The Global Ionosphere Thermosphere Model and the Ridley Ionosphere Model (or GITM and RIM)

Aaron Ridley and the CSEM Crew
Spherical Magnetosphere
Global Ionosphere-Thermosphere Model

GITM solves for:
- 6 Neutral & 5 Ion Species
- Neutral winds
- Ion and Electron Velocities
- Neutral, Ion and Electron Temperatures

GITM Features:
- Solves in Altitude coordinates
- Can have non-hydrostatic solution
  - Coriolis
  - Vertical Ion Drag
  - Non-constant Gravity
  - Massive heating in auroral zone
- Runs in 1D and 3D
- Vertical winds for each major species with friction coefficients
- Non-steady state explicit chemistry
- Flexible grid resolution - fully parallel
- Variety of high-latitude and Solar EUV drivers
- Fly satellites through model
GITM - 2

• Developed at the University of Michigan.
• First paper published 2006 (Ridley, Deng and Toth - JASTP).
• Non-hydrostatic model, altitude grid, approximately 1/3 scale height resolution in the vertical. Lower boundary at 100 km.
• Block-based domain decomposition in the horizontal direction. Fully parallel. Flexible grid resolution – has been with resolutions from 20°x10° (lon x lat) to 2.5°x0.3125°. Runs on a laptop and a supercomputer (Have run on up to 256 PEs). Uses MPI. Written in Fortran-90. Ghostcells are used for vertical boundary conditions and message passing.
• Can run in 1D by turning nLons and nLats to 1.
• Runs on many different computers / operating systems.
  – Anything that the SWMF can run on.
• Uses a 4th order Rusanov scheme with an MC limiter for advective solver. Does vertical advection, then horizontal, then add sources.
Resolution

5 x 5 degree resolution
w(up) at 372.0 km Altitude 22-DEC-02 00:00:00.000

2.5 x 0.3125 degree resolution
w(up) at 372.0 km Altitude 22-DEC-02 00:00:00.000

2 x 16 times the resolution!
• GITM solves the Navier-Stokes equations on a sphere (with lots of source terms) for the neutrals. Can modify the number of primary constituents in the main module (ModEarth, ModMars, ModTitan -> ModPlanet). For Earth, these are N$_2$, O$_2$, O, N and NO.

• Each primary constituent has an individual vertical velocity, but a bulk horizontal velocity. Bulk vertical velocity is the mass density weighted average of the individual vertical velocities. Friction terms affect the individual velocities.
  – Gradient in partial pressure, gravity (varying), ion drag, Coriolis, geometry, and friction all affect the vertical wind.

• Bulk temperature driven by solar EUV, conduction, NO and O2 radiative cooling, Joule heating, and particle heating.

• Chemistry is done explicitly. There are no assumptions on steady-state. Subcyling is used to capture time-scales down to about 0.01 seconds.

• Molecular and Eddy diffusion treated specifically in the vertical momentum equation instead of the continuity equation.
Nonhydrostatic
• Ionospheric velocities are assumed to be in stead-state.
  – Equations are different across field-lines and along field-lines.
• Electron and ion temperatures solved for.
  – Electron temperatures are very complicated. They are solved for implicitly with a large number of source and loss terms. Only vertical direction is considered in the electron temperature equation.
  – Ion temperature is a combination of electron and neutral temperatures.
• Magnetic field is from IGRF of the start date.
  – Recently implemented dipole, tilted dipole, and tilted-offset dipole
• Electric field is from a wide variety of sources (AMIE, Weimer, etc). As is the auroral precipitation pattern (Just added Newell’s auroral model!)
• Code is initialized with MSIS and IRI, and allowed to evolve.
• MSIS typically drives lower boundary condition on neutrals, while the ions have a continuous gradient boundary conditions.
  – Student working on putting a plasmasphere model into the SWMF, so this (as well as the PWOM) would help with the upper BC).
Tides – MSIS Driven

Temperature at 119.3 km Altitude at 20-DEC-02 00:00 UT
Tides - GSWM Driven

Temperature at 119.3 km Altitude at 20-DEC-02 00:00 UT
Time Issues

• GITM is a relatively slow code, since it is completely explicit.
• Time step is around 3 seconds for 5°x2.5° (lon x lat) resolution.
  – Limited by the sound speed and the vertical grid size.
  – When running at 2.5°x1.25°, time step is reduced because of cells near the pole and strong ion flows.
• Typically run with 64 (9 cell x 9 cell) blocks (5°x2.5°) on 64 PEs.
• Runs one day in about 80 minutes (on 64 PEs).
• The code is pretty evenly split between horizontal advection, vertical advection and chemistry.
  – Could possibly speed code up by going to implicit chemistry in the lower thermosphere, although we have recently tried this and it does not save too much time.
• This all being said, we have done 1 year simulations at 5°x2.5° resolution.
Equatorial Electrodynamics
Equatorial Electrodynamic - 2

Potential under Potential at 100.0 km Altitude at 21-SEP-02 19:00 UT
Ridley Ionosphere Model (RIM)

- New Ionospheric Potential Solver
- Fully parallel – latitude slices
- Forces potential to be the same between Northern and Southern hemisphere on closed field line, while polar caps are free.
RIM Description

- Parallel
  - Typically run with $1^\circ$ latitude by $2.5^\circ$ longitude resolution
  - Doesn’t really help to run over about 8 processors
- Field Aligned Currents from
  - Global Magnetosphere Model (GM)
  - Inner Magnetosphere Model (IM)
  - Upper Atmosphere Model (UA)
- Calculates aurora using
  - Old method (based only on Jr)
  - Use MHD quantities that are passed to RCM (density and pressure)
  - Use RCM generated diffuse aurora
- Different regions
  - High latitude only (separate)
  - Low latitude only
  - Whole sphere
  - Solve across the equator (treating them separate)
  - Solve across the equator (with fold) – force Earth potential to be zero!
New Aurora
Example – May 4, 1998
Global Plot

Electric Potential (kV)

Issue – It is clear that the equator plays an important role!
Need to have proper field-line integrals (Not HEIGHT integrals!) and use a corresponding solver
Summary

• The Global Ionosphere Thermosphere Model is new
  – Nonhydrostatic, altitude coordinates
  – Navier-Stokes with lots of source terms
  – Can be run for different bodies
  – 1D and 3D with extremely flexible grid
  – Can use many different E-field and auroral models
  – Equatorial electrodynamics is work now, but with small issues

• The Ridley Ionosphere Model is also new
  – Folded potential solver, forces north and south potentials to be identical
  – Multiple auroral models
  – Multiple FAC sources
  – Need to add a capability for field-aligned integrals to be used
Questions?