Modeling and Forecasting the Geospace Environment

Tamas Gombosi

Konstantin Gringauz Distinguished University Professor of Space Science
Rollin Gerstacker Professor of Engineering
Department of Climate and Space Sciences and Engineering
University of Michigan

UN/USA Workshop on the International Space Weather Initiative  31 July – 4 August, 2017
Space Weather Scales

- **Multi-scale**
  - Temporal range: $2^{28} \sim 2.7 \times 10^8$
  - Spatial range: $2^{28} \sim 2.7 \times 10^8$
  - Cell volume range: $2^{84} \sim 1.9 \times 10^{25}$

- **Multi-physics – from kinetic to MHD**
  - Solar interior and dynamo
  - Transition region
  - Corona
  - Heliosphere
  - Magnetosphere
  - Ionosphere-upper atmosphere
  - Ground currents

Tamas I. Gombosi
tamas@umich.edu
http://www-personal.umich.edu/~tamas/
Multiphysics X-MHDCODE: BATS-R-US

Time-stepping
- Local explicit (CFL control) for steady state
- Global explicit
- Part steady explicit
- Explicit/implicit
- Point-implicit
- Semi-implicit
- Fully implicit

Conservation laws
Hydrodynamics
- X-MHD
- Ideal & non-ideal
- Hall
- Anisotropic pressure
- Semi-relativistic
- Multi-species
- Multi-fluid
- Ideal & non-ideal EOS

Numerics
- Conservative finite-volume discretization
  - 2nd (TVD), 4th (PPM) & 5th (MP) spatial order schemes
  - Rusanov/HLLE/AW/Roe/HLLD
- Splitting the magnetic field into $B_0 + B_1$
- Divergence B control
  - CT, 8-wave, projection, parabolic-hyperbolic cleaning

AMR Library (BATL)
- Self-similar blocks
- Cartesian grid
- Curvilinear grid (can be stretched)
- Supports 1, 2 and 3D block-adaptive grids
- Allows AMR in a subset of the dimensions

Source terms
- Gravity
- Heat conduction
- Ion-neutral friction
- Ionization
- Recombination
- Charge exchange
- Wave energy dissipation
- Radiative heating/cooling

Auxiliary equations
- Wave energy transport
- Radiation transfer (multigroup diffusion)
- Material interface (level set)
- Parallel ray-tracing
- Tabular equation of state

Block Adaptive-Tree Solar-wind Roe-type Upwind Scheme
SWMF/Geospace Model

XMHD options
- Ideal MHD
- Resistivity models
- Single species, multispecies, multifluid
- Hall MHD
- Isotropic or anisotropic temperatures

Input:
- Upstream solar wind
- Date/time (for magnetic axis)
- F10.7 flux

Simulated observables:
- Dst, Kp, regional K, CPCP, individual magnetometers, …
- Plasma parameters anywhere in the magnetosphere
- Ionospheric convection
SWMF/Geospace at the CCMC

ROR Runs per Year - Global Magnetosphere

ROR Users per Year - Global Magnetosphere

Tamas I. Gombosi
tamas@umich.edu
http://www-personal.umich.edu/~tamas/
SWPC Geospace Model Challenge by CCMC

Next Step: MHD-EPiC

Combines the efficiency of the global fluid code with the physics capabilities of the local PIC code

MHD provides the initial state and boundary conditions for PIC

PIC overwrites the overlapped MHD cells

Details
- Multi-ion MHD. Separate electron pressure.
- Different PIC and MHD grids including non-Cartesian AMR MHD grids.
- Different PIC and MHD time steps
- Multiple PIC domains
- Efficiency and robustness

P [nPa]

Daldorff et al., J. Comp. Phys., 2014 (doi: 10.1016/j.jcp.2014.03.009)
Chen et al., J. Comp. Phys., 2016 (doi: 10.1016/j.jcp.2015.11.003)
Crescent Distribution & Electric Field

(a) $E_x$

(b) Electron

(c) Ion

MMS observation

Magnetotail Reconnection

- Density cavity ($\log(n_e)$)
- Dipolarization front ($B_z$)

Chen et al., J. Geophys. Res., submitted, 2017
Summary

Over the last decade physics-based global geospace models became a bridge between experiment and basic theory and now they represent the “third pillar” of geospace research.

Geospace models are widely used by the space weather community via CCMC.

SWMF/Geospace has been transitioned to NOAA/SWPC and it is will enter operations in September 2017.

SWMF and all its components are available for download (after registration) at http://csem.engin.umich.edu.

The next challenge in geospace models is incorporating kinetic physics where needed (MHD-EPiC).