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Study of a Substorm on May 4, 1986

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Abstract

A substorm on May 4, 1986, midway through the PROMIS campaign of coordinated data acquisition, was uniquely well documented, both in its aspects at earth and in its magnetotail aspects. The expansive phase onset was imaged by the Viking satellite at 20 - cond time resolution. Most of the expansive phase was also imaged by DE 1 at 6-minute time resolution. ISEE 1 and 2 were near the tail's axis 18.5 R_E from earth operating at high data rate and data were recorded by several geosynchronous satellites. This multi-satellite study provides evidence that the active substorm aurora occurs at the feet of field lines that map to a magnetic X-line in the near tail. The longitudinal extension of the aurora during a substorm is associated with cross-tail lengthening of the near-earth neutral line. The concept of the "poleward leap" of the auroral electrojet (and the auroras) as the culminating feature of the expansive phase finds further support in these data.

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Introduction

The discipline of magnetospheric physics has grown, in large part, from nearly a century of effort to understand first the auroras and, later, magnetic storms and magnetospheric substorms. Our present understanding of these subjects, particularly of substorms, was made possible by the advent of space research which allowed the discovery of the magnetosphere and the solar wind and led to the recognition that substorms are episodic releases of magnetospheric energy earlier acquired from the solar wind. Substorm research has progressed to a large extent by correlative studies of substorm features measured at earth and plasma phenomena measured in space around the earth. Even with today's diversity and sophistication of capabilities for space measurements with satellites, the substorm phenomena at earth continue to be a focal point for substorm research. Thus the capability of picturing the entire auroral oval on a few-minute time scale that has been afforded by auroral imagers on the DE 1 and Viking satellites (Frank *et al.* /1/; Anger *et al.* /2/) represents a major increase of potential for studying substorms. But utilization of this potential is still at an early stage, and exploitation of the full possibilities will take many years.

During the spring season of 1986, the unprecedented situation existed of the two auroral-imaging satellites, DE 1 and Viking, operating concurrently and the research satellite pair, ISEE 1 and 2, operating in the magnetotail to distances of 23 R_E from Earth. There were also other satellites operating in the magnetosphere and the solar wind. So conditions were uniquely suited for major correlative studies involving data acquisition from various points in the magnetosphere simultaneously with imaging of the auroral oval (or both auroral ovals, since DE 1 and Viking were imaging the southern and northern hemispheres, respectively). In recognition of this unique opportunity, a program, Polar Region and Outer Magnetosphere International Study (PROMIS) was instituted whose emphasis was on maximizing overlapping operations of the various satellites to provide a maximum amount of simultaneous data.

The PROMIS campaign, running from early March through mid-June 1986, was very successful, and plans are now being made to conduct a PROMIS Coordinated Data Analysis Workshop (PROMIS CDAW) utilizing selected periods of the acquired data. This paper concerns a substorm that occurred on May 4, 1986, midway through the PROMIS campaign. The multi-satellite data set acquired for this event is a good representation of what PROMIS was intended to achieve. The analysis presented here uses only a small fraction of the data that are available for the May 4 substorm and thus constitutes only a preliminary examination of that event. A much more thorough study of it will probably be conducted in the PROMIS CDAW.

Observations

Figure 1 shows H- and Z-component magnetograms from a chain of ground stations in the Alaska sector of the auroral and polar cap region. These stations were near 2400 MLT. Onsets of negative H-bays are seen at 1155 UT at Anchorage, Talkeetna, and College. The Z-component went negative at Anchorage and positive at College and Ft. Yukon at 1155 UT, indicating that the substorm westward electrojet was initiated at latitudes between 61° and 65°, perhaps near Talkeetna which showed little Z-deflection. Figure 2 shows electron data from the Los Alamos Charged Particle Analyzer on geosynchronous satellite 1984-129, which was near 0130 MLT. There was a distinct change of character of the electron flux at 1155 UT, with the more energetic electrons rapidly decreasing in intensity. The combined ground and satellite data suggest the onset of a substorm expansive phase at 1155 UT.

Figure 3 shows a sequence of 16 northern hemisphere images from the Viking satellite from 1153 to 1223 UT. Viking was actually recording an image every 20 seconds but we show only every sixth image. The image at 115319 UT shows a localized brightening of the auroral oval at ~2200 MLT that later spreads east and west along the oval and expands poleward. The image taken 20 seconds earlier showed no such brightening, so the Viking images place the substorm onset between 115259 UT and 115319 UT.

