TIE-GCM v. 2.0

The NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model
at the
Community Coordinated Modeling Center

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Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM)

• Original development by Ray Roble, Bob Dickinson, Art Richmond, et al.

• The atmosphere/ionosphere element of the Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) and LFM-TIE-RCM (LTR) models

• Cross-platform community model, under open-source academic research license

• v. 1.95 release, 2013

• User manual complete

• Documentation mostly complete

• Runs-on-request at CCMC

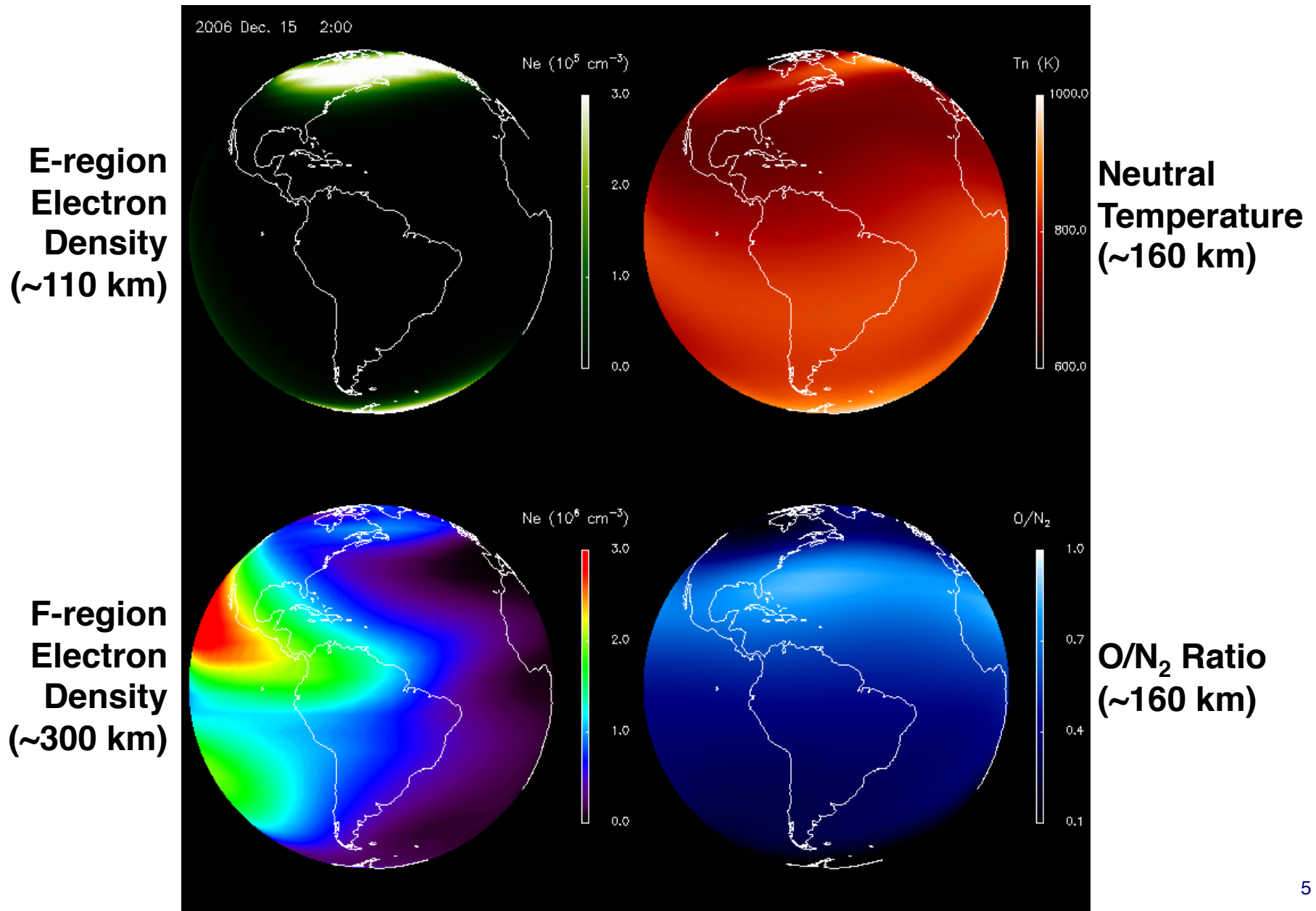• More information at: http://www.hao.ucar.edu/modeling/tgcm

