

A Community Terrain-Following Ocean Modeling System

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LONG-TERM GOALS

The efforts in this project are part of an ongoing, collaborative research at several institutions to develop, test, and improve terrain-following ocean models, and to provide support to the growing community of users of this class of models. Advanced numerical algorithms, as well as supporting diagnostic and analysis tools are built, and provided to users for testing in various applications. Interaction with U.S. Navy's modelers who use those models for scientific and operational purposes is essential for the long term goal of improving the Navy's modeling capabilities and in focusing research efforts on the Navy's needs.

OBJECTIVES

The objective of the research is to provide the most up to date modular expert modeling system for a wide range of applications. Idealized and realistic applications need to be tested in order to select the most robust and efficient algorithms and to test new differencing schemes and different parameterizations. Various modules such as nesting, data assimilation schemes, and mixing schemes need to be tested under different conditions. Development of useful web-based communication channels to provide online documentation, software, and users-support to the modeling community, is an area that has progressed considerably, but further improvements in this area will continue as web-based technology and tools are being developed.

APPROACH

This joint project combine model development efforts at Princeton University (T. Ezer, PI) and Rutgers University (H. Arango, PI); both groups now support terrain-following community models with over 1000 users worldwide. A close collaboration with other institutions, in particular with model developers at UCLA (A. Shchepetkin), is also essential. The two PIs also serve as coordinators between other modeling groups, Navy's modelers, and the ocean modeling community at large; they also organize biannual joint users modeling workshops (Arango and Ezer, 2001). The approach of testing new schemes includes model intercomparisons and sensitivity studies, but some important testing of new model elements is also being done by various users who provide feedback to the developers. The hope is to show that the new expert system can improve numerical accuracy and computational efficiency relative to models now in use by the Navy and by others.

WORK COMPLETED

The new Terrain-Following Ocean Modeling System (TOMS) code is based on the Regional Ocean Modeling System (ROMS) code but in Fortran 90/95 and includes both, shared and distributed memory options. The coding is almost completed with various advanced data assimilation and nesting capabilities, as well as new sets of general turbulence schemes. More detailed description of the progress in the coding is included in the annual report from Rutgers. Here we report on additional work done at Princeton that will allow to connect the Princeton Ocean Model (POM) users to the TOMS initiative. For example, there are now supporting tools such as Matlab-based diagnostic and grid generation codes that are provided to users of both groups. An intercomparison study that compares POM and ROMS and tests new numerical schemes has been completed (Ezer et al., 2002). The study demonstrates the advantages of new time stepping and pressure gradient differencing schemes, recently developed (Haidvogel et al., 2000; Shchepetkin and McWilliams, 2002), in making the code more efficient and less prone to numerical errors.

During the last year both groups completed the first stage in improving the web pages for their respective community models, both, in terms of look and services provided. A new generic ocean modeling web page (www.ocean-modeling.org) is under construction now, which will serve the needs of modelers of both groups as well as the ocean modeling community at large.

Additional work at Princeton (in collaboration with J. Hunter of Australia) includes a conversion of the POM code from its original old format (Blumberg and Mellor, 1987) that has been in use for more than 20 years, to a more modern and cleaner code (more similar to ROMS, but not yet modular); model output is now in netCDF format, like ROMS. These improvements will help the two groups to collaborate, to use common diagnostic tools, and will allow POM users to more easily adjust to the new TOMS codes that are being developed. A generalized version of POM has been constructed (Mellor et al., 2002) and tested in an idealized configuration, but more process and sensitivity studies are needed, in order to test the feasibility of implementing a similar approach in TOMS.

