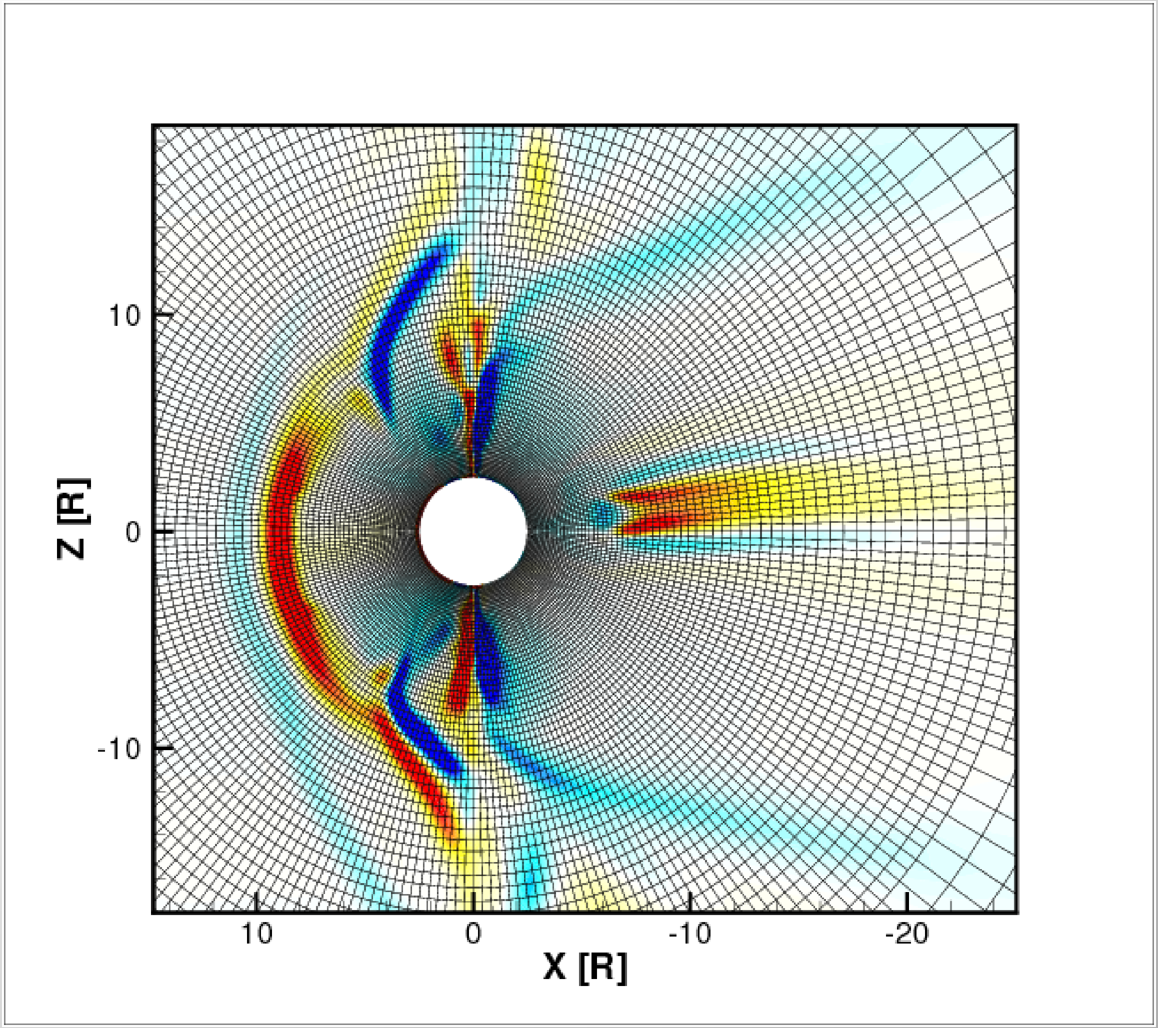
The Global Ionosphere Thermosphere Model and the Ridley Ionosphere Model (or GITM and RIM)

