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High latitude IT response during magnetic storms

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CEDAR-GEM Mini-Workshop

8 December 2013

IT Coupling During the August 2011 Magnetic Storm
3 Ongoing Research Studies

A magnetic storm occurred on 5-6 August, with onset at 1906 UT on 5 August (day 217), and recovery beginning at 0322 UT on 6 August (day 218).

Minimum Sym-H is -126 nT.

(1) *Energy budget*: Methodology - compute energy budget for storm including ionosphere, thermosphere and ring current sinks, using a combination of models and data.

Ionospheric sink: Use Weimer (2005; 2011) model (W05), modified by DMSP Poynting flux measurements and Hemispheric Power due to particle precipitation.

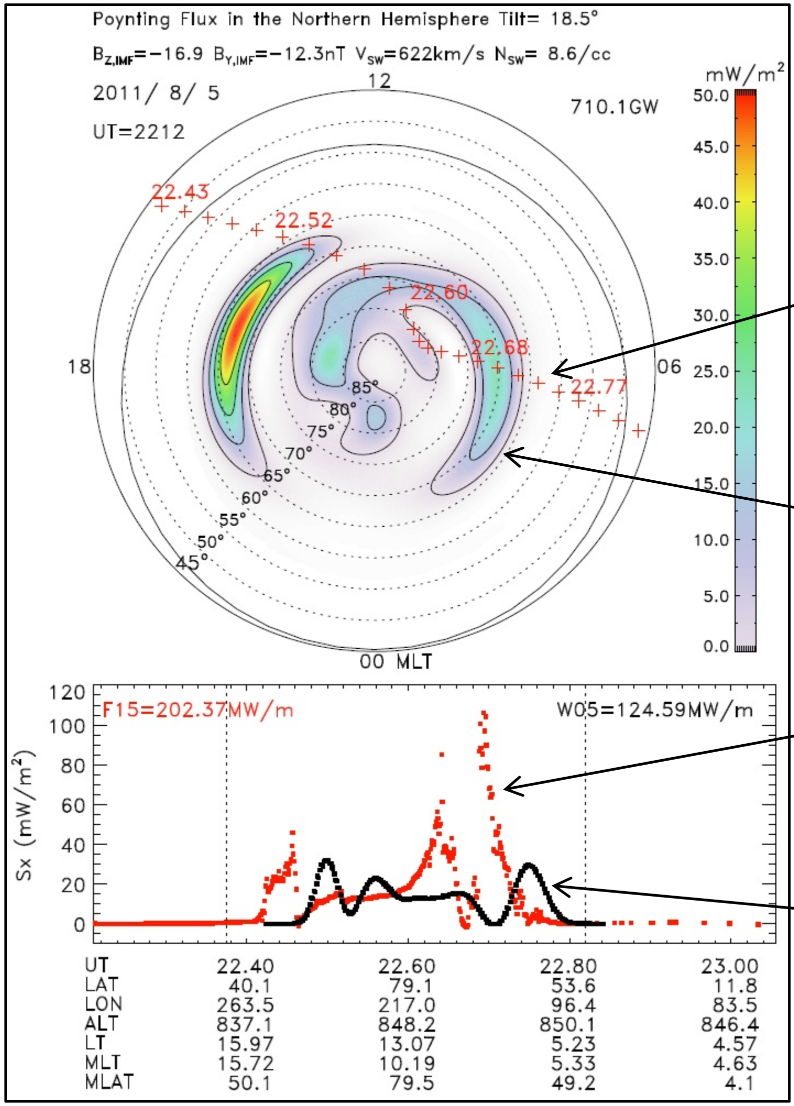
Thermospheric sink: Use method outlined by Burke et al (2009) to compute total energy change in ionosphere during the storm.

Ring current sink: Use Dessler-Parker-Sckopke relation with Sym-H index.

(2) Direct observations of *Joule heat*: Analyze ion temperatures during DMSP overflights of the polar caps during August and October 2011 magnetic storms.

(3) Ionization due to *particle precipitation at high latitudes*: Use DMSP measured particle precipitation flux to estimate ionization rate using Fang (2010; 2013) models. Compare with default ionization used in Global Convection Models (GCMs).

High Latitude IT Coupling During Magnetic Storms



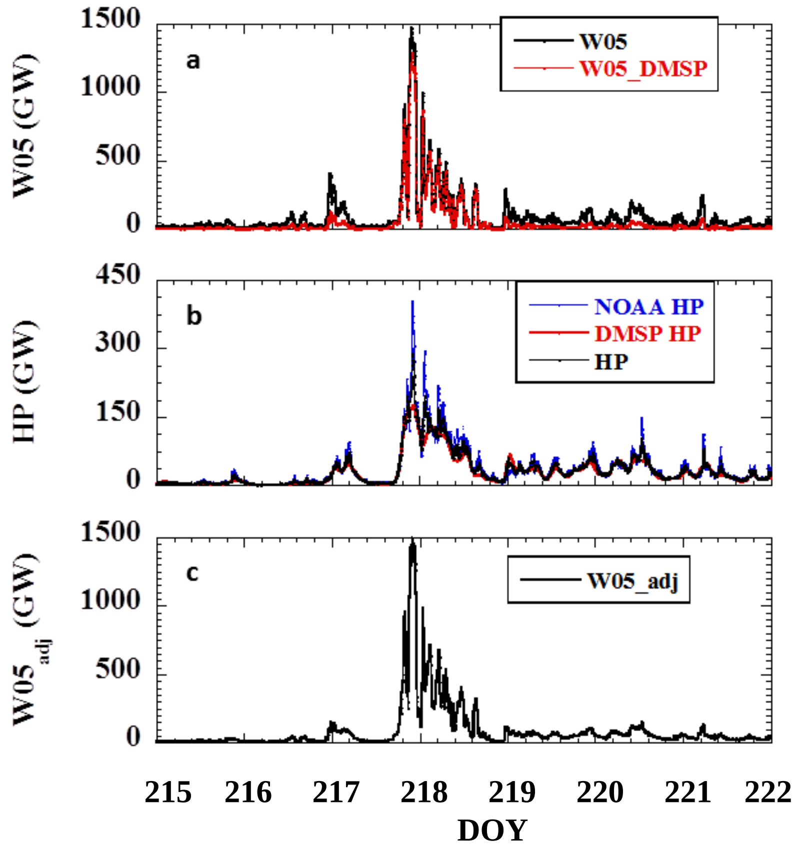
+ Footprint of DMSP F15 orbit

Contours of W05 model predictions of Poynting flux

... Poynting flux observed by DMSP F15

... W05 Poynting flux

Estimate of Ionospheric Energy During Storm



a) Poynting flux input from Weimer model (W05) and Weimer model scaled by DMSP (W05_DMSP)

b) Particle precipitation input from NOAA, DMSP and average of the two

c) Final model predictions of ionospheric input, including modified Poynting flux and particle precipitation

Estimate of Thermospheric Energy During Storm

Methodology: Assume neutral densities can be related to temperatures using a Jacchia-like model.

