Energy Transfer to the Coupled Ionosphere –Thermosphere (IT) During Magnetic Storms

Cheryl Huang[1], Yanshi Huang[2], Yi-Jiun Su[1], Eric Sutton[1], Marc Hairston[3], and W. Robin Coley[3]

[1]AFRL

[2] U. New Mexico

[3]U. Texas at Dallas

Acknowledgments: Eelco Doornbos[1], Yongliang Zhang[2]

[1] ESA

[2] APL

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GEM-CEDAR 1 - Modeling Challenges in the auroral zone

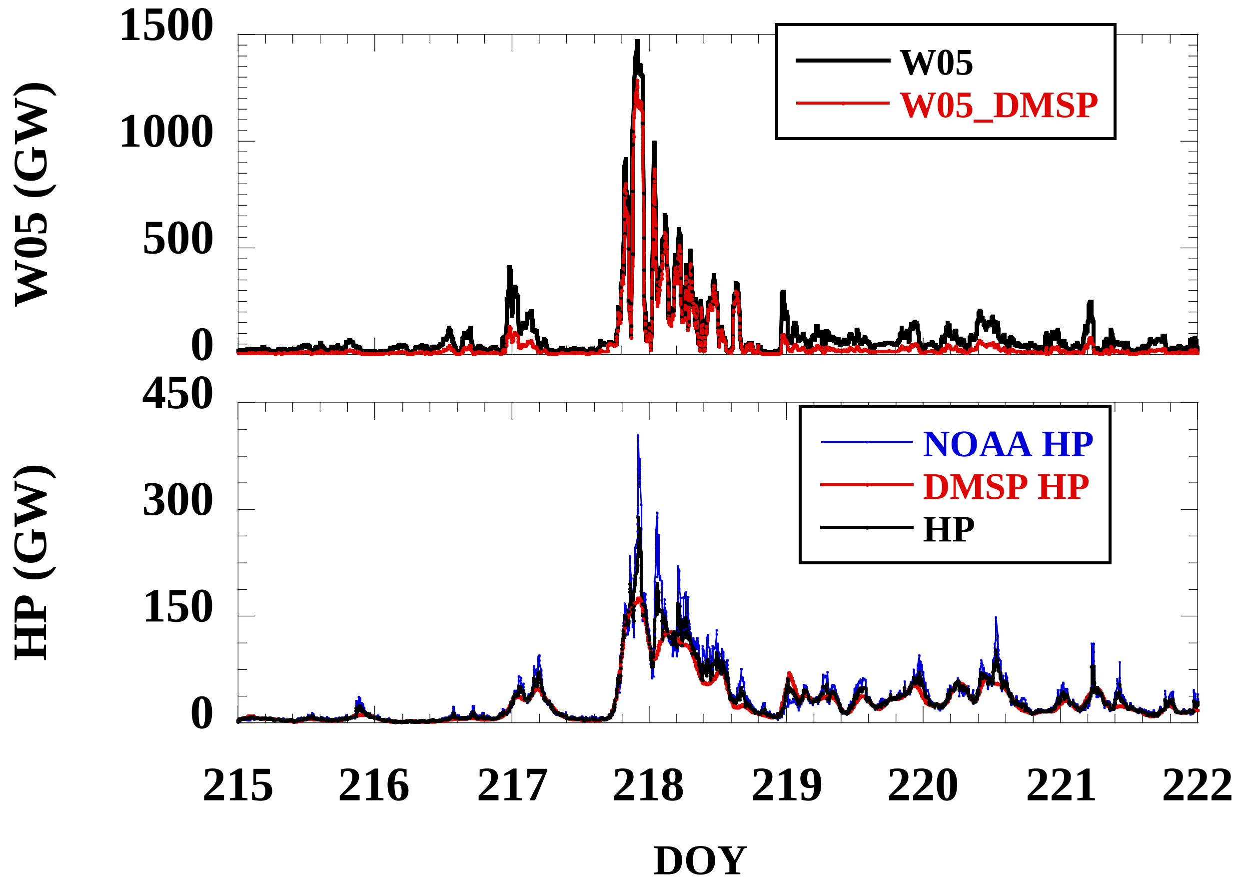
14 December 2014

Stormtime Energy

Where does it come from, where does it go?

- Energy input into IT system assumed to occur primarily in auroral zone. Is this justified by observations of energy flow?
- Dominant form of energy input is electromagnetic, i.e. Poynting flux. This can only interact with charged particles, not neutrals.
- Analyze observations of ion temperature, T_i from DMSP.
- Compare energy input with T_i and neutral densities measured by GRACE, GOCE.
- Analyze O/N_2 ratio (proxy for thermospheric Joule heating) and compare with direct measurements of neutral densities.
- Compare observations of (1) energy input (Poynting flux); (2) energy dissipation by Joule heating of ions; (3) energy dissipation by Joule heating of neutrals.

Comparison of Poynting Flux with Particle Precipitation During August 2011 Magnetic Storm



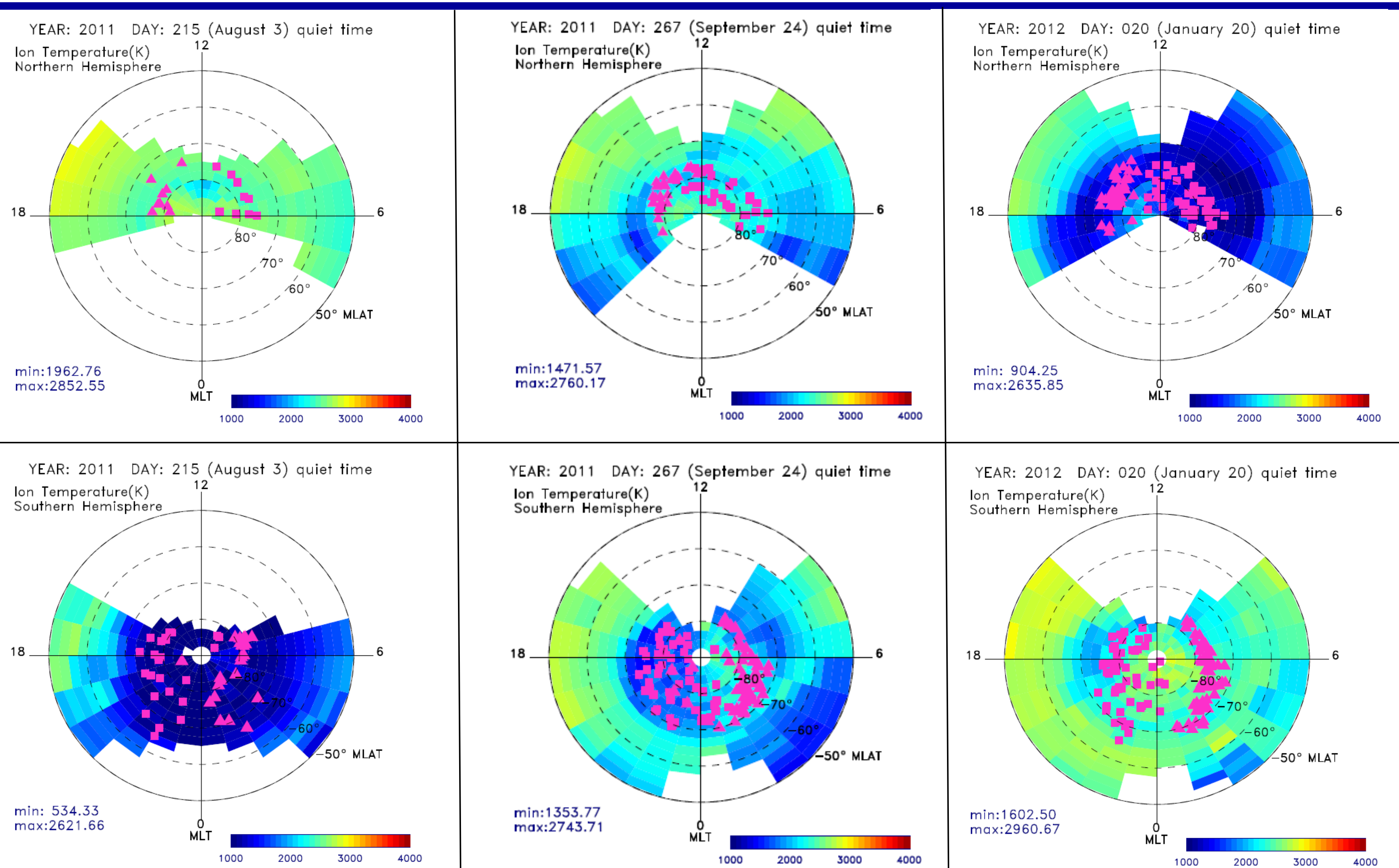
Poynting flux from Weimer model (W05), Poynting flux from Weimer model scaled by DMSP observations (W05_DMSP)

Hemispheric power (HP) from NOAA and DMSP models

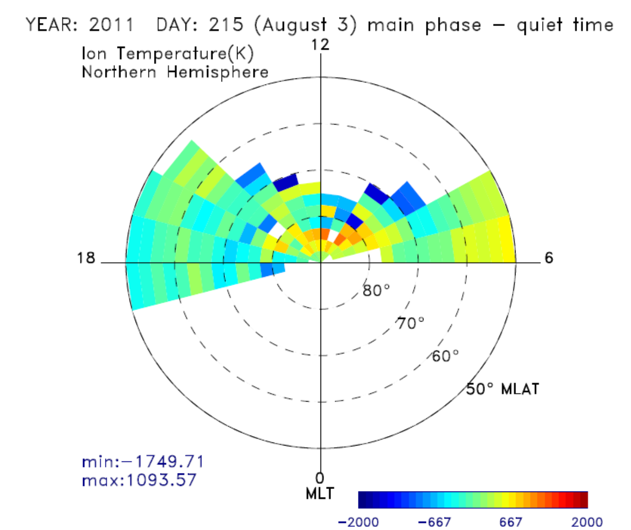
Dominant form of energy input is electromagnetic - Poynting flux

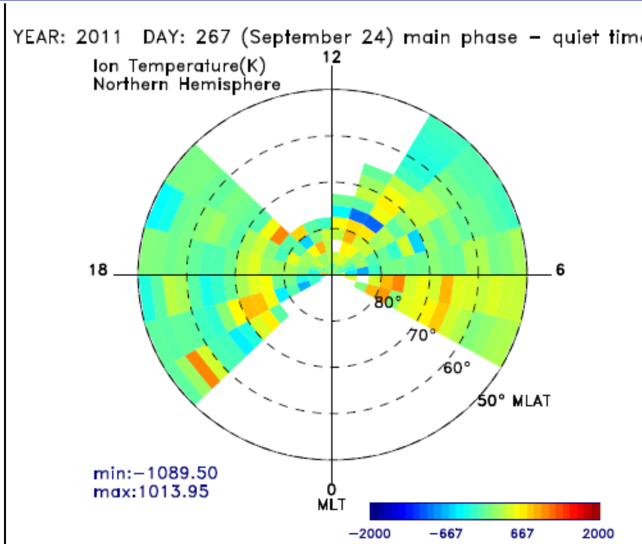
DMSP T_i Observations

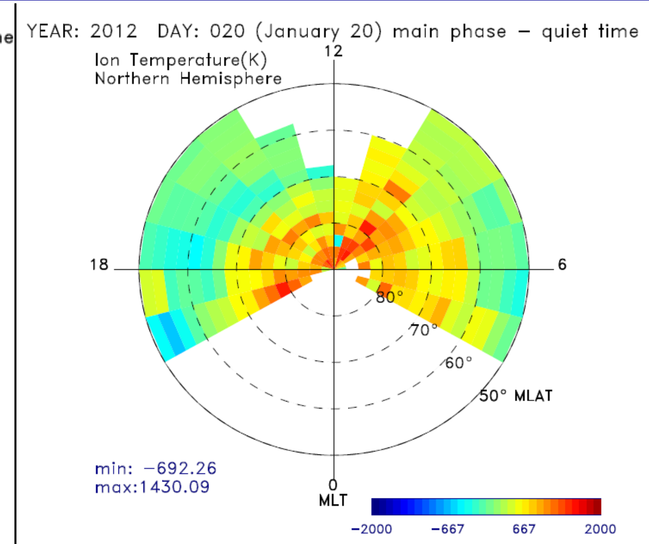
(1) Pre-Storm T_i

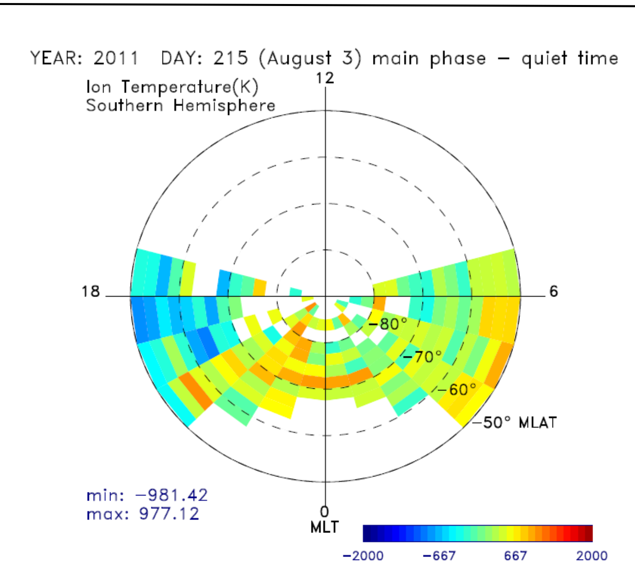


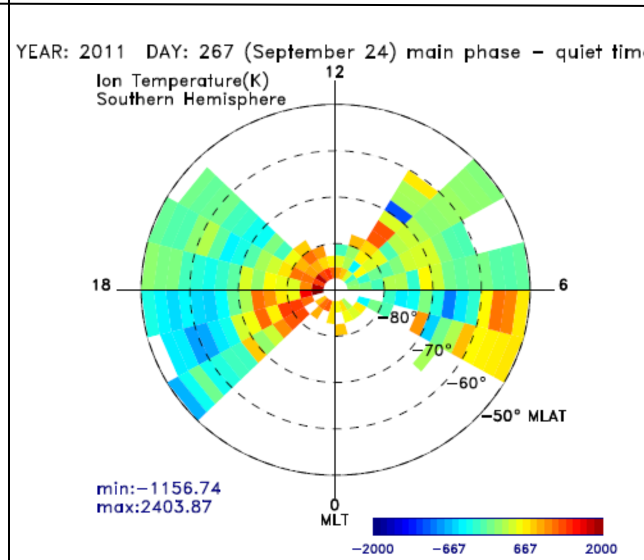
(2) Change in T_i at end of Storm Main Phase

