The Noon and Midnight Sector Response to IMF Changes.

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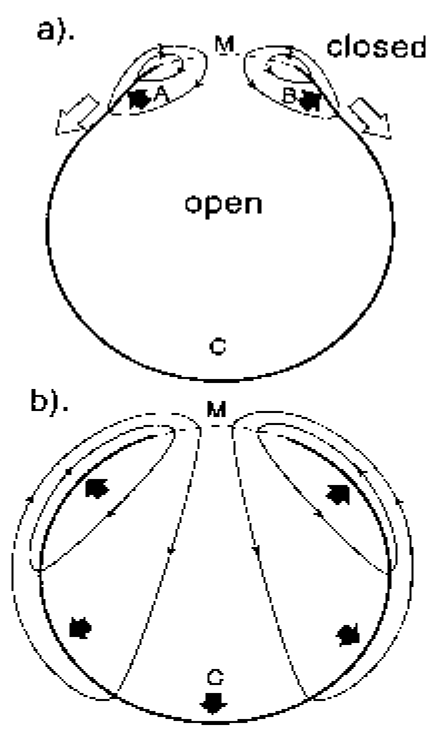
Abstract

We have attempted to test for a simultaneous, near-global response in polar convection resulting from the IMF changing from Bz northward to southward, as shown by Ridley et al. (1998) and Ruohoniemi and Greenwald (1998). The basis of our test is: if the polar convection is enhanced at all local times (and assuming that nightside reconnection is not) then we expect the nightside polar cap boundary to start moving equatorward immediately the cusp ionosphere responds to the IMF change. Noon magnetograms from Durmont D'Urville and midnight HF radar data from Halley, both in Antarctica, are used in this study. The total B field measured by the Durmont D'Urville magnetometer provides a sensitive indicator of when IMF changes first impact the ionosphere, and obviate the need to deduce accurate timings between spacecraft and the ionosphere. The HF radar data is used to detect the growth phase signature previously documented Lewis et al. (1998), which we take as a proxy for polar cap boundary motion. Ten events have been studied and the time delay between these two signatures measured. Within the accuracy of the experiment we find a range of time delays from near immediate to 30 minutes or greater. We speculate on the possible physical mechanisms that may give this range of results.

Introduction

Recent case studies have suggested that the ionospheric convection response to rapid transitions of the interplanetary magnetic field happens nearly simultaneously at all local times (Ridley et al, 1997, 1998; Ruohoniemi and Greenwald, 1998). The interpretation of these observations has been disputed (Lockwood and Cowley, 1999; Ridley et al, 1999) and other observations have suggested a much longer response time (e.g., Khan and Cowley, 1999). Variations in ionospheric convection velocity have been attributed to many processes, not all of them related to changes in the IMF.

Figure 1.

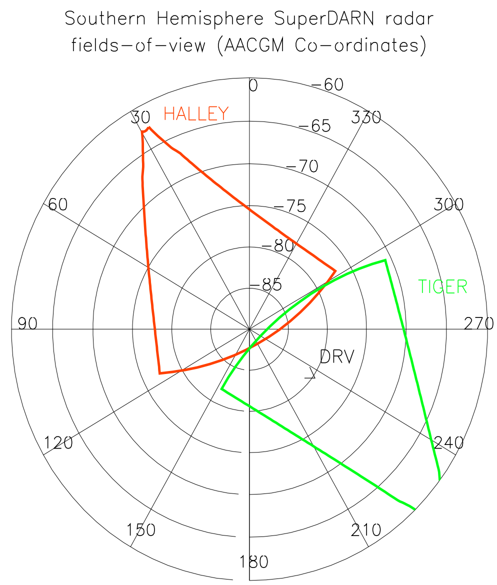


Lockwood and Cowley (1999, their figure 3 shown as figure 1 opposite) show that if a simultaneous response in convection existed at all local times (fig 1b) then the polar cap boundary would be expected to be set in motion on a similar time scale. By contrast, if the Cowley and Lockwood (1992) mechanism operates (fig 1a) then the polar cap boundary away from the noon sector will respond with a progressively longer time scale as the newly added flux is redistributed in the polar cap, with delays on the nightside of some 10-15 minutes. This provides an alternative to examining plasma velocity variations for testing for a simultaneous response. In this paper we use a proxy measurement of the midnight polar cap boundary and a ground polar cusp magnetometer to detect the midnight and noon responses to IMF transitions.

