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Dayside optical and magnetic correlation events

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Abstract. Sudden, short-lived dayside auroral activity is often observed equatorward of the quiescent auroral oval. Several cases from the 1996 South Pole and United States Automatic Geophysical Observatory data were examined. In all cases the optical events were accompanied by well-correlated magnetic impulsive events. Most optical auroral activity was primarily in 630-nm emission (soft electron precipitation presumably of plasma sheet or magnetosheath origin). Most optical events also show the presence of much shorter lived 427.8-nm emission (harder electron precipitation with associated electron acceleration). In almost all events the keograms showed repeated poleward propagation, indicating that the event started at lower latitudes and propagated to higher latitudes. The optical emissions showed distinct periodicities, which usually correlated well with the magnetic signature. All the events began equatorward of the preexisting quiescent aurora, indicating that they initiated in the region of closed field lines. The interplanetary magnetic field B_z component prior to the events was either small or positive in most cases. The majority of the observed events were consistent with being triggered by interplanetary B_z or solar wind pressure change. For some events, no specific trigger was found.

1. Introduction

Sudden, short-lived dayside auroral activity on the equatorward side of the quiescent auroral oval was reported by *Mende et al.* [1990]. They examined 630-nm all-sky images taken at South Pole Station and found that usually prior to such activity the quiescent auroral oval is located poleward of South Pole Station (74 degrees invariant latitude). The activity starts with the sudden appearance of optical aurora at lower latitudes, at the zenith, or even south of the zenith, of South Pole Station. The event generally lasts no more than a few minutes. After a few minutes of auroral display at the lower-latitude region the aurora generally retreats poleward, back to the position of the original quiescent auroral oval. This type of auroral activity is always accompanied by magnetic signatures in the form of Pc5 pulsations, magnetic impulse events (MIEs), or traveling convection vortices (TCVs).

Short-lived (few minute) MIEs have been observed at high-latitude ground-based magnetic observatories on the dayside, and much controversy still surrounds the nature of these events. MIEs, as originally defined by *Lanzerotti et al.* [1986] and *Glassmeier et al.* [1989], are characterized by a single bipolar pulsation in the north-south (H) component of the magnetic field accompanied by similar pulsation in the east-west component but in quadrature. Such signatures would be expected from ionospheric Hall currents, which are linked by field-aligned currents to the magnetosphere.

At one time it was thought that these events were a manifestation of the sudden impulsive reconnection, or so-called flux transfer events (FTEs) occurring on the dayside [*Goertz et al.*, 1985; *Todd et al.*, 1986; *Lanzerotti et al.*, 1986, 1987]. The measurements were in agreement with theoretical work proposed by *Saunders et al.* [1984], *Southwood and Hughes* [1985], and *Lee* [1986]. These theoretical models predicted that MIEs were poleward moving convective systems originating from reconnection sites which were generally on field lines mapping to sites equatorward of the station.

Friis-Christensen et al. [1988] reported that their identified MIE events were consistent with ionospheric current structures moving east-west above a chain of ground magnetometers. Since the near-Earth magnetic medium is incompressible, the field perturbations have to be rotational, or vortex like, and the TCVs were assumed to propagate with relatively small change in morphology. Many authors have believed that TCV events are a subclass of MIEs: *Friis-Christensen et al.* [1988] challenged the notion that these events are ground signatures of sudden impulsive reconnection and opened the door for other possible causes. *Sibeck et al.* [1989], *Potemra et al.* [1989], *Farrugia et al.* [1989], and *Sibeck and Croley* [1991] showed that solar wind pressure variations might play an important role in the production of MIEs as defined in their work. In summary, the linkage between MIEs and the externally imposed conditions by the interplanetary magnetic field (IMF) and/or

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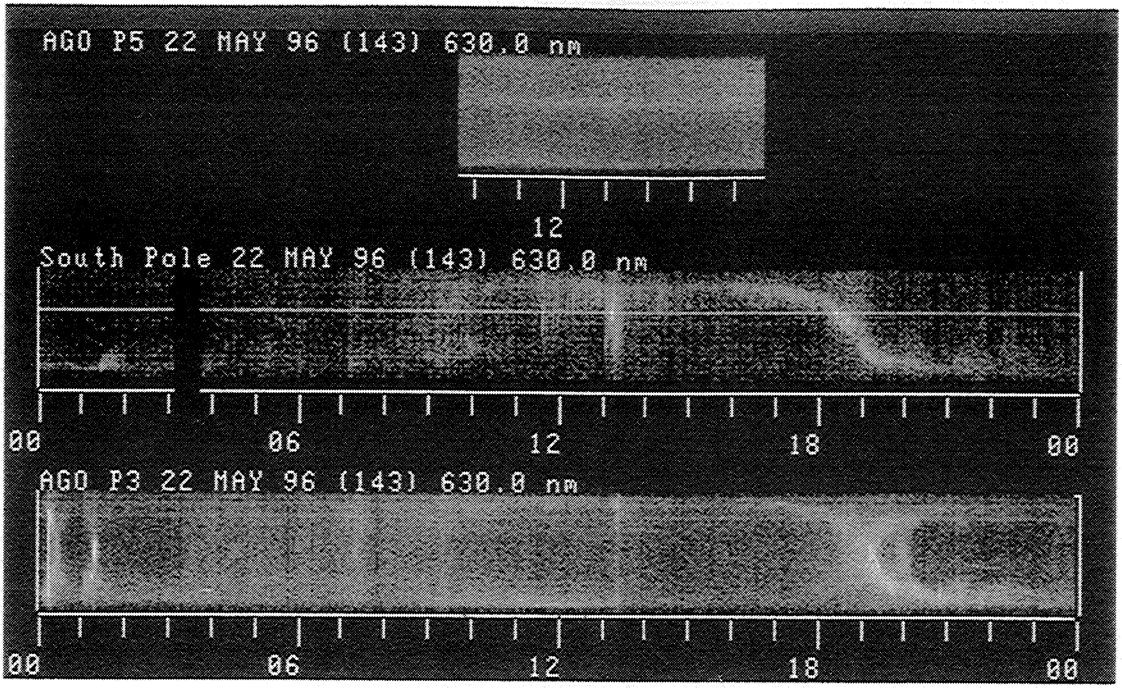

Figure 1. Example of a 24-hour stack plot keogram for May 22, 1996. The vertical scale is linear in zenith angle. South Pole (middle plot) covers 69.5 to 79.5 degrees latitude in the 630-nm emission. Top plot is AGO P5, 91 to 81 degrees latitude coverage. The bottom plot is AGO P3, covering from 67 degrees magnetic to about 76.

solar wind pressure conditions are not well understood [e.g., *Sitar et al.*, 1996].

As noted, *Mende et al.* [1990] found that prior to the MIE event the auroral situation is generally quiet with the auroral oval located poleward of the latitude of South Pole Station (invariant latitude (ILAT) =74°). The optical aurora representing the location of the MIE event located equatorward of the auroral oval would appear to be in conflict with an earlier FTE-related theoretical model, because the model represents a quasi-stationary field-aligned current structure moving antisunward (poleward). This suggests that MIE events propagate poleward from merging regions located equatorward of the observer. *Mende et al.* [1990] interpreted the appearance of optical aurora at lower latitudes as equivalent to a sudden equatorward leap of the low-latitude auroral boundary or the boundary of dipole-like and merged field lines. Thus they associated these optical events and their MIEs with the actual sporadic reconnection site. They proposed that the temporary equatorward movement of the equatorward boundary of the auroral oval represented the appearance of a merged flux region and that the size of the region filled by the aurora becomes a merged flux bundle. Subsequent to the cessation of the auroral activity equatorward of the auroral oval and the corresponding MIE, the boundary moves poleward and the oval returns to its prior quiescent configuration. None of the optical signatures of the events considered by *Mende et al.* [1990] resembled a quasi-stationary pattern moving north/south over a station on the poleward side of the quiescent oval. Instead, they resembled a short-lived temporal event taking place above the station on the equatorward side of the oval. Therefore *Mende et al.* [1990] did not consider these events consistent with the model of *Southwood and Hughes* [1985] and suggested that the MIE activity was associated with the merging process itself rather than poleward convection subsequent to merging.

The study of *Mende et al.* [1990] showed that the location of these events at their onset is well inside the poleward boundary of the auroral regions and the outer boundary of the plasma sheet. More recent observations of TCVs with an almost simultaneous DMSP overpass put TCVs also inside the plasma sheet near the central plasma sheet (CPS)/ boundary plasma sheet (BPS) boundary [*Yahnin et al.*, 1997].

Luhr et al. [1996] made a single case study of an MIE with incoherent scatter radar optics and a magnetometer chain and found that the precipitation pattern was sometimes consistent with the field-aligned current structure predicted for a TCV.

