

What can I do with the TIEGCM?

Astrid Maute and lots of people at HAO, and the community

High Altitude Observatory
NCAR

High Altitude Observatory (HAO) – National Center for Atmospheric Research (NCAR)

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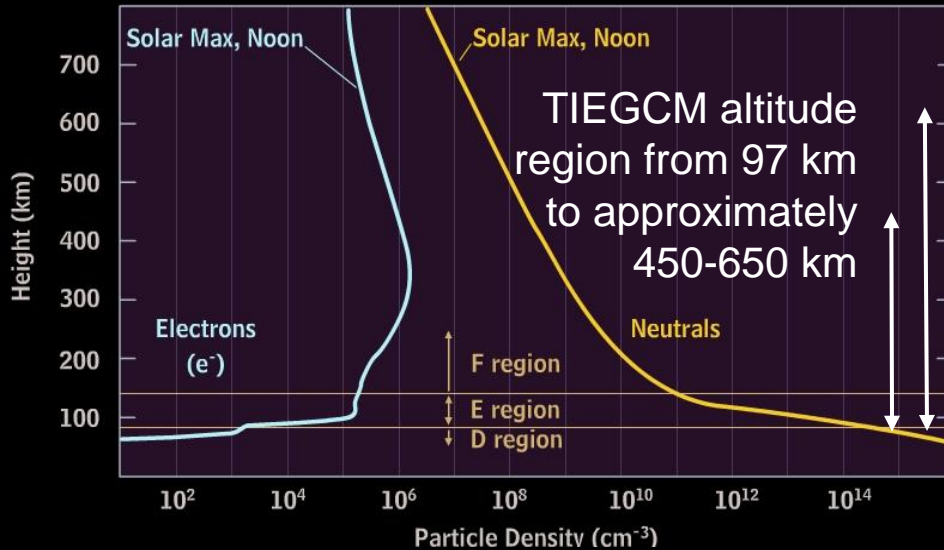
June 2013

Questions to answer?

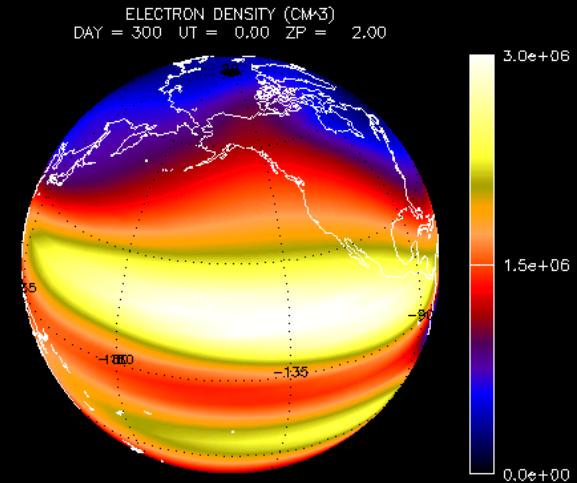
- What is the TIEGCM?
- How does it work?
- What do I need to specify?
- What can be simulated?
- Where can I run the TIEGCM?
- Examples of projects using the TIEGCM
- Additional information

What is the TIEGCM?

Electron and Neutral Particle Densities in the Ionosphere (45° N, Equinox)

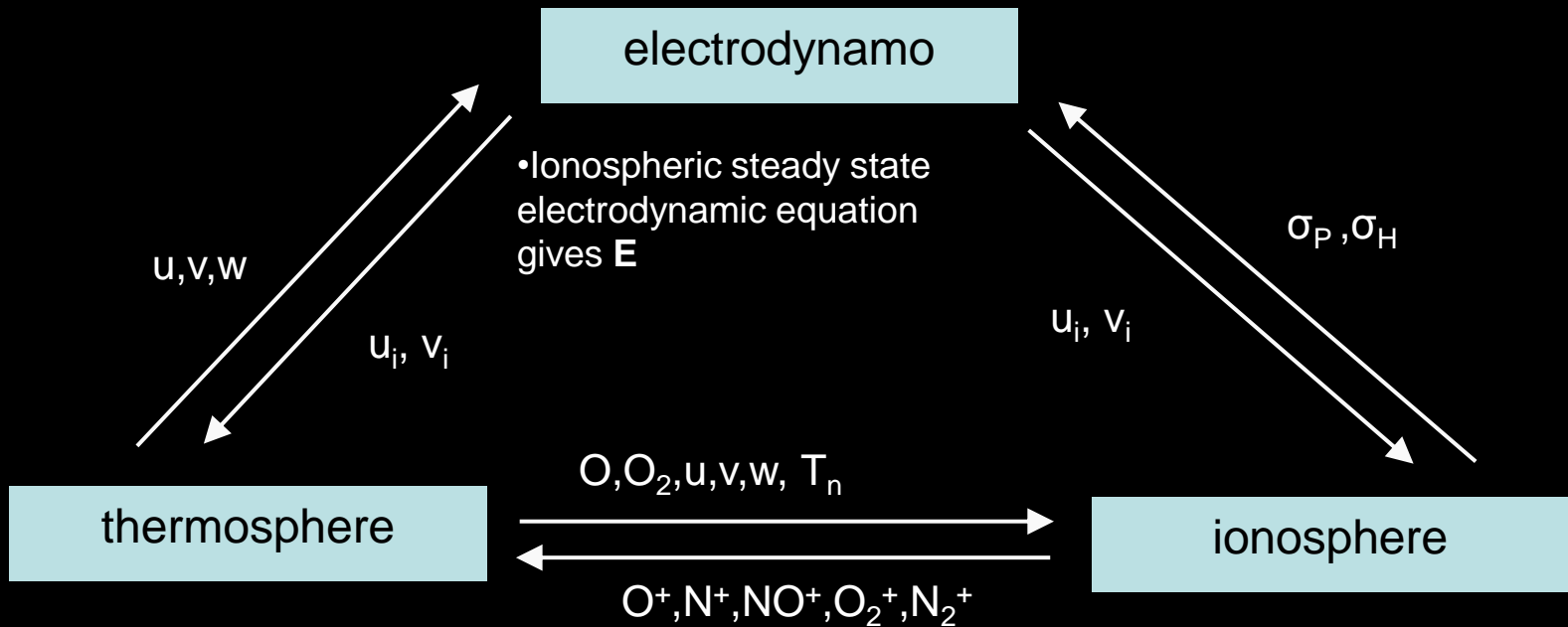


October 2003 "Halloween" Geomagnetic Storm



- TIEGCM stands for Thermosphere-Ionosphere Electrodynamics General Circulation Model.
- Simulates the dynamics, temperatures, composition and electrostatics from first principles.
- It is a global 3-dimensional, time dependent numerical model.

