The Challenge of Predicting the Ionosphere: Recent results from CISM.

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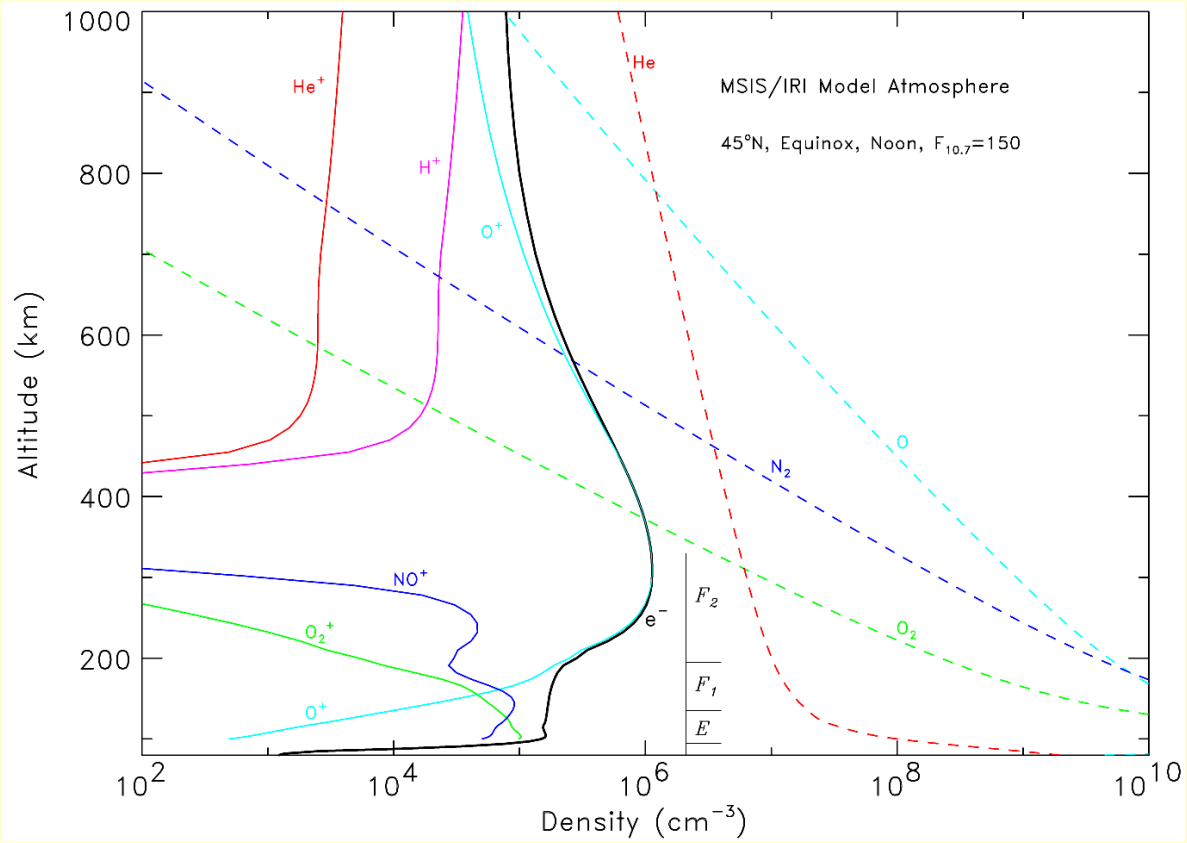
Overview

- The ionosphere – maintaining a delicate balance.
- Factors affecting the ionosphere – why is it a challenge to predict?
- Recent results from CISM:
  - Solar protons
  - Geomagnetic storms

The ionosphere – maintaining a delicate balance

- Only a tiny fraction of the upper atmosphere is ionized – varying from 10^{-6} in the E-region to 10^{-3} in the F-region



The ionosphere – maintaining a delicate balance

- The life time of an individual free electron is short – seconds to tens of minutes depending on altitude
- A steady ionosphere is maintained by a dynamic equilibrium between production, loss, and transport of ionization.

$$\frac{dn_e}{dt} = q - L - \nabla.(n_e v)$$

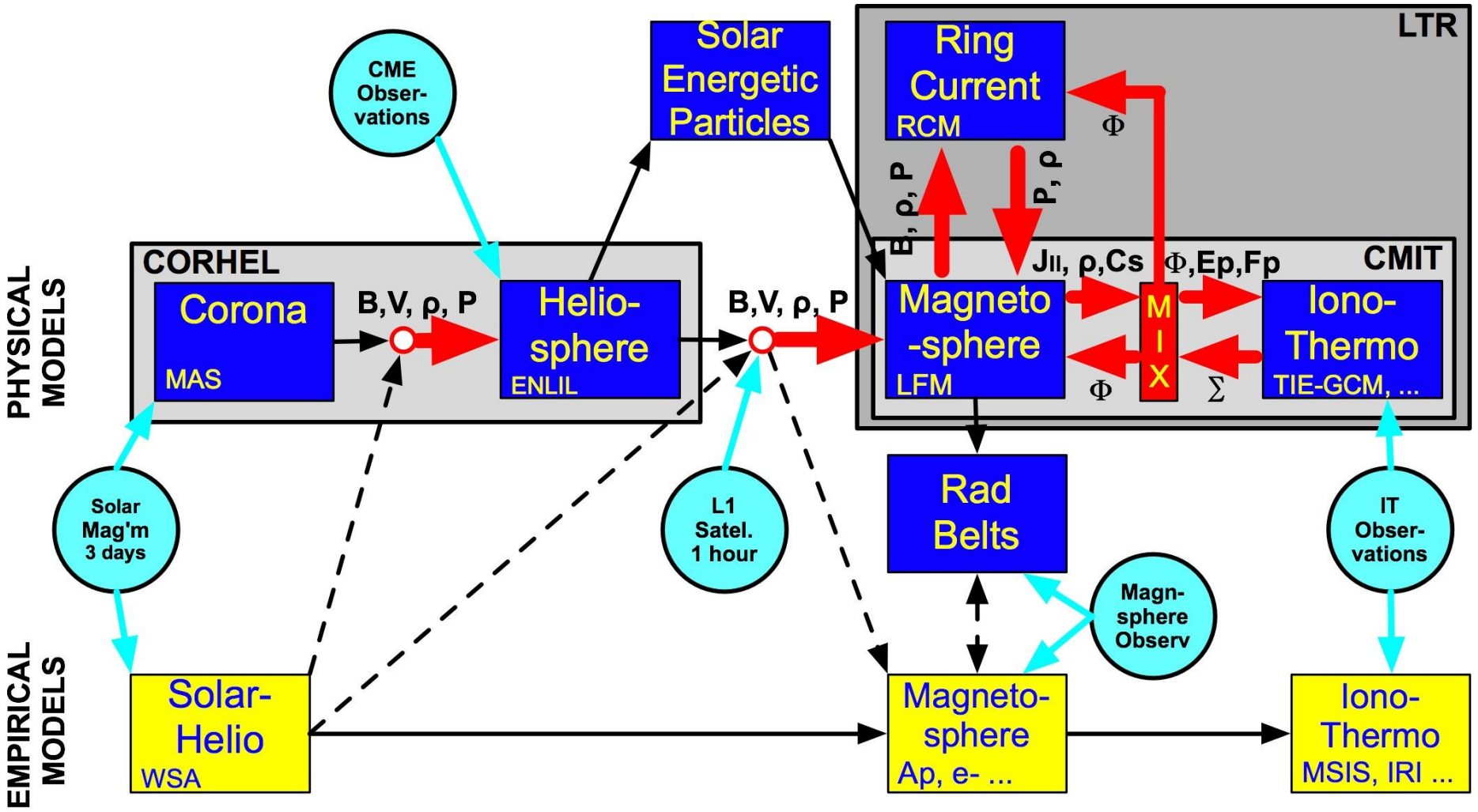
Production – Loss – Transport

- Changes in factors affecting these processes rapidly change the ionosphere.

