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O. de la Beaujardiere

Vincent B. Wickwar
Utah State University

J D. Kelly

J H. King

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EFFECT OF THE INTERPLANETARY MAGNETIC FIELD Y COMPONENT ON THE HIGH-LATITUDE NIGHTSIDE CONVECTION

O. de la Beaujardière, V. B. Wickwar, J. D. Kelly

SRI International, Radio Physics Laboratory, Menlo Park, California

J. H. King

National Space Science Data Center, NASA Goddard Space Flight Center, Greenbelt, Maryland

Abstract. Sondrestrom radar observations reveal that the dawn-dusk (B_y) component of the interplanetary magnetic field (IMF) strongly influences the nightside polar convection. This effect is quite complex. The convection for one orientation of B_y is not the mirror image of the other orientation. A positive B_y (i.e., pointing toward dusk) seems to organize the velocities such that, at all local times, they are predominantly westward within the radar field-of-view ($\simeq 68°$-to-$82°$ invariant latitude). Between dusk and midnight, on one such occasion, sunward flow is observed within the polar cap. In the midnight and dawn sectors, when B_y is negative, the plasma velocities often appear random. For large negative B_y, the afternoon cell appears shifted toward early hours such that large southward velocities are observed about 3 hours before midnight. These are the only times when the predominant velocity component is southward.

Introduction

The effect that the dawn-dusk (y) component of the IMF has on the polar ionospheric convection is still poorly known in spite of the fact that it has been the object of several recent investigations [see for example, Friis-Christensen et al., 1985, and references therein]. As an example, the last three publications on the subject each propose a different convection pattern for a given IMF orientation [Zanetti et al., 1984; Reiff and Burch, 1985; Friis-Christensen et al., 1985]. The focus of most studies of the B_y effect has been on the noon local time sector. In this paper, we concentrate on the nightside of the auroral zone and polar cap, using Sondrestrom radar measurements of convection.

The electric field and electron density measurements were obtained during 24-hr experiments. The latitude coverage was 68° to 82° invariant latitude (Λ). [The radar and operating mode are described in Wickwar et al. (1984) and references therein.] The IMF was measured from the IMP 8 spacecraft. We examined the fourteen such 24-hr runs for which IMF measurements were available. (Note, however, that the IMF data are not continuous; at times, large gaps are present in the data.) Particle data from the Defense Meteorological Satellite Program (DMSP) [Gussenhoven et al., 1983] were used to indicate the position of the auroral oval.

The Observations

Figure 1 shows plots of convection velocities for four experiments. These examples were selected because they illustrate the main features observed. The figure shows, for each experiment, the IMF orientation and the plasma convection. The velocity vectors are plotted in a clock-dial format, color-coded such that blue and red are for velocities with east and west components, respectively. The B_z (north-south) and B_y vectors in the Geocentric Solar Magnetospheric System (GSM) are represented in the inside circle using a similar color convention. As shown in figure 1d, positive B_z points toward the center of the circle, and positive B_y towards the west direction. The vectors are red and blue for positive and negative B_y, respectively. The two sketches of convection patterns, reproduced in Figure 2 from Reiff and Burch [1985] and Potemra et al. [1979] are both for $B_z > 0$. The one on the left (right) is for B_y positive (negative). As will be shown below, in the dawn and dusk sectors the observations match fairly well these sketches, but not in the midnight sector.

IMF B_y Positive

We first turn our attention to observations when B_y was positive. The first example is the April 23-24, 1983 experiment (Figure 1a). At 2100 UT the IMF B_y component changed from negative to positive. The convection responded almost instantly to this change (i.e., within the temporal resolution of the radar mode), becoming sunward (westward) within the entire field-of-view ($\Lambda = 68°$ to $82°$). Excluding a brief moment of plasma flow in the southward direction (2345 UT), the flow remained sunward over the radar field-of-view for as long as B_y remained positive (6 hours). Even as B_z became southward, the velocities remained westward.

