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**Summary of Accomplishments and Research on
Forward-in-time Differencing for Shallow Fluid Flows on the Sphere**

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This past year we have continued the development of our 3D grid point model. The general model is nonhydrostatic, is written in nonorthogonal terrain following coordinates, and consistently incorporates either Eulerian or semi-Lagrangian differencing. The nonhydrostatic formulation will be particularly useful when the grid size is small enough to resolve nonhydrostatic processes—for example: convective instabilities, and internal gravity wave dynamics in deep sheared atmospheres. However, we have also found that the nonhydrostatic formulation has numerical advantages on coarser grids, such as a better conditioning of the Laplacian matrix that must be inverted. In addition, use of the nonhydrostatic equations allows consistency as the mesh is refined, or when using nested grids.

We have used this model as a vehicle to compare the advantages of Eulerian and semi-Lagrangian methods. At present, it appears that each method has advantages for certain classes of problems, and that neither is uniformly superior. The nonhydrostatic model has additional options, including moving boundaries and treatment of moist precipitating processes.

We have incorporated more options into different versions of the basic model. The most significant step has been to move the semi-Lagrangian version of the model to the sphere, and to incorporate a hydrostatic option. In addition to providing an inexpensive alternative for large scale simulations, the hydrostatic solution provides an excellent first guess for the nonhydrostatic solution, thereby reducing the number of iterations required to solve the 3D elliptic equations for pressure. We have also developed an effective preconditioner for this equation.

We have implemented a fairly sophisticated subgrid scale turbulence parameterization in the basic model and performed a number of LES studies of planetary boundary layers to calibrate the model. We have ported the basic model to the Cray T3D using both a High Performance Fortran and a message passing approach. We have conducted detailed comparisons of the model performance for various options of model algorithms and concluded that the message passing approach offers uniformly superior performance for both semi-Lagrangian and Eulerian, and moist and dry variants, of the model. We have also implemented a volume of fluid (VOF) capability in the 2D model. VOF is an interface reconstruction method that approximates the motion of a Lagrangian interface on an Eulerian grid. For example, using VOF to represent the boundary of a cloud allows one to track the motion of the interface, keeping it sharp without using fine resolution. The cloud boundary is not exactly a Lagrangian surface because of the thermodynamic processes of condensation and evaporation. These processes are stiff, and the coupling of

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the VOF technique to thermodynamics requires some care.

In order to further improve the efficiency of our model, we have developed a new method for treating systems with a variety of time scales. Traditional strategies, including split explicit methods, semi-implicit methods, and mode splitting, all have some inaccuracies and/or stability problems. Our new method, which we have named the method of averages (MOA), is based on three steps. In the first step, we find a low-order solution of the linearized equations on the fast timestep. In the second step, we average these solutions over the slow timestep. In the third step, we use these average solutions to do a single high-order solution of the full equations over the slow timestep. The gain in efficiency comes about from solving only low-order linearized equations on the fast timestep. In particular, the advection can be simple donor cell and even an advective form of the equations can be used. To validate the method, we built a 2D shallow water model of an ocean basin. We used this model to simulate a problem of a vortex interacting with a boundary. The vortex evolves on a slow time scale, while the interaction with the boundary results in Kelvin waves that evolve on a fast time scale. Using the MOA, we were able to reduce the standard small-time-step integration CPU time by roughly 80. The efficiency factor is also predicted by our theory. Our results so far have served to validate the MOA; we believe further gains in efficiency are possible by treating some terms on the slow scale (but not the slow terms that are part of the principal balance).

Among others, we have written a review paper to help facilitate the transfer of the MPDATA technology that we have developed. The paper describes the basic use of MPDATA for advection problems, and then progresses to applications of the full equations of motion. We also describe many options developed to improve the accuracy and efficiency of application.

Publications:

a) refereed

Nadiga, B.T., L.G. Margolin, and P.K. Smolarkiewicz, 1996: "Dispersive shallow fluid flow over a mountain," *Phys. of Fluids*, **8**, 2066-2077.

Smolarkiewicz, P.K., Grubisic, V., and L.G. Margolin, 1996: "On forward-in-time differencing for fluids: Stopping criteria for iterative solutions of anelastic pressure equations," *Mon. Wea. Rev.*, **125**, 647-654.

Anderson, W.D., and P.K. Smolarkiewicz, 1997: "A comparison of high performance Fortran and message passing parallelization of a geophysical fluid model," in *Parallel Computational Fluid Dynamics: Algorithms and Results Using Advanced Computers*, Eds., P. Shiano, A. Ecer, J. Periaux, and N. Satofuka, Elsevier Science, 384-391.

Anderson, W.D., Grubisic, V., and P.K. Smolarkiewicz, 1997: "Performance of a massively parallel 3D non-hydrostatic atmospheric fluid model," in *Proceedings of the International Conference on Parallel and Distributed Processing Techniques and Applications, PDPTA'97*, Las Vegas, Nevada, USA, June 30-July 3, Ed. H.R. Arabnia, CSREA,