All Jacchia-like models are parameterized by Tc, the nighttime minimum in the global exospheric temperature. Once Tc is specified, all number densities, mass densities and temperatures are specified.

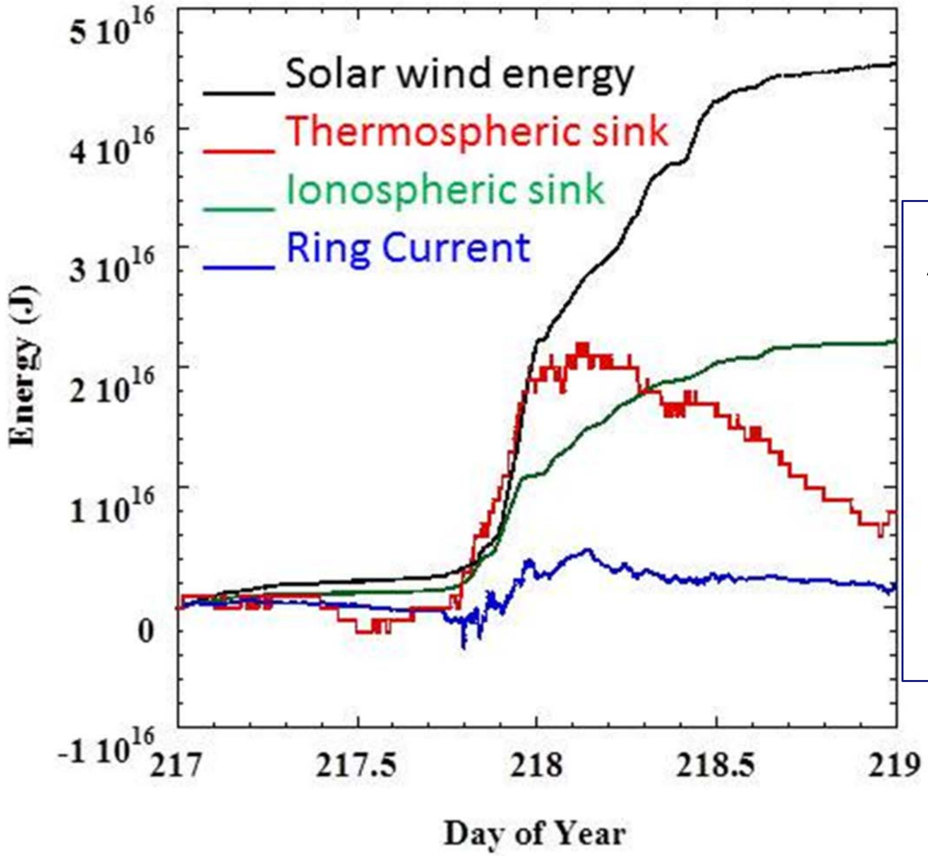
We fit number densities from models (HASDM, Jacchia-Bowman 2008, W05) and observations (GRACE) to find Tc which then specifies the thermosphere.

The thermospheric energy is estimated as:

$$E = H_T + \Phi_G$$

where H_T is the thermal energy in the thermosphere and Φ_G is the work done against gravity [Burke et al., 2009].

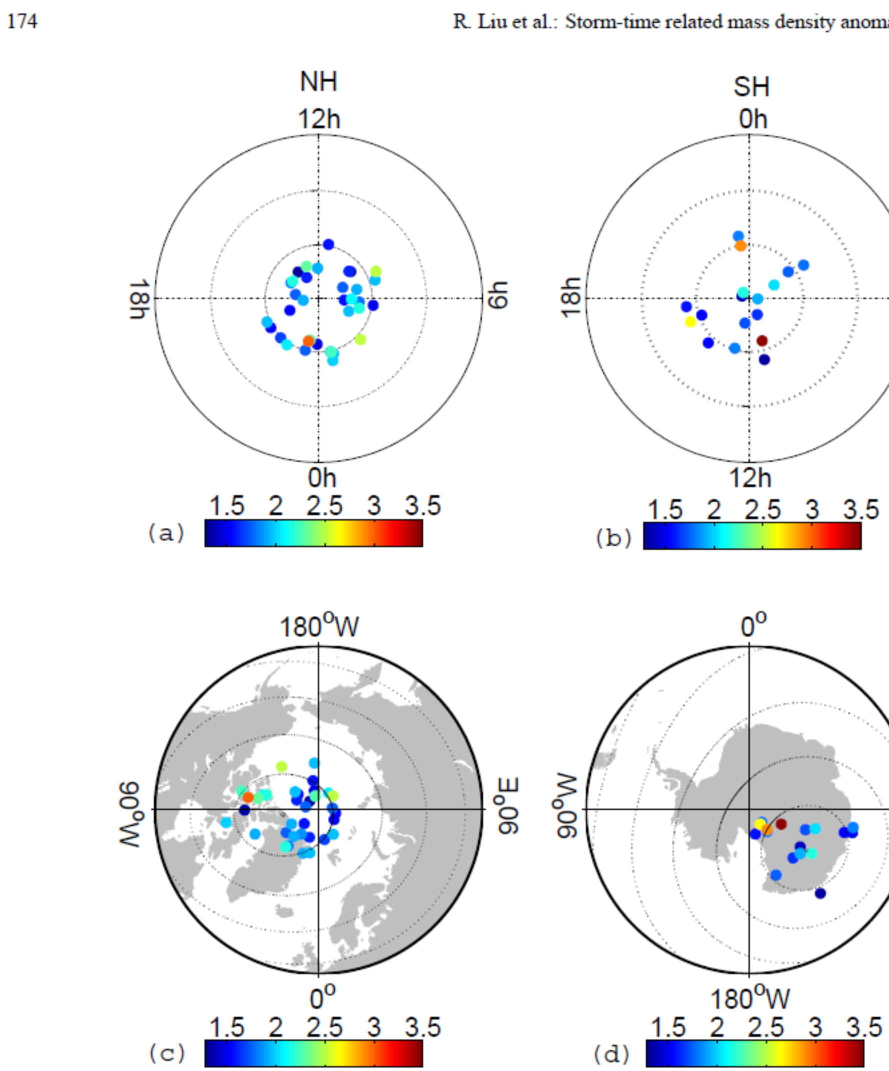
The Energy Budget



Assume: Energy entering the IT system must first energize ions which then transfer energy to neutrals.

