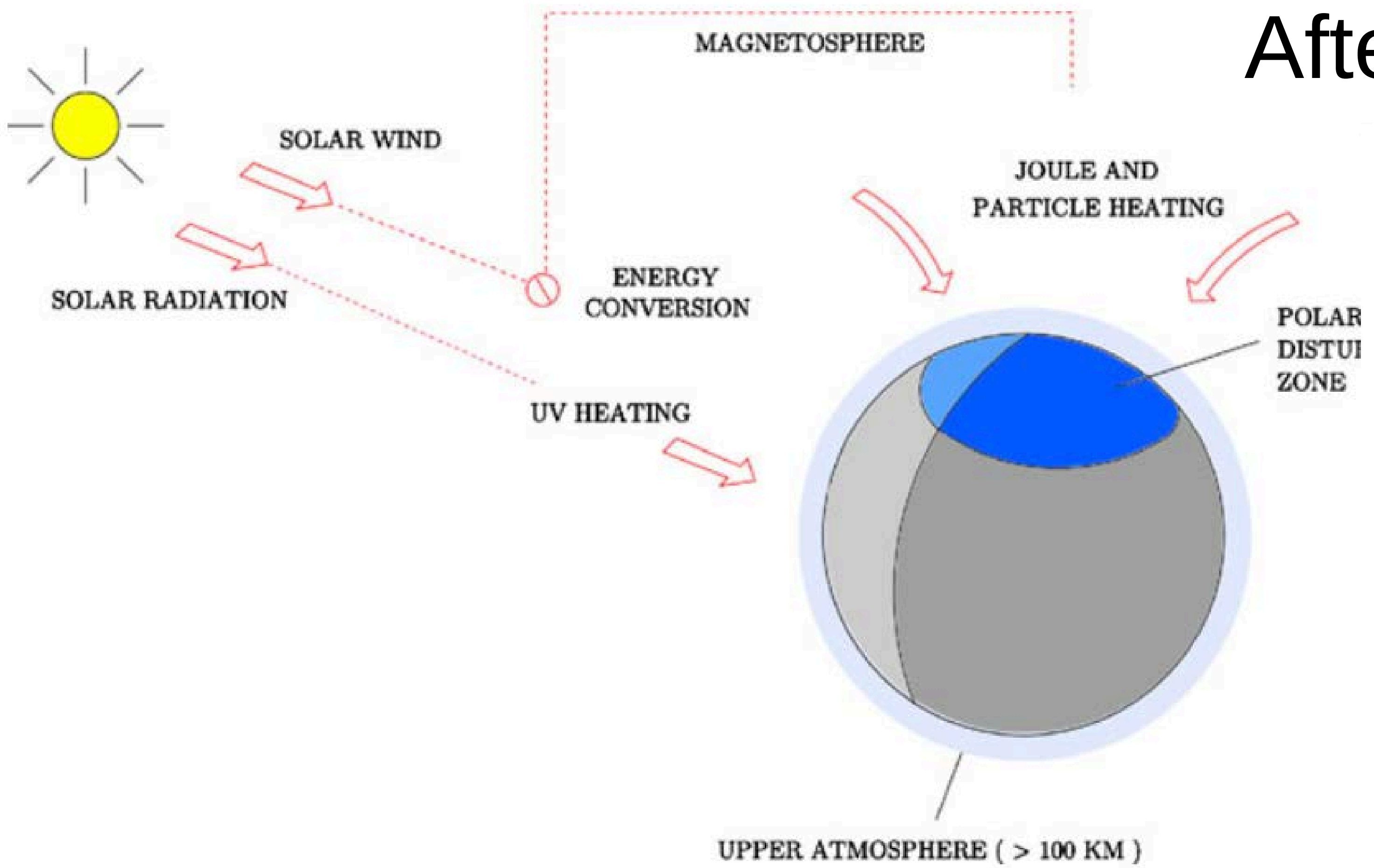
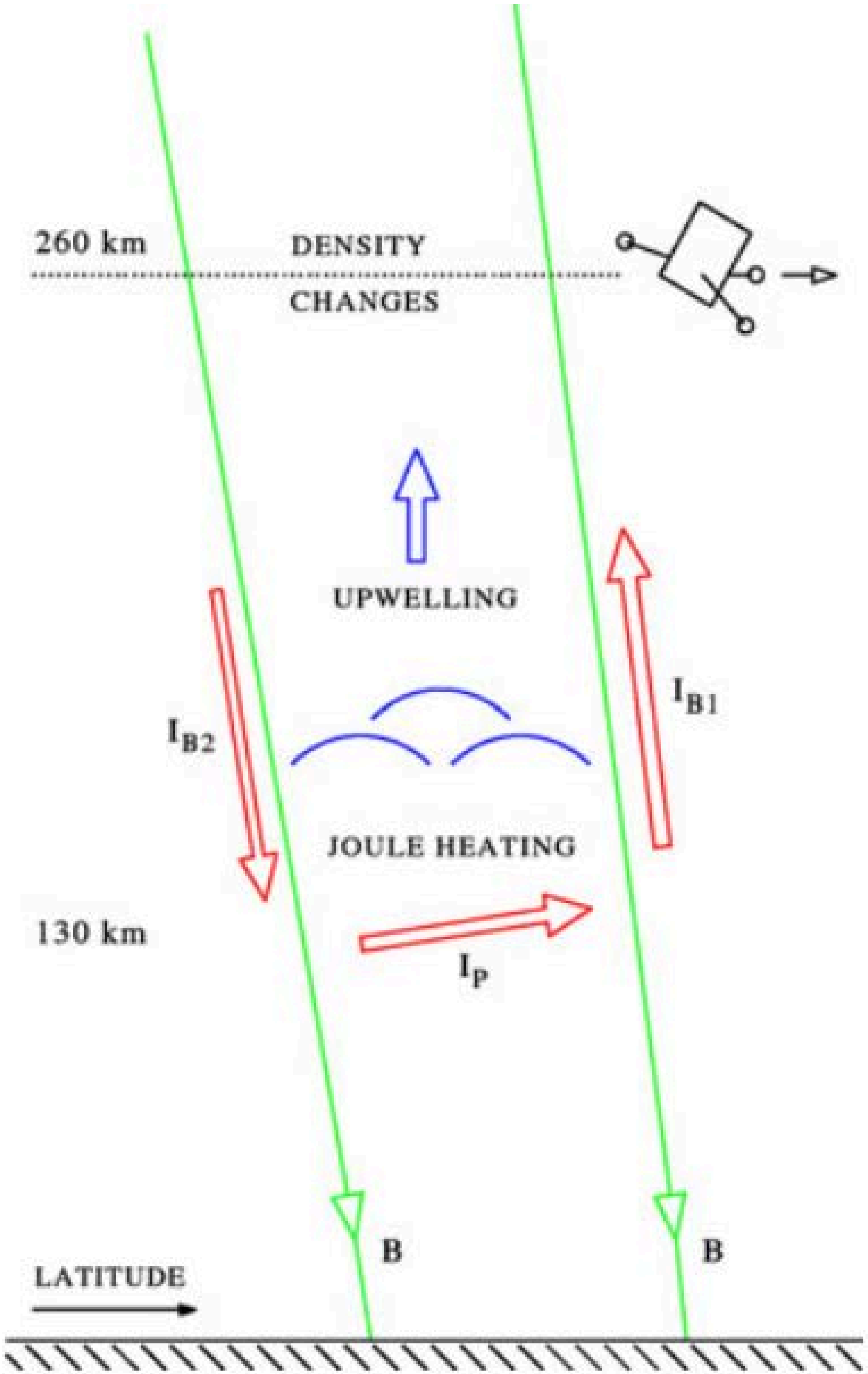
Ionosphere-thermosphere response to geomagnetic storms

Denny Oliveira (GSFC/UMBC), Eftyhia Zesta (GSFC), Peter Schuck (GSFC), Hyunju Connor (GSFC/now at UFA), Eric Sutton (AFRL)

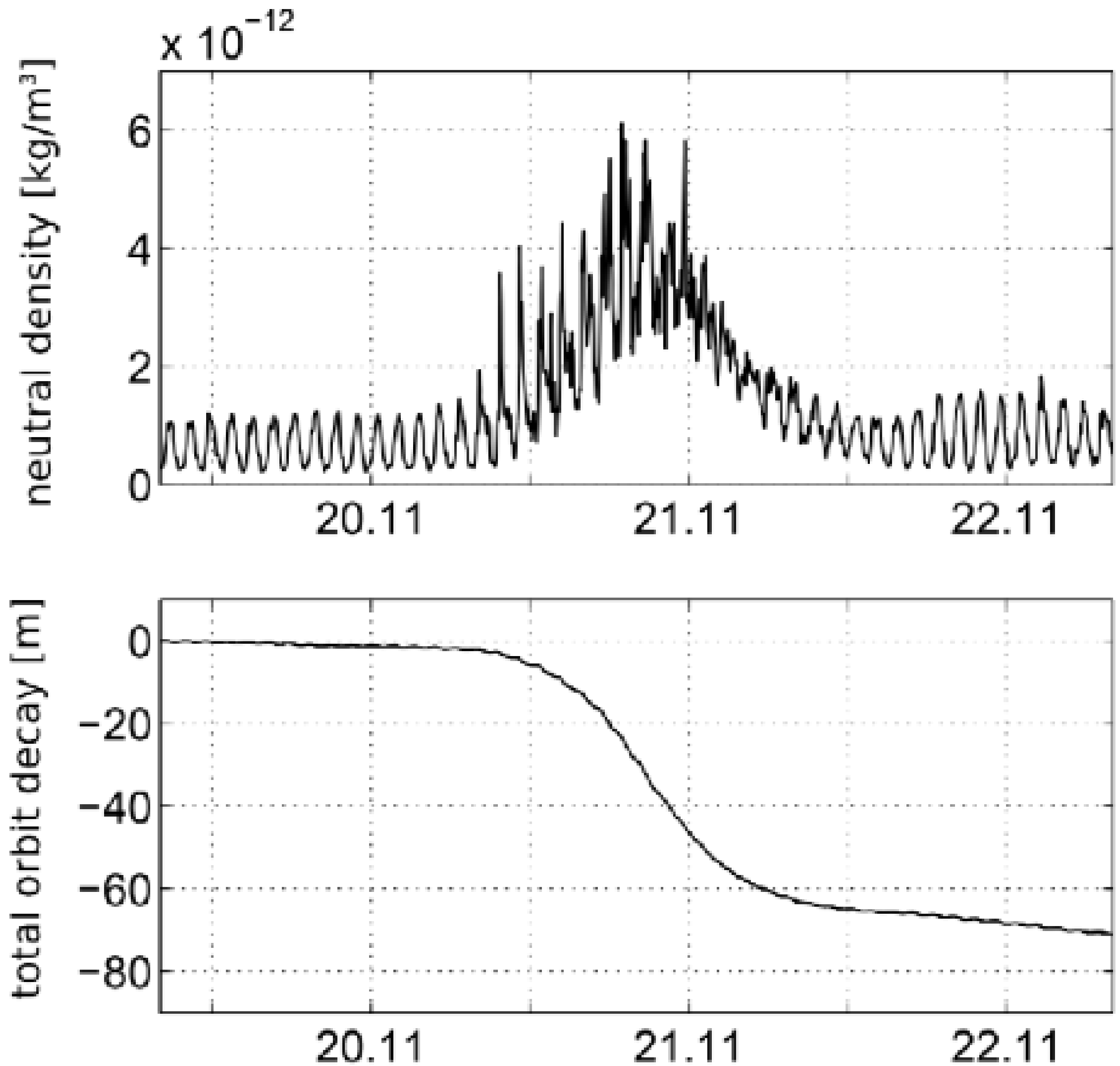
After Prolss [2011]