Figure 4 shows the AL index for the interval 1130–1500 UT. Below that is a sequence of seventeen 6-minute images of the southern polar region taken by DE 1 from 1202 UT through 1345 UT. Each image is centered under the 6-minute time interval during which is was accumulated. Below the images is a plot of the flux of 27–33 keV protons measured with the Ultra Low Energy Charge Analyzer (ULECA) on ISEE 1 (Hovestadt *et al.* /3/). ISEE 1 was near the tail axis about 18.5 R_E from earth. Its location is given under the second panel of Fig. 4. The bottom panel shows the latitude of the poleward auroral boundary at 2100, 0000, and 0300 MLT, measured on the DE 1 images using computer graphics equipment developed for this purpose by the University of Iowa. Also shown is the projection to the ionosphere of ISEE 1 along field lines of the magnetosphere model published by Tsyganenko (4). The model was computerized for this purpose at Los Alamos (J. Birn, private communication, 1988). In this model ISEE 1 mapped to 71° magnetic latitude and ~0120 MLT. Here we show it mapped to −71° magnetic latitude. This implies north-south symmetry of the magnetic field.

The proton flux at ISEE 1 (second panel of Fig. 4) did not show any effect of the substorm onset at 1155 UT. There was a significant drop of flux at 1200 UT and then, starting at ~1217 UT, a major decrease of flux began, ending at ~1222 UT in a reduction to less than one percent of the pre-substorm intensity. Figure 2 shows that synchronous satellite 1984-129, at ~0200 MLT, recorded a sudden drop of electron flux from 1215 to 1217 UT and then a large increase from 1217 to 1221 UT.

Figure 5 shows latitudinal contours of auroral intensity at 2-minute intervals at the 0200 MLT meridian. These were derived from the Viking images in Fig. 3 using computer techniques developed at the University of Calgary. Although there is some variation of the profiles through the first six panels, there is a major change in the seventh (121121) panel—that is, the appearance of the narrow spike at about 63° latitude that signifies the arrival of the eastward-extending substorm aurora at the 0200 MLT meridian. Latitudinal profiles measured at other magnetic local times suggest that the aurora advanced from 0100 MLT to 0230 MLT in the time interval 120322 UT to 121526 UT. The aurora thus spread well into the morning sector between 10 and 22 minutes after substorm onset. At 1217 UT (21 minutes after substorm onset) the proton flux at ISEE started its rapid decrease (the plasma sheet thinned there) and the electron flux at synchronous orbit suddenly increased (a particle injection occurred there).

The AE index peaks at ~1308 UT and starts to subside. At ~1320 UT the aurora at 0300 MLT surges poleward, and after 1325 UT the auroras at all three local times move rapidly poleward, that at 0000 MLT approaching ~80° latitude by 1340 UT. At 1335 UT the proton flux at ISEE 1 suddenly increases nearly to pre-substorm values, marking the plasma sheet's expansion over ISEE 1. At 1320 UT the H-component of the field at Inuvik (Λ_m = 71°) suddenly decreased while the Z-component suddenly increased. These signatures, together with the fact that the H component at the lower latitude stations was becoming less negative, are consistent with a poleward movement of the westward electrojet.

Discussion and Conclusions

We shall briefly discuss these results in the context of the expectations of the near-earth neutral line model of substorms, touching upon (a) the formation of the near-earth neutral line at expansive phase onset and (b) the retreat of the neutral line and plasma sheet recovery in the late stages of the substorm.

a) The expansive phase onset, seen in the Viking images, occurred at 1153 UT. No immediate effect of this onset was seen in the proton measurements at ISEE 1. However, the electron flux at synchronous orbit registered an almost immediate effect—great variability and a sharp drop at higher energies. Then, about 18 minutes later, at 121124, a sequence of events began, continuing until about 1222, that we believe signified an extension of the near-earth neutral line from the evening sector of the tail, where is was initiated, into the morning sector. The aurora advanced well into the morning sector (Figures 3 and 5), a plasma injection was experienced by the synchronous satellite in the morning sector (Figure 2), and plasma sheet dropout occurred at ISEE 1 in the morning sector (second panel of Figure 4). Figure 6 depicts our interpretation of the events during that 11-minute interval. We suggest that the auroral onset seen by Viking at 115319 was manifestation of formation of a short X-line in the near-earth evening sector of the tail. The neutral line then lengthened eastward (and westward as well), its lengthening marked by lengthening of the aurora around the auroral oval. Reconnection at the lengthening neutral line caused longitudinally progressive severance of the plasma sheet. Figure 6 depicts a time in this process when the neutral line has attained a length whose projection to earth extends from 2300 MLT to 0200 MLT. As it grew, earlier, through the 2300–0100 MLT sector of the plasma sheet it released an "elemental" plasmoid, A, and allowed the earthward collapse of the sector, A′ of the corresponding earth-tied field lines. At the time shown the neutral line has extended to the 0200 MLT meridian and the elemental plasmoid B is about to be released, allowing the earthward collapse of the field lines, B′. The sector, C, of the plasma sheet is shown necking down and will soon experience reconnection as did the earlier sectors. This process may occur quasi-smoothly rather than in increments as depicted (for illustration only) in Figure 6, or it may actually progress spasmodically, accounting for the sometimes spasmodic extension of the substorm aurora around the oval. Our observations suggest that

