Thermosphere/Ionosphere Lab:

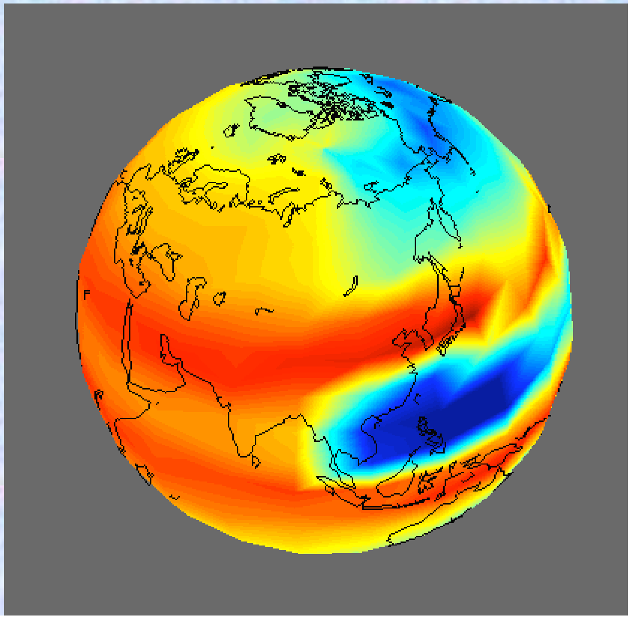
utilizing simulations from:

Coupled Thermosphere-Ionosphere-Plasmasphere electrodynamics model
CTIPe

Tim Fuller-Rowell
NOAA Space Environment Center and
CIRES University of Colorado

Coupled Thermosphere Ionosphere Plasmasphere Model with self-consistent Electrodynamics CTIPe

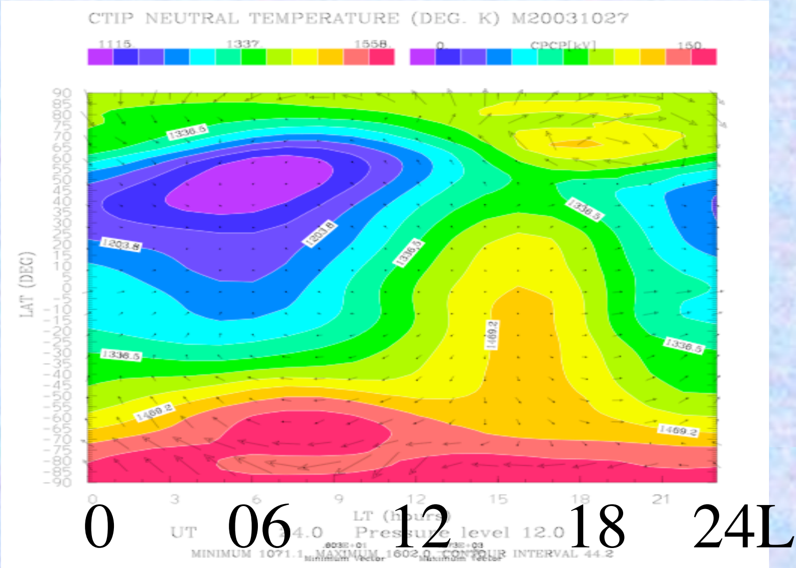
- **Global thermosphere 80 - 500 km, solves momentum, energy, composition, etc. V_x, V_y, V_z, T_n, O, O_2, N_2, ….**
- **High latitude ionosphere 80 -10,000 km, solves continuity, momentum, energy, etc. O^+, H^+, O_2^+, NO^+, N_2^+, N^+, V_i, T_i,**
- **Plasmasphere, and mid and low latitude ionosphere**
- **Self-consistent electrodynamics**
- **Forcing: solar UV and EUV, Weimer electric field, TIROS/NOAA auroral precipitation, tidal forcing**



Quiet-time global picture (~300 km, solstice)

