GEOPHYSICAL RESEARCH LETTERS, VOL. 23, NO. 14, PAGES 1725-1728, JULY 1, 1996

Auroral signature of lobe reconnection

P. E. Sandholt[1], C. J. Farrugia[2], M. Øieroset [1], P. Stauning[3] and S. W. H. Cowley[4]

Abstract. We report specific changes in the dayside auroral morphology in the winter hemisphere which occur in response to sharp transitions between northward and southward – directed interplanetary magnetic fields (IMF). In two case examples we show how a switch between large negative and large positive IMF B_Z component was accompanied by a corresponding switch in the location of the 630.0 nm aurora: the cusp aurora situated at ≈ 74° MLAT disappeared and another form this time situated at ≈ 77 – 78° MLAT appeared simultaneously (within 1 min.). We suggest that the lower- and higher-latitude auroras correspond to injections of magnetosheath plasma associated with, respectively, magnetic reconnection at low and high magnetopause latitudes. They may be called cusp/LLBL and cusp/mantle auroras, respectively. According to this interpretation the cusp/mantle aurora thus corresponds to reconnection tailward of the cusp, the so-called lobe reconnection. The auroral signature is observed to last for a few tens of minutes, indicating that lobe reconnection can occur in a quasi-steady mode. During the 17 December 1992 case event sunward plasma convection in the polar cap was inferred from magnetometer records obtained during the period when the high-latitude aurora occurred.

Introduction

It is believed that reconnection between the geomagnetic and interplanetary magnetic fields (IMF) can occur in two major modes corresponding, roughly, to southward- and northward-pointing IMF, respectively. In the latter case, depicted in Figure 1 reconnection occurs at high latitudes between the IMF and geomagnetic field lines tailward of the cusp (so called „lobe reconnection").

This paper focuses on the auroral signature of this mode.

Models of lobe reconnection have been discussed among others, by Dungey (1963), Russell (1972), Maezawa - (1976), Mc Diarmid et al. (1980), Crooker (1979), Cowley (1982), Reiff and Burch (1985) and Crooker (1988).

Experimental evidence for the occurrence of lobe reconnection has been obtained from (a) in situ spacecraft data during magnetopause crossings at high latitudes (Gosling et al., 1991), (b) polar cap convection patterns (e.g. Maezawa, 1976; Coley et al., 1987, Knipp et al., 1991; Freeman et al., 1993, Lu private communication., 1994) and (c) particle precipitation (Basinska et al., 1992; Woch and Lundin, 1992). The in situ spacecraft data show evidence of sunward directed, accelerated plasma flows satisfying the stress balance relation appropriate to a rotational discontinuity.

The convection signature consists of sunward flow on open field lines in the polar cap, giving rise to the so-called „lobe cell convection" which is entirely confined to the polar cap (Reiff and Burch, 1985, Freeman et al., 1993). According to one model, this is a summer hemisphere phenomenon (Crooker, 1992; Crooker and Rich, 1993). The particle signature is characterized by accelerated sheath ions whose energy increases with latitude (reversed energy dispersion) and which are located at the poleward edge of the cusp (Basinska et al., 1992; Woch and Lundin, 1992). The reversed energy dispersion is consistent with sunward convection.

Murphree et al. (1990) reported discrete auroral forms at high northern latitudes occuring predominantly during posi-