During intense storms, electromagnetic energy corresponds to up to ~70% of the total energy budget

GRACE satellite orbit decay during the 20 Nov 2003 storm



Density dynamics not captured in models cause satellite orbit prediction errors

IMPACTS:

- **within 72 hrs:**
  - satellite maintenance operations
  - collision avoidance
  - re-entry predictions.
- **within months-yrs**
  - reduce satellite lifetimes
  - on-board fuel usage

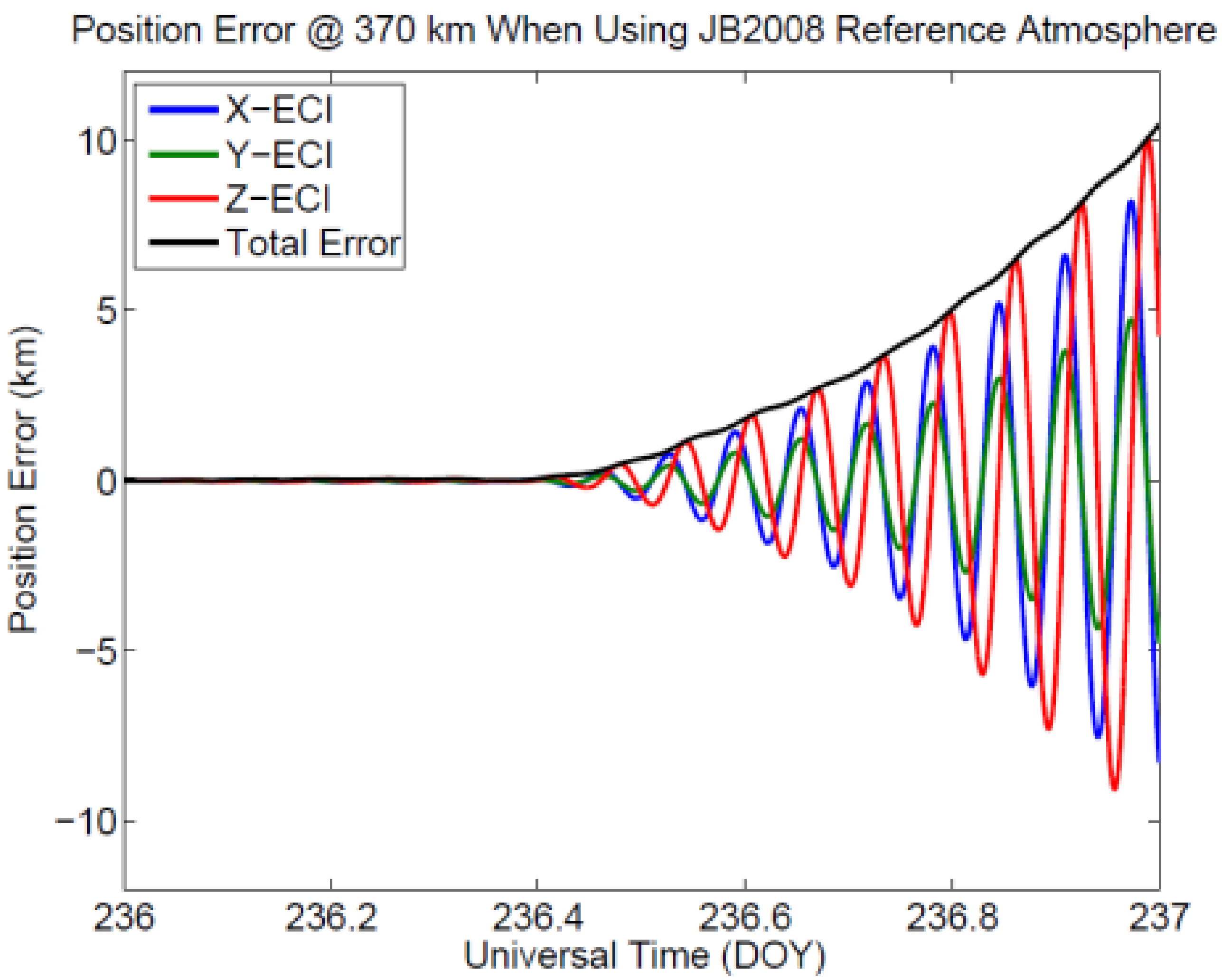
GRACE density data

Krauss et al [2015]

