# MAGNETOSPHERIC CONVECTION AND CURRENT SYSTEM IN THE DAYSIDE POLAR CAP

A. Nishida, T. Mukai, K. Tsuruda and H. Hayakawa

Institute of Space and Astronautical Science, 3-1-1 Yoshinodai, Sagamihara 229, Japan

## ABSTRACT

Field and particle observations on EXOS-D (Akebono) have yielded new information on convection and current system in the dayside polar cap. Convection patterns are distinctly different depending upon whether IMF $B_z$ is northward or southward. The number of convection cells is two when $B_z$ is southward but four when $B_z$ is northward. Lobe cells in which plasma flows sunward in the region of open field lines are observed as a pair (of which one is in the dawn and the other in the dusk sector) for any polarity of IMF $B_y$ and $B_z$. Ions in the keV range precipitate not only in the dayside cusp region but also along the sunward directed streamlines of the dawn and dusk lobe cells. These observations require reconsideration on the position and the extent of the reconnection region on the magnetopause. They also suggest that the magnetotail plays a vital role in some phenomena which have been ascribed to dayside magnetopause processes. We have not been able to find evidence to prove the presence of the viscous cell under southward IMF.

Key words: magnetosphere, convection, reconnection, interplanetary magnetic field

## 1. INTRODUCTION

Large-scale systems of plasma convection and electric current are produced in the magnetosphere by the interaction with the solar wind. This interaction can take the forms of magnetic reconnection and viscous-like force, and much effort has been made to deduce the nature of the interaction mechanisms from ground-based and satellite observations. Using the data obtained by low-altitude polar-orbiting satellites DMSP, DE and Viking, Burch et al. (Ref. 1), Bythrow et al. (Ref. 2), Newell and Meng (Ref. 3) and Kremser and Lundin (Ref. 4) have attempted to identify the signatures of reconnection and viscous-like interaction in plasma flow, electric current, and precipitating particles observed at low altitudes.

In February, 1989, ISAS launched EXOS-D (Akebono) to a semi-polar orbit (initial inclination 75°, apogee 10,500 km, and perigee 274 km). This spacecraft carried on board a comprehensive set of instruments for making simultaneous measurements of plasma and electric and magnetic fields. From the comparison of these simultaneously obtained data we could obtain new insights in magnetospheric dynamics and their projections in low altitudes. This paper summarizes the results obtained so far on the convection and current system in the dayside polar cap and discusses them in the context of previously published phenomenological models and interpretations. Information on the EXOS-D spacecraft and its instrumentation is given by Tsuruda and Oya (Ref. 5).

## 2. OBSERVED SYSTEM UNDER SOUTHWARD IMF

Since the EXOS-D data clearly demonstrate that distinctly different features are observed in fields and particles depending upon the sign of the northward component $B_z$ of IMF, we divide the section by the IMF polarity and discuss the case of the negative $B_z$ first.

Figure 1 reproduces the convection pattern in the northern polar cap suggested by Burch et al. (Ref. 1). Convection cells that are interpreted to be the result of reconnection on the dayside magnetopause are marked with an M (standing for the merging cell), and those that are attributed to viscous-like interaction are marked with V. The cells marked with L are lobe cells which are confined in the region of the open field lines. The left panel is for positive $B_y$ of IMF (in the solar magnetospheric coordinates) and the right panel is for negative $B_y$. Dashed line is the projection of the merging line from the magnetopause. According to Figure 1 there are merging cells and viscous cells on both dawn and dusk sectors for both signs of $B_y$, and there is only one lobe cell whose position and polarity depends on the sign of $B_y$.

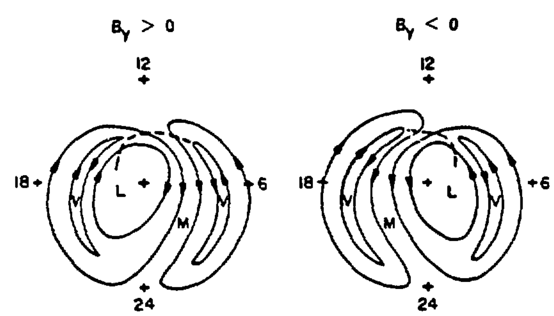



Fig. 1: Streamlines of convection in the northern hemisphere under the southward IMF obtained by Burch et al. (Ref. 1). V, M and L mean viscous, merging and lobe cells.

A typical EXOS-D data obtained on the dawn side in the northern hemisphere when $B_y$ is positive (with the azimuthal angle measured from the solar direction $\phi = 115°$) are shown in Figure 2. The upper two panels on the left hand side are the electric field data in the solar ecliptic coordinates projected to an altitude of 120 km. The lower four panels are energy versus time diagrams for electrons (top) and for ions with downward (second), perpendicular (third)

*Proceedings of the 26th ESLAB Symposium – Study of the Solar-Terrestrial System, held in Killarney, Ireland, 16–19 June 1992 (ESA SP-346, September 1992)*

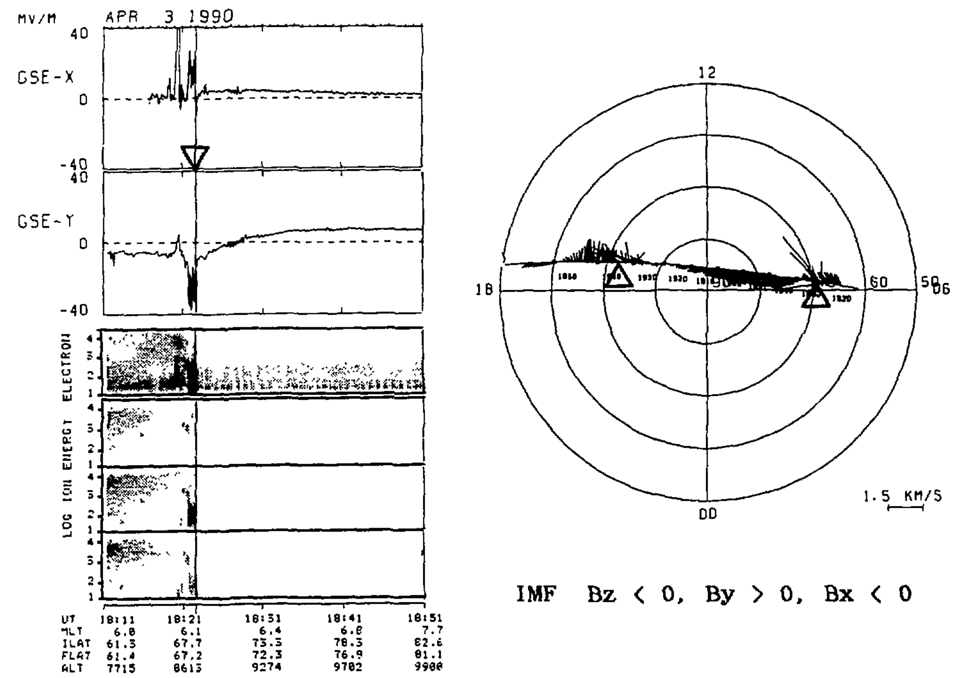



Fig. 2: Electric field and particle data of EXOS-D that demonstrate the presence of the lobe cell when $B_z < 0$ and $B_y > 0$. Wedge mark is used to show the transition boundary (TRB). For details, see text.