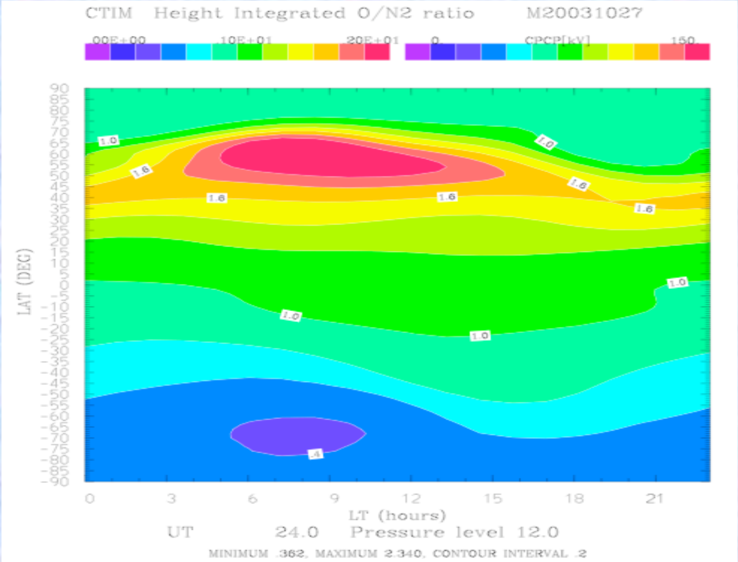
00UT

Temperature

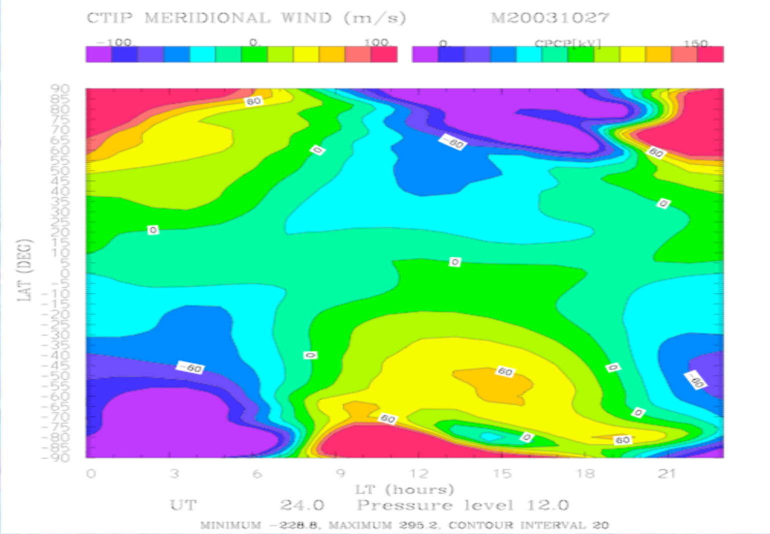


0 06 12 18 24LT

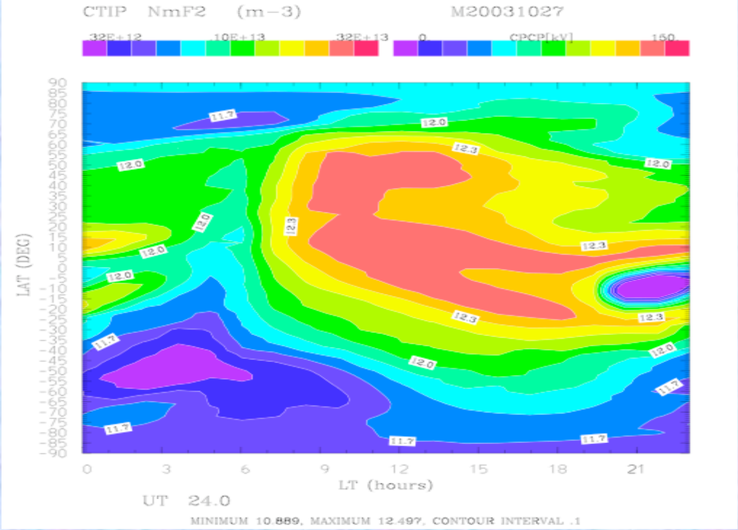
Height-integrated O/N_2 ratio



Meridional wind

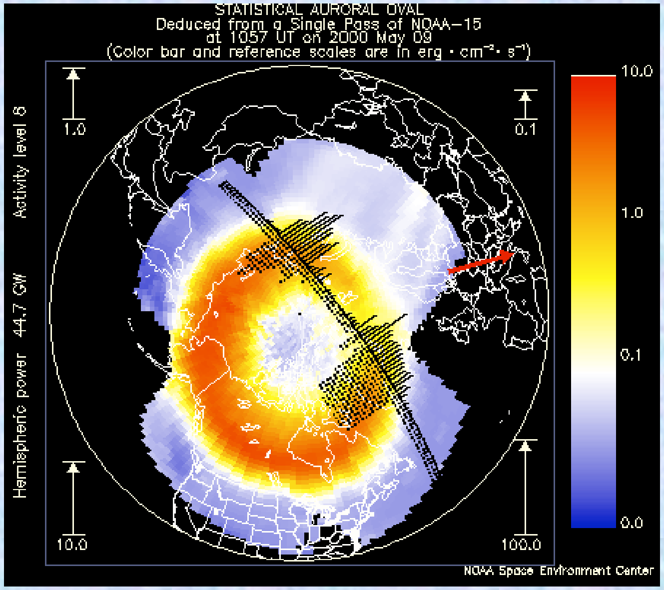


Ne

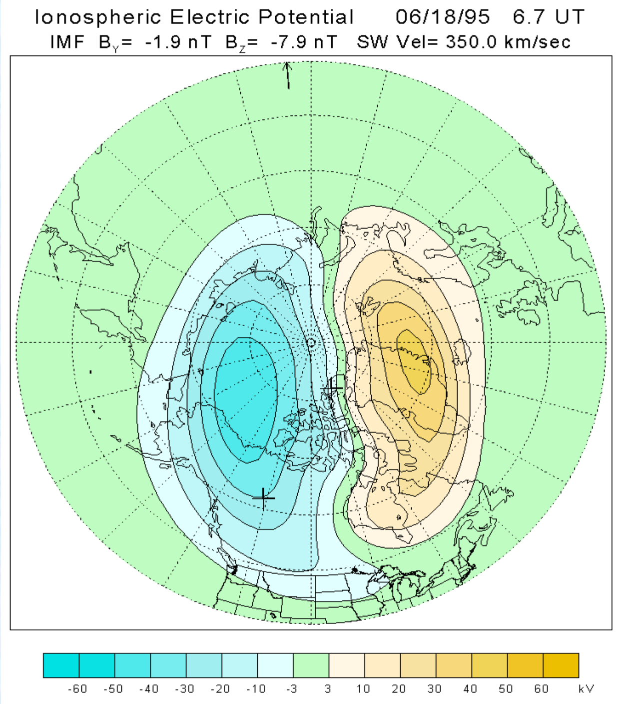


Magnetospheric Forcing of CTIPe

TIROS/NOAA auroral precipitation patterns driven by power index:



Weimer electric field patterns driven by solar wind data:



e.g. generic storm forcing: 15 minute ramp up to auroral activity level 10 and solar wind conditions consistent with ~ Kp 8; 11.5 hrs at elevated storm levels, return to quiet levels for recovery

Potential value of models:

- Physical models can be powerful tools if used wisely
- Chose a science question that has a reasonable chance of being answered - take small steps
- Important to know the model's limitations
- Chose the appropriate model to tackle your science question
- Can simulate real events (e.g. on CCMC) or analyze a generic simulation
- Comparison/agreement between model and observation is just the first step
- Physical models can be used to unravel complex combinations of physical processes

Words of Caution

- Sophisticated physics models are still just “tools”
- They are not the science
- Liken to a complex instrument
- Need diagnostic tools and understanding of the physics - can be a long and difficult process
- Make sure the results make sense physically - there may still be bugs in the code

CTIPe Model Limitations

- Does not have penetration electric field or feedback to magnetosphere
- Climatological tidal forcing from lower atmosphere
- No plasma instability physics included
- Simple magnetic field model
- Other models have these capabilities e.g. IDEA (WAM+GIP), RCM-CTIPe,……
- Models are never perfect but they don’t have to be in order to do good science, as long as you understand their limitations and chose appropriate science questions to address with the model

Reasons for Poor Agreement between Model and Data

- Model does not contain the appropriate physics to address the science question
- Model input (e.g. tides, auroal precipitation, magnetospheric electric field, EUV flux) not correct
- Check data!

CTIPe Simulations at CCMC

- Generic equinox storm: 12 hr increase in magnetospheric sources, Kp~8, and subsequent recovery, storm commence at 12UT. Quiet and storm, difference fields (storm-quiet), and animations possible, 15 min temporal resolution. Moderate solar activity F10.7~150.
- Same for December solstice, to examine seasonal difference in storm response
- April 2002 event
- May 2005 event
- Energy/power dissipation figure from January 2005 period

