Correlation of LBH Intensities with Precipitating Particle Energies

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TO BE
Submitted to Geophysical Research Letters
December 2003
Abstract

Precipitating particle data from the DMSP F12 and F13 satellites has been merged with image intensities from the Ultraviolet Imager (UVI) on the Polar satellite. UVI and EC imagers were combined within single transpolar passes of the DMSP F12 and F13 satellites. Intensities of the pixels were then averaged into 1°x1° bins along the satellite tracks, thus generating along-track intensity profiles. Similarly, particle data were averaged into 1° bins along the trajectory to form energy precipitation profiles. The inbound (ascending in latitude) and outbound (descending in latitude) peaks in each set of profiles were isolated in order to compare imager photon flux with particle energy flux. The particle data and image intensity data of hundreds of peaks were linearly correlated for January-February 1997 when the northern polar regions were in darkness and dayglow effects were minimal. In the pre-midnight quadrant, good correlations (r ~ 0.80) arise between the photon and electron energy fluxes, while correlations for other sectors are not as good, perhaps because the latter sectors do not present as large a range in energy fluxes of >200 eV particles as the pre-midnight sector. The high correlation in the pre-midnight sector suggests that UVI fluxes can be directly calibrated to measure energy input without the additional complication of modeling. Using this calibration, global maps of energy input into the aurora may be derived empirically.

Introduction

The intensities (or ratio of intensities) of certain auroral emissions can furnish information about the precipitating particles. Early attempts in this direction exploited visible emissions such as OI (630 nm) and N₂1NG (427.8 nm) to
obtain energy flux of precipitating electrons and their characteristic energy (Rees and Luckey, 1974). But impediments such as cloud-cover, ground albedo, sunlight and moonlight, etc, compromised observations in the visible, so strategies arose for exploiting ultraviolet emissions of the aurora. A number of theorists then suggested exploiting LBH and OI emissions in the far ultraviolet to obtain information about precipitating particles (e.g., Strickland et al., 1983; Germany et al., 1990). Specifically, the intensity of LBH emissions in the “long” part of the band (~170 nm) is proportional to the energy flux of precipitating electrons. The intensity of the LBH in the “short” part of the band (~150 nm), which is partially absorbed by atmospheric O₂, can be used in conjunction with the LBH-long emissions to estimate the characteristic energy of the electrons (Germany et al., 1997;1998).

The Polar UVI imager specifically employed the LBHS and LBHL bands to determine characteristics of auroral precipitation using near-global imaging in the FUV (Torr et al., 1995). Validation of the relation between auroral intensity and precipitating particle energy have met with some success but have been based on a few case studies that do not have the authority of an extended statistical analysis (e.g., Lummerzeim et al., 1997; Brittnacher et al., 1997). These validations have relied on models to relate particle precipitation and intensity, and the models themselves are subject to uncertainties caused by model assumptions or input errors (e.g., Germany et al., 2001). An alternate approach would directly relate observed electron energy flux to the observed LBHL intensity. This work empirically relates the UVI LBHL flux (in photons/cm²s) to the DMSP electron energy flux (in eV/cm²s). The resulting correlation, when statistically pursued, yields an immediately useful product for the auroral community.
Data Sets Used

Two data sets are employed in this investigation. The first data set consists of images from the LBH-L filter of the Polar Ultraviolet Imager (UVI). The Polar satellite has a highly elliptical orbit of 2x9 \( R_E \) that "loitered" above the north polar region during 1997 and 1998 to observe the aurora. The imager pixel size of 0.04° translates to a projected scale of 4 km at 1 \( R_E \) range and 36 km at 8 \( R_E \) range. A persistent wobble in the despun platform on which UVI resides degrades this resolution, but "de-wobble" corrections can overcome this. Images have an accumulation time of 36 seconds at a sample interval of about three minutes. The LBHL filter has a nominal wavelength passband of 160-180 nm and a detection threshold of ~0.5 photons/cm²s (Brittnacher et al., 1997, 1999). The present study uses UVI image data from January and February of 1997 because, during these months, dayglow presents manageable background.

