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

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Scientific Challenges in Thermosphere-Ionosphere Forecasting
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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
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.
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
Traveling Atmospheric Disturbances (TADs) on GRACE in both hemispheres indicate a source of Joule heating poleward of 83° MLat (NH) and -72° 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°MLat (GRACE) and 80° (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

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 → $T_i$, $\rho_n$
August 2011 Storm

YEAR: 2011  DAY: 215 (August 3) main phase – quiet time

Poynting Flux (mW/m²)  
Northern Hemisphere

min: -0.45  
max: 27.45

Ion Temperature (K)  
Northern Hemisphere

min: -1749.71  
max: 1093.57

GRACE density  
Northern Hemisphere

Poynting Flux (mW/m²)  
Southern Hemisphere

min: -20.40  
max: 50.04

Ion Temperature (K)  
Southern Hemisphere

min: -981.42  
max: 977.12

GRACE density  
Southern Hemisphere

DISTRIBUTION STATEMENT A – Unclassified, Unlimited Distribution
Energy Dissipation in IT Poynting Flux → $T_i$, $\rho_n$
January 2012 Storm
GRACE Density Maxima
2011

GRACE density
Northern Hemisphere

GRACE density
Southern Hemisphere

MLT

0 6 12

60° 70° 80° MLAT

6.0×10^{-16} 2.8×10^{-15} 5.0×10^{-15}

6.0×10^{-16} 2.8×10^{-15} 5.0×10^{-15}

DISTRIBUTION STATEMENT A – Unclassified, Unlimited Distribution
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.
Hypothesis 1: Poynting flux can enter polar cap at any local time – suggests direct connection between solar wind and IT. Can Alfvén 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?
Neutral Density Maxima
August 2011 Storm

threshold = 6.0e-16

threshold = 40
Neutral Density Maxima
January 2012 Storm
Energy Dissipation in IT
September 2011

YEAR: 2011  DAY: 267 (September 24) main phase - quiet time

**Poynting Flux (mW/m²)**
Northern Hemisphere

- min: -1.91
- max: 32.74

**Ion Temperature (K)**
Northern Hemisphere

- min: -1447.80
- max: 1461.89

**GRACE density**
Northern Hemisphere

YEAR: 2011  DAY: 267 (September 24) main phase - quiet time

**Poynting Flux (mW/m²)**
Southern Hemisphere

- min: -1.27
- max: 23.22

**Ion Temperature (K)**
Southern Hemisphere

- min: -1247.47
- max: 2193.22

**GRACE density**
Southern Hemisphere
Energy Dissipation in IT
September 2011

YEAR: 2011  DAY: 267 (September 24) main phase
Poynting Flux (mW/m²)
Northern Hemisphere

YEAR: 2011  DAY: 267 (September 24) main phase
Ion Temperature (K)
Northern Hemisphere

GOCE density
Northern Hemisphere

YEAR: 2011  DAY: 267 (September 24) main phase
Poynting Flux (mW/m²)
Southern Hemisphere

YEAR: 2011  DAY: 267 (September 24) main phase
Ion Temperature (K)
Southern Hemisphere

GOCE density
Southern Hemisphere
Energy Dissipation in IT
August 2011
Energy Dissipation in IT
January 2012