Ionospheric energy computed for this storm must be underestimated!

Polar Cap as a Source of Missing Energy?

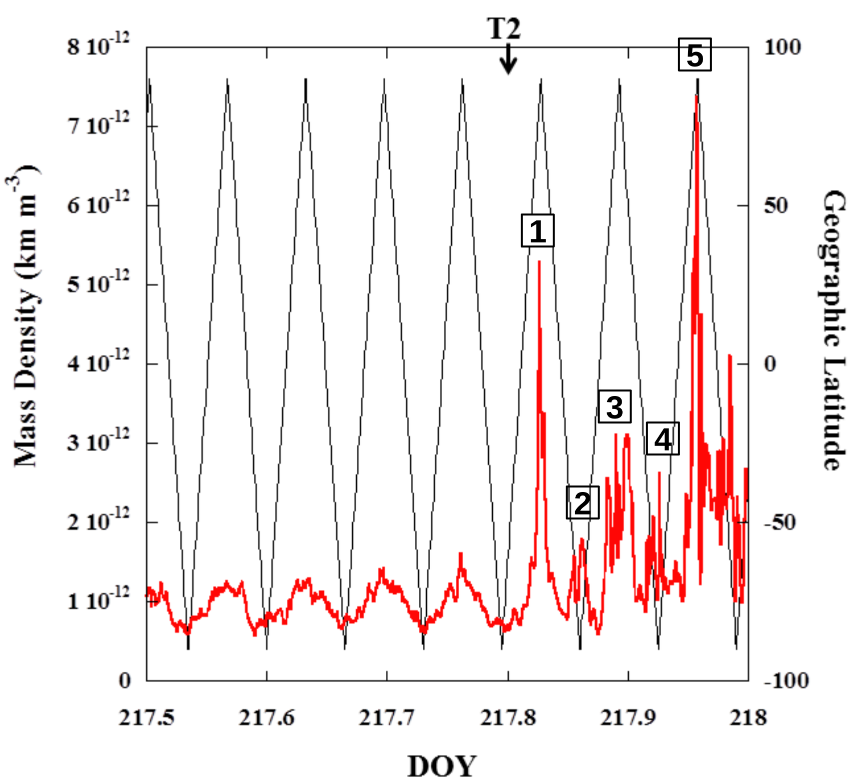


Magnetic Coordinates

Geographic Coordinates

[Liu et al., Ann. Geophys. 2010]

GRACE Neutral Densities During Storm Main Phase



Time T2 = 1906 UT, start of storm main phase

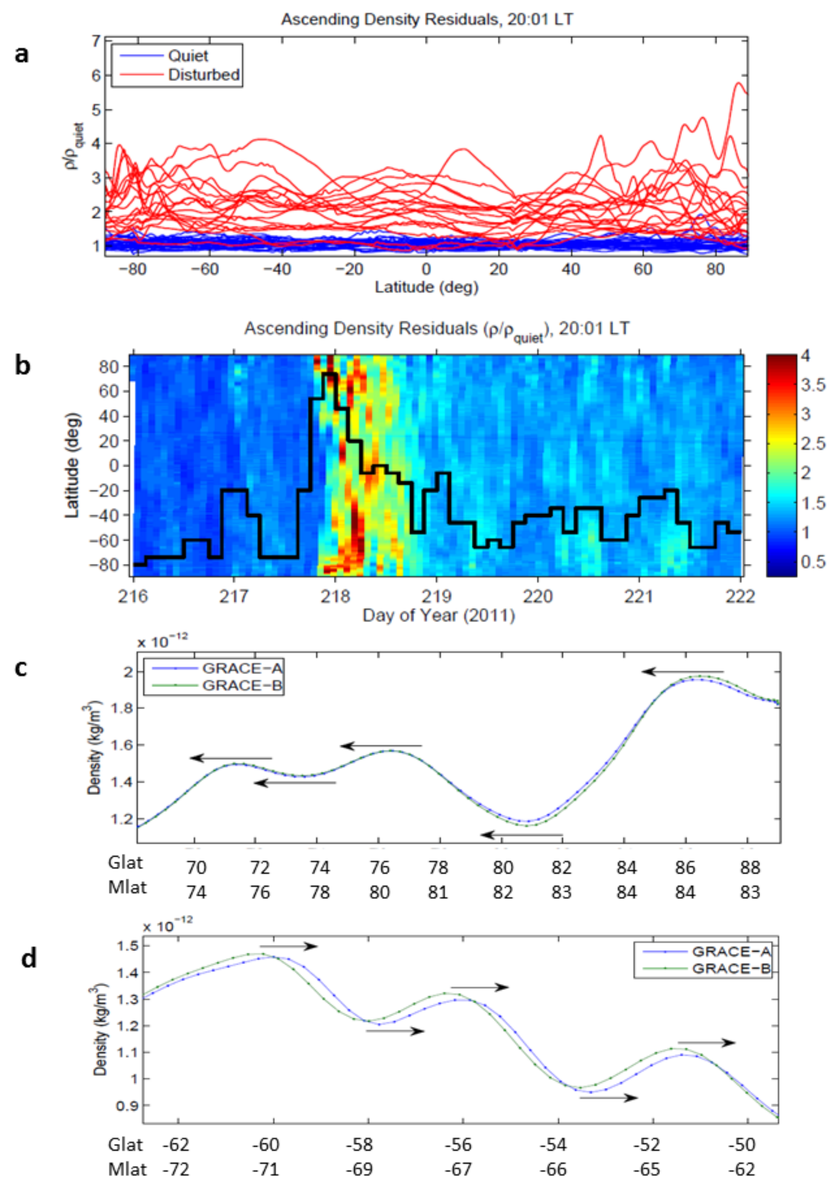
Neutral density peaks 1-5 occur at:

1 84^{o} GLat at 1950 UT
2 -82^{o} Glat at 2041 UT
3 75^{o} Glat at 2122 UT
4 -84^{o} Glat at 2213 UT
5 87^{o} Glat at 2259 UT

1.The GRACE observations agree with results of Liu et al (2010) and indicate that thermospheric heating occurs in the polar cap, and not at auroral latitudes.

