A Community Terrain-Following Ocean Modeling System

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LONG-TERM GOALS

The long-term goals of this effort are to: 1) develop and evaluate an expert Terrain-following Ocean Modeling System (TOMS) that will provide a state of the art model and supporting tools for simulations of a wide range of problems and scales; 2) support the Navy's efforts in improving operational coastal ocean forecasting systems; and 3) provide continuous support for the terrain-following ocean modeling community and provide coordination channels between developers, user and forecasters.

OBJECTIVES

The main objective is to develop a robust modeling system with various options for relocatable coastal forecasting systems for the Navy and for other problems ranging from coastal to global ocean circulation. Such a system should includes accurate and efficient numerical algorithms, the latest suite of vertical mixing schemes, interfaces for coupling with atmospheric models, nesting capability, various data assimilation schemes, and a parallel framework for both shared-memory (OpenMP) and distributed-memory (MPI) paradigms. The system should also includes web-based documentation and user-support software for model set-up, analysis and diagnostics.

APPROACH

Developing and supporting community ocean models requires a collaborative effort by ocean model developers and the terrain-following ocean modeling community. This effort is thus based on a joint collaboration between the two most widely used terrain-following community ocean modeling groups, at Princeton University (T. Ezer, PI) and at Rutgers University (H. Arango, PI). The two PIs, who manage the respective community models (POM, Blumberg and Mellor, 1987; ROMS/TOMS, Haidvogel et al., 2000; Shchepetkin and McWilliams, 2003; Ezer et al., 2002), play an important ambassador role by communicating and coordinating with developers at several other institutions (UCLA, MIT, University of Colorado and others) and with users. We also organize biennial users' workshops, as well as developers meetings. The approach of testing new schemes includes intercomparisons of various schemes (e.g., turbulence mixing options) and sensitivity studies with idealized and realistic cases. Important testing of new model elements is done by beta testers who provide feedback to the developers.

WORK COMPLETED

Several new numerical features developed during the past couple of years have been included in the latest version of the code known as TOMS/ROMS 2.0; this code was distributed to about fifty beta testers in January, 2003, and made publically available to the community in June, 2003.

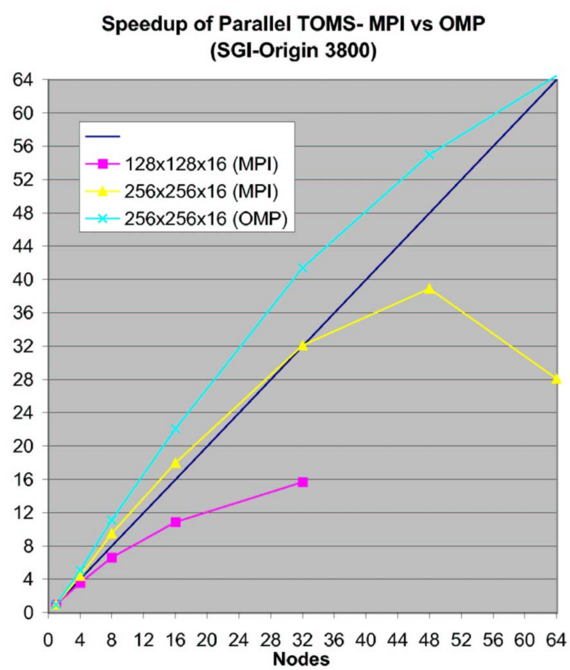
The code includes various pressure gradient algorithms (Ezer et al., 2002; Shchepetkin and McWilliams, 2003) that are more accurate and efficient than previous schemes used in SPEM, SCRUM and POM (Beckman and Haidvogel, 1993; Chu and Fan, 1997; Song, 1998; Mellor et al., 1994, 1998). Several advection algorithms are available with second-, third- and fourth-order accuracy, and a predictor-corrector time stepping scheme may allow the use of a longer time step than standard schemes do (for details, see an evaluation and comparison of these algorithms in Ezer et al., 2002). In collaboration with Warner and Sherwood (USGS), a sediment model and generic length scale (GLS) turbulence parameterization (Umlauf and Burchard, 2003) have been added to the code; this adds more options to the original Mellor-Yamada level 2.5 turbulent closure scheme (Mellor and Yamada, 1982) and the KKP mixing scheme (Large et al., 1994). A recent study (Warner et al., 2003) evaluated the performance of these turbulence closures in terms of idealized sediment transport applications. Various data assimilation schemes, including tangent linear, adjoint, variational data assimilation and ensamble forecasting have been developed and are being tested through collaboration with scientists from the University of Colorado (Moore) and Scripps (Miller and Cornuelle), see Moore et al., (2003) and Arango et al. (2003) for details.

