Source region of 1500 MLT auroral bright spots: Simultaneous Polar UV-images and DMSP particle data

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Abstract. We compare auroral images from the Polar ultraviolet imager (UVI) and simultaneous particle observations from the Defense Meteorological Satellite Program (DMSP) in the afternoon (1300 - 1600 MLT) sector along the oval in the northern hemisphere to determine the magnetospheric source region of postnoon auroral bright spots. Auroral bright spots are determined with Polar UVI, while their magnetospheric source regions are determined from DMSP F13 particle data. A total of 65 events of good temporal and spatial coincidence were identified after searching through over 1 year of data, from April 1996 to June 1997. Instances occur of auroral arcs mapping to each of several different regions, including the plasma sheet, the low-latitude boundary layer, and the plasma mantle. However, our results indicate that \( \sim 2/3 \) of the time the most prominent auroral arcs are associated with plasma sheet electron precipitation and slightly less than \( 1/3 \) of the time they are found to occur near (less than 1° in magnetic latitudes) the boundary between the plasma sheet and other regions.

1. Introduction

The auroral oval [Feldstein, 1960] is a continuous ring of luminosity around the geomagnetic pole within which auroras are most frequently observed. Apart from the midnight sector of the oval, where auroras are most active during magnetic disturbances, early morphological studies have identified two preferred regions for occurrence of optical intensification on the dayside: one in the postnoon 1400 - 1600 magnetic local time (MLT) sector [Cogger et al., 1977] and a much weaker one in the prenoon sector [Meng and Landin, 1986]. By using the scanning photometer on ISIS 2, Cogger et al. [1977] found persistent auroral emissions at 5577 and 3914 Å bands maximizing between 1400 and 1600 MLT and Shepley [1979] found the peak of 1 keV of 6300 Å emission between 1300 and 1400 MLT and 77° to 79° invariant latitude (ILAT). These two regions of enhanced auroral emission have also been confirmed recently with Polar ultraviolet imager (UVI) in a statistical manner [Liou et al., 1997]. On the basis of monthly averaged auroral emission in \( N_2 \) Lyman-Birge-Hopfield bands, we concluded that dayside auroras maximize at both 1500 MLT and 75° magnetic latitude (MLAT) and 1000 MLT and 75° MLAT, with the latter maxima much weaker and not clearly identified in all seasons.

Similar to the optical study of auroral morphology, in situ measurements of particle precipitation reveal two significant regions of maximum in the dayside sector. The average intensity contour map for precipitating electrons with an average temperature of \( \sim 150 \) eV measured with the energetic particle detector on ISIS 2 shows a primary maximum near 1500 MLT and 75° ILAT [McDiarmid et al., 1975]. In studying energy deposition in the atmosphere due to energetic particles, Evans [1985] used measurements of precipitating ele-
trons and positive ions over an energy range from 0.3 to 100 keV obtained with the TIROS-N satellite and found a statistical maximum in energy flux in the 1300 to 1500 MLT sector at invariant latitudes near 78°. He also determined that low-energy (<3 keV) precipitating electrons resulting from a direct solar wind-magnetosphere interaction are responsible for producing the postnoon auroras. Recently, on the basis of a massive statistical study of discrete electron acceleration events from DMSP, Newell et al. [1996] found a dayside peak in the 1400 - 1600 MLT region. They also found that this region consists of many weak electron acceleration events, with average acceleration of a few hundreds of eV, and that discrete auroras are more common at 1500 MLT than any other local time (although intense events are more common on the nightside).

Other observations have also indicated that many magnetospheric/ionospheric phenomena are intensified in the 1300 - 1600 MLT auroral zone. The most intense upward region 1 field-aligned currents (FACs) are located in this region [Iijima and Potemra, 1978], and the unbalanced system of region 1 and region 2 FACs (also known as “net” currents) are found most often here [Sugiura and Potemra, 1976]. The occurrence of dayside auroral pulsations (10 - 40 s periods) maximizes at 1000 - 1030 MLT and at 1400 - 1600 MLT, with the latter one much weaker, for 1 < Kp < 4 [Wu and Rosenberg, 1992] (higher ionospheric conductivity from drifting diffuse aurora favors magnetic disturbances prenoon over postnoon). The sources of acoustic gravity waves associated with travelling ionospheric disturbances (TIDs) are found to be clustered near the magnetospheric cusp and near 1600 MLT at ~75° MLAT [Bristow et al., 1994]. Brykiewicz et al. [1981] found that a portion of region 1 FACs on the dayside is coincident with the extension of the low-latitude boundary layer (LLBL) in the magnetosphere.

Collectively, the many previous studies on magnetospheric/ionospheric phenomena in the afternoon sector yield a generally consistent picture: the region 1 upward FACs [Iijima and Potemra, 1978], particle precipitation [McDiarmid et al., 1975; Evans, 1985; Newell et al., 1996], and auroral luminosity [Shepherd, 1979; Cogger et al., 1977; Liou et al., 1997] share a common statistical maximum location in the 1400 - 1600 MLT sector. This collocation of the most intense region 1 upward FACs with the peak of low-energy precipitating electrons support the view that postnoon auroral emissions are associated with the region 1 upward FACs carried by soft precipitating electrons. Other signatures, such as similar B_y effects on the occurrence and intensity of postnoon auroras [Murphy et al., 1981; Vo and Murphy, 1995] and region 1 FACs [McDiarmid et al., 1975] also lend support to this view.