and upward (bottom) pitch angles, respectively. In the electron E-t diagram there is a sharp transition equatorward (namely, to the left) of which energetic > 1 keV electrons are present while poleward of which only the polar-rain (< a few 100 eV) electrons of the solar-wind origin are seen. This boundary (marked by a triangle and a vertical line) can be interpreted as the transition from the plasma sheet to the polar cap; we shall designate this as the transition boundary (TRB). In this case the ion flux drops sharply at TRB. Bursty enhancements of electrons and upward flowing ions with low energies are seen in a narrow region equatorward of TRB.

In the electric field data it is noted that the sign of the y component is negative not only inside the plasma sheet but also for about 4° of latitudes poleward of TRB. This means that the flow is sunward not only in the plasma sheet but also in the region of open field lines. Convection velocities derived from 16 s averages of the electric field for this case are plotted on the right hand side of Figure 2. Thus a signature of the lobe cell, that is, the sunward flow of open field lines, is clearly present. (Although a definitive identification of the lobe cell has to prove that the streamlines do not cross the open-close boundary at any local time, we shall adopt this nomenclature and discuss its justification later.)

The observation of Figure 2 is made when $B_y > 0$ and the lobe cell is not expected to be present on the morning side according to Figure 1. EXOS-D observations have demonstrated that there tend to be two lobe cells instead of one for any polarity of $B_y$. The size of the lobe cell as measured by the distance between the convection reversal and TRB shows dependence on the sign of $B_y$, however, and in the northern hemisphere the lobe cell on the dusk side (dawn side) is larger when $B_y$ of IMF is positive (negative) (Ref. 6).

The viscous cell should be identifiable by the presence of anti-sunward flow in the region of the closed field lines. We have searched for the corresponding signature, namely a domain of positive $E_y$ inside the plasma sheet in the field and particle data of EXOS-D, but such a signature is very often absent. There are times when $E_y$ becomes positive for a short interval in the vicinity of the TRB crossing as illustrated in Figure 2, but excursions of $E_y$ into the positive range tend to be brief and weak; in this case the width of the positive $E_y$ is only 20 km and the associated potential difference is only 45 V. It is difficult to interpret them in terms of a macroscopic structure in the distant magnetosphere, and it seems more appropriate to consider that they belong to a distorted electric potential distribution that produces field-aligned beams of electrons and ions in the region around TRB.

Comparison with the magnetic field data shows that the equatorward part of the lobe cell (where the flow direction is sunward) is in the general domain of the region 1 current. Although the magnetic field is considerably variable and both upward and downward currents exist over the span of the equatorward part of the lobe cell, a smoothed-out trend is consistent with the polarity of the region 1 current. When TRB is sharply defined it tends to correspond to a sharp peak in the density of the region 1 current [Fukunishi et al., personal communications].

In the case of Figure 2 no ions are detectable poleward of TRB. However, a patch of ions with energies in the 0.1 - 10 keV range often extends beyond TRB. Figure 3 is a collection of four of such events that are obtained in intervals of negative $B_z$ and negative $B_y$. Examples are ordered in local time from prenoon (a) to dawn (d). For each case the electron (top) and ion (bottom) E-t diagrams are copied along the projection of the orbit to 120 km height. TRB is clearly recognizable (as marked by vertical lines) and the ion patch, which we choose to call "Circumpolar Ion Precipitation (CPIP)", is seen on the poleward side of TRB in each case. The span of CPIP which is indicated by thin bars along the orbit projection is in the region of the sunward/noonward flow of the morning-side lobe cell in every case.

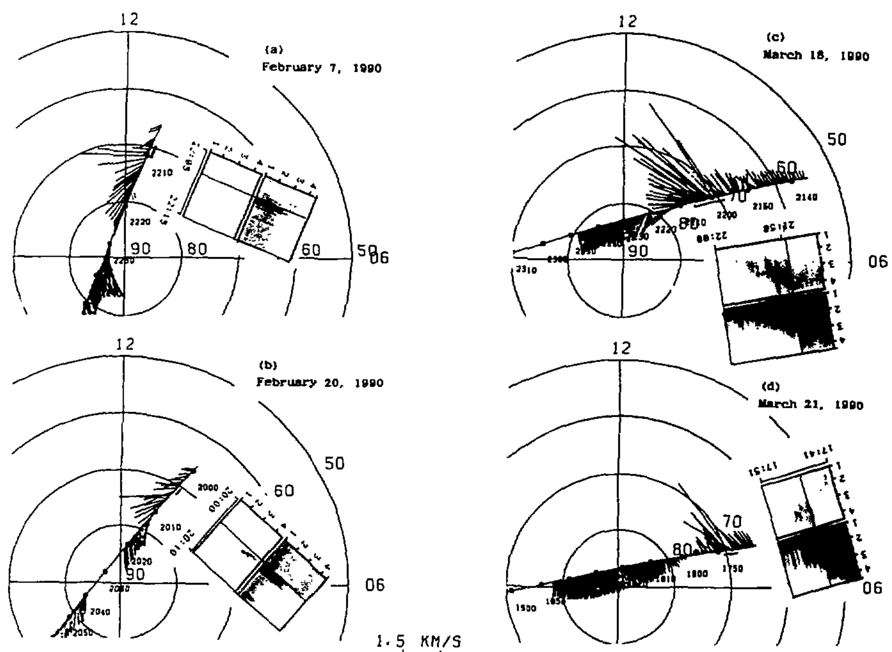


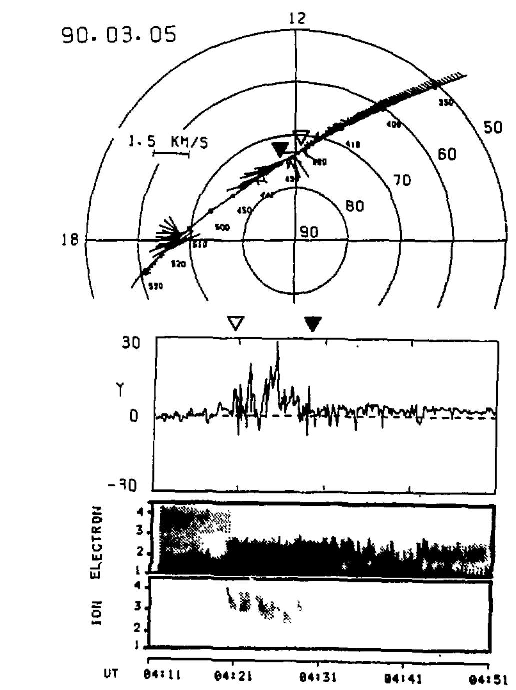

Fig. 3: Particle signatures of TRB and circumpolar ion precipitation (CPIP) are compared with flow velocities derived from electric field observations. The span of CPIP is indicated below the spacecraft orbit projected to 120 km height. Four examples in panels (a) to (d) are obtained at successively earlier local times. IMF $B_z$ < 0 and $B_y$ < 0 in all the cases.