Factors affecting the ionosphere – why is it a challenge to predict?

- Production is caused by ionizing radiation – solar EUV, X-rays, solar energetic particles, auroral electrons – acting on the neutrals.
- Loss is very sensitive to the neutral atmosphere (thermosphere) density, largely driven by temperature.
- Transport is caused by winds often forced from below and by magnetospheric flows imposed from above.

The CISM model suite



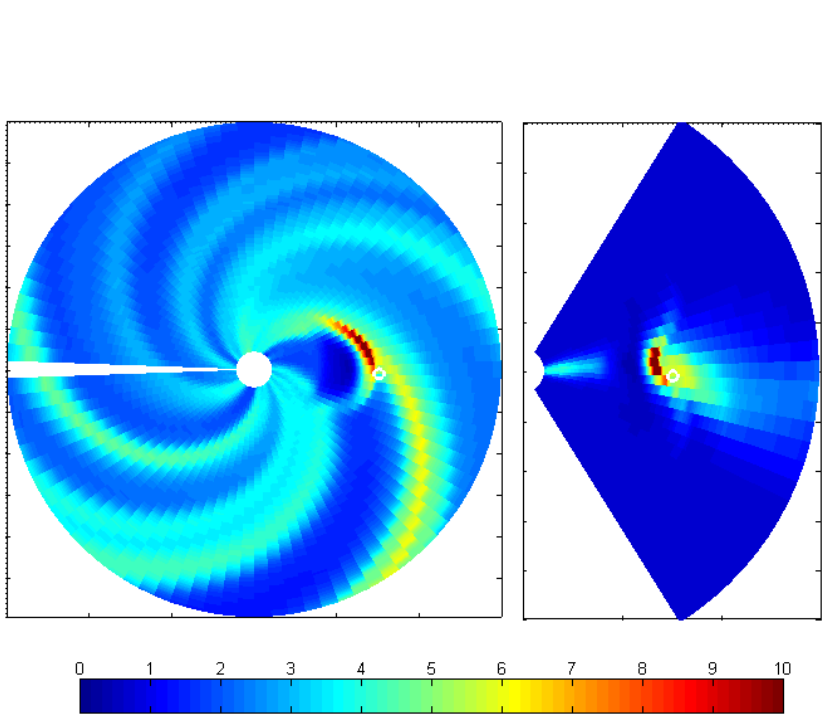
Solar Energetic Particle (SEP) Modeling

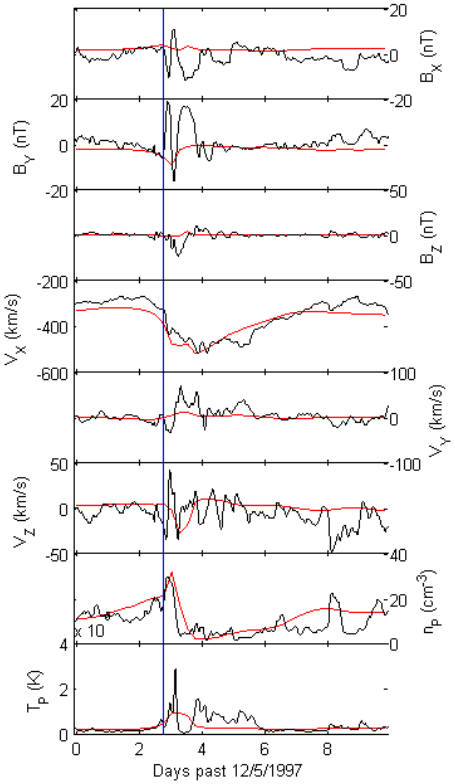
led by Janet Luhmann, UC Berkeley

- CISM is modeling the SEP's created at the shock waves generated by Interplanetary Coronal Mass Ejections (ICME) in the heliosphere.
- CISM's SEP modeling relies on a sufficiently accurate description of the underlying solar wind and ICME shock structure. This is needed to determine:
  - Shock source strength and attributes
  - Shock connectivity to an observer

  Both of which are time dependent
- In this example the Interplanetary ICME is simulated using the Cone Model (*D. Odstrcil*)

