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EFFECTS OF INTERPLANETARY MAGNETIC FIELD AZIMUTH ON AURORAL ZONE AND POLAR CAP MAGNETIC ACTIVITY

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ABSTRACT

During relatively quiet times (Ap $\leq$ 10) in the period 1964-1968, AE is found to be greater when the interplanetary magnetic field ($\vec{B}_{IMF}$) is directed toward the sun in Jan., Feb., and April, and when $\vec{B}_{IMF}$ is directed away from the sun in Oct. - Dec. Using Murmansk hourly H values and the AE components, AU and AL, it is shown that this sector dependence is present only in the negative H deviations. This observation, along with particle measurements during positive and negative bays, support the idea that negative bay magnitudes are determined chiefly by particle-produced ionization, while positive bay magnitudes are rather insensitive to increases in particle precipitation. The ratio of DP2-type magnetic activity in the southern polar cap to that in the northern polar cap is found to be greater by a factor of about 1.75 for $\vec{B}_{IMF}$ toward the sun. This result suggests that, if the DP2 activity is in fact caused by ionospheric currents, it is more likely that the dawn-dusk convection electric field which drives the currents is produced by a field-line merging process rather than by direct penetration of the solar wind electric field into the magnetosphere.

INTRODUCTION

It has recently become well-established that the existence at the earth of a geocentric-solar-magnetospheric (GSM) southward component of the interplanetary magnetic field is strongly correlated with polar substorm activity (see, e.g., Aubry and McPherron, 1971; Arnoldy, 1971; Foster et al, 1971). The planetary magnetic activity indices, such as Kp, Ap and C9, also show a correlation with the southward field, but these have been found to correlate well with many other solar wind phenomena including high magnetic field magnitudes and magnetic variability (see Hirshberg and Colburn, 1969). Nishida and co-workers (see Nishida and Kokubun, 1971, for a review of their work) have demonstrated that worldwide DP2 fluctuations show a one-to-one correlation with increases in the southward component of the interplanetary field ($\vec{B}_{IMF}$) with the DP2 fluctuations commencing nearly simultaneously with the arrival of the $\Delta\vec{B}_{IMF}$ at the earth. DP2 magnitudes were shown by Nishida (1968) to be proportional to the GSM southward component of $\vec{B}_{IMF}$. Substorm effects, as evidenced by the DP1 current system through the AE index, were found by Arnoldy and Foster et al. to follow the onset of the southward field by approximately one hour, with AE also proportional to the magnitude of the $\vec{B}_{IMF}$ southward component.

The effects of the azimuth of $\vec{B}_{IMF}$ are less clear. Schatten and Wilcox (1967), examining data from the last half of 1965, have found Kp to tend toward higher values when the field is directed away from the sun. These results are generally consistent with those of Siscoe (cited by Russell and McPherron, 1972) that C9 was higher for "toward" sectors in the half year centered on 24 April and for "away" sectors in the half year centered on 23 October for the years 1965 - 1968 and portions of 1962 and 1964 for which $\vec{B}_{IMF}$ measurements are available. Russell and McPherron (1971) have shown this behavior and the equinox peaks in Kp to be consistent with a model in which geomagnetic activity is proportional to the GSM southward component of $\vec{B}_{IMF}$ and the only effect of season and $\vec{B}_{IMF}$ azimuth is the increase or decrease of the GSM southward component of $\vec{B}_{IMF}$ for a given geocentric-solar-equatorial (GSEQ) component. This increase or decrease results from the transformation from the coordinate system in which $\vec{B}_{IMF}$ is ordered (GSEQ) to that which has been found to be more important for the interaction of $\vec{B}_{IMF}$ with the magnetosphere (GSM).

The model of Russell and McPherron allows for no northern-southern hemisphere differences in the times of peak magnetic activity. Thus, it is not consistent with the results of Mayaud (1967) and Siebert (1968) who formulated separate northern and southern hemisphere K indices. Mayaud found local summertime peaks for each hemisphere and a seasonal dependence that would produce equinox peaks when northern and southern activity were added. Siebert found the ratio of the northern to the southern auroral zone K indices to be higher when $\vec{B}_{IMF}$ pointed away from the sun during the period Nov. 1963 - Feb. 1964.

High latitude effects of $\vec{B}_{IMF}$ azimuth have also been studied by Arnoldy (1971), who found a slightly better correlation between B south and AE in "away" sectors during the period Jan. - Mar. 1967; and Rostoker (1968), who found that, during the period Dec. 1-14, 1963, substorms were often triggered in "away" sectors when $\vec{B}_{IMF}$ swung through the 45° spiral angle.

The purpose of this study is two-fold. The first is to investigate the long-term average effect of $\vec{B}_{IMF}$ azimuth on auroral zone magnetic activity during periods of relatively low worldwide magnetic activity ($C9 \leq 2$, $Ap \leq 10$) when effects due to the southward interplanetary field are less likely to be masked by the occurrence of interplanetary shock waves, ring currents, and other phenomenon associated with large magnetic storms. This will also serve to confine the analysis to times when the integrated southward component of $\vec{B}_{IMF}$ is relatively small, enhancing the role of $\vec{B}_{IMF}$ azimuth which is expected to be a second-order effect. The second purpose is to examine the effects of $\vec{B}_{IMF}$ azimuth on the DP2 current system using ground-station magnetograms from Thule and Vostok, near the northern and southern magnetic poles.

THE AE INDEX

The study of the effects of $\vec{B}_{IMF}$ azimuth on auroral zone magnetic activity is conducted in two parts. The first involves the use of the AE (auroral electrojet) index. AE hourly averages for the period 1964 - 1968 were obtained from the National Space Science Data Center (NSSDC) (see Davis and Sugiura, 1966, for a comprehensive description of the AE index). The longitude coverage of AE is typically incomplete, depending on the availability of digitized magnetograms. Stations used in compiling the AE indices presently available from NSSDC for the years 1965-1968 are shown in Figure 1. Since substorm activity is strongly peaked near midnight, it is evident from Figure 1 that AE is ill-suited for studies of the universal-time diurnal variation of auroral zone magnetic activity. However, with its limitations recognized, it is a fairly reliable index of seasonal and other longer term effects such as those due to the $\vec{B}_{IMF}$ sector structure. The basic difference between AE and Kp (aside from the latitude coverage) is that AE represents the magnitude of the difference between the largest and smallest values of $H-H_0$ seen at any of the AE stations, while Kp is a measure of the range of the most disturbed component over a three-hour period for stations at various local times. Therefore, while Sq effects are largely eliminated from Kp, they are not eliminated from AE. Also, the technique of subtracting the extreme values of $H-H_0$ seen at the various stations minimizes ring current effects in AE since a negative ΔH is produced by the ring current at all the stations. Finally, only northern stations are included in the AE index, at least for the time period 1964-1968. Therefore, the conjugate point study of Meng and Akasofu (1968) which showed the summer hemisphere positive bay magnitude to be roughly twice that at the winter conjugate station, indicates a further enhancement of the summertime peak expected from Sq currents.

