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Electric and Magnetic Field Observations During a Substorm on February 24, 1970

by

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February 1974

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ABSTRACT

In this brief note we report a series of electric field measurements obtained from the Injun 5 satellite and simultaneous magnetic disturbance observed in the interplanetary medium and on the ground during a magnetic substorm. The substorm analyzed took place on February 24, 1970. Prior to the onset of the substorm a greatly enhanced anti-sunward plasma flow was observed over the polar cap. The enhanced plasma flow occurred about 30 minutes after a switch in the direction of the interplanetary magnetic field from northward to southward. The electric fields across the polar cap immediately before and during the substorm were essentially unchanged indicating that an enhancement in the ionospheric conductivity rather than the electric field must be responsible for the large increase in the auroral electrojet current during the substorm.

I. OBSERVATIONS

In this brief note we report an interesting observation of electric fields and associated magnetic disturbances during an isolated substorm on February 24, 1970. The electric field measurements were obtained from the low altitude polar orbiting satellite Injun 5. Details of the electric field instrumentation on Injun 5 and the method of analysis are given by Cauffman and Gurnett [1971]. The ground magnetic field perturbations were obtained from a network of high latitude magnetometer stations and the interplanetary magnetic field data were obtained from the Explorer 35 satellite in orbit around the moon. During the period of interest Explorer 35 was located in the magnetosheath behind the earth at $X_{se} = -55\ R_E$, $Y_{se} = -31\ R_E$ and $Z_{se} = -2\ R_E$.

Figures 1, 2, and 3 give the direction and magnitude of the convection velocity component measured by Injun 5 for three successive polar passes during the magnetic substorm which occurred on February 24, 1970. The electric fields and low energy plasma measurements obtained during this event have been previously analyzed by Gurnett and Frank [1973]. Figure 4 shows the three component magnetogram records from eleven magnetometer stations in the northern hemisphere and also from the South Pole station in the southern hemisphere. The bottom panel of Figure 5 shows the superposed H magnetogram traces from these stations for the period between 1000 and 2000 UT on February 24, 1970. The difference between the upper and lower envelopes of these traces is the auroral electrojet activity index, AE. As can be seen, the period between about 1000 and 1345 UT was extremely quiet. At about 1345 there is a slight increase in the magnetic field fluctuations. These fluctuations remain small ($<$ 100 gammas) until about 1535 UT at which time a large substorm disturbance starts. The magnetic disturbances associated with this substorm reach a maximum intensity of about 500 gammas at 1630 UT and recover to the prestorm value by about 1900 UT.

The top three panels of Figure 5 show the corresponding interplanetary magnetic field data for this same period. Before about 1400 UT the interplanetary magnetic field has a northward component, as shown by the positive solar ecliptic latitude, θ, of the magnetic field direction. At about 1400 UT $\pm$ 30 minutes the interplanetary magnetic field intensified considerably, increasing from about 8 to 20 gammas, and switches southward. The interplanetary magnetic field remains southward until about 1730 UT. The switch from northward to southward field preceeds the onset of the substorm by about 90 minutes.

The times at which the three Injun 5 passes occurred are indicated by the three vertical arrows at the bottom of Figure 5. The first pass, shown in Figure 1, crosses over the northern polar region at about 1430 UT, after the interplanetary magnetic field turned southward, but before the onset of the substorm. The convection velocity components measured during this pass are indicated by the arrows in Figure 1. The convection velocity is generally small except for a small region in the local morning at about 80° invariant latitude. The corresponding magnetic disturbance vectors observed on the ground at 1430 UT, as the spacecraft passes over the polar cap, are also shown in Figure 1 by the line elements directed outward from the small circles which represent the locations of the magnetometer stations. During this pass the magnetic disturbances are small, less than 50 gammas. The second pass, shown in Figure 2, crosses over the southern polar region at about 1530 UT, shortly before the onset of the substorm. The convection velocity on this pass is much greater than during the previous pass over the northern polar region and consists of a region of strong anti-sunward flow over the polar cap and a corresponding sunward return flow at lower latitudes (70 to 75°) in the dawn and dusk regions. The electrostatic potential difference from dawn to dusk, across the region of anti-sunward flow, has been estimated by Gurnett and Frank [1973] to be about 235 kV, which is much larger than the typical potential differences of $\sim$ 50 kV normally observed [Cauffman and Gurnett, 1971; Heppner, 1972]. The ground magnetic disturbances observed as the spacecraft passed over the polar cap are shown in Figure 2 at 1530 UT. The magnetic disturbances at this time are still small despite the greatly enhanced convection electric field over the polar cap. Since the enhanced convection velocity was evident as early as 1515 UT, the anti-sunward convection over the polar cap was evidently established well before the onset of the substorm at 1535 UT.

