Forcing of the Coupled Ionosphere-Thermosphere (IT) System During Magnetic Storms

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Scientific Challenges in Thermosphere-Ionosphere Forecasting

21-23 October 2014

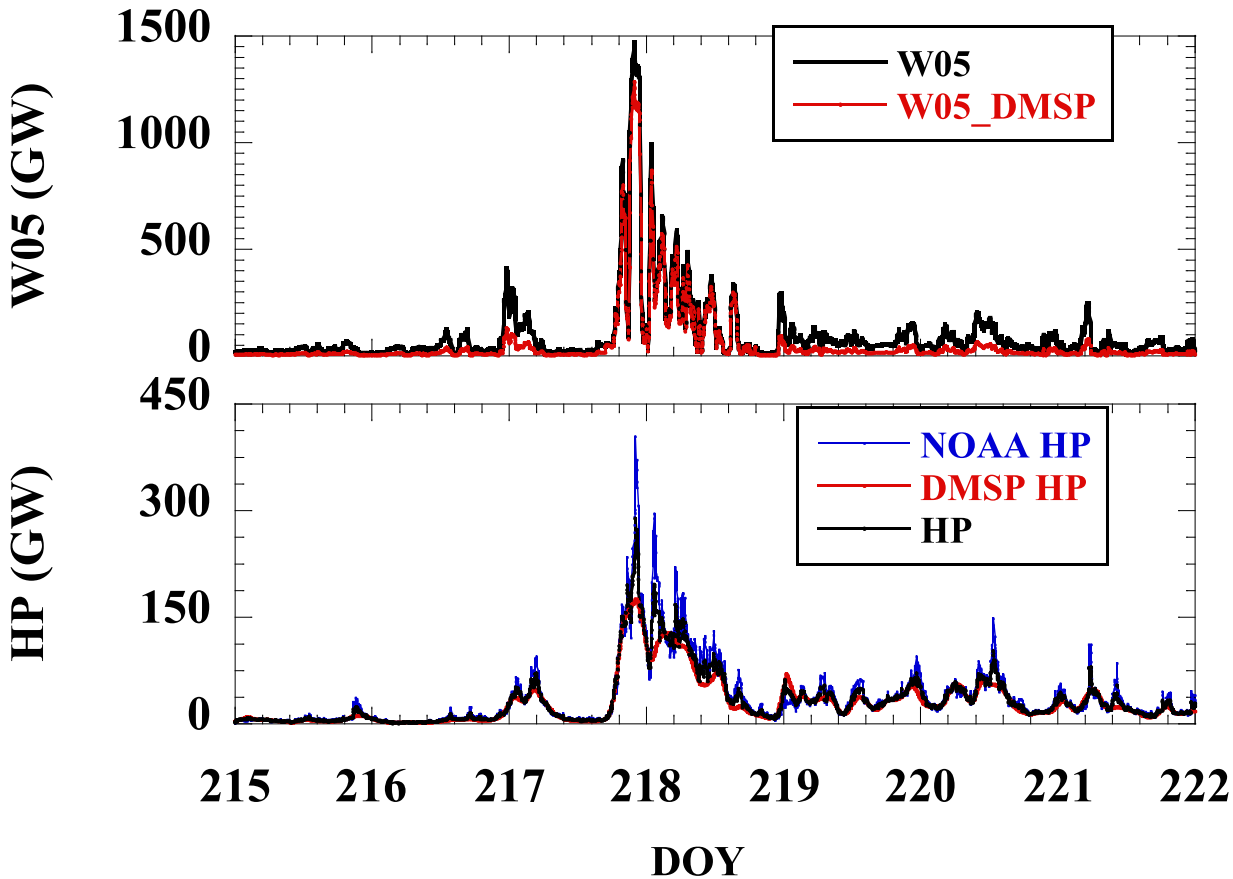
DISTRIBUTION STATEMENT A – Unclassified, Unlimited Distribution

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?
- Examine energy input during magnetic storms.
- Analyze observations of ion temperature, T_i from DMSP. Note that T_i is affected by several competing processes at DMSP altitude at 840km (solar radiation, convection, neutral winds).
- 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

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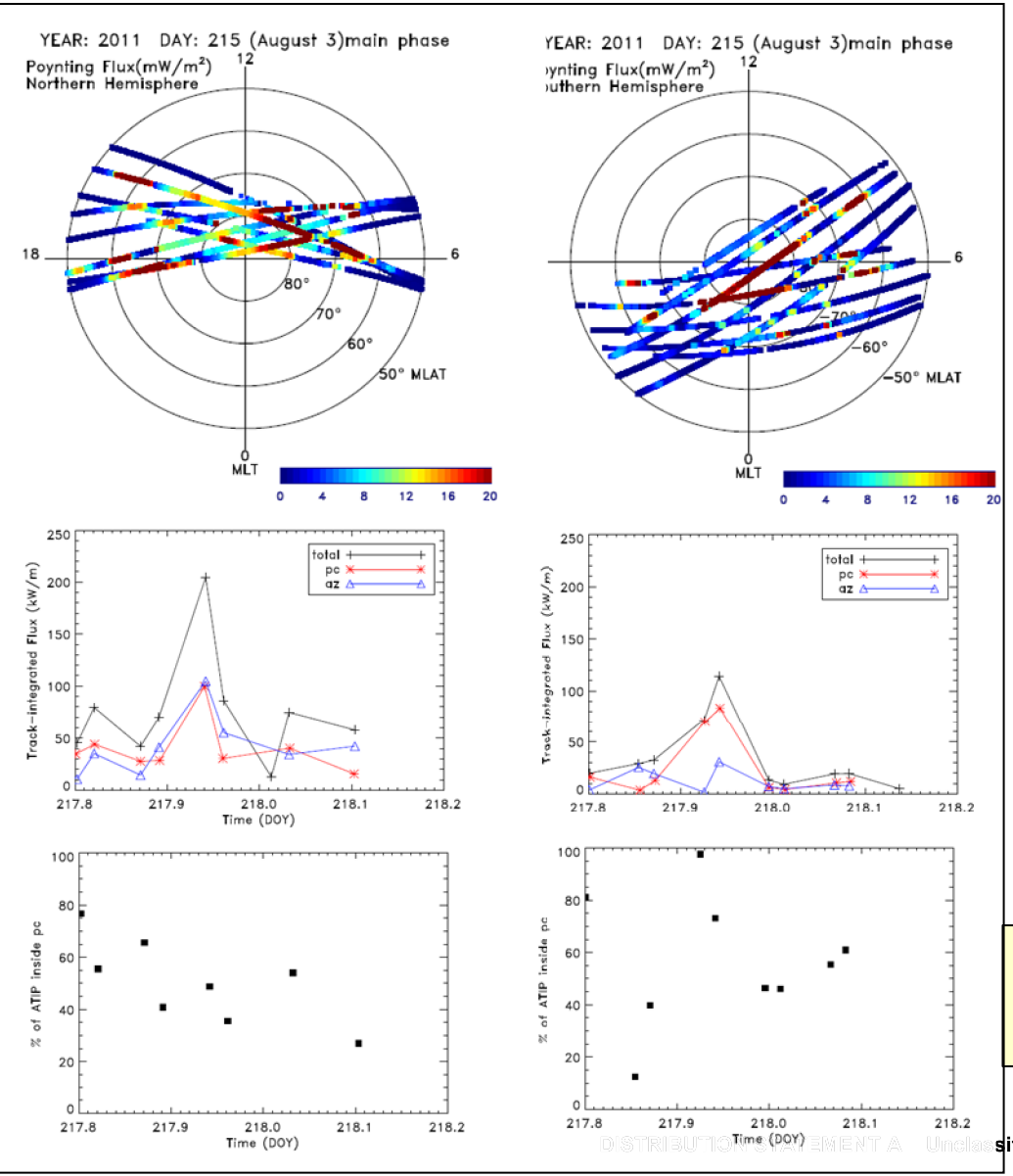
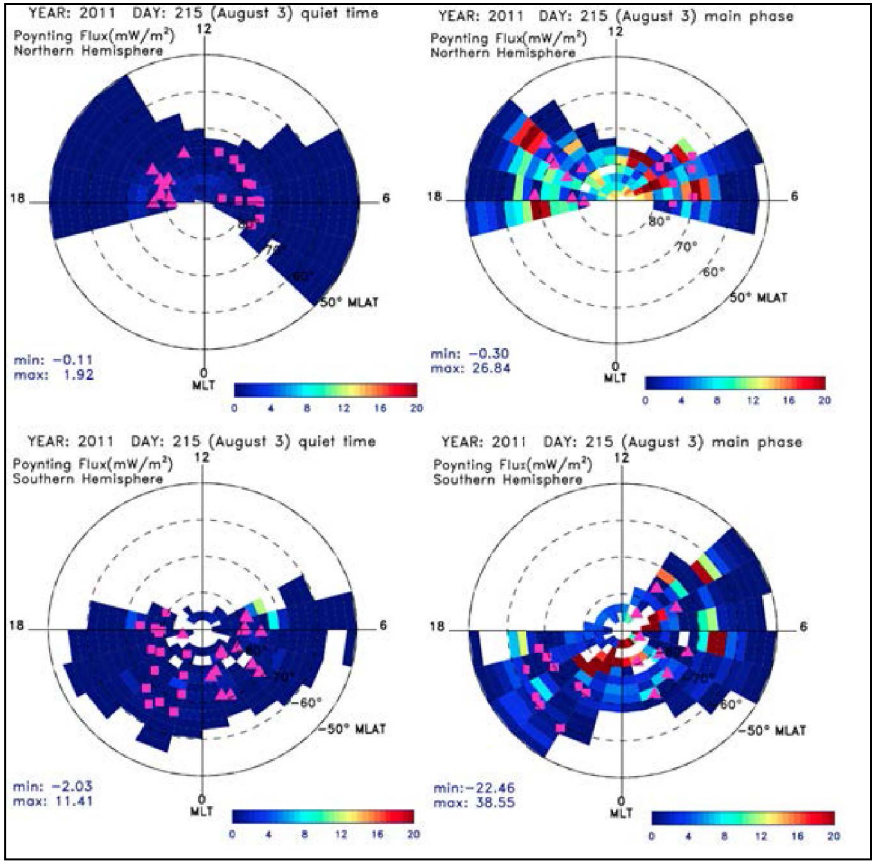
Measured Poynting Flux During August 2011 Magnetic Storm

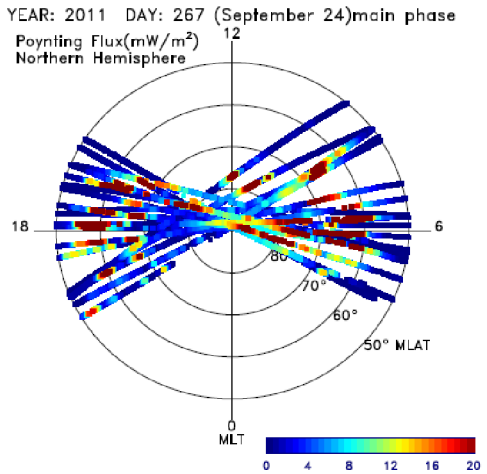


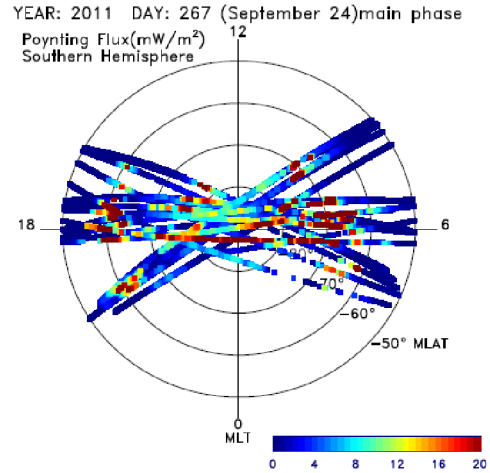


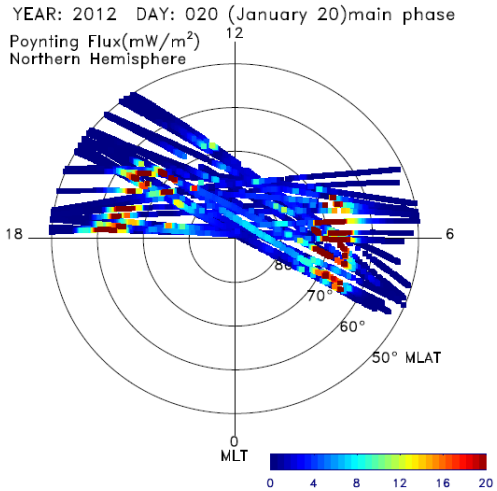
A substantial fraction of total EM power entering the IT system is deposited in the polar cap