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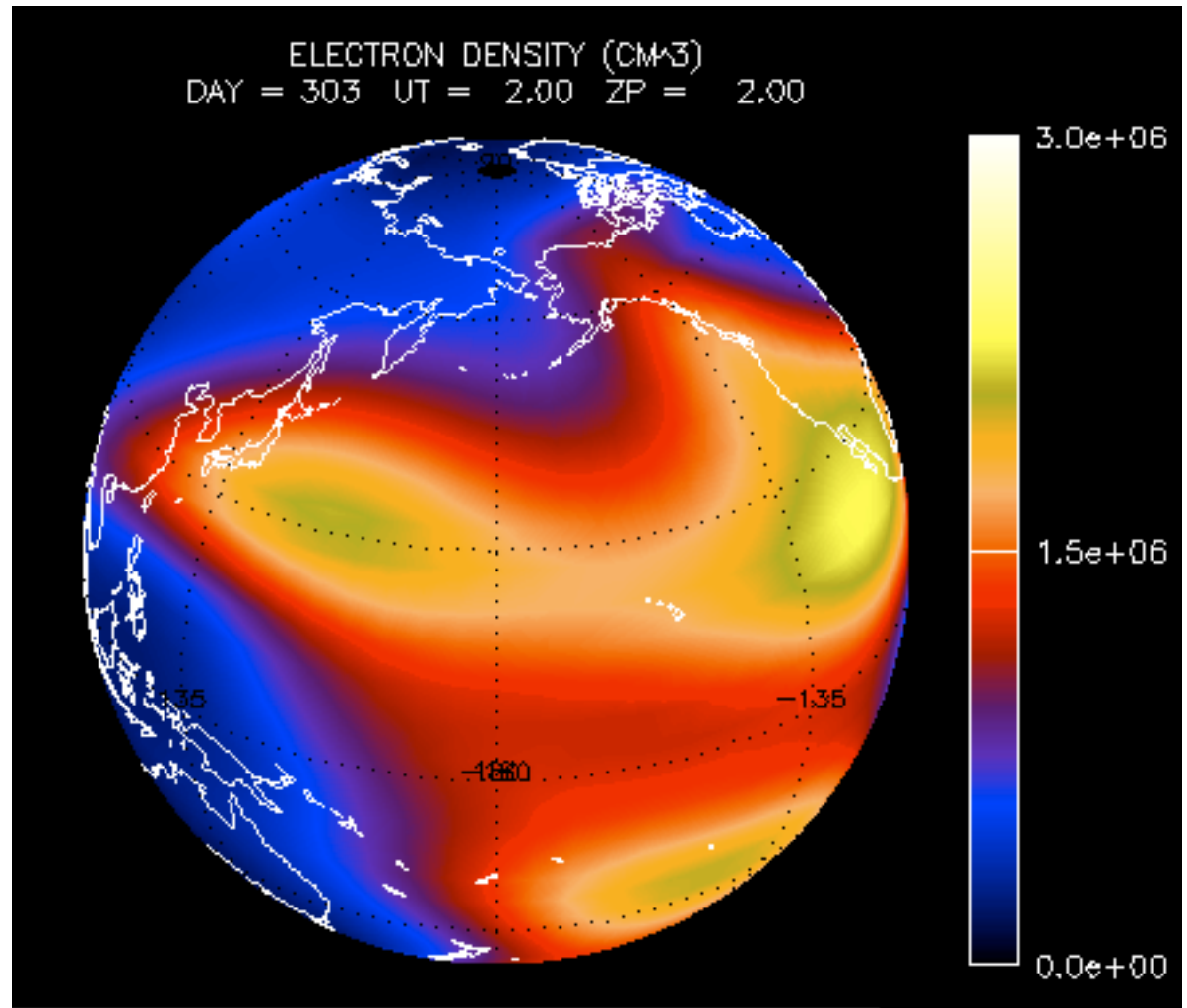
Numerical Approach

• The TIE-GCM is a comprehensive, first-principles, three-dimensional, non-linear representation of the coupled thermosphere and ionosphere system that includes a self-consistent solution of the low-latitude electric field.

• The model solves the three-dimensional momentum, energy and continuity equations for neutral and ion species at each time step, using a semi-implicit, fourth-order, centered finite difference scheme, on each pressure surface.

• 29 constant-pressure levels in the vertical at H/2, from ~97 km to ~500 km altitude.

• 5° x 5° latitude / longitude grid in the horizontal.

• Assumes Hydrostatic equilibrium, constant gravity, steady-state ion and electron energy equations, and incompressibility on constant pressure surfaces. Ion velocities are specified by the potential field and ExB drifts.

• Implemented in F90 and MPI. Runs on 1 to ~32 processors. Uses netCDF for I/O.

• Time step is 120 s.

• ~0.1 s / time step on many ~4 to ~8 processor systems (> 1200 x wallclock).
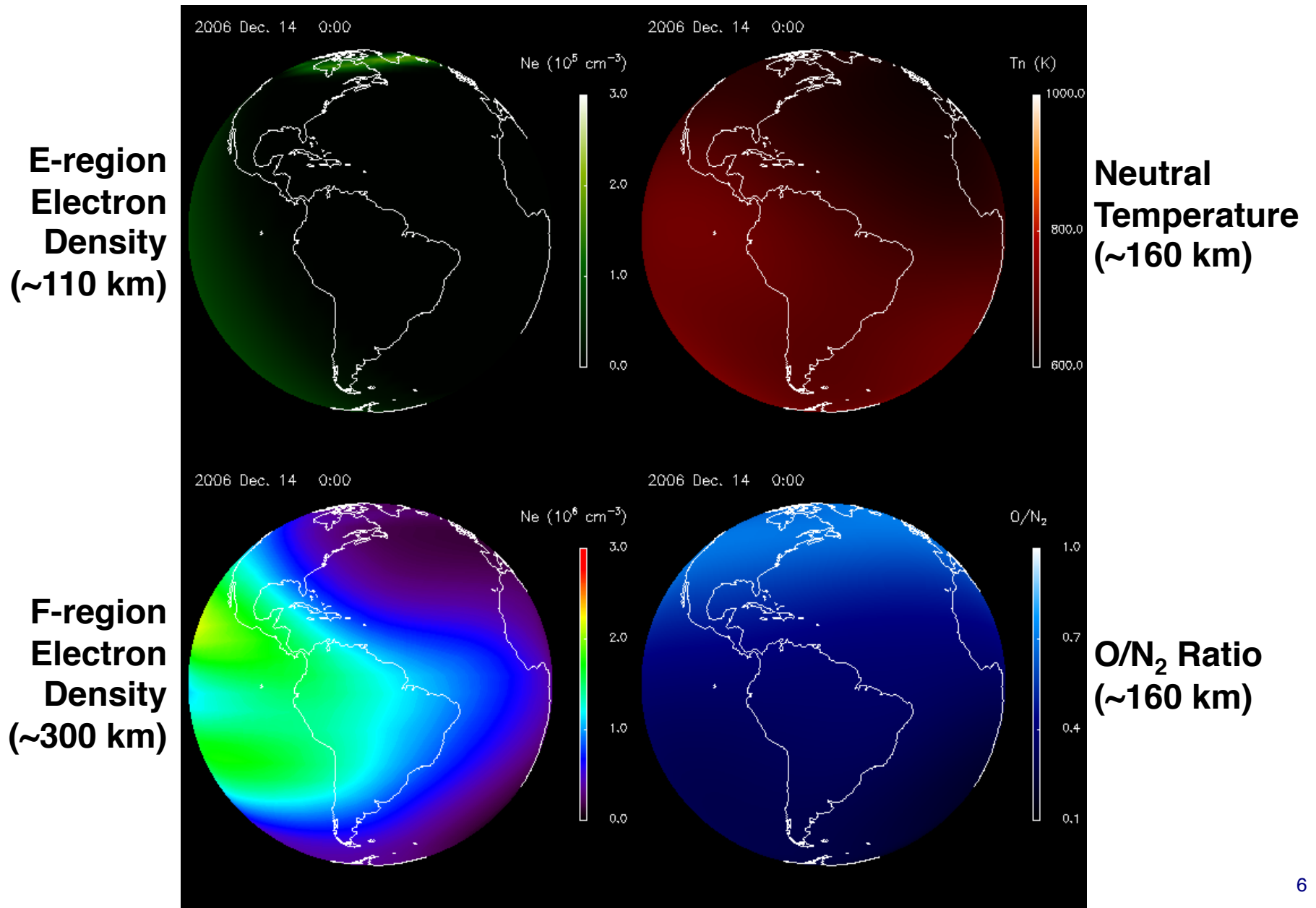
External Forcing of the Thermosphere/Ionosphere System

