Discovery of a New Auroral Signature of Solar Wind Pressure Pulses.

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A review of all noon sector keogram data (630 and 427 nm auroral emissions) for the austral winter 1999 from S. Pole station has revealed a phenomena associated with solar wind pressure increases impacting the magnetosphere. A short duration (10 minute) pulse of auroral emission is triggered in both wavelengths across a large part of the field of view (typically 80 to 70° AACGM) at the time a pressure pulse impacts the magnetosphere. Examination of event sequences (using all-sky images) suggests a two stage response. The first response is a longitudinally narrow emission which leaps equatorward at velocities too fast to be resolved with the resolution of the experiment. The second response is a longitudinally extended equatorward bulge of the auroral oval which commences several minutes after the first response. These observations are significantly different from earlier reports of the response to solar wind pressure pulses but bear a close resemblance to events tentatively associated with FTEs (Mende et al., 1990). It is suggested that the equatorward spur is triggered by a fast mode wave propagating in the equatorial plane which enhances pitch angle scattering of magnetospheric particles.

Introduction

A survey of the South Pole keogram data held at the Space Sciences Laboratory (SSL), University of California, Berkeley (http://sprg.ssl.berkeley.edu/atmos/data/) has revealed a distinctive signature of solar wind pressure pulses interacting with the day side magnetosphere. Examining previously published South Pole auroral imager data (Mende et al., 1990) has shown similar signatures and new evidence shows that those events also occurred at the time solar wind pressure pulses were incident on the magnetosphere. The signature bears some resemblance to fast and super-fast auroral waves reported on the night side during substorm recovery phase, although on the night side the events were of much longer duration. A tentative explanation for the characteristics of the events is given in terms of the theory of Perona (1972) for the triggering of magnetospheric electron precipitation at the time of sudden commencements.

Observations.

Figure 1 shows a sample of keograms from the S. Pole all sky imager operated by SSL, all are of the 630 nm emission. The keogram is constructed from a meridional slice of the all sky image. The top left keogram (8 June 1999) does not show any of the events being discussed, it is a typical keogram during IMF Bz southward conditions. Local magnetic noon is ~15 UT (check) in this keogram.. The diurnal variation of the 630 nm emission on the day side has been described by Eather (1985) and forms the characteristic U shape seen in this keogram between 1200 and 1800 UT. For IMF Bz northward conditions the 630 nm emission is usually sited poleward of the station (> 74°).

The other panels in Figure 1 have the same y-axis scaling as the top left panel, but only show the keograms on the day side (1200-1800 UT). The phenomena being discussed here is the short duration (~ 10 minutes) emissions that go from the pre-existing emission to some distance equatorward (typically 4-5° of latitude and sometimes greater). These are seen at:

27 April 1415 UT; 15 June 1555 UT; 3 July 1455, 1550, 1605 UT; 6 August 1550 UT; 15 August 1545 UT. On some of the records, e.g. 6 August, it is clear that the emission is also triggered poleward of the pre-existing emission latitude. From 1999 winter data, 116 days of data was surveyed and 17 days with events were identified. The phenomena was seen for both Bz north and southward conditions. Identical features are often seen in the 427 nm emission, indicating that the precipitation is not confined to soft electrons.

Two of the events are examined in more detail in figures 2 and 3. The 27 April event (fig. 2) illustrates the difference between the phenomena and the aurora's response to a transition of the IMF from Bz northward to southward. The WIND s/c (two lower panels) observed two solar wind features, a sharp increase in solar wind dynamic pressure (factor 3 increase) at 1405 UT and at 1455 UT the IMF clock angle rotated from northwards to southwards (but with a significant IMF By component). The GOES 8 geosynchronous satellite (~0920 MLT) observed the compression of the magnetosphere resulting from the solar wind pressure increase at ~1410 UT. The equatorward leap of the 630 nm emission seen at 1415 UT and lasting for ~6 minutes, extended from ~82° latitude to nearly the zenith (74° latitude). (No attempt has been made to calculate the delay from the WIND s/c to the ionosphere, but note that WIND is relatively close to the Earth at X=47 Re). By contrast, the equatorward expansion of the whole auroral emission at ~1455 UT would be associated with the IMF transition to southward.