(i) The active substorm aurora lies at the feet of field lines that map to a magnetic X-line in the near tail; (ii) Extension of the aurora along the oval manifests the extension of the neutral line across the near tail; (iii) In the May 4, 1986 event the neutral line was earthward of 18.5 R_E.

5) According to the substorm model, the near-earth neutral line suddenly retreats down-tail some 30 to 60 minutes after expansive phase onset, causing a refilling (thickening) of the near-earth plasma sheet (Hones /5/). This is accompanied at earth by an accelerated poleward motion (a poleward leap) of the auroral electrojet and, presumably, of the auroras (Hones *et al.* /6/; Hones /7/). The events on May 4, 1986 from ~1308 UT through ~1340 UT are consistent with such expectations for the substorm's late phase. The AL index (and negative bays at midnight auroral zone stations) began to subside after 1308 UT; magnetic effects of the westward electrojet began to occur at higher latitude stations after ~1320 UT; the auroras, over 5 hours of MLT, advanced poleward with increased rapidity after ~1320 UT; and the plasma sheet re-enveloped ISEE 1 at 1335 UT. These things all occurred in a ~25-minute interval that started about 75 minutes after the substorm's onset and seem to have marked the beginning of the magnetosphere's return to pre-substorm conditions.

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Figure Captions

Fig. 1. H- and Z-component magnetograms from several stations in the Alaska sector for 1130–1500 UT on May 4, 1986. Vertical dashed lines through the figures mark times of special significance that are mentioned in the text.

Fig. 2. Electron count rates at energies greater than 30, 45, 65, 95, 140 and 200 keV measured between 1130 UT and 1500 UT on May 4, 1986 with the Los Alamos Charged Particle Analyzer on geosynchronous satellite 1984–129. The local time of the satellite is indicated at the top.

Fig. 3. Images of the earth's northern polar region showing the evolution of the auroras during the May 4, 1986 substorm. The images were recorded, each in one second, by the Viking satellite in atomic oxygen (OI) 130.4 nm emission. The dawn meridian is toward upper right and the dusk meridian is toward lower left in each image. The 2200, 0000, and 0200 MLT meridians are drawn in four of the images.

Fig. 4. Data for the substorm on May 4, 1986.

Top panel: The AL index.