Information on the $\vec{B}_{IMF}$ sector structure and the C9 index is taken from Wilcox and Colburn (1970)(their Figure 1). The period 1965-1968 plus those days in Jan. - Feb. and Oct. - Dec. 1964 when actual measurements were made are used in this portion of the study. As discussed above, all days with C9 > 2 or during which the sector structure changed or was indeterminate are eliminated from consideration.

Daily sums of hourly AE averages are combined into twelve monthly averages covering the period 1964-1968. Even when limited to a restricted range of C9 values, there is a wide variation in AE. Therefore, a monthly average for a given sector polarity is considered significant only if a minimum of 15 days are included. These averages are plotted in histogram form in the upper plot of Figure 2. The solid line is for "toward" sectors --the dotted line for "away" sectors. A broad summertime peak is evident for both polarities. This peak is due in large part to solar-produced conductivity enhancements and Sq currents. For months in which sufficient data are available for both polarities, AE is higher for toward sectors in Jan., Feb., and April and for away sectors in Oct. - Dec. This result is in agreement with the behavior of C9 found by Siscoe and with the model of Russell and McPherron (1972) which predicts greater substorm activity for toward sectors for the half year centered near the spring equinox and for away sectors for that centered near the fall equinox.

The statistical significance of the indicated sector dependence of AE can be evaluated as follows. Restricting the study to periods of $Ap \leq 10$ results in 560 daily sums of hourly AE values. When classified into intervals 200γ wide, the probability distribution of the 560 values rises sharply to a maximum at $800 \leq AE \leq 1000$. Between 900γ ($\pm$ 100γ) and 3100γ ($\pm$ 100γ) the distribution follows closely the exponential function, $P(AE) = .2819 \exp(-8.4 \times 10^{-4} AE)$. Although the individual daily AE values are not normally distributed, it is expected that a group of sample means will be. Therefore, an estimate of the significance of any difference between two sample means can be made using the "t" test of significance. This test gives the probability that any two sample means from the same normal distribution of means will differ by a given amount. Calculated probabilities for the differences shown in the upper panel of Figure 1 are: Jan. (.22), Feb. (.66), April (< .01), Oct. (.04), Nov. (.06) and Dec. (.07). Therefore, while the sector dependence found for February is not statistically significant, a high degree of confidence can be placed in the differences found for the other five months.

HOURLY POSITIVE AND NEGATIVE ΔH VALUES

In this section, effects of $\vec{B}_{IMF}$ azimuth on auroral zone magnetic activity are studied further, using hourly H values, in order to examine possible differences in the behavior of positive and negative bay activity. Hourly H values for Murmansk (invariant latitude (Λ) = 64.5°) are examined for the same days in 1964-68 as in the AE compilation. For each month of each year the average hourly H value for the four or five quietest days is used as the base value. Each hourly H value for the days considered in a given month then represents either a positive or a negative deviation from this base line. Separate daily sums of the positive and negative deviations are then combined into twelve monthly averages each for toward and away $\vec{B}_{IMF}$ sectors. Again, only those months are considered for which 15 days of data are available. As with the AE index, Sq variations are not eliminated in this method. Unlike the AE index, ring current effects are not minimized, but this poses little difficulty for the quiet ($Ap \leq 10$) times considered. A similar technique, without the separation into positive and negative deviations, yields the index $\bar{I}$ (described by Lebeau, 1970) which has been found to relate to Ap as $\bar{I} = k\,\overline{Ap}^{\alpha}$, where k and α are approximately equal to 15 and 0.5 for auroral zone stations near 65° invariant latitude.

The results of the compilation of hourly negative and positive ΔH are shown in the lower two panels of Figure 2. The general dependence on season and $\vec{B}_{IMF}$ polarity for negative ΔH is very similar to that found for AE. However, no clear pattern of sector dependence is seen for positive ΔH.

An example of this behavior is shown in Figure 3. In this case the 2.5-minute average AE index is split into its components AU (the maximum positive deviation) and AL (the maximum negative deviation). Although the lack of local-time coverage in AE poses less of a problem when taking long-term averages it renders questionable the value of comparing average AE values for a series of single days. Therefore, in Figure 3 are simply plotted the maximum values of AU and AL occurring in each day during the period Nov. - Dec. 1968. Dashed lines are the mean values of the points shown for each sector. Again, as found for hourly H values, the magnitudes of positive deviations show no systematic dependence on sector polarity. Moreover, as found for the months Nov. - Dec. using hourly H values, there is a clear tendency toward larger negative disturbances for away sectors. Several of the high values that do appear for the toward sector during the period Nov. 16-20 are associated with sudden commencement magnetic storms during which $\vec{B}_{IMF}$ polarity is expected to play a very minor role. Although it is not known whether the away sectors produce a more frequent incidence of substorms, this example definitely indicates at least an enhancement in the magnitude of negative bays.

The lack of a clear $\vec{B}_{IMF}$ sector dependence of positive bay magnitudes provides further evidence (along with that of Meng and Akasofu discussed above) that the conductivities in the evening sector are determined to a large extent by solar radiation while in the midnight-early morning sector (where negative bays predominate) the conductivities are determined chiefly by particle precipitation. This is not to say that positive bays are not accompanied by a significant influx of particles. In Figure 4 are shown portions of two passes of the OGO-4 Auroral Particles Experiment through the auroral regions. During the pass of Dec. 11, 1968, OGO-4 crossed approximately 1 hr. to the east of Leirvogur ($\Lambda = 66.4^{\circ}$) at a magnetic local time of 19.4 hrs. during a positive bay. The Leirvogur magnetogram trace and that of Dixon Island (which was in the midnight sector and experiencing a large negative bay) are shown in the upper-left panel of Figure 4. Along the OGO-4 orbit are plotted fluxes of 7.3 kev electrons near 0° pitch angle. Electrons in this energy range are expected to produce significant ionization in the E-region, where the electrojet is most intense. These fluxes are typical of the early evening sector in that the 7 kev flux, although sometimes quite intense during substorms, is very localized in latitudinal extent. This is consistent with the general behavior discussed by Akasofu (1964) in which quiet auroral arcs are observed in the early evening sector even during large substorms. This highly localized precipitation results in a lower probability that a ground station will lie sufficiently near the more intense portions of the eastward current for the magnitude of the positive bay to respond with much sensitivity to changes in the particle flux. Frank and Akerson (1971) have also reported localized bands of electron precipitation in the evening sector at 1800 - 2200 MLT.

