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Ionospheric Response To Magnetospheric Electric Fields: Moderate to Severe Storms

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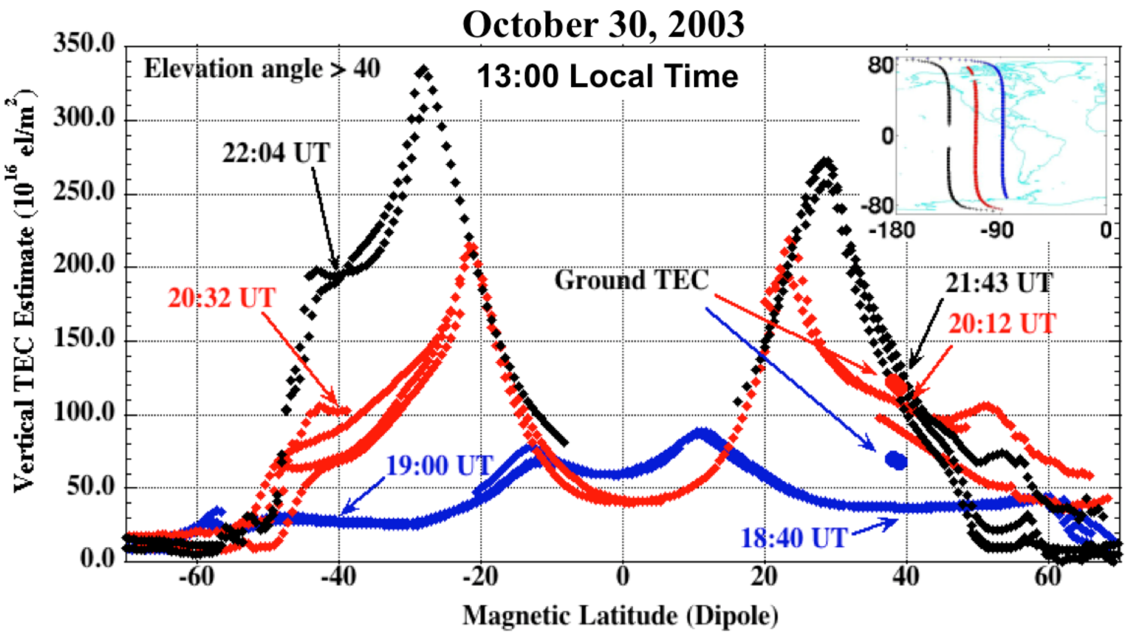
Outline

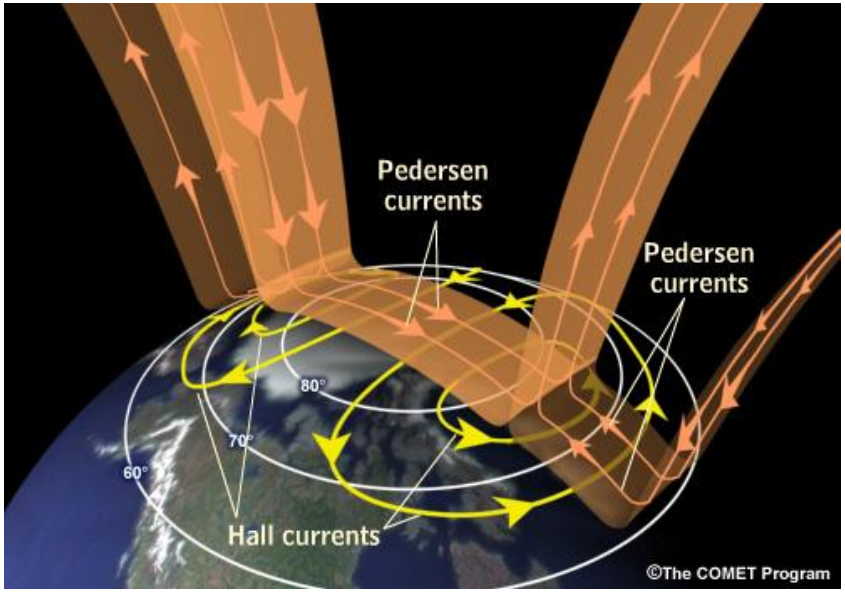
1. The science question: understanding prompt TEC response to superstorms
2. Role of B_y?
3. Moderate to Intense Storms
4. Summary



CHAMP altitude: 400 km

Mannucci et al., "Dayside global ionospheric response …" *GRL* 2005

Physics



Field aligned current Electric potential

$$J(\text{source}) = \underline{\nabla}_2 \cdot (\underline{\underline{\Sigma}} \cdot \underline{\nabla}_2 \Phi)$$

Conductivity model (global)

Pedersen: $\sigma_p(\theta,\phi) = 0.3 + 5.0 \exp\{-[\cos^{-1}(\sin\theta \cos\phi)]^2/1.804\} + 3.0 \exp\{-(\theta - 0.35)^2/0.01\}$

