TIE-GCM Updates

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

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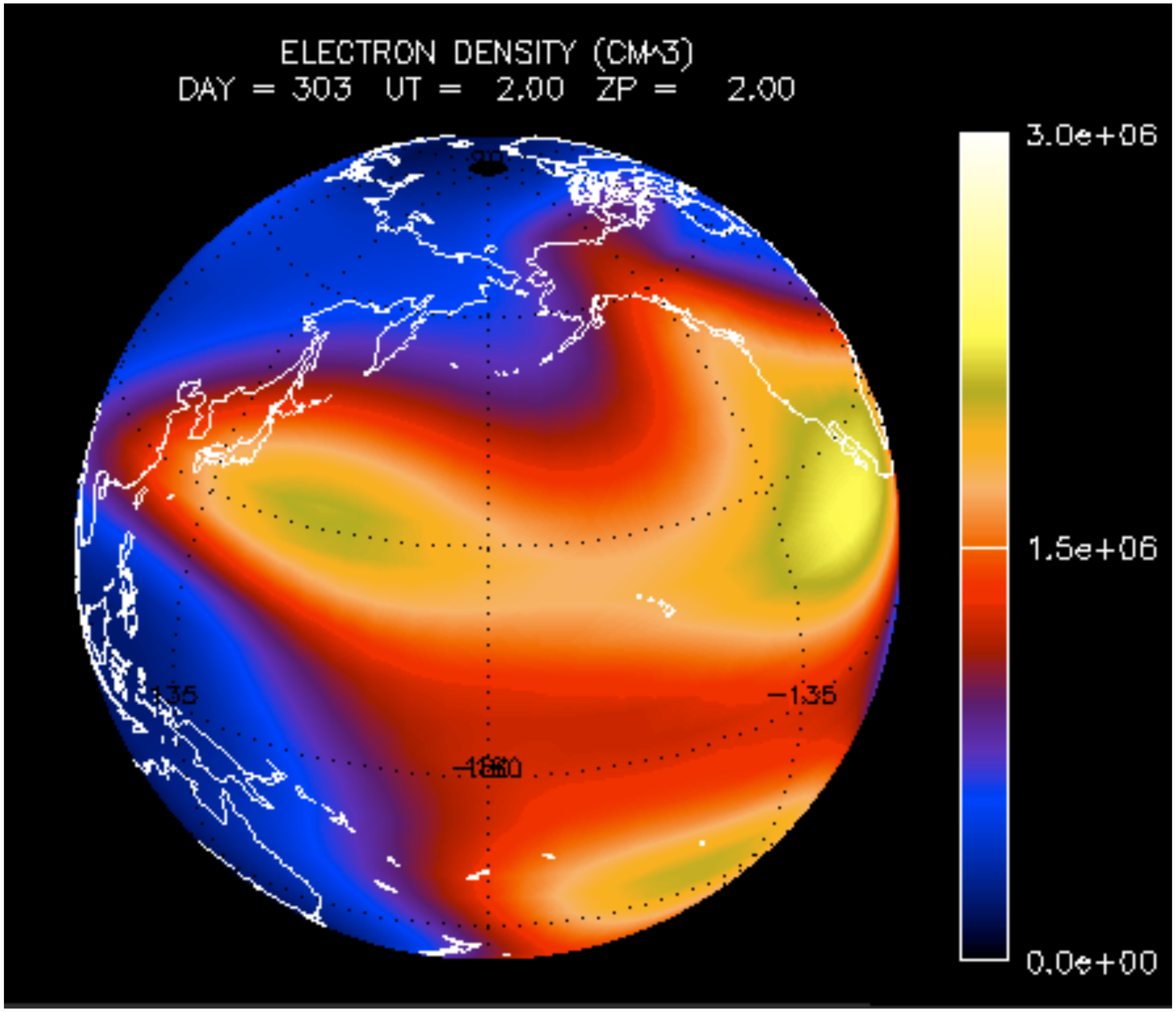
Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM)

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



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

What's New in TIE-GCM v. 1.94?

- TIE-GCM v. 1.94 released June 2011
  - Significant new feature is inclusion of Weimer high-latitude potential model
  - Magnetic latitude merging range now varies with auroral convection zone size
  - Several "standard output" derived parameters consolidated in code

- Note that this makes real-time runs possible, using measured IMF & solar wind input

- Minor update v. 1.94.2 released January 2012

  Intel ifort support
  Fixed memory accumulation bug
  Upgrades to MPI memory allocation
  Added no-dynamo option
  Data file names read from source history
  Fixed sign error in zigmc and zigma2
  Fixed timing calls in advance
  Added SECSTART and SECSTOP to namelist inputs
  Prohibited specifying SECSTART==START for initial run
  Renamed getpid
  Moved calccloc to util
  Multiplied Joule heating by JOULEFAC in standard ouput
  JOULEFAC in standard output

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

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.

