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Association of an Auroral Surge with Plasma Sheet Recovery and the Retreat of the Substorm Neutral Line

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Abstract

One of the periods being studied in the PROMIS CDAW (CDAW-9) workshops is the interval 0000-1200 UT on May 3, 1986, designated "Event 9C." A well-defined substorm, starting at 0919 UT, was imaged by both DE 1 over the southern hemisphere and Viking over the northern hemisphere. The images from Viking, at 80-second time resolution, showed a surge-like feature forming at about 0952 UT at the poleward edge of the late evening sector of the oval. The feature remained relatively stationary until about 1000 UT when it seemed to start advancing westward. ISEE 1 and 2, at GSM X, Y, Z, dz = (−16.5, 3.4, −0.5, −2.3) experienced plasma sheet dropout beginning at 0920 UT and plasma sheet recovery, with very fast earthward plasma flow, starting at 1002 UT. DMSP F7 crossed and photographed the surge head, located at −68° MLAT, 2225 MLT, at 1006:30 UT. ISEE 1 and 2 were closely conjugate to the surge as mapped from both the DMSP and Viking images. We conclude that the plasma sheet recovery was occasioned by the arrival at ISEE 1, 2 of a westward traveling wave of plasma sheet thickening, the wave itself being formed by westward progression of the substorm neutral line's tailward retreat. The westward traveling surge was the auroral manifestation of this nonuniform retreat of the neutral line. We suggest that the upward field aligned current measured by DMSP F7 above the surge head was driven by plasma velocity shear in the plasma sheet at the duskward "kink" in the retreating neutral line. By analogy with this observation we propose that the westward traveling surges and the current wedge field-aligned currents that characterize the expanding auroral bulge during substorm expansive phase

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are manifestations of (and are driven by) velocity shear in the plasma sheet near the ends of the extending substorm neutral line.

Introduction

During the Spring of 1986 a program called Polar Region and Outer Magnetosphere International Study (PROMIS) was conducted whose objective was to acquire satellite measurements of magnetospheric and solar wind plasmas, as well as enhanced ground-based observations of geomagnetic and ionospheric phenomena, in concurrence with imaging of the northern and southern auroras by auroral imagers on the DE-1 and Viking satellites (Hones, 1985). It was anticipated that such a body of multi-point measurements, especially including the global perspective afforded by the auroral images, would offer unique opportunities to study solarly wind-magnetosphere interactions and particularly substorms. The ninth series of Coordinated Data Analysis Workshops, CDAW 9 (PROMIS) was subsequently organized to exploit the PROMIS data set. Five intervals of potentially high interest were chosen for study. This paper deals with a substorm that is part of "Event C" which covers the interval 0000–1200 UT, May 3, 1986.

This study bears most heavily upon phenomena that occurred during the late expansive phase or the recovery phase of this substorm. The concept of a substorm was first presented in terms of variations of the distribution of auroral emissions (Akasofu, 1964). The substorm starts with sudden brightening of a previously quiet arc in the midnight sector of the auroral oval. This initiates the expansive phase of the substorm which lasts perhaps 30 minutes and is characterized by poleward expansion of bright active auroras in the late evening-to-early morning sector of the oval which results in the formation of an "auroral bulge" that can reach 10–15 degrees in latitudinal extent and an extension of six hours or more in magnetic local time. A prominent feature of the expanding bulge is the westward traveling surge, a bright wave-like auroral configuration that forms the leading edge of the bulge's westward expansion. Intense westward ionospheric current, called the westward electrojet, flows in the vicinity of the bright auroral arcs of the expanding bulge; the westward traveling surge is the leading edge of the extending electrojet (Akasofu, 1968). The westward electrojet causes a characteristic perturbation of the geomagnetic field at underlying ground locations and this appears as a "negative bay" in H-component magnetograms from such auroral zone locations.

The expansive phase is followed by a recovery phase during which auroral arcs become less bright and less active and gradually retreat equatorward, approaching the pre-substorm auroral distribution. The recovery phase can last one to two hours.

Years of measurements by satellites in the solar wind and the outer magnetosphere have shown that plasmas, fields, and energetic particles there exhibit a repeatable pattern of behavior concurrent with a substorm's occurrence at earth. Prominent features of this pattern are the following:

a) Southward turning of the interplanetary magnetic field (IMF) some tens of minutes before expansive phase onset.

b) In the near-earth tail ($|X| \approx 6$ to 15 R_E)

    i) tailward stretching of the magnetic field and gradual thinning of the plasma sheet for some tens of minutes before expansive phase onset

    ii) sudden "dipolarization" of the magnetic field and thickening of the plasma sheet at expansive phase onset.

c) At intermediate tail distances ($|X| \approx$ 15–30 R_E)

    i) sudden dropout of plasma (extreme plasma sheet thinning) a few minutes after expansive phase onset.

    ii)sudden recovery (thickening) of the plasma sheet about an hour after expansive phase onset.

d) In the very distant tail ($|X| \approx 220$ R_E)

    i) sudden appearance of tailward-streaming energetic electrons and protons on lobe-like magnetic field lines showing normal velocity dispersion (fastest particles encountered first) about 20 minutes after expansive phase onset.

    ii) isotropization of energetic particles and appearance of fast tailward-flowing hot plasma and disturbed magnetic field, starting ~5–10 minutes after (i) and lasting about 20 minutes.

    iii) disappearance of hot plasma, reoccurrence of tailward streaming energetic electrons and protons on lobe-like magnetic field lines, this time showing inverse velocity dispersion (fastest particles encountered last).

These phenomena, together with associated details of plasma flow and magnetic field variations that we do not have room to discuss here, have become widely understood to signify an acquisition of solar wind energy by the magnetosphere, followed by a sudden unloading of the energy, as depicted by the near-earth neutral line model of substorms (e.g., Hones, 1979). By that model the initial energy gain by the magnetosphere (in the growth phase of the substorm) is accomplished through increased coupling with the solar wind resulting from front-side magnetic reconnection with the IMF when the IMF turns southward. The magnetosphere's subsequent loss of energy occurs through magnetic reconnection at a near-earth neutral line (the substorm neutral line) that forms in the near earth plasma sheet at (or very near) the time of the expansive phase onset. the energy loss proceeds through two mechanisms: (a) severance of the plasma sheet at the substorm neutral line and release of its tailward portion as a plasmoid and (b) injection of plasma earthward of the neutral line into the inner magnetosphere and its precipitation to earth causing the auroras and associated ionosphere currents and heating.

