Development of Ocean and Coastal Prediction Systems

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LONG-TERM GOAL

Our long term goals are to evaluate and develop better community numerical ocean models based on bottom following coordinate systems in order to improve the capabilities of these models to simulate realistic coastal and open ocean dynamics and improve the skill of operational coastal forecasting systems that use these models.

OBJECTIVES

We wish to improve several crucial features of sigma coordinate ocean models such as the vertical discretization, numerical algorithms and bottom and surface boundary layers and to design a more flexible community ocean model for simulations of coastal regions, deep oceans and the interaction between the two. Of particular interest is to study the importance of bottom boundary layers in meso-scale high resolution models of western boundary currents and in basin-scale models.

APPROACH

The sigma coordinate Princeton Ocean Model, POM (Blumberg and Mellor, 1987; Mellor, 1996) with various configurations is being used for numerous applications around the world such as process studies and operational forecast systems. However, the basic numerics of the model have not been changed much in the last decade since it became a popular community model. The approach we take is to improve the model components that have the largest uncertainties and are most critical for users, and to make the model configuration more flexible to adapt for future applications. In particular, two recent model improvements include a correction to the Mellor-Yamada (Mellor and Yamada, 1982) turbulence scheme and the conversion of the model code to a generalized coordinate system.

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WORK COMPLETED

Our participation in the project "Data Assimilation and Model Evaluation Experiment in the North Atlantic Basin" (DAMEE-NAB) has been completed. An intercomparison study of several basin-scale North Atlantic models evaluates similarities and discrepancies between two sigma coordinate models, two z-level models and two layer models; this study, and sensitivity studies with each individual model, including POM (Ezer and Mellor, 1999) will be published in a special issue of Dynamics of Atmospheres and Oceans. In particular, we evaluated the sensitivity of the POM to horizontal diffusion parameterization, lateral boundary conditions and resolution and found spatial differences in the response of processes such as Gulf Stream separation and eddy shedding in the Gulf of Mexico to diffusivity and viscosity values.

A procedure to assimilate frontal position data, such as the Gulf Stream north wall analysis derived from AVHRR images (Ezer and Mellor, 1997), has been incorporated with assimilation of altimeter data (Ezer and Mellor, 1994) using Topex/Poseidon and ERS2 altimeters and implemented in the operational Coastal Ocean Forecast System (COFS, Aikman et al., 1996) running at NCEP. Evaluation of the operational data assimilation system continues.

RESULTS

A generalized vertical coordinate configuration has been implemented in POM, so that the distribution of numerical levels are unconstrained and may even vary temporally. Initial tests with a low resolution basin-scale model compared a standard z-level, a standard sigma and a combined z-plus-sigma grids; all models used identical numerics except the vertical grid (Mellor et al., 1999). For large horizontal viscosity, all schemes yield similar results, but for smaller viscosity, the z-level calculations show numerical instabilities associated with the step-like bottom topography. Follow up tests with an equator to pole heat flux distribution include 100-year long simulations which demonstrate the ability of the sigma and z-plus sigma grids to generate cold, deep water masses, whereas the model with a z-level grid lacks the appropriate Ekman-driven downslope process needed to generate the deep ocean water mass.

A common shortcoming in models that use the Mellor-Yamada turbulence scheme, namely, insufficient surface mixing and a too shallow summertime thermocline, has been revisited and correction to the turbulence scheme has been suggested. In particular, a modification to the turbulence dissipation term, making it a Richardson number dependent is consistent with laboratory experiments and produced a better comparison with observations. While the above turbulence correction has been tested and made a significant improvement in a one dimensional mixed layer model (Mellor, 1999), tests with a basin-scale three-dimensional model show that other factors, such as surface momentum and heat fluxes, which often include considerable errors, may have even larger influence on the model surface mixed layer and thermocline than the parameterization of turbulence does (Ezer, 1999). As an example, Fig. 1 compares observed temperature profiles, obtained from the GDEM climatology, and simulated profiles. While the deep mixed-layer during winter is well simulated in all cases, the creation of the seasonal thermocline during the spring and summer and the deepening of the mixed-layer during the fall are not simulated very well if only climatological winds are used; such forcing is common to many large-scale models. The inclusion of high frequency winds, the improvement of the turbulence dissipation and the inclusion of short wave radiation penetration, all contribute to the improvement of the model simulations. The inclusion of short wave radiation penetration in Run 4, compared to imposing the net surface heat flux as surface boundary conditions in Runs 1-3, is especially important as it increases surface mixing by heating the subsurface layers.