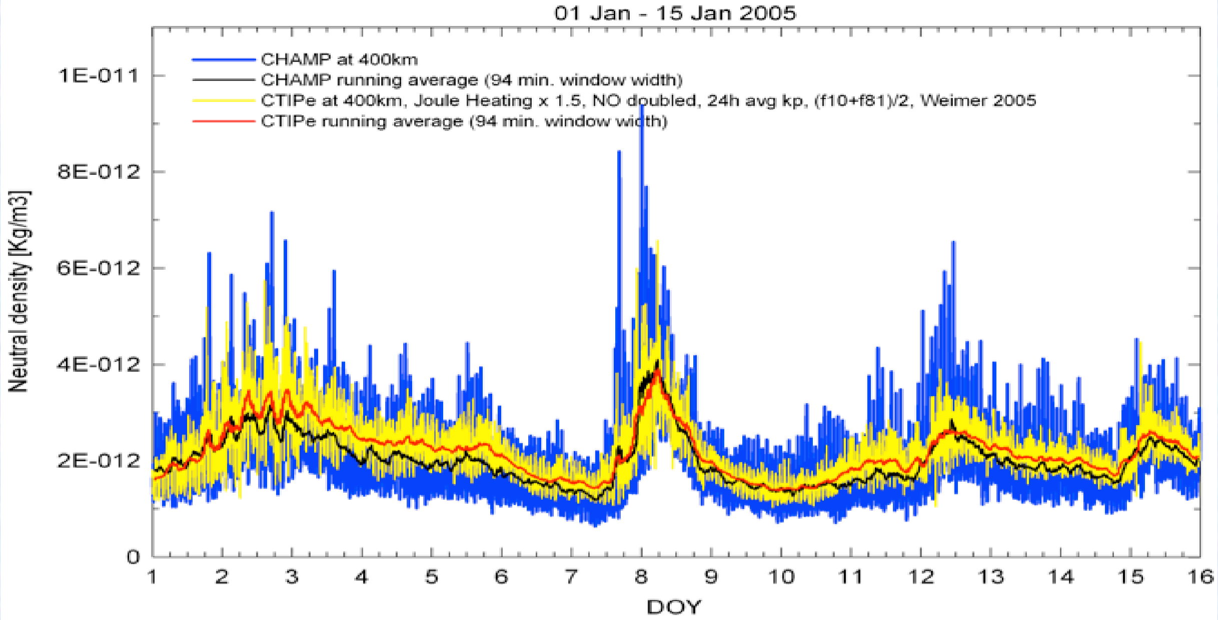
CTIPe Simulations

- Example model output parameters on pressure levels - plasma density N_e m^{-3}, neutral wind ms^{-1} (meridional Vn_lat positive south, zonal Vn_lon positive east, vertical Vn_IP positive up), temperature T_n K, mean molecular mass Rmt amu, mass density rho kg m-3, height of pressure level H m, plus many others…..rd( ) are storm-quiet fields
- Approximate altitudes: pressure level 1 (80km, lower boundary), level 3 (90km), level 5 (103km), level 6 (110km), level 7 (120 km, E-region ionosphere), level 8 (135km), level 9 (160km), level 12 (300 km, F-region ionosphere)
- Model output also on height levels, and NmF2 and hmF2
- View with CCMC Visualization Tools, some pre-computed animations available
- Masha will demonstrate the visualization package
- Address the following science questions:

