



Geomagnetic Energy Distribution and Influence on the Ionosphere/Thermosphere in the Polar Region

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Final Report

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14. ABSTRACT The objective of the project is to improve the specification of the magnetospheric energy inputs, including both Poynting flux and particle precipitation, in the polar upper atmosphere and to determine how the ionosphere and thermosphere respond to the geomagnetic energy distribution in order to improve the predictability of this response and effects on satellite drag and high frequency (HF) wave propagation paths. We made great progresses in the following directions: 1. Based on the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) satellites observations of electron density profiles from 2009-2014, Pedersen conductivity has been estimated. A climatologic study of the heightintegrated Pedersen conductances in both E (100150 km) and F (150600 km) regions and their ratio in different seasons, solar and geomagnetic conditions has been conducted. 2. To understand the significance of different physical mechanisms including Poynting flux and particle precipitation, and the correlation between them, a statistical study of Poynting flux and particle energy flux in the dayside cusp and low-latitude boundary layer (LLBL) regions has been conducted based on DMSP F15 measurements. 3. the electric field and the particle precipitation at different spatial scale sizes have been investigated by utilizing the Dynamic Explorer 2 satellite data set, focusing on conditions of moderately strong southward interplanetary magnetic field. 4. The influence of an idealized, smaller Carrington-type storm on the thermosphere in the high latitudes has been simulated using the nonhydrostatic Global Ionosphere-Thermosphere Model. 5. The energetic electrons and ions (0.130.2 keV) measured by DMSP are binned according to geomagnetic coordinates. The polar distributions of particle precipitation are then incorporated into the Global Ionosphere-Thermosphere Model (GITM)			
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Final Report

Geomagnetic Energy Distribution and Influence on the Ionosphere/Thermosphere in the Polar Region

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Collaborators: Delores Knipp & Yanshi Huang

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1. Project Objectives

The objective of the project is to improve the specification of the magnetospheric energy inputs, including both Poynting flux and particle precipitation, in the polar upper atmosphere and to determine how the ionosphere and thermosphere respond to the geomagnetic energy distribution in order to improve the predictability of this response and effects on satellite drag and high frequency (HF) wave propagation paths.

2. Work Carried Out and Results Obtained

2.1. Dependence of Pedersen conductance on the solar and geomagnetic activities:

Ionospheric conductance is very important to the magnetosphere-ionosphere coupling especially in the high latitude region, since it correlates the polar cap potential with the currents. Meanwhile, the altitudinal distribution of Pedersen conductivity gives us a rough idea about the altitudinal distribution of Joule heating at high latitudes, which is significant to the response of the ionosphere/thermosphere to the geomagnetic energy inputs. Based on the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) satellites observations of electron density profiles from 2009-2014, Pedersen conductivity has been estimated. A climatologic study of the height-integrated Pedersen conductances in both E (100–150 km) and F (150–600 km) regions and their ratio in different seasons, solar and geomagnetic conditions has been conducted. Figure 1 shows a strong dependence of conductance on F10.7 and Ap indices. Meanwhile, A significant interhemispheric asymmetry is identified in the dependence on F10.7 and AP, which also shows the variation with local time. This result will strongly help our understanding of the variation of the altitudinal energy distribution under different solar and geomagnetic conditions and the inter-hemispheric asymmetry of the high-latitude electrodynamics. The results have been reported in:

*Sheng, C., **Y. Deng**, Y. Lu, X. Yue (2017), Dependence of Pedersen conductance in the E and F regions and their ratio on the solar and geomagnetic activities, *Space Weather*, doi:10.1002/2016SW001486.