Hall: $\sigma_H(\theta,\phi) = 2.0\ \sigma_p(\theta,\phi)$

direct: $\sigma_O(\theta,\phi) = 31.62\ \sigma_p(\theta,\phi)$

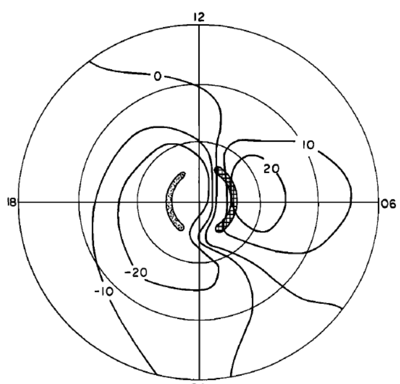
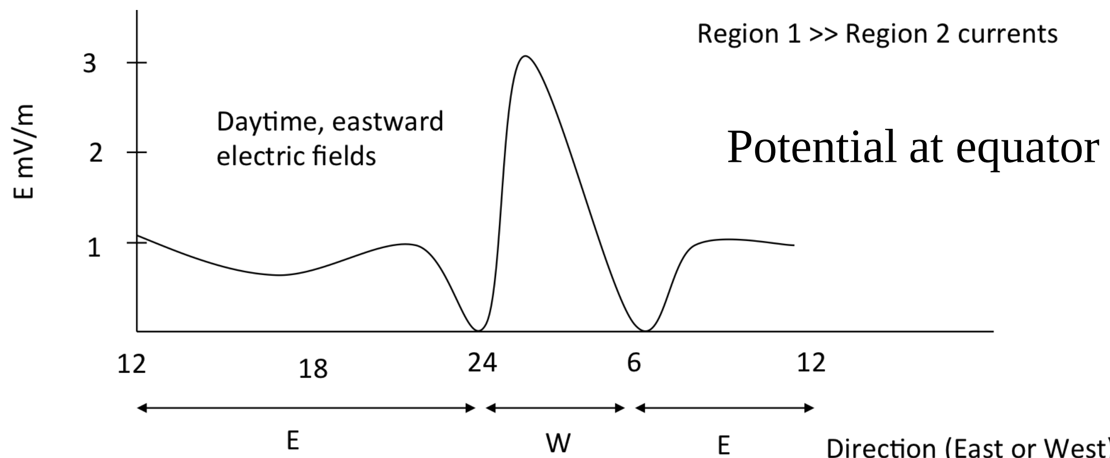
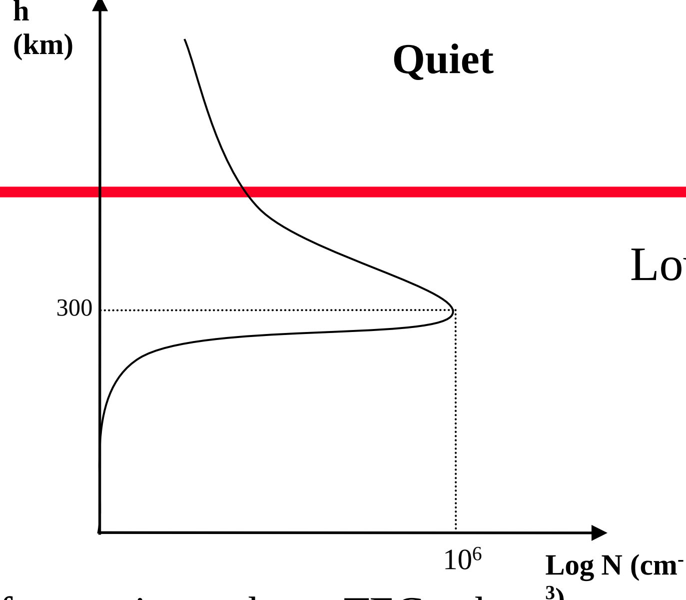


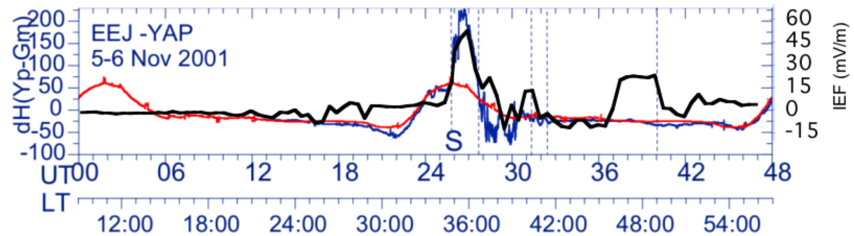
Fig. 1a. Polar plot of equipotential pattern (in kV) due to a region 1 current set of 10^6 A at 72°: into the ionosphere (cross-hatching) on the dawnside, outward (stippling) on the duskside. Noon is at the top, dusk to the left, etc.; the outer circle represents the equator, and the inner circles are at 30° and 60° latitude.



Nopper and Carovillano, 1978



Low latitude electric field ~ 10% of interplanetary electric field



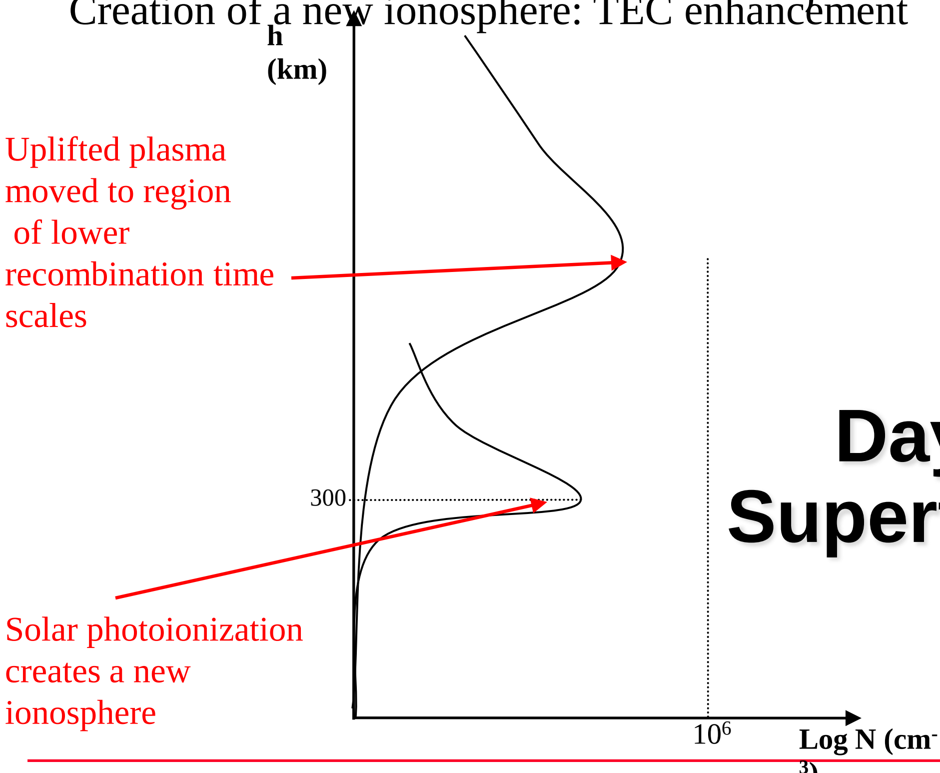
Mannucci et al., AGU Geophysical Monograph Series Vol. 159, 2005.

