

# The NCAR TIE-GCM:

## Model Description, Development, and Validation

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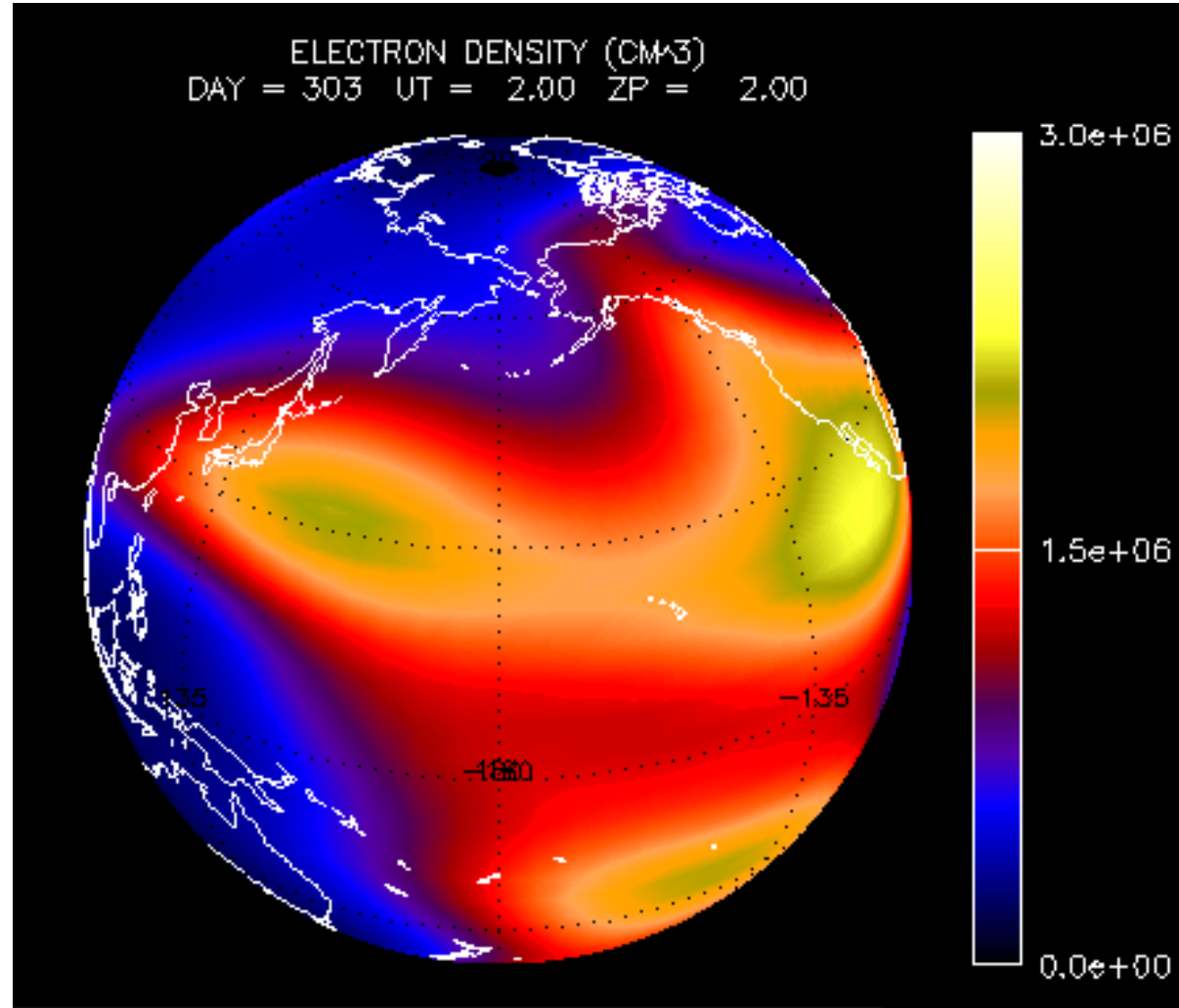


**NCAR**



# 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:  $w, O, O_2, N(^4S), NO, O^+$
- Hydrostatic equation:  $z$
- Thermodynamic equation:  $T_N, T_e$
- Quasi-steady state energy transfer—electron, neutral, ion:  $T_i$
- Photochemical equilibrium:  $N(^2D), O_2^+, N_2^+, N^+, NO^+$

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

**Resolution:** horizontal:  $5^\circ \times 5^\circ$ ; vertical: 0.5 pressure scale height. High resolution version ( $2.5^\circ \times 2.5^\circ \times H/4$ ) in test.

