Assessing the Accuracy of Tracer Transport Schemes in the Dynamical Cores of General Circulation Models

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Abstract
Tracer transport is an important component of any General Circulation Model (GCM) dynamical core. All transport schemes use some form of advection, either explicitly specified or inherent in the chosen numerical scheme, to ensure positivity, stability, and to prevent the accumulation of tracer variance at the grid scale. However, there is little physical justification for the many of the subgrid processes performed in GCMs today (Jablonowski and Willamson 2013). In this research project, we analyze the accuracy of tracer transport in the four dynamical cores in NCAR's Community Atmosphere Model (CAM) via a detailed dynamical core and tracer advection test cases. We focus on the impact of (1) resolution, (2) the numerical schemes and formulators, and (3) the consistency between the numerical schemes used for the dynamical cores and tracer advection.

Overview of the Dynamical Cores
We focus our attention on the finite-volume dynamical core, however, we also show snapshots of the diffusion characteristics of the other dycores in CAM described in Noile et al. (2010):
1) NCAR CAM 5.0 Finite-Volume (FV): finite-volume approach with monotonicity constraints (PPM), latitude-longitude grid, DEC grid staggering, Boussinesq vertical coordinate with hybrid coordinate as reference grid, explicit time-stepping with explicitly added downwind damping (diffusion of divergence). Advection is treated similarly.
2) NCAR CAM 5.0 Semi-Lagrangian (SLD): semi-Lagrangian spectral transform model with triangular truncation, Gaussian grid, hybrid (z) vertical coordinate, 2-time level, semi-implicit time-stepping with explicitly added 6th-order hyper-diffusion. Advection is treated similarly.
3) NCAR CAM 5.0 Eulerian (EUL): spectral transform model with triangular truncation, Gaussian grid, hybrid (z) vertical coordinate, 3-level, semi-implicit time-stepping with explicitly added 4th order hyper-diffusion. Advection is treated via a diffusive semi-Lagrangian algorithm.

All dynamical cores are hydrostatic and based on the Primitive Equations set. They are run in their operational configurations which include their typical diffusion mechanisms (e.g. horizontal divergence damping, diffusion and hyperdiffusion, digital filters, monotonicity for the limiters, and Asselin time filtering for the 3-level in EUL).

Impact of vertical resolution on CAM-FV

Measurements of the consistency between the dynamical core and tracer advection algorithms via potential vorticity

Conclusions and Future Work:
Vertical resolution has a significant impact on the accurate transport of tracers, and increases in horizontal resolution should be carefully weighed against increases in the vertical. Further investigation into the impact of vertical resolution on other models and dynamically relevant test cases will be pursued.

Deformational test cases indicate that CAM-FV is monotonic in 2 dimensions. Further development of deformation test cases and of 3D deformational tests are being explored, as well as investigation of the effect of these tests on the subgrid scales of tracer variance. An intercomparison of the dynamical cores in CAMs using these tracer test cases will be performed.

Potential vorticity can be used to explore the consistency between a model's dynamic and tracer transport algorithms. Further sensitivity of the PV to subgrid dissipative processes can be explored to determine the effect of these processes on a model's consistency.

Quantification of the difference between the numerical treatment of passive linear advection, and integration of the full momentum equations will be pursued following the motivation provided by the PV experiments.

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