See also:

Kelley et al., Geophys. Res. Lett., doi:10.1029/2002GL016321, 2003

Kelley et al., JASTP **72** (2010) pp. 285–291

Creation of a new ionosphere: TEC enhancement



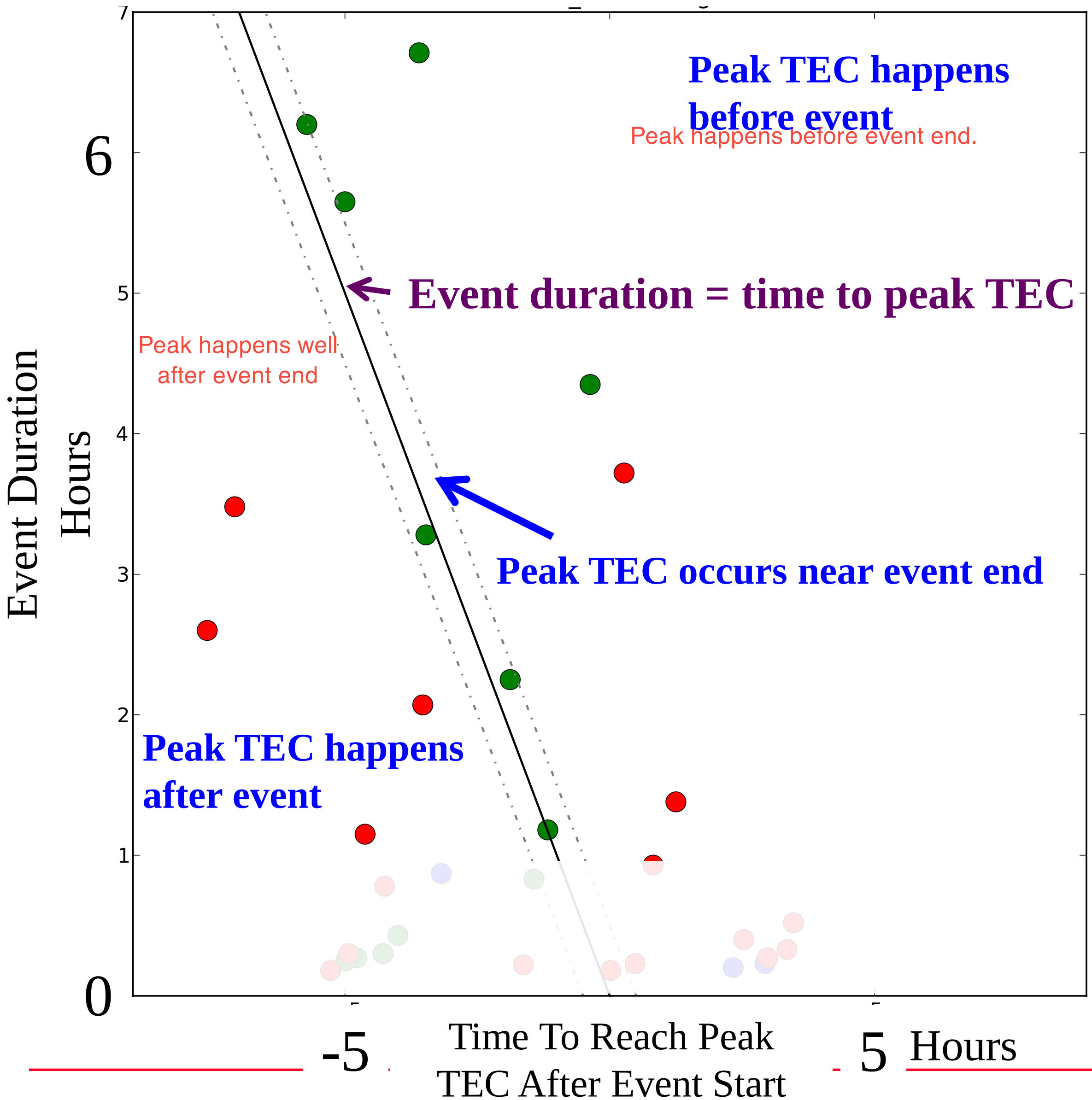
Daytime Superfountain

Hypothesis

- **A significant IMF B_y component decreases the penetration electric field preventing daytime TEC increases**
- **Reconnection electric field remains large (B_z southward), as does coupling function**

- **Analyze solar wind and ionospheric TEC**
  - **"TEC" means average between +- 40 geomagnetic, 1200-166LT**

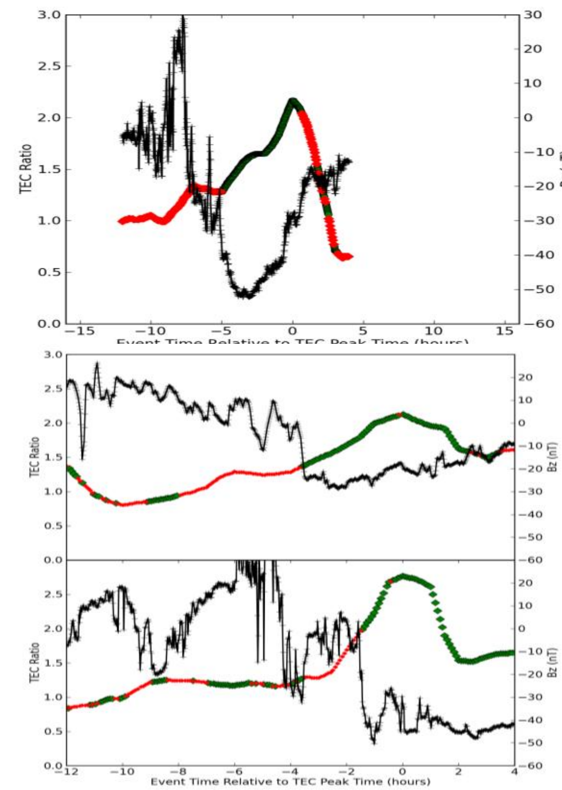
Event Study Results: Solar Cycle 23 Superstorms (Dst < -250 nT)