# Numerical Techniques

- **Horizontal:** explicit 4<sup>th</sup> order centered finite difference;
- **Time:** 2<sup>nd</sup> order centered difference;
- **Vertical:** Implicit 2<sup>nd</sup> 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

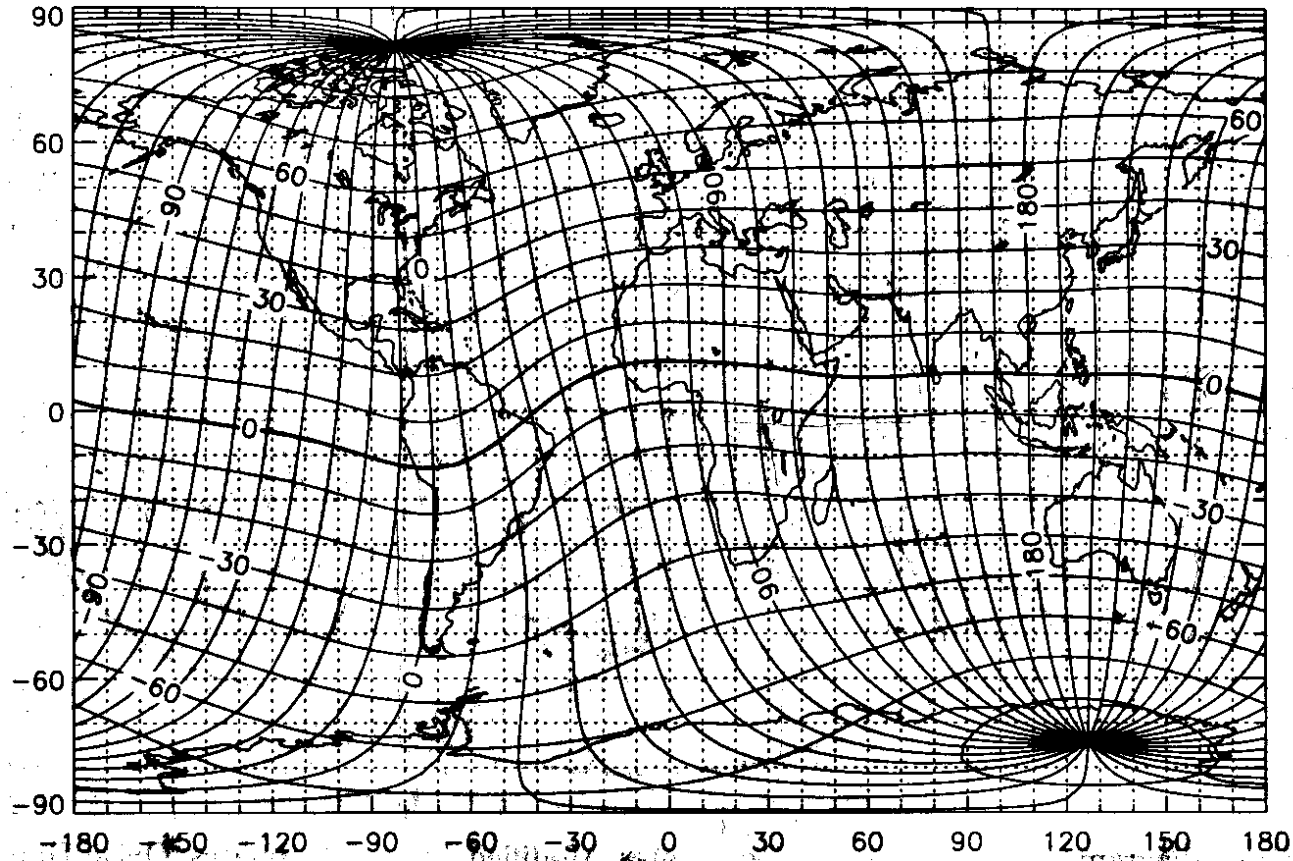
## Upper boundary conditions:

- $u, v, w, T_N, O_2, O$ : diffusive equilibrium;
- $N(^4S), NO$ : 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
- $N(^4S), O^+$ : photochemical equilibrium
- $NO$ : constant density of  $(8 \times 10^6)$
- $T_e$ : equal to  $T_N$ .