The second data set comes from the precipitating electrons detected by the SSJ/4 sensor on DMSP F12 and F13 satellites (Hardy et al., 1984). The DMSP satellites fly in polar orbits at altitudes of 840 km and cross the aurora about 25 times a day. The SSJ4 detectors detect electrons and ions at 20 logarithmically-spaced energies from 30 eV to 30 keV. The detectors point toward the local zenith, so they observe the precipitating particles that cause auroral emissions. The energy fluxes from the SSJ/4 detectors are determined by essentially integrating the energy spectrum over the available energy channels. One spectrum is obtained each second, during which time the satellite moves ~7 km. The DMSP data set has served as the basis for several statistical models of auroral precipitation (e.g., Hardy et al., 1985; Sotirelis and Newell, 2000).
Analysis Method

Standard UVI calibrations are first applied to convert UVI pixel counts to photon flux (photon/cm² s); pixel intensities are adjusted using the cosine of the observer zenith angle. The pixels locations are then registered in geographic longitude and latitude and transformed to MLT and MLAT at 120 km using the Altitude-Adjusted Corrected Geomagnetic Model (AACGM, Baker and Wing, 1989). Similar registrations are applied to energy fluxes of DMSP electrons (eV/cm² s) to render their locations in MLT and MLAT. The MLT and MLAT positions are then mapped to two-dimensional rectangular coordinates in which system +x is along the dawn direction (0600 h), +y is along the noon direction (1200 h), and x and y are both in degrees.

Next, UVI images are combined for single DMSP passes, which are defined as the transpolar satellite trajectory up from +50° MLAT and down to +50° MLAT. One pass usually requires ~24 minutes, during which time the aurora is assumed to be approximately stable. During one pass, 6-8 LBHL images are obtained. Figure 1 shows a typical DMSP F12 pass overlaid on a composite of 8 UVI images.

Points on the DMSP trajectory are placed into along-track segments (or bins) of 1°. The (x, y) coordinates of DMSP and UVI pixels are transformed (translation and rotation) into (x', y') coordinates where x' is along the trajectory and y' is perpendicular to the trajectory. The DMSP energies are averaged into one-dimensional 1° bins along track (i.e., $x_n < x'_{DMSP} < x_{n+1}$ for bin n), while the UVI pixel intensities are averaged into similar two-dimensional 1° x 1° bins (i.e., $x_n < x'_{UVI} < x_{n+1}$ and $-0.5° < y'_{UVI} < +0.5°$). Typically, one bin contains 30 DMSP samples and well
over 100 UVI samples. This bin averaging serves two purposes: it reduces the UVI and DMSP data to a common spatial resolution and it ensures good statistical sampling within a bin. Figure 2 displays the typical locations of UVI and DMSP pixels within a small segment of six along-track bins.

The bin averaging generates a DMSP energy profile and a comparable UVI intensity profile for a single pass. Figure 3 shows an example of two such profiles. In the top panel, the DMSP profile has two peaks— one for crossing the oval going poleward (the “left” peak) and one for crossing the oval going equatorward (the “right” peak). In the bottom panel, the UVI profile shows only the poleward-bound peak because the imager field of view does not extend to the equatorward side of the trajectory. The “inbound” DMSP and UVI peaks occur at approximately the same location, but some misregistration of features is evident. Previous comparisons of DMSP and UVI features have noted a similar misregistration (e.g., Baker et al., 2000; Carbary et al., 2003), which renders a pixel-to-pixel comparison of profiles problematic. Such comparisons usually result in questionable correlations of DMSP energy and UVI fluxes (e.g., Brittnacher et al., 1997).

However, the isolated peaks from oval crossings are always recognizable, especially by automatic computer algorithms, provided the trajectory crosses the oval perpendicularly (i.e., does not “skim” the oval tangentially). Therefore, this investigation correlates only peak energy fluxes and peak intensities on trajectories coming within 10° of the pole. This eliminates oval-skimming and promotes automatic feature recognition. Possible misidentification of peaks is reduced by requiring DMSP and UVI peaks agree to within 2° of magnetic latitude.
Results

Figure 4 exhibits the correlations of the energy peaks from DMSP F12 and F13 with the photon flux peaks of UVI for oval crossings in January and February. The correlations are segregated between ascending crossings (labeled “L” in the top panels) and descending crossings (labeled “R” in the bottom panels) with the appropriate sector designations. A straight line indicates a power law fit of the form:

\[ E(x) = A \left( x/x_0 \right)^P \]  \hspace{1cm} (1)

where \( x \) is UVI photon flux in photons/cm\(^2\)s (\( x_0 = 10 \) photon/cm\(^2\)s is a base level), \( A \) is amplitude in eV/cm\(^2\)s, and \( P \) is the power. For comparison, a dashed line indicates the theoretical relation between precipitating energy and photon flux (Brittnacher et al., 1997; Germany et al., 1998).

Although scatter is evident in all panels, a clear linear relation exists between the DMSP energy fluxes and the UVI intensities. This relation is clearest in the pre-midnight panel, but is also evident in the other sectors. The pre-midnight peaks have higher energy and photon fluxes (and hence greater ranges) because higher energy fluxes are statistically more likely there (e.g., Hardy et al., 1985; Newell et al., 1996). The scatter results primarily from oval variations that occur within the 25-minute duration of a pass. The good statistical sample, however, ensures that agreeable fits result.

