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Vertical Discretization of Hydrostatic Primitive Equations with Finite Element Method

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A vertical finite element (VFE) discretization of hydrostatic primitive equations is developed for the dynamical core of a numerical weather prediction (NWP) system at KIAPS, which is horizontally discretized by a spectral element on a cubed-sphere grid. The governing equations are discretized on a hybrid pressure-based vertical coordinate [1].

Compared with a vertical finite difference (VFD) discretization, which is only first order accurate for non-uniform grids, the VFE has many advantages such that it gives more accurate results, all variables are defined in the same full level, the level of vertical noise might be reduced [2], and it is easily coupled with existing physics packages, developed for a Lorentz staggering grid system. Due to these reasons, we adopted the VFE scheme presented by Untch [2] for the vertical discretization. Instead of using semi-Lagrangian and semi-implicit schemes of ECMWF, we use the Eulerian equations and second-order Runge-Kutta scheme as the first step in implementing the VFE for the dynamical core of the KIAPS's NWP model. Since the Eulerian hydrostatic equations are used in this study, both integral and derivative operators are required to implement the VFE using the Galerkin method with b-splines as basis functions.

To compare the accuracy of the VFE with the VFD, the two-dimensional test case of mountain waves is used where physical configuration and initial conditions are the same as that of Durran [3]. In this case, the horizontal and vertical velocities obtained by the analytical solution, VFD, VFE-linear and VFE-cubic are compared to understand their numerical features and the vertical flux of horizontal momentum is also presented as the measurement of solution accuracy since it is sensitive to errors in a solution [3]. It is shown that the VFE with a cubic b-spline function is more accurate than the VFD and VFE with a linear b-spline function as the vertical flux is closer to unity, which will be presented in the conference.

Reference

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