- Solar XUV, EUV, FUV (0.05-175 nm)
    - Solar energy and photoelectron parameterization (Solomon & Qian, 2005)
    - Default: F10.7-based solar proxy model (EUVAC)
    - Optional: solar spectral measurements; other empirical models

- Magnetospheric forcing
    - High latitude electric potential: empirical models (Heelis et al., 1982; Weimer, 2005), or data assimilation model (e.g., AMIE), or magnetosphere model (LFM)
    - Auroral particle precipitation: analytical auroral model linked to potential pattern (Roble & Ridley, 1987), or magnetospheric model (LFM)

- Lower boundary wave forcing
    - Tides: Global Scale Wave Model (GSWM , Hagan et al, 1999)
    - Eddy diffusion (with option for seasonally-varying term, Qian et al., 2009)
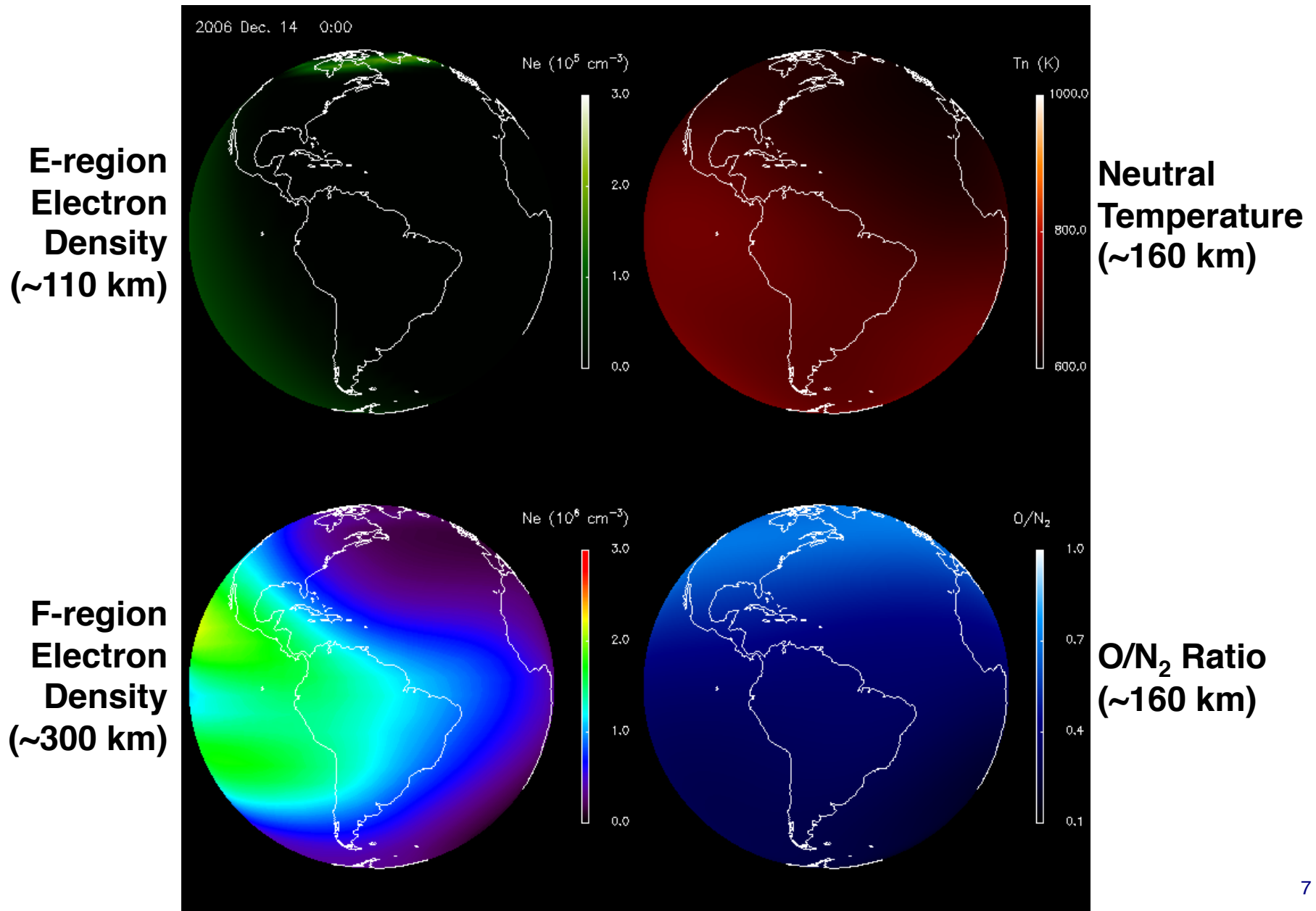
Thermosphere-Ionosphere Modeling during Storms

E-region Electron Density (~110 km)

F-region Electron Density (~300 km)

Neutral Temperature (~160 km)

O/N$_2$ Ratio (~160 km)

Thermosphere-Ionosphere Modeling during Storms

Thermosphere-Ionosphere Modeling during Storms

# What's New in TIE-GCM v. 2.0?

- TIE-GCM v. 2.0 planned release in June 2014
  - "Double Resolution" (2.5° x 2.5° x H/4) supported
  - Helium included as a major species
  - Electrodynamics calculations parallelized