Aaron Ridley and the CSEM Crew

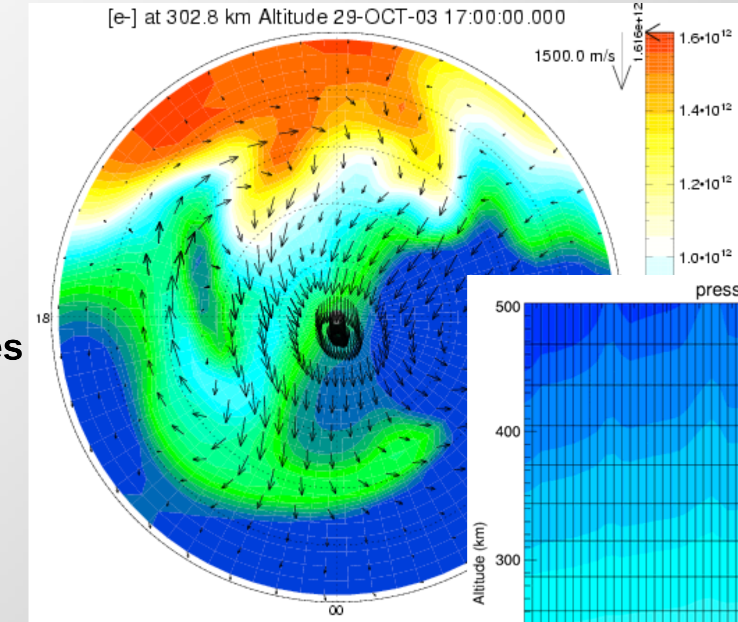
Spherical Magnetosphere

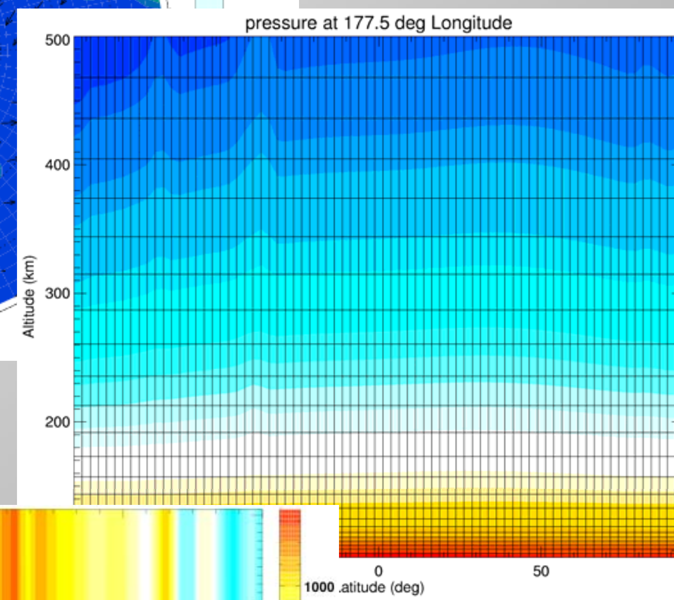


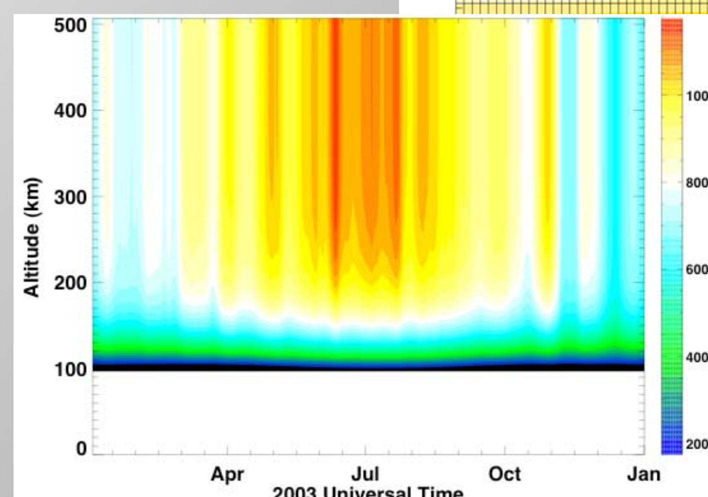
Global Ionosphere-Thermosphere Model

GITM solves for:

- **6 Neutral & 5 Ion Species**
- **Neutral winds**
- **Ion and Electron Velocities**
- **Neutral, Ion and Electron Temperatures**







GITM Features:

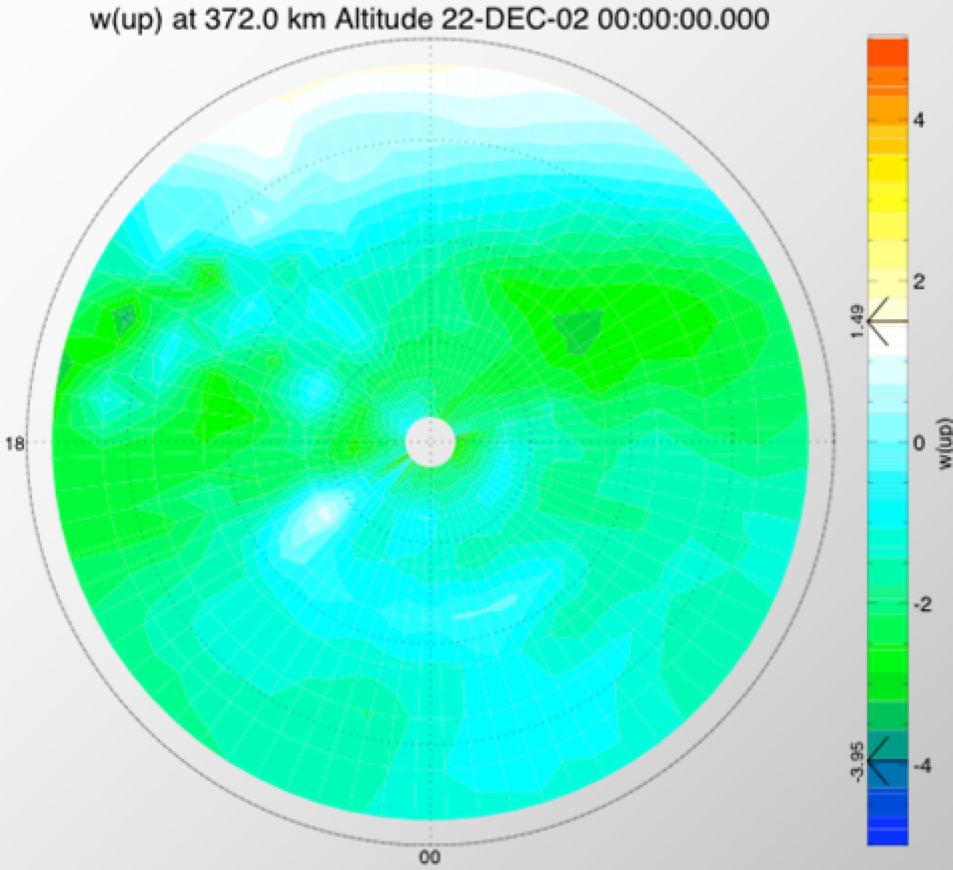
- ✓ Solves in Altitude coordinates
- ✓ Can have non-hydrostatic solution
  - ✓Coriolis
  - ✓Vertical Ion Drag
  - ✓Non-constant Gravity
  - ✓Massive heating in auroral zone
- ✓ Runs in 1D and 3D
- ✓ Vertical winds for each major species with friction coefficients
- ✓ Non-steady state explicit chemistry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

GITM - 2

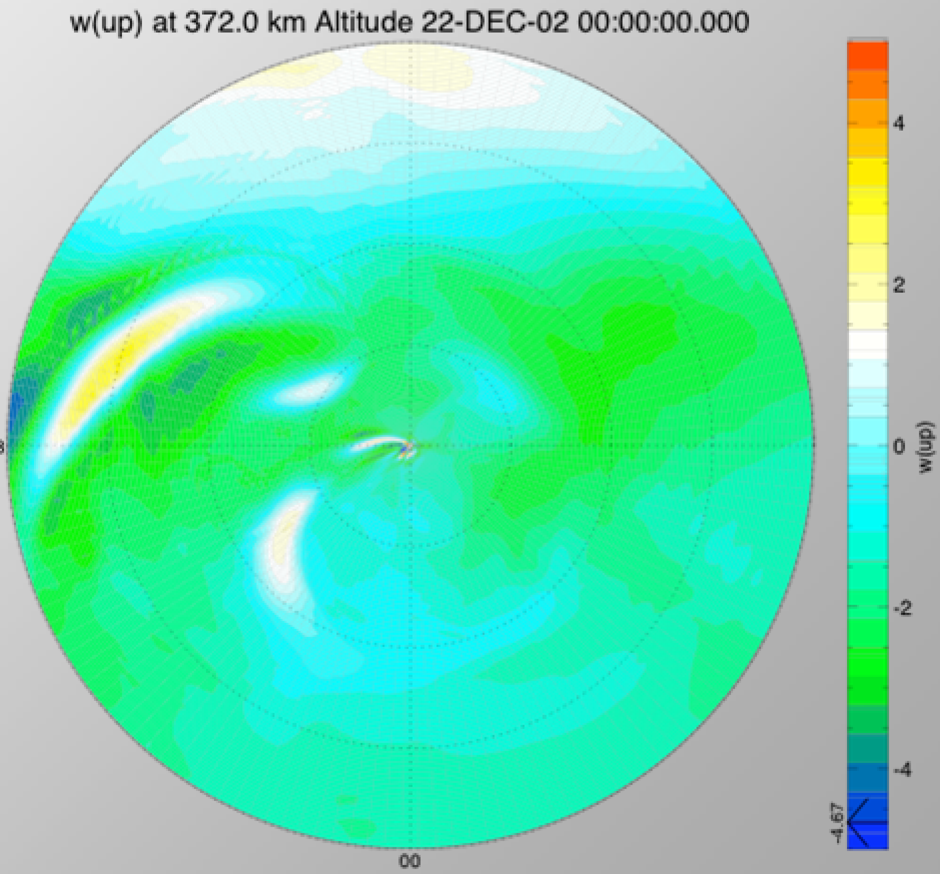
- Developed at the University of Michigan.
- First paper published 2006 (Ridley, Deng and Toth - JASTP).
- Non-hydrostatic model, altitude grid, approximately 1/3 scale height resolution in the vertical. Lower boundary at 100 km.
- Block-based domain decomposition in the horizontal direction. Fully parallel. Flexible grid resolution – has been with resolutions from 20^{o}x10^{o} (lon x lat) to 2.5^{o}x0.3125^{o}. 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



