JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 103, NO. A4, PAGES 6891–6897 APRIL 1, 1998

# Dayside auroral dynamics: South Pole - AMPTE/CCE observations

S. B. Mende

Space Sciences Laboratory, University of California, Berkeley

D. M. Klumpar and S. A. Fuselier

Lockheed Palo Alto Research Laboratories, Palo Alto, California

B. J. Anderson

Johns Hopkins University, Applied Physics Laboratory, Laurel, Maryland

**Abstract.** Coordinated observations were made between the South Pole Station 630-nm all-sky imager and the Active Magnetospheric Particle Tracer Explorer (AMPTE) CCE satellite when it was at 9 $R_E$ apogee in the midday sector in an effort to understand the variety of dynamical changes at the magnetopause that map to the dayside aurora. On June 18, 1988, three events were observed. The first, at 1150 MLT, was a local event showing a rotation of the magnetic field and the sudden appearance of low-energy electrons indicating the satellite entering the magnetosheath or low-altitude boundary layer. This event was preceded by a type of poleward expansion of the aurora which had been previously interpreted as a possible signature/footprint of a flux transfer event (FTE). Although the magnetic field signatures at the satellite are not characteristic of an FTE, the event could be a magnetic field change produced by an FTE, which after some delay propagated to the vicinity of the satellite. The foot of the field line containing the satellite was at some distance from the south pole meridian. The second event, starting at 1610 UT (1240 MLT), was a clear case of field erosion during which the satellite entered the magnetosheath characterized by a reduction in energetic electrons, an increase in soft electrons, and a decrease in the magnetic field strength accompanied by an equatorward motion of the aurora. The third event, in the afternoon at about 1900 UT (1530 MLT), showed similar changes in the electron fluxes and similar equatorward motion of the aurora. However, this event was associated with an increase in the magnetic field at the satellite. Such a field increase could be characteristic of a pressure pulse. However, there was a corresponding equatorward motion of the aurora, which suggests that the event was also a flux erosion event in which the fringing fields of the region 1 current system, which normally cause a field depression at the subsolar region, created an increase in the field at the CCE satellite near the late afternoon side. The latitudinal (equatorward) movements of the aurora for all three events were strongly correlated with the global *AE* index which was dominated by stations in the dawn/dusk sectors.

## 1. Introduction

The dayside magnetopause is an important location for particle energization and entry into the magnetosphere. The dayside magnetopause has been the subject of many studies of the plasma entry and energization processes. It has been suggested that merging at the low-latitude magnetopause during southward interplanetary magnetic field (IMF) conditions is the primary energy source for the dayside high-latitude ionosphere. This merging is expected to take place in a quasi-steady manner in order to maintain the magnetospheric convection flow [e.g., *Gosling et al.*, 1990; *Fuselier et al.*, 1991 ]. Impulsive reconnection of larger magnetic flux tubes, flux transfer events (FTEs), has also been observed at the low-latitude magnetopause. The magnetopause boundary position is also affected by variation of the solar wind pressure [e.g., *Sibeck et al.*, 1991].



Paper number 97JA03235.
0148-0227/98/97JA-03235 $09.00

The dayside magnetopause region maps down to the ionosphere as the dayside aurora. The dayside aurora has been studied because it is assumed to be a conveniently observable two-dimensional projection of the magnetopause region. Search for evidence for dynamic changes at the magnetopause that map to the atmosphere has centered on the footprints of FTEs [*Sandholt et al.*, 1986, 1990; *Rairden and Mende,* 1989]. FTEs occur during southward directed IMF, when patchy intermittent magnetic field line merging takes place. Although some possible ground-based signatures of FTEs have been found, there are still some problems with this interpretation [e.g., *Sibeck et al., 1989*]. In order to study the connection between the magnetopause and the corresponding ionospheric region the obvious approach is to correlate observations of FTEs and other dynamic events at the magnetopause with ground observations of the auroral footprints.

In an effort to do this correlation, a type of auroral poleward expansion event was identified in the optical aurora as the possible footprint of an FTE. Examples of such events are shown in the form of stack plots of meridian scanning photometer data by *Sandholt et al.* [1986], *Sandholt et al.*

[1992], and *Sandholt et al.* [1994] and in the form of keograms by *Eather* [1985]. In such events the quiescent dayside auroral east-west arc suddenly widens and expands poleward. The part which had expanded poleward subsequently separates off and produces a separate poleward propagating auroral form. In the meridional (north-south) luminosity profiles or in the keograms this separation appears as the development of an intensity minimum between the peaks representing the old equatorward arc and the new poleward-displaced feature.

In this paper we present a case study that correlates such dayside auroral forms with spacecraft observations near the dayside magnetopause. The spacecraft data are from the Charge Composition Explorer (CCE) of the Active Magnetospheric Particle Tracer Explorer (AMPTE) program. Because of the orbital precession of CCE, the apogee of the satellite, located at about $L$=9.4 near the equator, drifted across the dayside magnetosphere during the austral winter of 1988. During this time the aurora was monitored at South Pole Station (geomagnetic latitude of 74.5) routinely by an all-sky imager operating in a narrow wavelength region at 630-nm. We examine a 6-hour period of these ground-based and spacecraft observations for large-scale dynamic processes.