RESULTS

In addition to the model development and intercomparison studies mentioned above, both Rutgers and Princeton groups are taking part in the Dynamics of Overflow Mixing and Entrainment (DOME) project. This project will allow to compare newly developed models with other models and to test different mixing parameterizations. In particular, within the framework of DOME, research at Princeton during FY02 involved comparisons of different vertical grids in an idealized configuration using the generalized coordinate system. Fig. 1 demonstrates the effect of the vertical grid on mixing and advection processes when a dense bottom plume spreads from a shallow (600 m depth) and narrow (100 km wide) embayment into a continental slope (where the depth increases from 600 m in the north to 3500 m in the south). The same model with the same mixing parameters is used in two experiments, one with 32 horizontal (z-level) vertical layers (left panels) and another with 24 bottom-following (sigma) layers. The differences between the two experiments are significant.

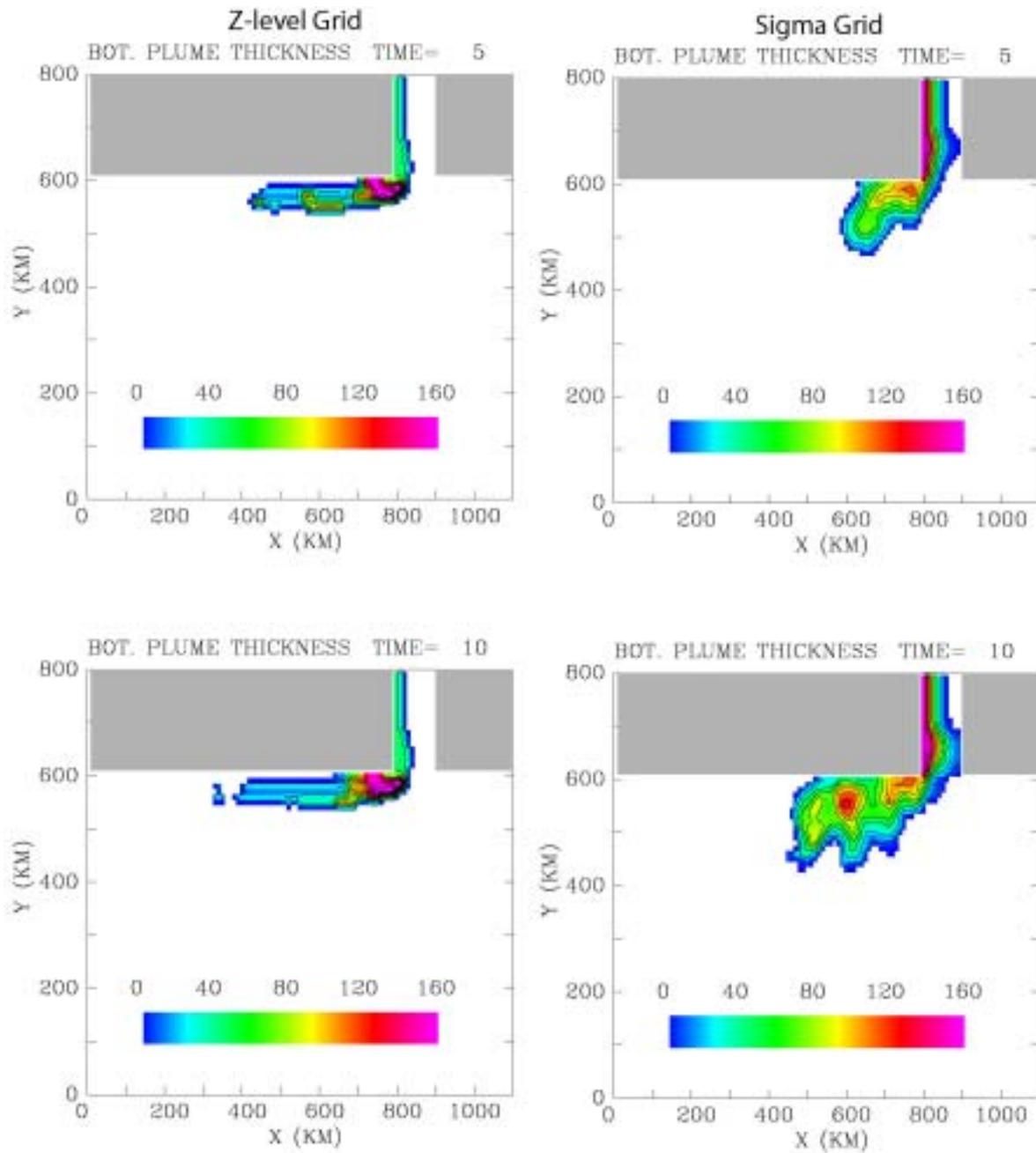


Figure 1. Thickness of a bottom plume after 5 days (top panels) and 10 days (bottom panels) simulations with a z-level (left panels) and sigma (right panels) vertical grids.

When z-level grid is used, the bottom plume is very thin, too diffused, and remains attached to the coast. On the other hand, when sigma grid is used, a thick bottom boundary layer is developed (as often observed in the ocean), which propagates downslope. This example demonstrates the advantage of terrain-following ocean models for resolving processes where flow-topography interaction is important. Z-level models may be able to resolve such processes only with special numerical additions such as partial cells or embedded bottom boundary layers. As part of the DOME project, various models (z-level, sigma and isopycnal) will be compared in a set of sensitivity experiments, in order to evaluate the effect of various parameterizations on the mixing in different models.

Various vertical mixing closure schemes have been made available to us from the General Ocean Turbulence Model (GOTM, Burchard et al., 1999). There are also recent improvements (Ezer, 2000; Mellor, 2001) to the Mellor-Yamada turbulence scheme (Mellor and Yamada, 1982), and an attempt to include the effect of the surface wave action in the turbulence closure (Mellor, 2002). All these recent developments call for further testing within the framework of the TOMS efforts, which we plan to do in the upcoming years.