Table 1 presents the essential results of this investigation. The table gives the number \( N \) of peak-peak correlations, the correlation coefficient, the amplitude \( A \)
and power $P$ from a fit (equation 1), and the standard deviation of the fit ($\sigma_{\text{FIT}} = \left[ \sum (E_i - A(x_i/x_0)^P) \right]^{1/2}$). The correlations are divided into regions sampled by the F12 and F13 satellites (e.g., F12 pre-midnight corresponds to the ascending “L” peaks). The best correlation appears for the pre-midnight sector where the range of energy fluxes is greatest. Presumably, a greater sampling range in fluxes would provide a similar correlation in the other sectors.

**Conclusions**

The peak photon intensities from UVI images and peak energy fluxes from DMSP satellites have been correlated for several hundred transpolar passes in an attempt to empirically derive a relation between image intensity and energy flux. A good correlation (correlation coefficient $\approx 0.80$) does exist between the photon flux and electron energy flux in the pre-midnight sector, while other sectors show less pronounced correlations. The correlation is presumably improved by the larger range of electron energies common in the pre-midnight sector.

Accepting the uncertainties in the power-law fits (see Table 1), the empirical relation between photon and energy fluxes can determine the global influx of energy into the aurora and help validate the several models of auroral precipitation. Some care should be taken, however, in extending the empirical relation outside the UVI-DMSP data sets. Vagaries of calibrations and wavelength band passes, always a potential danger, may promote somewhat different relations for different satellite instruments.
Acknowledgements

Funding for this research was provided by the University Partners for Operational Support through NAVSEA Grant 6606 Task LCR09.

References


Lummerzheim, D., M. Brittnacher, D. Evans, G.A. Germany, G.K. Parks, M.H. Rees, and J.F. Spann, High time resolution study of the hemispheric power


Table 1. Correlations for January-February 1997 using $\Delta_{\text{MLAT}} < 2^\circ$

<table>
<thead>
<tr>
<th>Quantity</th>
<th>DMSP F12</th>
<th>DMSP F13</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-midnight</td>
<td>Pre-Noon</td>
</tr>
<tr>
<td>N</td>
<td>103</td>
<td>37</td>
</tr>
<tr>
<td>Correl Coef</td>
<td>0.83</td>
<td>0.47</td>
</tr>
<tr>
<td>A (eV/cm$^2$/s)</td>
<td>2.3x10$^{11}$</td>
<td>2.1x10$^{11}$</td>
</tr>
<tr>
<td>P</td>
<td>1.36</td>
<td>0.53</td>
</tr>
<tr>
<td>$\sigma_{\text{FIT}}$ (eV/cm$^2$/s)</td>
<td>1.8x10$^{12}$</td>
<td>1.5x10$^{11}$</td>
</tr>
</tbody>
</table>
Fig. 1. The pixels from seven UVI images were averaged into 1°x1° bins to construct this picture of the auroral oval for one DMSP F12 transpolar pass. The usual MLT (sun at top) and MLAT grids are overplotted. The DMSP pass (heavy line) begins in the pre-midnight sector at 50° MLAT and ends in the pre-noon sector at 50° MLAT. (For DMSP F13, the trajectory would begin in the dusk sector and end in the dawn sector.) Dots indicate the region outside the UVI field of view.
Fig. 2. Typical UVI pixel placement (dots) about a short segment of DMSP trajectory. The crosses indicate placement of DMSP samples. The line segments perpendicular to the trajectory indicate the boundaries between 1° along-trajectory bins. The pixels from seven UVI images appear in a swath that lies within ±0.5° of the trajectory.
Fig. 3. DMSP electron energy flux (eV/cm²s, top) compared to UVI photon flux (photon/cm²s, bottom) for the seventh DMSP F12 pass (same as in Fig. 1). The dashed vertical line separates the ascending part of the pass (poleward-bound on left) from the descending part (equatorward-bound on right). Both the DMSP and UVI data have been averaged into 1° bins along the DMSP trajectory. The hatched region at the bottom of each frame indicates no data are present.
Fig. 4. Correlations between UVI photon flux peaks (FLX in photon/cm$^2$s) and DMSP electron energy peaks (JEE in eV/cm$^2$s) for January-February 1997. ("L" and "R" designations refer to ascending and descending parts of a pass.) Peak locations between UVI and DMSP matched to within 2° magnetic latitude. The solid line shows a least square fit to a power law (equation 1), and the dashed line shows the theoretical relation (Brittnacher et al., 1997).