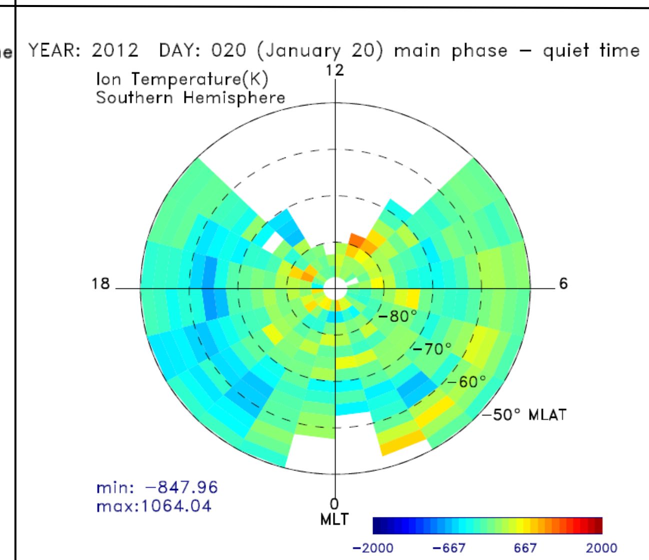






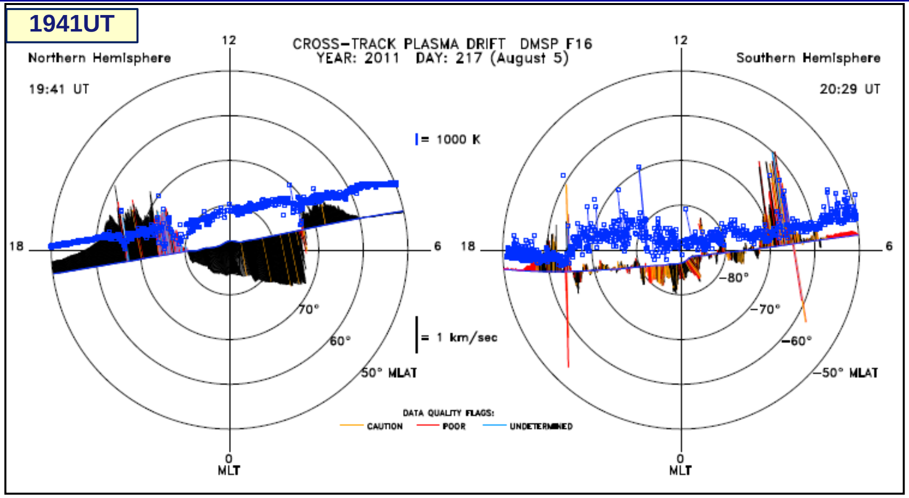


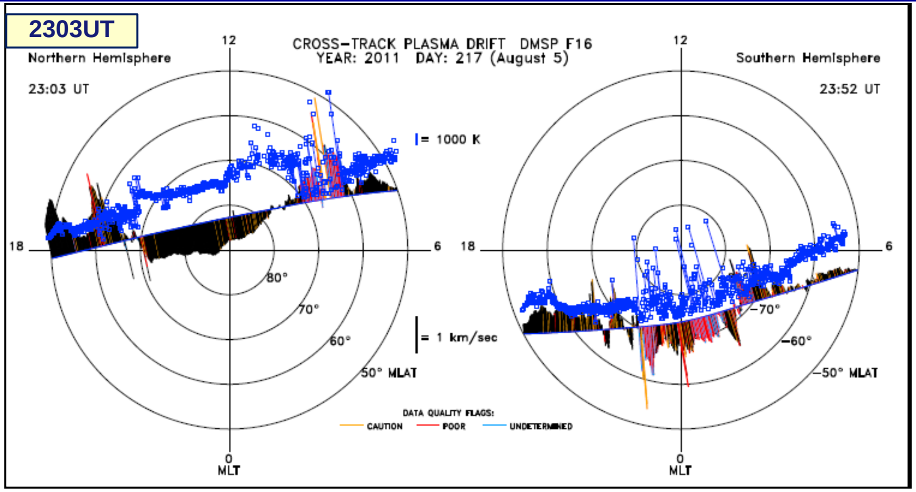


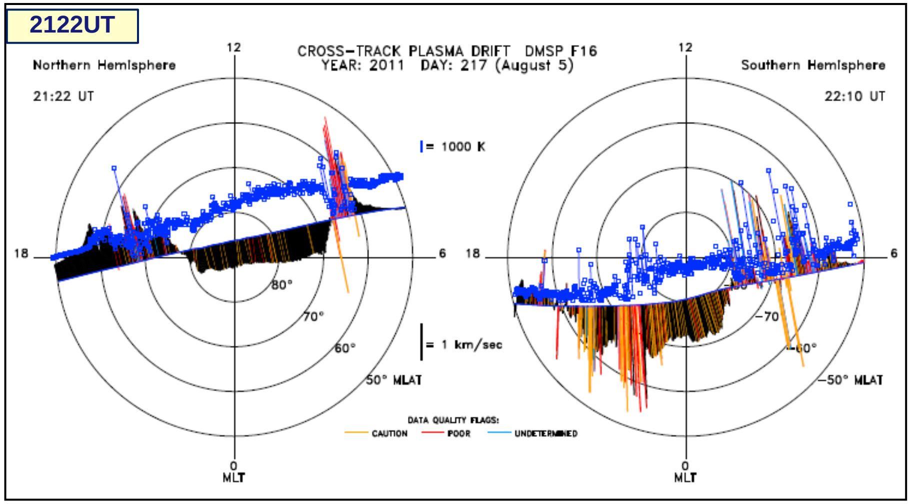


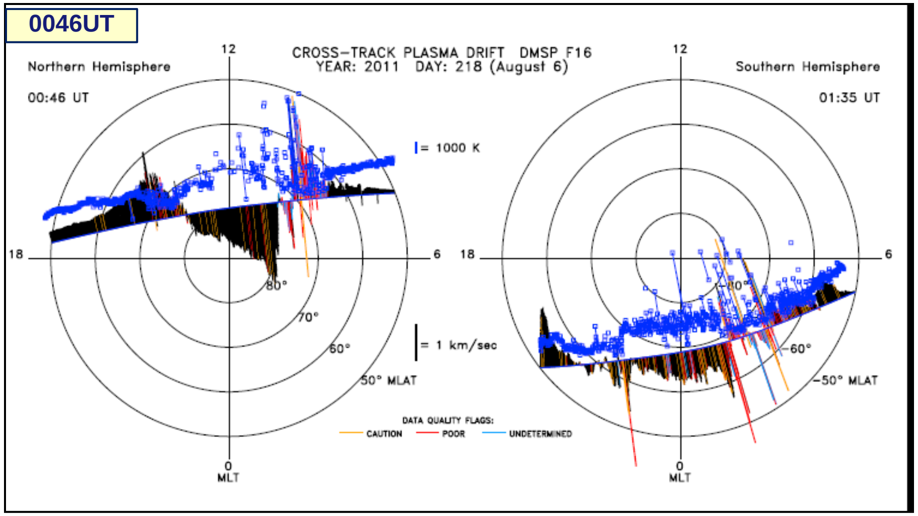
DMSP T_i during August 2011 Magnetic Storm

Onset at 1906 UT, 5 August 2011





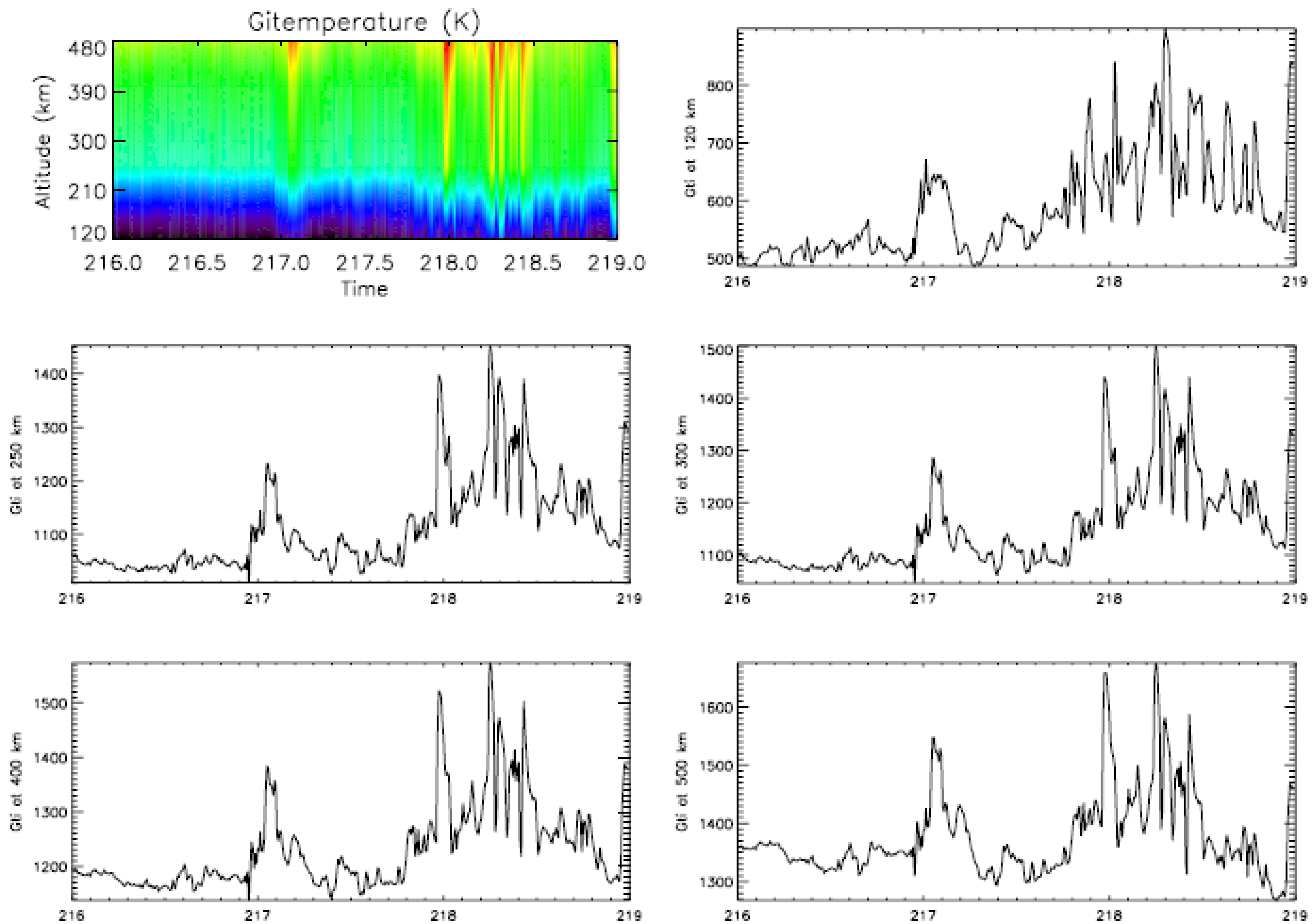




Note T_i increase in antisunward flow region, sharp drop in T_i at convection reversal boundary
T_i in polar cap increases from 2655K to 3270 K; T_i in auroral zone is relatively constant at 2000-2300K

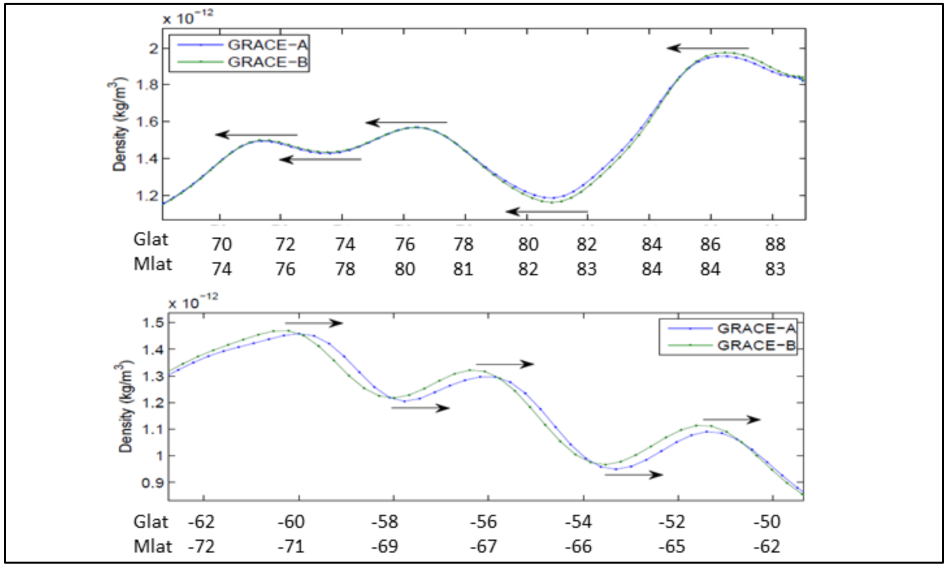
TIEGCM results for August 2011 storm

T_i as function of altitude, UT, at 82.5º Glat (averaged over all longitudes)