- Recommend 1-minute time step for climate; 30-second time step for storms
  - Normal-resolution model runs ~1700 x wallclock on 16 processors
  - Double-resolution model runs ~200 x wallclock on 64 processors

- Other minor changes, updates, and bug fixes (since v. 1.94)

  Include N_2 explicitly as a major species (instead of 1-O-O_2-He)
  Fixed Kp so it can't go negative
  Modified FFT filters for double-res version
  Fixed error in GSWM interpolation
  Added time-dependent CO_2 concentration at lower boundary
  Added new diagnostics for magnetic and electric fields,
  Introduced refactored Apex code apex.F90.
  Change minimum EUVAC solar flux from 0.8 x Refspec to 0.1 x Refspec
  Fixed bug in eddy and molecular viscosity coefficients in duv.F
  Various yellowstone-specific script mods
  Various performance improvements

Normal (5°) vs. Double (2.5°) Resolution
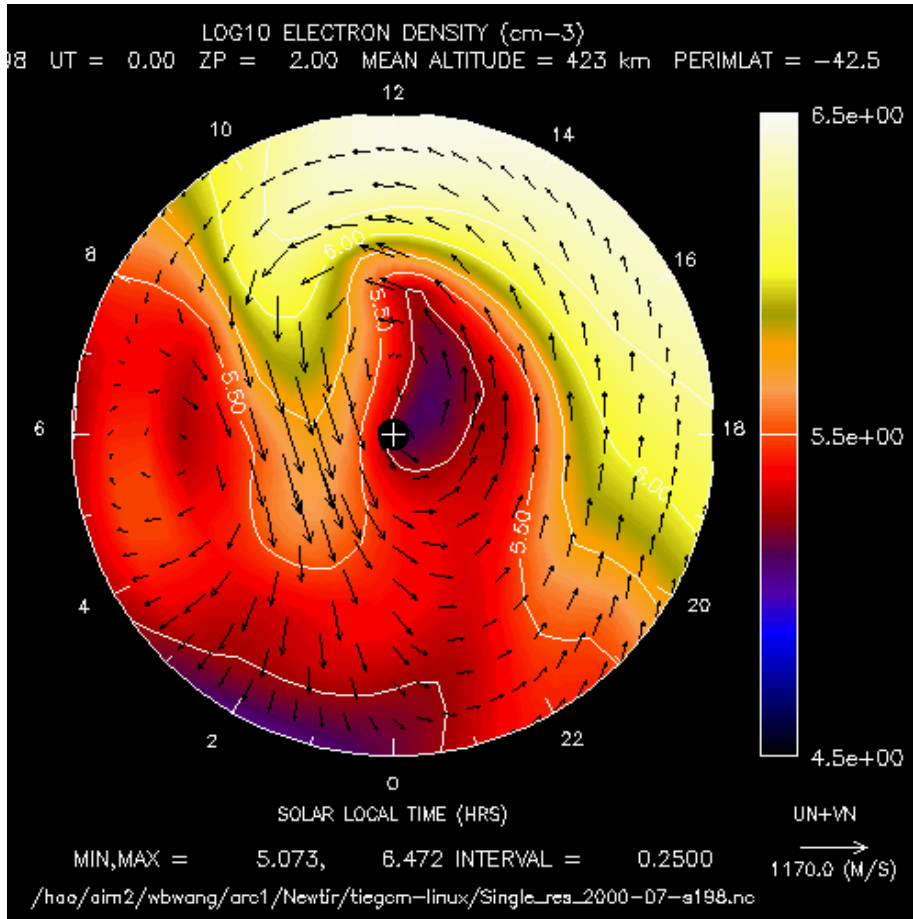
Normal Resolution   Double Resolution
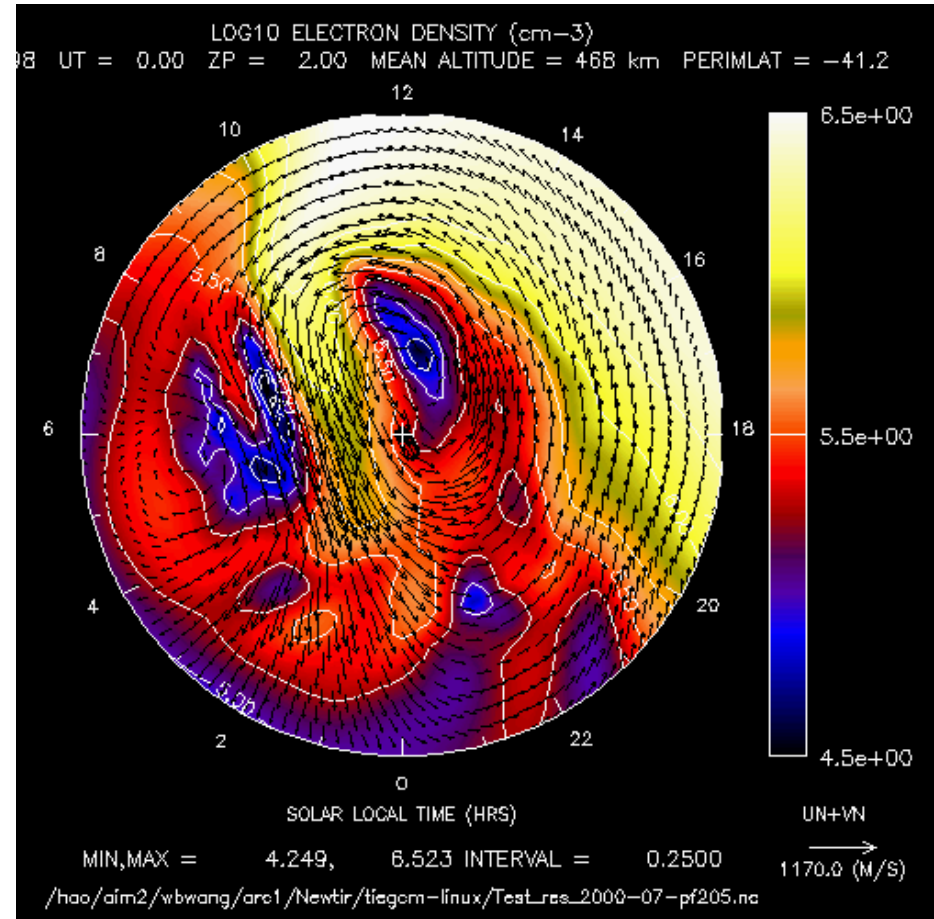
Electron densities with neutral wind vectors superimposed over the southern hemisphere polar region during a geomagnetic storm. The "tongue" of ionization is significantly more resolved in the double-resolution version of the model.

