Model Performance and Evaluation

Paul J. Martin,
NRL Code 7322
Stennis Space Center, MS 39529
Phone: 601-688-5447 Fax: 601-688-4759 email: martin@nrlssc.navy.mil
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LONG-TERM GOALS

Determine and/or develop the best models and model parameterizations to meet the Navy's needs for coastal ocean simulation and prediction.

OBJECTIVES

Determine the best models and model parameterizations for coastal ocean simulation and prediction. Determine which models and model parameterizations are best suited to particular situations. Identify problems with the models, and problems with applying the models in particular situations. Provide a baseline for testing future models.

APPROACH

Several coastal ocean models were compared for their ability to simulate basic physical processes that are important in the coastal ocean. The models included in the comparison were the Princeton Ocean Model (POM), the Estuarine and Coastal Ocean Model, semi-implicit version (ECOM-si) from Alan Blumberg, the Sigma/Z-level Model (SZM) developed at the Naval Research Laboratory (NRL), and the S-Coordinate Rutgers University Model (SCRUM), Version 2.1.

The physical processes for which the models were compared included advection, vertical mixing, wave propagation (freely propagating surface and internal waves, surface and internal Kelvin waves, and barotropic shelf waves), and frontal formation (the formation of coastal upwelling and downwelling fronts).

The reasons for comparing the models' ability to simulate basic physical processes, rather than comparing them against observations taken in a real coastal environment, were several. Coastal models are sometimes applied to real coastal situations without a good knowledge of how well they simulate basic physical processes. Knowledge of model performance in simulating basic processes can aid interpretation of results when simulating or predicting real situations. Model evaluations with real data are not always conclusive because of uncertainties in initial conditions, boundary conditions, forcing, and validation data. Particular simulations with real data may not provide a good test of all the processes that are important in the coastal ocean. Testing the ability of the models to simulate basic processes can uncover problems that may not be evident in particular simulations with real data.

It is recognized, however, that the final arbiter of model skill is comparison of model results

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with observations. There are a number of projects at NRL and within the research community where these kinds of comparisons are being done, although these investigations usually only involve only a single model. Comparison of several coastal models with observations is a task that may be undertaken at a later time.

WORK COMPLETED

The main tasks this past year (FY97) were to complete the current coastal model comparison study and to finish writing a report documenting the results of the study. These tasks were completed and the report of the study, which is entitled "A Comparison of Several Coastal Ocean Models", is being published as an NRL Report.

RESULTS

Most of the work on this project this past year was involved in preparing a report of the results. The main findings of the coastal model comparison study were reported in last years progress report, and consisted of a discussion of some of the shortcomings of the individual models, relative to the other models, and some general problems that were encountered. Since this progress report represents the conclusion of the current coastal model comparison study, the main results of the study reported last year will be summarized here again.

The forward temporal differencing scheme used by ECOM-si suffers from significantly higher temporal truncation error than the leapfrog and Adams-Bashforth schemes used by the other models. The forward treatment of the advection terms by ECOM-si is highly dispersive. The forward treatment of the Coriolis term is intrinsically numerically unstable in that it tends to cause inertial oscillations to grow with time. The rate of growth is small and generally not noticeable with small timesteps, i.e., 200 s or less, but can become significant with larger timesteps. Conversion of the Coriolis term in ECOM-si to an Adams-Bashforth treatment avoided this timestep limitation and appeared to give satisfactory results for the test cases that were conducted. The forward time differencing scheme in ECOM-si can also cause some modification of the ambient stratification during internal wave propagation. This is caused by numerical diffusion due to a phase (timing) error between the vertical velocity and temperature (or salinity) values in the vertical advection terms of the temperature (or salinity) conservation equations.

The implicit treatment of the free surface mode in ECOM-si and SZM (with the timesteps typically used in these models) is much less accurate for the propagation of surface waves than the split-explicit treatment used by POM and SCRUM. The partially implicit scheme used by SZM is less damping than the fully implicit scheme used by ECOM-si, but is still considerably more damping than the split-explicit scheme used by POM.

Models with sigma vertical coordinates can suffer from problems with their advection, diffusion, and pressure gradient terms in regions of steep bathymetry. A problem was encountered with overshoot of the spatially centered advection term in the bottom sigma layers of the models at a steep escarpment. This was due to the sharp change that can occur in the bottom sigma layers when a shallow point lies next to a deep point. Advection between the shallow and deep points can result in severe advective overshoot due to the large change in the advected field between the two points.