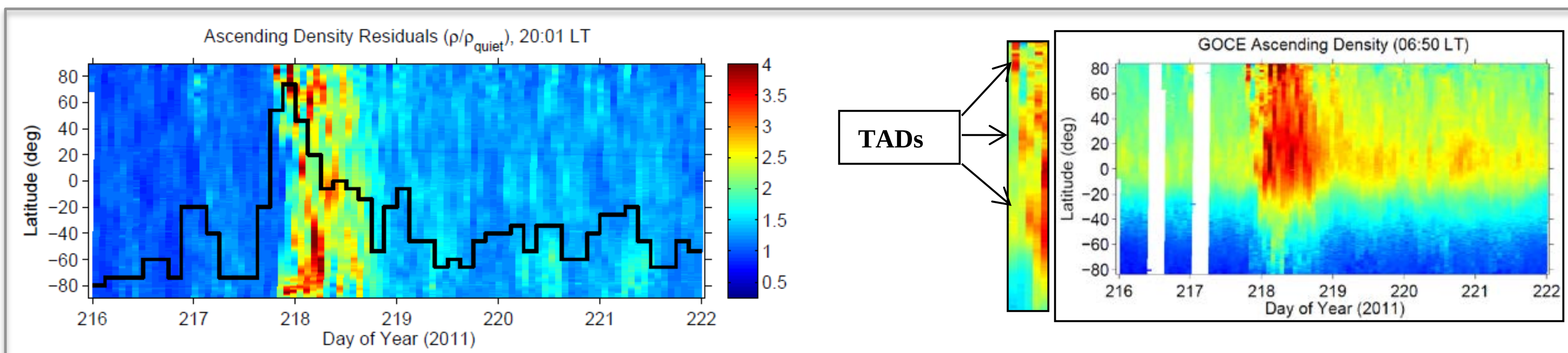


Response of Neutrals to Stormtime Energy Input

GRACE and GOCE Observations During August 2011 Storm

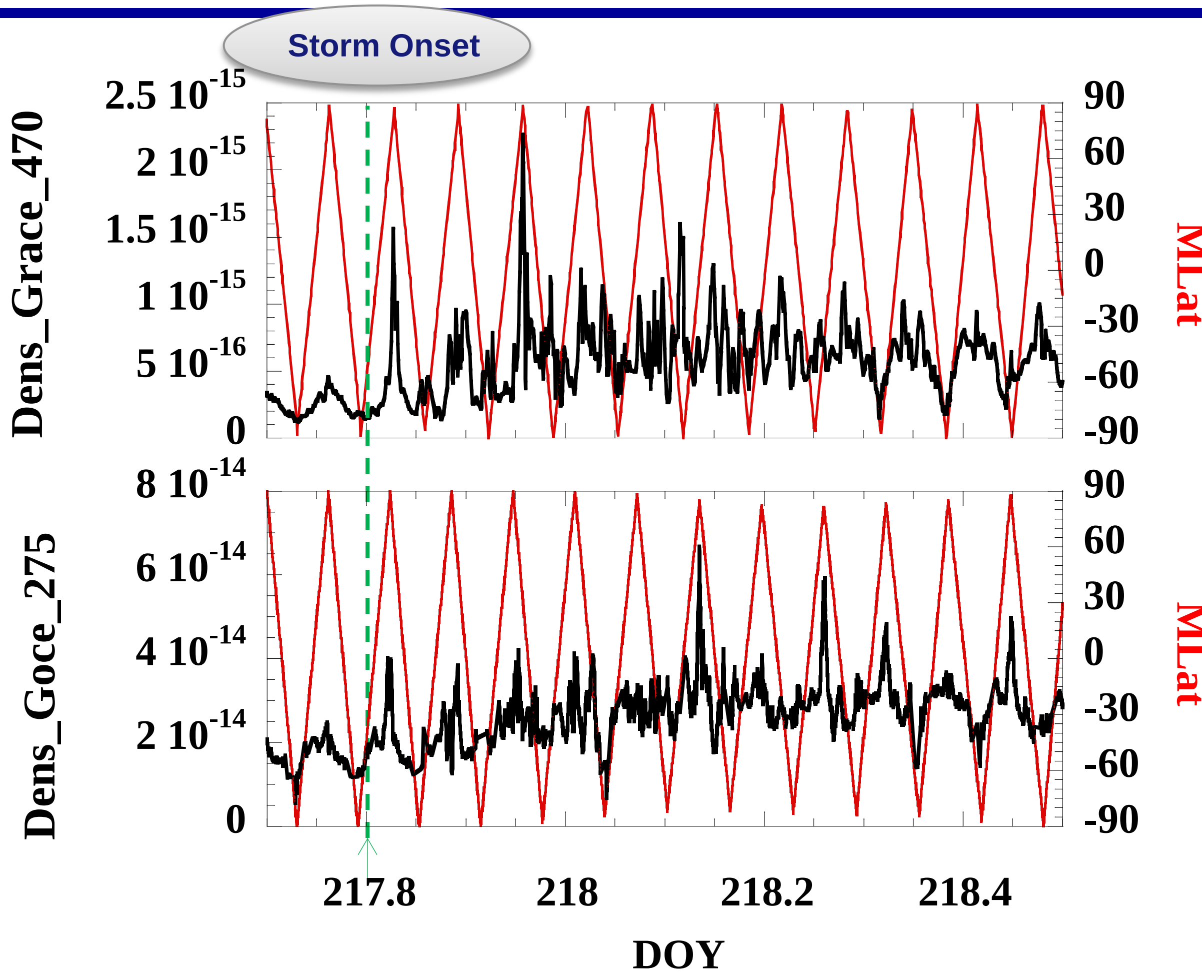


Traveling Atmospheric Disturbances (TADs) on GRACE in both hemispheres indicate a source of Joule heating poleward of 83º MLat (NH) and -72º Mlat (SH).



TADs detected simultaneously at GRACE at 2001 LT (left) and GOCE at 0650 LT (right). Source of Joule heating must be poleward of 83⁰MLat (GRACE) and 80⁰ (GOCE).

Comparison of GRACE, GOCE Densities During August 2011 Storm

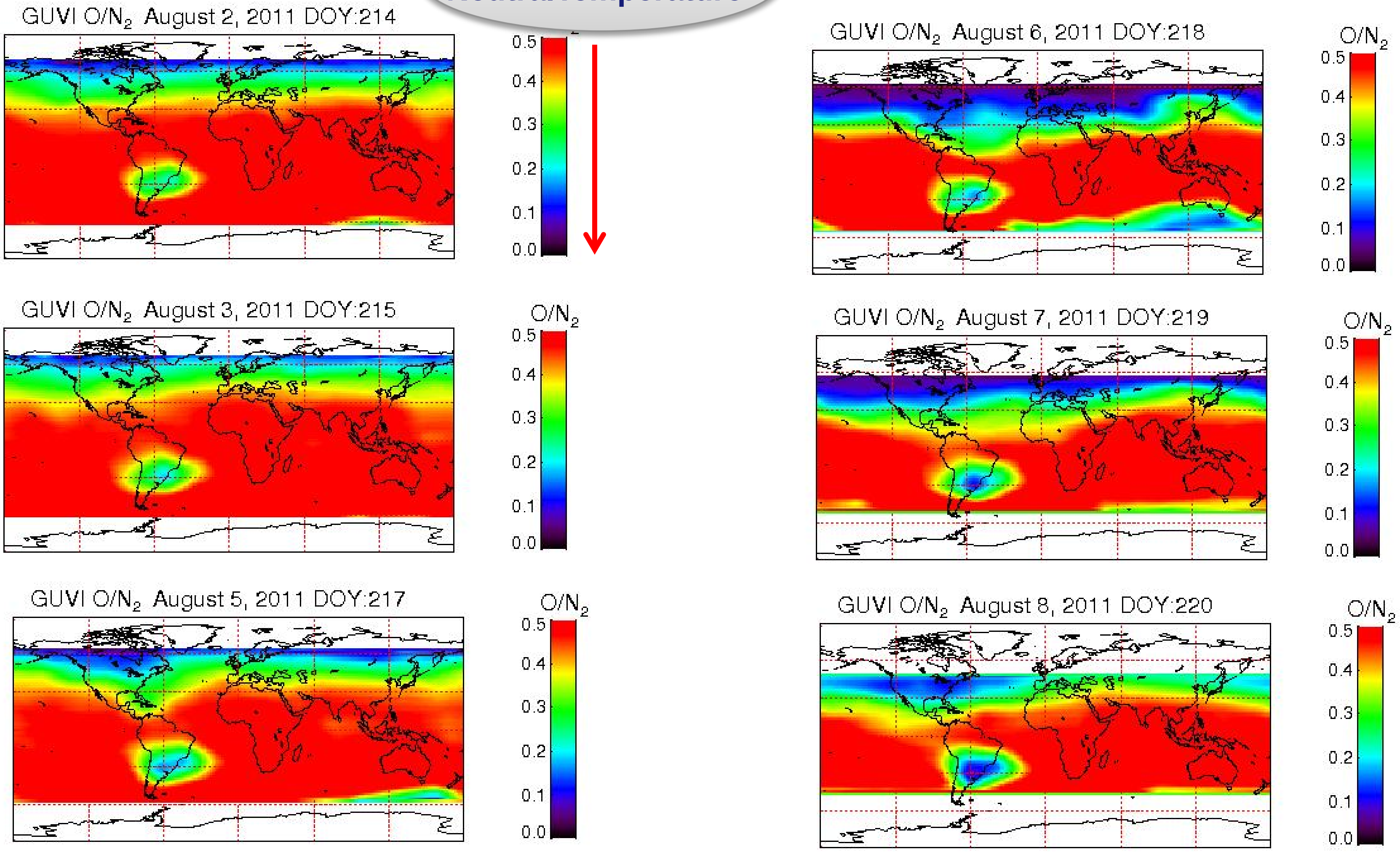


Response of thermosphere is
(1) fast;
(2) maximal at highest latitudes

At 275 and 470 km, sharp localized density maxima were observed within minutes of storm onset. Large localized density maxima occur through storm main phase.

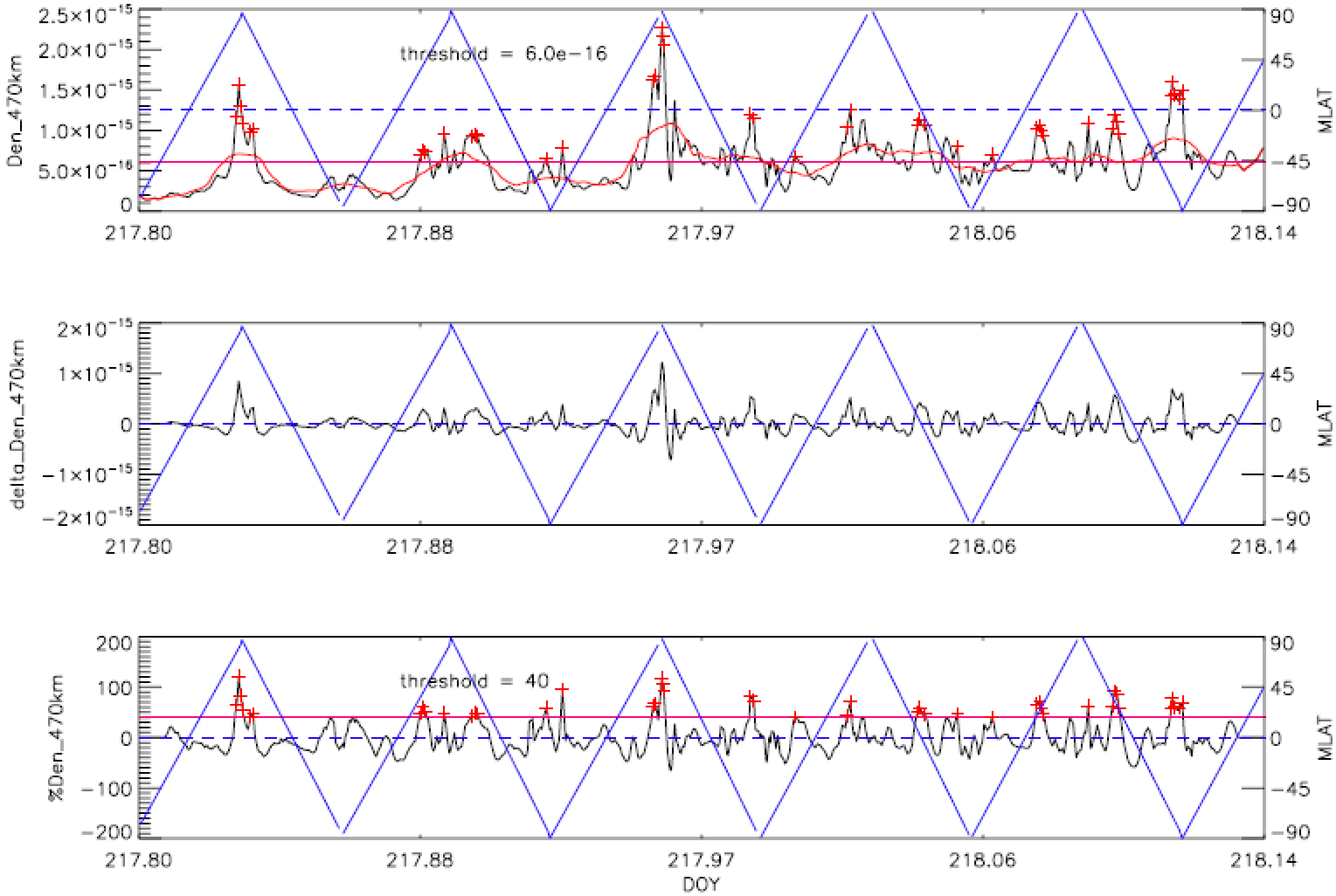
GUVI Observations of O/N_2 Ratio During August 2011 Storm

Increasing NeutralTemperature



Decrease in atomic oxygen at 135 km altitude caused by Joule heating and recombination.
Polar cap is always warmer than lower latitudes.
Decrease in O/N_2 proceeds from polar to lower latitudes.

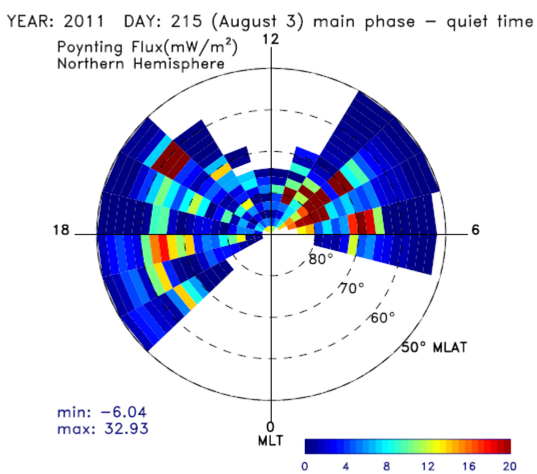
GRACE Neutral Density Maxima
August 2011 Storm

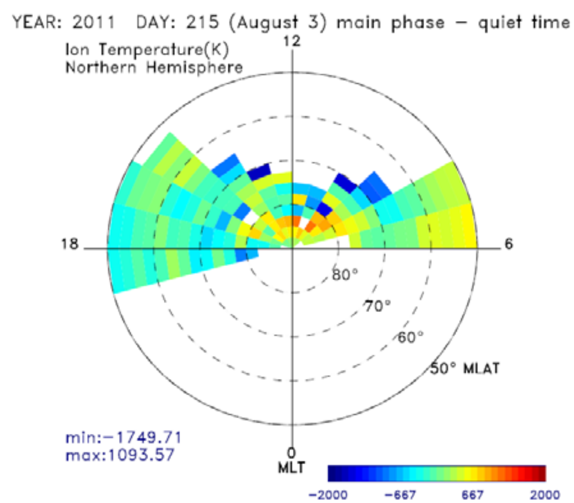


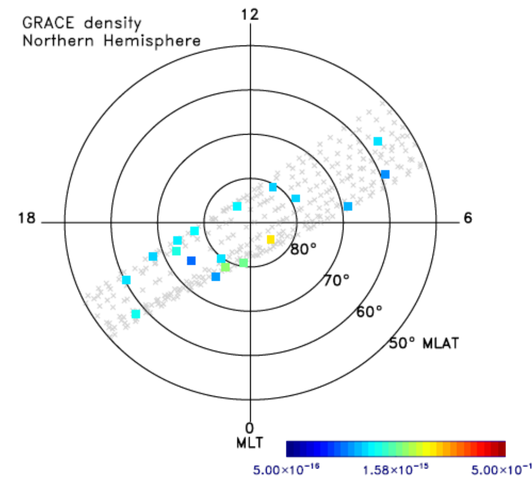
Energy Dissipation in IT
Poynting Flux (S_x) → T_i, ρ_n