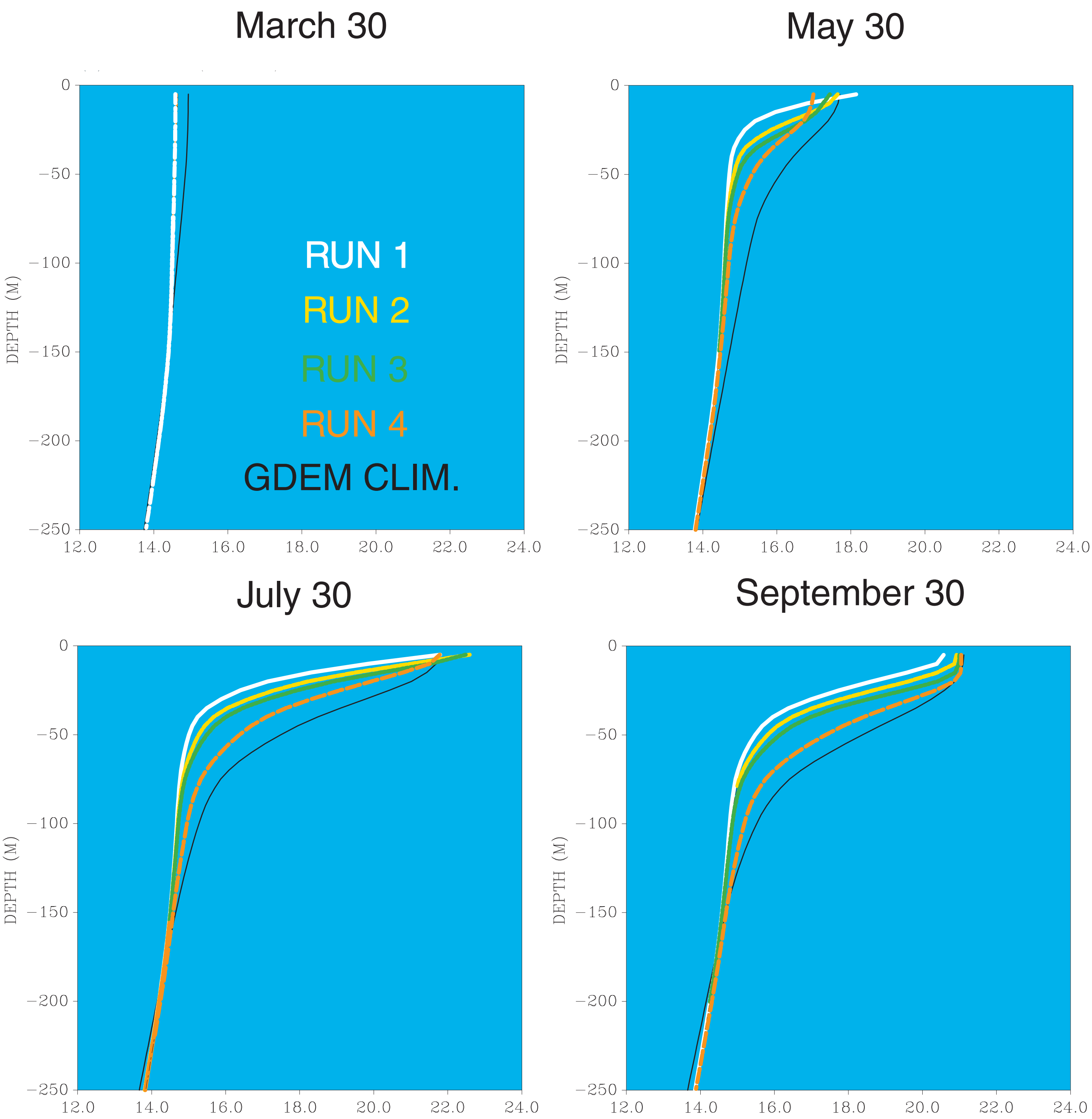

Figure 1. Temperature profiles in the north-east Atlantic Ocean for different months of the year. Observed profiles are indicated in solid black lines and different model simulations are indicated by different colors as shown in Fig. 1a. Run 1 is forced by monthly mean climatological winds, Run 2 by 6 hours winds, Run 3 adds a correction to the turbulence scheme and Run 4 adds short wave radiation penetration. As forcing and mixing parameterization improve from Run 1 to Run 4, the agreement between the model and the observed thermocline during summer and fall improves.

IMPACT/APPLICATION

The improved numerics and turbulence parameterization should affect many of the POM applications, from coastal simulations to large scale climate studies. The assimilation scheme, implemented recently in the operational coastal forecasting system for the U.S. east coast has already improved some aspects of the ocean forecasts such as the ability to produce some of the observed subsurface thermal structure associated with Gulf Stream eddies.

TRANSITIONS

The transition of model and data assimilation algorithms as well as knowledge from the research and development stage to the operational environment has been going on during the past few years and will continue. Continuous transition of model developments from the Princeton group to the ocean modeling community is done through our internet-based POM users group, which includes more than 500 registered users from 40 countries.

RELATED PROJECTS

Our involvement in the development of the Coastal Ocean Forecast System (COFS) for the U.S. east coast has continued as part of the Coastal Marine Demonstration (CMD) project supported by the National Ocean Partnership Program (NOPP); the first demonstration experiment has been conducted last summer, where real-time forecasts were distributed to uses and evaluated, the second experiment is planned for winter 1999/2000. We had fruitful collaborations with many scientists through our involvement in the Data Assimilation and Model Evaluation Experiments (DAMEE). A new ONR initiative now under planning will create a joint infrastructure for two modeling groups from Princeton and Rutgers universities in order to develop a better future community ocean model and to better support the ocean modeling community.

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