Physics of TIEGCM

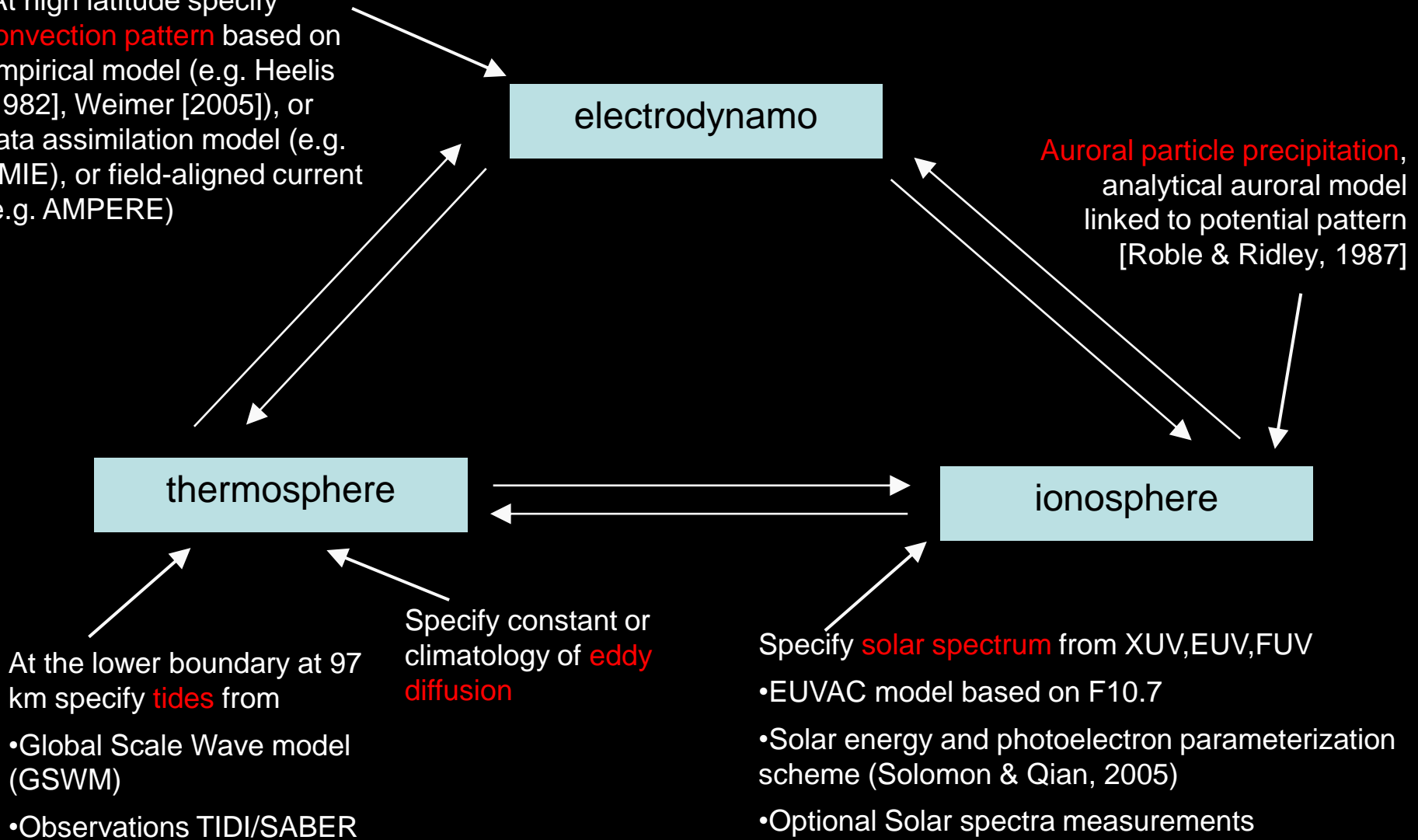


- Solves momentum equation for neutral wind u, v
- Solves continuity equation for w
- Hydrostatic equation gives geopotential height
- Thermodynamic equation gives T_n
- Solves continuity equation for $O, O_2, N(4S), NO$

- Solves continuity equation for O^+
- Quasi-steady state energy transfer gives T_e, T_i
- Photochemical equilibrium give $N(2D), O_2^+, N_2^+, N^+, NO^+$

User options

- At high latitude specify **convection pattern** based on empirical model (e.g. Heelis [1982], Weimer [2005]), or data assimilation model (e.g. AMIE), or field-aligned current (e.g. AMPERE)



- At the lower boundary at 97 km specify **tides** from
- Global Scale Wave model (GSWM)
- Observations TIDI/SABER