# ITM coupling: Electrodynamics



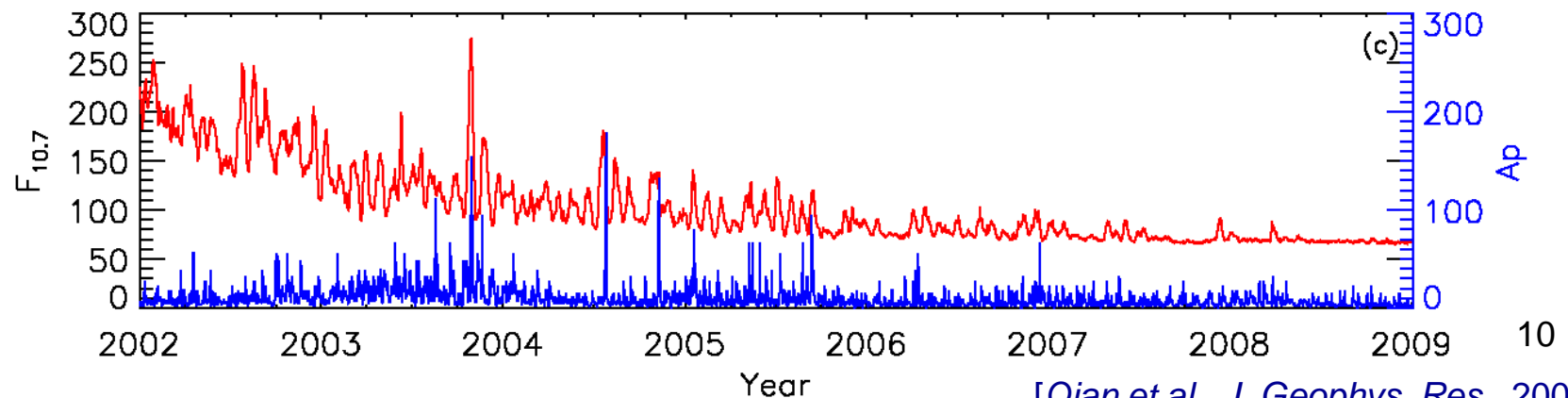
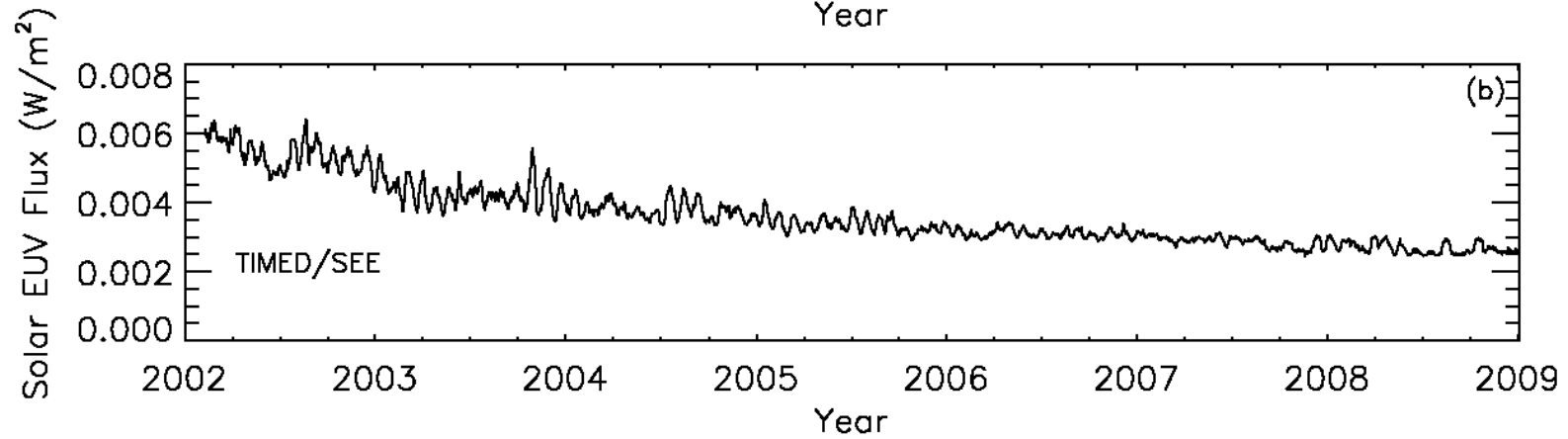
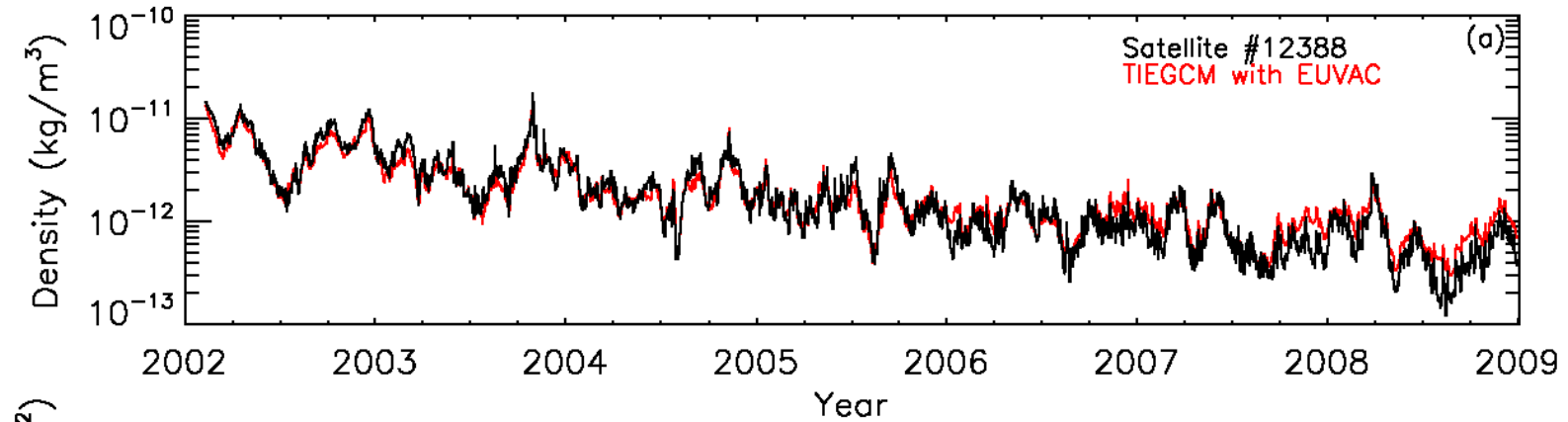
- **Low and mid-latitude:** neutral wind dynamo equations solved on geomagnetic apex coordinates. [Richmond et al., 1992; 1995]
- **High latitude:** specified by convection models such as Heelis, Weimer, and AMIE, or coupled to the LFM Magnetosphere Model.