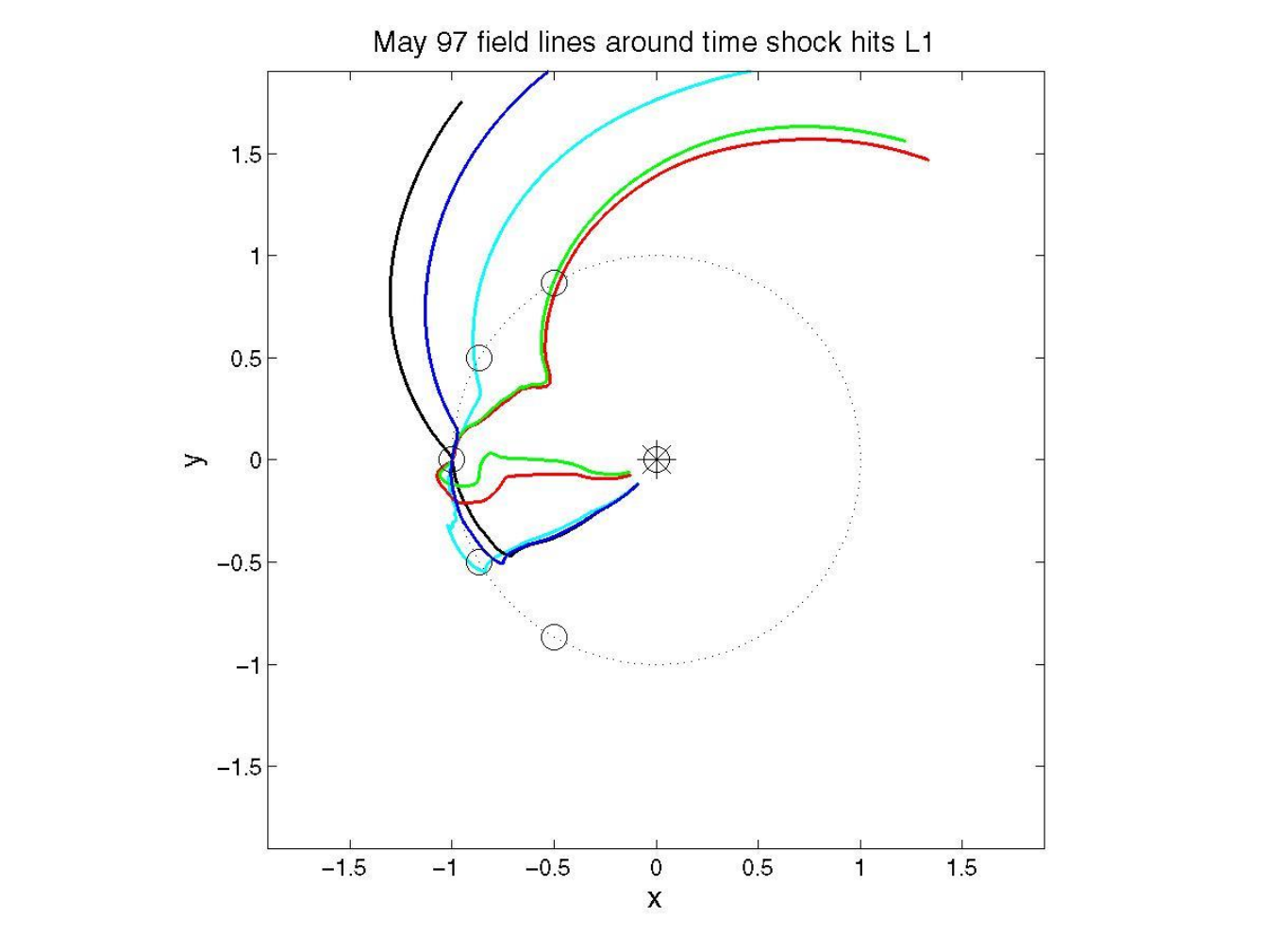
May 1997 ICME cone model results





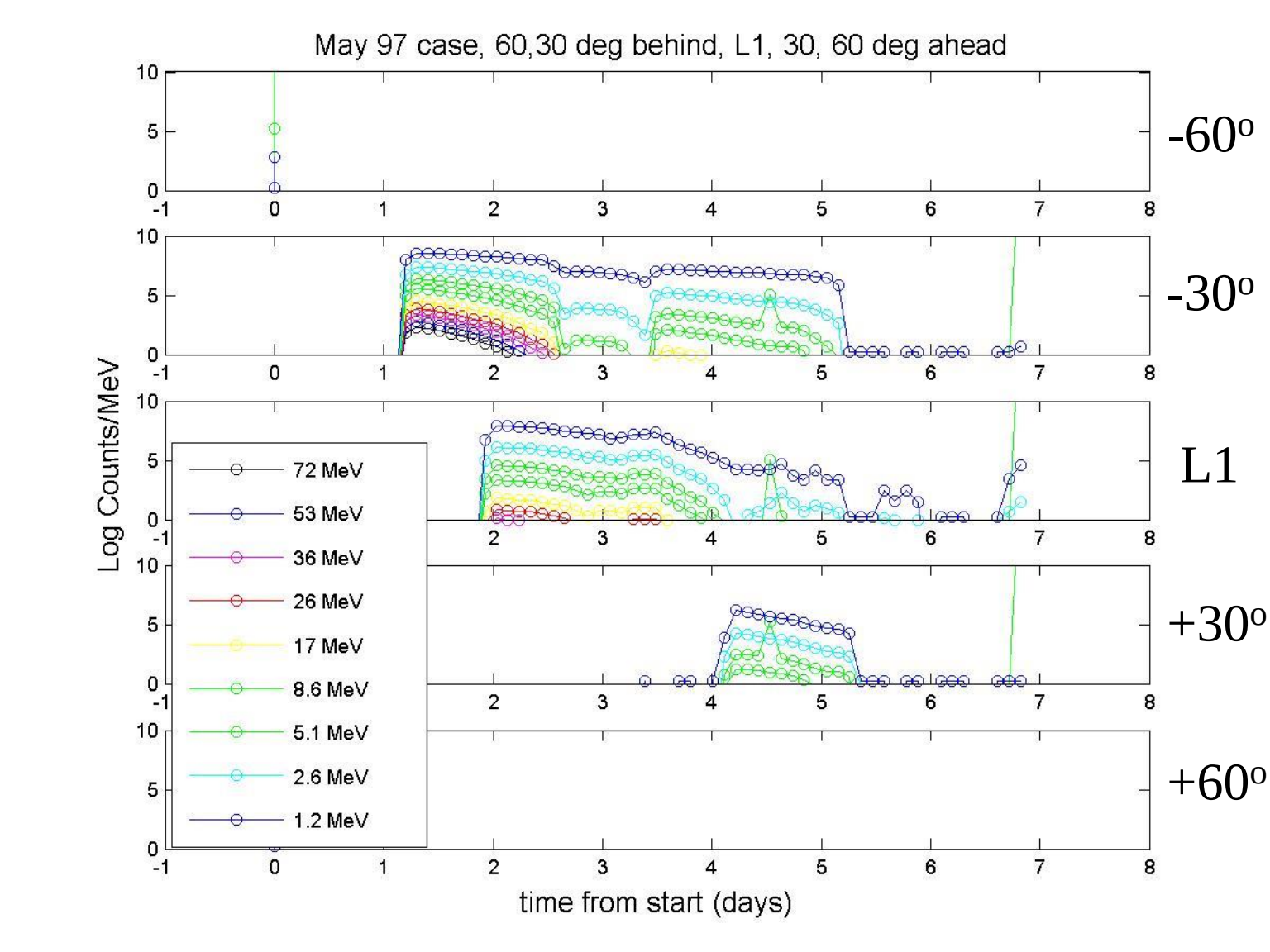
A snapshot of solar wind density in the equatorial and meridional planes.

Cone model results (red) and Observations (black) at L1 superposed.

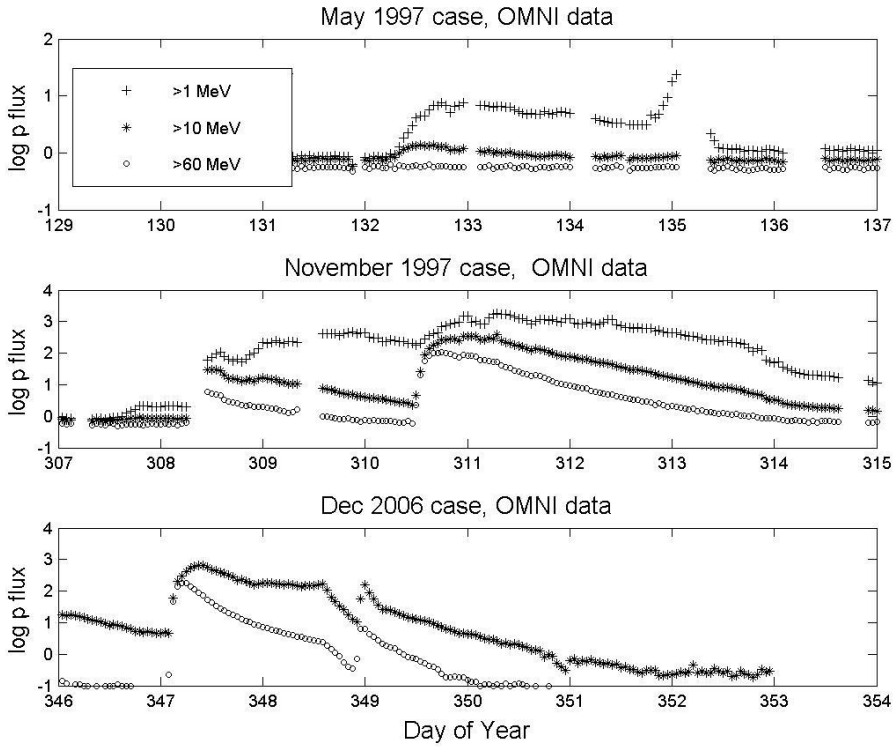


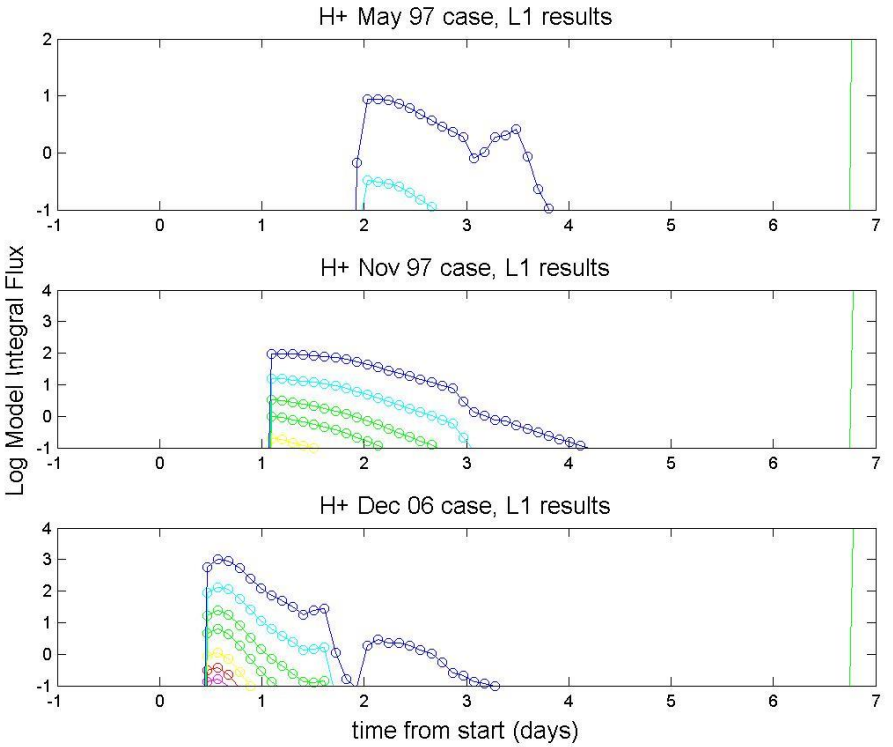
Snapshots of the magnetic field line connecting the L1 point to the Sun. This illustrates the challenges faced by the evolution of complex field line shapes in the structured interplanetary medium.