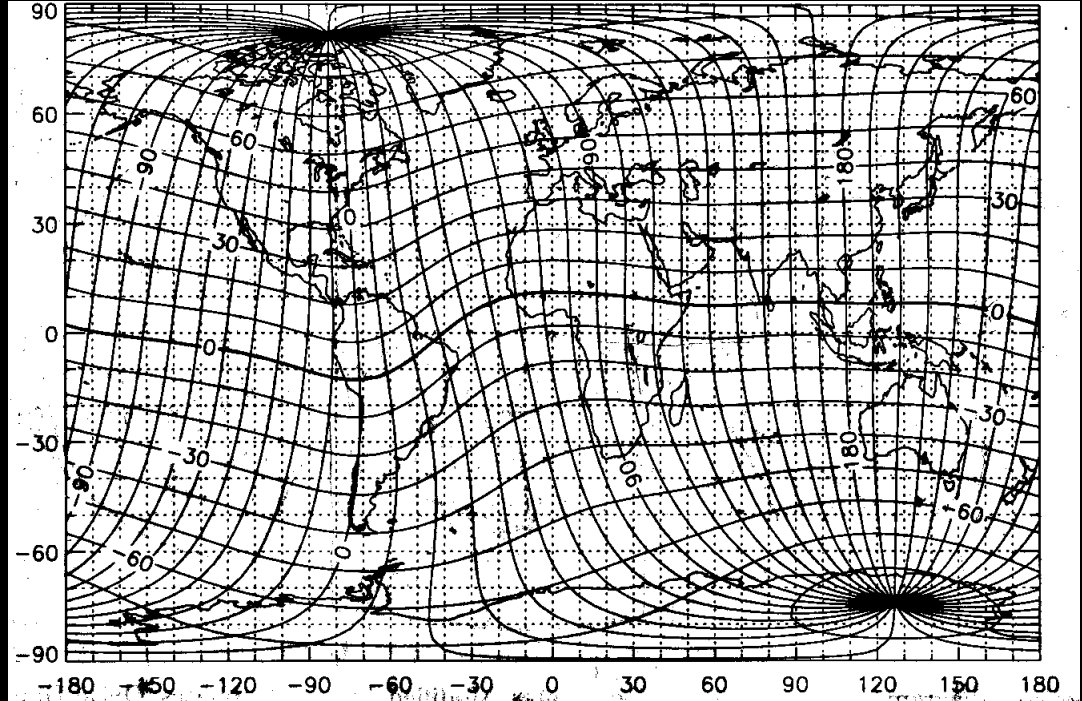
Specify constant or climatology of **eddy diffusion**

- Specify **solar spectrum** from XUV,EUV,FUV
- EUVAC model based on F10.7
- Solar energy and photoelectron parameterization scheme (Solomon & Qian, 2005)
- Optional Solar spectra measurements



Coordinate systems

- Regular spherical coordinate system
- The thermosphere and ionosphere are defined in the geographic coordinate system: $5^\circ \times 5^\circ$ and $\frac{1}{2}$ scale height or $2.5^\circ \times 2.5^\circ$ and $\frac{1}{4}$ scale height



[Richmond 1995]

- The ionospheric electrodynamics is solved on the geomagnetic coordinate system with modified apex coordinate and based on the International Geomagnetic Reference Field (IGRF). The latitudinal grid point distribution is irregular and can be adjusted.

What can be simulated?

- Realistic simulation: TIEGCM can be driven by 3-hourly K_p or IMF conditions, and daily and 81 day average $F_{10.7}$ time varying data is obtained from NGDC.
- “Steady-state” simulations: simulations of a particular day with constant solar flux and geomagnetic forcing.
- Combinations of the above, e.g. year long run with constant geophysical conditions or constant solar flux but varying geomagnetic forcing.
- Simulation of the upper atmosphere with varying geomagnetic main field between 1900 and 2015, or aligned / tilted dipole approximation.

Where can I run the TIEGCM?

- The TIEGCM is a Community model and can be downloaded (source code) at <http://www.hao.ucar.edu/modeling/tgcm/download.php>
- The TIEGCM runs serial or parallel MPI, and is written in standard Fortran-90.
- It is supported on 64 bit Linux systems, from desktops to large Linux cluster such as NCAR's Yellowstone system.
- By default it is either using Portland group (pgf90) or intel (ifort) compiler.
- The simulation results are written to netCDF files. The netcdf library is needed.
- TIEGCM is under SVN version control, and constantly further developed.
- User guide with “quick start” step-by-step
<http://www.hao.ucar.edu/modeling/tgcm/doc/userguide/html/>
- Documentation draft
http://www.hao.ucar.edu/modeling/tgcm/doc/description/model_description.pdf
- Postprocessing and visualization is available via IDL or fortran code
- Runs on request by NASA's Community Coordinated Modeling Center
<http://ccmc.gsfc.nasa.gov/models/modelinfo.php?model=TIE-GCM>