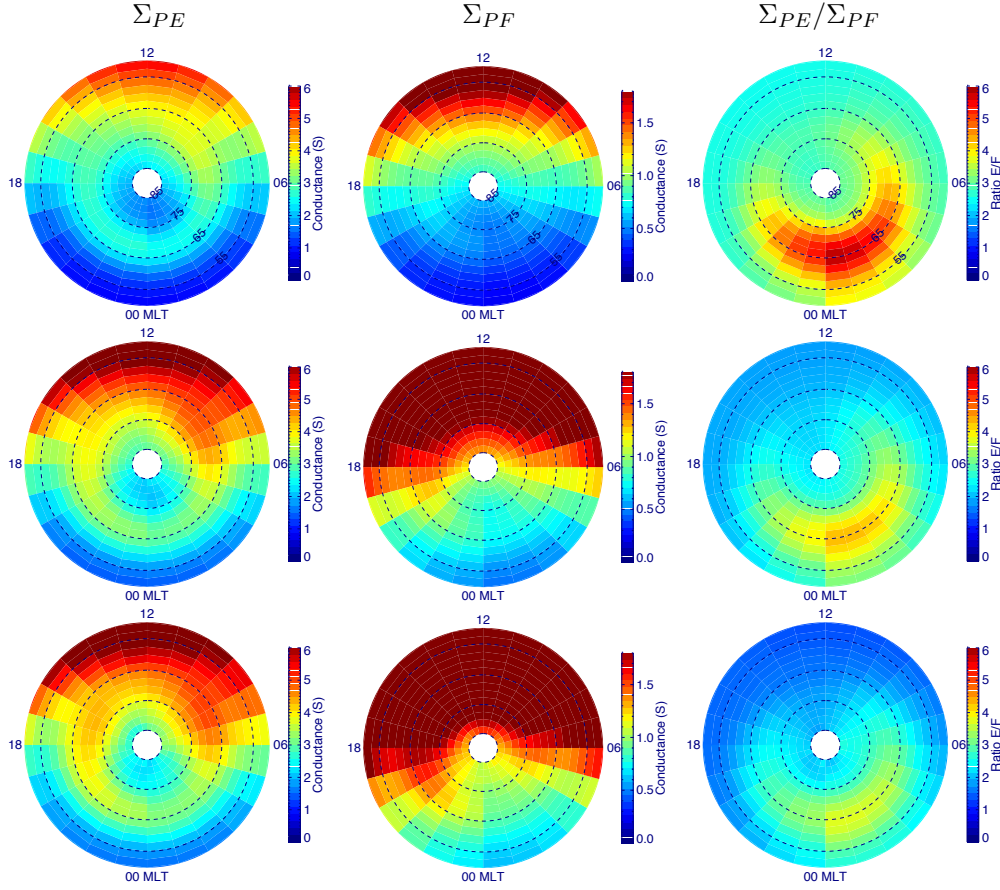


Figure 1: Σ_{PE} (left column), Σ_{PF} (middle column), and their ratio (Σ_{PE}/Σ_{PF} , right column) under different levels of solar radiation, $F10.7 < 100$ (top row), $100 < F10.7 < 150$ (middle row), and $F10.7 > 150$ (bottom row) in the northern hemisphere.

2.2. Poynting Flux in the Dayside Polar Cap Boundary Regions:

Poynting flux, which describes electromagnetic energy flux, is an important energy source for the high-latitude upper atmosphere. After the launch of Defense Meteorological Satellite Program (DMSP) F15 spacecraft with a boom-mounted magnetometer on board, there was a new opportunity to calculate Earth-directed Poynting flux at satellite altitudes (~ 850 km) in the upper atmosphere. A persistent enhancement of thermospheric density in the dayside polar cap boundary regions has been reported in the CHAMP satellite observations. To understand the significance of different physical mechanisms including Poynting flux and particle precipitation, and the correlation between them, a statistical study of Poynting flux and particle energy flux in the dayside cusp and low-latitude boundary layer (LLBL) regions has been conducted based on DMSP F15 measurements. DMSP satellite observations showed a dominate downward Poynting flux for most cases in the cusp region. Our analysis of DMSP F15 data for five years (2000–2004) reveals that approximately 53% of 660 cusp crossings at 800–850 km showed strong downward Poynting flux ($S > 10$ mW/m²), 32% of the crossings had

noticeable downward Poynting flux ($S > 3 \text{ mW/m}^2$), and 7% of the crossings did not show clear Poynting flux ($S < 1 \text{ mW/m}^2$), as shown in Figure 2. Only 13 out of 660 cusp crossings ($\sim 2\%$) showed noticeable upward Poynting flux. In the LLBL region, 35% of 11,641 LLBL crossings showed significant downward Poynting flux, 34% of the crossings had noticeable downward Poynting flux, and only 13% of the crossings did not show clear Poynting flux. On average, Poynting flux in LLBL is smaller than that in the cusp. The results show a slightly negative correlation between Poynting flux and particle precipitation energy flux in the dayside polar cap boundary regions. Statistically, Poynting flux in the cusp is enhanced during interplanetary magnetic field By positive conditions. The results have been reported in:

*Lu Y., Y. Deng, C. Sheng, L. Kilcommons, D. Knipp (2018), Poynting Flux in the Dayside Polar Cap Boundary Regions from DMSP F15 satellite measurements, *J. Geophys. Res.*, 123.
<https://doi.org/10.1002/2018JA025309>.