# 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

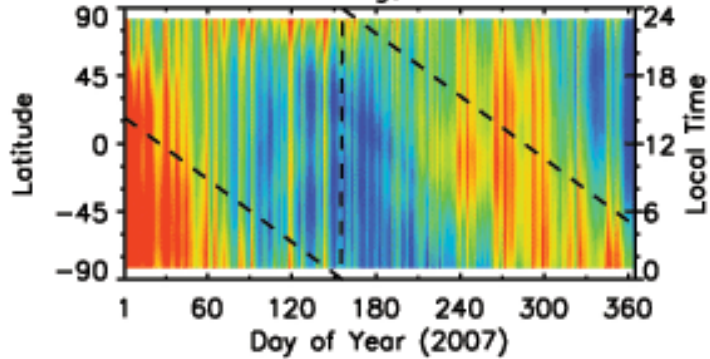
# Thermospheric Density—Declining Phase of SC #23



# Thermosphere Neutral Density, 2007

Ascending

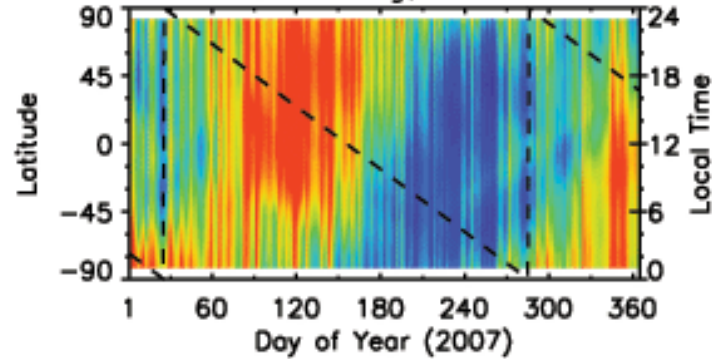
Ascending, CHAMP



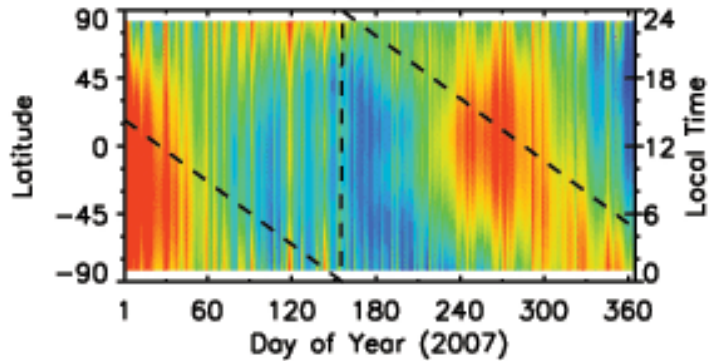
CHAMP

Descending