Predicted SEP fluxes at five locations for the May 97 case



Comparison of model SEP fluxes with observations for three ICME events: May 1997; Nov 1997; Dec 2006.



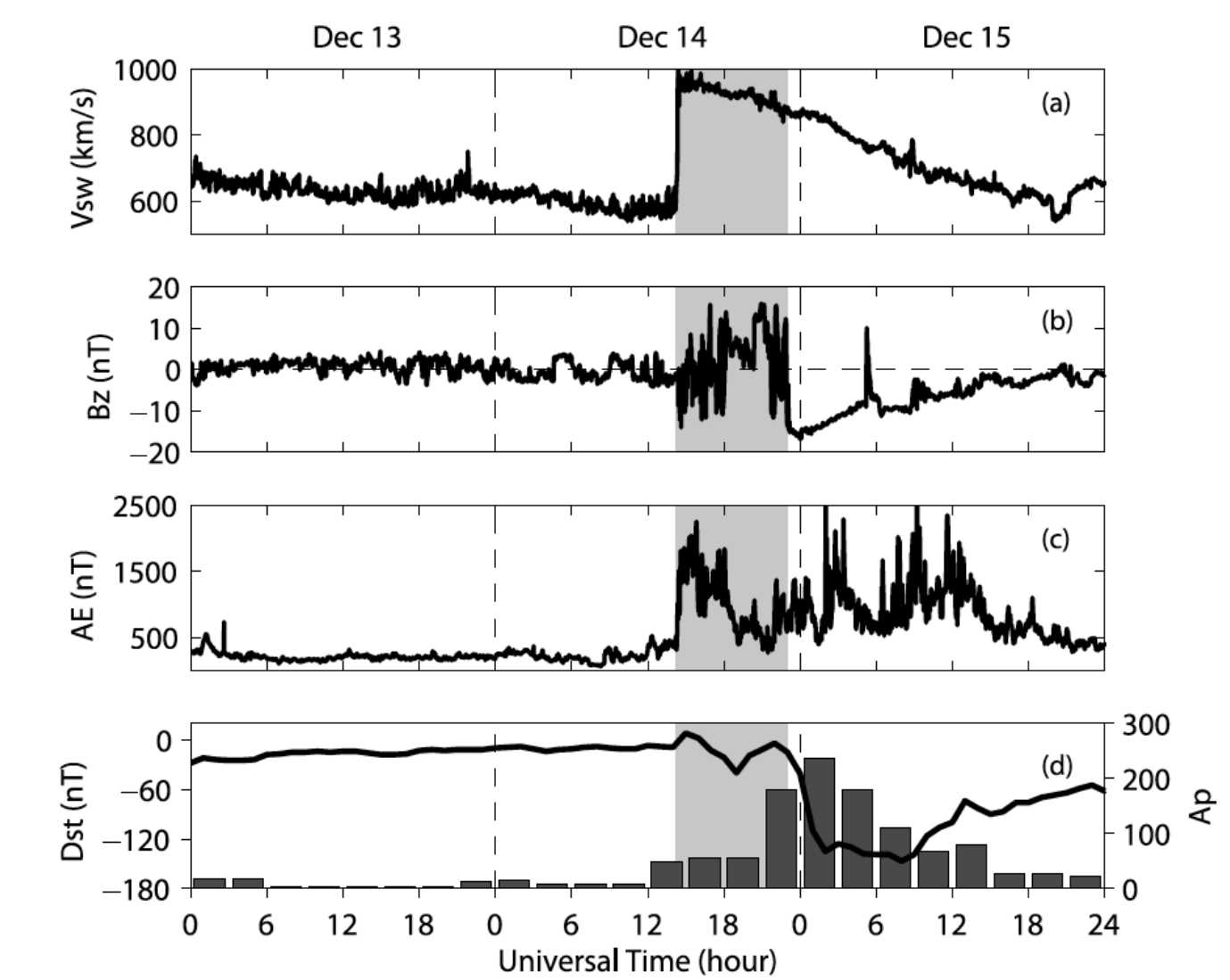


Magnetosphere-Ionosphere Coupling

Led by Stan Solomon, NCAR/HAO

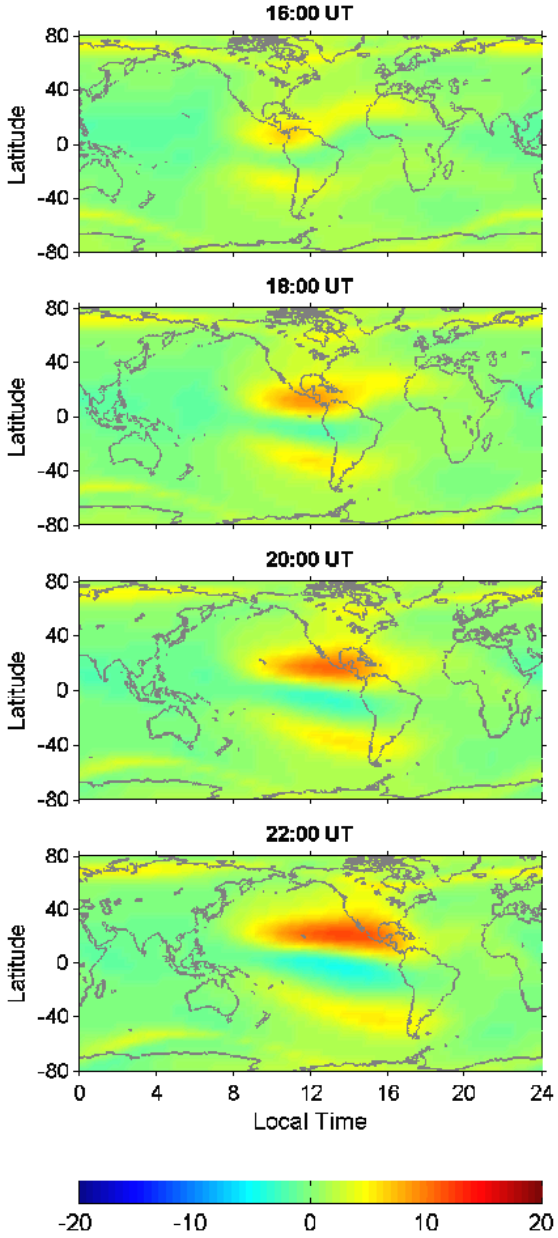
- CISM models magnetosphere-ionosphere coupling with CMIT – the LFM global magnetospheric MHD model coupled with the global thermosphere-ionosphere TIEGCM model.
- During geomagnetic storms, strong magnetospheric forcing of the ionosphere/thermosphere occurs causing significant changes to the ionosphere.
- Comparisons of results from both CMIT and TIEGCM alone with observations confirm the importance of magnetospheric coupling.