2. The time delay from storm onset to appearance of heated neutrals is minutes, and not hours.

Polar Cap as a Source for Missing Energy? GRACE Observations During August Storm



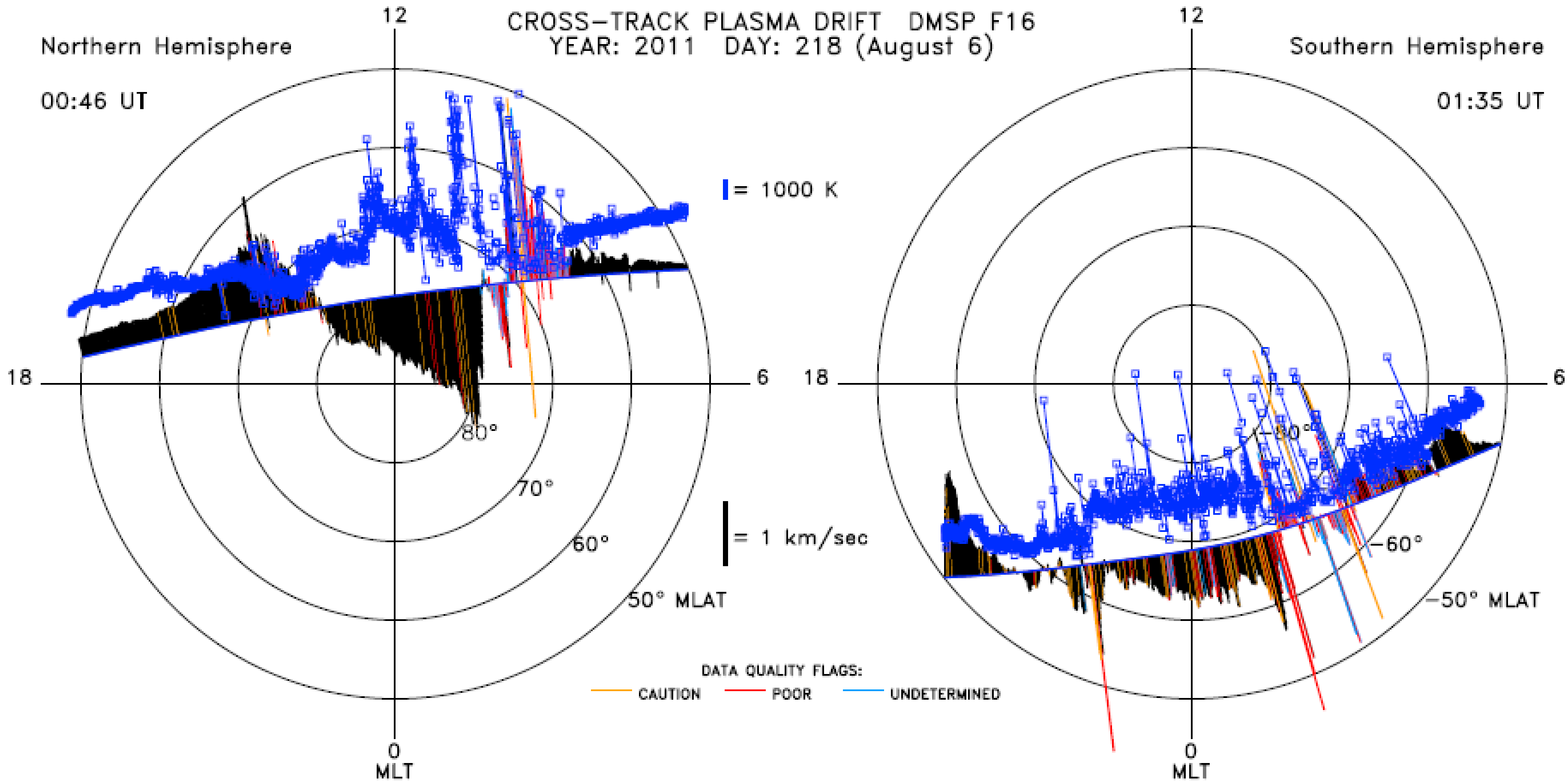
Perturbations in neutral density residuals on disturbed day (red) and preceding quiet period (blue)

Neutral density residuals as functions of latitude and time

TADs in both hemispheres indicate a source of Joule heating poleward of 83º MLat (NH) and -72º Mlat (SH)

