Multiscale techniques

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Multi-scales means a lot of different things to a wide-span of researchers. In what follows we are interested in the ability to resolve scales from the numerical and physical modeling standpoints. First, numerical techniques for resolving scales in space (AMR: adaptive mesh refinement) are studied and compared with the state of the art in geosciences (1). It is shown that the high-order approach is the a technique that exhibits a correct convergence behavior. For a given accuracy, the method is also faster for a more realistic shallow water test involving a mountain. Secondly, the calculation power of supercomputers has increased to such levels that the unabridged flow equations might now be employed in climate and weather modeling. However, this implies dealing with sound waves in a way or another. In (2), a linear implicit method is combined with a high-order discontinuous Galerkin solver to solve non-hydrostatic model problems. The novelty of the approach resides in the use of a Jacobian-free approach and is thus one step towards a multi-physics solver. On the physical modeling side, a new convective parameterization named multicloud is investigated in a full general circulation model (3) (this is a first). The idea behind the multicloud scheme is to employ only a couple of modes, or scales, of the vertical structure matrix of the atmosphere. The approach seems to trigger the correct wave phenomena: in particular a MJO is observable. Finally the scalability of the High-Order Methods Modeling Environment, coupled to CAM-3 physics is reported in (4) and establishes that modern numerical techniques is the only path towards petascale simulations.

(1) Comparison of Two Shallow-Water Models with Non-conforming Adaptive Grids

Joint work with: C. Jablonowski (University of Michigan), J.M. Dennis, H.M. Tufo, and S.J. Thomas:

Summary. In an effort to study the applicability of adaptive mesh refinement (AMR) techniques to atmospheric models, an interpolation-based spectral el-
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A shallow-water model on a cubed-sphere grid is compared to a block-structured finite-volume method in latitudelongitude geometry. Both models utilize a nonconforming adaptation approach that doubles the resolution at fine-coarse mesh interfaces. The underlying AMR libraries are quad-tree based and ensure that neighboring regions can only differ by one refinement level. The models are compared via selected test cases from a standard test suite for the shallow-water equations, and via a barotropic instability test. These tests comprise the passive advection of a cosine bell and slotted cylinder, a steady-state geostrophic flow, a flow over an idealized mountain, a Rossby-Haurwitz wave, and the evolution of a growing barotropic wave. Both static and dynamics adaptations are evaluated, which reveal the strengths and weaknesses of the AMR techniques. Overall, the AMR simulations show that both models successfully place static and dynamic adaptations in local regions without requiring a fine grid in the global domain. The adaptive grids reliably track features of interests without visible distortions or noise at mesh interfaces. Simple threshold adaptation criteria for the geopotential height and the relative vorticity are assessed.

(2) A Fully Implicit High-Order Discontinuous Galerkin Solver for Mesoscale Flows

Joint work with: D. Stanescu (University of Wyoming) and D. Neckels.
Summary. It this work it is shown how to discretize the compressible Euler equations around a vertically stratified base state using the discontinuous Galerkin approach on collocated Gauss type grids. The spatial integration is performed exactly thanks to the block-wise invertible mass matrix. Exact integration enables the solution of the resulting discrete system for any polynomial order. A stiffly stable Rosenbrock W- method is combined with an approximate evaluation of the Jacobian to integrate in time the resulting system of ODEs. Simulations with fully compressible equations for a rising thermal bubble due are performed. Also included are simulations of an inertia gravity wave in a periodic channel. The proposed time-stepping method accelerates the simulation times with respect to explicit Runge-Kutta time stepping procedures having the same number of stages.

(3) The Multicloud parametrization models for tropical convection: Implementation in a GCM

Joint work with: B. Khouider (University of Victoria), A. Majda (Courant institute) and J. Tribbia.
Summary. (In progress) We report results concerning the multicloud parameterization scheme of Khouider-Majda and its coupling to a next generation AGCM based on the spectral element method (HOMME: High-Order Method Modeling Environment). The latter is ran in a stand-alone aquaplanet mode to examine the organization of coherent convection in the simplest possible
setting. Hopefully, this will help understand the role of bimodal heating in the upscale organization of equatorial wave modes and the Madden Julian Oscillation (MJO).

(4) Petascale atmospheric models for the Community Climate System Model: new developments and evaluation of scalable dynamical cores

Joint work with: M.A. Taylor (Sandia National laboratories) and J. P. Edwards (IBM)

Summary. We present results from the integration and evaluation of the spectral finite-element method into the atmospheric component of the Community Climate System Model (CCSM). This method overcomes the atmospheric scalability bottleneck by allowing the use of a true two-dimensional domain decomposition for the first time in the CCSM. Scalability is demonstrated out to 86,200 processors with an average grid spacing of 0.25 (25 km). We present initial evaluations results using a standardized test problem with the full suite of CCSM atmospheric model forcings and subgrid parametrizations but without the CCSM land, ice, or ocean models. For this realistic setting, the true solution is unknown. Even convergence under mesh refinement is not expected, so we cannot rely on high-resolution reference solutions. Instead we focus on intermodel comparisons and use the Williamson equivalent resolution methodology to evaluate the results.