

Magnetospheric control of the energy input into the thermosphere

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[1] A thermospheric photochemical model has been used in conjunction with satellite observations of nitric oxide to determine the flux of precipitating electrons into the thermosphere in the northern auroral region. Satellite measurements have shown that electron precipitation occurs predominantly between 1800 and 2400 hours magnetic local time. This time dependence has been incorporated into the thermospheric model calculation of nitric oxide density. Polar displays of the results of the model calculations show that the electrons deposit their energy between geomagnetic latitudes 60° – 70° N. The longitudinal distribution is asymmetric with more energy being deposited at western geomagnetic longitudes and less at eastern longitudes. A calculation for equinox conditions shows that energy input as a function of longitude is 50% greater at 90° W than at 90° E. Therefore, the tilted, offset magnetic dipole field of the Earth seems to be controlling the precipitation of electrons in the northern auroral region. *INDEX TERMS*: 0310 Atmospheric Composition and Structure: Airglow and aurora; 0358 Atmospheric Composition and Structure: Thermosphere—energy deposition; 2704 Magnetospheric Physics: Auroral phenomena (2407); 2716 Magnetospheric Physics: Energetic particles, precipitating; 2736 Magnetospheric Physics: Magnetosphere/ionosphere interactions

1. Introduction

[2] The Earth's magnetosphere is strongly asymmetric in local time with a compressed dayside structure and an elongated nightside tail region. This leads to a pronounced day-night asymmetry in auroral properties and large-scale current systems. The upper atmosphere of the Earth, of course, also shows very obvious local time asymmetries, but the corotation of the atmosphere with the Earth itself means that a decoupling of the magnetosphere from the atmosphere must ultimately occur to at least some degree. This decoupling has important consequences that we wish to explore in this paper.

[3] Satellite observations of nitric oxide in the thermosphere show that the flux of precipitating auroral electrons has an asymmetric distribution in geomagnetic longitude [Barth *et al.*, 2001]. These results have been interpreted as being the result of the asymmetric distribution of the magnetic field strength of the Earth's offset, tilted dipole field. To better understand the relationship between the magnetosphere and the thermosphere, we have used a thermospheric photochemical model to calculate the expected nitric oxide distribution. We start with well-known satellite measurements of the magnetospheric distribution of precipitating electrons. With the photochemical model, we calculate the thermospheric distribution of nitric oxide which results from the interaction of the precipitating electrons with the constituents of the upper atmosphere. We pay particular attention to the use of

the appropriate coordinate systems for the magnetosphere and for the thermosphere. In the magnetosphere, the appropriate coordinates are geomagnetic latitude and magnetic local time (MLT). The Earth with its magnetic field is rotating beneath this magnetospheric coordinate system. The results of the electron precipitation are imprinted on the rotating thermosphere and are best described in geomagnetic latitude and geomagnetic longitude coordinates. The goal here is to clarify how the magnetosphere controls the energy input into the thermosphere.

2. Model Calculations

[4] Electron precipitation associated with discrete auroral arcs occurs predominately in the 1800–2400 MLT sector. A comprehensive survey [Newell *et al.*, 1996] described a number of satellite measurements of the flux of precipitating electrons as a function of magnetic local time. Figure 1 which is taken from a review [Newell *et al.*, 2001] shows quite clearly that the precipitating electron flux is concentrated in the 1800–2400 MLT sector. The electron flux in this figure produces the discrete auroral that is visible to ground-based observers. The weaker diffuse aurora has a different distribution in MLT.

[5] The MLT dependence of the satellite electron flux measurements has been used as a guide to determine the energy input into a thermospheric photochemical model [Bailey *et al.*, 2002]. The input into the model has the auroral electron flux turned on during the 1800–2400 MLT period and off for the remaining time of the day. The energy of the auroral electrons is 4 keV. The model calculates nitric oxide as a function of latitude, longitude, altitude, and time. The coordinate system for this model is geographic latitude and longitude and solar local time. An example of the results of such a calculation is shown in Figure 2 where nitric oxide density in the auroral region is plotted as a function of local time from 0600 hours on the first day until 1800 hours on the second day. The conditions for this calculation are: fall equinox, altitude 106 km, geographic latitude 65° N, and geographic longitude 144° W. For initial conditions, it has been assumed that there has not been an aurora for the previous three days and that the initial amount of nitric oxide is produced solely from solar x-rays. During the daylight hours, 0600–1800 of the first day, the nitric oxide density is nearly constant at this latitude. At 1800 hours, the auroral electron precipitation is turned on. The nitric oxide density increases rapidly during the time that the auroral flux is switched on reaching a value four times greater at midnight than existed at sunset. At midnight (0000 hours) the electron precipitation is turned off. For the remaining hours of the night there is no auroral precipitation and the nitric oxide density remains nearly constant. From sunrise throughout the daylight hours, the nitric oxide density decreases because of photodissociation. After twelve hours of daylight, it has decreased to about half of its value at sunrise.