Technique

Figure 2 shows the configuration of the experiment. Figure 2.

The Halley SuperDARN radar has its boresight close to the 30° E longitude and the data used in this paper is in the midnight sector. Durmont d'Urville is at 81° S, 235° E and data from the fluxgate magnetometer is used and is typically in the post-noon sector (13 to 14 MLT) for the epochs studied.



We use the HF radar signature of the substorm growth phase signature (Lewis et al., 1998; Yeoman et al., 1999, Voronkov et al., 1999) as a proxy for the polar cap boundary motion. Lewis et al. (1998) showed that for small, isolated substorms (the cases examined here) the equatorward boundary of F-region scatter in the HF radar data in the midnight sector showed a steady equatorward motion during the growth phase of a substorm. This equatorward motion exceeded the normal diurnal variation of the auroral oval. They noted the similarity of this signature to that reported by Samson et al. (1992) for the proton aurora. Voronkov et al (1999) made a more conclusive link between the motion of the radar backscatter and that observed in the auroral emissions at 630 and 427 nm. In particular, they showed a very close link between the 630 nm emissions and the HF radar backscatter, similar to that found for cusp 630 nm emissions and HF radar backscatter on the dayside (Rodger et al., 1995). We note that the night side 630 nm emissions have been shown to be a good proxy for the nightside polar cap boundary (Blanchard et al., 1996) In summary, although it has not been shown that the HF radar backscatter marks the polar cap boundary it is clear that the equatorward motion of the scatter during the substorm growth phase mimics the equatorward motion of the polar cap boundary.

Our technique requires that the start time of the equatorward motion of the polar cap boundary on the nightside be defined. We do this by finding the average latitude of the equatorward edge of the HF radar backscatter during the IMF Bz northward period, for the 30 minutes prior to the IMF transition. We then note the first time that the scatter steps equatorward by one range gate (45 km) in the meridional pointing beam, with the proviso that the equatorwad motion must be the start of a sustained equatorward drift characteristic of the HF radar growth phase (Lewis et al., 1998).

The radar operating parameters and the polar cap boundary motion set the resolution of the experiment. For example, with an integration time of 90 s, and a 45 km range gate on the meridional pointing beam, to detect an equatorward shift of the boundary by one range gate within one integration period requires a polar cap boundary velocity of 500 ms^{-1}. Ruohoniemi and Greenwald (1998) reported plasma flows of this magnitude in the 21 MLT sector following an IMF transition.

Note that an implicit assumption in our technique is that the nightside reconnection does not commence simultaneously with dayside reconnection, that all the plasma flow on the nightside is being driven by dayside reconnection.

Examples

Ten cases studies have been assembled, from which we present two examples. Both examples are taken from Lewis et al. (1998), the first is from the period 20 October 1995. Figure 3 shows a stack plot of the IMF clock angle (arctan (By/Bz)) determined from the WIND satellite data. The IMF transition occurred at approximately at 01:42:43 UT, when the IMF clock angle went from 60 to ~0°. Although not a sharp transition to IMF Bz negative, many studies have shown that low latitude reconnection on the magnetopause is initiated for clock angles of 0° or even greater (e.g. Freeman et al. 1993)

The second panel shows the total magnetic field recorded by the Durmont d'Urville magnetometer. The station gives a very characteristic signature of the IMF switching to IMF Bz (seen in all the case studies examined), the total magnetic field is reduced by several hundred nT. Such a depression was observed at 0230 UT (marked by the vertical dashed line). We take this to be the time at which the IMF transition is clearly detected at 80° latitude in the noon sector.