The 2006 "AGU Storm"

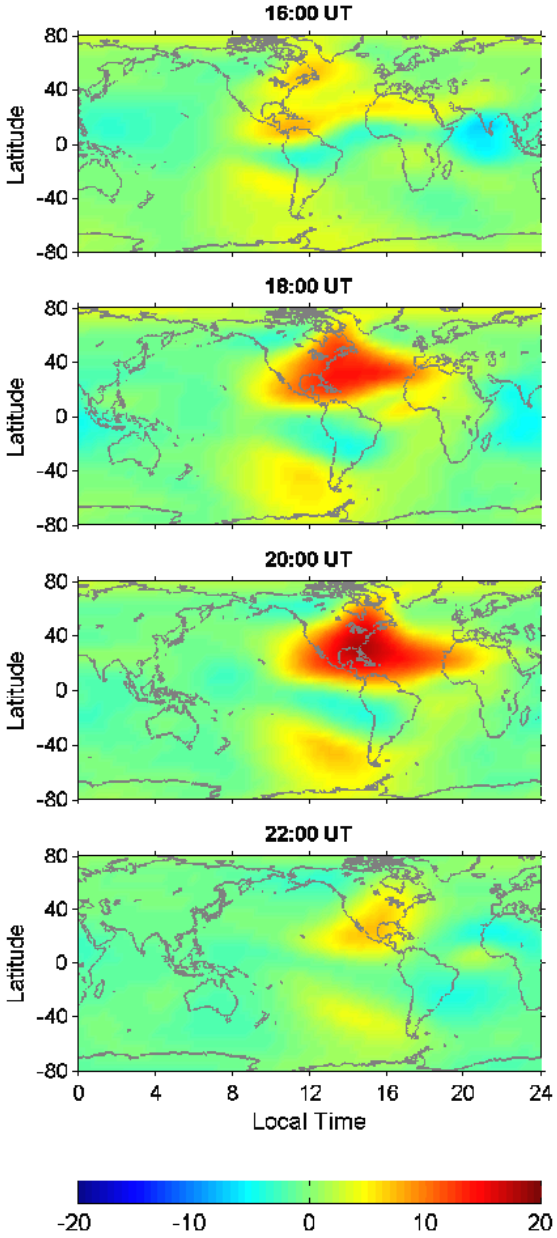


The December 2006 "AGU Storm"