Figure 3 shows data from the 3 July, when multiple events were detected. The Geotail and IMP-8 spacecraft were in the solar wind. The period has both IMF Bz northward and southward intervals . GOES 8 (at ~11 MLT) detected two very clear compressions of the total field in the magnetosphere, at around 1600 UT (double humped feature) and 1715 UT. We associate these with the auroral events seen at around 1600 UT (two events) and 1715 UT, in which the auroral emisison leapt equatorward by ~8° of latitude for a period of ~10 minutes. However, there is an auroral event at 1500 UT but this is only associated with a very weak increase in the total field at GOES8. The Geotail spacecraft shows a highly variable pressure term in the solar wind, although there is an enhancement just after 1500 UT.

So far only the all sky images (taken at one minute intervals) for one event, 27 April, have been examined. A selection of these is shown in figure 4 in order to illustrate the characteristics of the event. The top left panel shows the pre-existing aurora, well poleward of the station and seen as an arc of emission. At 1416 UT an equatorward "spur" is seen towards the centre of the field of view, stretching from the pre-existing arc and reaching the zenith. The spur was evident (but a weaker emission) in the previous two images The pre-existing arc has intensified its emission, consistent with the recently reported global response to solar wind pressure increases (Zhou and Tsuratani, 1999). The equatorward spur remains as a distinct entity for 2 to 3 minutes but then appears to develop in to a much larger equatorward bulge of the auroral emission (1420 UT). This feature then persists for nearly 10 minutes. In the discussion section the case is made that it is the equatorward spur that is the new feature being reported, as a previous paper has reported the equatorward bulge that develops after this. The apparent contradiction in time scales between the keogram data (typically 10 minutes or less) and the above description (closer to 15 minute duration) can be reconciled by considering the orientation of the meridional slice given in the keogram data with respect to the auroral features.

Previous Observations

Several auroral signatures of solar wind pressure pulses have been reported in the literature but it is suggested that the phenomena of the equatorward "spur" discussed here has not been clearly identified in the literature.

The only previous literature that appears to have reported similar events is the paper by Mende et al., (1990). They published all-sky images similar to those shown here (see their figure 1, 14 August, 1985, 1439 UT event). They noted that the events occurred at the same time as ground-based magnetometers recorded magnetic impulse events (MIE, Lanzerotti et al., 1986). Although reaching no firm conclusions about the trigger for the events, the discussion in Mende et al was framed in the context of enhanced reconnection. It should also be noted that the equatorward spur was not explicitly identified, rather the general equatorward expansion of auroral emissions was described. We have examined GOES5 geosynchronous satellite data for all the events shown in Mende et al. (1990) and find that it always shows evidence for solar wind pressure pulse activity at the time of the event. More importantly, the equatorward spur is found to occur at the very start of the magnetospheric compression. Figure 5 shows the total magnetic field measured by GOES5 at the time of one of the Mende et al. (1990) events. The equatorward spur is seen at the leading edge of an initial reduction in the total field, at 1440 UT. By contrast the MIE event and the equatorward bulge in the auroral emission is associated with the large increase in the magnetic field seen at GOES5 and peaking at 1448 UT. This behaviour is consistently seen in other examples were a geosynchronous satellite is positioned optimally to detect the magnetospheric compression.

For completeness we note that the events reported here are distinctly different from that shown by Frey et al., (1998). They reported an enhancement of auroral emission (particularly in the blue line, 427 nm) across the whole field of view of the camera following a solar wind pressure pulse incident on the magnetosphere . But their event persisted for 140 minutes and thus appears to be quite different in character compared to the short lived transient event reported here. Zhou and Tsurutani (1999), described the global response to pressure pulses seen by the POLAR UVI instrument. An initial auroral brightening in the day side cusp region was seen to subsequently propagate to the night side. The images shown in figure 4 show the initial intensification of the pre-existing aurora. Finally, we note that our events are substantially different in character from the equatorward steps of ~ 50 km observed in 630 nm emission reported by Sandholt et al (1998) and which were associated with a magnetopause erosion event and pulsed reconnection.