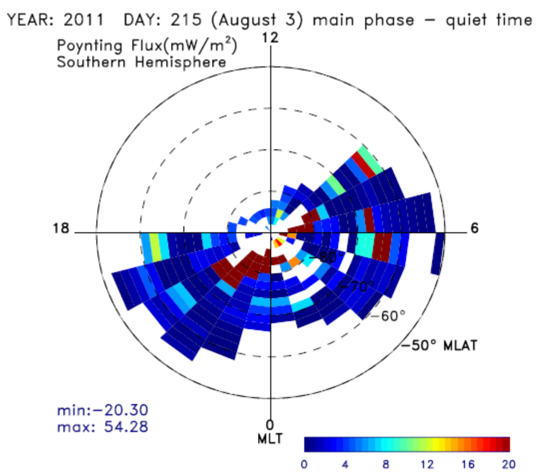
August 2011 Storm Main Phase

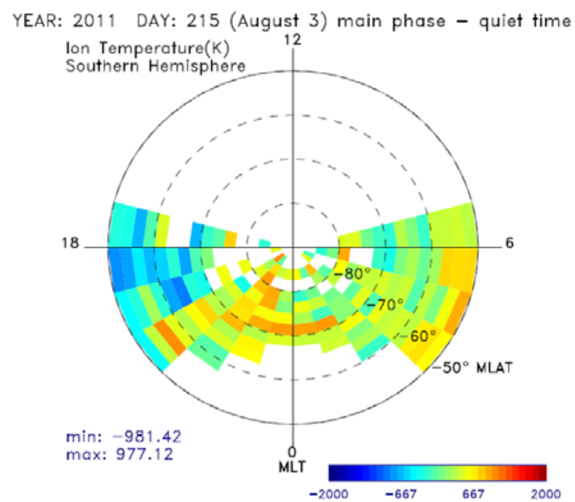
S_x | T_i | ρ_n

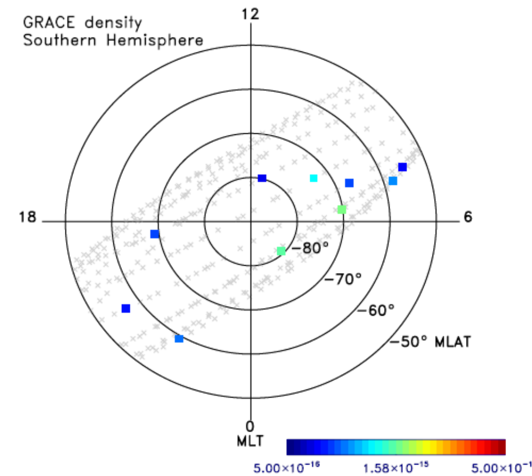










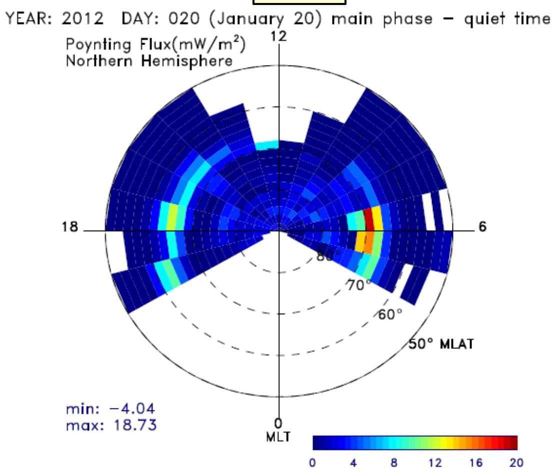


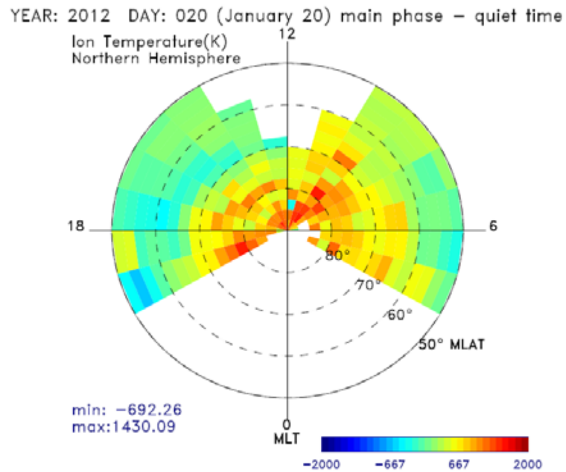
$S_x \neq$ Joule heat?

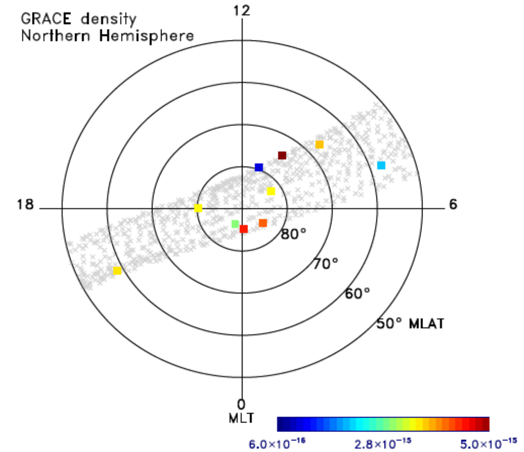
Energy Dissipation in IT
Poynting Flux (S_x) → T_i, ρ_n

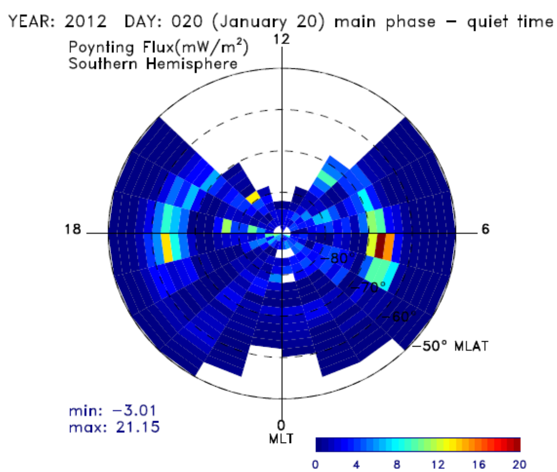
January 2012 Storm Main Phase

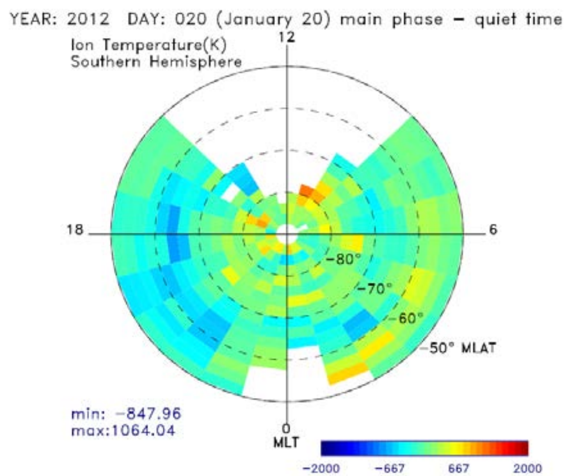
S_x | **T_i** | **ρ_n**

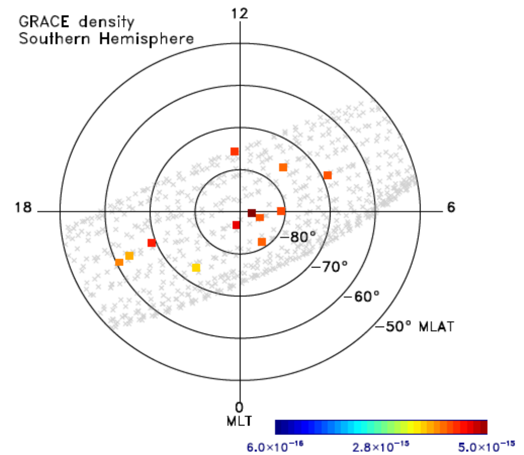






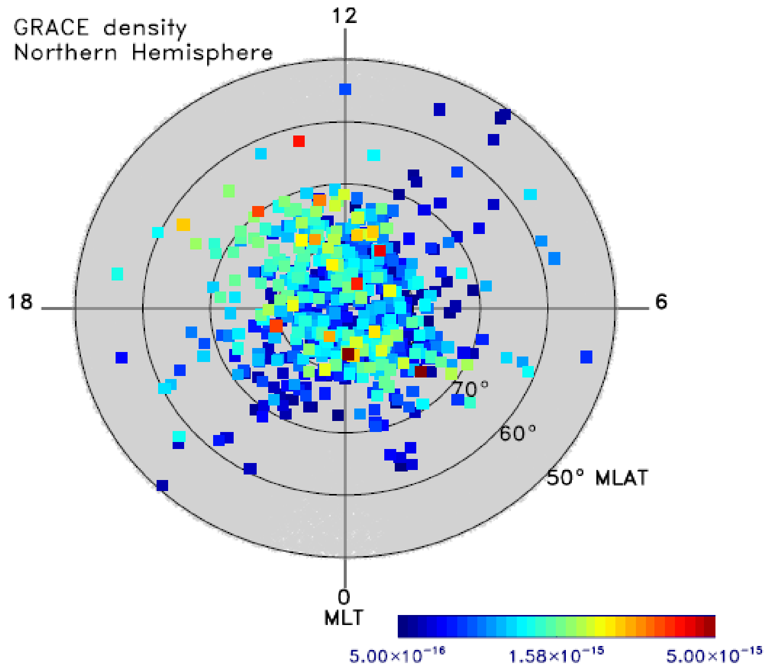


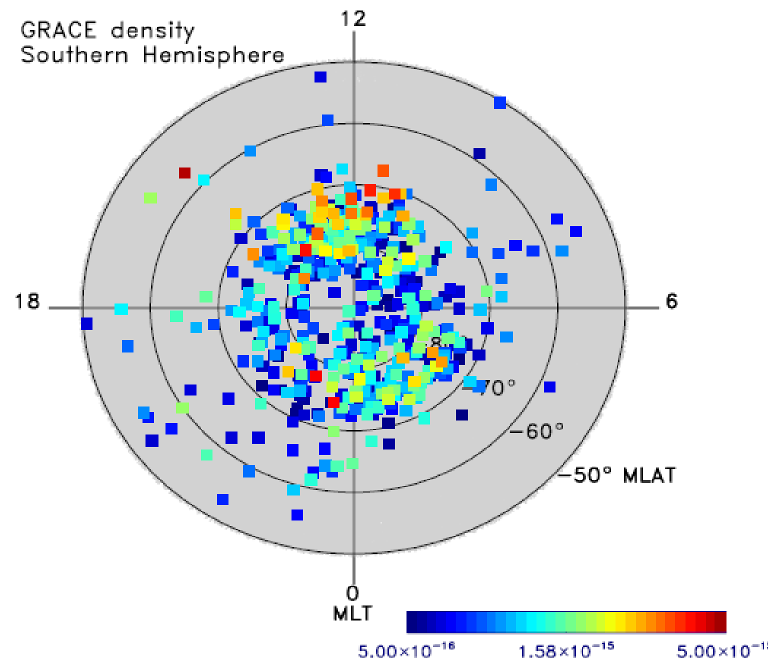




$S_x \neq$ Joule heat

GRACE Density Maxima in 2011



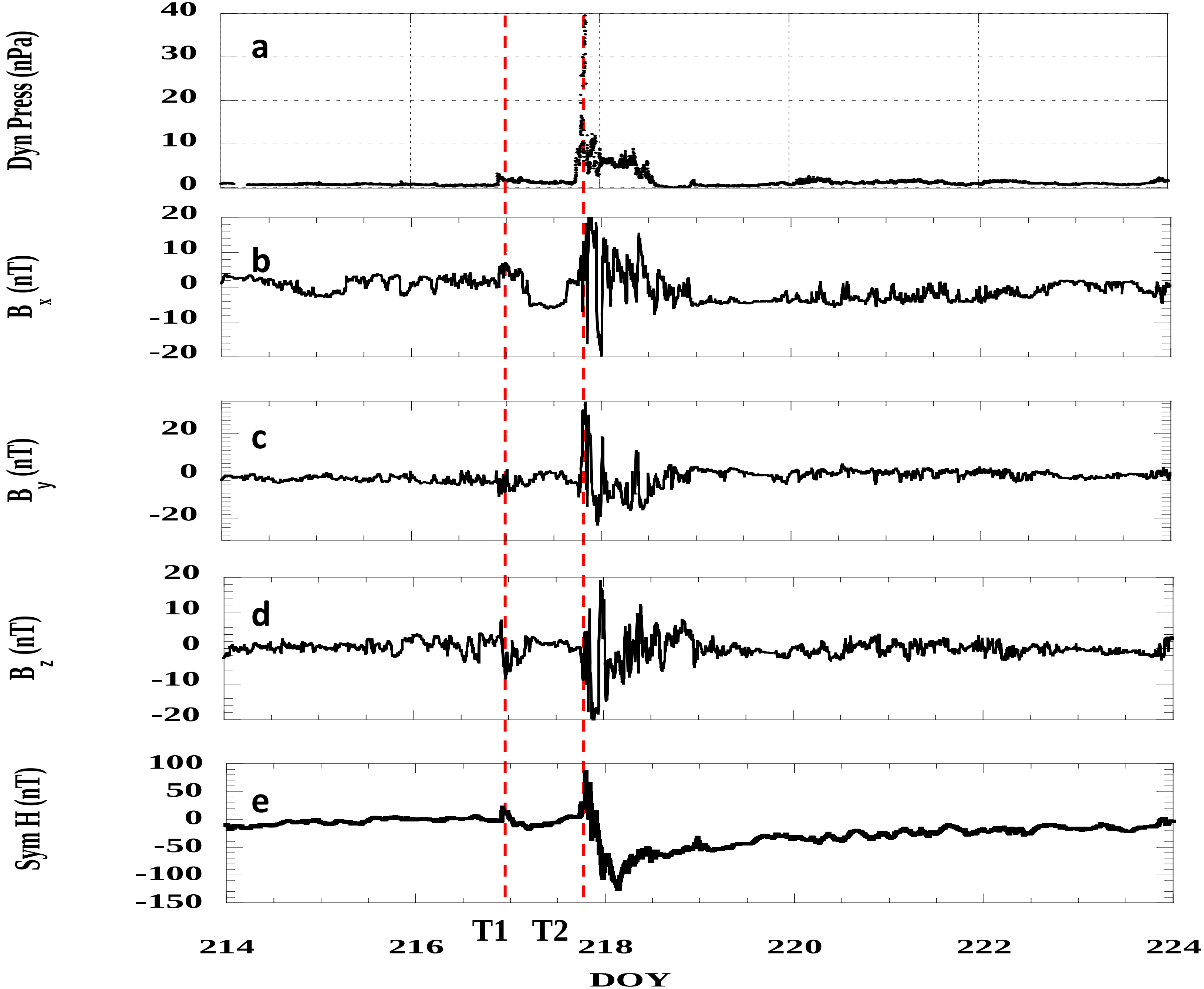


All GRACE density maxima 30% above average during 2011 ($\rho \geq 5 \times 10^{-16}$ g cm^{-3})