## 2. Observations

An important difficulty in this correlative study is that the mapping of the magnetic field is not known precisely and one can only approximate the relative position of the foot of the field line threading the satellite. The dipole $L$ value corresponding to the satellite orbit apogee of 8.9 Re is equivalent to a magnetic latitude of 71°. Most models of the magnetosphere which include dayside field compression have the foot of the field line higher in latitude. The south pole camera observed 630-nm O I emission, which in the aurora is mainly created by electron impact on atomic oxygen. The excitation threshold is only about 1.9 eV, and for this reason the 630-nm emission is a sensitive measure of any form of electron heating or secondary electron production process such as low-energy electron precipitation. The emission lifetime is so long that the emission can originate only from the low-pressure high-altitude (200 km and above) range. In energetic precipitation events where the bulk of the emissions are produced at low altitude (<200 km), the relative intensity of this emission is low. In soft auroras frequently seen in the dayside where the emission region is at high altitude, the 630-nm emission is dominant. The all-sky field of view at South Pole in the 630-nm emission (emission height is 220 km or more) is more than +- 6 degrees, i.e., it covers a latitude range from about 69° to 81°, and we expect that the aurora seen by the ground-based instrument would include the latitude of the field line containing the satellite. In the longitudinal direction the extent of the all-sky image field is equivalent to 1.5-2 hours of local time at 75° latitude.

Data in this paper are from a 6-hour period from 1400 to 2000 UT (1030 to 1630 MLT, late morning to early afternoon, at South Pole on June 18, 1988. During this period the CCE satellite traversed from 1337 to 1535 LT (early afternoon) while staying at apogee approximately at 9 $R_E$ at equatorial latitudes. The CCE trajectory and the position of a nominal magnetopause are illustrated in Figure 1. For the purposes of this illustration the magnetopause was represented as a paraboloid of revolution with a subsolar standoff distance of 11 Re and flank distances of 14 Re. The broken lines represent South Pole meridian magnetic local times at corresponding UT times. It can be seen that the closest coordination between South Pole field of view and CCE occurs just before 2000 UT. (1630 MLT). Unfortunately, no IMF data were available for the entire period in this study. However, compression of the magnetopause inside the CCE orbit indicates that the polar caps were probably enlarged, suggesting that the IMF was southward for most of the period presented in this paper.

The all-sky imager at South Pole recorded a set of three images per minute, each with different exposure, to extend the dynamic range by exposure bracketing. The central meridian slice of each image was assembled into a time series image called a "keogram" [*Eather et al.*, 1976]. The keogram, produced from the medium exposure images for the 6-hour period discussed in this case study, is shown on Figure 2 at the top. In this keogram, although the vertical coordinate was marked in latitude for the 200-km emission height, they were plotted in zenith angles which were not linearized to a latitude grid. Magnetic midday at South Pole occurs at 1530 UT.

Corresponding CCE electron fluxes are plotted below the keogram in Figure 2. At the beginning of the period (1400

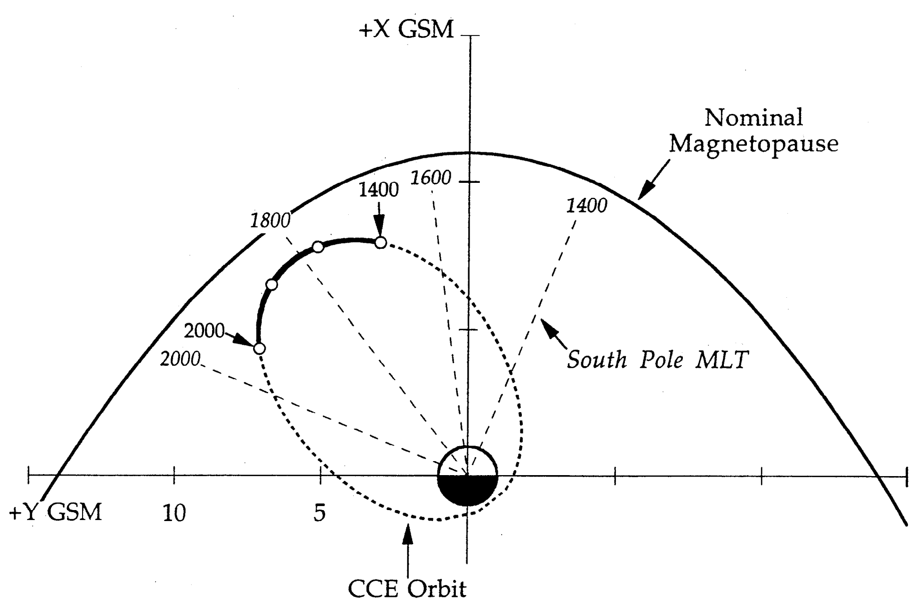


**Figure 1.** The position of CCE. The nominal magnetopause position and directions labeled "south pole MLT" represent the south pole magnetic meridian at different UT times.

