ON THE REVERSAL FROM "SUNWARD" TO "ANTISUNWARD" PLASMA CONVECTION IN THE DAYSIDE HIGH LATITUDE IONOSPHERE

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Abstract. Preliminary observations of dayside high latitude ionospheric plasma convection with the Sondrestrom incoherent-scatter radar indicate that plasma can be observed to enter the polar cap region through rotational reversals at most local times between dawn and dusk and not just in a narrow region around noon. Assuming that rotational reversals are signatures of a solar wind-magnetosphere interaction which drives magnetospheric convection, the observations indicate that this interaction occurs over a longitudinally wide area of the dayside magnetosphere. The observations also show that the distribution of F-region plasma in the polar cap is dependent on ionization sources anywhere between dawn and dusk in the dayside high latitude ionosphere.

Introduction

Plasma convection in the magnetosphere is generally observed to be sunward within the plasma sheet in the dawn and dusk sectors and antisunward in the tail lobes. This implies that reversals in the convection must occur somewhere in the dayside magnetosphere. Such reversals are observed, for example, by Heelis et al. [1976] who described two types observed with the Atmosphere Explorer C satellite in the ionosphere. Rotational reversals are characterized by a change in direction of the sunward velocity to antisunward during which the velocity vector rotates through a poleward direction with little change in speed. Shear reversals are characterized by antiparallel flows separated by a boundary across which no or very little plasma flows.

The reversals occur in high latitude regions in which the earth's magnetic field lines are likely to extend to the neighborhood of the magnetopause. It seems probable, therefore, that the reversals in the ionosphere must reflect, in some manner, properties of the solar wind-magnetosphere interaction mechanism, or mechanisms, which drive the magnetospheric convection. For example, considering an open magnetosphere model, in which polar cap magnetic field lines are connected to the interplanetary magnetic field by a merging mechanism, while those equatorward of the polar cap are closed field lines, the rotational reversals may in some way reflect the merging processes on the magnetopause.

Observations of plasma convection in the dayside high latitude ionosphere have been made by means of satellites,

rockets, and balloons. See, for example, the review by Jorgensen [1981]. These observations show that the plasma convection in this region is primarily east-west and comprises an equatorward zone with convection toward noon and a poleward zone with convection away from noon, but they do not provide profound information about the occurrence and nature of the reversals separating these zones. The imperfect knowledge about the convection reversals is indicated in the difference between models describing dayside high latitude convection. In models by Heelis et al. [1976, 1982] rotational as well as shear reversals occur, whereas rotational reversals only appear in Heppner's [1977] models.

A signature of the plasma convection in the dayside high-latitude ionosphere is reflected in the ground-based magnetometer observations of ionospheric currents. Although not uniquely determined from such observations, they do confirm the predominant east-west component of the currents in this region [e.g., Friis-Christensen et al., 1984]. Incoherent-scatter radars have also been used to investigate dayside high latitude convection [Evans et al., 1980; Foster et al., 1980, 1981, 1982], but since they could not reach beyond 75° Λ they were in general unable to obtain adequate information about the plasma reversals. However, Evans et al. [1980] found little evidence for the existence of a narrow throat through which all plasma must funnel as suggested by Reiff et al. [1978].

With the move of the Chatanika incoherent-scatter radar to Sondre Stromfjord, Greenland (66.99° N, 50.95° W, 74° Λ) ionospheric plasma convection in and around the cusp region now can be experimentally investigated with a thoroughness hitherto not possible. The purpose of this paper is to present and discuss such preliminary observations of plasma convection reversals. Of course, the classification of a convection reversal as "rotational" or "shear" requires some criteria which will be dependent on the observing technique and apply to certain scale sizes. The criteria adopted here will be discussed below along with some details of the experimental technique.

Technique

The observations were made with the general survey mode described by Wickwar et al. [1984]. The portion used for velocity determination consisted of a sequence of F-region measurements in 5 pairs of directions symmetric about the magnetic meridian plane at -27° geographic azimuth and one parallel to the magnetic field. The determinations of plasma drift velocities perpendicular to the magnetic field are made by combining these line-of-sight

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Fig. 1. Plasma convection velocities in the dayside high latitude F-region ionosphere observed with the Sondrestrom incoherent-scatter radar. Coordinates are time and invariant latitude. At the tail end of each velocity vector is a point.

velocities [Foster et al., 1981; Wickwar et al., 1984]. At low elevation angles, where velocities parallel to the magnetic field contribute little to line-of-sight velocities, pairs of measurements are combined. At higher elevation angles, the measurements parallel to the magnetic field are also included. Five sets of up to eight vectors, corresponding to the eight radar range gates, are obtained over a range of invariant latitude from about 68 to $81^\circ \Lambda$. A gap exists between 73 and $74.5^\circ \Lambda$ because the radar beam is too nearly aligned along the magnetic field to derive meaningful perpendicular velocities.