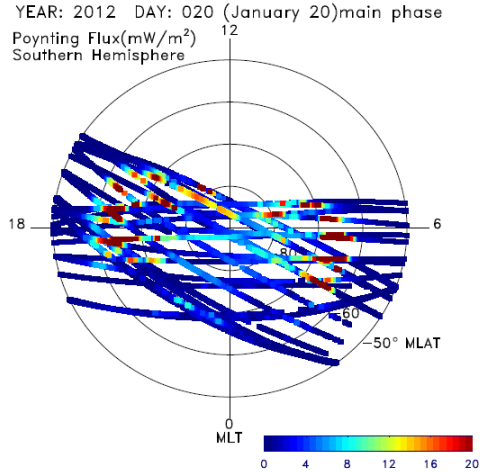
Poynting Fluxes

September 2011 (equinox), January 2012 (solstice) Storms



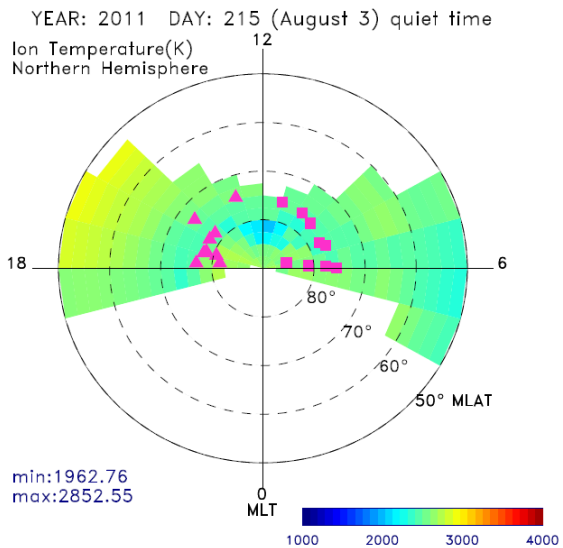


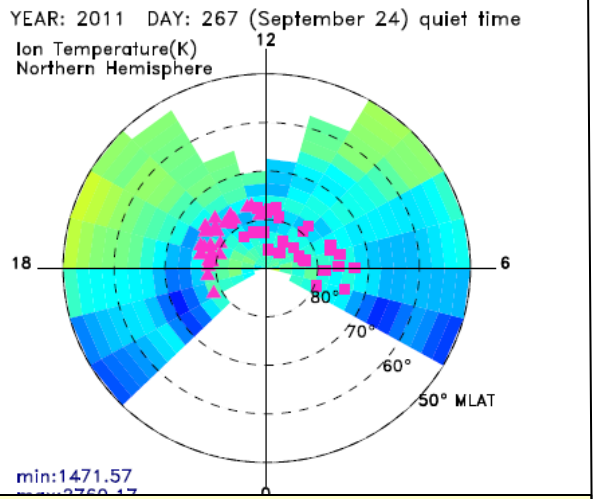


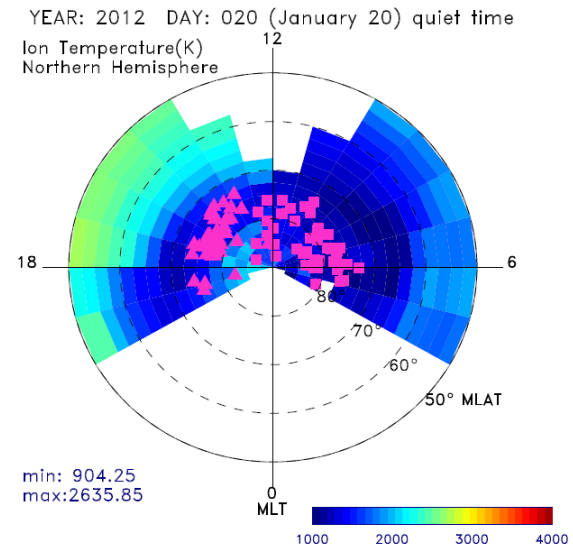


DMSP T_i Observations

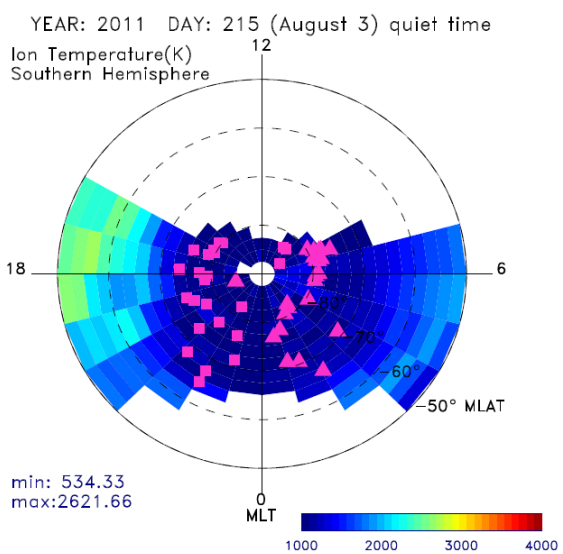
(1) Pre-Storm T_i

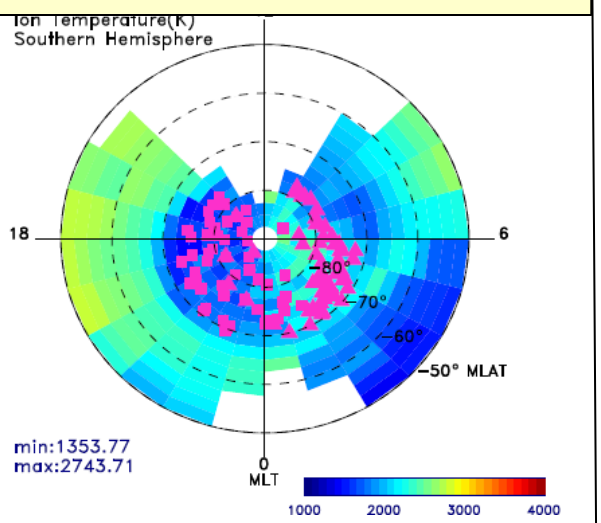


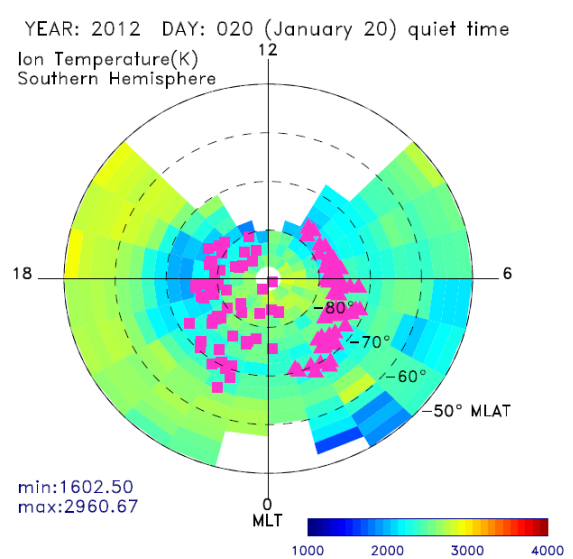




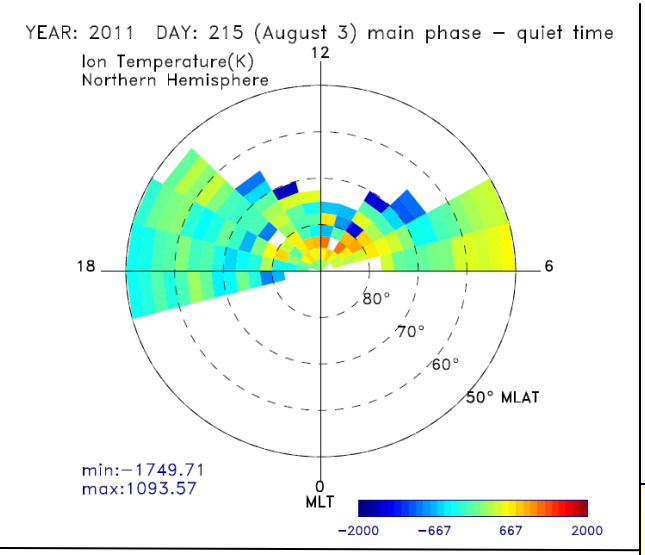
The polar cap during quiet times is warmer than the auroral zone in virtually every case

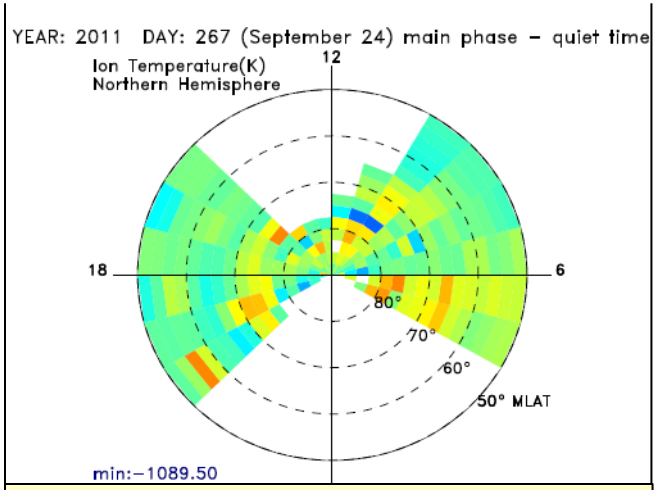


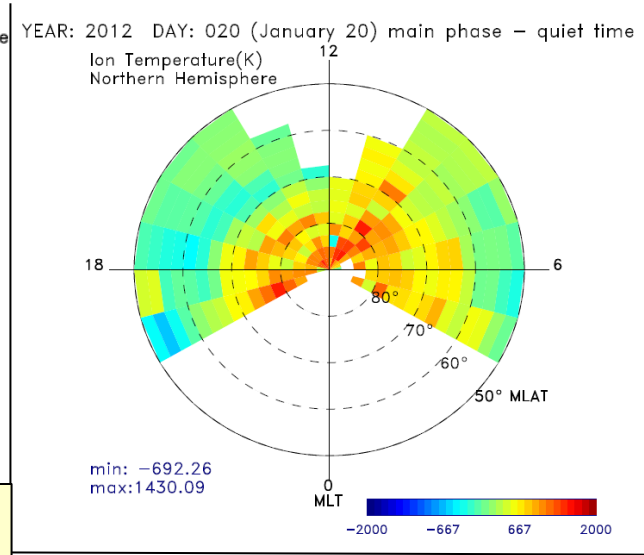




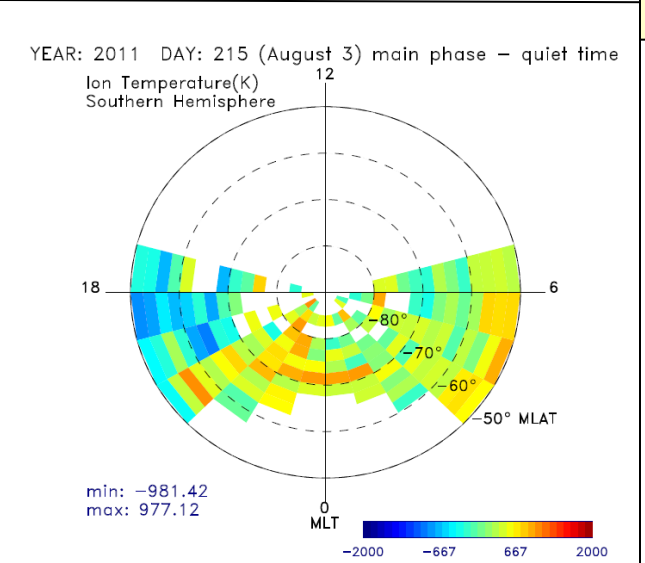
(2) Change in T_i at end of Storm Main Phase

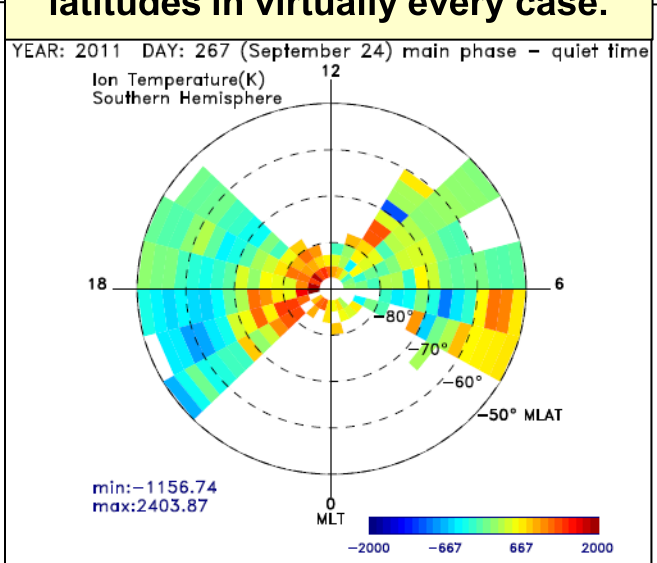


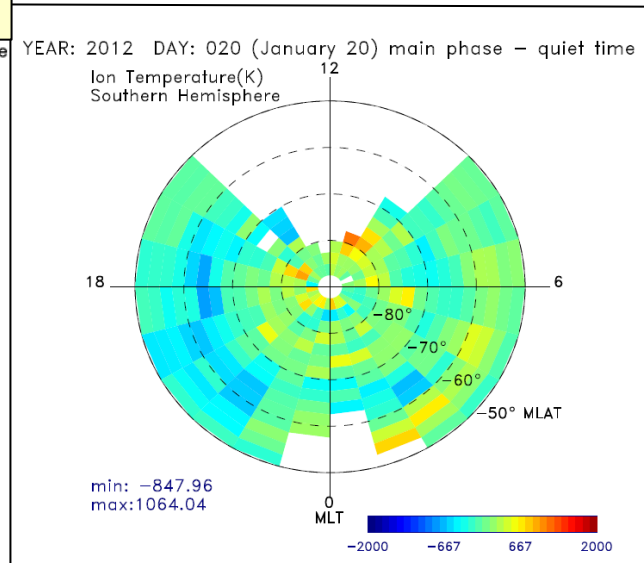




Increase in T_i significant at polar latitudes in virtually every case.







