GEOPHYSICAL RESEARCH LETTERS, VOL. 25, NO.14, PAGES 2605-2608, JULY 15, 1998

The aurora during the passage of the May 27, 1996 magnetic cloud

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Abstract. On May 27, 1996 two all-sky cameras in Antarctica observed the aurora during the passage of a magnetic cloud. Compression of the magnetosphere by the solar wind dynamic pressure pulse in front of the magnetic cloud caused a short, strong, and localized blue auroral emission which moved towards noon in the late morning sector. The emission was caused by electrons of 8 keV energy. The high dynamic pressure caused a diffuse large-scale (at least 3 h MLT and 5° latitude) blue emission on closed field lines. The high energy electron precipitation disappeared after the enhanced solar wind dynamic pressure region had passed the sub-solar magnetopause.

1. Introduction

Magnetic clouds are ejections of solar plasma characterized by strong magnetic fields, a smooth rotation of the magnetic field direction, a low plasma β and a low plasma temperature [*Burlaga*, 1988]. Magnetospheric phenomena can be studied under stable interplanetary conditions because the duration of the cloud passage (20-30 hours) is long when compared to the relaxation time of the magnetosphere ($\approx$ 30 minutes). The interaction of a significant and persistent southward interplanetary magnetic field (IMF) with the magnetosphere generally triggers geomagnetic activity and may cause geomagnetic storms. It was shown that most of the large geomagnetic storms were caused by either compound streams or/and magnetic clouds [*Burlaga et al.*, 1987; *Lepping et al.*, 1991]. Periods of high and suddenly changing solar wind dynamic pressure, southward, and northward IMF are characterized by the occurrence of dayside auroral phenomena like the dayside auroral breakup and flux transfer events [*Sandholt et al.*, 1990; *Lockwood et al.*, 1990].

Paper number 98GL00409.
0094-8534/98/98GL-00409$05.00

One recent magnetic cloud passed the Earth between October 18 and 20, 1995 and another between May 27 and May 29, 1996. The October 1995 cloud got much attention due to the strong IMF and geomagnetic activity [*Lepping et al.*, 1997]. Unusual auroral emission was described as the rare type A global red aurora [*Sivjee and Shen*, 1997]. However, optical observations could only be performed during 10 hours of southward IMF.

In May 1996 the Antarctic Automatic Geophysical Observatories (AGO) and South Pole station were in darkness during the whole magnetic cloud passage. This paper presents optical data taken with all-sky cameras at South Pole (18.7°E magnetic longitude and 73.9°S latitude) and P3 (40.2°E and 71.8°S). The cameras operate in 1 min time resolution.

2. Observations

On May 27, 1996, a shock wave traveling at 425 km/s hit the WIND spacecraft at 1210 UT followed by a magnetic cloud which arrived at the spacecraft at 1442 UT. Within the shock the solar wind dynamic pressure increased rapidly to 4 nPa (Figure 1). Behind it, the IMF B_z component jumped from $\approx$0 nT to -8 nT. During the following 33 hours, the magnetic field remained relatively constant at 8-10 nT but the direction rotated steadily from southward to northward.

The shock and the cloud passed WIND at 150 R_E upstream and passed IMP8 at 36.5 R_E 28.5 min later (not shown). Extrapolating to the bow shock and taking into account the magnetosheath velocity and the time it takes for the IMF information to travel to the ionosphere [*Jacobsen et al.*, 1995], ionospheric responses would be expected after 1250 and 1522 UT.

On May 27, 1996, the all sky camera at South Pole observed the usual diurnal movement of the red 630.0 nm aurora during negative to zero IMF B_z conditions (Figure 2). The movement is due to the rotation of the Earth under the asymmetric auroral oval producing an apparent poleward motion to -76 to -80° magnetic latitude prior to local magnetic noon (1530 UT) and

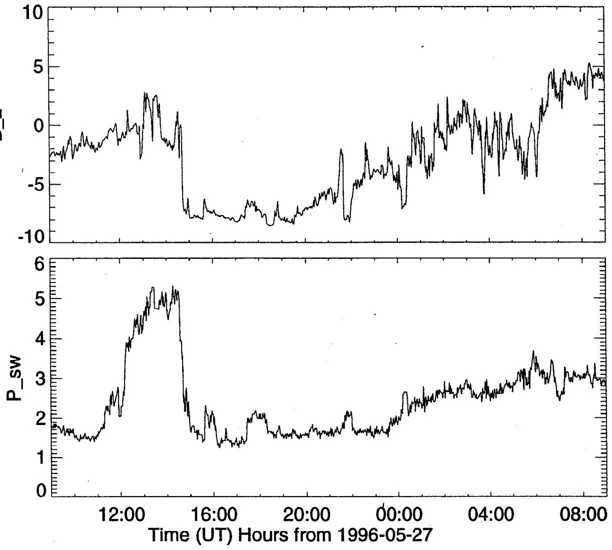

Figure 1. Solar wind B_z and dynamic pressure measured by WIND on May 27, 1996.

equatorward motion to -70 to -72° magnetic latitude around 1700 UT (1400 MLT).