Descending, CHAMP

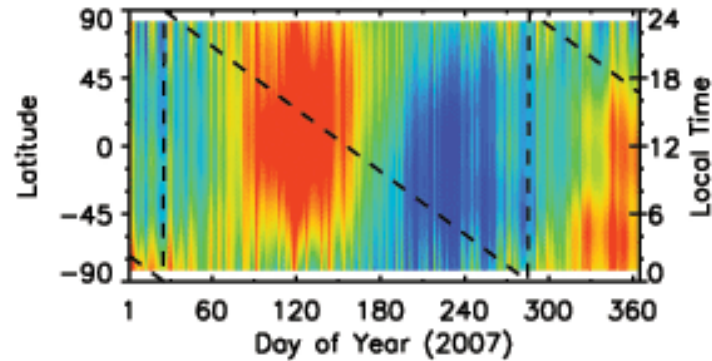


MSIS00

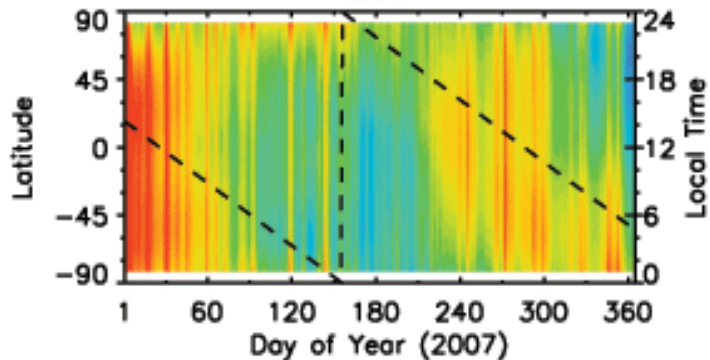


MSIS00

MSIS00

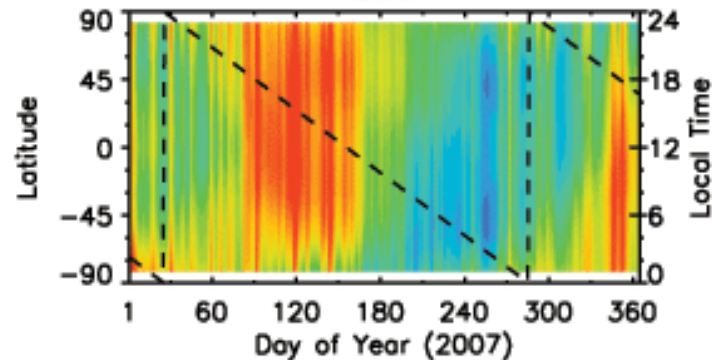


TIEGCM



TIE-GCM

TIEGCM



kg/m<sup>3</sup>

1.4e-12

1.2e-12

1.0e-12

8.0e-13

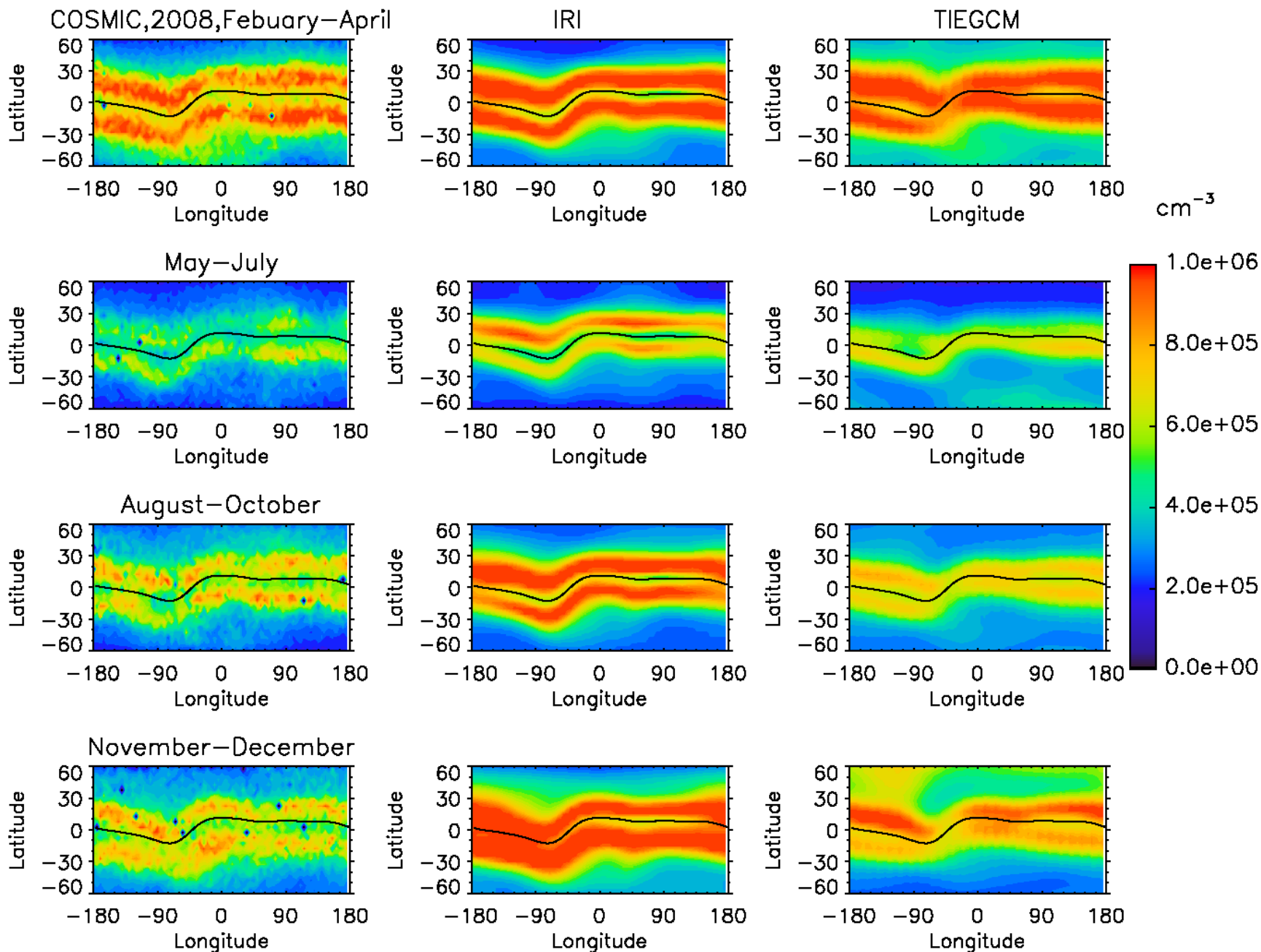
6.0e-13

4.0e-13

2.0e-13

0.0e+00