The dynamics of postnoon auroras has been extensively studied using the Viking ultraviolet imager [Murphy et al., 1981; C. D. Anger, 1987]. Auroral bright spots observed in the 1400 - 1600 MLT sector sometimes exhibit a spatially periodic pattern and can last for a few minutes [Lui et al., 1987], and they are found to be associated with magnetic pulsations [Rostoker et al., 1992]. It is also reported that postnoon auroral bright spots are most common during high solar wind speed (>500 km/s), low solar wind density, B_y < 0, and radially oriented interplanetary magnetic field (IMF) conditions [Vo and Murphy, 1995]. These results suggest that the occurrence of postnoon periodic auroral forms is associated with small-scale FACs resulting from the dynamic change of vorticity associated with the Kelvin-Helmoltz (K-H) instability at the inner edge of the LLBL [Lui et al., 1989]. Other models have also been promoted to explain auroral emissions in this dynamic region. On the basis of the study that compared simultaneous measurements of hot boundary layer plasma from Prognoz-7 and particle precipitation from the TIROS/NOAA satellite, Lindal and Evans [1985] proposed that high-latitude, early afternoon, auroras are powered by a dynamo process in the dayside boundary layer resulting from a local injection of magnetosheath plasma. By comparing simultaneous optical, particle, and field observations from Viking satellite, Potemra et al. [1990] proposed a large-scale wave, probably generating by the K-H instability, in the LLBL to be the source of periodic UV emission features reported by Lui et al. [1989].

Although there is disagreement among the proposed models, one can easily notice a common ground among them: the LLBL is the ultimate source region of postnoon auroral emissions. Indeed, Brykiewicz et al. [1981] reported that a portion of the region 1 currents on the dayside is coincident with the extension of the LLBL. Ground-based auroral observations performed by Moen et al. [1994] indicated that multiple auroral arcs in the 1400 - 1500 MLT sectors were observed within sunward convection flow, i.e., equatorward of the flow reversal boundary. They associated the observed multiple arcs with the postnoon region 1 upward FACs and proposed an LLBL source origin.

Although this speculated LLBL origin for the postnoon auroral bright spots seems physically reasonable, there is no direct supporting observational evidence. A recent study of dayside auroral emissions in the prenoon
oval between 0945 and 1000 MLT, using simultaneous observations of auroras from the Polar Bear satellite and particle from the DMSP satellite, indicated that auroral arcs can be mapped to several different regions, including the boundary plasma sheet, the LLBL, and the plasma mantle, and ~50% of the time the most prominent auroral arcs are located at the interfaces between distinct plasma regions [Newell et al., 1991b]. For this reason, it is interesting to see what the source regions are for the postnoon auroral bright spots by using low-altitude particle data. In this study we will conduct a similar study by taking advantage of a large amount of global auroral images acquired from the Polar UVI. The present study has the advantage of using an imager with much greater time resolution, allowing for more numerous and better quality coincidences.

The reminder of this paper is organized as follows: Section 2 includes the description of the satellites and instruments and data presentation and interpretation. Discussion will be given in section 3 followed by a conclusion in section 4.

2.2. Data Presentation

2.1. Satellites and Instruments

Images used here were collected by the ultraviolet imager (UVI) [Torr et al., 1995] on board the Polar satellite. The Polar UVI is a narrow-angle (8° circular field of view) large-aperture (f/2.9) design. A despun system allows UVI to monitor the northern hemispheric auroral oval continuously for ~9 hours out of every 18 hour orbit, providing ~2400 images (37-s telemetry rate). The optical sensor operates from 1300 to 1900 Å, and it combines with specially designed narrow-bandwidth interference filters to perform specific measurements. The major filters operated on the UVI are centered at 1304 and 1356 Å for atomic oxygen lines, the short Lyman-Birge-Hopfield (LBH-short) filter centered at ~1500 Å, and the long Lyman-Birge-Hopfield (LBH-long) filter centered at ~1700 Å for molecular nitrogen lines. Polar UVI provides a spatial resolution of 0.04° per pixel, which corresponds to ~5 km per pixel at 120-km height for images taken at perigee (~1.8 RE) and 40 km per pixel at apogee (~9 RE) (although platform wobble degrades this resolution).

DMSP F13, launched in March 1994, is in a nearly circular, Sun-synchronous orbit at an altitude of ~830 km, in dusk-dawn meridian with the nominal orbital period of 101 min. The on-board SSJ/4 (special sensor for precipitating particles, version 4) detector measures the flux of precipitating electrons and ions in the range of 32 eV to 30 keV [Hardy et al., 1984]. The instrument package consists of four electrostatic analyzers, one high-energy detector and one low-energy detector for each of the particle types. Each detector has 10 logarithmically spaced energy steps. The high-energy detectors step from 1 to 30 keV and the low-energy detectors step from 1 keV to 32 eV. The satellites are three-axis stabilized so that the apertures of detector (2° by 5° for the high-energy channels and 4° by 5° for the low-energy channels) are always orientated toward the satellite zenith. This means that only particles well within the loss cone are observed at the latitudes of interests to the present research.