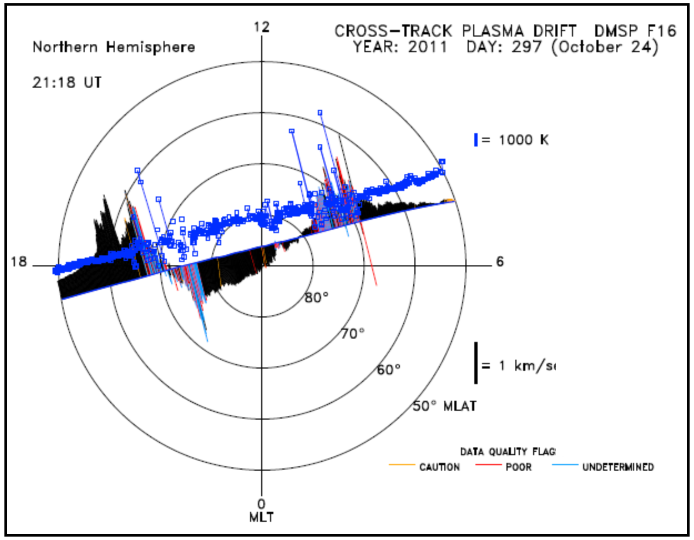
August 2011 storm

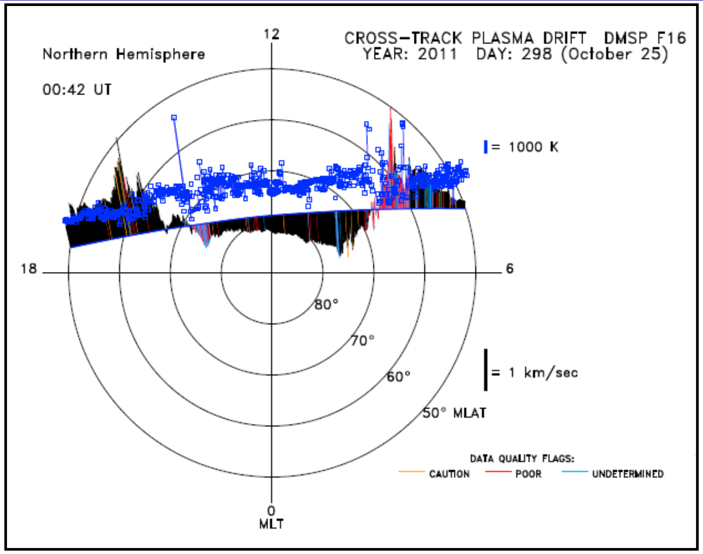
Ion Temperatures, Horizontal Velocities from DMSP F16

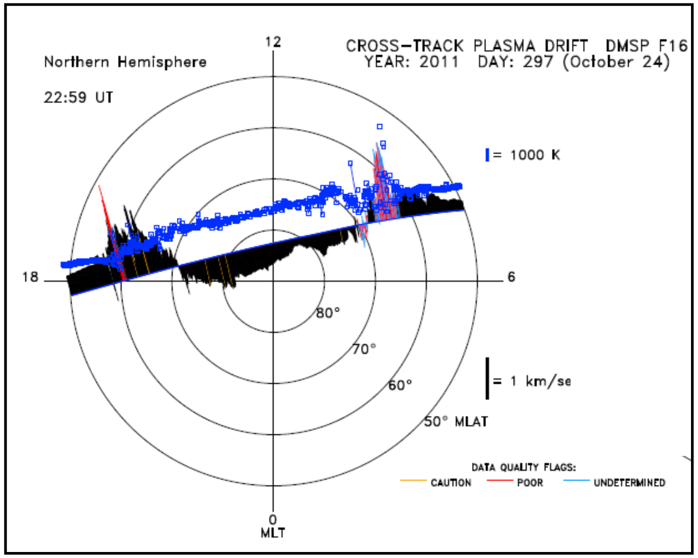


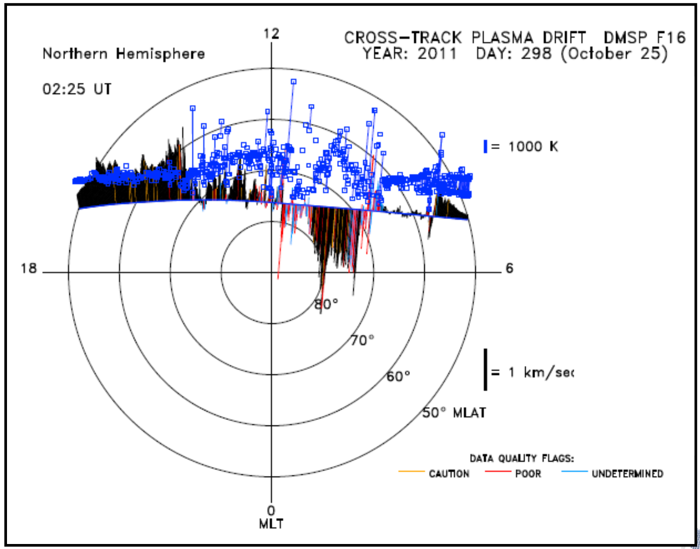
Ion temperatures increase in polar cap and not in the auroral zone

DMSP F16 Plasma Temperatures and Velocities in the Northern hemisphere during the October 2011 storm
(Storm onset ~ 2233 UT on DOY 297)