Eastward flows across the noon meridian in the 70° - 75° range in the panels (a) and (b) reflect the deflection of the anti-sunward flow in the throat region toward the afternoon side that tends to occur when $B_y$ is negative (c.f., Figure 1, right panel).

CPIP in dawn and dusk sectors has often been interpreted as the low-altitude projection of the low latitude boundary layer or the magnetospheric cleft (e.g., Ref. 3). Since flows in such boundary regions of the magnetosphere are directed characteristically anti-sunward, this interpretation implies that the CPIP plasma flows anti-sunward as well. However, in none of the cases in Figure 3 the flows are anti-sunward in the region of CPIP, and our statistical study of the EXOS-D data set has supported this with few exceptions. Since CPIP on both morning and afternoon sectors are on sunward flows over a wide range of local times and for both polarities of IMF $B_y$ , it is not possible to consider that an intrinsically anti-sunward flow is made sunward-directed because of the magnetic tension that is exerted on open field lines. Hence it cannot be concluded that CPIP is the low-altitude signature of LLBL or cleft. (In a recent paper, Newell and Meng (Ref. 7) have suggested that the projection of the LLBL occupies only a small region equatorward of the cusp.)

Sometimes CPIP is not seen in dawn/dusk sector as in the case of Figure 2. Such cases are relatively infrequent but tend to be found in active intervals when Kp is high (Ref. 6).

As for the CPIP around noon, the magnetosheath plasma that has entered the magnetosphere from the dayside cusp has been considered to be the origin. This is not evident in such cases as Figure 3(a) where even close to the noon CPIP is on streamlines that extend toward the afternoon from the prenoon sector and can represent the plasma that has been transported from earlier local times toward noon. However, connection of the noon-time CPIP with the cusp seems to provide an adequate explanation to cases such as Figure 4 where CPIP is clearly on anti-sunward directed flows and




IMF Bz < 0, By ≧ 0, Bx < 0

Fig. 4: Flow velocity (top), y-component of the electric field (middle), and E-t diagram for a crossing of the possible cusp projection. Open and filled wedge marks encompass the interval of the cusp precipitation.

shows the characteristic energy dispersion which has been interpreted in terms of the velocity filter effect. This example is obtained when IMF $B_y$ (in solar magnetospheric coordinates) at IMP 8 is almost zero during 0404 - 0417 and then about 5 nT for an hour afterwards. It is interesting to note that the ion precipitation is not smooth but patchy and that patches seem to correlate with enhancements in $E_y$ . The idea that reconnection on the dayside magnetopause would be time-dependent and patchy rather than steady has been advanced recently [e.g., Smith and Lockwood (Ref. 8)] and seems to compare favorably with the example of Figure 4.

Convection streamlines, precipitation regions, and field-aligned currents under the southward IMF condition on the dayside of the northern hemisphere are summarized in Figure 5. Symmetry is assumed with respect to the noon meridian and only the morning sector is illustrated. The assumed symmetry could be realized when IMF $B_y$ is zero; in fact, some asymmetry may remain even then but our analysis has not proceeded far enough to demonstrate it. In Figure 5 the transition boundary (TRB) is marked by a thick curve. Since the polar rain is observed immediately on its poleward side when IMF $B_x$ has an appropriate sign, we take TRB as the demarcation between closed and open field lines. Streamlines that traverse TRB constitute the merging cell. Inside these there are streamlines of the lobe cell that are supposed to be confined inside the polar cap. The potential difference of the lobe cell is 20 - 50 % of the total potential drop across the polar cap. The circumpolar ion precipitation (CPIP) is mainly on open field lines poleward of TRB but in the dawn sector it also extends slightly equatorwards into the region of closed field lines (Ref. 6). When Kp is high there are occasions when CPIP exists only within a few hours of the noon meridian. The region 1 field-aligned current that is directed downward on the morning side is distributed mostly in the equatorward part of the lobe cell and tends to be intense on TRB. The convection reversal boundary is embedded in the domain of the region 1 current, and much of the region 1 current is coupled to the region 2 current or to filamentary currents of the opposite sign on the equatorward side of the same sector.

The spatial extent of the region of open field lines deduced from the polar rain is appreciably larger than that determined by the Tsyganenko's magnetic field model. In his model the ionospheric projection of the open field lines has a shape of a tear drop whose narrower end is in the noon meridian. Field lines from a saddle-shaped region outside this tear-drop extend to the dawn/dusk boundary regions of the magnetosphere but are closed according to this model [e.g., Elphinstone et al.(Ref. 9)]. However, the observation of the polar rain demonstrates that most of these field lines are in fact open.

The convection pattern of Figure 5 leaves little room for streamlines that are confined entirely in the region of closed field lines equatorward of TRB. All the streamlines in the closed field-line region extend to TRB around noon and traverse it. This means that under the southward IMF condition the flow in the low-latitude boundary layer (LLBL) just inside the magnetopause cannot form a separate convection cell confined to the closed field line region but belongs to the convection system generated by the reconnection at the magnetopause. The anti-sunward flow in LLBL could either be due to anti-sunward dragging of closed field lines by the viscous-like force just before they become reconnected or to stretching of the newly opened field lines. This line of interpretation has been adopted by Mitchell et al. (Ref. 10).

There are times when TRB is not clearly defined. Such cases tend to be found when Kp is low, and under the condition of southward IMF the occurrence frequency of the diffuse TRB, namely the diffuse boundary of the plasma sheet, is about 15 %. In such occasions CPIP is within the region of the diffuse boundary where the field-aligned current shows high variability.