The sudden optical events described by *Mende et al.* [1990] and the associated MIEs are rather different from the so-called midday auroral breakup events [*Sandholt and Asheim*, 1985; *Oguti et al.*, 1988; *Sandholt and Egeland*, 1988; *Sandholt*, 1987, 1988; *Sandholt et al.*, 1989, 1990]. Midday auroral breakup events consist of auroral activity initiating

Table 1. Location of the U.S. Automatic Geophysical Observatories (AGOs) Used in the Present Study

	Geographic		Geomagnetic	
Station	Latitude	Longitude	Latitude	Longitude
AGO P3	-82.50°	30.00°	-71.78°	40.09°
South Pole	-90.00°	000.00°	-73.91°	18.76°
AGO P5	-77.23°	123.51°	-86.74°	29.44°

within the region of the quiescent dayside aurora and the production of an auroral form which subsequently moves poleward. For example, typical events described by *Sandholt et al.* [1990] showed no detectable activity equatorward of the quiescent oval. The development of the activity was confined within the preexisting quiescent aurora, and the pronounced poleward propagation showed that these events were related to the poleward cusp/cleft boundary of the auroral region corresponding in location to the boundary region of dayside open and closed field lines. The midday auroral breakup phenomena therefore was most likely associated with the merging region on the dayside. The midday auroral events were observed to occur predominantly in the 0900-1500 magnetic local time (MLT) region, and they are exclusively observed during conditions of negative B_z. Their longitudinal motion is westward or eastward corresponding to positive or negative B_y in the Northern Hemisphere. Latitudinal width of the arcs is 50-100 km, whereas longitudinal (east-west) extension is 500-1000 km. The arcs persist for about 2-10 min with a recurrence frequency of 3-15 min. Precipitating fluxes in the arcs have average energies of 0.3-2 keV, and the associated magnetic signatures occur with intensities of 0-200 nT and their monopolar or bipolar magnetic signatures do not conform to the classical MIE definition of *Lanzerotti et al.* [1986] or of *Glassmeier et al.* [1989].

It is interesting to realize that for various practical considerations the stations which are most likely to observe midday/cusp associated auroras are located in between 70 and 80 degrees magnetic latitude range. When there is a high degree of magnetic activity, presumably when B_z is negative, the auroral oval tends to move to lower latitudes, and such stations are best situated to observe the poleward side of the auroral regions. Thus the stations can see midday auroral breakup events most distinctly and the associated high-latitude poleward propagation. During times of low magnetic activity the auroral regions move to higher latitudes, and the stations generally observe the region equatorward of the auroral boundary where the auroras associated with MIEs are observed to occur.

In this paper we discuss recent optical observations of suddenly occurring optical events equatorward of the auroral oval. They were invariably accompanied by simultaneous MIE activity. Similarly to *Sitar et al.* [1996], we will take a broader interpretation of MIEs and will include all sudden (lasting only a few minutes) dayside impulsive events regardless of whether they exhibit the classic MIE phasing definition of *Lanzerotti et al.* [1986] or *Glassmeier et al.* [1989]. The new observations take advantage of the dual-wavelength observation capability of new all-sky imagers, which allow distinguishing between soft and hard electron precipitation. We also take advantage of the multistation view afforded by the network of the U.S. Automatic Geophysical Observatory (AGO) chain fielded in Antarctica. Last but not least, we are able to use measurements from the simultaneous IMF field instruments on the Wind and IMP 8 satellites. We discuss one typical event, which was seen on May 22, 1996, in some detail. Following that, we will illustrate the general properties of several such events observed in 1996 by the AGO chain with special emphasis on the accompanying IMF field situation.

2. Observations

We have looked at several optical events, which have accompanying magnetic impulses from our Antarctic data. A typical 24-hour plot of the optical data taken with the Antarctic observatory chain was included in the form of a typical keogram stack plot (Figure 1) available on our Web site (http://sprg.ssl.berkeley.edu/atmos/data/welcome.html).

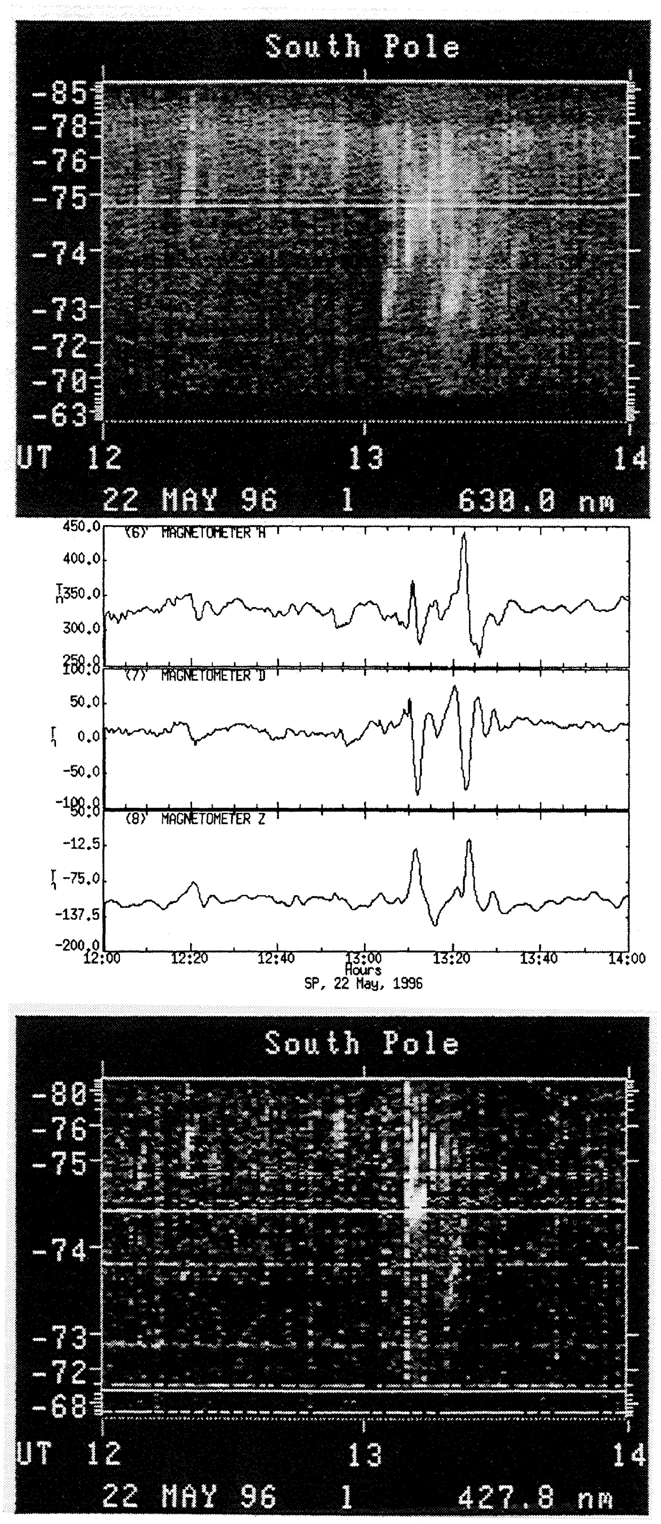

Figure 2. South Pole keogram and magnetic field data showing the optical signature of the magnetic impulsive event (MIE) at 1310 UT. The top panel is 630 nm, the middle panel is the magnetometer (H, D, Z), and the bottom panel is 427.8 nm.

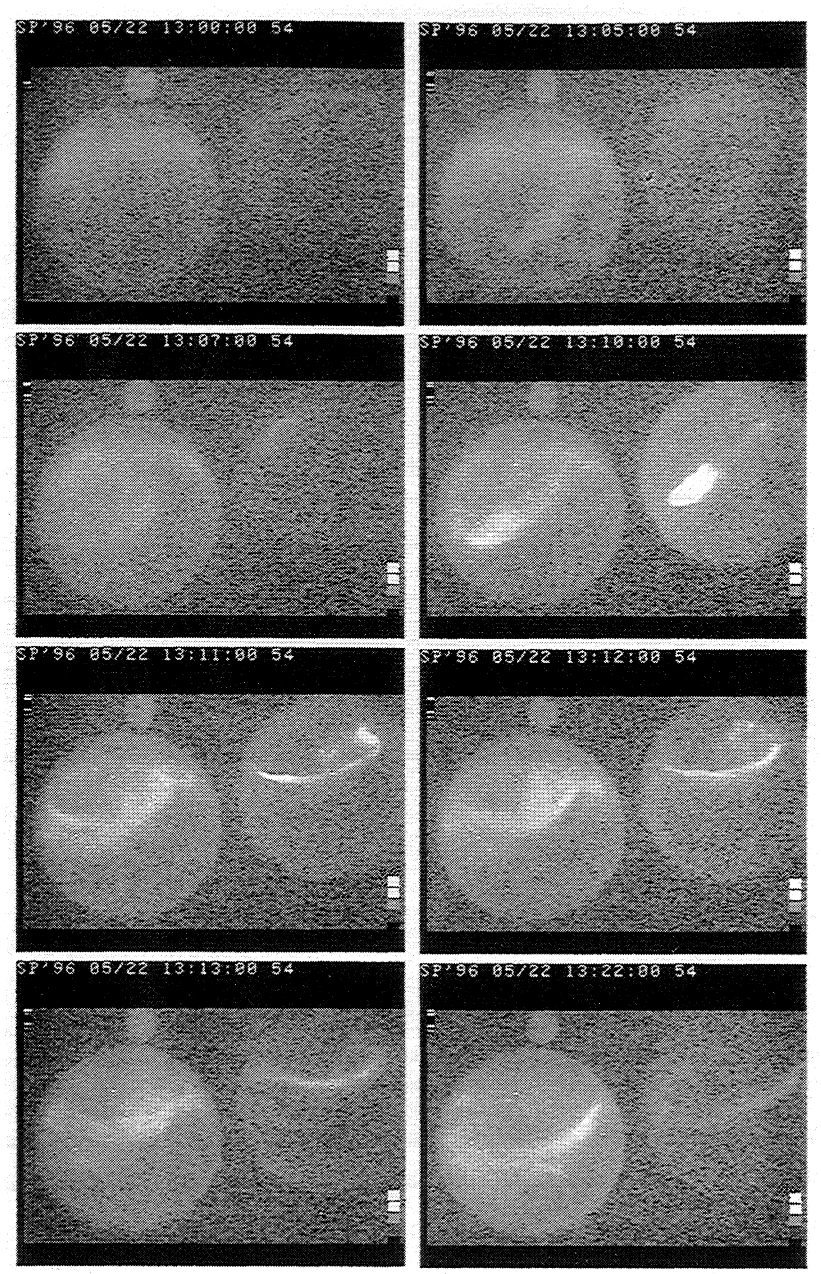

Figure 3. Collage of selected all-sky images taken at South Pole from 1300 (1306 UT) to 1322 (1328 UT) (May 22, 1996, day 143). Left side is 630 nm, and the right side is 427.8 nm. Image is looking up at the sky from the ground in the Southern Hemisphere. The view is the same as looking down at the aurora from above in the Northern Hemisphere through a transparent globe, thus poleward (south magnetic) is toward the top, east on the right, and west is on the left. Note there is a clock correction, which has to be added to each image time.