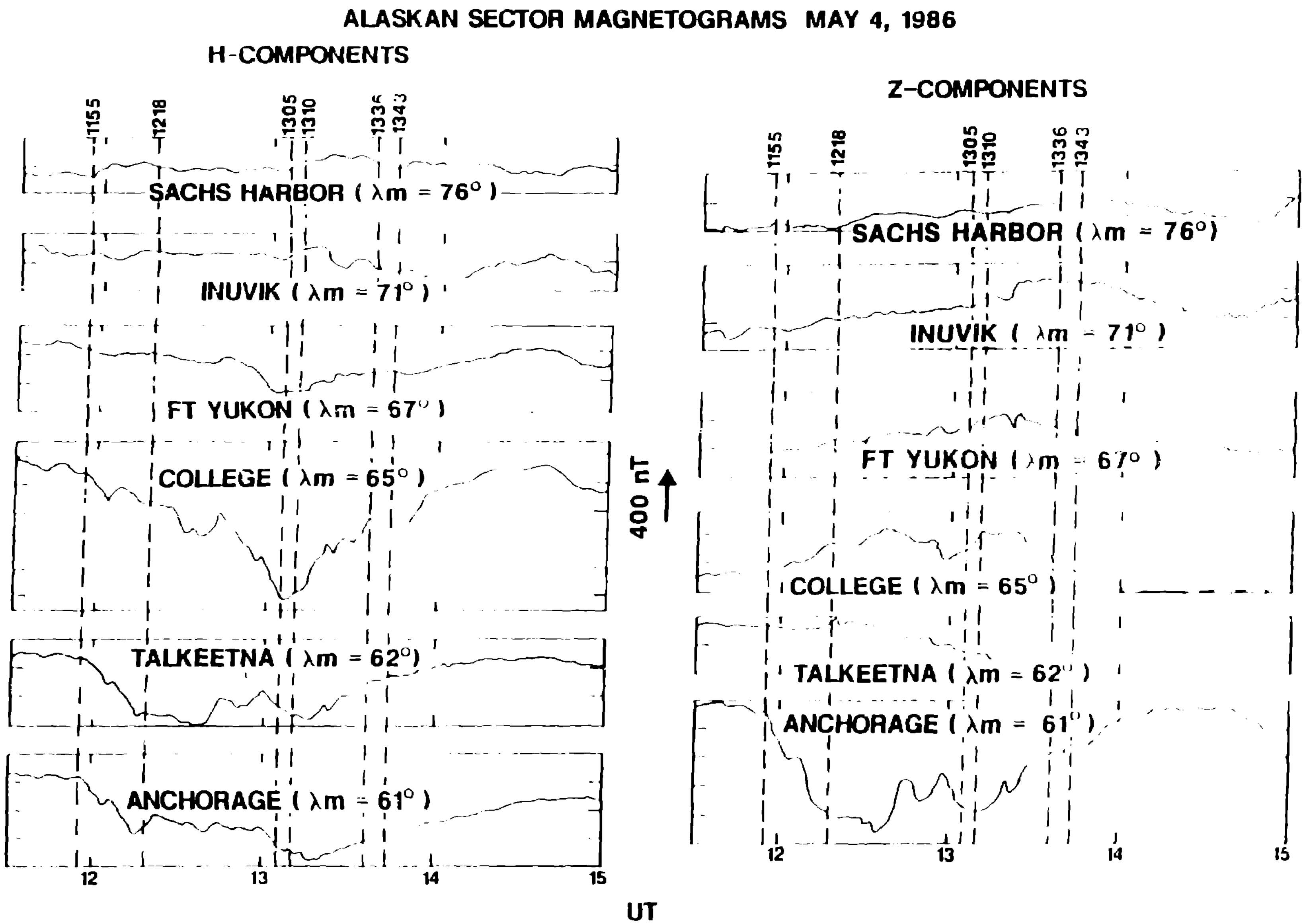
Auroral Images: DE 1 images of the southern auroral zone as seen in atomic oxygen (OI) 130.4 nm emission. The dawn meridian is toward the upper left and the dusk meridian is toward the lower right in each image. The width of each image is equal to 6 minutes on the horizontal time scale of the figure and each image is centered at the mid-time of its 6-minute accumulation interval.

Middle panel: Flux of 27-33 keV protons measured with the ULECA instrument on ISEE 1. The location of ISEE 1 is given under this panel.

Bottom panel: Latitude of the poleward edge of the auroras at 2100, 0000, and 0300 MLT, determined by computer graphics analyses of the DE 1 images. Also shown, by the straight long-dashed line, is the latitude of the foot-point of the field line from ISEE 1 (see text). The MLT of the foot-point is given every hour.

Fig. 5. Latitudinal profiles of auroral intensity along the 0200 MLT meridian, derived from the Viking images. The smooth curve is the computer-derived background intensity level. The ordinate scale is in numbers of counts per pixel.

Fig. 6. Side view and top view of the magnetosphere illustrating the proposed effects of progressive lengthening of the near-earth neutral line after its initial formation at the onset of a substorm expansive phase (see text).



ALASKAN SECTOR MAGNETOGRAMS MAY 4, 1986
H-COMPONENTS
Z-COMPONENTS
1155
1218
1305
1310
1336
1343
SACHS HARBOR (λm = 76°)
INUVIK (λm = 71°)
FT YUKON (λm = 67°)
COLLEGE (λm = 65°)
TALKEETNA (λm = 62°)
ANCHORAGE (λm = 61°)
400 nT
12
13
14
15
UT