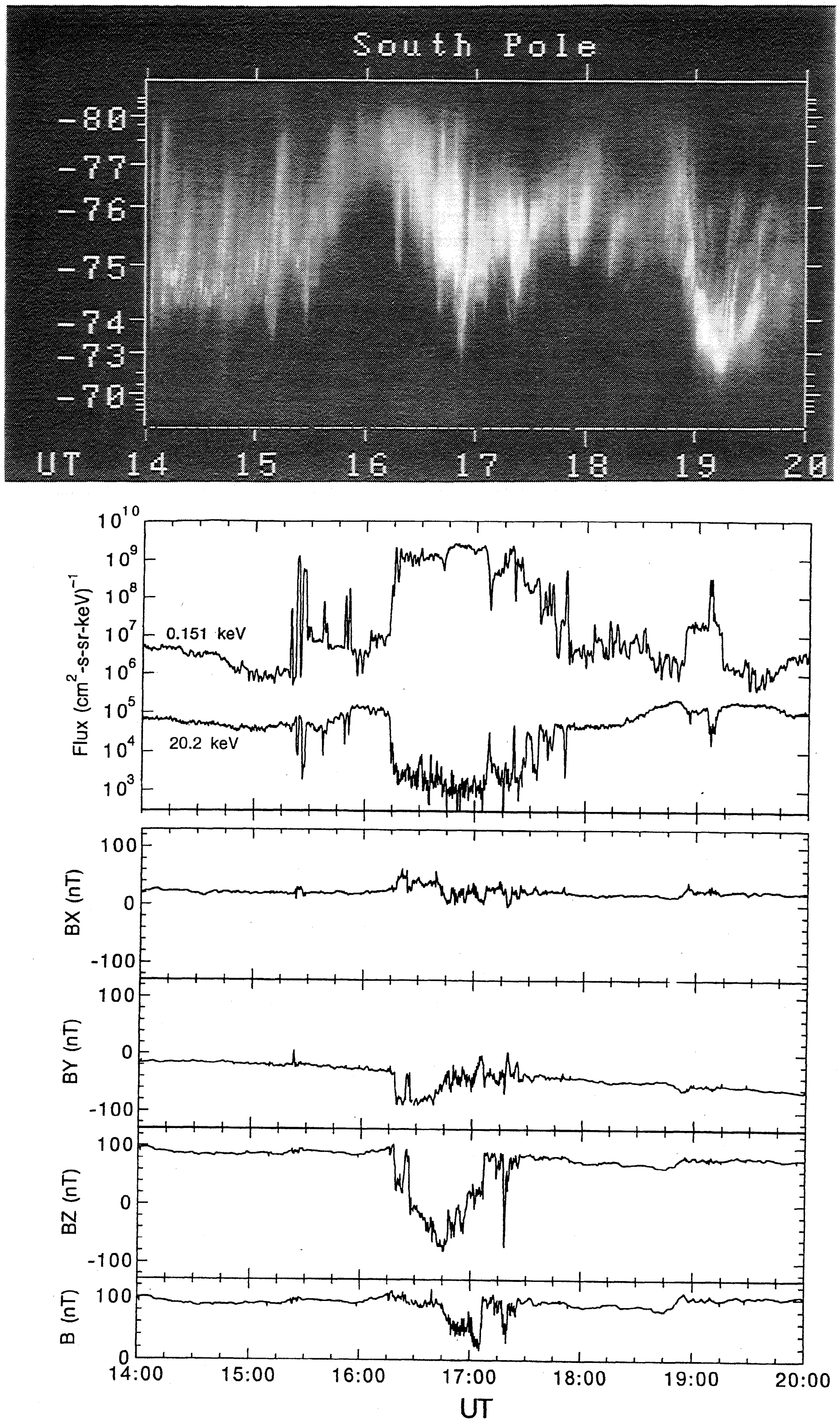


**Figure 2.** (top) Keogram intensity plot of central meridian slice of each medium exposure 630-nm image as a function of zenith angle (vertical scale is labeled as latitude for 200 km emission height) and UT time. Magnetic midday at South Pole is at 1530 UT. Underneath CCE electron fluxes are labeled as flux for the soft (0.161 keV) and hard (20.2 keV) detectors. The bottom four panels are the spacecraft magnetic field data vector components in and total field (nanoteslas).

