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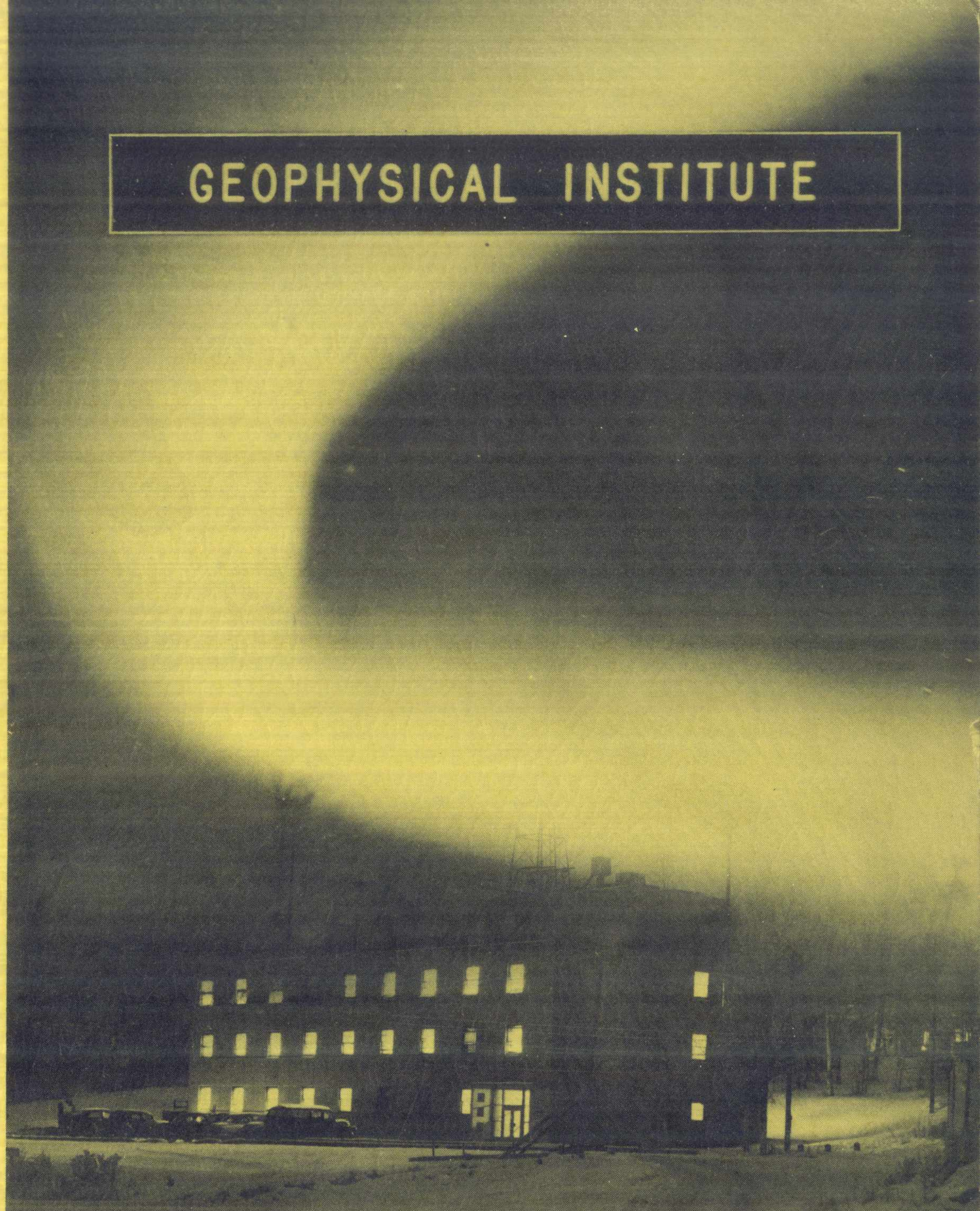

UNIVERSITY
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Final Report

August 31, 1958

AF 19(604)-2163

A STUDY OF THE MORPHOLOGY OF MAGNETIC STORMS
GREAT MAGNETIC STORMS

The research reported in this document has been sponsored by the Air Force Cambridge Research Center, Air Research and Development Command.

GEOPHYSICAL INSTITUTE

of the

UNIVERSITY OF ALASKA

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ABSTRACT

Average characteristics are determined for 74 great magnetic storms with sudden commencements that occurred in 1902-1945. The storm field is resolved for different epochs of storm time into two parts: (i) Dst, which is independent of local time, that is, of longitude λ, relative to the sun, and (ii) DS, which depends on λ. They are obtained, for each of the three magnetic elements, declination, horizontal force, and vertical force, at eight geomagnetic latitudes ranging from 80°N to 1°S. DS is harmonically analyzed; the first harmonic component is shown to be the main component of DS. The storm-time course of this component is compared with that of Dst; DS attains its maximum earlier and decays more rapidly. The results of the analysis of great storms are compared with those for weak and moderate storms that were reported previously. Some characteristics of Dst change with intensity. Except in magnitude, main characteristics of DS are independent of intensity.

I. INTRODUCTION

This paper is the third of a series of studies on the morphology of magnetic storms and of its dependence on their intensity. The first paper[1] (hereafter referred to as FR-1, signifying Final Report 1) discussed the morphology of weak magnetic storms, and the second[2] (FR-2) that of moderate magnetic storms. The present study deals with great magnetic storms. These investigations were sponsored by the Air Force Cambridge Research Center, Air Research and Development Command, under contract with the Geophysical Institute, College, Alaska.

Three hundred and forty-six suddenly commencing storms that occurred during the interval 1902-1945 were analyzed. These storms are listed in FR-1, 25-33, where an intensity number is assigned to each storm. This number is based on the average decrease of H, the horizontal force, in low latitudes at the epoch of maximum activity of each storm (FR-1, 14-15). The intensity numbers were used to divide the 346 storms into three groups: weak (136), moderate (136), and great (74). In each of the groups of weak and moderate storms, three seasonal sub-groups were formed (FR-1,16): December solstice (November to February), June solstice (May to August) and equinox (March, April, September and October). These seasons are referred to as d, j, and e, respectively. The number of great storms is much less than those of weak and moderate storms; hence they are divided into two seasonal sub-groups: solstice (November to February and May to August) and equinox (March, April, September and October). These are referred to as season s and season e. Each of the two seasonal sub-groups for great storms includes 37 storms (FR-1, 16).

The storm field is resolved into two parts: Dst, the storm-time variation, and DS the disturbance longitudinal inequality (FR-1, 34-40, 69-72). Consider the storm change Δf in a magnetic element f at a station P on gm (geomagnetic) latitude θ at storm time st, measured from the storm commencement. At this epoch, the station P is at some longitude λ relative to the sun; λ, measured eastward from the midnight meridian, is the local time at P reckoned in angle, as well as being a position coordinate of P at the epoch. The mean value of Δf at storm time st, averaged over all longitudes λ along the circle of latitude θ, is denoted by Dst(f); it is a function of st, and gives the storm-time variation Dst for this element at this epoch and latitude. The deviation from the mean, Δf - Dst(f), is denoted by DS(f); like Dst, it is a function of st and θ, but unlike Dst it is also a function of λ. As such, it can be analyzed into harmonic components with respect to λ; the coefficients are functions of st and λ.

The variation of DS, regarded as a function of local time λ, and averaged with respect to storm time st over each of the first, second, and third storm-days, is called the disturbance daily variation, SD, of the storm field; the number n of the day (1,2, or 3) is added to the symbol, SD^n.

The previous reports, FR-1 and FR-2, describe Dst, DS and SD^n for weak and moderate storms, respectively. In the latter of these reports the results for moderate storms are compared with those for weak storms. In the present paper, the corresponding variations for the 74 great storms are presented, and compared with the previous results for weak and moderate storms.

In the studies of the morphology of magnetic storms, begun by Moos[3], and extended by Chapman,[4,5,6] main characteristics of magnetic storms were found to be substantially the same over a large range of intensity, but some important detailed changes dependent on intensity were noted. In the present investigation these changes are studied with more extensive material than in the previous studies. A general account of the subject is given in reference 7.

In this paper, seasonal variations in Dst and DS for weak, moderate and great storms are also investigated.

2. OBSERVATORIES

The data used in the study of great storms (as in the study of moderate storms) refer to 19 observatories: Nos. 1-19 in Table 1, FR-1, 11-12. The geographical distribution of the observatories is shown in Fig. 1, FR-1, 10. These observatories are divided into eight groups, according to their geomagnetic latitudes, as shown in Table 1 of this report. The grouping is the same as for the moderate storms. (In the study of weak storms two southern groups, Nos. 9 and 10, were included.)

The last column in Table 1 indicates the extent of the available storm data for the group of great storms. For example, the one observatory in group 1 had records for 50 of the 74 storms; and the three observatories of group 2 had, in all, 127 records out of the 3 x 74 possible for the group. The fractions in the last column are less than 1 mainly because some observatories did not begin operation until after 1902.

TABLE 1. The Grouping of Observatories According to Geomagnetic Latitudes, for the Group of Great Storms.

Group Number	Number of Observatories	Mean Geomagnetic Latitude	Observatory	Proportion of Records Available
1	1	80°	Godhavn	50/74
2	3	65	Tromsö, Sodankylä, Lerwick	127/222
3	4	58	Sitka, Eskdalemuir Lovö, Rude Skov	203/296
4	4	52	DeBilt, Greenwich, Val Joyeux, Cheltenham	291/296
5	2	42	Ebro, Tucson	98/148
6	2	28	Porto Rico, Kakioka	129/148
7	2	21	Honolulu, Zikawei	132/148
8	1	-1	Huancayo	51/74
	Total 19			1,081/1,406

3. STORM-TIME VARIATIONS

3.1 Dst in the geomagnetic-north component Hgm

The Dst variations in the horizontal force and declination are transformed into those of the geomagnetic-north component Hgm and the geomagnetic-east component Egm.

Figs. 1,2, and 3 show the Dst variations in Hgm for the average weak storm, the average moderate storm and the average great storm, for the observatory groups 1-8. The group number and the mean geomagnetic latitude are indicated to the left of each graph. In the time scale, given at the foot of the diagram, storm time 0 hour coincides, on the average, with the time of

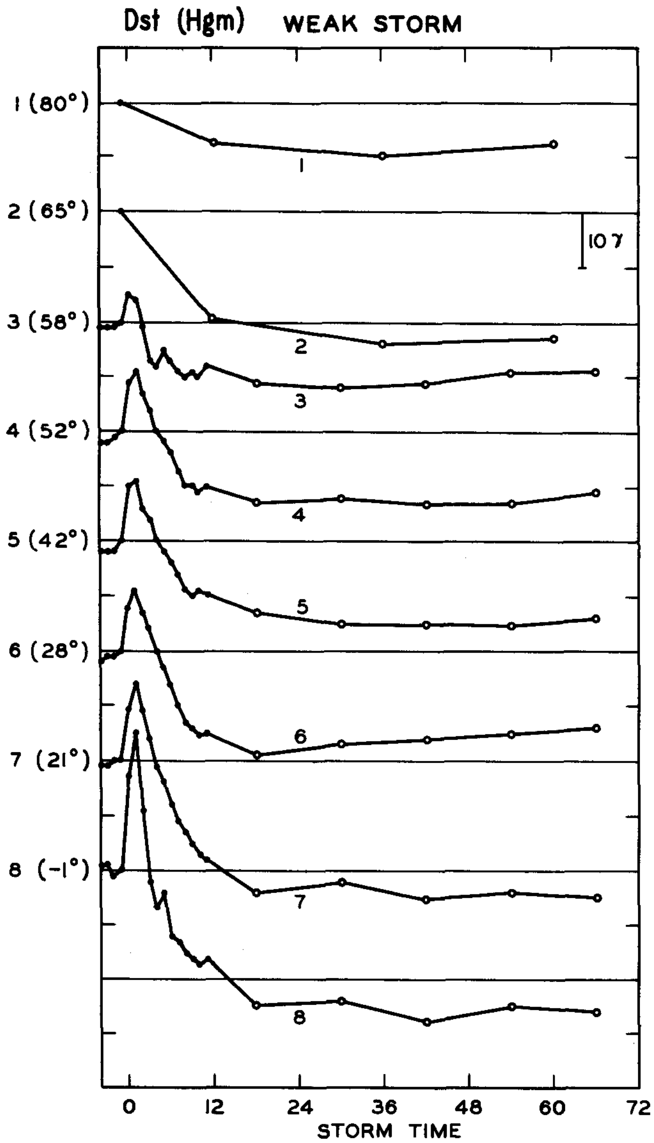


Fig. 1

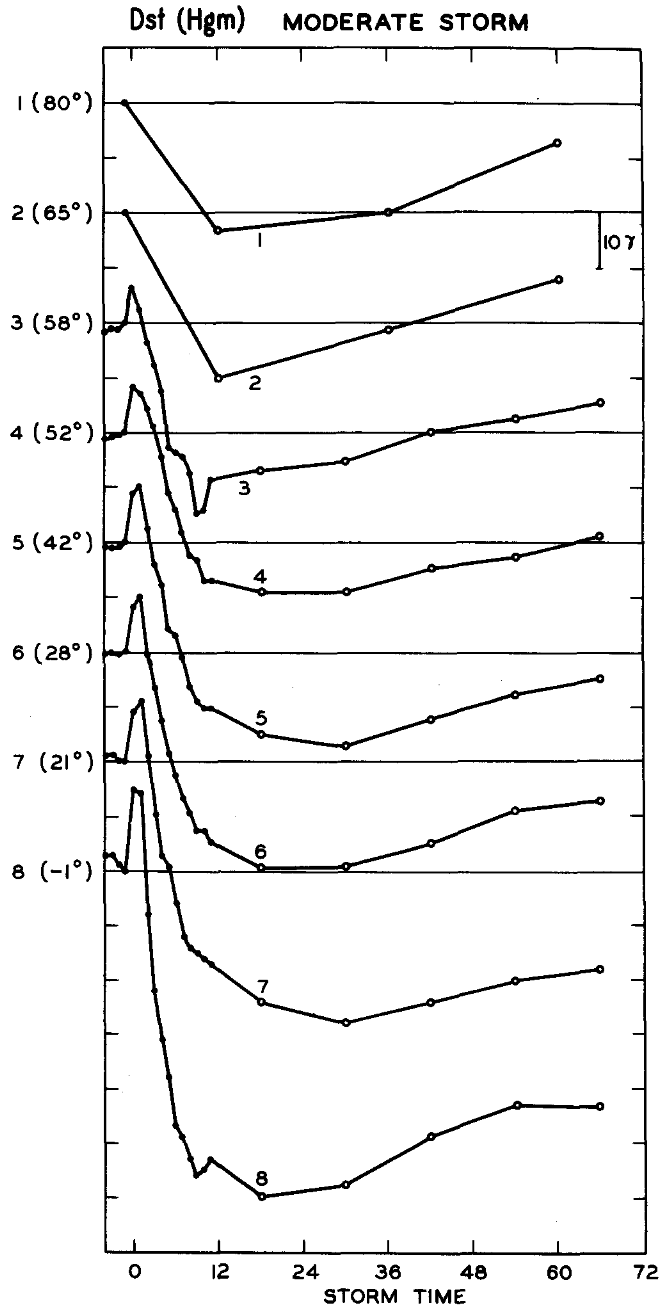


Fig. 2

Figs. 1 and 2. Dst variations in the geomagnetic-north component Hgm at different geomagnetic latitudes for the average weak and the average moderate storm.

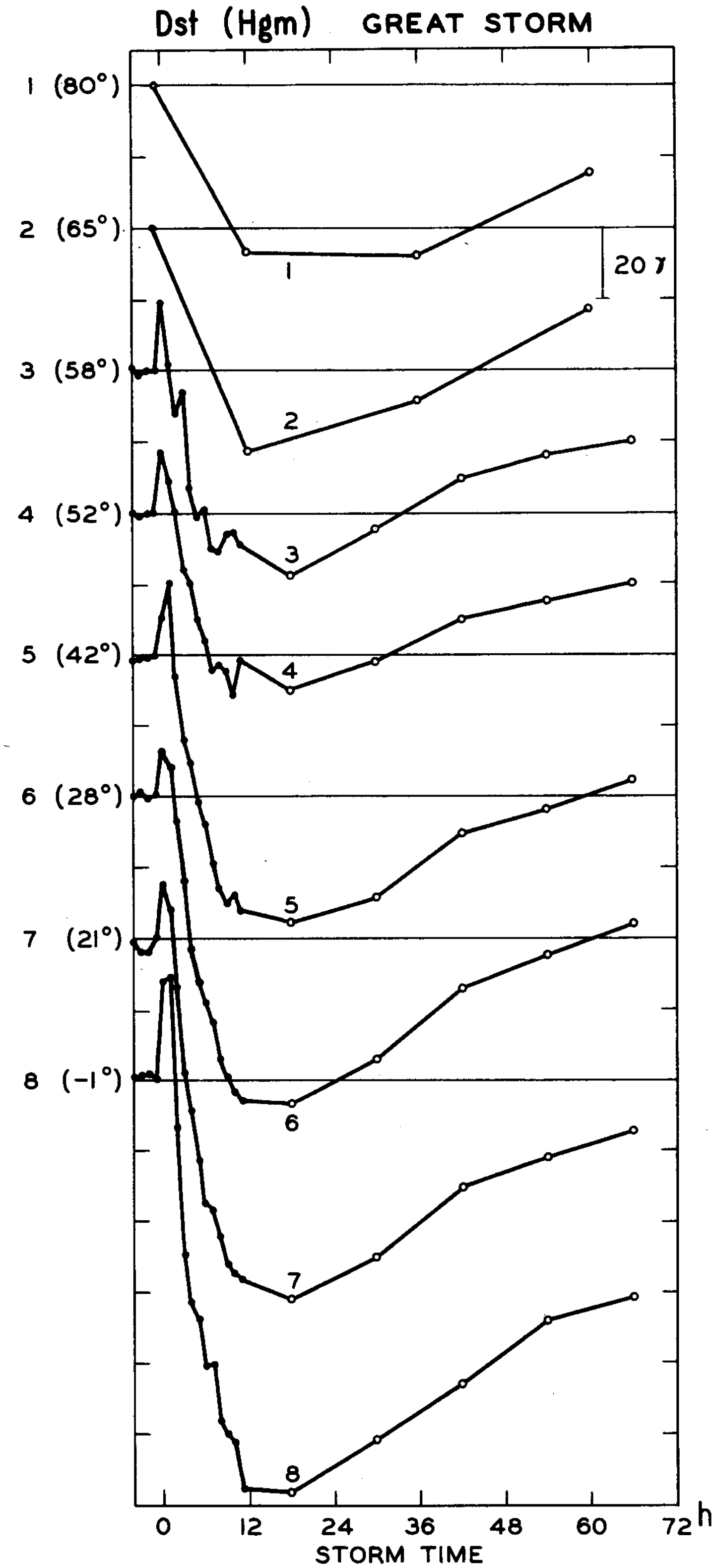


Fig. 3. Dst variations in the geomagnetic-north component Hgm at different geomagnetic latitudes for the average great storm.

sudden commencement. The curves show the variations from four hours before to 72 hours after the storm commencement. For groups 1 and 2, the changes in the pre-storm interval are not shown. The force scale is the same for the average weak storm and the average moderate storm, but it is contracted for the average great storm.