The third panel shows the vertical (Z) component of the Halley station magnetometer. Halley (62° S AACGM latitude) is a sub-auroral station during quiet periods and the electrojets are usually positioned polewards of it. It is thus the Z trace which responds most clearly to changes in either the position or intensity of the electrojet. The Z trace shows a steady decrease from about 0232 UT, indicating either an increase in the intensity of the DP2 current system or an equatorward displacement of the electrojet (or a combination of both).

The fourth panel shows a time series of the radar backscatter recorded on the meridional pointing beam (8), the colour codes giving the power, line-of-sight velocity and Doppler spectral width. We detect the start of an equatorward motion of the equatorward boundary of the backscatter at 0232 UT, which is then sustained until the onset of a substorm expansion phase at 0330 UT (as described in more detail in Lewis et al. 1998).

In this case the dayside and nightside response occurs with 2 minutes (the resolution of the radar data). It should also be noted that the meridional velocity component is towards the radar at 0232 UT and that in fact it showed an enhancement in velocity (at the poleward boundary of the scatter) as early as 0225 UT. The difference between the onset of enhanced velocities and the movement of the boundary is to be expected: the plasma drift must act on the boundary for a period of time to produce a shift of 45 km in the boundary.

Figure 3.

20 October 1995 - noon and midnight sector response to IMF transition

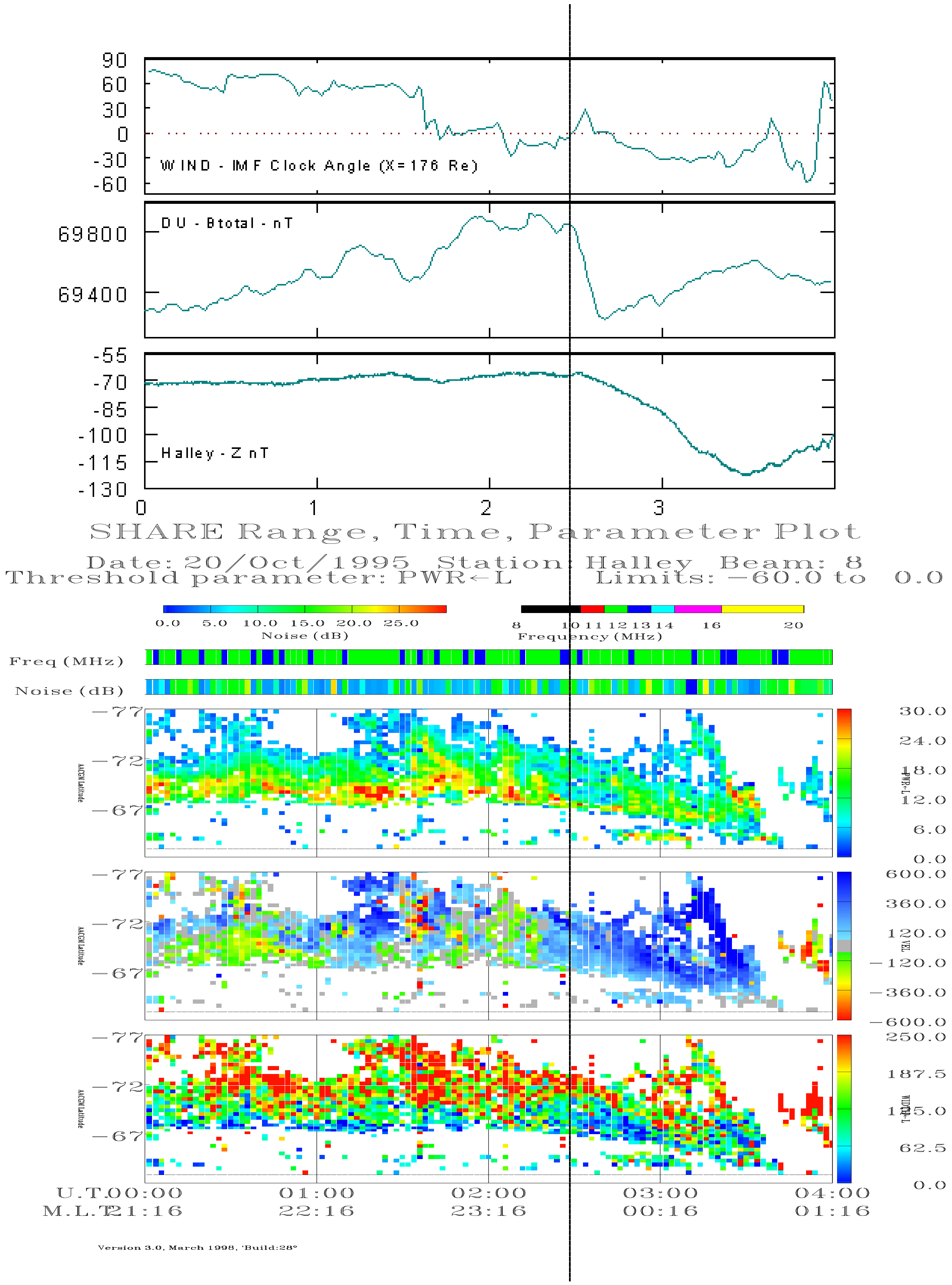
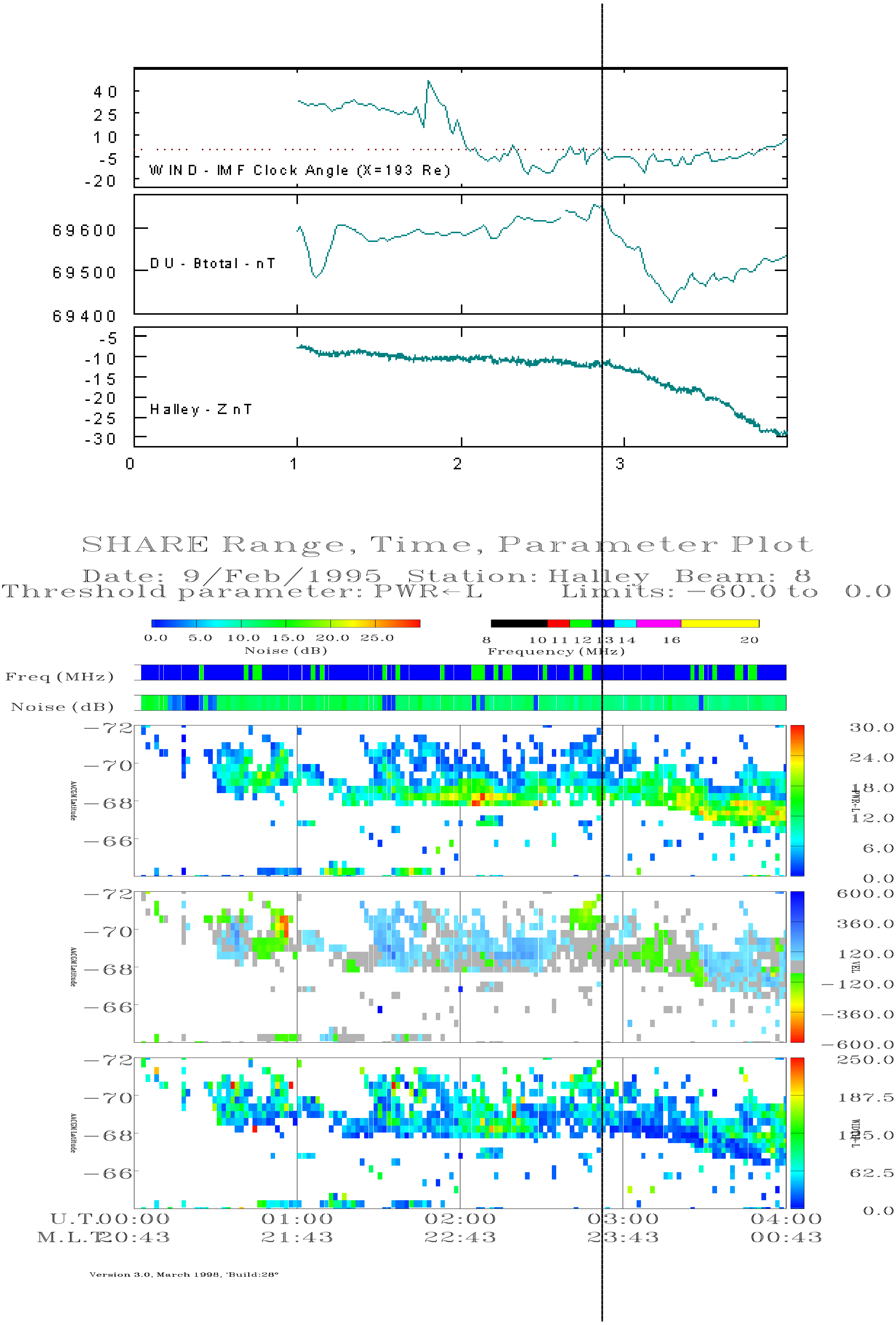


