The NCAR TIE-GCM:

Model Description, Development, and Validation

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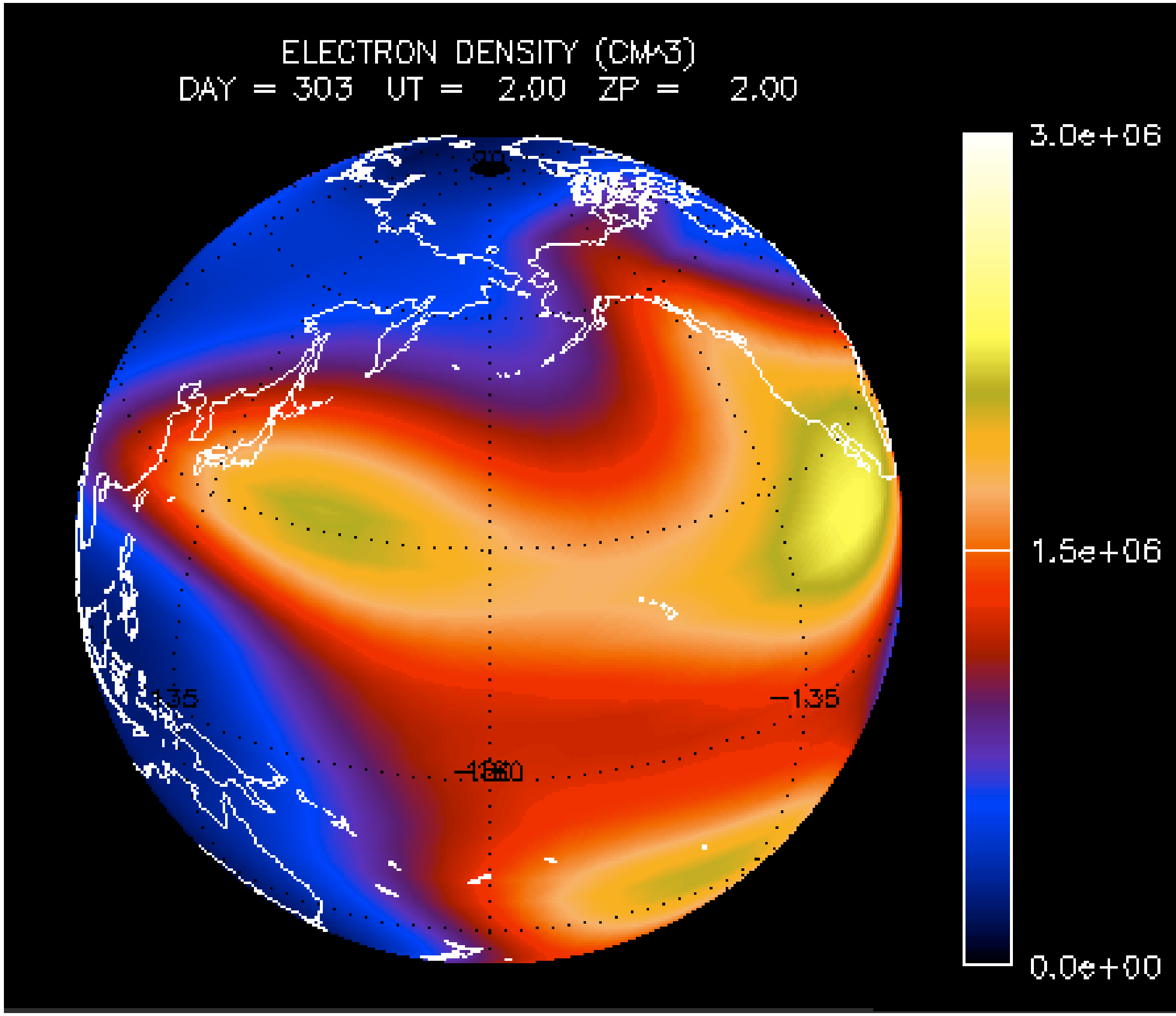
Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM)

- Original development by Ray Roble, Bob Dickinson, Art Richmond, et al.
- The atmosphere/ionosphere element of CMIT and the CISM model chain
- Cross-platform community release (v. 1.93), under open-source academic research license
- v. 1.94 release, May 2011
- User manual complete
- Documentation mostly complete
- Runs-on-request at CCMC