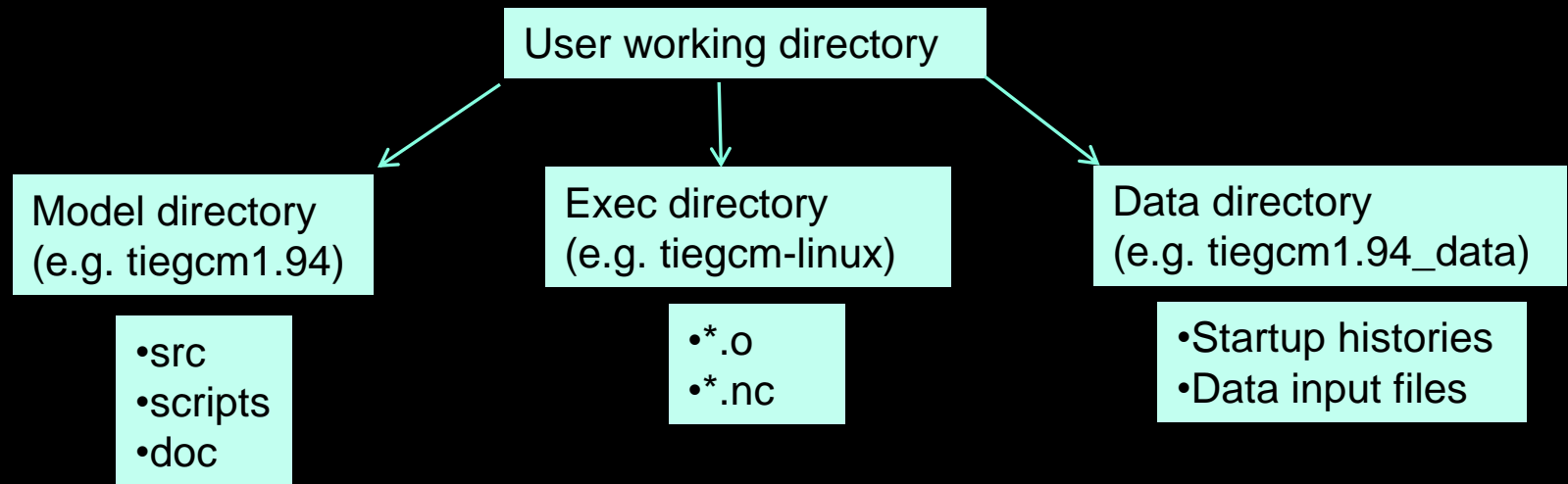


Quick Start

(see also Quick-start chapter of the User's Guide)

Obtain and build the model, and execute a default run:

- Download and extract model and data tar files (download page)
- Set modeldir and other shell variables in the job script: tiegcm-linux.job
- Set envvar TGCMDATA to the data directory (.cshrcfile or job script)
- Execute by typing “tiegcm-linux.job &” (build and execute default run)
- Rename and edit namelist input file tiegcm_default.inp for a new run

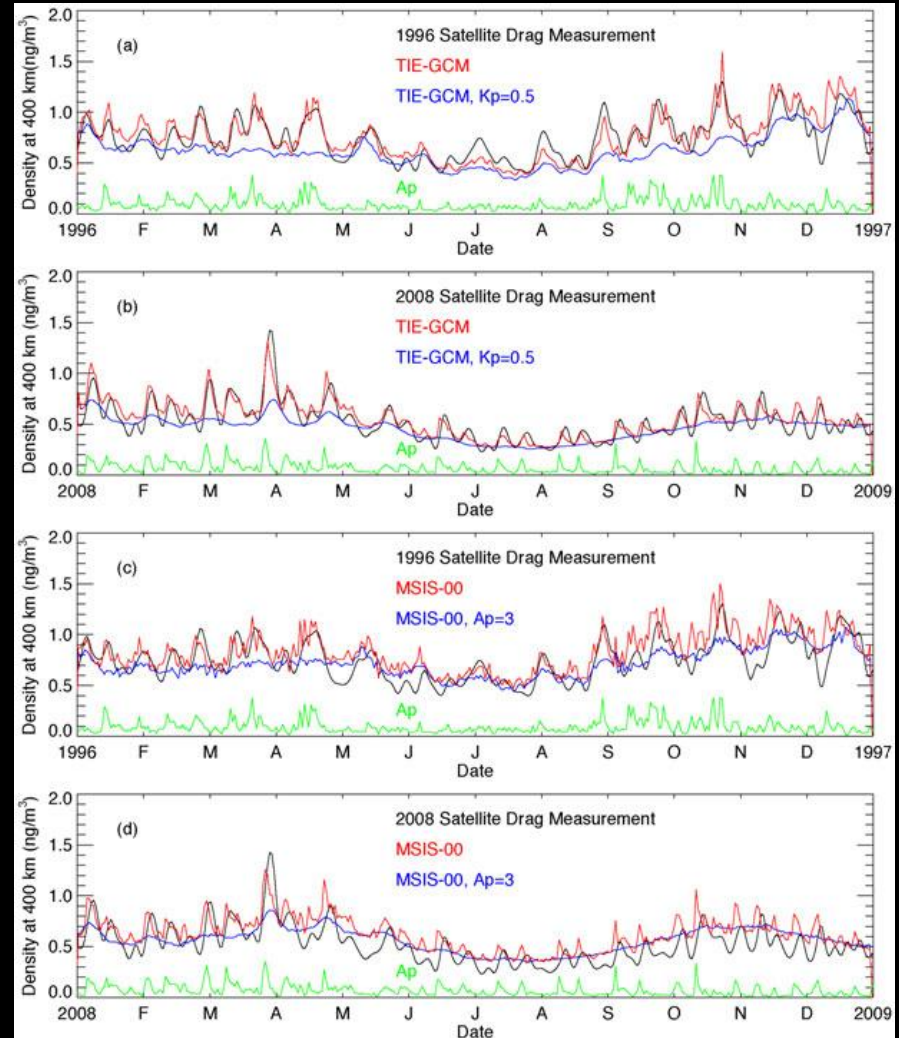


Examples of projects using the TIEGCM

Solar minimum thermospheric density

- The in-situ thermospheric density can be derived from satellite drag data.
- During the solar minimum year 2007-2009 the thermospheric density was lower than in previous solar minimum years.
- Measurements also indicated that solar extreme-ultraviolet (EUV) irradiance was lower than observed before.
- The TIEGCM was used to quantify the thermospheric density contributions due to the geomagnetic activity and low EUV irradiance.
- The model result suggest that the low solar EUV irradiance is the primary cause of the low densities.