In the midnight sector, where negative bays predominate, a quite different pattern of electron precipitation is typically seen. The OGO-4 pass of Feb. 27, 1968, shown in Figure 4, provides an example of midnight electron precipitation during a large negative bay. The magnetogram trace from Abisko ($\Lambda = 65.2^{\circ}$), which lay nearly under the satellite track at 23.6 hrs. MLT is shown in the upper right-hand panel of Figure 4. During this pass, intense 7.3 kev electron precipitation covering fully 10° of invariant latitude was present overhead and well to the north and south of Abisko. In this instance the magnitude of the negative bay is expected to be quite sensitive to large changes in particle flux.

POLAR CAP DP2 ACTIVITY

The sector dependence of magnetic activity in the polar cap is investigated in this section using events of the type which are referred to as DP2 by Nishida and co-workers (see Nishida and Kokubun, 1971, and references therein). The general pattern of worldwide DP2 currents and their correlation with southward $\vec{B}_{IMF}$ have been described in detail by Nishida (1968) and Nishida and Maezawa (1971). Whereas substorm activity has been found to correlate well with the integrated southward $\vec{B}_{IMF}$ during the preceding hour, DP2 activity responds within minutes to a southward field. This indicates that DP2 currents are a more direct manifestation of the interaction between the magnetosheath and magnetosphere fields, while substorms are part of a general magnetospheric reaction to the increased energy input resulting from this interaction. Therefore, it appears that if there is a difference in the degree of interaction in the northern and southern hemispheres for a given $\vec{B}_{IMF}$ polarity, it will be more likely to show up in the polar cap DP2 currents than in the substorm DP1 currents. There is a known north-south difference in polar cap current intensity due to the difference in solar-produced ionization. Therefore, in this study only times within one month of the fall and spring equinoxes (1967) are considered. The stations selected are Thule ($\Lambda = 86.5^{\circ}$, geo. lat. = 77.5°, geo. long = 290.8°) and Vostok ($\Lambda = -83.3^{\circ}$, geo. lat. = -78.4°, geo. long. = 106.9°). In the universal time sector 1930 - 2230 (local times 1450 to 1750 at Thule and 0240 to 0540 at Vostok) both stations respond to a southward turning $\vec{B}_{IMF}$ almost entirely in the D component with very little H or Z activity. On the other hand, when a substorm-associated magnetic bay reaches the polar regions all three components are affected significantly. Also, by restricting the study to this 3 hour UT sector, large diurnal effects of solar radiation are eliminated to some degree.

An example of a typical DP2-type response at the two stations on March 7, 1967 is shown in Figure 5. Also shown are the geocentric-solar-equatorial latitude of $\vec{B}_{IMF}$, as measured by the Ames experiment on Explorer 33, and the Huancayo, Peru ($\Lambda = 11.6^{\circ}$) magnetogram. The DP2 event at $\sim$ 19 hours UT follows the onset of the period of southward $\vec{B}_{IMF}$ by approximately seven minutes. At this time Explorer 33 was located $\sim 40\ R_E$ upstream of the earth in the solar wind so a delay time of seven minutes is roughly consistent with the solar wind velocity of $\sim$ 375 km/s measured by the MIT plasma experiment on Explorer 33. The most striking difference between the DP2 and DP1 current systems is the nearly undiminished appearance of the DP2 return current at the equator compared to the negligible equatorial current observed even during very large auroral zone magnetic bays. Note also in Figure 5 that the sudden but short-lived southward $\vec{B}_{IMF}$ did not produce electrojet currents at the auroral zone stations Murmansk and Cape Chelyuskin although both stations were favorably located near the midnight sector. However, negative bays are seen in the morning hours at both stations near 2200 hours UT. This activity occurs after a considerable period of southward $\vec{B}_{IMF}$ and is accompanied by very little activity in the polar caps. Although a general enhancement in DP2 is seen at Vostok, Thule and Huancayo throughout this second period of southward $\vec{B}_{IMF}$, both Murmansk and Chelyuskin are quiet until the sudden onset of the negative bays. Nishida (1971) has shown the DP2 fluctuations to be consistent with an ionospheric Hall current produced by a dawn-dusk convection electric field. Thus the polar cap and equatorial stations appear to respond with some sensitivity to increased magnetospheric convection soon after its onset. On the other hand, the auroral electrojet is enhanced much later (if at all) when the increased convection has resulted in an increase of particle precipitation, hence conductivity, along the auroral oval.

Although the auroral electrojet is at least partially understood in terms of ionospheric Hall currents, it has by no means been proven that the polar cap and equatorial DP2 fluctuations are in fact caused by ionospheric currents. Other current systems, perhaps flowing on the magnetospheric boundary, could be of importance in the generation of DP2 activity. In this study nothing has been assumed about the nature of the DP2 current system. However, it is assumed that the DP2 fluctuations are distinct from those due to sudden impulses and the auroral electrojet, which are also observed at polar cap stations.

Periods containing DP2 variations at the two polar cap stations were selected as follows: (1) All days in 1967 within one month of the spring and fall equinoxes were examined for the presence of apparent DP2 fluctuations between 1930 and 2230 hours local time. (2) Equatorial magnetograms from Huancayo and Bangui ($L < 1$) were examined to verify that the fluctuations were also present at equatorial latitudes. (3) Magnetogram data from Explorers 33 and 35 were examined to verify that a direct connection existed between the polar cap activity and a southward-turning $\vec{B}_{IMF}$. (4) 2.5-minute AE values were examined so that possible magnetic bay activity could be eliminated. (5) Plasma data from the MIT plasma experiment was available for only about 35% of the period covered. When it was available, effects of sudden impulses caused by rapid increases in solar wind momentum were eliminated. When this data was not available the presence of sudden impulses was deduced from the two equatorial magnetograms using the criteria described by Nishida and Maezawa (1971). All days in which confirmed DP2-type activity was found between 1930 and 2230 UT are included in the analysis. However, those periods which contain possible bay activity or sudden impulses are first eliminated.

There are often significant diurnal variations in the polar cap magnetograms due to Sq and S_q^p currents and other non-DP2 effects. Therefore, any quantitative study of these magnetograms requires some technique of removing such long-term effects. A high-pass numerical filtering technique has been used by Nishida (1968). A similar procedure has been adopted in this study. Specifically, the "low-low pass filter" described by Martin (1959) is used. Magnetograms from Thule and Vostok are digitized at 5-minute intervals giving a series of D values, each of which is transformed to a filtered value using the following equation:

$$D(t_0') = \sum_{k=-20}^{+20} B_k\, D(t_o + k\tau), \text{ where}$$

$$B_k = \frac{\cos(2\pi kh)\ \sin(2\pi kh)}{(1-16k^2h^2)\pi k},$$

with τ = 5 minutes, and h = .028. The gain of this filter is .96 for DC inputs, decreasing sinusoidally to 0.5 and 0.0 for variations of period 3 hours and 1.5 hours respectively. The output of the low-pass filter then represents a long-term mean or trend which can be subtracted from the original D values, effectively eliminating the slower variations caused mainly by changes in solar zenith angle.