In Figs. 1, 2, and 3, dots represent hourly values and circles represent 12- or 24-hour means; no smoothing is made. These remarks apply also to the corresponding diagrams for Egm and Z, Figs. 4, 5, 6, 7, 8, and 9 in Sections 3.2 and 3.3.

The morphological characteristics of rapid variations near the storm commencement cannot be determined by an analysis of mean, or instantaneous, hourly data; the study of such changes requires records registered at intervals much shorter than one hour.

Table 2 gives the maximum values of Dst(Hgm) at different latitudes for the average great storm together with those for the average weak storm and the average moderate storm. The maximum Dst(Hgm) for the average great storm appears greater than the corresponding quantity for the average weak storm and for the average moderate storm.

TABLE 2. Maximum Dst(Hgm) in the initial phase, in low and moderate latitudes, for the average weak storm, the average moderate storm, and the average great storm. Unit: 1 gamma.

Observatory group	3	4	5	6	7	8
Mean geomagnetic latitude	58°	52°	42°	28°	21°	-1°
Weak storm	5	11	11	11	14	25
Moderate storm	6	8	10	10	11	15
Great storm	19	17	20	12	15	29

In FR-2, 8, we stated that the size of the initial phase in the average moderate storm is smaller than that in the average weak storm. It now appears that the dependence of the maximum Dst(Hgm) on the storm intensity is as yet uncertain. In Section 8* in this report it is shown that the initial phase of Dst(H) has appreciable seasonal variations in low and moderate latitudes. Fig. 35, in Section 8, illustrates Dst(H) for different seasons for the mean of groups 4, 5, and 6; the figure indicates that the seasonal changes are probably greater than the differences between the maxima of Dst(H) for the three intensity groups. It should be borne in mind, however, that the data used in this work are hourly values; hence they do not give the absolute peak values of the Dst changes in Hgm.

The Dst(Hgm) reverses its sign (when measured from pre-storm level) one to two hours after the sudden commencement in the average great storm. The approximate reversal time in Dst(Hgm), at different latitudes, for the three intensity groups, is given in Table 3. The values in Table 3 show that at all latitudes, the greater the storm intensity the earlier the reversal time of Dst(Hgm).

TABLE 3. The approximate storm time at which Hgm crosses its pre-storm level in the average weak storm, the average moderate storm, and the average great storm. Unit: 1 hour.

Observatory group	3	4	5	6	7	8
Mean geomagnetic latitude	58°	52°	42°	28°	21°	-1°
Weak storm	1.9	4.0	4.0	4.0	3.8	2.8
Moderate storm	1.2	3.2	2.3	2.0	2.1	1.6
Great storm	1.0	2.0	1.8	1.5	1.2	1.5

* Strictly speaking, the discussions in Section 8 refer to H, not to Hgm. But in low and moderate latitudes, the difference between H and Hgm is small. Especially in Dst, the contribution of Dst(E) to Dst(Hgm) is negligible in these latitudes because of the small size of Dst(E).

Values of minimum Dst(gm), at different latitudes, for the three intensity groups, are listed in Table 4. The ratios of the minimum values for the moderate to those for the weak storm, and the corresponding ratios of the great storm to the moderate storm are also given in Table 4. These quantities for the observatory groups 1 and 2 are less accurate than those for the other groups, because they are derived from the daily means for the three storm days.

TABLE 4. Values of minimum Dst(Hgm), at different latitudes, for the average weak storm, the average moderate storm, and the average great storm. Unit: 1 gamma.

Observatory group	1	2	3	4	5	6	7	8	
Mean geomagnetic latitude	80°	65°	58°	52°	42°	28°	21°	-1°	
Weak storm	-10	-14	-12	-13	-15	-19	-25	-28	
Moderate storm	-23	-30	-28	-29	-37	-39	-48	-60	
Great storm	-48	-62	-58	-52	-76	-88	-102	-116	
									Mean
Moderate/weak	2.3	2.1	2.3	2.2	2.5	2.1	1.9	2.1	2.2
Great/Moderate	2.1	2.1	2.1	1.8	2.1	2.3	2.1	1.9	2.1

The storm time at which the minimum of Dst(Hgm) is attained is near 18 hour in the average great storm, and is about 24 to 30 hour in the average moderate storm; but in the average weak storm Dst(Hgm) remains near its minimum level throughout the second and third days.

The recovery phase begins earlier in the average great storm than in the average moderate storm; it is much delayed in the average weak storm. More detailed discussions on the decay of Dst(H) (and of DS) are given in Section 7 of this report.

3.2 Dst in the geomagnetic-east component Egm

Figs. 4, 5, and 6 show the Dst variations in the geomagnetic-east component Egm, respectively for the average weak storm, the average moderate

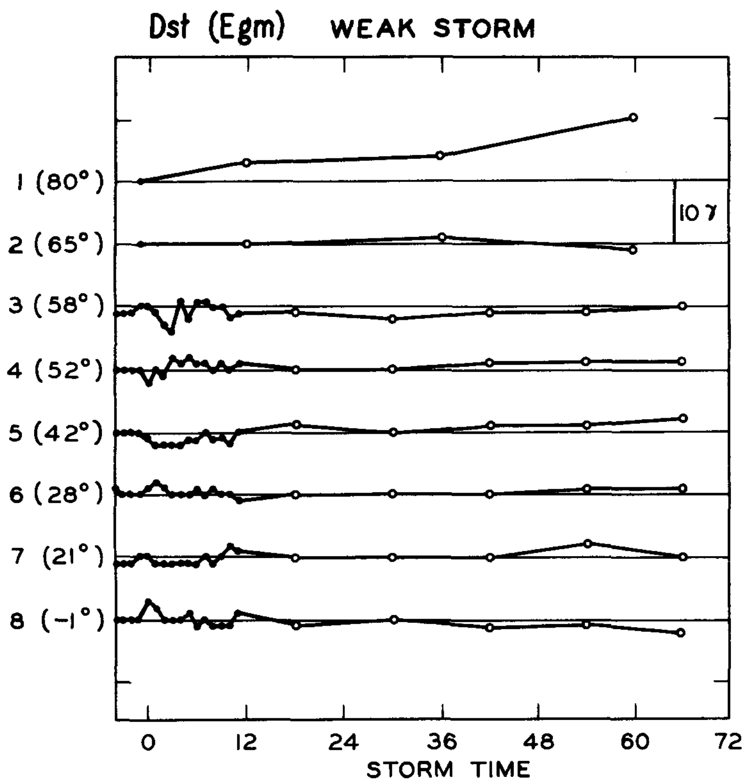


Fig. 4

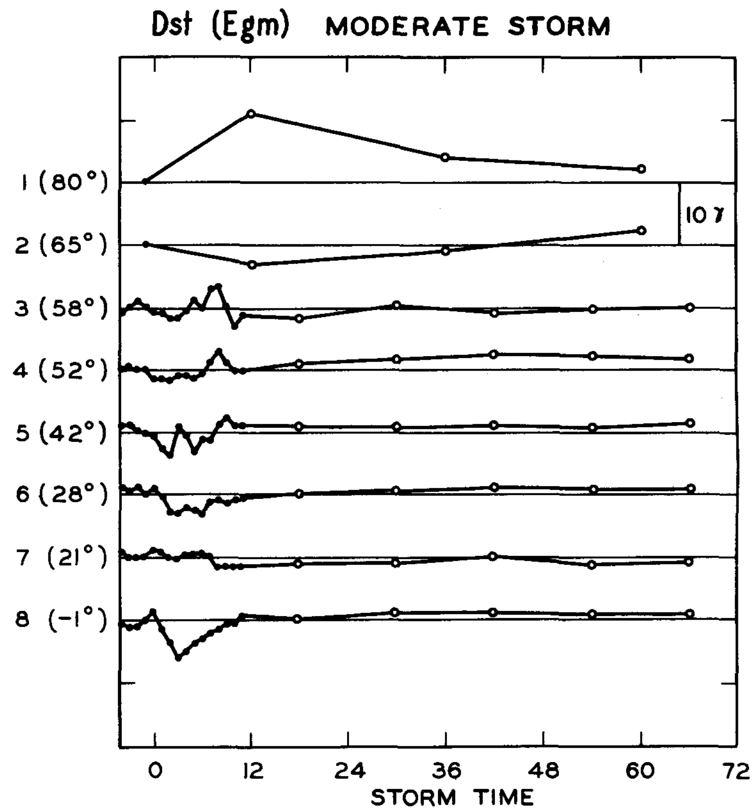


Fig. 5

Figs. 4 and 5. Dst variations in the geomagnetic-east component, Egm, at different geomagnetic latitudes for the average weak storm and the average moderate storm.

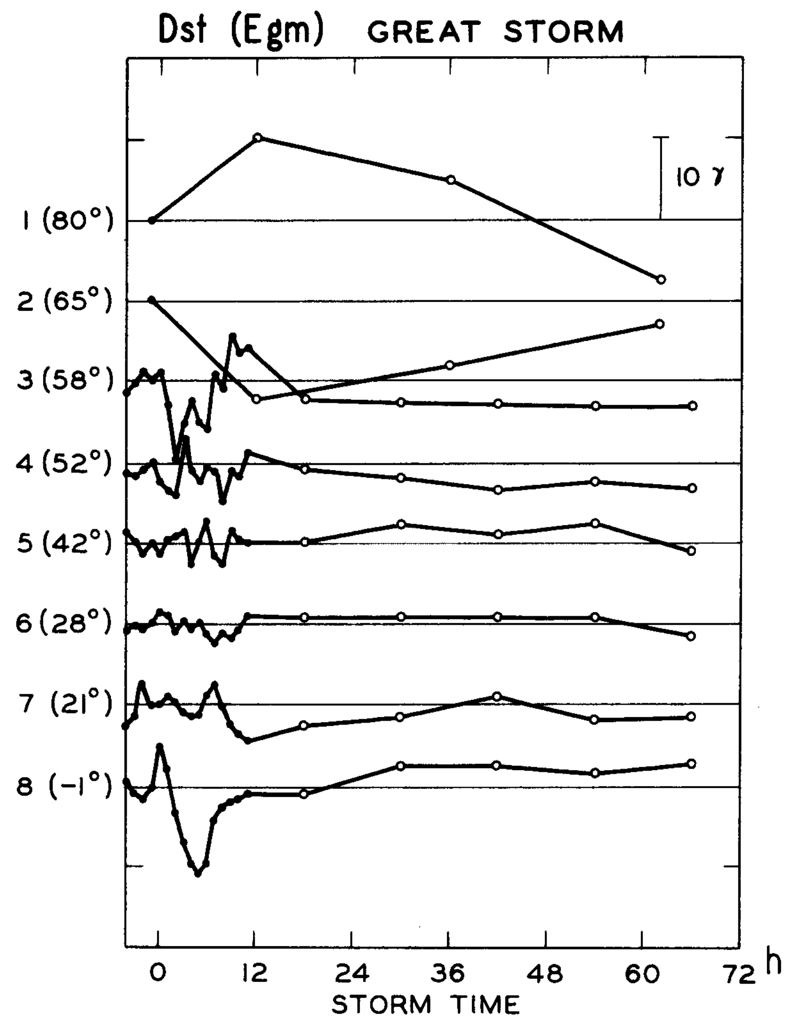
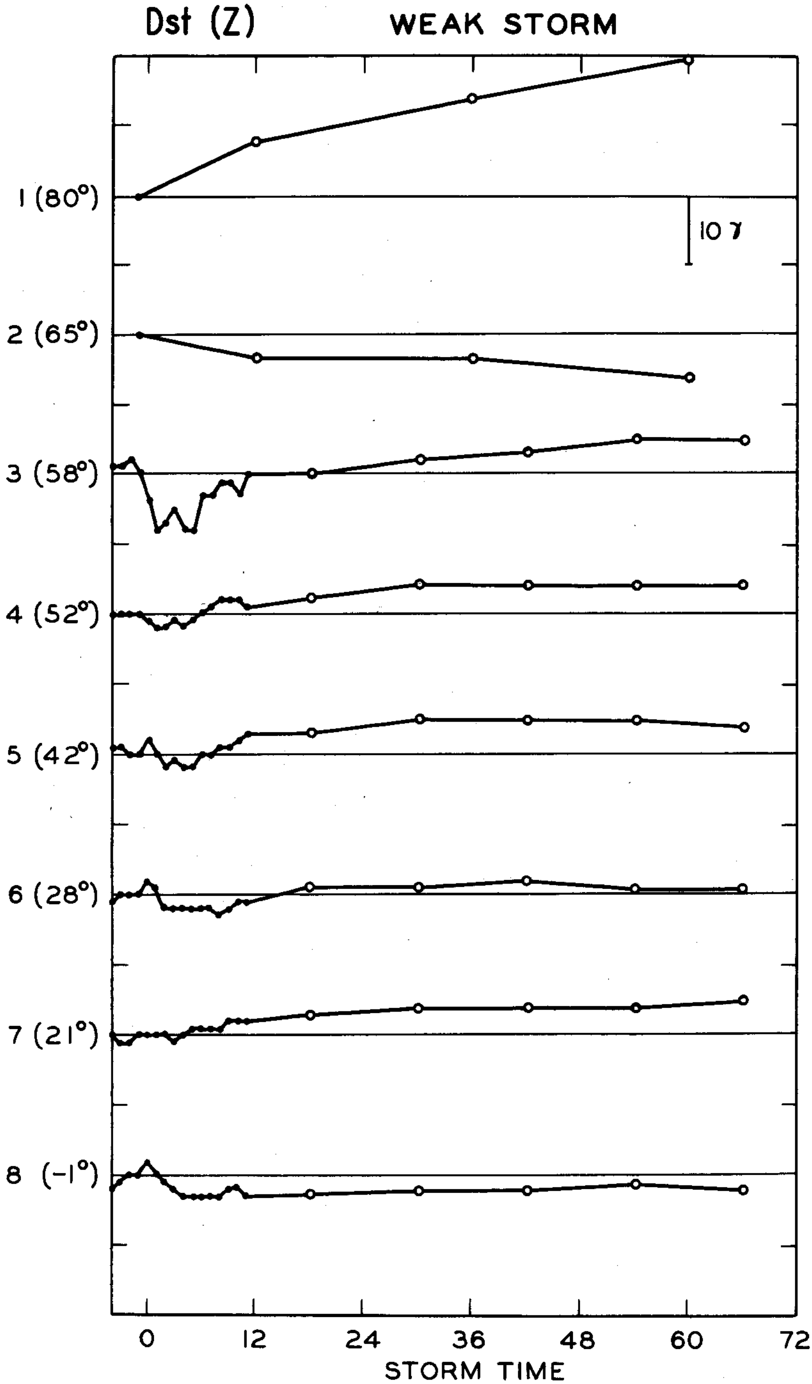
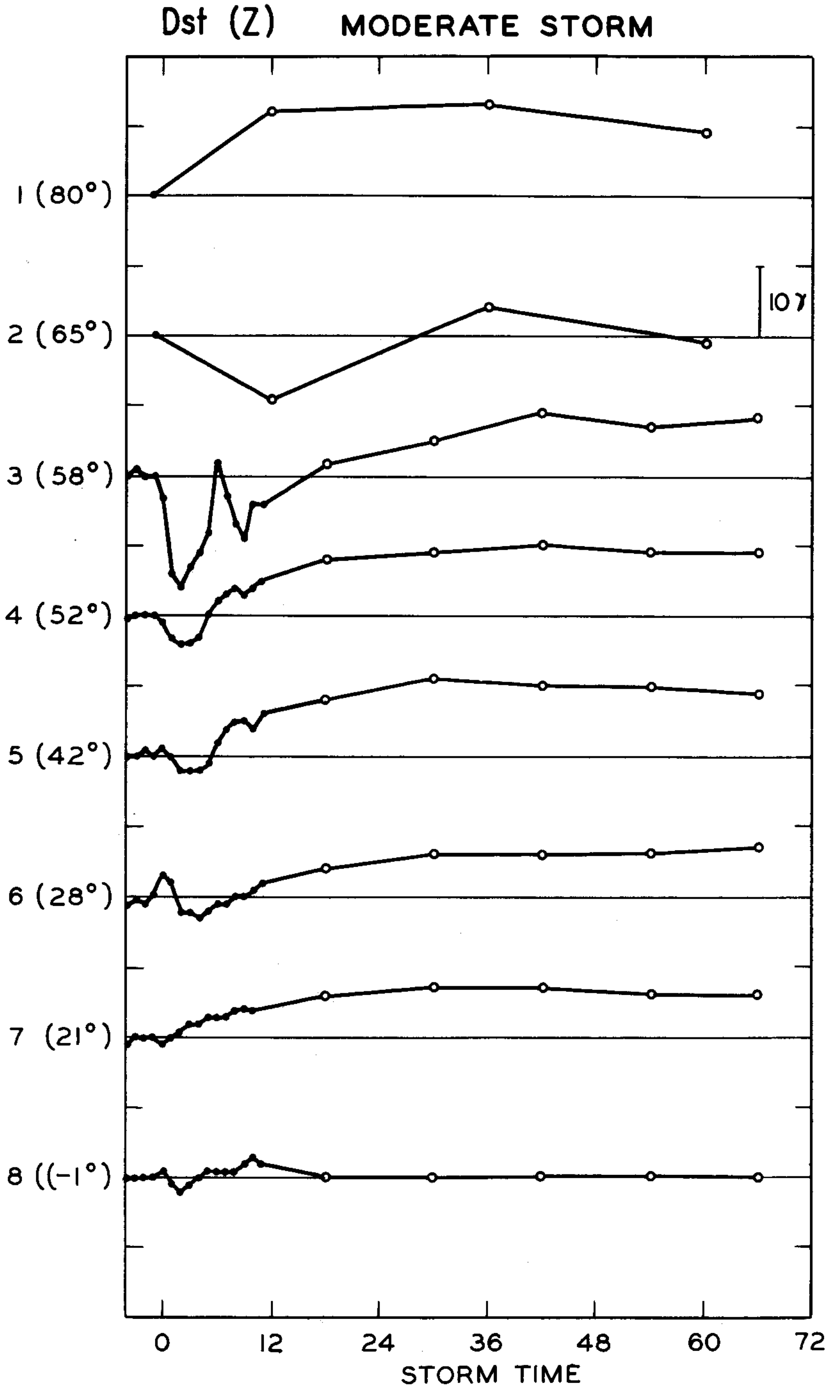


Fig. 6. Dst variations in the geomagnetic-east component, Egm, at different geomagnetic latitudes for the average great storm.



