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14. Abstract/Notes

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STORM TIME CHANGES OF GEOMAGNETIC FIELD AT MAGSAT ALTITUDES (325-550 km) AND THEIR COMPARISON WITH CHANGES AT GROUND LOCATIONS

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Abstract. The values of H, X, Y, and Z at MAGSAT altitudes were first expressed as residuals ΔH, ΔX, ΔY, and ΔZ after subtracting model values HMD, XMD, YMD, and ZMD. The storm time variations of ΔH showed that ΔH(dusk) was larger (negative) than ΔH(dawn) and occurred earlier, indicating a sort of hysteresis effect. Effects at MAGSAT altitudes were roughly the same (10% accuracy) as at ground, indicating that these effects were mostly of magnetospheric origin. The ΔY component also showed large storm time changes. The latitudinal distribution of storm time ΔH showed north-south asymmetries varying in nature as the storm progressed. It seems that the central plane of the storm time magnetospheric ring current undergoes latitudinal meanderings during the course of the storm.

1. Introduction

The quiet day patterns of geomagnetic field and its periodic variations (e.g., Sq) are occasionally violently disturbed, exhibiting what are known as geomagnetic storms. The anatomy of such storms and their relationship with solar events have been studied for almost a century and a detailed exposition is available in the literature [e.g., Chapman and Bartels, 1940; Matsushita and Campbell, 1967; Akasofu and Chapman, 1972]. A typical geomagnetic storm is characterized by a sharp initial increase called storm sudden commencement (SSC), which may last for a few minutes and may be associated sometimes with a preliminary reverse impulse (PRI), followed by a large drop in the H component of a few hundred nano teslas within a few hours, followed later by a slow recovery. These features have different magnitudes at different latitudes and longitudes, indicating a UT component called storm time variation Dst and a LT component called disturbance local-time inequality DS. From a detailed analysis of several hundred storms, Sugiura and Chapman [1960] demonstrated that whereas Dst had a pattern as mentioned above viz. SSC followed by the main phase and the recovery, the DS was characterised by a dawn maximum and a dusk minimun. Kane [1971] obtained similar results.

The source of these storm time changes is known since long to be far away from the earth, in the form of a ring current, several earth radii away in the magnetosphere. The axially symmetric ring current causes the Dst. The asymmetric part DS was earlier thought to be due to ionospheric return currents from an extended westward electrojet in the auroral region. From spacecraft observations, Cahill [1966] and Langel and Cain [1968] concluded that the DS variations too were of magnetospheric origin. However, whether DS has some ionospheric contribution too is still a debatable question [Kane, 1972, 1973, 1974]. It would be of great interest if observations were available from spacecrafts above, but not very far from the ionosphere. MAGSAT provides such an opportunity, as the spacecraft, though confined to the dawn-dusk sectors because of its sun-synchronization, was in the altitude range of 325-550km. In this communication, we report results for storm time changes, observed by MAGSAT.

2. Data analysis

The MAGSAT investigator B tapes supplied to us contained data for the equatorial and low latitude region (±35°), and hence all the results we report pertain to low latitudes only. Values for the X, Y, and Z components were available and from these the H component was computed as $H=(X^2+Y^2)^{1/2}$. Since a major part of the observed values of X(or H) was of internal origin (earth's interior) and the effects we wanted to study were of external origin and quite small (only a few hundred nT as compared with the several tens of thousands of nano teslas of observed X or H), it was necessary to remove first some sort of a gross, background level of internal origin. The tapes contained MAGSAT(4/81) model values XMD, YMD, and ZMD, which are supposed to contain no external terms. From these, we calculated $HMD = (XMD^2 + YMD^2)^{1/2}$ and further, residuals were obtained as ΔH = H (observed) - HMD, ΔX = X (observed) - XMD, ΔY = Y (observed) - YMD and ΔZ = Z (observed) - ZMD. All further analysis was conducted by using ΔH, ΔX, ΔY, and ΔZ only.

The MAGSAT spacecraft was launched on October 30, 1979, into a twilight, sun-synchronous orbit, with inclination 96.76°, perigee 352km, and apogee 561km. Thus, in the low latitude region, the passes were almost north-south or south-north along the dawn or dusk meridians. The equatorial crossings of successive dawn and dusk passes were about 0.8 hours apart, while successive dawn (or dusk) passes were about 1.6 hours apart.

2.1. Study of values at equatorial crossings

Values of ΔH, etc., at the equatorial crossing, are henceforth designated as ΔH_o, etc.

Figure 1 shows a plot of ΔH_o (dusk, indicated by crosses) and ΔH_o (dawn, indicated by dots) for the period November 2-7, 1979, in the top frame, November 8-13, 1979, in the middle, and November 14-19, 1979, in the bottom frame. The conventional Dst [Sugiura and Poros, 1971] is also plotted and the Kp values are indicated. The data for November 2 showed very large fluctuations in every pass and did not seem to be reliable and hence are omitted from the analysis. In the interval November 3-19, 1979, there was one major storm on November 13-15, 1979. The following points may be noted:

1. In general, ΔH_o is nonzero and negative. ΔH_o (dusk) is more negative than ΔH_o (dawn). However, both follow the Dst trend at least roughly and hence do seem to represent the storm time changes.

2. During the storm time (November 11-15, 1979), ΔH_o (dusk) seems to show a behavior similar to Dst; but ΔH_o (dawn) shows a different behavior, viz., lesser magnitude of storm time effects, generally occurring with a delay.

Figure 2 shows a plot of ΔH_o (dusk) versus ΔH_o (dawn). Figure 2a refers to November 3-5, 1979, a moderately disturbed period. Since ΔH_o (dusk) and ΔH_o (dawn) were observed always about 0.8 hours apart, simultaneous observations were impossible. Hence the arithmetic average of two successive values of ΔH_o (dawn our dusk) is plotted against the corresponding ΔH_o (dusk or dawn) value. The scatter in Figure 2a is rather large. The correlation coefficient for the 87 pairs of points is only +0.42 ±0.09 and the two regression lines, one with ΔH_o (dusk) as the independent variable (solid line) and the other with ΔH_o (dawn) as the independent variable (dashed line), are wide apart, making different intercepts on the two axes.

Figure 2b shows a similar plot for November 6-10, 1979, again a moderately disturbed period. Here, some points (marked as dots) seem to fall reasonably well on a straight line, giving a good correlation (+0.91 ±0.02) for 89 pairs of points, and the upper line represents the corresponding regression line. However, there are many other points (marked as crosses) that deviate considerably from the above group. These points represent the peculiar events on November 7, 8, and 9 (see Figure 1) when the dawn and dusk values (dots and crosses) differed considerably from each other, either because of some physical cause or may be due to some data errors also. For all pairs taken together (total of 153 values), the correlation is only (+0.71 ±0.04) and the regression is represented by the lower line.

Figure 2c shows a similar plot for the storm period November 11-15, 1979. Here, the recovery period November 14-15 is marked as crosses. Two separate regression lines are indicated: one for the main storm (November 11-13) of slope exceeding unity and another for the recovery period (November 14-15) of slope almost unity. Thus differences in the storm time evolution in the dusk and dawn sector are indicated.

Figure 2d refers to November 16-20, 1979, a moderately disturbed period. Here, too, the scatter is large, just like in Figures 2a and 2b.

Thus, whereas Figure 2c shows marked differences in the evolution of ΔH_o (dawn) and ΔH_o (dusk), the scatter in Figures 2a, 2b, and 2c makes it difficult to draw any reliable conclusions. It is obvious that the ΔH_o values are polluted by some other factors unconnected with storms. Possible causes are as follows. First, the MAGSAT (4/81) model used for base subtraction may not be fully adequate for this purpose. If so, there is nothing one can do about it except wait for a better model. Second, it may be that Sq effects are not negligible even at dusk and dawn and may even be dissimilar for dusk and dawn [Sugiura and Hagan, 1979]. Third, the quiet time ring current may not be negligible and may have dissimilar effects for dusk and dawn. In practice, this effect will be mixed up with the possible Sq dissimiliarity. Fourth, since every successive pass (dawn or dusk) is about 1.6 hours apart, the earth would have turned under the satellite by about 24^o in longitude. Thus, every pass would be covering a different ground terrain and hence perhaps a different kind of ground anomaly. These effects need to be estimated and corrected either individually or collectively. We acheived this in the following way.

We used data for about 1200 dawn and 1200 dusk passes that occurred during November 2, 1979, and January 18, 1980. The passes were separated first into 72 longitude groups (longitude of equatorial crossing), viz., -180^o to -175^o, ... -5^o to 0^o, 0^o to $+5^o$, ... $+175^o$ to $+180^o$. For each one of these longitude groups, ΔH_o (dusk) and ΔH_o (dawn) were plotted separately against the corresponding geomagnetic Dst. Figure 3a left half shows ΔH_o (dawn) versus Dst, and the right half shows ΔH_o (dusk) versus Dst, for the longitude belt 0^o to $+5^o$. There were about 15 passes involved of each type. The correlation coefficients are reasonably high (about +0.80 or more), and the regression lines drawn are for ΔH_o (dawn or dusk) as the independent parameter and Dst as the dependent parameter. In each case, the intercept on the ΔH_o axis (ordinate) corresponds to Dst = 0 and hence gives us an estimate of the quiet time base level of ΔH_o (dawn or dusk). For example, for the longitude belt 0^o to $+5^o$, the base value of ΔH_o (dawn) is -26nT and for ΔH_o (dusk), it is -40nT.

Figure 3b shows similar plots for the longitude belt +5° to +10°. The base levels are now -31nT for ΔH_o (dawn) and -41nT for ΔH_o (dusk).

Similar plots were made for all the other lontitude belts. Figure 4 shows a plot of the base values ($\Delta\overline{H}_o$, $\Delta\overline{Y}_o$, $\Delta\overline{Z}_o$) versus longitude, for ΔH_o (dusk) in the first row and ΔH_o (dawn) in the second row. Considerable longitude variation is noticed, probably due to varying ground anomaly effects, which are brought out clearly in the third row depicting the average of dawn and dusk. The Bangui anomaly at longitudes 0° to +20° is evident. The fourth row depicts the difference (dusk minus dawn) and represents dusk-dawn asymmetries due to Sq effects [Sugiura and Hagan, 1979], quiet time ring currents, etc. These too seem to be longitude dependent. The other rows in Figure 4 show similar base levels for the Y and Z components.