Keograms are meridian intensity plots of the aurora, where time is displayed horizontally and zenith angle is displayed vertically with the magnetic poleward direction toward the top. The day chosen for illustration is May 22, 1996. IMF data were available from Wind (x=123, y=-24, z=-8) and Geotail (x=26, y=10, z=-3). The IMF B_z was generally positive until about 1100 UT after that it fluctuated strongly and had several negative excursions, the largest being at 1045 UT. After some fluctuations, B_z went negative, and there was an abrupt positive jump at 1300 UT. B_y was generally negative except between 0630 and 1100 UT. The coordinates of AGO P3, AGO P5, and South Pole are presented in Table 1. It should be noted that the midnight position of the auroral oval is usually <70 degrees magnetic latitude, and at midday it is usually >78 degrees. At the longitude of South Pole, magnetic midnight (0000 MLT) occurs at 0330 UT. At this time the auroral oval is generally equatorward of South Pole Station and usually only substorm-associated sporadic intensifications are seen. After about 0500-0600 UT the auroral oval is diffuse but continuous and moves gradually poleward. This motion between 0600 and 1230 UT is a relative motion of the auroral oval with respect to the station, caused by the diurnal rotation of the magnetic pole and the day-night offset of the oval in magnetic latitude. Although the position of the oval is expected to vary largely with magnetic activity, usually the centroid position of the auroral oval reaches about 78 degrees by about 1530 UT ("magnetic midday"). Between 0600 and 1230 UT the morningside auroral oval is wide and quite

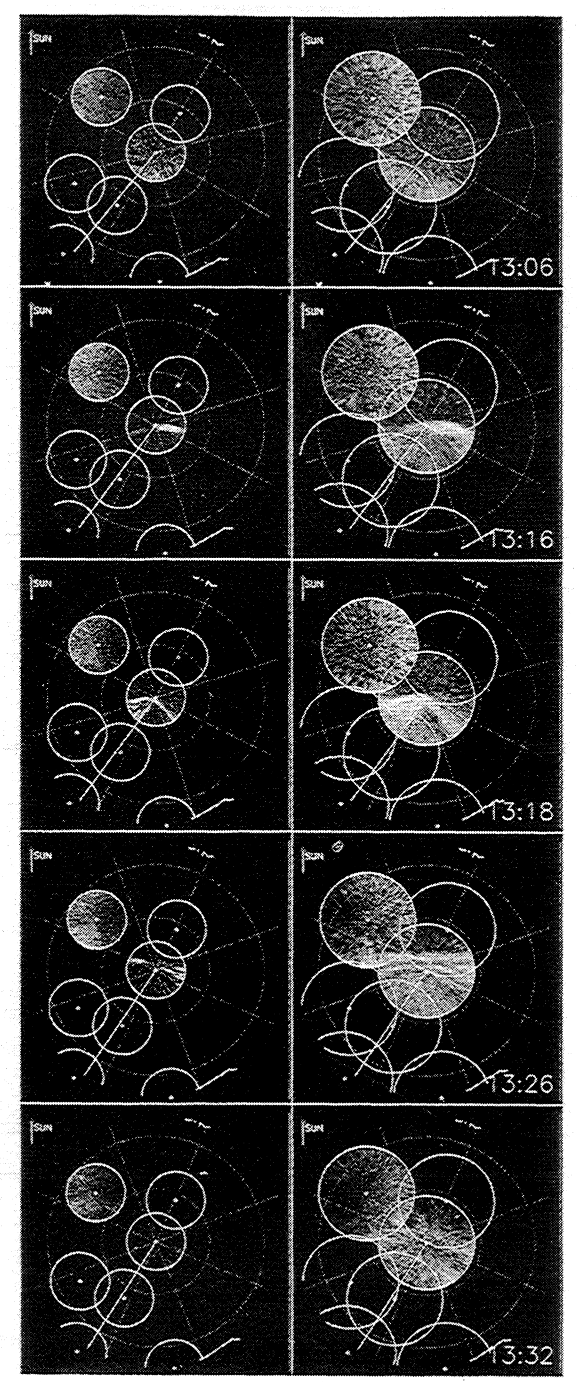

Figure 4. Composite of the AGO all-sky imagers for the MIE event on May 22, 1996. Left image is 427.8 nm, right is 630 nm. Corrected times are 1306, 1316, 1318, 1326, and 1332 UT.

diffuse. From 1230 UT onward the zone is narrow and essentially poleward of the station. The subject of this paper is exemplified in the distinct intensification starting after 1300 UT and lasting approximately until 1330 UT. The intensification starts at the zenith or somewhat equatorward of the zenith in the South Pole (74.5 degrees latitude) imager's field of view.

The simultaneous data taken with P5 (geomagnetic latitude=86.74) is shown on the top plot of Figure 1 and shows that no activity was seen at this higher-latitude station. The data from AGO P3 (geomagnetic latitude=71.78) are given in the bottom plot. This station is an auroral latitude station displaying most activity in the night sector between 0000 and 0200 UT and after 1800 UT. On the dayside the auroral oval is generally too far poleward to be seen from AGO P3; however, a brief but intense response is observed at about 1320 UT.

We have presented a full-day keogram above, however, the event is best illustrated by the expanded keograms shown in Figure 2 with the simultaneous data taken by the South Pole magnetometer. The axes are labeled H (+north), D (+east), and Z (+ up in the Southern Hemisphere). The event started suddenly just after 1310 UT (MLT=1040) with a positive H, negative D, and positive Z component placing the equivalent eastward horizontal line current poleward and eastward of the station. A few minutes later at 1323 UT (MLT=1053) a second intensification of the current at South Pole is seen. This time we also have a positive H component with a positive Z. A minute later H becomes negative possibly, signifying a reversal of the simple line current. However, this line current model is not expected to produce a complete story because TCVs generally produce complex magnetic signatures.

The keogram segment from 1200 to 1400 UT (Figure 2) summarizes the optical observations. The top panel is 630 nm and the bottom panel is 427.8, representing soft and hard precipitation, respectively. The soft aurora is continuous and is located near the top of the keogram, near the poleward horizon at South Pole. This is consistent with the usual quiet-time situation because South Pole is located at 74 degrees magnetic latitude and the position of the low K_p midday aurora is regularly located at 78 degrees latitude. Figure 2 shows only the group that begins at 1316 UT, although three groups of events occurred on May 22, (1146, 1316, and 1426 UT). (Note that there is a clock correction of 6 min, which had to be added to the timescale of the optical data.) We see the sudden appearance of aurora at latitude lower than the preexiting auroral zone. Being farther equatorward signifies that the magnetic field lines connected to the event should be inside the magnetosphere. The brightest group begins at 1316 UT. The event has signatures in the 427.8-nm emission showing the presence of harder electrons. We have simultaneous data from AGO P5 and P3, and an event is observed at 1322 UT at AGO P3, and no activity is seen at AGO P5.

The imaging data are very important because they show the spatial morphology of the precipitation event and are presented in a collage of images in Figure 3. In each panel the left circular image is the 630-nm image showing the aurora and the airglow. The direction to the south magnetic pole is up, left is west, and right is east. Above the 630-nm image a calibration stimulus is displayed. When the aurora becomes more active, the 427.8-nm image is seen on the right side.