# Ionospheric Climatology, 2008



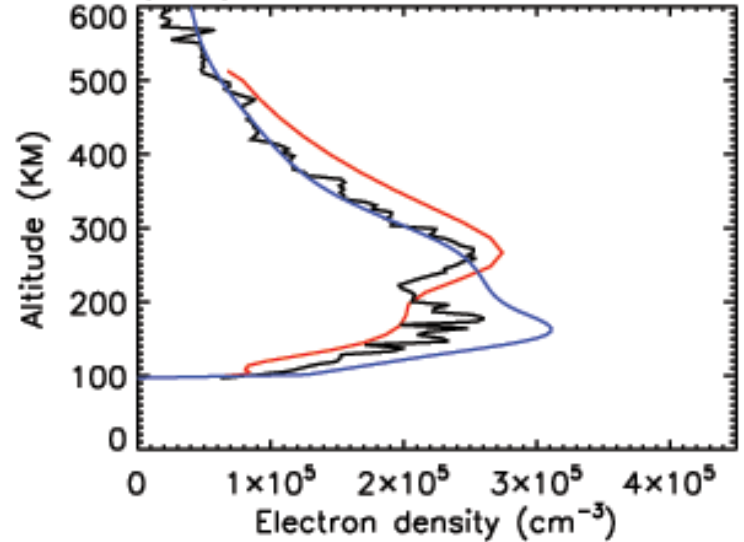
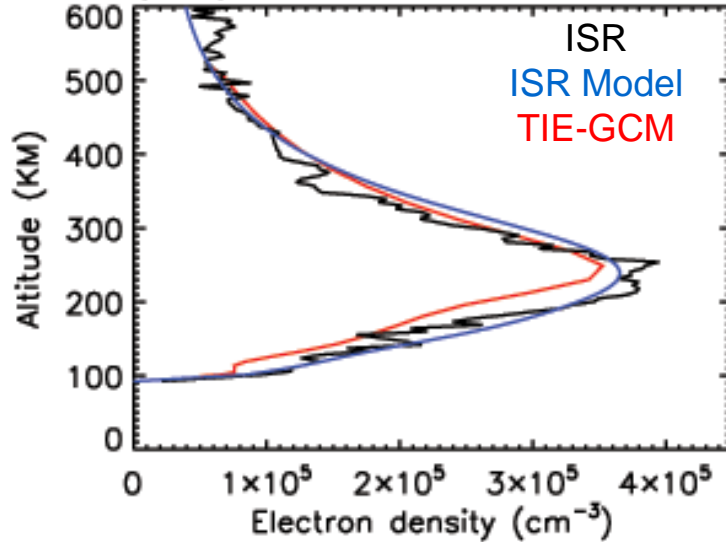
# Electron Density Profiles

03/30/2007

06/21/2007

03/30/2007, UT=17, Millstone Hill

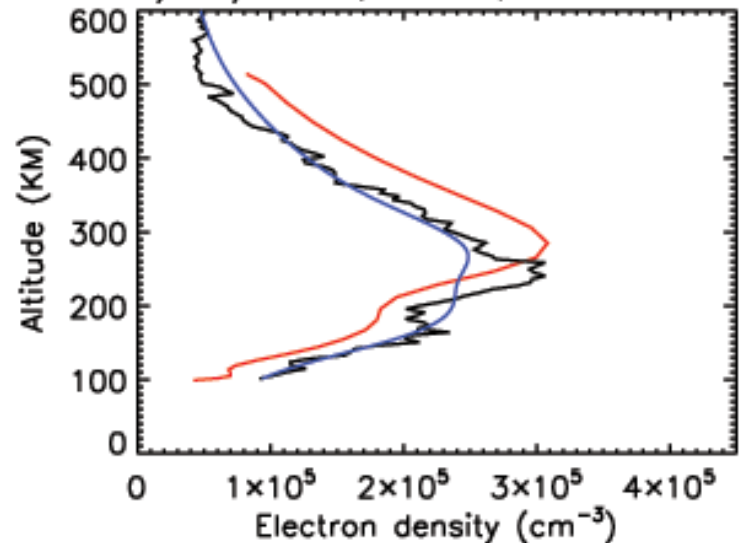
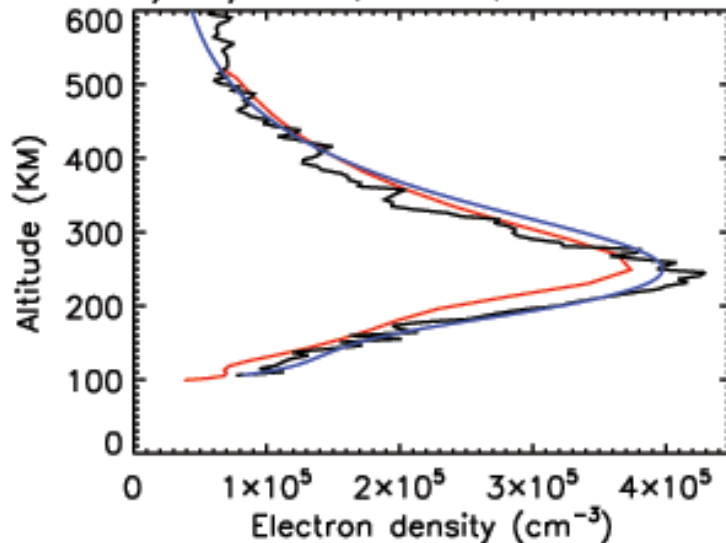
06/21/2007, UT=17, Millstone Hill