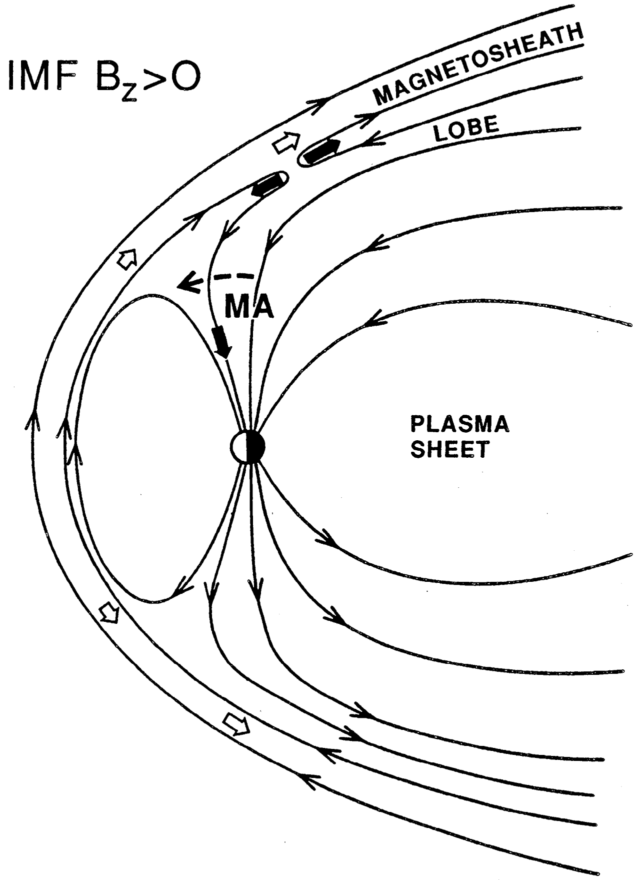

Figure 1. Reconnection geometry for positive IMF B_Z (after Gosling et al., 1991) and related plasma flow and particle precipitation in the cusp/mantle (MA) region. The corresponding auroral form is marked by label 2 in figures 2 and 3. Dashed arrow mark the direction of plasma flow.

---

[1] Department of Physics, University of Oslo, Norway
[2] Department of Mathematics, Science and Technical Education, University of Malta, Msida, Malta
[3] Danish Meteorological Institute, DK-2100 Copenhagen, Denmark
[4] Blackett Laboratory, Imperial College, London

Paper number 96GL01846
0094-8534/96/96GL-01846$05.00

tive IMF B_Z and negative B_X conditions, based on VIKING UV imagery. They suggested that merging (reconnection) on the front surface of the magnetotail is involved in producing these emissions.

The latter observations are recorded by satellites in polar orbit, so that a separation of spatial and temporal scale is generally not possible. This means that the temporal scale of the plasma entry processes cannot be inferred from the satellite observations. Thus, an important outstanding question is whether the plasma injection from the magnetosheath during lobe reconnection is quasi-steady or transient.

In the present work we shall be able to address this question on the basis of continuous observations from the ground of the 630.0 nm aurora, which is very sensitive to the precipitation of low-energy electrons of magnetosheath origin. Thus, these observations represent an extension towards lower energies ($<$ 1 keV) of previous UV observations of similar auroral precipitation. The auroral observations we present in two case studies show the appearance (fading) of 630.0 nm midday aurora at high latitude ($\approx 77-78°$ MLAT) and near-simultaneous fading (appearance) of a lower-latitude ($\approx 74°$-MLAT) aurora when the polarity of the IMF B_Z component changes abruptly from negative (positive) to positive (negative). We interpret the transition from one auroral form to another as a clear signature of a change of the site of plasma injection from the magnetosheath towards higher (lower) magnetopause latitude (cf. Onsager et al.,1993). This is a type of cusp auroral dynamics which is different from the cusp movements which have been documented in previous studies (e.g. Eather et al., 1979; Sandholt et al., 1994). By tracing the particles from low altitude back to the magnetopause Onsager et al. demonstrated the relationship between the latitude of the injection site at the magnetopause and the latitude of low-altitude particle precipitation for negative B_Z-conditions. Our interpretation of the positive B_Z aurora in terms of lobe reconnection is supported by the simultaneous occurrence of sunward (reverse) polar cap convection, as inferred from ground magnetograms.