Irrespective of the nature of these base levels, viz., whether due to Sq effects, ring current effects, ground anomalies, etc., it should be enough for our purposes to subtract these from the actual values of ΔH_o (dusk) and ΔH_o (dawn) of every pass (with due consideration for the longitude belt), so that the residuals so obtained could be considered as depicting true storm effects. Figure 5 is a reproduction of some parts of Figure 2, after such a correction (base level subtraction) is applied. Figure 5a refers to November 3-5, 1979, and a comparison with Figure 2a shows that the scatter has reduced considerably and values are now clustered mostly near zero. Figure 5b refers to the storm period November 11-15, 1979, and a comparison with Figure 2c shows a clear-cut hysteresis loop in contrast to the earlier confusion of points. Thus, in the main phase of the storm (November, 11-13) (full dots and lines), ΔH_o (dusk) seems to attain negative values numerically almost double of those of ΔH_o (dawn). Somewhere near the end of the main phase, ΔH_o (dusk) saturates. The ΔH_o (dawn) continues to increase (negative) but never catches up with ΔH_o (dusk). Only after a partial recovery of ΔH_o (dusk), the ΔH_o (dawn) catches up with the same and, thereafter, the two recover together.

In the interval of 78 days (november 2, 1979-January 18, 1980) that we studied, there were two major storms, one during November 11-16, 1979, and another during January 1-3, 1980, besides several minor storms as during November 7-8, November 24-25, December 3-5, December 28-30, 1979, and January 13-14, 1980. In Figure 5c we show a plot of ΔH_o (dusk) versus ΔH_o (dawn) for the other major storm, viz., December 31, 1979 - January 3, 1980. There is a hysteresis loop clearly visible, remarkably similar to the loop of Figure 5b.

Figure 6 shows a plot of ΔH_o (dusk) and ΔH_o (dawn) for the storm of November 11-15, 1979. The top curves (row 1) and the Dst (second row) are the same as those shown in Figure 1. Rows 3 and 4 show ΔY_o and ΔZ_o. All these are uncorrected for base levels. When the base level corrections are applied, the plots look as shown in rows 5, 6, and 7. Considerable modifications seem to have occurred because of the base level corrections. Figure 7 shows the plots of base level corrected values of ΔH_o, ΔY_o, and ΔZ_o for dawn and dusk for the storm of December 31, 1979 - January 2, 1980.

2.2. Comparison of MAGSAT and ground data

For this analysis, we used the hourly values of the H component for several low and mid-latitude locations, as listed in Table 1 according to geographical longitudes. Some of these could be considered as in the same longitude belt. For example, Tsumeb, Bangui, and Hermanus have roughly the same longitude (about 15°E). For these locations, there would be one dawn pass and one dusk pass per day that could be compared with ground ΔH values at dawn and dusk, choosing the proper geographical latitudes on the passes to match with the geographical latitudes of the ground stations as given in Table 1. Since only hourly values near dusk or dawn were used, a possible error of half an hour in time is involved. Also, a pass may not have occurred exactly at a particular ground location longitude; but there would generally exist a pass within ±12° of the longitude of the location. Thus, inaccuracies of about 1/2 hour in time and about 12° in longitude may be involved. During quiet periods, successive hourly values at dawn and dusk did not change by more than a few nano teslas. During disturbed periods, inaccuracies of about ±5 nT could occur.

For November 1979, we omitted data for November 1, as ΔH values in every pass showed large fluctuations. For the 28 days November 3-30, 1979, Figure 8 shows a plot of ΔH at ground for Bangui (4.6°N, 18.6°E) versus ΔH at MAGSAT for passes near 18.6°E longitude (±12°), for dawn passes in the left half and dusk passes in the right half. Each graph has 28 points. A correlation analysis was carried out between the 28 values of ΔH at satellite (for geographical longitude 5°N, appropriate for Bangui) and ΔH at Bangui. The correlation coefficient was high (exceeding +0.9). Similar analysis was carried out by using ΔH at ground for all the other locations. Table 1 lists the values of the correlation coefficients and the slopes. As can be seen, all the correlation coefficients are high (exceeding +0.80). Also, all the slopes are near unity. Since the 28-day interval (November 3-30, 1979) had one major storm (November 11-15) and a few minor storms, the range of values was quite large (about 100 nT). In this range, the ground values and satellite values tallied within a limit of about 10 nT. Thus, with a probable inaccuracy of about 10%, the storm at ground and at MAGSAT altitude seem to be identical and hence mostly of magnetospheric origin. Ionospheric contributions, if any, would be about 10% or less.

At the bottom of Table 1, we give the average values of the slopes. These seem to be slightly higher when ΔH (satellite) is the independent variable. Thus, storm effects at the satellite may be ~3% larger than those a ground.

The analysis in Table 1 referred to variations observed at ground and at MAGSAT altitudes, which include induction effect in the conducting earth. A number of investigations using Sq and Dst variations [e.g., Eckhardt et al., 1963; Banks, 1969] suggest a highly conducting layer at depths between 400-600 km. Hermance [1982] mentions that for MAGSAT altitudes, the effect of conducting mantle at a depth of 400 km would be an induced contribution of about 35% of the external field. At the surface of the earth, it would be about 40%. Thus, if the external ring current has an effective field of say 100 nT, the MGASAT will record it as 100 + 35 = 135 nT, while the ground locations would record it as 100 + 40 = 140 nT. Thus, MAGSAT response is expected to be about 3-4% less than the ground response, if the source field is in the magnetosphere. If, however, even a part of the source is in the ionosphere, the effect would be a partial cancelling of the external and internal field for MAGSAT altitudes. Thus, the response at MAGSAT would be much lesser than that at ground. Thus, in both these cases, one expects the MAGSAT response at least a few percent less than at ground. In our analysis, the satellite values seem to be either equal to or larger than the ground values. We do not understand this result. The scatter of points in Figure 8 is rather large, and it may be that the accuracy of this analysis is not good enough to judge differences of the order of a few percent. Hence, all that we claim is that ground and MAGSAT responses are the same within an accuracy of about 10%.

It is interesting to note that Araki et al. [1982], who studied the occurrence of SSC at MAGSAT, found that for one event (the SSC at 0738 UT on November 30, 1979, only a minor storm) there was some contribution from ionospheric sources. Thus, ionospheric contributions at dusk and dawn may be occurring either very infrequently, or probably are too small to be detected in an analysis of hourly values.

2.3. Latitudinal variation of storm effects

Figure 9a shows the latitudinal variation of ΔH for the dusk pass no. 184, which occurred on November 13, 1979, at about 2300 UT at an equatorial longitude of about -79^o, i.e., 79^oW. On its face value, there seems to be a significant latitude dependence, with the largest storm effects (ΔH = -140nT) at about 15^oS latitude. However, it is necessary to check that such a minimum at -15^o latitude is not a permanent feature in this longitude zone. For studying this, the average latitudinal variation of ΔH for six quiet day dusk passes (Dst within ±10 nT), which occurred in the longitude belt 75^o-80^oW during the period November 1979 - January 1980, was evaluated. Figure 9b shows this average. As can be seen, the minimum at 15^oS is an average quiet day feature for this longitude zone, probably due to ground anomaly effects. The real storm time latitude dependence of ΔH would be obtained by subtracting Figure 9b from 9a. The difference is shown in Figure 9c. Now the latitudinal distribution is almost flat.

Quiet time patterns like Figure 9b were obtained for 72 longitude belts, each of 5^o width. Figure 10 shows the latitudinal variation of ΔH for longitude belts 0 to $+5^o$, $+5^o$ to $+10^o$, ... $+85^o$ to $+90^o$. As can be seen, considerable variations are observed, many of which are common to dusk and dawn and hence must be due to ground anomalies. However, there are some differences too, indicating that the Sq effects at dusk and dawn are not alike. Figure 11 shows similar plots for the Y component. Here, a curious fact is noticed. The dawn plots show very little latitudinal variations but the dusk plots show large variations. The vertical arrows indicate the position of the dip equator. As can be seen, ΔH (dusk) shows a clear transition symmetric about the dip equator. Maeda et al. [1982] have showed this effect from the MAGSAT data and have commented that the D(i.e., Y) variation appears everyday on the low-latitude duskside and is antisymmetric about the dip equator. They have interpreted this as indicative of meridional current systems in the equatorial ionosphere and associate these with the equatorial electrojet as envisaged in the Untiedt [1967] and Sugiura and Poros [1969] models. We have noticed, however, that these changes are very large in the Y component only and hence, probably indicate the usual Sq pattern of roughly circular currents which, in low latitudes near midday, are mostly east-west but which, at dawn or dusk, are mostly north-south. In the equatorial region, longitudinal differences could arise from the excursions of the Sq currents of one hemisphere into the other [Hutton 1967a, b] and/or due to solstitial

Sq currents through the magnetosphere [Van Sabben, 1970]. Since the present investigation is not directly related to the quiet time variations (Sq or quiet time ring current), we will not discuss this matter any furthur here, but we will use these quiet time patterns as base levels for subtracting from the disturbed day patterns.

As shown in Figure 1, the period November 11-15, 1979 was a storm period. On November 13, the dusk pass 170 at about 0100 UT was only moderately disturbed (Dst = -17). However, the successive passes 171, 172, etc., were highly disturbed. All these occurred at different longitudes. From each of these passes, we subtracted the quiet time latitudinal pattern appropriate to its longitude. The residual patterns so corrected are shown in Figure 12. The dots and full lines refer to ΔH and the crosses and dashes refer to ΔX. The left half shows consecutive dusk passes 170-181. In the right half, the upper half shows dusk passes 182-188. The vertical arrows indicate the position of the dip equator. The pass number, Dst and longitude of equatorial crossing are marked for each pass.

It seems from Figure 12 that the ΔH and ΔX variations are very similar to each other, and these are not always symmetric about the geographical or dip equator. In the early stage of the storm (passes 170-171), the northern hemisphere shows larger storm effects. By about pass 178, the pattern is roughly symmetrical. For later passes, the southern hemisphere has larger storm effects. Thus, during the course of the storm, there was a considerable north-south asymmetry of a variable nature. In the case of the present storm, the early part of the storm exhibited stronger storm effects in the northern hemisphere. However, as shown in the lower right half of Figure 12 for the successive disturbed day dusk passes 936-939, which occurred on the storm day January 1, 1980, at about 1800-2200 UT, the storm effect seems to be stronger in the southern hemisphere.