T-I Lab - Exercise 1

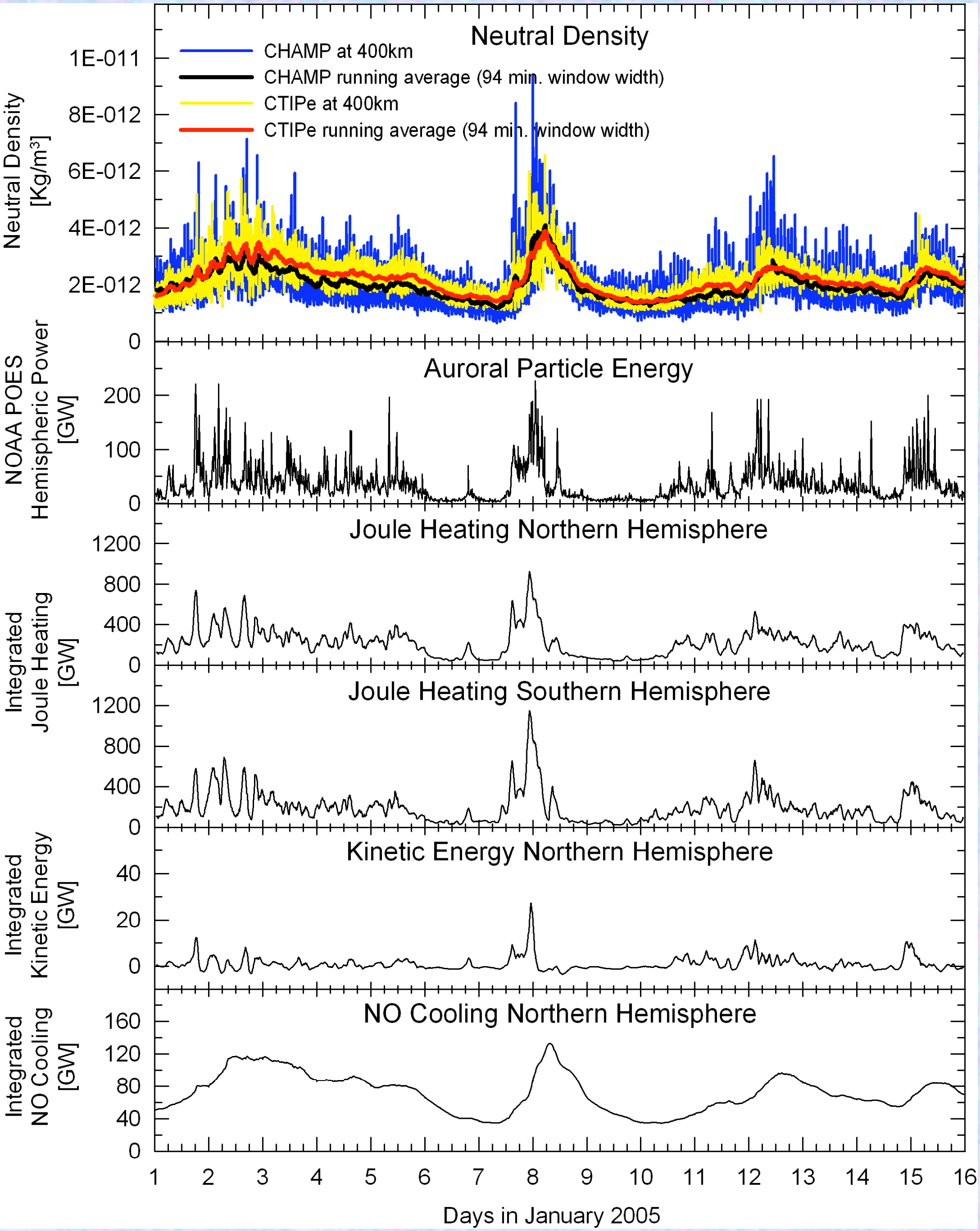
- Below is an example of the response of thermospheric density to time-varying magnetospheric energy input into the upper atmosphere during a geomagnetic disturbance. The increase in density directly affect satellite drag. The figure shows a comparison CHAMP orbit averaged density (black) compared with CTIPe (red). The good agreement between observations and CTIPe, enables the model to be used to estimate the magnetospheric power deposition (see next slide).

  Solar UV and EUV powers the upper atmosphere with between 400 and 1000 GW globally, depending on the level of solar activity. Using the next figure and the utility available on the CCMC Summer School web site to plot the power for the April 2002, May 2005 events, or the generic storms, what is the typical peak magnitude of the magnetospheric power deposited into the thermosphere-ionosphere system during a storm? How is it partitioned between Joule heating, kinetic energy, and auroral precipitation? Does the total magnetospheric energy ever exceed the energy deposited from solar radiation? Estimate how many tera-Joules of energy are typically deposited for the duration of a large storm?