Discussion

Our observations and those of Mende et al (1990) suggest the following:

1) When a solar wind pressure pulse is incident on the magnetopause a day side auroral signature is triggered in both the 630 nm and 427 nm observations made at S. Pole station.
2) The signature has two components. The initial equatorward spur is azimuthally narrow (100-200 km) and extends for at least 400-500 km equatorward of the pre-existing aurora. It exists as a discrete entity for some 3 - 4 minutes. The second component is a large equatorward bulge in the aurora, which possibly develops from the equatorward spur. This too extends 400-500 km equatorward of the pre-existing aurora but has a much greater azimuthal extent (cannot determine accurate figure as limited by field-of-view of the all-sky camera). This feature persists for ~10 minutes before fading.
3) Coincident geosynchronous satellite observations from the day side show that the equatorward spur occurs at the start of the compression of the magnetosphere. The large equatorward bulge which follows is associated with MIEs (Mende et al, 1990) and is coincident with the geosynchronous satellite seeing the greatest compression of the magnetospheric field.

Most of the models presented in the literature (e.g. Araki, 1994) for the magnetosphere/ionosphere effects of solar wind pressure variations suggest that the main coupling mode between the ionosphere and magnetosphere is by shear mode Alfven waves. These convert from the fast mode compression wave launched in to the magnetosphere. The timing of the equatorward spur events, right at the beginning of the magnetospheric compression, suggest that this is a fast mode wave signature. Perona (1972) presented a theory to account for the observations of precipitating magnetospheric electrons at the time of an sc (sudden commencement). This involved compression of the magnetospheric B field and consequent enhancement of VLF wave activity (which has been observed) to a level where much more efficient pitch angle scattering of particles can occur. This would account for the relatively energetic (3-4 keV) particle precipitation but it is noted that it is unlikely to produce significant fluxes of the soft electrons required to trigger 630 nm emissions.

One very intriguing aspect of the equatorward spur is its very narrow azimuthal extent. In this respect it is very similar to a night side, substorm recovery phase phenomena that has been reported from the post midnight sector. Fast- and super-fast auroral waves have been reported in just four papers in the literature. Cresswell (1968) and Hough et al (1992) reported azimuthally confined (~200 km) waves of auroral enhancement propagating equatorward from the main auroral oval with velocities of 100's of kms^{-1} (maximum observed velocity in one case was 1200 kms^{-1}). These events are significantly different from the ones reported here, in that they lasted for a long period (typically one hour). They had a wave like appearance, the auroral intensity being enhanced with a frequency of 1 Hz. The resolution of the S. Pole observations does not permit us to comment on whether this wave-like activity exists, or the velocity of propagation equatorward. The latter is obviously fast as fig. 1 shows events propagating up to 800 km within a one minute integration period. Cresswell (1968) postulated that the events must be associated with fast mode waves travelling in the equatorial plane of the magnetosphere.

Summary
The day side auroral signature of solar wind pressure pulses has been examined using South Pole all-sky camera images in the 630 nm and 427 nm emissions. The new observation reported here is that the equatorward bulge is preceded by an equatorward spur of auroral emission, observed in both the 630 and 427 nm emissions. Coincident geosynchronous satellite observations show that this equatorward spur occurs right at the beginning of the compression of the magnetospheric field. It is suggested that the enhanced magnetic field caused by the compression wave, and its impact on wave-particle interactions, produces an auroral signature - the equatorward spur. An intriguing feature of the phenomena, its confinement to an azimuthally narrow area (100-200 km), must provide an important clue as to the nature of the wave-particle interaction.

Araki, T., A physical model of the geomagnetic sudden commencement, in "Solar wind sources of magnetospheric ULF waves", Geophysical Monograph 81, AGU, 1994.
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Zhou XY, Tsurutani BT, Rapid intensification and propagation of the day side aurora: Large scale interplanetary pressure pulses (fast shocks), GRL, 26, 1097, 1999.