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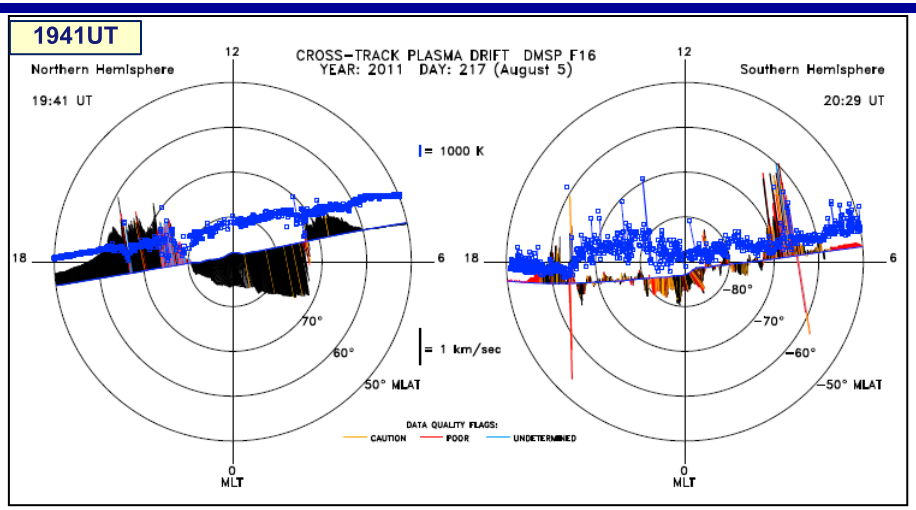
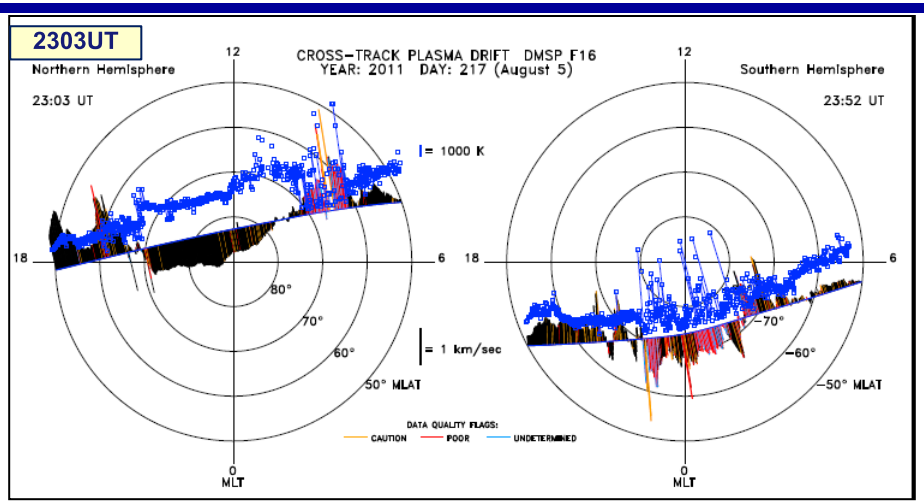
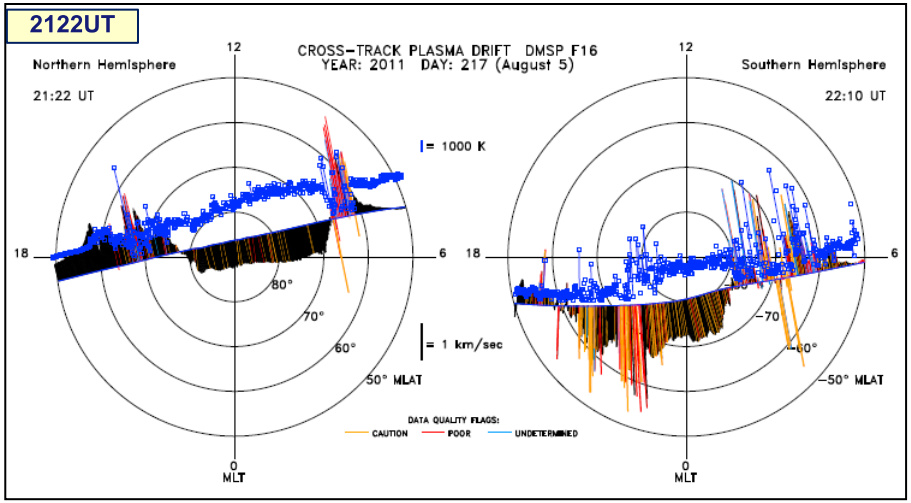
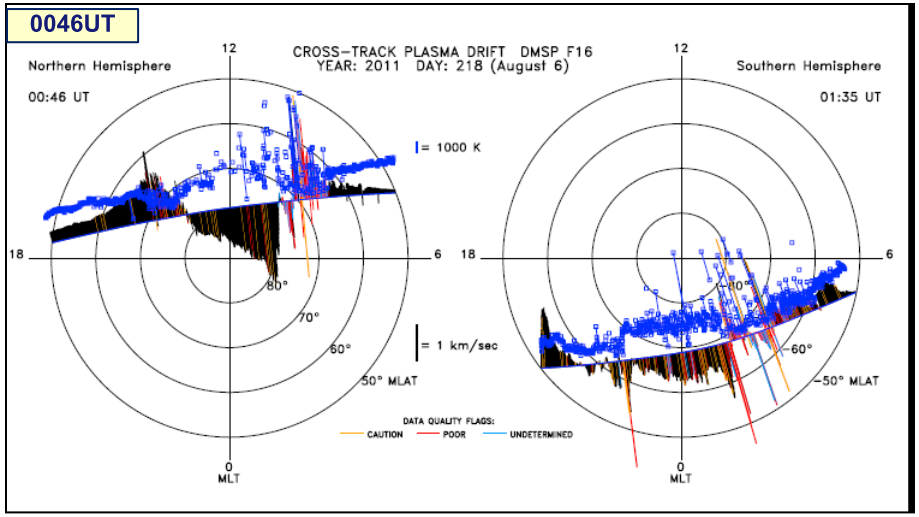
DMSP T_i during August 2011 Magnetic Storm

Onset at 1906 UT, 5 August 2011





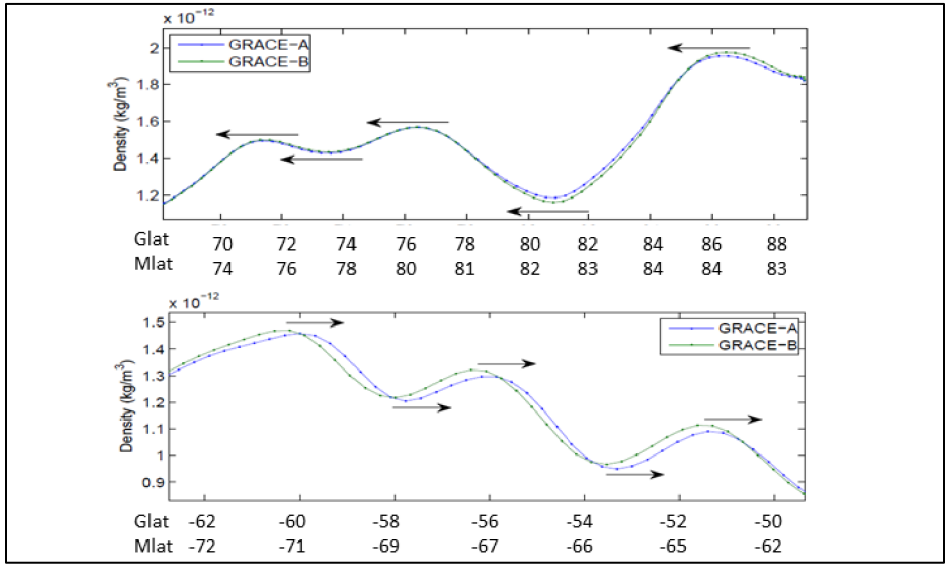




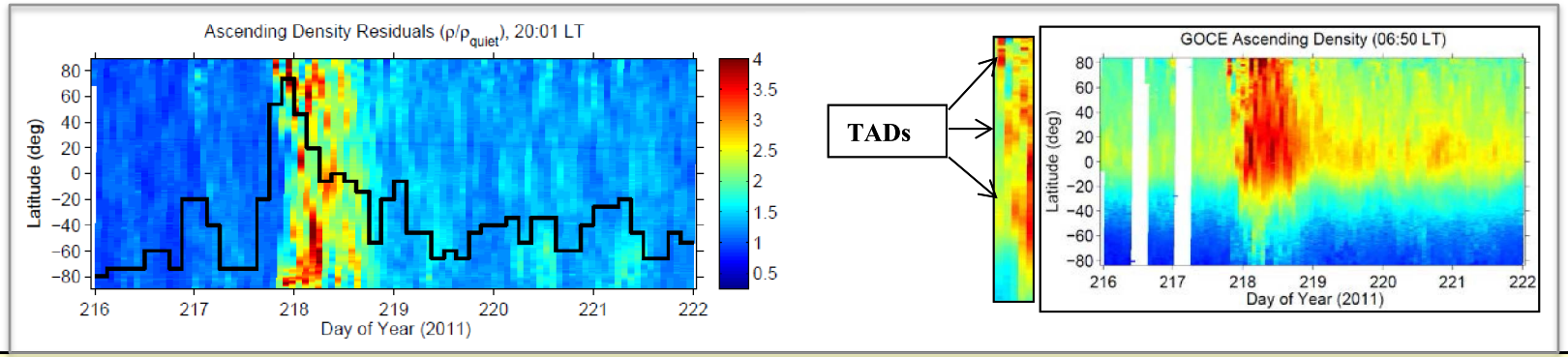
Note T_i increase in antisunward flow region, sharp drop in T_i at convection reversal boundary

Response of Neutrals to Stormtime Energy Input

GRACE and GOCE Observations During August 2011 Storm

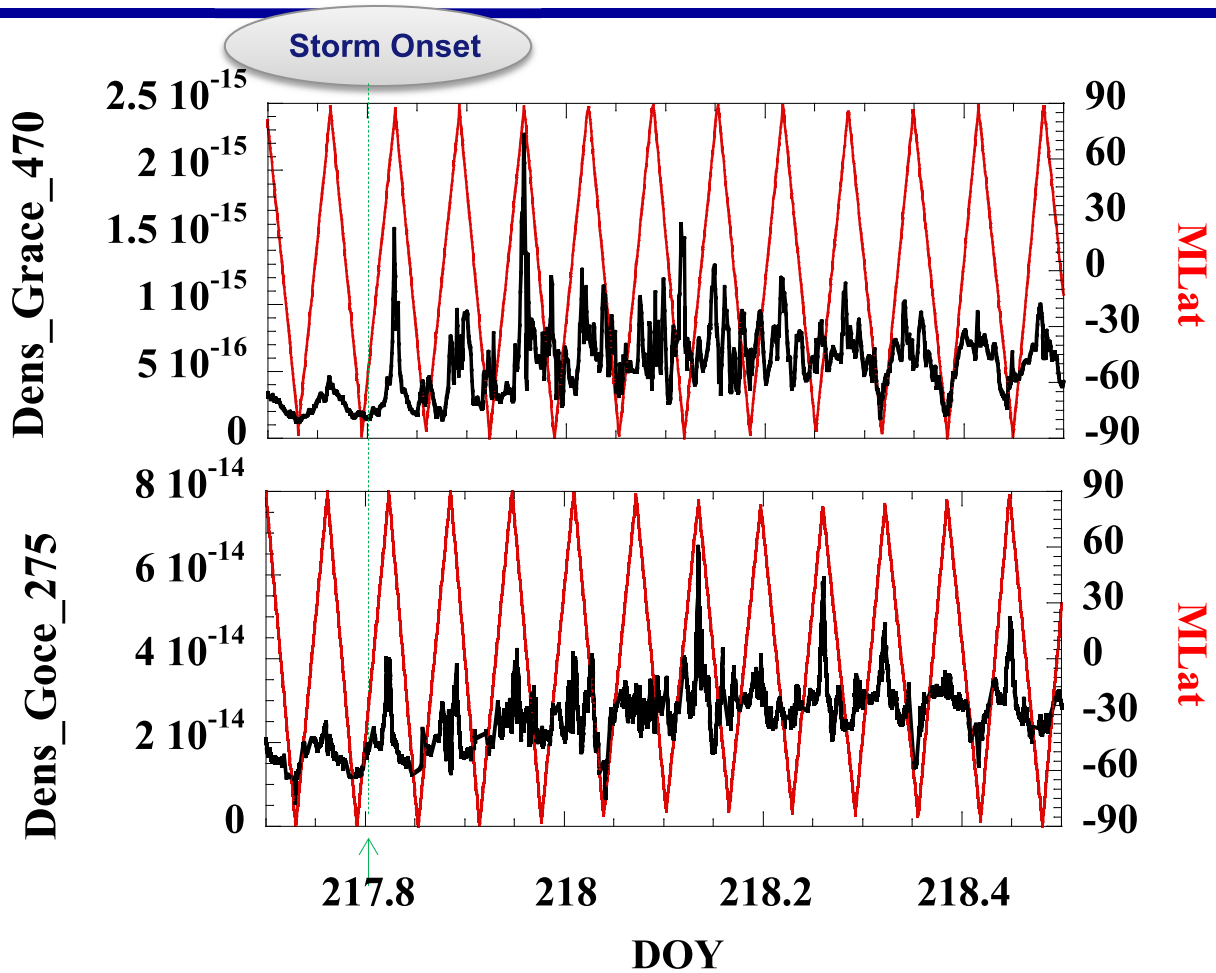


Traveling Atmospheric Disturbances (TADs) on GRACE in both hemispheres indicate a source of Joule heating poleward of 83º MLat (NH) and -72º Mlat (SH).



TADs detected simultaneously at GRACE at 2001 LT (left) and GOCE at 0650 LT (right). Source of Joule heating must be poleward of 83^{0}MLat (GRACE) and 80^0 (GOCE).

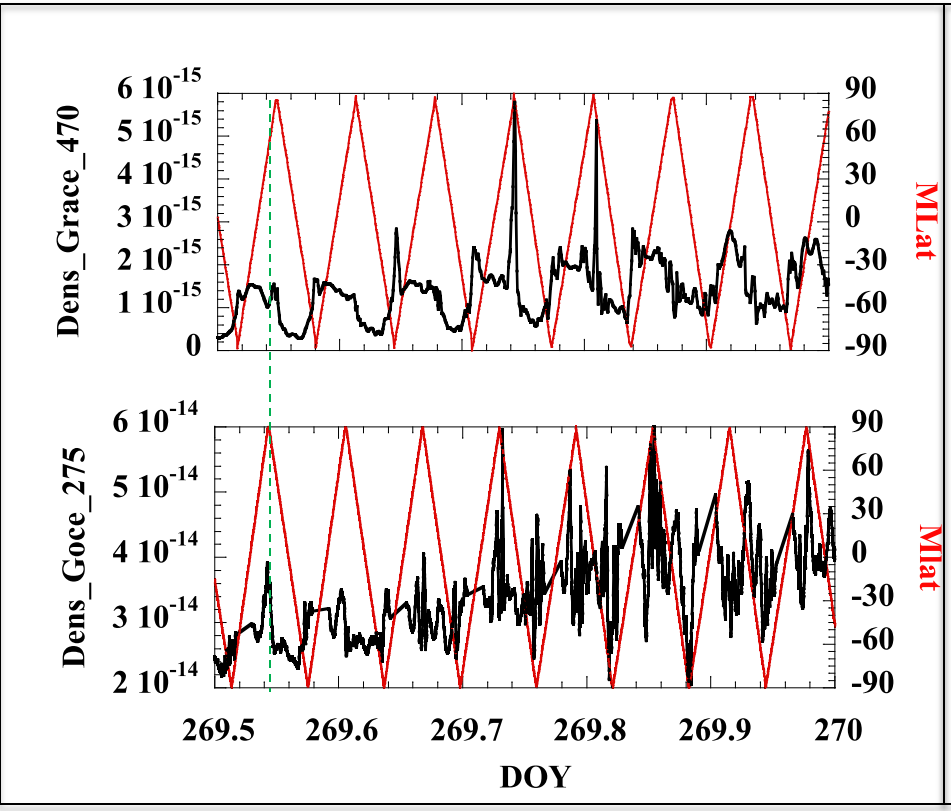
Comparison of GRACE, GOCE Densities During August 2011 Storm