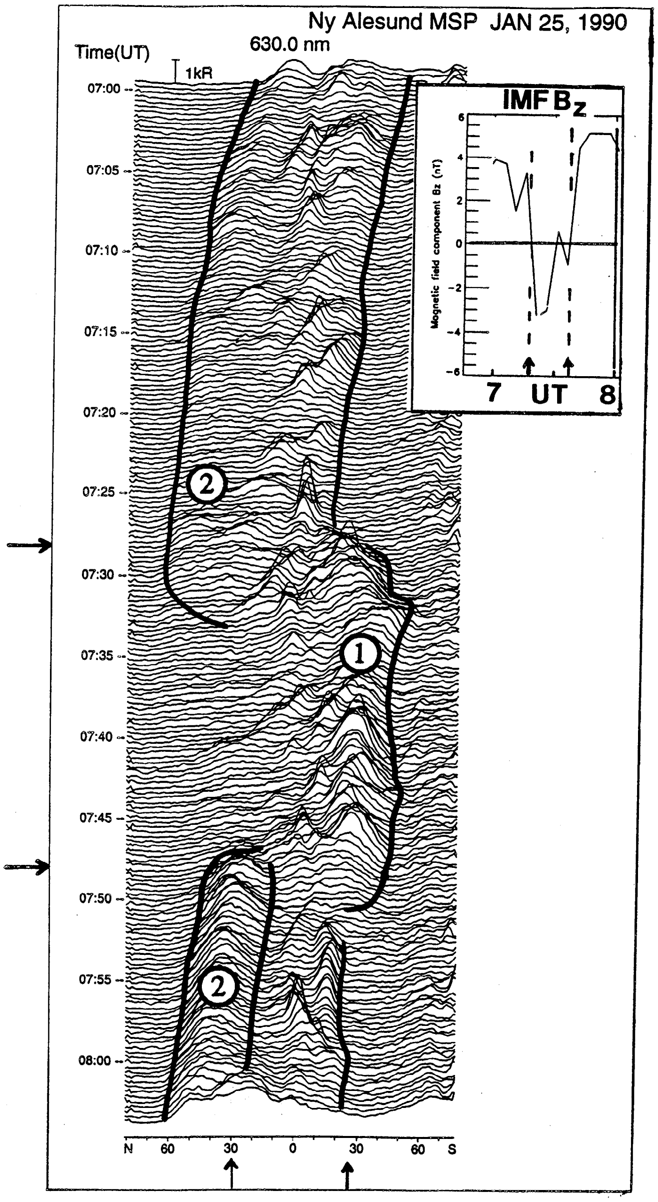

Figure 2. Meridian scanning photometer observations of line-of-sight auroral intensities at 630.0 versus zenith angle. Two auroral forms are marked with labels. Arrows along the vertical axis mark the appearence and fading of the cusp/LLBL aurora. Arrows along the horizontal axis mark the approximate latitudinal location of the two auroral forms, i.e. at ≈ 74 and $77°$ MLAT. The IMF B_Z component for 0700 – 0800 UT, January 25, 1990 is shown in insert.

Observations

January 25, 1990

Figure 2 shows meridian scanning photometer (MSP) observations from Ny Ålesund, Svalbard (75.5° MLAT) of auroral emissions at 630.0 nm for the 0700 – 0800 UT interval on Jan. 25, 1990. Line-of-sight intensities along the magnetic meridian are plotted as a function of zenith angle (latitude). North is to the left. Thick curves mark the poleward and equatorward boundary of the auroral luminosities. Arrows along the time axis mark important transitions of the location (zenith angle) of the major auroral form.

A clear feature in the data is seen during the $\approx$ 0730 - 0750 UT interval when the 630.0 nm auroral intensity maximized at $\approx 30°$ south of zenith (category 1 aurora). Before and after this interval a major form (category 2 aurora) was located to the north of zenith in Ny Ålesund, i.e. typically around 30° north. Assuming an emission altitude of 250 km, a typical value for the 630.0 nm emission in the cusp aurora, zenith-angles of $+30°$ and $-30°$ correspond to $\approx 77°$ and 74° MLAT, respectively. Thus an abrupt change of the location of maximum 630.0 nm intensity from ≈ 74 to $77°$ MLAT occurred at $\approx$ 0748 UT (cf. arrow along the horizontal axis). The onset of the high-latitude aurora (category 2) at 0748 UT is also seen in the green line (557.7 nm), at $\approx 40°$ north of zenith (not shown). The transition from category 1 to category 2 aurora took place within $\approx$ 1 min. (Figure 2).

From Figure 2 it is seen that the poleward edge of the high-latitude aurora migrated steadily northward. Furthermore, the poleward edge of the high-latitude aurora is much more pronounced after the transition at 0748 UT than before that at $\approx$ 0730 UT. This may be the signature of a sharp poleward boundary of the electron precipitation. The insert in Figure 2 shows the GSM Z-component of the IMF during the 0700–0800 UT interval, recorded by spacecraft IMP-8 located at $X_{SE} = 18.6, Y_{SE} = -32.4, Z_{SE} = 12.2\,R_E$.

Arrows along the time axis mark the major IMF B_Z changes at 0718 and 0738 UT, respectively. Evidently the two sudden changes of auroral location at ≈ 0730 and 0748 UT are associated with these IMF B_Z polarity shifts. That would imply that the time delay between IMF B_Z transition recorded by IMP-8 and the corresponding auroral response was 10–12 min. in the present case. This is a reasonable delay time given the IMP-8 position at this time. IMF B_X was mainly positive (3–4 nT) up to 0730 UT. And then it fluctuated around zero until 0820 UT. IMF B_Y was predominantly negative (0–÷6 nT), during the 07–08 UT interval.