After the long-term variations have been subtracted, the standard deviations of the D values about the zero line are computed for 1930 - 2230 UT with times containing sudden impulse or substorm variations excluded. It should be emphasized that completely unambiguous classification of events into certain types is not always possible. However, by limiting the study to selected local times and carefully applying the criteria listed above, it was possible to classify events on 25 days which were within one month of the 1967 equinoxes as events which satisfied the DP2 criteria of Nishida and Maezawa (1971).

During the period 1930 - 2230 UT on the dates considered, it is required that the $\vec{B}_{IMF}$ polarity be clearly toward or away from the sun. Days when the $\vec{B}_{IMF}$ longitude was within a few degrees of 90^o or 270^o are not included in the study. The ratio of the standard deviations calculated for Vostok to that for Thule are plotted in Figure 6. Toward sectors are represented by solid points -- away sectors by open circles. Although the changing solar zenith angle is seen to have a large effect, even near the equinoxes, there is a clear tendency for the ratio of southern to northern activity to be larger for $\vec{B}_{IMF}$ toward the sun. The solid lines are obtained by linearly regressing the logarithms of the individual data points and so represent their best exponential fit. The toward-sector line lies approximately a factor of 1.75 above the away sector line.

SUMMARY

During relatively quiet times ($Ap \leq 10$) the daily sum of hourly AE values is found to increase when $\vec{B}_{IMF}$ is directed toward the sun in Jan., Feb. and April and when $\vec{B}_{IMF}$ is directed away from the sun in Oct. - Dec. This result is consistent with similar studies using Kp and C9 and with the model of Russell and McPherron in which magnetic activity is proportional to the GSM southward component of $\vec{B}_{IMF}$. Using hourly H values from Murmansk and the AE components, AU and AL, it is found that the dependence on $\vec{B}_{IMF}$ polarity occurs only in the negative deviations, suggesting further that, although positive and negative bays generally occur together, their respective magnitudes are determined by different sets of conditions. This result is in agreement with that of Meng and Akasofu (1968) who found larger positive bays in the summer hemisphere but no clear seasonal dependence of negative bay magnitudes. In this study negative variations were found to peak in local summertime as well. However, daily averages were used instead of the magnitudes of individual negative bays, and a larger Sq dependence is expected. Heppner (1972) has noted that electric fields in the dawn and dusk sectors increase only moderately during substorms while it is known that particle precipitation can increase by several orders of magnitude. It appears, then, that the chief contributor to electrojet current enhancements is particle precipitation. This viewpoint is substantiated in Figure 4 where the particle precipitation into the positive bay region is shown to be highly localized while that into the negative bay region is intense and widespread. Assuming that the magnitudes of both positive and negative bays are dependent on the ionospheric electric fields and solar - and particle - produced ionization, it is likely that the main effect of $\vec{B}_{IMF}$ azimuth (perhaps through its enhancement of the $\vec{B}_{IMF}$ GSM southward component as described by Russell and McPherron, 1972) is increased particle precipitation and not enhanced electric fields, although they may occur as a secondary effect.

The ratio of DP2-type magnetic activity in the southern polar cap to that in the northern polar cap is found to be greater by a factor of approximately 1.75 for toward sectors than for away sectors. This result supports the suggestion by Forbes and Speiser (1971) that the current system may be enhanced over one pole when $\vec{B}_{IMF}$ has a solar or antisolar component. Forbes and Speiser did not indicate which pole should experience greater activity for a given $\vec{B}_{IMF}$ azimuth. However, their results indicated that for $\vec{B}_{IMF}$ toward the sun a Dungey-type neutral point would be formed in the northern hemisphere with a proportionately larger degree of magnetic field-line reconnection in the southern hemisphere. It also agrees well with the dependence found by Siebert using K indices for northern and southern hemisphere auroral zone stations. As mentioned above, Siebert's results are in apparent conflict with the supposition of Russell and McPherron (1972) that magnetic activity depends only on the GSM southward component of $\vec{B}_{IMF}$ and the only effect of $\vec{B}_{IMF}$ azimuth is an increase or decrease of the GSM southward component for a given GSEQ southward component. Southern hemisphere auroral zone activity was not presented in this study since hourly H values were not available for a single southern station over the entire period 1964 - 1968. However, a partial study covering 1964 - 1967 was conducted for Novolazarevskaya (Λ = - 62.35) which indicated the same general sector dependence as for Murmansk. That is, where Siebert's study concerned only the difference between northern and southern hemisphere activity, it is possible that the northern and southern activities alone could show the same sector dependence. In that case, Siebert's results would indicate a secondary effect which could be consistent with, although not explained by the model of Russell and McPherron. The same could be said about the polar cap variations studied herein. That the ratio of southern to northern activity is greater for toward sectors does not rule out the possibility that, on the average, northern and southern hemisphere activity depend in a similar way on $\vec{B}_{IMF}$ azimuth. Since each DP2 event is expected to depend in some way on the magnitude of southward $\vec{B}_{IMF}$, and possibly on other solar wind parameters, a long-term statistical study of many events is necessary to answer this question decisively.

Nishida and Kokubun (1971 and references) have demonstrated that the DP2 fluctuations are at least consistent with an ionospheric current system associated with a dawn-dusk electric field across the polar cap. The fact that the fluctuations only appear following a southward turning $\vec{B}_{IMF}$ instead of appearing in the reverse direction for northward $\vec{B}_{IMF}$ indicates that the solar wind electric field ($\vec{E} = \vec{v}_s \times \vec{B}_{IMF}$) does not continuously penetrate to any significant degree into the magnetosphere. Whether the southward $\vec{B}_{IMF}$ provides access to the magnetosphere through a magnetic merging process or instead, the magnetic merging itself produces the dawn-dusk electric field has not been answered. The model of Forbes and Speiser (1971), considered in light of the results described herein, appear to favor the latter process since a simple penetration of the solar wind electric field would not be expected to result in a significant north-south asymmetry.

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FIGURE CAPTIONS

Figure 1: Stations used in compiling the AE indices now available from NSSDC for the years 1964-1968. Shaded areas denote months when magnetograms from the indicated stations are included in AE.

Figure 2: Average daily sums of hourly AE averages (upper panel). Average daily positive and negative deviations of Murmansk hourly H values from a quiet day value obtained by averaging the H values for the four or five quietest days in each month of each year. Solid lines represent $\vec{B}_{IMF}$ toward the sun--dashed lines $\vec{B}_{IMF}$ away from the sun.

Figure 3: Maximum daily values of the AE components, AU (positive bays) and AL (negative bays), during the period Nov.-Dec., 1968. Dashed lines indicate the mean values of the points shown for each sector. The labels "toward" and "away" denote $\vec{B}_{IMF}$ directed predominantly toward and away from the sun.

Figure 4: A plot in geographic coordinates of two passes of the OGO-4 Auroral Particles Experiment through the polar regions. Fluxes of precipitated 7.3 kev electrons are plotted along the satellite track. The orbit of Dec. 11, 1968, passed near Leirvogur, which was experiencing a positive bay. The orbit of Feb. 27, 1968, passed nearly over Abisko, which was experiencing a negative bay.