Although the disturbance vectors shown in Figure 2 are from the northern hemisphere, the corresponding magnetic records from South Pole (Figure 4), Vostok and Byrd stations show a very similar tendency. Thus the delay in the intensification of the magnetic disturbances after the enhancement in the convection occurred in both the northern and southern polar regions. Therefore, it is unlikely that the delay was caused by the lack of electrical conductivity over the northern polar cap stations. Indeed, the ionospheric E layer over Resolute Bay shows no obvious change during the substorm, so that the sudden intensification of the disturbance at 1545 UT at Resolute Bay and Alert was unlikely to be due to an enhancement of the electrical conductivity over those stations. The intensification of the corresponding negative bays were also delayed at the midnight auroral zone stations, such as Tixie Bay, Dixon Island and Cape Cheluskin, so that the westward electrojet did not grow significantly for at least 20 minutes after the enhancement of the electric field. Unfortunately, all-sky camera records from these stations are not available to examine when the onset of brightening of auroral arcs (the first indication of the expansive phase of substorms) began.

Auroras over Alaska were not visible during this period, because of heavy overcast skies at College, Fort Yukon, Kotzebue and other stations. However, the corresponding riometer record from College indicates that cosmic noise absorption began at about

1515 UT and that it was considerably intensified at 1552 UT. Therefore, one possible cause of the delay of the intensification of geomagnetic disturbances was due to the initial slow growth of the precipitation intensity of auroral particles. Thus, it is likely that the corresponding enhancement of electrical conductivity did not occur until about 1535 to 1540 UT. If one assumes that the intensification of the precipitation began at 1540 UT, it is not difficult to explain the onset of the suddenly enhanced cosmic noise absorption at 1552 UT at College which was located in the morning sector. As shown by Berkey et al. [1971], a narrow belt of absorption develops from the midnight sector toward the morning sector after the onset of a substorm.

By 1600 UT, the substorm reached maximum epoch (see Figure 5). The third pass, shown in Figure 3, crosses over the northern polar region at about 1630 UT. The convection velocity during this pass has decreased slightly from the preceeding pass over the southern polar region. Large magnetic disturbances are now evident at the ground observatories as shown in Figure 3. It is interesting to note that although only one component of the convection electric field could be measured (for details, see Cauffman and Gurnett, 1970), the deviation of the direction of the magnetic disturbance vectors from the expected direction (perpendicular to the $\vec{E} \times \vec{B}$ direction) at Alert and Resolute may be explained in terms of the field-aligned current discussed by Haerendel et al. [1971] and Heppner et al. [1971].

II. DISCUSSION

The temporal sequence of electric and magnetic fields observed during this substorm has several interesting features. Prior to the substorm a greatly enhanced anti-sunward plasma flow was observed over the polar cap. This enhanced plasma flow was established at least 20 minutes before the onset of the substorm (see Figure 2). Although large magnetic disturbances were observed over a large region of the auroral zone during the substorm, the electric fields across the polar cap immediately prior to and during the substorm were essentially unchanged.

Because of the gap in the interplanetary magnetic field data between 1322 and 1419 UT, it is not possible to determine the southward switching time of the interplanetary magnetic field. The onset of the minor magnetic disturbance at about 1345 UT suggests that the southward switch may have occurred near the front of the magnetosphere at that time [Nishida, 1968]. Even if one assumes that the southward switch occurred at the end of the data gap (1419 UT), which corresponds to about 1402 UT at the front of the magnetopause (assuming a solar wind speed of 400 km/sec), the electric field did not grow for about 28 minutes after the switch, since there was no significant electric field during the first orbit (~ 1430 UT). Thus, the growth of the electric field was delayed for at least 28 minutes after the southward switch in the interplanetary magnetic field. Although the growth of the electric field preceeds the substorm in this case, one must be cautious in interpreting the growth of the electric field as the growth phase of the substorm since substorms are also quite common even when the interplanetary magnetic field has a northward component [Akasofu et al., 1973].