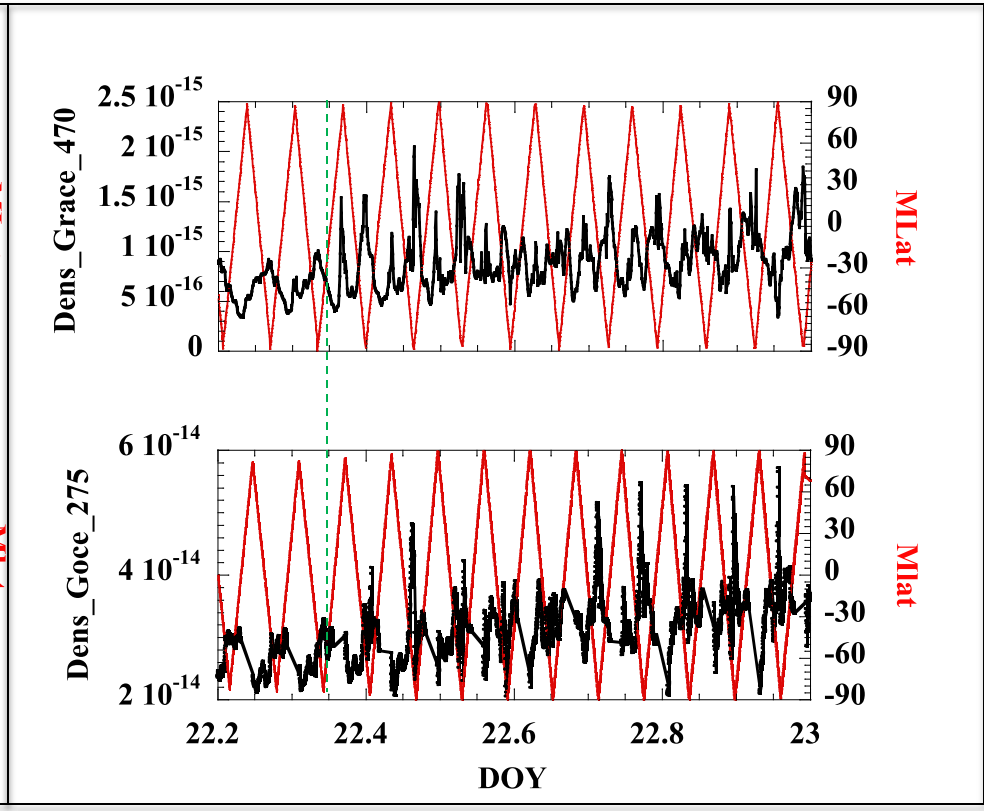


Response of thermosphere is (1) fast; (2) maximal at highest latitudes

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

September 2011 , January 2012 Storms

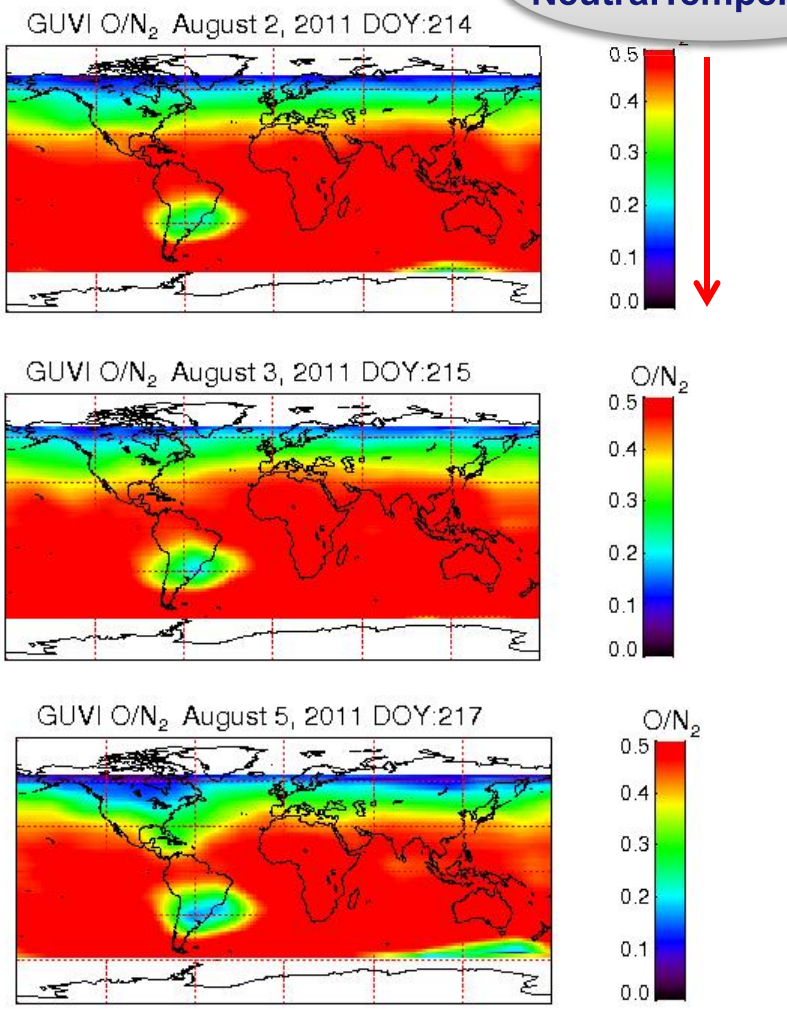


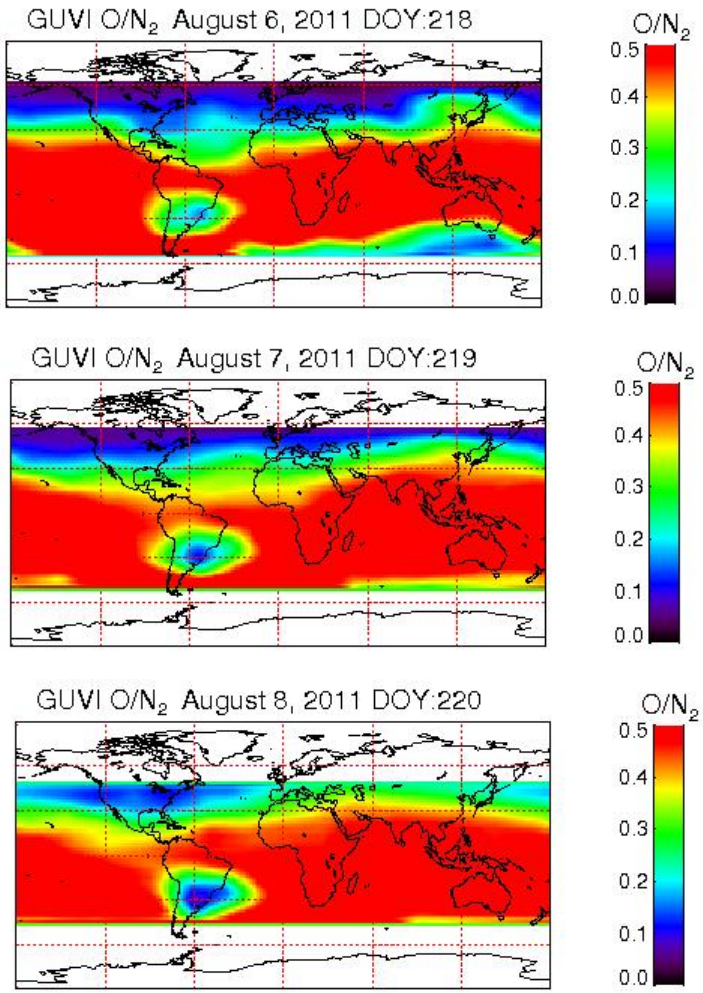


Joule heating of neutrals is dynamic in space and time

GUVI Observations of O/N_2 Ratio During August 2011 Storm

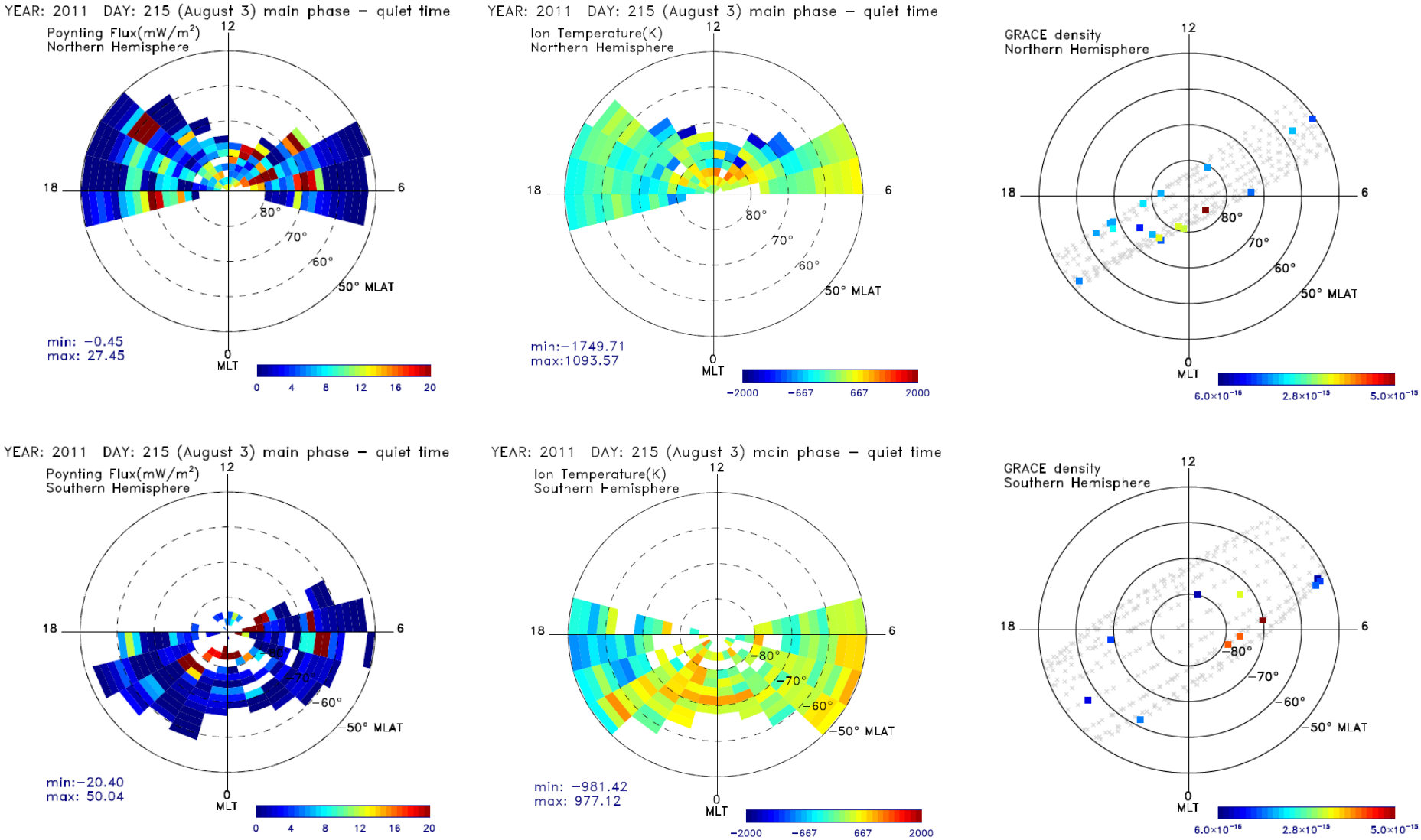
Increasing NeutralTemperature





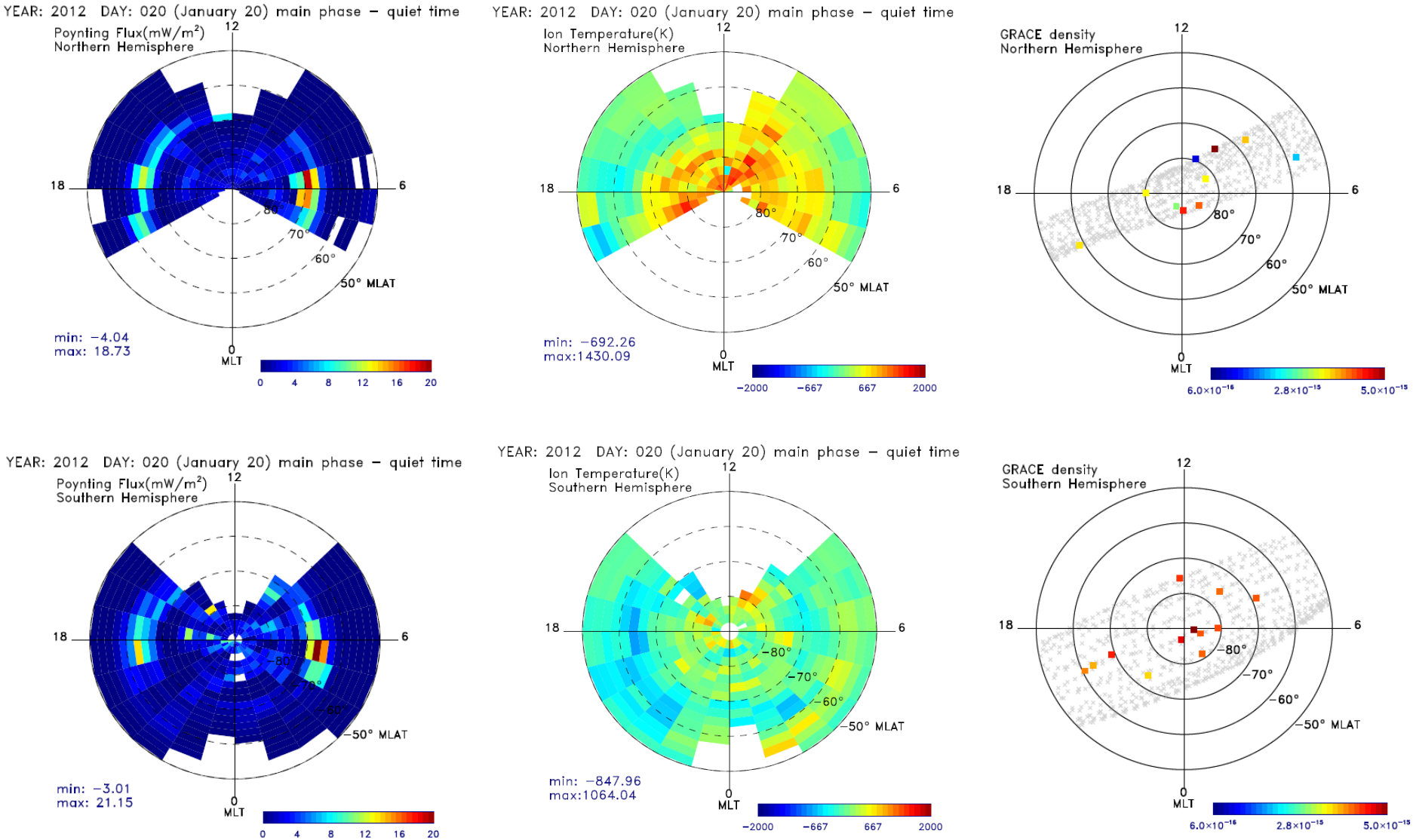
Decrease in atomic oxygen at 135 km altitude caused by Joule heating and recombination
Polar cap is always warmer than lower latitudes
Decrease in O/N_2 proceeds from polar to lower latitudes

