean Prediction (ECMOP). Leese *et al.* (1992a,b, this issue) describe the assessment and ECMOP.

The Navy has a long history in ice observation and the prediction of its movement. In her article, Preller (1992, this issue), gives an excellent overview of recent achievements toward sea-ice prediction. Lastly, Horton *et al.* (1992, this issue) present results attained through a quick-reaction effort. They configured and implemented a Persian Gulf predictive model in support of Operation "Desert Storm." Reports indicate that the mine drift predictions provided by the model were very useful.

Future Efforts

The future direction of ocean prediction certainly depends on computational capabilities and our ability to efficiently access and use new high-speed computers. The implementation of ocean-atmosphere coupled nowcast (an estimate of the three-dimensional fields of temperature and salinity using climatology, observations, and analysis models) and forecast systems having 10-km horizontal resolution, up to 40 levels (surface to bottom), complete thermodynamics, and data assimilation will require processors with speeds approaching the Tera-Flop range (1 trillion floating point operations per second). In contrast, operational Cray vector computers are in the Giga-Flop range (1 to 16 billion floating point operations per second). Parallel processing supercomputers are evolving and offer the promise of achieving Tera-Flop speeds in the near future. Considerable effort is being directed toward this goal through government sponsorship and commercial enterprise. The Defense Advanced Research Projects Agency (DARPA) is, for example, heavily involved in hardware and software development of parallel processors and has established programs to accelerate the implementation of computer applications. The Office of the Chief of Naval Research is funding programs to advance the science and technology related to parallel processing. The Naval Research Laboratory, Washington, DC, has with DARPA support established a strong effort aimed at the development of applications. Other agencies, namely, the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), and the National Oceanic and Atmospheric Administration (NOAA) are sponsoring and promoting activities aimed at the advancement of parallel processing capabilities over a wide range of applications. The next decade should provide testimony to a revelation of new computational methods and techniques, which in turn will likely lead to a revolution in environmental predictions.

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Acknowledgements

The establishment of this program is the result of considerable effort on the part of its sponsors, namely, F. Saalfeld, Director of the Office of Naval Research; P. Selwyn, Director of the Office of Naval Technology; and R. Winokur, Technical Director to the Oceanographer of the Navy. Their continuing support will unquestionably lead to the first global ocean forecasting system implemented in an operational environment. In this context, the foresight of the Oceanographer of the Navy has led to the acquisition of powerful com-

puters necessary for this job and has put in place a mechanism for their upgrade over the next 10 years. The Commander, Naval Oceanography Command, and his Technical Director, D. Durham, are assuring that the Navy will implement the best available computer systems and technology to run the models. The Navy shipboard computers, the Tactical Environmental Support System [TESS (3)] now being procured, are the product of the dedicated work of J. Jensen, now Commanding Officer of FNOC, and C. Hoffman, Director of the Environmental Systems Program Office at the Space and Warfare Systems Command. We owe thanks to Captain J. Tupez for his major contribution in organizing resources at the Naval Research Laboratory and tailoring and focusing energies toward the development and testing of prototype systems. Not to be forgotten is M. Salinas, who was instrumental in structuring the modeling program for the Navy. The Institute for Naval Oceanography continues to provide needed support leading to the development of an operational ocean forecast capability.

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References

Clancy, R.M., 1992: Operational modeling: ocean modeling at the Fleet Numerical Oceanography Center. *Oceanography, 5,* 31–35.

Fox, D.N., M.R. Carnes and J.L. Mitchell, 1992: Characterizing major frontal systems: a nowcast/forecast system for the northwest Atlantic. *Oceanography, 5,* 49–54.

Ghil, M. and C.R. Mechoso, 1992: Data assimilation and predictability studies for the coupled ocean-atmosphere system. *Oceanography, 5,* 19–24.

Horton, C., M. Clifford, D. Cole, J. Schmitz and L. Kantha, 1992: Operational modeling: semienclosed basin modeling at the Naval Oceanographic Office. *Oceanography, 5,* 69–72.

Hurlburt, H.E., A.J. Wallcraft, Z. Sirkes and E.J. Metzger, 1992: Modeling of the global and Pacific oceans: on the path to eddy-resolving and ocean prediction. *Oceanography, 5,* 9–18.

Leese, J.A., M.S. Foster and J.H. Corbin, 1992: An experimental center for mesoscale ocean prediction. *Oceanography, 5,* 60–63.

Leese, J.A., R.C. Willems and L.A. Yeske, 1992: Evaluation capability for the Navy Ocean Modeling and Prediction Program. *Oceanography, 5,* 55–59.

Preller, R.H., 1992: Sea-ice prediction: the development of a suite of sea ice forecasting systems for the northern hemisphere. *Oceanography, 5,* 64–68.

Robinson, A.R., 1992: Shipboard prediction with a regional forecast model. *Oceanography, 5,* 42–48.

Rosmond, T.E., 1992: A prototype fully coupled ocean-atmosphere prediction system. *Oceanography, 5,* 25–30.

Thompson, J.D., T.L. Townsend, A. Wallcraft and W.J. Schmitz, Jr., 1992: Ocean prediction and the Atlantic basin: scientific issues and technical challenges. *Oceanography, 5,* 36–41. ❑