UT) the satellite is within the magnetosphere. During this time, energetic magnetospheric electrons (lower trace) show high fluxes, and the upper trace representing low-energy or magnetosheath electrons show low fluxes, both characteristic of regions inside the magnetosphere. When the satellite enters the low-latitude boundary layer (LLBL)/magnetosheath, the low-energy electrons show a sudden increase such as at ~1615 UT. This increase occurs simultaneously with the dropout of the energetic magnetospheric electrons (lower trace). Later, the satellite returns to the magnetosphere between 1730 and 1800 UT in a more gradual fashion. Another LLBL/magnetosheath entry occurs at 1845 UT with a corresponding return at around 1910 UT. Both of these events were accompanied by an equatorward motion of the aurora at South Pole.

Perhaps the events can be best illustrated by looking at the CCE magnetometer data which are presented in Figure 2. A small transient signature in the $B_x$ and $B_y$ components is detected at 1522 UT. This event coincided with the spikes in the CCE electron data, signifying that a boundary was very close to the satellite, and the field movement caused the satellite to see a different population of electrons, a series of burst of magnetosheath-like fluxes. The magnetic field signature is not characteristic of an FTE because there is no increase in the total field, and there is no typical FTE bipolar signature. Nevertheless, it should be noted that just preceding this event the keogram shows a strong poleward expansion. Poleward expansions such as these have been identified as the possible signature of FTEs.

The timing of the poleward expansion event preceded the small fluctuation of the magnetic field at 1522 UT, showing either that the two occurrences are independent of each other or that the time taken by the propagation of the magnetic signature to the satellite was several minutes. We have presented the images in Figure 3 to demonstrate the morphology of the poleward expansion in the aurora. This type of poleward movement would look identical to the meridian scanning photometer data presented by *Sandholt et al.* [1986], *Sandholt et al.*, [1992], and *Sandholt et al.* [1994] and which they interpreted as the auroral signature of and FTE. Figure 3 is a collage of the four most representative all-sky images during the poleward expansion event of 1510-1520 UT. The arc thins at around 1448 UT (top left) and shows breakup-like activity (top right). A second east-west "arc-like" feature develops at 1513 UT (bottom left) which shows a clear separation as it moves poleward. (Poleward direction is toward the bottom right corner). By 1524 UT, (bottom right) the poleward feature disappears, and the arc more or less returns to a normal quiescent state.

The third event, occurring around 1850 UT, is interesting because it shows an increase in the magnetic field at the same time when the South Pole aurora shows a strong equatorward leap, and there is a corresponding increase in the in the low-energy particles. The increase in field strength suggests that the magnetopause was pushed in, causing the internal magnetic field to increase.

In Figure 4 we have reproduced the *AE* index plots for the time period presented for the data above. The *AE* index was inverted, with larger values plotted downward. The remarkable similarity of the *AE* index and the position of the dayside aurora and possible causes of this similarity was pointed out by *Eather et al.* [1979]. In this case the agreement between this plot and the keogram of Figure 2 is quite remarkable. The increase in the *AE* index at 1620 UT is virtually coincident with the beginning of the equatorward motion of the aurora. The *AE* index peaks at about 1650 UT, which is coincident with the time when the aurora reaches its most equatorward position. There is also a remarkable similarity between the shape of the *AE* enhancement from 1850 to 2000 and the inward excursion of the aurora during the same period.

To study the location of the ionospheric currents from which *AE* was derived for this period, we have examined the *AE*