Dst (Z)
WEAK STORM
1 (80°)
10 γ
2 (65°)
3 (58°)
4 (52°)
5 (42°)
6 (28°)
7 (21°)
8 (-1°)
0
12
24
36
48
60
72
STORM TIME

Fig. 7



Dst (Z) MODERATE STORM
1 (80°)
2 (65°)
3 (58°)
4 (52°)
5 (42°)
6 (28°)
7 (21°)
8 ((-1°)
10γ
0
12
24
36
48
60
72
STORM TIME

Fig. 8

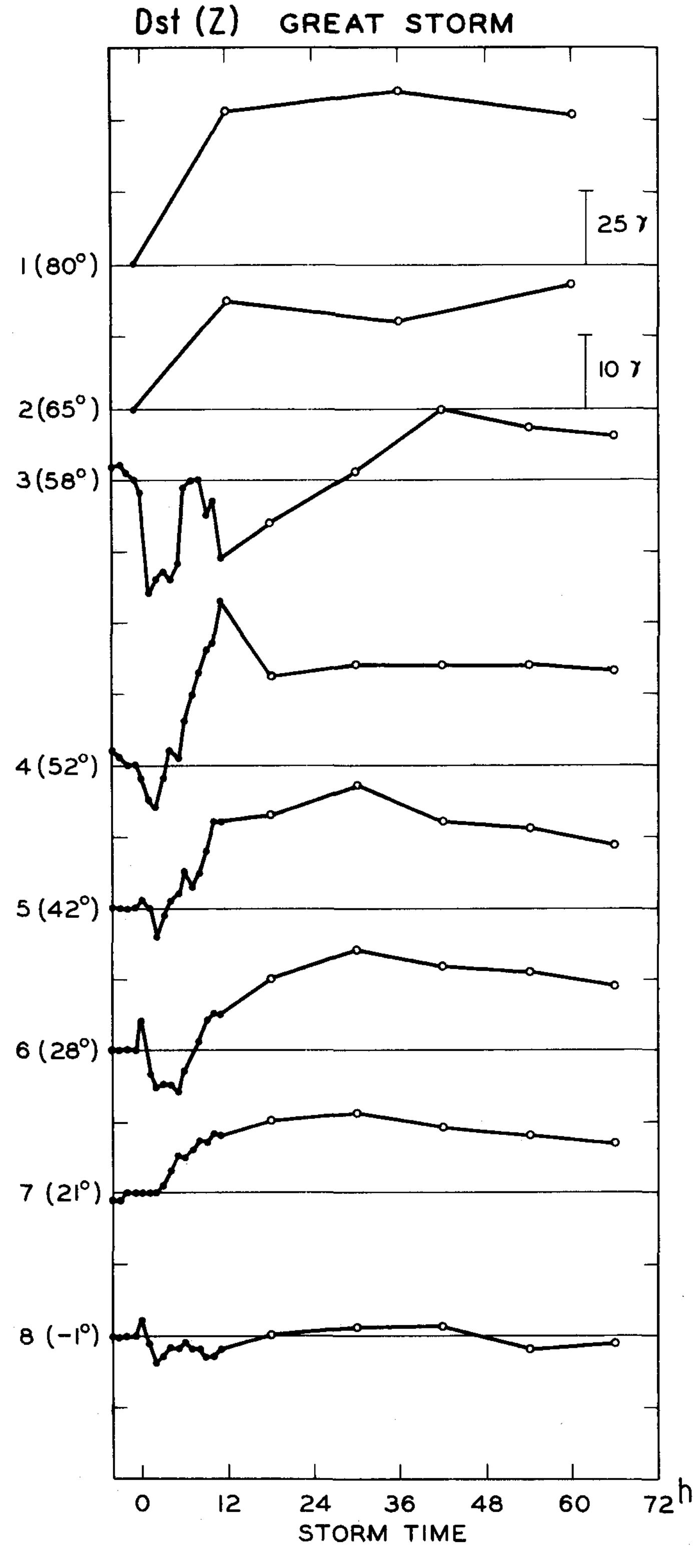


Fig. 9

Figs.7, 8, and 9. Dst variations in the vertical force Z at different geomagnetic latitudes for the average weak storm, the average moderate storm, and the average great storm, respectively. Z is measured positively toward nadir.

storm, and the average great storm, for the observatory groups 1 to 8. For groups 3 to 8 the Dst(Egm) variations seem to be irregular and due to accidental variations not fully smoothed out. Hence it appears that the lines of magnetic force for the Dst field lie, in moderate and low latitudes, very nearly in planes through the geomagnetic axis.

There appears to be a systematic eastward component in group 1 (80° gm latitude) in all three intensity groups. There may also be a westward component in group 2 in the average great storm and possibly in the average moderate storm.

3.3 Dst in the vertical force Z

Figs. 7, 8, and 9 show the Dst variations in the vertical force for the average weak storm, the average moderate storm, and the average great storm, respectively. It should be noted that in Fig. 9, the force scale for group 1 is contracted by a factor of 2.5. Except in group 1 for the average great storm, the Dst(Z) is much less than Dst(Hgm), in all latitudes, for all three intensity groups.

The recovery in this component is notably slower than in the horizontal force.

4. DISTURBANCE DAILY VARIATIONS

The disturbance longitudinal inequalities DS(H), DS(E) and DS(Z) are determined for each of the eight six-hour intervals of the first and second days, and for each of the three eight-hour intervals of the third day. When averaged over a whole day, these variations are called disturbance daily variations, and are denoted by SD. As determined for the first, second, and third storm days, they are denoted by SD^1, SD^2, and SD^3, respectively.

Figs. 10-18 show such SD variations, together with the average solar quiet daily variations, Sq, derived by taking the average of the mean of the five international quiet days of the months in which the storms occurred. When a storm continued from one month to the next, the mean Sq for the two months is adopted.

Figs. 10, 13, 16 refer to the average weak storm, Figs. 11, 14, 17 to the average moderate storm, and Figs. 12, 15, 18 to the average great storm.

The time absciasae for the average moderate storm and the average great storm refer to geomagnetic local time. The mean difference in hours, averaged over the day, between geomagnetic and standard local time, for each observatory, is given in Table 1, FR-1, 12; the method of determining geomagnetic local time is given in reference 8. The difference is small for the low latitude observatories, but for the observatories in groups 1-5 it is worth taking into account. In the diagrams of the SD variations for the average weak storm, standard local time was used without correcting for the difference. The time abscissae for the Sq curves refer to standard local time.

In examining Figs. 10-18 it should be carefully noted that the force scales are not uniform.

These diagrams resemble those previously given by Chapman[4,5], which are reproduced in geomagnetism (Ch.IX, Fig. 6-11). The discussion of them, there given, points out the contrast between the Sq and SD graphs, and also the similarity of SD for the successive days of the storm. These points are more fully exemplified by the figures shown in this Section.

The SD variations in H for group 4 show, in all three intensity groups, a transitional character between the types for more northerly and southerly latitudes. There is some indication that the focal latitude is lower,

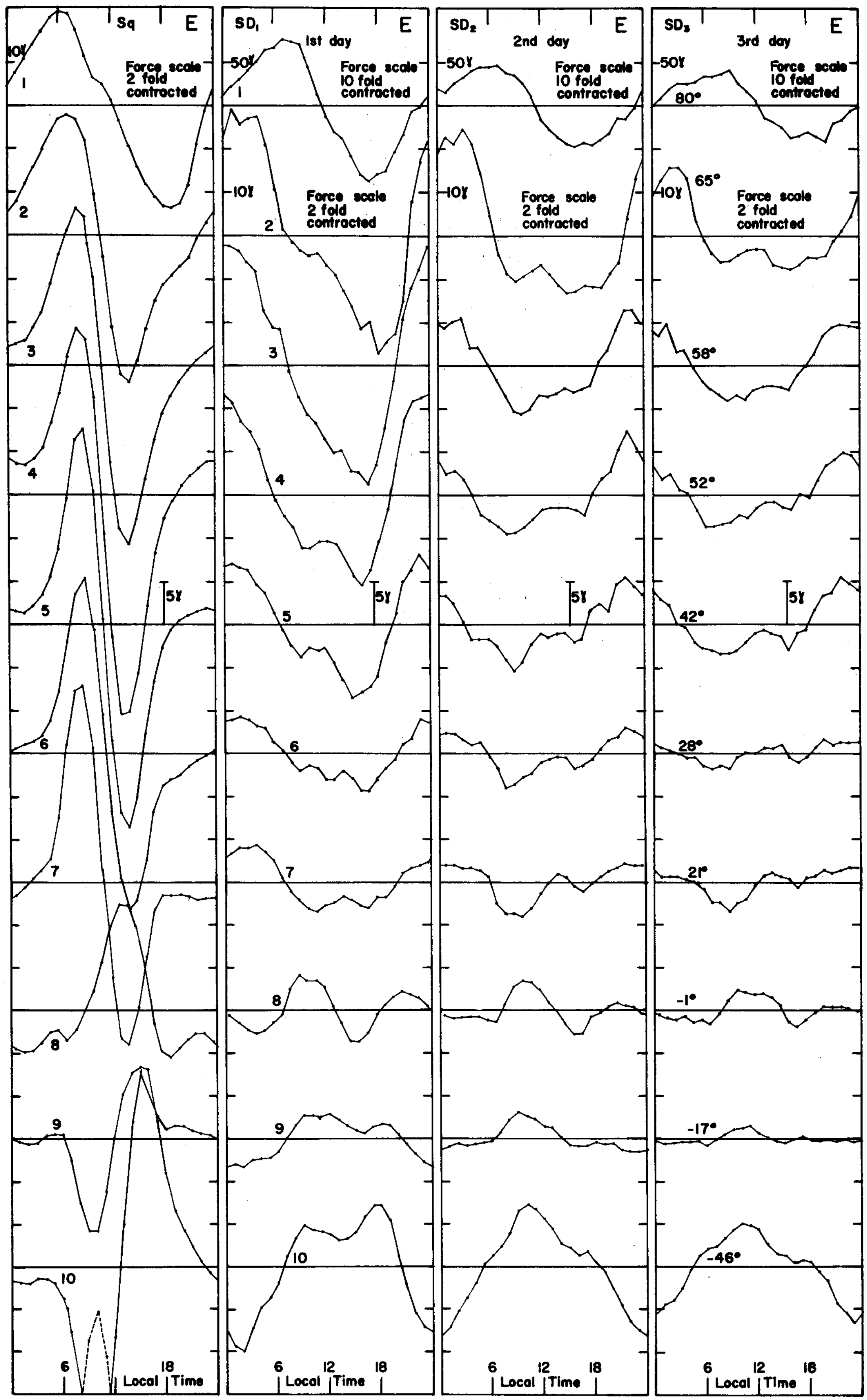


Fig. 10. Sq and SD in the east declination E, measured in the force unit, at different geomagnetic latitudes, for the average weak storm. The three columns for SD, i.e. the second, third, and fourth from the left, refer to the first, second, and third days of the storm, respectively.

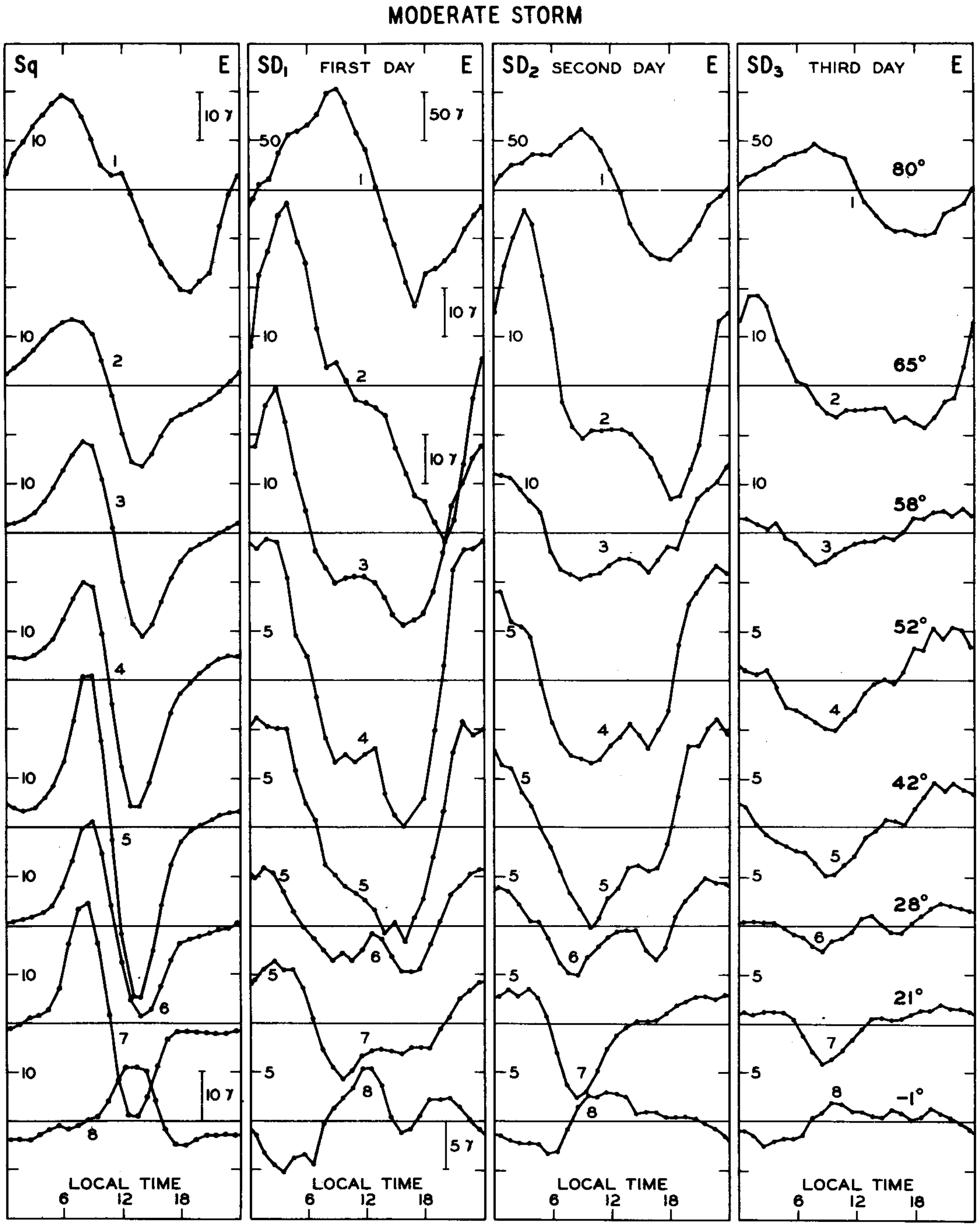


Fig. 11. Sq and SD in the east declination E, measured in the force unit, at different geomagnetic latitudes, for the average moderate storm. The three columns for SD, i.e. the second, third, and fourth from the left, refer to the first, second, and third days of the storm, respectively.

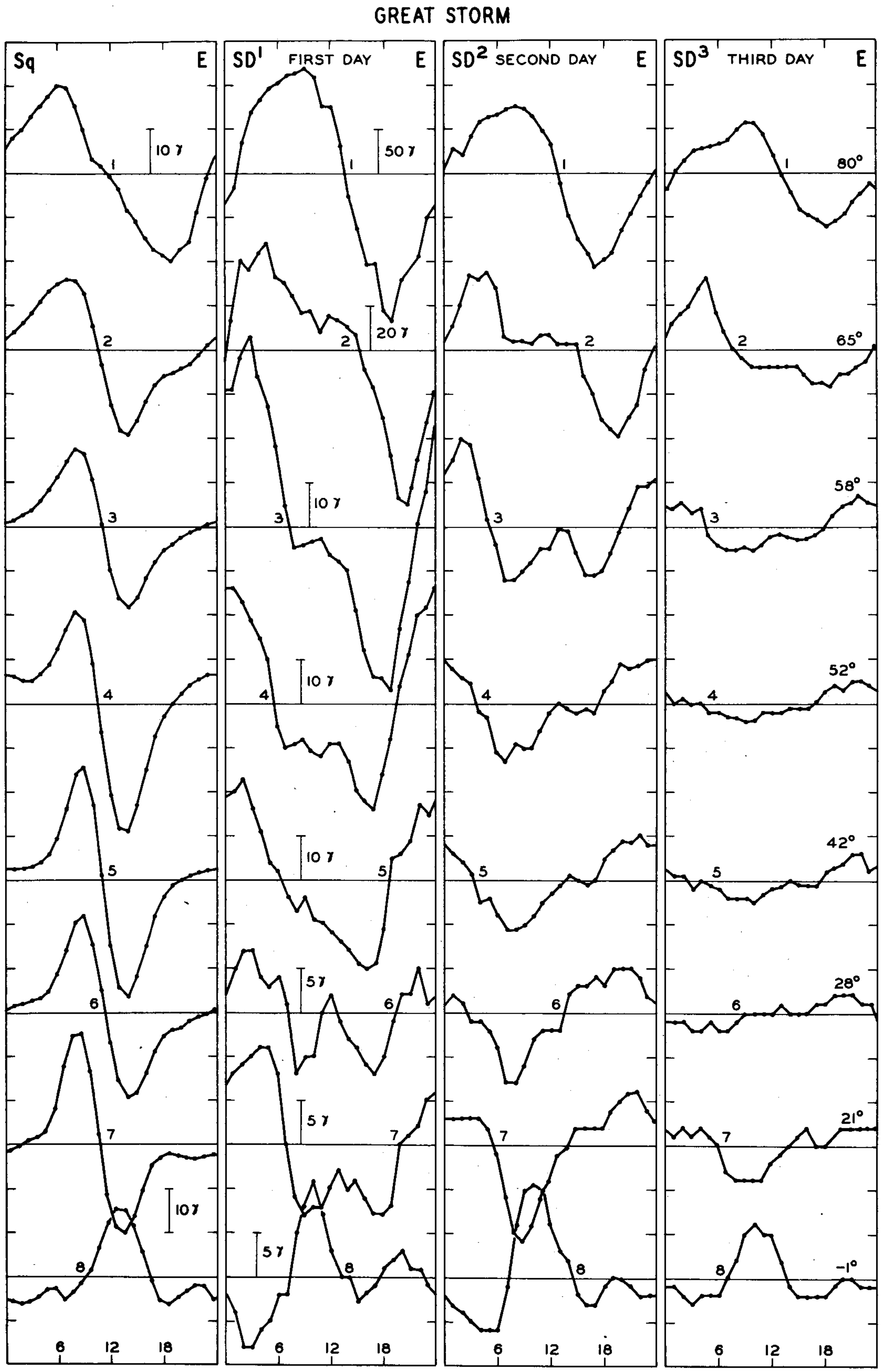


Fig. 12. Sq and SD in the east declination E, measured in the force unit, at different geomagnetic latitudes, for the average great storm. The three columns for SD, i.e. the second, third, and fourth from the left, refer to the first, second, and third days of the storm, respectively.