December 17, 1992

Figure 3a shows Ny Ålesund photometer (MSP) observations at 630.0 nm for the 0700–0745 UT interval on December 17,1992. The period from 0700 to 0715 UT is characterized by a zone of weak (< 1 kR) emission located between zenith and 55° north of zenith, similar to the category 2 aurora seen on January 25, 1990, prior to ≈ 0730 UT. A new auroral form (category 1) appeared $\approx 30°$ south of zenith at 0715 UT. The category 2 aurora disappeared at ≈ 0720 UT, first in the eastern and subsequently in the western part of the field of view of the all-sky camera in Ny Ålesund. After this time the dominating emission was located south of zenith. This form first appeard in the eastern part of the field of view, near magnetic noon. The equatorward boundary of this luminosity (category 1), including poleward-moving auroral forms, are marked by thick curves in the figure. The category 1 aurora in this example is similar to the corresponding form discussed in the previous section, i.e. rather narrow, intense forms located $\approx 20-30°$ south of zenith, with some poleward-moving structures.

Figure 3b shows plots of equivalent convection for 0710 and 0720 UT on December 17,1992, obtained from magnetograms in Greenland, Scandinavia and Svalbard. The coordinate system is eccentric dipole time versus magnetic latitude. Each vector is obtained by rotating the horizontal magnetic perturbation vector by 90° in the counter-clockwise direction. Assuming the magnetic deflection is due to ionospheric Hall currents the equivalent convection vectors point in the direction of the $E \times B$-drift.

The upper panel shows sunward convection above 80° MLAT and in the prenoon sector, in the vicinity of the category 2 aurora (bar along the Ny Ålesund meridian). The lower panel of Figure 3b marks the location of the category 1 aurora (hatched area) where an enhenced, antisunward convection prevails.

IMF data are not available for this case.

Discussion and Conclusions

We have shown 2 categories of midday auroral forms which are separated in latitude by $\approx 2-3$ ° MLAT and which are associated, respectively, with intervals of (predominantly) southward and a northward pointing IMF. Transitions from one category to the other occur abruptly when the polarity of the IMF B_Z component changes.

The observations suggest that the jump in latitude of the auroral luminosity is a signature of a change in the latitude of the plasma injection site at the magnetopause (cf. Onsager et al., 1993). The category 1 and 2 auroras are assosiated respectively, with anti-sunward and sunward (reverse) convection in the dayside polar cap. From this information we conclude that the actual auroral forms are signatures of plasma entry via reconnection at low (sub-cusp) and at high latitudes (mantle/lobe), respectively (cf. Figure 1). Refering to the magnetic field configuration (midday cusp) and the plasma sources (LLBL and mantle) the two auroral forms may be called cusp/-LLBL and cusp/mantle, respectively. The two auroral forms then correspond to the two IMF B_Z-dependent modes of particle precipitation in the cusp region which were reported by e.g. Woch and Lundin (1992). The present ground-based optical observations add to the earlier reported evidence of an