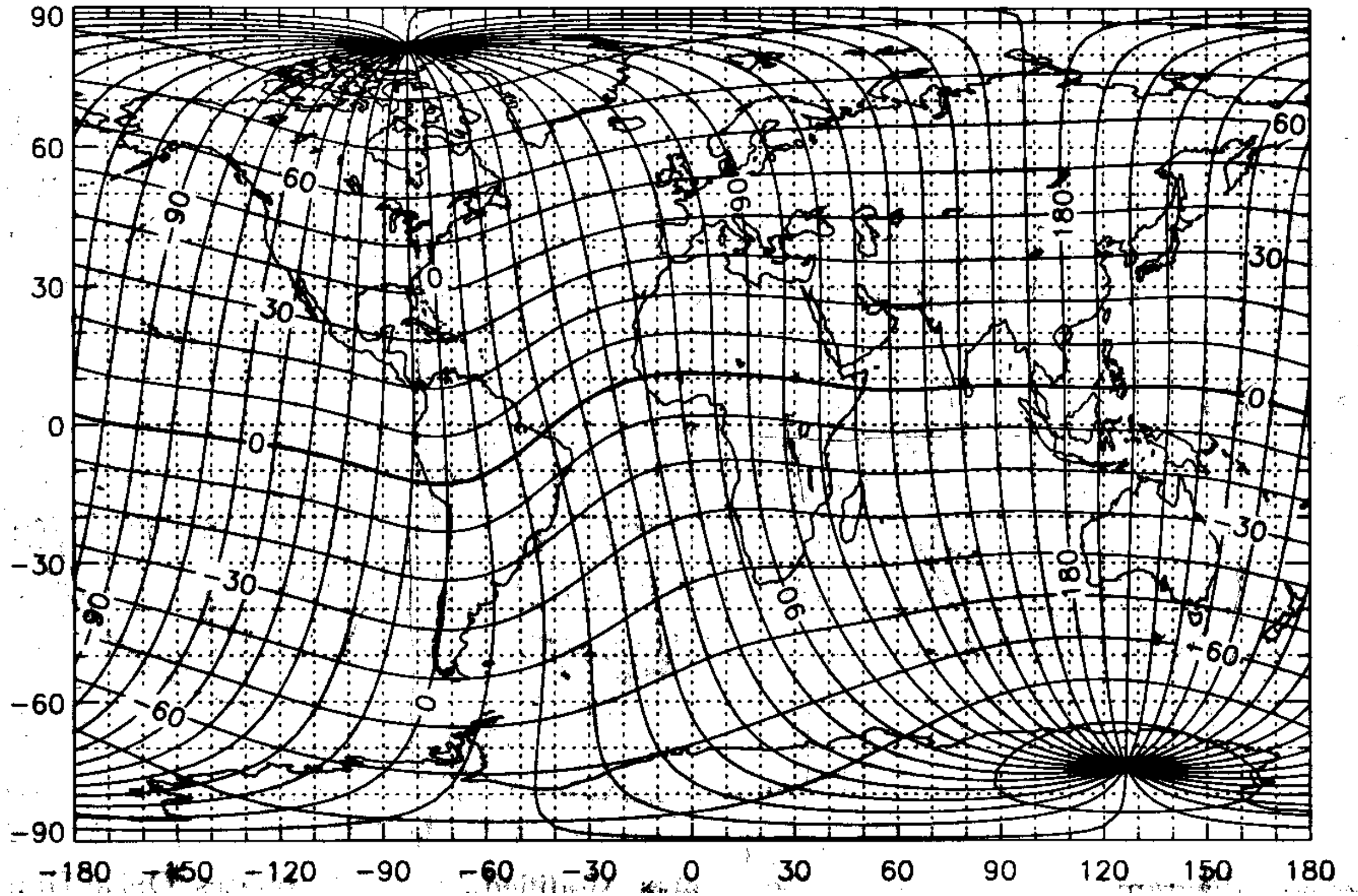
• Time step is 120 s.

• 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.

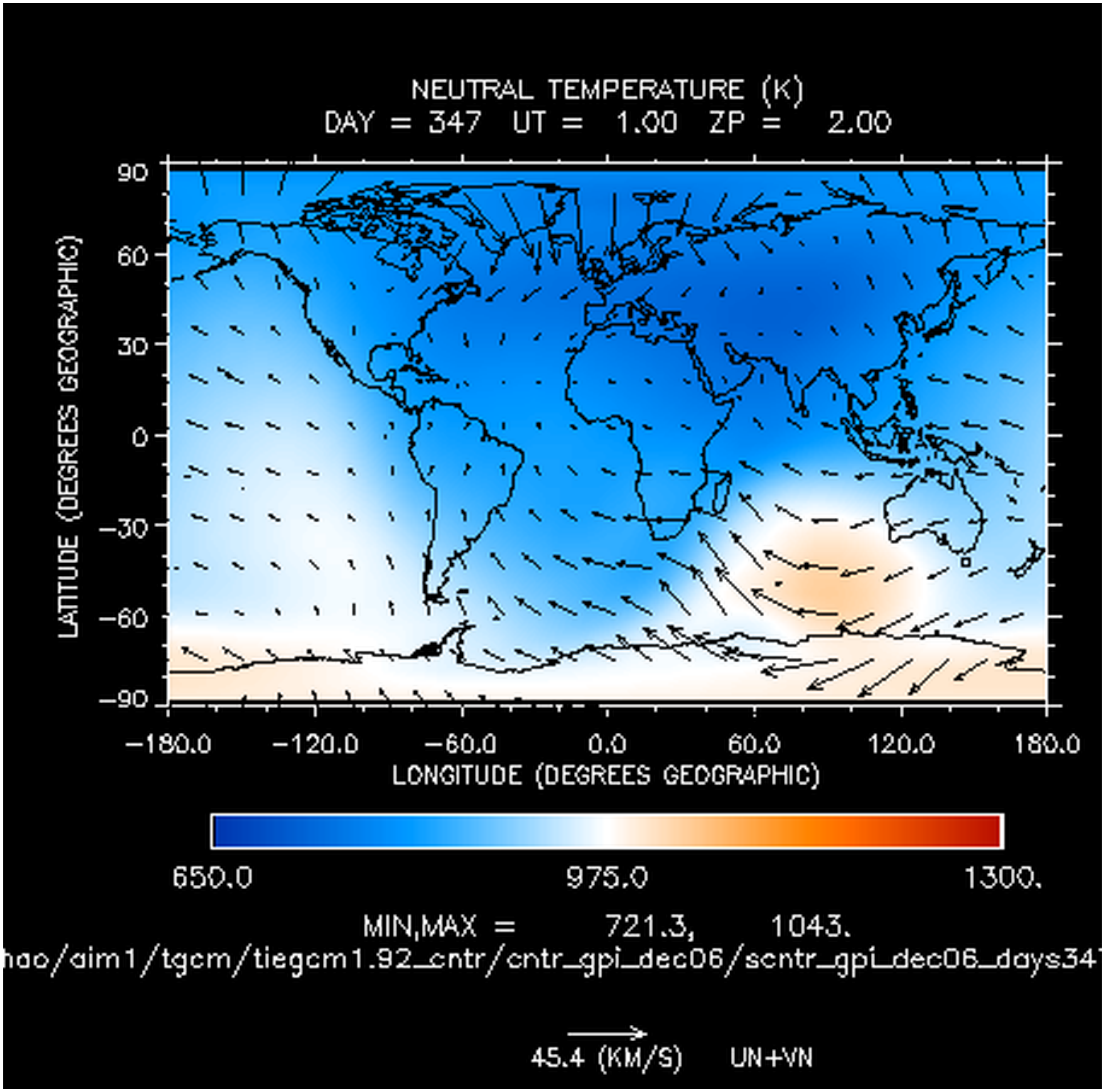
• ~0.2 s / time step on many ~4 to ~8 processor systems (>600 x wallclock).

Ionosphere-Thermosphere Coupling and 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.