An important feature of the model that has received relatively little attention (and of which there is still little theoretical understanding) is the last step (which has not been described above)—the tailward retreat of the substorm neutral line that is manifested at intermediate tail distances by the sudden thickening of the plasma sheet. The neutral line retreat has been shown to be often associated with a rather notable displacement (or leap) of the westward electrojet toward higher latitudes (e.g., Hones *et al.*, 1984; Hones *et al.*, 1986) that is evidenced by the peak and beginning of subsidence (or recovery) of magnetic bays at auroral zone latitudes (i.e., ~65° magnetic latitude) and onset or deepening of bays at higher latitudes. The AE index, whose stations are situated within a few degrees of 65° magnetic latitude, typically depicts the response of such stations and it has become customary to refer to the subsidence of the AE index as the recovery phase of a substorm. But is has not been established how the "recovery" of the AE index is related to the auroral substorm "recovery" as described by Akasofu (1964). Possibly the AE index recovery is a feature of the auroral substorm's late expansive phase rather than its recovery phase (see Rostoker (1986) and Hones (1986) for further discussions of this matter). Thus it is not clear whether or not the poleward leap of the electrojet, which seems closely tied to the neutral line retreat, also implies a sudden poleward extension of the distribution of auroral emission. One observation (Hones *et al.*, 1987) suggests that it does not and that the sudden poleward displacement of the electrojet is associated simply with a sudden brightening of the poleward edge of a relatively unchanging spatial distribution of the auroras.

As we stated earlier, this paper deals most closely with phenomena observed during the late expansive phase or recovery phase of a substorm whose expansive phase onset was at 0919 UT, May 3, 1986. This study reveals new information regarding the nature of the neutral line's retreat and the plasma sheet processes that produce auroral surges and the substorm current wedge.

Data Presentation

The substorm's onset at 0919 UT was marked (see Figure 1) by onset of negative bays at College and Anchorage, Alaska, which were located at ~2200 magnetic local time (MLT); by an "injection" of energetic electrons (signifying a dipolarization of the local magnetic field) at geosynchronous satellite 1984-129 at ~2300 MLT; and by a plasma dropout at ISEE 1 whose location (X, Y, Z, dZ) GSM was approximately (−16.3, 3.4, −0.6, −2.3) R_E and ~2300 MLT. The substorm can, perhaps, be regarded as a multiple onset substorm with second and third onsets at ~0936 and 0942 UT when the bays at College and Anchorage show sudden further deepenings and the electron fluxes at 1984-129 show further sudden sharp increases. Notice that the bays at Anchorage and College start to subside after 0953 UT but that at the high latitude station, Inuvik, continues to deepen past 1003 UT and that at the very high latitude station, Cape Parry, begins at about 1013 UT. It is such late-substorm features as these, occurring in this case about 35 to 55 minutes after expansive phase onset but within a span of only 10 to 20 minutes around plasma sheet recovery (see Figure 1c) that suggest a delayed sudden poleward displacement (leap) that may be causally related to plasma sheet recovery, as discussed in the previous section.

Figure 2 presents many of the images of the northern aurora recorded by Viking at 80 second time resolution. Unfortunately the images did not start until 0930:29 UT and the midnight meridian of the oval and the region eastward of it began to be imaged only by 0939:33. Nevertheless, an auroral bulge is seen to start forming in the pre-midnight sector by ~0938:12 and to continue expanding eastward, westward, and poleward until it reaches its maximum extensions by ~0950 UT. After that the equatorward regions of the bulge tend to fade and become more diffuse while the poleward edge remains quite bright and sharply delineated. The brightness along the poleward edge is partly due to (and seems to extend from) the surge, at ~2200 MLT, that becomes evident at 0952:17 UT and remains evident thereafter.

We now briefly summarize events associated with the substorm's growth and early expansive phases and will then devote the rest of the paper to phenomena surrounding the plasma sheet recovery. Unfortunately there are no measurements of the IMF for this period. Figure 3 shows that the magnetic field intensity at ISEE 1 begins to increase at ~0830 UT and its latitude begins to decrease. This tail-like development of the field (the growth phase, quite probably due to an earlier southward turning of the IMF) continues through the plasma sheet dropout and until ~0930 UT. After ~0935 the latitude of the (lobe) field at ISEE 1 increases and its magnitude decreases. These are signs of a weak partial dipolarization of the field and consumption of stored energy to power the expansive phase which became greatly enhanced after ~0936 UT. Hones *et al.* (1990) argue, from the magnetic field and plasma signatures at ISEE 1, that the substorm neutral line formed somewhere tailward of ISEE 1 but less than 26 R_E from Earth.

The plasma sheet recovery at ISEE 1 began with a burst of earthward-jetting plasma at ~1002 UT (Figure 4). Large variations of the magnetic field accompanied the reappearing plasma, culminating at ~1013 UT, in an increase of latitude to ~30 degrees, an increase of longitude to ~230 degrees and a decrease of intensity to 10 nT that suggested a plasma beta value of ~10 at this time. After ~1015 UT, all three field parameters returned to less extreme values (Figures 3 and 4) and ISEE 1 then remained in hot, nearly isotropic plasma. The impression given by these data is that ISEE 1 entered the recovering plasma sheet through an environment of rapidly earthward collapsing flux tubes filled with intense hot plasma, twisted with a right-hand helicity. The large few-minute reduction of field intensity centered at ~1013 UT suggests that this collapsing body of twisted flux tubes may have constituted a large plasma bulge at the leading edge of a westward progressing thickening of the plasma sheet. This is the view we hold of this event, an interpretation that is supported by the concurrent observations of the surge in the Viking images (Figure 2).

This view is depicted schematically in Figure 5, where the thickening wave is represented as resulting from a nonuniform or segmental, retreat of the substorm neutral line. In regions earthward of the neutral line the plasma sheet will be thicker earthward of the retreated segment than earthward of the nonretreated segment because of the greater amount of collapsed magnetic field there. It is our view, suggested by the Viking images, that the auroral surge was a mapping of the duskward leading edge of the extending bulge of collapsed flux, i.e., it was a projection of the duskward "kink" in the segmentally retreating neutral line. The DMSP F7 satellite, at 800 km altitude, crossed the southern auroral oval at about 2200 MLT very close to the time of plasma sheet recovery at ISEE 1, passing over, and imaging, a surge from 1006:26 to 1007:23 UT. That image and other measurements by DMSP F7 are presented in some detail by Hones *et al.* (1990). Briefly, the bright surge head was about 500 km in diameter. Upward field aligned current of $\sim 2\ \mu A/m^2$ flowed from the surge head carried, presumably, by the intense flux of precipitating >30 keV electrons that was measured above it. It was bordered on its north and south by nonluminous regions of downward field aligned currents of similar magnitudes. The surge head represented a poleward step of about 4 degrees in the poleward edge of the auroras, i.e., the edge of the oval lay about 4° farther poleward east of the surge head than west of it. Mapping of the Viking surge and the DMSP F7 surge into the outer magnetosphere by the Tsyganenko (1987) showed, not surprisingly, that the two surges were magnetically conjugate and, furthermore, that they were quite closely conjugate to the ISEE 1 spacecraft at the time it was enveloped by the recovering plasma sheet. (See Hones *et al.*, 1990 for a discussion of this mapping.)