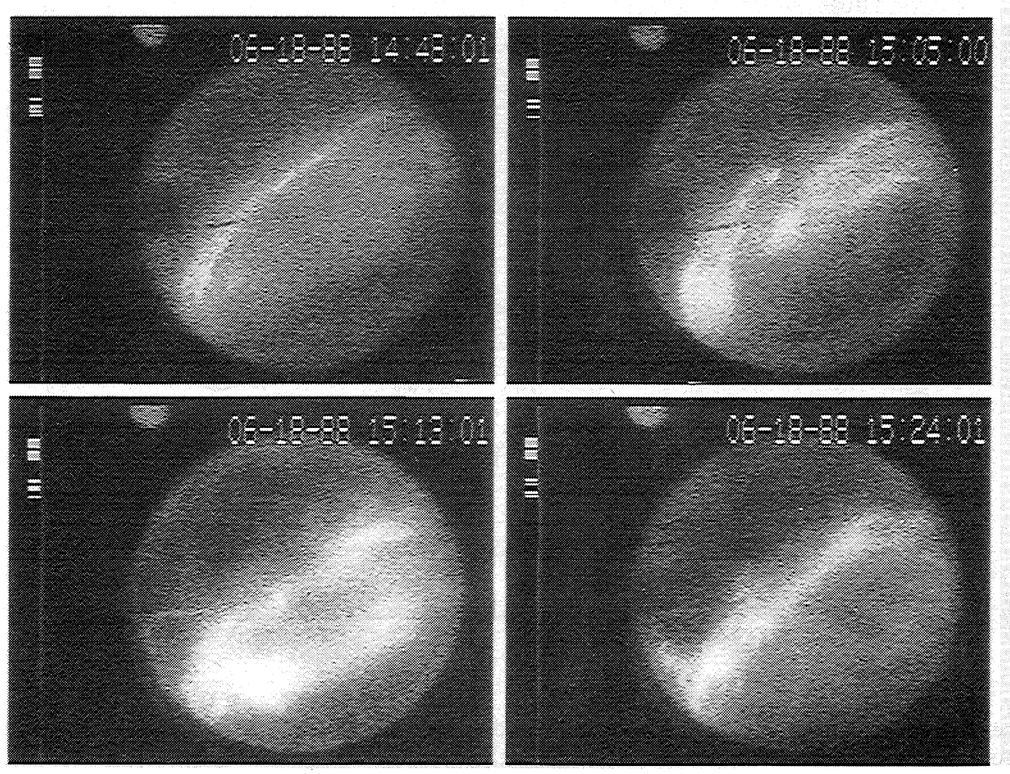


**Figure 3.** South pole all-sky images. The poleward direction is toward the bottom right corner of the images. East is top right, and west is bottom left.

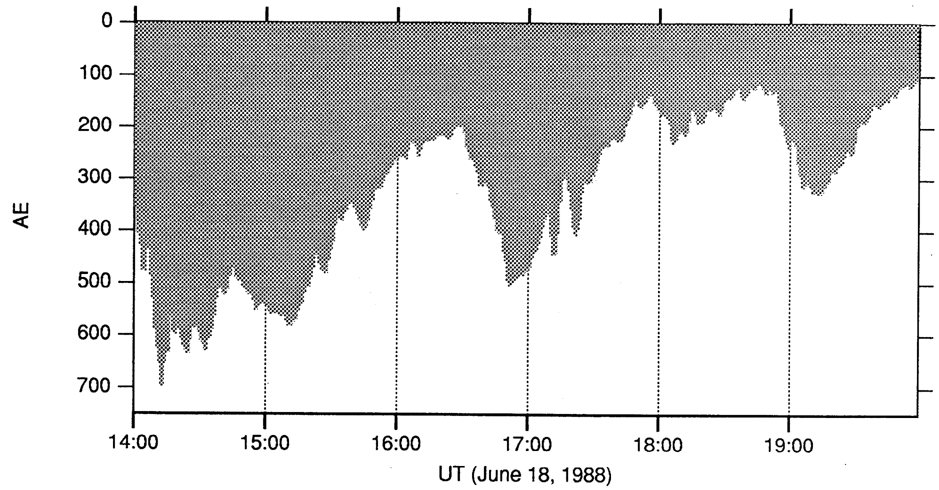


**Figure 4.** The *AE* index plotted vertically downward for the period shown in Figure 2.

data compilation and found that from 1530-1930 the *AU* was dominated by stations in the early dawn sector (MLT from 0300 to 0700) and by a midday station from 1930 UT on. The *AL* index was dominated by stations which were located in the late afternoon evening sector ( MLT from 1500 to 2100) except from about 1930 on when a midday station was dominant. During most of the period the *AE* indices showed such correlations, the dominant currents were flowing at dawn and dusk and not at midnight.

## 3. Discussion

We have looked at a single case of dayside auroral data at South Pole correlated with CCE electrons and magnetic field. The most interesting events are the large inward motions of the aurora accompanying the appearance of magnetosheath-like plasma at the satellites at 1615-1730 and 1845-1910 UT. The 1615-1730 UT event seems to be a classical field line erosion event. The aurora moves equatorward, signifying the motion of the boundary of closed and open field lines. During the event the boundary crosses the position of the CCE satellite, which is approximately stationary, and afterward the satellite is no longer in the magnetosphere, as shown by the decrease in the field and the change in the electron spectral signature.

It seems that with our coordinated data set it should be possible to distinguish between flux erosion and pressure pulses. We have illustrated the difference between the two mechanisms in Figure 5. The top portion represents the initial configuration in which the CCE satellite is on the auroral field line. The middle illustration represents the postcompression situation in which the auroral field line had been compressed but the foot of the field line remains unchanged, suggesting that changes should be observed in the satellite particle fluxes but not in the auroral position. The bottom illustration shows flux erosion when enhanced reconnection opens up more magnetic field lines. From the satellite's point of view the two events could be identical. However, in the case of erosion the aurora moves significantly equatorward because the auroral source was assumed to exhibit parallel motion with the last closed field line.

*Sandholt et al.* [1994] actually made a study of the position of the dayside aurora and the solar wind pressure for 10 hours. They found that there is a distinct dependence on solar wind pressure. The apparent disagreement with the above discussion can be resolved by suggesting that in their observations, which were performed during periods of negative $B_Z$, pressure increases enhanced erosion, which then moved the aurora equatorward. In our observations, there appears to be a distinct motion of the aurora at the 1615 UT event, and we assume that we were observing a clear erosion event at this time.