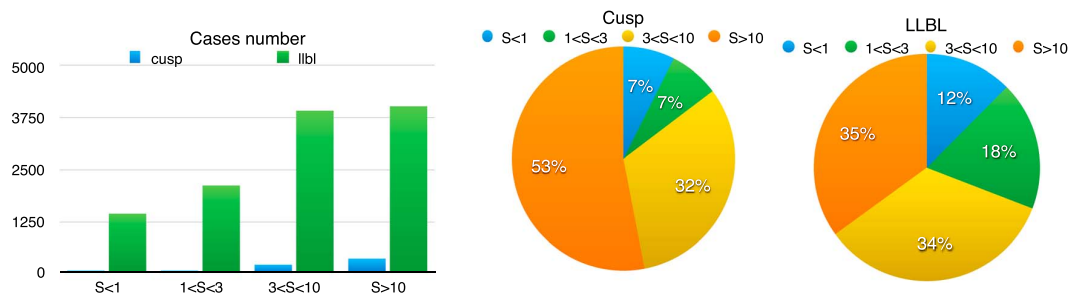


Figure 2: The histogram shows the number comparison between the cusp and LLBL in each category. The pie charts show the percentage of downward Poynting flux observations in each category. The left side is the cusp, and the right side is the LLBL.

2.3. Small-scale variability in electric field and particle precipitation:

In this study, the electric field and the particle precipitation at different spatial scale sizes have been investigated by utilizing the Dynamic Explorer 2 satellite data set, focusing on conditions of moderately strong southward interplanetary magnetic field. Dynamic Explorer 2 data from the period between 1981 and 1983, from all universal times, seasons, and both hemispheres, have been processed and binned over geomagnetic latitude and local time. It is found that, as compared with the large-scale ($>500 \text{ km}$) average electric field and particle precipitation, the variabilities (i.e., departures from the large-scale average) of electric field and particle precipitation are not negligible. Moreover, the electric field variability tends to be anti-correlated with the particle precipitation variability in the auroral regions on small scale and meso-scale ($<500 \text{ km}$), as shown in Figure 3. The impacts associated with the small-scale and meso-scale electric field and particle precipitation variabilities on Joule heating have also been addressed in this study by using the Global Ionosphere and Thermosphere Model. It is found that although Joule heating can be significantly enhanced by the small-scale and meso-scale electric field variabilities ($\sim 27\%$ globally), the corresponding change in the particle precipitation tends to depress such enhancement (5% globally), which is not negligible

on the dusk side (up to 17.5% locally). It is the first time that the correlation between electric field and particle precipitation variabilities on small scale and meso-scale has been quantified. Furthermore, the impact on Joule heating associated with the correlation between the small-scale and meso-scale electric field and particle precipitation variabilities has been evaluated unprecedentedly in a general circulation model. The results have been reported in:

*Zhu, Q., **Y. Deng**, A. Richmond, A. Maute (2018), Small-scale variability in electric field and particle precipitation and its impact on Joule heating, *J. Geophys. Res.*, 123.