Fig. 1

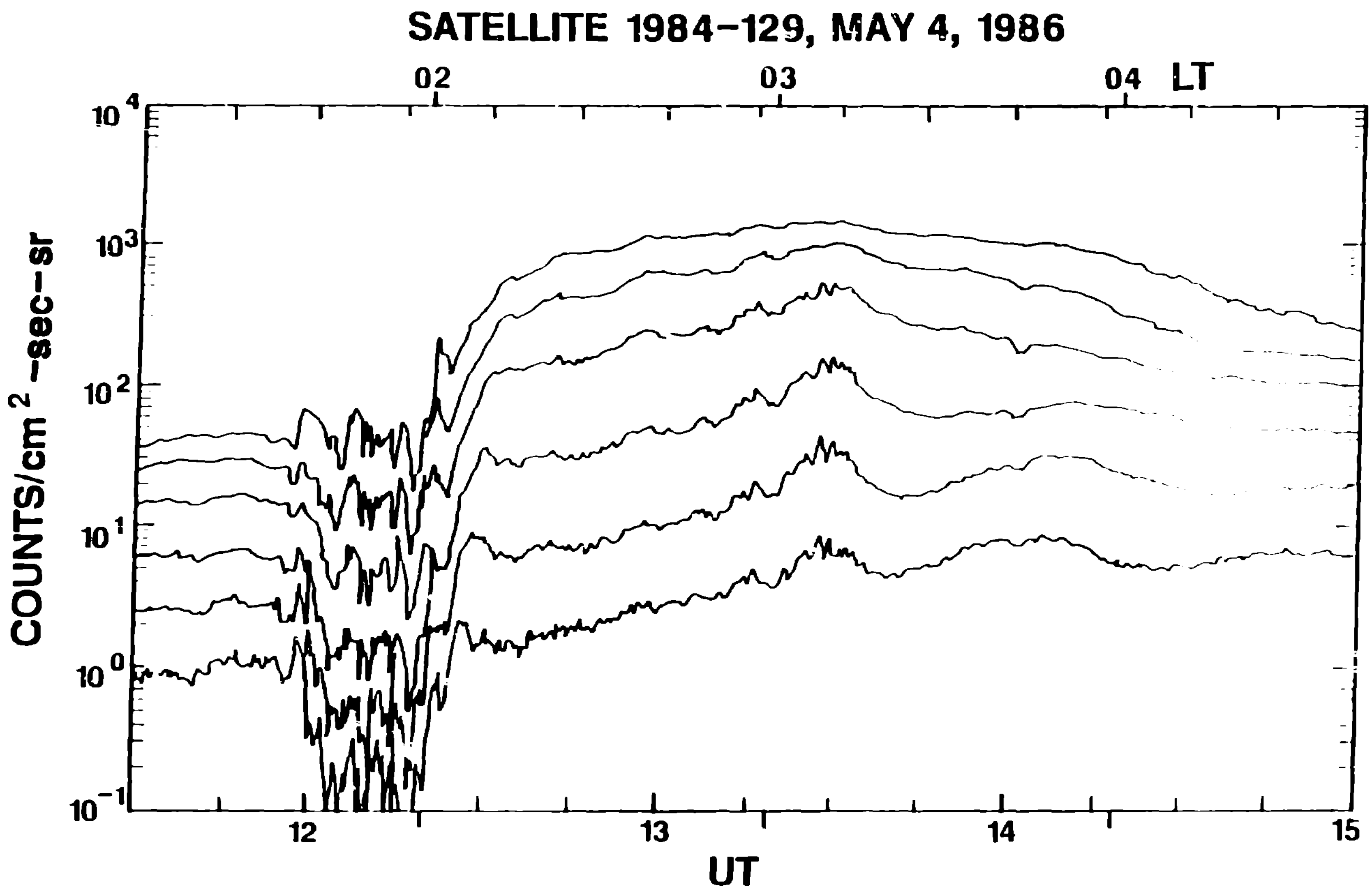

SATELLITE 1984-129, MAY 4, 1986
02
03
04 LT
10^4
10^3
10^2
10^1
10^0
10^{-1}
COUNTS/cm^2-sec-sr
12
13
14
15
UT