In the middle of the right half of Figure 12, we show a similar plot for the disturbed day dawn pass 184. In contrast to the dusk pass 184, the dawn pass shows a very erratic latitudinal distribution. There is no semblance of a maximum storm effect either at geographic or at dip equator. Instead, one notices maximum storm effects at about $\pm 15^{\circ}$ geographical latitudes. We examined some other disturbed day dawn passes and noticed largely variable patterns, different for different passes.

Figure 13 shows similar plots for the Y component. Here, symmetry about the geographic or the dip equator (vertical arrows) seems to be more an exception than a rule. In general, the Y variation is erratic, with no systematic variation from one pass to the next. To us, it seems that these variable patterns of ΔX and ΔY storm time variations may be related to latitudinal meanderings of the central plane of the magnetospheric storm time ring current and/or complications due to field-aligned currents, different in different local time zones (dawn or dusk).

Figure 14 shows the latitudinal patterns of ΔX and ΔY averaged for all the storm time passes 170-188. The upper half has geographic latitude as abcissa. ΔX shows a maximum storm effect (largest negative values) near the geographic equator (at about 5^oS) with roughly a cos Θ dependence on either side. However, ΔY does not show any such effect clearly. Instead, one observes a minimum storm effect (smallest negative values) at about -10^o, i.e., 10^oS. Thus, on the average, the central plane of the storm time ring current is almost coincident with the geographic equatorial plane, with a probable shift slightly southward.

The lower half of Figure 14 shows similar average latitudinal patterns for ΔX and ΔY with dip latitude as abscissa. No clear latitude dependence is noticed, for either ΔX or ΔY. Thus the storm time ring current does not seem to be influenced by the dip equator.

These results are in general agreement with our earlier published results [Kane and Trivedi, 1981] about the central plane of the ring current.

3. Summary and Conclusions

The results of the present investigation may be summarized as follows:

1. From the values of X, Y, and Z as given in the investigator B tapes, H was calculated as $H = (X^2 + Y^2)^{1/2}$. The tapes also gave model values of X, Y, and Z, viz. XMD, YMD, and ZMD for MAGSAT (4/81). From these, HMD was calculated as $HMD = (XMD^2 + YMD^2)^{1/2}$. The residuals $\Delta H = H - HMD$, $\Delta X = X - XMD$, $\Delta Y = Y - YMD$, and $\Delta Z = Z - ZMD$ were further corrected for base levels. The residuals of ΔH (dusk), ΔH (dawn), ΔY (dusk), ΔY (dawn) ΔZ (dusk), and ΔZ (dawn) so obtained showed the following characteristics: (1) During the storm of November 11-15, 1979, Dst started increasing (negative) at about 0200 UT on November 13. ΔH_o (dusk) started increasing (negative) too and followed Dst almost faithfully. However, ΔH_o (dawn) started increasing (negative) somewhat later and never reached the highest level attained by ΔH_o (dusk). When ΔH_o (dusk) started recovering, ΔH_o (dawn) caught up with the same. Thus, ΔH_o (dusk) showed more intense storm effects, occurring earlier than ΔH_o (dawn). A sort of hysteresis loop was noticed. Another storm of December 31, 1979 - January 2, 1980,

showed a similar behavior. (2) During the storm main phase, ΔY_O (dawn) and ΔY_O (dusk) showed large variations. Thus, some meridional currents were indicated. Noncoincidence of the central plane of the ring current with the geographic equatorial plane is also a possibility. ΔZ_O changes were small.

2. A comparison was made of ΔH at ground near dawn and dusk (separately) and ΔH at MAGSAT altitudes, for the latitude and longitude appropriate for the ground location. Excellent correlations were obtained with slopes almost unity. Thus, within a possible error of about 10%, the storm effects at MAGSAT altitudes were found to be the same as at ground, indicating predominantly a magnetospheric origin at dusk and dawn hours.

3. To study the latitude dependence of ΔH, ΔX, and ΔY during storms, the quiet day average patterns were subtracted from the individual storm time passes with due regard to the appropriate longitudes. The storm-time passes so corrected indicated the following: (1) For the storm of November 13-14, 1979, the latitudinal distribution of ΔH (which was the same as for ΔX), was not symmetrical either about the geographic equator or the dip equator. Instead, in the initial part of the storm main phase, the storm effect was larger in the southern hemisphere and later, it became larger in the northern hemisphere. In the storm of December 31, 1979 - January 2, 1980, the pattern was reverse. Thus, variable north-south asymmetry seems to be a prominent feature of the storm time ring current. (2) When the average for several consecutive storm time passes was obtained, the latitudinal distribution looked roughly symmetric about the geographic equator with a possible cos Θ dependence. No such relationship with dip equator was obtained. (3) The Y component did not show any symmetry about the geographic or dip equator nor any consistent latitudinal distribution from pass to pass. Variations were large but erratic during the main phase of the storm.

4. From these variations, it seems that the central plane of the storm time ring current does not remain steady during the course of the storm, but shows latitudinal meanderings, variable north-south asymmetries and probably nonconfinement to the geographic equatorial plane. Complications could be present such as field-aligned currents connecting the equatorial magnetosphere to the auroral ionosphere that are different in the dawn and dusk sectors. However, in the low--latitude region for both dusk as well as dawn hours, the storm effect seems to be mostly (about 90%) above the MAGSAT altitudes and hence not in the ionosphere.

The average characteristics of storm time geomagnetic variations were studied in detail by Sugiura and Chapman [1960], who showed that, superimposed upon the axially symmetric,worldwide Dst, there was a disturbance local time inequality DS that has a sinusoidal variation with a maximum in the morning (dawn) sector and a minimum in the evening (dusk) sector. Thus, the net effect would be to hamper the negative Dst change in the morning and to accentuate Dst in the evening. In our analysis, ΔH_0 (dusk) is always greater (negative) than ΔH_0 (dawn), which seems to agree with the above average picture. However, the hysteresis effect we observed indicates more complexities in the dusk-dawn asymmetry, probably owing to field-aligned currents as envisaged in the model of Kamide and Fukushima [1972]. The MAGSAT data are restricted to the dawn and dusk sectors and hence give only a glimpse of the local time DS effect. It is hoped that future programs would yield a more comprehensive look at this problem. What MAGSAT has yielded is certainly enough to warrant an attempt at a more elaborate program.

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Fig. 1. Plots of ΔH_o, i.e., ΔH = H (observed) minus H (model) for equatorial crossings, for dusk (crosses and dashes) and dawn (dots and full lines) as also of Dst and Kp, for November 2-19, 1979.

Fig. 2. ΔH_o (Dusk) versus ΔH_o (Dawn) for (a) November 3-5, 1979, (b) November 7-10, 1979 (crosses show doubtful dusk values), (c) November 11-15, 1979 (storm period, crosses represent recovery period November 14-15, 1979), and (d) November 16-20, 1979. Regression lines and correlation coefficients γ are indicated.

Fig. 3. ΔH_o (dawn) versus Dst (left half) and ΔH_o (dusk) versus Dst (right half) for the 5° longitude belts (a) longitude 0° to +5° and (b) longitude +5° to +10°.

Fig. 4. Longitude distribution of the base values $\Delta\overline{H}_o$, $\Delta\overline{Y}_o$, and $\Delta\overline{Z}_o$ for dawn and dusk, the average AVER = (dusk + dawn)/2 and, the difference DIFF = (dusk - dawn). Negative values are shown shaded.

Fig. 5. ΔH_o (dusk) versus ΔH_o (dawn) using base-corrected values for (a) November 3-5, 1979, (b) November 11-15, 1979 (storm period, crosses refer to recovery November 14-15), and (c) December 31, 1979 - January 3, 1980 (storm period, crosses refer to recovery January 2-3).

Fig. 6. Plots for the storm period November 11-15, 1979, for dawn (dots and full lines) and dusk (dashes and crosses).

Fig. 7. Plots of Dst and the base level corrected values of ΔH_o, ΔY_o, and ΔZ_o for dawn (dots and full lines) and dusk (dashes and crosses), for the storm period December 31, 1979 - January 2, 1980.

Fig. 8. ΔH at Bangui (5°N, 19°E) versus MAGSAT ΔH values at 5°N for dawn and dusk passes near 19°E longitude, for November 3-30, 1979.

Fig. 9. Latitudinal variation of ΔH for (a) The specific disturbed day dusk pass no. 184 at a longitude of about -79°. (b) Quiet day base level obtained as average of six quiet day passes in the longitude belt 75°-80°W. (c) The difference (a) minus (b).

Fig. 10. Average latitudinal variations for ΔH (dusk) (left half) and ΔH (dawn) (right half) for successive 5° longitude belts in the longitude range 0° to +90°. + = east, - = west.

Fig. 11. Average latitudinal variations for ΔY (dusk) (left half) and ΔY (dawn)(right half) for successive 5° longitude belts in the longitude range 0 to +90°. Vertical arrows indicate the position of the dip equator.

Fig. 12. Latitudinal variation of ΔH (dots and full lines) and ΔX (crosses and dashes), both corrected for base levels, for the dusk passes Nos. 170–188, during the storm of November 11–15, 1979, as also for the dawn pass no. 184 and for the dusk passes nos. 936–939 in January 1980. The pass number, longitude, and Dst are indicated for each pass. Vertical arrows indicate the position of the dip equator.

Fig. 13. Same as Figure 12, but for ΔY.

Fig. 14. Average latitudinal distribution of ΔX and ΔY for the storm time dusk passes Nos. 170–188 on November 13–14, 1979. Upper half: For geographical latitudes. Lower half: For dip latitudes.

