Computational strategies for the next generation of global Earth system models

Organizer:
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Abstract

The past 10 years of global and regional climate simulation development and analysis have resulted in significant gains in prediction capability. However, further gains such as the ability to capture and predict subglobal features and characterize and quantify model sensitivities and uncertainties are restricted by many factors, including stability and accuracy limited numerical methods and the infrastructure to couple additional model components. The next-generation of Earth system models need scalable numerical methods that can be accessed through interchangeable and extensible kernels and libraries along with increased flexibility to enable a wider range of experiements. This mini-symposium will present ongoing work to develop and implement novel numerical methods within testbeds and optimize the performance of the production-level Community Earth System Model.

Session 1:

- **Speaker:** *Katherine J. Evans* (evanskj@ornl.gov), Oak Ridge National Laboratory,

  Title: Computational Challenges for Next Generation Earth System Models

  Abstract: Recent simluations using the coupled, high-resolution Community Earth System Model (CESM) are presented to highlight the benefits of higher spatial resolution, including the ability to resolve regional features in a global framework. Early analysis of these runs also shows that although high-resolution improves some climate features, the mean climate state suffers from a lack of scale-aware diagnostic schemes, and has motivated the development of more complex and mutliscale improvements. Creating high-resolution simulations already presents challenges in throughput, accuracy, and robustness that will continue to expand with near-term model development. Several examples of this will be presented to set the stage for some ideas for improvement presented in this minisympoisum.

- **Speaker:** *Matthew R. Norman* (normanmr@ornl.gov), Oak Ridge National Laboratory,

  Title: Multi-Moment ADER methods for Efficient Atmospheric Simulation

  Abstract: Given throughput constraints, climate codes are suffering low strong scaling efficiency at ultra-high resolution on current computers. High-order-accurate, single-stage time integrators better cluster computation and reduce communication frequency for improved parallel efficiency. The ADER formulation, with these properties, was recently accelerated by using Differential Transforms to cheaply compute a high-order-accurate, space-time Taylor expansion of all PDE terms, each of which can then be analytically integrated, sampled, and differentiated without quadrature to flexibly couple with any spatial operator and mesh. ADER methods non-linearly couple time and multiple spatial dimensions to achieve high accuracy over even large time steps, and they preserve non-oscillatory properties of limited spatial interpolants. Coupled with communication minimizing multi-moment spatial operators such as Galerkin, Multi-Moment Finite-Volume (MMFV), and Spectral Volume, multi-moment ADER scheme shows promise for better scaling properties, preparing for future architectures. Particularly, ADER+MMFV retains a constant maximum stable time step during p-refinement to produce a very large time step, communication-avoiding scheme.

- **Speaker:** *Richard K. Archibald* (archibaldrk@ornl.gov), Oak Ridge National Laboratory,

  Title: ELP methods applied to the shallow water equations

Abstract: We present a new approach to increase the time-step size for an explicit discontinuous Galerkin numerical method. The attributes of this approach are demonstrated on standard tests for the shallow-water equations on the sphere. The addition of multi-wavelets to discontinuous Galerkin method, which has the benefit of being scalable, flexible, and conservative, provides a hierarchical scale structure that can be exploited to improve computational efficiency in both the spatial and temporal dimensions. This presentation explains how combining a multiwavelet discontinuous Galerkin method with exact linear part time- evolution schemes, which can remain stable for implicit-sized time steps, can help increase the time-step size for shallow water equations on the sphere.

- **Speaker:** *Jun Jia* (jiaj@ornl.gov), Oak Ridge National Laboratory,

  Title: Spectral Deferred Corrections in HOMME

  Abstract: In this talk we present a spectral deferred correction method for the shallow water equation on a sphere. Temporal order up to eight has been demonstrated. Because this method is stable and of high order, larger time-step sizes can be taken while still yielding accurate long-time simulations. The method has been tested on a suite of popular benchmark problems, and when compared to the explicit leapfrog, 5-stage Runge-Kutta, and fully implicit (FI) BDF2time integration methods, it achieves higher accuracy for the same or larger time-step sizes.

Session 2:

- **Speaker:** *Patrick H. Worley* (worleyph@ornl.gov), Oak Ridge National Laboratory,

  Title: Parallel implementation and performance of the SEACISM version of the Community Ice Sheet Model

  Abstract: The Community Ice Sheet Model was recently upgraded to include higher order Payne-Price 3D momentum and mass balance equations and new nonlinear and linear solver techniques and technologies. It was also parallelized, enabling execution on both distributed and shared memory architectures using the Message Passing Interface (MPI). We describe the parallelization strategy, followed by a description and analysis of performance for benchmark problems simulating the Greenland Ice Sheet. Of special note is the impact of the parallelization strategy on the numerical convergence behavior for the nonlinear and linear systems, and the role this plays in performance and performance scalability.

- **Speaker:** *Matthew R. Norman* (normanmr@ornl.gov), Oak Ridge National Laboratory

  Title: GPU Porting of the Community Atmosphere Model - Spectral Element (CAM-SE)

  Abstract: With the advent of hybrid massively parallel computing architectures with off-chip accelerators such as Graphics Processing Units, we have ported the Community Atmosphere Model - Spectral Element (CAM-SE) to efficiently utilize GPUs. We port the tracer transport routines for a target science problem of 14km horizontal grid spacing, using the MOZART chemistry and CAM5 physics packages for a total of over 100 transported tracer species. We describe the initial profiling efforts, targetting of dense, data-parallel routines for porting, the kernel optimization process, minimization of PCI-e transfers, and overlapping of MPI transfers, PCI-e transfers, GPU kernels, and CPU execution. We also discuss future directions for the port as well as performance measures.

- **Speaker:** *Chris G. Baker* (bakercg@ornl.gov), Oak Ridge National Laboratory

  Title: Efficient interfacing of numerical libraries in the Community Earth System Model

  Abstract: We discuss ongoing efforts to improve the performance of the Community Earth System Model (CESM) by deploying more advanced solution methodologies. This talk will discuss multiple issues of efficiency that arise in this context. The use of third-party numerical libraries (in particular, Trilinos) and the design of application and library interfaces have significant impact on developer efficiency. We will discuss our efforts in maximizing run-time efficiency of the code, including the obstacles to this that occur for a general purpose third-party library.

- **Speaker:** *Roger Pawlowski* (rppawlo@sandia.gov), Sandia National Laboratories

  Title: Solution Techniques for Large-scale Fully-Implicit Multi-Physics Systems Using Trilinos

  Abstract: Robust, efficient and accurate simulations of complex nonlinear multi-physics systems are challenging. This talk will focus on a number of emerging technologies being developed in the Trilinos project [1] to implement fully-coupled globalized Newton-based solvers. This will include a discussion of abstract numerical algorithm design for nonlinear systems, requirements for physics-based and block decomposition preconditioners and efficient techniques for sensitivity evaluation. Examples will be shown for conjugate heat transfer simulations of a nuclear reactor and magnetohydrodynamics.