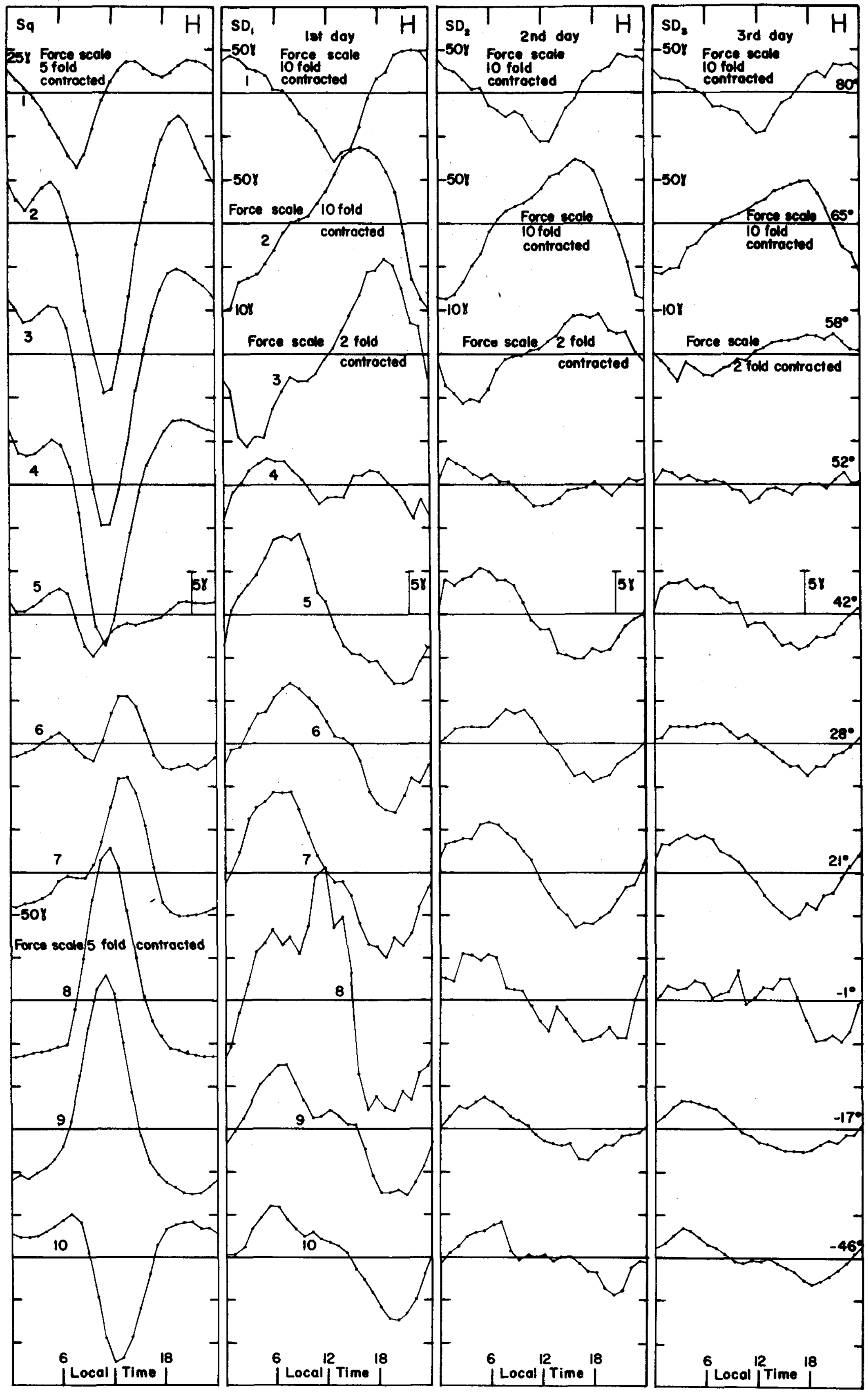


Fig. 13. Sq and SD in the horizontal force H, at different geomagnetic latitudes, for the average weak storm. The three columns for SD, i.e. the second, third, and fourth from the left, refer to the first, second, and third days of the storm, respectively.

MODERATE STORM

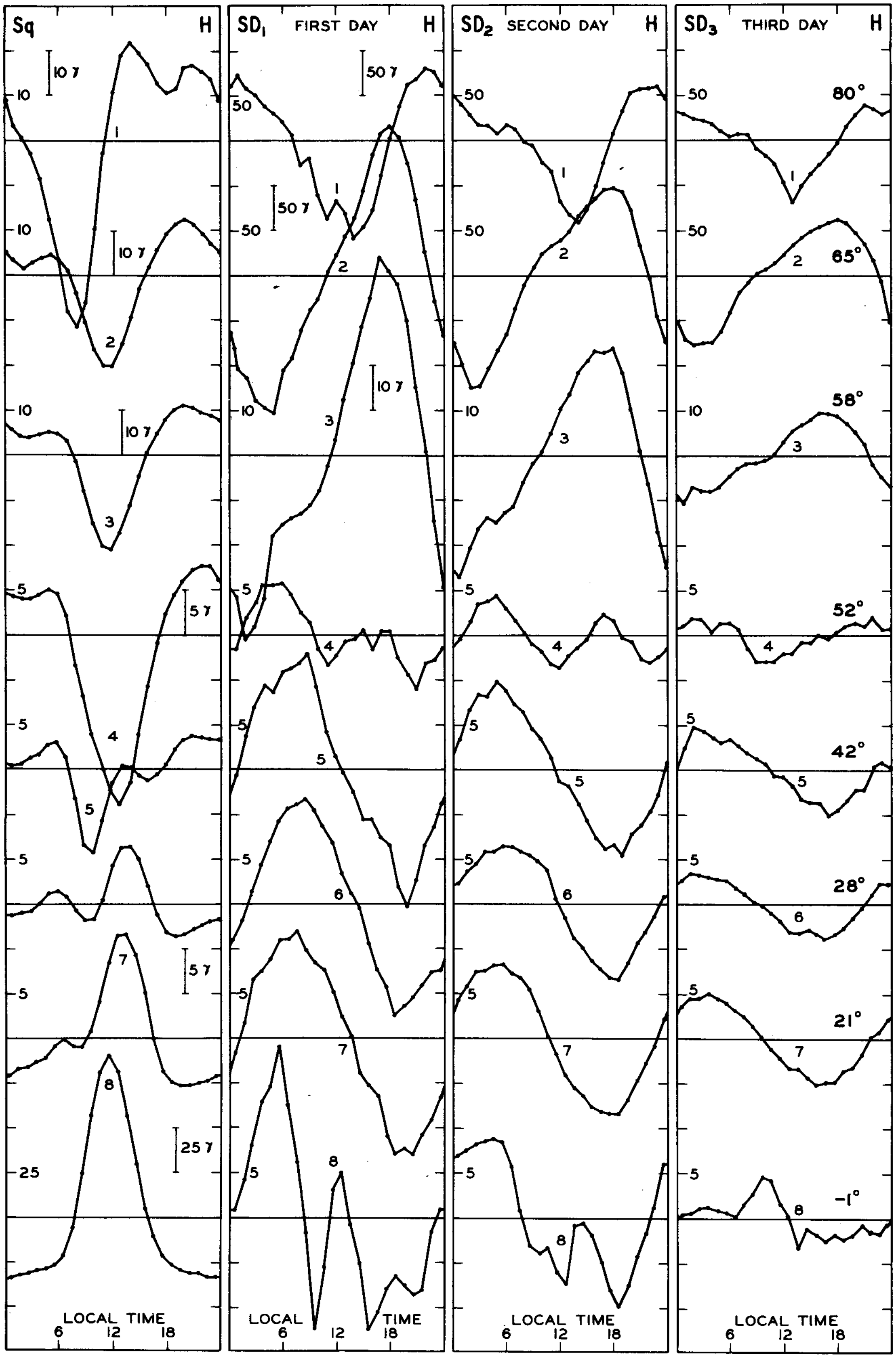


Fig. 14. Sq and SD in the horizontal force H, at different geomagnetic latitudes for the average moderate storm. The three columns for SD, i.e. the second, third, and fourth from the left, refer to the first, second, and third days of the storm, respectively.

GREAT STORM

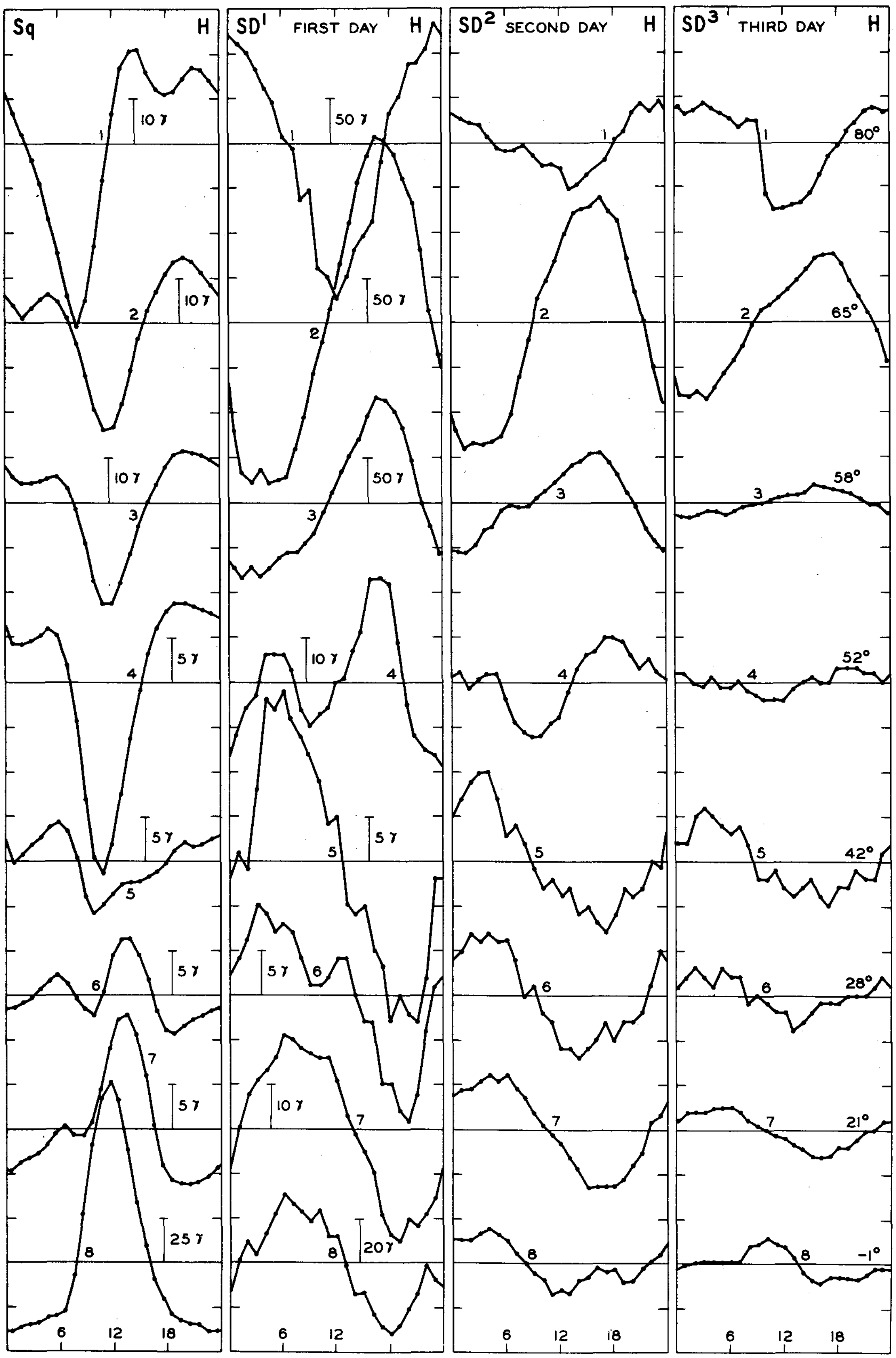


Fig. 15. Sq and SD in the horizontal force H, at different geomagnetic latitudes, for the average great storm. The three columns for SD, i.e. the second, third, and fourth from the left, refer to the first, second, and third days of the storm, respectively.

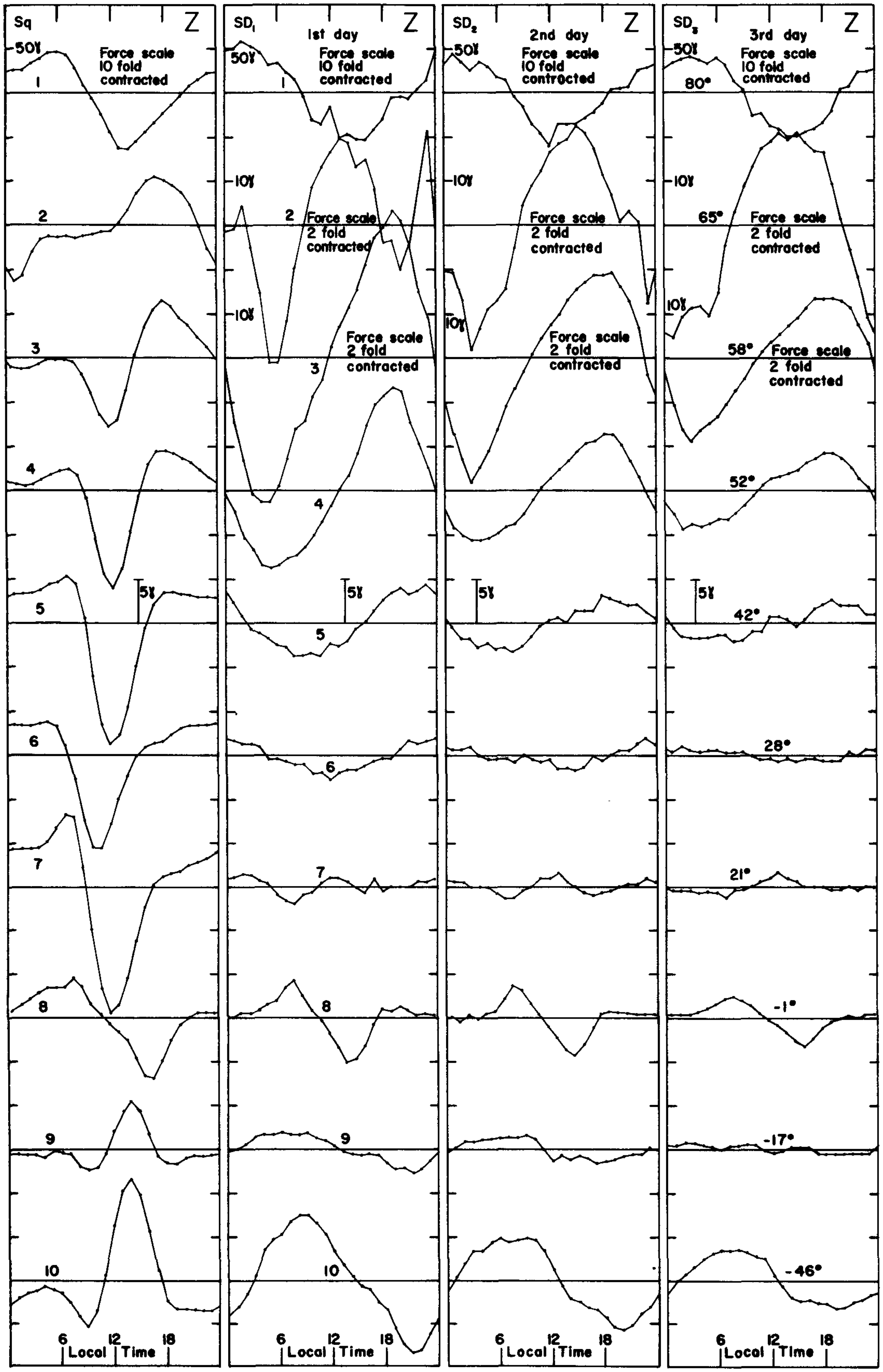


Fig. 16. Sq and SD in the vertical force Z, at different geomagnetic latitudes, for the average weak storm, Z being measured positively toward nadir. The three columns for SD, i.e. the second, third and fourth from the left, refer to the first, second, and third days of the storm, respectively.