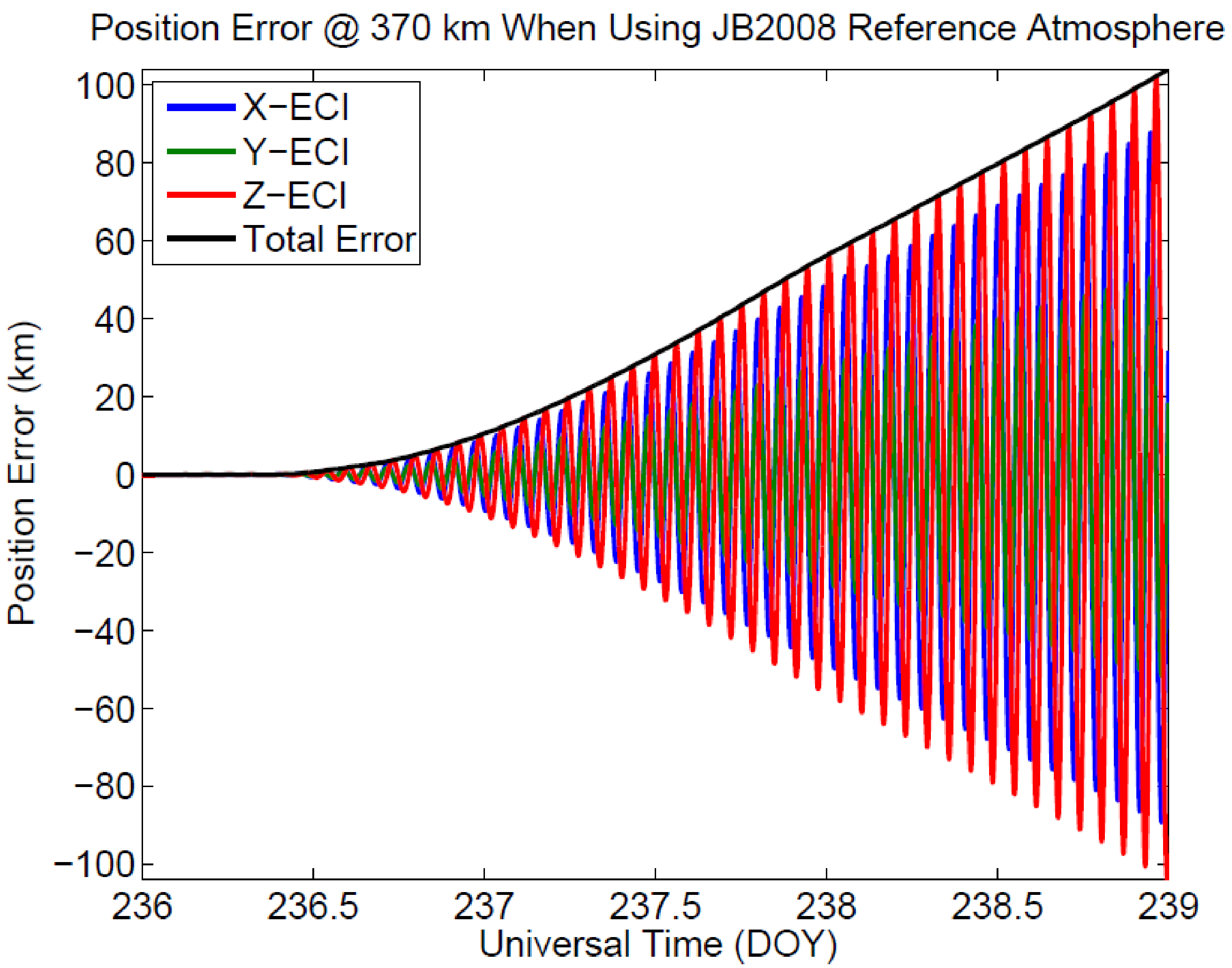
Storm of 24 Aug 2005 drag effects

PREDICTION ERRORS

JB08 error after 12 hrs

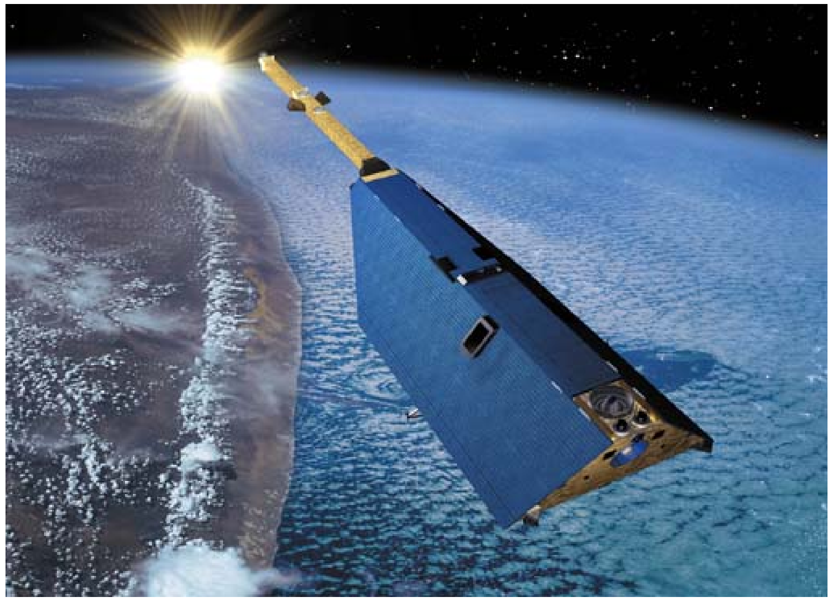


JB08 error after 72 hrs



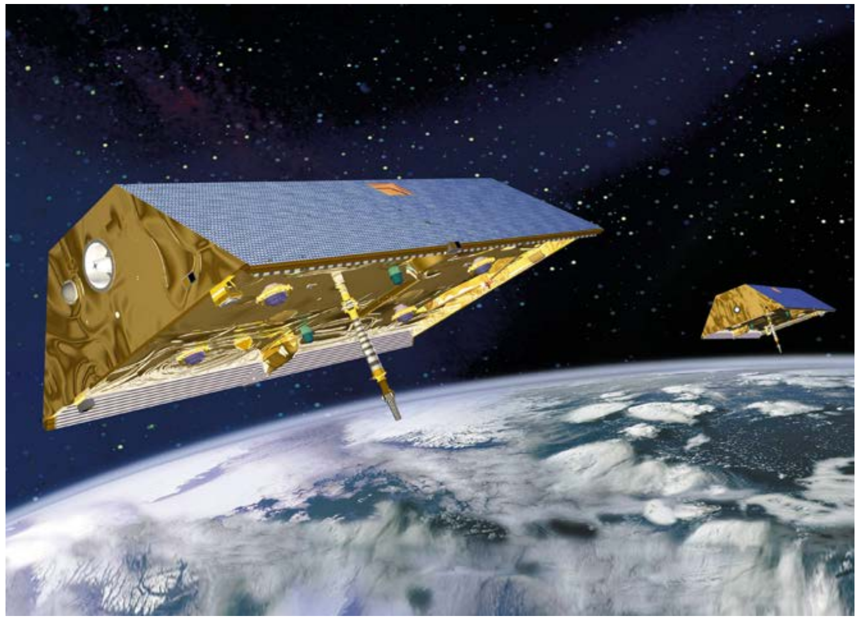
New generation of LEO spacecraft

CHAMP (2001-2010)



H = 456 km

GRACE (2002-present)



H = 500 km

Accelerometers

$$\boldsymbol{a} = -\frac{1}{2}\rho\frac{C_D}{m}A_{\text{eff}}V^2\boldsymbol{v}$$

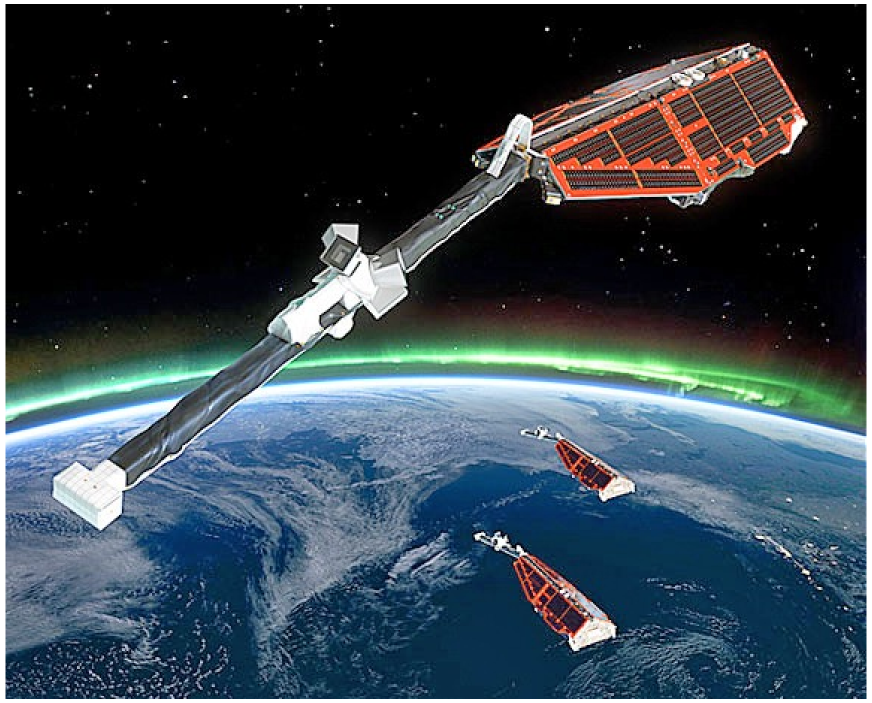
High-level density data

New storm time models

GOCE (2009-2013)

H = 255 km

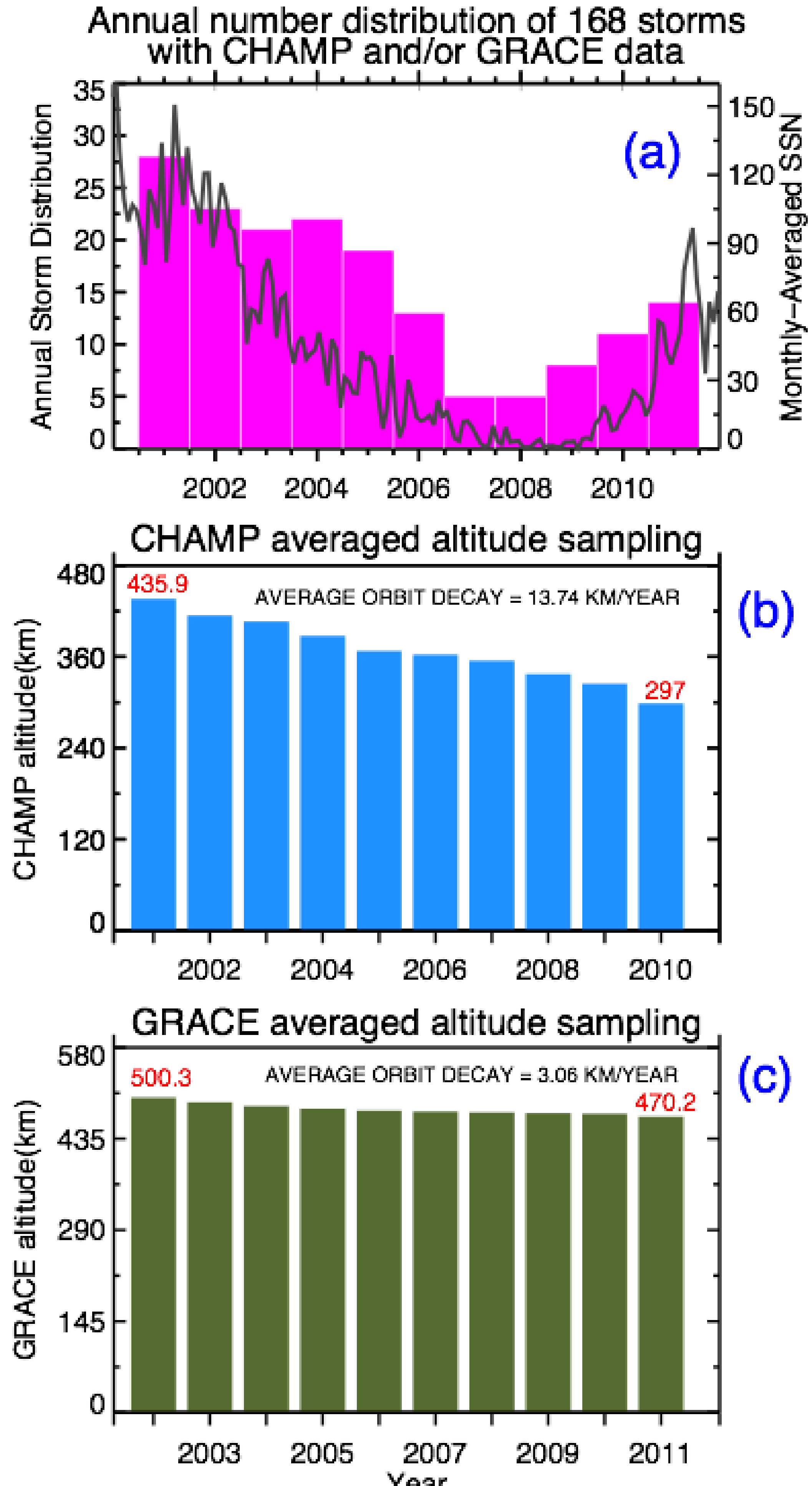
SWARM (2013-present)