December 2006 "AGU Storm"



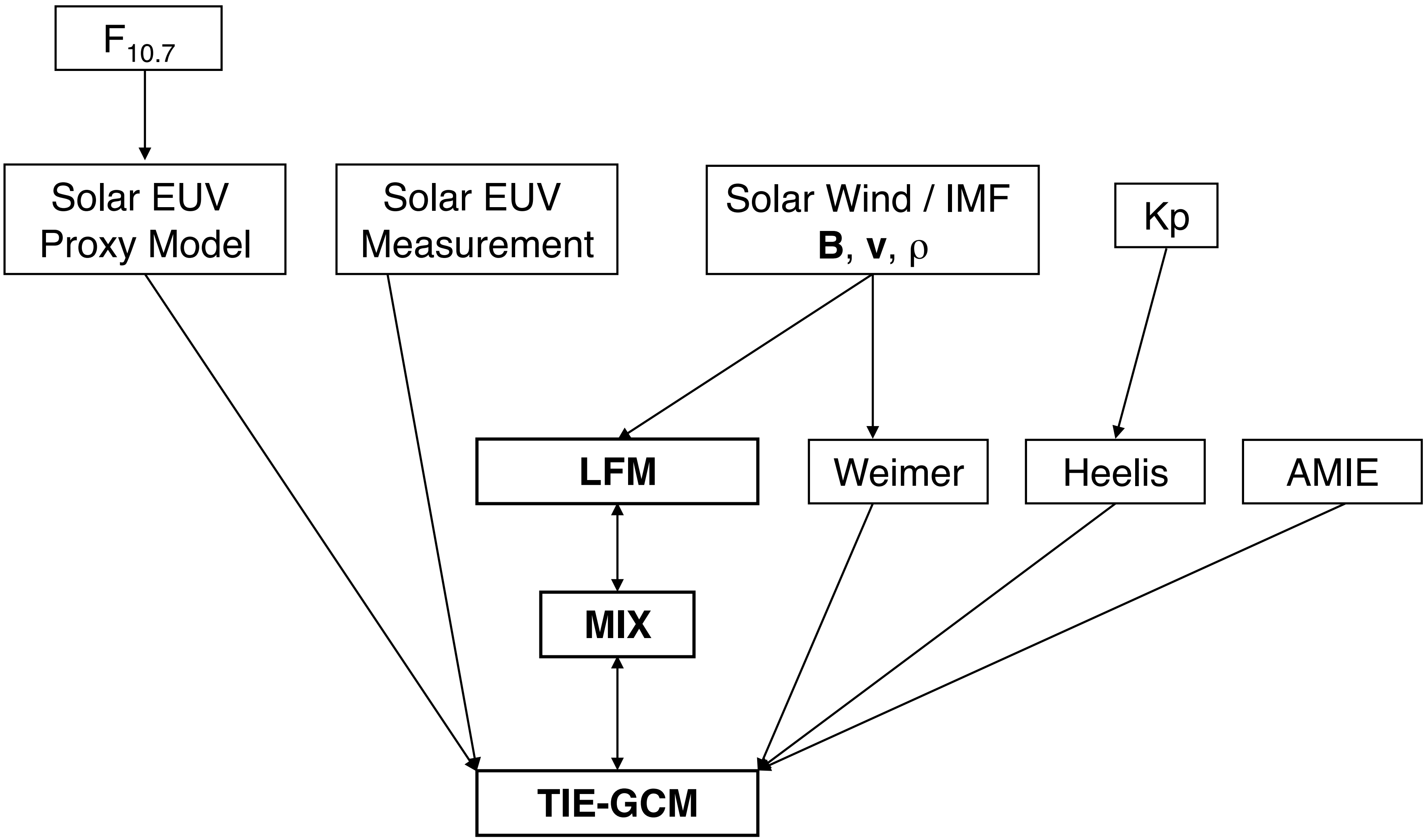
External Forcing of the Thermosphere/Ionosphere System

- 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 (Solomon & Qian, 2005)

- 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)