Figure 5: An example of the magnetic activity seen in the polar caps, at the equator, and in the auroral zone in response to a southward turning $\vec{B}_{IMF}$. The sharp onset of southward $\vec{B}_{IMF}$ at $\sim$ 19 hrs. UT produces large DP2-type events at Vostok, Thule and Huancayo but very little activity in the auroral zone. The more gradual southward turning $\vec{B}_{IMF}$ at $\sim$ 22.5 hrs. produces a gradual enhancement of activity at the polar cap and equatorial stations and sharp negative bays in the auroral zone approximately 1.5 hours later. M's indicate midnight MLT at Murmansk and Chelyuskin.

Figure 6: The ratio of standard deviations of magnetogram traces at Vostok (southern polar cap) to those at Thule (northern polar cap). Magnetograms were digitized at 5-minute intervals for the hours 1930-2230 UT on days within one month of the spring and fall equinoxes in 1967. The digital values were passed through a low pass numerical filter whose output gave a long-term mean or trend which was subtracted from the original values to remove diurnal variations. Standard deviations were calculated about the resulting zero line. Periods containing effects of sudden impulses or magnetic bays were first eliminated.

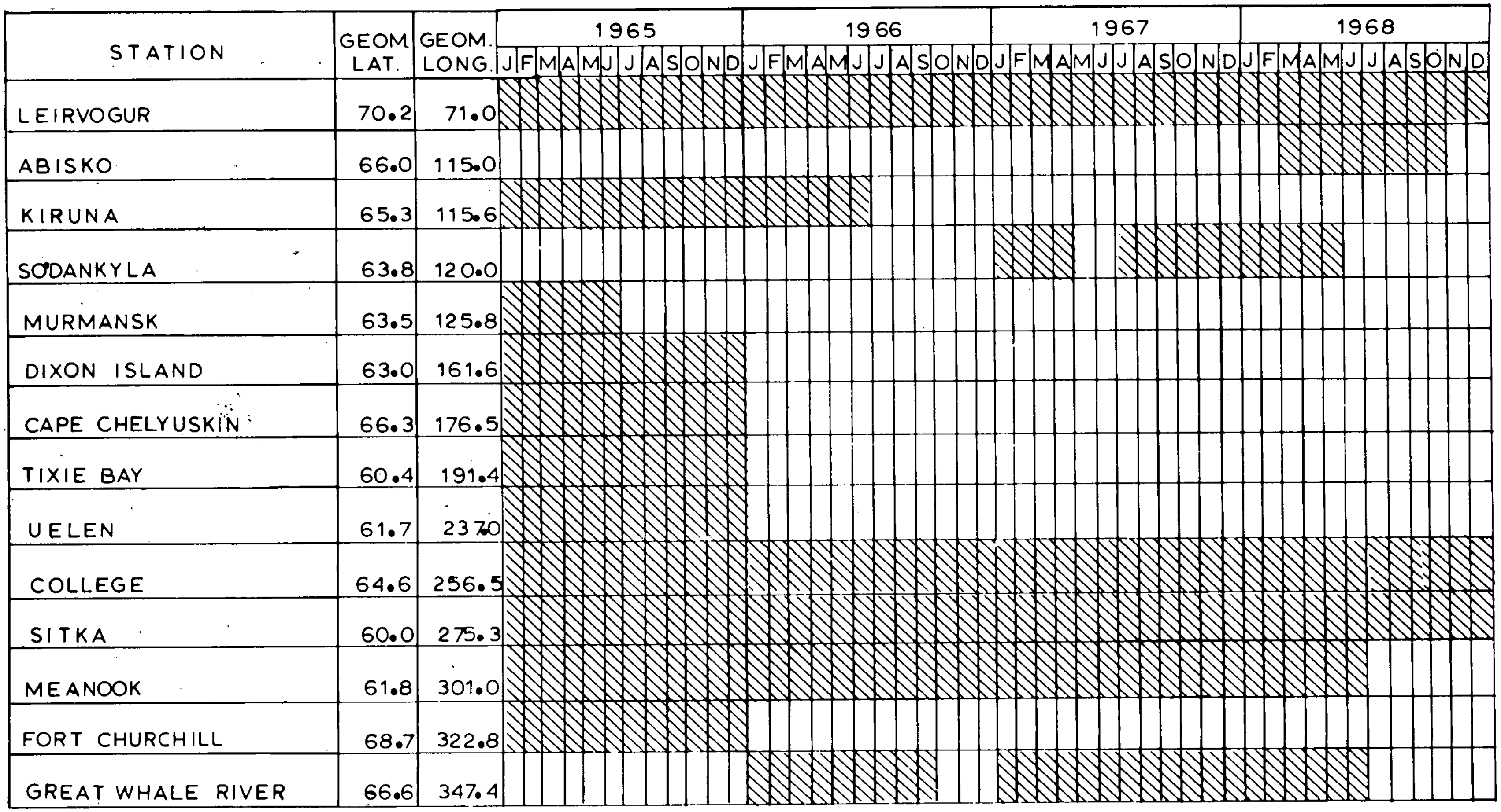
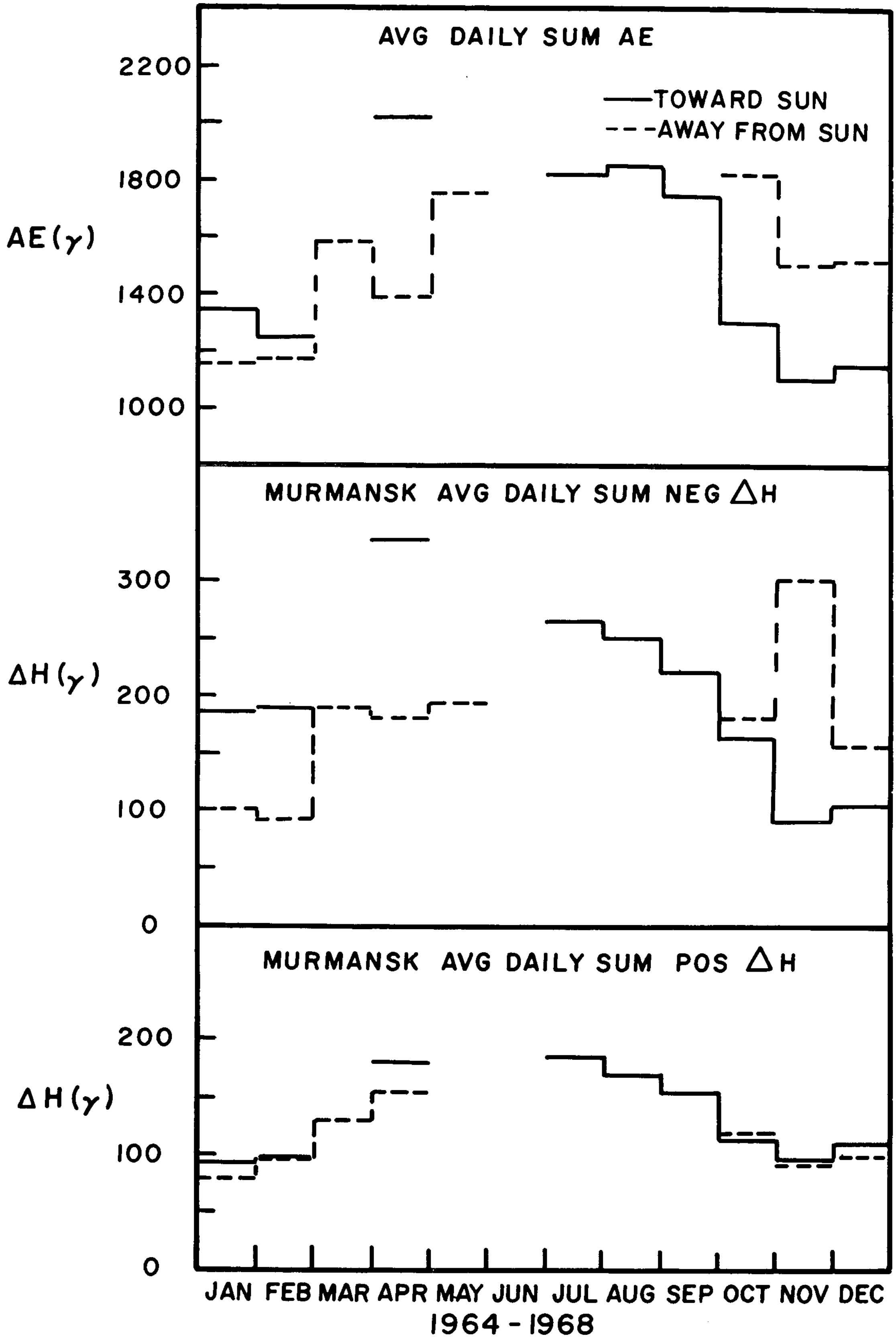
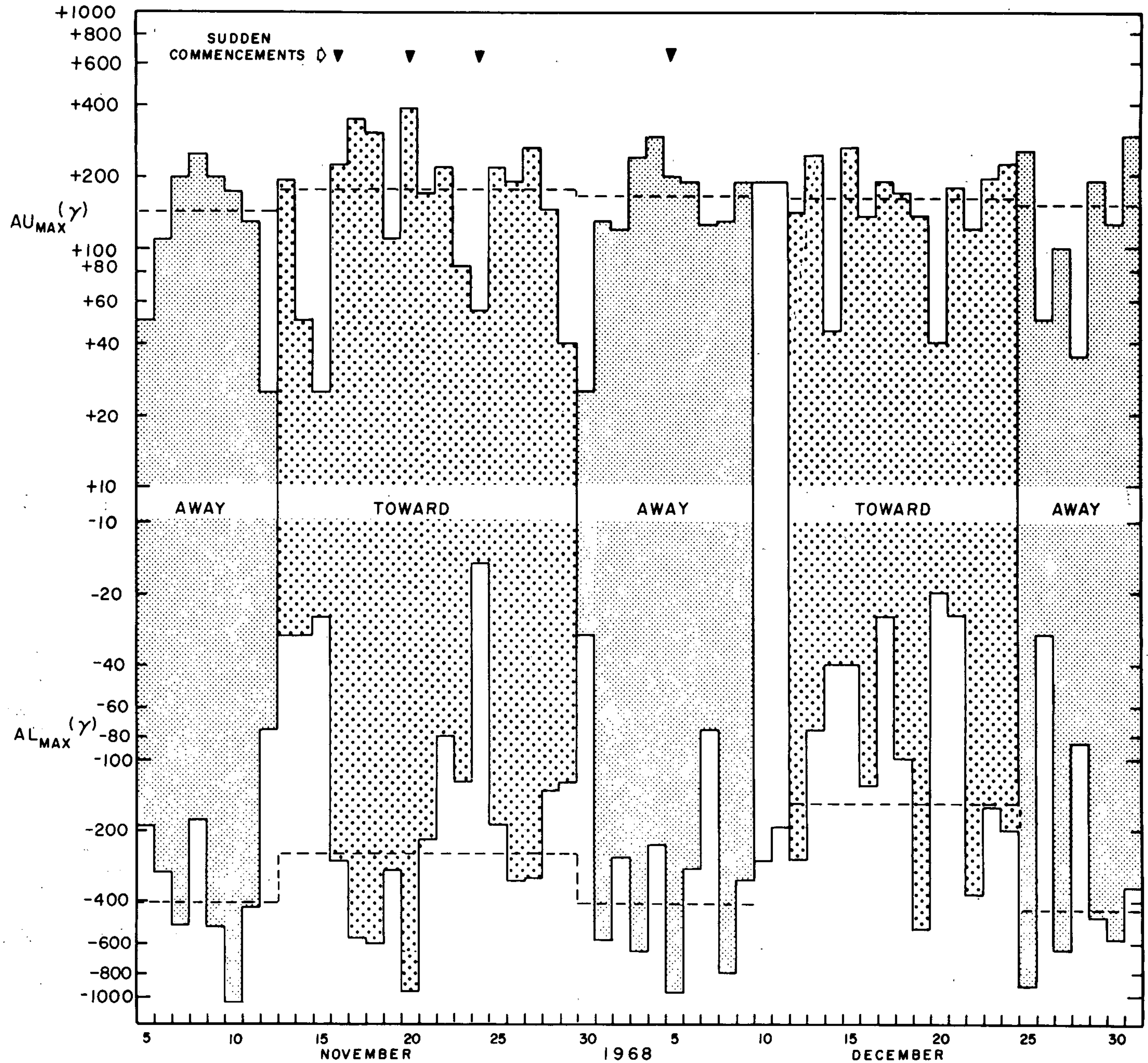

STATION
GEOM. LAT.
GEOM. LONG.
1965
1966
1967
1968
J F M A M J J A S O N D
LEIRVOGUR 70.2 71.0
ABISKO 66.0 115.0
KIRUNA 65.3 115.6
SODANKYLA 63.8 120.0
MURMANSK 63.5 125.8
DIXON ISLAND 63.0 161.6
CAPE CHELYUSKIN 66.3 176.5
TIXIE BAY 60.4 191.4
UELEN 61.7 237.0
COLLEGE 64.6 256.5
SITKA 60.0 275.3
MEANOOK 61.8 301.0
FORT CHURCHILL 68.7 322.8
GREAT WHALE RIVER 66.6 347.4