LT=12

03/30/2007, UT=20, Millstone Hill

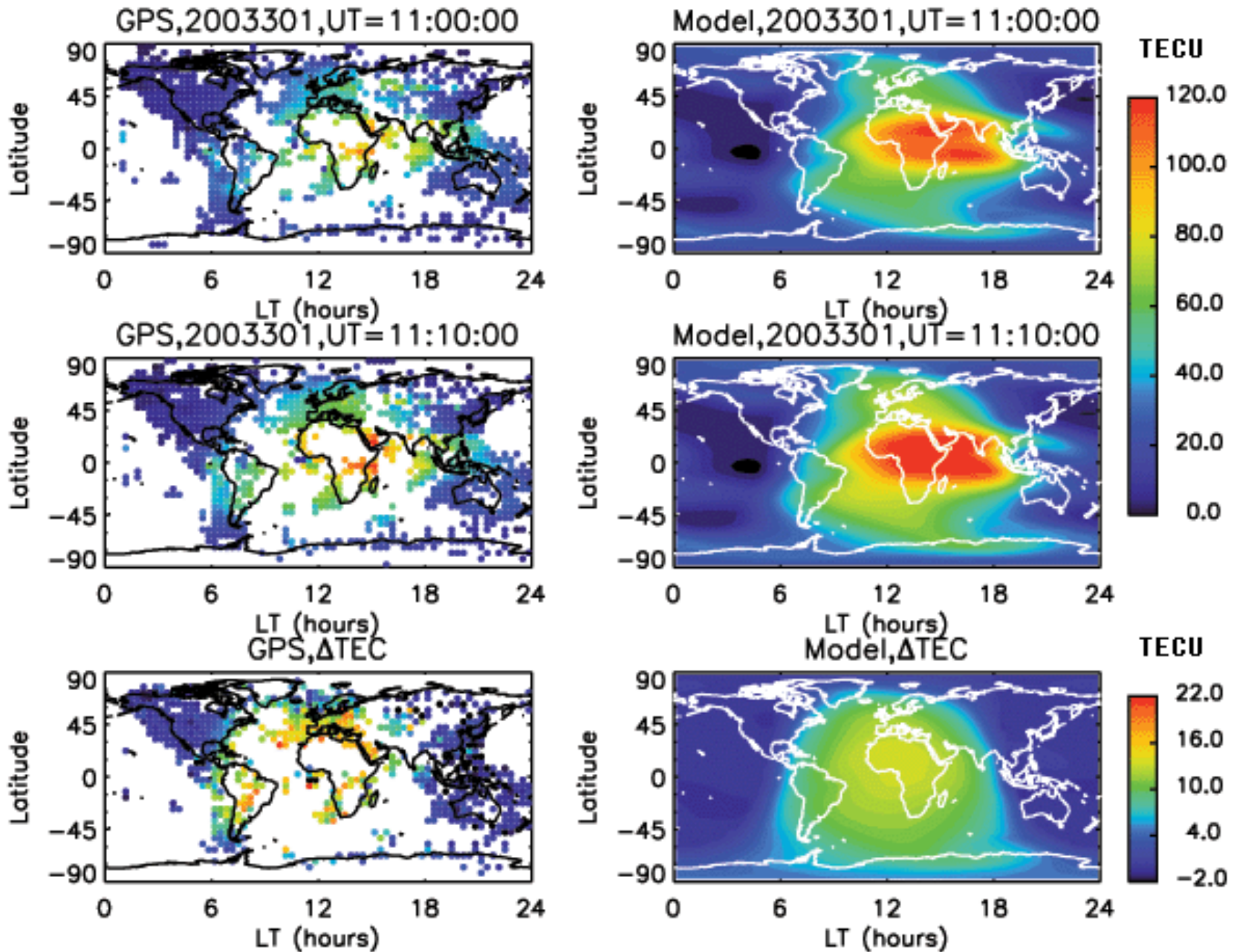
06/21/2007, UT=20, Millstone Hill



LT=15



# 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 ( $2.5^\circ \times 2.5^\circ \times H/4$ ) 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