[6] In order to compare model calculations with global images of nitric oxide obtained with the Student Nitric Oxide Explorer (SNOE) [Barth *et al.*, 2001], the model was run for 9 latitudes and 15 longitudes for the thirty-six hour period shown in Figure 2. The

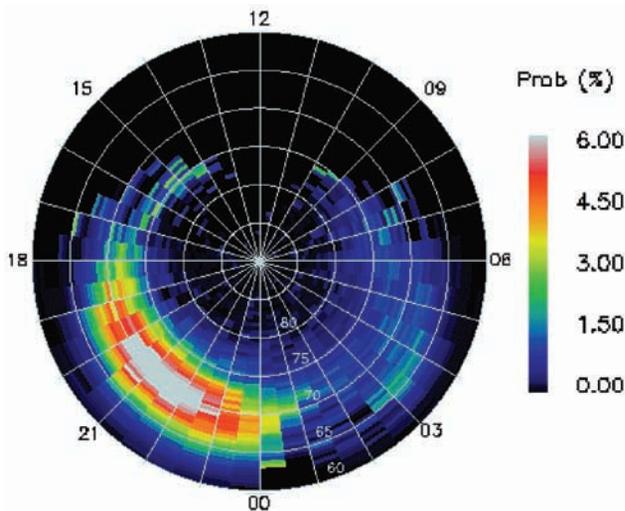


Figure 1. Probability of observing electron precipitation with energy flux greater than $5 \text{ erg cm}^{-2} \text{ s}^{-1}$ as a function of geomagnetic latitude and MLT [Newell *et al.*, 2001].

9 geographic latitudes are spaced 5° apart between 40° and 80°N . (The SNOE satellite does not make observations poleward of 82.5°N). The 15 geographic longitudes correspond to the 15 orbits a day of the SNOE spacecraft. The longitude bins are 24° apart equally spaced in geographic coordinates. Following the model calculations, the nitric oxide densities are binned into corrected geomagnetic latitude and longitude. In the photochemical calculation, sunrise and sunset are calculated in solar local time. For convenience, the turning on and off of the auroral precipitation is also calculated in solar local time when in fact, it should be calculated in magnetic local time. The conversion of magnetic local midnight to solar local midnight varies by about plus or minus one hour for the 15 SNOE orbits (solar local time = local mean solar time = universal time (UTC) + geographic longitude/15); magnetic local time (MLT) = universal time (UTC) + (geomagnetic longitude + geographic longitude of zero geomagnetic longitude)/15). The variation of the difference between magnetic local time and solar local time does not affect the results of the model in Figure 2 since the nitric oxide density does not vary during the part of the night when the auroral electron precipitation is turned off. For comparison with SNOE observations, the nitric oxide density at 1030 local time is used. Although the time of turning off of the electron precipitation may vary between 2300 and 0100 hours MLT, the time between sunrise and 1030 hours is constant and the value of nitric oxide density at 1030 hours is related to the density at the cessation of auroral precipitation in the same way for all orbits.

3. Comparison with Observations

[7] For comparison with the model calculations, a dataset of SNOE measurements was constructed from 2.5 years of observations [Barth *et al.*, 2001]. This time period is during the ascending phase of the solar cycle with the average 10.7 radio flux index increasing from 110 to 200. The nitric oxide density at 106 km was summed and averaged for the equinox periods plus and minus 30 days between March 20, 1998 and September 22, 2000. The dataset consists of 15 longitude bins between 180°W and 180°E and 9 latitude bins between 40° and 80°N geographic latitude. The model was run in a time-dependent mode with geophysical conditions changing throughout the day and night. The model was run in the forward direction starting with an estimate of the flux of precipitating electrons. The results of the model calculations were compared to the measured nitric oxide

densities and new estimates were made for the electron flux as a function of latitude and longitude. Then, the model was run again with the new electron flux array. After this process was iterated a number of times, a stable result was obtained. The resulting flux was a function of geographic latitude and longitude. The flux was then interpolated onto a latitude-longitude grid in corrected geomagnetic coordinates.