2.5 x 0.3125 degree resolution

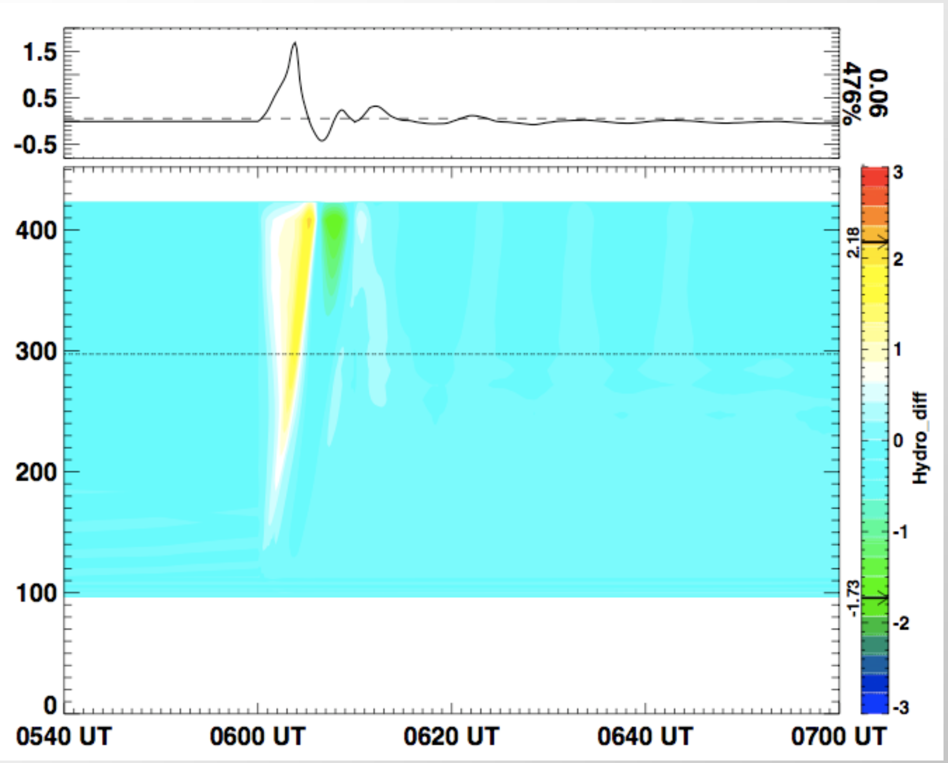


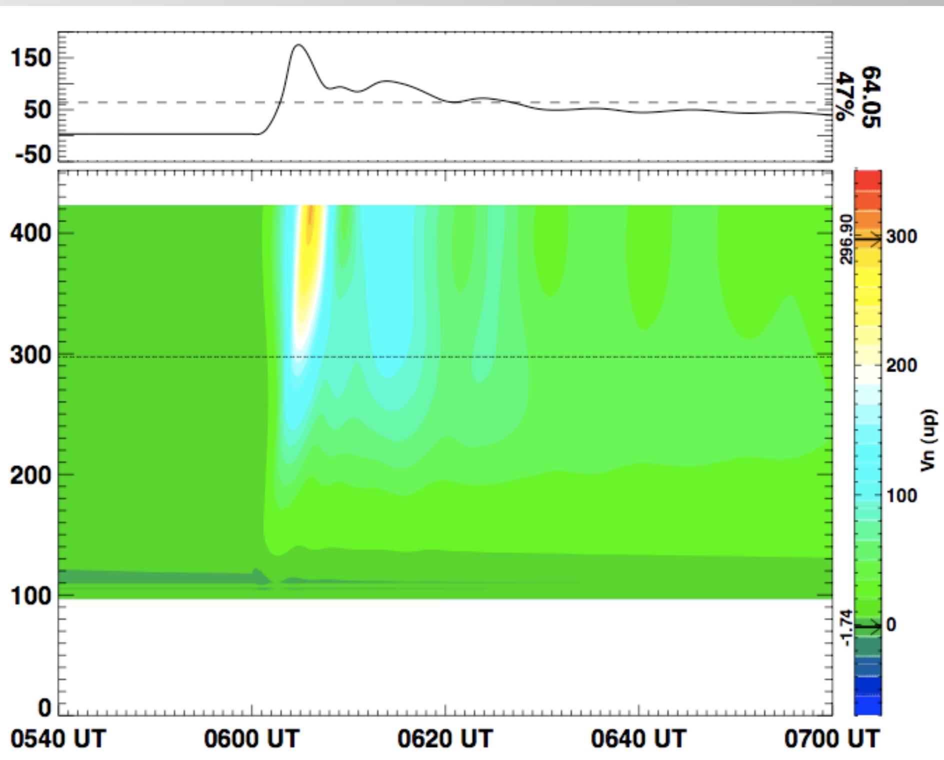
2 x 16 times the resolution!