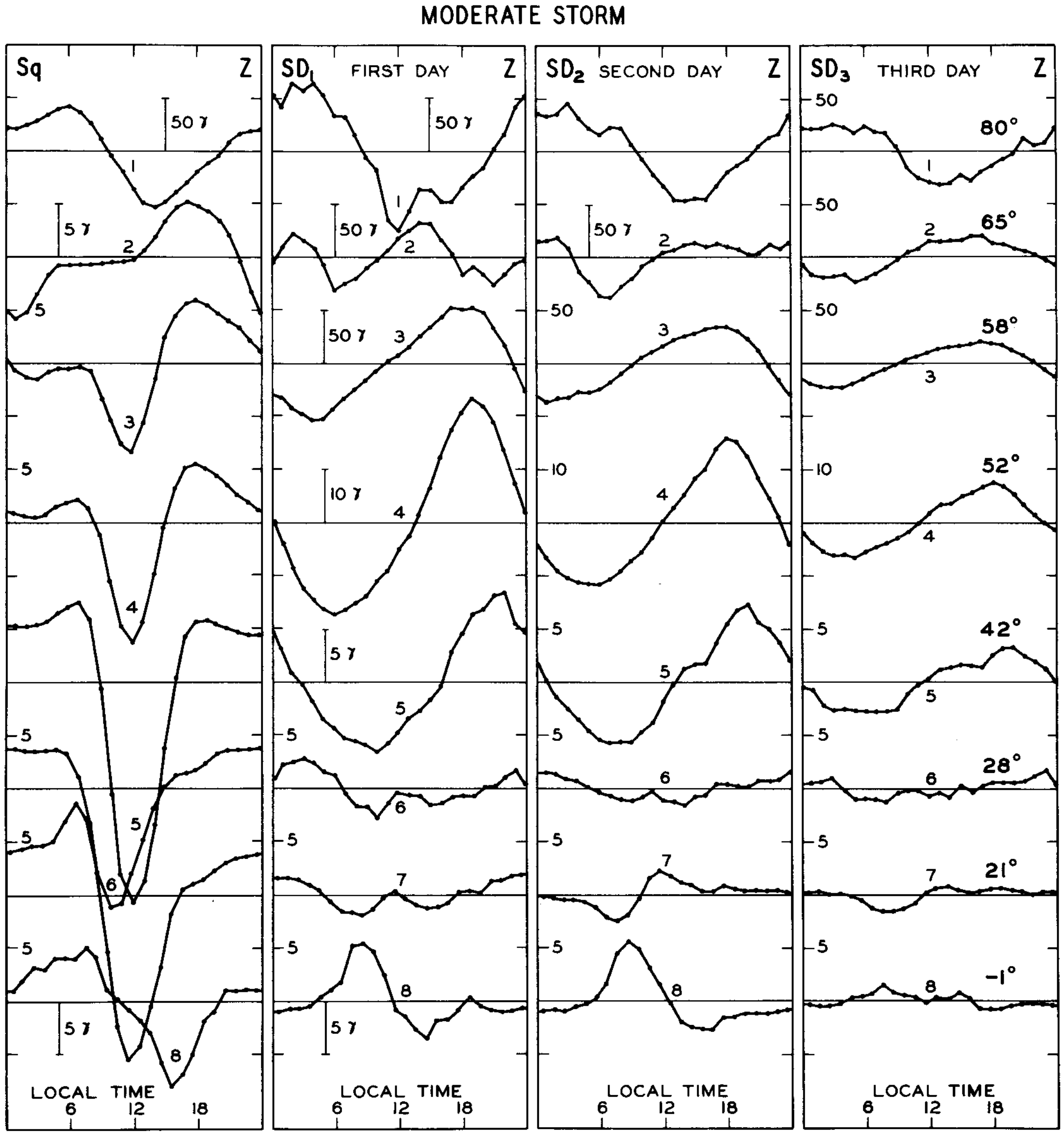


Fig. 17. Sq and SD in the vertical force Z, at different geomagnetic latitudes, for the average moderate storm, Z being measured positively toward nadir. The three columns for SD, i.e. the second, third, and fourth from the left, refer to the first, second, and third days of the storm, respectively.

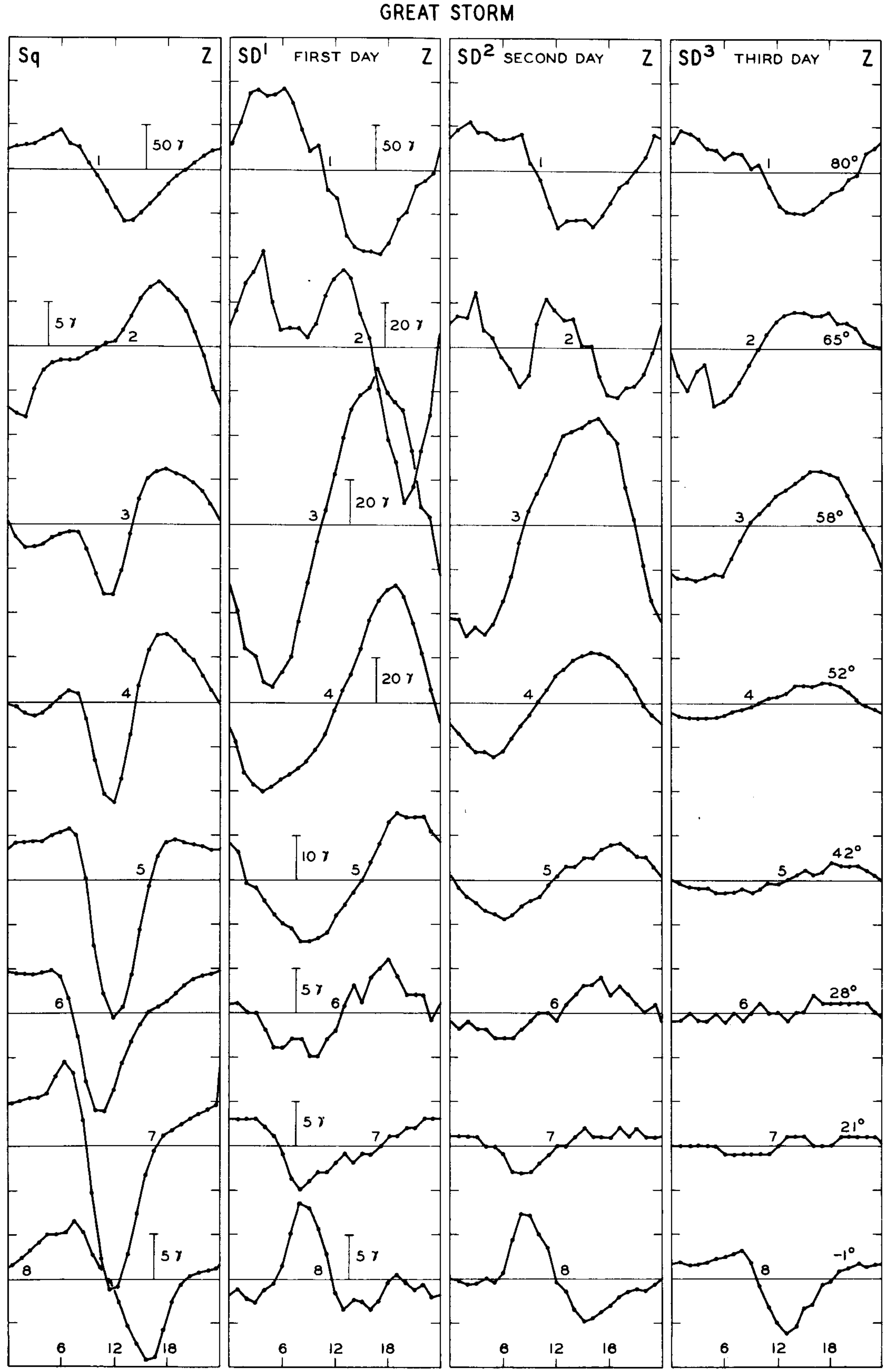


Fig. 18. Sq and SD in the vertical force Z, at different geomagnetic latitudes, for the average <u>great</u> storm, Z being measured positively toward nadir. The three columns for SD, <u>i.e</u>. the second, third and fourth from the left, refer to the first, second, and third days of the storm, respectively.

especially in the first and second days, in the average great storm than in the average moderate and the average weak storm. In the average weak storm, the focal latitude appears to remain slightly to the north of 52°, the mean latitude of this observatory group, throughout the three days of the storm. In the average moderate storm, this focal latitude seems still to the north of 52° throughout the storm, but it appears to move slightly southward from the first to the second day and to recede northward subsequently. In the average great storm, the focal latitude is probably to the south of 52° on the first and second days of the storm; its position on the third day is less certain than on the first two days.

5. FIRST HARMONIC COMPONENT OF DS

The yearly mean DS variations of E, H, and Z are harmonically analyzed for the first eight 6-hour intervals and the succeeding three 8-hour intervals for each of the observatory groups. They are expressed as:

$$\sum_n (a_n \cos n\Lambda_s + b_n \sin n\Lambda_s) \quad ,$$

$$\text{or} \quad \sum_n c_n \sin (n\Lambda_s + \sigma_n)$$

where a_n, b_n, and c_n are in gamma and σ_n in degrees for all three elements; Λ_s is (linearized) geomagnetic local time measured from the (geomagnetic) midnight meridian. The harmonic coefficients and phases for the eleven intervals give the DS variations for the three elements as functions of storm time. The harmonic data a_1, b_1, c_1, and σ_1, for the average great storm, for the eight observatory groups are presented in Table 5.

Figs. 19-24 consist of sets of harmonic dials. Figs. 19 and 22 refer to the average weak storm, Figs. 20 and 23 to the average moderate storm, and Figs. 21 and 24 to the average great storm. In each pair the earlier figure refers to groups 1 to 4, and the later figure to groups 5 to 8; for the average weak storm the dials for the two southern groups are also included. Each dial shows a connected set of 11 dial points for the first harmonic of DS, for the 11 storm-time intervals. They may be considered as referring to 11 epochs of storm time from 3 to 45 hours at 6-hour intervals, and at 52, 60 and 68 hours. To accommodate all these dials in a moderate space, the scales differ from dial to dial. However, the dials for the three elements are the same for each group of observatories and storms.

The amplitude and phase of the diurnal component of DS vary systematically with storm time in all latitudes except when the amplitude of DS itself is very small. The substantial change in phase appears to occur during the first twelve hours of storm time. The harmonic dials for the average weak storm, the average moderate storm, and the average great storm are essentially of the same character for all latitudes, if irregular changes are ignored. There is no indication that the phase of DS changes more rapidly in the average great storm than in the weaker storms. This significant feature is more clearly demonstrated in Fig. 25 in this section.

The size of DS(H) is much larger near the magnetic equator (group 8) than for the other groups in low and moderate latitudes. The whole magnetic storm change, i.e. the sum of Dst and DS, is greatly augmented near the magnetic equator, from the onset of the storm through the initial phase, during the hours of sunlight, the maximum effect is near noon (FR-1, 95-114). The dials of DS(H) for group 8 for the average weak storm and the average great

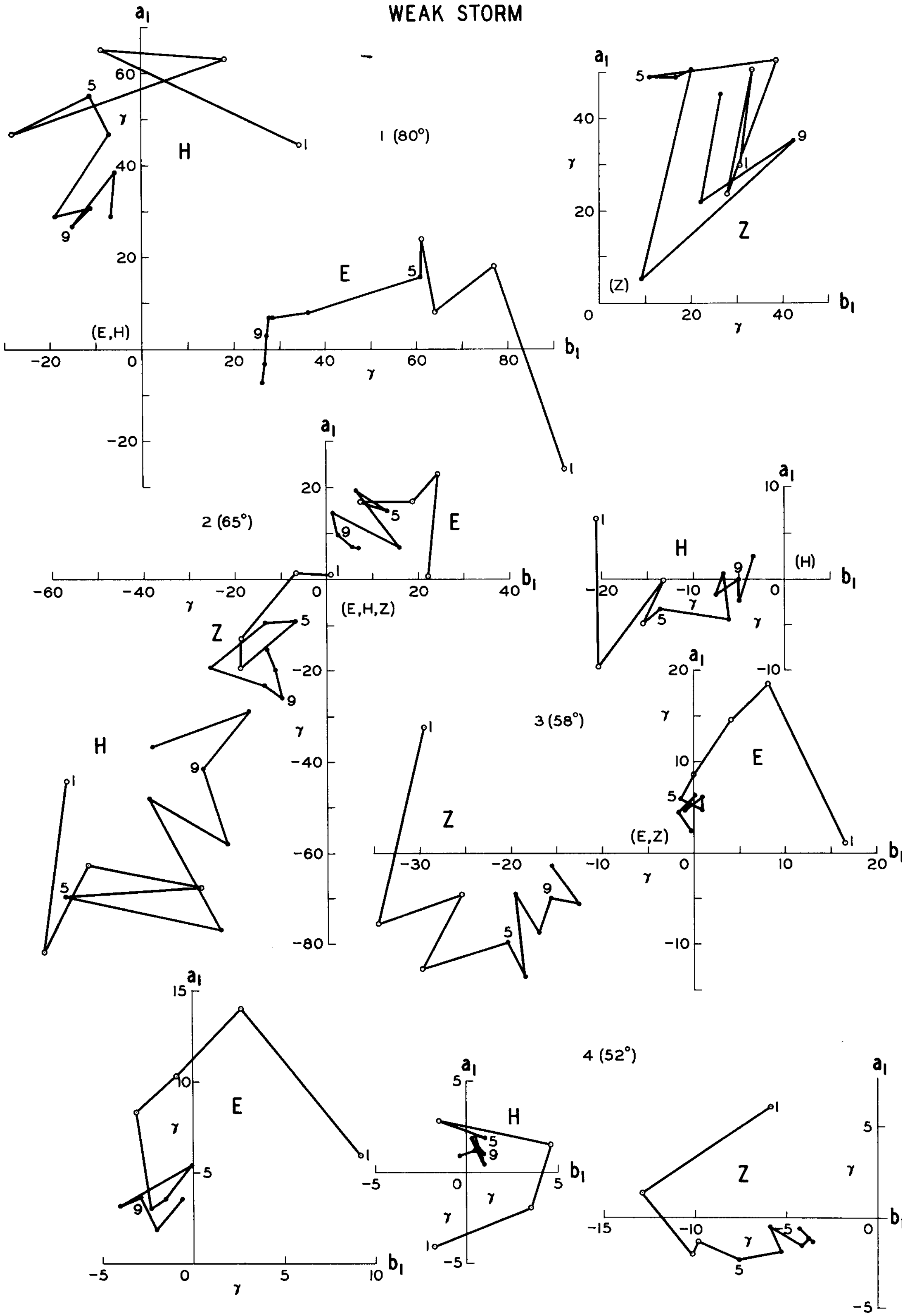


Fig. 19. Harmonic dials for the first component of DS in H, E, and Z, for the average weak storm, for the observatory-groups 1, 2, 3, and 4. The numbers in parentheses are the mean geomagnetic latitudes. The eleven points refer to the eight 6-hour intervals and the following three 8-hour intervals.

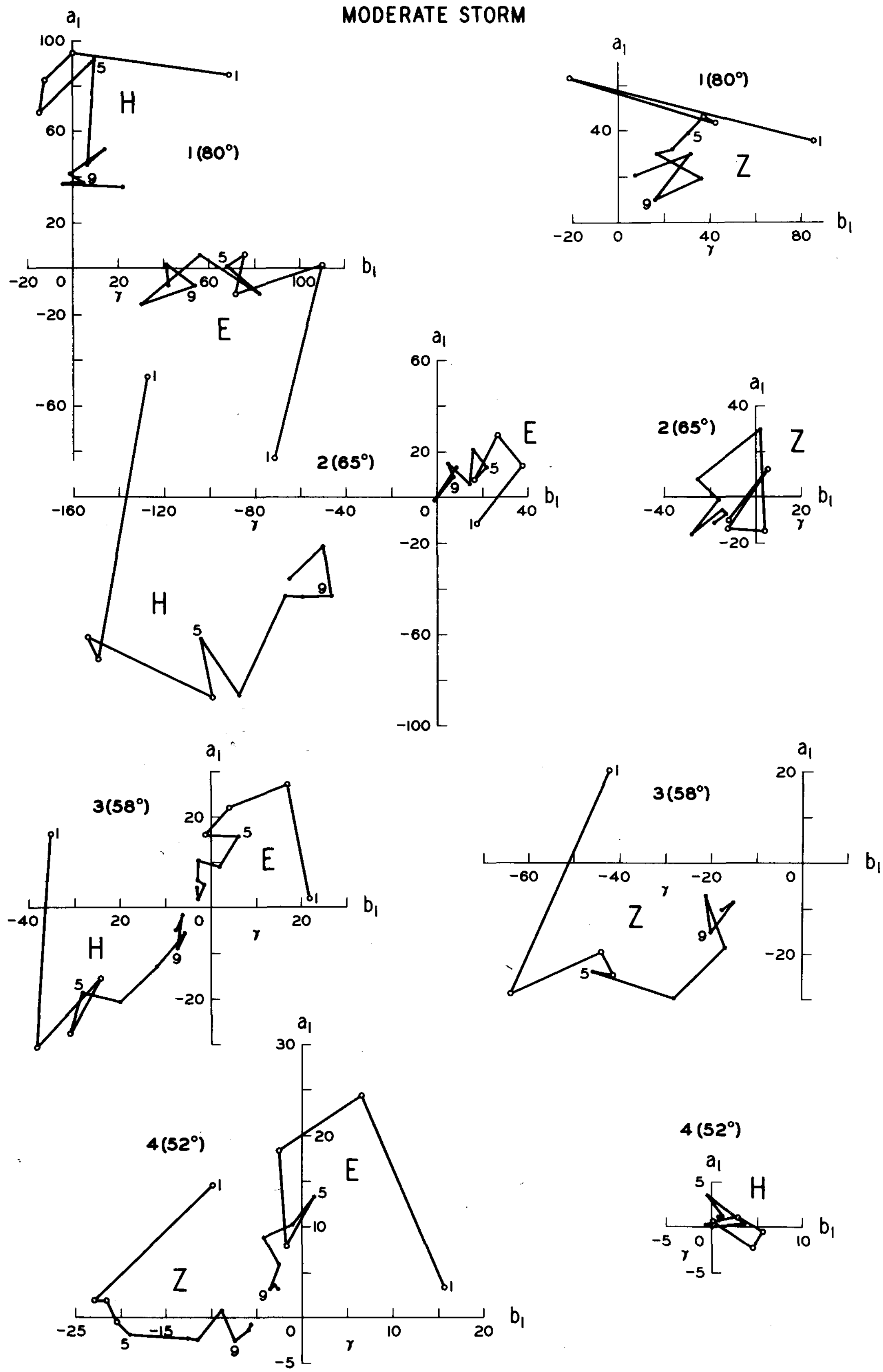


Fig. 20. Harmonic dials for the first component of DS in H, E, and Z, for the average moderate storm for the observatory-groups 1, 2, 3, and 4. The numbers in parentheses are the mean geomagnetic latitudes. The eleven points refer to the eleven intervals as in Fig. 19.

