Title: Adaptive Numerical Algorithms in Space Weather Modeling

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Abstract

Space weather describes the various processes in the Sun-Earth system that present danger to human health and technology. The goal of space weather forecasting is to provide an opportunity to mitigate these negative effects. Physics-based space weather modeling is characterized by disparate temporal and spatial scales as well as by different physics in different domains. A multi-physics system can be modeled by a software framework comprising of several components. Each component corresponds to a physics domain, and each component is represented by one or more numerical models. The publicly available Space Weather Modeling Framework (SWMF) can execute and couple together several components distributed over a parallel machine in a flexible and efficient manner. The framework also allows resolving disparate spatial and temporal scales with independent spatial and temporal discretizations in the various models. Several of the computationally most expensive domains of the framework are modeled by the Block-Adaptive Tree Solarwind Roe Upwind Scheme (BATS-R-US) code that can solve various forms of the magnetohydrodynamics (MHD) equations, including Hall, semi-relativistic, multi-species and multi-fluid MHD, anisotropic pressure, radiative transport and heat conduction. Modeling disparate scales within BATS-R-US is achieved by a block-adaptive mesh both in Cartesian and generalized coordinates. Most recently we have created a new core for BATS-R-US: the Block-Adaptive Tree Library (BATL) that provides a general toolkit for creating, load balancing and message passing in a 1, 2 or 3 dimensional block-adaptive grid. We describe the algorithms of BATL and demonstrate its efficiency and scaling properties for various problems. BATS-R-US uses several time-integration schemes to address multiple time-scales: explicit time stepping with fixed or local time steps, partially steady-state evolution, point-implicit, semi-implicit, explicit/implicit, and fully implicit numerical schemes. Depending on the application, we find that different time stepping methods are optimal. Several of the time integration schemes exploit the block-based granularity of the grid structure. The framework and the adaptive algorithms enable physics based space weather modeling and even forecasting.