The fact that the growth of the electrojet was considerably delayed after the enhancement of the electric field and that the electric field across the polar cap immediately prior to and during the substorm were essentially unchanged suggest that the electrojet must have developed in response to a marked modification in the ionospheric conductivity rather than a change in the ionospheric electric field. This possibility has been pointed out by Haerendel et al. [1969] and Heppner et al. [1971] and others.

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FIGURE CAPTIONS

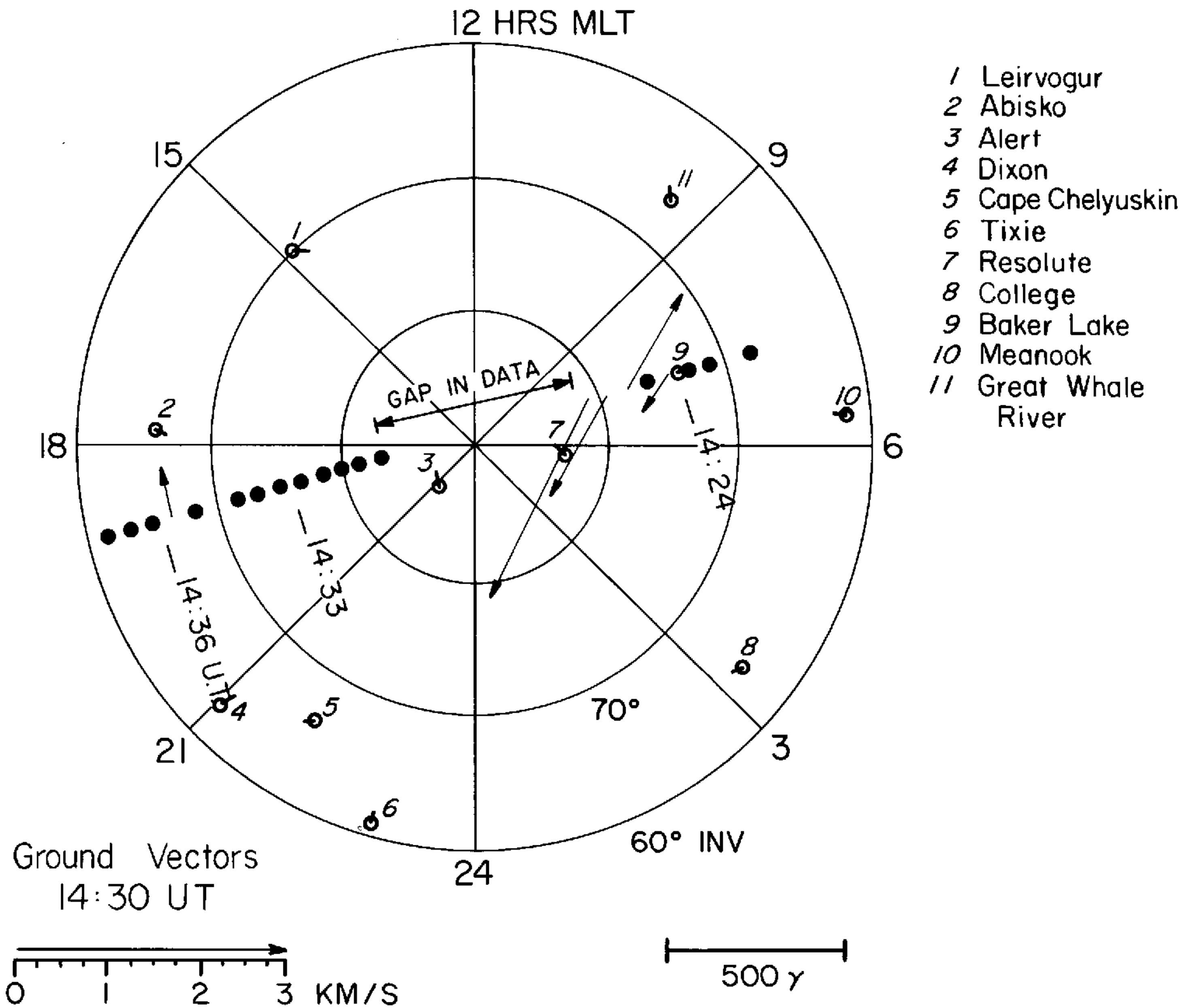
Figure 1. Northern hemisphere polar pass of Injun 5 approximately one hour before the onset of the substorm. The arrows directed outward from the spacecraft track are the convection velocity components determined from the electric field measurement. The ground magnetic disturbance vectors are also shown for the eleven ground stations listed on the right of the figure. Both the convection velocities and magnetic disturbances are small during this pass.