Fig. 2

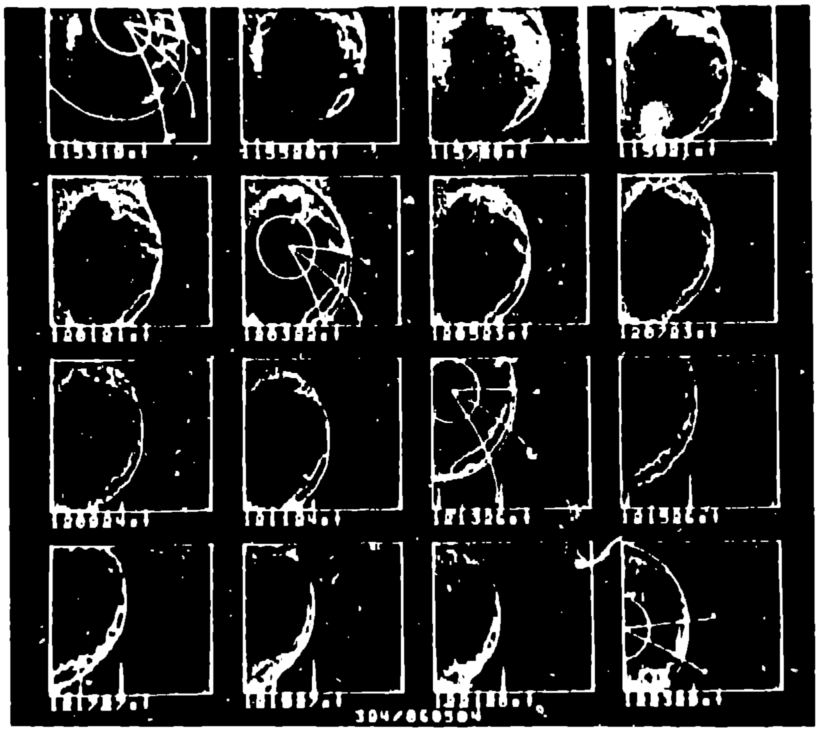
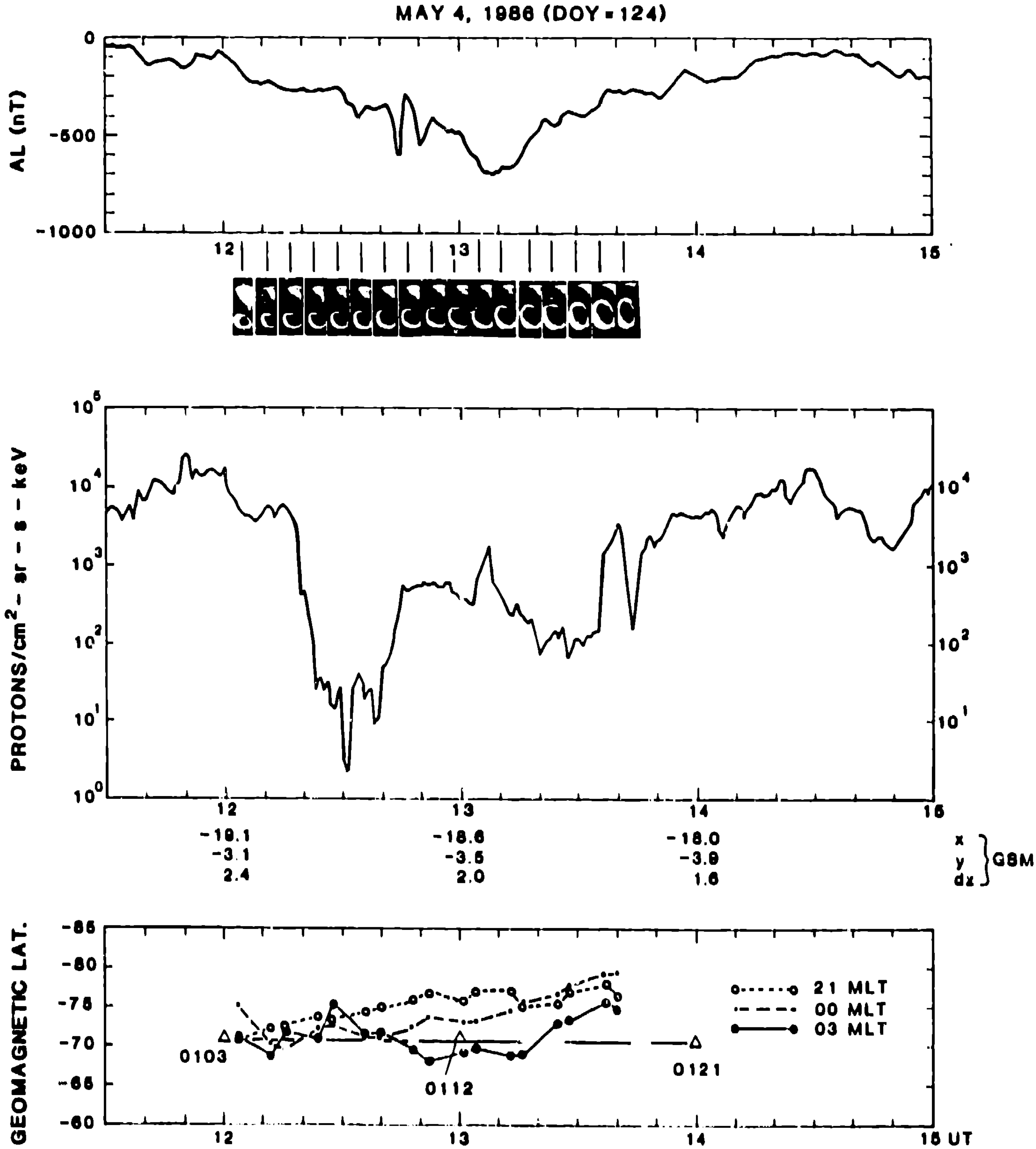


Fig 3.