Mappings of the surge head into a magnetotail cross-section at $X_{GSM} = -15\ R_E$ are shown in Figure 6 for 1003:00 UT and 1012:24 UT. In the tail projection the surge head appears as an abrupt rise, or "wall" of plasma $\sim 4\ R_E$ tall as one progresses from west to east. Note that the auroral luminosity to the west of the surge, seen in the images at top, does not appear in the projections. This is because those field lines do not extend to 15 R_E in the Tsyganenko model. It is notable that the luminous surge head projects into the ~ 30 nT magnetic field at $X_{GSM} = -15\ R_E$ as an area equivalent to a circle of $\sim 4\ R_E$ diameter, lending credibility to the large amplitude of the rise depicted in Figure 6. Taking this estimated $\sim 4\ R_E$ dimension of the projected surge head together with the ~ 10 minute time interval required for the initial high-beta plasma regime to pass ISEE 1 (see above and Figure 3) one can estimate that this regime, taken to be the projection of the surge into the tail, moved duskward over ISEE 1 at ~ 40 km/sec.

Outer Magnetosphere Source of the Surge

The recovering plasma sheet is a regime of fast earthward flowing plasma—a fact that is well established by many past observations and that is shown again in the present event. One expects, then, that earthward of the kinks of the segmentally-retreating neutral line there is a region of plasma shear between the fast flowing plasma earthward of the retreated segment and the slower or nonflowing plasma earthward of the not-yet retreated segment. The sense of the vorticity will be clockwise, when viewed parallel to $\vec{B}$, earthward of the duskward kink. Figure 7 illustrates this geometry for a flux tube near the dusk-side kink. The vorticity is such that the field lines above the midplane are twisted with a left-hand helicity while those below the midplane are given a right-handed helicity. In both cases an upward field-aligned current is implied to produce the field twist. This is the current that was measured over the surge head by DMSP F7 and that is inferred from the sense of the field twist observed by ISEE 1. An X in Figure 7 suggests a point where ISEE 1 may have entered the advancing surge flux tube.

Hones *et al.* (1990) proposed that one could readily extrapolate the arguments advanced above, based on the May 3 substorm observations, to the situation of the westward travelling surge associated with the growth of the auroral bulge during substorm expansive phase. By the near-earth neutral line model a neutral line forms, and magnetic reconnection begins, in the near-earth plasma sheet at expansive phase onset. Plasma flows rapidly earthward in the region earthward of the neutral line. Thus, as the neutral line extends westward (and eastward) plasma shear regions form earthward of its two ends, that earthward of its duskward end having the same sense of vorticity and direction of field-aligned current as were observed in the May 3 event. The shear region near the dawnward end of the extending neutral line would produce a downward field aligned current. Thus, as was earlier proposed by Birn and Hesse (1990), the substorm current wedge can be explained as a direct consequence of the formation and extension of the substorm neutral line, its field-aligned currents being driven by the plasma shear near the ends of the neutral line. This concept is illustrated in Figure 8.

Conclusions

The observations reported here allowed us to relate an auroral surge, imaged simultaneously by satellites viewing the northern and southern auroral ovals, to plasma sheet recovery recorded by a satellite ~17 R_E from earth in the southern pre-midnight quadrant of the magnetotail. Mappings of the surge form into a cross-section of the tail suggested that the tail satellite was closely conjugate to the northern and southern hemisphere surges when the plasma sheet recovery was recorded and that the recovery signaled envelopment of the satellite by a large amplitude (~4 R_E) thickening of the plasma sheet progressing duskward across the tail, the surge being the ionospheric mapping of the leading edge of this large plasma wave. We propose that the westward-proceeding plasma sheet thickening wave was created by a tailward retreat of the substorm neutral line that was not uniform along the neutral line's length but that progressed more rapidly in the near-midnight sector, resulting in "kinks" of the neutral line duskward (and probably dawnward) of the midnight sector. A twisting of the magnetic field in the wave's leading edge was consistent with the presence of upward field-aligned current, probably the continuation of the upward field-aligned current that was measured over the southern hemisphere surge head.

We propose that the twisting of the field lines and the attendant upward field-aligned current were caused by shear of plasma flow, earthward of the neutral line kink, between the faster earthward plasma flow earthward of the retreated portion of the neutral line and the slower earthward flow earthward of the duskward not-yet-retreated portion. We extrapolate from this set of observations to propose that, in general, auroral surge forms, which are features primarily of the evening-to-midnight sector of the auroral distributions (Davis and Hallinan, 1976) are produced by plasma shear in the plasma sheet having the same sense of vorticity as that of the present event, i.e., clockwise when viewed parallel to $\vec{B}$. We propose, in particular, that the westward traveling surge that typically leads the duskward expansion of the auroral bulge during the expansive phase is produced by plasma shear earthward of the duskward end of the westward-extending neutral line. A corollary of this (in agreement with the work of Birn and Hesse (1990)) is that the downward and upward field aligned currents that mark the dawnward and duskward regions of the expanding auroral bulge and that define the edges of the substorm current wedge are driven by the plasma flow shears earthward of the ends of the extending substorm neutral line.

Finally, we wish to impress upon the reader the importance, in magnetospheric research, of multi-point observations in general and of outer magnetosphere measurements with concurrent global auroral imaging in particular. The results reported here could not have been achieved without such a set of simultaneous observations.

Acknowledgments

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Figure Captions

Fig. 1. (From Hones *et al.*, 1990)

(a) H- or X-component magnetograms (top) and Z-component magnetograms (bottom) from the Alaska chain of magnetometer sites, Anchorage (AMU), Talkeetna (TLK), College (CMO), Ft. Yukon (FYU), Barrow (BRW), Inuvik (INK), and Cape Parry (CPY). Magnetic latitudes of the stations are indicated.

(b) Fluxes of electrons of energies greater than 30, 45, 65, 95, 140, and 200 keV but less than 300 keV, measured by the charged particle analyser on satellite 1984-129 between 0900 and 1030 UT, May 3, 1986.

(c) Four-second averaged fluxes of 6 keV electrons (top) and 2 keV protons (bottom) measured at ISEE 1 on May 3, 1986. The GSM coordinates of ISEE 1 are shown, together with its estimated distance from the neutral sheet.

Fig. 2. Images of the northern auroral oval taken with the Viking UV auroral imager (Anger *et al.*, 1987). The day side of the oval (upper left) is sunlit. The night side (lower right) is in twilight. In these color-coded images color changes from dark blue through light blue to yellow signify increasing UV intensity. In most instances alternate pictures were made with different sensitivities, causing some picture-to-picture fluctuations in apparent intensities. This is evident, for example, in the pictures at 10:00:20, 10:01:40, 10:03:00, and 10:04:21. (From Hones *et al.*, 1987.)

Fig. 3. Total magnetic field strength (BT) and the GSM latitude and longitude of the field measured by ISEE 1 from 0800 to 1100 UT, May 3, 1986.