Projection of the streamlines and the particle structures to the tail is illustrated in Figure 6 assuming symmetry with respect to the midnight meridian. Streamlines of the merging cell enter the tail section at high-latitude boundaries, flow into the plasma sheet, and reach the tail midplane. Those of the lobe cell circulate inside the tail lobe. CPIP in morning and evening sectors project to the boundary region between the plasma sheet and the lobe. Although this is similar to the region which has often been designated as the boundary plasma sheet (BPS), substantial part of CPIP projects to open field lines outside the plasma sheet as manifested by the presence of the polar rain. The supply of plasma therefore should occur into open field lines on the nightside. CPIP around noon, on the other hand, projects to high-latitude boundaries of the tail (including open field lines that exist outside). Interpretation of these streamlines in terms of reconnection is discussed in a later section.

It has to be noted that we have not yet proved rigorously

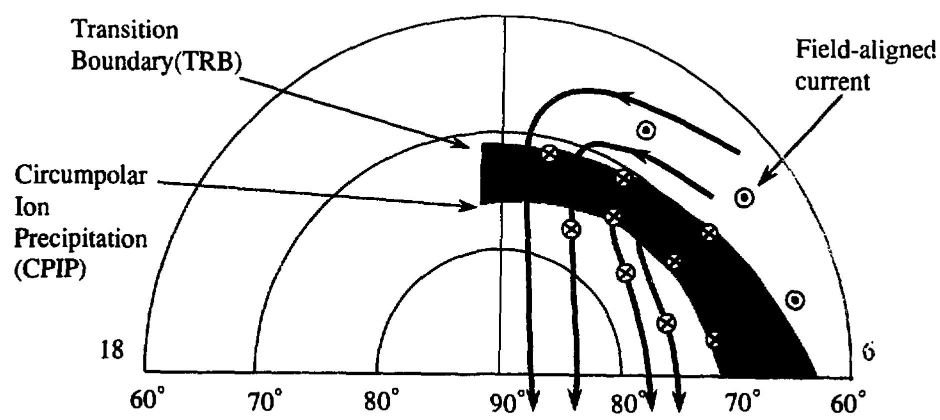



**Fig. 5: Streamlines of convection, region of the CPIP precipitation, and direction of the field-aligned current under the southward IMF for an idealized condition of symmetry with respect to the noon meridian (Ref. 6).**

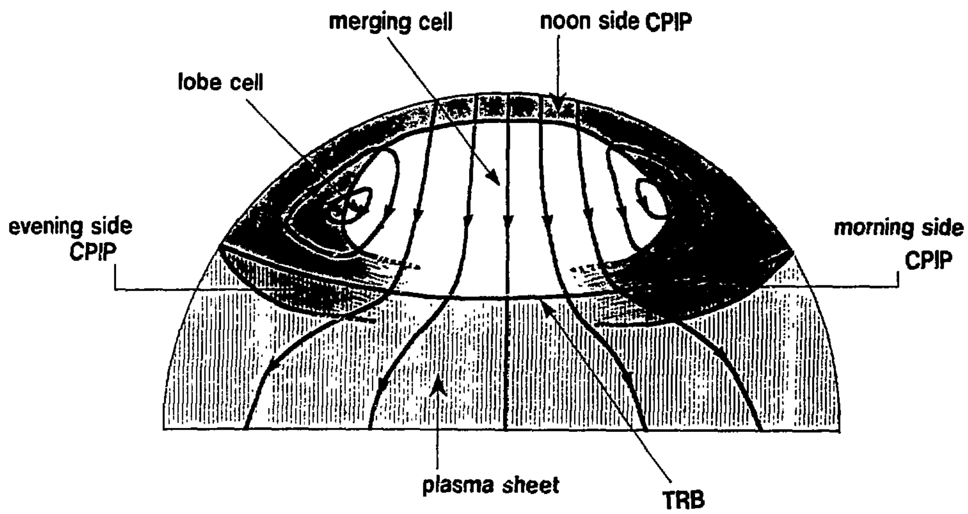



Fig. 6: Projection of Figure 5 to a section of the tail at some distance earthward of the distant neutral line (Ref. 6).

that streamlines of the lobe cell are literally confined in the polar cap. Those streamlines which are directed sunward in the dawn sector of the polar cap could have traversed the polar cap boundary at earlier local times as illustrated in Figure 7a. This means that field lines of these cells are opened either at the magnetopause or inside the tail. The latter is not likely since it requires that the closed field lines make contact with IMF inside the tail. The former requires that reconnection with IMF occurs over a very wide region of the magnetopause including the low-latitude surface of the tail. In this case the streamlines in the equatorial plane would be as illustrated in Figure 7b. Closed field lines flow not only toward the dayside magnetopause but also to the flanks of the tail. This convection profile is similar to the one derived by Richardson et al. (Ref. 11) from the observation of anti-sunward flow of a distinct population of plasma along the flank of the tail which differ from the typical plasma sheet population. Figure 7c illustrates streamlines in the section of the tail. The streamlines which are directed toward the tail surface in low latitudes represent the flow of closed field lines. The streamlines that enter the tail lobe at higher latitudes represent the flow of open field lines. The poleward defection of these streamlines just inside the magnetopause corresponds to the sunward flow of open field lines in Figure 7a. The reason for this deflection has to be understood in order to make Figure 7 a viable model of the convection profile.

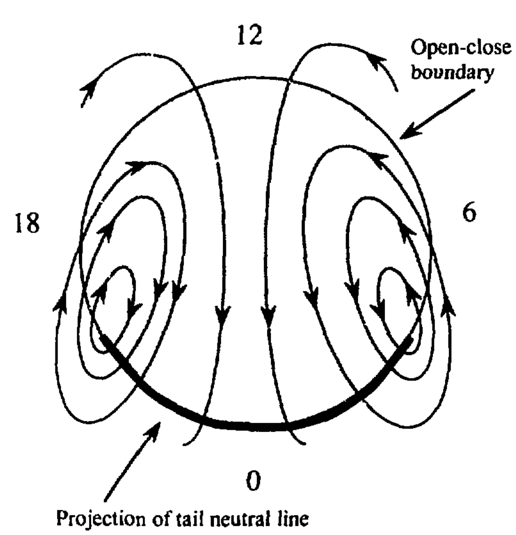



Fig. 7a: An alternative model of the position of convection streamlines relative to the open-close boundary. Streamlines of the "lobe cell" cross this boundary and there is actually no lobe cell.

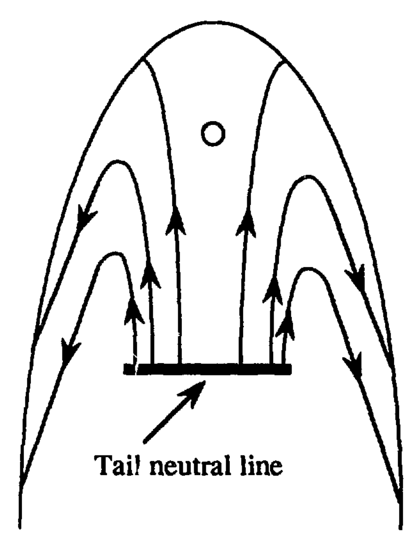



Fig. 7b: Streamlines in the equatorial plane corresponding to 7a.