To see if this wide region of sunward flow was associated with auroral oval precipitation, we examined data from the DMSP satellite. A satellite overpass occurred at 2200 UT, 15° east of Sondrestrom. Following the procedure outlined by Gussenhoven et al. [1983] the location of the auroral oval boundaries can be determined. The oval is defined as the region where the integral number flux and the energy flux rise noticeably above background. The poleward limit of the oval was at $\Lambda = 69.6°$ as shown in Figure 1a. Therefore, the auroral precipitation was near the southern limit of the radar field-of-view, and the sunward flow observed around 2200 UT was within the polar cap. This conclusion is supported by the radar electron-density measurements, which showed no auroral precipitation. Except for a brief period at
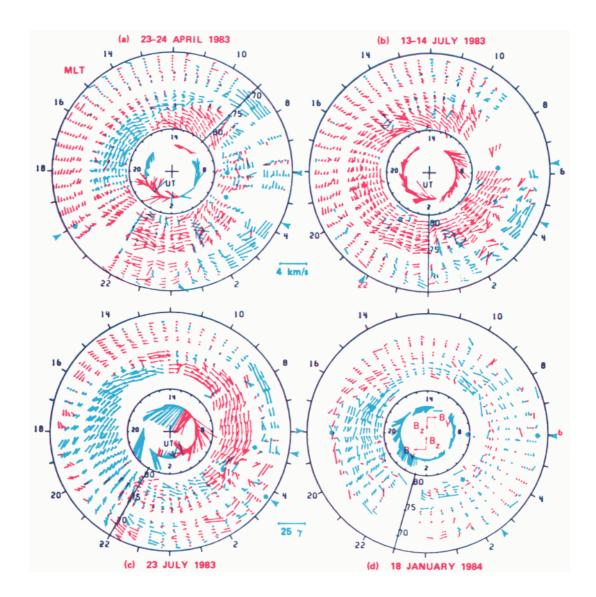
Fig 1.   Plasma drift and IMF vectors for four typical examples. The thick blue arrows indicate the poleward or equatorward boundaries of the auroral oval, as determined from coincident DMSP passes. The times at which the satellite passes occurred are marked by a thinner arrow on the periphery.

2400 UT, the E region density remained small (Ne $<$ 3 × 10^4 at 150-km altitude) until 0300 UT, when the IMF changed orientation. Consequently, the westward velocities observed between 0010 and 0310 UT were also within the polar cap, at least between Λ = 72.5° and 76°, the radar field-of-view at 150 km altitude.

We should point out however that soft-particle precipitation was observed poleward of the auroral oval. Bursts of electron precipitation are seen in the DMSP data, between the two auroral oval crossings. In addition, analysis of the radar F-region temperatures and density suggests that soft electrons were precipitated. In this paper, polar cap and auroral oval are defined in terms of their signature in the electron and proton detectors on board DMSP, and in the radar-measured E region density.

Another example of IMF B$_y$ $>$ 0 is the July 13-14, 1983 experiment (Figure 1b). The IMF B$_y$ was large and positive (between 5 and 10 γ) during virtually the whole observation period. Most or all the latitudes probed by the radar were within regions of westward velocity. It appears that the radar remained under a large westward vortex for 24 hours. The pattern is not a snapshot. In fact, the pattern probably
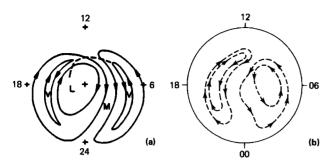
Fig. 2. Convection patterns from (a) *Reiff and Burch* [1985], and (b) *Potemra et al.* [1979] for By positive and negative, respectively.

changed substantially around 1300 UT. At this time the geomagnetic activity abruptly decreased. [The AE index, which had averaged $\simeq$ 500 γ during the previous 24 hours, decreased to $\simeq$ 100 γ at this time and remained low until the end of the experiment (H. Kroehl, private communication, 1984).] Nevertheless, this example is typical of other observations in the sense that, when By > 0, the convection remains westward within the poleward part of the field-of-view at all local times, and it is often westward within the whole field-of-view in the premidnight sector.

Premidnight on July 13-14, the velocities were westward within almost the entire field-of-view, as was the case on April 24 (Figures 1a and b). However, contrary to April 24, most of the radar field-of-view was within the auroral oval, as indicated by particle data from a coincident DMSP overpass and by radar data that show energetic particle precipitation (the oval poleward boundaries determined from DMSP are shown in Figure 1b).

Gaps in the data occurred on July 13 while the radar was in the dawn sector. The July 23, 1983 data (Figure 1c) offer a better example in this time sector. An examination of these two July dawn sector observations reveals that when By is positive and Bz negative, a strong antisunward flow is observed north of $\Lambda \simeq$ 76, and a sunward flow is observed south of this latitude. The velocities often exceed 2000 m/s and their north-south (N-S) components are small compared to the east-west (E-W) components. In fact, the E-W component is dominant at all local times in virtually all observations when By > 0.

IMF By Negative

Cases of observations while By was negative are found on April 24, July 23, 1983 and January 18, 1984 (Figure 1). (The July 23 experiment is unusual because it corresponds to the largest By, 25 γ, seen so far during Sondrestrom operations.) The January 18 conditions are of interest because they are symmetric to those of July 13 in the sense that IMF By was strong on both days but of opposite polarity.

The dusk sector in these examples is characterized by antisunward velocities within most or all of the field-of-view and by sharp reversals (for example January 18 $\sim$ 1700 UT). A coincident DMSP overpass indicated that around 2000 UT on January 18, the convection reversal was collocated with the poleward oval boundary (Figure 1d).