[8] A polar display of the resulting flux is presented in Figure 3. This is an orthographic projection in geomagnetic coordinates with the magnetic north pole at the center. The outlines of the continents are plotted in geomagnetic coordinates and, hence, are distorted compared to how they look in an orthographic projection in geographic coordinates. The maximum in the electron flux generally follows the 60° – 70°N geomagnetic latitude band, but there are important deviations from this circular pattern. The electron flux varies as function of geomagnetic longitude: the maximum lies between 108°W and 36°W and the minimum between 36°E and 108°E . This longitude dependence may be seen more clearly in Figure 4 where the flux at geomagnetic latitude 65°N is plotted as a function of longitude. The largest value of the electron flux is 1.5 times the smallest value. The average flux as a function of latitude is plotted in Figure 5 which shows the maximum to occur at 65°N with the half-intensity levels at 55°N and 75°N geomagnetic latitude. The average electron flux in the 60° – 70°N geomagnetic latitude band is 4 mW/m^2 .

[9] The model calculation described above should be thought of as an illustrative example. With different initial conditions, the magnitude of the electron flux needed to explain the observed nitric oxide density would be different. For example, if there had been auroral activity on the days preceding the calculation, the amount of electron flux needed to match the observations would be less than that calculated above. For the same conditions that were used in Figure 2 occurring for 5 days in a row, the calculated electron flux would be 1.6 mW/m^2 .

4. Discussion

[10] The terrestrial magnetic field strength controls the precipitation of electrons from the magnetosphere into the thermosphere. The magnetic field strength at 65°N and S geomagnetic latitude has been plotted in Figure 4 as a function of geomagnetic longitude.

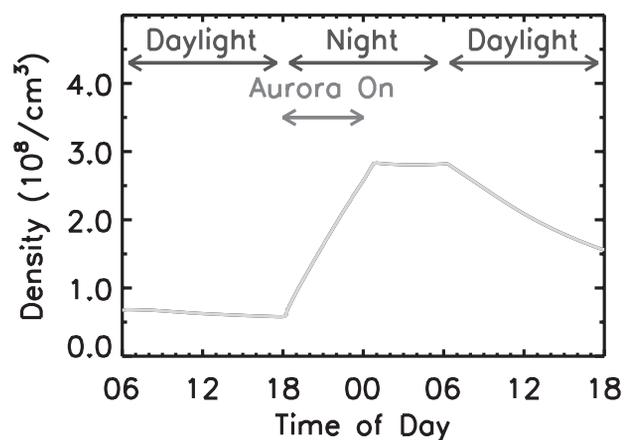


Figure 2. Model calculation of the nitric oxide density at 65°N , 216°E geographic coordinates at the time of equinox. Starting at sunrise, there is no auroral precipitation. At sunset, electron precipitation begins and the nitric oxide density increases. At midnight, the electron precipitation ends and the nitric oxide density remains constant throughout the rest of the night. At sunrise, the nitric oxide density decreases and the decrease continues during daylight because of photodissociation.