Fig. 4. Data from ISEE 1 from 0950 UT to 1020 UT on May 3, 1986. The top panel shows the directional flux of protons (53–69 keV) measured by the ULECA sensor of the MPI-UMd instrument (Hovestadt *et al.*, 1978). The scale at the right indicates the direction of motion (GSE) of the protons. Panels 2–5 show fluxes of electrons (2 and 6 keV) and protons (2 and 6 keV) measured by the UC Berkeley-CESR instrument. This is a narrowly collimated instrument looking upward perpendicular to the ecliptic plane (Anderson *et al.*, 1978). The bottom three panels show the magnetic field strength (BT), and its solar magnetospheric latitude and longitude. The measurements were made with the UCLA fluxgate magnetometer (Russell, 1978).

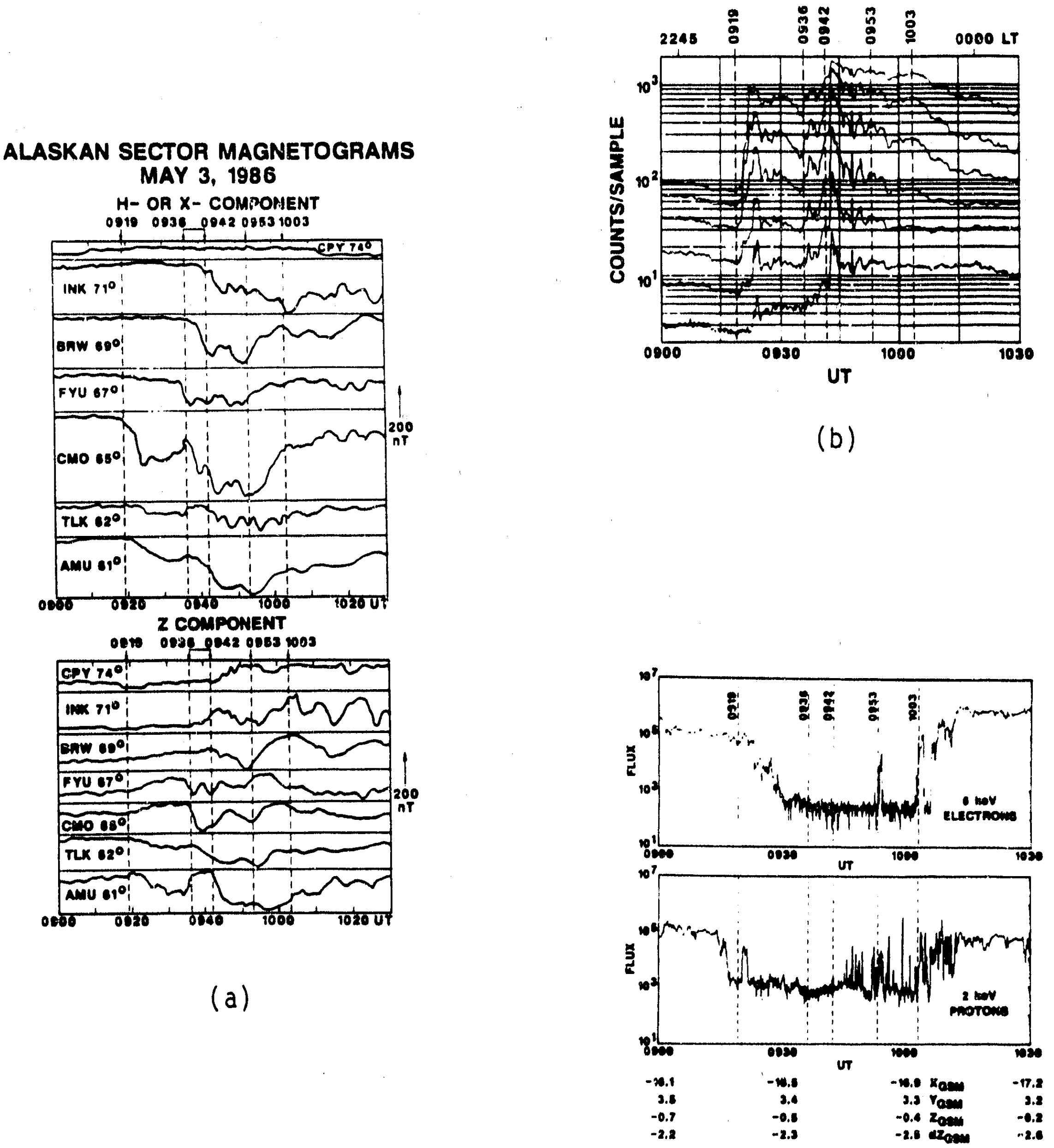
Fig. 5. Schematic representation of the proposed relationship between a westward traveling auroral surge, a segmented retreat of the substorm neutral line and the resulting thickening of the plasma sheet. In the top diagrams the earth is represented by the small black half circle. The earth's polar region above 60° MLAT is contained in the large half-circle. The shaded region within that is the night-side aurora. The substorm neutral line (at X_{GSM} =-20R$_{\mathrm{E}}$) is depicted by the dashed line labeled N.L. The ISEE 1 satellite is represented by a square and the Section A-A$'$ is drawn through its location. The bottom diagrams depict a cross-section of the magnetotail at $X_{\mathrm{GSM}} = -17\mathrm{R_E}$ (the Section A-A$'$ in the top panels). The shaded region is the plasma sheet. The diagrams at left represent conditions shortly after the end of the expansion phase when the substorm neutral line has attained its full extension in the near-earth tail (i.e., ~0952 UT in the May 3 substorm). The middle diagrams represent the situation when the neutral line first starts to retreat, its central section starting to sag tailward. A bulge in the plasma sheet at the ISEE 1 distance has appeared because of this localized retreat but it has not yet enveloped ISEE (e.g., ~1000 UT). The diagrams at right represent the situation when a neutral line segment has retreated far tailward resulting in a large bulge of the plasma sheet, which has just enveloped ISEE 1 and which is manifested at earth by a pronounced auroral surge (e.g., ~1006 UT).

Fig. 6. Top row: expanded views of surge images at 1003:00 UT and 1012:24 UT showing a net westward motion of the surge head in this time interval. Bottom Row: projections of the surge images to a tail cross section at X_{GSM} =-15R$_{\mathrm{E}}$ using the Tsyganenko model. White dots in these panels show the location of the tail axis $(x,z)_{GSM} = 0$ (the dot to the right) and the location of ISEE 1 (the dot to the left).

Fig. 7. View of a magnetic flux tube situated in the transition region of the plasma sheet between the sector where the neutral line has not yet retreated (the + Y region) and the sector where the neutral line has retreated (the − Y region of the diagram). Plasma flow is indicated by the large white arrows, faster in the − Y region than in the + Y region. The ellipse represents a circumference of the flux tube and shaded arrows indicating the different relative flow directions on its two sides are shown. The upward arrow indicates the direction of the net rotation (clockwise looking along $\overline{B}$) of the flux tube. A helical magnetic field line on the surface of the twisted flux tube is shown. The twisting of the flux tube at the midplane results in a left-hand helicity in the northern part of the flux tube

leading to Earth and a right-hand helicity in the southern part. These both imply an upward field aligned current from the earth as shown by the arrows labeled j.