Each circle is an event

Green: By/Bz < 1

Red: By/Bz > 1



Time resolution ~30 minutes

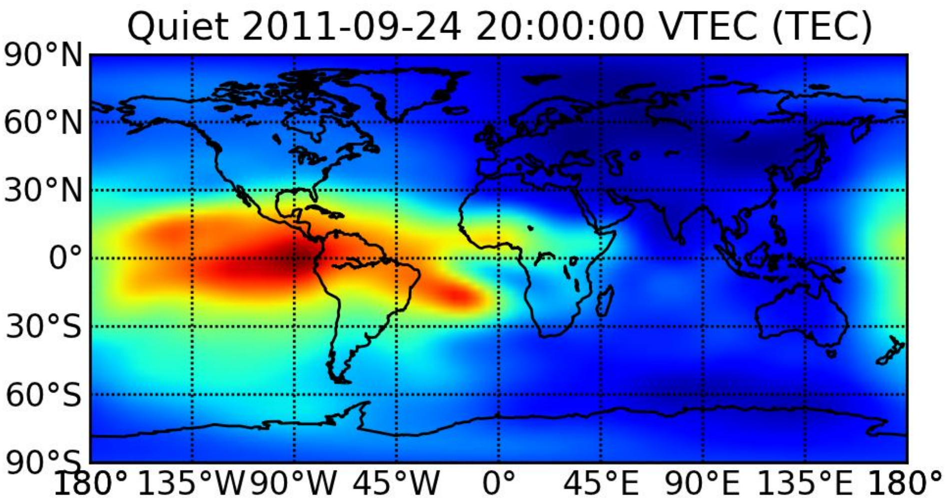
What About Moderate to Intense Storms?

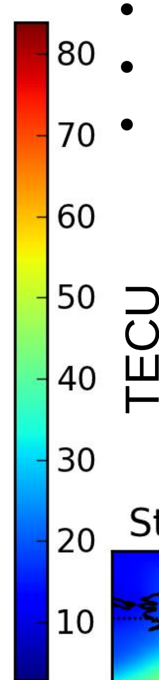
- **First step: examine positive phase response**
- **Use global TEC maps**
  - **Crude but simple to analyze**
  - **2-hour time resolution**
- **10 ICME events 2003-2006**
  - **-95 nT < *Dst* peak < -70 nT**
- **6 “Intense” storms (2000-2002, 2012)**
  - **-190 nT < *Dst* peak < -130 nT**

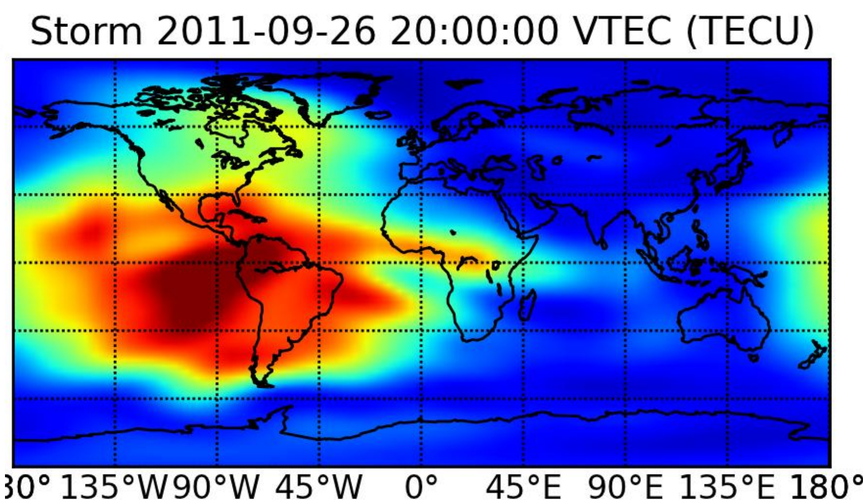
Echer, Tsurutani, Gonzalez, “Interplanetary Origins of Moderate (-100 nT < *Dst* < 50 nT) geomagnetic storms during solar cycle 23 (1996-2008)” JGR 2013