Inclusion of Helium as a Major Species

- Helium has very small concentration from ground level through the turbopause

- Diffusive separation causes the mixing ratio to increase, approaching unity in the upper thermosphere

- Seasonal variation termed "Winter Helium Bulge"

- Local Time preference near ~8:00 LT

- Helium scale height is less sensitive to solar cycle variations (i.e. temperature changes) than are other species

- Helium can be important for satellite drag calculations, particularly at 500–700 km, and partiuclarly during solar minimum
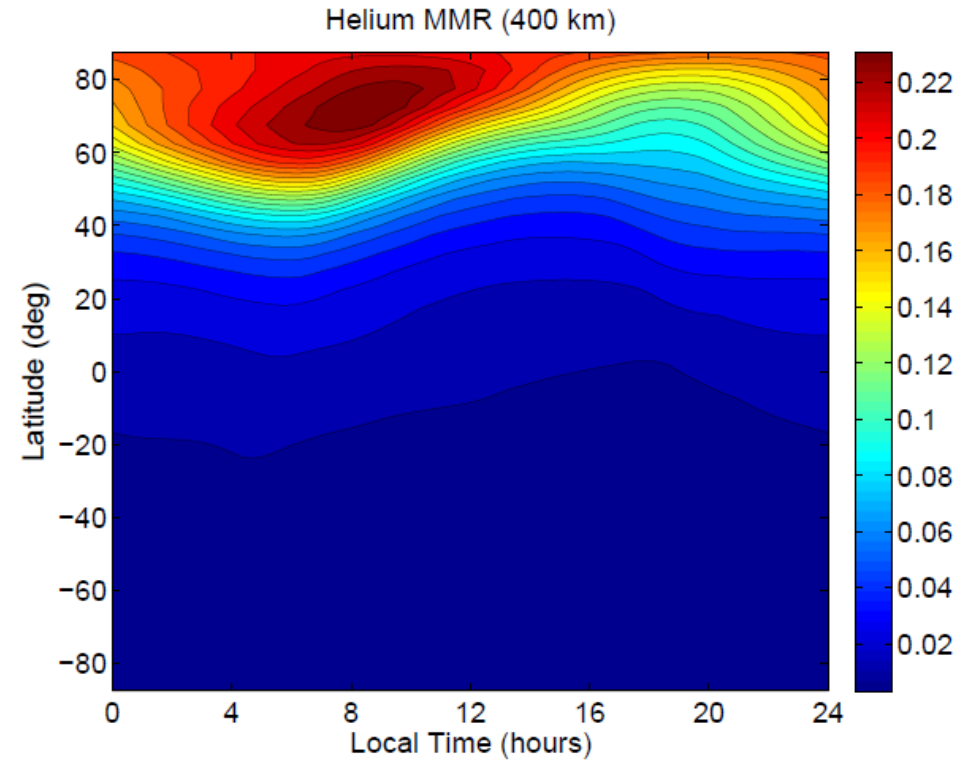
Mass Densities
(Dec. 2004, 72.5° N)
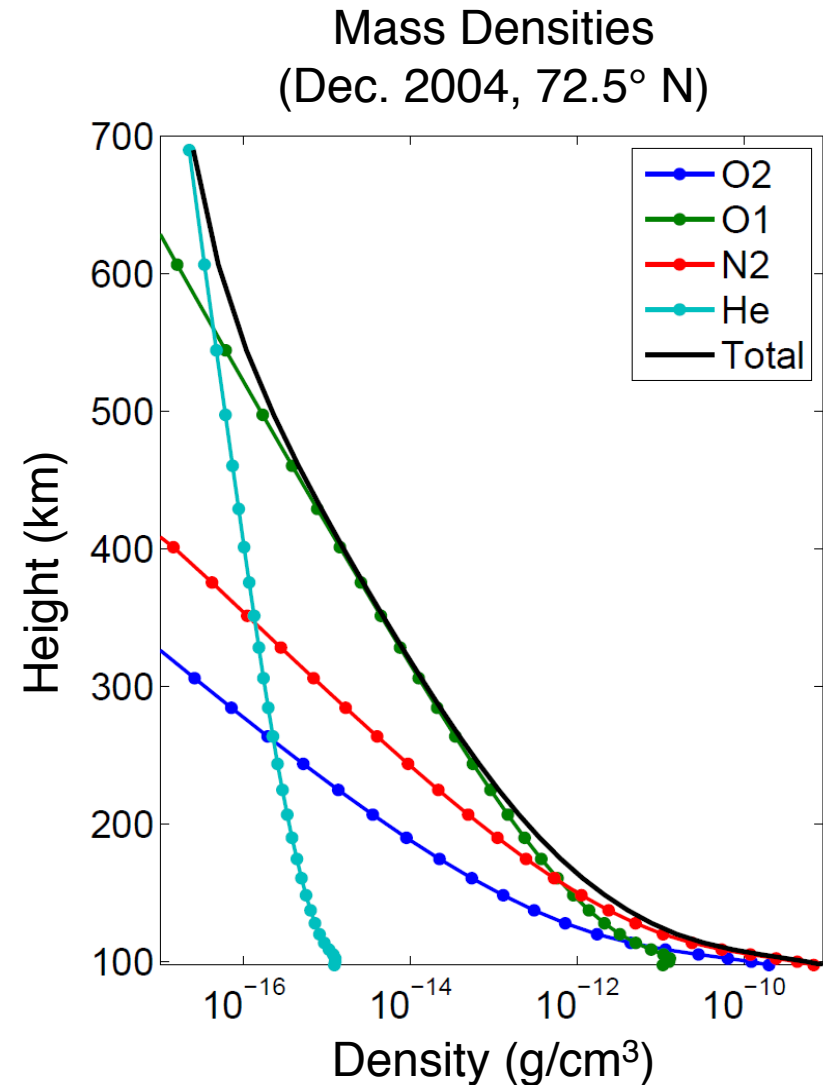
Simulation of the Winter Helium Bulge