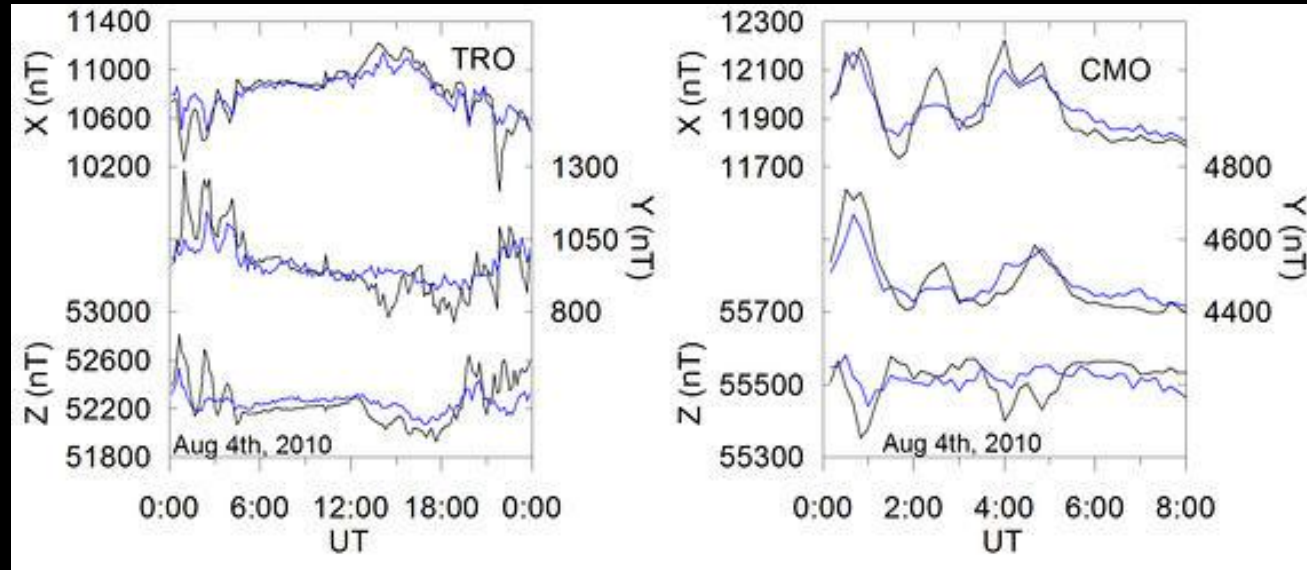
Global mean thermospheric density at 400km



[Solomon et al., JGR, 2011]

Magnetosphere-Ionosphere Coupling

- Magnetosphere-Ionosphere coupling was simulated in TIEGCM using the FAC from the AMPERE project using the Iridium satellites.
- Ground magnetic perturbations from different stations were compared with the modeled ones.

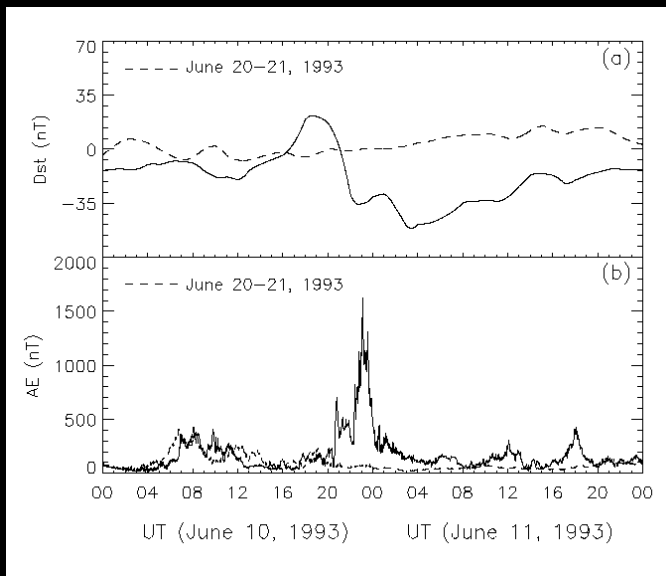


Observation (black line)
Model (blue line)

- Using more realistic spatial and temporal variation of the high latitude forcing leads to an improvement in the simulated magnetic perturbation between time scales of 6 hrs and 30 min.

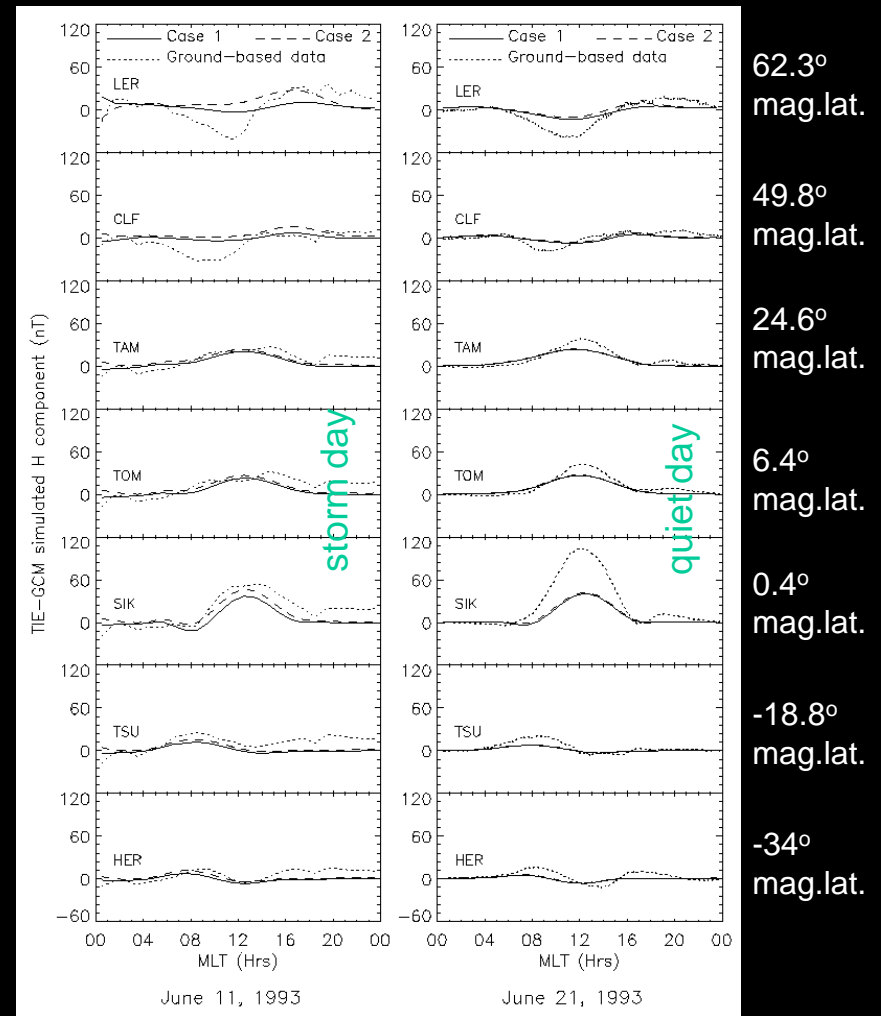
[Marsal et al. 2012]

Disturbance dynamo signature



- In observations it is very difficult to separate effects from penetration electric field and the disturbance dynamo.
- Zaka et al. compared observed ground magnetic perturbations with simulated ones from TIEGCM to separate the two effects.