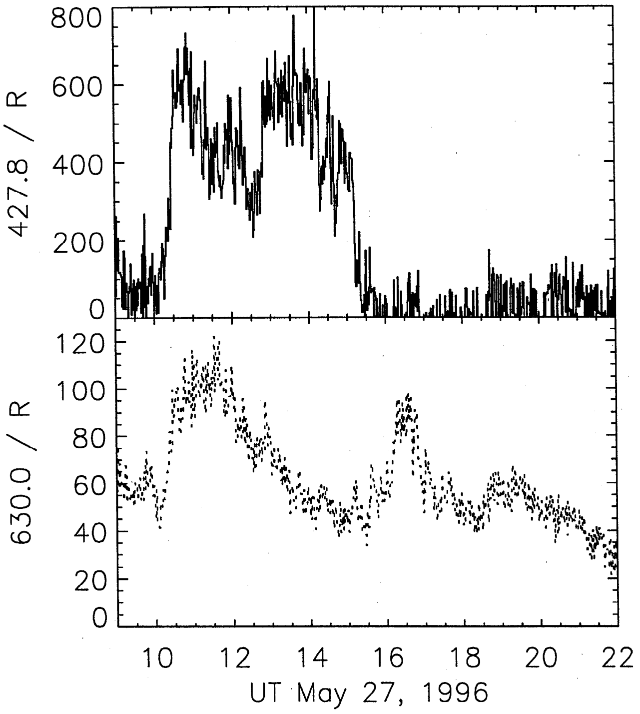

Figure 3. Mean intensities in the South Pole all-sky camera field of view on May 27, 1996.

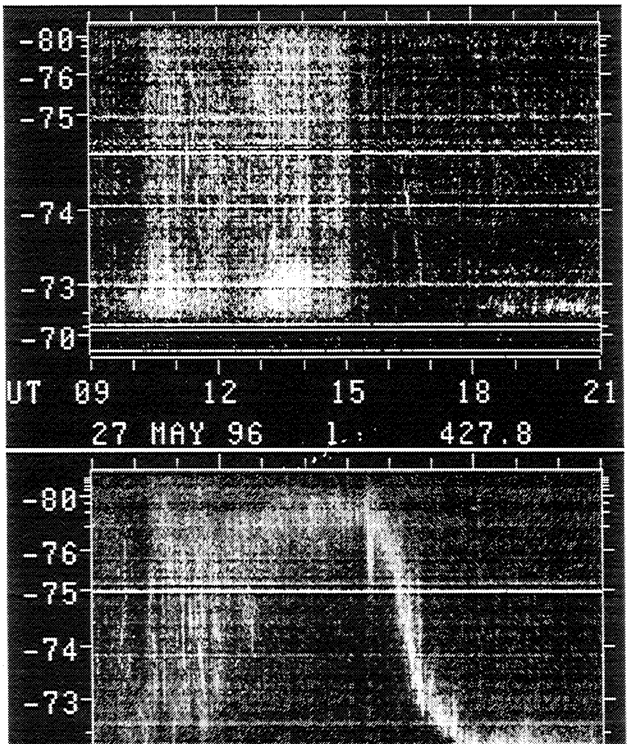

Figure 2. Keogram of South Pole in 427.8 nm (upper part) and 630.0 nm. Horizontal stripes are data gaps.

At 1016 UT, the intensity of the red and blue emission suddenly increased due to a substorm at magnetic midnight (Figure 3) identified from the ISTP key parameters of POLAR and magnetometer recordings in Canada and Scandinavia (not shown). During the following decrease of the blue and red emissions, the pressure pulse hit the magnetosphere and caused a short (5 min) increase of the red at 1250 UT and a long lasting (140 min) diffuse blue emission. Figure 3 shows the mean intensity of the emissions in the central 90° field of view of the all sky camera. A similar behavior could be determined with the P3 all sky images, however due to a malfunction of the camera only 40 images were recorded between 1000 and 2000 UT (not shown). Therefore, the diffuse blue emission appeared in an area of at least 3 hours MLT and 5° magnetic latitude.

