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Verification of a non-hydrostatic dynamical core using the horizontal spectral element method and vertical finite difference method: 2-D aspects

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Abstract. The non-hydrostatic (NH) compressible Euler equations for dry atmosphere were solved in a simplified two-dimensional (2-D) slice framework employing a spectral element method (SEM) for the horizontal discretization and a finite difference method (FDM) for the vertical discretization. By using horizontal SEM, which decomposes the physical domain into smaller pieces with a small communication stencil, a high level of scalability can be achieved. By using vertical FDM, an easy method for coupling the dynamics and existing physics packages can be provided. The SEM uses high-order nodal basis

functions associated with Lagrange polynomials based on Gauss–Lobatto–Legendre (GLL) quadrature points. The FDM employs a third-order upwind-biased scheme for the vertical flux terms and a centered finite difference scheme for the vertical derivative and integral terms. For temporal integration, a time-split, third-order Runge–Kutta (RK3) integration technique was applied. The Euler equations that were used here are in flux form based on the hydrostatic pressure vertical coordinate. The equations are the same as those used in the Weather Research and Forecasting (WRF) model, but a hybrid sigma–pressure vertical coordinate was implemented in this model.

We validated the model by conducting the widely used standard tests: linear hydrostatic mountain wave, tracer advection, and gravity wave over the Schär-type mountain, as well as density current, inertia–gravity wave, and rising thermal bubble. The results from these tests demonstrated that the model using the horizontal SEM and the vertical FDM is accurate and robust provided sufficient diffusion is applied. The results with various horizontal resolutions also showed convergence of second-order accuracy due to the accuracy of the time integration scheme and that of the vertical direction, although high-order basis functions were used in the horizontal. By using the 2-D slice model, we effectively showed that the combined spatial discretization method of the spectral element and finite difference methods in the horizontal and vertical directions, respectively, offers a viable method for development of an NH dynamical core.

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