Energy Dissipation in IT
Poynting Flux → T_i, ρ_n
August 2011 Storm

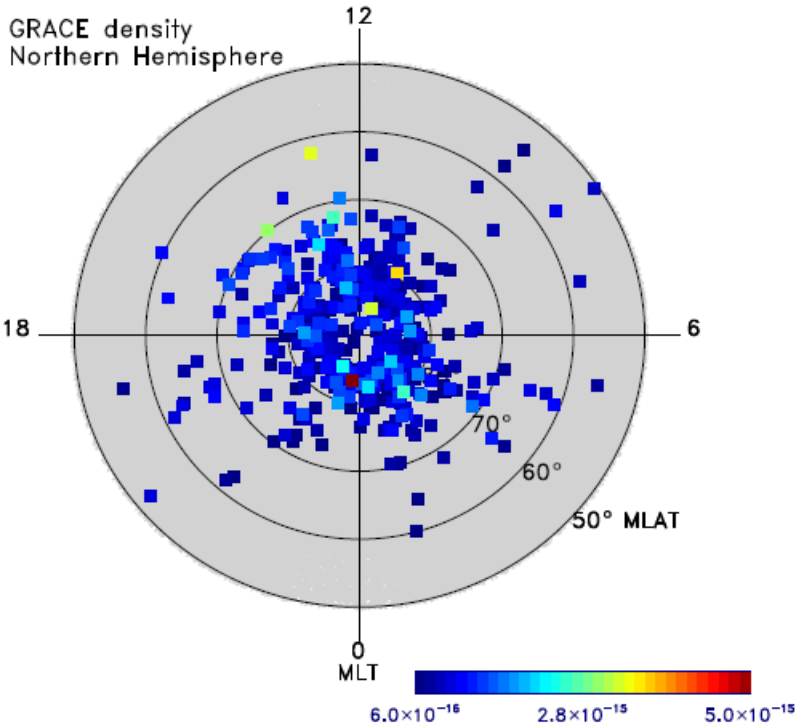


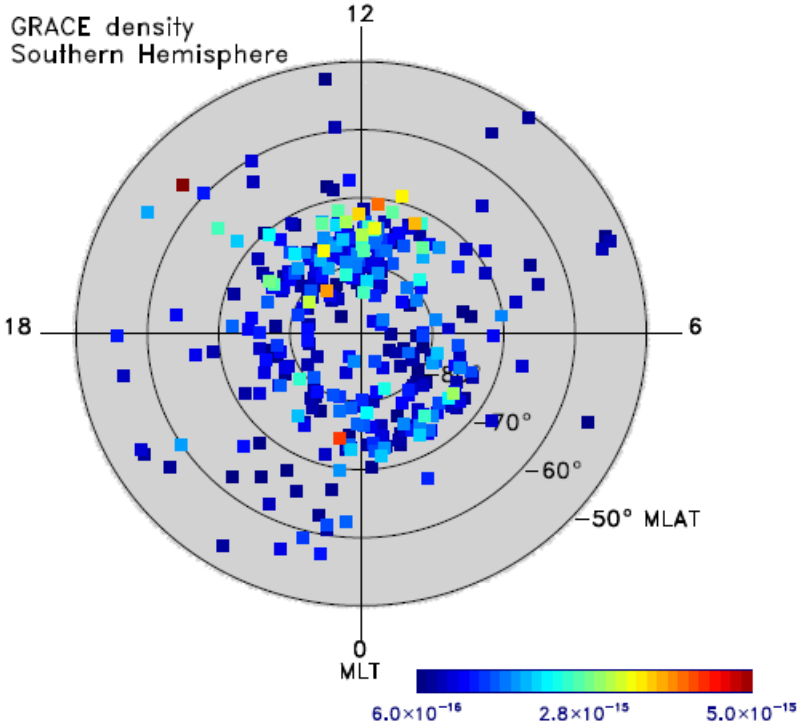
DISTRIBUTION STATEMENT A – Unclassified, Unlimited Distribution

Energy Dissipation in IT
Poynting Flux → T_i, ρ_n
January 2012 Storm

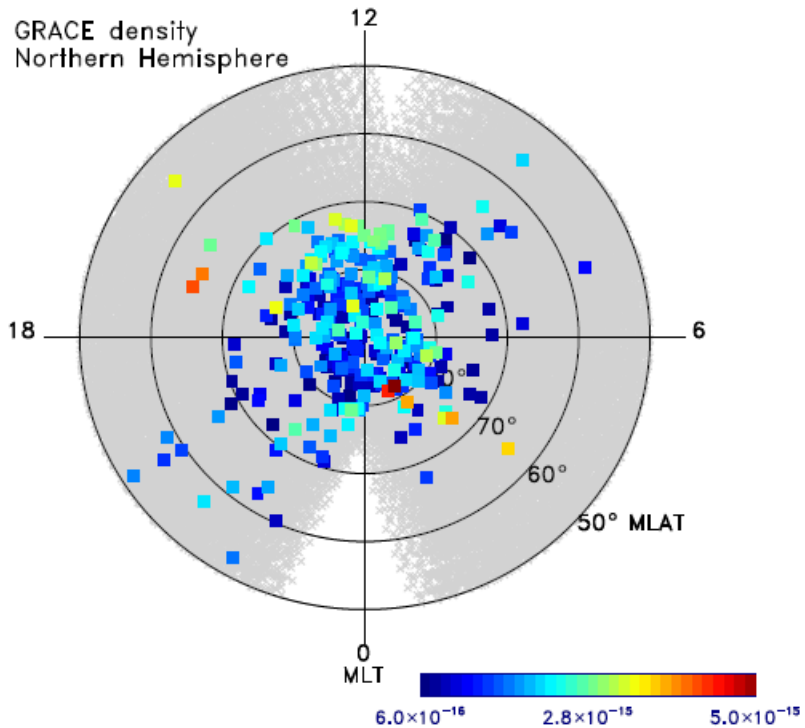


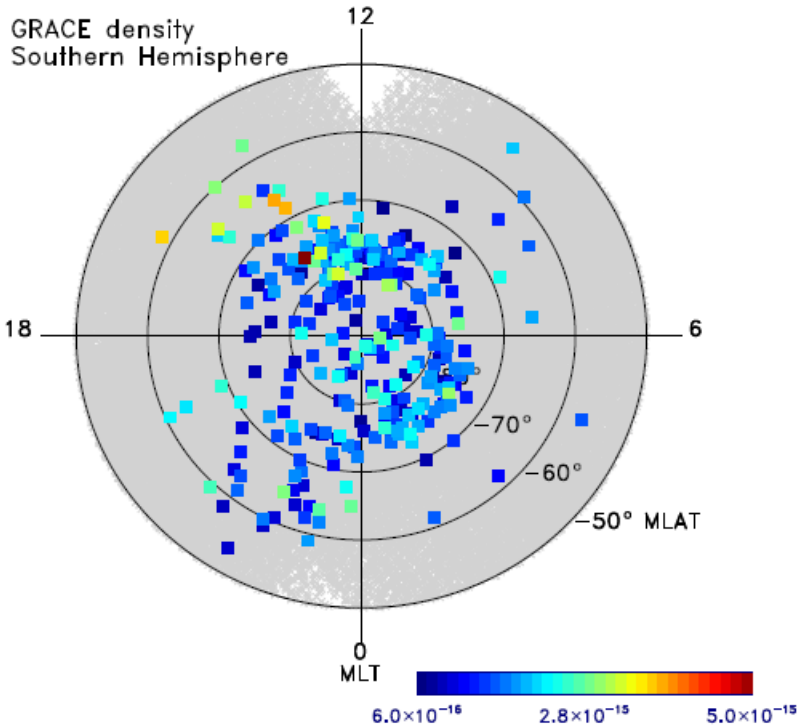
GRACE Density Maxima
2011





GRACE Density Maxima
Jan – June 2012





Summary (1)

- Poynting flux shows peaks around auroral zone AND inside polar cap. Energy enters IT system at all local times in polar cap. Track-integrated flux at DMSP often peaks at polar latitudes – probably due to increased area of polar cap during storm main phases.

- 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 maxima at polar latitudes without clear auroral signatures. Response is fast, minutes from onset to density peaks.

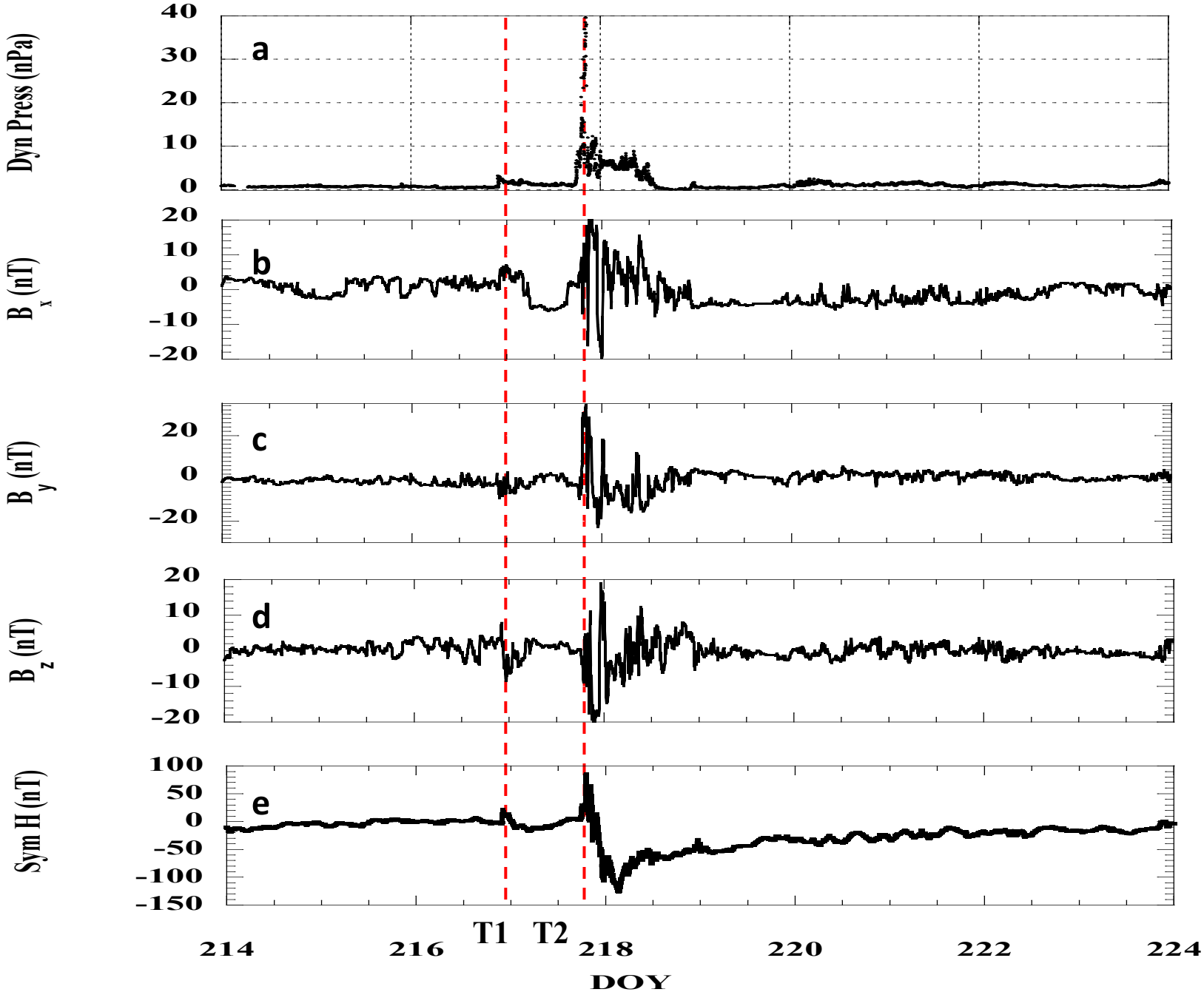
- GUVI observations of O/N_2 ratio during storms show similar response as direct measurements of ion and neutral densities, i.e. high temperatures in polar cap during pre-storm quiet period, heating proceeding from polar cap to lower latitudes during storm main phase.

- Discrepancy between maps of Poynting flux and of ion temperatures/neutral densities suggests that connection between Poynting flux and Joule heating is not simple.

Summary (2)