Particular model development work at Princeton (in collaboration with G. Mellor and others) includes the testing of a generalized coordinate system (Mellor at al., 2002) that allows to compare mixing processes in z-level grid with sigma coordinate or generalized terrain-following grids, using otherwise identical numerics (Ezer and Mellor, 2003). This work may support the future development of a hybrid, or a general coordinate version of TOMS. Other work at Princeton in recent years focused on improving turbulence mixing schemes by including: 1. better parameterizations of dissipation due to internal waves (Ezer, 2000; Mellor, 2001), and 2. current-wave interaction and breaking waves energy contribution to both the bottom and the surface mixed layers (Mellor, 2002, 2003; Mellor and Blumberg, 2003).

As part of the PIs role in coordinating the efforts of model developers and in providing a forum for exchange of ideas and research within the ocean modeling community, two workshops were organized during FY03. The second TOMS developers workshop was held in Boulder, CO, July 10-11, 2003, with participation of most model development teams involved and ONR personnel. The third biennial, terrain-following users workshop was held in Seattle, WA, August 4-6, 2003. The meeting focused on several important modeling issues such as mixing parameterizations, data assimilation and new developments in numerical techniques (the meeting's proceedings, Ezer et al., 2003, is available from the ROMS or POM web pages). During the last two years both groups completed the first stage in improving the web-based information for their respective community models (www.aos.princeton.edu/WWWPUBLIC/htdocs.pom; marine.rutgers.edu/po), both, in terms of look and services provided. Due to the collaboration between the two groups, there are now more common diagnostics and grid generation tools (matlab and netcdf based) that are being used by users of different models. A new generic ocean modeling web page (www.ocean-modeling.org) is partly completed; it will serve the needs of modelers of both groups as well as the ocean modeling community at large.

RESULTS

The modular TOMS coded has been converted to F90/F95, with a parallel framework that allows both shared- (OpenMP) and distributed-memory (MPI) paradigms. Benchmark tests are underway to evaluate code performance on different computer architectures. For example, an idealized upwelling test with small (128x128x16) and larger (256x256x16) grid resolutions is used to evaluate and compare OpenMP versus MPI on the NOAA/GFDL Origin 3800 supercomputer cluster (Figure 1). The MPI code improves its efficiency (up to 32 nodes) in the larger grid, but its performance is degraded due to the increased communications cost over 48 nodes. On the other hand, the OpenMP code exhibits super-linear performance up to 64 processors in the larger grid (Figure 1a). Time profiling over all processors reveals that, as the number of processor increases, the MPI code spends considerable more time than the OpenMP code on output (Figure 1b). Serial I/O (NetCDF) is much cheaper in shared-memory configurations. We are currently working on a parallel I/O option for TOMS based on HDF. Unidata is now working on a parallel version of the NetCDF library, which will be available sometime next year.