TIE-GCM “Extraterrestrial” Inputs and Options



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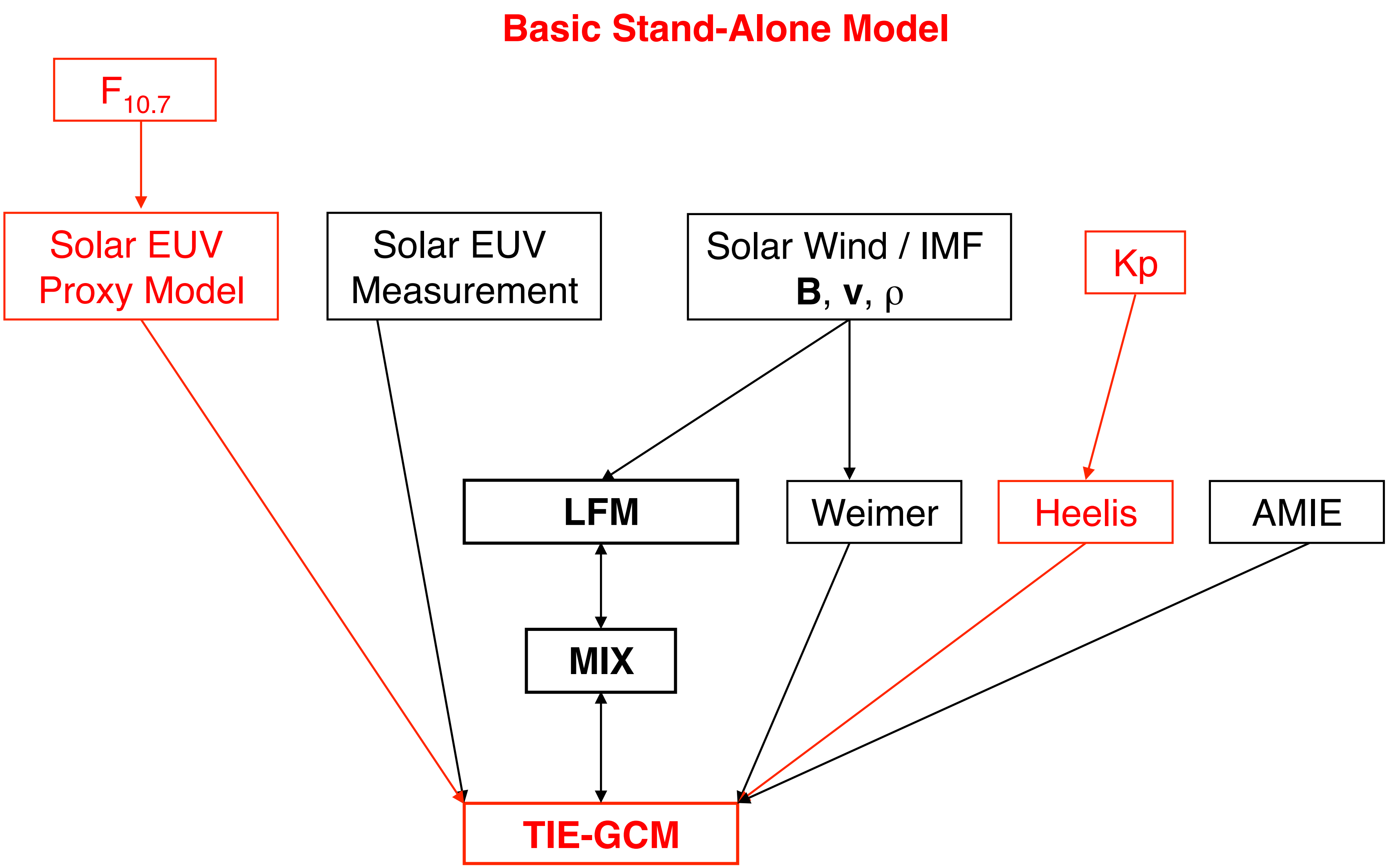
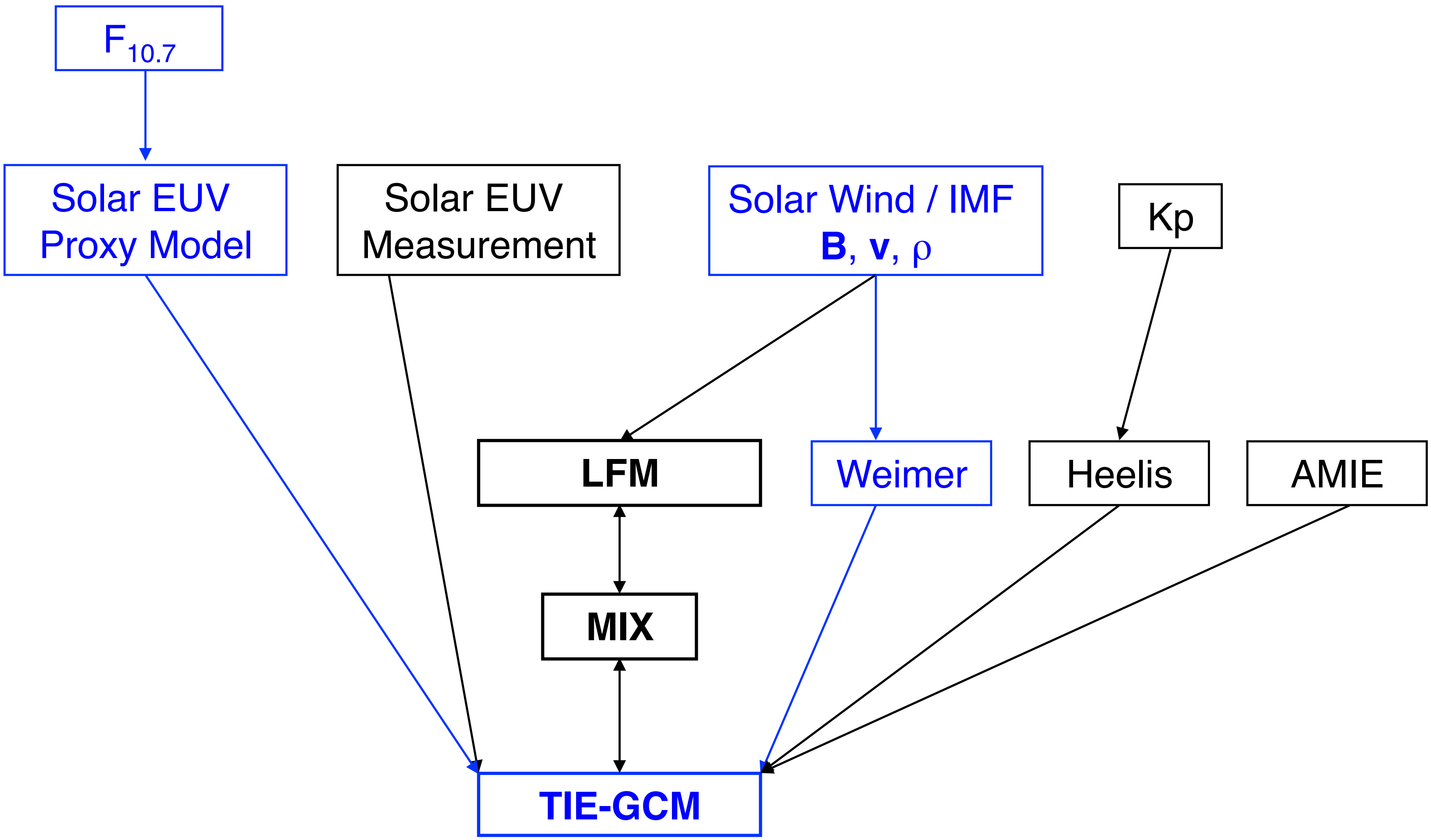


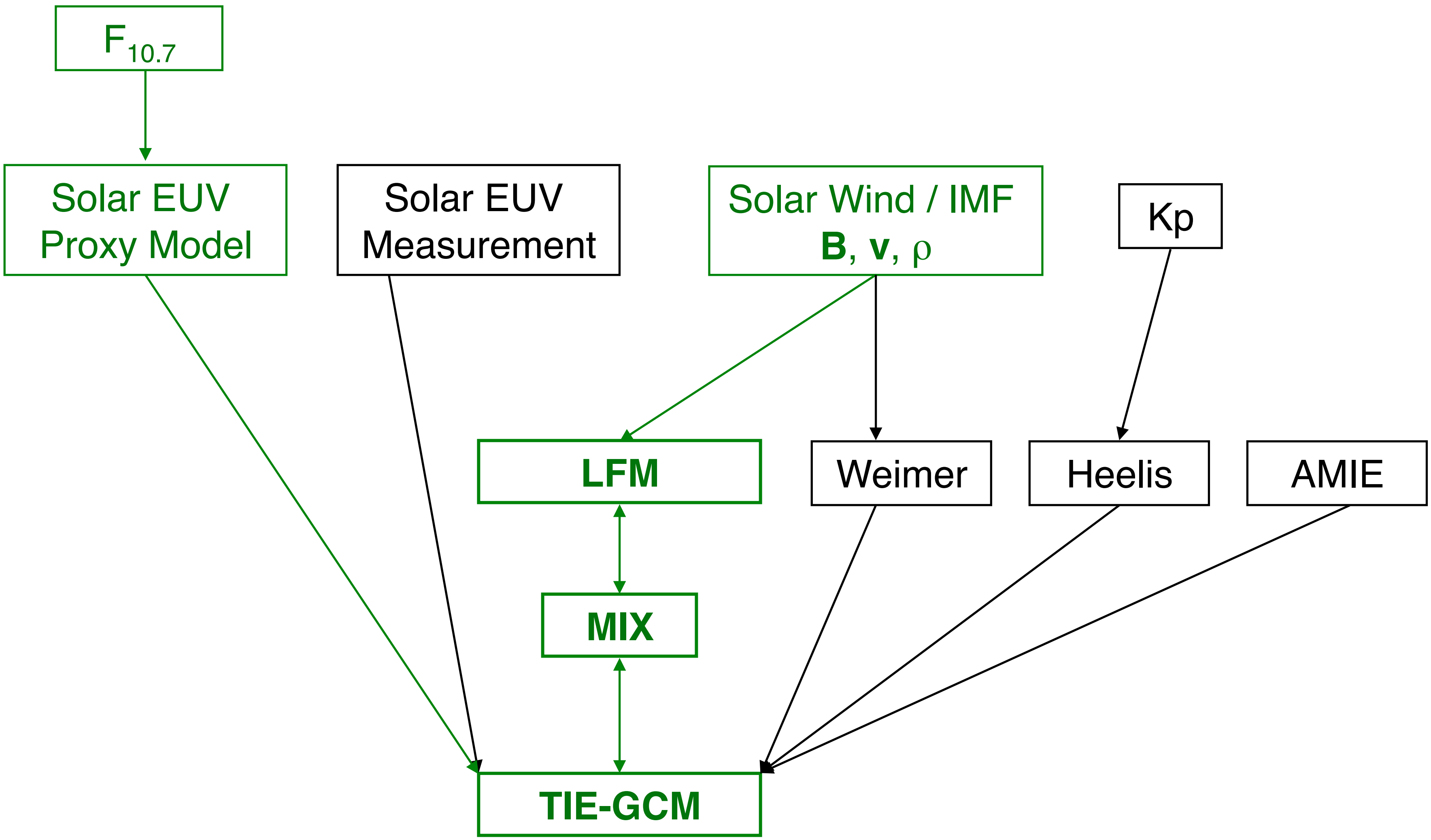
TIE-GCM “Extraterrestrial” Inputs and Options