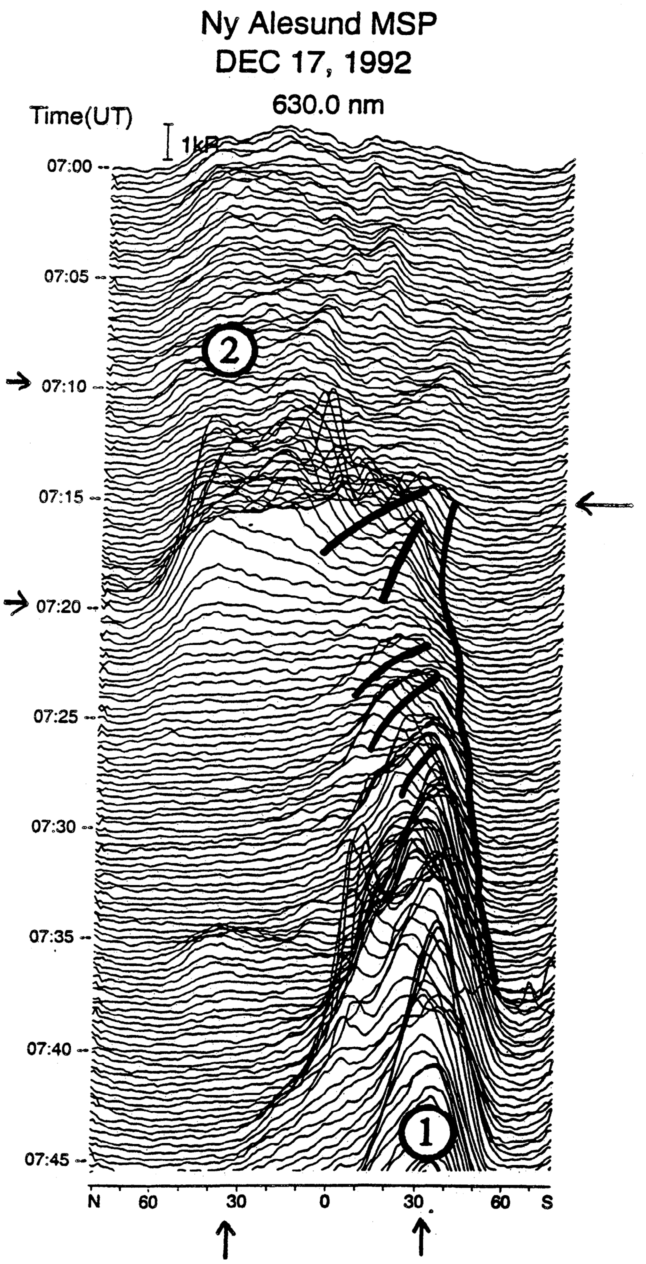

Figure 3a *Top:* Meridian scanning photometer observations at 630.0 nm for 0700–0745 UT on December 17, 1992.

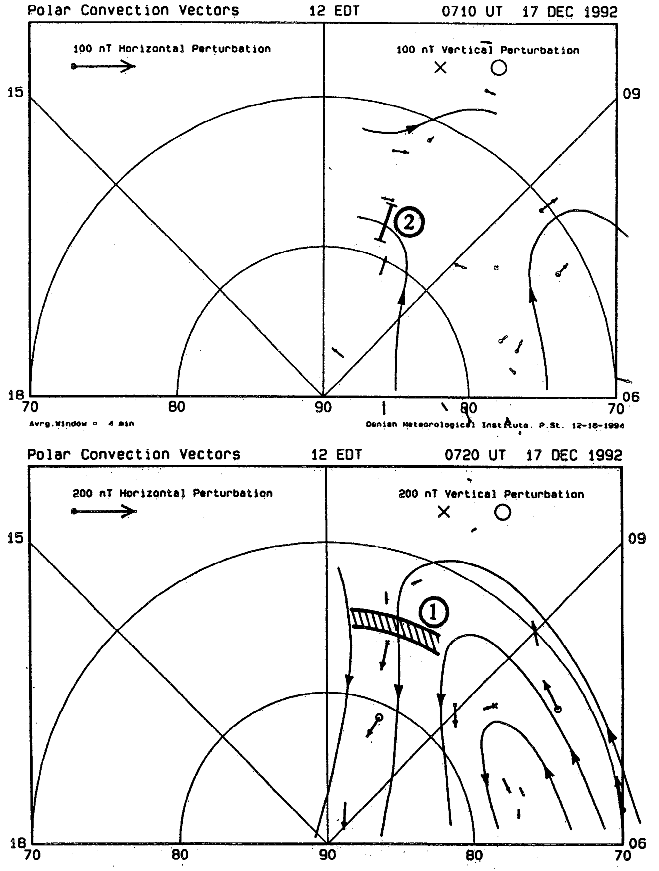

Figure 3b*Bottom*: Equivalent ionospheric convection for 0710 and 0720 UT obtained from ground magnetograms in Svalbard and Greenland. Two different auroral forms have been marked with labels.

auroral signature of lobe reconnection, which was based on UV observations (Murphree et al., 1990).

The auroral form which we interpret in terms of lobe reconnection (cusp/mantle aurora) is seen to last for several tens of minutes, i.e. it is quasi-steady. This indicates that lobe reconnection can occur as a quasi-steady process in the winter hemisphere.