Global TEC Maps Database

- Trough/plasmapause observations
- Plume structure
- Large scale convection





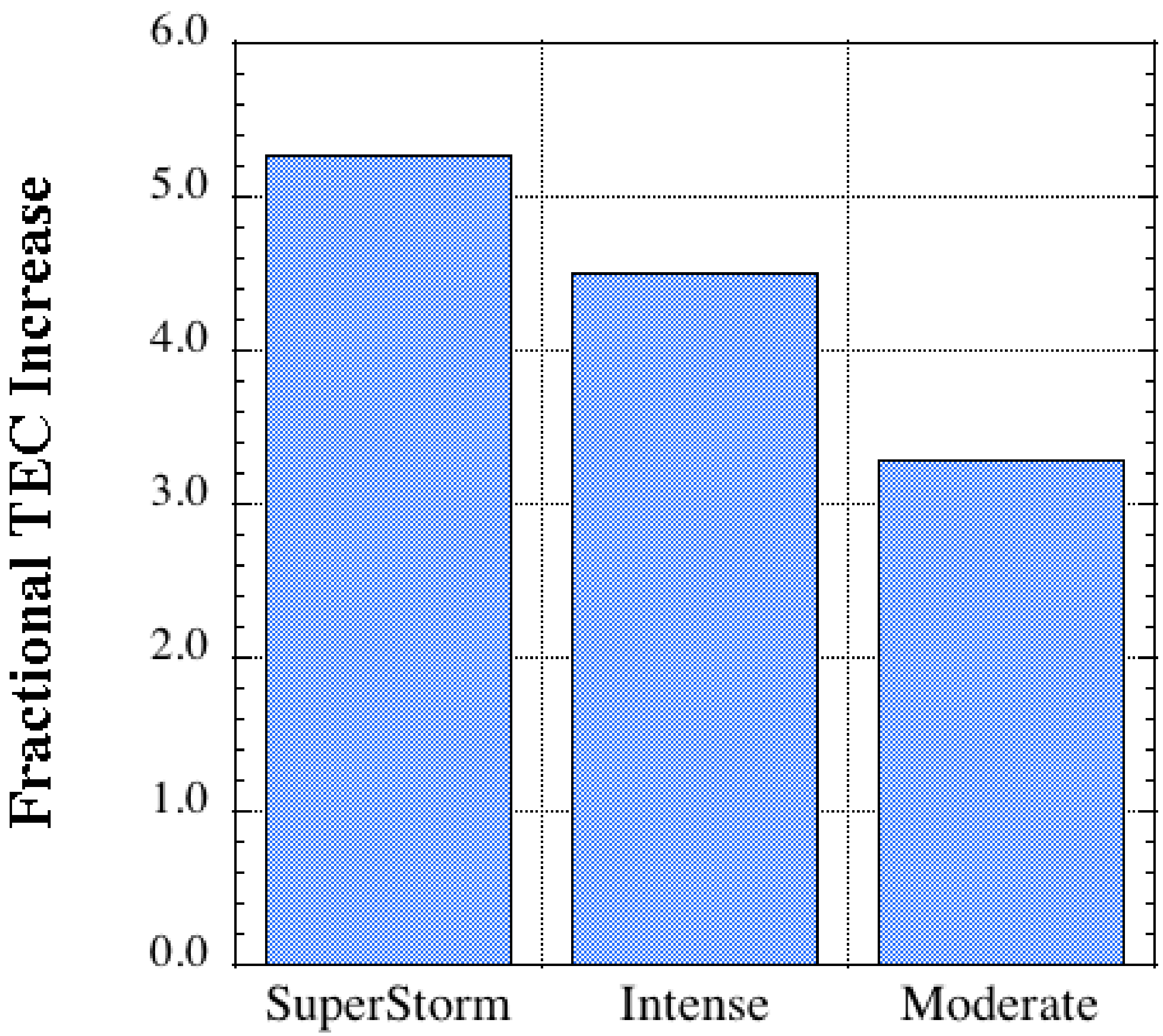


International GNSS Service (“Global Navigation Satellite Systems”)

TEC maps available 1998-2012

http://cddis.nasa.gov/gnss_datasum.html
ftp://cddis.gsfc.nasa.gov/pub/gps/products/ionex/

Results using TEC maps: average over all storms in category



Fractional peak TEC increase relative to preceding quiet time, in "units of" quiet time variability

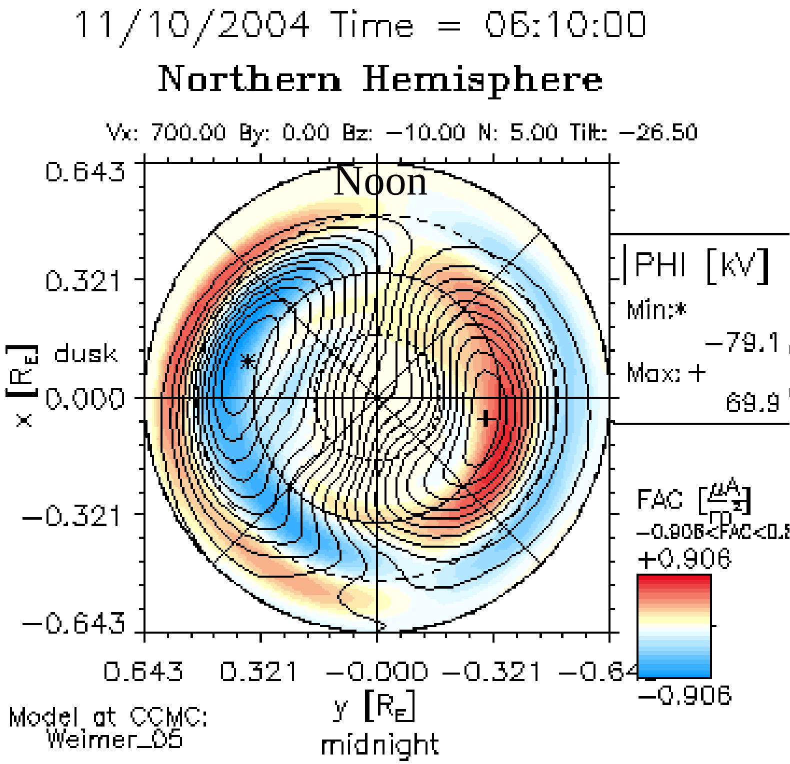
Quiet time variability of moderate storms much higher due to solar cycle phase

Time cadence of TEC maps reduced superstorm increase in two cases

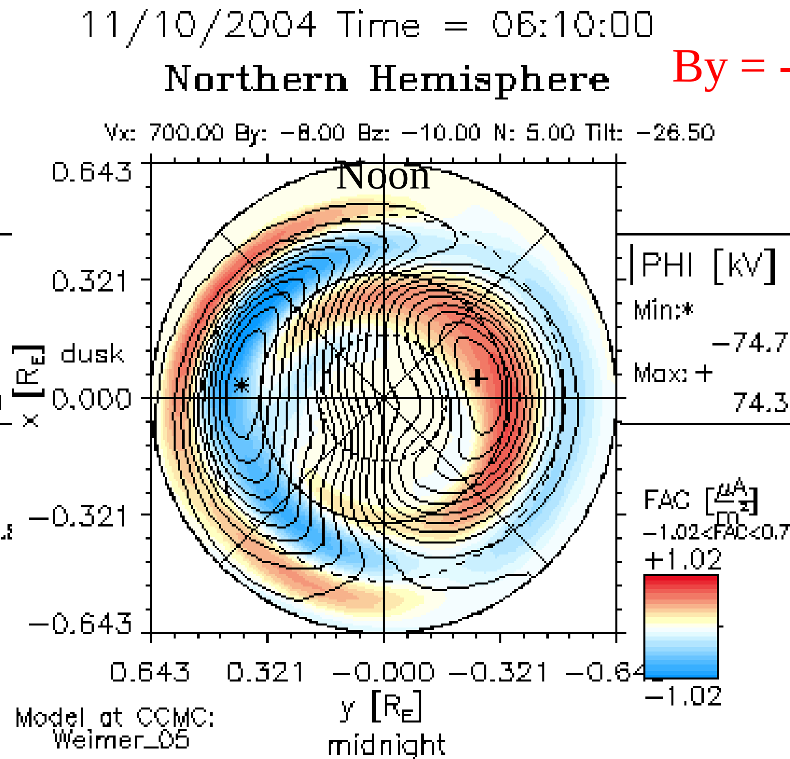
"Rule of thumb": nearer to solar minimum, "background" variability of the ionosphere is much more prominent relative to external drivers

