A Scalable High-Order Discontinuous Galerkin Method for Global Atmospheric Modeling

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ABSTRACT

The future evolution of the Community Climate System Model (CCSM) into an Earth system model will require a highly scalable and accurate flux-form formulation of atmospheric dynamics: flux form is required in order to conserve long-lived trace species in the stratosphere; accurate numerical schemes are essential to ensure high-fidelity simulations capable of capturing the convective dynamics in the atmosphere and their contribution to the global hydrological cycle; scalable performance is necessary to exploit the massively-parallel petascale systems that will dominate high-performance computing (HPC) for the foreseeable future.

The High-Order Method Modeling Environment (HOMME), developed by the Computational Science Section at the National Center for Atmospheric Research (NCAR), is a vehicle to investigate using high-order-element-based methods to build conservative and accurate dynamical cores. Currently, HOMME employs the Discontinuous Galerkin (DG) and spectral element methods on a cubed-sphere tiled with quadrilateral elements, can be configured to solve the shallow water or the dry/moist primitive equations, and has been shown to efficiently scale to 32,768 processors of an IBM BlueGene/L (BG/L) system.

In this paper we discuss extending the HOMME framework to include a DG option as a first step towards providing the atmospheric science community a new generation of atmospheric general circulation models (AGCMs). The DG method [1] is a hybrid technique combining the finite element and finite volume methods. The method is employed on a quadrilateral mesh of elements using a high-order nodal basis set of orthogonal Lagrange-Legendre polynomials with Gauss-Lobatto-Legendre (GLL) quadrature points. Time integration is the strong stability-preserving Runge-Kutta (SSP-RK) scheme of Gottlieb et al. [3]. The global geometry is the singularity-free cubed-sphere used in [8]. Parallelism is effected through a hybrid MPI/OpenMP design and domain decomposition through the space-filling curve approach described in [2]. Our work extends earlier efforts [9, 8, 2] in several important ways: first, we develop a scalable conservative 3D DG-based dynamical core based on the hydrostatic primitive equations; second, we employ the vertical Lagrangian coordinate approach, developed by Starr [11] and later generalized by Lin [5]; and finally, we apply the 1D cell-integrated semi-Lagrangian method [7] to preserve conservative remapping.

To validate the proposed atmospheric model, we consider the baroclinic instability test proposed by Jablonowski and Williamson [4]. This test evaluates the evolution of an idealized baroclinic wave in the Northern hemisphere. Figure 1 (left) demonstrates the triggering baroclinic waves and corresponding temperature field after 8 days of integration. Performance data is obtained on an IBM Blue Gene/L supercomputer with 2048 CPUs capable of 5.73 TFLOPS peak. Strong scaling results with $N_e = 12$ (i.e., total 864 elements) and $N_p = N_v = 8$ for a baroclinic instability simulations are shown in Figure 1 (right). Sustained performance of 194 to 222 Mflops per second per processor (8% peak) are attained in coprocessor mode and 178 to 209 Mflops per second per processor (8% peak) in

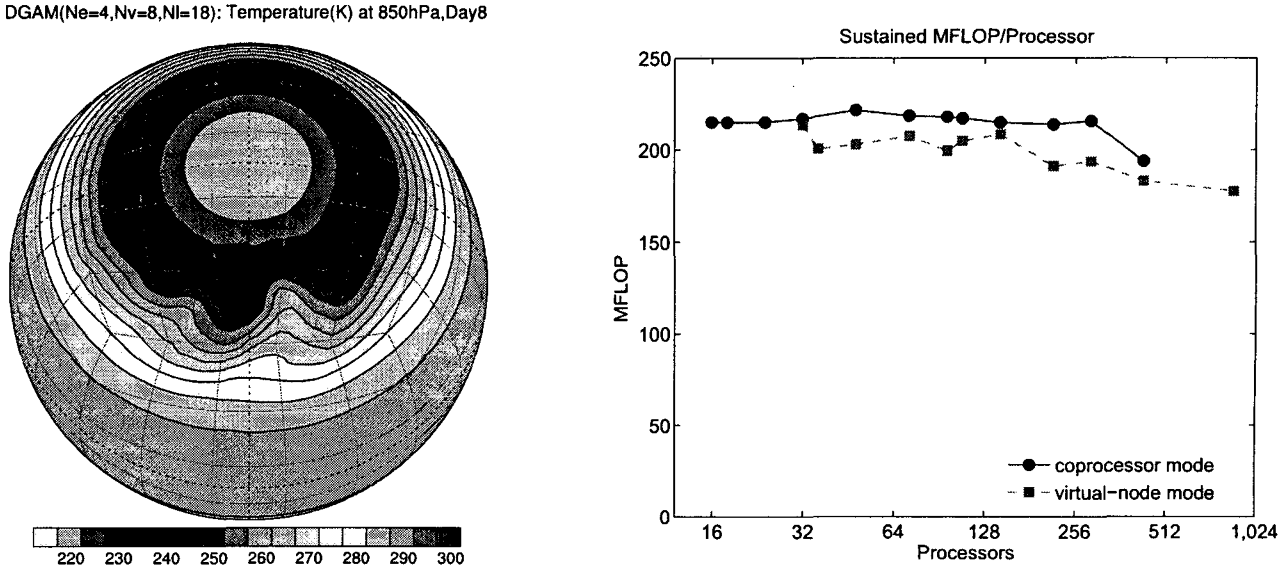

Figure 1: Preliminary results of the DG baroclinic model for the Jabonowski–Williamson test [4]: Temperature field (K) at 850 hPa after 8 days of integration (left); Sustained performance per processor in MFLOPS (right).

virtual-node mode. We note that the model is still under development and expect that the final product will exhibit levels of single processor performance and scalability comparable to those exhibited by the spectral element dynamical core in HOMME [6, 10].

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