The source region for particle precipitation in the afternoon sector is determined by using the 32 eV to 30 keV particle characteristics from the low-altitude DMSP F13 satellite, based on previously published research [Newell and Meng, 1988; Newell et al., 1991a]. An overview of dayside particle precipitation is given by Newell et al. [1991b] (section 4). The Polar UVI images are used primarily for the identification of auroral bright spots.

We first searched more than 1 year (April 1996 to June 1997) of DMSP particle data for northern postnoon (1300 - 1600 MLT) auroral oval crossings with electron energy fluxes over ~10^{12} eV/(cm^2 s sr). This is equivalent to selecting fairly intense auroral bright spot events (~2 ergs/cm^2 s). Then instances when the northern auroral oval was imaged at the same time are determined from the Polar UVI database. Events where the images do not show clear auroral bright spots are further eliminated. We have compiled 65 nearly concurrent events for a statistical study, and they can be summarized into three categories according to the regions where postnoon auroral enhancement takes place.

2.2. Plasma Sheet Origin

The most intense electron precipitation is located well within the plasma sheet. We will examine two such events as follows.

2.2.1. Case 1: April 1, 1996, 0749 UT. The first case of bright spots with plasma sheet origin occurred on April 1, 1996, around 0749 UT. The interplanetary magnetic field (IMF), recorded by the Wind spacecraft at about (62.6,-10.7,-1.2) RE GSM, turned southward from a 3-hour northward condition at ~0620 UT and stayed relatively stable at ~4 nT until ~0900 UT except for a short period (~10 min) of northward excursion occurring at ~0745 UT. Magnetic activity was moderate (Kp = 3 for 0300 - 0600 UT interval and Kp = 2+ for 0600 - 0900 UT interval).
Plate 1. (a) A Polar UVI Lyman-Birge-Hopfield image of the auroral oval on April 1, 1996, ~0749 UT. Magnetic local noon is at the top, dusk to the left, and contours of 60°, 70°, and 80° MLAT are also shown. The white line segment shows a 5 min trajectory of the DMSP satellite centered at the imaging time (shown as a square box) at the auroral source height. (b) A DMSP F13 spectrogram showing electron and ion precipitat ion from 32 to 30 keV for the time interval around the imaging time. The color scale indicates differential energy flux (eV/cm² s sr eV). The top line plot is total energy flux (eV/cm² s eV); the bottom line plot is average energy (eV). The arrow indicates the UVI imaging time. The regions are labeled under the spectrogram.
Plate 1a shows the Polar UVI image at the LBH-long band taken at 0749:26 UT. The image has been mapped onto the AAGCM magnetic coordinates [Baker and Wing, 1989] at an assumed source altitude of 120 km. Magnetic local time meridian lines are drawn every hour, with noon to the top and dawn to the left. On the basis of earlier UVI images (not shown), this event occurred during the late expansion phase of a substorm which commenced at ~0720 UT. Note that the dawn sector of the auroral oval (0300 - 1100 MLT) is located outside the field of view of UVI during this time interval. The afternoon aurora features two bright spots extending ~1 hour of local time in size: one at ~1400 MLT and the other at ~1530 MLT. A 5-min DMSP trajectory is overlaid on the image as a white solid line, showing that DMSP F13 made a glancing pass off the southeastern edge of the 1400 MLT bright spot around the image time. The DMSP footprint at 120 km at the image time is marked by a square box centered along the trajectory.

Plate 1b shows particle spectrogram of dayside oval from DMSP F13 for a 5-min interval between 0747 and 0752 UT. The ion and electron differential energy flux are plotted in units of eV/(cm² s sr eV); note that the ion energy scale is inverted, so that zero energy occurs in the center for both electrons and ions. The top dotted-line plots give electron and ion total energy flux (eV/cm² s sr) and average energy (eV) in logarithmic scales. The labels show the identification of the various particle regions and the up-arrow indicates the image time. The particle data indicate that the DMSP F13 first encountered a region populated with plasma sheet-like ions (average ion energy much greater than 1 keV) as it approached the postnoon oval from low latitudes at 0747 UT. This first encountered region may correspond to the CPS despite the lack of electron precipitation. CPS-type electrons normally do not cross the noon as they drift eastward from the nightside of the magnetosphere due to magnetic gradient and curvature forces. The first sign of electron precipitation occurred at 0748:30 UT when the DMSP F13 reached 73.5° MLAT and 1410 MLT and started entering one of the auroral bright spots centered at 1400 MLT. Particle spectra in this region resemble those often found in the nightside BPS. Since most of the low-altitude BPS maps to the high-altitude central plasma sheet [e.g., Feldstein and Galperin, 1985], we will simply refer to the whole region as plasma sheet.

The maximum electron total energy flux ($7 \times 10^{12}$ eV/cm² s sr) was recorded at 73.8° MLAT and 14:05 MLT at ~0748:35 UT while the DMSP F13 was still inside the bright spot. The electron total energy flux decreased (mainly due to the decrease in the average energy of the electrons) below $10^{11}$ eV/(cm² s sr) as soon as DMSP F13 exited the bright spot and subsequently reached the mantle at 75.1° MLAT and 13:29 MLT at ~0749:34 UT. The mantle plasma is characterized by very low ion average energy (<1 keV), indicating deenergized magnetosheath plasma, and weak electron precipitation at polar rain energies. The 1400 MLT auroral bright spot was actually characterized by a few large, spatially narrow electron acceleration events (average energy of 3 keV) which were well into the plasma sheet and extended at weaker levels to the poleward edge of the plasma sheet.