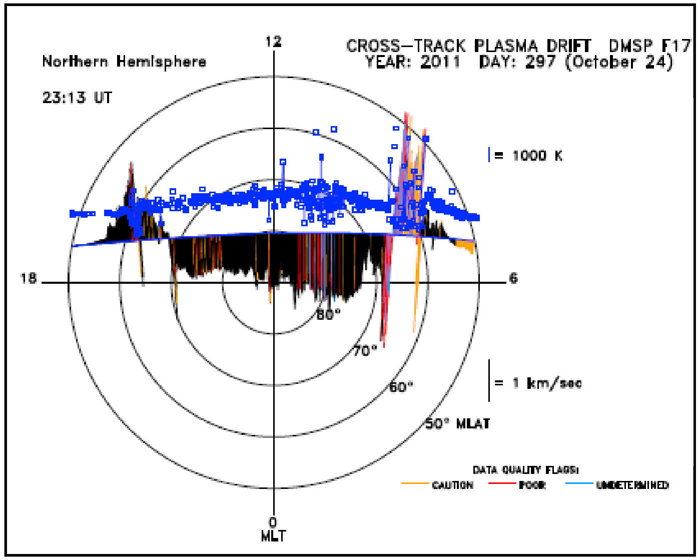


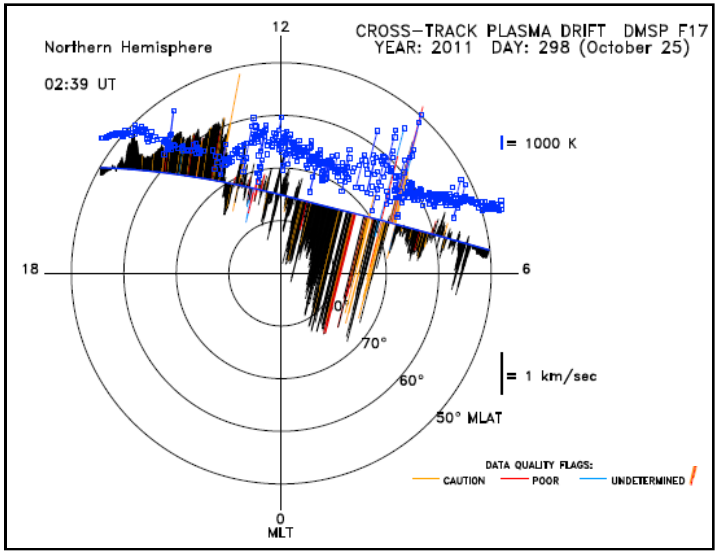


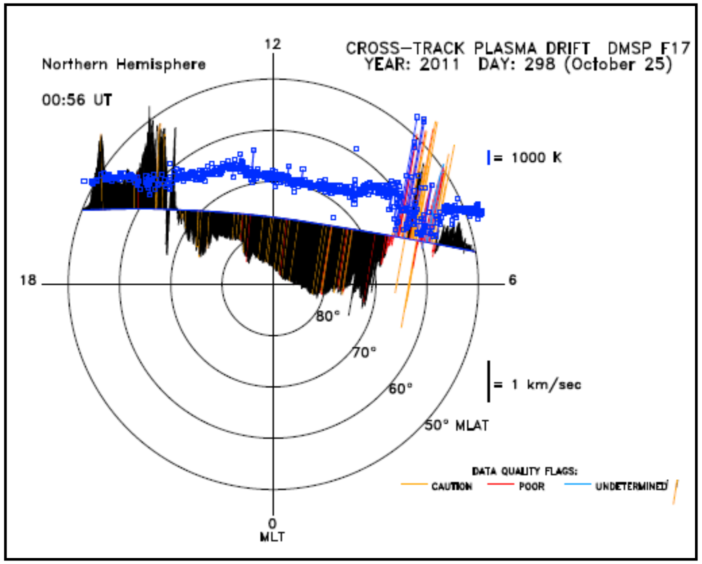


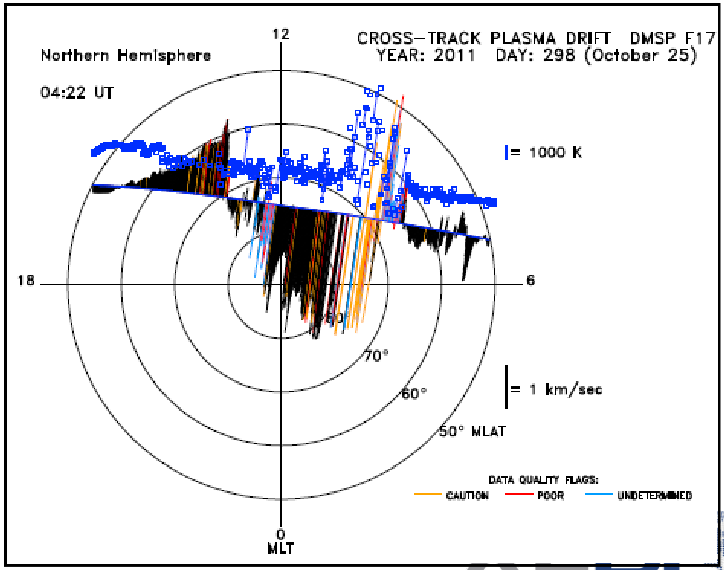


DMSP F17 Plasma Temperatures and Velocities in the Northern hemisphere during the October 2011 storm
(Storm onset ~ 2233 UT on DOY 297)