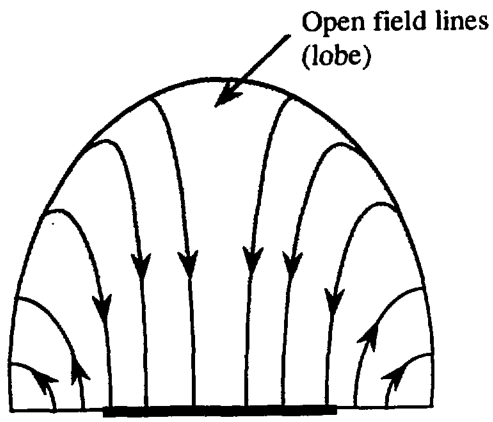



Fig. 7c: Streamlines in the tail section corresponding to 7a.

3. OBSERVED SYSTEM UNDER NORTHWARD IMF

When IMF polarity is northward, the convection system consists of four cells, of which two are in the dayside polar cap and the other two are centered in dawn and dusk sectors. The dayside lobe cells are characterized by the sunward flow around noon as illustrated in Figure 8a. The presence of this pair of cells has not been universally accepted, however, and a "distorted two cell" model (Figure 8b) has been suggested as an alternative [Heppner and Maynard (Ref. 13)]. In this model the flow is essentially anti-sunward in the polar cap but is distorted locally to produce a sunward flow.

EXOS-D observations during northward IMF seem to leave little doubt that the convection pattern of Figure 8a

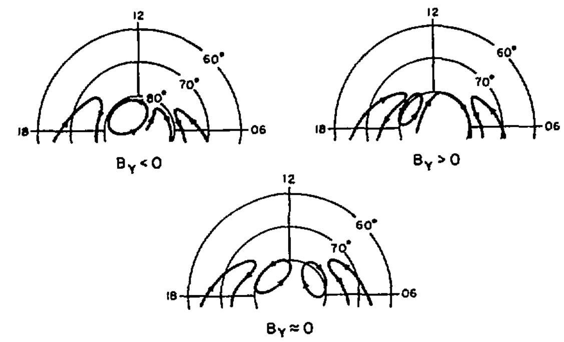



Fig. 8a: Polar cap convection pattern for northward IMF that is characterized by a pair of convection cells confined in the polar cap [Heelis et al. (Ref. 12)].

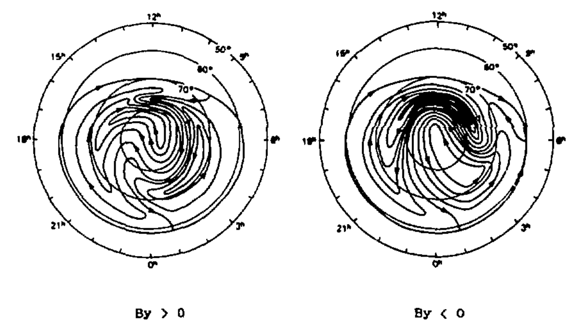
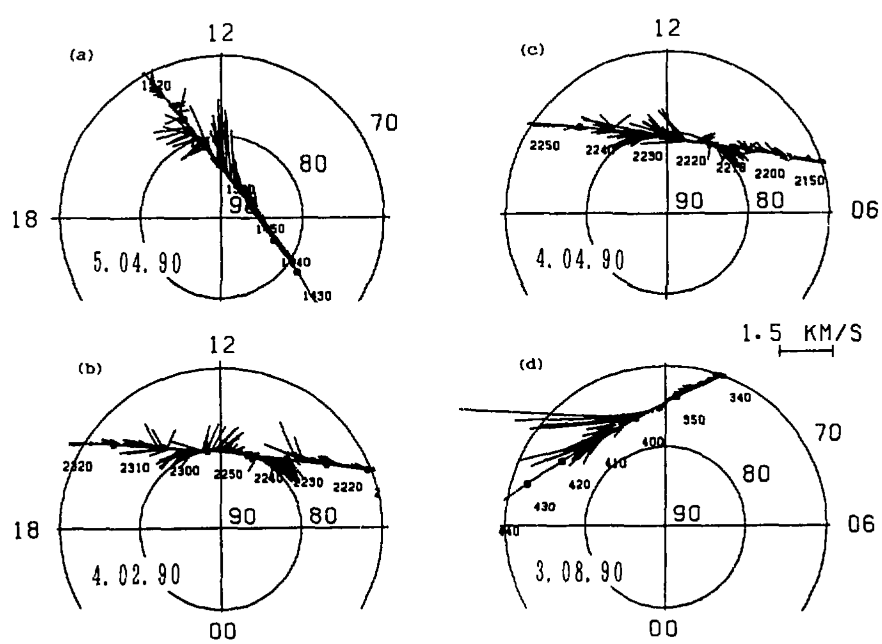



Fig. 8b: Distorted two cell pattern in the northern hemisphere for northward IMF [Heppner and Maynard (Ref. 13)].

Fig. 9: Flow velocities derived from the electric field data of EXOS-D during northward IMF.



is real while the pattern of Figure 8b is inadequate. Figure 9 shows convection velocities which are observed in four passes that took place under northward IMF. In cases (b) and (c) in which the spacecraft traversed the dayside polar cap from dawn to dusk reaching the highest corrected geomagnetic latitude of 80° , sunward and anti-sunward flows are observed in turn just as expected from Figure 8a. In all cases the eastward flow is observed in the post-noon region between 75° to 80° where the westward flow should have been observed according to Figure 8b for any polarity of IMF $B_y$ .

In Figure 10 the particle and electric field data are shown for the case of Figure 9(b). IMF $B_y$ at IMP 8 is positive before 2230 and negative afterward. As the spacecraft traversed the polar cap from dawn to dusk, a clearly defined TRB is observed first and then the reversal in the flow velocity (as derived from the smoothed value of $E_y$ ) from sunward to anti-sunward is seen at CRB:Convection Reversal Boundary. The dawnside CPIP is mostly within the region of the sunward flow, in the same way as we have seen earlier for the cases under southward IMF. In the region of the anti-sunward flow the flux of precipitating ions is very weak. Around noon where the flow direction becomes sunward again a patch of ions with energies from about 100 eV to several keV is observed. This probably represents the precipitation from the cusp. In E-t diagrams taken at dawn-to-dusk passes under northward IMF, the cusp precipitation is often triangular shaped and the energy bandwidth is the largest around the middle. In the afternoon there is another region of anti-sunward flow and very weak ion precipitation. The flow becomes sunward again and CPIP is observed as the spacecraft moves into lower latitudes. TRB is not sharply defined on the afternoon side in this case.