Development History

Thermosphere General Circulation Model

TGCM, 97~500 km, *Dickinson et al., 1981; 1984; Roble et al.*, 1982

Thermosphere-Ionosphere General Circulation Model

TIGCM, 97~500 km, *Roble et al., 1987; 1988*

Thermosphere-Ionosphere-Electrodynamics General Circulation Model

TIE-GCM , 97~500 km, *Richmond et al., 1992; Richmond, 1995*

Thermosphere-Ionosphere-Mesosphere-Electrodynamics GCM

TIME-GCM, 30~500 km, *Roble and Ridley, 1994; Roble, 1995*

Whole Atmosphere Community Climate Model

WACCM, 0~140 km, *Marsh et al., 2007; Garcia et al., 2007*

Extended Whole Atmosphere Community Climate Model

WACCM-X, 0~500 km, *Liu et al.*, 2010

Equations

- Momentum equation: *u, v*
- Continuity equation: *w*, O, O_2, N(^{4}S), NO, O^+
- Hydrostatic equation: *z*
- Thermodynamic equation: T_N, T_e
- Quasi-steady state energy transfer—electron, neutral, ion: T_I
- Photochemical equilibrium: N(^{2}D), O_2^+,N_2^+,N^+,NO^+

Coordinate system: horizontal: rotating spherical geographical coordinates; vertical: pressure surface (hydrostatic equilibrium)

Resolution: horizontal: 5°x 5°; vertical: 0.5 pressure scale height. High resolution version (2.5° x 2.5° x H/4) in test.

Numerical Techniques

- Horizontal: explicit 4^{th} order centered finite difference;
- Time: 2^{nd} order centered difference;
- Vertical: Implicit 2^{nd} order centered difference;
- Shapiro filter: achieve better numerical stability;
- Fourier filter: remove high frequency zonal waves generated by finite difference (high latitudes)

External Forcing of the Thermosphere/Ionosphere System

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

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

- Lower boundary wave forcing
  - Tides: Global Scale Wave Model (GSWM , Hagan et al, 1999)
  - Eddy diffusion

Boundary Conditions

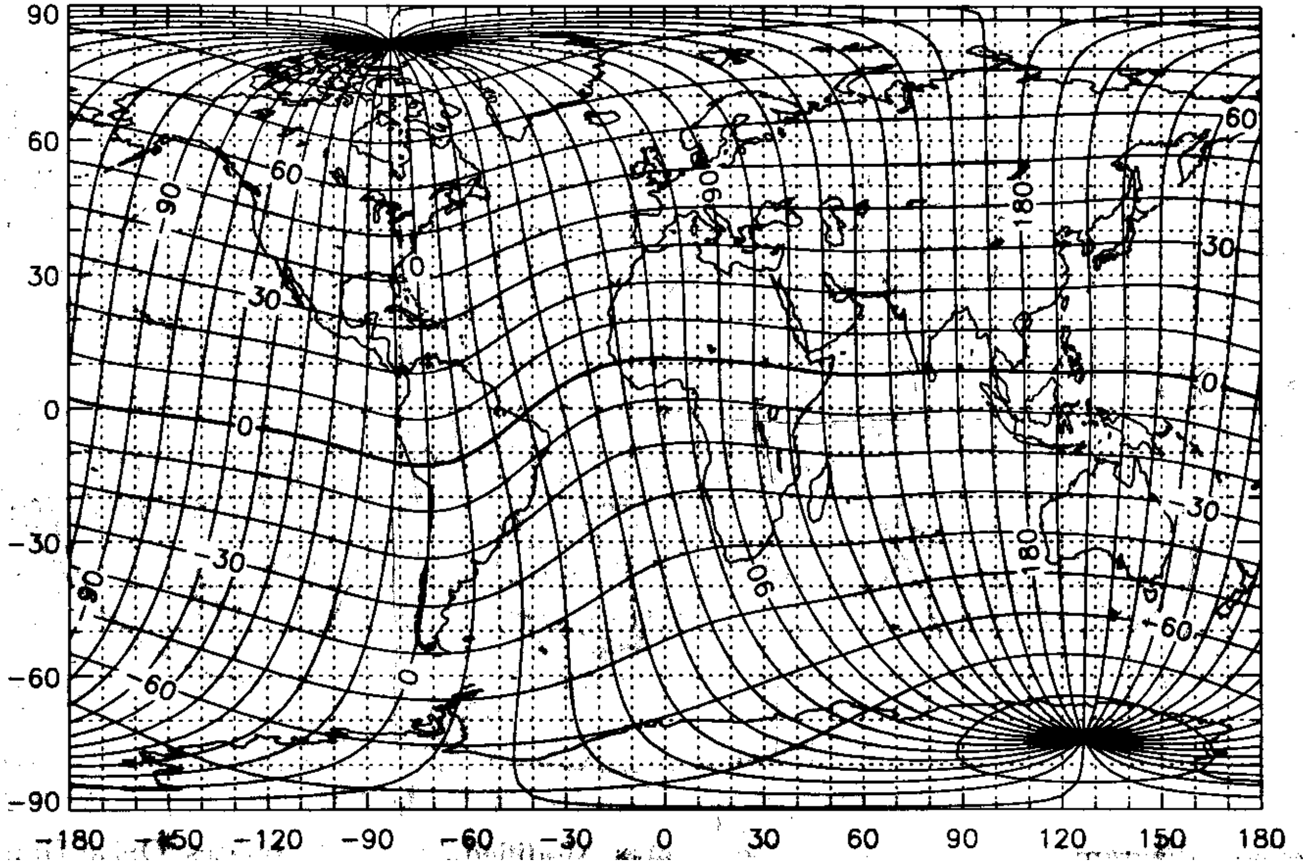
Upper boundary conditions:

- u, v, w, T_N, O_2, O: diffusive equilibrium;
- N(^{4}S), NO: photochemical equilibrium;
- O^+: specify upward or downward O^+ flux;
- T_e: specify upward or downward heat flux.

Lower boundary conditions:

- u, v: specified by tides (GSWM)
- T_N: 181 K + perturbations by tides (GSWM)
- O_2: fixed mixing ratio of 0.22
- O: vertical gradient of the mixing ratio is zero
- N(^{4}S), O^+: photochemical equilibrium
- NO: constant density of (8×10^6)
- T_e: equal to T_N.

ITM coupling: Electrodynamics

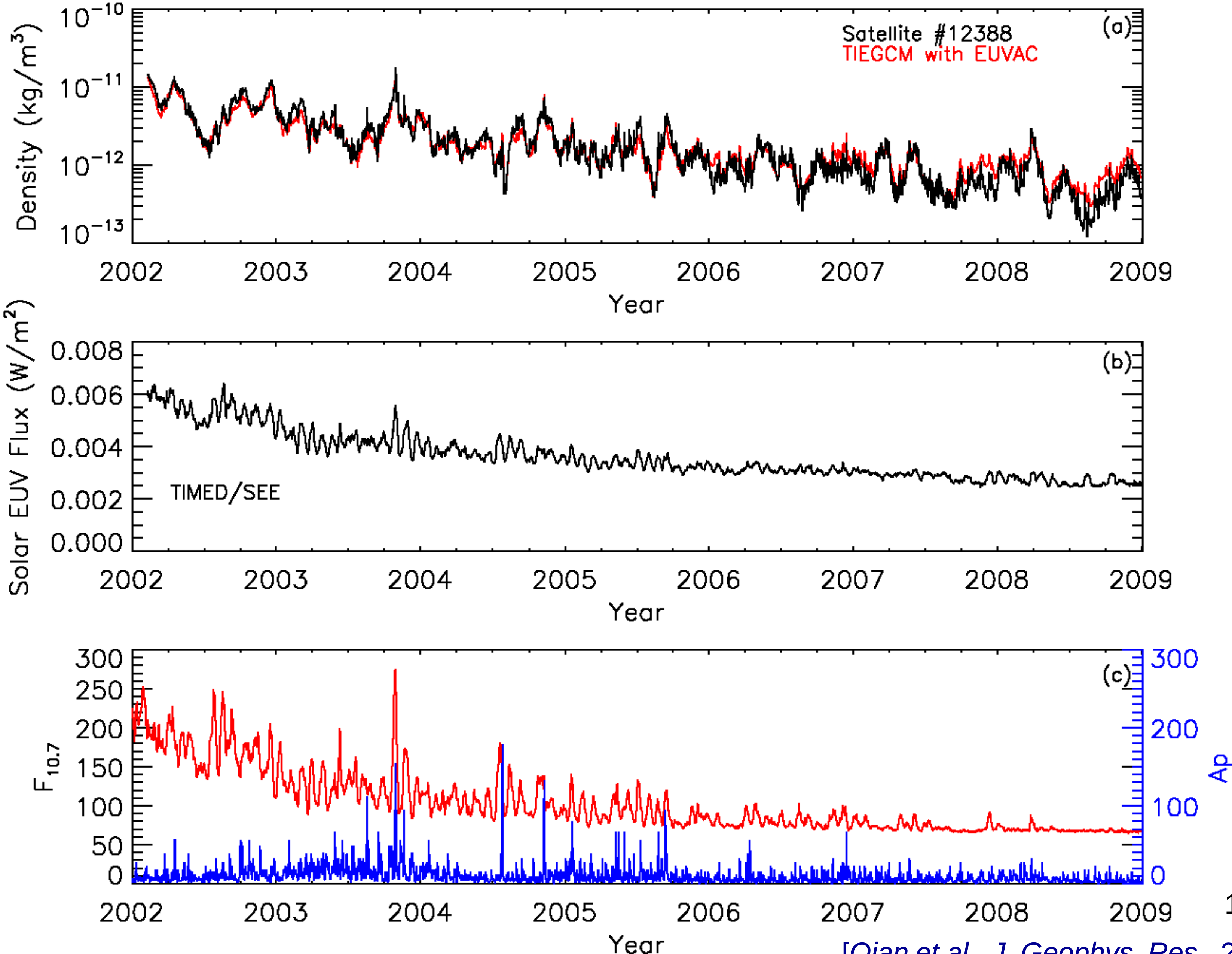