FIGURE 1



AVG DAILY SUM AE
TOWARD SUN
AWAY FROM SUN
2200
1800
1400
1000
AE(γ)
MURMANSK AVG DAILY SUM NEG ΔH
300
200
100
0
ΔH(γ)
MURMANSK AVG DAILY SUM POS ΔH
200
100
0
ΔH(γ)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1964 - 1968

FIGURE 2



SUDDEN COMMENCEMENTS
+1000
+800
+600
+400
+200
$AU_{MAX}(\gamma)$
+100
+80
+60
+40
+20
+10
-10
-20
-40
-60
$AL_{MAX}(\gamma)$
-80
-100
-200
-400
-600
-800
-1000
AWAY
TOWARD
AWAY
TOWARD
AWAY
5
10
15
20
25
30
5
10
15
20
25
30
NOVEMBER
1968
DECEMBER

FIGURE 3

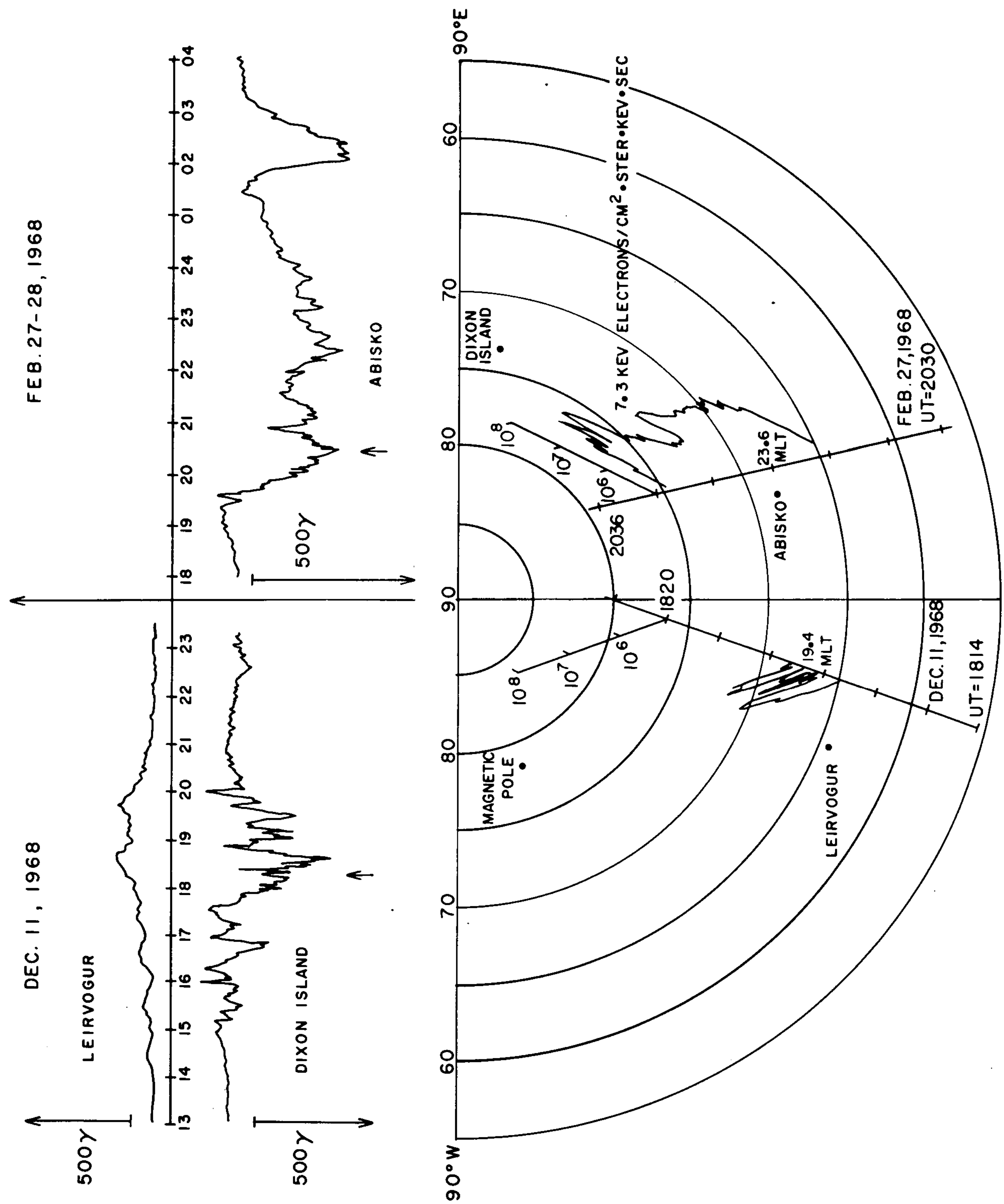

DEC. 11, 1968
LEIRVOGUR
DIXON ISLAND
500γ
500γ
FEB. 27-28, 1968
ABISKO
500γ
7.3 KEV ELECTRONS/CM2·STER·KEV·SEC
FEB. 27,1968
UT=2030
DEC. 11,1968
UT=1814
23.6 MLT
19.4 MLT
2036
1820
MAGNETIC POLE
DIXON ISLAND
ABISKO
LEIRVOGUR
90°E
90°W
0°