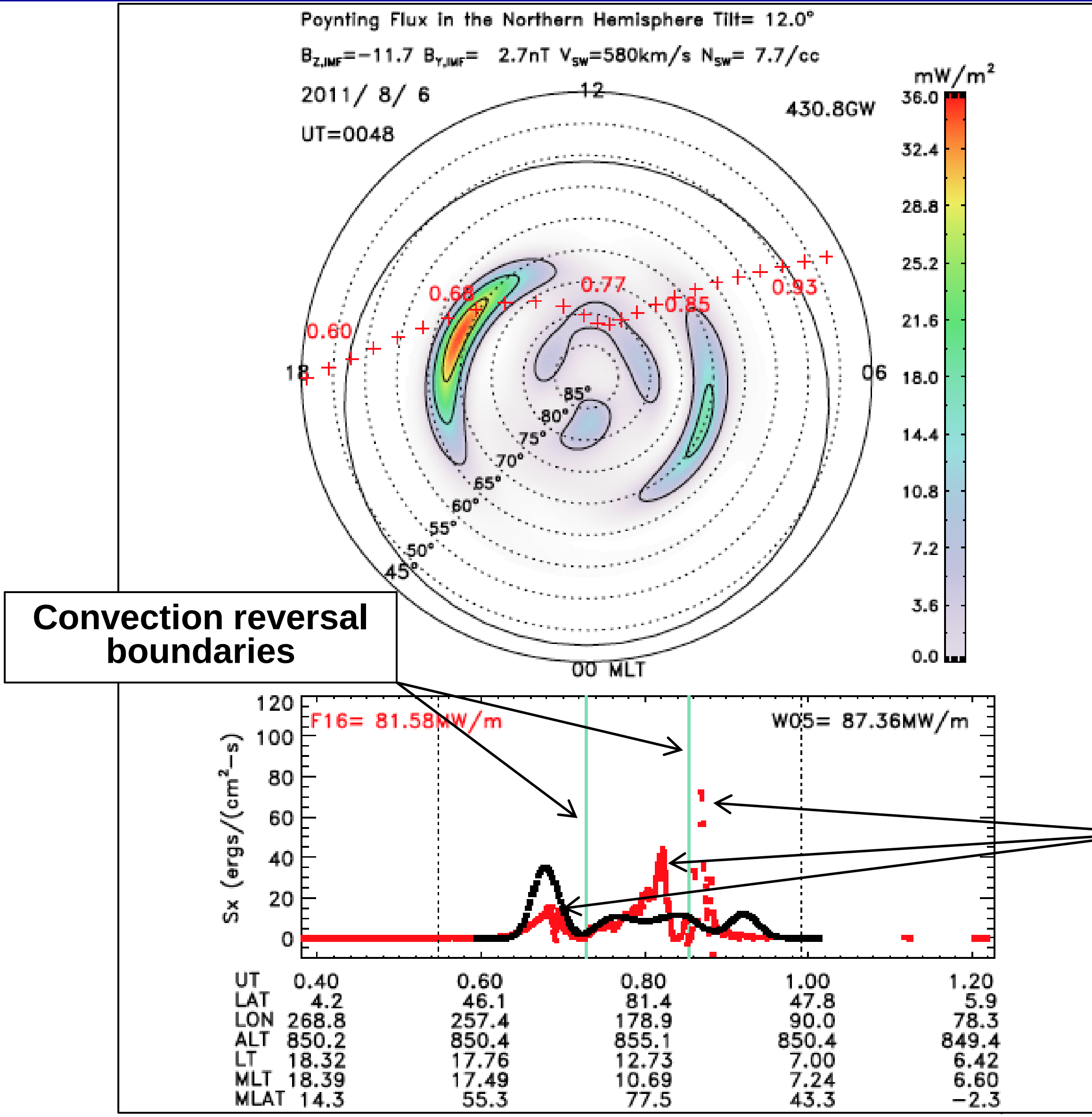






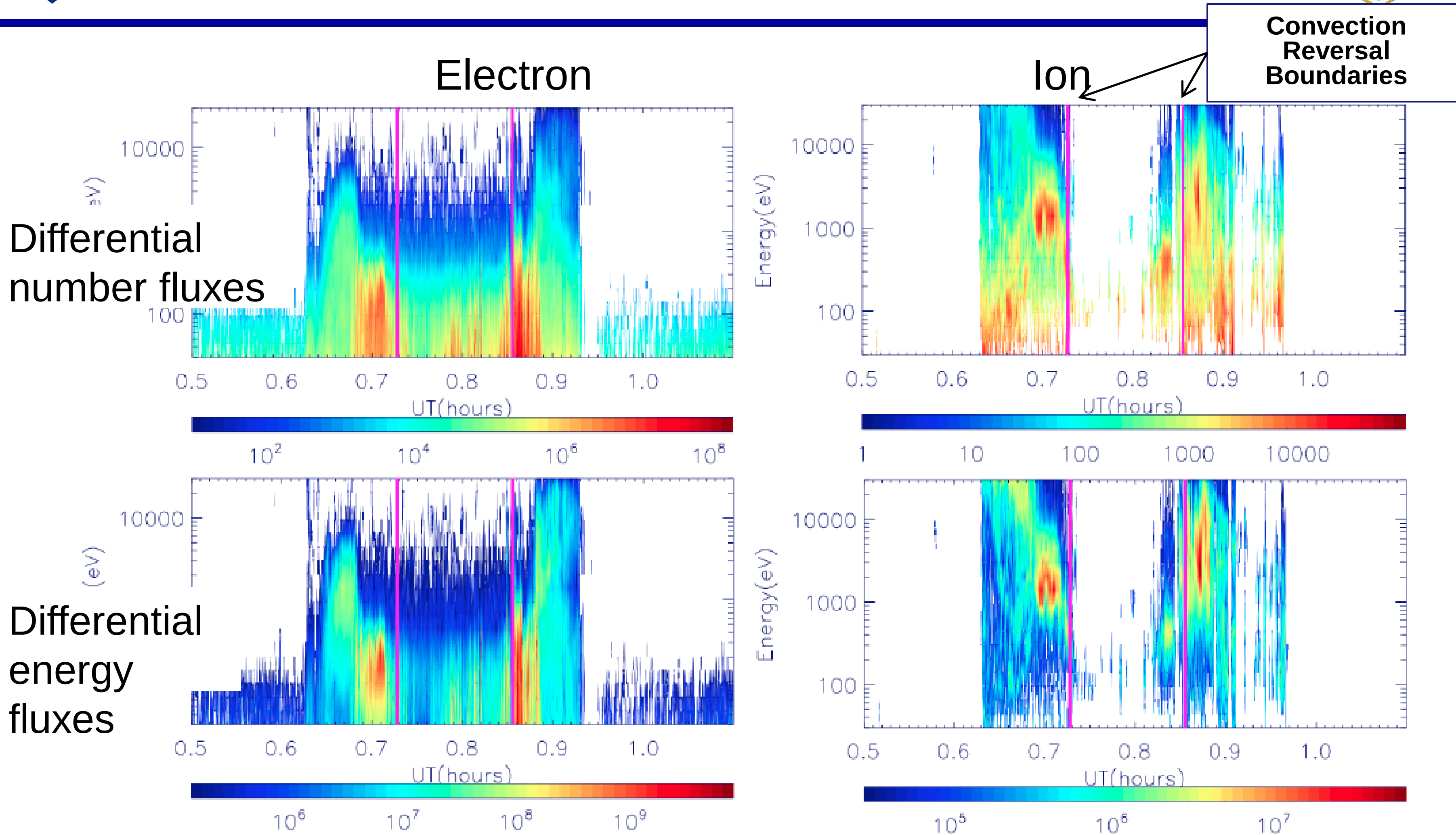
DMSP F16 Poynting Flux During August 2011 Storm

Polar Cap Crossing Starting at 0048 UT on 6 August



Measured Poynting flux shows 3 maxima, two in closed field line region, one in polar cap

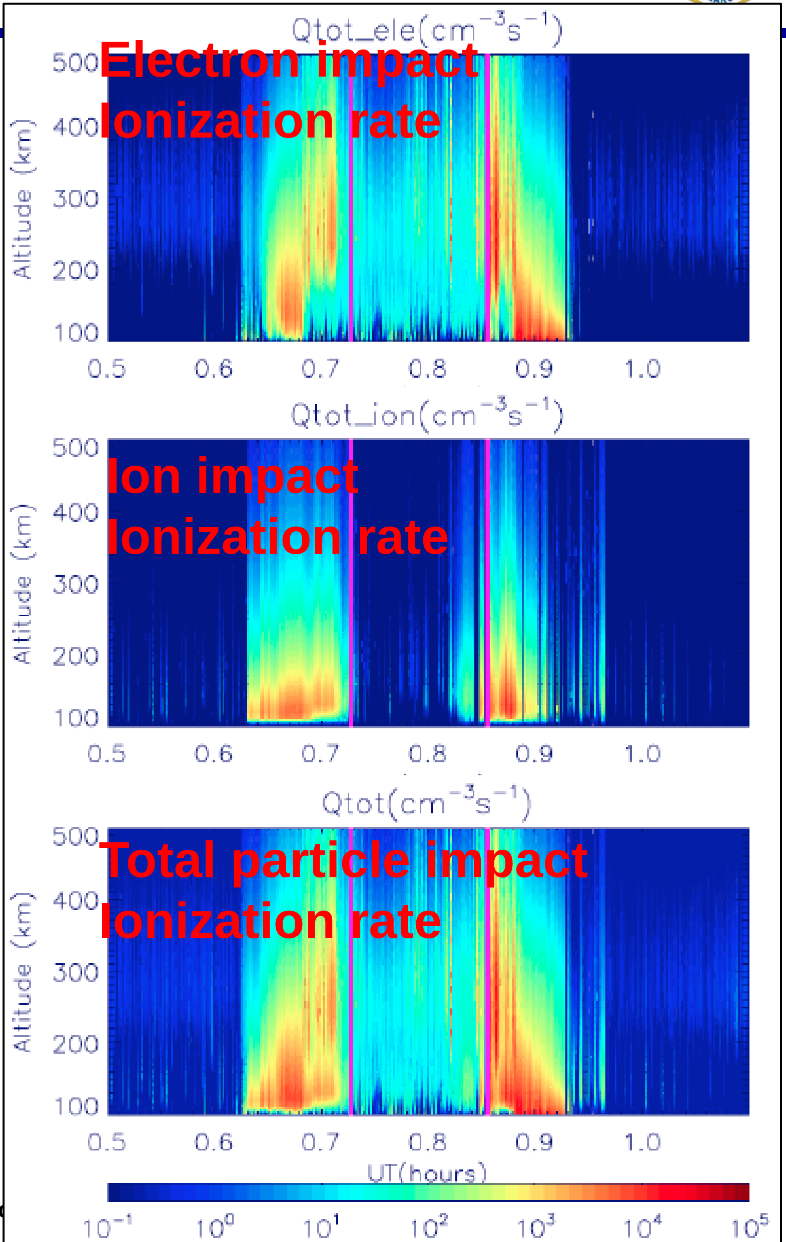
DMSP F16 Particle Precipitation During August 2011 Magnetic Storm (0030 UT – 0106 UT)