(probably due to coupling from the lower atmosphere)

Weimer 2005 Empirical Model

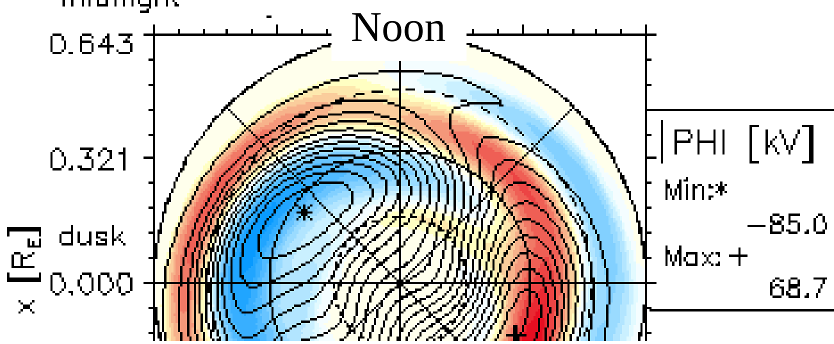


By = 0, Bz = -10.0

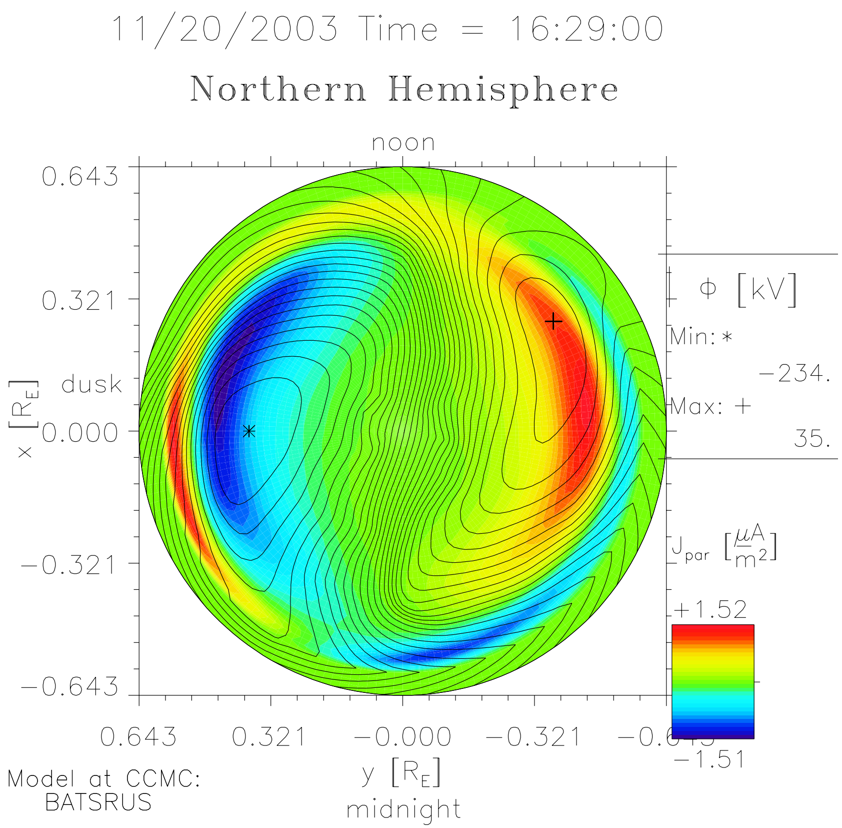


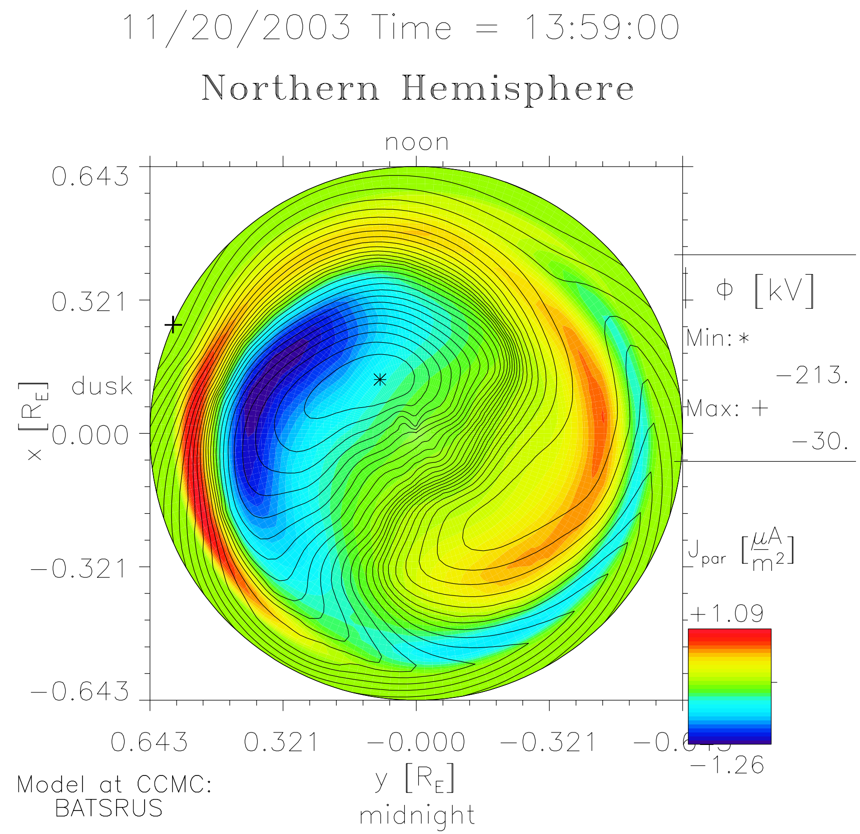
By = -8.0, Bz = -10.0

By = 8.0, Bz = -10.0



Global MHD Runs – November 20, 2003



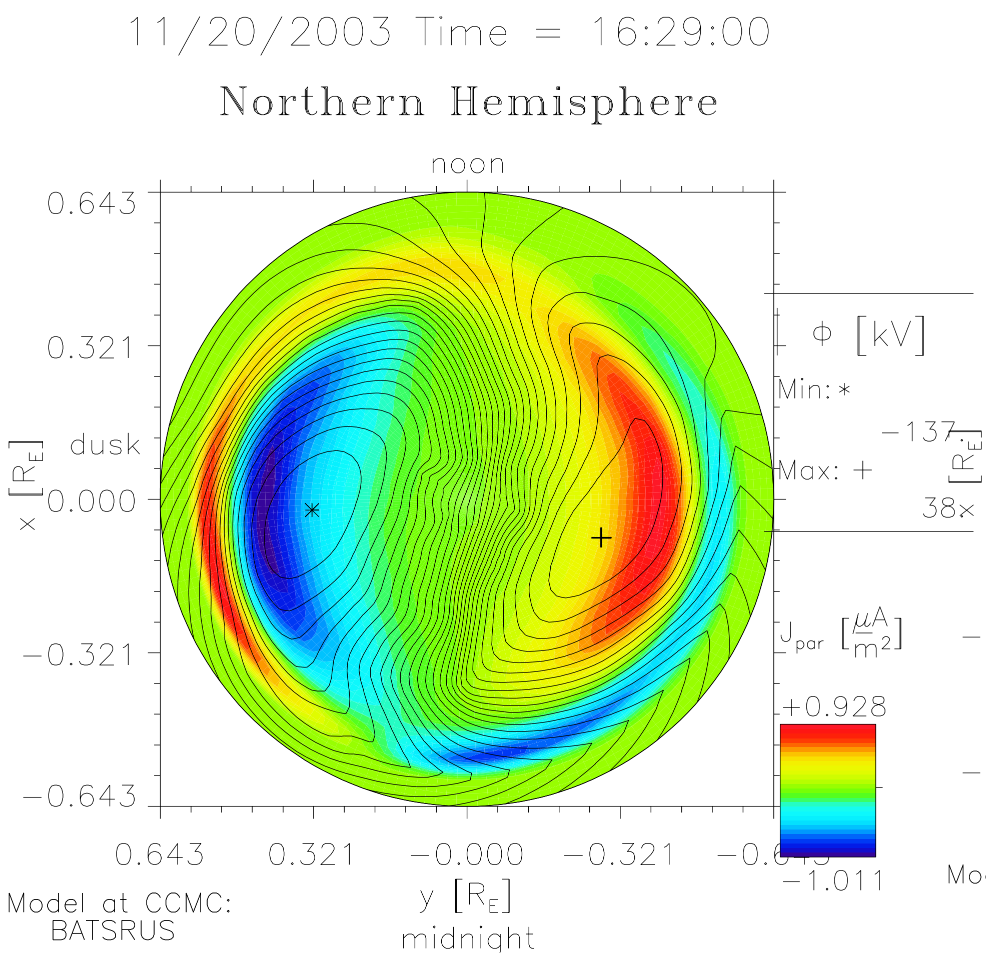


By = 0.0 nT
Bz = -45.0 nT

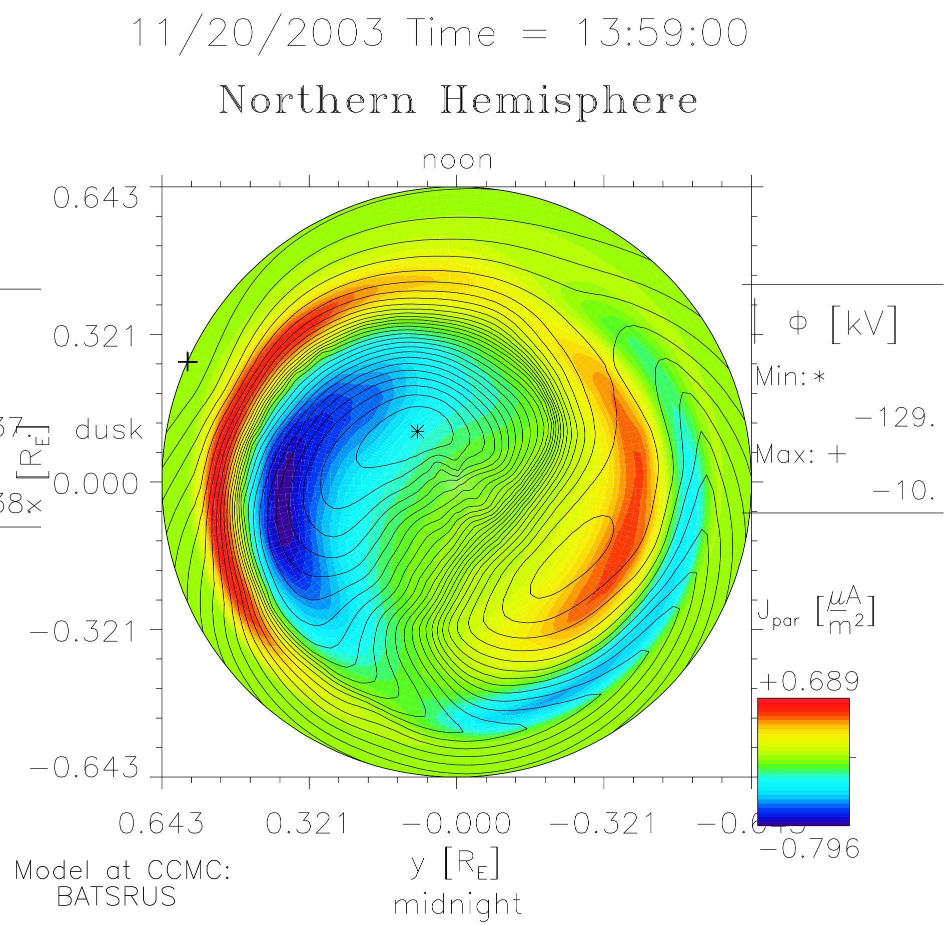
By = 36.0 nT