Top Pressure Level: (Z_p=+7)

Constant Altitude: 400 km

Helium MMR (lev(29)=7.25)
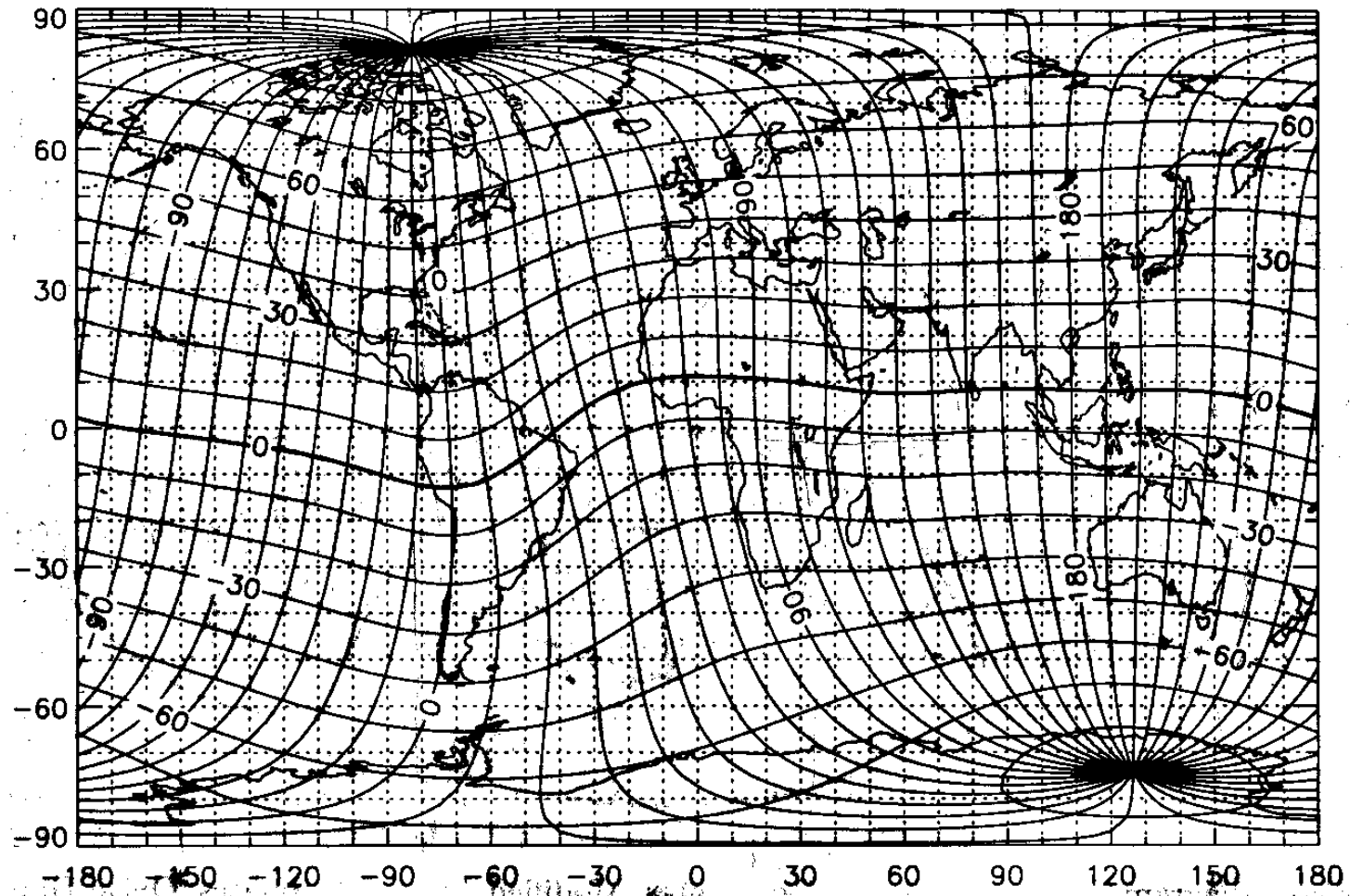

Helium MMR (400 km)
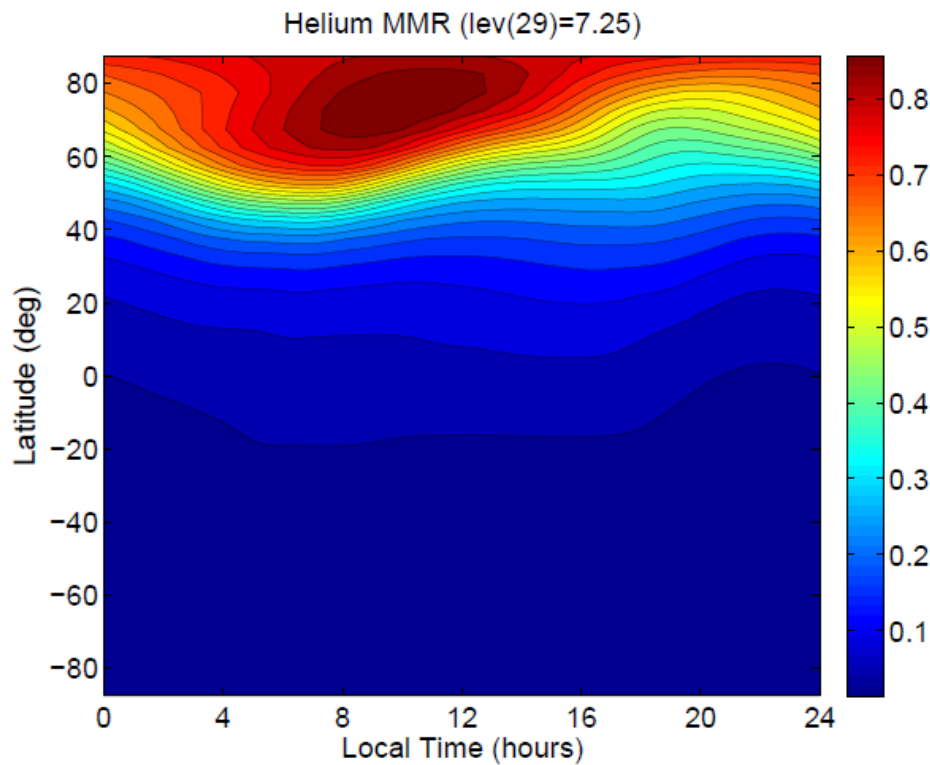
On a constant pressure surface,
MMR > 0.8 in the winter hemisphere