A 110 km long and 20 km wide region of strong blue emission suddenly appeared in the 1250 UT image and moved towards noon at 5 km/s (Figure 4 A-C). It reached the edge of the field of view after one minute and was not visible in the next image. This motion produced a trail in the red emission from the original position at zenith to the position at 1251 UT and this is evidence that the blue emissions in both images (1 min apart) are correlated to and caused by the motion of a single feature. At 1255 when there were simultaneous images from South Pole and P3 (Figure 4 D) the feature had already left the field of view of both stations.

Another short lived region of blue emission appeared at 1628 UT. It may be correlated to the short pressure and B_z increase observed by WIND at 1538 UT. It disappeared after 1630 UT, but this time it moved at only 250 m/s sunward.

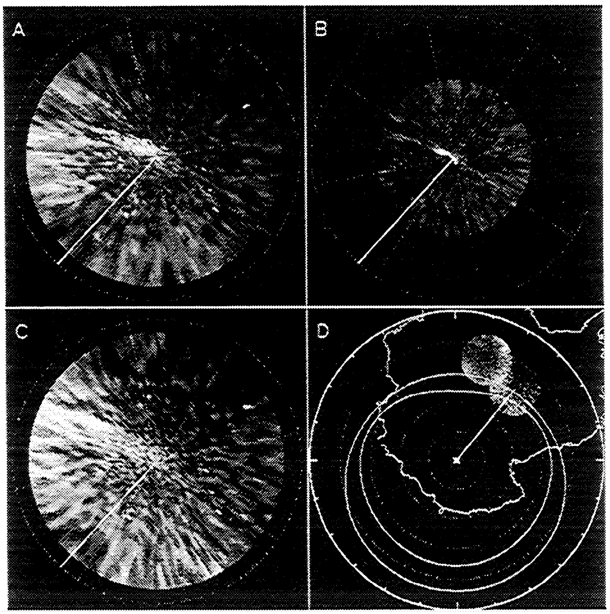

Figure 4. Geographic projections of the all sky images conforming with viewing the aurora from above in the northern hemisphere or looking from the north pole through the Earth to the southern hemisphere. The sun is towards the top, dawn is to the right, and the direction to the magnetic pole is marked by the solid line. A) South Pole 1250 UT, 630.0 nm; B) South Pole 1250 UT, 427.8 nm; C) South Pole 1251 UT, 630.0 nm; D) South Pole and P3 in geomagnetic presentation 1255 UT, 630.0 nm; the average auroral oval is given.

3. Discussion

The structure of the magnetic cloud very much resembles that from October 18-20, 1995 [*Lepping et al.,* 1997]. Both were south-north turning clouds preceded by a solar wind pressure enhancement. However, the magnetic field strength in October 1995 was much higher (20 nT) as well as the pressure in the front shock (8-20 nPa). The October 1995 cloud caused a major magnetic storm and the May 1996 cloud did not. The maximum negative excursion of the Dst index was -127 nT in October, while in May 1996 it was only -31 nT.

When a pressure pulse hits the magnetosphere, an inward motion is expected at the sub-solar point [*Roelof and Sibeck,* 1993]. South Pole was at 0920 MLT and the localized strong blue emission must be related to the compression of the magnetosphere and the energization of plasma. Except at 1628 UT no other such structure was observed during this and the two days before and after. The brightness within the short-lived bright spot was 0.2 kR and 3.0 kR in the red and blue, respectively. An electron energy of 8 keV can be estimated [*Rees and Luckey,* 1974]. Simultaneous imaging riometer observations from South Pole (not shown) confirm the motion of an absorption structure from west to east above the observation site. The riometer absorption up to 0.7 db is consistent with precipitation of ≈ 8 keV electrons.

Some transient structures in the dayside aurora were described as midday auroral breakup [*Sandholt et al.,* 1990] and our short lived blue emission is somewhat similar in spatial scale, appearance of red and blue emission, and longitudinal motion at 5 km/s. However, the keogram data confirm that the main red aurora was poleward of South Pole and the blue spot overhead was equatorward of the dayside soft aurora, most probably on closed field lines. Furthermore, this structure did not move poleward across the cusp/cleft aurora, no periodic occurrence was observed, and the average precipitation energy was much higher than 0.3-2 keV. The ground signature of a dynamic pressure pulse is an anti-sunward moving convection vortex associated with north/south magnetic field perturbations and increased particle precipitation [*Sibeck,* 1990]. However, the magnetic recording from South Pole (Figure 5) does not show the typical bipolar magnetic field variation. The motion of the bright blue spot towards noon is also inconsistent with this interpretation. The sunward convection direction is consistent with the local closed field line configuration. But the motion at 5 km/s can not be related to the motion of plasma in the ionosphere because these motions generally are an order of magnitude slower.