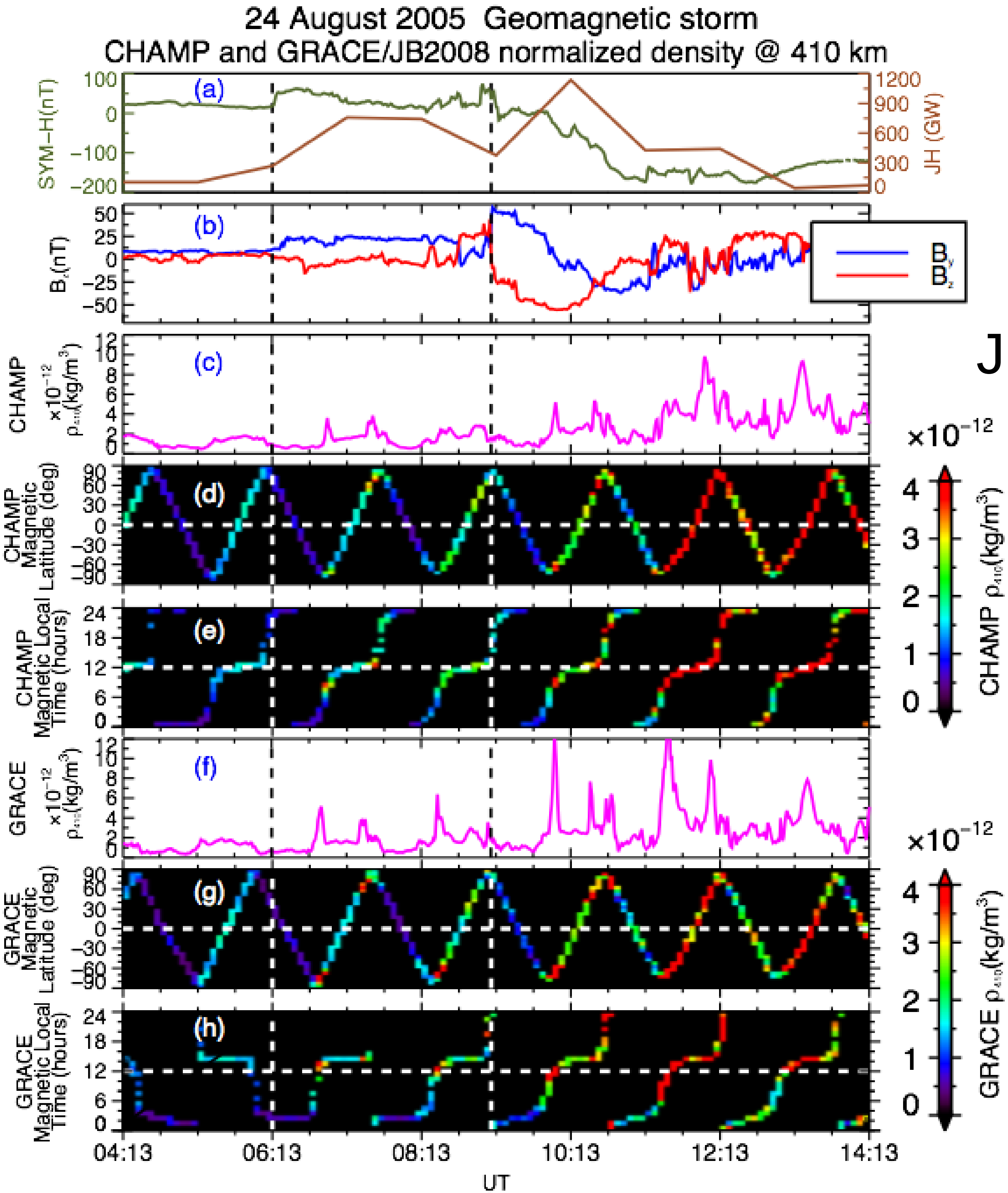


H = 450-530 km

SOHO/LASCO C2 CME images

Superposed epoch analysis with 168 storms caused by CMEs from 2001-2011





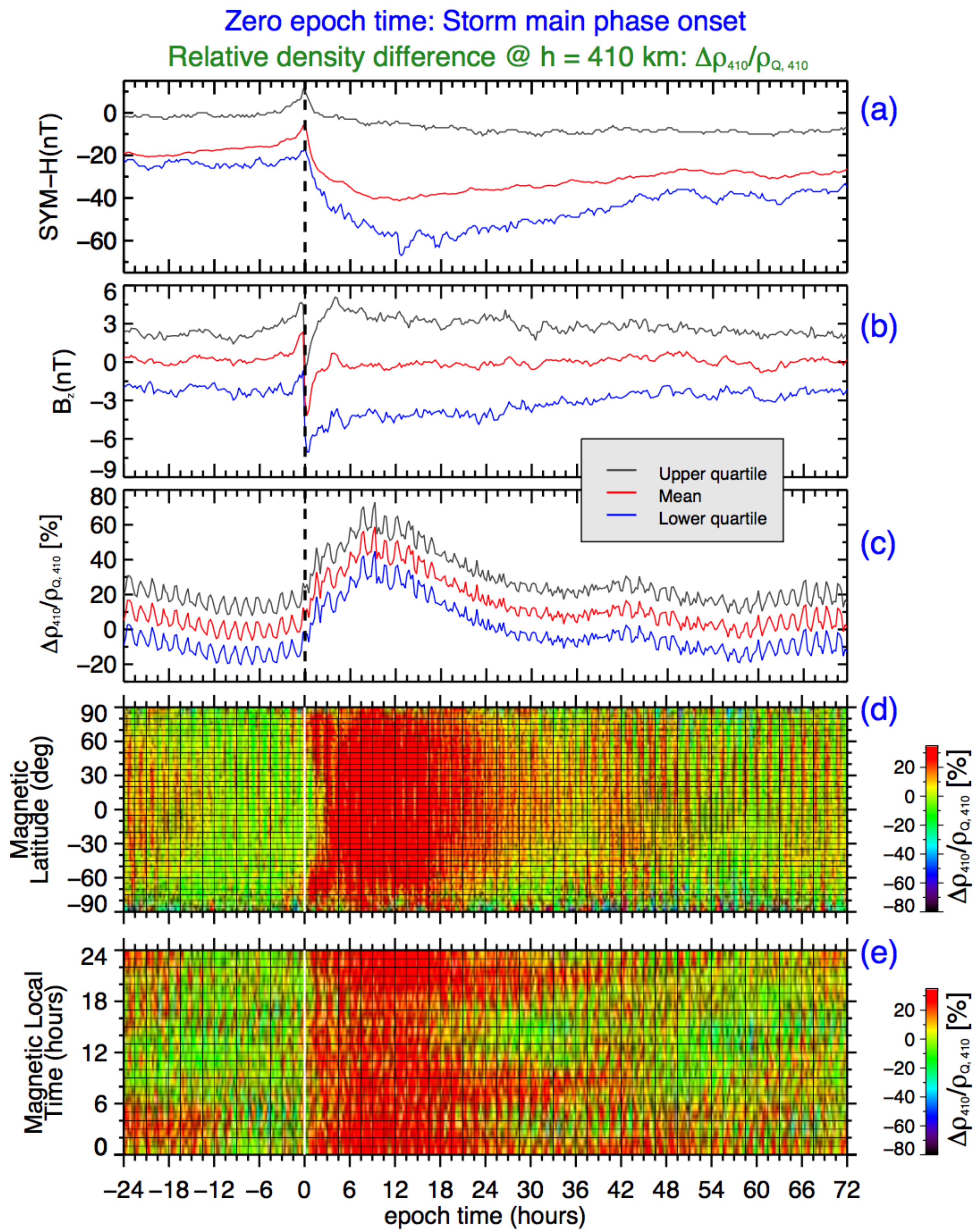
Example of an event

JH: Knipp et al. [2004] model

By (blue)
Bz (red)
OMNI data

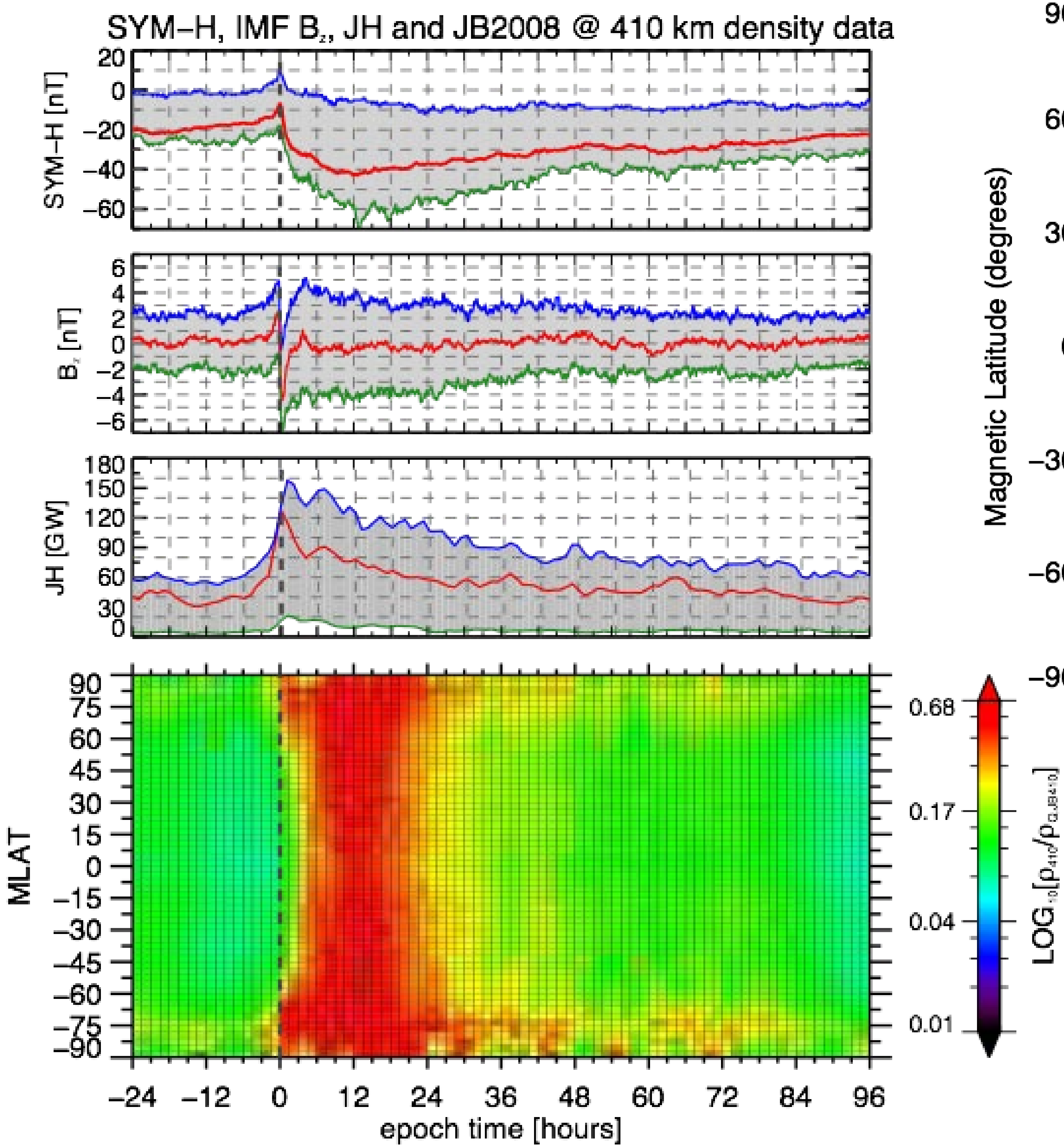
$$\rho_{410} = \frac{\rho_{JB410}}{\rho_{JB}} \times \rho$$