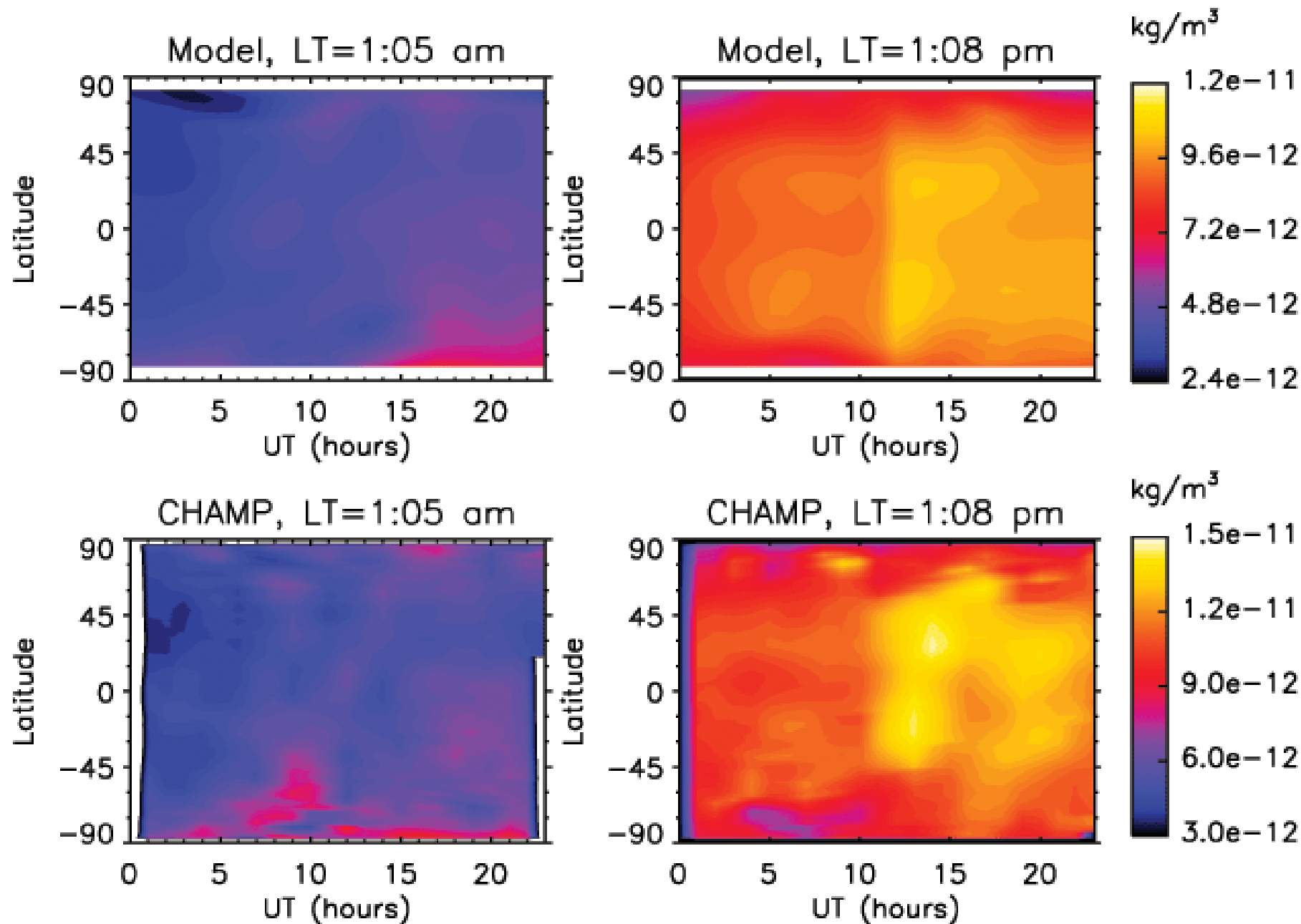
## Strengths:

- 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<sub>2</sub> cooling** at 15 μm (peaks ~ 120 km)
- **NO cooling** at 5.3 μm (peaks ~ 150 km))
- **O(<sup>3</sup>P) fine structure cooling** at 63 μm (maximizes > 200 km)

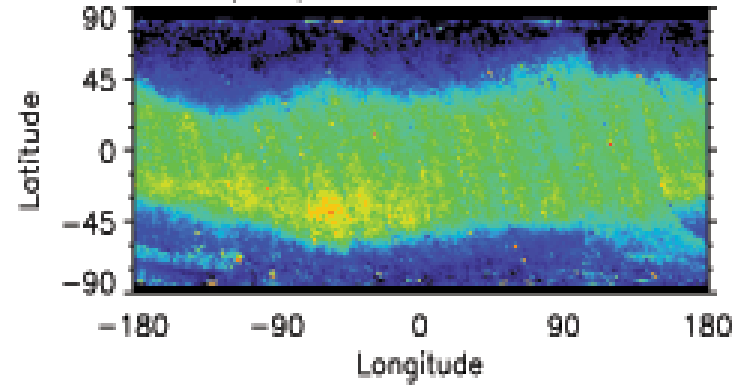
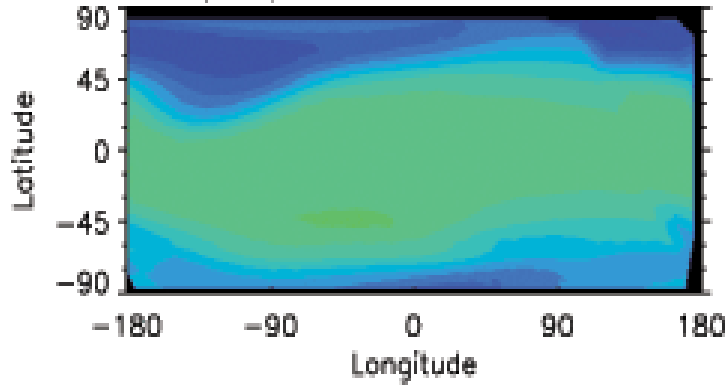
# Thermosphere (O/N<sub>2</sub>)

TIE-GCM

GUVI

04/01/2007,LT=9:00, TIEGCM

04/01/2007,LT=9:00, GUVI



06/21/2007,LT=17:18, TIEGCM

06/21/2007,LT=17:18, GUVI