- Low and mid-latitude: neutral wind dynamo equations solved on geomagnetic apex coordinates. [Richmond et al., 1992; 1995]
- High latitude: specified by convection models such as Heelis, Weimer, and AMIE, or coupled to the LFM Magnetosphere Model.

Some Model Validation Examples

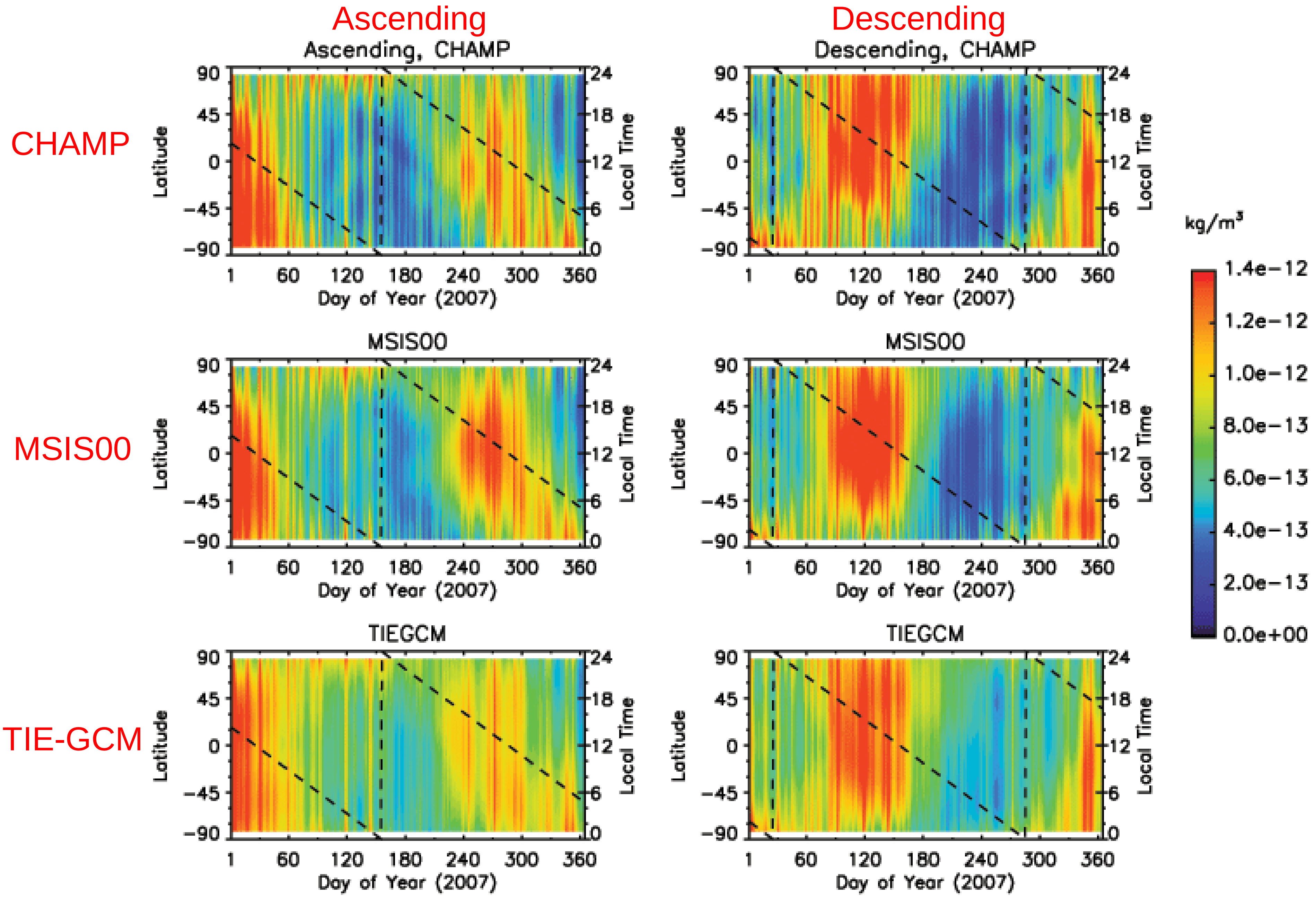
- Thermosphere
  - Neutral density data from satellite drag
  - Neutral density data from CHAMP
  - Composition data from GUVI
- Ionosphere
  - Electron density measurements from COSMIC
  - Ground-based incoherent scatter radar measurements
  - Ground-based GPS data