Fig. 8. Schematic representation of the substorm current wedge, indicating that the field-aligned currents of the wedge are driven by plasma velocity shear in the shear regions (S.R.) earthward of the ends of the substorm neutral line as discussed in the text.


ALASKAN SECTOR MAGNETOGRAMS
MAY 3, 1986
H- OR X- COMPONENT
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CPY 74°
INK 71°
BRW 69°
FYU 67°
CMO 65°
TLK 62°
AMU 61°
200 nT
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CPY 74°
INK 71°
BRW 69°
FYU 67°
CMO 65°
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0919 0936 0942 0953 1003
5 keV ELECTRONS
0900 0930 1000 1030
UT
10^7
FLUX
10^5
10^3
10^1
2 keV PROTONS
0900 0930 1000 1030
UT
-16.1 -16.5 -16.9 X_{GSM} -17.2
3.5 3.4 3.3 Y_{GSM} 3.2
-0.7 -0.5 -0.4 Z_{GSM} -0.2
-2.2 -2.3 -2.5 dZ_{GSM} -2.6

(a)

(b)

(c)

Fig. 1

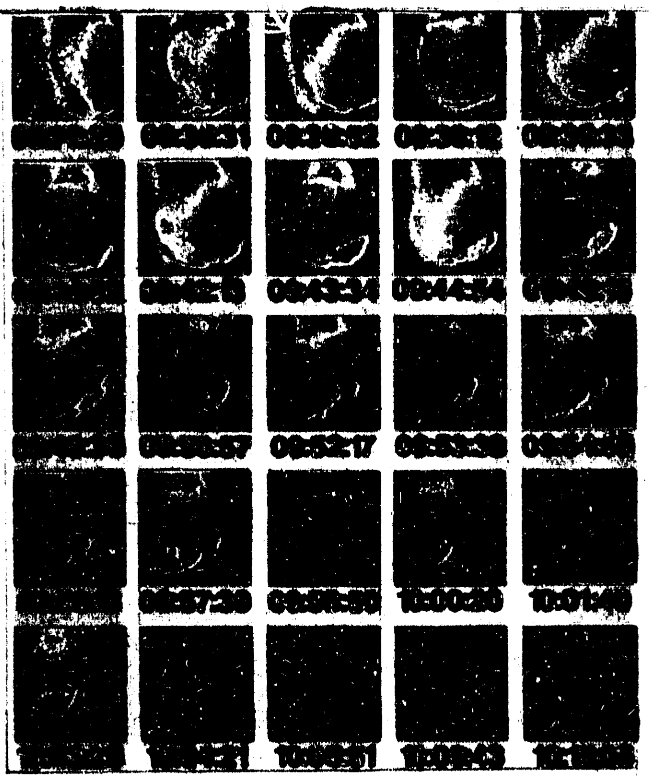

Fig. 2

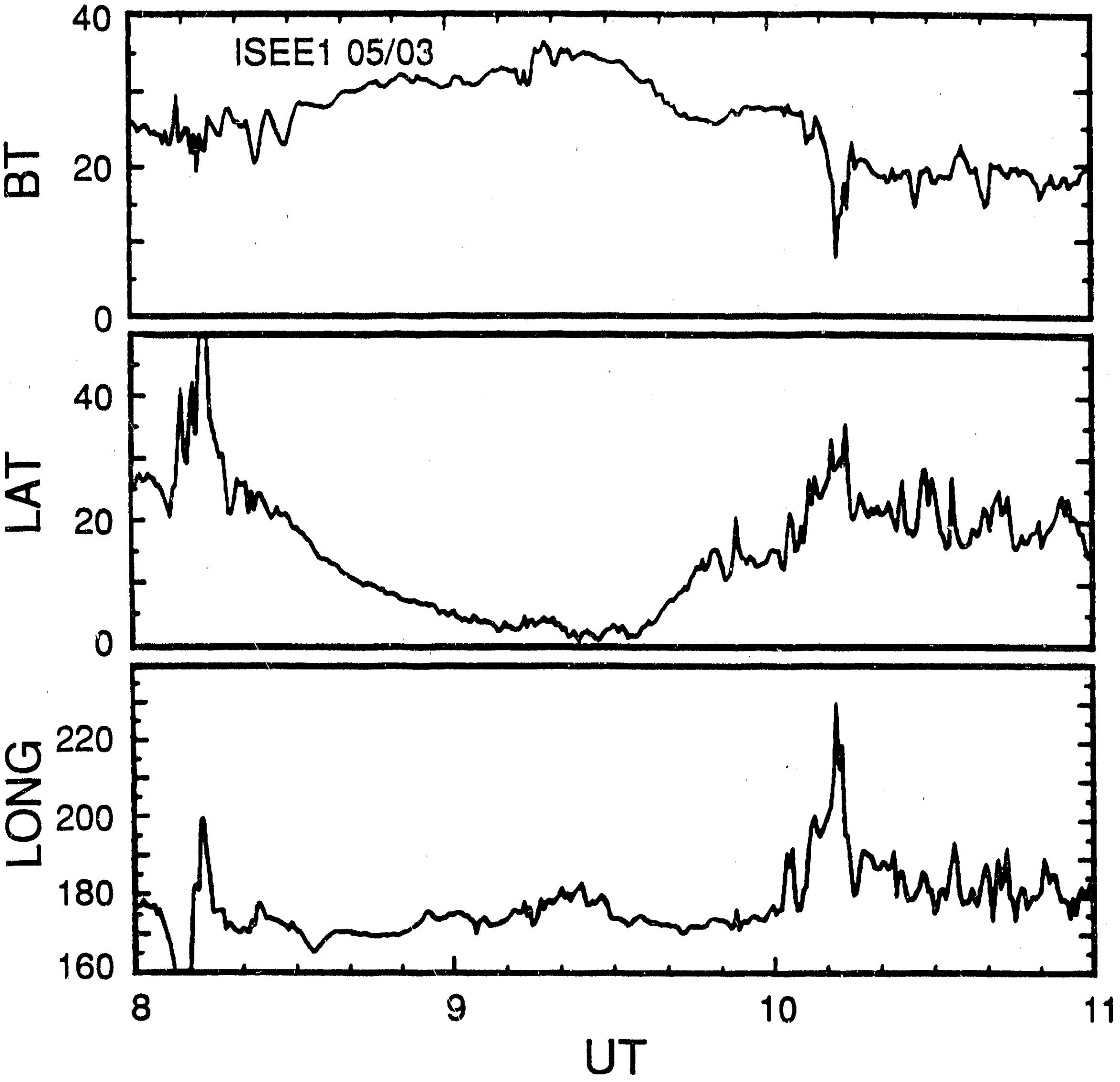

Fig. 3

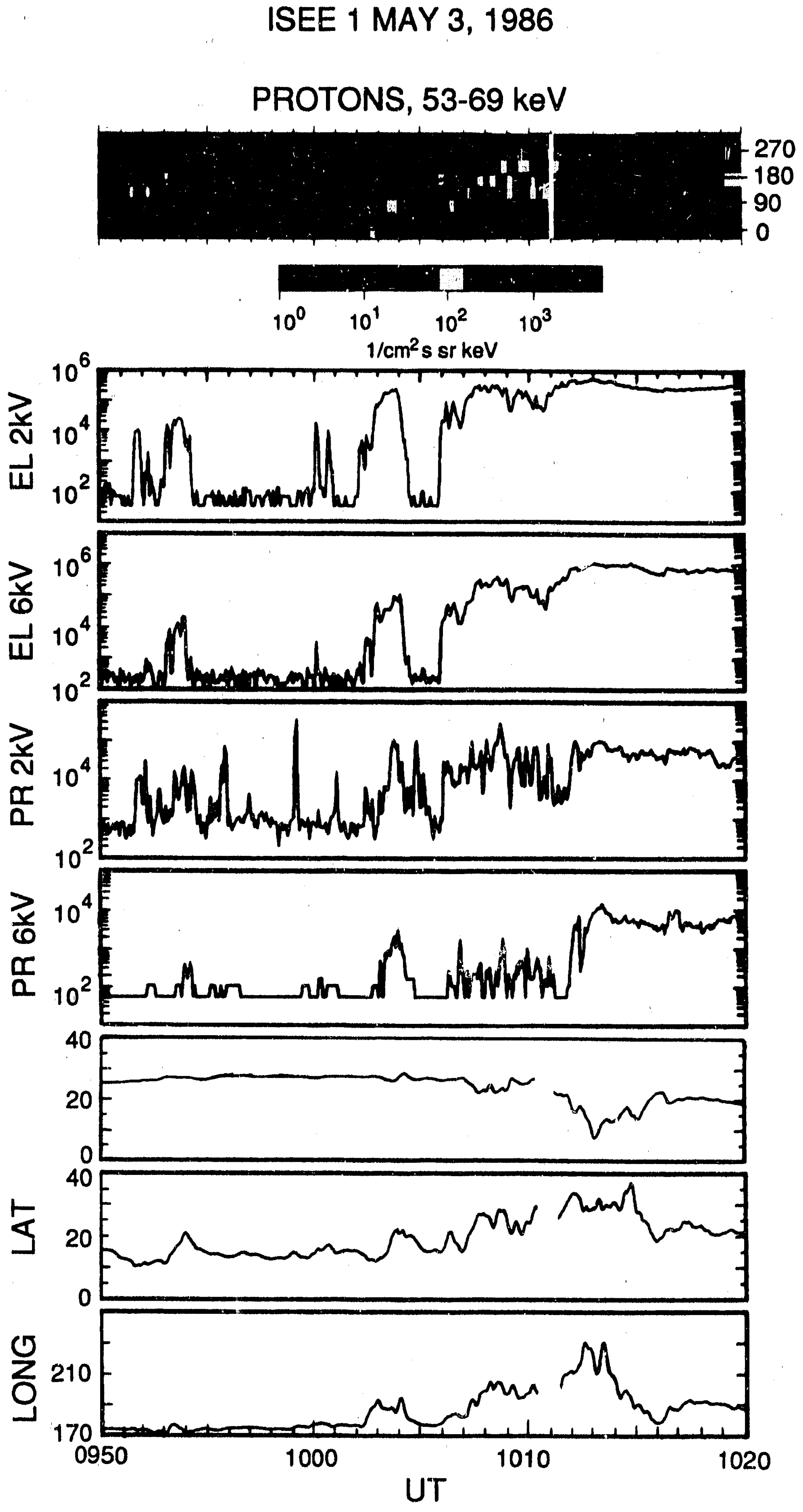
ISEE 1 MAY 3, 1986
PROTONS, 53-69 keV
270
180
90
0
10^0
10^1
10^2
10^3
1/cm^2 s sr keV
EL 2kV
10^6
10^4
10^2
EL 6kV
10^6
10^4
10^2
PR 2kV
10^4
10^2
PR 6kV
10^4
10^2
40
20
0
LAT
40
20
0
LONG
210
170
0950
1000
1010
1020
UT