MAY 4, 1986 (DOY = 124)
AL (nT)
0
-500
-1000
12
13
14
15
PROTONS/cm2 - sr - s - keV
10^5
10^4
10^3
10^2
10^1
10^0
-19.1
-3.1
2.4
-18.6
-3.5
2.0
-18.0
-3.9
1.6
x
y
dx
GSM
GEOMAGNETIC LAT.
-85
-80
-75
-70
-65
-60
21 MLT
00 MLT
03 MLT
0103
0112
0121
15 UT

Fig. 4

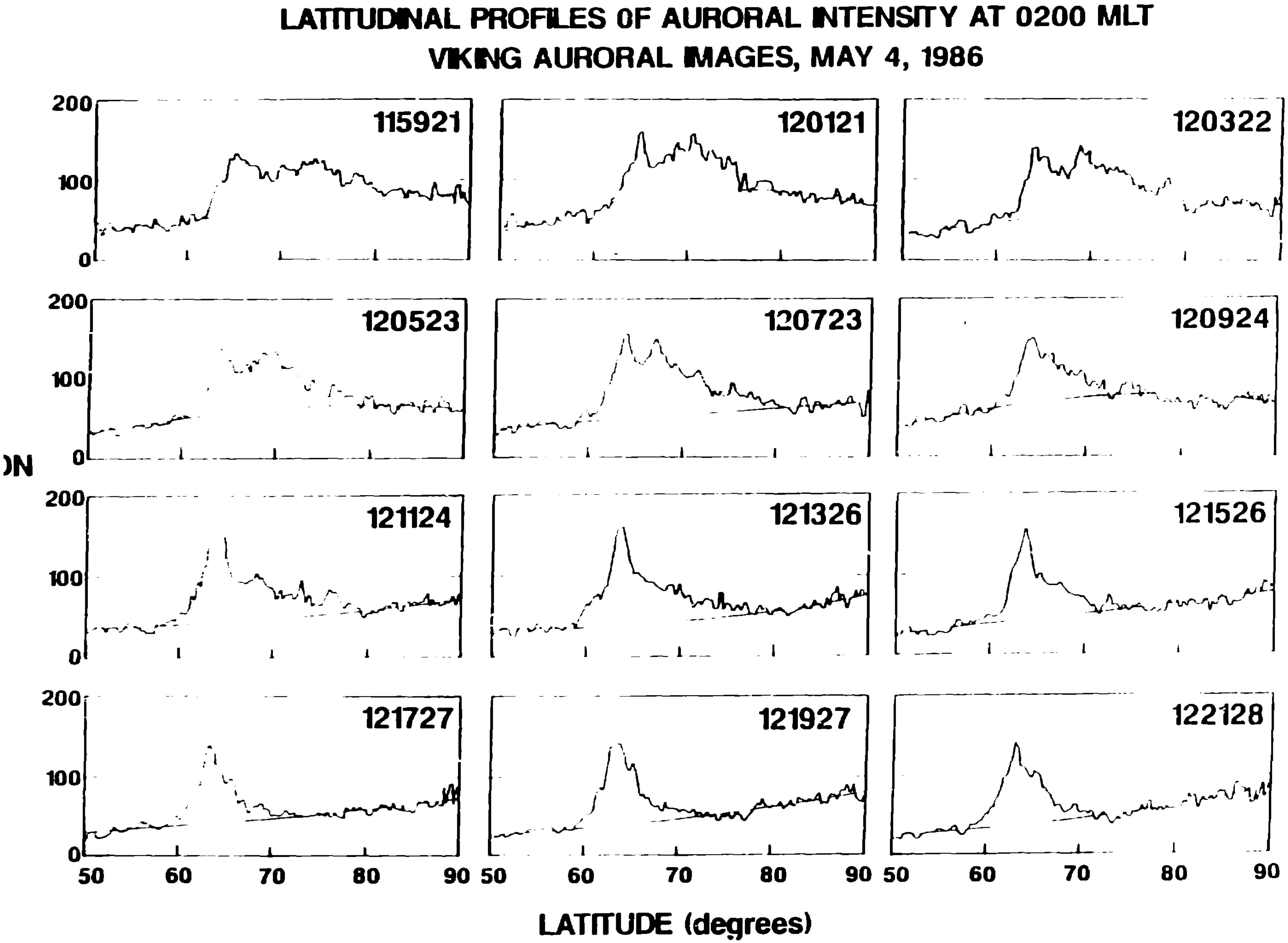

LATITUDINAL PROFILES OF AURORAL INTENSITY AT 0200 MLT
VIKING AURORAL IMAGES, MAY 4, 1986
200
100
0
115921
120121
120322
120523
120723
120924
121124
121326
121526
121727
121927
122128
50
60
70
80
90
LATITUDE (degrees)