Relation between energy and pitch angle of ions is shown for the intervals of the morning side CPIP (interval A) and of the noon-time CPIP (interval B) in Figure 11. Intervals A and B are indicated in Figure 10 below the lowest panel. Each block consists of the data obtained in successive 8 second intervals and the pitch angle varies from downward (left) to upward (right). In Panel A the crossing times of CRB and TRB are marked. (It is seen that CPIP starts from slightly equatorward side of TRB although it is more intense and extended on the poleward side.) If the source size is small in the direction of the convection, a rising pattern is expected to be produced in each block due to the velocity filter effect. In Panel A such a pattern is not recognizable, and this is consistent with the presence of dawn/dusk CPIP all the way along the streamlines of the flow. Therefore a decrease in energy of CPIP ions with latitude which is often observed in dawn-dusk passes as in Figure 10 cannot be due to the velocity filter effect and has to be interpreted by the energy dependent structure of the source region. In Panel B, on the other hand, the rising pattern is recognized and the source distance of 4 to 15 $R_e$ can be derived. This is consistent with the view that the slot through which precipitating ions are injected into the magnetosphere has a narrow width in the latitudinal direction and the energy dispersion, in which energy increases with increasing latitude, is produced by the velocity filter effect. The estimated distance is sometimes made unrealistically small, however, probably because of finite width and time variability of the source as well as scattering of pitch angles of the ions in transit.

In the electron data of Figure 10 there is a uniform background that seems to represent the polar rain since the IMF condition ($B_x < 0$) is favorable for entry of the solar wind electrons into the northern hemisphere. The electrons how-

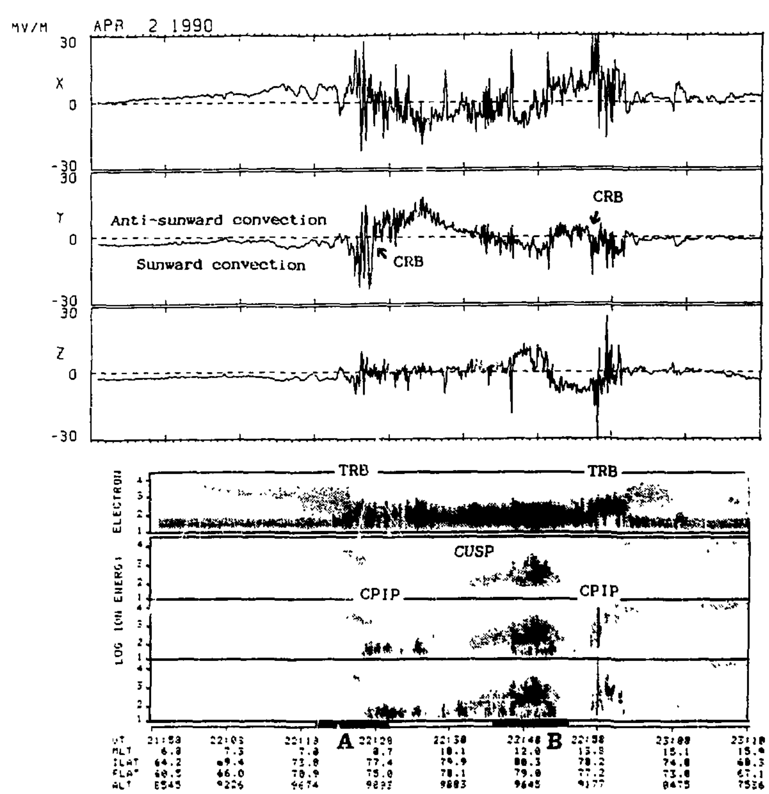



Fig. 10: Comparison of particle and electric field for a dawn-to-dusk traversal of the polar cap under northward IMF. Three components of the electric field refer to the solar ecliptic coordinates, and the three panels of the ion flux are for downward, perpendicular to **B**, and upward pitch angles.

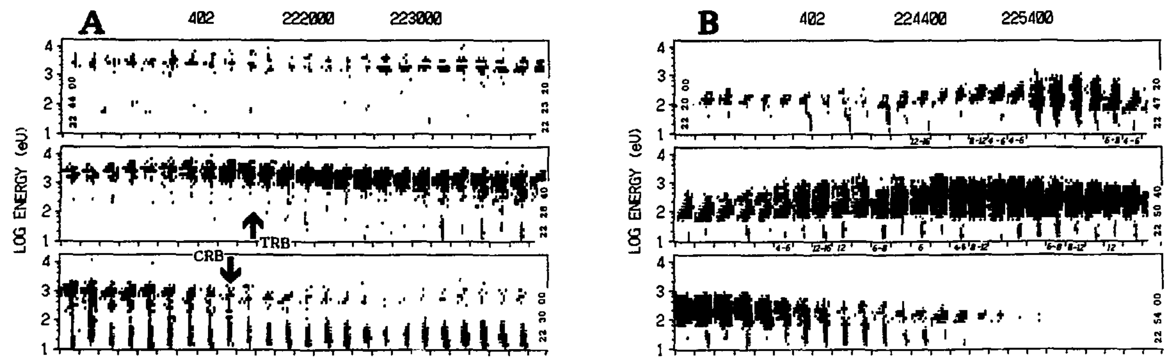



Fig. 11: Pitch angle versus energy diagrams for the interval A of dawnside CPIP and the interval B of the noon-time CPIP (cusp). These intervals are indicated at the bottom of Figure 10. Each panel contains 3 min 20 sec of data, and each block represents the pitch angle versus energy relation in the ion flux obtained in 8 seconds. In each block the pitch angle increases to the right from downward to upward. The estimated distance to the source region is written under the panels.

ever show structured intensifications that are due probably to accelerations inside the magnetosphere. Such intensifications are seen for example in association with the cusp type ion precipitation around noon.

Convection streamlines and ion precipitation regions under northward IMF are summarized in Figure 12 for the dayside region. Symmetry with respect to the noon meridian is assumed. Under this assumption the convection pattern is the same as the $B_y = 0$ case of Figure 8a. Streamlines comprise (at least) four cells. The pair of lobe cells in the dayside polar cap is the characteristic feature of the northward IMF condition. The other two cells are present on dawn and dusk sides under both northward and southward $B_z$. They used to be interpreted to be the product of the viscous force exerted by the solar wind but this interpretation is untenable since both sunward and anti-sunward flows in these cells are found in the region of the open field lines. Although we have illustrated them as lobe cells confined in the polar cap, we cannot deny the possibility that they traverse the polar cap boundary on the nightside as noted in the previous section. CPIP around noon is on the sunward directed streamlines, and the high latitude limit of this CPIP varies widely from case to case. CPIP extends toward dawn and dusk along TRB on sunward directed streamlines.