At 400 km, the MMR is reasonably
consistent with MSIS

Electrodynamics

- Low and mid-latitude: neutral wind dynamo equations solved in geomagnetic Apex coordinates [Richmond et al., 1992; 1995].

- High latitude: specified by convection models such as Heelis, Weimer, or AMIE, or coupled to the LFM Magnetosphere Model.

Performance Scaling using new Parallel Dynamo Module

Average seconds per timestep: 5-day runs of 2.5-deg tiegcm
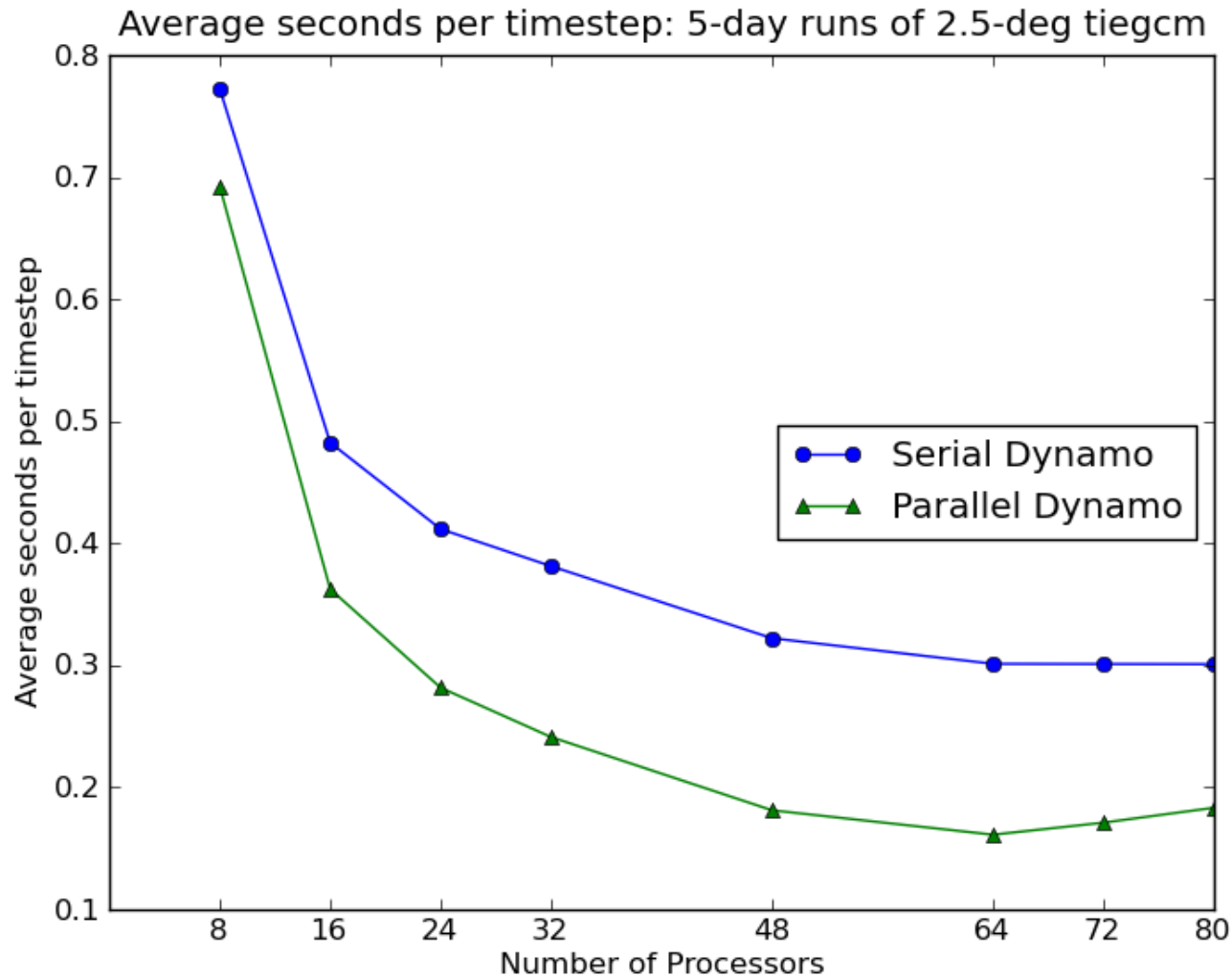
- Uses ESMF to perform parallel grid interpolations for ion-neutral coupling.
- Low resolution (5°) model now runs at ~1700 x wallclock on 16 processors.
- High resolution (2.5°) model now runs at ~200 x wallclock on 64 processors.
    (2.6-GHz Intel Xeon E5-2670)

Recent Work on Thermospheric Neutral Density

• The variation of neutral density in the thermosphere, on time scales ranging from an hour to a decade, has important effects on the trajectories of objects in low-Earth orbit.

• This problem has been re-discovered as an important aspect of space weather.

• It is also a tractable problem, on time scales of hours to days, and numerical models have the potential to make significant advances over the current empirical models used in operations.

• Using satellite drag observations to validate and improve numerical models has the distinct advantage that the data used for comparison are precisely the same as the data that are of operational importance.

