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# OBSERVATION OF INTERPLANETARY MAGNETIC FIELD AND OF IONOSPHERIC PLASMA CONVECTION IN THE VICINITY OF THE DAYSIDE POLAR CLEFT

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*Abstract.* Dayside ionospheric convection at high latitudes has been examined during a series of experiments using the Sondrestrom radar together with ancillary observations of the interplanetary magnetic field (IMF) by the IMP-8 spacecraft. The radar experiments obtained a latitude coverage of 67.6°Λ to 81.3°Λ and a temporal resolution of between 14 to 25 minutes. A total of 17 rotations through the dayside cleft region during April, June and July, 1983 have been examined. The observations show two convection cells with sunward flow at lower latitudes and antisunward flow at higher latitudes. The flow commonly rotates through a 180° angle resulting in the predominant appearance of east-west flows. Rapid temporal variations in the convection velocities are frequently observed. Many of the high latitude variations in convection velocity appear to be directly related to variations in the IMF $B_y$ component, with eastward (westward) velocity associated with negative (positive) $B_y$. This is strong evidence for a direct electrical coupling between the solar wind and dayside high latitude ionosphere.

## Introduction

The signature of the magnetospheric convection pattern in the high latitude ionosphere is generally regarded as a simple two-cell pattern with antisunward flow at the highest latitudes and sunward return flow at lower latitudes. Some uncertainty, however, exists in the accurate description of this convection pattern. For example the convection model of Heelis et al. (1982) shows a pattern which exhibits a dayside region of constricted, relatively high speed antisunward flow into the polar cap. Away from local noon, the boundary between sunward and antisunward convection is a tangential discontinuity. Heppner (1977) models a convection pattern in which the transition in flow from sunward to antisunward occurs over a broad region across the dayside. There is no tangential discontinuity in the flow on the dawn and dusk sides in the Heppner model.

It is understood that these models are only approximations to the actual convection pattern which may exist at any given instant. It is well known that the pattern is quite variable. For example, the sign of the IMF $B_y$ component is known to affect the patterns of electric fields, currents and convection in the dayside high latitude ionosphere (Russell, 1972; Friis-Christensen and Wilhjelm, 1975; McDiarmid et al., 1979). When $B_y < 0$ the dawn cell is generally thought to be larger than the dusk cell, and the converse when $B_y > 0$. This has the effect of shifting the location of the center of the dayside antisunward flow toward the prenoon or afternoon side or it may cause the intrusion of one cell into the other distorting the pattern or producing smaller local cells. The polar cap convection velocity is also generally considered to increase with increasingly negative IMF $B_z$ component. On the other hand, the intriguing situation of sunward convection within portions of the polar cap has been observed when $B_z >> 0$. The relationship between $B_y$, $B_z$, and the observed variations in dayside high latitude currents and convection patterns has been interpreted by some to be the result of an electrical connection between the solar wind and ionosphere via magnetospheric field-aligned currents. (D'Angelo, 1980; Primdahl and Spangslev, 1981; 1983; Barbosa, 1984; Banks et al., 1984).

The Sondrestrom radar (73.9°Λ.) provides a new opportunity to obtain continuous detailed observations of the convection pattern and ionospheric electrodynamic parameters in the cleft region over a wide range of geomagnetic activity conditions (Kelly, 1983). In this paper we report examples from a series of experiments which were conducted in April, June, and July, 1983. Geomagnetic activity ranged from semiquiet ($Kp = 2$) to active ($Kp = 6+$). The examples displayed here were chosen to show convection observed during periods of both positive and negative IMF $B_y$ component as well as the response of the convection to changes in sign of $B_y$.



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## Observations

The experiments which we report on here used pairs of antenna positions on either side of the Sondre Stromfjord magnetic meridian to obtain the N-S and E-W components of the ion drift velocity as a function of latitude. Details of this technique are discussed by Foster et al. (1981). During the course of our experiments we used several variations of the positions and dwell times. These changes affected the cycle time of the observations, the latitudinal range covered, and the uncertainty in the velocity measurements. Additional details of the radar capabilities and analysis techniques can be found in Wickwar et al. (1984).