Figure 2 The southern hemisphere polar pass of Injun 5 approximately ten minutes before the onset of the substorm. At this time a region of strong antisunward plasma flow exists over the polar cap with corresponding regions of sunward return flow at lower latitudes (70° to 75°) in the dawn and dusk regions. The electrostatic potential across the region of antisunward plasma flow is estimated to be about 235 kV. The ground magnetic perturbations are, however, still small, less than 50 gammas at this time.

Figure 3 The northern hemisphere polar pass of Injun 5 near the time of maximum magnetic disturbance for this substorm. The region of strong anti-sunward plasma flow is still present over the polar cap and the electrostatic potential across this region is comparable to the pre-substorm value of 235 kV in Figure 2. Large magnetic disturbances are now evident at all the ground magnetometer stations, particularly in the local evening and morning regions.

Figure 4 Ground magnetogram records from a selection of high latitude observatories during the February 24, 1970, substorm.

Figure 5 The top three panels give the magnitude, $|B|$, and direction, θ and ϕ, of the interplanetary magnetic field at Explorer 35. The bottom panel shows the superposed H magnetogram records from Figure 4. The arrows at the bottom of this panel give the approximate times of the Injun 5 passes shown in Figures 1, 2, and 3.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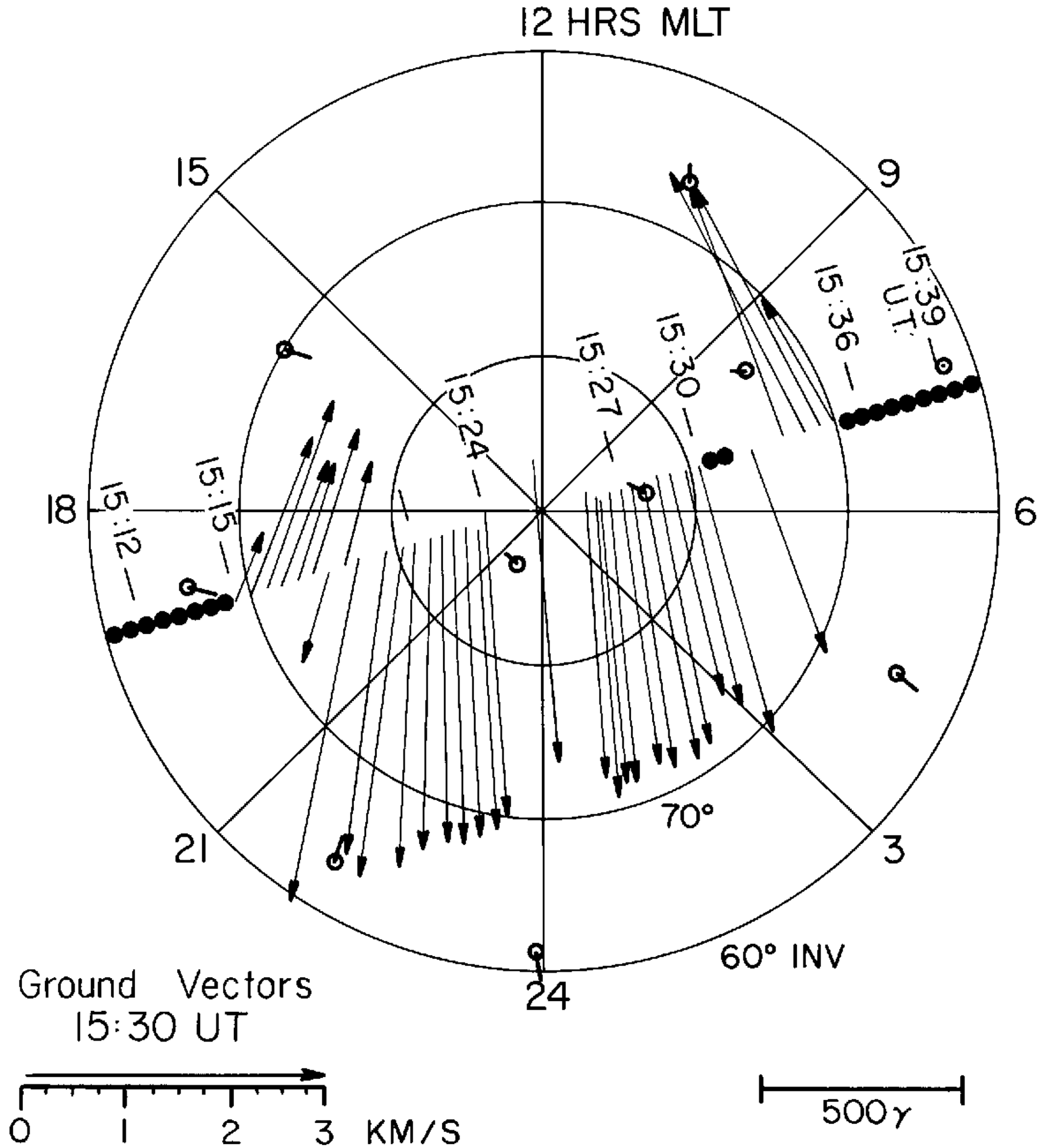
15
9
18
6
21
3
24
70°
60° INV
GAP IN DATA
14:24
14:33
14:36 U.T.
1 Leirvogur
2 Abisko
3 Alert
4 Dixon
5 Cape Chelyuskin
6 Tixie
7 Resolute
8 College
9 Baker Lake
10 Meanook
11 Great Whale River
Ground Vectors
14:30 UT
0 1 2 3 KM/S
500 γ

