The Evolution of Multi-Cell Convection during Northward IMF with $*B_Z/B_Y* > 1$

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Abstract

In this talk, the evolution of the convection pattern in response to changes in $*B_Z/B_Y*$ during northward IMF conditions on Nov. 11/98 is followed. Symmetric four-cell convection, with two normal cells at lower latitudes and two reverse cells at high latitude, occurs for $*B_Z/B_Y*$. 7. The four-cell pattern is shown to persist when $*B_Z/B_Y*$ falls to about 2.3, but the reverse cells shift toward earlier magnetic local time (MLT) for negative B_Y and toward later MLT for positive B_Y. When $*B_Z/B_Y*$ decreases to ~1.7, the convection appears as a three-cell pattern, with two normal cells and a single reverse cell focused near noon. The normal cells are focused at quite high latitudes (from 76 - 80E MLAT), with a large latitudinal spatial extent of about 10 - 15E MLAT (1000-1500 km). It is notable that DMSP satellite passes over the southern hemisphere polar cap show sunward convection and four-cell convection at the same time that the HF radars see the reverse convection cells in the northern hemisphere. An illustrated model of the evolution of the convection patterns with changing $*B_Z/B_Y*$ is shown for the negative By case.

INTRODUCTION

For Bz+ IMF conditions, there have been a number of observations of the convective flow patterns for various ratios of Bz to |By|. These observations can be summarized roughly as follows.

(a) For dominant Bz, i.e. for |Bz/By| >> 1, there are four cells observed, with two reverse cells in the polar cap and two Anormal@ cells at lower latitudes. (Huang et al., JGR, 105, 7419, 2000; Knipp et al., JGR, 98, 19273, 1993; Cumnock et al., JGR, 100., 14537, 1995).

(b) For dominant By, i.e. for |Bz/By |< 1, there is a distorted two-cell pattern consisting of a large dominantly dayside cell (which may enclose the polar cap) and a smaller cell (Huang et al., GRL, 26, 405, 1999; Huang et al., JGR, 105, 5231, 2000; Greenwald et al., JGR, 100, 19661, 1995: Knipp et al., loc. cit.; Cumnock et al., loc.cit.).

(c) For intermediate values of the ratio |Bz/By| between about 1 and 3, there can be a transition from four cells to 3 cells as the ratio decreases, which is the theme of this report. At the lower ratio values of |Bz/By| ~ 1 - 2, there is often just a single polar cap reverse cell and two normal cells, i.e. a 3-cell convection pattern (Greenwald et al., JGR, 100, 19661, 1995).

The purpose of this paper is to follow the evolution of the convection pattern as it changes from a four-cell to a 3-cell pattern when Bz goes from being totally dominant (|Bz/By| > 5) to somewhat less dominant (|Bz/By| ~ 1.7).

SuperDARN DATA FOR MULTICELL CONVECTION ON NOV. 11, 1998

November 11, 1998, was a particularly good day for the multicell convection study because, as shown in the WIND IMF data in Figure 1, the interval 08 - 18 UT was dominated by strong +Bz, but the ratio of |Bz/By| fluctuated. In particular, for the negative By conditions during the period 1415 - 1615 UT, the ratio |Bz/By| decreased smoothly from about 7 during the period 1426-1442 UT (denoted by a blue band labelled A1") to about 2.3 during the interval 1522-1538 UT (band 2) and finally to 1.7 from 1558-1606 UT (band 3). In addition, there is an earlier example of positive By conditions at about 0854-0910 UT when |Bz/By| was also 2.3 (band 4).

We first discuss the transition from 1=> 2 => 3 when the ratio fell from 7 to 1.7, during By- conditions. Figure 2 shows the convection when |Bz/By| ~7 during the period 1504-1508 just after Interval 1. The pattern is obtained using the Ruohoniemi and Baker fitting technique (JGR, 103, 20797, 1998), in which the observed radar data is supplemented by the APL statistical convection model of Ruohoniemi and Greenwald (JGR, 101, 21743, 1996). As expected for the high ratio |Bz/By| ~ 7, there is a 4-cell pattern with two reverse cells, one on each side of the noon-midnight meridian.