The cycle time for the sequence of 11 positions is 15 min, with 2 to 4 min required for each set of vector determinations. The spatial separation between points used to derive the vectors varies from 145 km at 200 km altitude to 358 km at 500 km altitude. Thus the vector determinations depend on the assumptions that the velocity field is constant for these time periods and homogeneous over these distances along contours of invariant latitude. A discussion of uncertainties in the derived velocities is given by Clauer et al. [1984].

The derived velocities are shown in Figure 1 in the corotating frame of reference. The five sets of vectors show up clearly, each a few minutes later than the preceding one, as

the radar moved from north to south. The 15-min cycle time for the velocities is apparent along with an experiment cycle time closer to 30 min. It follows that the vectors in each part of this figure are not "snapshots," but rather pieces of a time-varying velocity field under which the radar rotates. When the signal-to-noise ratio is good enough to determine vectors at all eight range gates, then vectors from different sets of measurements occur at the same latitude. A comparison of these vectors tells about the time evolution and spatial homogeneity of the velocity field. For instance, compare the vectors in Figure 1(B) at $73^\circ \Lambda$ at 1150 MLT and at 1315 MLT.

In the first case the vectors at overlapping latitudes have approximately the same magnitude and direction. This is consistent with the assumptions of time constancy (the equatorward set of observations were 3 min later) and spatial homogeneity (the equatorward measurements from the earlier set of observations were separated by 358 km whereas the poleward measurements from the later set were separated by 145 km). In the second case the vectors do not agree in either magnitude or direction. Either of the assumptions could have broken down.

The classification of convection reversals in the observed plasma flow is based on examination of the ion velocity vectors displayed in Figure 1. The reversal, from eastward to westward or vice versa, is considered to be rotational if the horizontal velocity vectors show a gradual rotation over latitude in the flow measured at the different range gates in one or two sets of positions in the north-south measurement sequence. The gradual rotation must also include poleward velocities. Such is the case at 1000 MLT in Figure 1(A) between 75 and $77^\circ \Lambda$. If, on the other hand, the flow does not show a rotation, but rather seems to stagnate between the eastward and westward velocities, the reversal is considered to be shear. Such is the case at 1500 MLT in Figure 1(A) at about $76^\circ \Lambda$.

Observations

April 23, 1983, shown in Figure 1(A), was a relatively quiet day with Kp values of 2 and 2+ during the period of observations. During the first one and a half hours until about 1100 MLT the convection rotates anticlockwise from an eastward flow at $75^\circ \Lambda$ through a poleward flow to a westward flow at 76 to $78^\circ \Lambda$. At about 1130 MLT, observations indicate that a shear type reversal existed at about $78^\circ \Lambda$, but during the following hour rotational reversals similar to those observed earlier again occurred. A rotational reversal may be indicated in the observations shortly after 1300 MLT at 76 to $79^\circ \Lambda$, but now it is a clockwise rotation ending with an eastward flow at about $79^\circ \Lambda$. Observations from 1400 to 1800 MLT show undetectable drift velocities between the westward flow below about $76^\circ \Lambda$ and the eastward flow above $77^\circ \Lambda$, indicating that a shear reversal occurred during this period. All observations together suggest that the dayside boundary between the dawn and dusk convection cells was located around 1300 MLT. During the whole period shown in Figure 1(A), the drift velocities are consistently largest on the poleward side of the reversal.

April 24, 1983, shown in Figure 1(B), was a geomagnetically disturbed day with Kp between 5- and 6- during the

period of observations. The convection reversals are more difficult to distinguish than on April 23, because the latitude range of the reversals often overlaps the latitude range where measurements of plasma drift perpendicular to the magnetic field cannot be made. However, signatures of rotational reversals are apparent in any MLT hourly interval from about 0830 until the end of observations at about 1600 MLT. Before about 1100 MLT the rotations are anticlockwise, while later they are clockwise suggesting that the dayside boundary separating the dawn and dusk convection cells is located near 1100 MLT. The latitude of rotational reversals varies between $76^\circ \Lambda$ at 0900 MLT and $71^\circ \Lambda$ at 1530 MLT. Although shear reversals may have occurred during the 10-hr observation period, no observations indicate that such reversals did occur. The largest drift speeds during the period of observations, exceeding 2 km/s, occurred between 0800 and 0900 MLT on the equatorward side of the reversal in the region of sunward convection.