2.2.2. Case 2: April 24, 1997, 0844 UT. Another typical case of plasma sheet origin is shown in Plates 2a and 2b.

This event took place at the early recovery phase of a substorm commencing at ~0807 UT. The hourly IMF values from the Wind spacecraft, which was located at ~221, -4.0, 24.3 RE in GSM, were $B_x = -2.2$ nT, $B_y = 0.5$ nT, and $B_z = 0.3$ nT. Magnetic activity was moderate ($K_p = 3$) for the time interval 0600 - 0900 UT. Plate 2a shows the Polar UVI image at LBH-short taken at 0844:08 UT. An enhanced bright spot is seen on the eastern leg of an “M”-shaped dayside oval which loosely detached from the fading auroral bulge in the nightside oval. This postnoon auroral bright spot first brightened at ~0840 UT then faded away at ~0854 UT. The bright spot had a spatial extent of ~5° wide along the oval and 4° wide latitudinally and was centered at ~1500 MLT and ~73° MLAT. The DMSP footprints at 120 km altitude indicate an inward crossing along the equatorward edge of the bright spot.

A particle spectrogram from DMSP F13 for the 5-min interval between 0842 and 0847 UT is shown in Plate 2b. Below 75.7° MLAT, DMSP sees a typical hot plasma sheet ion spectrum. A “soft” electron precipitation was recorded after 0844 UT, approximately when DMSP F13 entered the bright spot. The most intense electron precipitation, indicated by an electron energy flux of ~1.2 x $10^{12}$ eV/(cm² s sr) and an average energy of 1 keV, occurred at 73.6° MLAT and 1445 MLT at ~0845:04 UT when DMSP was still inside the bright spot. The electron total energy flux decreased (mainly due to the decrease in the average energy of the electrons) as DMSP F13 moved downward; it reached the LLBL at 75.7° MLAT and 1350 MLT at ~0846:15 UT, about 20 - 30 s after exiting the auroral bright spot and entering a weaker background oval. The ionospheric signature of the LLBL is a mixture of hot magnetosphere
Plate 2. (a) A Polar UVI Lyman-Birge-Hopfield image of the auroral oval on April 24, 1997, at 0844 UT; (b) The DMSP F13 spectrogram corresponding to the image shown in Plate 2a.
and cold magnetosheath ions. For this event the center of the auroral bright spot was located ∼2° south and 14° east of the LLBL seen by DMSP F13.

2.3. Interfaces Between Two Regions

The most intense electron precipitation is often seen at boundaries between the plasma sheet and the LLBL, the plasma mantle, or the polar rain. We will use the following two events to illustrate this fact.  

2.3.1. Case 1: May 2, 1997, 1031 UT. Our first example of boundary origin took place at ∼1031 UT on May 2, 1997.

Plate 3a shows the Polar UVI image at LBH-short taken at 1031:05 UT. It indicates an intense auroral bright spot that extended from ∼1430 to ∼1630 MLT and between 63° and 67° MLAT. The hourly IMF values were \( B_y = -1.8 \) nT, \( B_y = -1.4 \) nT, and \( B_z = -1.6 \) nT. According to UV images, this event took place at the growth phase of a substorm that went off at ∼1044 UT. Magnetic activity was \( K_p = 2 \) for 0900 - 1200 UT.

Plotted in Plate 3b is a 5-min DMSP F13 particle spectrogram from 1030 to 1035 UT. Along the trajectory of the DMSP F13 satellite the peak electron energy flux occurred at 76.1° MLAT and 1448 MLT at ∼1032:00 UT, about the time when DMSP F13 reached the most intense part of the bright spot. This energy flux peak (∼10^{12} eV/cm^2 s sr) was associated with electron acceleration to a peak energy of ∼4 keV falling very close to the interface between the plasma sheet and the plasma mantle at 76.5° MLAT and 1444 MLT. The latitudinal width of the acceleration region is ∼0.8° MLAT which is much narrower than that of bright spots observed by UVI. This inconsistency is probably due to the wobble of the Polar satellite, which can blur the image up to 4° in one direction; indeed, during this time the wobbly direction was close to the 1500 to 0300 MLT meridian. On the other hand, it may indicate that auroral acceleration events in this region vary on time scales shorter than the 37-s integration time provided by UVI.

2.3.2. Case 2: June 29, 1997, 0710 UT. Plates 4a and 4b show another boundary origin event which took place at ∼0710 UT on June 29, 1997, during a prolonged, large negative IMF \( B_z \) condition. The hourly IMF values from the Wind spacecraft which was located at ∼(68.0, 20.5, -10.6) \( R_E \) in GSM were \( B_z = 1.47 \) nT, \( B_y = -4.0 \) nT, and \( B_z = -3.2 \) nT. The Polar satellite was located in an unfavorable viewing position until ∼0630 UT, with only the dayside part of oval covered by UVI. One of the IMAGE chain stations at Bear Island (BJN) measured a large negative bay starting at ∼0300 UT and reaching a maximum value of -400 nT at ∼0415 UT. Magnetic activity was moderate (\( K_p = 2 \) for the 0600 - 0900 UT time interval), a slight decrease from a previous value of \( K_p = 3 \) for the 0300 - 0600 UT time interval. The UVI image (Plate 4a) at the LBH-short band taken at 0710:08 UT seems to indicate a quiet evening oval (1900 - 2200 MLT) during this time interval. The auroral feature in the afternoon sector is characterized by four approximately equally spaced bright spots at 1415, 1530, 1720, and 1830 MLT along the afternoon oval. The DMSP footprints at 120 km altitude indicate an inward pass through one of the bright spots located at ∼1415 MLT.