Figure 1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15:27
15:24
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Ground Vectors
15:30 UT
0
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KM/S
500γ

Figure 2

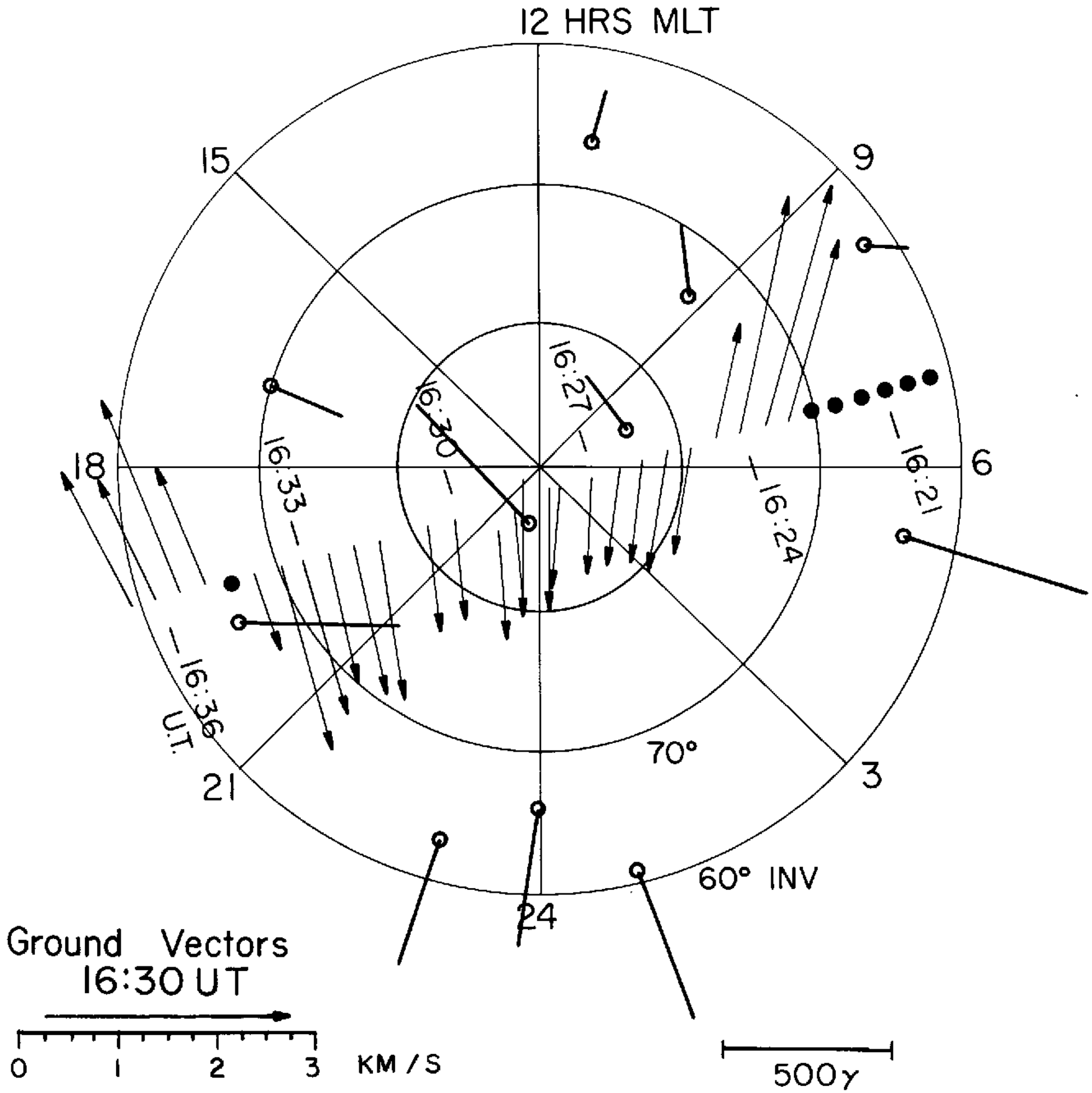

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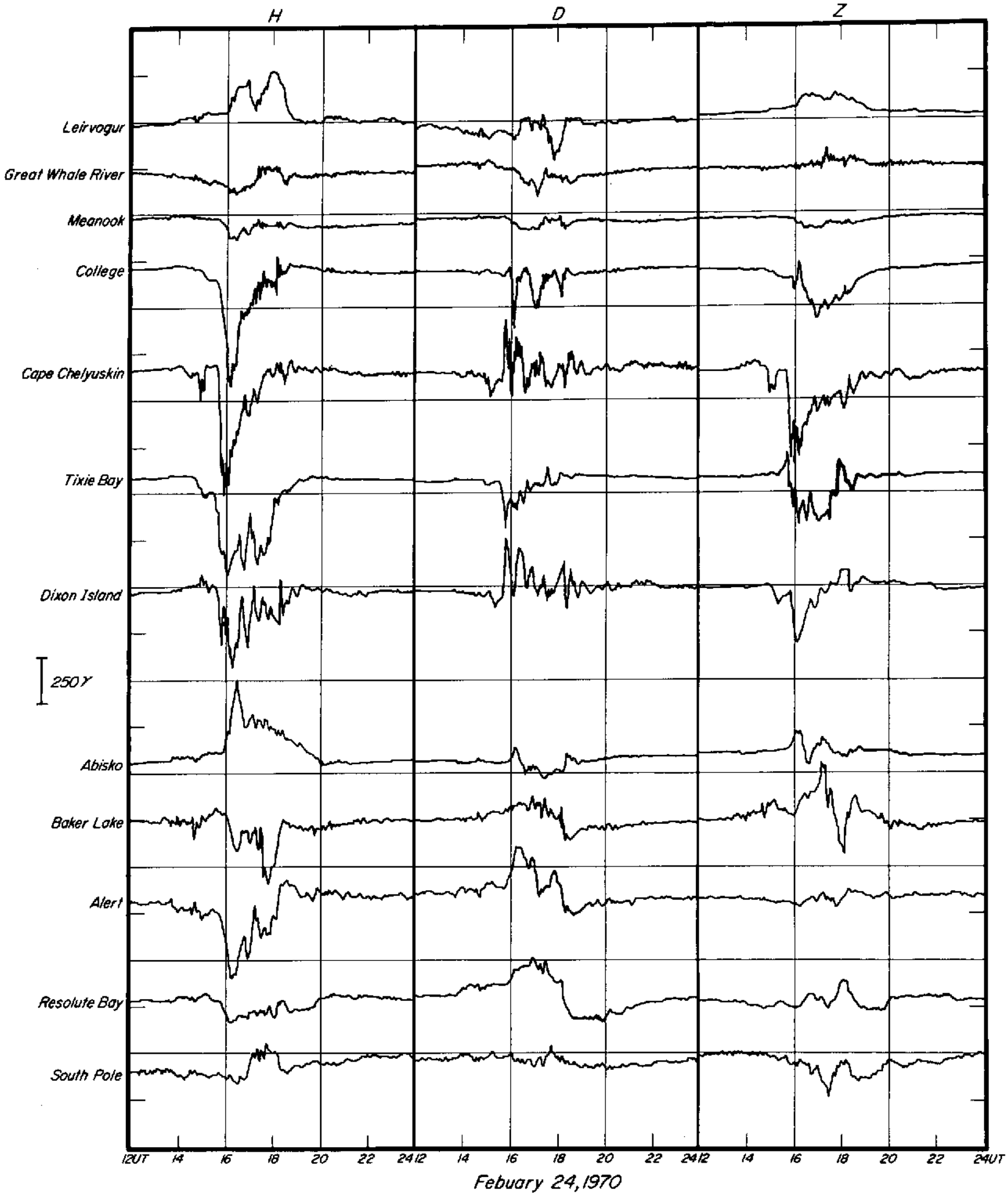