Reduction of the line of sight velocity measurements from pairs of antenna positions to determine a horizontal velocity vector relys on the assumption that the velocity is uniform over the range of the two antenna positions. If this assumption is not valid, the analysis procedure can overestimate the E-W component of velocity and underestimate the N-S component of velocity.

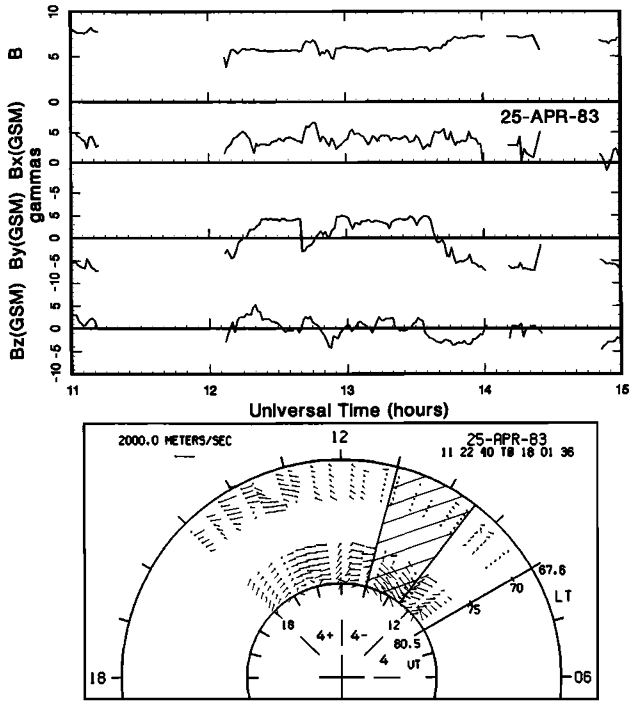


Fig. 1. (a) IMP-8 interplanetary magnetic field measurements on April 25, 1983 plotted in GSM coordinates. From the top are the total field $B, B_x, B_y$, and $B_z$. These data are 1-minute averages and data gaps of less than 5 minutes have been interpolated across. (b) F region horizontal ion velocities measured by the Sondre Stromfjord incoherent scatter radar on April 25, 1983. Local time is indicated around the outer circumference of the plot and Universal Time is indicated around the inner circumference. $Kp$ values are shown around the inner circumference of the plot.

We have examined the velocity computations by conducting an experiment using 4 beam positions at 30° elevation in the northward direction. The azimuths of the positions were -26°, -13°, +13°, and +26° measured from magnetic north. Velocities were computed separately using the inner pair and the outer pair of positions. This experiment was run on April 25, 1983 and again on April 27, 1983 during periods of quiet to moderate geomagnetic activity ($Kp$ between 2 and 4+). In the subsequent analysis of these data we find occasional differences in the velocity vectors computed using the inner and outer pairs of measurements. However, there is good agreement overall, suggesting that, in general, the multiposition experiments provide accurate velocity measurements. There may be occasional small scale features in the real ion velocities which cause errors in our velocity determination. We feel, however, that the points which we will discuss in the following examples will not be altered by the uncertainty in the measurements.

## April 25, 1983

Figure 1a shows 1 minute averaged magnetic field data in GSM coordinates measured by IMP-8 located upstream in the solar wind ($X_{gse} = 26R_e, Y_{gse} = -22R_e$). The expected delay time between the spacecraft and magnetopause is about 4 or 5 minutes assuming a 400 Km/sec solar wind velocity and assuming that the IMF variation lies in a plane orthogonal to the earth-sun line. A slowing of the solar wind in the magnetosheath would produce about 4 additional minutes of delay. If the variation were to lie in a plane oriented orthogonal to the typical 45° Parker spiral angle, the variation would reach the magnetopause about 1 minute before reaching IMP-8. Therefore, a conservative estimate of the time delay between the observation at IMP-8 and encounter with the magnetopause is between +8 minutes and -1 minute assuming nominal magnetopause and bow shock positions.