Stand-Alone Model using Weimer ’05 High-Latitude Potential



TIE-GCM "Extraterrestrial" Inputs and Options

CMIT Configuration



Science Highlight: Thermospheric Neutral Density

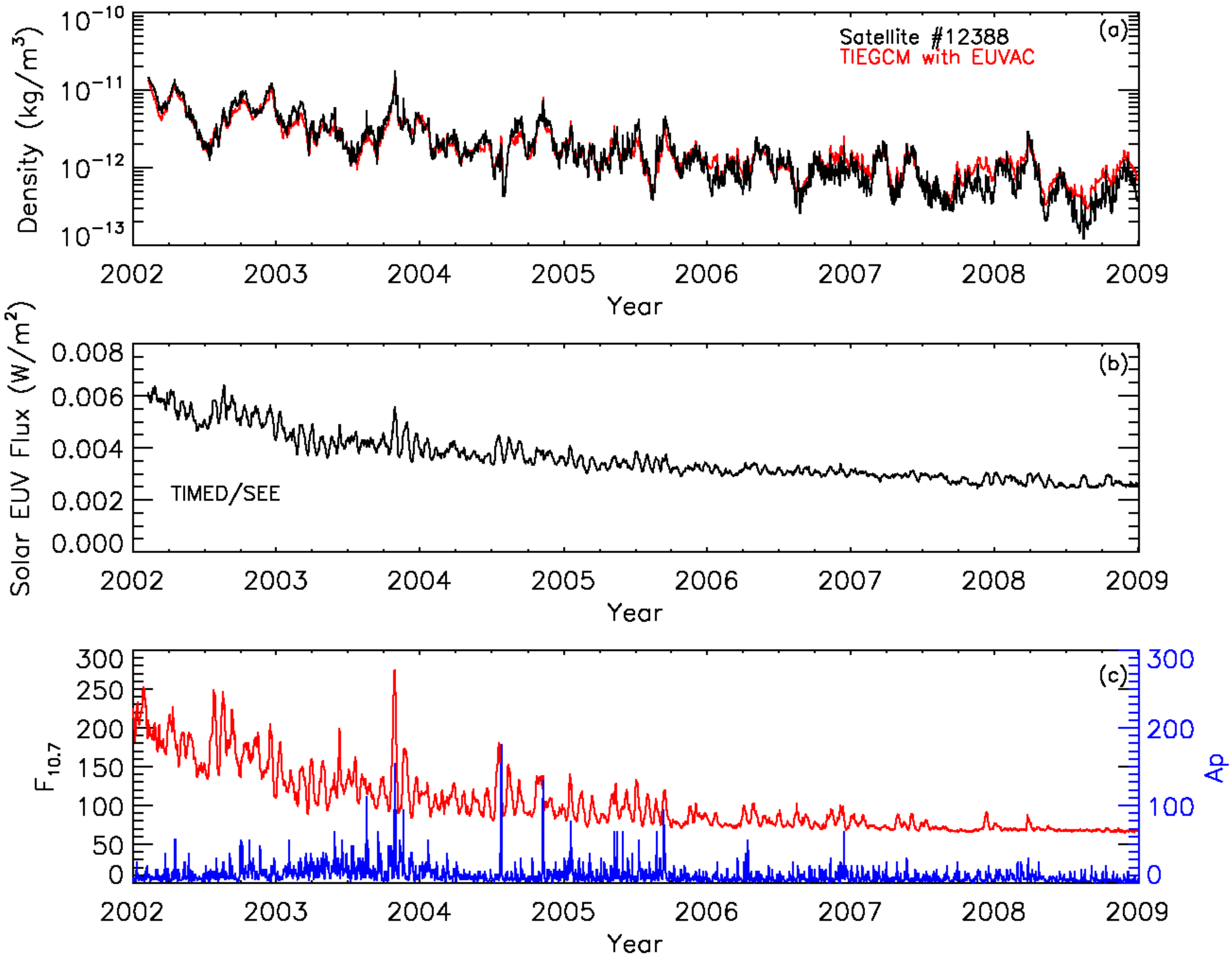
- The variation of neutral density in the thermosphere, on time scales ranging from an hour to a decade, has important effects on the trajectories of objects in low-Earth orbit.

