A Unified Dynamical Model for Atmospheric and Oceanic Flows

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The purpose of this study is to test the feasibility of converting an atmosphere model code into an ocean model code, hence producing a single code that is valid for both atmosphere and ocean modelling. There are several motivations for doing this. Recent developments on numerical methods in the atmospheric sciences have permitted the elimination of some approximations that are traditionally applied in the primitive equations (hydrostatic approximation; filtering sound waves). The system of equations used in oceanographic models is a subset of the equations used in atmospheric model codes. The resources available to the Canadian atmospheric and oceanographic scientific community are limited, so sharing the same dynamical core would optimize its development and improvement. There will be increasing use of coupled atmosphere-ocean systems, which could be simplified by using the same code for both fluids. If this preliminary project is successful, a more general project would be conducted using a model with tangent linear and adjoint code for advanced data assimilation, thus facilitating future atmosphere-ocean data assimilation research and development.

Here a semi-implicit, semi-Lagrangian algorithm developed for air flows (Benoit et al., 1997, hereinafter referred to as the RPN code) has been adapted for water. A unified nonhydrostatic and compressible system of equations is used for both fluids. The dynamical kernel (fourth order semi-Lagrangian advection and solver) is shared by both applications. The capability to treat flow around solid objects in the horizontal has been added, together with the ability to handle solid objects using a partial step method with the vertical z-coordinate.

The RPN code has been validated by comparing its performance with that of a well developed ocean model (Saucier et al., 2003, hereinafter referred to as the IML code) on theoretical test cases that are well recognized by the oceanographic community. The IML code is based on hydrostatic and incompressible dynamics, uses second order (flux corrected transport) Eulerian advection, horizontal solid objects, z-coordinate with solid objects in the vertical, has an implicit flexible top, and uses an explicit solver for the remainder of the system of equations.

The first problem examined is that of the overturning of initially adjacent zones of air and water separated by a vertical front of depth H. In the theoretical inviscid solution, in the top half of the domain the vertical front moves into the space formerly occupied by the water, and vice versa in the lower half of the domain. The fronts remain vertical and move with a speed $\frac{1}{2}\,(gH)^{1/2}$ in opposite directions, leaving a horizontal interface separating the air in the top from the water in the bottom halves of the domain. Due to the strong vertical shear in velocities across the horizontal interface, it is a dynamically unstable zone and some viscosity has to be introduced in the problem in order for numerical solutions to be obtained. In Eulerian model solutions, the sharp frontal zones give rise to fictitious wave dispersion, whereas the semi-Lagrangian solutions are prone to overshoot / undershoot problems. The presence of diffusion alleviates these difficulties. By using a linear interpolation in the vicinity of the sharp gradients in the RPN code it has been possible to produce very good simulations, with frontal speeds, monotonicity, and conservation that rival those of the IML code.

The second comparison was to test the inclusion of solid objects in the RPN code. Inviscid flow past a square was simulated. The RPN and IML simulations were very similar in their early stages, but an increasingly “noisy” pattern developed around the corners of the object later in the IML simulation. The RPN simulation continued to be well behaved.

Encouraged by these results, simulations of Von Karman vortex streets for flow past a cylinder were also performed with the RPN code and compared with laboratory experiment results. The RPN simulation did very well, quantitatively reproducing details of the boundary layer separation and stagnation points, as well as the turbulent wakes.

These results provide confidence that a unified atmosphere-ocean model is indeed feasible. First comparisons and evaluations using the complete three-dimensional model in a coastal region have begun.

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References

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