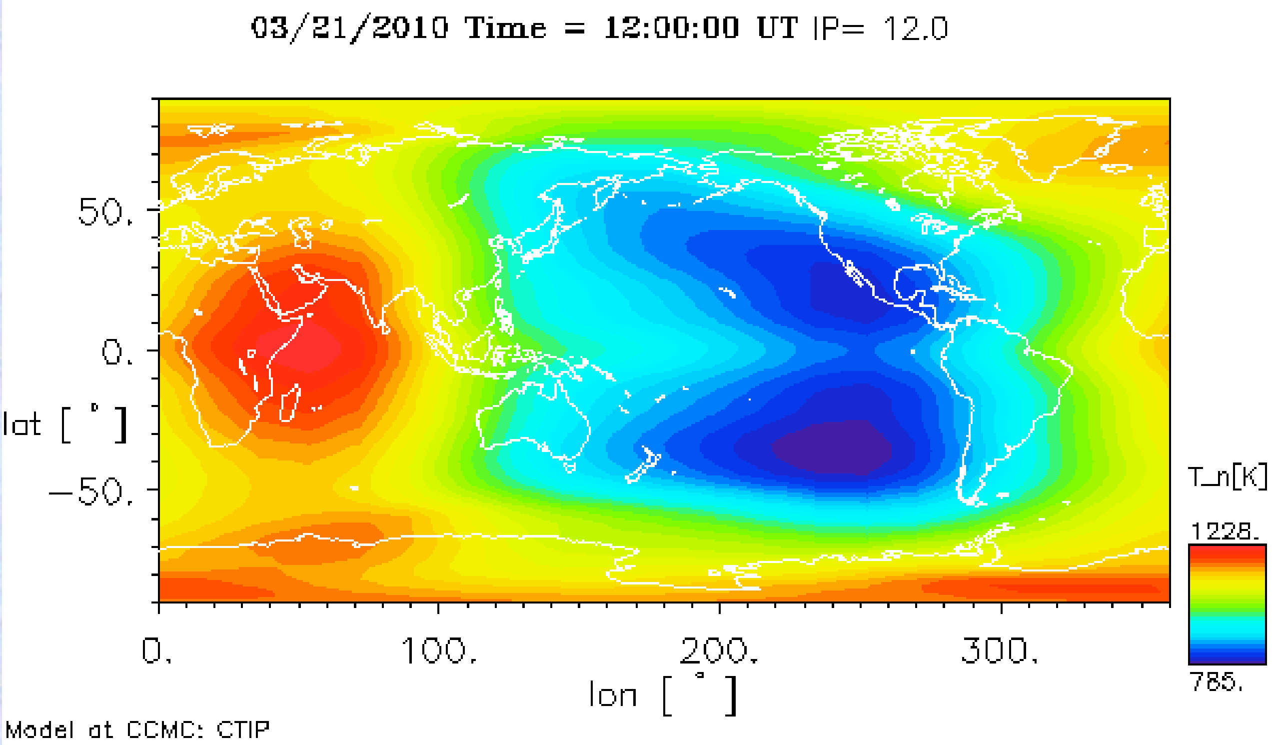
T-I Lab - Exercise 1 (cont)

Example of the magnetospheric power deposition by Joule heating and kinetic energy deposition in the northern and southern hemisphere, and the aurora globally for an active period in Jan 2005.



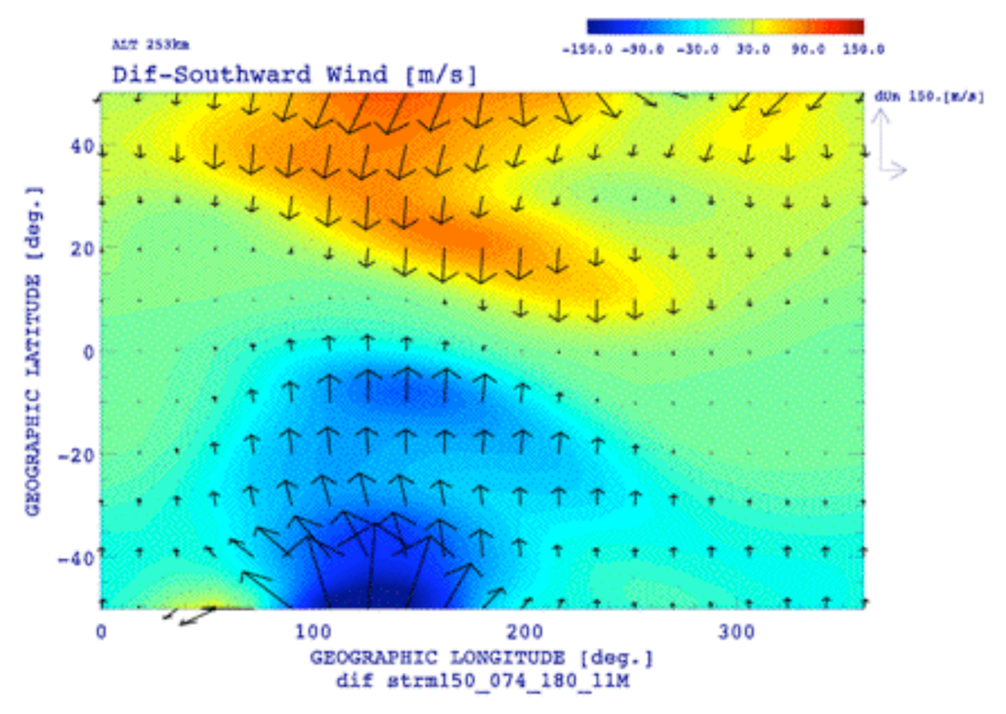
T-I Lab - Exercise 2

- The magnetospheric energy from Joule heating (see Exercise 1) raises the temperature as well as the neutral density of the thermosphere. What is the typical peak temperature increase in the upper thermosphere during a geomagnetic storm (50K, 100K, 500K, 1000K.?). Use the CTIPe equinox simulation of a generic storm on the CCMC Summer School web site. Plot the temperature change (rdT_n) on pressure level 12 across the globe 6 hours after storm onset and compare with the temperature before the storm, or quiet case, as in the example below. What is the typical percentage increase (5%, 10%, 50%, 100%?).