TABLE 1. List and Details of Stations and Results of a Correlation Analysis

Station	Geographic Latitude	Geographic longitude	Dawn Passes (0600): Y = Satellite, X = Ground — Correlation Coefficients	Dawn Passes (0600): Y = Satellite, X = Ground — Slope, m	Dawn Passes (0600): Y = Ground, X = Satellite — Correlation Coefficients	Dawn Passes (0600): Y = Ground, X = Satellite — Slope, m	Dusk Passes (1800): Y = Satellite, X = Ground — Correlation Coefficients	Dusk Passes (1800): Y = Satellite, X = Ground — Slope, m	Dusk Passes (1800): Y = Ground, X = Satellite — Correlation Coefficients	Dusk Passes (1800): Y = Ground, X = Satellite — Slope, m
Tsumeb	19.2°S	17.7°E	+0.93	1.05 ± 0.08	+0.93	0.82 ± 0.07	+0.99	0.97 ± 0.03	+0.99	1.00 ± 0.03
Bangui	4.6°N	18.6°E	+0.93	1.07 ± 0.08	+0.93	0.81 ± 0.06	+0.97	0.91 ± 0.04	+0.97	1.04 ± 0.05
Hermanus	34.4°S	19.2°E	+0.78	0.85 ± 0.14	+0.78	0.71 ± 0.11	+0.97	1.10 ± 0.06	+.097	0.85 ± 0.04
Gnangara	31.8°S	116.0°E	+0.85	0.84 ± 0.10	+0.85	0.87 ± 0.11	+0.81	0.97 ± 0.14	+0.81	0.67 ± 0.10
Muntinlupa	14.4°N	121.0°E	+0.95	1.07 ± 0.07	+0.95	0.84 ± 0.06	+0.92	0.94 ± 0.08	+0.92	0.91 ± 0.07
Lunping	25.2°N	121.2°E	+0.97	0.99 ± 0.05	+.097	0.95 ± 0.05	+0.97	0.90 ± 0.05	+0.97	1.05 ± 0.05
Guam	13.6°N	144.9°E	+0.97	0.95 ± 0.05	+0.97	0.99 ± 0.05	+0.98	1.01 ± 0.04	+0.98	0.95 ± 0.04
Port Moresby	9.4°S	147.1°E	+0.96	1.00 ± 0.06	+0.96	0.92 ± 0.05	+0.97	0.92 ± 0.05	+0.97	1.02 ± 0.05
Honolulu	21.3°N	158.1°W	+0.90	0.98 ± 0.09	+0.90	0.82 ± 0.08	+0.94	1.03 ± 0.08	+0.94	0.86 ± 0.06
Tahiti	17.7°S	149.3°W	+0.95	0.86 ± 0.05	+0.95	1.05 ± 0.07	+0.96	0.99 ± 0.06	+.096	0.93 ± 0.05
Tucson	32.0°N	111.5°W	+0.94	0.90 ± 0.06	+0.94	0.98 ± 0.07	+0.95	0.99 ± 0.07	+0.95	0.91 ± 0.06
Huancayo	12.1°S	75.3°W	+0.92	1.02 ± 0.08	+0.92	0.83 ± 0.07	+0.92	0.94 ± 0.08	+0.92	0.90 ± 0.08
Fuquene	5.5°N	73.8°W	+0.94	1.03 ± 0.08	+.094	0.85 ± 0.06	+0.92	0.99 ± 0.08	+0.92	0.87 ± 0.07
San Juan	18.1°N	66.2°W	+0.96	0.84 ± 0.05	+0.96	1.10 ± 0.06	+0.95	0.93 ± 0.06	+0.95	0.97 ± 0.07
Vassouras	22.4°S	43.6°W	+0.88	0.73 ± 0.08	+0.88	1.06 ± 0.11	+0.96	0.89 ± 0.05	+0.96	1.03 ± 0.06
M'Bour	14.4°N	17.0°W	+0.97	0.95 ± 0.05	+0.97	0.99 ± 0.05	+0.98	0.99 ± 0.04	+0.98	0.97 ± 0.04
Average				0.946 ± 0.015		0.912 ± 0.015		0.967 ± 0.015		0.933 ± 0.015

The correlation analysis given above is for a linear fit where Y = independent variable, X = dependent variable, and m = slope.

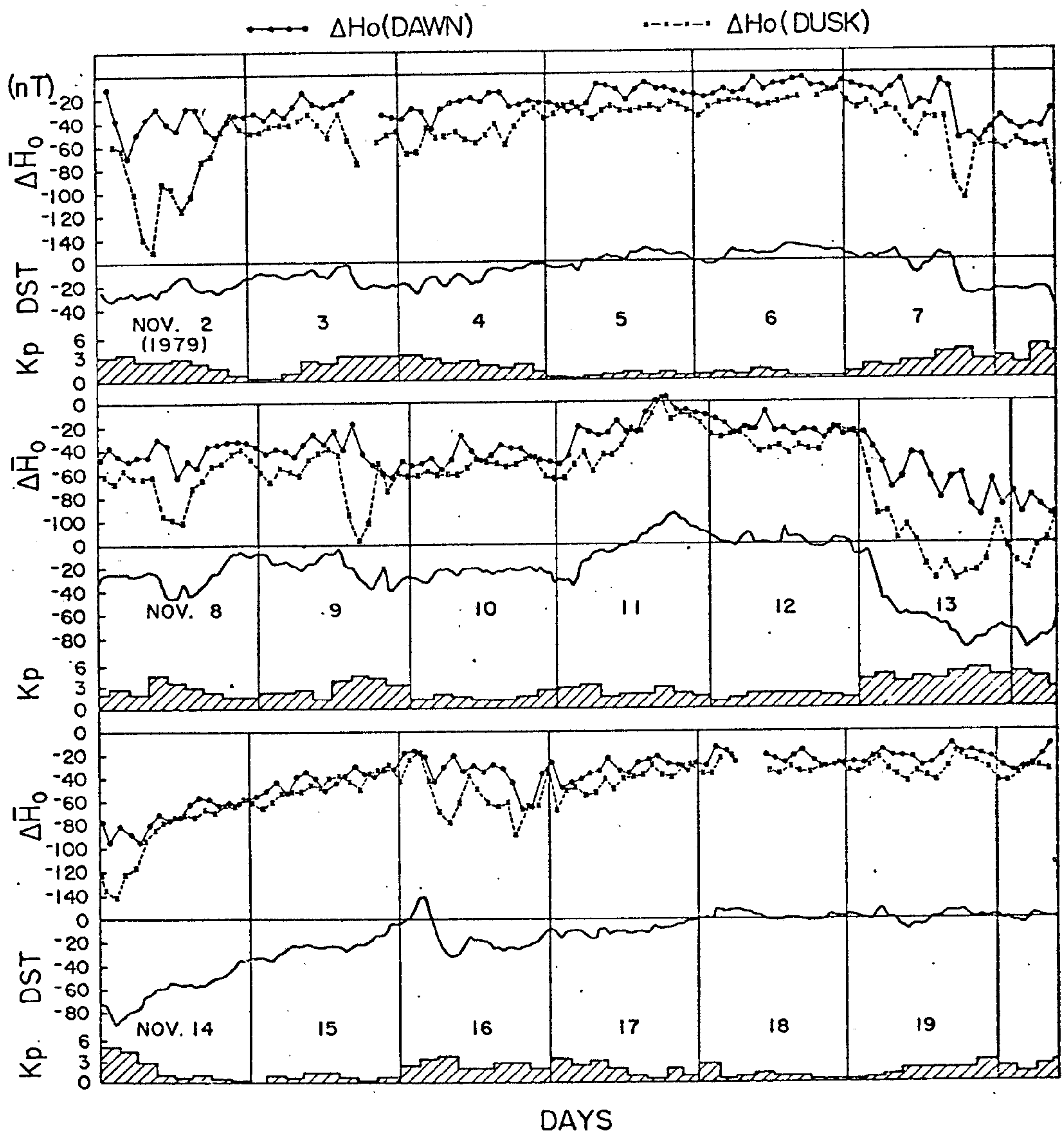
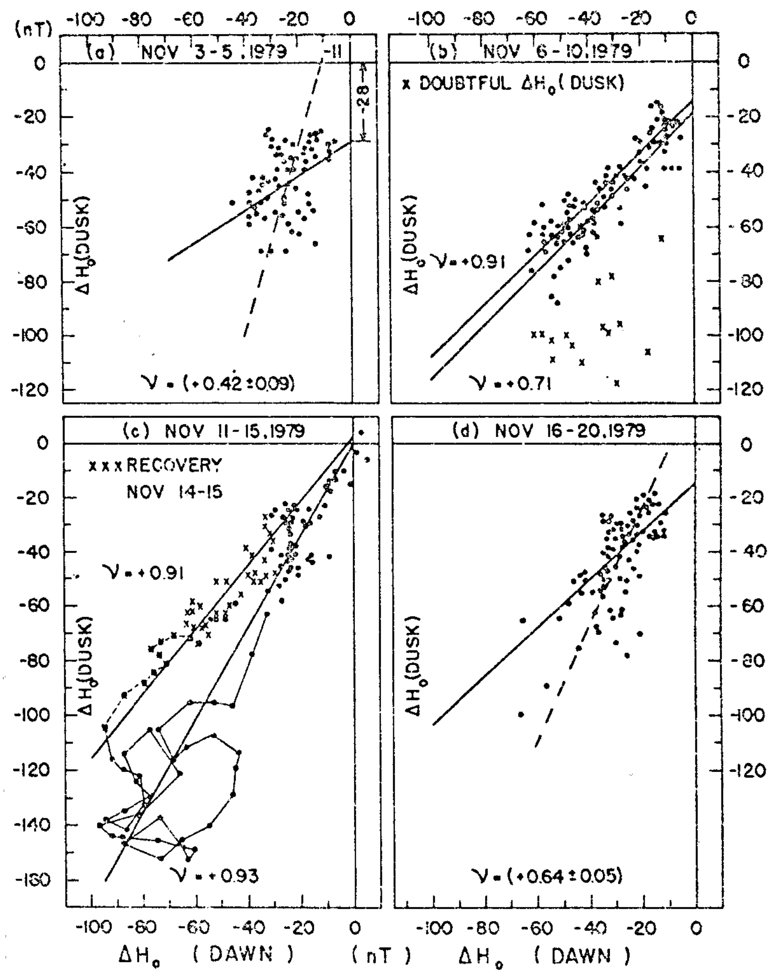