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

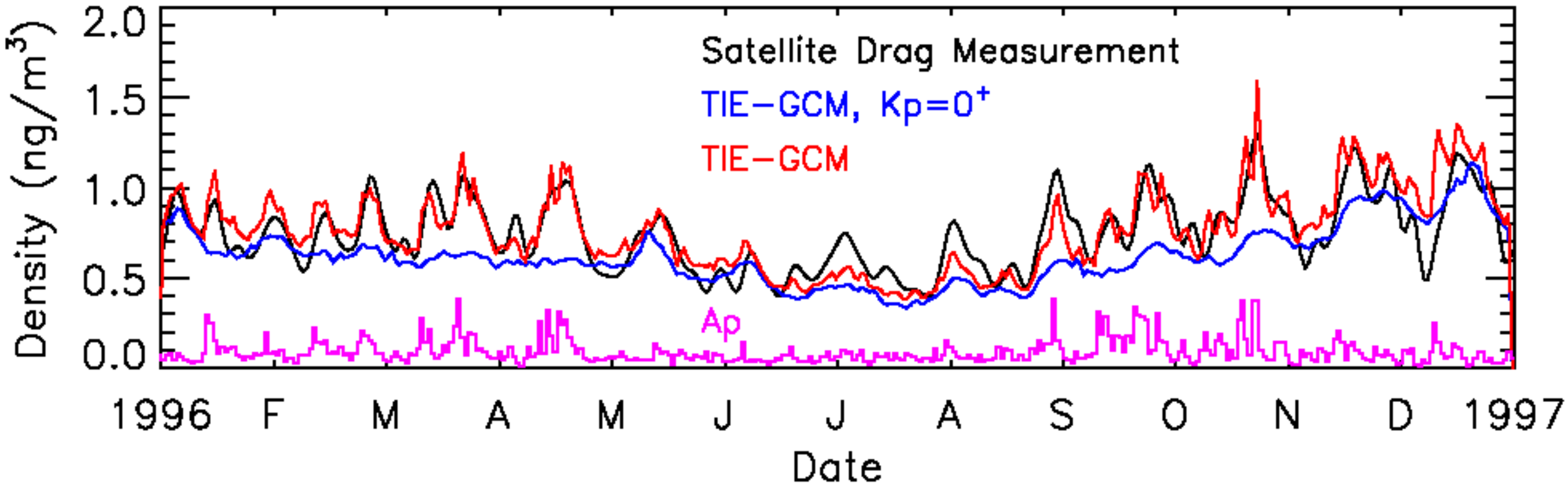
- It is also a tractable problem, on time scales of hours to days, and numerical models have the potential to make significant advances over the current empirical models used in operations.

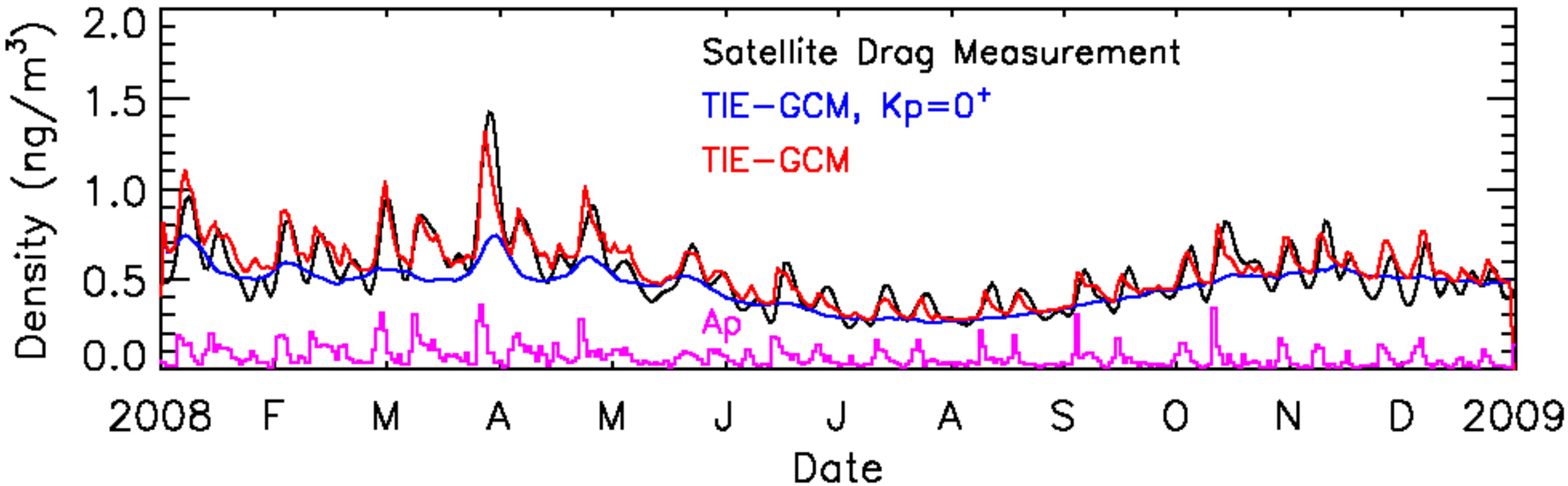
- Using satellite drag observations to validate and improve numerical models has the distinct advantage that the data used for comparison are precisely the same as the ones of importance for the "larger impacts."