GREAT STORM

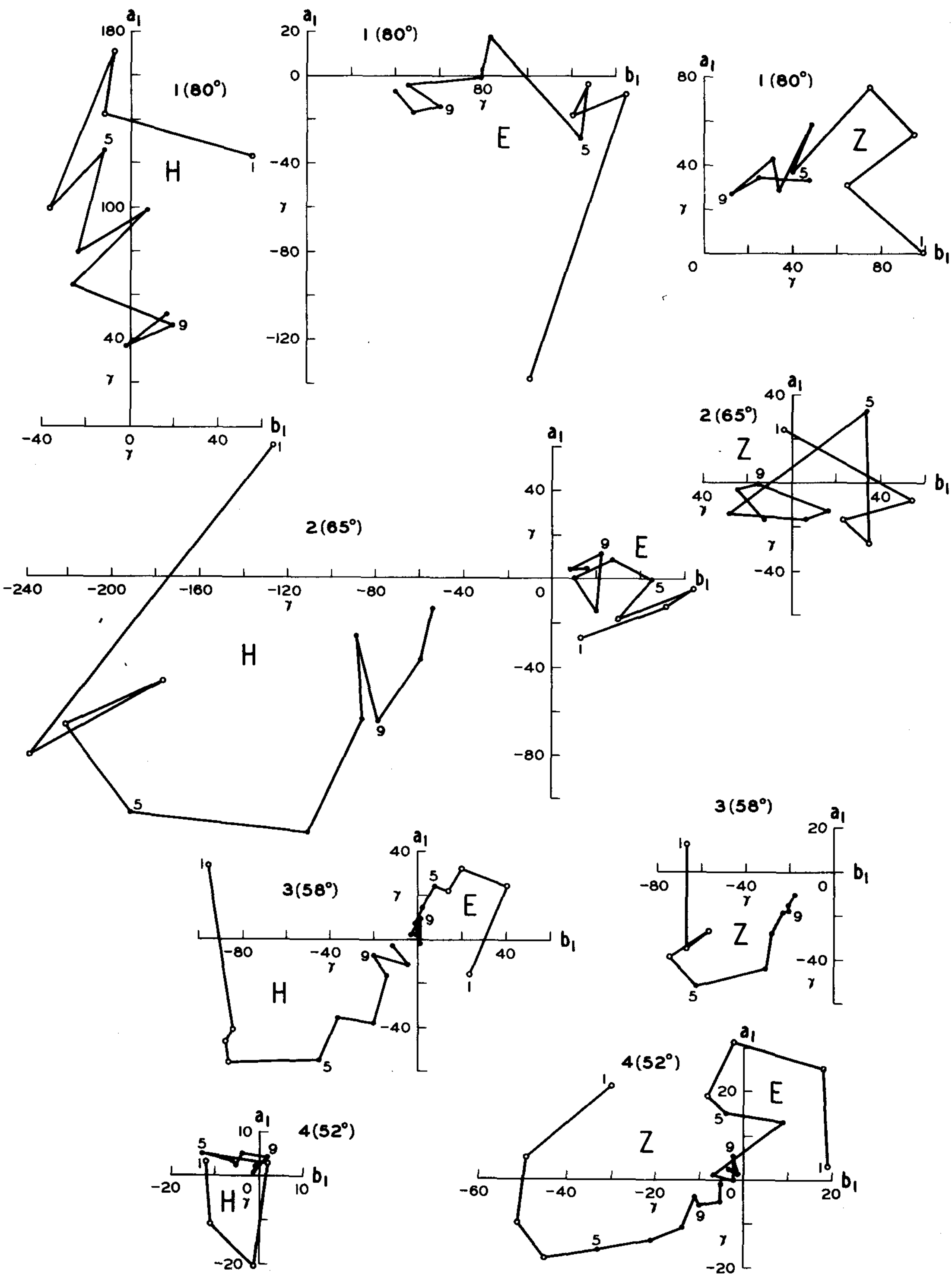


Fig. 21. Harmonic dials for the first component of DS in H, E, and Z, for the average <u>great</u> storm for the observatory-groups 1, 2, 3, and 4. The numbers in parentheses are the mean geomagnetic latitudes. The eleven points refer to the eleven intervals as in Fig. 19.

WEAK STORM

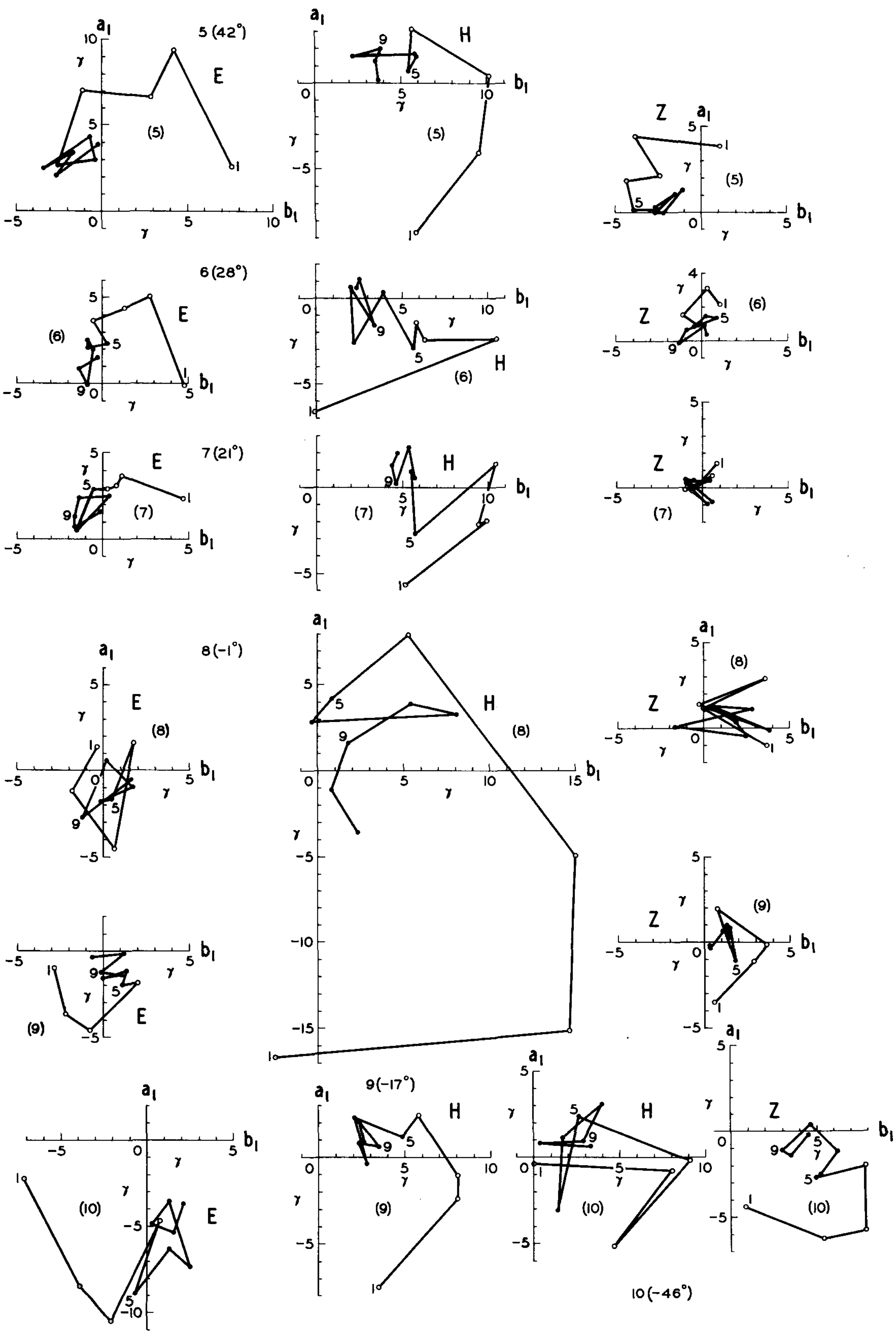


Fig. 22. Harmonic dials for the first component of DS in H, E, and Z, for the average weak storm, for the observatory-groups 5, 6, 7, 8, 9, and 10. The numbers in parentheses are the mean geomagnetic latitudes, negative sign indicating southern latitude. The eleven points refer to the first eight 6-hour intervals and the following three 8-hour intervals.

MODERATE STORM

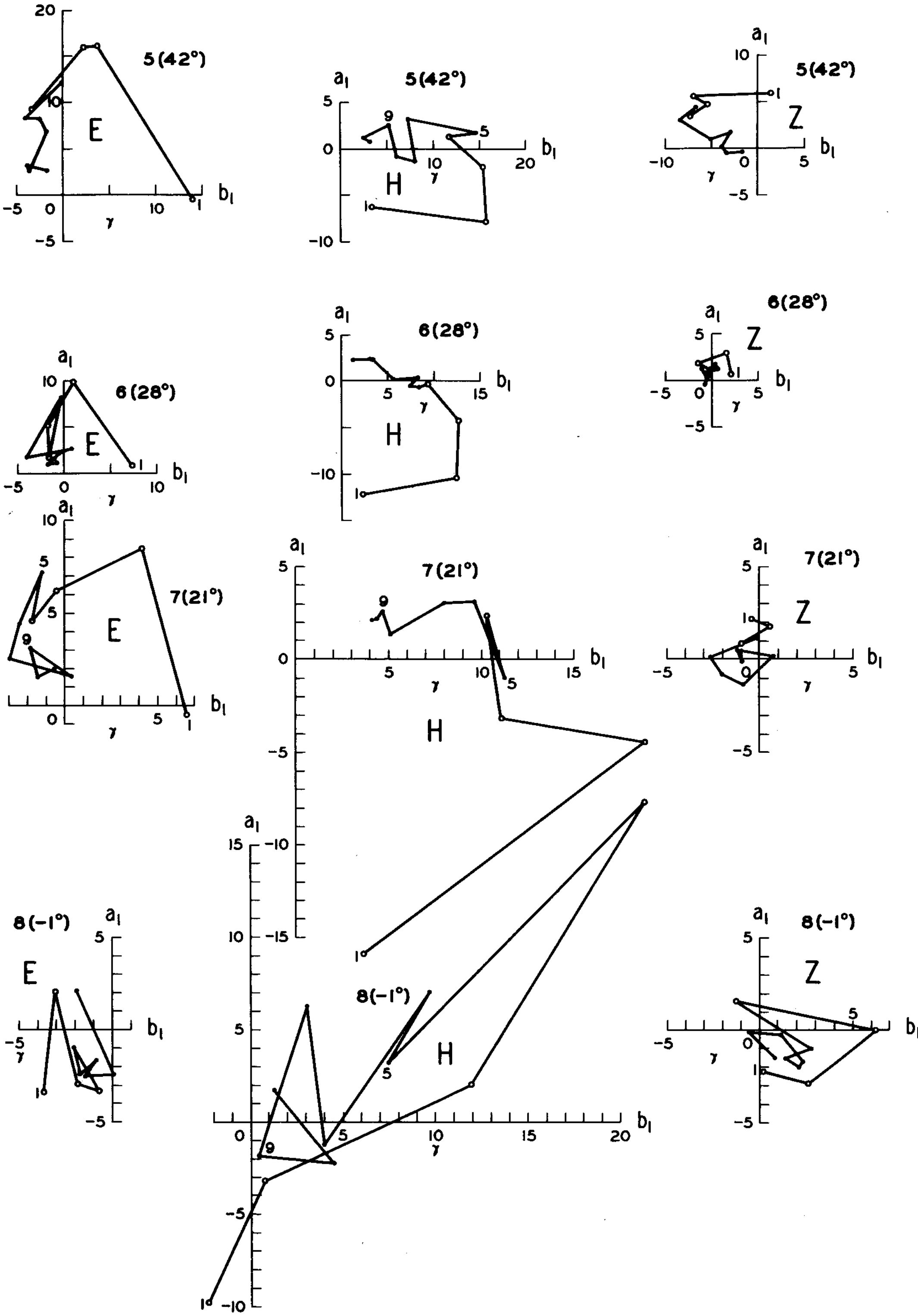


Fig. 23. Harmonic dials for the first component of DS in H, E, and Z, for the average moderate storm for the observatory groups 5, 6, 7, and 8. The numbers in parentheses are the mean geomagnetic latitudes, negative sign indicating southern latitude. The eleven points refer to the same intervals as in Fig. 22.

GREAT STORM

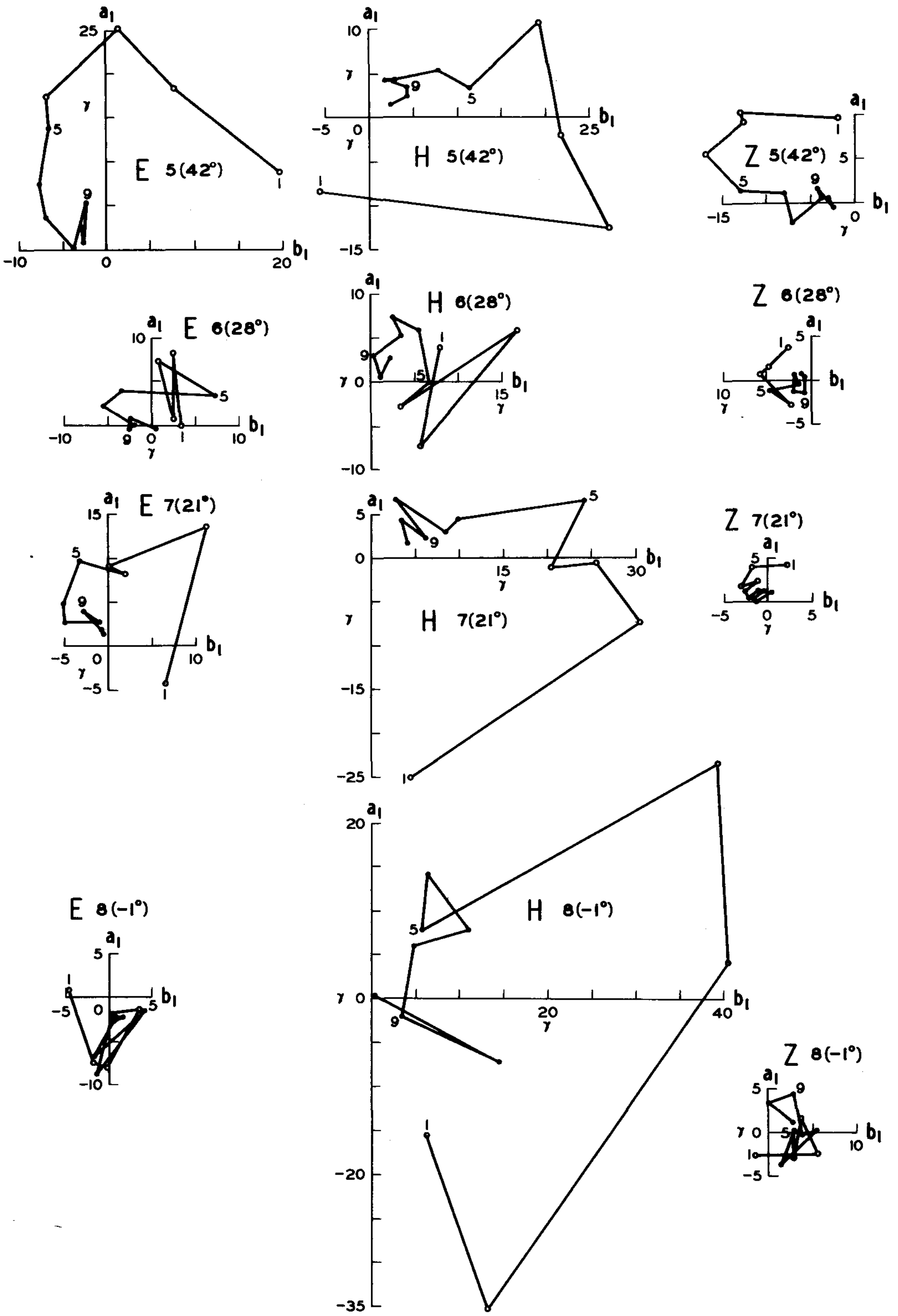


Fig. 24. Harmonic dials for the first component of DS in H, E, and Z for the average great storm for the observatory-groups 5, 6, 7, and 8. The numbers in parentheses are the mean geomagnetic latitudes, negative sign indicating southern latitude. The eleven points refer to the same intervals as in Fig. 22.