Thermospheric Density—Declining Phase of SC #23

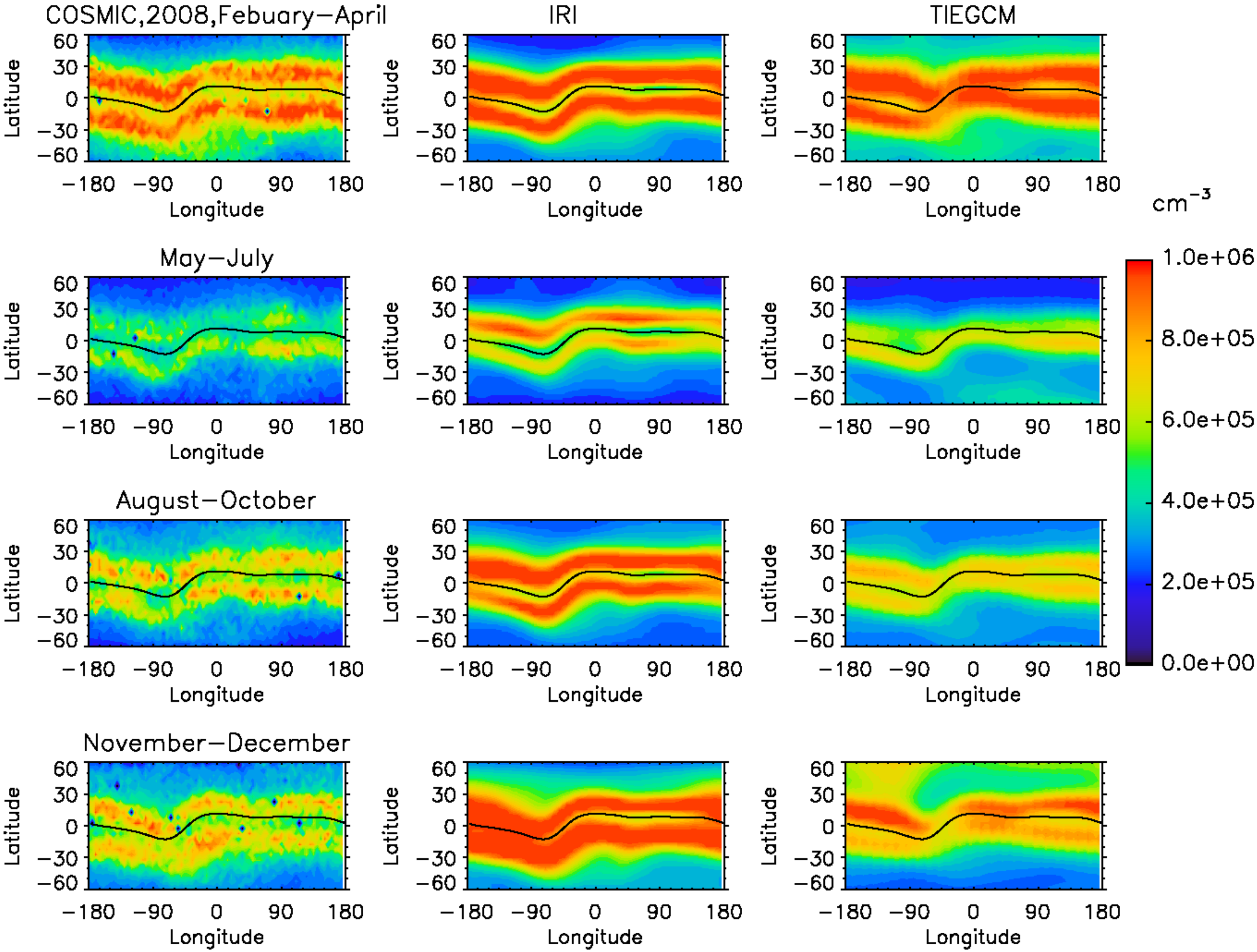


[*Qian et al.*, *J. Geophys. Res.*, 2009]