The situation prior to the event is illustrated by the image taken at time mark 1300 (because of a 6- min clock error, the actual time was 1306 UT). The displays show 630 nm on the left and 427.8 nm on the right. This image and the keogram (Figure 2) show the presence of a quiescent auroral oval on the poleward horizon. A faint 630-nm feature appears, stretching overhead from the east at the image labeled 1305 (1311 UT). This feature intensifies, and a faint 427.8-nm aurora appears on the poleward horizon at 1307 (1313 UT) on the left (west). This is the first evidence of hard electron precipitation associated with the event. The following

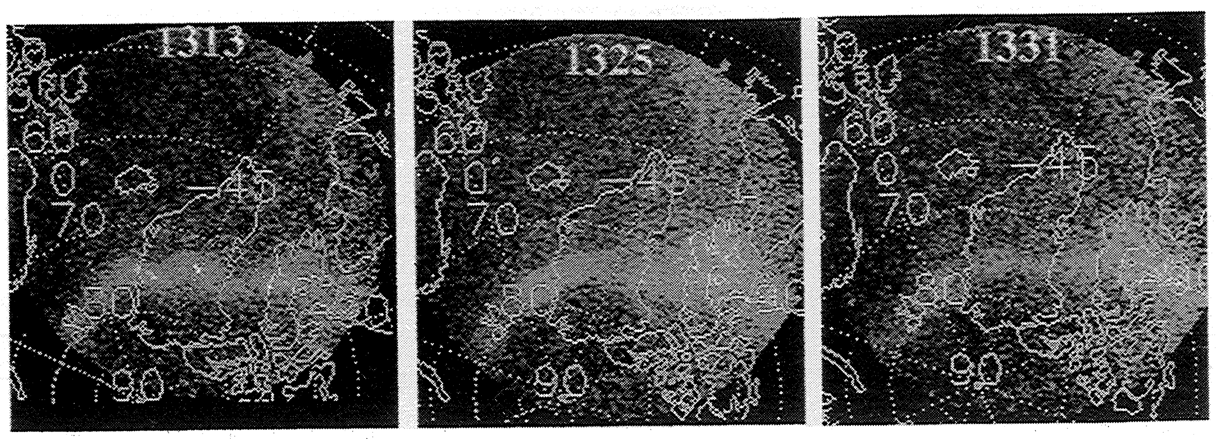

Figure 5. Polar Ultraviolet data for the conjugate (Northern Hemisphere.)

images, 1308 (1314 UT) and 1309 (1315 UT), show the development of a faint equatorward 630-nm feature which encircles a large westward region of the sky equatorward of the quiescent aurora. At 1309 (1315 UT) the most equatorward part of the 630-nm aurora brightens at two spots. At the spots we see the appearance of a 427.8-nm aurora. The next image, taken at 1310 (1316 UT) shows the brightest 427.8-nm feature. This isolated feature shows that in this example we have captured the initial patch of accelerated electrons and the hard aurora did not propagate into the image from regions outside the field of view. This electron precipitation is located near the zenith slightly equatorward and westward of the center of the picture. From the following frames, 1311 (1317 UT) and 1312 (1318 UT), it seems that an eastward moving surge develops. The latitudinal expansion of the aurora takes a surge-like appearance. The subsequent panels (not shown) display a progressive fading with the aurora returning poleward to its quiescent state residing poleward of the station.

AGO P3 saw some activity on the poleward horizon culminating at 1318 UT. The available images from the AGO stations are shown in Figure 4. These are the map projections of the all-sky images from South Pole and P3.

The left-hand panels are 427.8-nm energetic electron auroras, permitting observation to 80° zenith angles at a height level of 110 km, and the right-hand ones are 630 nm, representing soft precipitation at an altitude of 220 km. Display has been rotated to be consistent with sun direction at the top. The magnetic pole is near the bottom left of each image, and the first image set at 1306 UT shows the poleward quiet red aurora at the bottom left of the South Pole 630-nm frame. By 1316 UT the activity in the soft precipitation has reached the South Pole zenith, and we can see the strong 427.8-nm emission also in the zenith at South Pole stretching toward dawn. In the following three panels, 1318, 1326, and 1332 UT, we can see how the aurora spreads eastward reaching P3.

The gross features of the IMF data were described previously for the entire day. Immediately prior to the event the IMF B_z was negative. Geotail saw a sudden northward turning of the IMF at 1244 UT. It appears that this same event was seen by Wind at 1258 UT, showing that the discontinuity was more nearly parallel to the Earth-Sun line than perpendicular to it (as is often envisioned) and perhaps propagating in the $-y$ direction. This being the case, the discontinuity should have arrived at the magnetopause sometime after 1300 UT, which would suggest that the event was triggered by the B_z change.

3. Polar UVI data

The conjugate hemisphere in the north was largely daylit at this time. Fortunately, the Ultraviolet Imager (UVI) on Polar was operational at this time. The conjugate of South Pole is near Iqaluit, Canada (63.75°N 291.47°E). As seen in Figure 5, the UVI image, taken at 1313 UT, shows several auroral patches. A weak one is located at around 68°N and 300°E near South Pole conjugate, and two stronger ones are located over Greenland east of the South Pole conjugate. The west patch could be the aurora conjugate to the one observed at South Pole, albeit displaced by a few degrees poleward. The subsequent images taken by UVI at 1325 and 1331 UT show that all the activity is declining.

The conjugate images in the UVI data do not show the latitudinal displacement of the enhancements from the quiescent oval. It is suspected that UVI did not have the spatial and intensity resolution required to separate the patches from the faint quiescent aurora in the dayglow. However, the UVI aurora confirms that there was some auroral intensification at the conjugate hemisphere accompanying the event.

4. Other Events

The May 22 event was chosen as an example. We will now summarize the most important features of all the other events. An extended timescale keogram for the April 18 event is presented in Figure 6 for both the 630-nm and 427.8-nm wavelength bands with the data taken by the South Pole magnetometer.

There are two events on April 18, at 1740 and 1825 UT. The events are relatively short-lived impulsive events. The similarity between the 427.8-nm keogram and the magnetometer trace is quite apparent. There is a slight poleward slant to the traces, showing poleward propagation. Inspection of the images showed that the event propagated into the South Pole field of view from the east. Since these events were after midday, this propagation signifies antisunward motion.

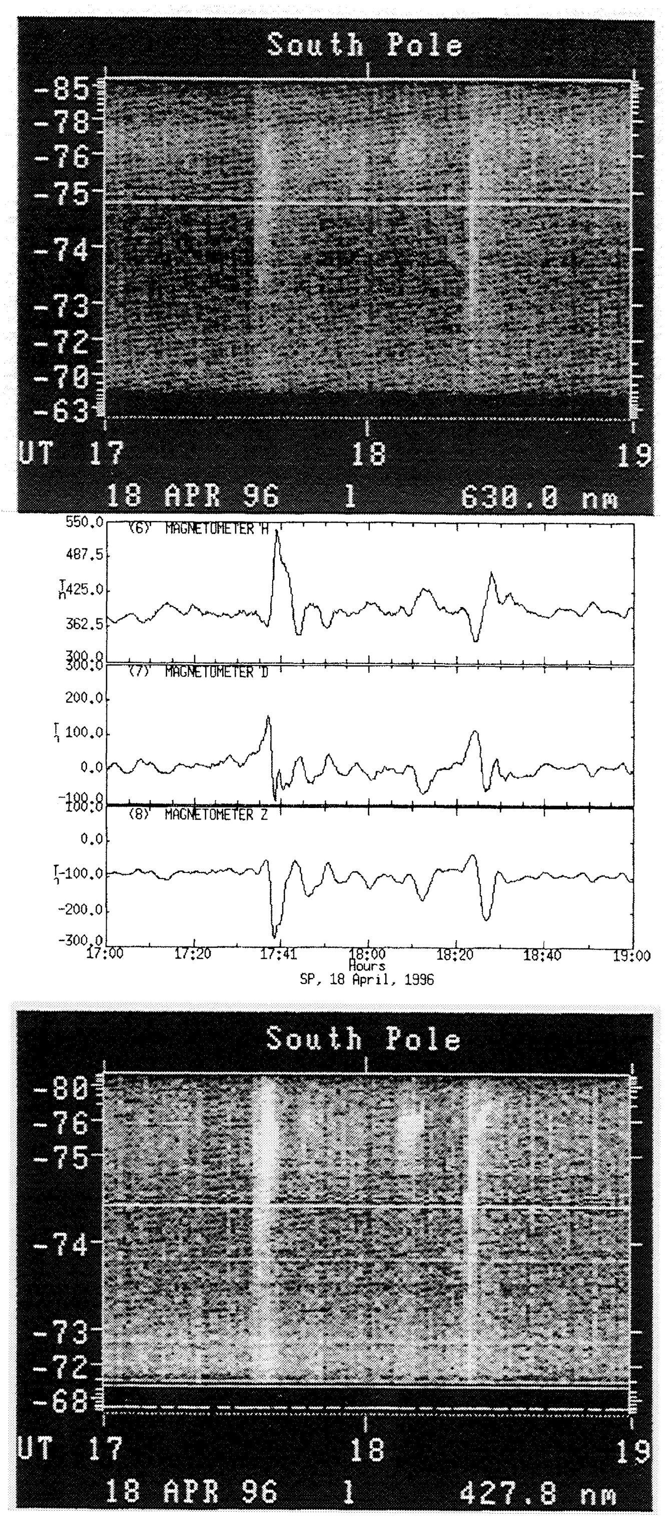

Figure 6. Combined keogram and magnetometer data for April 18, 1996.

On April 27 the event occurred at 1130 UT (Figure 7). Several repetitive poleward dispersion traces are evident in the keogram. Only faint activity is seen in 427.8 nm. There is good association with the magnetometer, especially in the D component. Analysis of the all-sky images did not reveal any definitive east-west motion.

On April 28 the event started at 1100 UT and showed several repetitive poleward traces on the 630-nm keogram (Figure 8). Strong activity is seen in 427.8nm at 1117 UT. Once again there is good correlation with the field variations measured by the magnetometer. Analysis of the all-sky images showed that the activity begins in the west and propagates in from the west. After 1123 UT the activity fades out as it moves back to the west.

On May 26, there are small precursor events from 1130 UT onward (Figure 9). However, the brightest part of the event starts only at 1150 UT, showing at least two poleward traces on the 630- and 427.8-nm keograms. Once again there is good association with the magnetic variations.

On July 21 there were several relevant events (Figure 10). The event starting at 1055 UT showed several features in 630 nm and one bright and one faint in 427.8 nm. The correlation with the magnetic field is not quite as clear. The all-sky images showed that the event moved from the east toward the west. There is another single event at 1140 UT.

