DSMC Model Development for Earth's Upper Atmosphere

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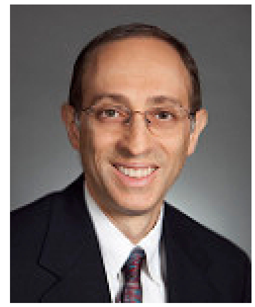

Abstract: Understanding the Earth's weather and climate often involves solving the fluid dynamics equations of motion as a global circulation model, or GCM. The difficulties in a GCM in part stem from a lack of definite knowledge of the boundary conditions, an incomplete understanding of the physics, the broad range of important scales, and the computational resources needed. Above the atmosphere in near-Earth space, the "space weather" environment is becoming increasingly important to understand due to its influence on space operations and communications. In this region, chemistry, radiation, and electromagnetic field effects must be accounted for. This is particularly difficult, especially for creating a predictive ability, due to the uncertain forcing of the solar input. Between the continuum atmosphere and space lies a region where thermodynamic, chemical, and radiative non-equilibrium occur. This region, extending from the base of the thermosphere up to above the exobase (where the local molecular mean free path begins to exceed the atmospheric scale height), is not modeled well as fully continuum and thus amenable to simulation with some version of the Navier Stokes equations. It is correctly modeled by a version of the Boltzmann equation of rarefied gas dynamics.

Directly solving the Boltzmann equation, including the appropriate physical models for chemistry, multiple species, radiation, charged particles, etc., at a planetary scale is infeasible. My group has instead been developing a direct simulation Monte Carlo (DSMC) planet-scale simulation ability under NASA sponsorship over many years. In DSMC, numerical particles representing molecules, atoms, and ions are moved and collided during a time step. We have applied our code to simulations of plumes, impacts, and escape from several moons and small bodies in the solar system, and developed within it a broad range of physics modules. I have also recognized that there is a strong scientific argument why our same DSMC methods and codes can now be brought home to Earth. The "grand challenge" in this problem is to provide a predictive ability to simulate upper atmospheric conditions a couple of days into the future, better than is currently possible. I believe we now have the method – DSMC – that correctly links the continuum lower atmosphere models with the magneto-hydrodynamic space models. But scientific/physics models are incomplete, and real engineering issues remain. These issues include true unsteady hybridization between the continuum, DSMC and MHD regions, coupling of radiation transport across domains, general inter-code data compatibility, running linked but different codes in parallel, gross inhomogeneity of actual boundary data, etc. Beyond such issues, there exist fundamental science questions we can uniquely address, such as: How do upwardly propagating gravity waves spread and break and deposit energy to heat the thermosphere? These open issues will be explored as part of the Grand Challenge award.