In addition to the four cells illustrated by solid curves in Figure 12, there may actually be viscous cells around noon in low latitudes below TRB as indicated by dashed curves. It has been known from high-altitude observations near the magnetopause that LLBL has a substantially larger thickness under northward than southward IMF [Mitchell et al. (Ref. 10)]. The anti-sunward flow in the well developed LLBL could form convection cells of their own in the region of closed field lines. Our analysis of the EXOS-D data has not proceeded far enough to judge this possibility.

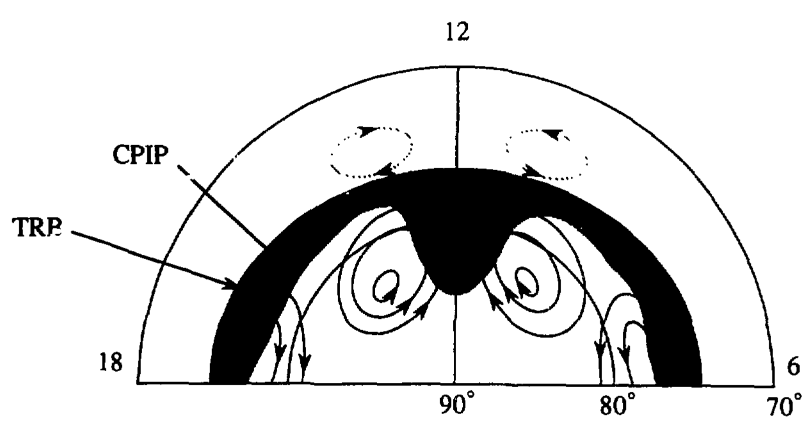



Fig. 12: Convection streamlines and ion precipitation regions under northward IMF.

## DISCUSSION

The formation of the lobe cell under northward as well as southward IMF has been explained by Crooker (Ref. 14) on the basis of the anti-parallel merging model, and the concept of the reclosure cell has been introduced by Reiff and Burch (Ref. 15) as an extension. Although our observations have confirmed the existence of the lobe cell as a basic constituent of the convection system, we have found important differences in the number of the cells. Under southward IMF where the anti-parallel merging model predicts only one cell whose polarity is determined by the sign of $B_y$ of IMF, we have observed two cells although the relative size of the two cells depends on $B_y$. Under northward IMF the same model predicts one or two (when $B_y$ is small) lobe cells, but four cells have been observed.

If the lobe cells are indeed products of reconnection, the occurrence of these cells as a pair (one in prenoon and the other in postnoon region) suggests that reconnection of IMF with magnetospheric field lines on the lobe surface takes place on both pre-noon and post-noon sides of the noon meridian although internal and external field lines are far from being anti-parallel to each other on at least one of these sides. We do not yet understand the global condition which forces the reconnection to proceed in such a manner regardless of the relative orientation of magnetic fields inside and outside the magnetopause.

If the lobe cells are indeed confined in the region of the open field lines, under southward IMF the ionospheric projection of the merging line links the centers of two lobe cells and runs across the streamlines of the merging cell as illustrated in Figure 13a. Positions of CPIP relative to this line differ between noon and dawn/dusk. The noon-time CPIP is on the downstream side of the merging line so that it is attributable to the ion injection from the reconnection region at the magnetopause. The dawn/dusk CPIP, on the other hand, is on the upstream side of the merging line. The ions of this CPIP are on the open field lines that are to be reconnected on the surface of the tail, and they should have been supplied to open field lines somewhere in the nightside magnetosphere. This supply process has to be explained.

It is also necessary to explain why intense ion precipitation is not seen on the downstream side of the dawn/dusk part of the merging line where the magnetosheath plasma should have an easy access.

If the convection streamlines are as illustrated in Figure 7a, on the other hand, CPIP on the open field line region is on the downstream side of the ionospheric projection of the merging line everywhere (Figure 13b) and thus can be attributed to the entry of the magnetosheath plasma along the open field lines. This makes the interpretation easier, while the extension of the low-latitude part of CPIP inside the plasma sheet still need be explained.

In the case of northward IMF, a model has been proposed to explain the lobe cells in the noon-time polar cap in terms of reconnection on the surface of the tail lobe, but it is not clear how the lobe cells in dawn and dusk sectors can be formed by reconnection. Figure 14a illustrates the low-altitude projection of the merging line that has been considered to produce the lobe cells around noon. Projection of the merging line for the dawn/dusk lobe cells cannot be a contiguous extension of this line. Alternatively, it may be considered that the projection of the merging line does not run across the noon meridian but consists of two lines that connect the centers of the noon-time and dawn/dusk lobe cells as illustrated in Figure 14b. If this is the case it has to be considered that the noon-time CPIP (i.e., the cusp precipitation) is not related to reconnection but merely represents diffusive entry of the magnetosheath ions from the cusp region. This also may be feasible, but it is still puzzling why precipitating ions are not observed in the region of the anti-sunward flow of Figure 10 which corresponds to the downstream side of the merging line.

In view of these difficulties, it does not seem obvious that the lobe cells are the direct consequences of the reconnection process. Alternatively it may be considered that the dawn/dusk lobe cells are generated internally in the magnetosphere due to the viscous-like force that is exerted from the merging cell. However, this idea also has a difficulty since the convection velocity is often higher on the poleward side of TRB than on the equatorward side.

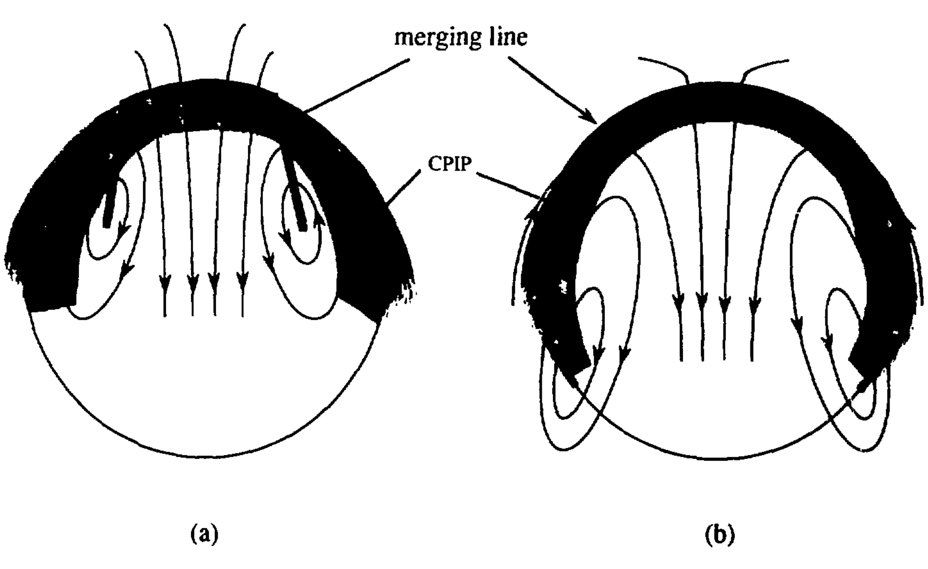



Fig. 13: Two conceivable positions of the projection of the merging line to low altitudes relative to the convection pattern under southward IMF.