Thermospheric Density over 1.5 Solar Cycles
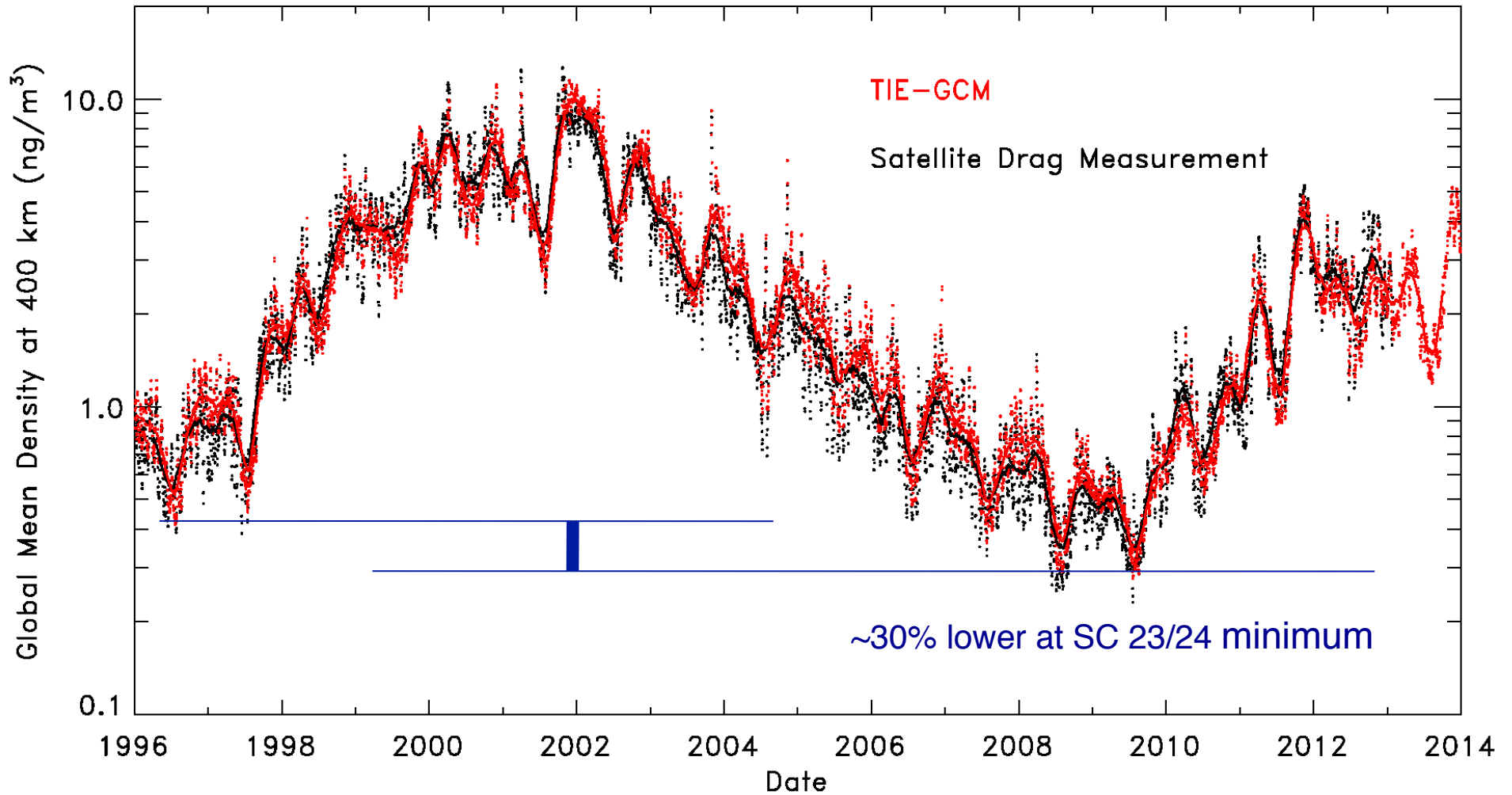
Current Development and Future Plans

- TIE-GCM v. 1.95 released June 2013.
  - Mostly minor updates and bug fixes, and yellowstone-specific changes
- TIE-GCM v. 2.0 to be released June 2014.
  - High resolution version supported
  - Helium included
  - Parallel Electrodynamics
- Other key research developments include:
  - Lower boundary conditions:

    Seasonal/spatial variation of zonal mean climatolgy (T, u, v, z_g)

    Seasonal/spatial variation of lower boundary eddy diffusion

    Tidal forcing updates to GSWM and data-driven methods
  - External forcing:

    Solar EUV from TIMED/SEE, SDO/EVE, and alternative proxies

    New auroral precipitation specification based on GUVI data
  - Continued development of the CMIT and LTR models
  - High-altitude extension, including light ion species
  - Plasmaspheric extension, and high-latitude outflow...

A Community Model at the Community Center

• To us, a community model means that scientific researchers can share the model results, run the model themselves, and/or participate in model development.

• *The source code is available through an open-source academic research license.*
      Meaning, you can have the code, but you can't sell it, and we request that you
      adhere to academic norms with regard to collaboration, collegiality, and citation.

• *If you want to look at archived model results...*
      Available from the NCAR Data Portal at http://cdp.ucar.edu

• *If you want to do a particular model run...*
      Available through "runs on request" at CCMC

• *If you want to run the model yourself...*
      Download, install, and run the model on your computer, or,
            Obtain an account on HAO/NCAR computers and run it there

• *If you want to participate in model development...*
      ...give us a call
            ...come for a visit

Information, User Guide, Documentation, Source Code...

Main page:

http://www.hao.ucar.edu/modeling/tgcm

User Guide:

http://www.hao.ucar.edu/modeling/tgcm/doc/userguide

Documentation:

http://www.hao.ucar.edu/modeling/tgcm/doc/description/model_description.pdf

Code Map:

http://www.hao.ucar.edu/modeling/tgcm/download/files/tiegcm_codestruct.pdf

Post-Processors:

http://www.hao.ucar.edu/modeling/tgcm/doc/userguide/html/postproc.html