Bz = -36.0 nT

BATSRUS at CCMC

BATSRUS Runs With Nature/3.0



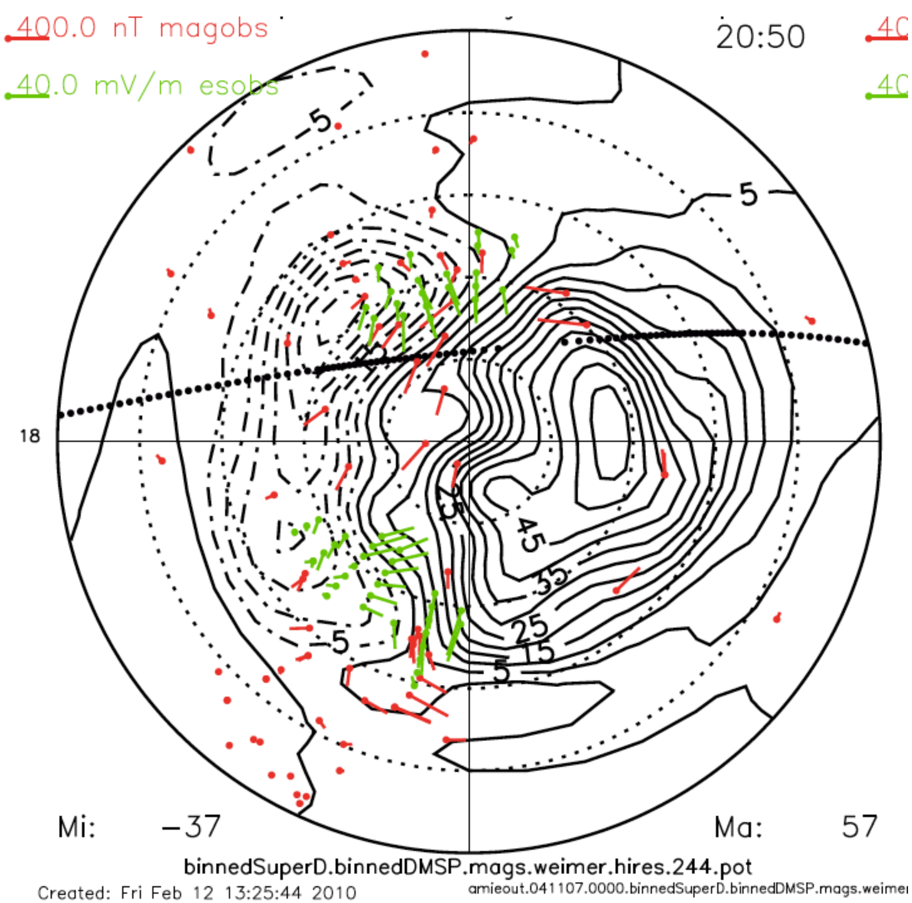
By = 0.0 nT
Bz = -15.0 nT



By = 12.0 nT
Bz = -12.0 nT

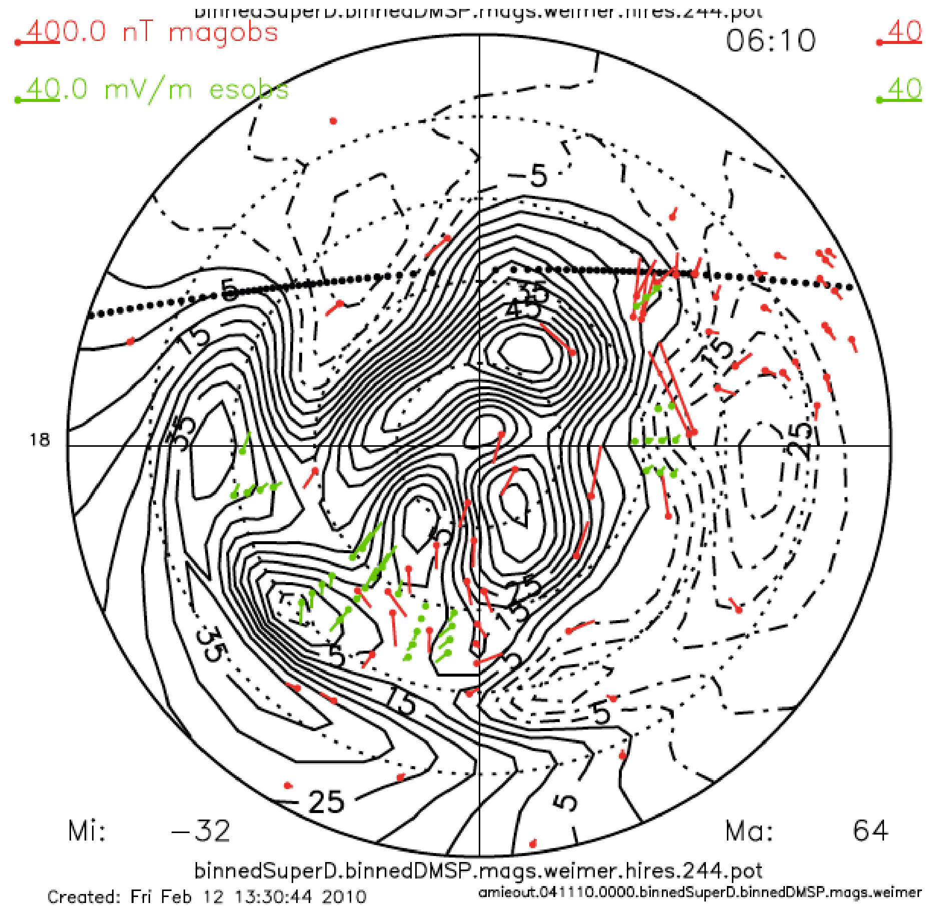
AMIE Potentials Nov 7 & Nov 10

Nov 7, 2004



By = 1.4
Bz = -28.2

Nov 10, 2004



By = -10.0
Bz = -24.0

Summary

- **Significant variation among superstorms for daytime TEC increases**
- **Hypothesis that B_y is a primary factor is plausible**
- **Initial look using global TEC maps of moderate to intense storms**
- **Pursuing additional modeling studies: can existing models establish the boundary conditions (including role of B_y) that agree with observations?**

Acknowledgements: Model runs performed at NASA CCMC
D. Weimer, Virginia Tech (Weimer_05)
T. Gombosi, CSEM U. Michigan (BATSRUS Magnetosphere)
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