H component [nT] of Europe-Africa chain

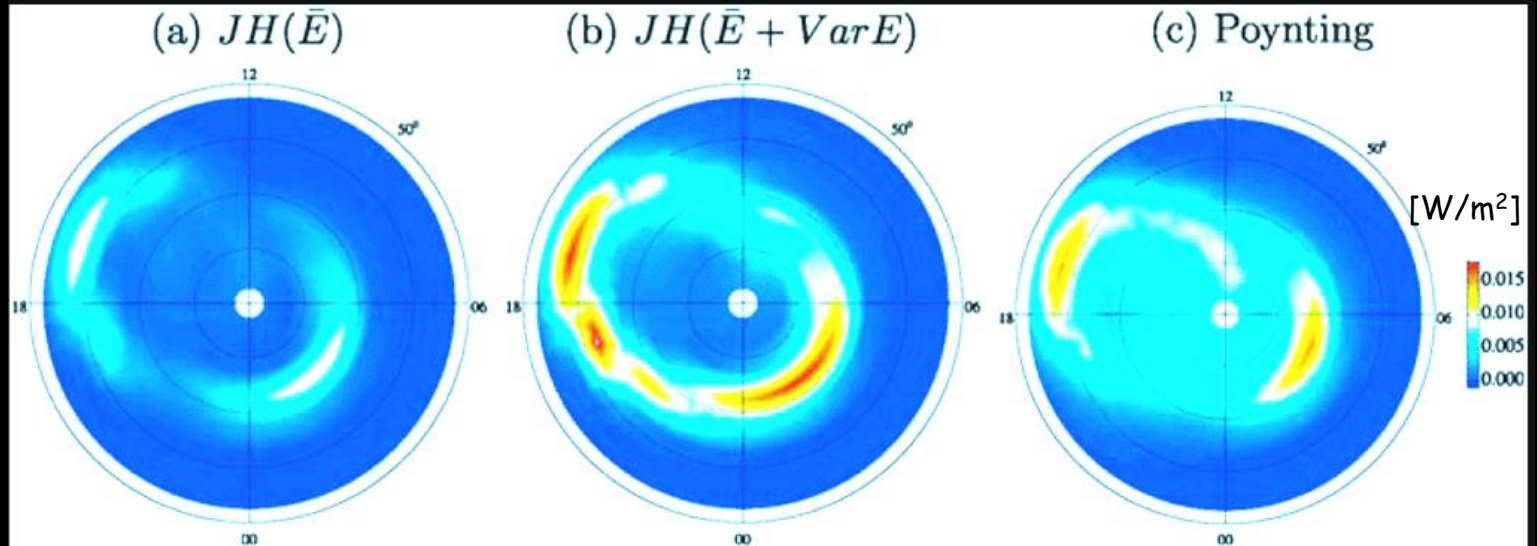


[Zaka et al., JGR 2010]

Joule Heating

Northern hemisphere

$B_y = 0$ nT
 $B_z = 5$ nT



Using average
E-field

Adding E-field
variability

Poynting flux

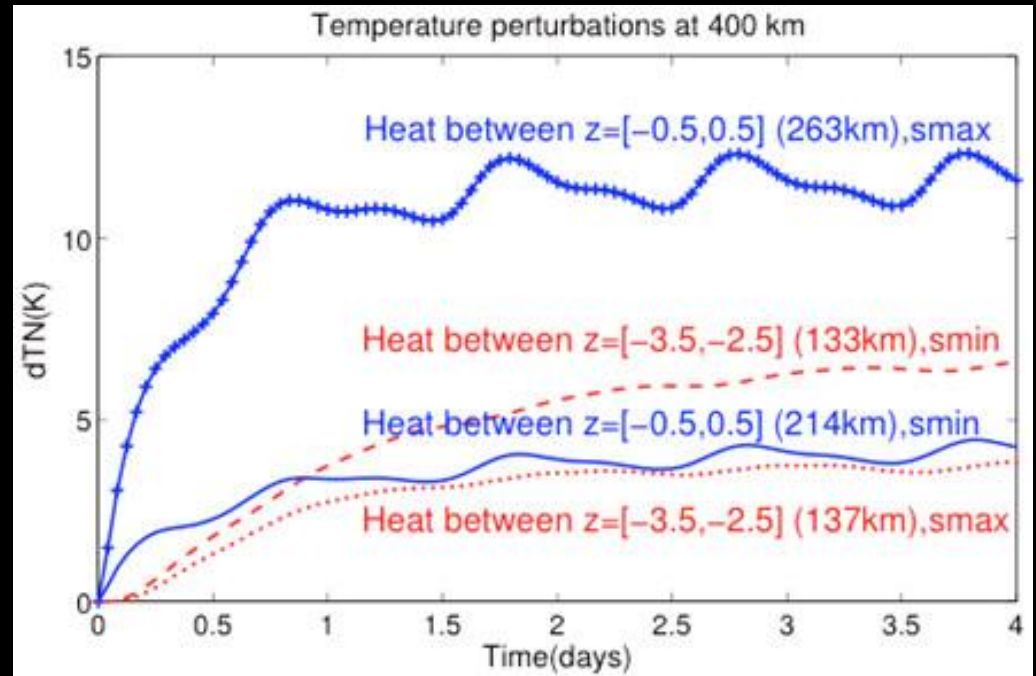
- Deng et al. used an empirical model which quantifies the high latitude forcing.
- This empirical model quantifies the variability of the electric field.
- Deng et al. showed that the total Joule heating which measures the energy between the magnetosphere and thermosphere is increased by approximately 100% if the electric field variability is considered in the Joule heating calculation.
- This improves the agreement with the Poynting flux, although the spatial distribution is different.