A particle spectrogram from DMSP F13 for a 5-min interval between 0708 UT and 0713 UT plotted in Plate 4b. Along the DMSP F13 trajectory, two distinct plasma regions were observed during this time interval. The region equatorward of 72.2° MLAT was populated with hot, dense plasma sheet ions and the region poleward of it was populated with very low ion energy (\( \lesssim 1 \) keV) mantle plasma. There was little electron precipitation for the entire interval except for a narrow region inside the plasma sheet just equatorward of the interface, where the most intense electron precipitation, indicated by an electron energy flux of ∼10^{13} eV/(cm^2 s sr) and an average energy of 2 keV was recorded. The maximum in electron energy flux very likely corresponds in Plate 4a. The electron flux decreased immediately after DMSP F13 exited the bright spot and entered the mantle. In agreement with the particle data the bright spot also exhibits a sharp decrease in intensity at its poleward edge.

2.4. Regions Other Than the Plasma Sheet

Occasionally, intense electron precipitation appears to occur in regions other than the plasma sheet. We present two events illustrating this category.

2.4.1. Case 1: July 28, 1996, 2253 UT. This event took place at ∼2253 UT on July 28, 1996, during a large, prolonged (more than 7 hours) positive \( B_y \) condition. The hourly IMF values were \( B_x = -3.1 \) nT, \( B_y = 7.5 \) nT, and \( B_z = 0.2 \) nT. Magnetic activity was moderate (\( K_p = 2 \) +) for the time interval 2100 - 2400 UT, a large decrease from a previous value of \( K_p = 4 \) for the 1800 - 2100 UT interval. Plate 5a shows the Polar UVI image at LBH-short band taken at 2252:53 UT. The dayside aurora had been active for many hours. Postnoon auroras during this time consisted of a large bright spot centered at ∼74° MLAT and ∼1530 MLT and extending ∼3 hours in MLT. A Sun-aligned arc of
Plate 3. (a) A Polar UVI Lyman-Birge-Hopfield image of the auroral oval on May 2, 1997, at 0011 UT; (b) The DMSP F13 spectrogram corresponding to the image shown in Plate 3a.
Plate 4. (a) A Polar UVI Lyman-Birge-Hopfield image of the auroral oval on February 6, 1997, at 1031 UT; (b) The DMSP F13 spectrogram corresponding to the image shown in Plate 4a.
Plate 5. (a) A Polar UVI Lyman-Birge-Hopfield image of the auroral oval on July 28, 1996, at 22:53 UT; (b) The DMSP F13 spectrogram corresponding to the image shown in Plate 5a.
equally brightness was connected to the bright spot at
\(~1400\) MLT and to the evening oval at \(\sim2000\) MLT. In-
terestingly, this Sun-aligned arc was found to separate
from the postnoon bright spot beginning at \(\sim2200\) UT.
Around this time, DMSP F13 made a pass of the bright
spot at \(\sim1600\) MLT and \(74^\circ\) MLAT and the Sun-aligned
arc at \(1500\) MLT and \(79^\circ\) MLAT.

A particle spectrogram from DMSP F13 for a 10-
min interval between 2247 and 2257 UT is shown in
Plate 5b. DMSP F13 first encountered the region pop-
ulated with the plasma sheet ions at \(\sim2247:22\) UT. One
minute later it entered a region of soft \((<500\) eV) elec-
tron precipitation which approximately corresponds to
the equatorward edge of the postnoon auroras just pole-
ward of \(70^\circ\) MLAT. The electron energy fluxes increased
more than a \(100\)-fold to \(10^{12}\) eV/(cm\(^2\) s sr), mainly
due to an increase in the energy of precipitating elec-
trons, at \(\sim74^\circ\), and stayed relatively flat over \(2250 -
2254\) UT interval, approximately corresponding to the
region where the bright spot and the Sun-aligned arc
were connected. Although the peak electron energy flux occurred near the boundary of the plasma sheet
and polar rain regions, similar electron precipitation of
roughly equal energy fluxes associated with many small
monoelectric acceleration events was found to extent
into the polar rain region from the plasma sheet along
the satellite trajectory. This event strongly indicates
that intense auroral emissions in the afternoon sector
can occur on field lines that map to distinct plasma
regions in the magnetosphere.