Figure 4.

9 February 1995 noon and midnight sector responses to IMF transition



The second example is from 9 February 1995, shown in figure 4 which is the same format as figure 3. In this example, the WIND spacecraft detected an IMF transition at approximately 02:01:54 UT, when the IMF clock angle went from ~30 to ~0°. At Durmont d'Urville a depression in the total magnetic field commenced at 0253 UT (marked by the vertical dashed line). The Halley magnetometer Z trace shows a steady decrease in the period from 0255 UT to 0400 UT but it is very difficult to determine, in this example, when the decrease really started. We detect the start of an equatorward motion of the equatorward boundary of the radar backscatter at 0315 UT, which is then sustained until the onset of a substorm expansion phase at 0430 UT (as described in more detail in Lewis et al. 1998).

In this case there is a delay of 22 minutes between the dayside and nightside response. It should also be noted that the meridional velocity component is very weak in this case, typically around 0 m/s.

These two examples are typical of the case studies we have examined. Using this technique we observe a range of responses from 2 minutes (resolution of the experiment) to 30 minutes. Furthermore, the rapid response times are always associated with relatively large meridional velocity components observed by the radar (as per 20 October 1995 example).

Discussion

If the dayside and nightside coupling is achieved by the magnetosonic wave/incompressible ionosphere mechanism discussed in Ridley et al. (1999) then we would expect it to scale as the voltage applied across the dayside merging gap. Using a simple analytic convection model (Freeman et al, 1991) we can model the electrostatic potential pattern imposed on the polar ionosphere by applying a reconnection potential across the dayside merging gap. The model assumes a circular polar cap and although it is clearly unrealistic for IMF transitions, we simply wish to illustrate order of magnitude effects..

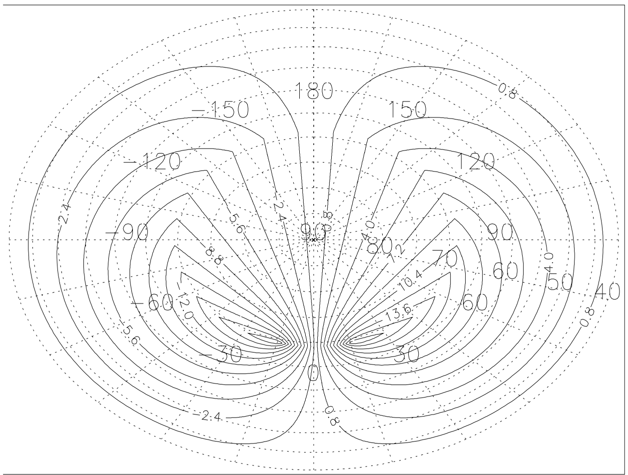


Figure 5 (left) illustrates the electrostatic pattern that results when a 40 kV potential is applied across a dayside merging gap (bottom centre of plot, i.e. at 0° longitude) centred about noon and 2 h wide. The potential contours are at intervals of 1.6 kV. We have experimented with a wide range of potentials and merging gaps, the findings are not substantially altered. From figure 5 the electric field at midnight and, for example, 70° latitude can be determined and is found to be 2.8 mVm^{-1}. The resulting plasma flow would be 56 ms^{-1}. To achieve a flow of 500 ms^{-1} in this region (which is required if we are to detect a midnight boundary movement of one range gate within one integration period) requires a dayside merging gap potential of 350 kV, clearly unrealistic.

