On the use of the _oating Lagrangian vertical coordinate for hydrostaic and non-hydrostatic models of the atmosphere

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4th August 2006

Abstract

A global-regional weather-climate modeling system is being developed at NOAA/Geophysical Fluid Dynamics Laboratory (GFDL). The foundation of this uni_ed modeling system is a nonhydrostatic extension of the _vertically Lagrangian_ _nite-volume dynamical core currently used at GFDL, NASA, and NCAR for both weather and climate applications. This talk will focus on the vertical discretization using the Lagrangian control-volume concept introduced by Lin (2004, Monthly Weather Review).

Unlike the well-known _isentropic coordinate_, which is only Lagrangian for adiabatic _ows, the _oating Lagrangian vertical coordinate system described in Lin 2004 is genuinely Lagrangian, terrain following, and it can be used equally e_ectively for both hydrostatic and non-hydrostatic flow, offering tremendous computational advantage over existing Eulerian non-hydrostatic models.

Under hydrostatic approximation, the mass contained within the Lagrangian control-volume balanced *exactly the vertical pressure gradient force, and there will be no vertical advection terms involved for both* adiabatic and non-adiabatic _ow. From this perspective, it can be argued that the Lagrangian coordinate system of Lin 2004 is the most natural vertical coordinate for hydrostatic flows.

For non-hydrostatic _ow, the inviscid Euler equations or the full Navier-Stokes equations permit meteorologically un-important sound waves in all 3 spatial directions. The Lagrangian vertical coordinate system, if it can handle vertically propagating sound waves e_ciently, clearly would allow a much larger time step and better accuracy than the conventional Eulerian coordinate approach.

We will describe in details how one can e_ciently discretize the un-approximated Euler equations using the terrain-following Lagrangian vertical coordinate system. The most critical part of the methodology is the realization that the non-hydrostatic component of the solution (the vertically propagating sound waves) can be separated cleanly from the hydrostatic part, resulting in a simple set of 1D (z) equations, which can then be solved semi-analytically by a newly developed Lagrangian Riemann Solver that is stable for large time step. The validity of this new approach will be demonstrated using common 2D (x-z) non-hydrostatic test cases with and without terrains. A global-regional modeling framework based on this approach on the cubed sphere is being built, and it will be used in NOAA/GFDL's next coupled modeling system for climate and weather predictions.