2.4.2. Case 2: December 31, 1996, 0812 UT.
This event occurred at 0812 UT on December 31, 1996,
during a series of weak auroral activations at high lati-
tudes \((70^\circ\) MLAT) in the premidnight sector. IMF
data are not available for this time event. Magnetic
activity was quiet \((K_p = 1\) for the \(0600 - 0900\) UT in-
terval and \(K_p = 2\) for the \(0300 - 0600\) UT interval).
Plate 6a shows the Polar UVI image at the LBH-long
band taken at 0812:21 UT. The afternoon aurora ex-
hibits two enhanced bright spots, one at \(\sim1300\) MLT
and one at \(\sim1530\) MLT. The latter was embedded in a
weak background oval that seemed to connect to the
auroral activities in the nightside oval. There is, how-
ever, clear evidence of disconnection of the \(1300\) MLT bright
spot from the nightside auroras. UVI images (not pre-
sented here) show weak postnoon auroral bright spots
occur intermittently at least one hour before and after
this time. DMSP F13 satellite passed through the \(1300\)
MLT bright spot about \(45\) s after this image was taken
(i.e., \(\sim0813:06\) UT).

The particle spectrogram from DMSP F13 for a five-
minute interval between 0809 UT and 0814 UT is shown
in Plate 6b. The particle data show that DMSP F13
first encountered a region populated with plasma sheet
ions poleward of \(70^\circ\) MLAT up to \(\sim75^\circ\) MLAT where the
hot plasma sheet ions started to drop-out and the
LBBL-type low-energy ions \((\sim1\) keV) started to ap-
pear. Enhanced electron precipitation was first ob-
served at this transition region and extended clearly
into the LLBL. The most intense electron energy flux
\((\sim10^{13}\) eV/cm\(^2\) s sr) occurred at \(76.2^\circ\) MLAT and \(1319\)
MLT at \(\sim0813:00\) UT, in agreement with the UVI ob-
servation, and found to reside inside the LLBL. This
energy flux peak is associated with a large keV accel-
eration event which may have caused the dropouts of
the LLBL ions at the same time.

3. 2.5. Statistical Study

We have presented six events of good temporal and
spatial coincidence from Polar UVI and DMSP F13. Re-
results are mixed in terms of the magnetospheric source
locations of the largest electron energy fluxes or bright
spots. It appears that auroral bright spots in the \(1300 -
1600\) MLT sector can actually originate from many dif-
f erent regions in the magnetosphere, such as the plasma
sheet, the LLBL, the plasma mantle, and the polar rain
region.

Which region is typical for hosting intense large elec-
tron acceleration events? We compiled a total of 65 si-
multaneous UVI/DMSP observations of auroral bright
spots in the \(1300 - 1600\) MLT region. The spatial dis-
tribution of the events is plotted in Plates 7a and 7b
separately for clarity. The blue crosses correspond to
the largest electron energy identified by DMSP F13,
which are always coincident with bright spots observed
by the Polar UVI, and the red squares correspond to the
poleward boundaries of plasma sheet. The two physical
points are connected by the DMSP F13 trajectories. It
is shown from Plate 7 that the majority of the events
selected were located within the \(1300 - 1600\) MLT sec-
tor between \(70^\circ\) and \(80^\circ\) MLAT, and most of the largest
electron energy fluxes (auroral bright spots) are found
to be located equatorward of the plasma sheet poleward
boundary. Figure 1(c) shows a histogram of events stud-
yed as a function of the difference in magnetic latitudes
between the location of poleward edge of the plasma
sheet and the largest electron energy flux. A positive
\(x\) axis value in Plate 7c indicates that the most intense
events take place within the plasma sheet. Therefore it
indicates that \(63\%\) (41 events) of the time auroral arcs
are found well into the plasma sheet. Of the remaining
Plate 6. (a) A Polar UVI Lyman-Birge-Hopfield image of the auroral oval on December 31, 1996, at 0812 UT; (b) The DMSP F13 spectrogram corresponding to the image shown in Plate 6a.
24 events there are only 4 (~6%) mapped to regions other than the plasma sheet and 20 (~31%) mapped to the transition region.

For completeness we plot in Plate 7d the change in local time between where DMSP encountered the most intense precipitation and the poleward edge of the plasma sheet. Plate 7d illustrates that the satellite usually moved no more than 1/2 hour in MLT before reaching the plasma sheet poleward boundary. Hence local time effects are not crucial to our analysis.

4. 3. Discussion

Simultaneous observations of auroral bright spots in the 1300 - 1600 MLT sector made with DMSP F13 and Polar UVI were used to study their possible source regions. DMSP F13 footprints at an assumed LBP auroral altitude (120 km) were superimposed on UVI images taken near the time of the DMSP F13 crossings to ensure the coincidence between bright spots and the most intense electron precipitation. Indeed, all cases do show agreement. Therefore the location of the most intense electron precipitation within each spectrogram can be used to infer the source region of auroral bright spots. It is important to note that although the wobbling effect of the platform may introduce an error in matching particle precipitation and the auroral emissions, we believe this kind of error does not affect the final result because the source region of auroral bright spots is determined with particle data. Besides, it is very unlikely to have optical emissions occurring where there is little precipitating energy flux. It is also important to note that the auroral features seen from the ground in the 1400 - 1600 MLT region have not been studied. Therefore the appearance of these bright spots observed by Polar UVI look like from the ground is yet to be investigated. They may be curls, folds, or east-west oriented multiple arcs for all that we know. On the basis of the softness of electron precipitation in this region, they may likely be in the form of patches and/or blobs. Of course, terminology depends strongly on the spatial coverage and resolution of instruments.