<https://doi.org/10.1002/2018JA025771>

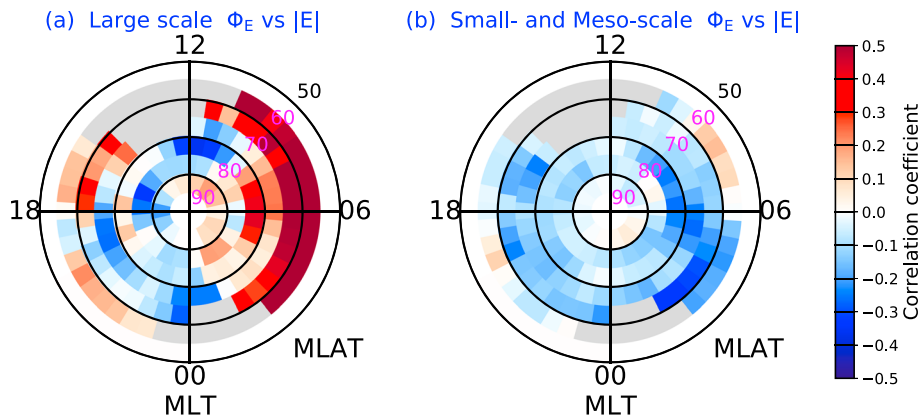


Figure 3: The distributions of the linear correlation coefficient (a) between the large-scale electric field intensity and particle energy flux and (b) between small-scale and mesoscale variabilities of electric field intensity and particle energy flux when IMF clock angle is between 135° and 225° , and IMF B_t ranges from 4 to 10 nT.

2.4. Possible influence of extreme magnetic storms:

Solar and interplanetary events can create extreme magnetic storms, such as the Carrington storm in 1859 with intensity up to $Dst \sim -1,760$ nT. The influence of an idealized, smaller Carrington-type storm on the thermosphere has been simulated using the nonhydrostatic Global Ionosphere-Thermosphere Model. For the storm conditions we simulated, the solar wind BZ and velocity were -50 nT and $1,000$ m/s, respectively. The corresponding cross polar cap potential reached 360 kV, and the hemispheric power was 200 GW. Consequently, the hemispheric integrated Joule heating exceeded $3,500$ GW, which is more than 70 times higher than normal conditions. The thermosphere variations at high latitudes were examined through the comparison of three cases: reference, storm with geomagnetic energy enhancement only, and storm with both solar and geomagnetic energy enhancement. At 400 -km altitude, the neutral density increased by >20 times at certain locations and by >10 times globally averaged. The atmosphere experienced a temperature of 4000 K, more than $1,500$ m/s horizontal wind, and exceeding 150 m/s

vertical wind. In general, additional energy increase from solar irradiation resulted in 20–30% more perturbation in neutral density and temperature. The exobase (top boundary of the thermosphere) expanded to altitudes $>1,000$ km, and the buoyancy acceleration (difference between vertical pressure gradient force and gravity force) can be as large as 3 m/s^2 . The results will help to determine possible extreme responses to interplanetary coronal mass ejections for various phenomena occurring in geospace. The results have been reported in:

Deng Y., C. Sheng, B. Tsurutani, A. Mannucci (2018), Possible influence of extreme magnetic storms on the thermosphere in the high latitudes, *Space Weather*, 16.
<https://doi.org/10.1029/2018SW001847>.

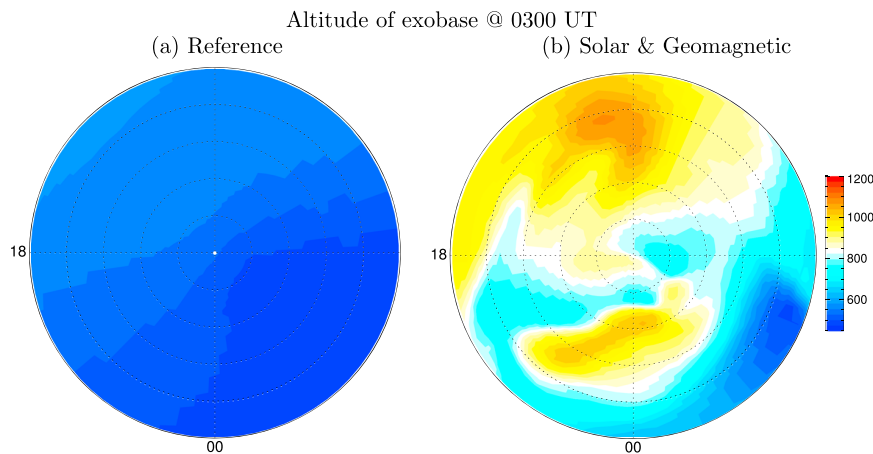


Figure 4: Altitude of exobase for the (a) reference case and (b) storm case with enhancement of both solar and geomagnetic energy at 0300 UT. The maximum altitude is close to 600 and 1,200 km for the reference and storm cases, respectively.