- 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.
  - What is the dissipation mechanism that converts Poynting flux to Joule heat? What is the altitude/latitude profile for energy transfer?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30
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B x (nT)
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B y (nT)
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-10
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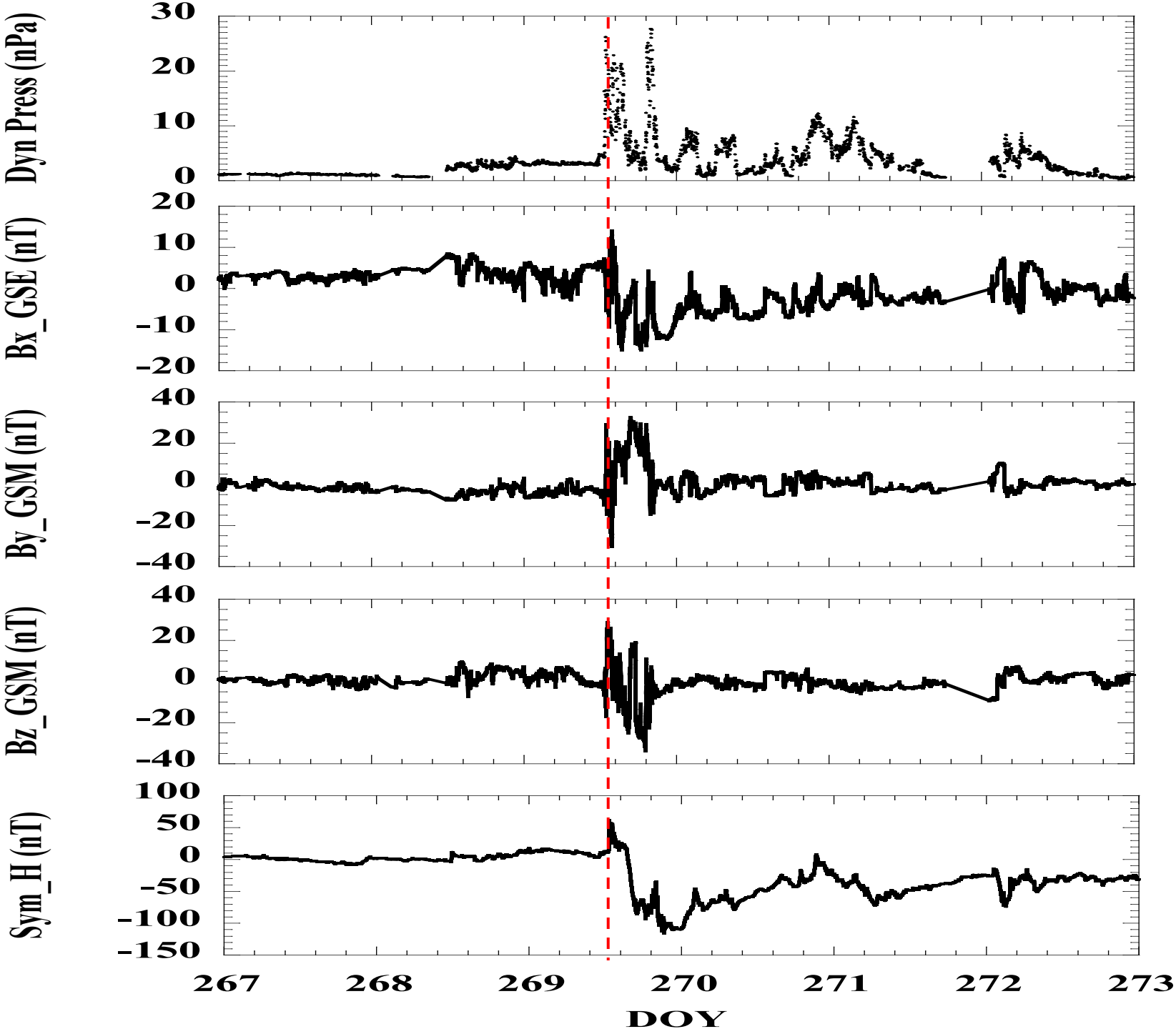
218
220
222
224
DOY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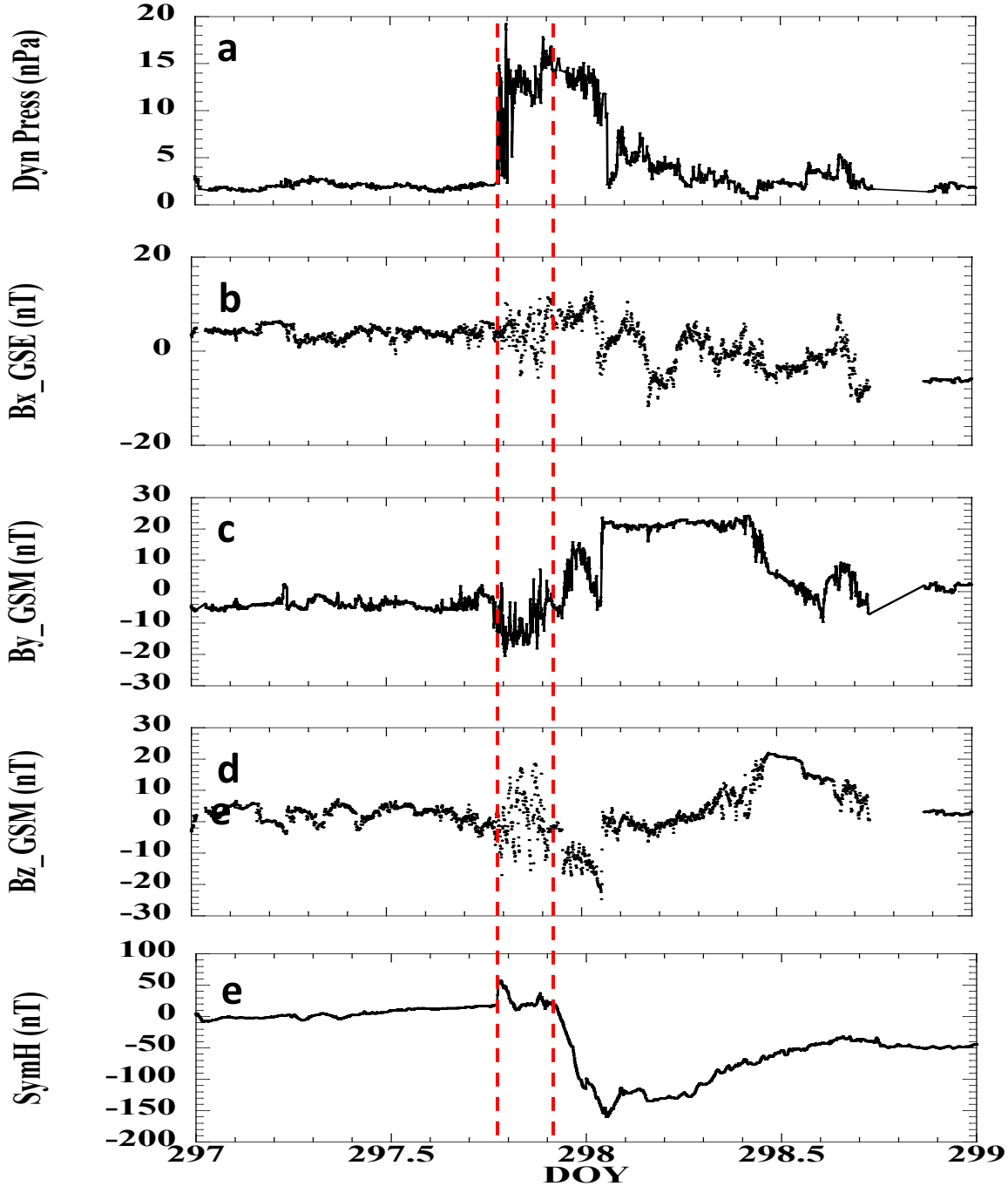
DOY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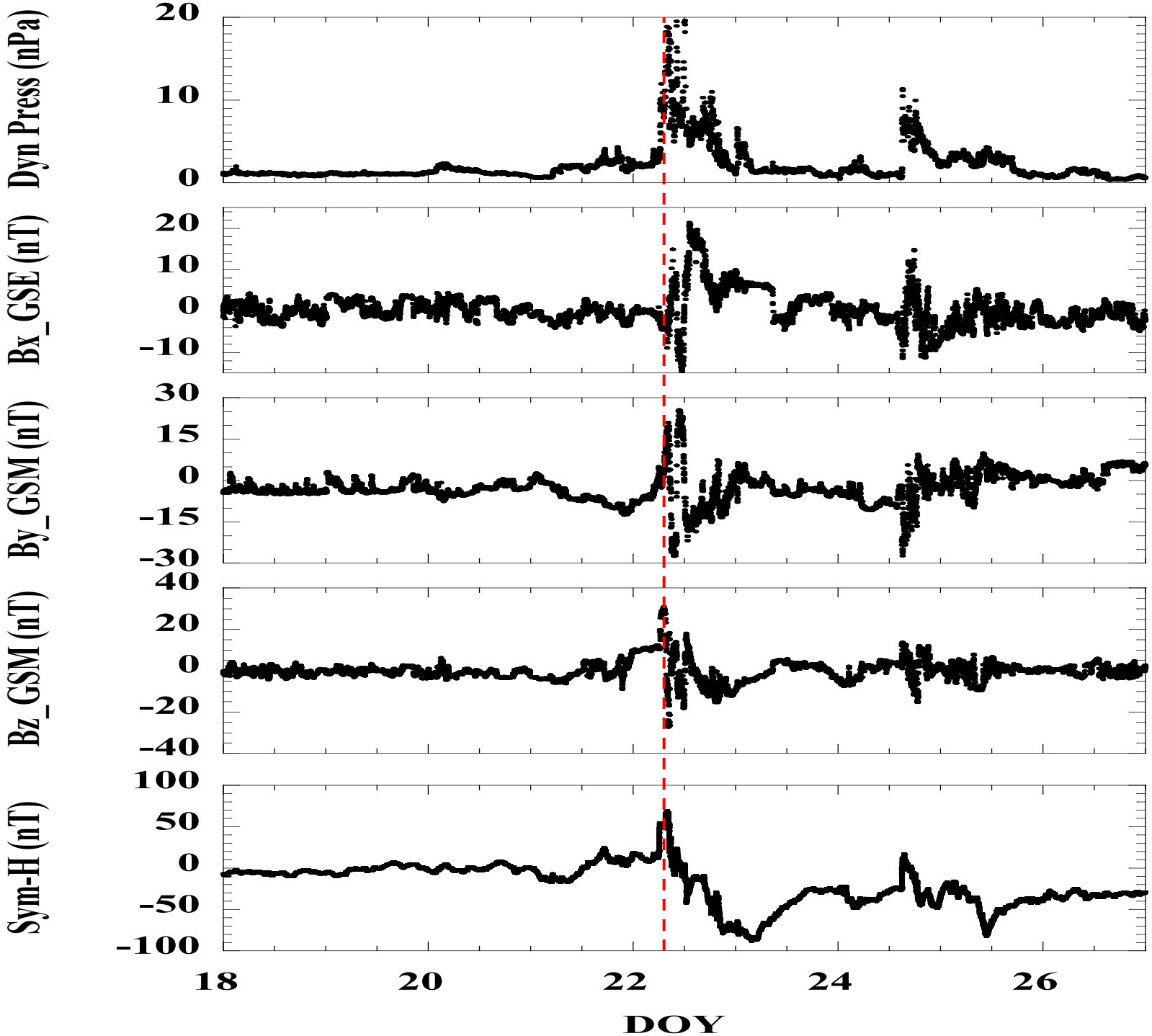
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Bz_GSM (nT)
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0
-20
-40
Sym-H (nT)
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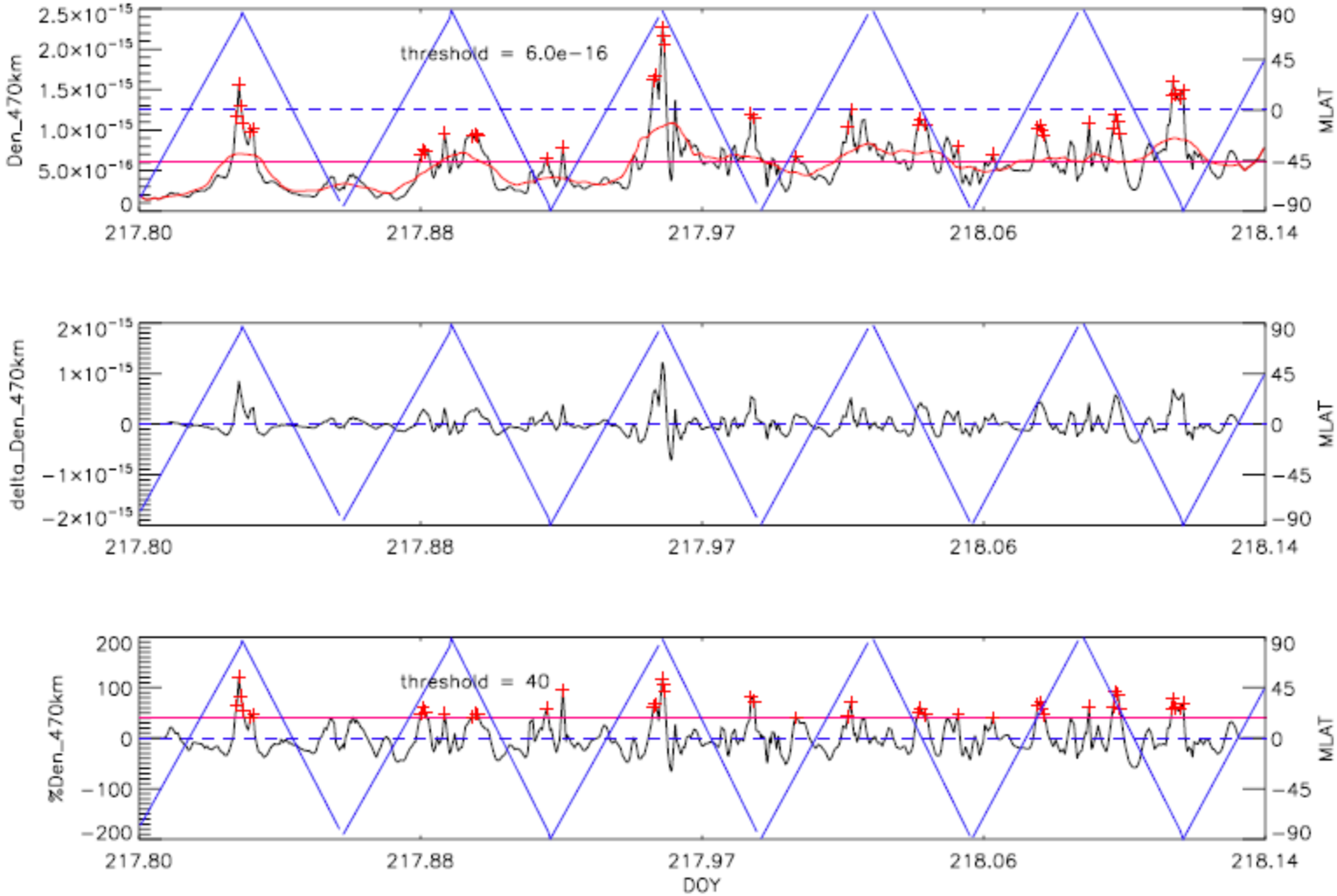
26
DOY