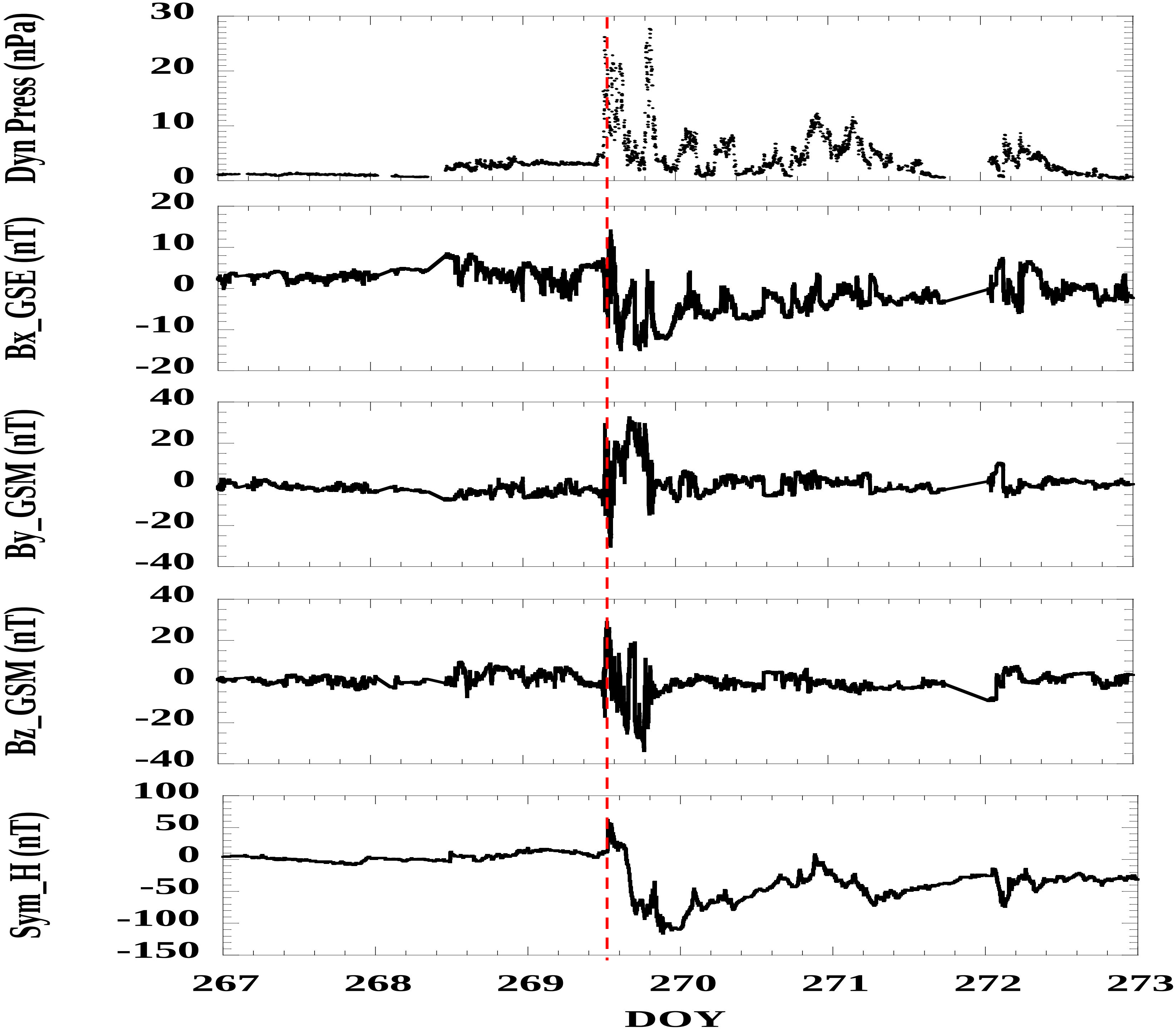
GOCE shows similar latitudinal distribution but with limited longitudinal coverage.

Summary

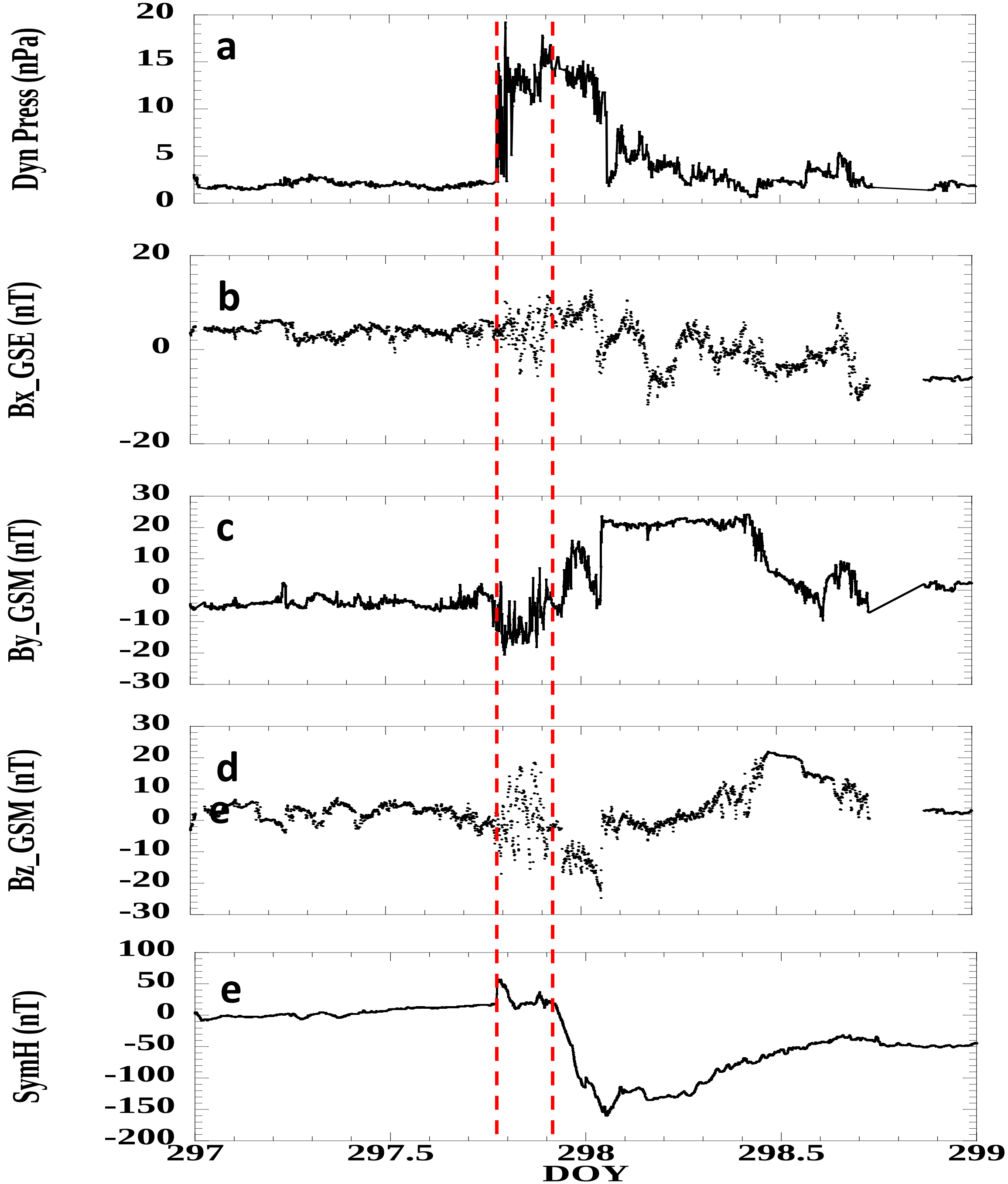
- Ion temperatures at DMSP show large increases in polar region at all local times; cusp and auroral zones do not show distinctively high T_i.
  - Ion temperatures in the polar cap are *higher* than in the auroral zones during quiet times.
- Neutral densities at GRACE and GOCE show localized maxima at polar latitudes without clear auroral signatures. Response is fast, minutes from onset to density peaks.
- Discrepancy between maps of Poynting flux and of ion temperatures/neutral densities suggests that connection between Poynting flux and Joule heating is not simple.
- Hypothesis 1: Poynting flux can enter polar cap at any local time – suggests direct connection between solar wind and IT. Can Alfven waves enter directly from solar wind? What controls wave entry?
- Hypothesis 2:
  - Joule heating of neutrals occurs rapidly in the polar cap at both GRACE and GOCE and not in the auroral zones.
  - Joule heating of ions at DMSP altitudes is higher in the polar cap than the adjoining auroral zone at ALL levels of activity, quiet as well as disturbed. Highest ion temperatures occur consistently in the polar cap.



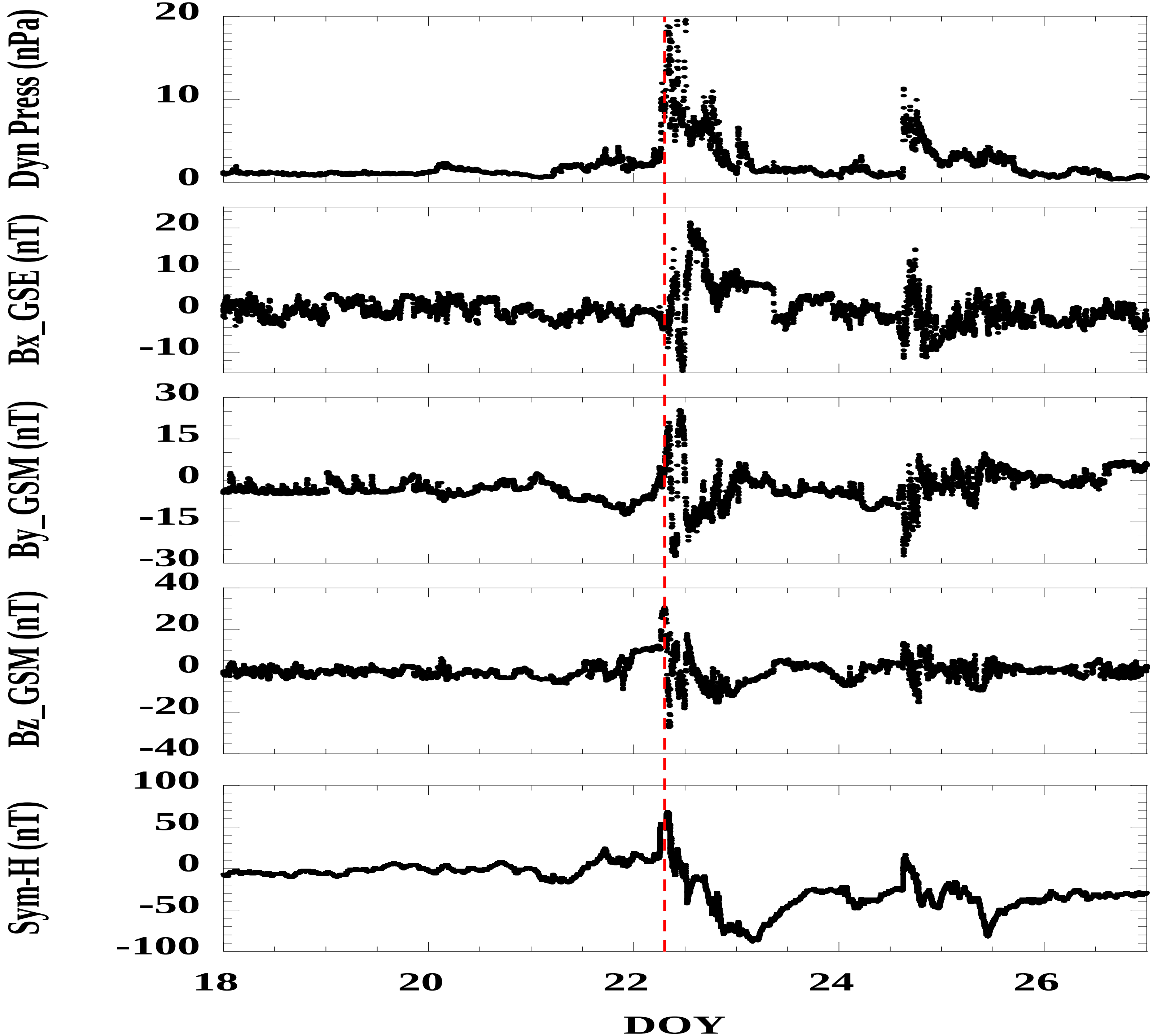
Dyn Press (nPa)
40
30
20
10
0
a
B_x (nT)
20
10
0
-10
-20
b
B_y (nT)
20
0
-20
c
B_z (nT)
20
10
0
-10
-20
d
Sym H (nT)
100
50
0
-50
-100
-150
e
T1
T2
214
216
218
220
222
224
DOY



Dyn Press (nPa)
30
20
10
0
Bx_GSE (nT)
20
10
0
-10
-20
By_GSM (nT)
40
20
0
-20
-40
Bz_GSM (nT)
40
20
0
-20
-40
Sym_H (nT)
100
50
0
-50
-100
-150
267
268
269
270
271
272
273
DOY



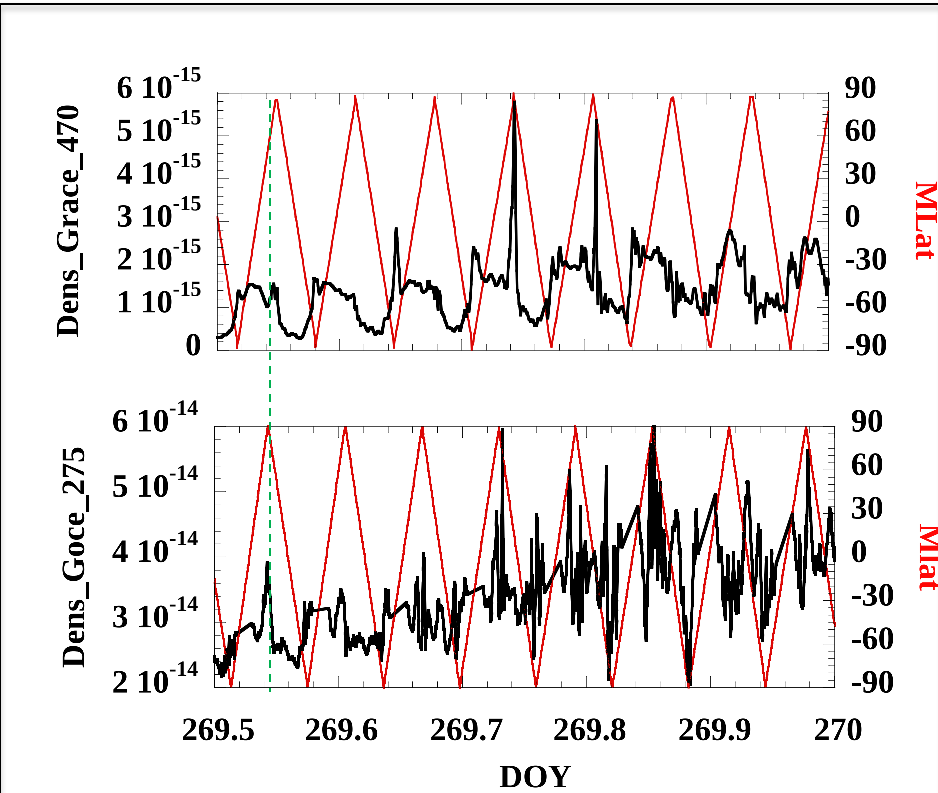
a
Dyn Press (nPa)
20
15
10
5
0
b
Bx_GSE (nT)
20
0
-20
c
By_GSM (nT)
30
20
10
0
-10
-20
-30
d
e
Bz_GSM (nT)
30
20
10
0
-10
-20
-30
e
SymH (nT)
100
50
0
-50
-100
-150
-200
297
297.5
298
298.5
299
DOY