IMPACT/APPLICATIONS

Developments of new numerical schemes for TOMS will have an important impact on the many users, including those in the Navy's labs and operational centers. The creation of a well tested, expert, modular, ocean modeling system will allow users more flexibility to improve simulations of a wide range of applications.

TRANSITIONS

The transition of the latest TOMS to operational centers has not been done yet. However, there are several operational codes using either POM or ROMS that are being used in the NOAA's and Navy's operational centers for forecasting purposes. These experiences and the interaction of the PIs with the operational centers will benefit future transitions. In fact, the POM-based Coastal Ocean Forecast System (COFS) for the U.S. east coast, which was partially supported in the past by ONR, has become officially operational at NOAA/NCEP in early 2002.

RELATED PROJECTS

The Princeton group is involved in the development and testing of forecasting systems for the western North Atlantic and the Gulf of Mexico. We hope to try some of the new numerical schemes in realistic model configurations. Studies of wave-induced turbulence by G. Mellor may help to improve future mixing schemes in TOMS. Both, the Princeton and Rutgers groups are part of the international model-intercomparison project, the Dynamics of Overflow Mixing and Entrainment (DOME), which will help to evaluate important test cases for TOMS, relative to other models. There is also ongoing collaboration at Princeton University with model development efforts at the Geophysical Fluid Dynamics Laboratory (NOAA/GFDL).

REFERENCES

Arango, H. and T. Ezer (Eds.), 2001: Proceedings from the 2001 Terrain-following Ocean Models Workshop, 20-22 August, Boulder, Co, Princeton University, 17 pp.

Blumberg, A. F., and G. L. Mellor, 1987: A description of a three-dimensional coastal ocean circulation model. *Three-Dimensional Coastal ocean Models*, edited by N. Heaps, American Geophysical Union, 1-16.

Burchard, H., K. Bolding, and M. R. Villarreal, 1999: GOTM- a general ocean turbulence model. Theory, applications and test cases. Tech. Rep., EUR 18745 EN, European Commission.