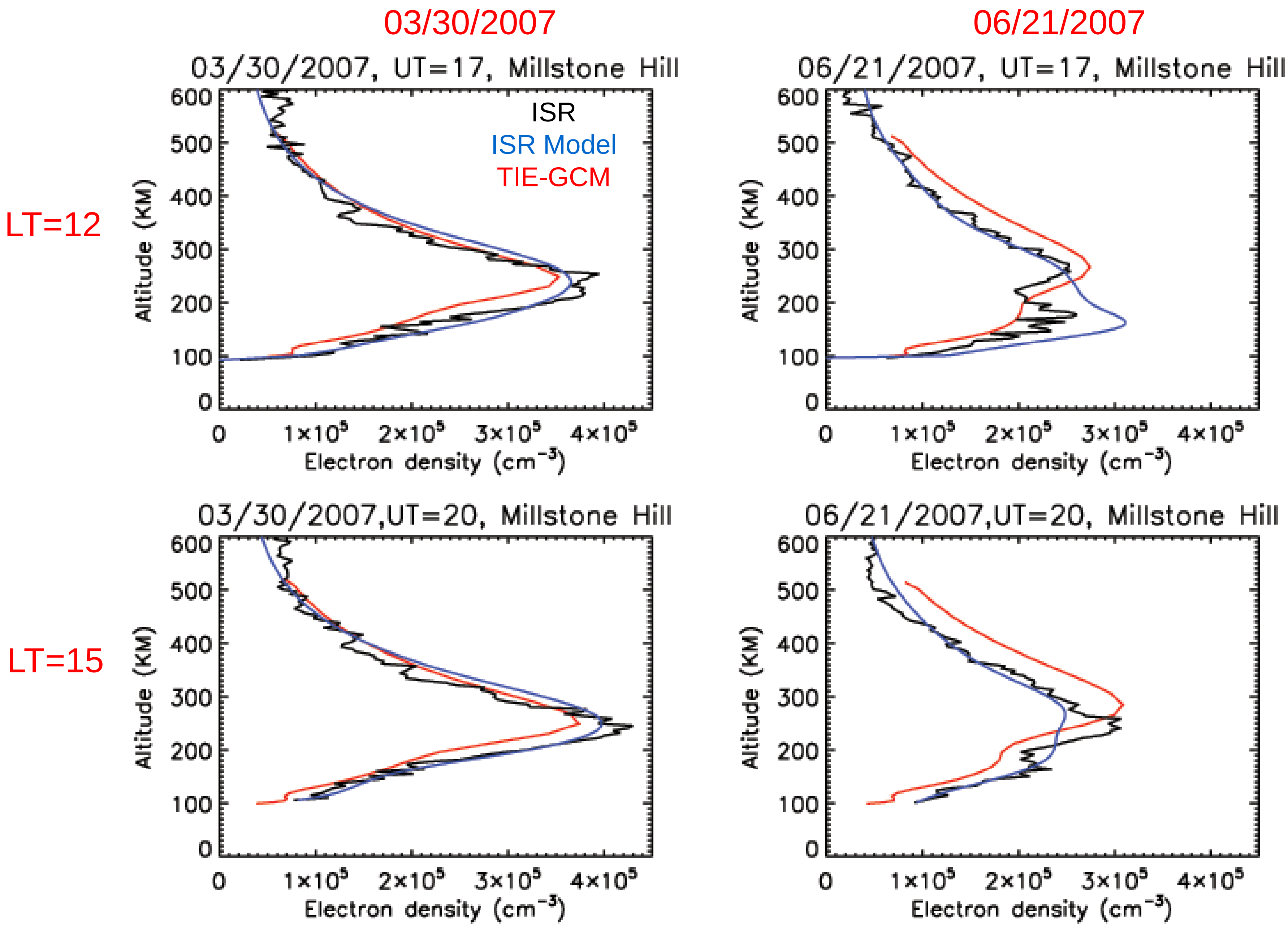
Thermosphere Neutral Density, 2007



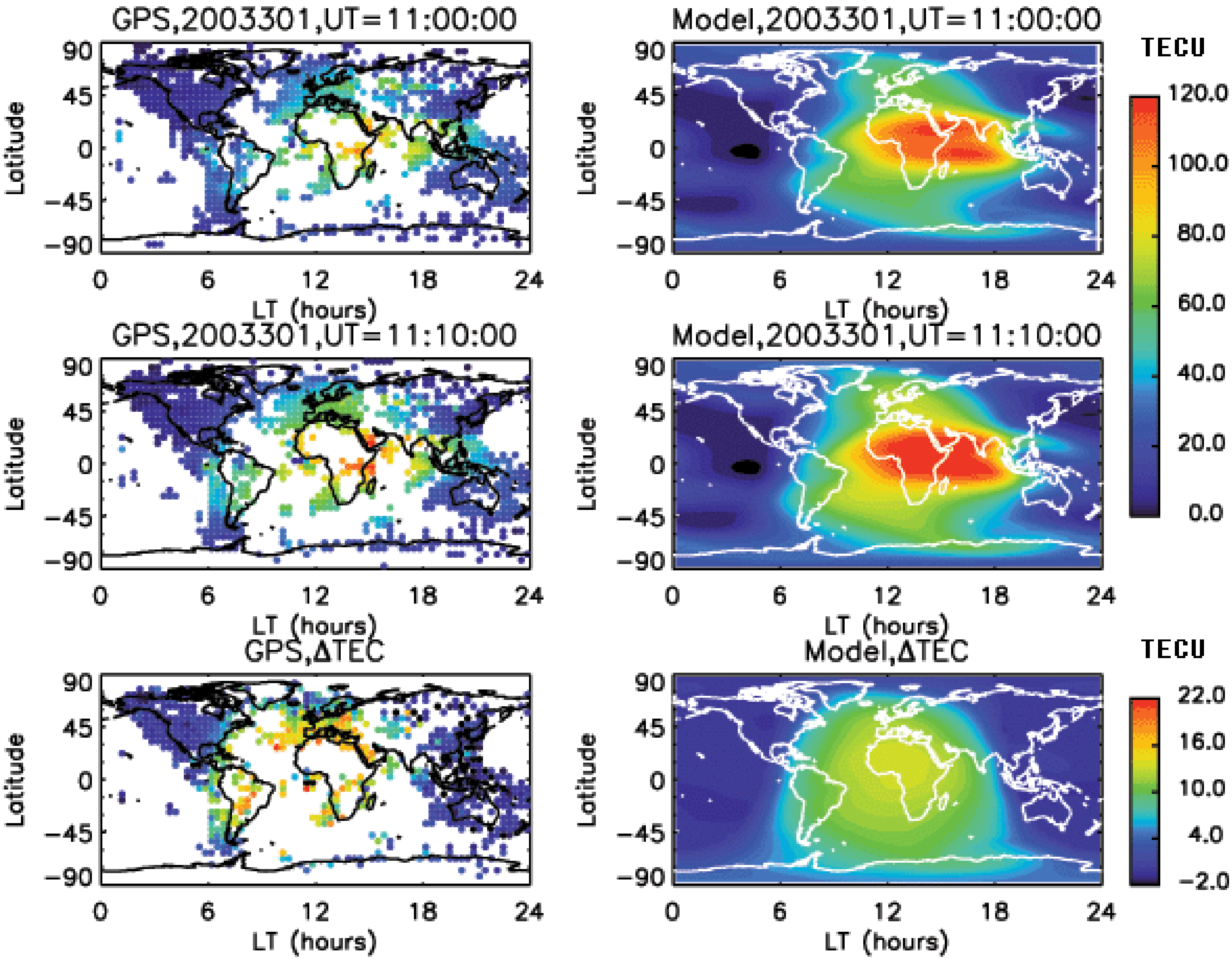
Ionospheric Climatology, 2008



Electron Density Profiles



Ionospheric Response to X17 flare on 28 October 2003



Current Development and Future Plans

- TIE-GCM v. 1.94 is undergoing benchmark tests and will be released soon
- Significant new feature is inclusion of the Weimer high-latitude potential model, using solar wind / IMF input
- High-resolution version (2.5° x 2.5° x H/4) is also in test
- Other key research developments include:
  - Lower boundary conditions:
    - — Seasonal/spatial variation of lower boundary eddy diffusion
    - — Tidal forcing derived from TIMED TIDI & SABER data
  - External forcing:
    - — Solar EUV from TIMED/SEE, SDO/EVE, and alternative proxies
  - — Auroral precipitation derived from GUVI data
  - Global Ionosphere Plasmasphere (GIP) model (closed field lines)
  - Continued development of the Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) model