ΔHo(DAWN)
ΔHo(DUSK)
(nT)
ΔH̄o
DST
Kp
NOV. 2
(1979)
3
4
5
6
7
NOV. 8
9
10
11
12
13
NOV. 14
15
16
17
18
19
DAYS

Fig. 1



(nT)
-100 -80 -60 -40 -20 0
(a) NOV 3-5, 1979
-11
-28
ΔH₀(DUSK)
V = (+0.42 ± 0.09)
(b) NOV 6-10, 1979
x DOUBTFUL ΔH₀(DUSK)
V = +0.91
V = +0.71
(c) NOV 11-15, 1979
x x x RECOVERY
NOV 14-15
V = +0.91
V = +0.93
(d) NOV 16-20, 1979
V = (+0.64 ± 0.05)
ΔH₀ (DAWN) (nT) ΔH₀ (DAWN)

Fig. 2

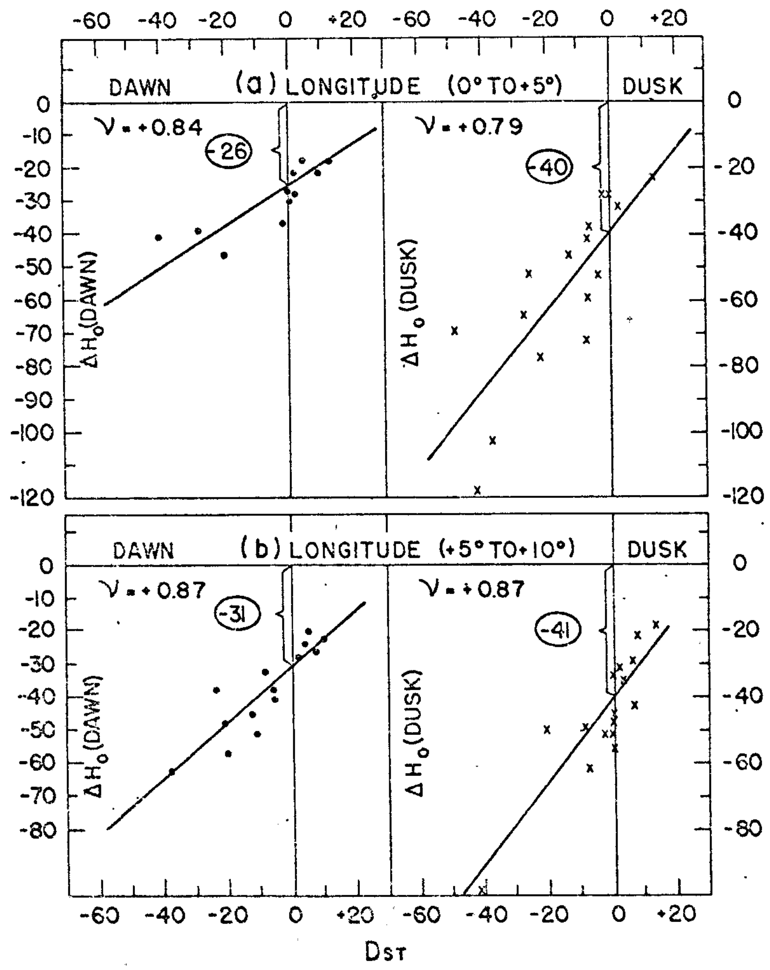
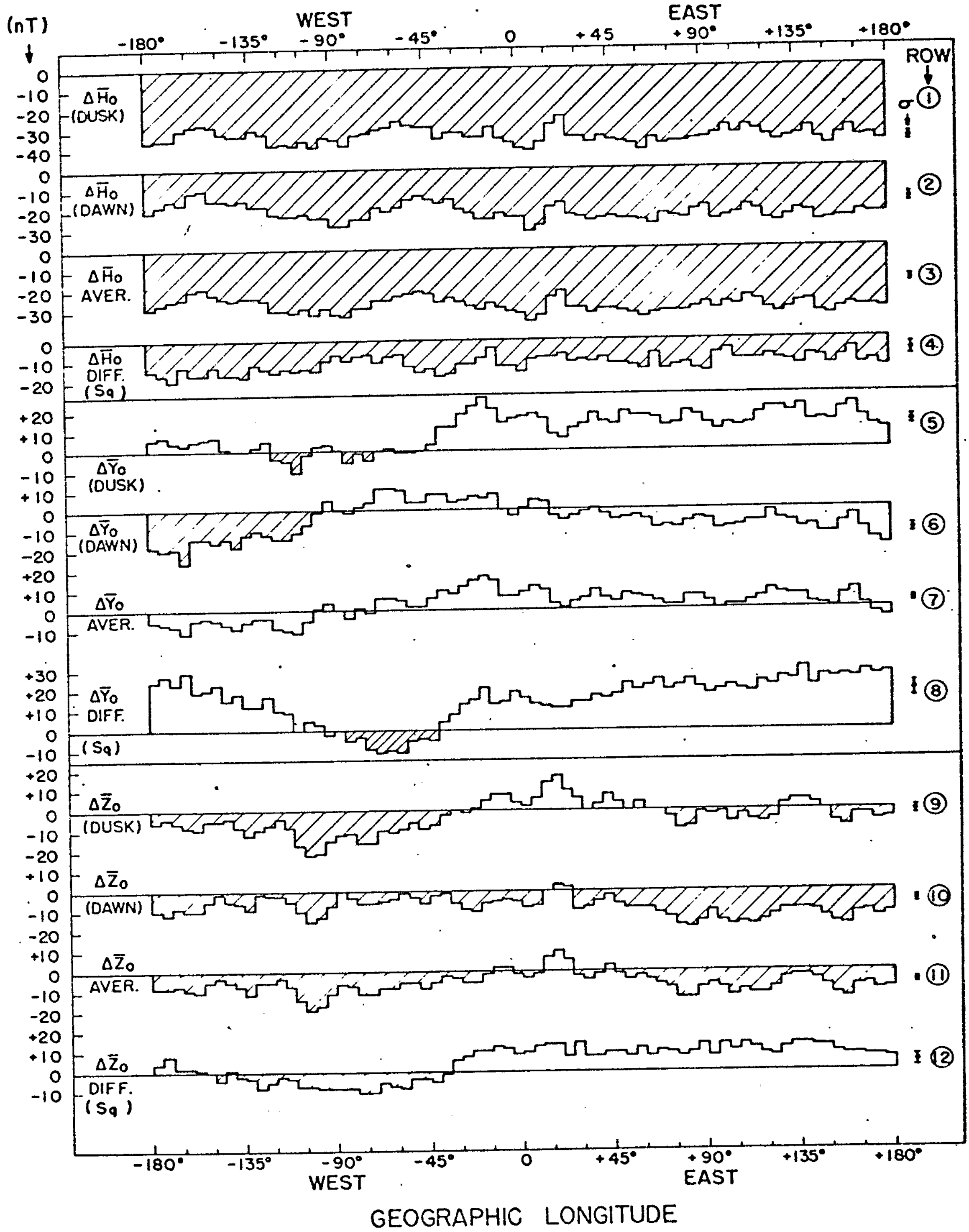

DAWN
(a) LONGITUDE (0° TO +5°)
DUSK
ν = +0.84
-26
ν = +0.79
-40
ΔH₀ (DAWN)
ΔH₀ (DUSK)
DAWN
(b) LONGITUDE (+5° TO +10°)
DUSK
ν = +0.87
-31
ν = +0.87
-41
ΔH₀ (DAWN)
ΔH₀ (DUSK)
DST

Fig. 3



(nT)
WEST
EAST
-180°
-135°
-90°
-45°
0
+45
+90°
+135°
+180°
ROW
σ
ΔH̄o (DUSK)
ΔH̄o (DAWN)
ΔH̄o AVER.
ΔH̄o DIFF. (Sq)
ΔȲo (DUSK)
ΔȲo (DAWN)
ΔȲo AVER.
ΔȲo DIFF. (Sq)
ΔZ̄o (DUSK)
ΔZ̄o (DAWN)
ΔZ̄o AVER.
ΔZ̄o DIFF. (Sq)
GEOGRAPHIC LONGITUDE

Fig. 4

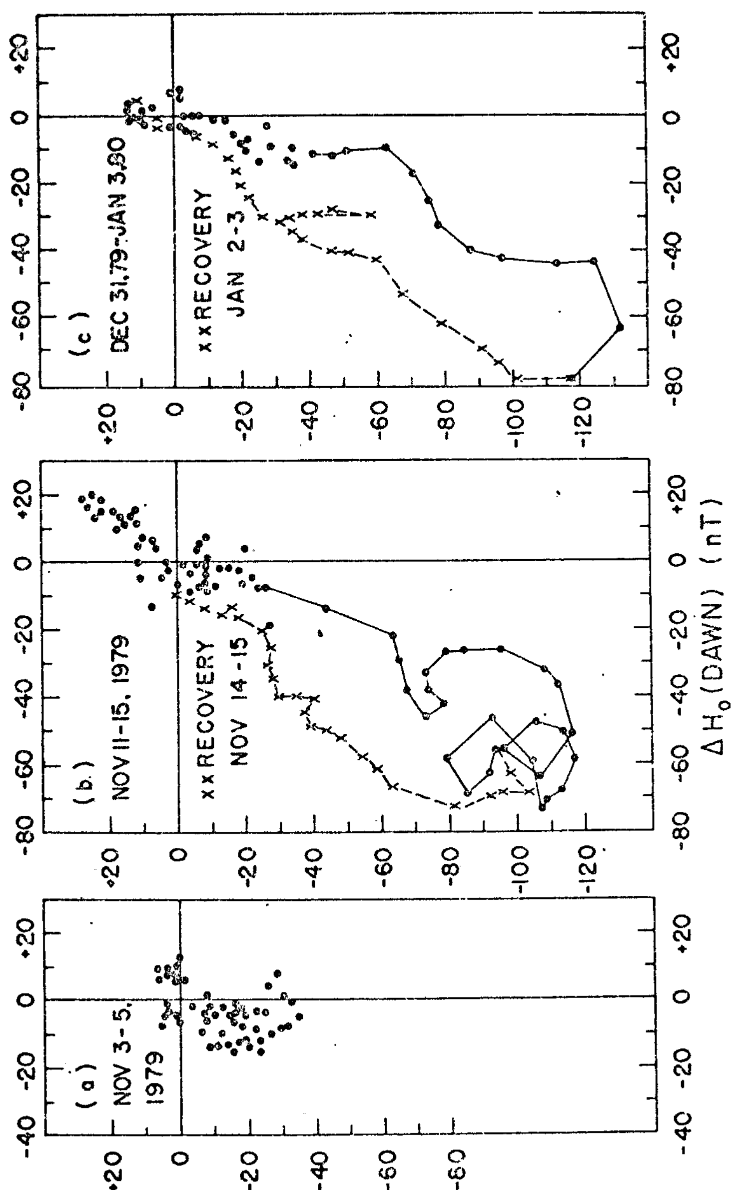

(a)
NOV 3-5, 1979
(b)
NOV 11-15, 1979
xx RECOVERY NOV 14-15
(c)
DEC 31,79-JAN 3,80
xx RECOVERY JAN 2-3
ΔH0 (DAWN) (nT)
ΔH0 (DUSK) (nT)