Auroral precipitation in the dayside region consists of magnetosheath related boundary layer precipitation, and plasma sheet related BPS/CPS precipitation (the former being an extension of the nightside precipitation region). For a discussion of dayside precipitation regimes refer to Newell and Meng [1988] and Newell et al. [1991a, b]. It is important to understand that low-altitude particle data within the bright spots themselves cannot be used to identify plasma regions, be-

Plate 7. A distribution of the 65 simultaneous measurement events from the (a) Polar UVI and (b) DMSP F13. The blue crosses correspond to the locations where peak in electron energy flux was identified and the red boxes correspond to the locations of where interfaces between the plasma sheet and other regions are located by the DMSP F13 satellite. The two symbols are connected by an orange line indicating the satellite trajectory. (c) The histogram of the bright spot events with respect to the latitude (local time) difference between the two locations plotted in Plate 7a. A positive (negative) value in the latitude (local time) difference indicates that peak electron energy flux was found equatorward (westward) of the plasma sheet boundary.
cause FACs potentials greatly alter the particle spectra. Thus we must rely on the plasma surrounding the bright spots (and lacking the signatures of field-aligned acceleration).

Previous studies on magnetospheric/ionospheric phenomena in the afternoon sector have generally yielded a consistent morphology: the region 1 upward FACs [Iijima and Potemra, 1978], particle precipitation [McDiarmid et al., 1975; Evans, 1985; Newell et al., 1996], and auroral luminosity [Shepherd, 1979; Cogger et al., 1977; Liou et al., 1997] are found to maximize in the 1400 - 1600 MLT sector. Therefore it is generally believed that intense auroral arcs (bright spots) in the postnoon region map to the LLBL [e.g., Lui et al., 1989; Potemra et al., 1990] because region 1 upward FACs are found to be connected to that region [Bythrow et al., 1981]. Moen et al. [1994] reported ground-based auroral observations that show multiple auroral arcs in the 1400 - 1500 MLT sector on sunward convective flow and they suggested an LLBL source origin. Note that none of these observations provides evidence that directly connects postnoon auroral bright spots to the LLBL; actually, they do not disagree with the less mentioned possibility of plasma sheet origin either. On the other hand, recent studies of FACs by using the assimilative mapping of ionospheric electrodynamics (AMIE) have suggested that the region 1 upward FACs in the postnoon region are usually associated with plasma sheet particle precipitation [Lu and et al., 1995; Troshichev et al., 1996]. More recently Yamauchi et al. [1998] used particle and magnetic field data from Freja and found that in the afternoon sector the region 1 upward FACs are in the BPS. All these measurements suggest that the plasma sheet, indeed, may as well be the source region of the postnoon auroral bright spots observed by Polar UVI.

Coley et al. [1987] examined the DE 2 ion drift and energetic particle data and reported that auroral particle precipitation was most often found in the sunward convective flow region on both duskside and duskside. Newell et al. [1991b] compared particle data from DMSP F9 satellite with the convection reversal boundary (CRB) determined by either the Sondrestromflord radar or the drift meter on board DMSP F9, in the prenoon local time sector. They found the region of LLBL-type plasma was clearly associated with a tailward convection; however, the equatorward boundary of the LLBL plasma region was generally a bit equatorward of the CRB. If the dusk flank LLBL maps to the tailward convection in the postnoon region in a symmetric sense like its prenoon counterpart, one can reasonably say that auroral particle precipitation is most likely to occur equatorward of the LLBL. Note that the observation of Moen et al. [1994] of multiple auroral arcs in the 1400 - 1500 MLT sectors also take place on sunward convection flow. Therefore postnoon auroral arcs may actually map to the dayside extension of plasma sheet. However, Bythrow et al. [1981] reported that the poleward limit of plasma sheet electrons (>1 keV) can extend beyond the CRB by ~0.5° MLAT and this poleward limit is observed to be nearly coincident with the region 1 currents. This may indicate that auroral precipitation can also occur in the LLBL and probably the plasma mantle and is consistent with our observation.

Note that 1 keV precipitating electrons are found here to be most often responsible for producing auroral bright spots at LBH bands seen by the Polar UVI imager. By contrast, Newell et al. [1996] reported from particle data that afternoon electron acceleration events typically had energy less than 1 keV. The difference apparently lies in selection criteria: the earlier particle study included all events above 0.25 ergs/(cm² s), almost an order of magnitude lower than our selection criteria (10¹² eV/cm² s str). Thus the present study consists of relatively intense events.

One more line of evidence supports our result. Magnetic field line tracing can also be used for projecting ionospheric phenomena to their magnetospheric source regions and vice versa. The ionospheric region within which most of our events were identified is most likely mapped to the dayside magnetosphere within 4 Re from the magnetopause [Kaufmann et al., 1993] where the width of LLBL is believed to be less than 1 Re. Therefore, a large portion of this area is actually mapped to the dayside extension of the plasma sheet. However, we do not want to exclude the possibility of inner edge of nightside plasma sheet being the alternative because a small portion of the afternoon sector at higher latitudes is mapped to the nightside magnetotail [Kaufmann et al., 1993].