Figure 3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Leirvogur
Great Whale River
Meanook
College
Cape Chelyuskin
Tixie Bay
Dixon Island
250γ
Abisko
Baker Lake
Alert
Resolute Bay
South Pole
12UT
14
16
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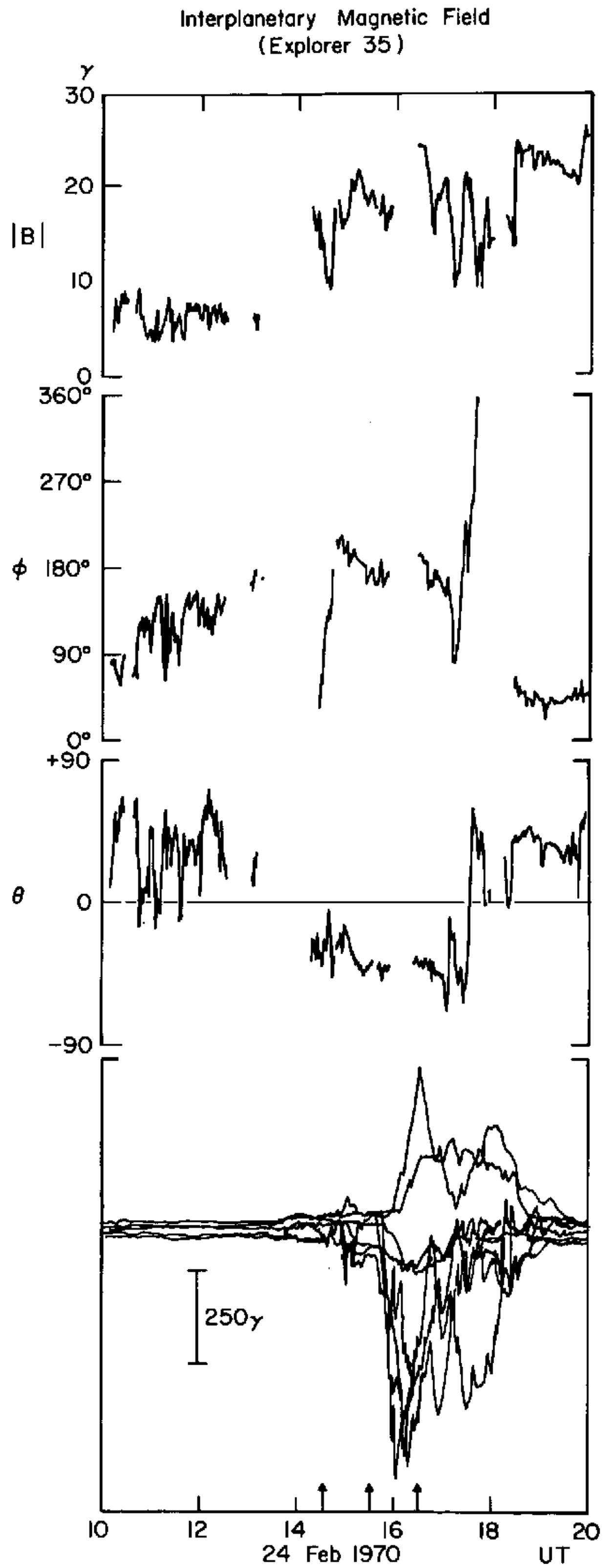
24UT
Febuary 24,1970

Figure 4


Interplanetary Magnetic Field
(Explorer 35)
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270°
φ 180°
90°
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θ
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-90
250γ
10
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20
24 Feb 1970
UT

Figure 5