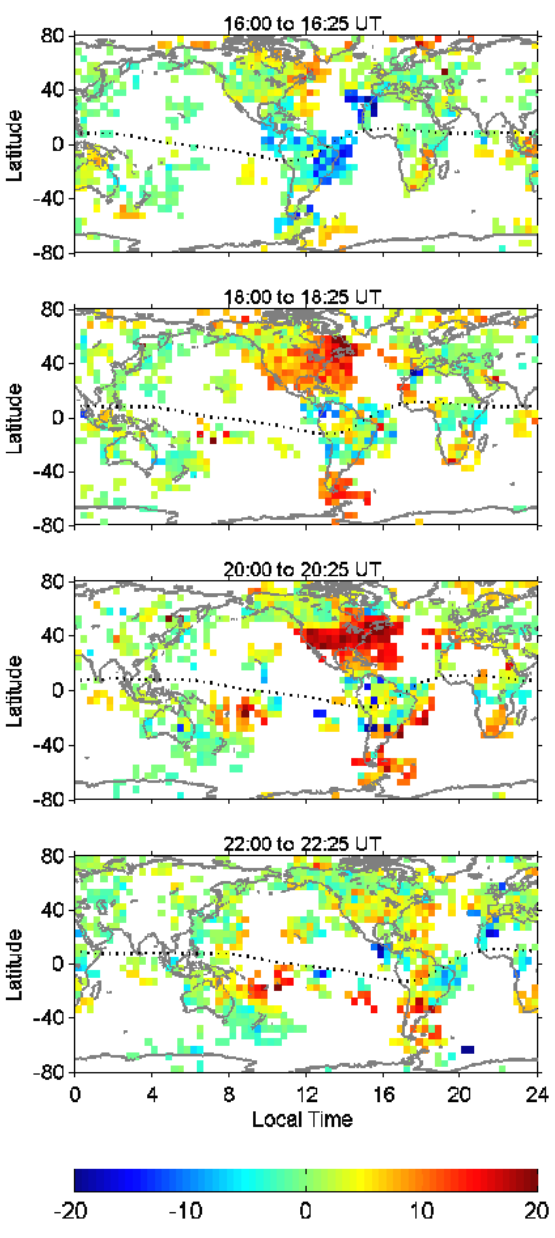
ΔTEC from TIE-GCM



ΔTEC from CMIT

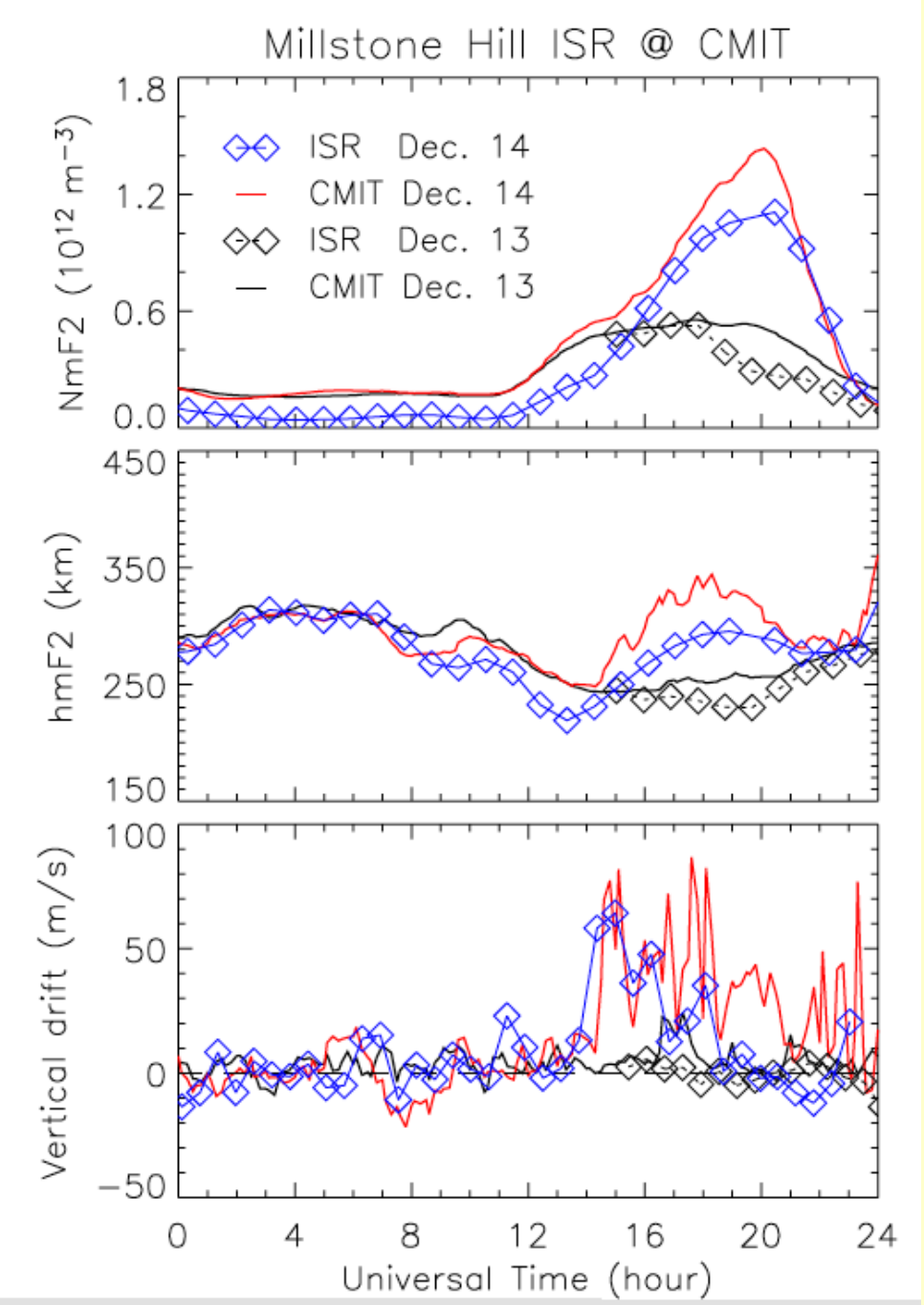


ΔTEC from GPS network

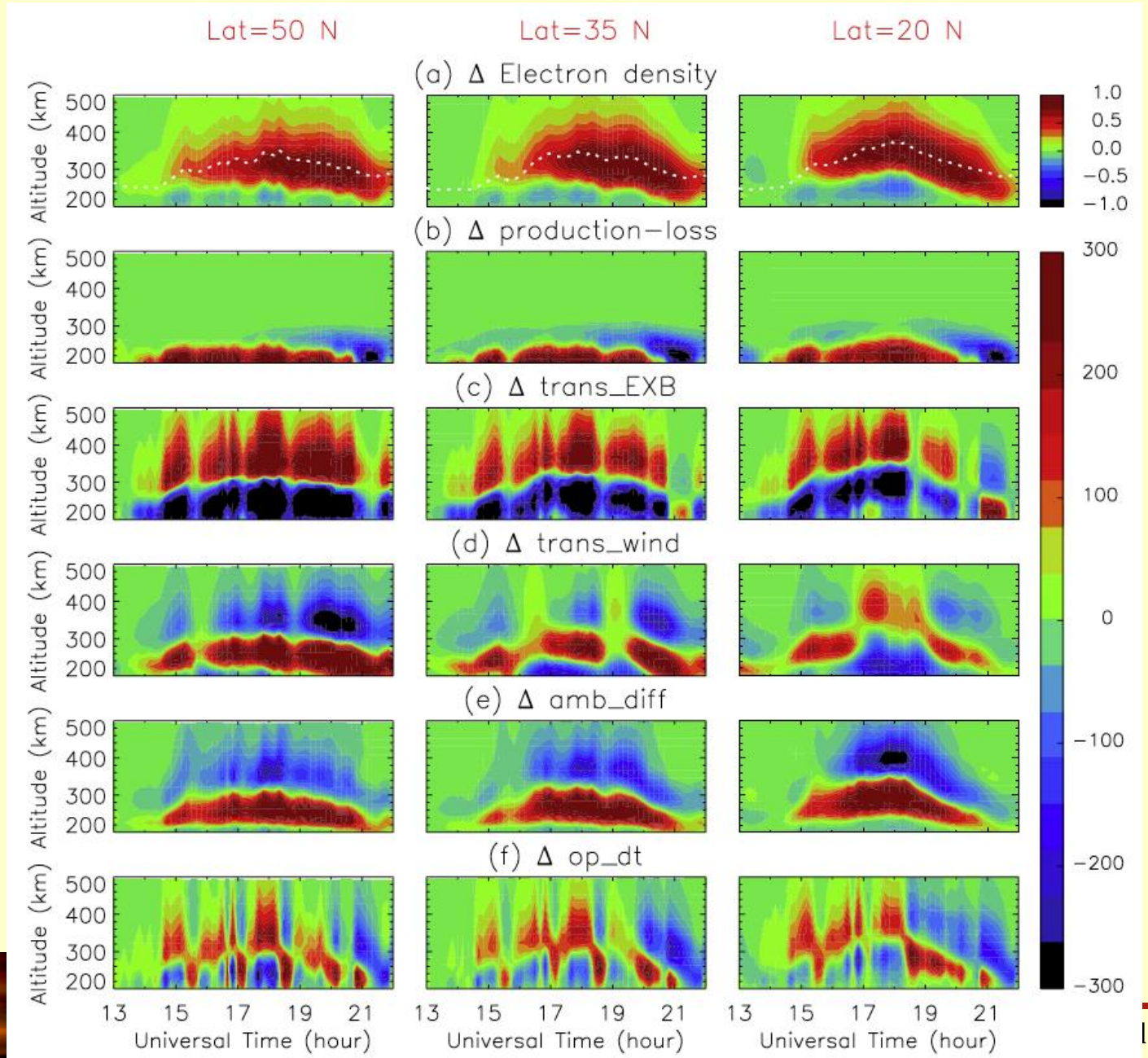


December 2006 Storm

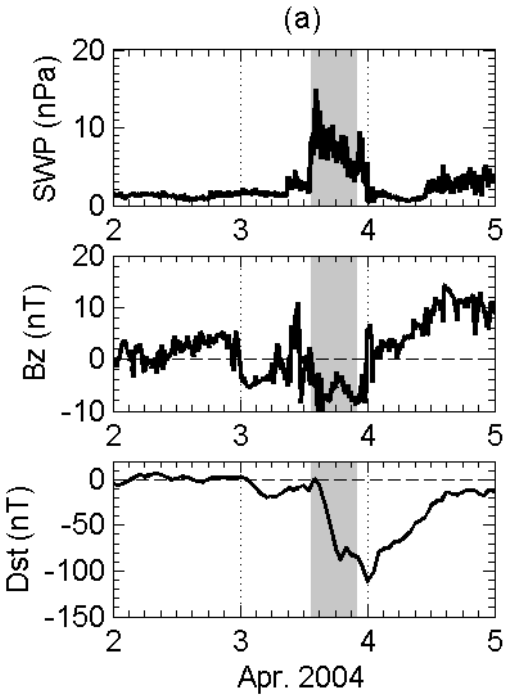
Comparison of CMIT model with Millstone Hill Incoherent Scatter Radar observations.