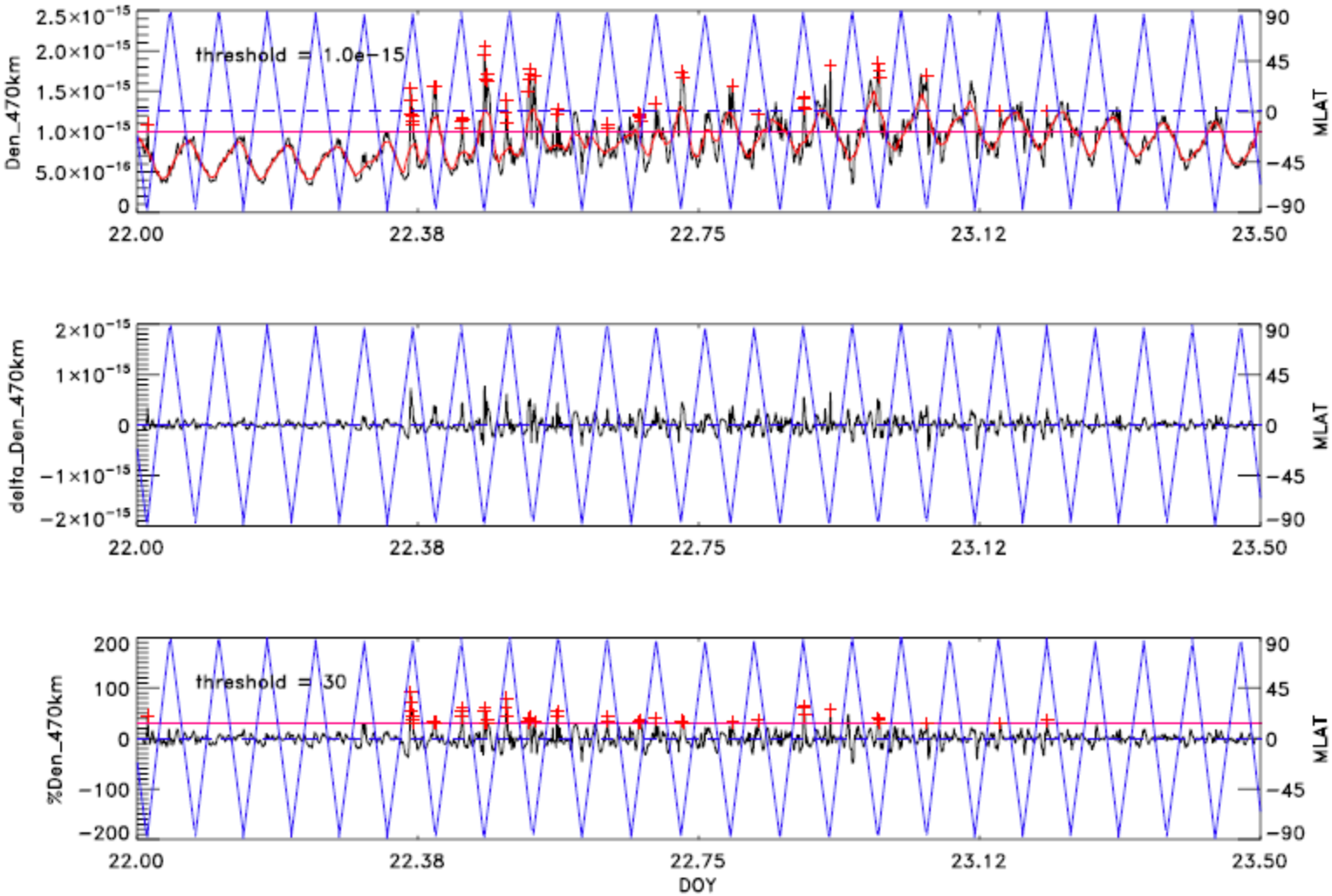
Neutral Density Maxima

August 2011 Storm

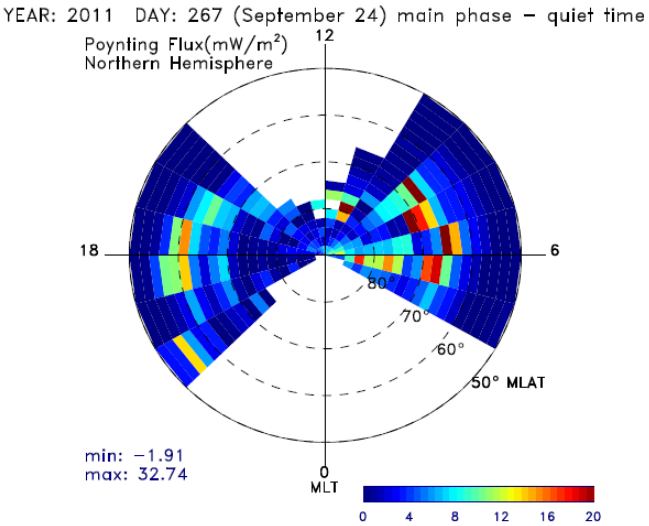


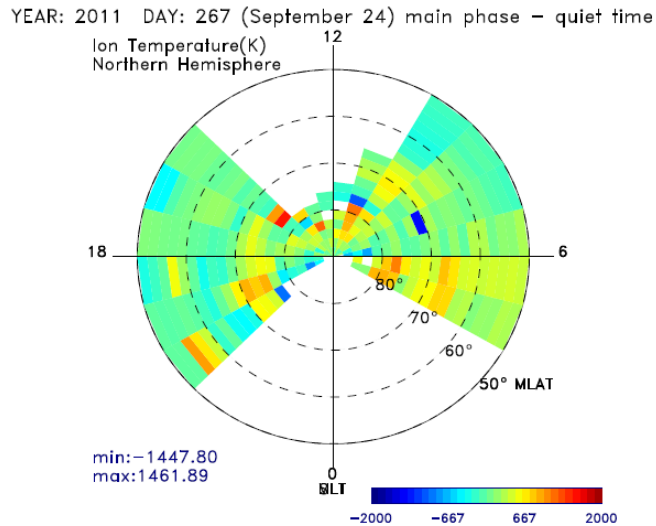
Neutral Density Maxima

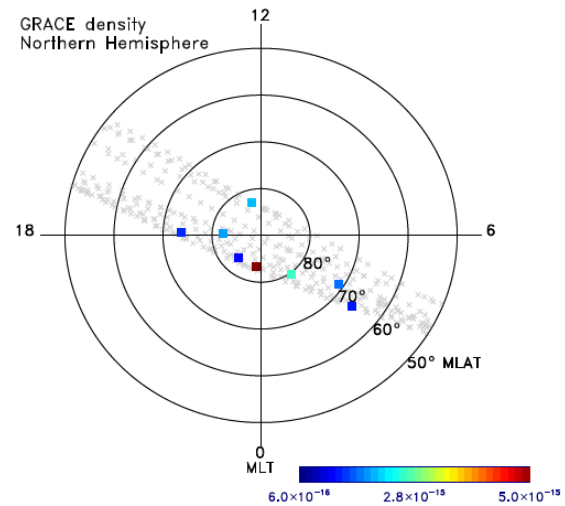
January 2012 Storm

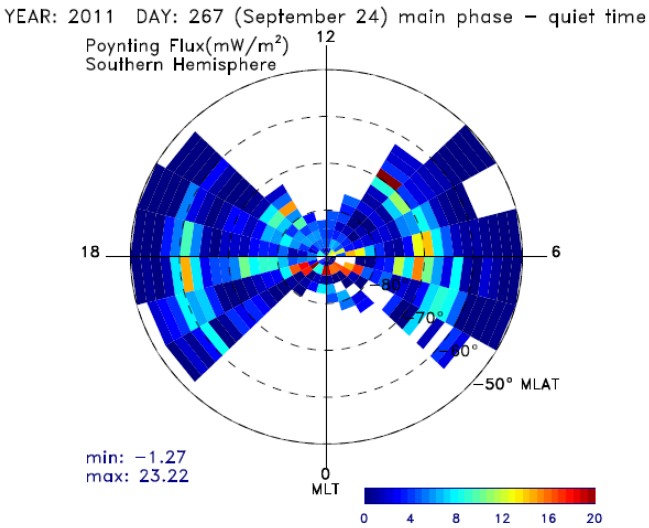


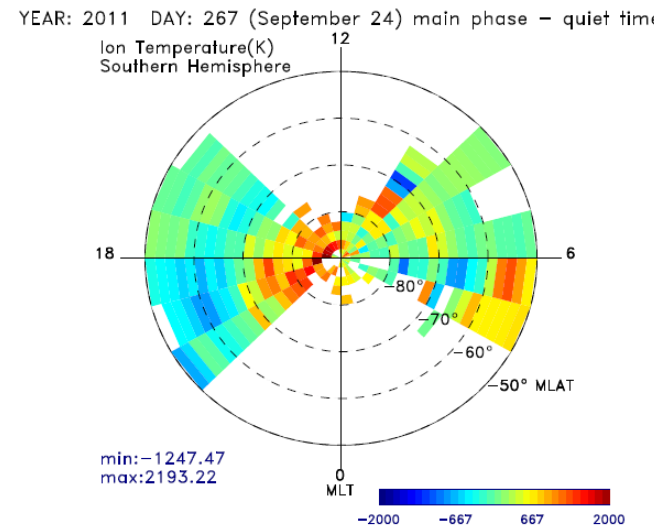
Energy Dissipation in IT
September 2011

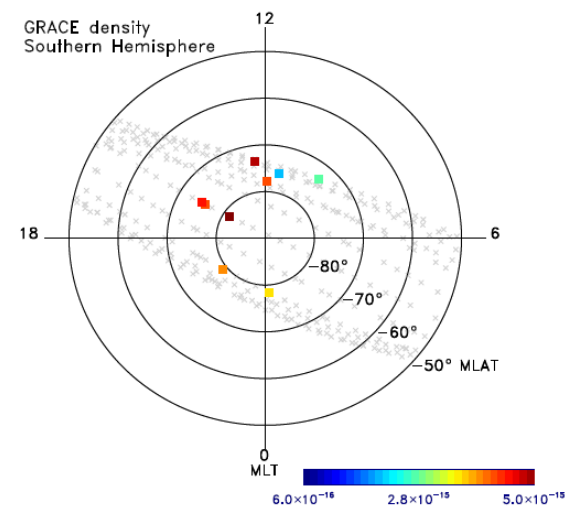






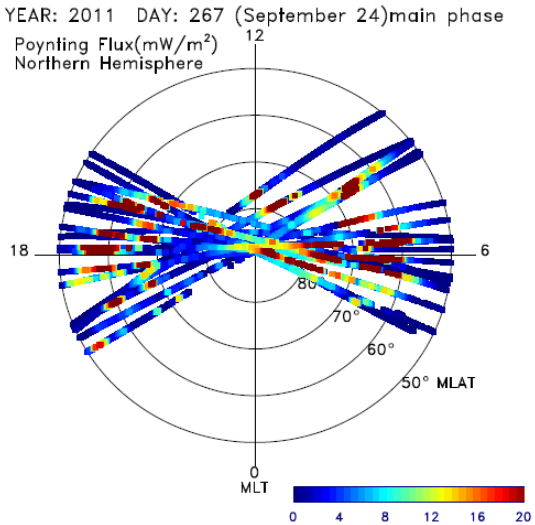


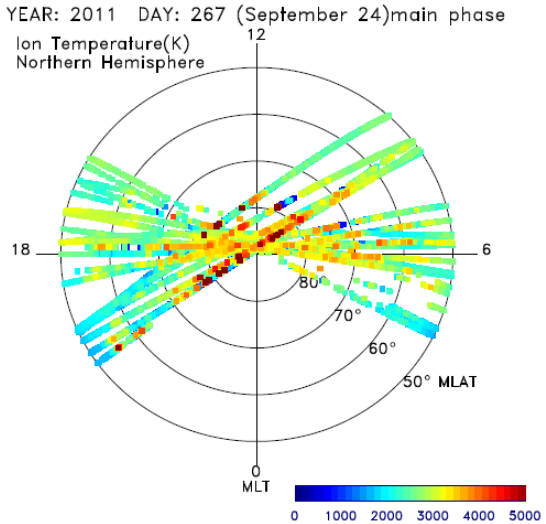


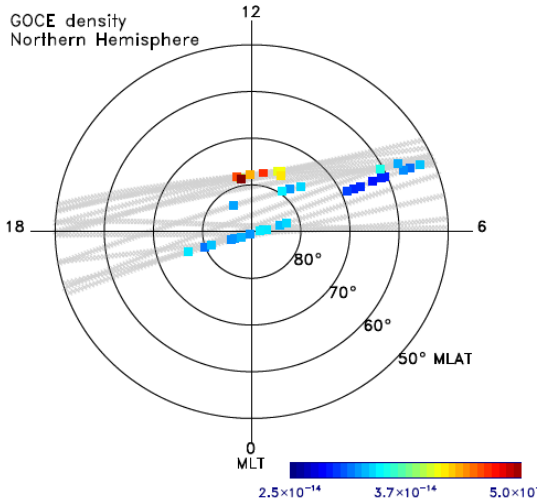


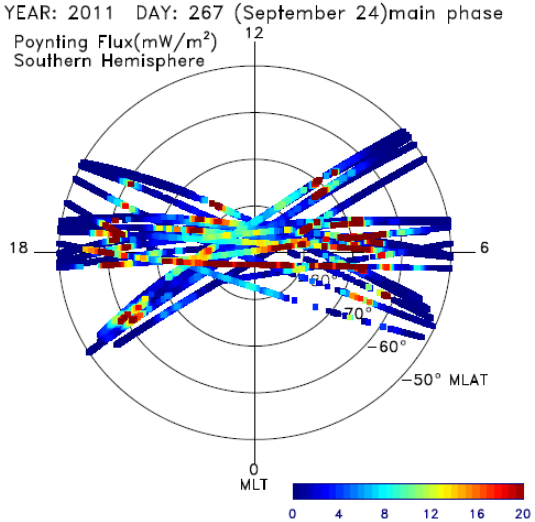
DISTRIBUTION STATEMENT A – Unclassified, Unlimited Distribution