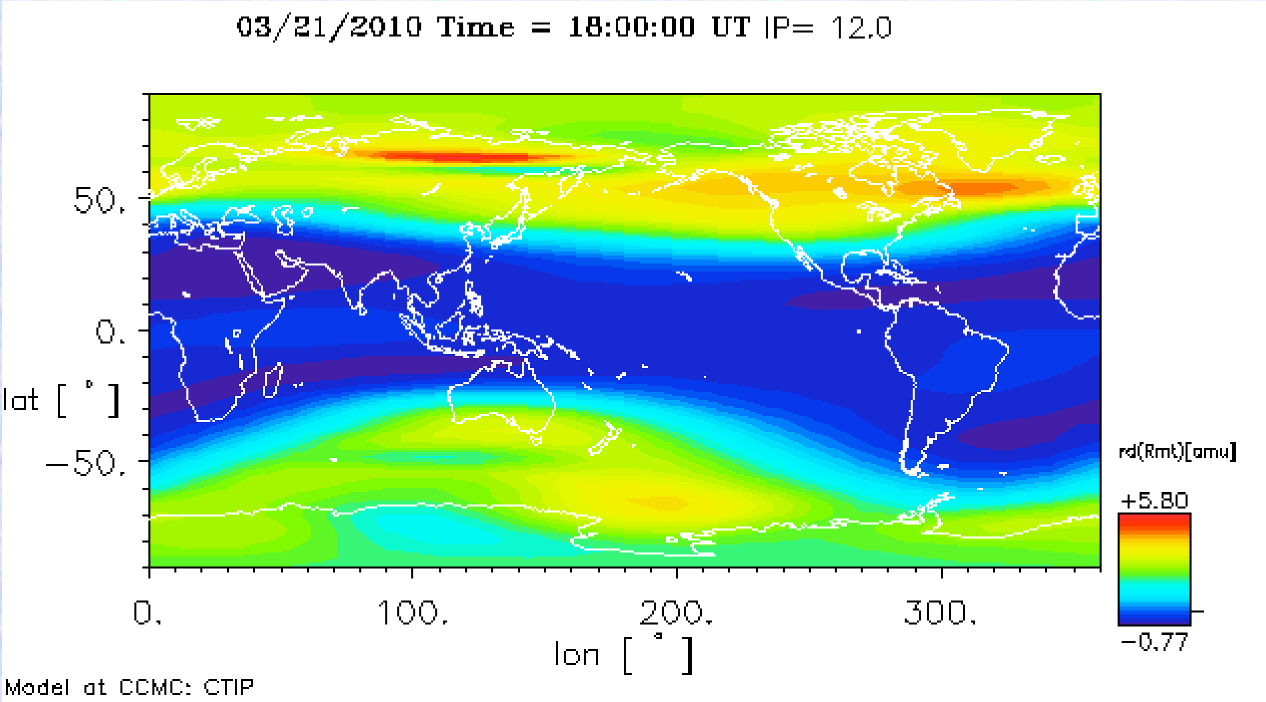
T-I Lab - Exercise 3

- How long does it take for the energy deposition at high latitudes to be felt globally, or at the equator? Use the animation of change in meridional winds (rdVn_lat) of the generic equinox storm from the CCMC Summer School web site, cartesian plot, +/- 50 latitude, latitude vs longitude, as in the example frame below. How fast is the propagation? How does the propagation speed compare with the storm wind velocities themselves (Vn_lat) over same latitude range? What is the mechanism for transport to the equator or into the opposite hemispshere, waves or mean flow? Speculate as to what drives the wave and what drives the circulation?