Thermospheric Density during the Declining Phase of SC #23

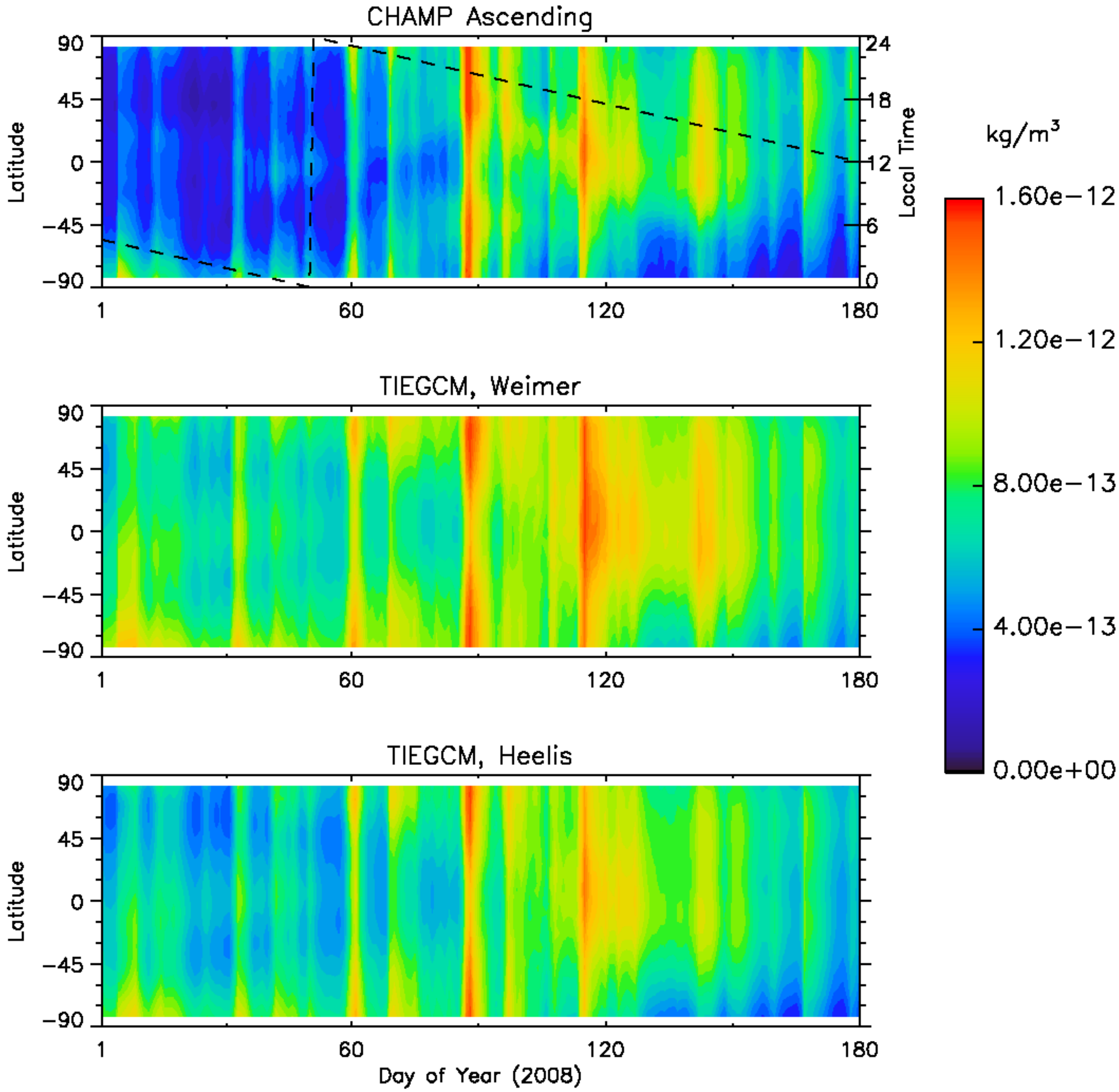


Global Mean Density at 400 km during 1996 and 2008

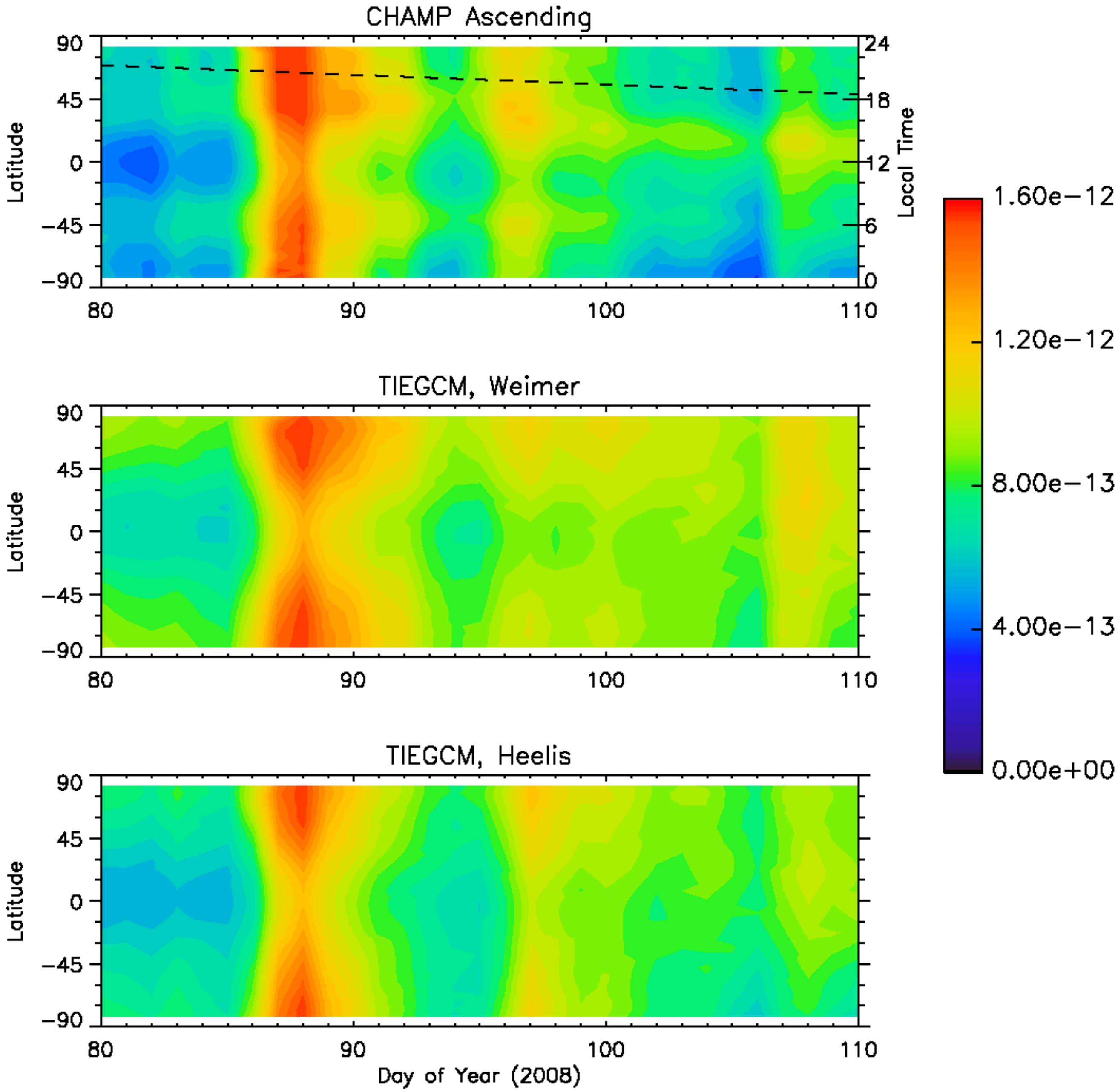




Comparison of Model Runs to CHAMP Data for 2008



Comparison of Model Runs to CHAMP Data for CR 2068



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 under the auspices of 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

Thermospheric General Circulation Models

THE THERMOSPHERIC GENERAL CIRCULATION MODELS (TGCM'S)

Introduction

The High Altitude Observatory at the National Center for Atmospheric Research has developed a series of numeric simulation models of the earth's upper atmosphere, including the upper Stratosphere, Mesosphere, and Thermospere. The Thermospheric General Circulation Models (TGCM's) are three-dimensional, time-dependent models of the EARTH's neutral upper atmosphere. The models use a finite differencing technique to obtain a self-consistent solution for the coupled, nonlinear equations of hydrodynamics, thermodynamics, continuity of the neutral gas and for the coupling between the dynamics and the composition.

Recent models in the series include a self-consistent aeronomic scheme for the coupled Thermosphere/Ionosphere system, the Thermosphere Ionosphere Electrodynamic General Circulation Model (TIEGCM), and an extension of the lower boundary from 97 to 30 km, including the physical and chemical processes appropriate for the Mesosphere and upper Stratosphere, the Thermosphere Ionosphere Mesosphere Electrodynamic General Circulation Model (TIME-GCM). A global mean, or column model, has also been developed in parallel with the TGCM's. The global mean model is used as a time-dependent, one-dimensional platform from which new chemical, dynamic and numeric schemes are developed and tested before being introduced into the 3-d GCM's.