Ezer, T., 2000: On the seasonal mixed-layer simulated by a basin-scale ocean model and the Mellor-Yamada turbulence scheme. *J. Geophys. Res.*, **105**, 16,843-16,855.

Ezer, T., H. Arango and A. Shchepetkin, 2002: Developments in terrain-following ocean models: Intercomparisons of numerical aspects, *Ocean Modelling*, **4**, 249-267.

Haidvogel, D.B., H.G. Arango, K. Hedstrom, A. Beckmann, P. Malanotte-Rizzoli, and A.F. Shchepetkin, 2000: Model evaluation experiments in the North Atlantic Basin: Simulations in nonlinear terrain-following coordinates, In: *Ocean Circulation Model Evaluation Experiments for the North Atlantic Basin*, E. P. Chassignet and P. Malanotte-Rizzoli (Eds.), *Dyn. Atmos. Ocean*, **32**, Elsevier Sci. Ltd., 239-281.

Mellor, G. L., 2001: One dimensional, ocean surface layer modeling, a problem and a solution. *J. Phys. Oceanogr.*, **31**, 790-809.

Mellor, G. L., 2002: Oscillatory bottom boundary layers. *J. Phys. Oceanogr.*, In Press.

Mellor, G. L. and T. Yamada, 1982: Development of turbulent closure model for geophysical fluid problems. *Rev. Geophys.*, **20**, 851-875.

Mellor, G. L., S. Hakkinen and T. Ezer and R. Patchen, 2002: A generalization of a sigma coordinate ocean model and an intercomparison of model vertical grids, In: *Ocean Forecasting: Conceptual Basis and Applications*, N. Pinardi and J. D. Woods (Eds.), Springer, 55-72.

Shchepetkin, A. F. and J. McWilliams, 2002: A methods for computing horizontal pressure gradient force in an oceanic model with non-aligned vertical coordinate. *J. Geophys. Res.*, In press.

PUBLICATIONS

Arango, H. and T. Ezer (Eds.), 2001: Proceedings from the 2001 Terrain-following Ocean Models Workshop, 20-22 August, Boulder, Co, Princeton University, 17 pp.

Ezer, T., 2001: On the response of the Atlantic Ocean to climatic changes in high latitudes: Sensitivity studies with a sigma coordinate ocean model, In: *The Oceans and Rapid Climate Change: Past,*

Present, and Future, D. Seidov, B. J. Haupt and M. Maslin (Eds.), *Geophysical Monograph Series*, **126**, American Geophysical Union, Washington, D.C., 199-215.

Ezer, T., 2001: Can long-term variability in the Gulf Stream transport be inferred from sea level? *Geophys. Res. Lett.*, **28**, 1031-1034.

Ezer, T., H. Arango and A. Shchepetkin, 2002: Developments in terrain-following ocean models: intercomparisons of numerical aspects, *Ocean Mod.*, **4**, 249-267.

Ezer, T., L.-Y. Oey and H.-C. Lee, 2002: Simulation of velocities in the Yucatan Channel, In: *Proc. Oceans 2002, MST/IEEE*, In Press.

Ezer, T., L.-Y. Oey, H.-C. Lee and W. Sturges, 2002: The variability of currents in the Yucatan Channel: Analysis of results from a numerical ocean model, *J. Geophys. Res.*, 10.1029/2002JC001509.

Mellor, G. L., S. Hakkinen and T. Ezer and R. Patchen, 2002: A generalization of a sigma coordinate ocean model and an intercomparison of model vertical grids, In: *Ocean Forecasting: Conceptual Basis and Applications*, N. Pinardi and J. D. Woods (Eds.), Springer, 55-72.

Wang, D.-P., L.-Y. Oey, T. Ezer and P. Hamilton, 2002: Nearsurface currents in DeSoto Canyon (1997-1999): Comparison of current meters, satellite observation, and model simulation, *J. Phys. Oceanogr.*, In Press.