As the local time approaches magnetic midnight, the relative importance of the N-S component increases such that around 1900 to 2000 MLT, the E-W component is very small, and the flow is nearly equatorward.

The midnight and dawn sectors are characterized by fairly small and irregular velocities. At times, several reversals occur within the field-of-view (see for example, January 18 after 0200 UT and April 23 0600 to 0900 UT).

Observation Summary and Discussion

In spite of the limited number of observations when IMF data are available, a few salient features have emerged so far from the data, which can be summarized as follows:

Conclusions for By positive: (1) The velocities are predominantly westward at all local times at the latitudes covered by the radar. This remains true even when By is small. In the afternoon convection cell, the sunward (westward) flow spans most latitudes; in the morning convection cell antisunward (westward) velocities are seen poleward of a sharp convection reversal. (2) On April 23-24, sunward flow was observed in the polar cap in the premidnight sector, between 2100 and 0300 LT (2200 and 0400 MLT).

Conclusions for By negative: (1) A sharp reversal is observed in the dusk cell. It is only in this dusk sector that velocities are predominantly eastward within the field-of-view. (2) A feature only observed when By < 0 is that, before midnight, the dominant flow component is southward. (3) The midnight and dawn sectors are characterized by smaller, fairly irregular velocities.

Observations of sunward flow within the polar cap have been reported previously [e.g., Heppner, 1972; Burke et al., 1979; Burch et al., 1985]. What is new here is that, even close to midnight, and as far as $\sim$ 15° from magnetic pole, sunward (westward) drift is observed in the polar cap. A difficulty, however, in drawing a parallel between different sets of observations is that, to each set of instruments, there corresponds a different definition of polar cap. The issue of defining exactly the polar cap is very complex, still unresolved [Torbert et al., 1981], and not within the scope of this paper.

Our observation of disorganized velocity vectors when By is negative, is reminiscent of Birkeland-current observations from MAGSAT [Iijima et al., 1984]. At local times between dusk and dawn, the MAGSAT satellite observations reveal that field-aligned currents are highly structured, and form a pattern that is not persistent from one pass to the next. However, these observations were only for Bz > 0. The radar data seem to indicate that disorganized velocities are also observed when Bz < 0; additionally, they seem to be a characteristic of a negative By orientation.

Conclusion

In conclusion, the observations described in this paper indicate that the effect of the By component is not limited to the noon hours, but is felt at all local times. It is clear that the convection pattern is not symmetric for opposite By directions. That is, the convection pattern for By > 0 is not the mirror image of that for By < 0. This finding is contrary to the models proposed by Burch et al. [1985] and Reiff and

Burch [1985], Potemra et al. [1984], or by Zanetti et al. [1984]. However, these models were based on observations close to magnetic noon. On the other hand, empirical models proposed by Heppner [1977], or Friis-Christensen et al. [1985], based on observations at later local times, are not symmetric for opposite B$_y$ directions.

This asymmetry in the nightside of the convection may be attributed to the role of the IMF B$_x$ component, as was proposed by Heelis [1984] to explain noontime observations. Reiff and Burch [1985] have suggested that in the polar cap the plasma flows within a distinct and separate "lobe cell," marked L on Figure 2a. The flow within it is clockwise when B$_x$ is negative and B$_y$ positive, which was the IMF configuration during the radar observations on April 23-24 when sunward flow was recorded poleward of the auroral oval. Consequently, the region of westward flow observed with the radar when B$_y$ > 0 may, at times, be part of the "lobe cell." However, the reversal due to the viscous cell ("V" in Figure 2a) is not apparent in these data, nor in the other 24-hr periods of observations. Thus, the radar observations are more consistent with a single cell in the dusk sector as proposed by Potemra et al. [1979]. More observations are required, with all possible orientations of B$_x$ and B$_y$ to determine if the observations are consistent with the existence of a "lobe cell," and to fully assess the influence of B$_x$.

In this paper, we have tried to isolate the effects of IMF B$_y$, but the convection also depends on other factors such as season, B$_z$, magnetic activity, or the presence of substorms. It is not easy to assess the relative importance of all of these factors. Work has started on a statistical study of the relationship between the IMF orientation and the convection pattern. As more observations become available, our confidence in this statistical study will increase. The coincident data from Millstone Hill and EISCAT will also be incorporated to extend the coverage of the observations.

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O. de la Beaujardière, V. B. Wickwar, and J. D. Kelly, SRI International, Menlo Park, CA 94025.

J. H. King, National Space Science Data Center, NASA Goddard Space Flight Center, Greenbelt, MD 20771.