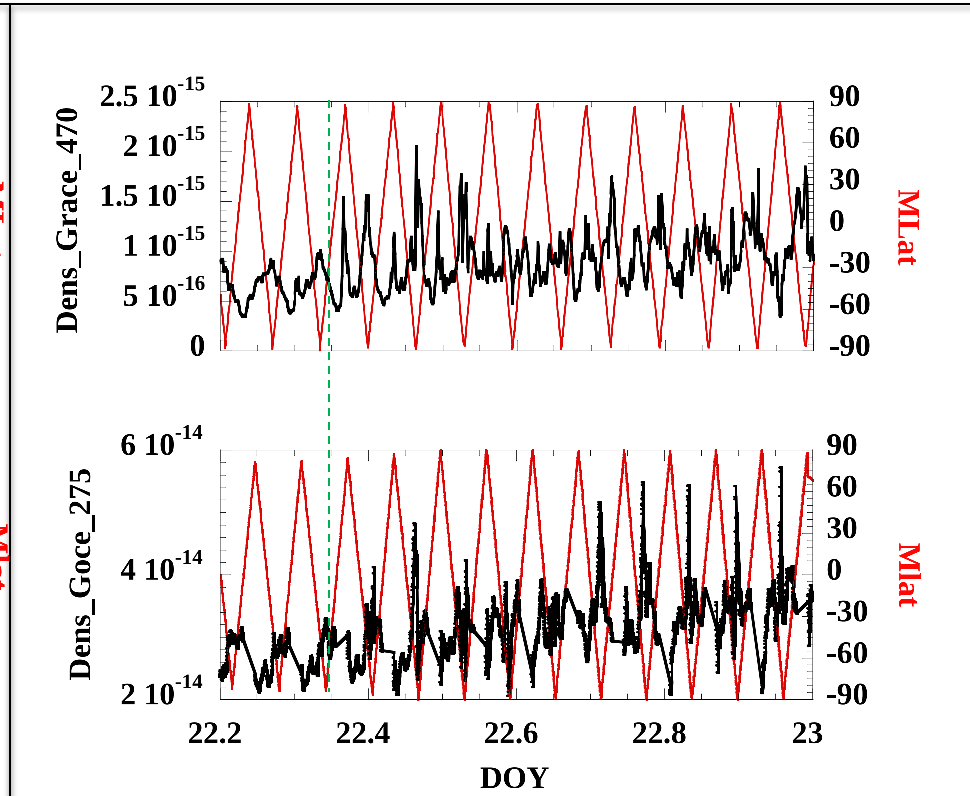


Dyn Press (nPa)
20
10
0
Bx_GSE (nT)
20
10
0
-10
By_GSM (nT)
30
15
0
-15
-30
Bz_GSM (nT)
40
20
0
-20
-40
Sym-H (nT)
100
50
0
-50
-100
18
20
22
24
26
DOY

GRACE (470 km), GOCE (275 km) Observations

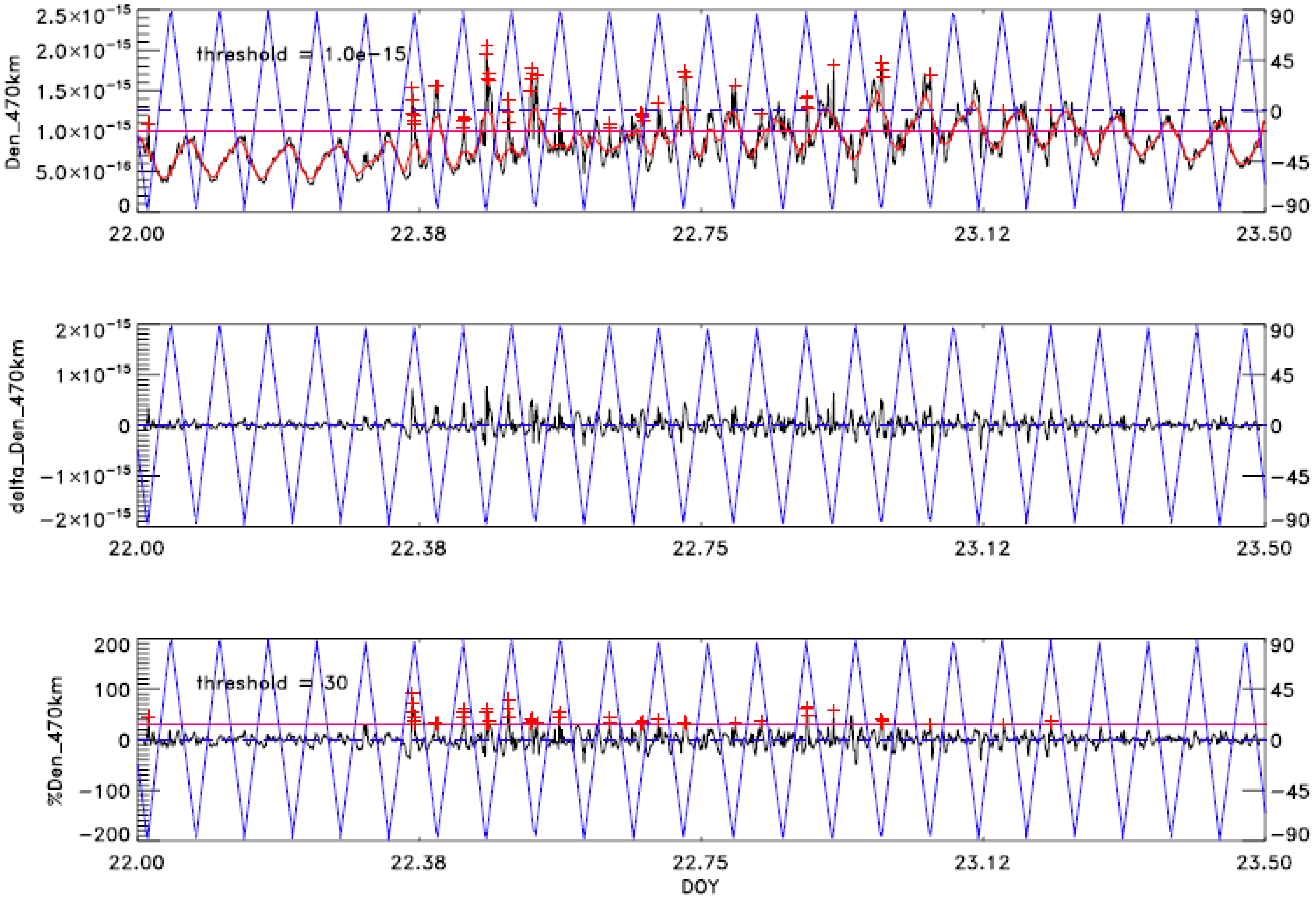
September 2011 , January 2012 Storms



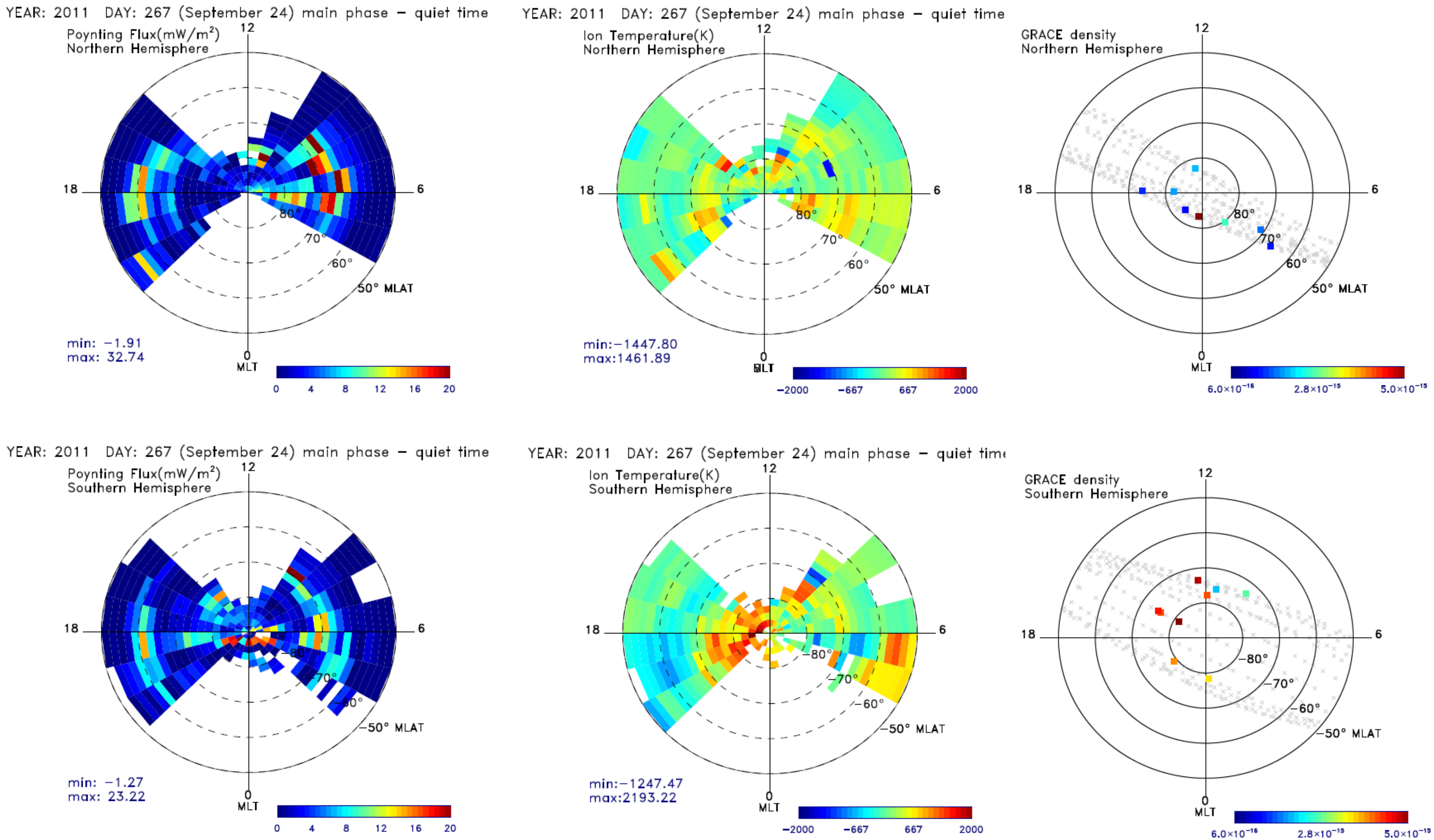


Joule heating of neutrals is dynamic in space and time

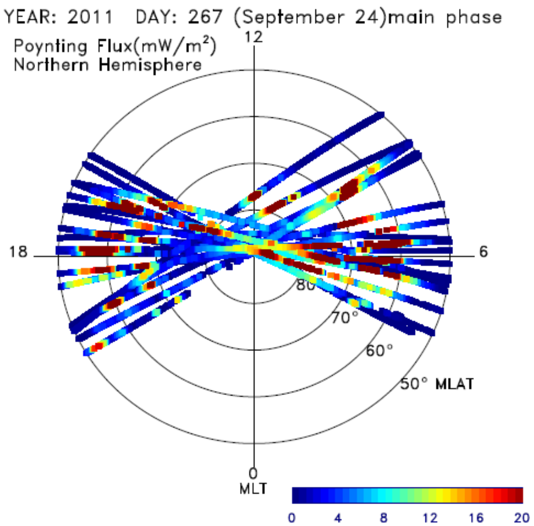
Neutral Density Maxima
January 2012 Storm