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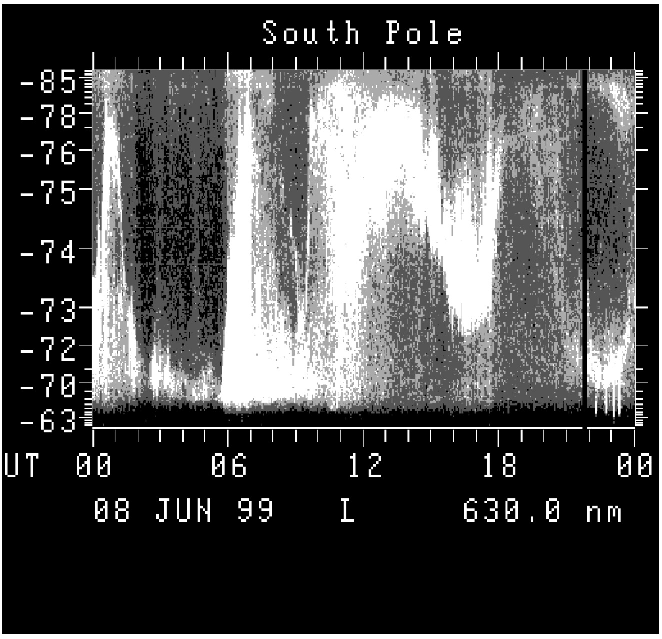
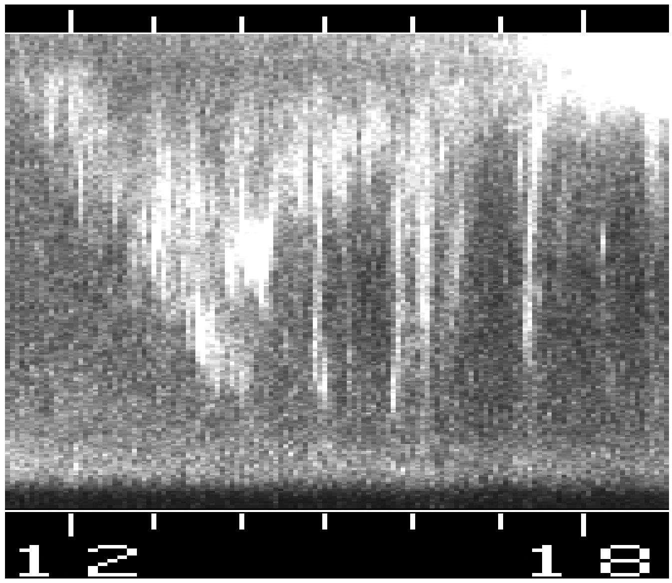
FIGURE 1. S. Pole Keograms - 630 nm emission

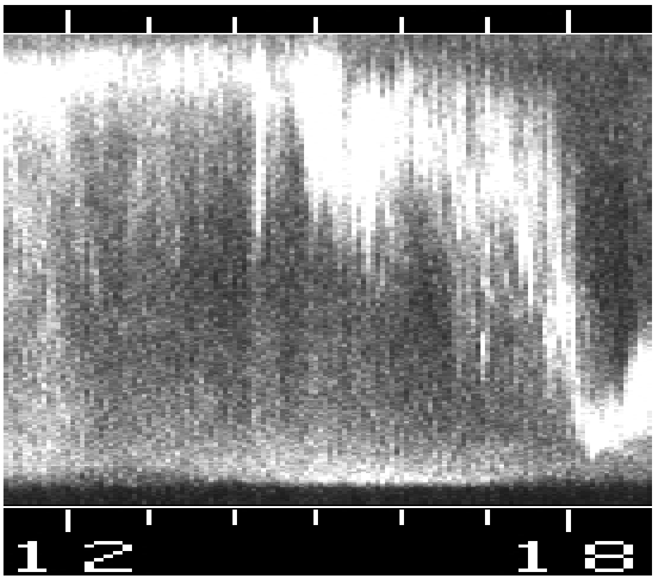
8 June 1999 - illustrates typical Bz southward period