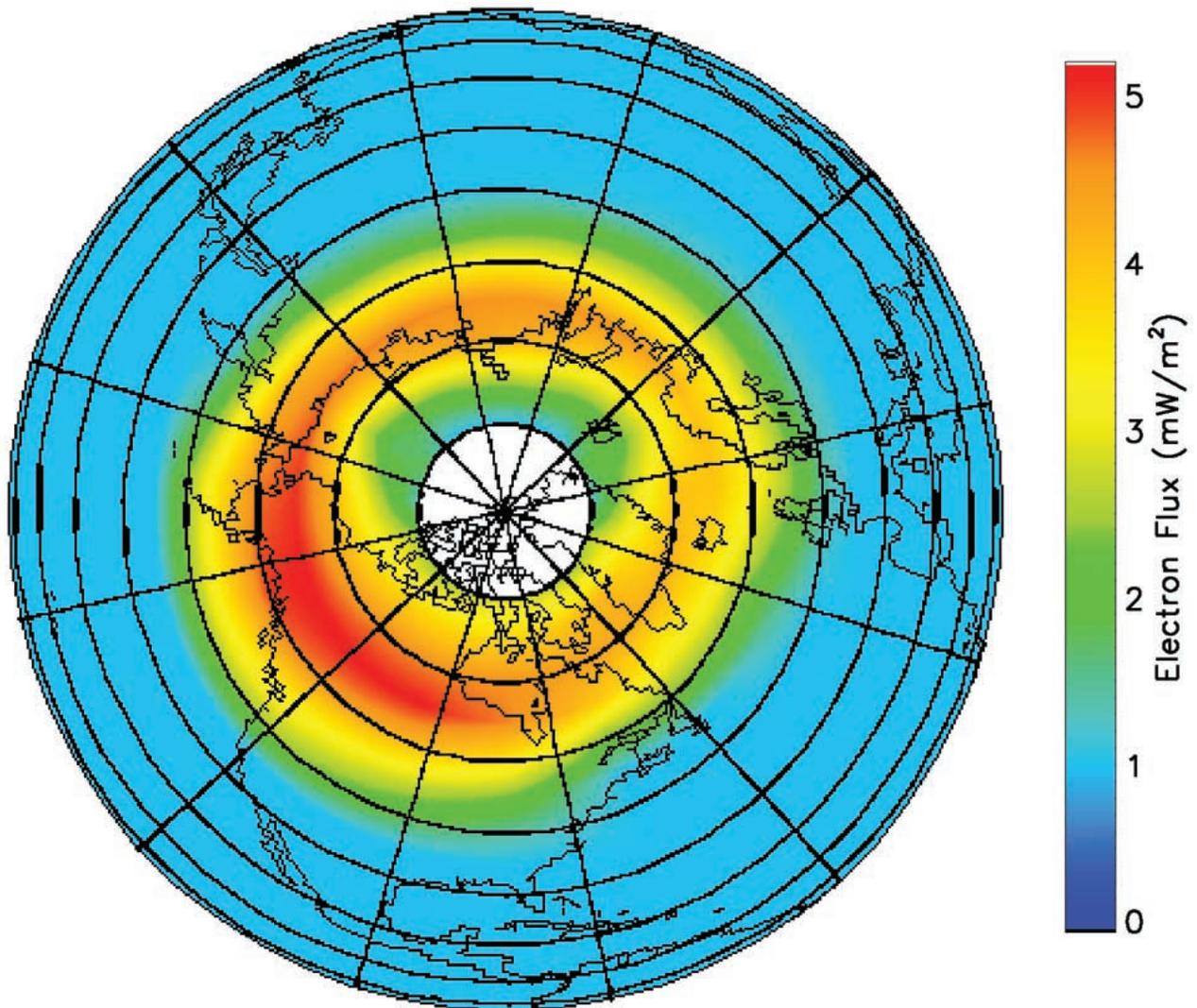


Figure 3. Polar image of the flux of precipitating electrons at 106 km as a function of corrected geomagnetic latitude and longitude (CGM). The 0° longitude line crosses the east coast of the United States. The lines of longitude are space 24° apart. The outlines of the continents have been converted into geomagnetic coordinates. The electron flux is greater at western geomagnetic longitudes than at eastern longitudes.

Between geomagnetic longitudes 30°W to 120°E , the magnetic field strength is lower in the southern auroral region than in the northern region. Mirroring electrons penetrate deeper into the atmosphere in the south and preferentially deplete the supply of electrons available for precipitation in the north. Since the mirroring electrons drift eastward, the effect of the weak magnetic field in the south Atlantic region is seen in the north eastward of 90°E geomagnetic longitude where the SNOE observations show the nitric oxide density to be the lowest. An examination of Figure 4 suggests how this mechanism works. An eastward shift of the magnetic field strength in the south (solid line in Figure 4(bottom) mimics the magnitude of the precipitating electrons in the north (solid line in Figure 4(top)).

[11] Polar displays of nitric oxide plotted in geographic coordinates show the northern auroral region to have the appearance of an oval [Barth *et al.*, 2001]. However, when the electron flux which is derived from the nitric oxide observations is plotted in geomagnetic coordinates as shown in Figure 3, the northern auroral region becomes circular. One way to view Figure 3 is that northern auroral region lies between 60° and 70°N geomagnetic latitude, but some of the precipitating electrons between geomagnetic longitudes 0° and 120°E are missing.

These missing electrons are those that have been lost in the southern hemisphere where the magnetic field strength is weaker than in northern hemisphere (see Figure 4). As viewed from above the north pole, a certain part of the Earth's auroral region is regularly subjected to a larger input of precipitating electrons and thus contributes to nitric oxide production. This region (west of the South Atlantic magnetic anomaly) is therefore a site of much greater nitric oxide, on average, than occurs east of the South Atlantic anomaly.