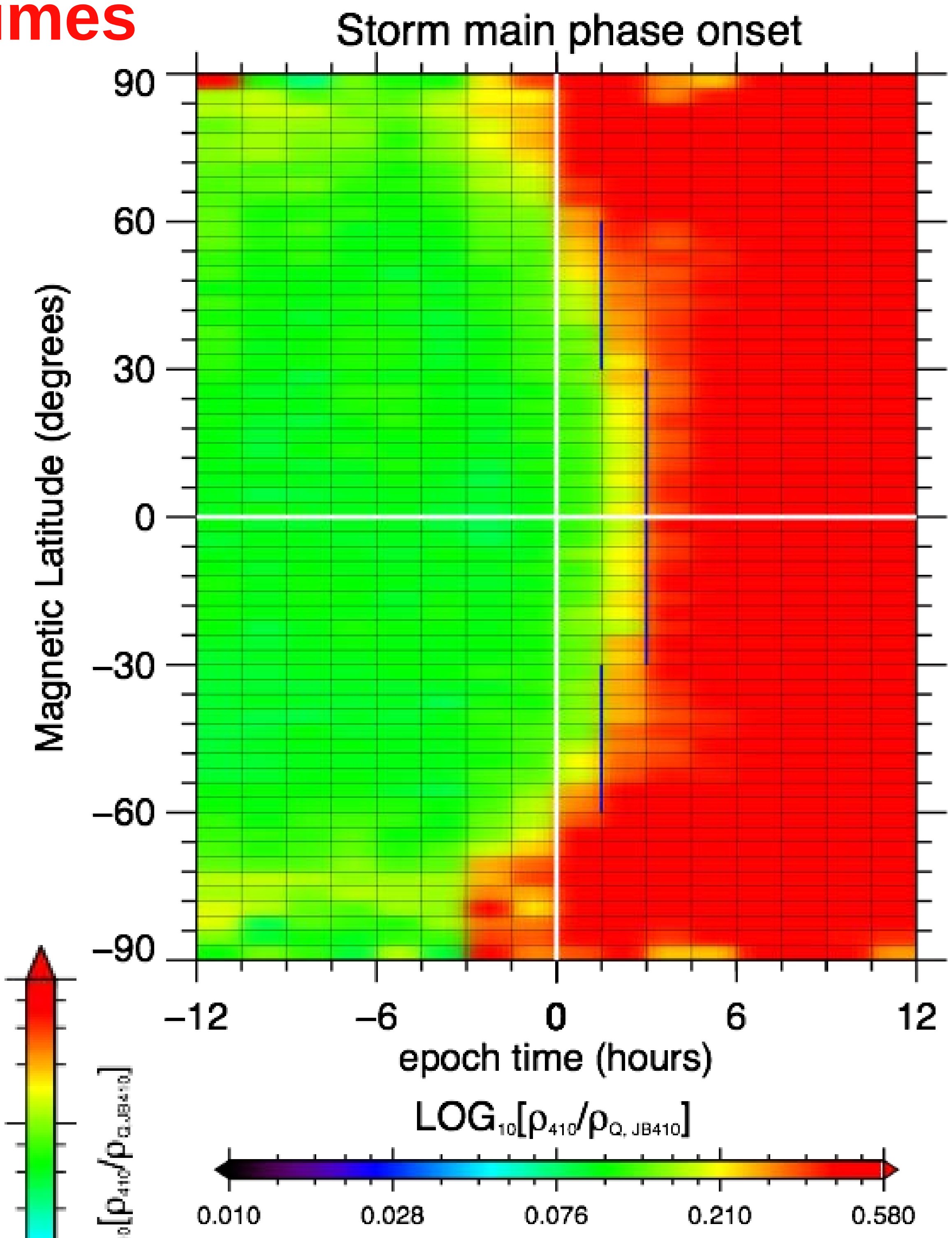
slide

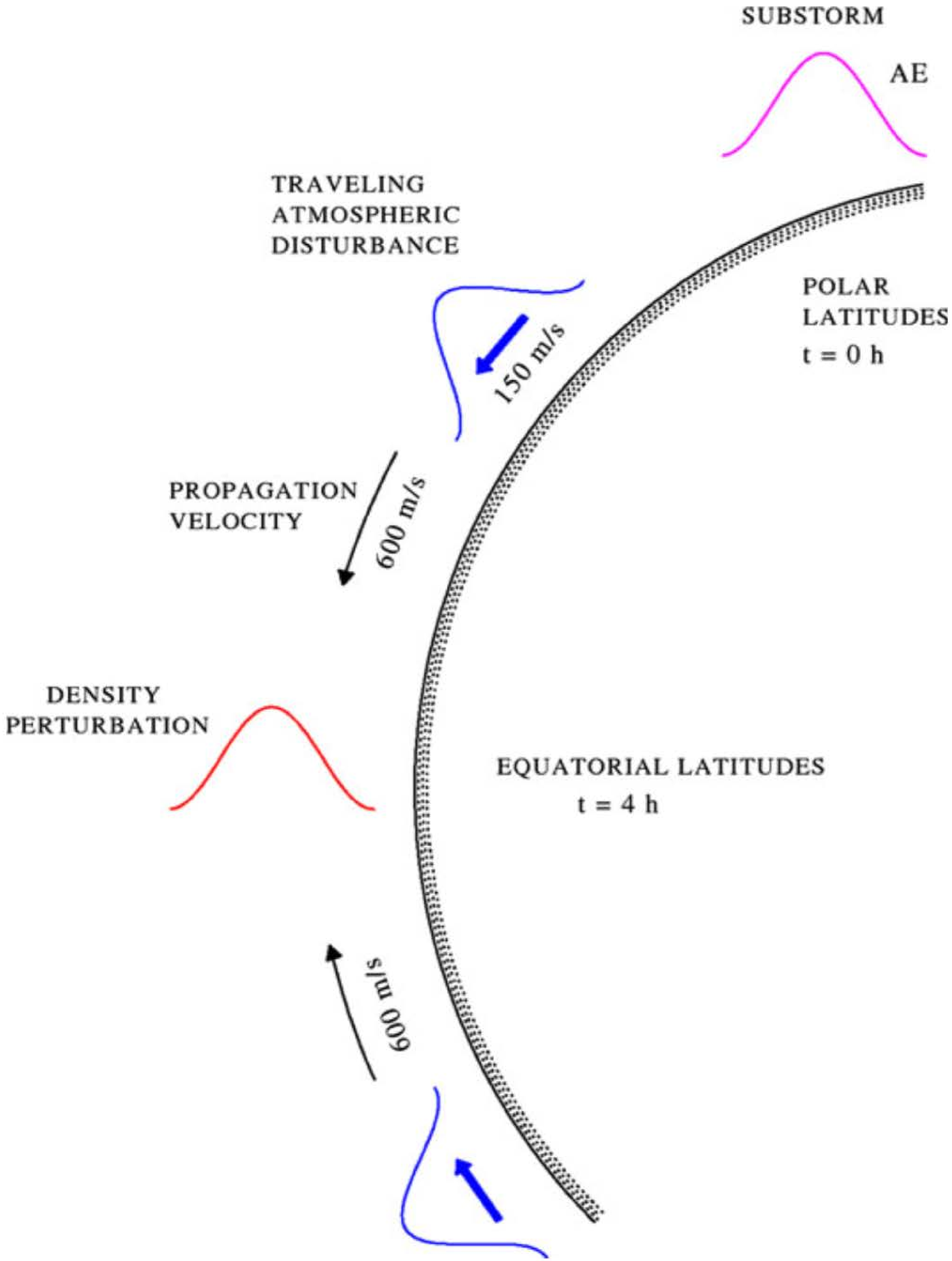


Zero epoch time: Storm main phase onset
Relative density difference @ h = 410 km: Δρ410/ρQ, 410
SYM−H(nT)
(a)
Bz(nT)
(b)
Upper quartile
Mean
Lower quartile
Δρ410/ρQ, 410 [%]
(c)
Magnetic Latitude (deg)
(d)
Magnetic Local Time (hours)
(e)
epoch time (hours)