Fig. 4

IS-12/90 2663 /43

RELATIONSHIP OF A WESTWARD TRAVELING SURGE TO NEUTRAL LINE RETREAT AND THE RESULTING PLASMA SHEET THICKENING

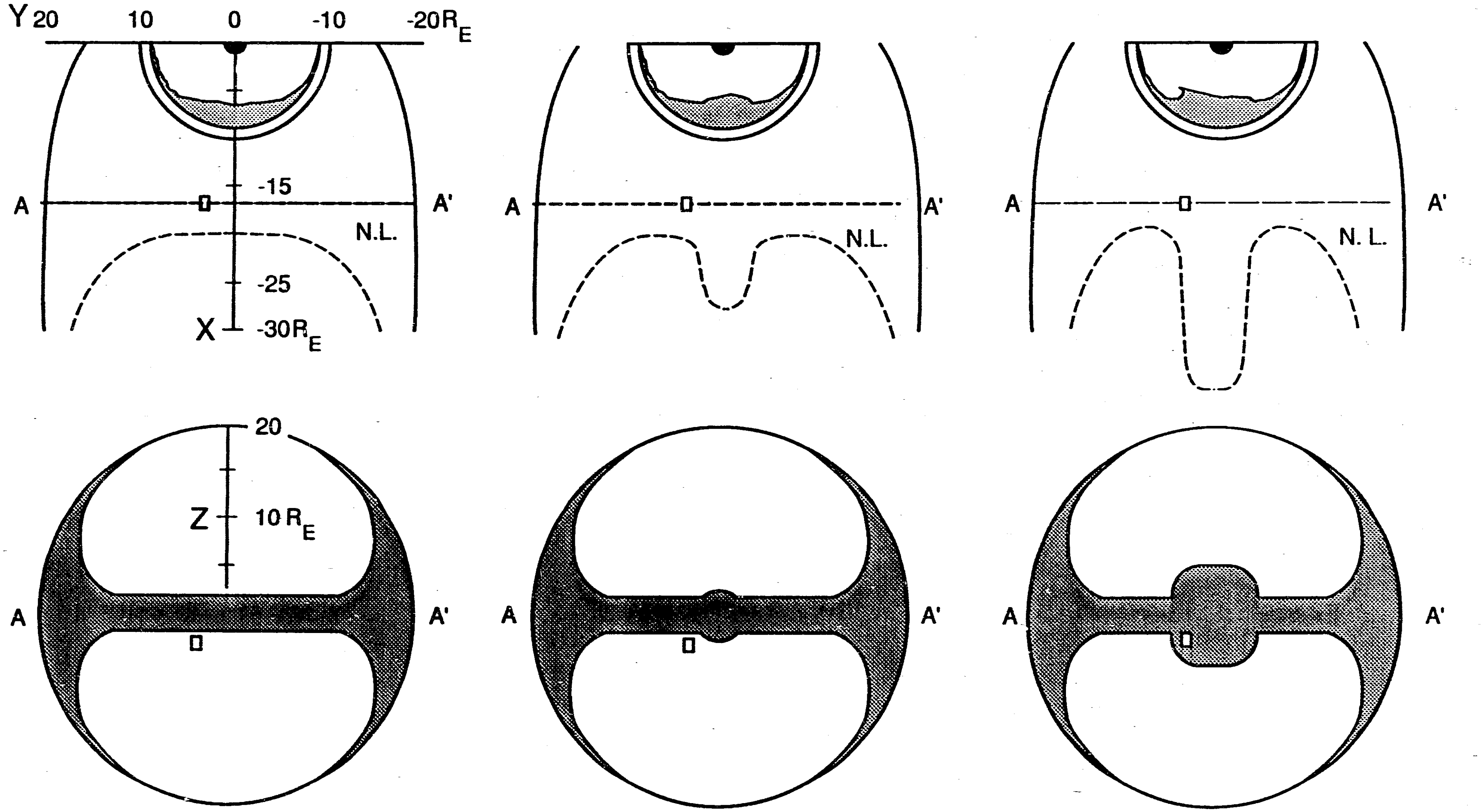

Fig. 5

that is supported by the concurrent observations of the surge in the Viking images (Figure 2).

This view is depicted schematically in Figure 5, where the thickening wave is represented as resulting from a nonuniform or segmental, retreat of the substorm neutral line. In regions earthward of the neutral line the plasma sheet will be thicker earthward of the retreated segment than earthward of the nonretreated segment because of the greater amount of collapsed magnetic field there. It is our view, suggested by the Viking images, that the auroral surge was a mapping of the duskward leading edge of the extending bulge of collapsed flux, i.e., it was a projection of