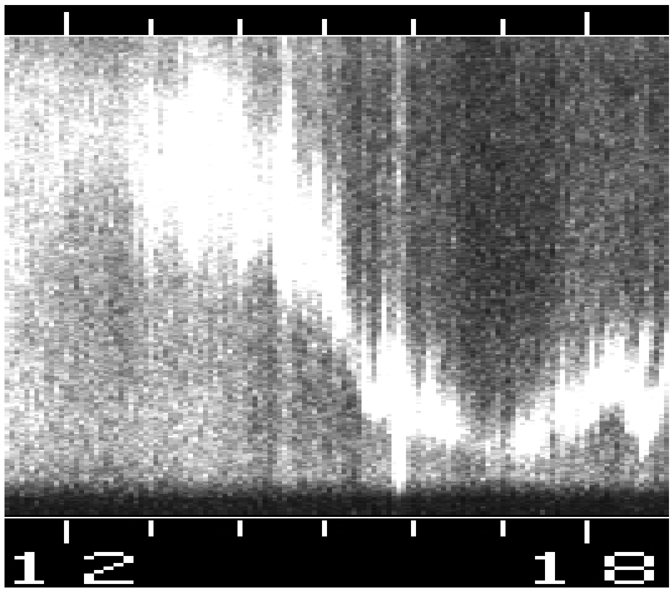
3 July 1999



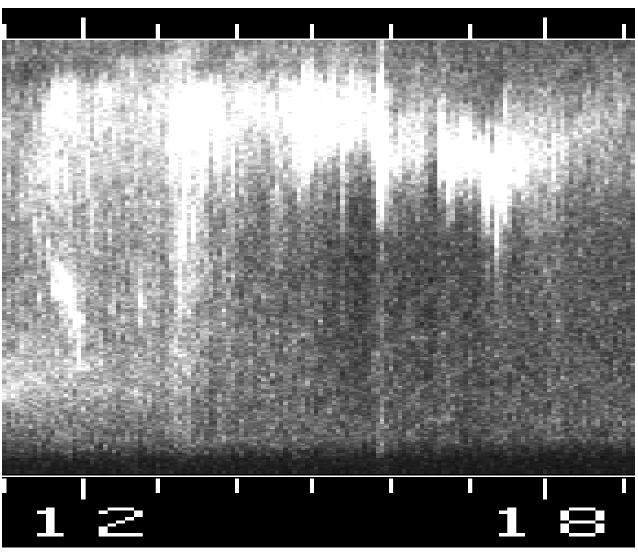
27 April 1999



6 August 1999



15 June 1999



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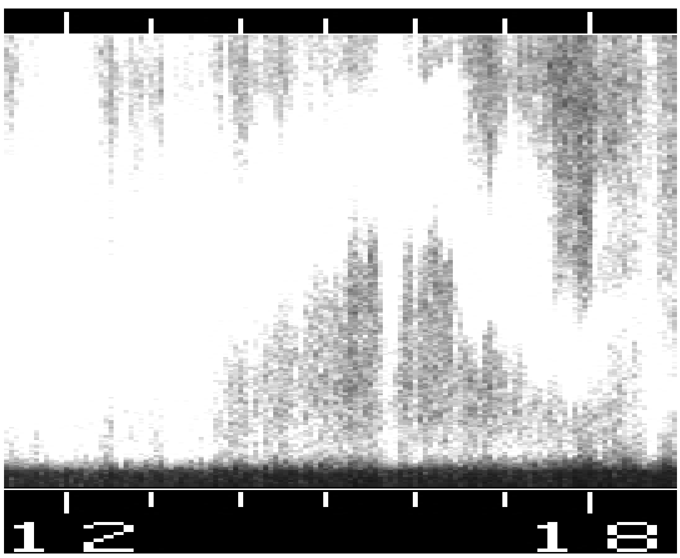