The second event starting at 1315 UT is presented separately in Figure 11. There is a sudden onset in the 630-nm keogram, which is followed by several poleward moving forms. There seem to be minimal or no traces of these latter events in the 427.8-nm keogram. The magnetometer shows very distinct but not too well correlated pulsations. The all-sky images (not shown) confirm that the aurora gets suddenly very bright and they show the fading out and no explicit east-west movement can be observed in the all-sky images.

The July 27 event started at 1145 UT (Figure 12). There are two or three poleward moving forms in the 630-nm keogram. There is no optical emission in the 427.8-nm keogram. The magnetometer shows the associated pulsations.

5. Discussion

Prior to all the events that are discussed here the 630-nm keogram showed that the location of the quiescent aurora caused by low-energy precipitation was at higher magnetic latitudes than South Pole. The source of these soft electrons is pitch angle scattering in either the plasma sheet or the magnetosheath. Generally, electrons need some form of acceleration to produce detectable amounts of 427.8-nm emission when the 630-nm emission intensity is only moderately strong. Thus 427.8-nm emission is evidence of the acceleration of the source electrons. The quiet-time dayside auroral oval is generally devoid of 427.8-nm emission. On the keogram, there is often a moderately brighter band near both the northward and southward horizons, which is the Van Rhijn enhancement of atmospheric background light, and in most instances it should not be confused with particle precipitation.

As noted above, in general, all the events that are discussed herein begin abruptly several degrees equatorward of South Pole Station (74 degrees magnetic latitude = dipole L of 14) while the quiescent auroral oval seems to remain located at 77 or 78 degrees magnetic latitude (dipole L=25). In other words the events show a sudden onset substantially equatorward of the auroral oval. If these onset positions were mapped to the equatorial plane along the magnetic field, they would be several Earth radii closer to the Earth than the mapped position of the auroral oval. It appears that after onset in all of the events, the aurora propagates poleward until the new aurora merges with the quiescent auroral oval. The speed of poleward propagation is of the order of 1 degree of latitude (110 km) in about 10 min~20 m sec^{-1}.

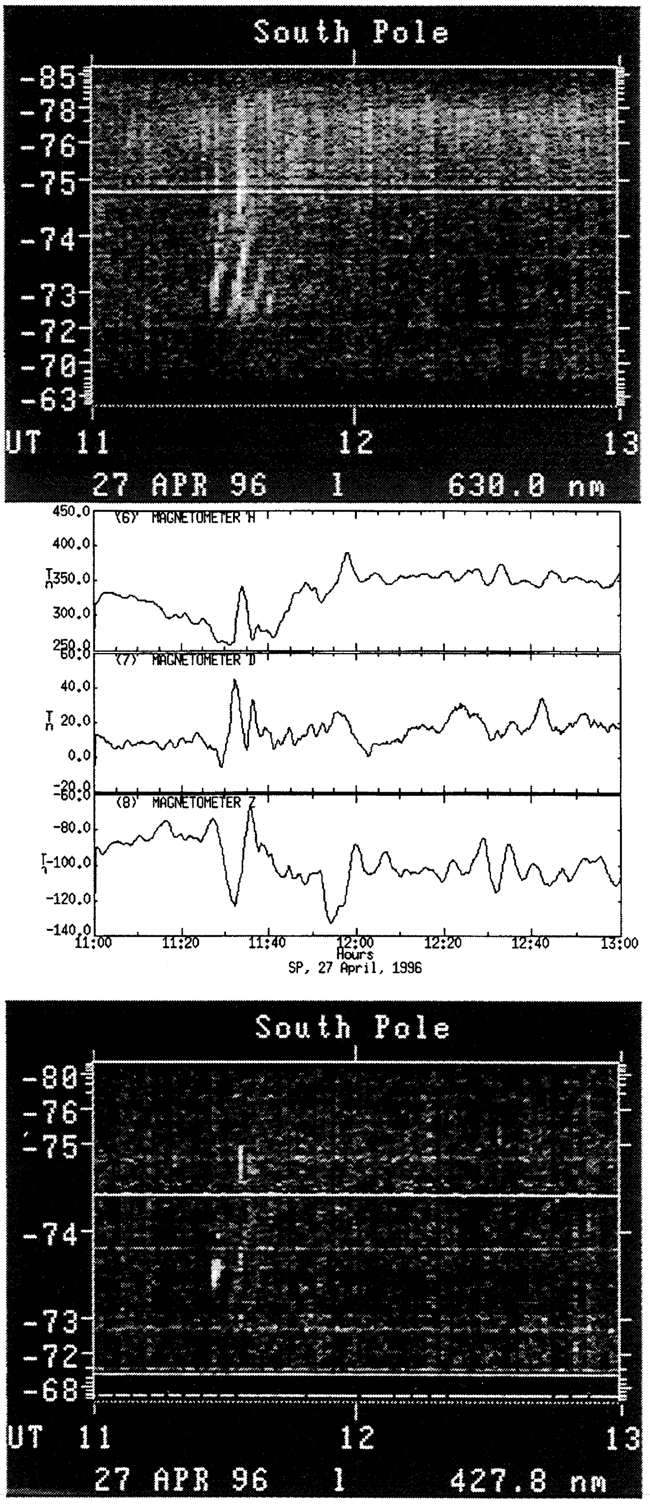

Figure 7. Combined keogram and magnetometer data for April 27, 1996.

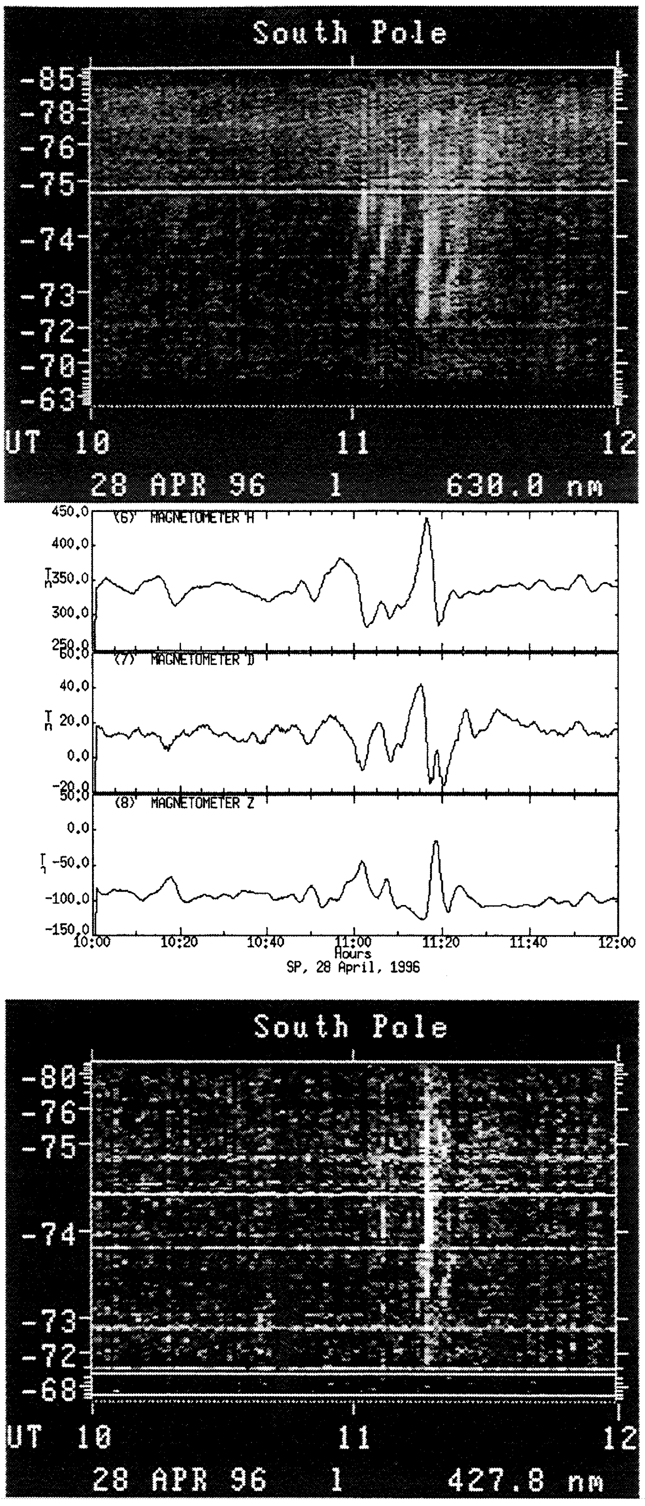

Figure 8. Combined keogram and magnetometer data for April 28, 1996.

Table 2 shows the corresponding solar wind and interplanetary magnetic field conditions accompanying the events. The third column from the left represents the time when the field measurement needed to be made by the Wind satellite to allow for solar wind propagation from the satellite to the magnetosphere. The fourth column is the value of B_z at that time, and columns 5 and 6 describe recent changes in the B_z value and the time when the change occurred. The last two columns are the solar wind data associated with the events.