There is a change in sign from negative to positive in the $B_y$ component at 1215 UT. Unfortunately the interval prior to 1215 UT consists of missing data. However, magnetic observations from the high latitude Greenland meridian chain of stations indicate that $B_y$ was negative for the interval from 1100 UT to 1215 UT. Except for a brief 5 minute negative fluctuation at 1240 UT, the $B_y$ component remains positive at near 4 gammas until 1338 UT when it drops to near 0 gammas and eventually becomes strongly negative at 1343 UT. $B_z$ is positive or small for most of this interval, turning negative at 1333, slightly before $B_y$ turns negative.

Figure 1b shows a polar plot of the ion convection velocities measured perpendicular to B on April 25, 1983. As can be seen from the $Kp$ values shown around the center of the plot, this interval is characterized by moderate magnetic activity, with $Kp \simeq 4$ during the period of dayside measurements. We would remind the reader that the plot is not a "snapshot" but rather is obtained as the radar scans north and south while rotating through the dayside on the earth's surface.

The feature of primary interest in this data is indicated by the shaded region, an interval between 1230 UT and 1400 UT where the high latitude flow direction changed by about 180 degrees compared with the flows on either side of this interval. While we are aware that changes in flow direction can be explained by several situations, such as crossing the boundary between convection cells, it is our feeling that the change in ion flow direction observed during the interval 1230 to 1400 UT is directly related to the change in polarity of the IMF $B_y$ component. In this data, we see two changes in the sign of $B_y$: one at 1215 which is followed by a change in ion flow direction at 1230 UT (0930 LT) and the other at 1343 followed by a change in ion flow direction at 1400 UT (1100 LT). One would not necessarily expect both of these flow changes to be the result of crossing convection cell boundaries.

Using the timing estimates discussed above, if the solar wind disturbance lies in a plane orthogonal with the earth sun line, then the change in ionospheric electric field polarity occurs within about 10 or 15 minutes of the time that the $B_y$ polarity change in the IMF would encounter the magnetopause.

## April 13, 1983

Figure 2a and b shows data for April 13, 1983 in the same format as Figure 1. Unfortunately, the transition of $B_y$ from positive to negative occurs during a data gap. It is possible, nevertheless, to make some interesting comparisons with Figure 1. Whereas eastward flow is observed between 11 UT and 1230 UT on April 25 during an interval of negative $B_y$, the high latitude velocities on April 13 are westward at the same local times during an interval of positive $B_y$. This comparison suggests that it is likely that the observed changes in high latitude ion flow on April 25 are directly associated with the changes in the sign of $B_y$.

In addition, we note that the observations in Figure 2 begin shortly after 0900 UT when $B_y$ and $B_z$ are both positive. The convection is antisunward between $\Lambda \approx 75°$to 80°and sunward at lower latitudes. At about 11 UT $B_z$ becomes negative at about $-10\gamma$ and $B_y$ becomes almost zero. The convection velocities beginning at 1130 and definitely at 1200 UT show a change in convection which could be interpreted as an equatorward movement of the region of antisunward convection in response to the large negative $B_z$. Magnetograms from College near local midnight shows the onset of large negative bays in the H component at about 11 UT indicating a substorm onset immediately following the IMF change. The magnetogram from Tromso near local noon shows the onset of large positive bays at about the same time.

Additionally we note that the velocities are predominantly east-west. Small poleward velocities are observed near 0800 - 0930 LT. There is, however, no region of strong poleward flow as suggested by models which incorporate a throat. The convection reversal boundary on the afternoon side appears to be shear like, while the reversal boundary on the morning side appears to be rotational. A more thorough discussion of the convection reversal boundary is given by Jorgensen et al. (1984).

The afternoon high latitude velocities on April 13 are eastward and are associated with negative $B_y$. It is interesting to compare these velocities with the observations on June 28, 1983 shown in the next example.

June 28, 1983

Figure 3 shows the ion velocity measurements obtained on June 28, 1983 in the same format as Figure 1b. Only quick look plots of the IMF provided by Drs. N. Ness and J. King were available at the time of this writing. These plots reveal that $B_y$ is positive while $B_z$ is variable, fluctuating positive and negative for most of the interval shown in Figure 3. The $Kp$ values indicate moderate geomagnetic activity during this interval. The convection reversal boundary is observed only on the morning side and appears to be a rotational boundary from 0700 LT to 1000 LT. The reversal boundary is not observed on the afternoon side.