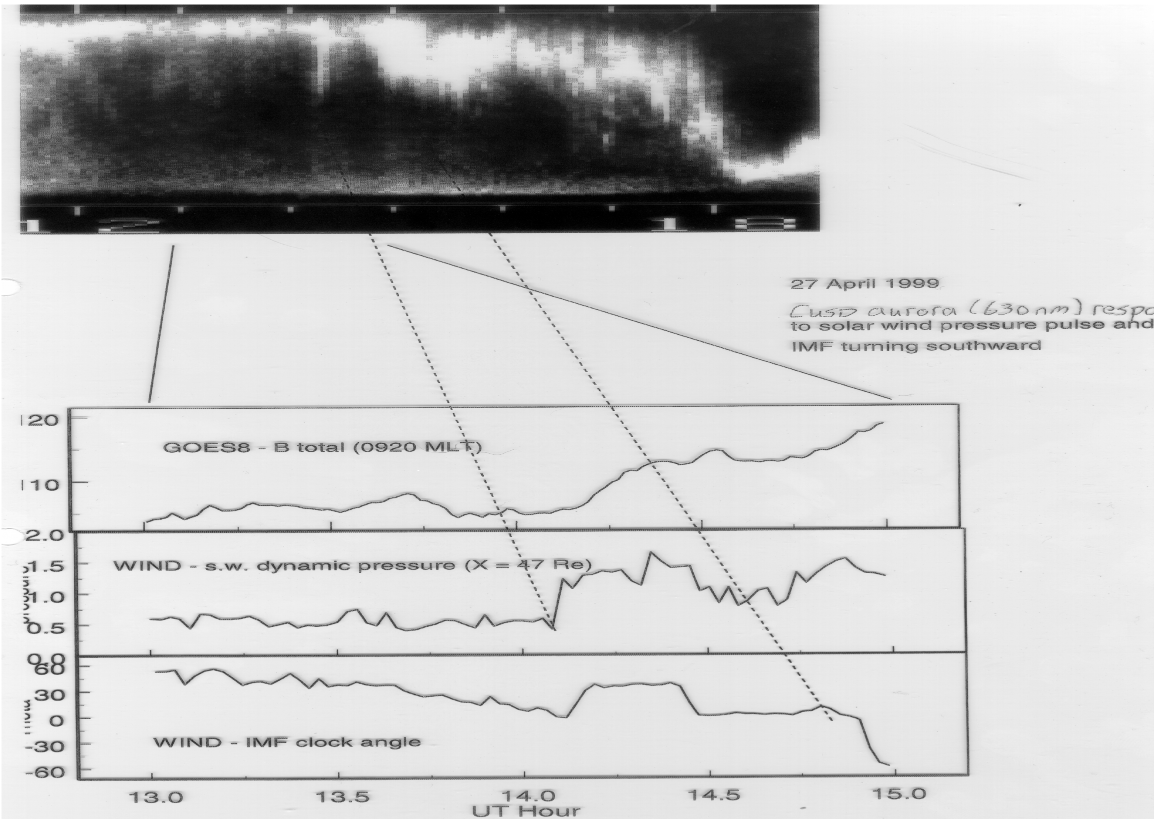


Figure 2. 27 April 1999. The top panel shows the S. Pole keogram (630 nm) y-axis has the same scaling as the top left panel in figure 1 (i.e. centre of keogram is 74 degrees latitude). The next panel down shows the total magnetic field recorded by the GOES8 magnetometer. The final two panels show data from the Wind spacecraft, the solar wind dynamic pressure and the IMF clock angle (arctan (By/Bz). On the latter 0° corresponds to an easterly pointing IMF, +90° and -90° to a purely northward and southward IMF, respectively. There is no time delay applied to the spacecrafts x-axis.