April 26, 1983, shown in Figure 1(C) was moderately active geomagnetically with K_p between 3 and 4 during the period of observations. Anticlockwise rotational reversals were observed from about 0900 to 1100 MLT between 75° and $80^\circ \Lambda$. From about 1130 to 1230 MLT clockwise rotational reversals were indicated by the northwest directed flow at about 75° to $76^\circ \Lambda$. Again from about 1330 to 1400 MLT rotational reversals occurred, but this time between 70° and $74^\circ \Lambda$. After 1400 MLT it is difficult to determine the type of reversal, but the northwestward drift at about $73^\circ \Lambda$ around 1500 MLT indicates that rotational reversals occurred here also.

Figure 2 summarizes the reversals discussed above. The three days of observations do show that sunward convecting plasma in the dayside high latitude ionosphere may enter the polar cap region through rotational reversals at any time between 0800 and 1600 MLT. Since only a few observations were made outside this time interval, additional observations are needed to investigate whether plasma may enter the polar cap before 0800 and after 1600 MLT.

Discussion and Conclusion

These observations of plasma convection in the dayside ionosphere at Sondrestrom show both rotational and shear reversals of the plasma flow. However, rotational reversals appear to be much more common and they extend over a longitudinally wide portion of the dayside. Thus these observations are consistent with previous incoherent-scatter observations from equatorward of $75^\circ \Lambda$ [Evans et al., 1980; Foster et al., 1981, 1982] that showed the sunward convection turning poleward over a considerable range of local time around magnetic noon. These observations are in agreement with the behavior deduced by Jorgensen [1981] from the analysis of plasma drifts, which were obtained by several techniques, in the cusp region. The importance of the rotational reversal is also in agreement with the convection models of Heppner [1977].

These observations of the limited occurrence of a shear reversal and the apparent lack of a longitudinally limited region of poleward flow are not consistent with satellite observations or models that include a narrow "throat" near magnetic noon as described by Heelis et al. [1976] and Reiff

Fig. 2. Same data as in Figure 1, but with heavy arrows drawn to indicate the occurrence of rotational reversals in the plasma convection. However, the two heavy east-west oriented arrows after 1600 UT on April 23, 1983, indicate convection on either side of a shear reversal region.

et al. [1978]. However, this apparent discrepancy may be a function of the limited amount of data available or of spatial and temporal differences between radar and satellite measurements. Properly coordinated radar and satellite observations should resolve these apparent inconsistencies.

Another aspect of the observations that stands out is that the reversals, whether rotational or shear, are typically through 180° . Thus the velocities on either side are basically parallel to the contours of invariant latitude. This behavior is inconsistent with the models of Heppner [1977], which show antisunward flow across the polar cap after a rotational reversal.

The source of F-region ionization in the polar cap and the distribution of that ionization will depend greatly on the convection pattern and the nature and location of the convection reversals. This is so because the long lifetime of F-region ionization enables it to be transported considerable distances. If shear reversals dominate, very little ionization produced equatorward of the polar cap could be transported into the polar cap. If rotational reversals dominate, as appears to be the case, then considerable ionization could be transported into the polar cap. In either case ionization produced in the cusp region by low energy (< 1 keV) particle precipitation would contribute [Chacko and Mendillo,

1977]. However, the 180° reversals in these observations raise a question about the nature of the plasma flow in the central polar cap and whether ionization can be transported into that region.

Finally, the nature of the convection reversals provides information on the interaction of the solar wind and magnetosphere. Assuming that the earth's magnetic field lines are equipotential lines, a shear reversal in the high latitude ionosphere corresponds to an equipotential surface in the outer magnetosphere, which cannot be identified with either a merging region or a region with viscous interaction. In contrast, rotational reversals in the ionosphere may be footprints of a nonequipotential boundary in the outer magnetosphere which may be identified with a merging region or a viscous interaction region. With the assumption that rotational reversals in the dayside high latitude ionosphere are signatures of one or both of these solar wind-magnetosphere interaction mechanisms, the common occurrence of rotational reversals in most of the dayside ionosphere indicate that field line merging and/or viscous interaction is effective over a longitudinally wide part of the dayside magnetosphere. Whether a rotational reversal in the ionosphere is caused by merging or viscous interaction is not easy to say except perhaps in a region of several hours' duration around magnetic noon where the flow direction around the convection reversal boundary is clearly related to the IMF By component [Jorgensen, 1981; Clauer et al., 1984]. This suggests that the ionospheric flow is electrically coupled to the solar wind, consistent with merging.

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