Fig. 5

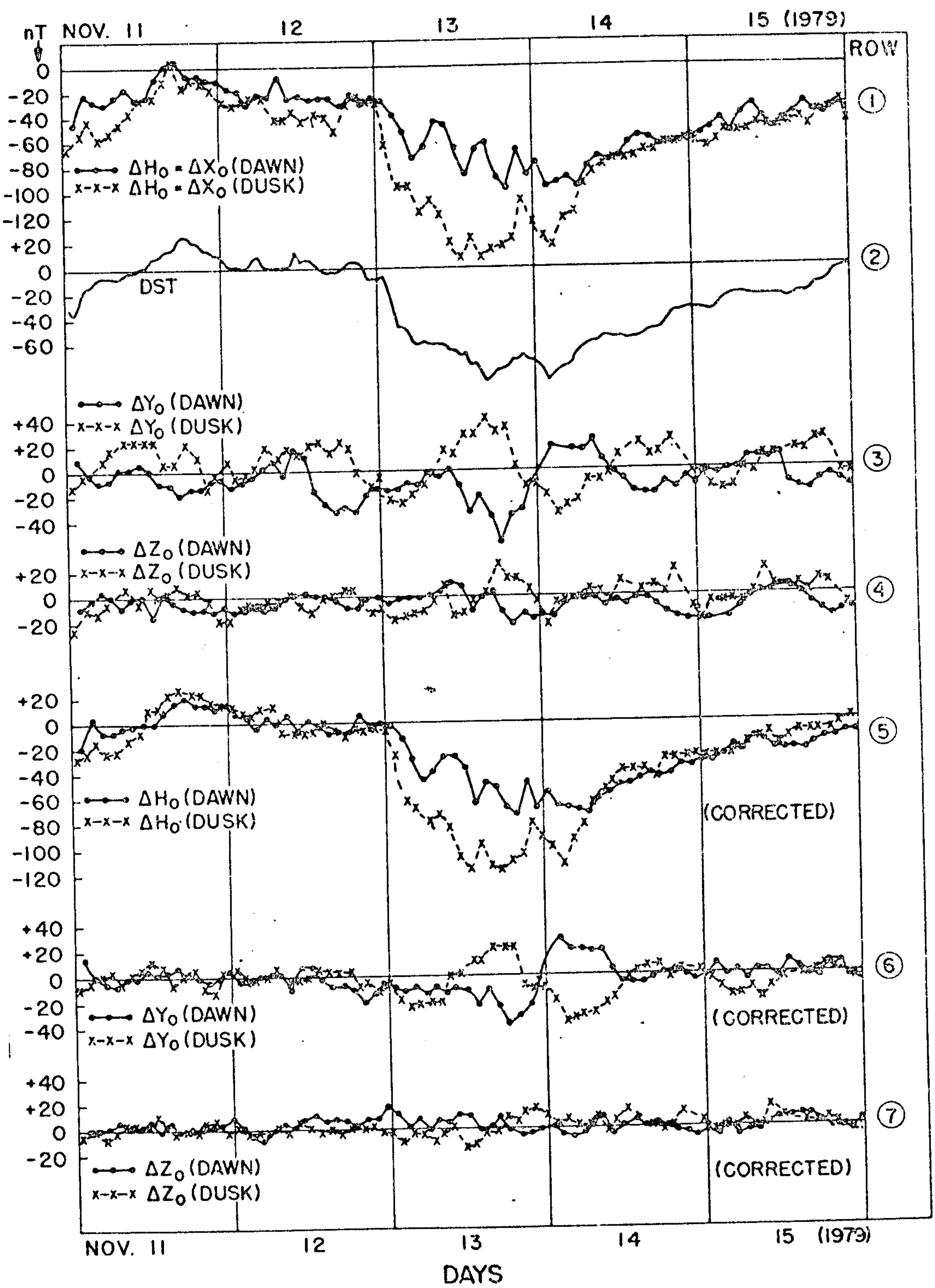
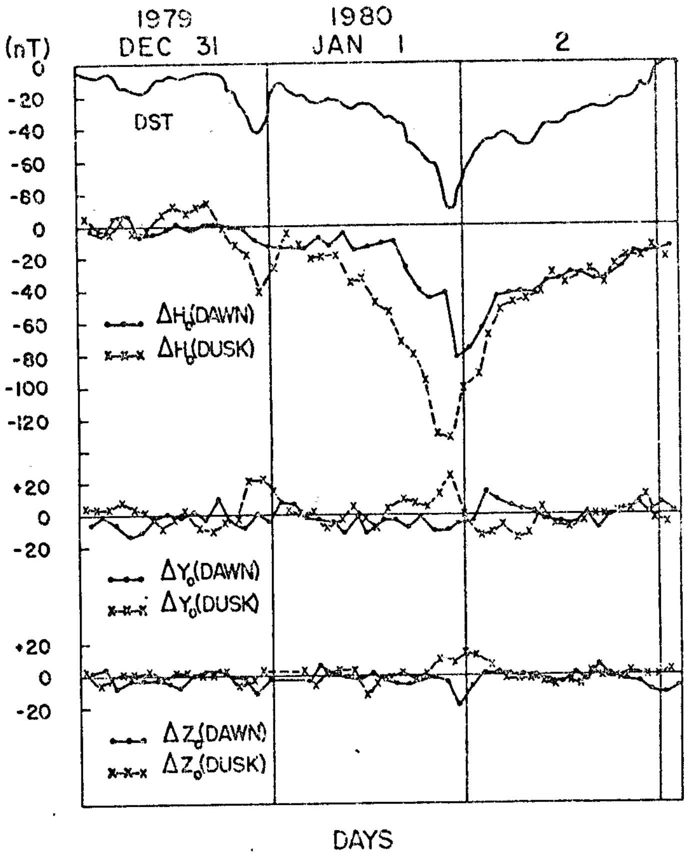

nT
NOV. 11
12
13
14
15 (1979)
ROW
ΔH0 = ΔX0 (DAWN)
x-x-x ΔH0 = ΔX0 (DUSK)
DST
ΔY0 (DAWN)
x-x-x ΔY0 (DUSK)
ΔZ0 (DAWN)
x-x-x ΔZ0 (DUSK)
ΔH0 (DAWN)
x-x-x ΔH0 (DUSK)
(CORRECTED)
ΔY0 (DAWN)
x-x-x ΔY0 (DUSK)
(CORRECTED)
ΔZ0 (DAWN)
x-x-x ΔZ0 (DUSK)
(CORRECTED)
NOV. 11
12
13
14
15 (1979)
DAYS

Fig. 6



1979
DEC 31
1980
JAN 1
2
(nT)
0
-20
-40
-60
-80
DST
0
-20
-40
-60
-80
-100
-120
ΔH0(DAWN)
ΔH0(DUSK)
+20
0
-20
ΔY0(DAWN)
ΔY0(DUSK)
+20
0
-20
ΔZ0(DAWN)
ΔZ0(DUSK)
DAYS

Fig. 7

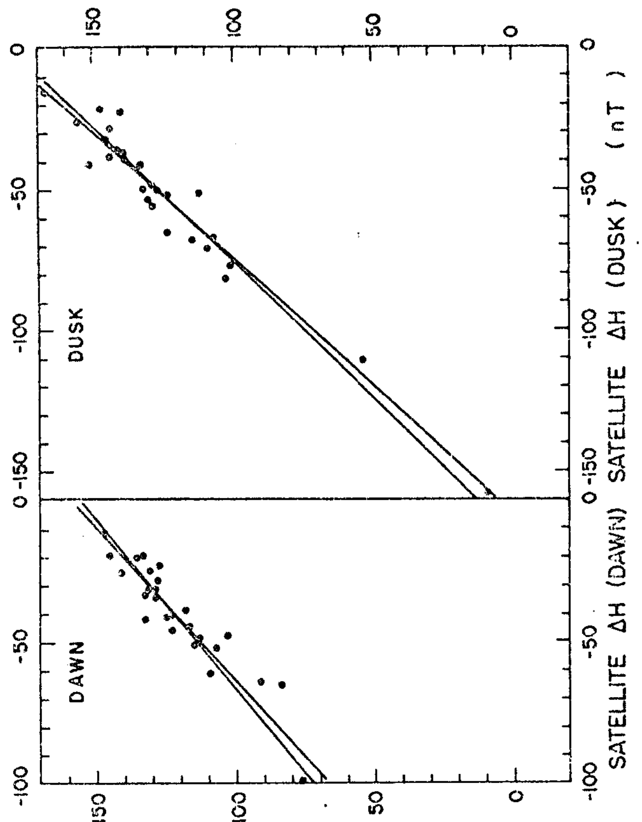

DAWN
DUSK
SATELLITE ΔH (DAWN) SATELLITE ΔH (DUSK) (nT)
GROUND ΔH AT BANGUI (nT)

Fig. 8

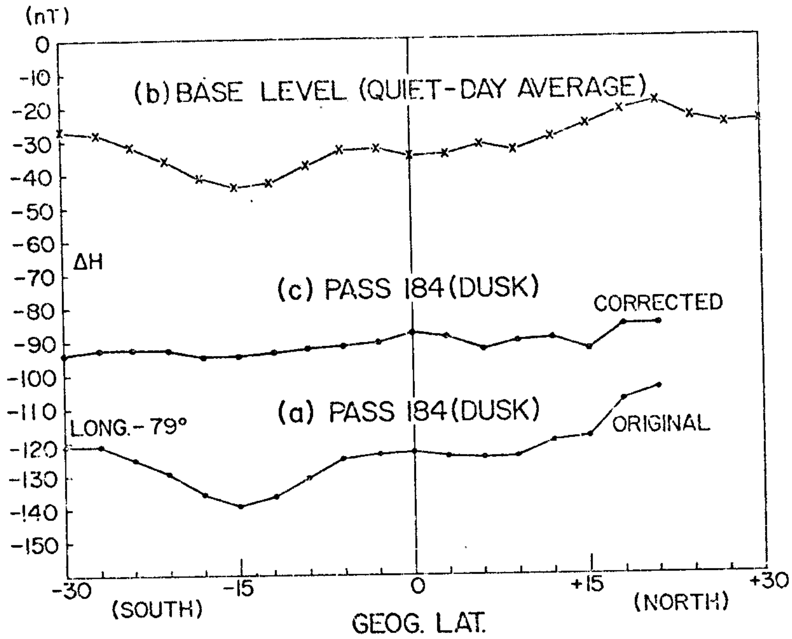

(nT)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
(b) BASE LEVEL (QUIET-DAY AVERAGE)
ΔH
(c) PASS 184 (DUSK)
CORRECTED
(a) PASS 184 (DUSK)
ORIGINAL
LONG. - 79°
-30
-15
0
+15
+30
(SOUTH)
(NORTH)
GEOG. LAT.