On the basis of above discussion, it is not surprising that auroral bright spots can actually originate from many different regions in the magnetosphere. Our result, based on 65 simultaneous observations for the auroral bright spots in the 1300 - 1600 MLT region, indicates that more than 90% of the time intense auroral arcs are found equatorward of, including the poleward edge of plasma sheet.

We briefly note that because the ionosphere is an incompressible fluid, a disturbance anywhere near the open/closed boundary (or CRB) will profoundly affect the electrodynamics across the boundary. Kan et al.
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[1996], on the basis of such considerations, argued that even phenomena relating to open field lines such as merging transients would produce more intense aurora equatorward of the CRB than poleward of it. Thus, for example, Plate 5 shows electron acceleration events distributed over a wide latitudinal range, including the plasma sheet and the polar rain. The fact that the most intense electron acceleration event is within the plasma sheet does not necessarily specify the location of whatever is driving the event (if, indeed, they all have a single driver).

Plasma flow vortices have generally been considered the source of dayside region 1 FACs, and these vortices can be produced by K-H instabilities [e.g., Wei and Lee, 1993]. Large-scale plasma flow vortices have been observed to be very common in the near-Earth (within \( \sim 20 R_E \)) plasma sheet and may also present in the dayside projections of the plasma sheet [Hones et al., 1981]. The sense of vortex rotation is clockwise in the morning hours and counterclockwise in the evening half of the plasma sheet, with a sharp line of demarcation on the midnight meridian, suggesting that plasma sheet vortices are driven by K-H instabilities at the interface between the plasma sheet and the boundary layer [Hones et al., 1981]. We suggest that a portion of postnoon auroral bright spots may originate from this region.

Theoretically, the largest flow vortices occur where plasma flows reverse, and the stronger the flow vortex is, the larger the current is. This often occurs at interfaces between different regions and decays away from the interfaces. Indeed, the most prominent auroral arcs in the prenoon region were located at the interfaces between distinct plasma regions in a smaller previous study [Newell et al., 1992] (the previous work lacked the present high time resolution). Although, a part of our results support this view, the majority of the largest electron energy fluxes came from the plasma sheet.

We wish to propose another possible explanation for why it is comparatively rare for the most intense electron precipitation to occur poleward of the CRB, where the LLBL resides. First, recall that the CRB may lie \( \sim 1^\circ \) poleward of the LLBL equatorward boundary [Newell et al., 1991b, and references therein]. The corresponding effect has also been observed in high-altitude passes through the LLBL; i.e., the plasma boundaries do not precisely correspond to the convection boundaries (with the same sense of offset at low and high altitudes).

It was shown that locations in the ionospheric convection electric field with electric potential differences and electron precipitation in the evening sector [Lyons, 1980]. This condition applied to the postnoon sector produces upward region 1 FACs. The ionospheric width of an arc system, \( \Delta k \), is estimated to be

\[
\Delta k \sim \left( \frac{\Sigma P T^2}{n_c} \right)^{1/2} \text{[Lyons, 1980; Borovsky, 1993,]} \]

where \( \Sigma P \) is the Pettersson conductivity, and \( T_e \) and \( n_c \) are the electron temperature and density, respectively. For a constant \( P \), the typical values of electron temperature and density will result in a smaller width of an arc system in the LLBL than in the PS by a factor of \( \sim 5 \); therefore a large portion of the arcs appears in the PS. Furthermore, the asymmetry in the magnetospheric sunward and antisunward convection can also affect the arc location with respect to the discontinuity [Lyons, 1980]. An asymmetric potential difference profile will be achieved due to an asymmetric electric field on the two sides of a discontinuity; the potential profile skew toward a small electric field, in magnitude, region due to the spatial variation of \( \Sigma P \) (see Figure 5 of Lyons [1980]). Therefore a smaller electric field within the sunward convection zone of plasma sheet will result in a larger area of potential difference in this region. The potential difference in the dayside LLBL has been reported ranging from 3 to 5 keV [Moxer, 1984; Happgood and Lockwood, 1993; Newell et al., 1991b]. With an average LLBL thickness of 0.34 \( R_E \) on the dusk flank [Eastman and Hones, 1979], the average magnitude of electric field is estimated to be \( \sim 0.15 \text{ keV/} R_E \) in the postnoon LLBL. This is 1 order of magnitude larger than the typical dawn-dusk electric field of \( \leq 1 \text{ keV/} R_E \) in the sunward convection plasma sheet.

5. 4. Conclusions

Simultaneous global UV imaging by the Polar satellite combined with DMSP in situ particle observations were used to determine the source regions of the postnoon auroral bright spots in the postnoon sector between 1300 and 1600 MLT. The magnetospheric source regions were determined according to the classification scheme developed in earlier research. We found that discrete arcs within the auroral oval could lie inside any of several source regions, including the plasma sheet, the LLBL, the plasma mantle and even polar rain. However, the typical situation, based on 65 events that span a time interval of \( \sim 1 \text{ year} \) (April 1996 to June 1997), strongly suggests that plasma sheet electron precipitation is the dominant source of the most intense postnoon auroral bright spots, at least in the 1300 - 1600 MLT sector.

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References


Lyons, L. R., Generation of large-scale regions of auroral currents, electric potentials, and precipitation by the divergence of the convection electric field, J. Geophys. Res., 85, 17-24, 1980.


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