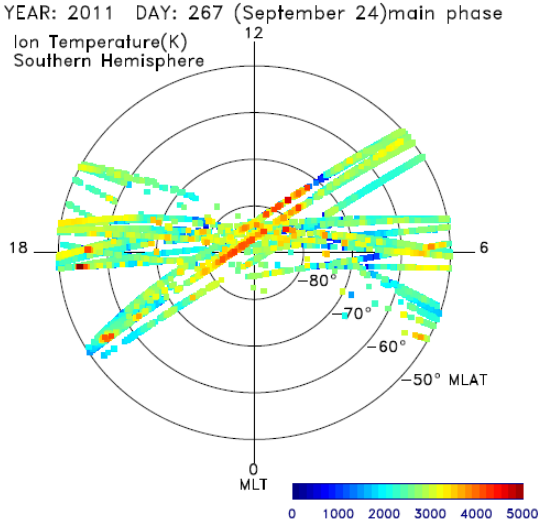
Energy Dissipation in IT
September 2011

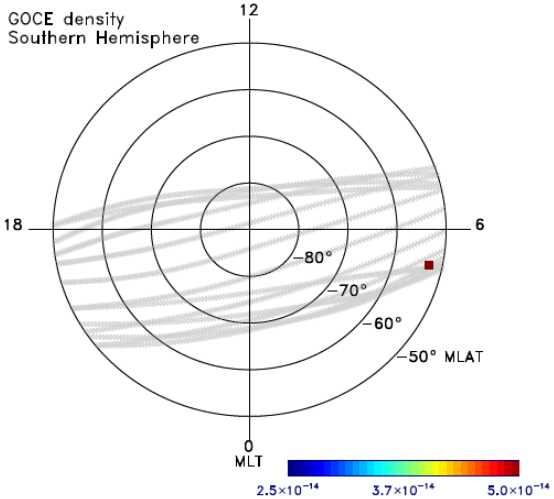




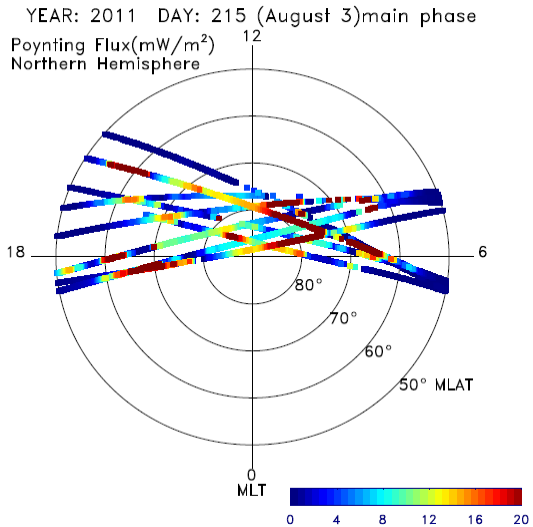


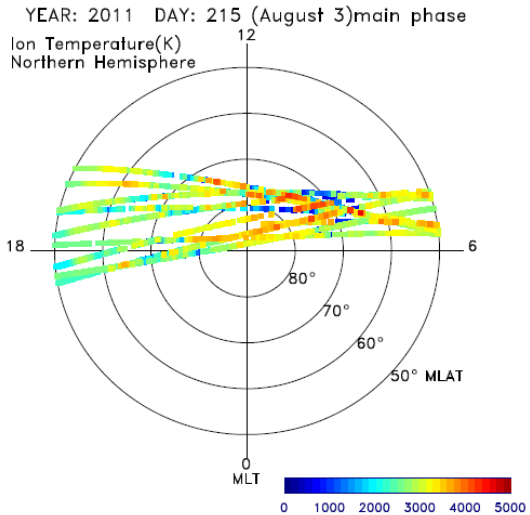


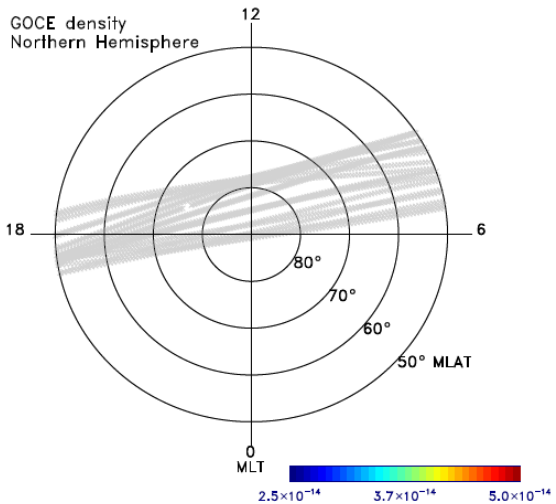


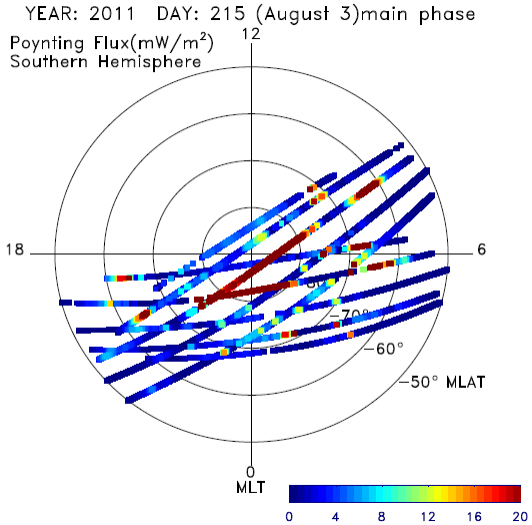


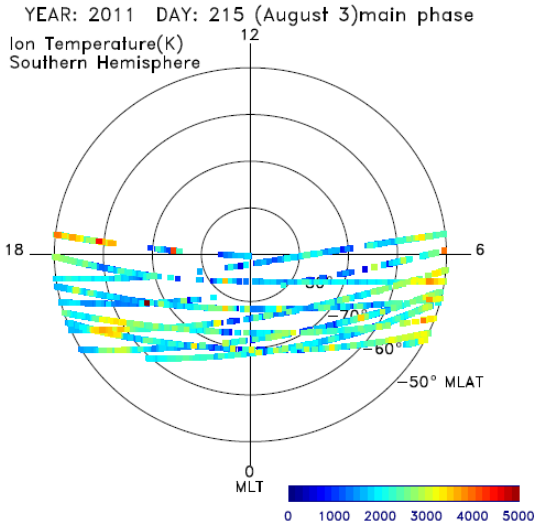
Energy Dissipation in IT
August 2011

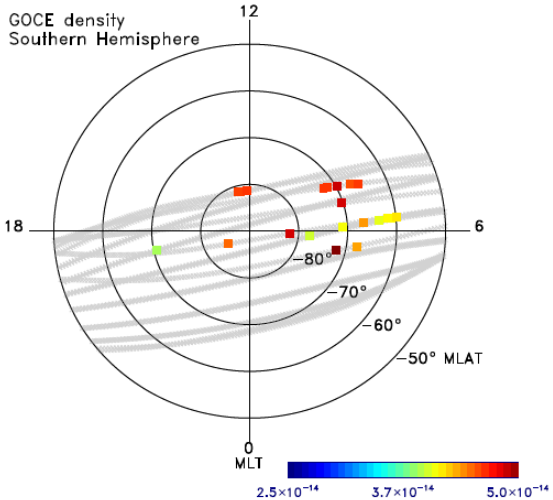




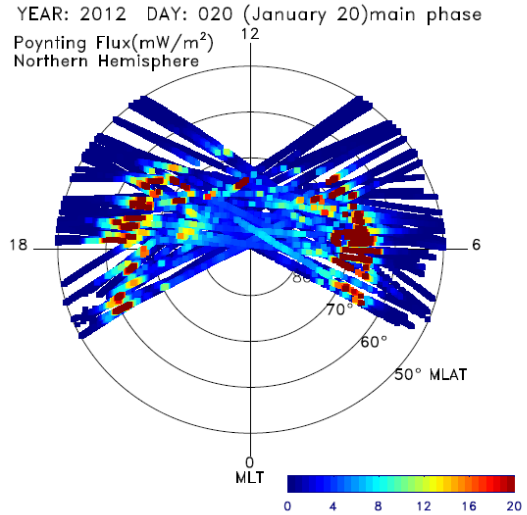


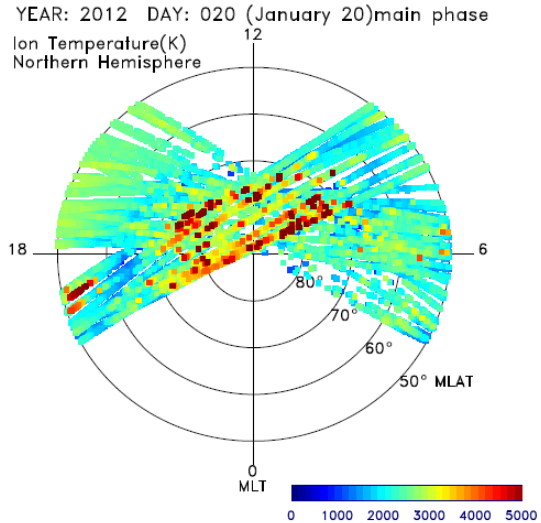


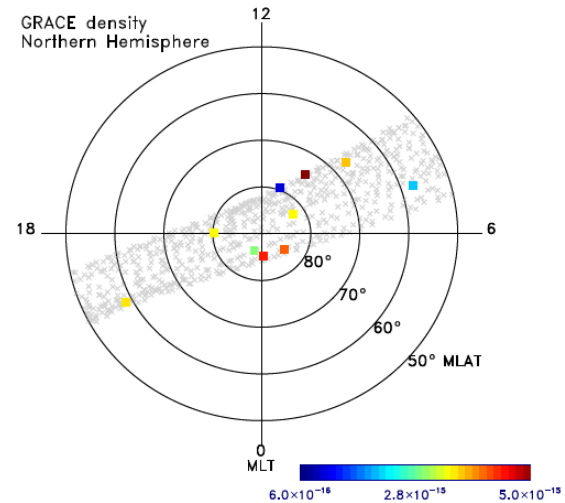


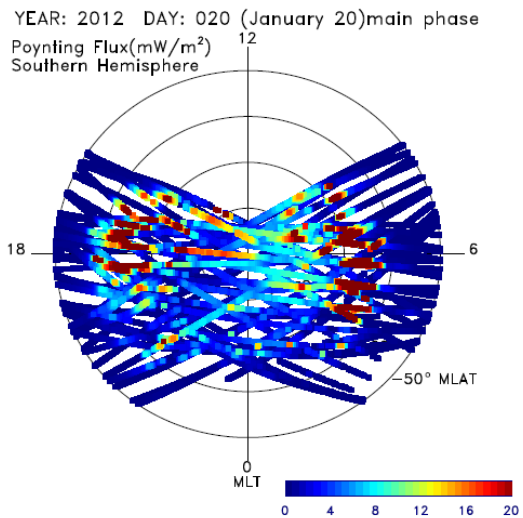


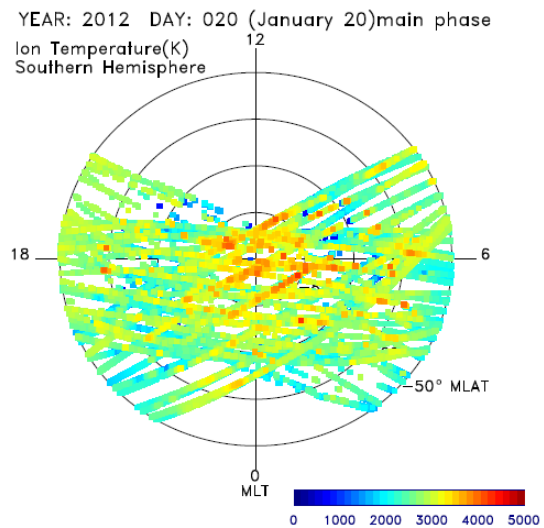
Energy Dissipation in IT
January 2012

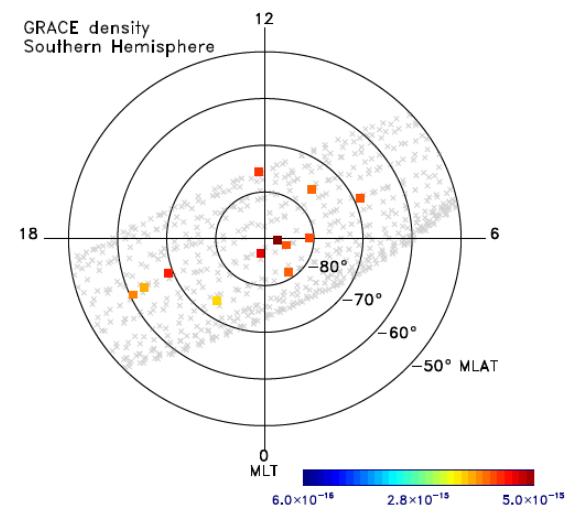


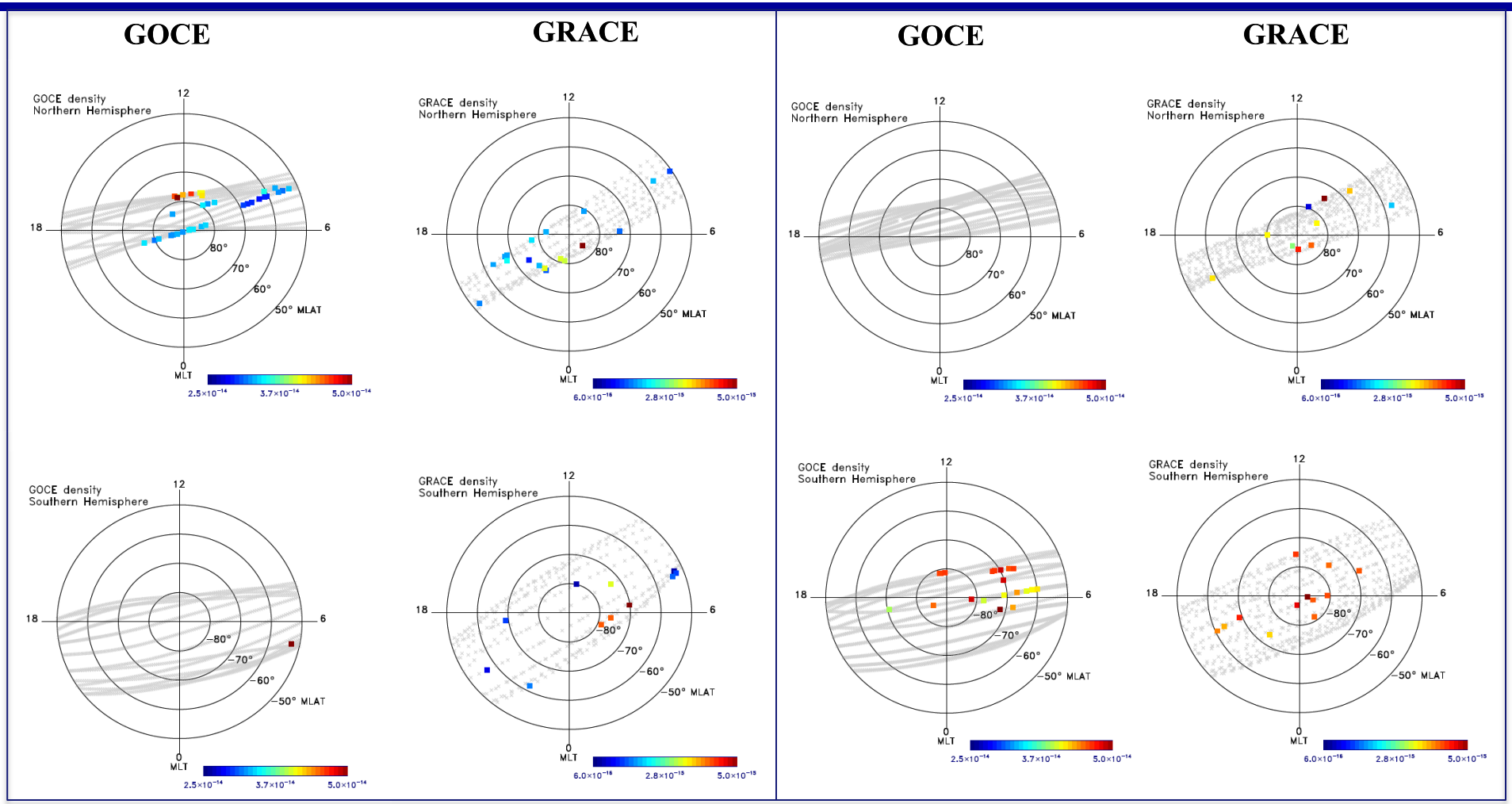










DISTRIBUTION STATEMENT A – Unclassified, Unlimited Distribution

Comparison of GRACE with GOCE
August 2011, January 2012 Storms