It is difficult to make definitive, one-to-one, associations between ground based observations, IMF B_z and solar wind pressure changes because often the WIND satellite was some distance from the magnetosphere. Depending on the angle of the discontinuity in the solar wind, the calculation of the time

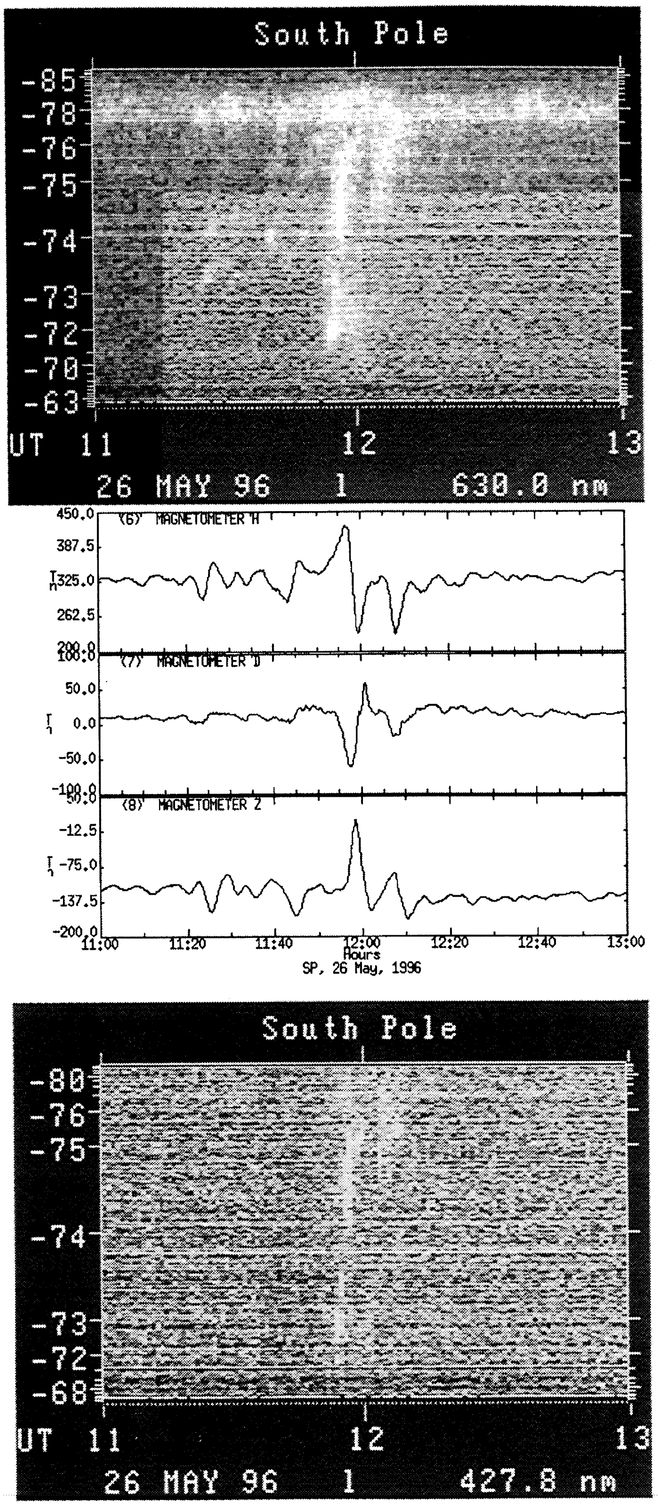

Figure 9. Combined keogram and magnetometer data for May 26, 1996.

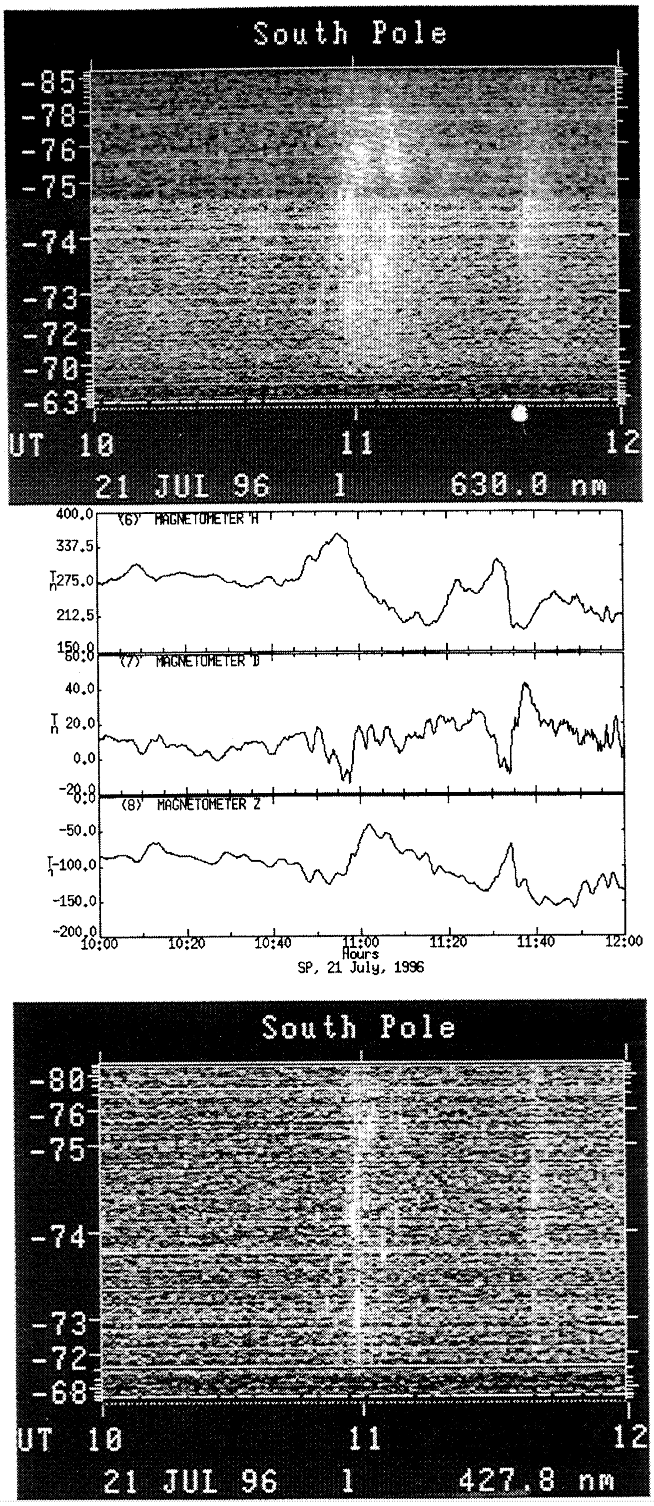

Figure 10. Combined keogram and magnetometer data for July 21, 1996 (1055 UT).

delay to the ionosphere could be in error. A good example of this occurred in the May 22 case. Nevertheless, we see that some of these MIE events can be associated with either a positive jump in the IMF B_z or an increase in the solar wind pressure [*Sibeck et al.*, 1989].

Several cases of dayside auroral optical events were observed consisting of the sudden onset of low-latitude precipitation with subsequent poleward propagation. These events were always accompanied by sudden magnetic field variations. Such correlation would be expected for two reasons. First, auroral precipitation modifies the local conductivity of the ionosphere above the station and will cause changes in the ionospheric current flow. Thus the auroral precipitation could induce the observed change in currents and related magnetic fields. Second, the more favored mechanism is a change of the current intensity or

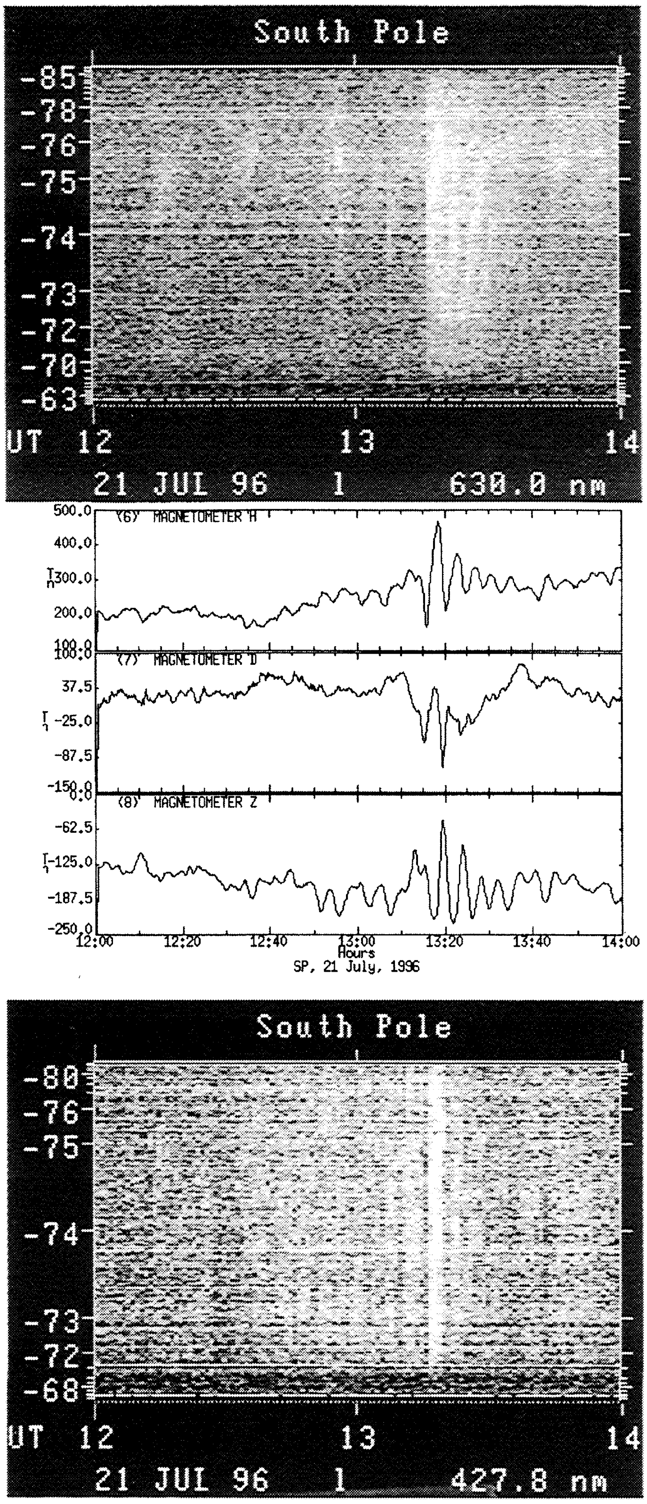

Figure 11. Combined keogram and magnetometer data for July 21, 1996 (1315 UT).