First superposed epoch analysis study of thermosphere response during storm times







TADs - traveling atmospheric disturbances [Prolss, 1997]

Highly correlated with solar activity

Responsible for the global transport of perturbations from auroral to equatorial regions

Dayside TADs are quickly dissipated through ion drag; ightside TADs propagate farther away from high latitude regions Richmond and Matsushita, 1975]

[Bruinsma and Forbes, 2007]

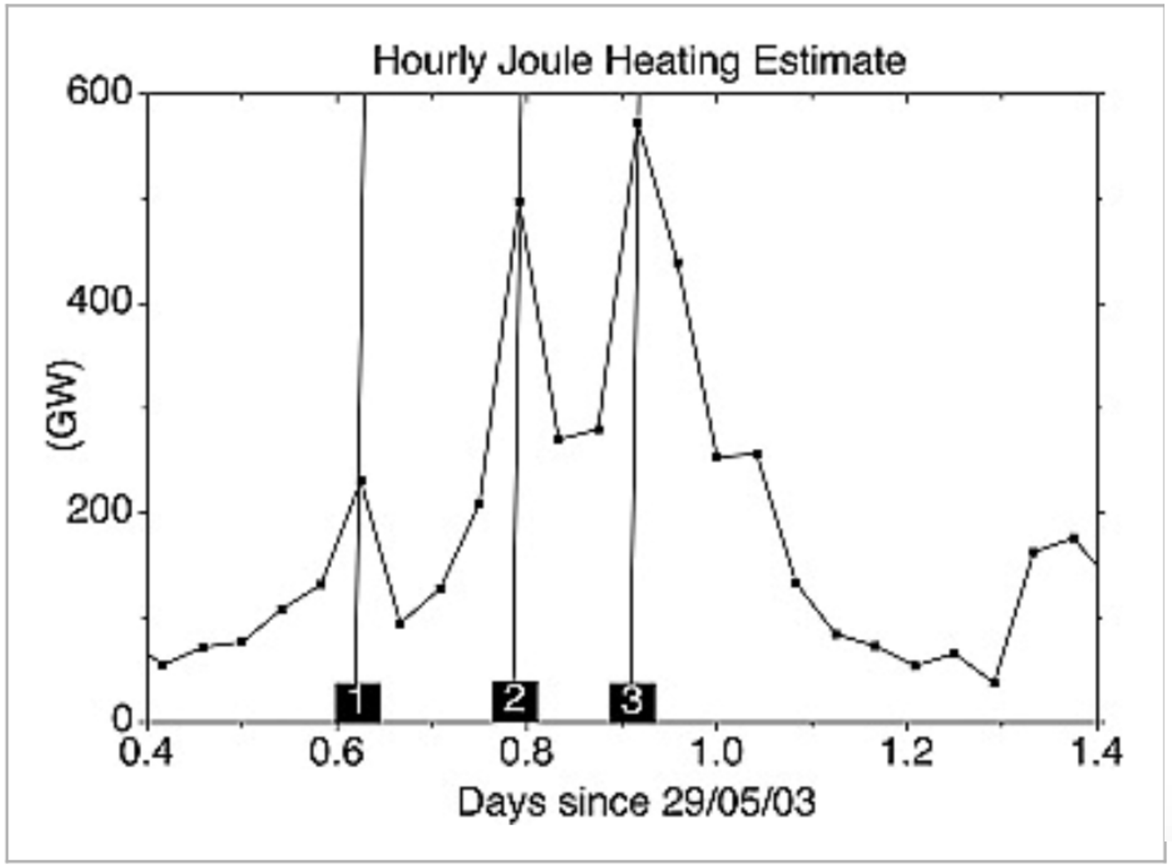
CHAMP observations of TADs

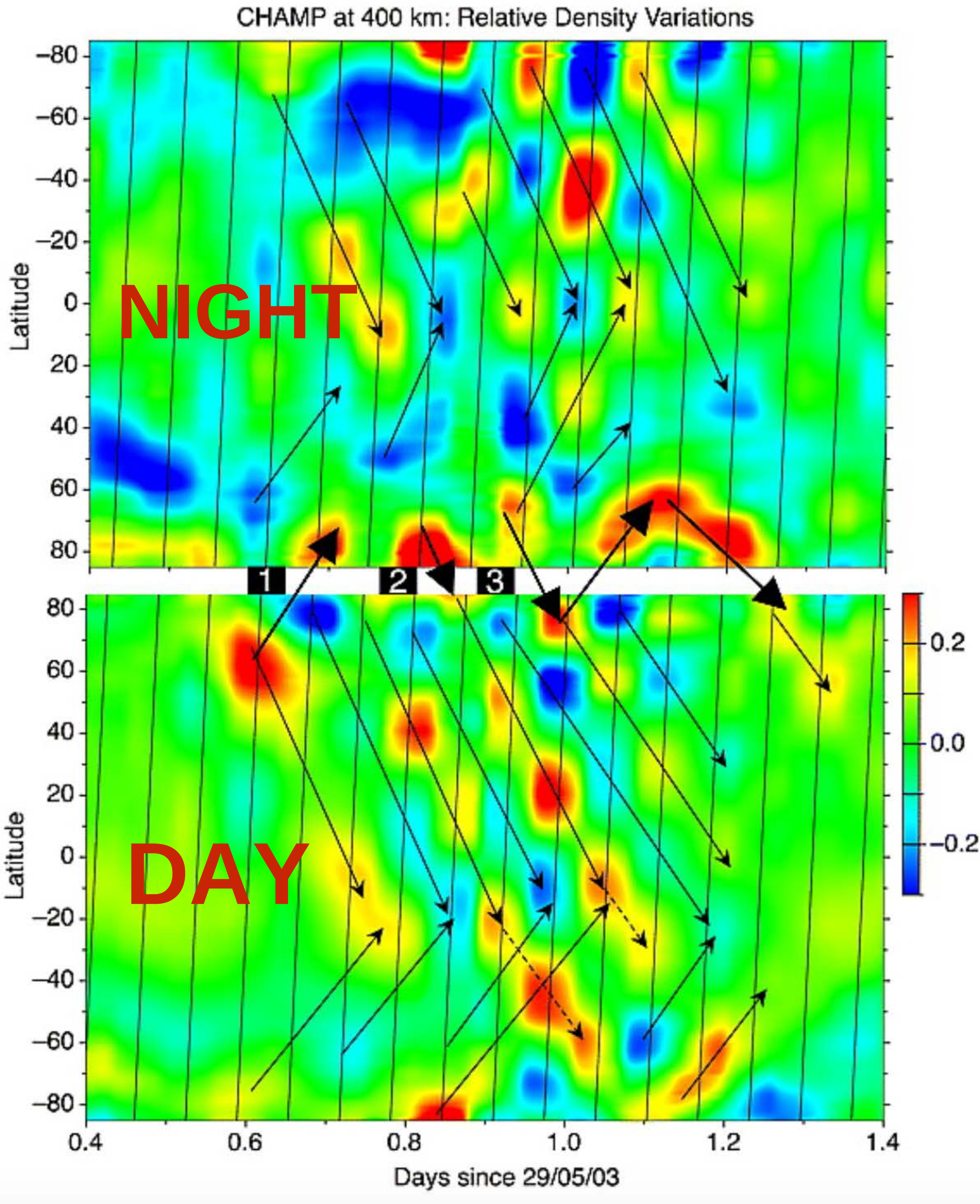
Daytime wave structures with speeds o

730 m/s (NH, summer)

460 m/s (SH, winter)