The practice of subtracting the mean profile from the temperature and salinity fields when calculating horizontal diffusion in sigma coordinates can result in significant spurious diffusion if the local temperature or salinity structure is much different from the mean profile that is subtracted. In a downwelling problem, the positive temperature anomaly in the downwelling region, relative the the mean temperature profile in the model domain, resulted in a spurious warming of the water shoreward of the downwelling area due to diffusion of heat from the downwelling area towards the shore.

Some problems were also noticed with the use of z-level vertical grids. If the bathymetry is truncated to the nearest z-level, as is done with a number of z-level models (e.g., the various versions of the Bryan-Cox model, and the z-level part of the grid of SZM, which was included in this model comparison), the problem that the model actually solves is that for the stair-step bathymetry being used in the model, and not the problem for the true bathymetry that the stair-step bathymetry is approximating. (This may seem obvious, but there is a tendency to think in terms of the bathymetry one is simulating, rather than in terms of the bathymetry that is actually in the model.)

Onshore and offshore barotropic flows can be noticeably distorted by the stair-step approximation in z-level models. A main problem is that the horizontal convergence of the flow is focused at the faces of the stair-steps, rather than being spread out over the region of decreasing depth, i.e., the flow in the model is the flow that would result if the step were actually present. In a problem with an onshore, barotropic tidal flow, the isotherms were distorted by the vertical "jets" that occurred at the faces of the steps. Short-wavelength internal waves can be generated by tidal flows in regions where there actually are sharp bathymetric changes, but this should not happen in a region where the bathymetry is changing gradually. Topographic shelf waves, which depend on changes in bottom depth for their existence, can be quite distorted by a stair-step approximation to a smoothly varying bathymetry. The best solution to these problems with z-level vertical coordinates may be to truncate the bottom grid cell of the z-level grid to the bathymetry. This adds complication to the model, but is being done by some modelers.

Checkerboard mixing, where a fluctuation in the mixed-layer depth sets up at alternate grid points, was found to occur with the models under certain conditions of light winds and surface heating (or a positive surface buoyancy flux). The checkerboard mixing occurs because of the horizontal averaging that is used when computing vertical mixing on a C grid where the velocity and the temperature-salinity points are at different locations. As a practical matter, checkerboard mixing is not usually observed in realistic simulations because of the temporal and spacial changes in the surface forcing, so that the conditions under which checkerboard mixing occurs may not last long enough for the checkerboard patterns to form.

Due to some problems with the Version 2.1 SCRUM code that was obtained from Rutgers and significant changes made to SCRUM by Rutgers during the course of the coastal model comparison study, testing of SCRUM 2.1 in the coastal model comparison study was limited.

IMPACT/APPLICATIONS

The coastal model comparison study has made us more aware of the capabilities and limitations of several coastal ocean models. Experience gained with these models though this study has helped provide technical support and advice to other projects at NRL. It is hoped that the report of the results of this study will be useful to other investigators involved in coastal ocean modeling.

TRANSITIONS

Results from the coastal model comparison study are being utilized in the development of an ocean model for the Navy's Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS). Because of the generally favorable performance of POM in the coastal model comparison tests, the COAMPS ocean model will be based largely on POM, but will include the combined sigma/z-level grid of SZM, the option of a simpler vertical mixing scheme to improve efficiency in situations where a simpler mixing scheme may be adequate, and some additional enhancements.

RELATED PROJECTS

The NOMP 6.2 Coastal and Semi-Enclosed Seas project at NRL (PIs - Ruth Preller, Shelly Reidlinger, and Dong Shan Ko) is using POM to simulate the circulation in the Yellow Sea and in the larger domain of the East Asian Seas.

The NRL 6.2 Very High Resolution (VHR) Currents Project (PI - Tim Keen) is using POM to simulate coastal currents at high resolution.

The NRL 6.1 Coastal Remote Sensing Project (head PI - Richard Mied) is using POM and SZM to simulate the ouflow plume from Chesapeake Bay.

REFERENCES

Martin, P. J., G. Peggion, and J. K. Yip, 1997: A comparison of several coastal ocean models. Submitted as an NRL Report. NRL Code 7322, Stennis Space Center, MS 39529.