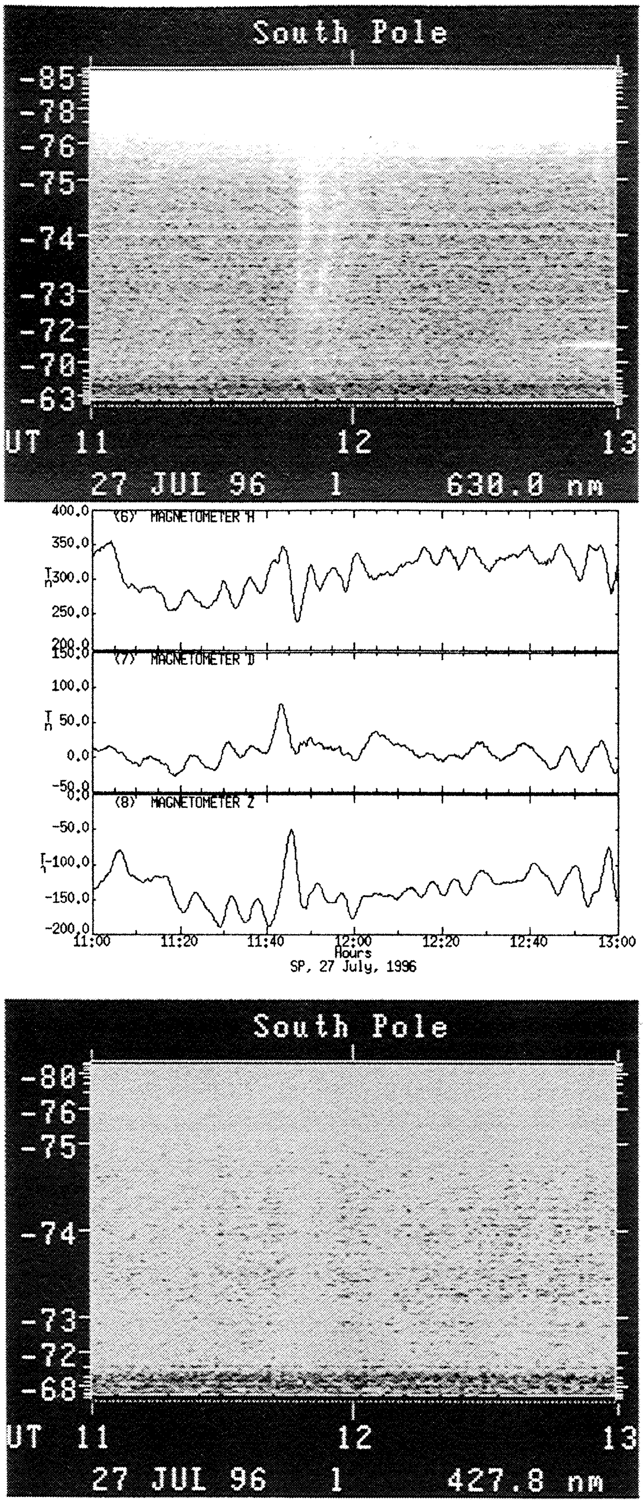

Figure 12. Combined keogram and magnetometer data for July 27, 1996.

configuration in the magnetosphere producing enhanced field-aligned currents, which in turn produce the auroral precipitation and provide the acceleration field for the particles. Our observations alone could not distinguish between the two.

The majority of auroral activity occurs in 630-nm emission which is caused by low electron precipitation in the energy regime of plasma sheet or magnetosheath electrons. Each optical event also shows the presence of short-lived 427.8-nm emission. The presence of the 427.8 emission suggests electron acceleration.

The sudden optical events described here and associated with MIEs are different from the so-called midday auroral breakup events [*Sandholt and Asheim*, 1985; *Oguti et al.*, 1988; *Sandholt and Egeland*, 1988; *Sandholt*, 1987, 1988; *Sandholt et al.*, 1989, 1990]. Midday auroral breakup events

Table 2. The IMF B_z field and Solar Wind Pressure Conditions Related to the MIE Observations

Date		Corrected	Bz, nT			Pressure	
1996	UT	Time	Bz	Bz change	Remarks	P, nPa	Remarks
April 18	1738	1742			in magnetosphere	NA	
	1825	1829			in magnetosphere	NA	
April 27	1130	1106	0	-3 to 0	B_z was positive and then monotonically decreased to −3; It increased to reach +4 at 1145	2.6	quite steady
April 28	1120	1057	2.5	0 to 2.5	B_z went up from 0 to 2.5 quite sharply at 1050	1.7	pressure increase at 1020 UT from 1.7 to 2.3.
May 22	see text	1300	-2	-2 to 2	the field sharply jumps to +2	from 2 to 3.2	pressure jump velocity change at 1225
May 26	1157	1120	0	-3 to 3	at 1110, B_z jumps from −3 to +3	2	flat at 2, although there is a change in velocity at 1110
July 21	1100	1005	-1		fluctuating between −1 and +1	from 4 to 5	pressure jump velocity change at 1010
	1320	1228	0		at 1220 it is zero, starts going up to 2 nT at 1230	5.8	pressure jump at 1200
July 24	1143	1049	2		there is a sudden positive pulse at 1015 reaching 2nT	1.8	flat
July 27	1147	1056	1.8		there is a negative impulse at 1055 reaching -1nT	1.7	flat

consist of auroral activity initiating within the region of the quiescent dayside aurora and the production of an auroral form which subsequently moves poleward. The MIE events described here are initiated in regions separated from the quiescent auroral oval and equatorward of it, and they move toward the oval. Assuming that the quiescent aurora represents the open/closed field boundary, the midday auroral breakup begins at the boundary and propagates poleward away from this boundary [*Sandholt et al.,* 1990]. The propagation takes place within the region of open field lines. The MIE events begin in the region of closed magnetic field lines and propagate toward the boundary of open/ closed field lines. Because of these differences, fundamentally different mechanisms must be involved.

In all the events discussed the keogram shows repeated upward striping, which indicates that the events start at lower latitudes and propagate to higher latitudes. There are several such stripes in succession observed every time, showing the periodic nature of the phenomena.

All the events begin equatorward of the preexisting quiescent aurora, which indicates all the events appear to begin in the region of closed field lines. This is in good agreement with *Yahnin et al.* [1997], who find from simultaneous DMSP observations that the TCVs they examined occur near the CPS/BPS boundary. The morphology of the propagating aurora is reminiscent of the poleward and westward propagation of nightside auroral substorms.

In the May 22, 1996, case the energetic 427.8-nm aurora appeared to form within the field of view of the all-sky imager; in the other cases the images are consistent with activity propagating either east or west into the field of view. In the May 22 case the propagation was eastward during prenoon, i.e., sunward. This is inconsistent with the antisunward propagation discussed by *Luhr and Blawert* [1994].

With reference to Table 2 during first two events on April 18, the satellites Wind and IMP 8 were both inside the magnetosphere and no IMF fields or solar wind plasma parameters were available. The April 27, 1996, optical event occurred at 1130 UT (second column). Allowing for the location of the Wind satellite, the relevant time when the solar wind passes the satellite at 1106 is shown in third column. Thus the positive jump of B_z from -3 to 0 just prior to this time could act as the trigger for the event. On April 28, 1996, there was a similar positive jump of 2.5 nT at 1050 UT just prior to the corrected event time of 1057 UT. There was also a pressure increase at 1020 UT preceding the event by some 37 min. On May 22 (corrected event time of 1240 UT), B_z was zero and it jumped positive at 1255 UT. According to our computation from Wind and Geotail position and solar wind speed this jump was at about the right time to trigger the observed phenomena. On May 26, 1996, there was a positive B_z jump at about 1110 UT. The two cases on July 21, 1996, both show solar wind pressure jumps at about the correct time. No associated B_z or solar wind pressure change could be associated with events on July 24 and 27. An optical event was observed on July 25, 1996, however, there was no corresponding South Pole magnetic data. This event had a positive B_z jump of 3 nT at about the appropriate time.