The last event, starting at around 1850 UT on June 18, shows an interesting inward motion of the aurora accompanied by a slight increase in the magnetic field. If the increased field were interpreted to represent a pressure pulse, then we would not expect to see the observed sudden motion of the aurora. The aurora seems to contradict our interpretation of the morphology represented in Figure 5. A possible explanation comes from *Sibeck* [1994]. He shows that the contribution of the magnetospheric currents depends very strongly on the local time position of the satellite near the magnetopause. During $B_Z$ negative periods when erosion occurs, the field decreases strongly near noon, but away from noon, in the morning and afternoon side, it actually increases. During our last event the local time at the satellite was 1516 UT, which is just at the point where an increase in negative $B_Z$ represents an increase in the field *SIbeck,* 1994, Figure 1. Accordingly, the third event starting at 1850 UT could also be interpreted as an erosion and that during the event the satellite was in the region where the field would have increased as the magnetosphere flared out on the flanks.

An earlier event, commencing at 1513 UT, is a poleward expansion event. Poleward expansion events of this type have been identified as the possible footprints of FTEs by *Sandholt et al.* [1985, 1990, 1992] and *Rairden and Mende* [1990]. *Sibeck et al.* [1989] have pointed out that there are some problems at times with such interpretations. The coordinated measurement of an FTE in space and its true "footprint" is rather problematic since the scarcity of dayside aurora and simultaneous satellite observations. As we have pointed out previously, the magnetic signatures at 1522 UT were not typical for an FTE. In addition, there is a 9-min time difference between the poleward expansion event at 1513 UT and the plasma and field event which occurred at about 1522 UT. At the time of the poleward expansion event the local time at South Pole was about 1146 MLT and 1400 MLT at the satellite (See Figure 1). Of course, it is possible that the poleward moving aurora and the brief appearance of magnetosheath plasma at the satellite 9-min later were unrelated events, however, if we assume that there was an event near noon which propagated directly along the 9-$R_E$ magnetopause boundary (30,000 km in 9-min) to the satellite, which was 2 hours of local time away. The delay would be consistent with a propagation speed of about 55 km/s. The Alfven speed is given by $B/(4 \pi n m)^{1/2}$, and

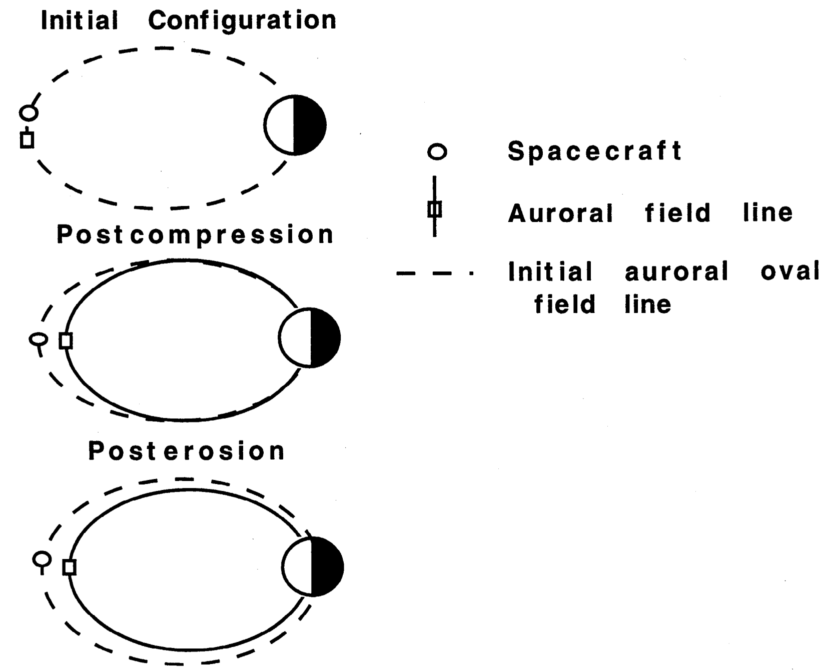


**Figure 5.** Illustration of pressure pulses versus field erosion.

if we assume a magnetic field strength of 10 nT and a cold plasma density of 2, we obtain an Alfven wave speed of 154 km/s. To reconcile the apparent discrepancy, we favor an alternative model in which the field signature could propagate through the ionosphere and then out along the field line. In this case the distance is about 80,000 km, giving a velocity of propagation of 140 km/s. In summary, it is possible that the auroral event was a footprint of an FTE which is nonlocal at the satellite. One interpretation of the appearance of the large flux of soft electrons at this time is that the magnetic field signature propagated up along the field line to the satellite and caused it to momentarily enter the magnetosheath region.