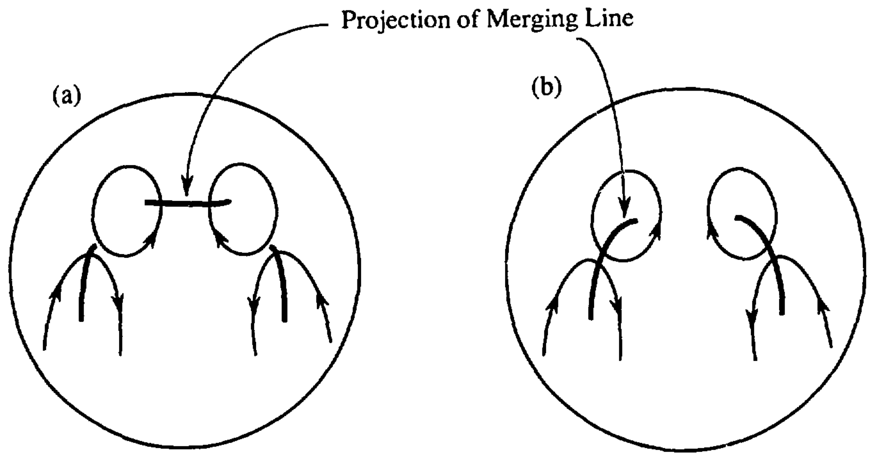



Fig. 14: Conceivable positions of the projected merging line under northward IMF. Noon is to the top of the figure.

## CONCLUSIONS

From the analysis of field and particle observations by EXOS-D in the dayside polar cap, we have found the following new feature of convection and particle precipitation.

When IMF is southward,

(1) there are often two lobe cells instead of one in which the plasma flows sunward in the region of open field lines in dawn and dusk sectors; (2) a patch of precipitating ions with energies around 1 keV is observed in this region of the sunward flow; and (3) the presence of the viscous cell cannot be confirmed.

When IMF is northward,

(4) among the four convection cells in the polar cap, two are lobe cells in the dayside polar cap and are characterized by the sunward flow around the noon meridian; and (5) the other two lobe cells are in dawn and dusk sectors and shows the features (1) and (2) above.

Thus the observations have raised new questions on, (6) why dawn/dusk lobe cells tend to be produced as a pair whi'· :nodels in which magnetic tension plays a key role predict only one cell except when IMF $B_y$ is very small; and (7) why keV ions are present on sunward directed streamlines.

These seem to suggest the importance of processes in the nightside magnetosphere even in some phenomena which have hitherto been considered to be due entirely to daytime processes.

### References


1. Burch J L, Reiff P H, Menietti J D, Heelis R A, Hanson W B, Shawhan S D, Shelley E G, Sugiura M, Weimer D R & Winningham J D 1985, IMF $B_y$-dependent plasma flow and Birkeland currents in the dayside magnetosphere, 1. Dynamics Explorer observations, *J. Geophys. Res.* 90, 1577.
2. Bythrow P F, Potemra T A, Erlandson R E, Zanetti L J, & Klumper D M 1988, Birkeland currents and charged particles in the high-latitude prenoon region: A new interpretation, *J. Geophys. Res.* 93, 9791.
3. Newell P T & Meng C-I 1988, The cusp and the cleft/boundary layer: Low altitude identification and statistical local time variation, *J. Geophys. Res.* 93, 14549.
4. Kremser G & Lundin R 1990, Average spatial distributions of energetic particles in the midlatitude cusp/cleft region observed by Viking, *J. Geophys. Res.* 95, 5753.
5. Tsuruda K & Oya H 1991, Introduction to the EXOS-D (Akebono) project, *Geophys. Res. Let.* 18, 293.
6. Nishida A, Mukai T, Hayakawa H, Matsuoka A, Tsuruda K, Kaya N & Fukunishi H 1992, Unexpected features of the ion precipitation in the so-called cleft/LLBL region; association with sunward convection and occurrence on open field lines, *J. Geophys. Res.* 97, in press.
7. Newell P T & Meng C-I 1992, Mapping the dayside ionosphere to the magnetosphere according to particle precipitation characteristics, *Geophys. Res. Let.* 19, 609.
8. Smith M F & Lockwood M 1990, The pulsating cusp, *Geophys. Res. Let.* 17, 1069.
9. Elphinstone R D, Hearn D, Murphree J S, & Cogger L L 1991, Mapping using the Tsyganenko long magnetospheric model and its relationship to Viking auroral images, *J. Geophys. Res.* 96, 1467.
10. Mitchell D G, Kutchko F, Williams D J, Eastman T E, Frank L A & Russell C T 1987, An extended study of the low-latitude boundary layer on the dawn and dusk flanks of the magnetosphere, *J. Geophys. Res.* 92, 7394.
11. Richardson I G, Owen C J, Cowley S W H, Galvin A B, Sanderson T R, Scholer M, Slavin J A & Zwickl R D 1989, ISEE 3 observations during the CDAW 8 intervals: Case studies of the distant geomagnetic tail covering a wide range of geomagnetic activity, *J. Geophys. Res.* 94, 15189.
12. Heelis R A, Reiff P H, Winningham J D & Hanson W B 1987, Ionospheric convection signatures observed by DE 2 during northward interplanetary magnetic fields, *J. Geophys. Res.* 92, 5819.
13. Heppner J P & Maynard N C 1987, Empirical high-latitude electric field models, *J. Geophys. Res.* 92, 4467.
14. Crooker N U 1979, Dayside merging and cusp geometry, *J. Geophys. Res.* 84, 951.
15. Reiff P H & Burch J L 1985, IMF $B_y$-dependent plasma flow and Birekeland currents in the dayside magnetosphere 2. A global model for northward and southward IMF, *J. Geophys. Res.* 90, 1595