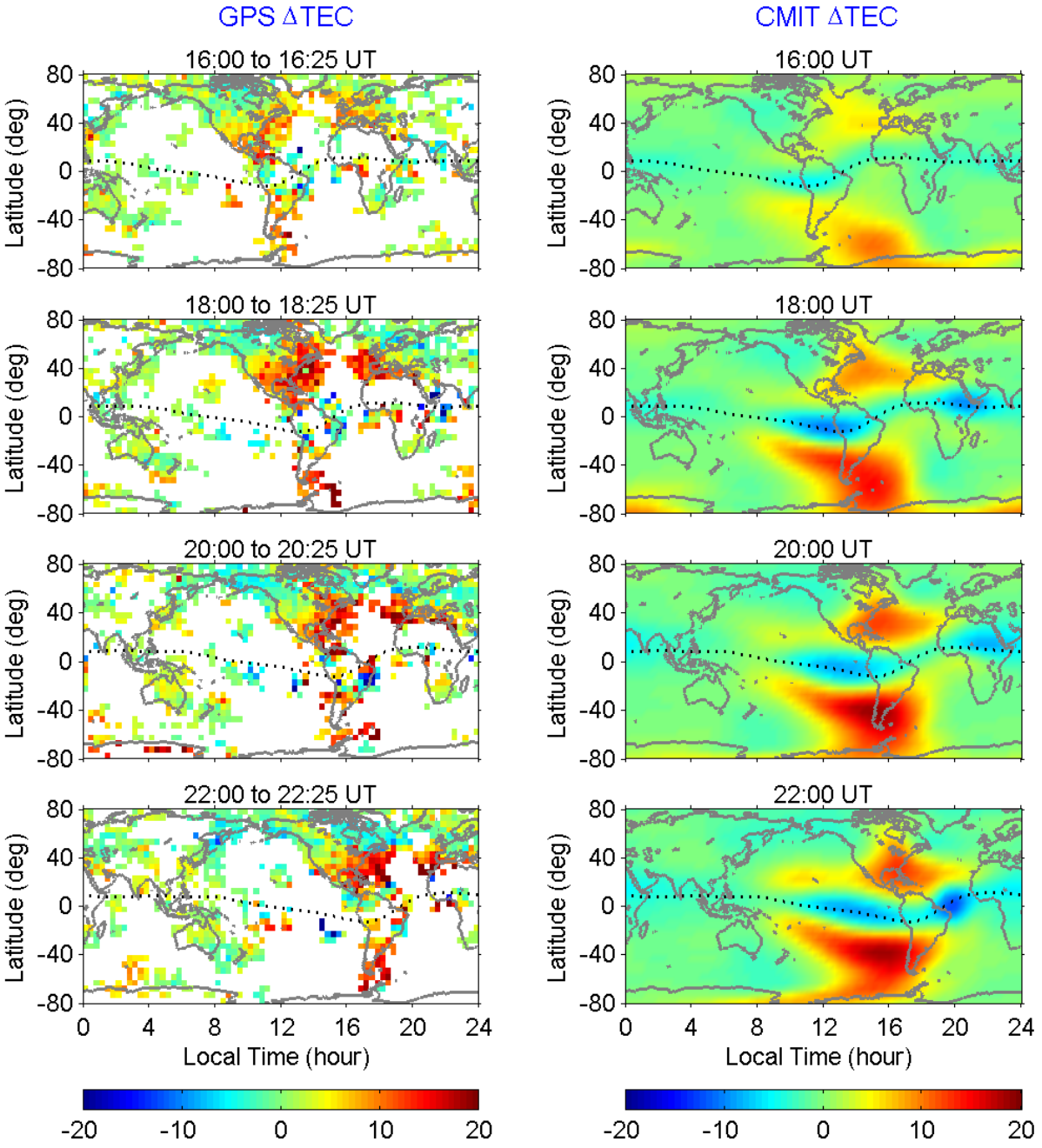


Processes Driving Storm-Time Changes in Electron Density

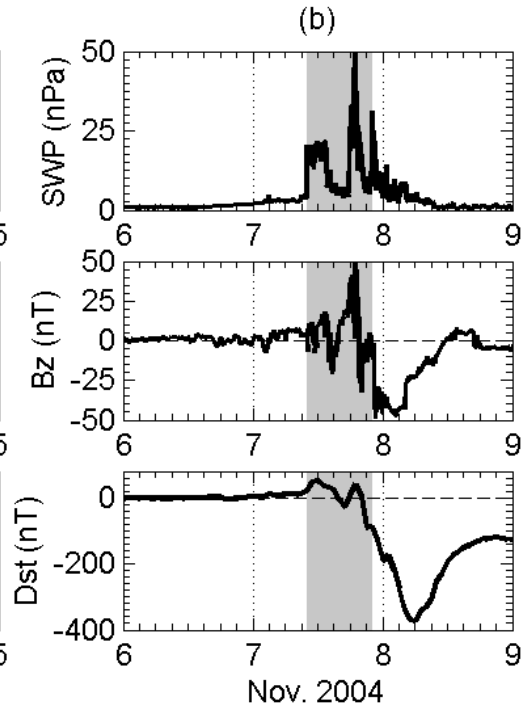


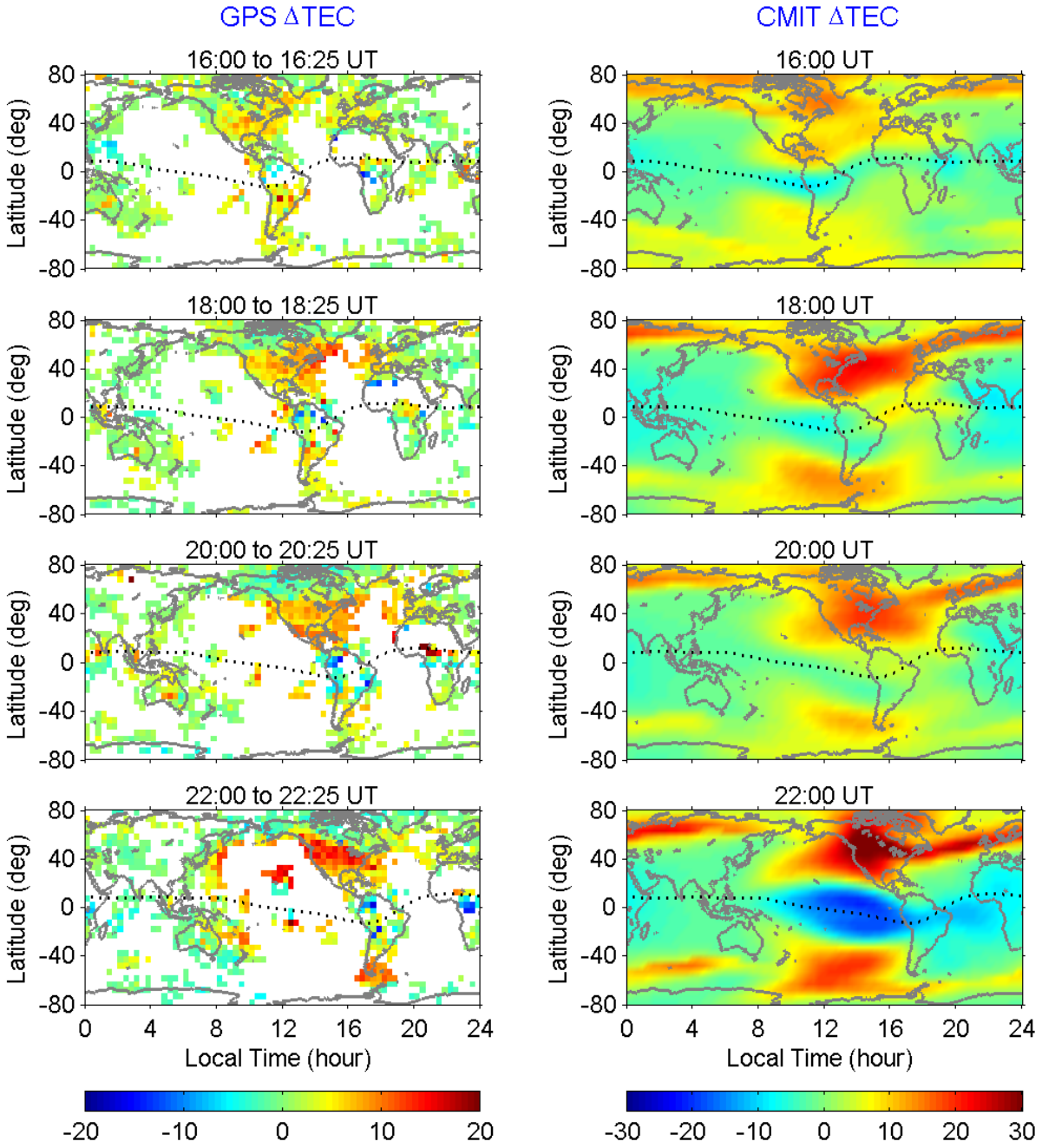
April 2004 Storm



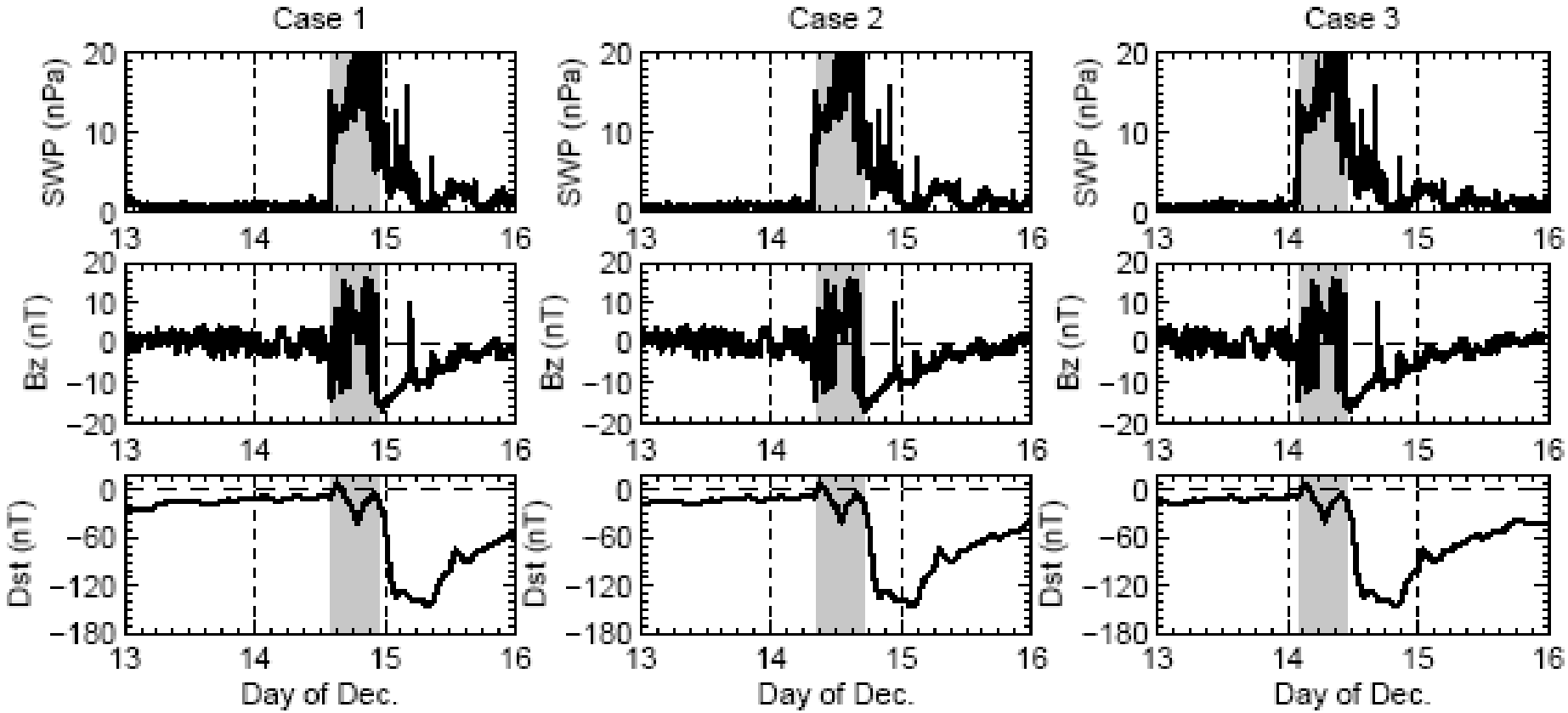


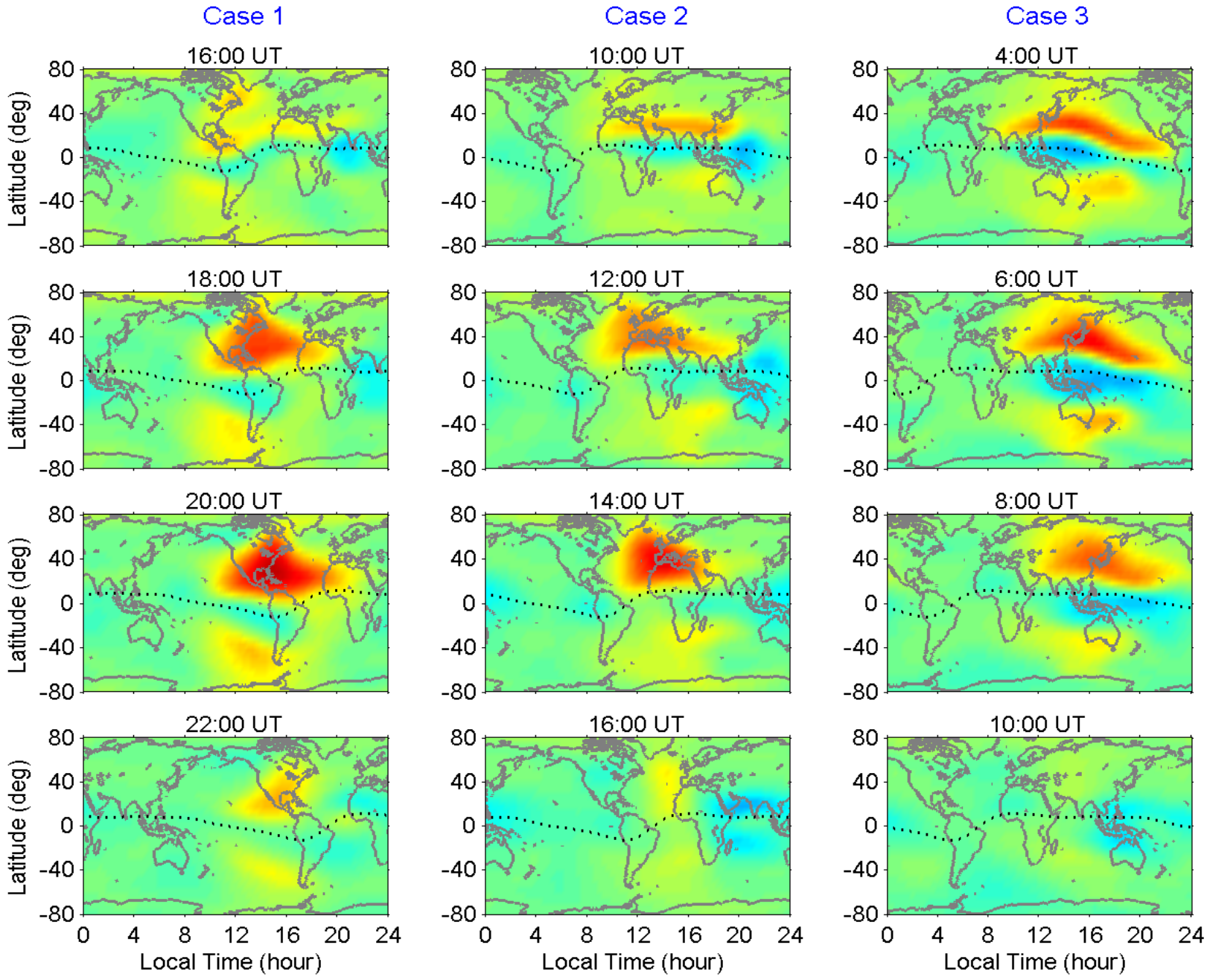
November 2004 Storm





Ionospheric Response to Different Storm Onset Times




Case 1
Case 2
Case 3
16:00 UT
10:00 UT
4:00 UT
18:00 UT
12:00 UT
6:00 UT
20:00 UT
14:00 UT
8:00 UT
22:00 UT
16:00 UT
10:00 UT
Latitude (deg)
80
40
0
-40
-80
0
4
8
12
16
20
24
Local Time (hour)
-20
-10
0
10
20

Conclusions

- Predicting the ionosphere is challenging as the electron density depends sensitively on a number of disparate parameters.
- Ionospheric memory is short (several hours), data assimilation doesn't help for more than a few hours.
- The ionosphere can change abruptly in response to solar flares and other sudden transients.
- Models can provide guidance to probabilistic forecasts.
- Currently Geospace models are best for short-term (1-hour) forecasts and nowcasts.
- For a 1-day forecast, current observational/modeling capabilities suggest most is to be gained from a time dependent heliospheric model with CME propagation.

The CISM Space Weather Summer School
This year: July 20 - 31, 2009

Students and faculty working at the CISM Summer School – a two-week school held each year.