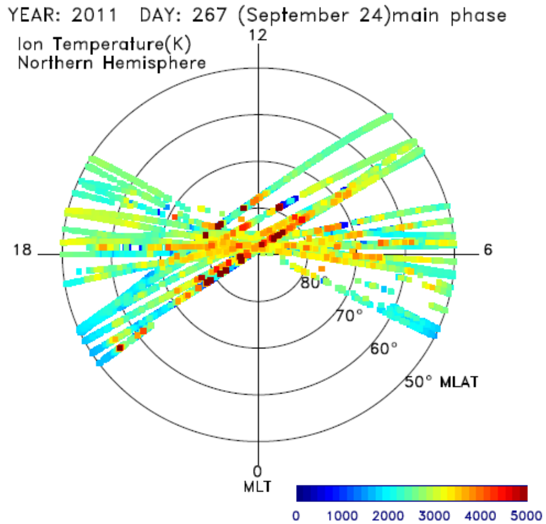


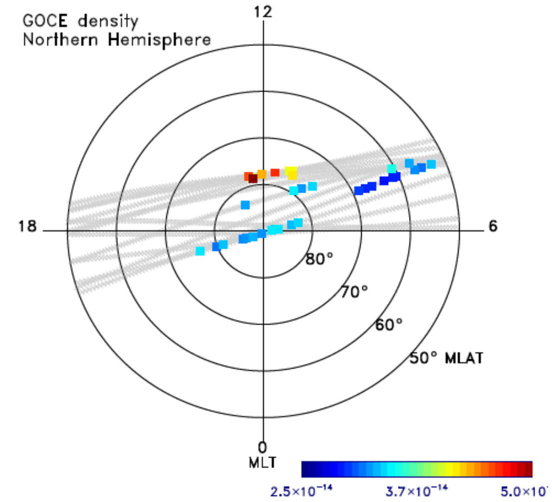
Energy Dissipation in IT
September 2011

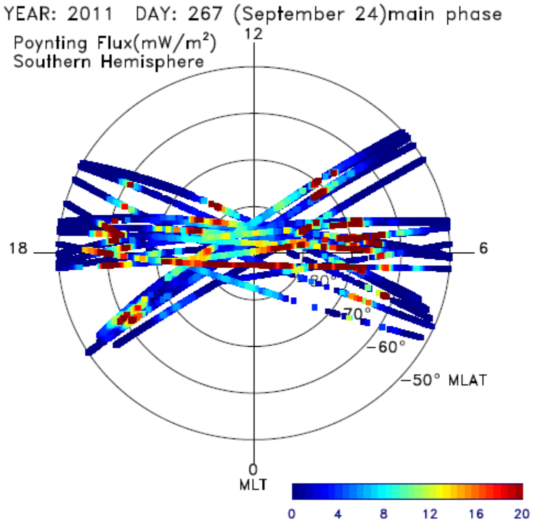


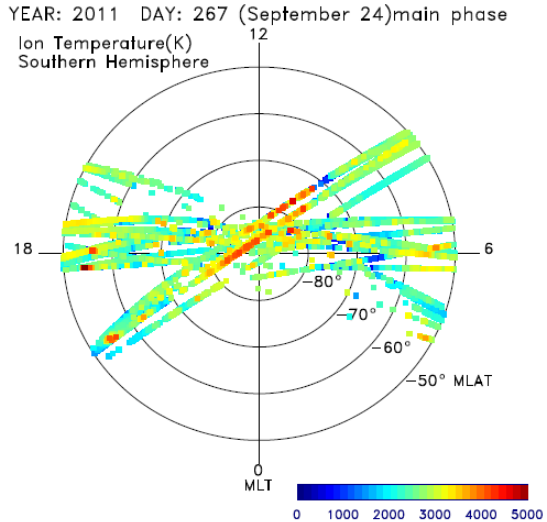
Energy Dissipation in IT
September 2011

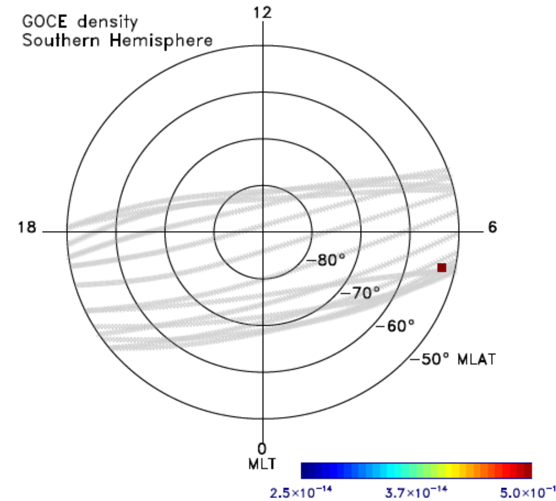




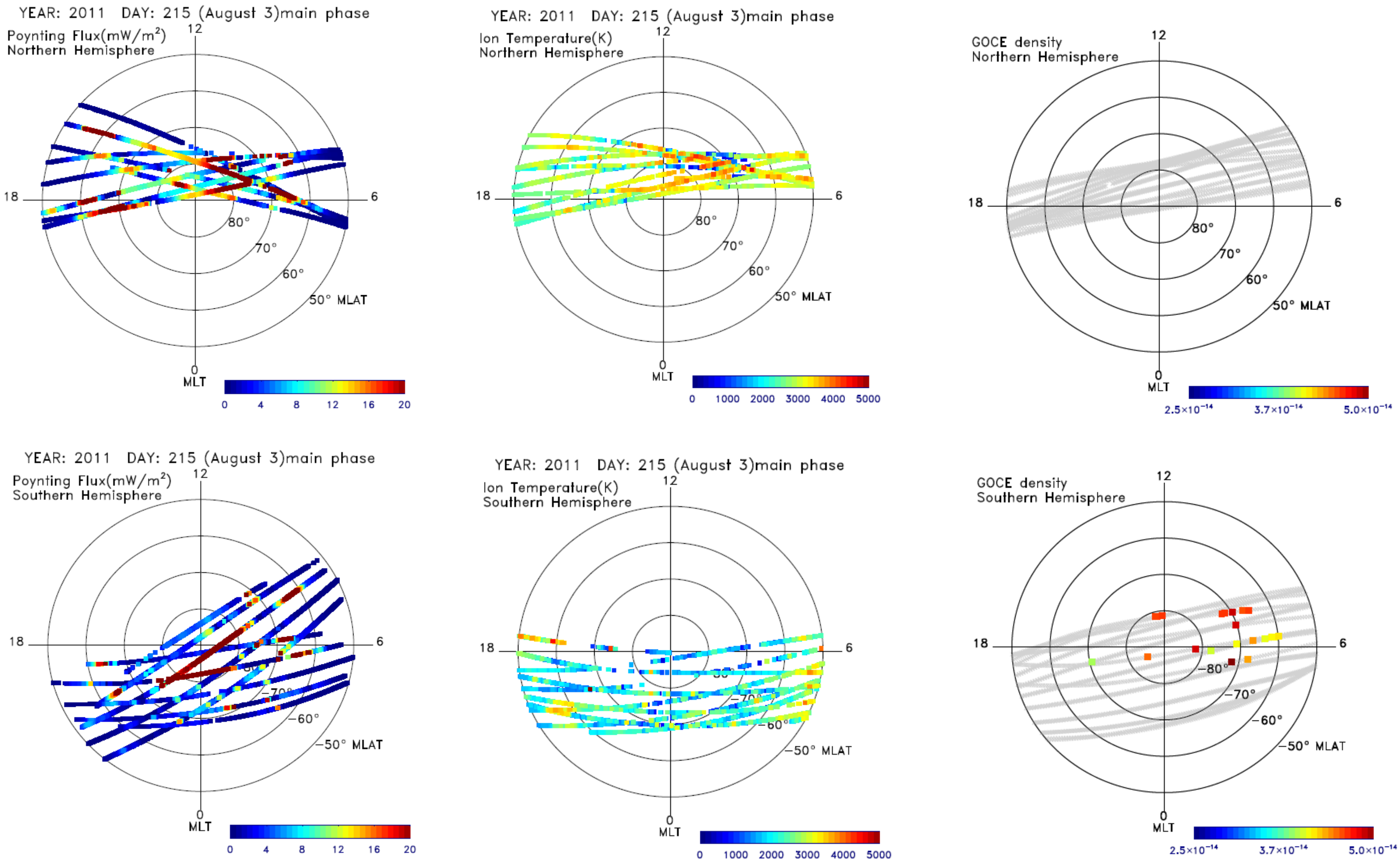




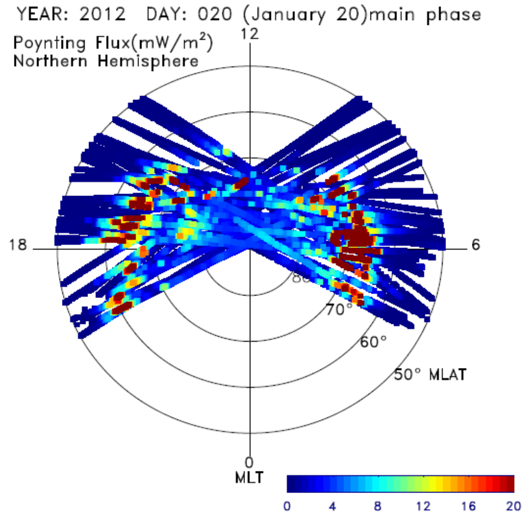


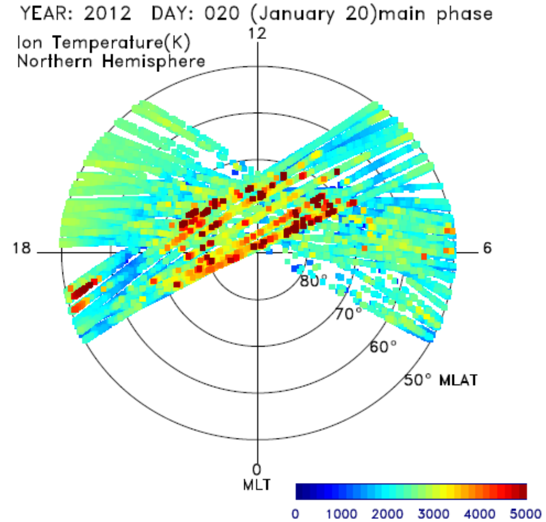


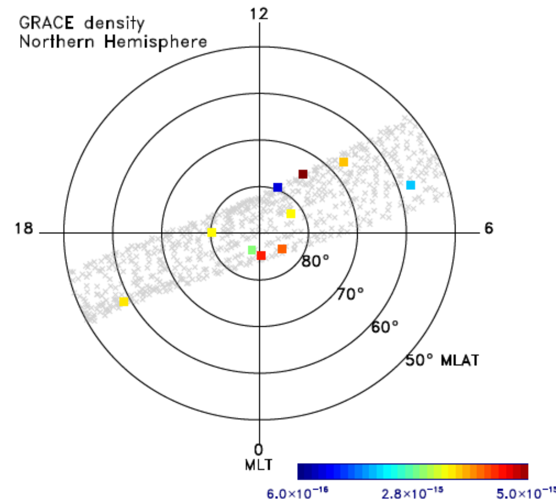
Energy Dissipation in IT
August 2011

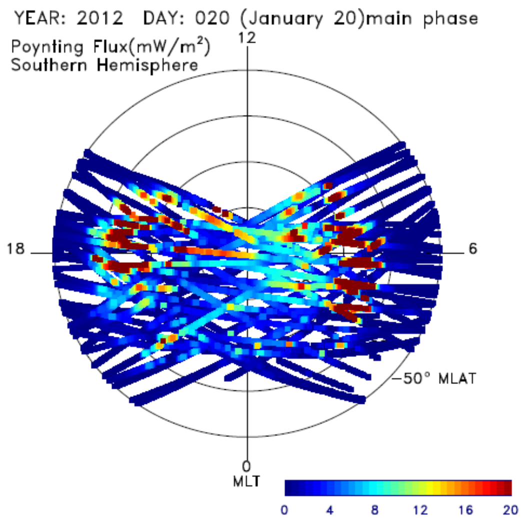


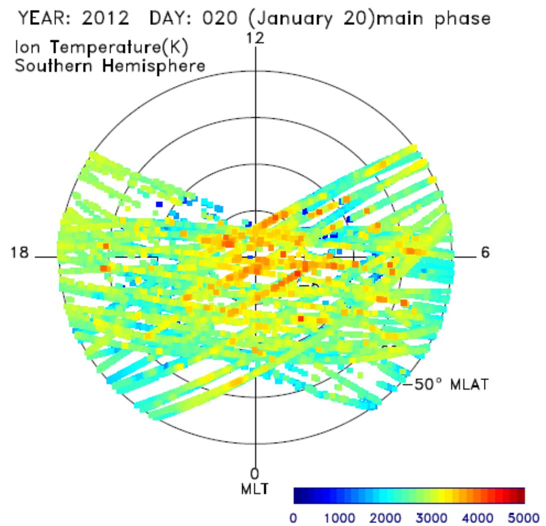
Energy Dissipation in IT
January 2012

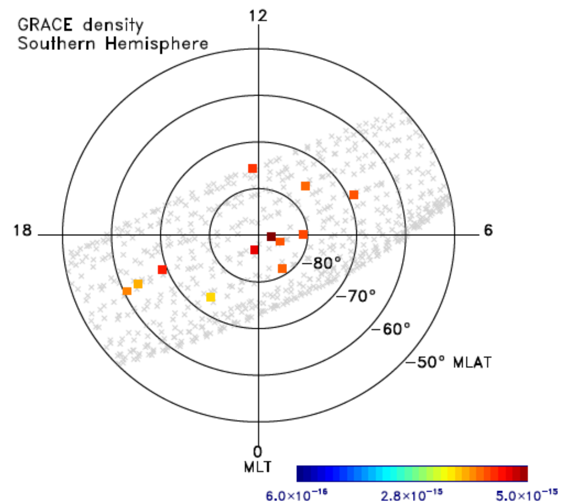




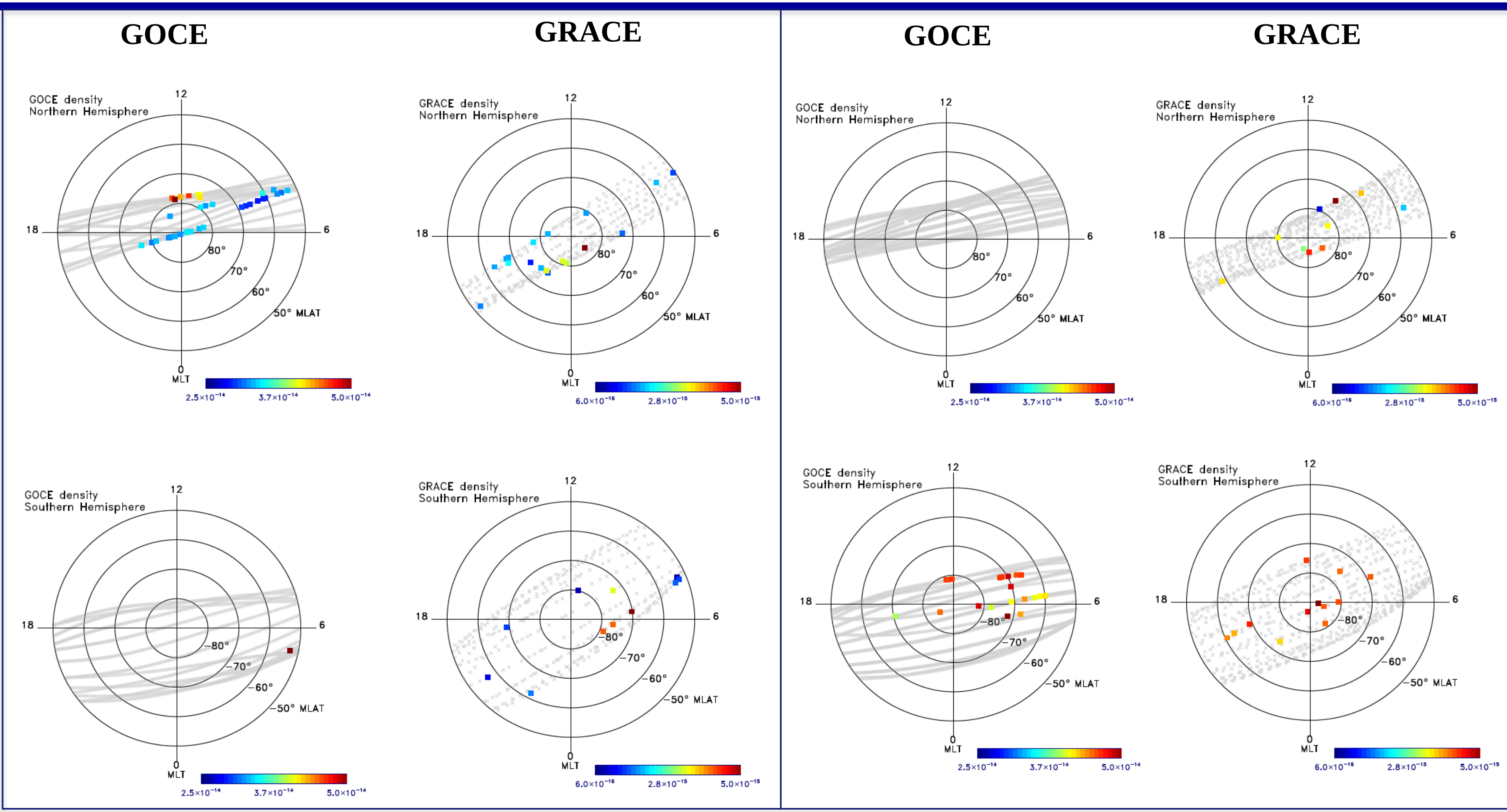




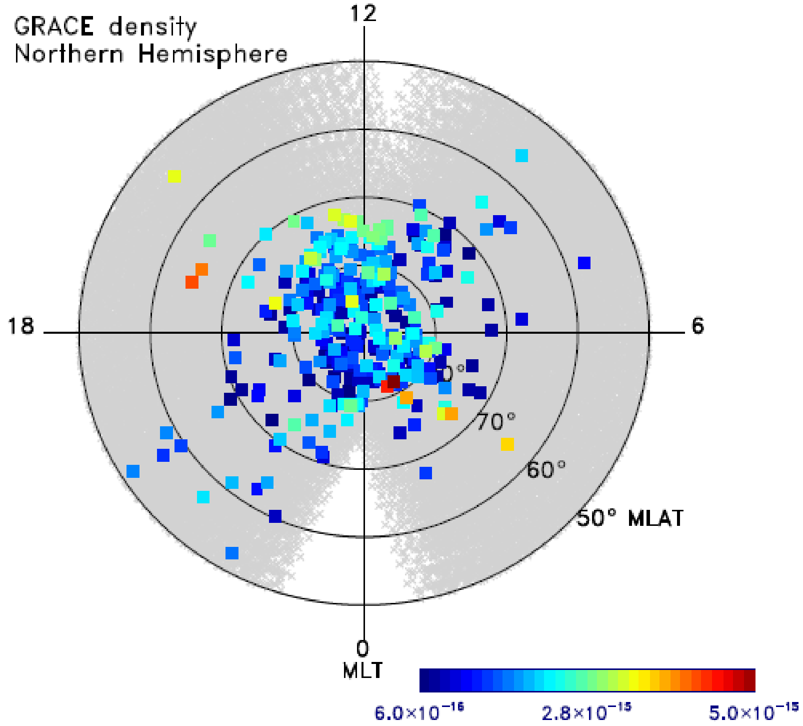


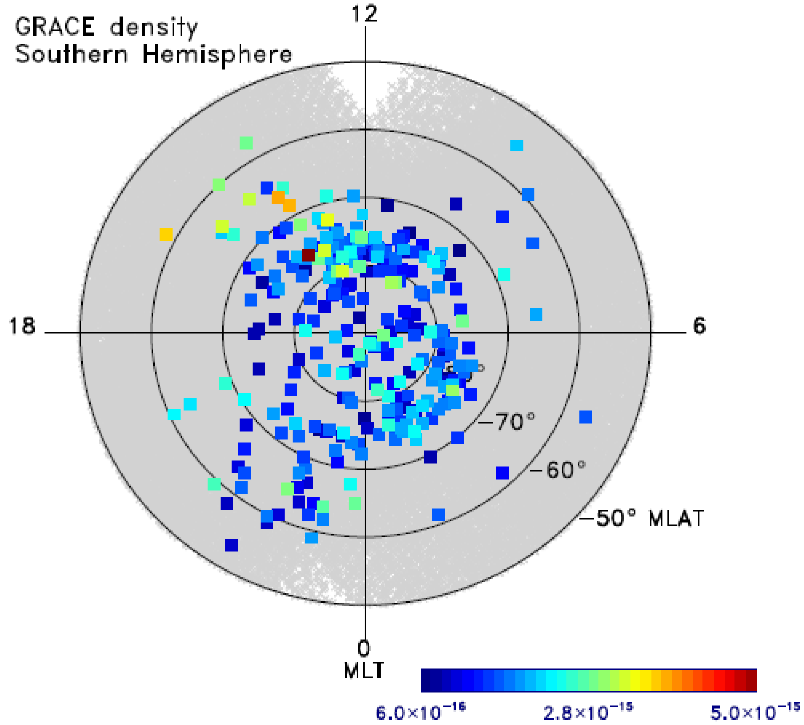


Comparison of GRACE with GOCE
August 2011, January 2012 Storms