Fig. 5

CROSS-TAIL LENGTHENING OF THE NEAR EARTH NEUTRAL LINE DURING SUBSTORMS

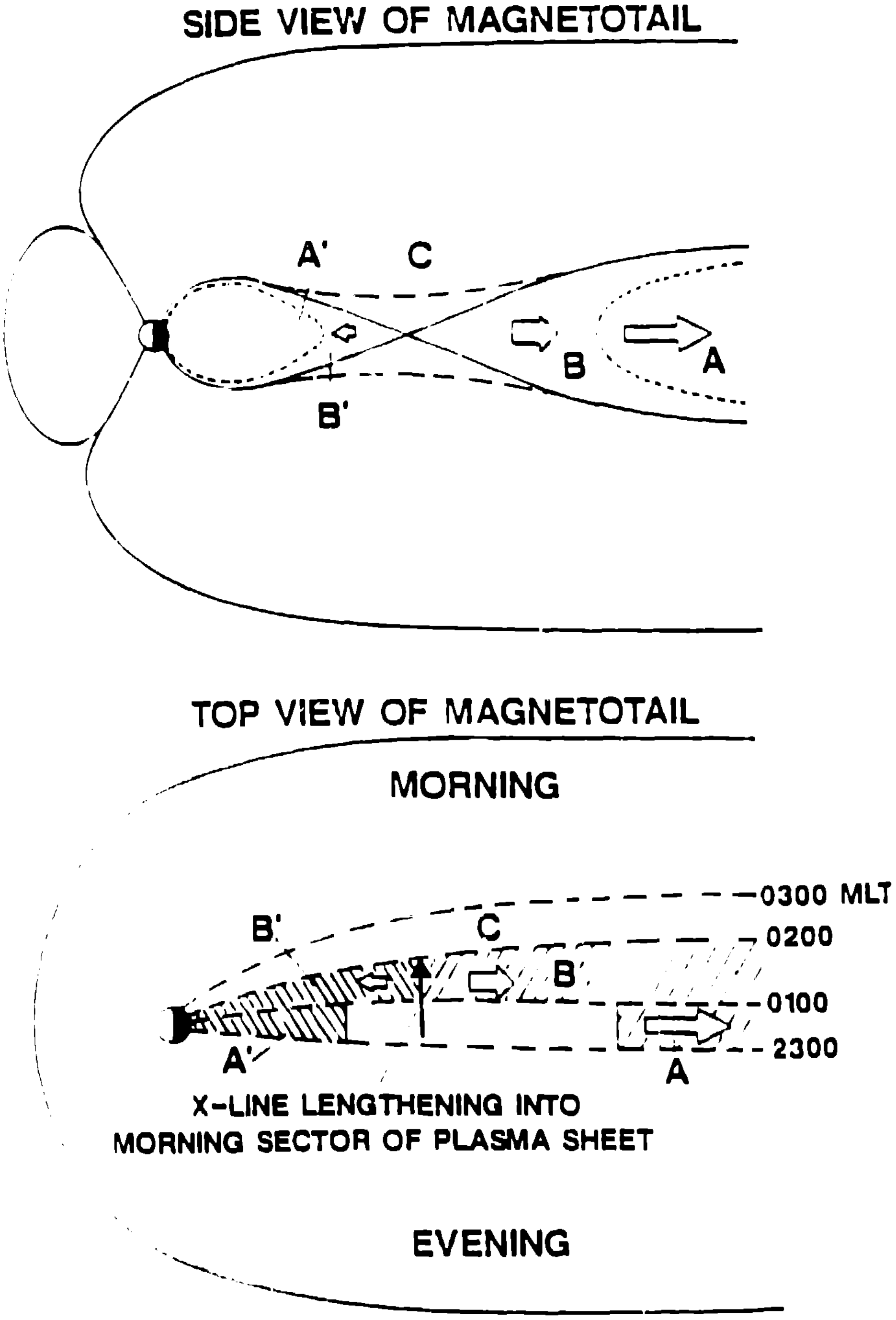


Fig. 6