[Deng et al. 2009]

Effects of height distribution of Joule heating

Global mean neutral temperature at 400 km

- Magnetospheric energy input to the polar upper atmosphere can significantly affect the dynamics and structure of the coupled ionosphere-thermosphere system.
- The thermospheric response depends on the height distribution of the Joule heating.



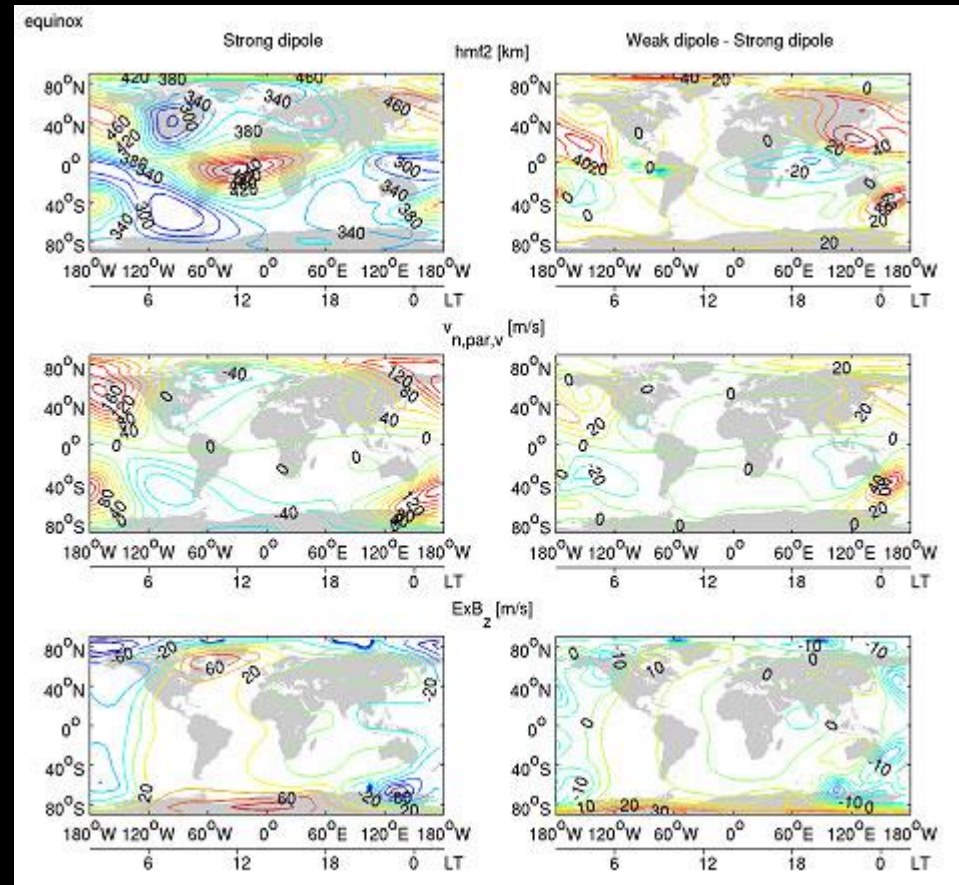
- Huang et al. conducted numerical experiments by depositing heat at different altitudes for solar maximum and minimum conditions.
- The temperature and density changes at 400 km are largest for heat deposited ~140 km for solar minimum and ~260 km for solar maximum.
- Heat deposited at low altitudes needs more time to conduct upward, and therefore low altitude heating is more important for longer term variations (days).

[Huang et al. 2012]

Influence of geomagnetic main field variation

(13-15 UT)

- Cnossen et al. used the Coupled Magnetosphere-Ionosphere-Thermosphere model to examine how changes in the dipole moment will change the magnetosphere-ionosphere-thermosphere system.
- Strong dipole ($8 \cdot 10^{22} \text{ Am}^{22}$) presents present day.
- Weak dipole ($6 \cdot 10^{22} \text{ Am}^{22}$) might be future value.
- Changes in hmF2 (top plot) can be explained by differences in the wind component parallel to the magnetic field line (middle), or by the difference in the vertical drift (bottom).

