PHYSICS-DYNAMICS COUPLING WITH GALERKIN METHODS: EQUAL-AREA PHYSICS GRID

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Abstract

Local Galerkin methods often make use of quadrature grids to exactly integrate basis functions over an element. Typically parameterization tendencies are based on the atmospheric state at the quadrature points. This leads to an non-equi-distant 'sampling' of the atmospheric state (Figure 1a,b).

The functionality to run physics on an equal-area finite-volume grid inside each element in CAM-SE (Community Atmosphere Model - Spectral Elements; Dennis et al., 2012; Neale et al., 2010) has been implemented (see Figure 1c,d). The motivation for this functionality was fourfold:

- The purpose of the quadrature grid (Figure 1a) is to exactly integrate polynomials over an element inside the spectral element fluid flow solver. It may be more physically consistent to integrate these polynomial representations of the atmospheric state over equal-area control volumes rather than sampling them an-isotropically in space at the quadrature points when passing the atmospheric state to the physics package.
- Noise in, e.g. vertical velocity, typically appears near element boundaries, where the globally continuous polynomials are only C^0. By using an equal-area finite-volume-type physics grid within each element, the vertical velocity is averaged over a control volume and not evaluated at the element edge.

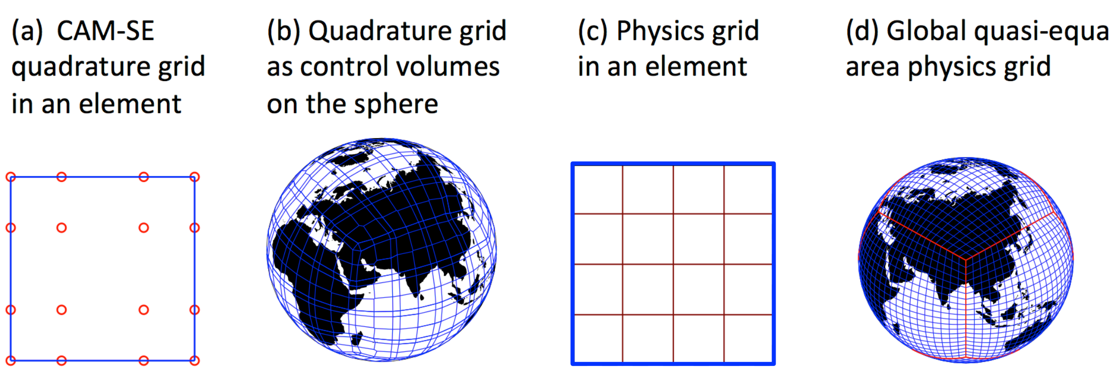

Figure 1. (a) Depicts the location of the quadrature points in the CAM-SE $ne30np4$ configuration. (b) The grid that the coupler in the NCAR-DOE CESM (Community Earth System Model) uses where control volumes around the quadrature grid are used. (c) The equal-area physics-CSLAM grid inside each element. (d) The physics-CSLAM grid on the sphere.

- A physics grid supports the finite-volume multi-tracer scheme CSLAM (Conservative Semi-LAgrangian Multi-tracer scheme in CAM-SE; Lauritzen et al., 2010; Erath et al., 2012, 2013) in that tracer transport can be computed on the same grid as the physics grid.
- Running physics on a finer or coarser grid will enable new science in CAM-SE. Using linear numerical analysis theory it is well known that the dynamical core has not converged at the grid-scale. This advocates computing sub-grid scale tendencies on a grid coarser than the dynamical core grid so that only the 'converged' model state is forwarded to the sub-grid scale parameterizations (Williamson, 1999). Perhaps counter-intuitively running physics on a grid finer than the dynamical core grid resulted in improved forecast scores in the ECMWF IFS (Niels Wedi; personal communication). Clearly this paradigm needs further investigation.

Preliminary results from Held-Suarez and Aqua-planet simulations using the physics grid in CAM-SE will be presented.

References

John M. Dennis, Jim Edwards, Katherine J. Evans, Oksana Guba, Peter H. Lauritzen, A. .A. Mirin, Amik St-Cyr, Mark A. Taylor, and Patrick H. Worley. CAM-SE: A scalable spectral element dynamical core for the Community Atmosphere Model. *Int. J. High. Perform. C.*, 26(1):74–89, 2012. doi: 10.1177/1094342011428142. URL `http://hpc.sagepub.com/content/26/1/74.abstract`.

C. Erath, Peter H. Lauritzen, and Henry M. Tufo. On mass-conservation in high-order high-resolution rigorous remapping schemes on the sphere. *Mon. Wea. Rev.*, 141:2128–2133, 2013. doi: 10.1175/MWR-D-13-00002.1.

Christoph Erath, Peter H. Lauritzen, Jose H. Garcia, and Henry M. Tufo. Integrating a scalable and efficient semi-Lagrangian multi-tracer transport scheme in HOMME. *Procedia Computer Science*, 9:994–1003, 2012.

P. H. Lauritzen, R. D. Nair, and P. A. Ullrich. A conservative semi-Lagrangian multi-tracer transport scheme (CSLAM) on the cubed-sphere grid. *J. Comput. Phys.*, 229:1401–1424, 2010. doi: 10.1016/j.jcp.2009.10.036.

Richard B. Neale, Chih-Chieh Chen, Andrew Gettelman, Peter H. Lauritzen, Sungsu Park, David L. Williamson, Andrew J. Conley, Rolando Garcia, Doug Kinnison, Jean-Francois Lamarque, Dan Marsh, Mike Mills, Anne K. Smith, Simone Tilmes, Francis Vitt, Philip Cameron-Smith, William D. Collins, Michael J. Iacono, Richard C. Easter, Steven J. Ghan, Xiaohong Liu, Philip J. Rasch, and Mark A. Taylor. Description of the NCAR Community Atmosphere Model (CAM 5.0). NCAR Technical Note, National Center of Atmospheric Research, 2010.

D. L. Williamson. Convergence of atmospheric simulations with increasing horizontal resolution and fixed forcing scales. *Tellus A*, 51:663–673, 1999. doi: 10.1034/j.1600-0870.1999.00009.x.