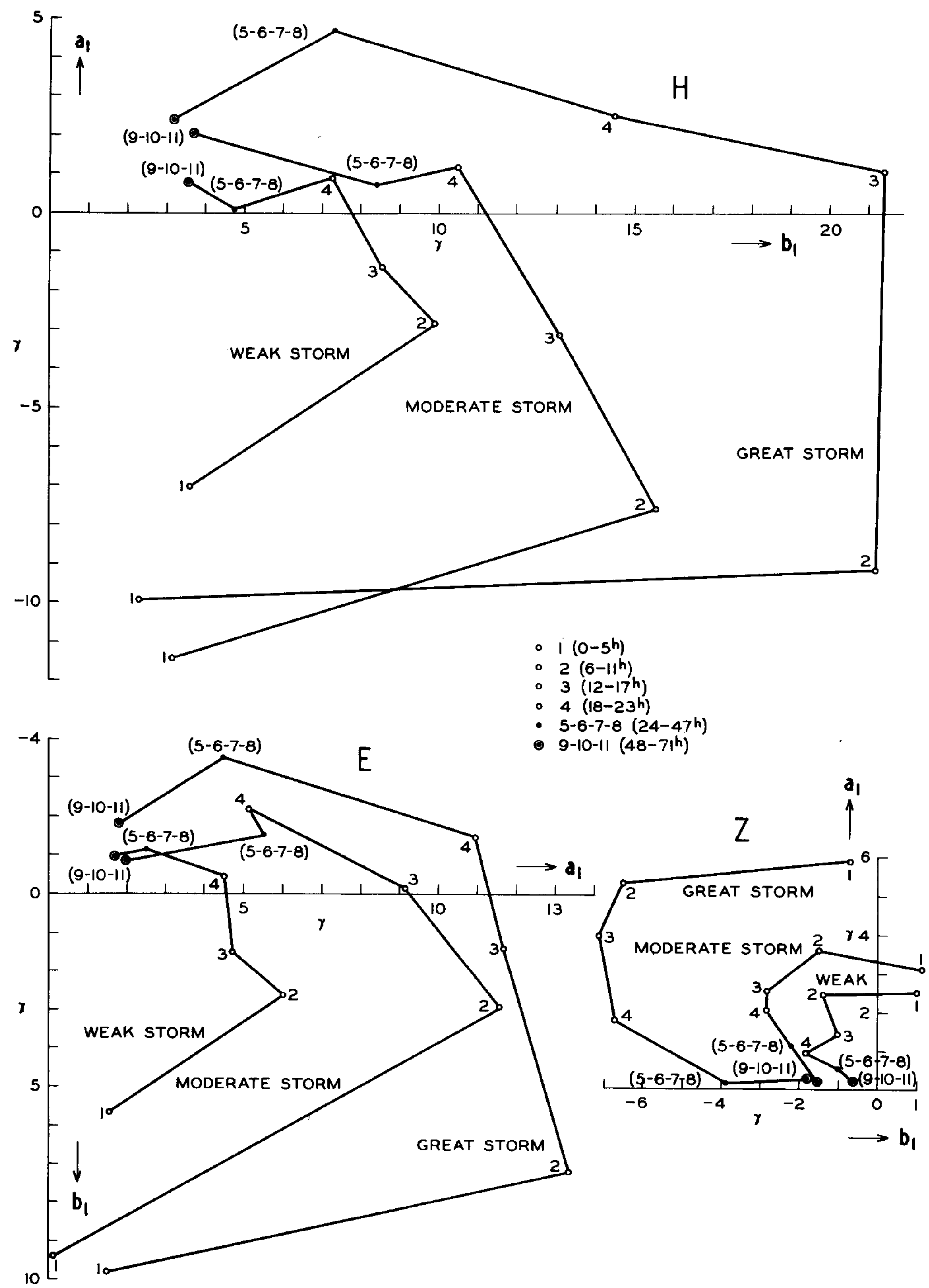


Fig. 25. Harmonic dials for the first component of DS in H, E, and Z for the average weak storm, the average moderate storm, and the average great storm, mean of the observatory-groups 5(42°), 6(28°), and 7(21°), the numbers in parentheses being geomagnetic latitudes. The dial points 1 to 4 refer to the first four six-hour intervals (in the first day), and the points marked by (5-8) and those by (9-11) refer to the second and third days, respectively. The harmonic dial for E is rotated clockwise through 90°.

storm seem to show characteristics similar to those for the groups in low and moderate latitudes. However, the dial for DS(H) for the average moderate storm is irregular. Thus it is as yet uncertain whether the DS variation in H is merely augmented near the magnetic equator, preserving its normal phase, characteristic in the low latitude regions, or it changes its phase also.

In order to summarize the characteristics of the DS variations in the three elements for low to middle latitudes, the harmonic data for groups 5, 6 and 7 are combined. Since the changes in the second and third days are small and of magnitudes comparable with the irregularities, means are formed of a_1 and b_1 for the intervals 5 to 8 (the second day) and intervals 9 to 11 (the third day). The harmonic dials so obtained are shown in Fig. 25. In the figure the harmonic dial for E is rotated clockwise by 90°, which brings it to nearly the same phase as in the dial for H. The numerical data for Fig. 25 are given in Table 6. The comparison of the phase angles σ_1, for the weak, moderate, and great storms, given in Table 6, shows remarkable agreement between them.

From the harmonic dials in Fig. 25 it is possible to determine for these latitudes the statistical averages of the amplitudes and phases of DS in the three elements for any given moment of storm time, or for any storm phase, in a magnetic storm of any intensity within the range considered here.

6. HIGHER HARMONIC COMPONENTS OF DS AND SD

Figs. 26 and 27 show the harmonic dials for E, H, and Z for the second component of DS for the mean of the observatory-groups 4, 5, 6, and 7, for the average moderate storm and the average great storm, respectively. In these figures the eleven dial points for each element refer to the same eleven epochs of storm time as in Figs. 19-24. The second component is clearly much smaller than the first.

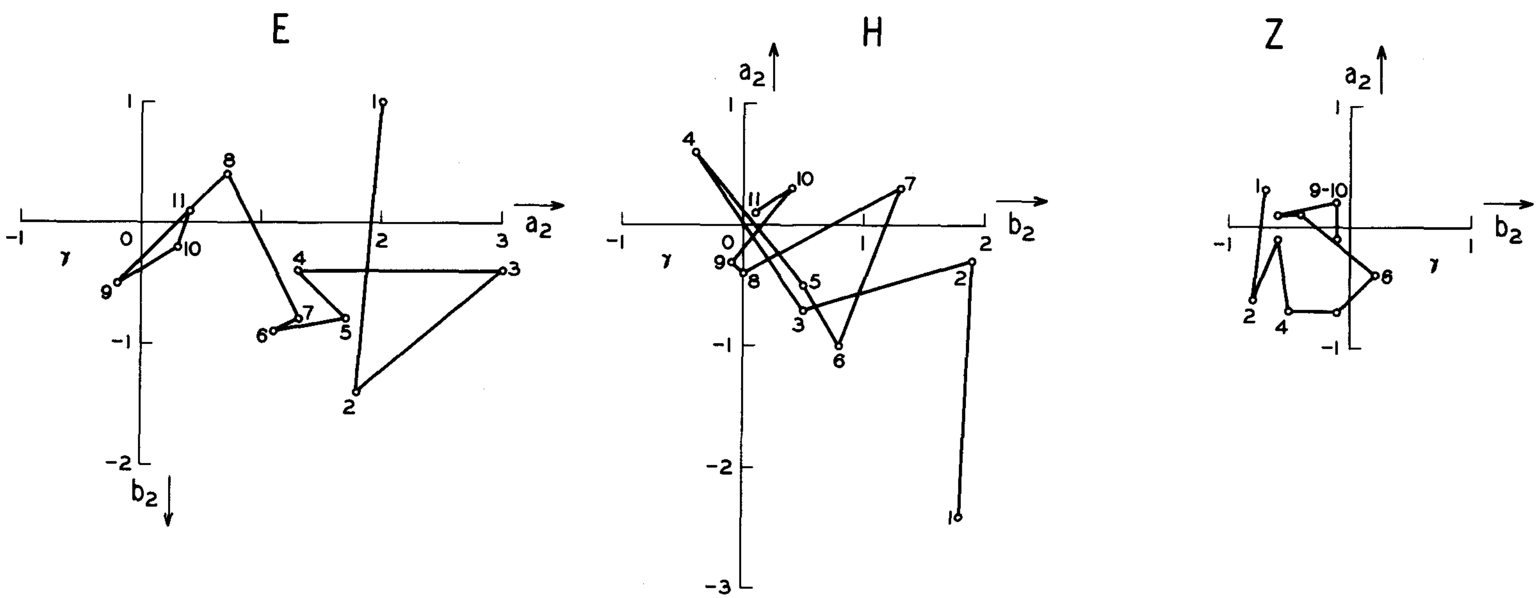


Fig. 26. Harmonic dials for the second component of DS in H, E, and Z for the average <u>moderate</u> storm; mean of the observatory-groups 4(52°), 5(42°), 6(28°), and 7(21°), the numbers in parentheses being geomagnetic latitudes. The eleven dial points refer to the first eight 6-hour intervals (in the first and second days) and the following three 8-hour intervals (in the third day).

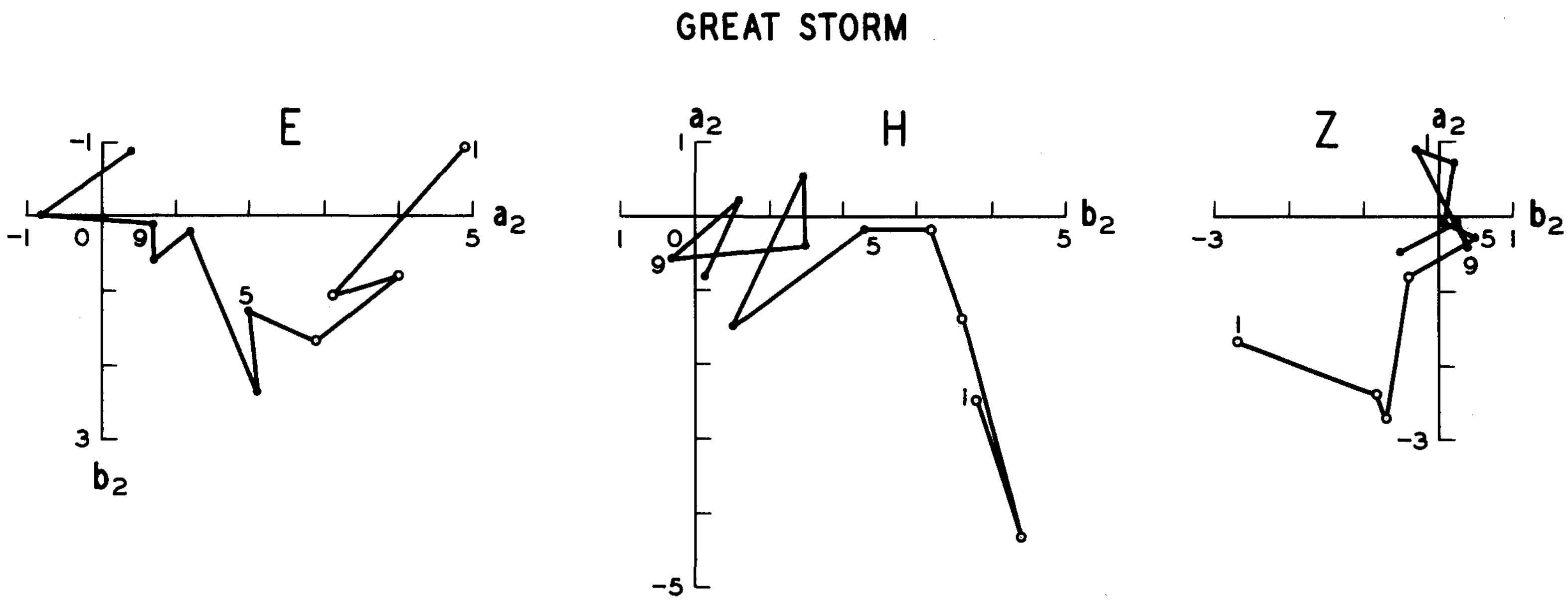


Fig. 27. Harmonic dials for the second component of DS in H, E, and Z for the average <u>great</u> storm; mean of the observatory-groups 4(52°), 5(42°), 6(28°), and 7(21°), the numbers in parentheses being geomagnetic latitudes. The eleven dial points refer to the first eight 6-hour intervals (in the first and second days) and the following three 8-hour intervals (in the third day).

TABLE 5. Harmonic data for the first component of DS in E, H, and Z, measured in gamma, for the average great storm. Intervals 1 to 11 refer to the storm-time intervals 0-5, 6-11, 12-17, 18-23, 24-29, 30-35, 36-41, 42-47, 48-55, 56-63, 64-71, hours; DS is expressed as:

$$\sum_n (a_n \cos n\lambda_s + b_n \sin n\lambda_s), \quad \text{or} \quad \sum_n c_n \sin(n\lambda_s + \sigma_n),$$

where λ_s is gm time reckoned from the gm midnight meridian.
Unit for a_1, b_1, and c_1 : gamma.

Group 1 (80°). Godhavn.

Interval	a_1	b_1	c_1	σ_1	
					E
1	-138.4	102.3	172.1	306°	
2	-8.0	144.8	145.0	357	
3	-18.1	121.4	122.7	352	
4	-3.3	127.6	127.6	359	
5	-28.8	125.2	128.5	347	
6	18.3	83.0	85.0	12	
7	-0.8	79.2	79.2	359	
8	-5.2	45.8	46.1	354	
9	-13.9	61.2	62.8	347	
10	-16.8	49.2	52.0	341	
11	-7.2	39.8	40.4	350	
					H
1	122.9	54.5	134.4	66°	
2	142.4	-11.7	142.9	95	
3	171.0	-7.0	171.1	92	
4	99.2	-35.5	105.4	110	
5	126.3	-12.3	126.9	96	
6	78.8	-23.9	82.3	107	
7	98.0	8.4	98.4	85	
8	65.0	-26.1	70.1	112	
9	45.7	18.8	49.4	68	
10	36.9	-1.3	36.9	92	
11	51.0	17.3	53.9	71	
					Z
1	0.1	98.4	98.4	0°	
2	30.6	65.1	71.9	25	
3	54.0	94.6	108.9	30	
4	75.3	74.8	106.1	45	
5	37.4	40.3	55.0	43	
6	58.0	48.8	75.8	50	
7	28.6	33.7	44.2	40	
8	43.2	31.1	53.2	54	
9	26.9	13.0	29.9	64	
10	33.8	24.6	41.8	54	
11	33.0	46.8	57.3	35	

Group 2 (65°). Sodankylä, Tromsö, Lerwick.

Interval	a_1	b_1	c_1	σ_1	
					E
1	-27.1	13.2	30.1	296°	
2	-12.5	51.8	53.3	346	
3	-4.8	64.1	64.3	356	
4	-17.6	29.5	34.4	329	
5	-0.3	44.6	44.6	0	
6	8.8	27.2	28.6	18	
7	0.8	9.5	9.5	5	
8	-15.3	19.2	24.6	321	
9	11.2	22.3	25.0	27	
10	4.9	8.9	10.2	29	
11	4.4	16.0	16.6	15	
					H
1	59.7	-137.3	149.7	156°	
2	-81.4	-240.3	253.7	199	
3	-47.3	-175.9	182.1	195	
4	-68.0	-220.9	231.1	197	
5	-107.0	-191.3	219.2	209	
6	-116.0	-111.2	160.7	226	
7	-63.9	-85.9	107.1	217	
8	-26.0	-89.3	93.0	196	
9	-64.9	-78.5	101.9	220	
10	-36.7	-58.8	69.3	212	
11	-13.0	-53.7	55.3	194	
					Z
1	21.5	-3.4	21.8	99°	
2	-7.6	54.3	54.8	352	
3	-17.3	22.9	28.7	323	
4	-30.8	34.8	46.5	318	
5	32.7	33.9	47.1	44	
6	-14.1	-27.8	31.2	207	
7	-16.1	6.1	17.2	291	
8	-12.8	17.1	21.4	323	
9	-0.6	-15.2	15.2	182	
10	-2.8	-24.7	24.9	186	
11	-16.3	-12.1	20.3	233	

Group 3 (58°). Sitka, Eskdalemuir, Lovö, Rude Skov.

Interval	a_1	b_1	c_1	σ_1	E
1	-15.8	24.2	28.9	327°	
2	23.7	40.5	46.9	30	
3	33.0	19.7	44.4	48	
4	22.0	14.4	26.3	57	
5	24.8	8.0	26.1	72	
6	13.5	2.1	13.7	81	
7	6.2	-1.0	6.3	99	
8	-1.9	1.3	2.3	304	
9	9.9	0.1	9.9	89	
10	2.3	-3.9	4.5	149	
11	3.4	-1.3	3.6	111	
					H
1	32.6	-94.8	100.3	161°	
2	-42.0	-84.2	94.1	207	
3	-47.3	-87.0	99.0	209	
4	-56.8	-86.0	103.0	213	
5	-54.5	-45.3	70.9	230	
6	-36.1	-36.3	51.2	225	
7	-38.3	-19.7	43.1	243	
8	-16.8	-13.5	21.6	231	
9	-7.9	-20.4	21.9	201	
10	-11.7	-3.9	12.3	252	
11	-3.2	-11.9	12.3	195	
					Z
1	12.8	-65.6	66.8	169°	
2	-36.3	-65.6	75.0	209	
3	-26.6	-55.5	61.5	206	
4	-39.0	-74.3	83.9	208	
5	-51.7	-62.3	81.0	220	
6	-45.3	-30.5	54.6	236	
7	-26.8	-27.8	38.6	224	
8	-18.3	-22.8	29.2	219	
9	-18.4	-21.4	28.2	221	
10	-15.7	-20.6	25.9	217	
11	-10.5	-18.3	21.1	210	

Group 4 (52°). DeBilt, Greenwich, Cheltenham, Val Joyeux.

Interval	a_1	b_1	c_1	σ_1	
					E
1	2.7	18.8	19.0	8°	
2	25.0	17.7	30.6	55	
3	31.2	-1.6	31.2	93	
4	19.0	-8.0	20.6	113	
5	15.2	-3.9	15.7	104	
6	12.8	9.3	15.8	54	
7	1.0	-7.3	7.4	172	
8	0.0	-1.9	1.9	180	
9	5.5	-2.3	6.0	113	
10	1.0	-1.5	1.8	146	
11	2.4	-3.4	4.2	145	
					H
1	2.7	-11.5	11.8	167°	
2	-11.1	-11.3	15.8	224	
3	-20.3	-0.9	20.3	267	
4	2.6	2.1	3.3	51	
5	5.2	-12.8	13.8	158	
6	3.5	-6.2	7.1	151	
7	2.8	-5.4	6.1	153	
8	5.3	-3.8	6.5	126	
9	3.5	3.7	5.1	43	
10	0.6	-1.0	1.2	149	
11	1.6	-0.1	1.6	94	
					Z
1	20.6	-29.8	36.2	145°	
2	5.1	-48.5	48.8	174	
3	-10.3	-50.8	51.8	191	
4	-17.7	-45.3	48.6	201	
5	-15.5	-33.4	36.8	205	
6	-13.9	-21.2	25.4	213	
7	-10.7	-13.6	17.3	218	
8	-3.7	-10.8	11.4	199	
9	-5.9	-9.8	11.4	211	
10	-4.5	-5.4	7.0	220	
11	-1.4	-4.9	5.1	196	

Group 5 (42°). Ebro, Tucson.