Inter-hemisphere TAD propagation





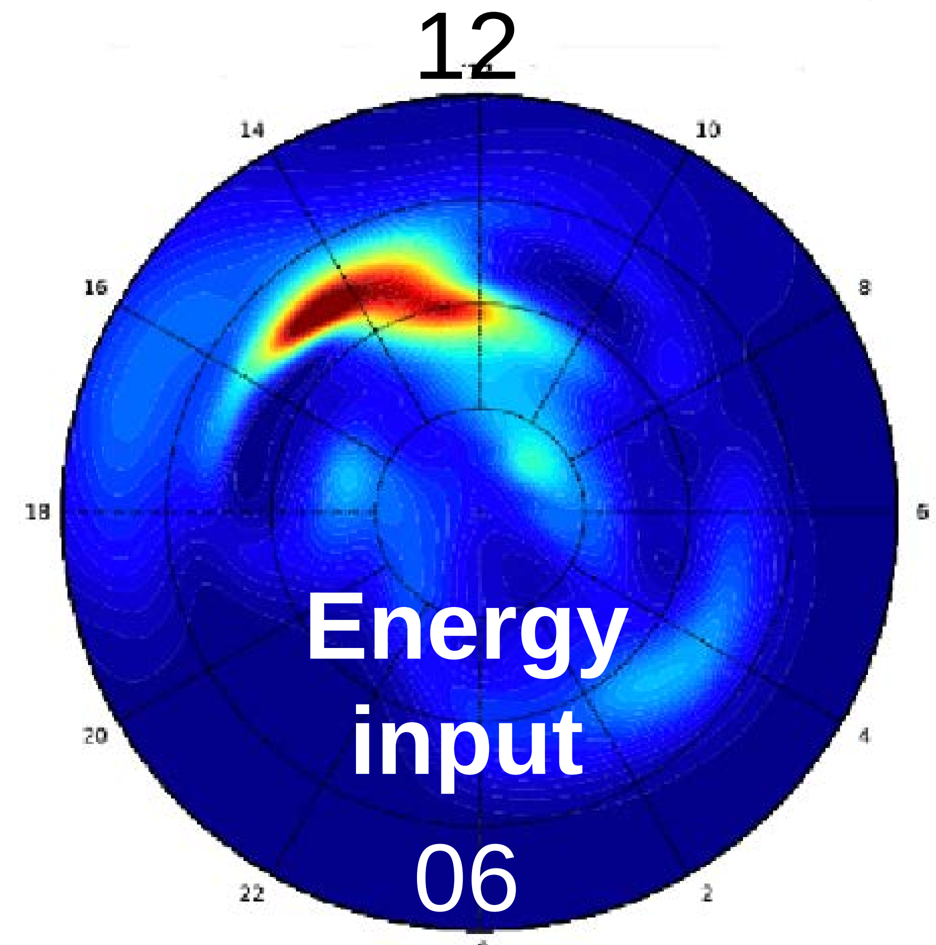
Conclusions

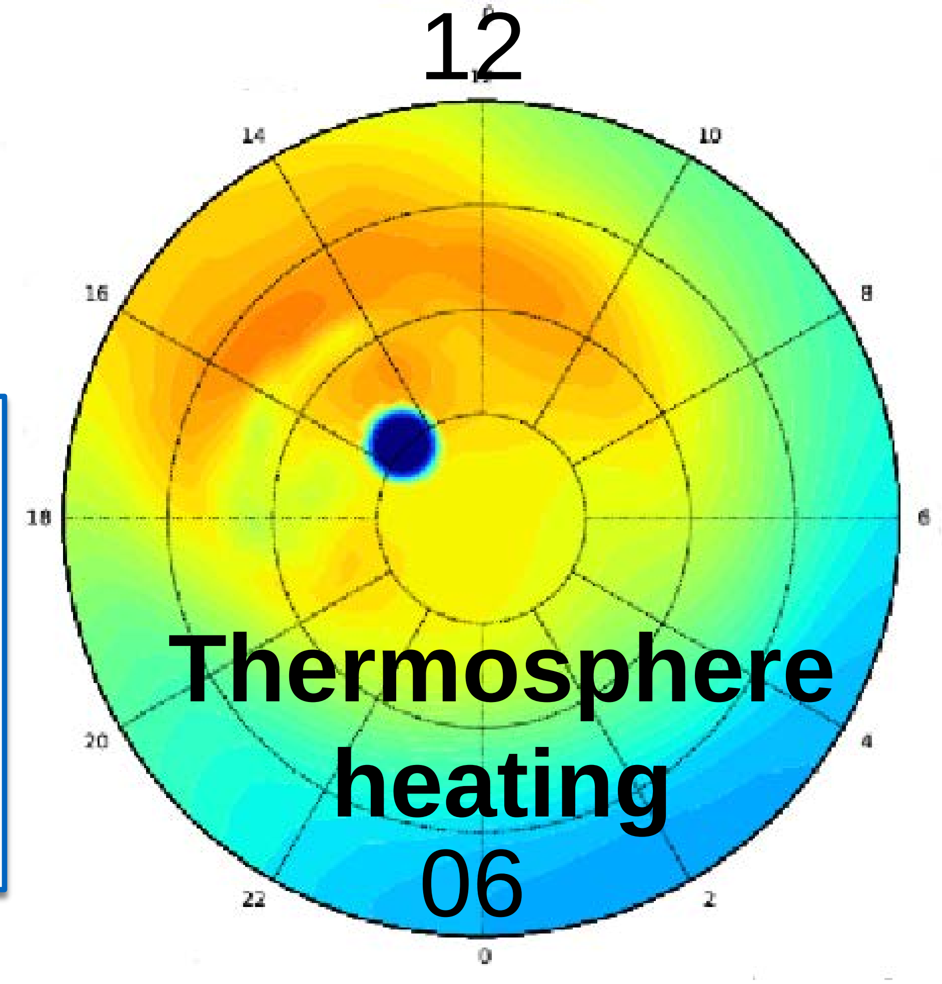
- ✦ Thermosphere density variations are the major contributor to satellite orbit prediction errors

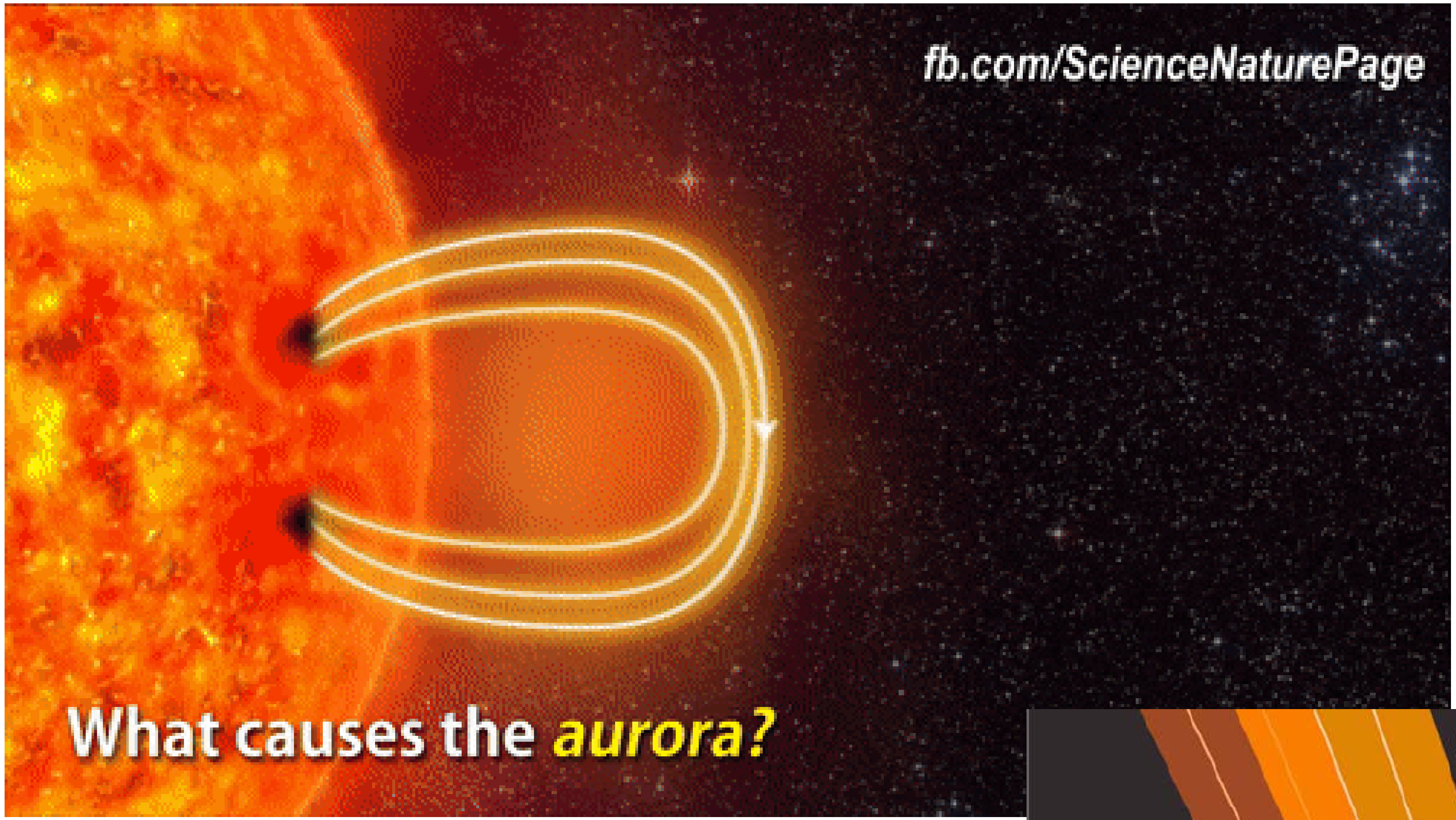
- ✦ Density enhancements are immediate (within minutes), strong and localized at high latitudes in the first hrs during geomagnetic storms.

- ✦ Globalization of the thermosphere response occurs in ~3 hours after storm main phase onset

We are creating new storm epoch empirical models that will ultimately provide the global density structure through storms in high time cadence.