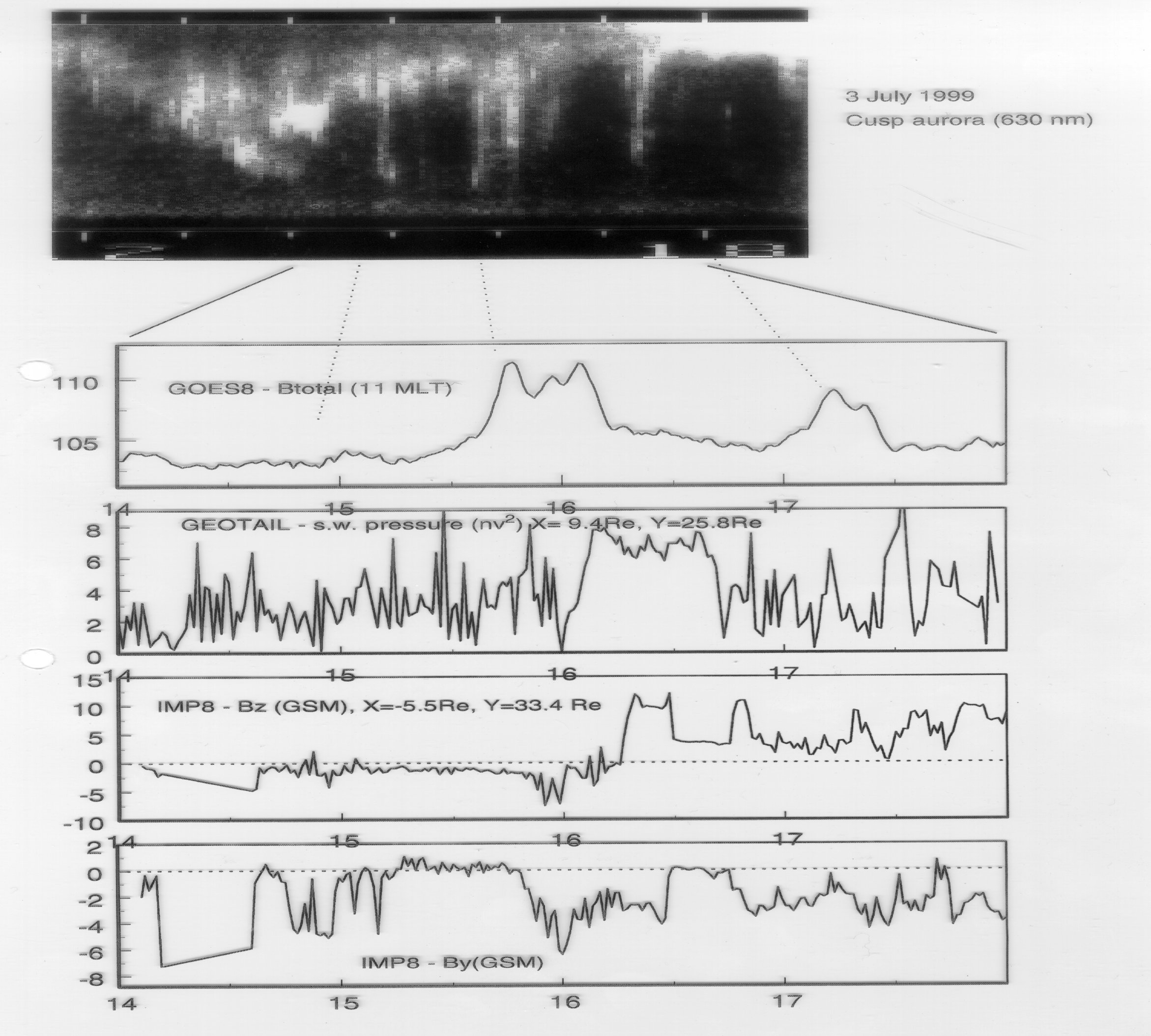
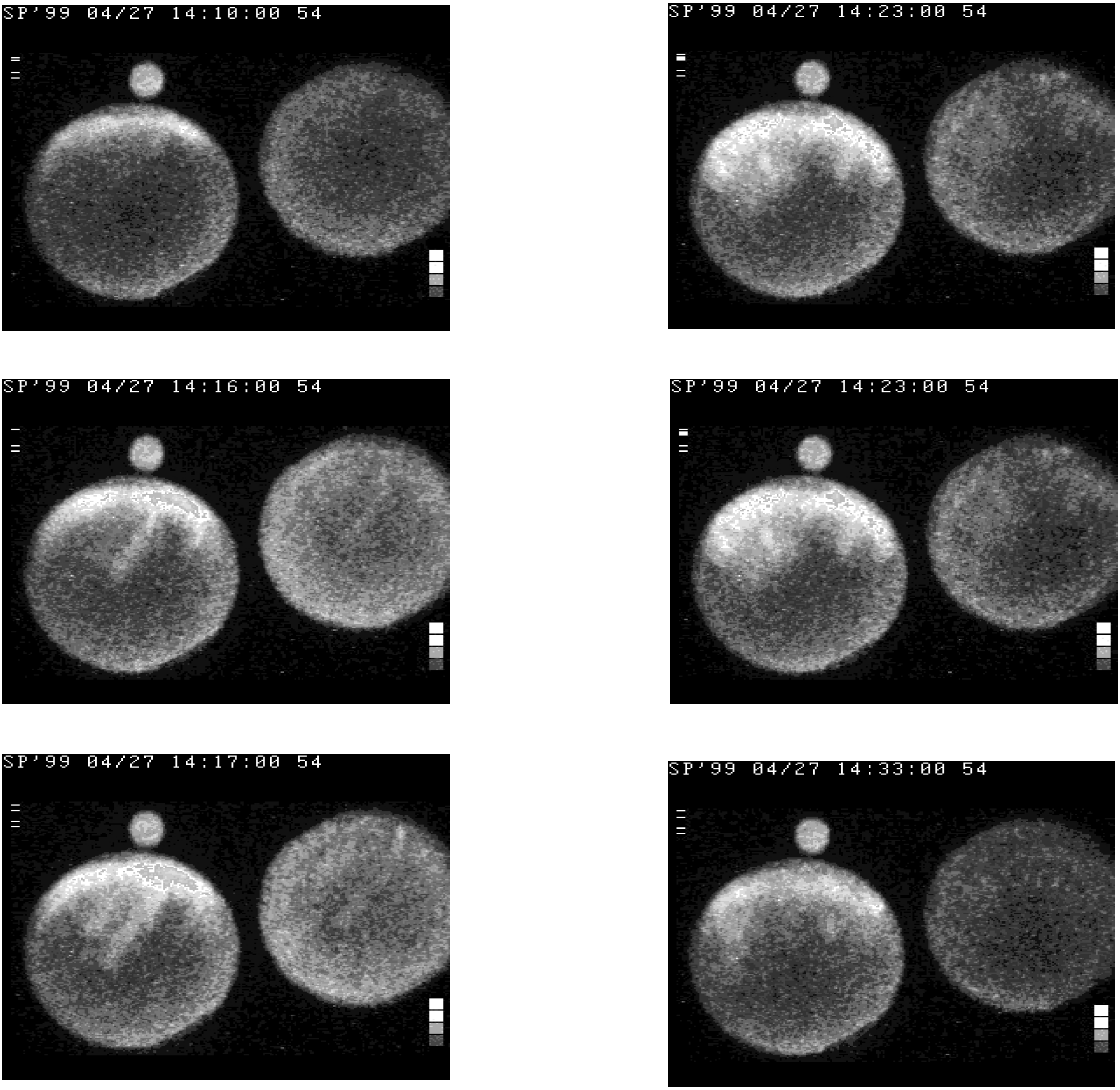