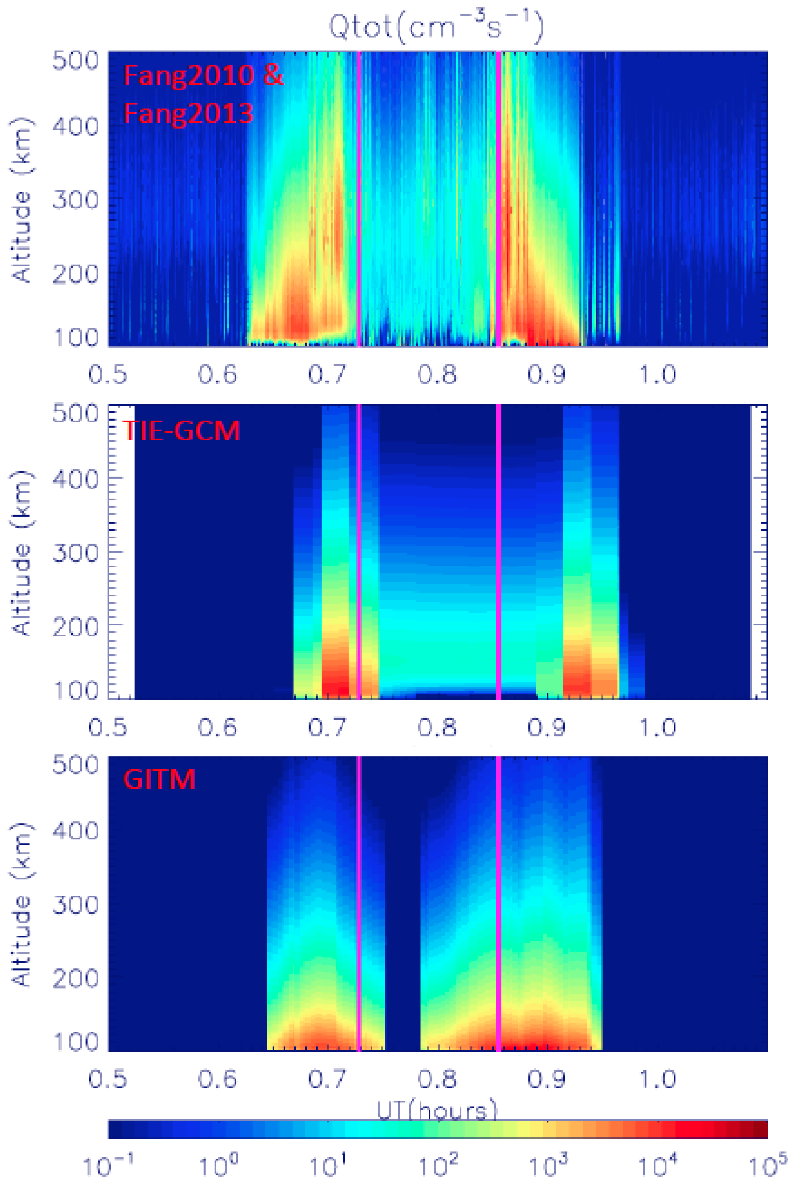
- Clear enhancement of soft electron fluxes in the polar cap .
- Polar rain region (0.73 UT~0.82 UT) is identified with typically low accompanying ion precipitation.

Electron and Ion Impact Ionization Rates with Fang (2010; 2013) model and NRLMSISE-00

- In the polar cap region, majority of ionization is due to electrons at F-region altitudes.
- Most of the ion impact ionization is in the auroral zones with peaks under 200 km.
- The two peaks above 200 km in the auroral zones are probably associated with the two peaks of Poynting fluxes in the same locations.
- Broad Poynting flux enhancement in the polar cap corresponds well to the ionization enhancement due to particle precipitation.



Comparison of Total Ionization Rates using DMSP Particles and Fang (2010; 2013) and GCMs



- Clear ionization enhancements in the auroral zones.
- Most of the particle impact ionization is below 200 km in GCMs.
- GCMs do not capture the strong ionization enhancements due to low-energy electrons at the F-region altitudes in both auroral zone and polar cap.

Summary

- The energy budget for a magnetic storm in August 2011 shows a deficit in ionospheric energy sufficient to account for thermospheric heating
- GRACE measurements show Joule heating in the polar cap, in agreement with Liu et al (2010)
- DMSP measurements of plasma temperatures show increased T_i in the polar cap, and not in the auroral zone, during magnetic storms in August and October 2011
- The DMSP orbit during the time after storm onset in both cases does not reach magnetic latitudes greater than ~ 83º. Could this contribute to missing Poynting flux during the August storm?
- Using DMSP F16 particle precipitation spectra, the ionization due to electrons and ions was modeled for a polar cap crossing which showed ionization at F-region altitudes.
- Do IT coupling and energy dissipation occur primarily within the polar cap? What are the mechanisms?