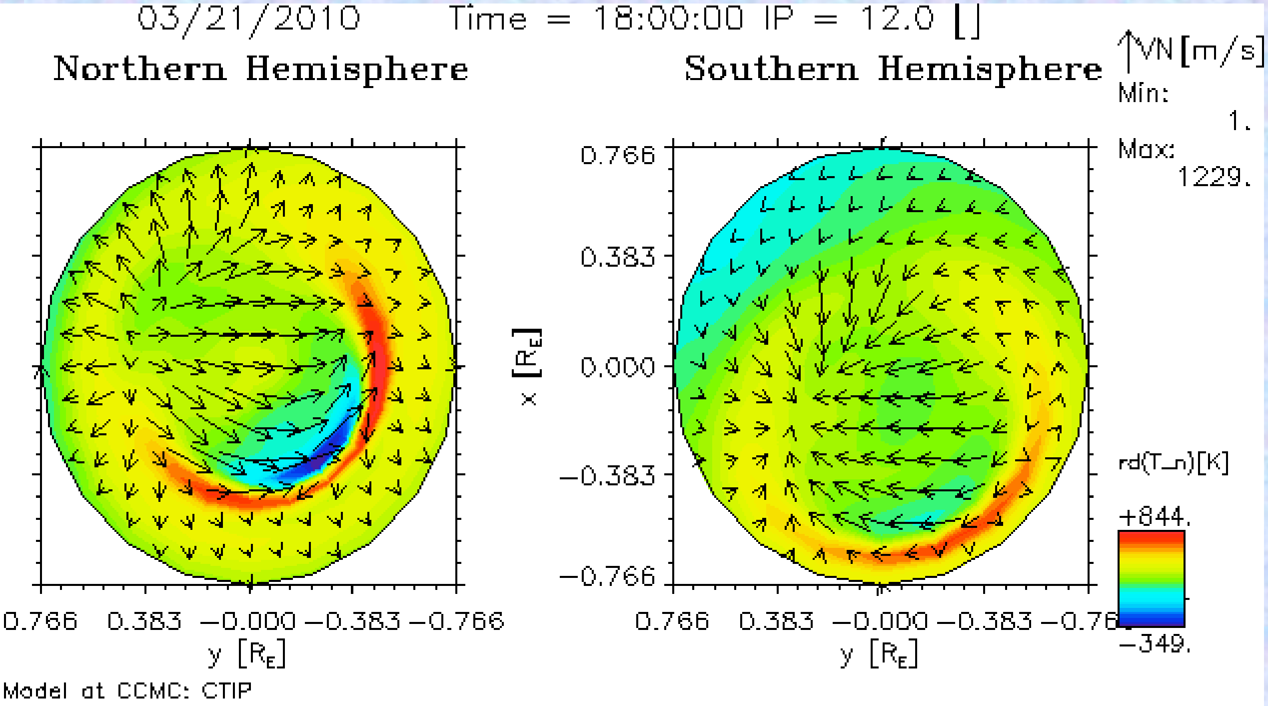
T-I Lab - Exercise 4

- Compare the neutral composition response (change in mean molecular mass rd(rmt)) after 6 and 12 hours in the equinox and storm cases (see example for equinox below) at pressure level 12. From the time-scale for the change, what drives the composition change, the waves or the winds?
- Does the increase in mean mass reach the equator? If so, how long does it take. How long does it take for the composition change to recover? Use animation of change in mean molecular mass (storm-quiet differences rd(rmt)) at pressure level 12, ~300 km altitude.
- Which neutral parameter at mid and high latitude has the strongest correlation with plasma density changes (temperature, meridional winds, zonal winds, mean mass composition)? Compare storm-quiet ratio of NmF2, rd(NmF2) with changes in neutral parameters



T-I Lab - Exercise 5

- How deep into the atmosphere does the storm impact the neutral winds? Compare wind response after 6 hours at pressure level 3 to 12, covering 90 to 300 km altitude, as polar plot, 50 co-latitude to pole, difference storm - quiet. Use “color+vector” plot, temperature difference, rd(T_n) and rd(Vn_lat) (see example below).
- Roughly, at what pressure level/altitude does the *momentum forcing* (ρv), as opposed to wind velocity, reach its maximum? Note mass density decreases exponentially with altitude/ pressure level. Is this the level were we expect the maximum dissipation of solar wind/magnetospheric energy?
- How long does it take for the winds to wind up, as a function of altitude? How long does it take for the winds to wind down, as a function of altitude? Animate difference winds, polar plot, storm-quiet.



T-I Lab - Exercise 6……

- Use the “real” storm simulations, May 2005 and April 2006, to see if the same physical processes appear to be operating. How easy is it to interpret simulation of real events rather than generic storms?
- An earlier figure showed that CTIPe compared well with CHAMP observations of neutral density. Use the CCMC capability to compare the model with CHAMP data for the other storms, speculate as to possible reasons for disagreement.
- Or think of your own science question to address from the simulation ……