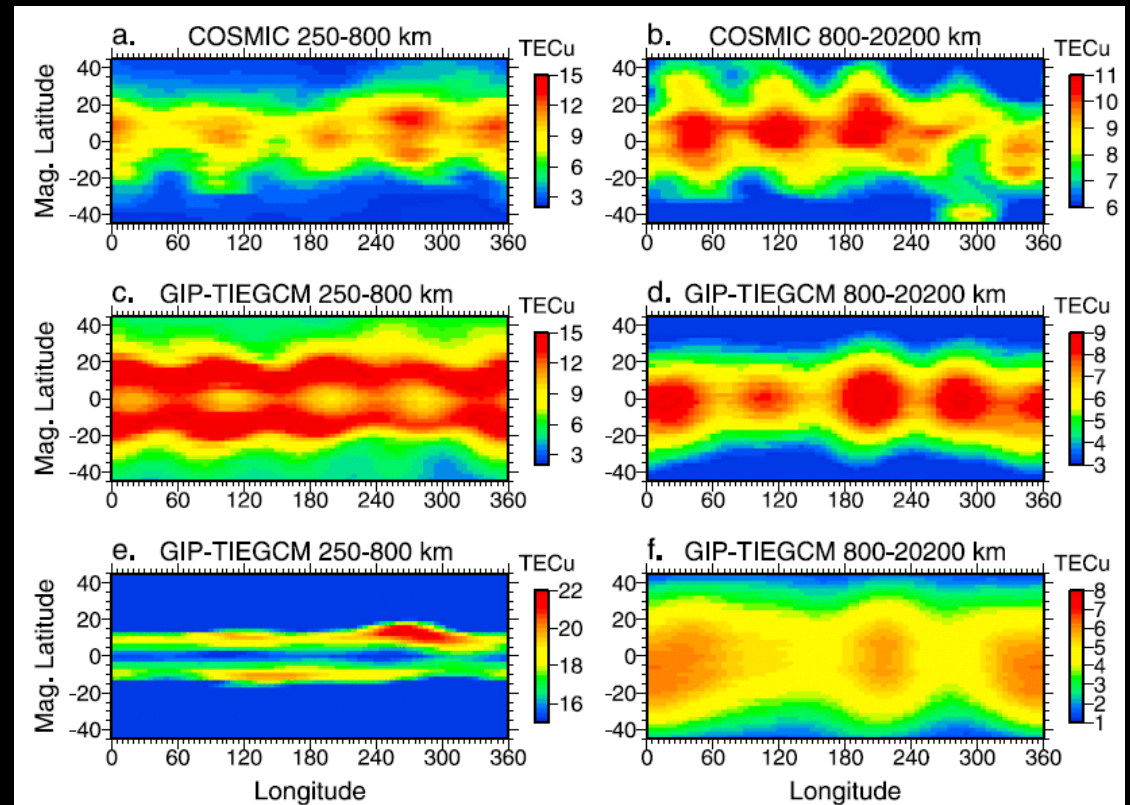


[Cnossen et al. 2012]

Longitudinal Variation of the Ionosphere

Around September equinox between 16 and 18 LT

- Comparison of COSMIC TEC observation with TIEGCM coupled to a plasmasphere model (GIP).
- The study examined the longitudinal variation of F-region ionosphere and topside ionosphere/plasmasphere which varies with season and local time.
- The study finds that orientation of geomagnetic field is important for topside longitudinal variation.

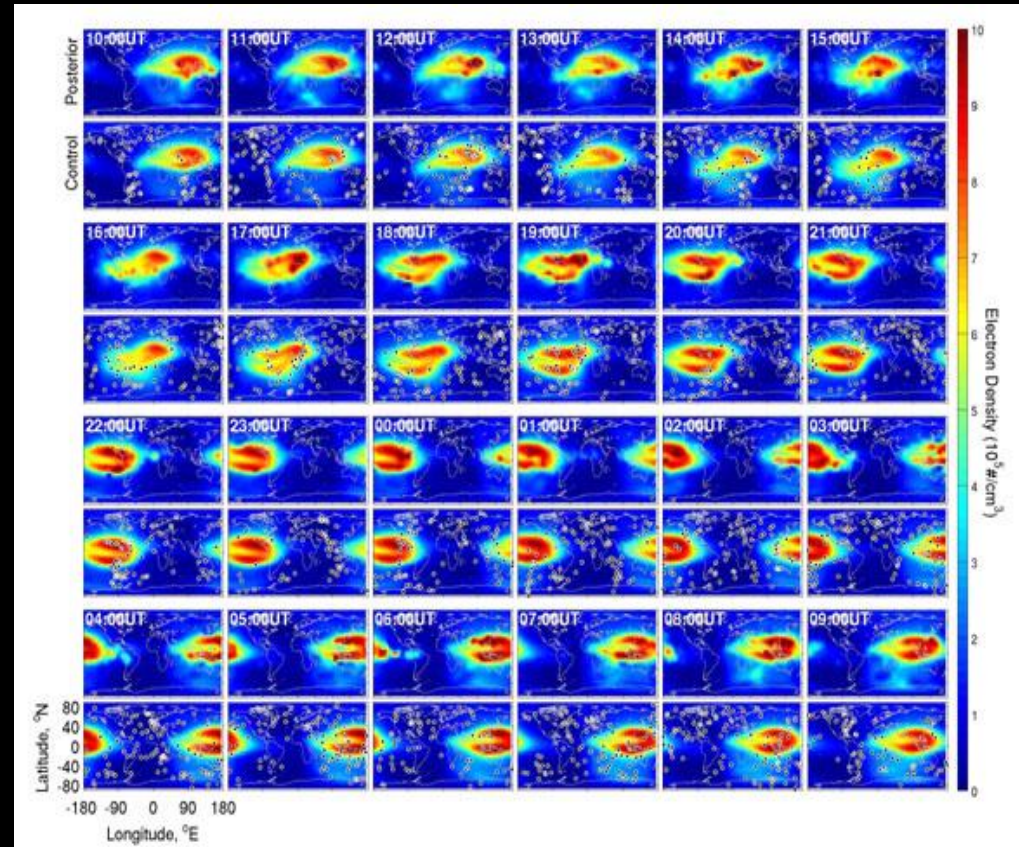


[Pedatella et al. 2011]

Data Assimilation

NmF2 from April 12-13, 2008

- Assimilating data into a model is a way of constraining the numerical model and getting more realistic results.
- Lee et al. assimilated FORMOSAT-3/COSMIC GPS occultation observations into the TIEGCM using an ensemble Kalman filter algorithm.
- The primary ionospheric parameters, e.g. NmF2 and hmF2, have improved.
- Black dots in the figure indicate the location of observations.



[Lee et al. 2012]

Additional Information

TIE-GCM web page: <http://www.hao.ucar.edu/modeling/tgcm/tie.php>

User Guide: <http://www.hao.ucar.edu/modeling/tgcm/doc/userguide>

Draft Documentation:

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

Release Notes:

<http://www.hao.ucar.edu/modeling/tgcm/tiegcm1.95/release/html/>

Post-Processing:

<http://www.hao.ucar.edu/modeling/tgcm/doc/userguide/html/postproc.html#tgcmproc-idl>

TIEGCM output available at the UCAR/NCAR Community Data Portal:

<http://cdp.ucar.edu/browse/browse.htm?uri=http%3a%2f%2fdataportal.ucar.edu%2fmetadata%2ftgcm%2ftgcm.thredds.xml>



Thank you!
Questions?