Until 1500 UT the red intensity decreased to less than 50 R and the mean intensity of the blue remained quite stable around 0.6 kR. Thus, the average electron energy was about 8-10 keV. This long period of enhanced hard precipitation is caused by the high solar wind dynamic pressure. The continuous compression of the magnetosphere creates an increased dayside magnetic field strength and this changed magnetic topology leads to increased pitch angle scattering and created the enhanced precipitation in the dayside region from 900 to 1300 MLT.

The disappearance of the blue emission at 1514 UT (Figure 3) can be explained by the expansion of the magnetosphere after the solar wind dynamic pressure decreased and the IMF B_z component jumped to -8 nT. The lack of enhanced precipitation after that time

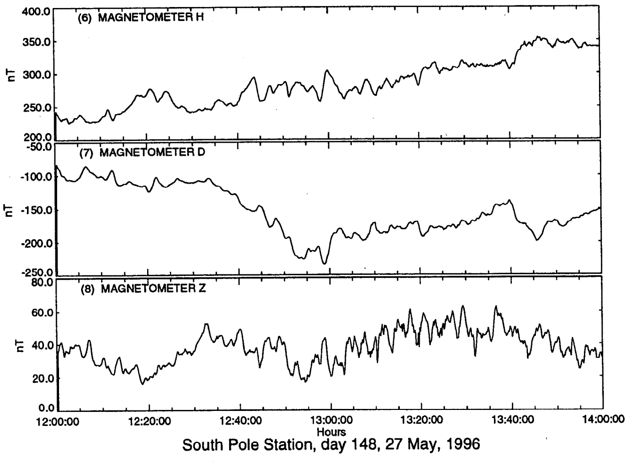

Figure 5. Magnetometer recording at South Pole.

shows that compression by the dynamic pressure is more likely to cause precipitation than the erosion caused by the southward IMF. The ratio of the red and blue emissions allows for an estimate of an average electron energy of less than 1 keV after 1530 UT. This is consistent with the 500 eV ± 100 eV reported for the October 18, 1995 magnetic cloud during the southward IMF period [*Sivjee and Shen,* 1997]. However, observations in only two wave length bands do not allow for an identification if the aurora of May 27, 1996 was type A global red aurora as well.

The apparent motion of the red aurora from poleward to equatorward between 1600 and 1800 UT on May 27 is a common feature during southward IMF conditions. On May 27 the IMF B_z was - 8 nT and $B \approx 8 - 9$ nT and the motion from -78° to -72° magnetic latitude took only 1.5 h. The velocity of this motion, however, was considerably larger than the velocity on other days e.g. May 16, 22, and 25, when it always took about 2.5 h with an IMF B_z of about - 4 nT and $B \approx 5$ nT.

4. Conclusions

This paper presents optical and riometer observations of an increased, long-lasting, diffuse blue auroral emission in the pre-noon and post-noon sector during the 140 min compression of the magnetosphere by an enhanced solar wind dynamic pressure in front of the magnetic cloud. This large area (at least 3 h MLT and 5° latitude) high energy precipitation (8-10 keV) is an important energy supply into the dayside ionosphere. Earlier investigations [*Sibeck,* 1990 and references therein] concentrated on transient and sudden events. The disappearance of the diffuse emission exactly matches the time when the dynamic pressure decreased again. The B_z negative phase of the cloud event did not cause such enhanced energetic precipitation.

The pressure pulse caused a localized enhanced blue auroral emission. A connection to local reconnection at the magnetopause is unlikely because the feature was located in the area of closed field lines and because the IMF B_z component was close to 0 nT. However, this transient phenomenon does not show the main characteristics of dayside auroral breakup and traveling convection vortices.

Acknowledgments. The U.S. Automatic Geophysical Observatory program in Antarctica is supported by National Science Foundation grant OPP9529177 to the University of Maryland. The South Pole riometer and magnetometer data were acquired with the support of NSF grant OPP9505823 to the University of Maryland. We thank J. Etter for assistance with the riometer data processing and display and L. J. Lanzerotti for providing us with the South Pole ground magnetometer recordings. The authors are indebted to R. P. Lepping for the permission to use the MFI data and to R. P. Lin for the 3DP WIND data.

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(Received October 14, 1997; revised December 24, 1997; accepted January 23, 1998.)