5. Summary

[12] Based on the results presented in this paper, a paradigm may be constructed that describes the magnetospheric control of the energy input into the thermosphere. In the magnetosphere, auroral electron precipitation occurs most strongly between 1800 and 2400 MLT. Magnetospheric activity causes variations in the flux of precipitating electrons. As the Earth rotates beneath the magnetosphere, the magnetic field lines of the offset, tilted dipole field determine where the electrons impact the thermosphere. The magnetic field strength controls the penetration of precipitating electrons into the atmosphere. The result is that there is a larger

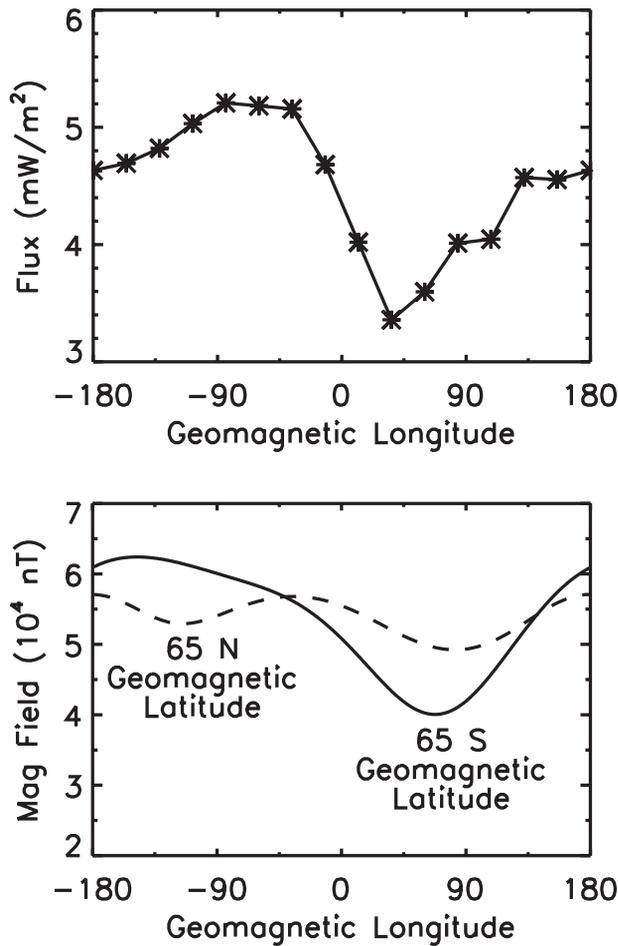


Figure 4. (top) A plot of the electron flux at geomagnetic latitude 65°N as a function of longitude (altitude 106 km). (bottom) The magnetic field strength at 65°N and 65°S geomagnetic latitude as a function of geomagnetic longitude.

energy input into the northern auroral thermosphere in the western geomagnetic hemisphere than in the eastern. This means that there is greater heating, ionization, and auroral luminosity in the west than in the east.

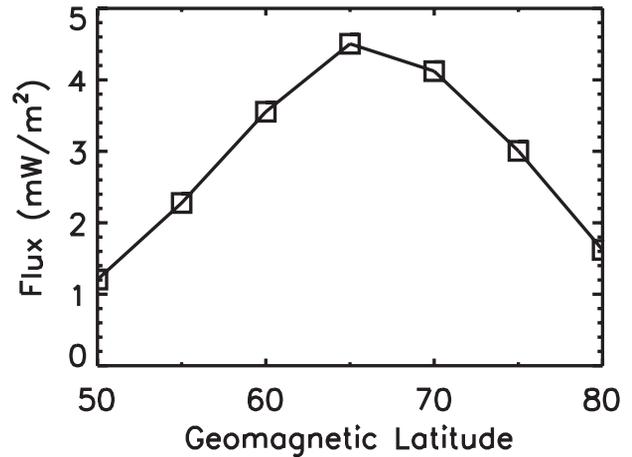


Figure 5. A plot of the average electron flux as a function of geomagnetic latitude (altitude 106 km).

[13] **Acknowledgments.** We appreciate the comments of Patrick Newell on the interpretation of Figure 1. The Student Nitric Oxide Explorer (SNOE) has been managed for the National Aeronautics and Space Administration by the Universities Space Research Association.

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