GITM - 3

- 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, Corriolis, 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

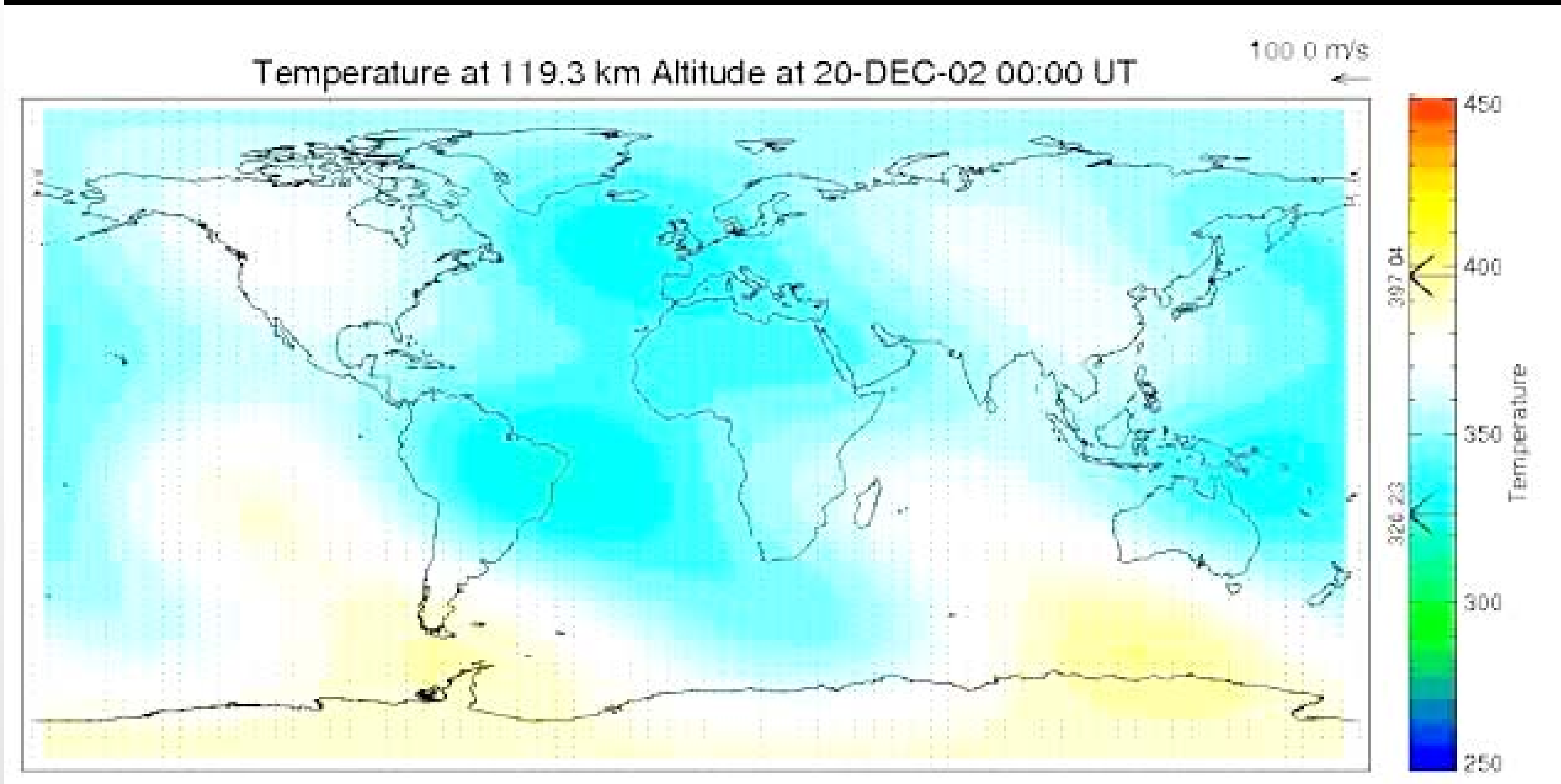




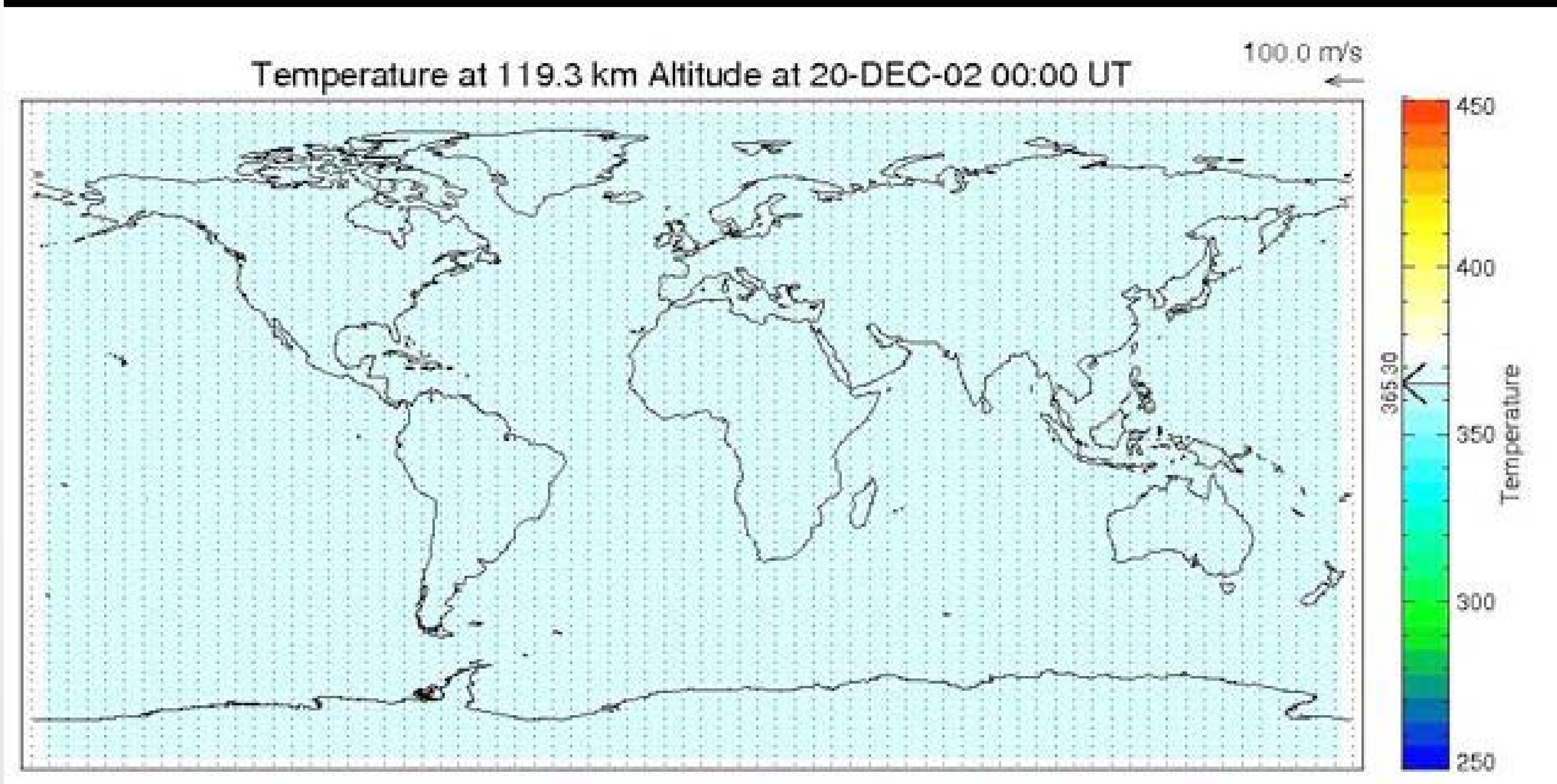
GITM - 4

- 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



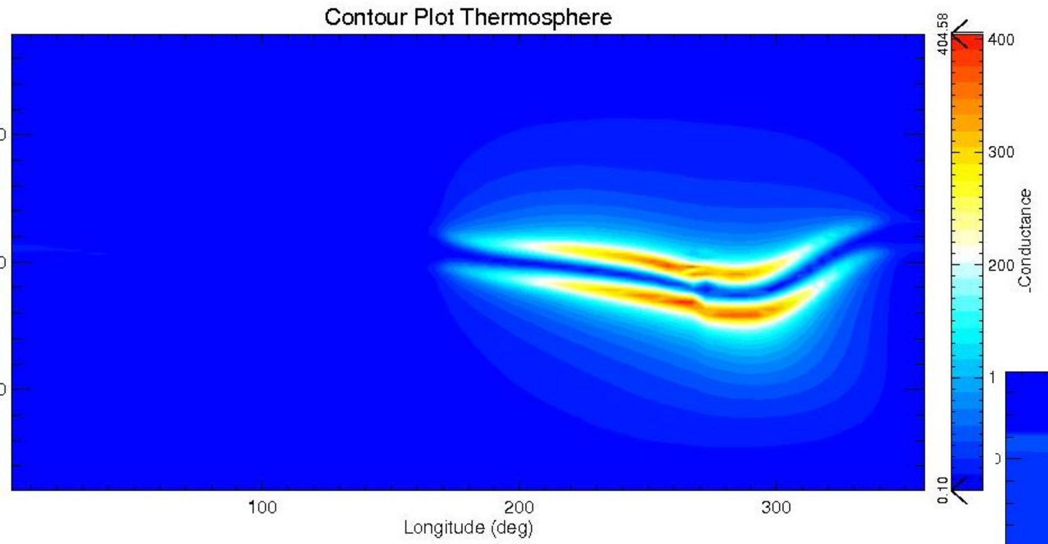
Tides - GSWM Driven

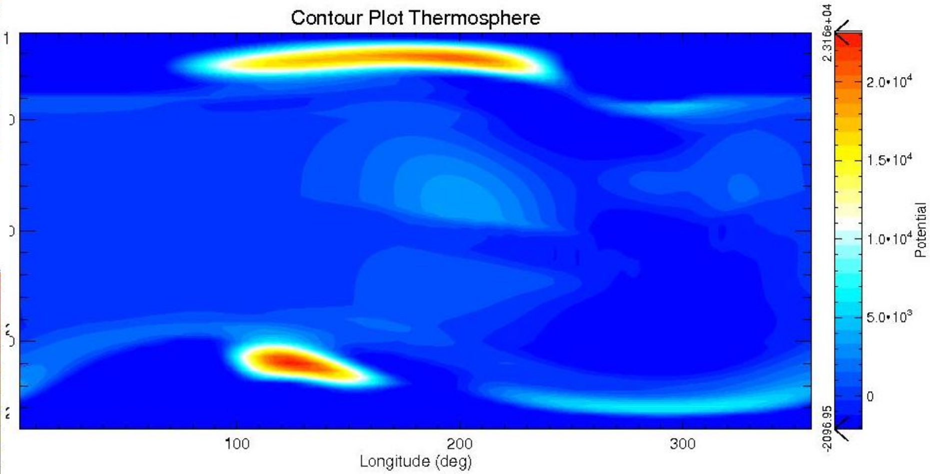


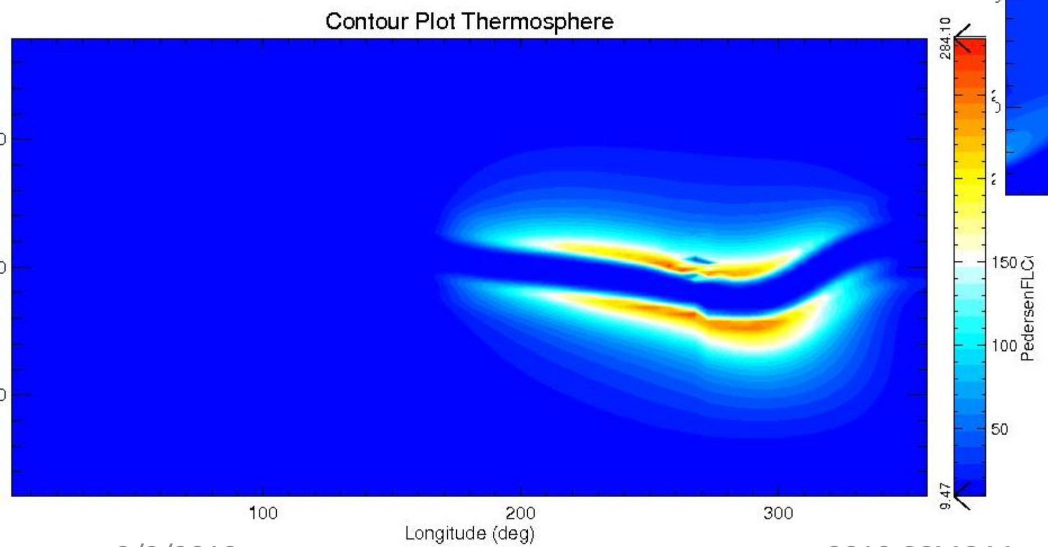
Time Issues

- GITM is a relatively slow code, since it is completely explicit.
- Time step is around 3 seconds for 5^ox2.5^o (lon x lat) resolution.
  - Limited by the sound speed and the vertical grid size.
  - When running at 2.5^ox1.25^o, 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^ox2.5^o) 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 themosphere, 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^ox2.5^o resolution.