Figure 3. 3 July 1999, similar format to figure 3 except the final 3 panels show data from Geotail spacecraft and the IMF Bz and By data recorded by IMP-8 s/c.



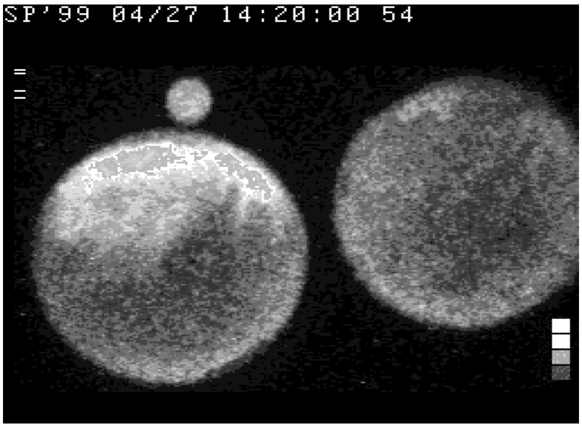


Figure 4. 27 April 1999. Each panel shows an all sky image in 630 nm (left) and 427 nm (right) The time stamp is in the top of each panel. The camera is orientated so that magnetic south is in the 12 o'clock position. The sequence shown lasts 23 minutes.

Figure 5. Total magnetic field data from GOES 5 satellite for 14 August 1985.