In order to cross check whether there was any possible triggering due to sudden changes in B_x or B_y, Table 3 was compiled. Table 3 is similar to Table 2 except that it tabulates changes in B_x and B_y. Summarizing Tables 2 and 3, we find that in most cases it is possible to associate some IMF or solar wind change associated which could be associated with triggering the events. Some of the cases were not too compelling because the assumed propagation delay needed to

Table 3. Summary of the Interplanetary B_x and B_y Components for the Events Used in the Present Study

Date		Corrected	B_x, nT			B_y, nT		
1996	UT	Time	B_x	B_x change	Remarks	B_y	B_y change	Remarks
April 18	1738	1742			in magnetosphere			
	1825	1829			in magnetosphere			
April 27	1130	1106	-5	-2	downward trend	-2	-2 - 0	field jumps at time of occurrence
April 28	1120	1057	0	-3 to 0	jump occurs at 1050	2		no significant jump
May 22	see text	1300	4	2 to4	jump at 1255	0	-2 to 0	slower change
May 26	1157	1120	0.5	3.5 to 0.5	slow change preceding the other components	1	-3 to +1	jumps same time as B_z
July 21	1100	1005	-3	-3 to -2	change takes place at 1010	0		no significant changes
	1320	1228	-4	-2 to -4	slower change	+3	-0.5 to + 3	change occurs at 1215
July 24	1143	1049	-1			+2.5		
July 27	1147	1056	-2	0 to -2	change few minutes prior	1	3 to 1	sudden change at 1055

be "adjusted " to make the event fit the trigger. One event occurring on July 24, 1996 could not fit any triggering scenario at all and therefore could be regarded as a spontaneous event.

From the IMF field and related observations we find the following:

1. The prevailing interplanetary magnetic field B_z component was generally close to 0 nT or positive. Optimum observation conditions at South Pole occur when the dayside aurora is substantially poleward of South Pole (74.5 degrees magnetic latitude), which is consistent with low magnetic activity and weak or positive B_z.
2. Some of the events discussed here were associated with an IMF change or a pressure increase in the solar wind field, and only one event was consistent with a spontaneous onset because it could not be associated with any noticeable change in the IMF or solar wind plasma.

The events all seem to originate deep inside the closed field line region on the dayside.

It is interesting to note that the best conditions at South Pole for observing these events are magnetically quiet periods with B_z small or positive when auroral ovals are located relatively poleward. Under these conditions, magnetic field merging is thought to take place poleward of the dayside aurora and there is an electric field transporting plasma into the region of closed field lines on the dayside. Thus it is conceivable that the closed portion of the dayside magnetosphere acts as a plasma reservoir during B_z positive conditions. The phenomena discussed here could be a spontaneous localized depletion of the reservoir when the system becomes overloaded or stressed. This could occur spontaneously or through triggering by a change in an external factor such as the IMF or the solar wind. This would argue for some spontaneous events in agreement with our observations.

Both the optical and magnetic signatures show a periodic pattern embedded in the process. The oscillatory nature of the events does not support a model based on a simple energy release.

In order to examine the east-west propagation of the optical events we produced east-west keograms of all the events by lining up the east-west central strip of each all-sky image to form a temporal sequence proceeding from left to right. It was hoped that in a manner analogous to a conventional north-south keogram these would give a history of the east-west motions of the aurora. Unfortunately, the attempt at obtaining east-west motions this way was unsuccessful. Auroras are usually east-west aligned, and it was found that the east-west keograms represented the combination of the angle of east-west alignment of the aurora and their north-south (not east west) motion.

As noted above, the IMF B_z field was generally small or positive for the events. This could be interpreted as a precondition of these events. However, it should be noted that the observation conditions are most favorable when the quiescent auroral oval is poleward of South Pole Station. Usually this situation is seen during quiet times. During disturbed periods, with strong B_z negative, the quiescent auroral oval tends to be located equatorward of South Pole and the observing conditions of seeing MIEs at South Pole are less favorable. This situation is the same for Northern Hemisphere observations, for example, in the Scandinavian sector where the dayside lower L shell regions are usually in daylight even at winter solstice.

6. Conclusions

1. Dayside auroral optical events consisting of the sudden onset of low-latitude precipitation with subsequent poleward propagation were always accompanied by magnetic signatures, magnetic impulse events (MIEs) in a broadly defined sense and show good temporal correlation between the optical and magnetic signatures.
2. In the cases presented herein the majority of auroral activity occurs in 630-nm emission, and most optical events also show the presence of short-lived 427.8-nm emission. The presence of the 427.8 emission suggests local electron acceleration.
3. All the events begin equatorward of the preexisting quiescent aurora, which indicates all the events begin in the region of closed field lines.
4. In the May 22, 1996, case the energetic aurora appeared to form within the field of view of the all-sky imager; in the other cases the images are consistent with activity propagating either east or west into the field of view.

5. The majority of the events discussed here are consistent with being triggered by IMF B_z change or a pressure increase in the solar wind field. For some events, no specific trigger was found.

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References

Farrugia, C. J., M. P. Freeman, S. W. H. Cowley, D. J. Southwood, M. Lockwood, and A. Etemadi, Pressure-driven magnetopause motions and attendant response on the ground, *Planet. Space Sci.*, *37*, 589, 1989.

Friis-Christensen, E., M. A. McHenry, C. R. Clauer, and S. Vennerstrom, Ionospheric traveling convection vortices observed near the polar cleft: A triggered response to sudden changes in the solar wind, *Geophys. Res. Lett.*, *15*, 253, 1988.

Glassmeier, K.-H., M. Honisch, and J. Untiedt, Ground-based and satellite observations of traveling magnetospheric convection twin vortices, *J. Geophys. Res.*, *94*, 2520, 1989.

Goertz, C. K., E. Nielson, A. Korth, K. H. Glassmeier, C. Haldoupis, P. Hoeg, and D. Hayward, Observations of a possible ground signature of flux transfer events, *J. Geophys. Res.*, *90*, 4069, 1985.

Lanzerotti, L. J., L. C. Lee, C. G. Maclennan, A. Wolfe, and L. V. Medford, Possible evidence of flux transfer events in the polar ionosphere, *Geophys. Res. Lett.*, *13*, 1089, 1986.

Lanzerotti, L. J., R. D. Hunsucker, D. Rice, L. C. Lee, A. Wolfe, C. G. Maclennan, and L. V. Medford, Ionosphere and ground-based response to field-aligned currents near the magnetospheric cusp regions, *J. Geophys. Res.*, *92*, 7739, 1987.

Lee, L.-C., Magnetic flux transfer at the Earth's magnetopause, in *Solar Wind-Magnetosphere Coupling*, edited by Y. Kamide and J. Slavin, p.297, Terra Sci., Tokyo, 1986.

Luhr, H., and W. Blawert, Ground signatures of convection vortices, in *Solar Wind Sources of Magnetospheric Ultra-Low-Frequency Waves, Geophys. Monogr. Ser.*, vol. 81, edited by M. J. Engebretson, K. Takahashi, and M. Scholer, p. 231, AGU, Washington, D. C., 1994.

Luhr, H., M. Lockwood, P. E. Sandholt, T. L. Hansen, and T. Moretto, Multi-instrument ground-based observations of a travelling convection vortices event, *Ann. Geophys.*, *14*, 162, 1996.

Mende, S. B., R. L. Rairden, L. J. Lanzerotti, and C. G. Maclennan, Magnetic impulses and associated optical signatures in the dayside aurora, *Geophys. Res. Lett.*, *17*, 131, 1990.

Oguti, T., T. Yamamoto, K. Hayashi, S. Kokubun, A. Egeland, and J. A. Holtet, Dayside auroral activity and related magnetic impulses in the polar cusp region, *J. Geomagn. Geoelectr.*, *40*, 387, 1988.

Potemra, T. A., H. Luhr, L. J. Zanetti, K. Takahashi, R. E. Erlandson, G. T. Marklund, L. P. Block, L. G. Blomberg, and R. P. Lepping, Multisatellite and ground-based observations of transient ULF waves, *J. Geophys. Res.*, *94*, 2543, 1989.

Sandholt, P. E., Interplanetary and geophysical effects of a coronal transient, *Ann. Geophys., Ser. A*, *5*, 219, 1987.

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

Sandholt, P. E., and S. Asheim, The relationship between reconnection electric field, field-aligned and ionospheric currents, *Ann. Geophys.*, *3*, 43, 1985.

Sandholt, P. E., and A. Egeland, Auroral and magnetic variations in the polar cusp and cleft-signatures of magnetopause boundary-layer dynamics, *Astrophys. Space Sci.*, *144*, 171, 1988.

Sandholt, P. E., B. Lybekk, A. Egeland, R. Nakamura, and T. Oguti, Midday auroral breakup, *J. Geomagn. Geoelectr.*, *41*, 371, 1989.

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 breakup events and related energy and momentum transfer from the magnetosheath, *J. Geophys. Res.*, *95*, 1039, 1990.

Saunders, M. A., C. T. Russell, and N. Sckopke, Flux transfer events: Scale size and interior structure, *Geophys. Res. Lett.*, *11*, 131, 1984.

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

Sibeck, D. G., W. Baumjohann, and R. E. Lopez, Solar wind dynamic pressure variations and transient magnetospheric signatures, *Geophys. Res. Lett.*, *16*, 13, 1989.

Sitar, R. J., C. R. Clauer, and E. Friis-Christensen, High-latitude ground-based response to sudden changes in solar wind dynamic pressure, *J. Geophys. Res.*, *101*, 27,001, 1996.

Southwood, D. J., and W. J. Hughes, Concerning the structure of Pi 2 pulsations, *J. Geophys. Res.*, *90*, 386, 1985.

Todd, H., B. J. I. Bromage, S. W. H. Cowley, M. Lockwood, A. P. van Eyken, and D. M. Willis, EISCAT observations of bursts of rapid flow in the high-latitude dayside ionosphere, *Geophys. Res. Lett.*, *13*, 909, 1986.

Yahnin, A. G., V. G. Vorobjev, T. Bosinger, R. Rasinkangas, D. G. Sibeck, and P. T. Newell, On the source region of traveling convection vortices, *Geophys. Res. Lett.*, *24*, 237, 1997.

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