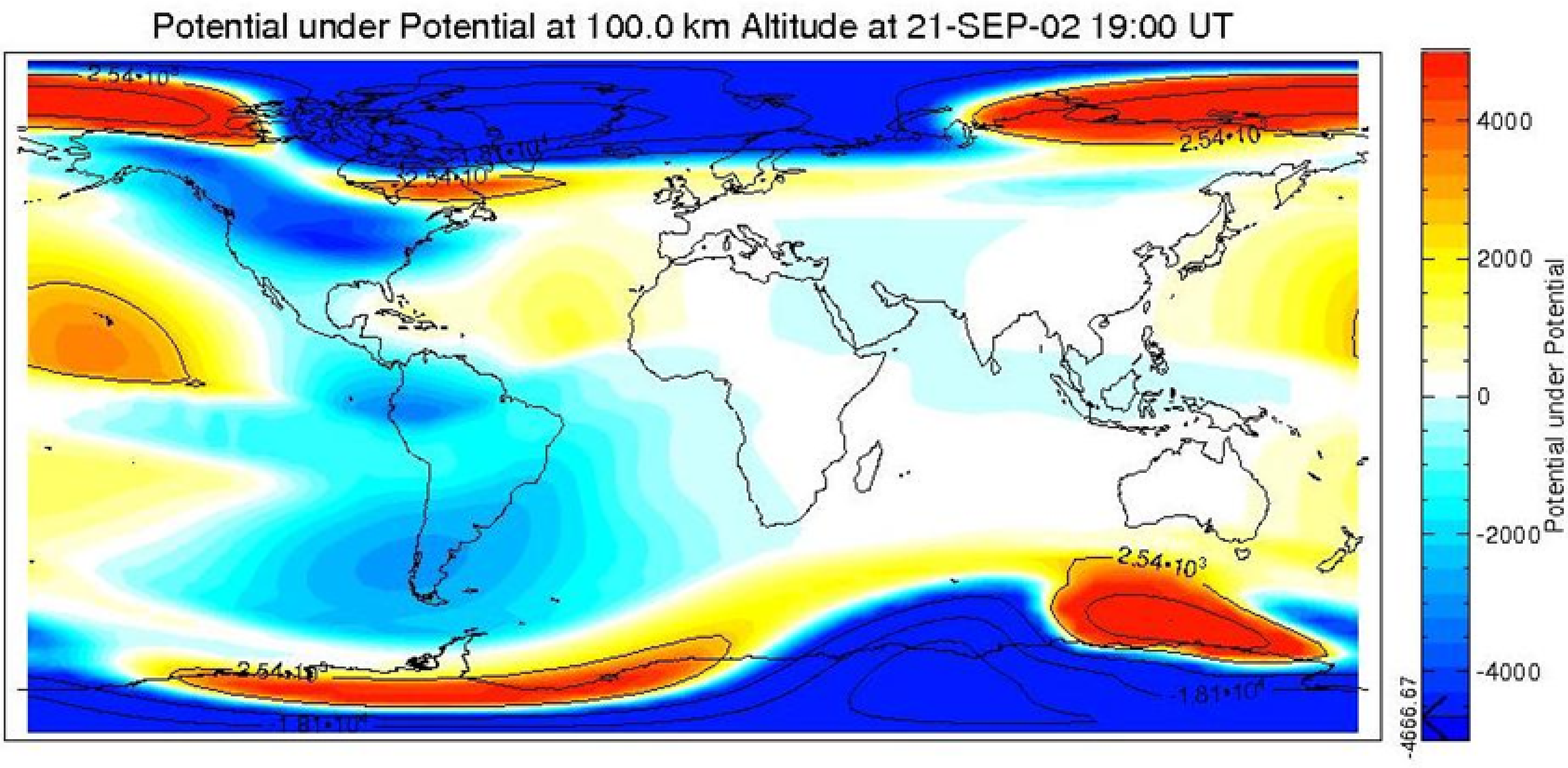
Equatorial Electrodynamics





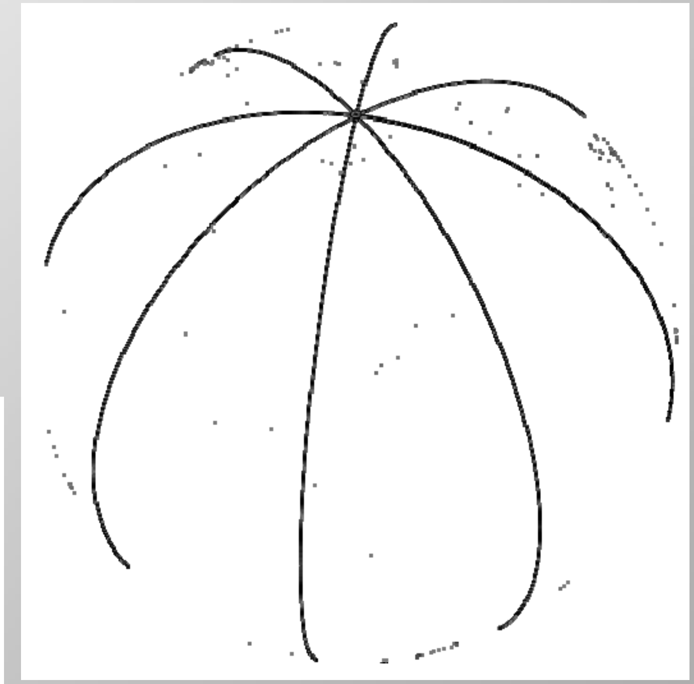


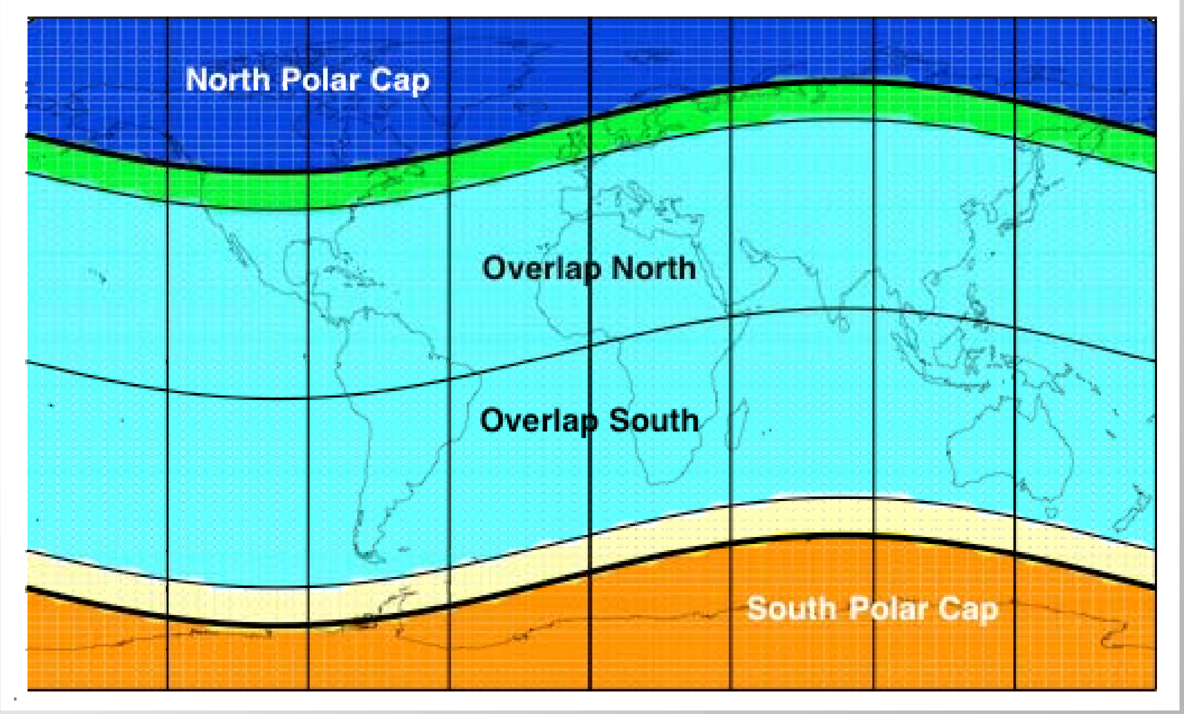
Equatorial Electrodynamics - 2



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.