Fig. 9

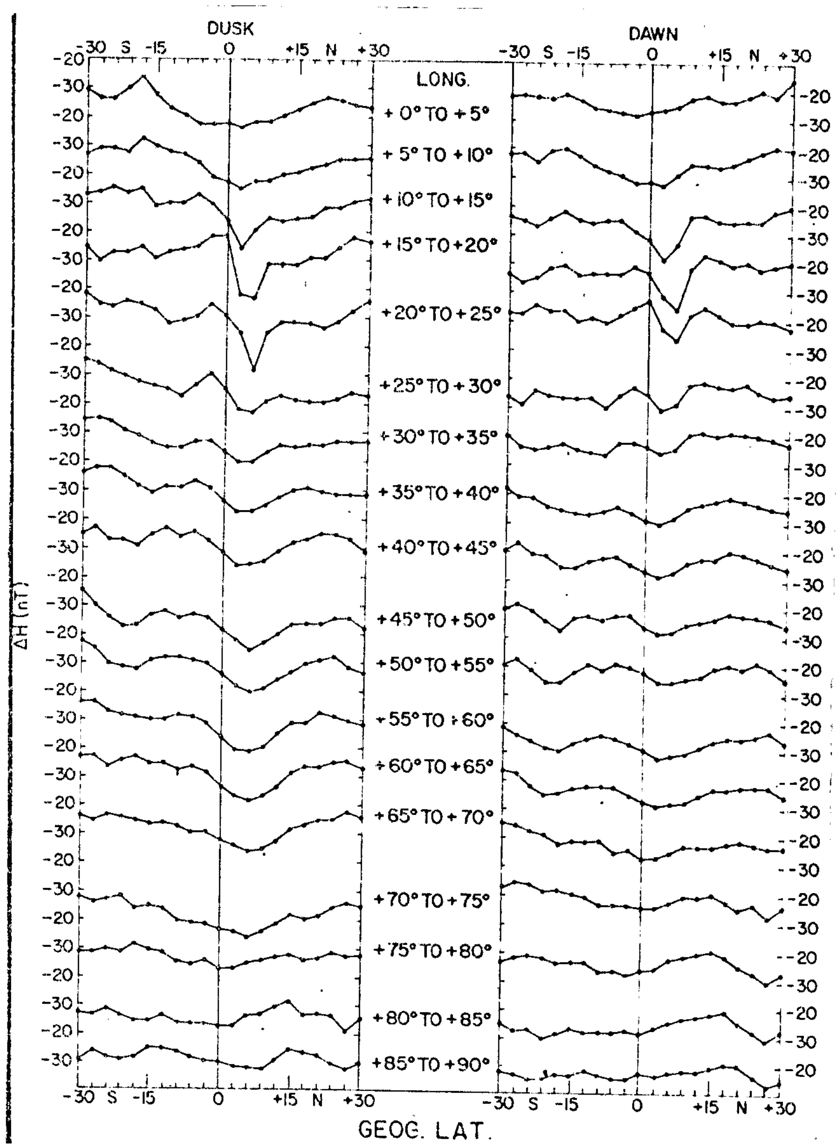

DUSK
DAWN
LONG.
+0° TO +5°
+5° TO +10°
+10° TO +15°
+15° TO +20°
+20° TO +25°
+25° TO +30°
+30° TO +35°
+35° TO +40°
+40° TO +45°
+45° TO +50°
+50° TO +55°
+55° TO +60°
+60° TO +65°
+65° TO +70°
+70° TO +75°
+75° TO +80°
+80° TO +85°
+85° TO +90°
ΔH (nT)
-30 S -15 0 +15 N +30
GEOG. LAT.

Fig. 10

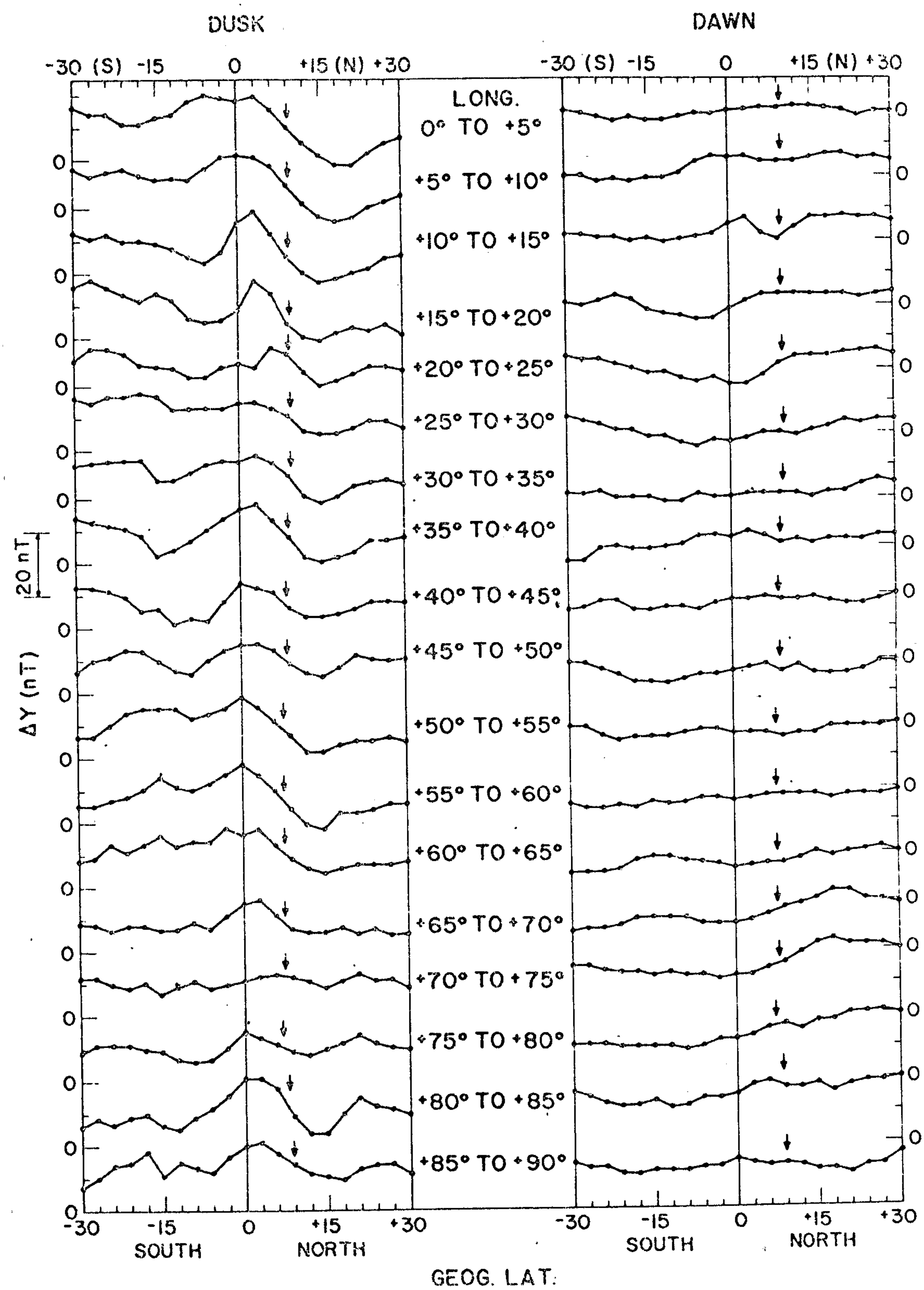

DUSK
DAWN
-30 (S) -15 0 +15 (N) +30
LONG.
0° TO +5°
+5° TO +10°
+10° TO +15°
+15° TO +20°
+20° TO +25°
+25° TO +30°
+30° TO +35°
+35° TO +40°
+40° TO +45°
+45° TO +50°
+50° TO +55°
+55° TO +60°
+60° TO +65°
+65° TO +70°
+70° TO +75°
+75° TO +80°
+80° TO +85°
+85° TO +90°
20 nT
ΔY (nT)
-30 -15 0 +15 +30
SOUTH
NORTH
GEOG. LAT.