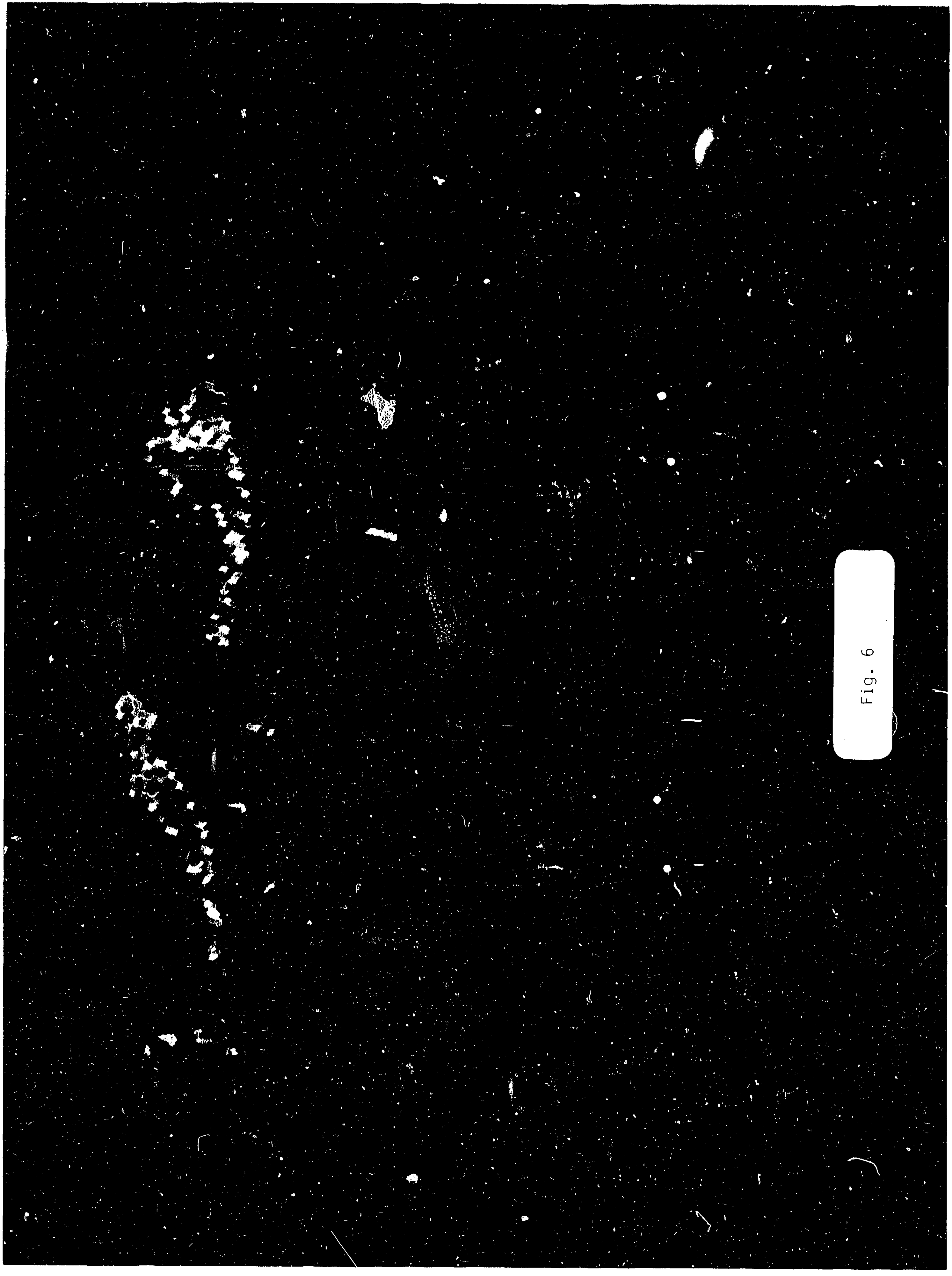

Fig. 6

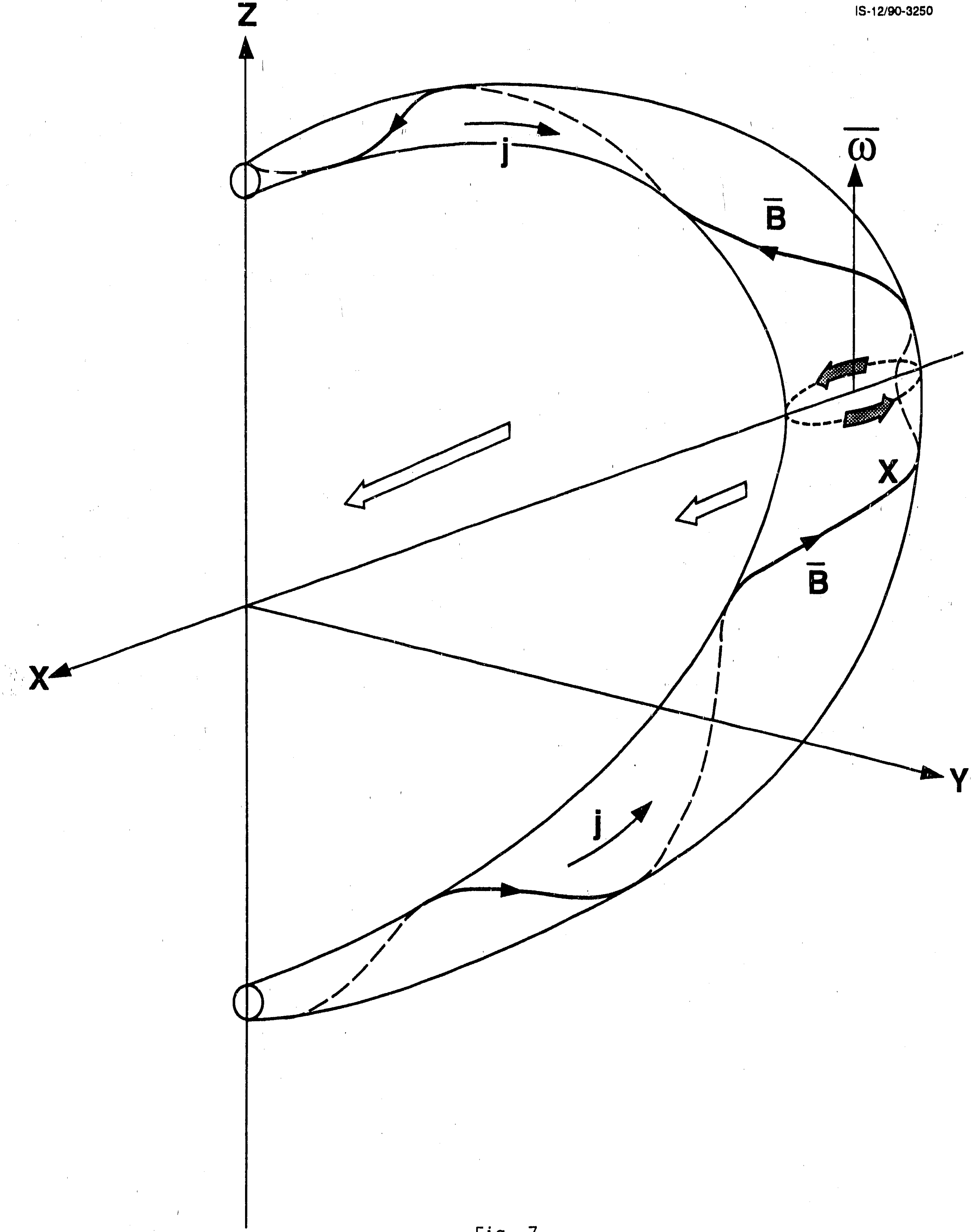

Fig. 7

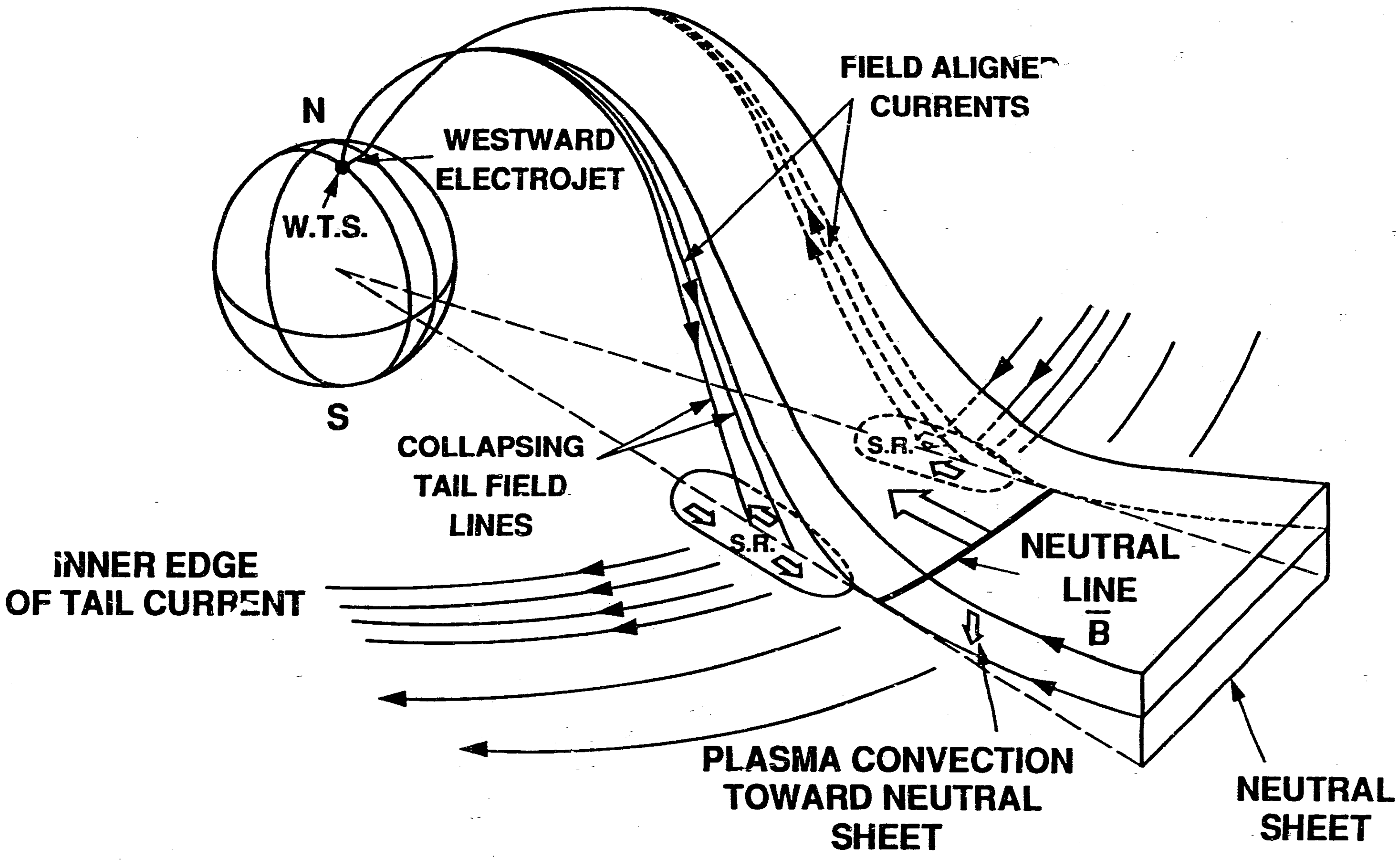
FIELD ALIGNED
CURRENTS
N
WESTWARD
ELECTROJET
W.T.S.
S
COLLAPSING
TAIL FIELD
LINES
S.R.
S.R.
INNER EDGE
OF TAIL CURRENT
NEUTRAL
LINE
$\overline{B}$
PLASMA CONVECTION
TOWARD NEUTRAL
SHEET
NEUTRAL
SHEET

Fig. 8

END

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