There is then an increase in the magnitude of the negative By component until, during the 1552-1556 and 1600-1604 intervals shown in Figures 3 and 4, the ratio |Bz/By| has fallen to 2.3. Figures 3 and 4 show that the result of this decrease in the |Bz/By| ratio during -By conditions is that the postnoon reverse cell moves toward noon until it is centered almost on the noon-midnight meridian, while the prenoon cell moves to lower latitudes (and subsequently disappears as the |Bz/By| ratio becomes even smaller).

When the ratio |Bz/By| has fallen to 1.7, Figure 5 shows that there is a single reverse cell centered near noon (the previously postnoon reverse cell) and a strong eastward flow toward noon at the position where the prenoon reverse cell was previously seen. In terms of the antiparallel merging picture of Crooker (JGR, 97, 19363, 1992) during Bz+ conditions, the SuperDARN results of Figure 5 can easily be explained. With Bz+ and By-, the IMF is antiparallel to the open lines of the dayside lobe on the morning side, so merging occurs there, and the resulting recently merged flux tube with its foot in the morning polar cap is so strongly curved near the merging region that the magnetic tension pulls that flux somewhat sunward but mostly strongly eastward toward noon. This strong eastward convection is seen clearly in the F-region by SuperDARN. Of course, in the lower E-region, the ion convection would be impeded and a strong westward current would result. This is the same reasoning employed to explain westward DPY currents in the presence of negative By-driven convection during Bz- conditions (Friis-Christensen and Wilhjelm, JGR, 80, 1248, 1975; Belehaki and Rostoker, JGR, 101,2397, 1996). It is interesting to note that this strong eastward convection takes place in just about the same region that the previously present prenoon reverse convection cell has disappeared, leaving only the single reverse cell that moved to the noon meridian from its original position on the postnoon side. Another point about this strong convection in Figure 5 is that it is consistent with the double-FAC structure of the original two reverse cells. On the poleward edge of the strong convection, the velocity is decreasing, and the shear there results in upward convection vorticity, as in the reverse cell at noon; both of these thus are consistent with downward FAC (Sofko et al., GRL, 22, 2041, 1995). On the equatorward side of the high velocity convection patch, there is a decrease in the velocity, and hence a downward vorticity. There is also some rotation in the flow with a downward vorticity sense. Both of these vorticities are of the same sign as that in the original prenoon reverse cell, in which there was upward FAC. Thus the double FAC structure near noon is maintained in spite of the fact that the prenoon reverse cell has disappeared.

The above scenario illustrates the transition from two reverse cells to one reverse cell during negative By conditions. What is the situation when By is positive? Although there was not a clearly defined smooth transition from large to smaller values of |Bz/By| for By+ conditions, Interval 4 from 0854-0910 UT indicated that the two reverse cells shift toward the afternoon side, so that the prenoon reverse cell moves until it is centered near noon. The postnoon cell, however, does not disappear, but instead rotates to later MLT until it is centered much closer to the dusk meridian, as shown in Figure 6 for the interval 0924-0928 UT.