2.5. Effects of Particle Precipitation on Nitric Oxide Cooling:

Satellite measurements have revealed significant enhancement of nitric oxide (NO) emission at $5.3\text{-}\mu\text{m}$ during shock-led interplanetary coronal mass ejection events. The abnormal enhancement of NO cooling during shock-led storm may contribute to the problem storms. While it is well-known the particle precipitation is primary mechanism for the NO emission enhancement, it is uncertain what is the relative significance of ions, soft electrons and kev electrons. The goal of this study is to identify contribution of ion and electron (from each energy band) particle precipitation to the thermospheric NO cooling enhancement. The energetic electrons and ions ($0.1\text{--}30.2 \text{ keV}$) measured by DMSP are binned according to geomagnetic coordinates. The polar distributions of particle precipitation are then incorporated into the Global Ionosphere-Thermosphere Model (GITM). The results show that the electrons play dominant role to NO cooling, but the ions are important as well and can contribute up to 30% of NO cooling during geo-effective events. Among four electron bands, NO cooling enhancement during the events is dominated by the electrons in the energy band of $1.4\text{--}6.5 \text{ keV}$. The global

thermospheric and ionospheric responses show that both total electron content and NO cooling enhance instantaneously at the source regions, but they have different lifetime and correlation with the particle precipitations. The results have been reported in:

*Lin, C., **Y. Deng**, Delores J. Knipp, Liam M. Kilcommons (2018), Effects of Energetic Particle Precipitation on Thermospheric Nitric Oxide Cooling, *J. Geophys. Res.*, to be submitted.

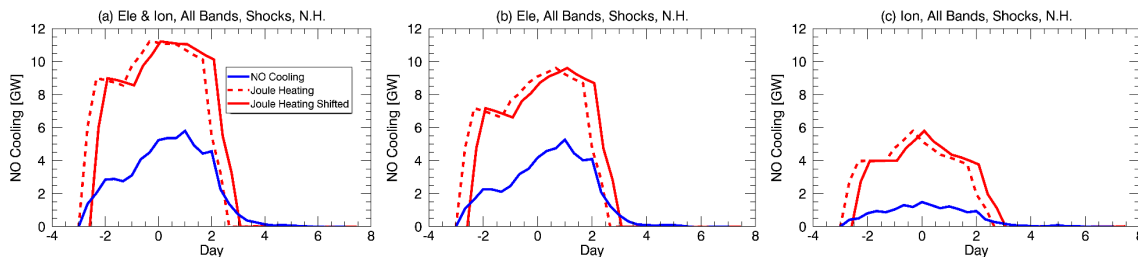


Figure 5: Enhancement of total NO cooling power poleward of 40°N (top row) during the shock-led events with (a) both electron and ion effects, (b) electron in all bands and (c) ion only.

3. Publications

1. *Sheng, C., **Y. Deng**, Y. Lu, X. Yue (2017), Dependence of Pedersen conductance in the E and F regions and their ratio on the solar and geomagnetic activities, *Space Weather*, doi:10.1002/2016SW001486.
2. *Lu Y., **Y. Deng**, C. Sheng, L. Kilcommons, D. Knipp (2018), Poynting Flux in the Dayside Polar Cap Boundary Regions from DMSP F15 satellite measurements, *J. Geophys. Res.*, 123. <https://doi.org/10.1002/2018JA025309>.
3. *Zhu, Q., **Y. Deng**, A. Richmond, A. Maute (2018), Small-scale variability in electric field and particle precipitation and its impact on Joule heating, *J. Geophys. Res.*, 123. <https://doi.org/10.1002/2018JA025771>.
4. **Deng Y.**, C. Sheng, B. Tsurutani, A. Mannucci (2018), Possible influence of extreme magnetic storms on the thermosphere in the high latitudes, *Space Weather*, 16. <https://doi.org/10.1029/2018SW001847>.
5. *Lin, C., **Y. Deng**, Delores J. Knipp, Liam M. Kilcommons (2018), Effects of Energetic Particle Precipitation on Thermospheric Nitric Oxide Cooling, *J. Geophys. Res.*, to be submitted.

***: Advised graduate student and postdoc publications.**