What's New

June 20, 2008: Announcing the release of TIEGCM version 1.9
tiegcm1.9 Release Notes
Model source code download coming soon (will require email registration)

Documentation

User's Guide to the Models and Post-processors (updated June, 2008): [html] [pdf]
Model description coming soon..

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/tiegcm_modeldes.pdf

Post-Processor:
http://www.hao.ucar.edu/modeling/tgcm/download/files/tgcmproc29_idl.tar.gz

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

Current Development and Future Plans

- TIE-GCM v. 1.94 released June 2011.
  - Significant new feature is inclusion of Weimer high-latitude potential model
  - Several new “standard output” parameters consolidated in code
- Minor update v. 1.94.2 released January 2012.
- High-resolution version (2.5° x 2.5° x H/4) is also in test
  - Reasonably stable at 1-minute time step up to Kp ~7
  - Still some issues with high-latitude filtering
- Other key research developments include:
  - Lower boundary conditions:
    - 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 Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) model
  - High-altitude extension, including light neutral species
  - Plasmaspheric extension, and high-latitude outflow...

Suggested Next Steps at CCMC

- TIE-GCM v. 1.94.2 with IMF / Solar Wind / Weimer inputs available for RoR.

- Start running in real-time.

Backup

Equations and Numerics

- **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, 5°x 5° grid
  - Vertical: pressure surface (hydrostatic equilibrium), 0.5 scale height grid
  - High resolution version (2.5° x 2.5° x H/4) in test.

- **Numerics:**
  - Horizontal: explicit 4th order centered finite difference
  - Vertical: Implicit 2nd order centered difference
  - Time: 2nd order centered difference
  - Shapiro filter: achieve better numerical stability
  - Fourier filter: remove spurious high frequency zonal waves at high latitudes

Boundary Conditions

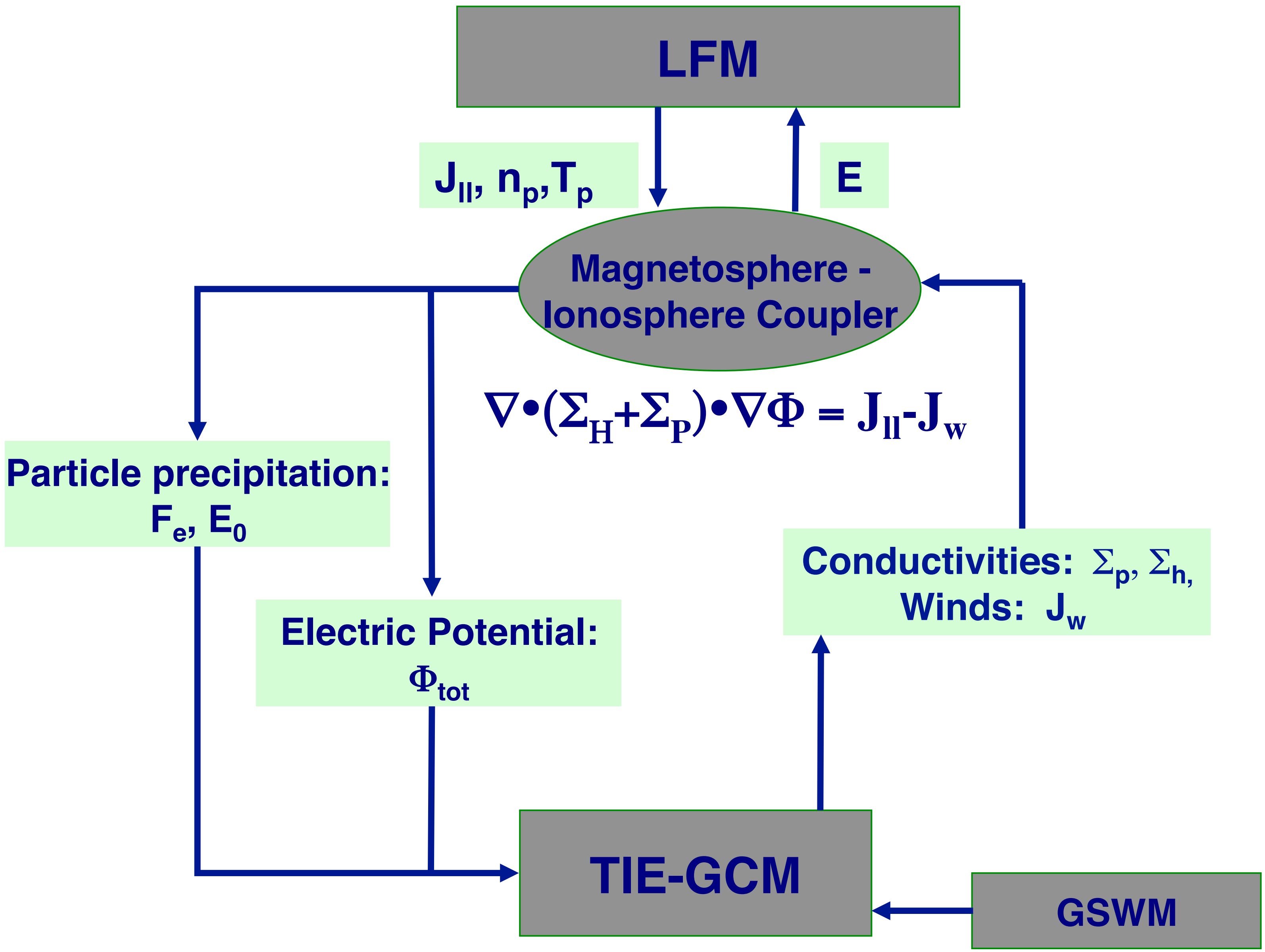
- **Upper boundary conditions:**
  - *u, v, w,* T_N, O_2, O: diffusive equilibrium;
  - N(^{4}S), NO: photochemical equilibrium;
  - O^+: specify upward or downward O^+ flux;
  - T_e: specify upward or downward heat flux.

- **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 O density is zero
  - N(^{4}S), O^+: photochemical equilibrium
  - NO: constant density of (8×10^6)
  - T_e: equal to T_N.

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 (CMIT)
  - Fully MPI parallel implementation, very fast performance (wallclock > 600 model time on multiprocessor desktops)
- **Weaknesses:**
  - Lower boundary — only migrating tides included
  - Upper boundary — assumptions for electron and heat flux — no plasmasphere
  - Uniform spherical grid — problems near the poles
  - Hydrostatic equilibrium assumed

Coupled Magnetosphere-Ionosphere-Thermosphere Model



Structural Diagram of the NCAR TIE-GCM