Another interesting feature of the data is the remarkable similarity between the position of the dayside aurora and the *AE* index during these erosions. The *AE* index is generated from a set magnetometer station data by superimposing the H traces and plotting the difference between minimum and maximum traces. The *AE* index is assumed to be dominated by the largest excursions, which usually occur on the nightside nearest to the location of the auroral electrojet which is the most active region during substorms. Thus the *AE* is regarded as a global indication of concurrent substorm activity. *Eather et al.* [1979] have attributed the correlation between *AE* and the position of the dayside oval to the fact that an enlargement of the polar cap must produce increased magnetopause currents encircling the tail lobes. The topology of the magnetosphere is such that some of the closure return path of these magnetopause currents is the region-1 current system which closes by currents flowing from dawn to dusk through the dayside and nightside polar cap. *Eather et al.* [1979] argued from the principle of the continuity of magnetic flux that the increased size of the polar cap represents larger tail lobe flux and necessitates an increase of either the size of the tail lobes or the current density around the tail lobes. In either case, current continuity demands that the return currents of the tail lobe boundary current through the polar cap increase, including the nightside ionospheric current. Since the equatorward motion of the dayside aurora and the dayside cusp represents the erosion of the dipolar closed flux, some additional southward magnetic component needs to be present at the subsolar point. The detailed morphology of the current loop and how it can produce a field reduction at the subsolar point was left open. *Sibeck* [1994] found that in a case when the IMF was strongly southward, the fringing field for the region-1 field-aligned currents was consistent with the field depression required to account for the depressed field on the dayside magnetopause. *Tsyganenko and Sibeck* [1994] used field modeling to show that the erosion is consistent with the region-1 Birkeland current enhancements.

*Eather et al.* [1979] assumed that the *AE* index represented substorm currents which intensify and, that in the nightside ionosphere the field-aligned currents close via a westward electrojet [*McPherron et al.*, 1973]. To explain the good correlation between the cusp latitude and *AE* they argued that an increase in this return current loop, part of which is the substorm current wedge, is coincident with the increase of the polar cap magnetic flux, and hence the observed equatorward motion of the cusp. This apparent connectivity between nightside substorms and dayside magnetopause motion remained an open issue. From statistical average data of the distribution of Birkeland currents and those of the discrete auroras accompanying field aligned currents, *Friis-Christensen and Lassen* [1991] showed that there are two distinct region-1 current systems, namely, the region-1a dayside and 1b nightside system. They considered the two to be relatively independent of each other, for example, each reacting differently to interplanetary field conditions. This prompted us to examine the origin of the *AE* indices for the cases under discussion in this paper, and we found that in all the cases when good correlation between *AE* and the dayside auroral latitude was seen, *AE* was dominated by magnetic stations located in the dusk and dawn sectors. This finding indicates that in our case the current system associated with *AE* was produced by the dayside region-1a current system and not the nightside substorm-related 1b system. This finding is consistent with the notion that the dayside field erosion creates increased dawn-dusk ionospheric currents which are the return flow of the increased polar cap magnetopause currents [*Eather et al.* 1979], however, only through the 1a dayside field-aligned current system. Accordingly, it is possible to explain the frequently observed close connectivity between the *AE* and the dayside cusp motion without finding a link to substorm activity.

## 4. Conclusions

On June 18, 1988, when the AMPTE/CCE satellite was in the midday sector at 9 $R_E$ apogee and the South Pole Station 630-nm all-sky imager was observing the midday aurora, three events were observed. The most significant event, starting at 1610 UT (1240 MLT at South Pole), was a clear case of field erosion during which the satellite entered the LLBL/magnetosheath region characterized by a reduction in energetic electrons, an increase in soft electrons, and a decrease in the magnetic field accompanied by equatorward motion of the aurora. This event at was preceded by an event at 1520 UT (1150 MLT at South Pole) showing a rotation of the magnetic field and the brief appearance of low energy electrons indicating the satellite entering the magnetosheath or LLBL region. The significance of this event was that it was preceded by a poleward expansion of the aurora which had been previously interpreted as a possible signature/footprint of a flux transfer event. Although in this case the magnetic field signatures were not characteristic of an FTE localized at the satellite, the event could have been magnetic field change produced by a nonlocal FTE, which after some delay propagated to the vicinity of the satellite. It is impossible to resolve from the data that the two observations, the ground-based FTE signature and the changes observed in the satellite plasma and field measurements, were related, especially since at this time the foot of the field line containing the satellite was at some distance from the south pole meridian. A third event, in the afternoon at about 1900 UT (1530 MLT), showed equatorward auroral motion and similar changes in the electron flux characteristic of LLBL/magnetosheath entry except that there was an increase in the field at CCE. The observations are consistent with a flux erosion event in which the fringing fields of the region-1 current system, which normally cause a field depression at the subsolar region at local noon, created an increase in the field near the late afternoon side. The equatorward movements of the aurora were strongly correlated with the global *AE* which was dominated by dawn-dusk stations, consistent with the concept that the ionospheric currents were flowing in the dawn-dusk region to produce the return currents necessary to permit the field configuration changes in the dayside magnetosphere. This correlation of the equatorward movement of the aurora with the *AE* index did not imply strong coupling between the dayside and night side.

**Acknowledgments.** The authors are grateful to all persons who assisted in performing the work supporting the Antarctic Auroral Imaging program. Special mention should be made of Dr. Jack Doolittle who made many trips to South Pole and made all the field installations. Helpful discussions with Dr. D. G. Sibeck are gratefully acknowledged. This work was funded by the National Science Foundation under Grant Numbers DPP-9616809 and ATM-9531695.