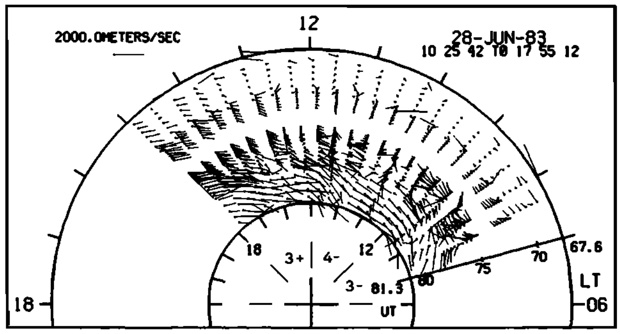


Fig. 3. F region ion velocities during June 28, 1983 using the same format as Figure 1b.

In this example the afternoon convection cell seems to reach into the prenoon sector. If so, then much of the plasma flow above 75°$\Lambda$ on the morning side may originate as part of the evening convection cell. This is consistent with previous studies of dayside convection (Foster and Doupnik, 1984). These examples, however, suggest that this situation is produced by $B_y > 0$ in contrast with April 13 where $B_y < 0$.

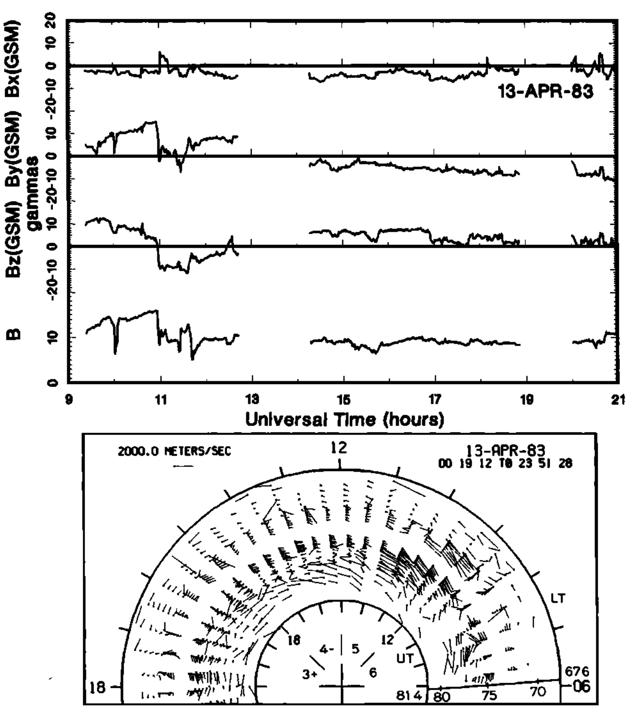


Fig. 2. (a) IMP-8 IMF and (b) F region ion velocities for April 13, 1983 using the same format as Figure 1.

## Discussion

We have presented examples of ion velocities from radar experiments which explored the ionosphere in the vicinity of the polar cleft. Several features characterize these observations and are important to the understanding of high latitude magnetospheric electrodynamics.

First, we note the rapid temporal variations which can occur in the convection. At least some of these rapid variations can be directly related to variations in the IMF with apparently little time delay. This suggests that the electrodynamic coupling between the solar wind and magnetosphere directly influences the distribution of currents and electric fields in the dayside high latitude ionosphere. It is difficult to unambiguously isolate the $B_y$ and $B_z$ dependent effects using a few examples such as shown here. However, the effects described here are consistent with other well established relationships between $B_y$ and high latitude convection, currents and also with models proposed by Friis-Christensen et al. (1984); Banks et al. (1984) and references therein.

Another interesting feature of these observations is the apparently common 180° change in velocity across the convection reversal boundary. We have rarely seen large poleward flows or a constricted region through which sunward flow turns antisunward. This is particularly true during periods when $B_y < 0$ such as the April 13 example. During periods when $B_y > 0$, like the June 28 example, the evening cell seems to intrude into the morning side and one may interpret the large north-westwardly high latitude flows as consistent with a throat potential pattern. We feel, however, that this will require further investigation.

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