The E3SM Non-Hydrostatic Dynamical Core

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We give an overview of the formulation of Energy Exascale Earth System Model’s (E3SM) non-hydrostatic dynamical core. We use a Larprise formulation with a terrain following mass based coordinate (Laprise, MWR 1992). The prognostic variables are u,v,w, potential temperature, geopotential height and the appropriate mass-coordinate pseudo-density. In the vertical, we use a Lorenz staggering and the SB81 compatible finite difference operators (Simmons & Burridge, MWR 1981) These operators are generalized to the non-hydrostatic system where some variables are now transported on layer interfaces. The generalization preserves the mimetic properties of the method, as well as the method’s discrete derivative product rule. In the horizontal we use the compatible spectral element discretization (Taylor & Fournier, JCP 2010). We have both Eulerian and vertically Lagrangian formulations (Lin, MWR 2004), with vertical remap based on Zerroukat et al, QJR 2005.

The scheme conserves all quantities advected in conservation form (mass, tracer mass) as well as 2D potential vorticity. With the vertically Eulerian formulation, it conserves energy to time-truncation error even in the moist case with many commonly used equations of state. The vertically Lagrangian formulation introduces vertical dissipation though the enforcement of monotonicity. with additional flexibility with in the treatment of vertical transport due to the SB81 discrete product rule.

We use a HEVI timestepping method, discretized with a high-stage IMEX method where the increased stages are used to increase the CFL efficiency (Steyer et al, CISC 2019). The Laprise formulation and choice of prognostic variables means that the vertical acoustic waves do not appear in the vertical transport terms and are isolated to source terms in the w and geopotential equations, which can be statically condensed to a single scalar system, solved via Newton iteration. In addition, the Laprise formulation makes it easy to compute a natural hydrostatic background state which is used to improve the pressure gradient error and reduce the effects of terrain following dissipation operators.

The code has been implemented in E3SM's version of the High-Order Method Modeling Environment (HOMME) and is available on the E3SM public github site.