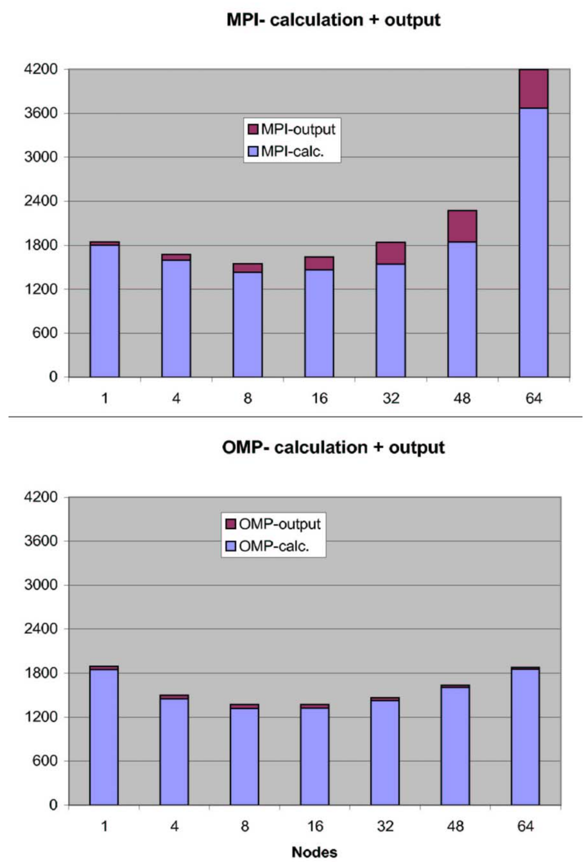


Figure 1a (left). The speedup factor of TOMS code as a function of the number of processors used. Purple and yellow lines represent small and large domains, respectively, using the MPI code; the cyan line represents large domain using the OpenMP code, which shows super linear behavior up to 64 processors. Figure 1b (right). The total cpu (sec) summed over all processors for the large domain MPI (top) and OpenMP (bottom) codes. The dark portion of each bar represents the relative portion of the calculations spent on writing output, which takes considerably more calculations in the MPI code as the number of processors increases.

During the past year, several projects at Princeton (some supported by other grants) contributed to the general model development efforts. Studies of mixing processes in the bottom boundary layers (BBL) and turbulence parameterizations used the generalized coordinate system as implemented by Mellor et al. (2002), to compare various grid classes. In particular, simulations of overflow transports and entrainment demonstrate that a relatively coarse resolution terrain-following grid performs as well as much higher resolution z-level grid when all other numerical aspects are identical (Ezer and Mellor, 2003). The study also indicates the difficulty that general coordinate or hybrid models may face in implementing horizontal and vertical mixing parameterizations. For example, increasing horizontal diffusion resulted in thinner BBL in the terrain-following grid, but caused a thicker BBL in the z-level grid. These studies may help in future developments of hybrid or generalized coordinate systems to be evolved from a basic terrain-following model (in contrast to hybrid models build from isopycnal models, such as HYCOM).

In recent years, attempts are being made to couple ocean circulation models with wave models. However, how to include the surface waves motion and breaking waves in the parameterization of oceanic mixing is still a new field of research (Mellor, 2002, 2003; Mellor and Blumberg, 2003). These studies (as well as other research efforts to develop a theory for wave-current interactions by McWilliams and others) give a new framework for improving turbulence mixing in ocean models; this efforts may be important in particular for coastal forecasting systems over shallow regions. Preliminary results (see above papers as well as the special session on this issue in the 2003 users meeting, Ezer et al., 2003) indicate the potential of improving simulations of surface currents, surface mixed layers and oceanic thermal structures.

IMPACT/APPLICATIONS

Improved numerical schemes and new features for terrain-following ocean models is having an immediate impact on the many users of this class of models (over 2000 users are now registered in the POM and TOMS/ROMS user groups). In particular, many users in the Navy's labs and operational centers presently use one of these models.

TRANSITIONS

An official transition of the latest TOMS to an operational Navy's code has not been done yet, but operational centers at NOAA and Navy labs has been using either POM or ROMS being used for research and forecasting purposes. These experiences and the interaction of the PIs with the operational centers will benefit future transitions.

RELATED PROJECTS

Under separate funding, the Princeton group is involved in the development and testing of forecasting systems for the western North Atlantic and the Gulf of Mexico (see the Princeton Regional Ocean Forecast System, PROFS, www.aos.princeton.edu/WWWPUBLIC/PROFS/). Studies of wave-induced turbulence by G. Mellor may help to improve future mixing schemes in TOMS. Our involvement in the project, the Dynamics of Overflow Mixing and Entrainment (DOME, www.rsmas.miami.udu/personal/tamay/DOME/dome.html), which recently became part of the gravity current entrainment Climate Process Team (CPT), will help to evaluate important test cases, improve mixing parameterizations, and compare results with other models. There is also ongoing collaboration at Princeton University with model development efforts at the Geophysical Fluid Dynamics Laboratory (NOAA/GFDL).

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