The Editor thanks P. C. Anderson and M. E. Greenspan for their assistance in evaluating this paper.

## References

Eather, R. H., Polar cusp dynamics., *J. Geophys. Res., 90*, 1569-1576, 1985.

Eather R. H., S. B. Mende, and R. J. R. Judge, Plasma injection at synchronous orbit and spatial temporal auroral morphology, *J. Geophys. Res., 81*, 2805-2824, 1976.

Eather, R.H., S. B. Mende, and E.J. Weber, Dayside aurora and relevance to substorm current systems and dayside merging, *J. Geophys. Res., 84*, 3339, 1979.

Friis-Christensen, E., and K. Lassen, Large scale distribution of discrete auroras and field aligned currents, in *Auroral Physics*, pp. 369-381, Cambridge Univ. Press, New York, 1991.

Fuselier, S. A., D. M. Klumpar, and E. G. Shelley, Ion reflection and transmission during reconnection at the Earth's subsolar magnetopause, *Geophys. Res. Lett., 18*, 139-142, 1991.

Gosling, J. T., M. F. Thomsen, s. J. Bame, R. C. Elphic, and C. T. Russell, Cold ion beams in the low-latitude boundary layer during accelerated flow events, *Geophys. Res. Lett., 17*, 2245-2248, 1990.

McPherron, R. L., C. T. Russell, and M. P. Aubry, Satellite studies of magnetospheric substorms on August 15, 1968, *J. Geophys. Res., 78*, 3131-3149, 1973.

Rairden, R. L., and S. B. Mende, Properties of 6300-A emissions at South Pole, *J. Geophys. Res., 94*, 1402-1416, 1989.

Sandholt, P. E., A. Egeland, J. A. Holtet, B. Lybekk, K. Svenes, and S. Asheim, Large- and small-scale dynamics of the polar cusp,. *J. Geophys. Res., 90,* 4407-4414, 1985.

Sandholt, P. E., C. S. Deehr, A. Egeland, B. Lybekk, R. Viereck, and G. J. Romick, Signatures in the dayside aurora of plasma transfer from the magnetosheath, *J. Geophys. Res., 91,* 10,063-10,079, 1986.

Sandholt, P. E., IMF control of the polar cusp and cleft auroras, *Adv. Space Res., 8(9)*, 21, 1988.

Sandholt, P. E. M. Lockwood, T. Oguti, S. W. H. Cowley, K. S. C. Freeman, B. Lybekk, A. Egeland, and D. M. Willis, Midday auroral break up events and related energy and momentum transfer from the magnetosheath, *J. Geophys, Res., 95*, 1039-1060, 1990.

Sandholt, P. E., J. Moen, and D. Opsvik, Periodic auroral events at the midday polar cap boundary: implications for solar wind magnetospheric coupling, *Geophys. Res. Lett., 19,* 1223-1226, 1992.

Sandholt P. E., et. al., Cusp/cleft auroral activity in relation to solar wind dynamic pressure, interplanetary magnetic field $B_Z$ and $B_Y$. *J. Geophys. Res., 99*, 17,323-17,342, 1994.

Sibeck, D. G., Transient magnetic field signatures at high latitudes, *J. Geophys. Res., 98*, 243-256, 1993.

Sibeck, D. G., Signatures of flux erosion from the dayside magnetosphere, *J. Geophys. Res., 99*, 8513-8529, 1994.

Sibeck, D. G., and D. J. Crowley, Solar wind dynamic pressure variations and possible signatures of flux transfer events, *J. Geophys. Res., 96*, 1669-1983, 1991.

Sibeck, D. G., R. E. Lopez, and E. C. Roelof, Solar wind control of the magnetopause shape, location and motion, *J. Geophys. Res.*, 5489-5495, 1991.

Sibeck, D. G., et al., The magnetopause response to 8-minute period strong-amplitude upstream pressure variations, *J. Geophys. Res.*, 2505-2519, 1989.

Tsyganenko, N. A., and D. G. Sibeck, Concerning flux erosion from the dayside magnetosphere, *J. Geophys. Res., 99*, 13,425-13,436, 1994.

B. J. Anderson, Applied Physics Laboratory, John Hopkins University, John Hopkins Rd., Laurel, MD 20723-6099. (e-mail: brian_anderson@spacemail.jhuapl.edu)

S. A. Fuselier and D. M. Klumpar, Lockheed Martin Advanced Technology Center, 3176 Porter Dr., Building 252, Org. H1-12. (e-mail: fuselier@lockhd.span.nasa.gov and klump@lockhd.space.lockheed.com)

S. B. Mende, Space Sciences Laboratory, University of California, Berkeley, CA 94720 . (e-mail:mende@ssl.berkeley.edu)\

(Received June 19, 1997; revised October 15, 1997; accepted October 20, 1997.)