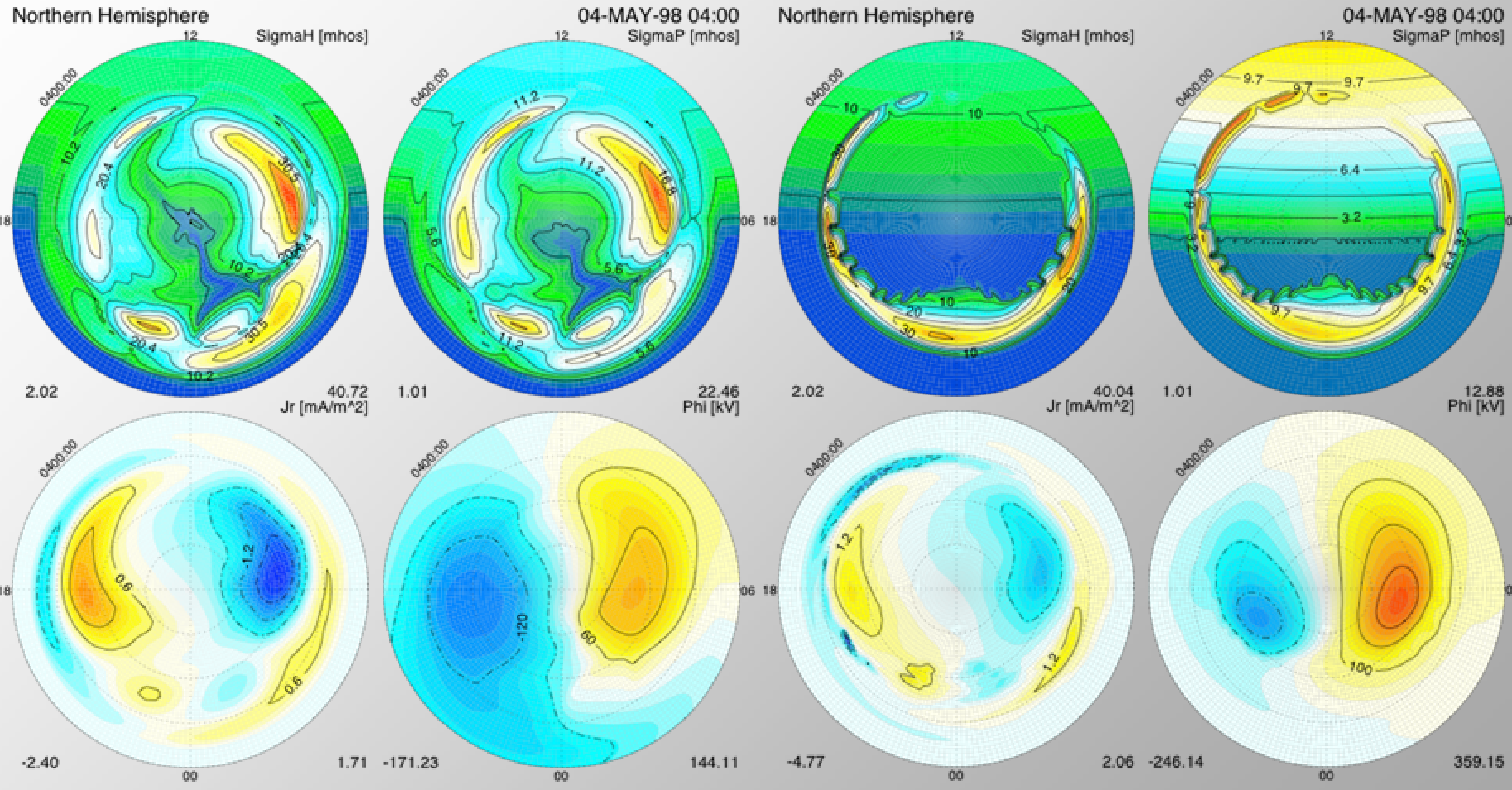




RIM Description

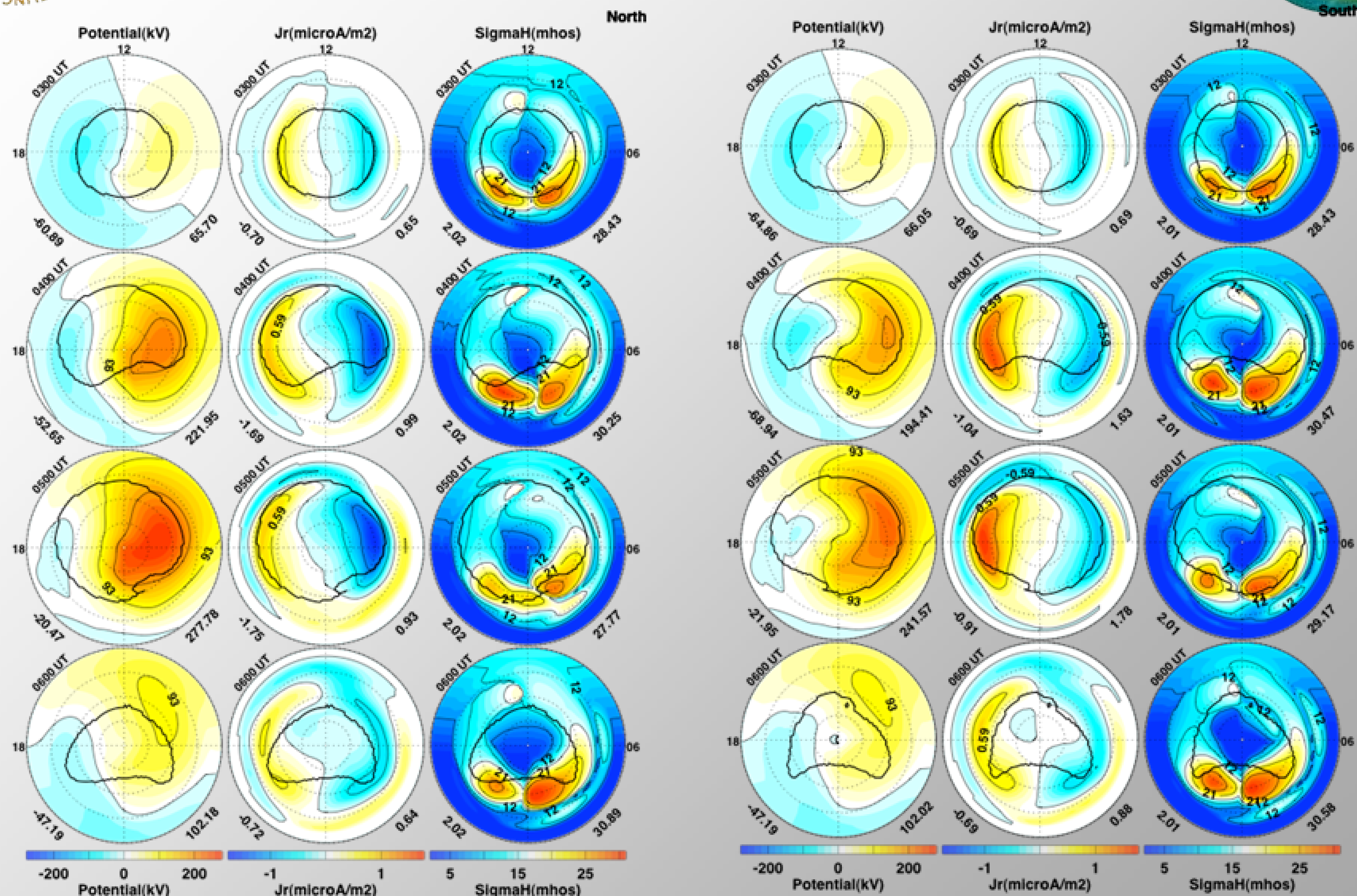
- Parallel
  - Typically run with 1^{o} latitude by 2.5^{o} longitude resolution
  - Doesn't really help to run over about 8 processors
- Field Aligned Currents from
  - Global Magnetosphere Model (GM)
  - Inner Magnetosphere Model (IM)
  - Upper Atmosphere Model (UA)
- Calculates aurora using