Acknowledgments. IMP-8 solar wind magnetic field data used in this study were kindly provided by R. L. Lepping, Goddard Space Flight Center, Maryland. Thanks are due to Ole Rasmussen, DMI, as responsible for the operation of the Danish magnetic observatories on Greenland, to Børre Holmeslet, Auroral Observatory, Tromsø, for supplying the data from the north-Norwegian magnetometers and to C. R. Clauer for the supply of data from the MAGIC stations on the Greenland icecap. Support for the MAGIC data acquisition has been provided by NSF grant ATM-9106958.

References

Basinska, E. M. et al., Small-scale electrodynamics of the cusp with northward interplanetary magnetic field, *J. Geophys. Res.*, *97*,6369, 1992.

Burch, J. L. et al., Cusp region particle precipitation and ion convection for northward interplanetary magnetic field, *Geophys. Res. Lett.*, *7*,393, 1980.

Coley, W. R. et al., Ionospheric convection signatures and magnetic field topology, *J. Geophys. Res.*, *92*,12352, 1987.

Cowley, S. W. H., Magnetospheric and ionospheric flow and the interplanetary magnetic field, in *The Physical Basic of the Ionosphere in the Solar-Terrestrial System*, AGARD CP295, pages 4-1 – 4-14, Neuilly sur Seine, France, 1982.

Crooker, N. U., Dayside merging and cusp geometry, *J. Geophys. Res.*, *84*,951, 1979.

Crooker, N. U., Mapping the merging potential from the magnetopause to the ionosphere through the dayside cusp, *J. Geophys. Res.*, *93*,7338, 1988.

Crooker, N. U., Reverse convection, *J. Geophys. Res.*, *97*,19363, 1992.

Crooker, N. U. and Rich, F. J, Lobe cell convection as a summer phenomenon, *J. Geophys. Res.*, *98*,13403, 1993.

Dungey, J. W., The structure of the ionosphere, or adventures in velocity space, in *Geophysics: The Earth's Environment*, edited by C. DeWitt, J. Hiebolt, and A. Lebeau, pages 526–536, Gordon and Breach, New York, USA, 1963.

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.

Freeman, M. P. et al., The interaction of a magnetic cloud with the earth: Ionospheric convection in the nothern and southern hemispheres for a wide range of quasi-steady interplanetary magnetic field conditions, *J. Geophys. Res.*, *98*,7633, 1993.

Gosling, J.T. et al., Observations of reconnection of interplanetary and lobe magnetic field lines at the high-latitude magnetopause, *J. Geophys. Res.*, *96*,14097, 1991.

Knipp, D. J. et al., Ionospheric convection response to changing IMF direction, *Geophys. Res. Lett.*, *18*,721, 1991.

Maezawa, K., Magnetospheric convection induced by the positive and negative Z components of the interplanetary magnetic field: Quantitative analysis using polar cap magnetic records, *J. Geophys. Res.*, *81*,2289, 1976.

McDiarmid, I. B. et al., Comparison of magnetic field perturbations and solar electron profiles in the polar cap, *J. Geophys. Res.*, *85*,1163, 1980.

Murphree, J. S. et al., Large-scale high-latitude dayside auroral emissions, *J. Geophys. Res.*, *95*,2345, 1990.

Onsager, T. G. et al., Model of magnetosheath plasma in the magnetosphere: cusp and mantle particles at low-altitudes., *Geophys. Res. Lett.*, *20*,479, 1993.

P. H. Reiff and J. L. Burch, B_Y-dependent dayside plasma flow and Birkeland currents in the dayside magnetosphere, 2, a global model for northward and southward IMF, *J. Geophys. Res.*, *90*,1595, 1985.

Russell, C. T., The configuration of the magnetosphere. in *Critical Problems of Magnetospheric Physics*, edited by E. R. Dyer, pages 1 – 16, National Academy of Sciences, Washington, D.C., 1972.

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*,17323, 1994.

Woch, J. and R. Lundin, Magnetosheath plasma precipitation in the polar cusp and its control by the interplanetary magnetic field, *J. Geophys. Res.*, *97*,1421, 1992.

S. W. H. Cowley, Blackett Laboratory, Imperial College, London

C. J. Farrugia, Department of Mathematics, Science and Technical Education, University of Malta, Msida, Malta

P. S. Sandholt and M. Øieroset, Department of Physics, University of Oslo, Norway

P. Stauning, Danish Meteorological Institute, DK-2100 Copenhagen, Denmark

(received October 4, 1995; revised December 29, 1995; accepted January 23, 1996.)