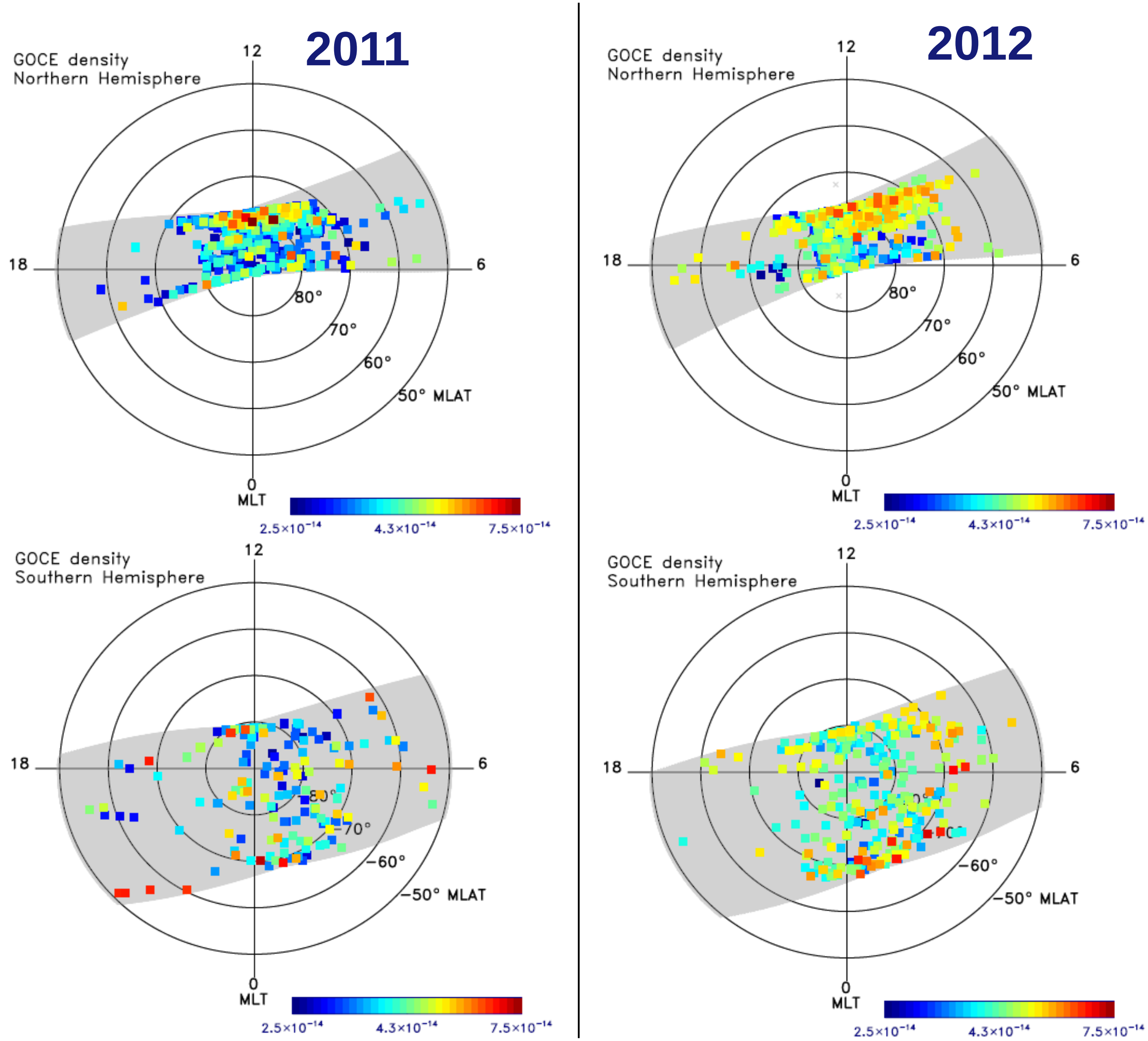
GRACE Density Maxima
Jan – June 2012





GOCE Neutral Density Maxima – 2011, 2012

ρ > 30% above average

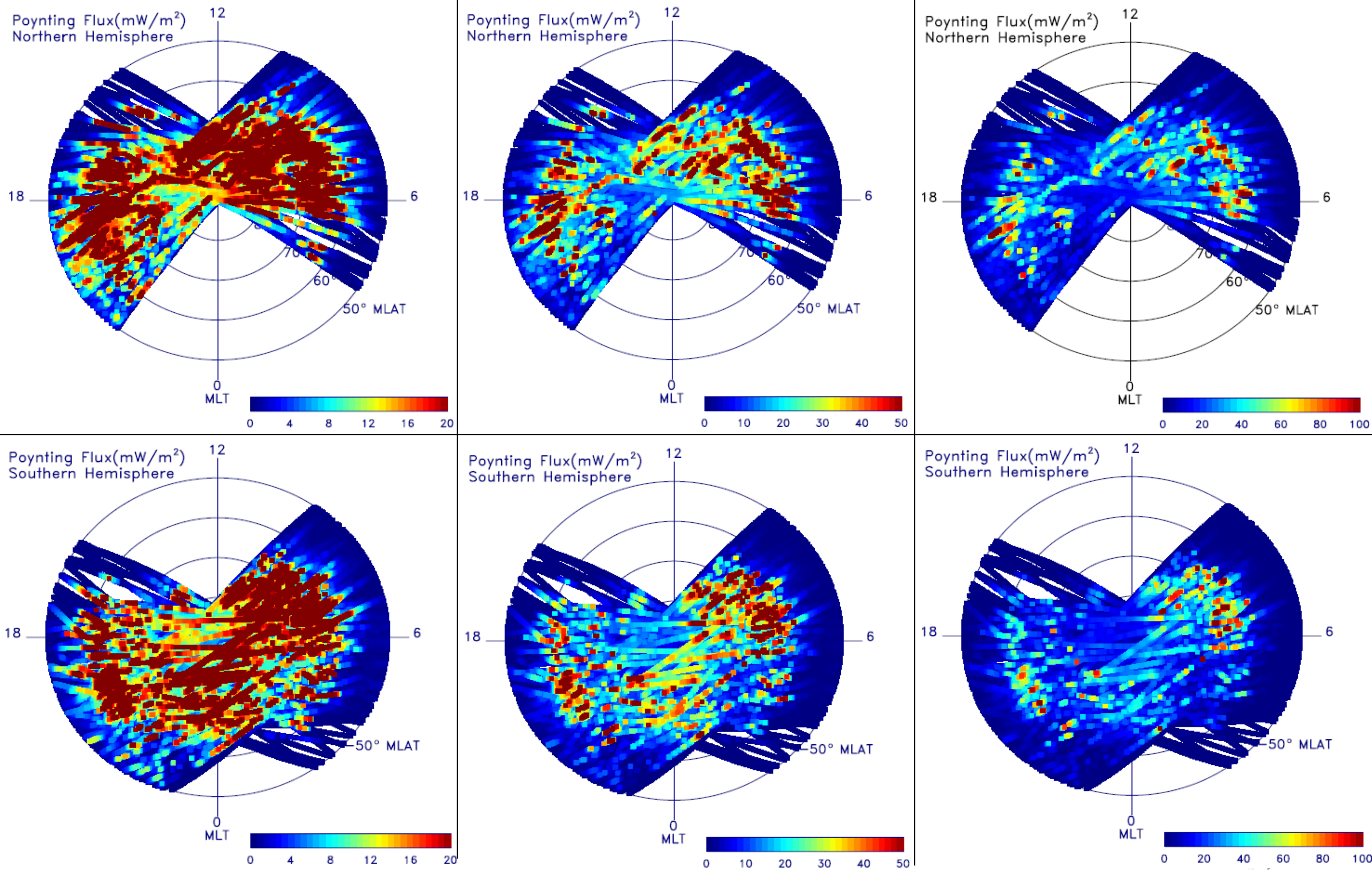


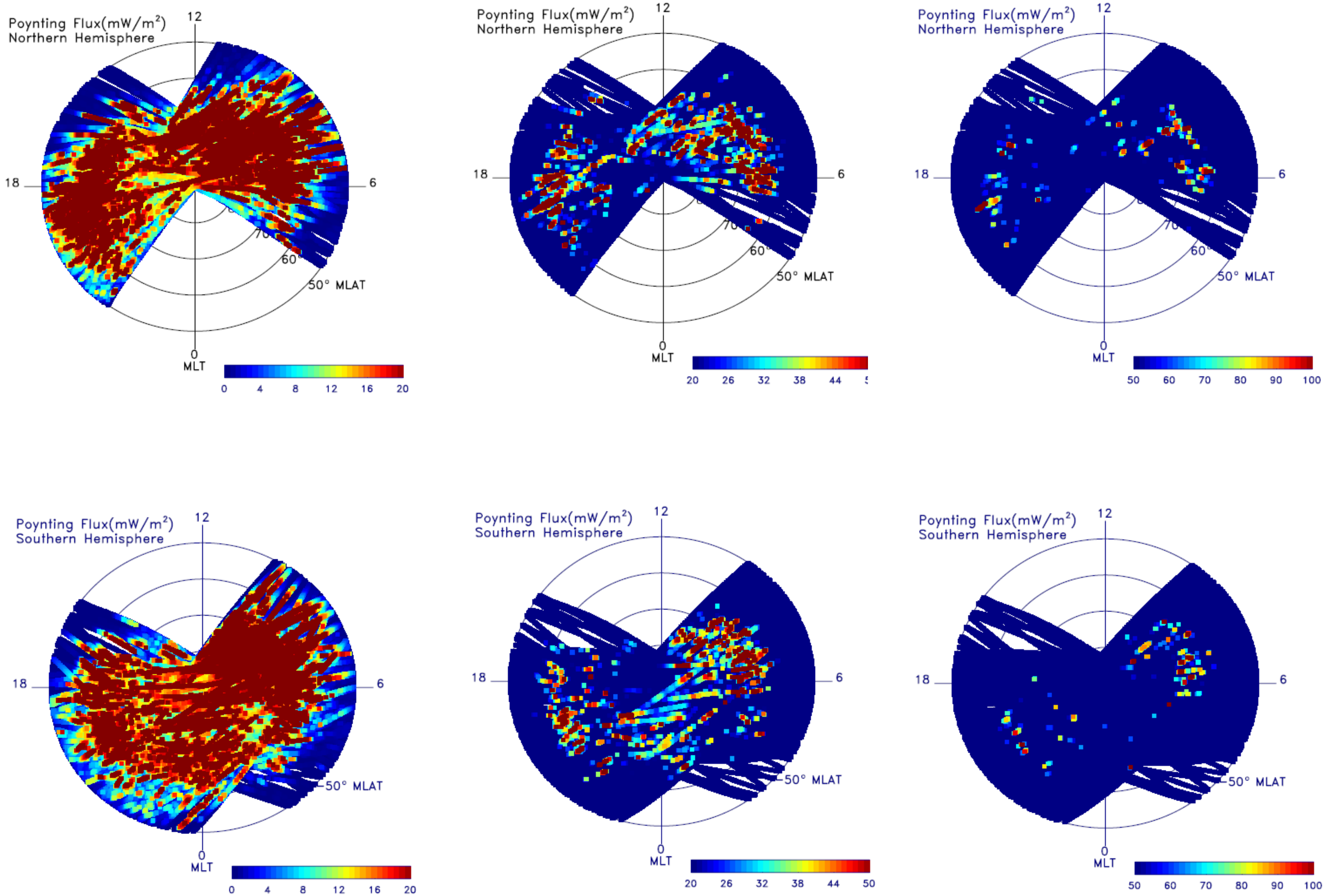
-100>SymH>-200 nT

S_x range = 0 to 20+ mW m^{-2}

S_x range = 0 to 50+ mW m^{-2}

S_x range = 0 to 100+ mW m^{-2}




Poynting Flux(mW/m²)
Northern Hemisphere
12
18
6
0
MLT
70°
60°
50° MLAT
0 4 8 12 16 20
Poynting Flux(mW/m²)
Northern Hemisphere
12
18
6
0
MLT
70
60°
50° MLAT
20 26 32 38 44
Poynting Flux(mW/m²)
Northern Hemisphere
12
18
6
0
MLT
70
60°
50° MLAT
50 60 70 80 90 100
Poynting Flux(mW/m²)
Southern Hemisphere
12
18
6
0
MLT
50° MLAT
0 4 8 12 16 20
Poynting Flux(mW/m²)
Southern Hemisphere
12
18
6
0
MLT
50° MLAT
20 26 32 38 44 50
Poynting Flux(mW/m²)
Southern Hemisphere
12
18
6
0
MLT
50° MLAT
50 60 70 80 90 100

Poynting Flux Prior to Onset in August 2011 Storm