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

Backup Material

Strengths and Weaknesses

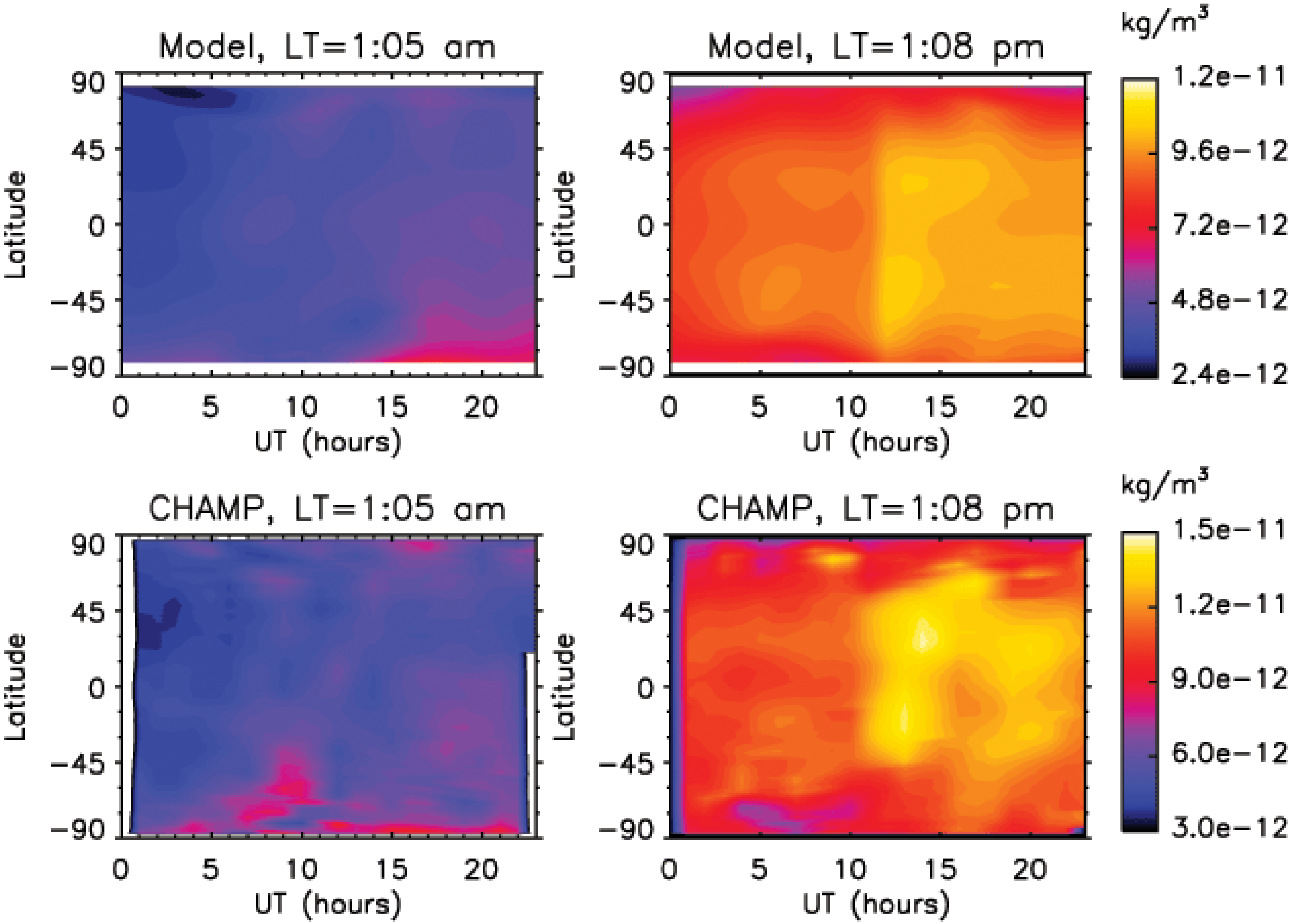
Strengths:

- Fully coupled neutral dynamics and ionospheric electrodynamics
- Accurate treatment of solar EUV and photoelectron processes, including capability of using EUV measurements
- Comprehensive photochemistry and thermodynamics
- Flexible high latitude inputs: Heelis, Weimer, AMIE, or coupling to magnetospheric models (CISM/CMIT)

Weaknesses:

- Lower boundary — only migrating tides included
- Upper boundary — no plasmasphere
- Uniform spherical grid — problems near the poles
- Hydrostatic equilibrium assumed

X17 flare on October 28, 2003—Thermosphere Responses



Infrared Cooling

- CO_2 cooling at 15 μm (peaks ~ 120 km)
- NO cooling at 5.3 μm (peaks ~ 150 km))
- $O(^3P)$ fine structure cooling at 63 μm (maximizes > 200 km)

Thermosphere (O/N_2)

TIE-GCM

GUVI

04/01

06/21