It is of some interest, particularly for the main Intervals 1, 2, 3 when the smooth transition of |Bz/By| from 7 down to 1.7 occurred, to establish what was happening in the southern hemisphere. During that time, Figure 1 shows that the Bx component of the IMF was uniformly negative. For winter conditions in the northern hemisphere, the dipole axis is tilted slightly backward into the -X axis direction, so if the incoming IMF has +Bz and -Bx, its orientation is roughly parallel to the tilted dipole axis. Under these conditions, one would expect that merging could occur nearly simultaneously in both hemispheres, which should lead to Amerging cells@ in the polar cap, using the terminology of Crooker (loc.cit.). The DMSP satellite data from the southern hemisphere are shown in Figure 7. All three dayside passes at 1413-1432 UT, 1554-1612 UT and 1734-1752 UT do indeed show sunward convection over the central polar cap, turning to antisunward convection roughly in the 75-81 MLAT range. This shows that the southern hemisphere convection is consistent with a four cell pattern. This certainly agrees with the northern hemisphere picture. By the time the last pass at 1734-1752 UT occurs, Figure 1 shows that Bz had increased again slightly compared to its value during Interval 3, so the 4-cell pattern could have been re-established in the northern hemisphere too. In summary, it appears that the convection is dominantly four-cell convection, with two reverse Amerging@ cells in the polar cap in each hemisphere.

The DMSP satellite data in Figure 7 confirms one of the most important features of the SuperDARN observations of the reverse convection cells in Figures 2 through 6, namely that they are predominantly a DAYSIDE phenomenon. The DMSP pass at 0911-0927 shown in the bottom right of Figure 7 occurs on the nightside in the southern hemisphere, and there is no evidence of the reverse cells seen by SuperDARN on the dayside in the northern hemisphere. Furthermore, all the reverse cell patterns shown in Figures 2-6 are basically dayside cells.

In Figure 8 are shown some of the important model convection patterns proposed in the past (Potemra et al., JGR, 89, 9753, 1984; Reiff and Burch, JGR, 90, 1595, 1985; Heelis et al, JGR, 91, 5817, 1986; Heppner and Maynard, JGR, 92, 4467, 1987). If one examines each of them in detail and compares with SuperDARN results above, there is a basic disagreement in each case, the model of Heelis et al. being closest to agreement, although their drawing of the partial reverse cell on the morning side indicates that it goes well back onto the nightside, in contradiction to the predominantly dayside cell behaviour above (only in the By+ case does one of the two reverse cells moves back to near the dusk meridian, with a slight overlap into the evening sector, as shown in Figure 6).

Finally, Figure 9 shows in diagrammatic form a summary of the behaviour of the reverse convection cells for the transition from |Bz/By| ~ 7 down to 1.7, for the By- case (Intervals 1,2 and 3, as shown in Figures 2 - 5).

Our emphasis in discussing the above data has been on the reverse cells in the polar cap, but there is an important feature of the Anormal@ cells that should be addressed. It can be seen in Figures 2 through 5 that the SuperDARN radars do see a well-developed Anormal@ convection cell on the afternoon side (morning side SuperDARN measurements are too sparse to make any firm conclusions about the morning Anormal@ cell). The main thing to note about the afternoon Anormal@ cell is its size, since it appears to cover a range of some 10 - 15 degrees in magnetic latitude; it is also shows a Afocus@ at a high latitude of about 80 degrees.

SUMMARY

The key features of the transition from two dayside reverse cells on either side of the noon meridian during large |Bz/By| values to one dayside reverse cell as the |Bz/By| ratio decreases to about 1.7 are shown in Figure 9, for the By- case. The two-reverse-cell pattern rotates in the direction indicated by the IMF By sign i.e. toward the morningside for - By, toward the afternoon for +By. When only one cell remains, it is the original postnoon cell for By- conditions, or the original prenoon cell for By+ conditions. The single reverse cell is usually centered on or near the noon meridian, and is such that the antisunward portion of the cell does not go back much further than the dawn-dusk meridian.

It is important to note that the reverse cells are almost totally confined to the dayside, and that they may be accompanied by Anormal@ cells of considerable latitudinal extent (over 10 degrees).

For By- conditions, the prenoon cell seems to disappear at low latitudes as |Bz/By| falls to about 2.3. On the other hand, for By+ conditions and the same value 2.3 of the ratio, the postnoon cell seems to migrate toward dusk, but doesn=t disappear and still remains focussed at high latitudes. More observations for the +By case are needed in the future to determine at what stage the second reverse cell disappears and only a single cell remains.