FIGURE 4

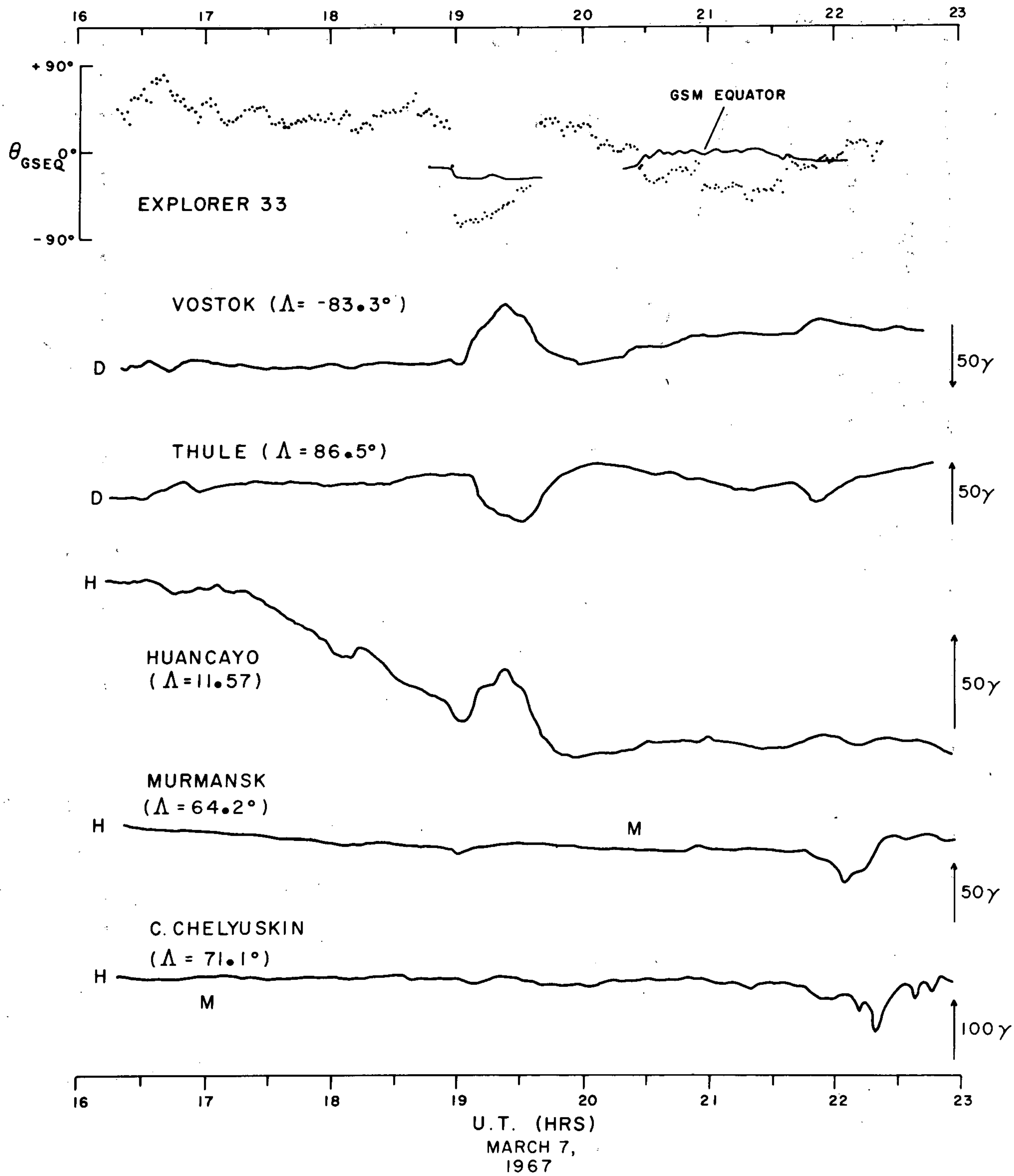
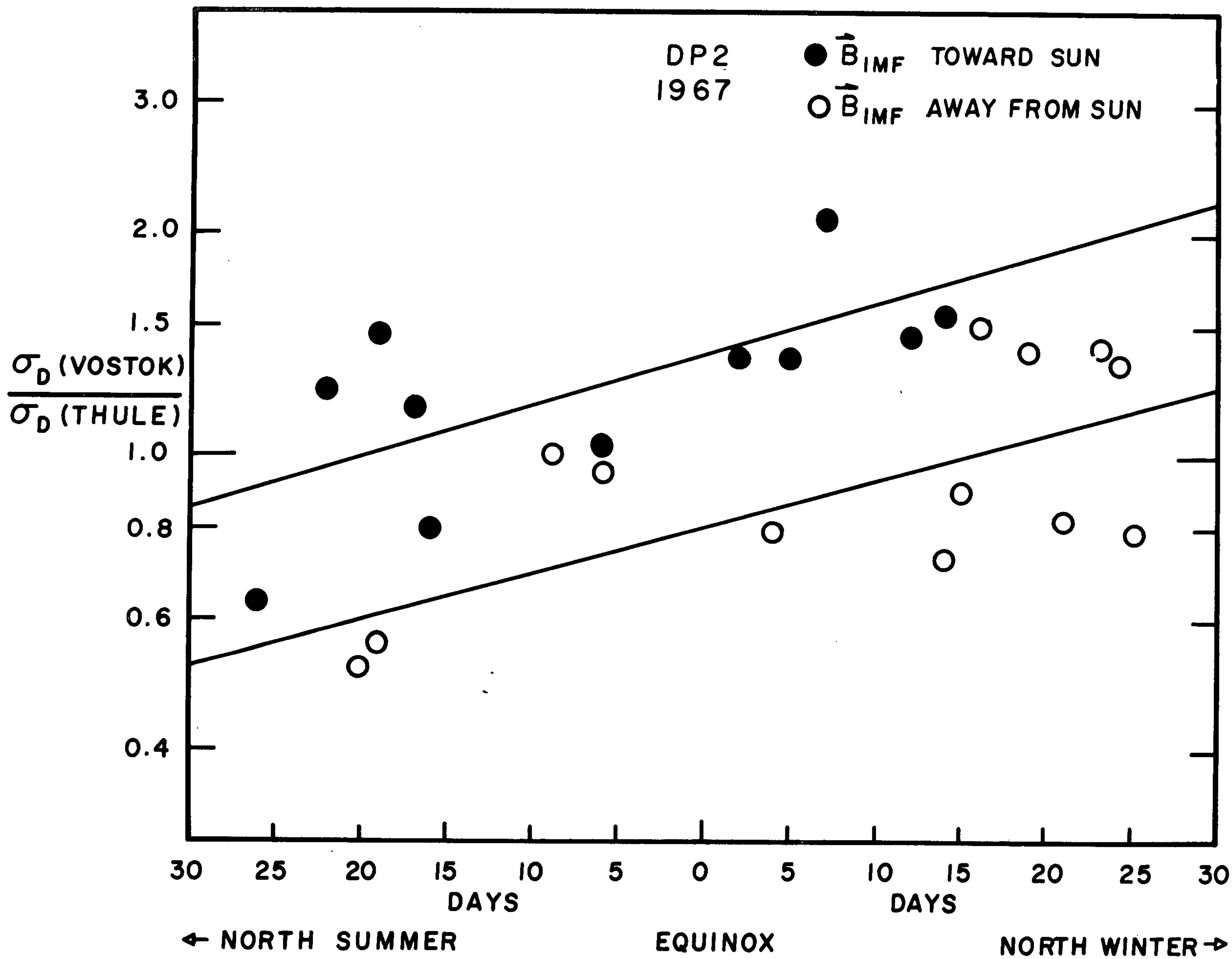

16
17
18
19
20
21
22
23
+90°
θGSEQ 0°
-90°
GSM EQUATOR
EXPLORER 33
VOSTOK (Λ= -83.3°)
D
50γ
THULE (Λ=86.5°)
D
50γ
H
HUANCAYO
(Λ=11.57)
50γ
MURMANSK
(Λ=64.2°)
H
M
50γ
C. CHELYUSKIN
(Λ = 71.1°)
H
M
100γ
U.T. (HRS)
MARCH 7,
1967

FIGURE 5



DP2
1967
● $\vec{B}_{IMF}$ TOWARD SUN
○ $\vec{B}_{IMF}$ AWAY FROM SUN
$\frac{\sigma_D\text{(VOSTOK)}}{\sigma_D\text{(THULE)}}$
3.0
2.0
1.5
1.0
0.8
0.6
0.4
30 25 20 15 10 5 0 5 10 15 20 25 30
DAYS
DAYS
← NORTH SUMMER
EQUINOX
NORTH WINTER →

FIGURE 6