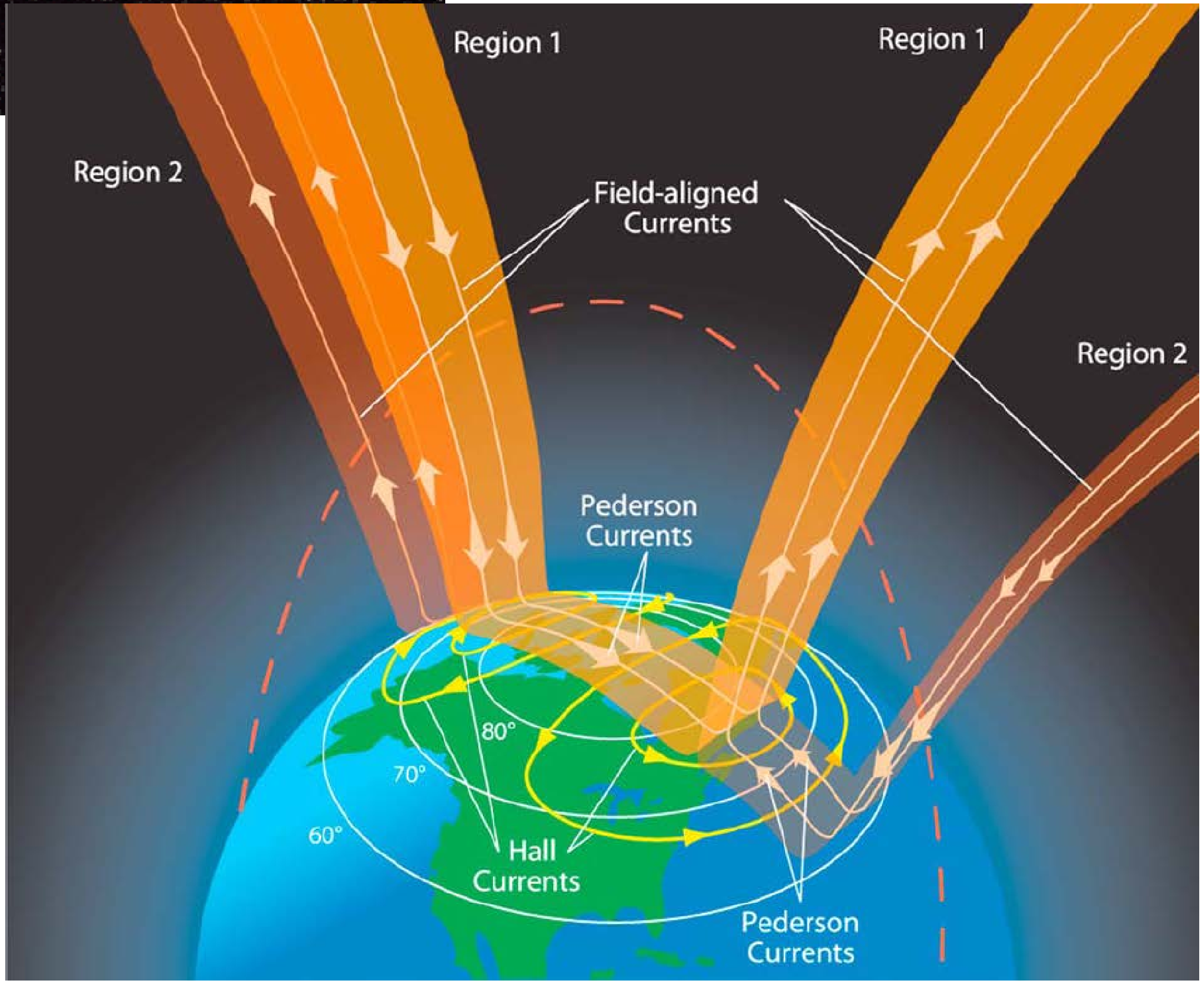


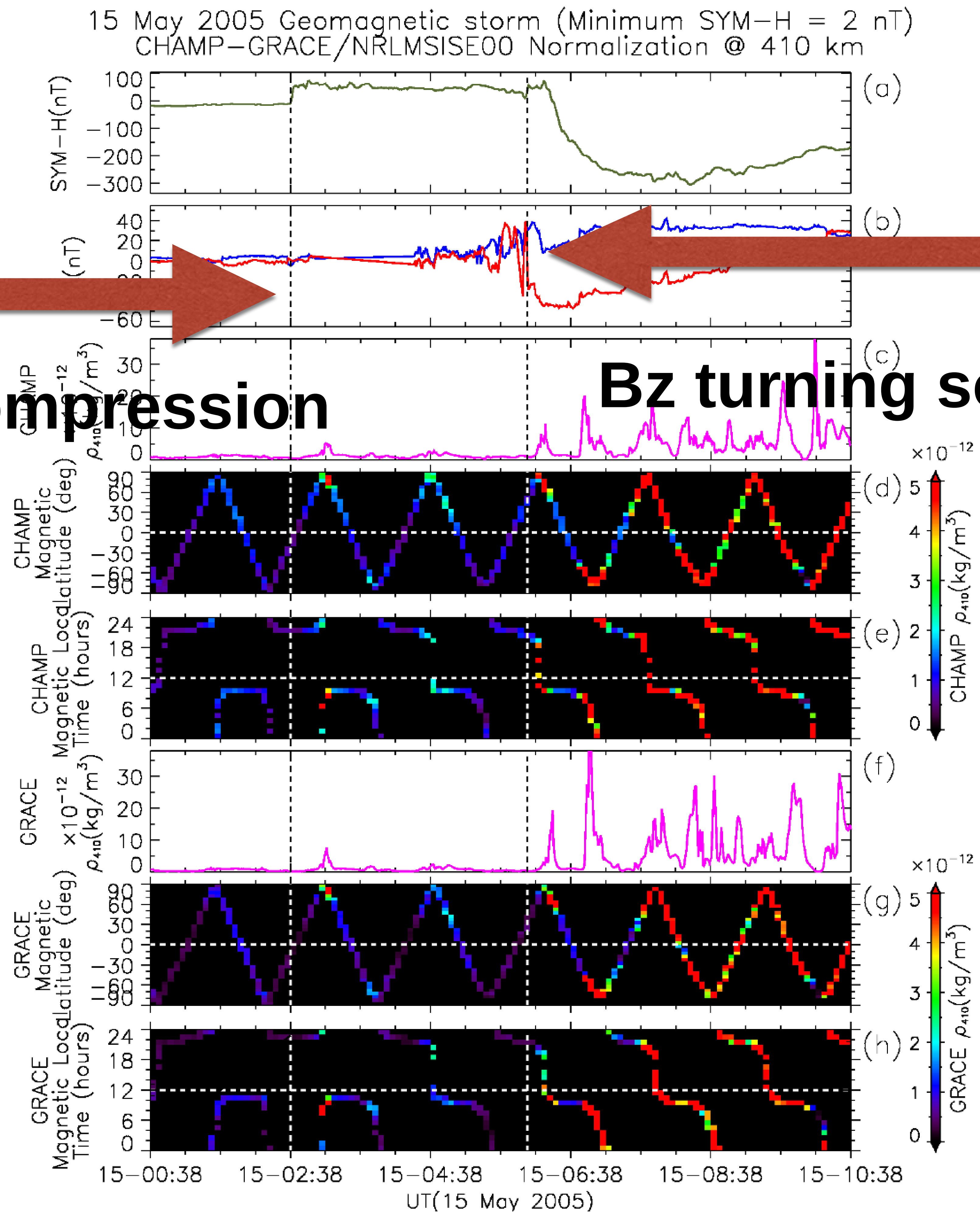




Energized plasma convects from magnetotail to the ionosphere high latitude regions

This convection pattern creates the flow of electric currents that dissipate energy through ion/neutral collisions that heats the atmosphere





a shock/compression

Bz turning southward

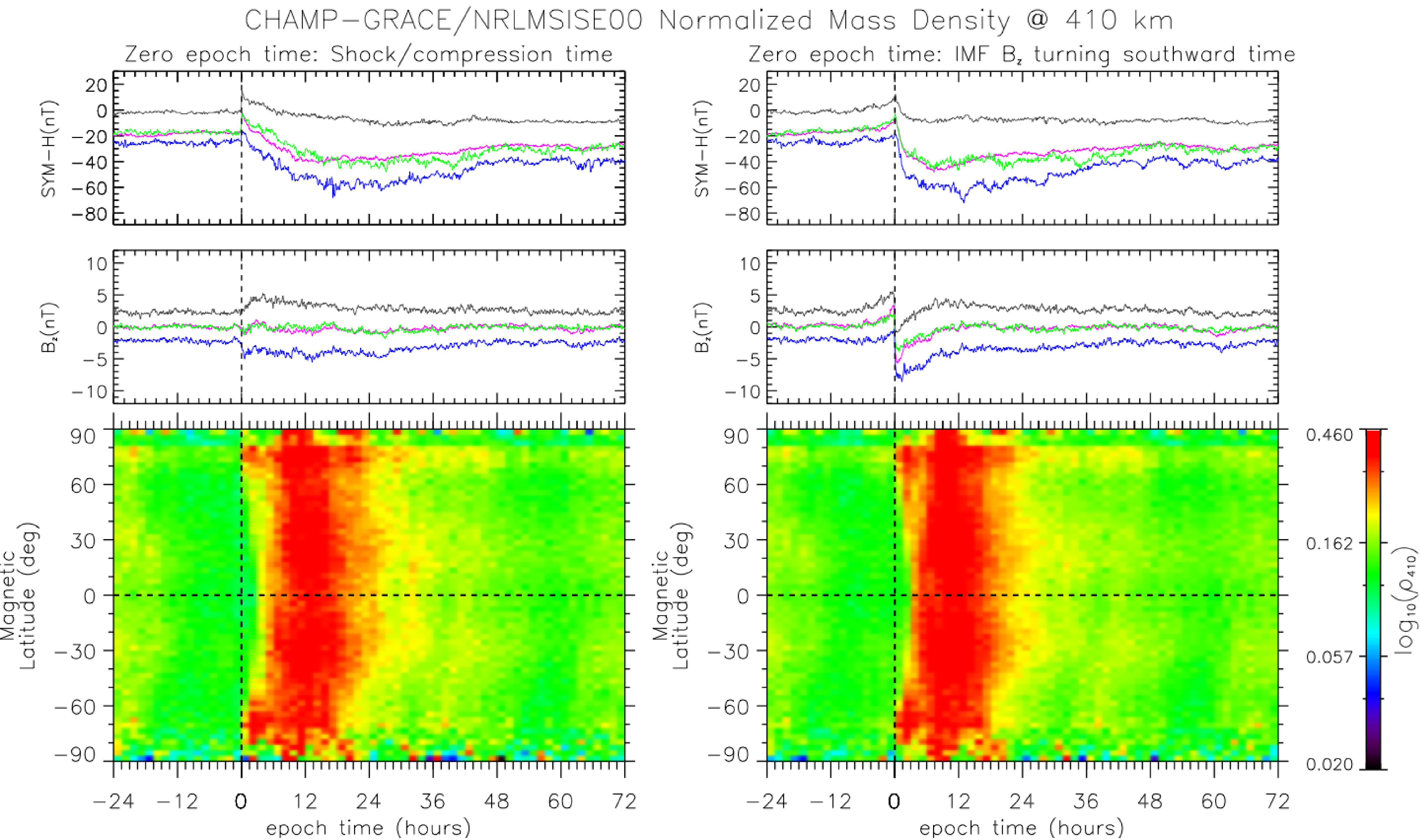
Satellite coverage is limited

UT: 5-min bins

MLAT: 5-degree bins

$$\rho_{410} = \rho_\mathrm{h} \frac{\rho_{410}^\mathrm{MSIS}}{\rho_\mathrm{h}^\mathrm{MSIS}}$$

MLAT: 3- degree bins, Epoch time: 90-minute bins



MLAT bin size: 90 minutes (~ SAT orbital period)