  - Old 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

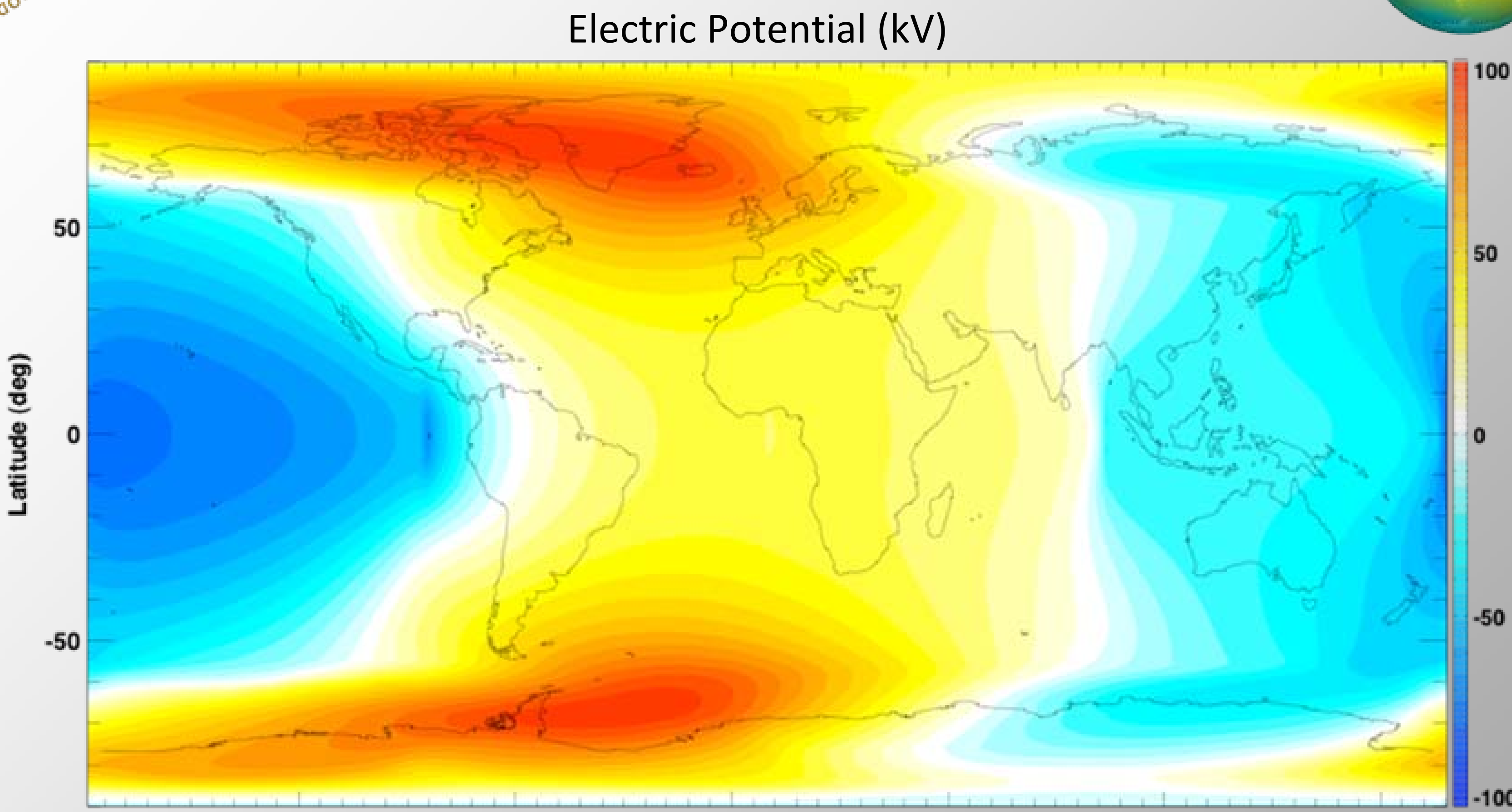


Northern Hemisphere
04-MAY-98 04:00
SigmaH [mhos]
SigmaP [mhos]
Jr [mA/m^2]
Phi [kV]
12
18
06
00
0400:00
2.02
40.72
1.01
22.46
-2.40
1.71
-171.23
144.11
Northern Hemisphere
04-MAY-98 04:00
2.02
40.04
1.01
12.88
-4.77
2.06
-246.14
359.15

Example – May 4, 1998



Global Plot



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?