Fig. 11

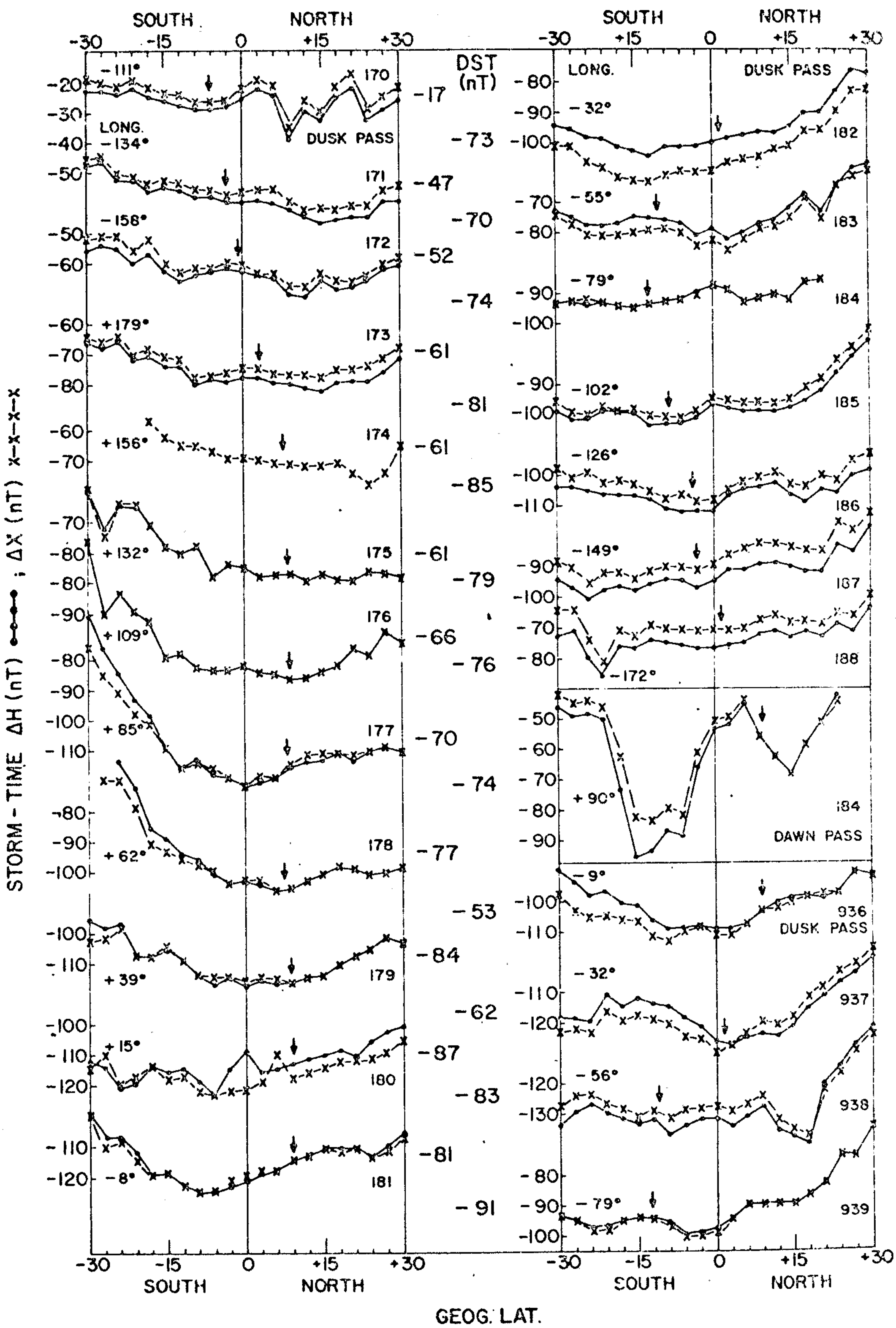

SOUTH
NORTH
DST (nT)
LONG.
DUSK PASS
DAWN PASS
STORM - TIME ΔH (nT) ; ΔX (nT) x-x-x-x
GEOG. LAT.

Fig. 12

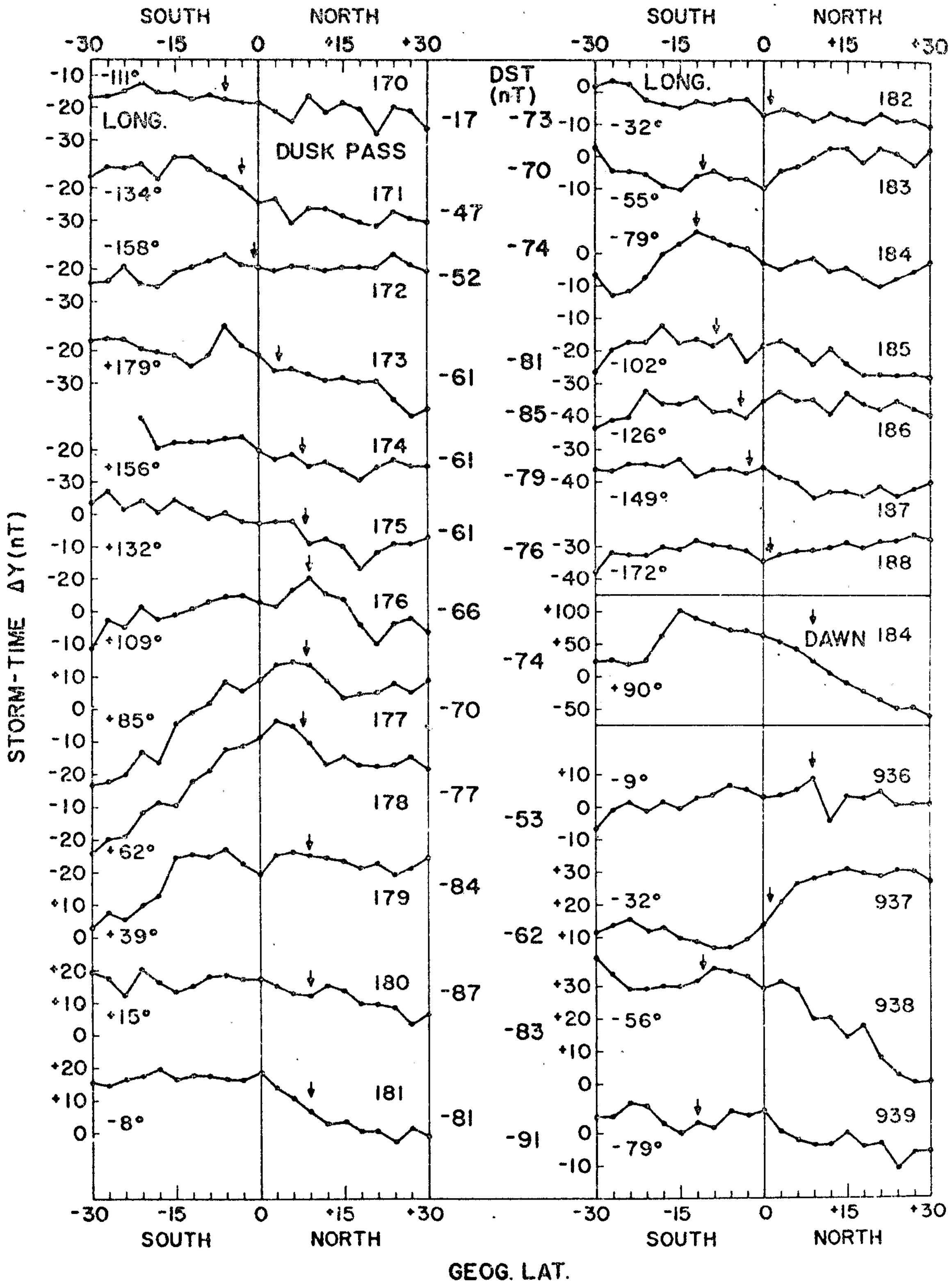

SOUTH
NORTH
DUSK PASS
DAWN
LONG.
DST (nT)
STORM-TIME ΔY(nT)
GEOG. LAT.

Fig. 13

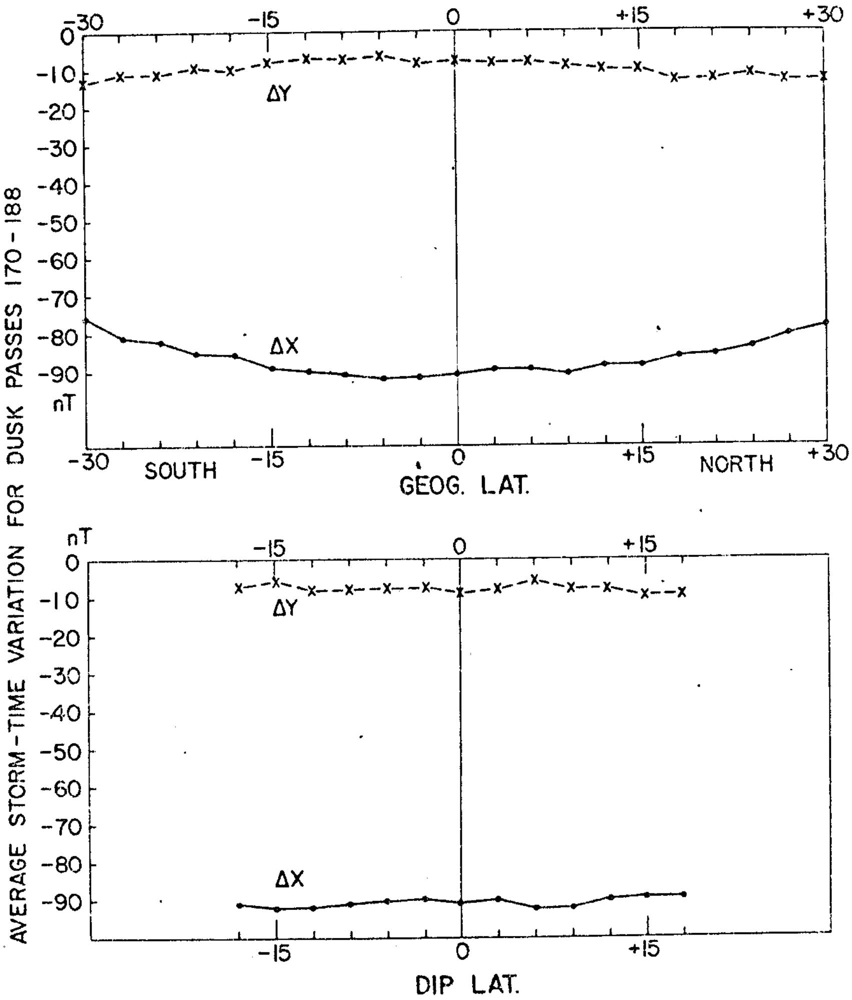

AVERAGE STORM-TIME VARIATION FOR DUSK PASSES 170-188
ΔY
ΔX
nT
SOUTH
NORTH
GEOG. LAT.
DIP LAT.

Fig. 14