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On the use of a depth-dependent barotropic mode for free surface ocean models

J. Demange (1), L. Debreu (1), P. Marchesiello (2), and E. Blayo (3)

(1) INRIA, LJK, Grenoble, France, (2) IRD, LEGOS, Toulouse, France, (3) University of Grenoble, LJK, Grenoble, France

It is well known from the linear theory that the strongest stability constraint on a numerical ocean model is given by the propagation of the barotropic mode. The rigid lid approximation removes this constraint at the price of the solution of an elliptic system with barotropic streamfunction or surface pressure as unknown. In the rigid lid approximation, the barotropic mode is vertically constant and so the barotropic part of the flow can be identified to the depth integrated flow.

When, for physical motivations, a free surface is introduced, the modification of the surface boundary condition renders the barotropic mode slightly non constant [3]. However since the first introduction of a free surface in an ocean model ([1], [4]), the barotropic mode is still assumed to be vertically constant in order to simplify the derivation of the barotropic system, which is then treated either using a time splitting method with small time steps or implicitly [2].

This assumption has two trade-off effects. First, the loss of orthogonality and aliasing between the barotropic and baroclinic modes results in the need for filtering [5] even in the linear case, albeit this is not theoretically required. This filtering can greatly alter the propagation of several physical signals (e.g. tidal waves). Second, again due to non orthogonality of the modes, the additional diffusion put on the approximated barotropic mode also alters the vertical structure of the baroclinic parts of the flow.

In this presentation, these two issues are illustrated in the case of the propagation of either a barotropic or baroclinic mode over a flat bottom ocean using linearized primitive equations, i.e. when the modal decomposition is valid. The continuous approach is recalled and the discrete implementation of a time splitting scheme based on a depth-dependent barotropic mode is introduced. This noticeably includes a 3D correction of the density field by its 2D barotropic counterpart.

The extension to the nonlinear case is obviously non trivial. Nevertheless, we propose to solve an approximate barotropic system which conforms to the theory when linearized. Numerical simulations of the propagation of internal gravity waves are showed and perspectives are drawn.

References

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