From this simple modelling exercise we conclude that the magnetosonic wave/incompressible ionosphere mechanism cannot account for the observations of a rapid response, at least not within the circular polar cap model used. A much more distorted polar cap boundary (e.g., the "horse collar" aurora reported by Hones et al) could lead to much larger potentials appearing in the midnight sector. However, we note that magnetometer studies of the propagation of the magnetosonic wave in the ionosphere have suggested severe attenuation of the wave, of the order of 10dB/100km (Neudegg et al., 2000), which also casts doubt on this mechanism.

We have reason to speculate that the instantaneous ionospheric response to IMF changes may be restricted to the polar cap (open field line region). The one case study that Ridley et al (1998) presented in detail shows a convection pattern that is severely restricted on the nightside, not going below 80° latitude in the midnight sector (see their figure 8). In Ruohoniemi and Greenwald (1998), in the 21 MLT sector (their figure 2) the instantaneous response is seen clearly down to 73.9°. However, at the lower range gates (73.6° latitude and equatorward) the response is delayed by some 5-6 minutes. The recent study by Khan and Cowley (1999), using EISCAT Tromso data (67° latitude), which used data from the closed field line region, found a mean nightside response time of 9.2 ± 0.8 min.

There are physical reasons why the response might be different on closed field lines compared with open field lines. Implicit in the ideas of Ridley et al. (1998,1999) is that the ionosphere, if it is to remain coupled to the magnetosphere, must drive the magnetospheric flux tubes (because the IMF transition is apparently propagating much more slowly in the magnetosphere). This implies that Alfven wave coupling is required. The relatively low plasma density field lines associated with the polar cap region may be more easily driven by the ionosphere than the closed field lines associated with the plasma sheet. However, if the ionosphere is to remain incompressible then it would probably be necessary to drive vortices in the polar cap to fulfill this requirement.

SUMMARY

A preliminary study of noon-midnight responses to IMF Bz transitions shows a range of delay times from one radar scan (100 s) to 30 minutes. The response times appear to relate to the measured meridional velocity component in the midnight sector, with the fastest response being observed for the strongest equatorward flows. Simple incompressible ionosphere arguments do not appear to account for the instantaneous response. We need to consider non-circular polar cap boundary (e.g. horse-collar aurora) or some other mechanism that confines the response of the ionosphere.

References

Blanchard et al., J GEOPHYS RES-SPACE 102: (A5) 9697-9703 MAY 1 1997

Cowley and Lockwood, ANN GEOPHYS 10: (1-2) 103-115 JAN-FEB 1992

Freeman et al, J GEOPHYS RES 96: (A9) 15735-15749 SEP 1 1991

Freeman et al., J GEOPHYS RES 98: (A5) 7633-7655 MAY 1 1993

Khan and Cowley, ANN GEOPHYS-ATM HYDR 17: (10) 1306-1335 OCT 1999

Lockwood and Cowley, J GEOPHYS RES-SPACE 104: (A3) 4387-4391 MAR 1 1999

Neudegg et al., ADV SPACE RES 25: (7/8) 1559-1565 2000

Ridley et al, J GEOPHYS RES-SPACE 102: (A7) 14563-14579 JUL 1 1997

Ridley et al., J GEOPHYS RES-SPACE 103: (A3) 4023-4039 MAR 1 1998

Ridley et al, J GEOPHYS RES-SPACE 104: (A3) 4393-4396 MAR 1 1999

Rodger et al., GEOPHYS RES LETT 22: (15) 2045-2048 AUG 1 1995

Ruohoniemi and Greenwald, GEOPHYS RES LETT 25: (15) 2913-2916 AUG 1 1998

Voronkov et al., J GEOPHYS RES-SPACE 104: (A12) 28491-28504 DEC 1 1999

Yeoman et al., J GEOPHYS RES-SPACE 104: (A7) 14867-14877 JUL 1 1999