Interval	a_1	b_1	c_1	σ_1	
					E
1	8.8	19.6	21.5	24°	
2	18.3	7.8	19.9	67	
3	25.2	1.4	25.2	87	
4	17.2	-6.8	18.5	112	
5	13.8	-6.6	15.3	116	
6	7.0	-7.8	10.5	138	
7	3.7	-7.0	7.9	152	
8	0.1	-3.8	3.8	179	
9	5.3	-2.3	5.8	113	
10	1.0	-2.7	2.9	160	
11	2.6	-2.8	3.8	137	
					H
1	-8.3	-5.6	10.0	236°	
2	-12.7	27.3	30.1	335	
3	-2.0	21.8	21.9	355	
4	11.4	19.6	22.7	30	
5	3.3	11.3	11.8	16	
6	5.3	7.8	9.4	34	
7	4.1	2.8	5.0	56	
8	4.1	1.8	4.5	66	
9	3.3	4.2	5.3	38	
10	2.2	4.1	4.7	28	
11	1.3	2.5	2.8	27	
					Z
1	9.7	-1.8	9.9	101°	
2	10.4	-12.8	16.5	141	
3	9.1	-12.5	15.5	144	
4	5.7	-16.8	17.7	161	
5	1.5	-12.7	12.8	173	
6	1.1	-7.9	8.0	172	
7	-2.2	-7.0	7.3	197	
8	0.3	-3.4	3.4	175	
9	1.6	-4.2	4.5	159	
10	-0.3	-2.3	2.3	187	
11	0.6	-3.2	3.3	169	

Group 6 (28°). San Juan, Kakioka.

Interval	a_1	b_1	c_1	σ_1	
					E
1	0.0	3.3	3.3	0°	
2	8.3	2.5	8.7	73	
3	0.9	2.7	2.8	18	
4	7.4	0.7	7.4	85	
5	3.4	7.1	7.9	26	
6	3.9	-3.4	5.2	131	
7	2.2	-5.4	5.8	158	
8	0.0	-2.0	2.0	180	
9	-0.6	-2.6	2.7	193	
10	0.9	-2.3	2.5	159	
11	-0.4	0.3	0.5	307	
					H
1	3.8	8.0	8.9	25°	
2	-7.3	5.7	9.3	308	
3	5.8	16.8	17.8	19	
4	-2.7	3.6	4.5	323	
5	-0.1	6.8	6.8	359	
6	5.9	5.7	8.2	46	
7	7.4	2.7	7.9	70	
8	5.2	3.5	6.3	56	
9	3.0	0.4	3.0	82	
10	0.5	1.2	1.3	23	
11	2.8	2.3	3.6	51	
					Z
1	3.8	-2.6	4.6	124°	
2	1.5	-4.8	5.0	163	
3	0.6	-5.8	5.8	174	
4	-2.6	-2.2	3.4	230	
5	-1.0	-4.7	4.8	192	
6	-0.5	-1.3	1.4	201	
7	0.5	-1.9	2.0	165	
8	-1.3	-1.8	2.2	216	
9	-1.4	-0.6	1.5	247	
10	0.4	-0.6	0.7	146	
11	0.5	-0.8	0.9	148	

Group / (21°). Honolulu, Zikawei.

Interval	a_1	b_1	c_1	σ_1	
					E
1	-4.3	6.4	7.7	326°	
2	13.6	11.2	17.6	51	
3	9.0	0.1	9.0	89	
4	8.3	2.0	8.5	76	
5	9.8	-3.1	10.3	108	
6	4.9	-5.0	7.0	136	
7	2.7	-4.8	5.5	151	
8	2.7	-0.8	2.8	106	
9	3.9	-2.8	4.8	126	
10	1.8	-0.6	1.9	108	
11	1.4	-0.5	1.5	110	
					H
1	-25.0	4.4	25.4	280°	
2	-7.3	30.6	31.5	347	
3	-0.4	25.5	25.5	359	
4	-1.0	20.3	20.3	357	
5	6.5	24.2	25.1	15	
6	4.5	9.9	10.9	24	
7	3.0	8.5	9.0	19	
8	6.6	2.9	7.2	66	
9	2.3	6.2	6.6	20	
10	4.3	3.4	5.5	52	
11	1.8	4.1	4.5	24	
					Z
1	4.3	2.3	4.9	62°	
2	4.0	-1.9	4.4	115	
3	1.9	-3.0	3.6	148	
4	2.4	-1.1	2.6	115	
5	1.2	-2.8	3.0	157	
6	0.3	-2.1	2.1	172	
7	1.3	-0.8	1.5	122	
8	1.3	-0.5	1.4	111	
9	0.3	-1.8	1.8	171	
10	0.0	-1.7	1.7	180	
11	1.2	0.5	1.3	67	

Group 8 (-1°). Huancayo.

Interval	a_1	b_1	c_1	σ_1	
					E
1	1.0	-4.6	4.7	168°	
2	-7.6	-1.8	7.8	257	
3	-8.0	-0.1	8.0	269	
4	-1.4	3.8	4.0	340	
5	-1.9	0.3	1.9	279	
6	-8.8	-1.2	8.9	262	
7	-1.6	4.1	4.4	339	
8	-6.8	-1.8	7.0	255	
9	-2.8	0.5	2.8	280	
10	-2.3	1.8	2.9	308	
11	-2.4	0.4	2.4	279	
					H
1	-15.5	6.2	16.7	292°	
2	-35.2	13.3	37.6	291	
3	4.1	40.5	40.7	6	
4	26.9	39.5	47.8	34	
5	7.8	5.8	9.7	53	
6	14.0	6.3	15.4	66	
7	7.7	11.1	13.5	35	
8	6.0	4.9	7.7	51	
9	-2.2	3.7	4.3	329	
10	-7.3	14.6	16.3	333	
11	0.3	0.3	0.4	45	
					Z
1	-2.6	-1.3	2.9	243°	
2	-2.6	5.7	6.3	335	
3	1.5	3.8	4.1	22	
4	-2.9	2.9	4.1	315	
5	0.3	4.5	4.5	4	
6	-3.9	1.8	4.3	295	
7	0.1	5.1	5.1	1	
8	-0.1	3.4	3.4	358	
9	4.4	3.0	5.3	56	
10	3.3	0.0	3.3	90	
11	1.1	2.8	3.0	21	

Interval	Weak Storm a_1	Weak Storm b_1	Moderate Storm a_1	Moderate Storm b_1	Great Storm a_1	Great Storm b_1	Weak Storm c_1	Weak Storm σ_1	Moderate Storm c_1	Moderate Storm σ_1	Great Storm c_1	Great Storm σ_1
E												
1	1.6	5.7	0.1	9.4	1.5	9.8	5.9	16°	9.4	1°	9.9	9°
2	6.0	2.7	11.6	3.0	13.4	7.2	6.6	66	12.0	75	15.2	62
3	4.7	1.6	9.1	0.1	11.7	1.4	5.0	71	9.1	89	11.8	83
4	4.5	-0.4	5.2	-2.2	11.0	-1.4	4.5	95	5.6	113	11.1	97
5-8	2.5	-1.0	5.5	-1.5	4.5	-3.5	2.7	112	5.7	105	5.7	128
9-11	1.7	-0.9	2.0	-0.9	1.8	-1.8	1.9	118	2.2	114	2.5	135
H												
1	-7.0	3.6	-11.4	3.2	-9.8	2.3	7.9	-63	11.8	-74	10.1	-77
2	-2.8	9.9	-7.6	15.6	-9.1	21.2	10.3	-16	17.4	-26	23.1	-23
3	-1.4	8.6	-3.1	13.1	1.1	21.4	8.7	-9	13.5	-13	21.4	3
4	0.9	7.3	1.2	10.5	2.6	14.5	7.4	7	10.6	7	14.7	10
5-8	0.1	4.7	0.7	8.4	4.7	7.3	4.7	1	8.4	5	8.7	33
9-11	0.8	3.6	2.0	3.7	2.4	3.2	3.7	13	4.2	28	4.0	37
Z												
1	2.5	1.0	3.1	1.1	5.9	-0.7	2.7	68	3.3	70	5.9	97
2	2.4	-1.4	3.6	-1.5	5.3	-6.5	2.8	120	3.9	113	8.4	141
3	1.4	-1.0	2.5	-2.8	3.9	-7.1	1.7	126	3.8	138	8.1	151
4	0.9	-1.8	2.0	-2.8	1.8	-6.7	2.0	153	3.4	144	6.9	165
5-8	0.5	-1.0	1.1	-2.2	0.2	-3.9	1.1	153	2.5	153	3.9	177
9-11	0.2	-0.6	0.2	-1.5	0.3	-1.6	0.6	162	1.5	172	1.6	169

TABLE 6. Harmonic data for the first component of the DS variations in E, H, and Z, for the average weak, average moderate, and average great storm for the average of the observatory-groups 5, 6, and 7. The DS variations are expressed in the form:

$$\sum_n (a_n \cos n\lambda_s + b_n \sin n\lambda_s), \text{ or } \sum_n c_n \sin(n\lambda_s + \sigma_n),$$

where λ_s is reckoned from the midnight meridian; a_1, b_1 and c_1 in the table are measured in gamma, and σ_1 in degrees. Intervals 1, 2, 3, and 4 refer to the storm-time intervals $(0^h\text{-}5^h)$, $(6^h\text{-}11^h)$, $(12^h\text{-}17^h)$, and $(18^h\text{-}23^h)$, respectively, and intervals 5-8 and 9-11 to the second and third day, respectively.

TABLE 7. The harmonic coefficients for the first four components of SD. Mean of the observatory-groups 4, 5, 6, and 7; SD is expressed in the form

$$\sum_{n=1}^{4} (a_n \cos n\Lambda_s + b_n \sin n\Lambda_s),$$

where Λ_s is measured from the midnight meridian; a_n and b_n are reckoned in gamma.

Average Weak Storm

	storm day	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
	1	-1.8	6.4	-0.5	0.8	0.3	-0.3	-1.3	0.1
SD(H)	2	0.8	3.7	0.0	0.1	0.0	0.1	-0.4	0.2
	3	1.2	3.0	0.3	0.3	0.1	0.2	-0.5	0.3
	1	5.3	1.8	1.4	0.3	-0.7	-0.5	0.4	-0.2
SD(E)	2	3.3	-1.1	0.7	0.6	-0.4	-0.8	0.5	0.3
	3	2.3	-1.1	1.0	-0.1	-0.2	-0.2	0.2	0.3
	1	2.0	-3.5	0.1	-0.2	-0.2	-0.2	0.6	0.2
SD(Z)	2	0.5	-2.6	0.2	-0.2	-0.2	-0.3	0.4	0.3
	3	-0.1	-1.9	-0.1	-0.4	-0.2	-0.3	0.5	0.2

Average Moderate Storm

	storm day	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
	1	-4.0	8.8	-0.7	1.0	0.5	0.1	-0.2	-0.3
SD(H)	2	0.7	6.6	-0.4	0.7	0.1	0.2	-0.1	-0.1
	3	2.0	2.7	0.0	0.1	-0.1	-0.2	-0.1	0.1
	1	8.3	3.1	2.0	0.3	-1.2	-0.8	-0.4	0.0
SD(E)	2	6.5	-1.5	1.2	0.5	-1.0	-1.1	-0.1	0.3
	3	2.4	-2.1	0.2	0.2	-0.4	-0.7	0.1	0.2
	1	3.2	-5.7	-0.3	-0.7	-0.5	0.0	0.2	-0.1
SD(Z)	2	0.5	-5.0	-0.2	-0.3	-0.4	0.1	0.3	0.1
	3	-0.2	-2.7	0.1	-0.1	-0.2	0.0	0.1	0.0

Average Great Storm

	storm day	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
	1	-4.5	9.8	-2.1	3.8	0.1	-0.3	3.7	-3.3
SD(H)	2	4.6	3.7	-0.4	1.5	-0.2	-0.1	0.7	-0.8
	3	2.3	2.6	-0.4	0.1	-0.1	-0.6	0.2	0.8
	1	12.0	4.9	3.7	0.7	-2.3	-0.7	-1.1	2.2
SD(E)	2	5.2	-2.9	1.5	1.1	-1.3	-0.4	0.1	0.3
	3	2.1	-2.0	0.1	-0.3	-0.6	-0.4	-0.2	0.0
	1	3.0	-14.9	-1.9	-1.1	-1.8	0.3	2.7	0.6
SD(Z)	2	-2.6	-7.9	0.3	0.1	-0.1	1.4	0.2	0.1
	3	-0.8	-2.9	-0.3	-0.1	-0.7	0.2	-0.1	-0.1

To eliminate the irregular variations, the dial points in Figs. 26 and 27 are combined into all-day points for each of the three days; the dial points so determined are therefore those for the semi-diurnal component of SD^1, SD^2, and SD^3. These harmonic dials are shown in the upper part of Figs. 28 and 29, respectively for the average moderate storm and for the average great storm. The amplitude of SD_2 decreases steadily from the first to the third day; its phase appears to remain nearly constant.

The harmonic dials for the third (8-hour) and the fourth (6-hour) harmonic component of SD are also shown in Figs. 28 and 29. These higher harmonics are still smaller. It is uncertain whether or not there are systematic variations in the third and the fourth harmonic component of SD.

The numerical data for the second, the third, and the fourth harmonic component of SD, for the average weak storm, the average moderate storm, and the average great storm, are given in Table 7.

7. COMPARISON OF Dst AND DS

It is of great interest to compare the storm-time courses of the Dst and DS variations. Figs. 30, 31, and 32 show the Dst variations and the range of the first harmonic component of the DS variations, for the three elements, for the average weak storm, the average moderate storm, and the average great storm, respectively. The range of DS, $2C_1$, is plotted with negative sign, so that the DS curves more resemble Dst(H), which is mainly negative. Circles and dots are used, respectively for Dst and DS, to represent the values computed from the observational data. Each curve shows the variation throughout the first three storm days.

In Fig. 30 the force scale is the same for the observatory-groups 3 through 8; for groups 1 and 2, the scale is contracted 5-fold. In Fig. 31 the force

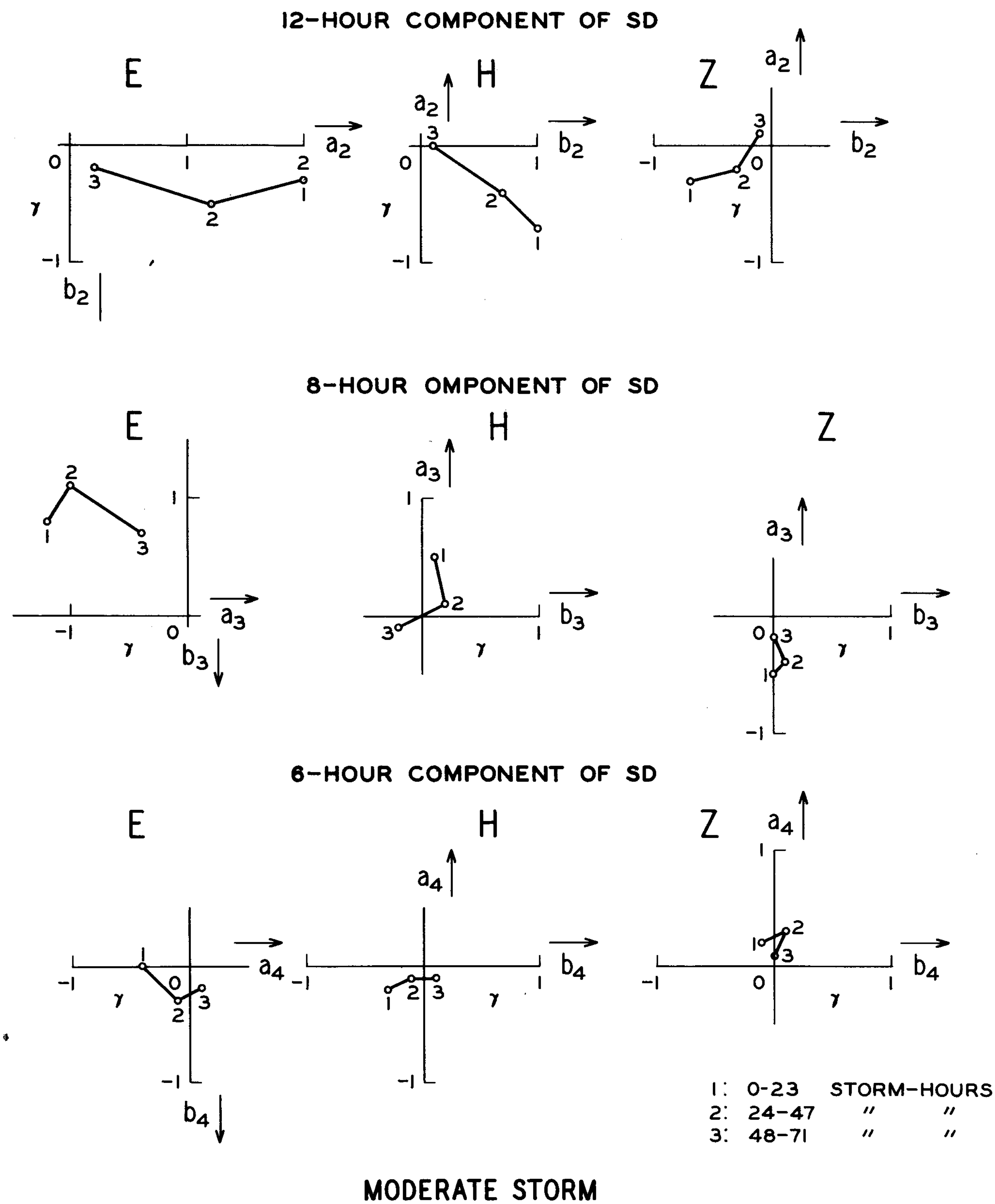


Fig. 28. Harmonic dials for SD_2, SD_3, and SD_4, for H, E, and Z for the average moderate storm; mean of the observatory-groups 4(52°), 5(42°), 6(28°), and 7(21°). The three dial points refer to the first, second, and third days of the storm.

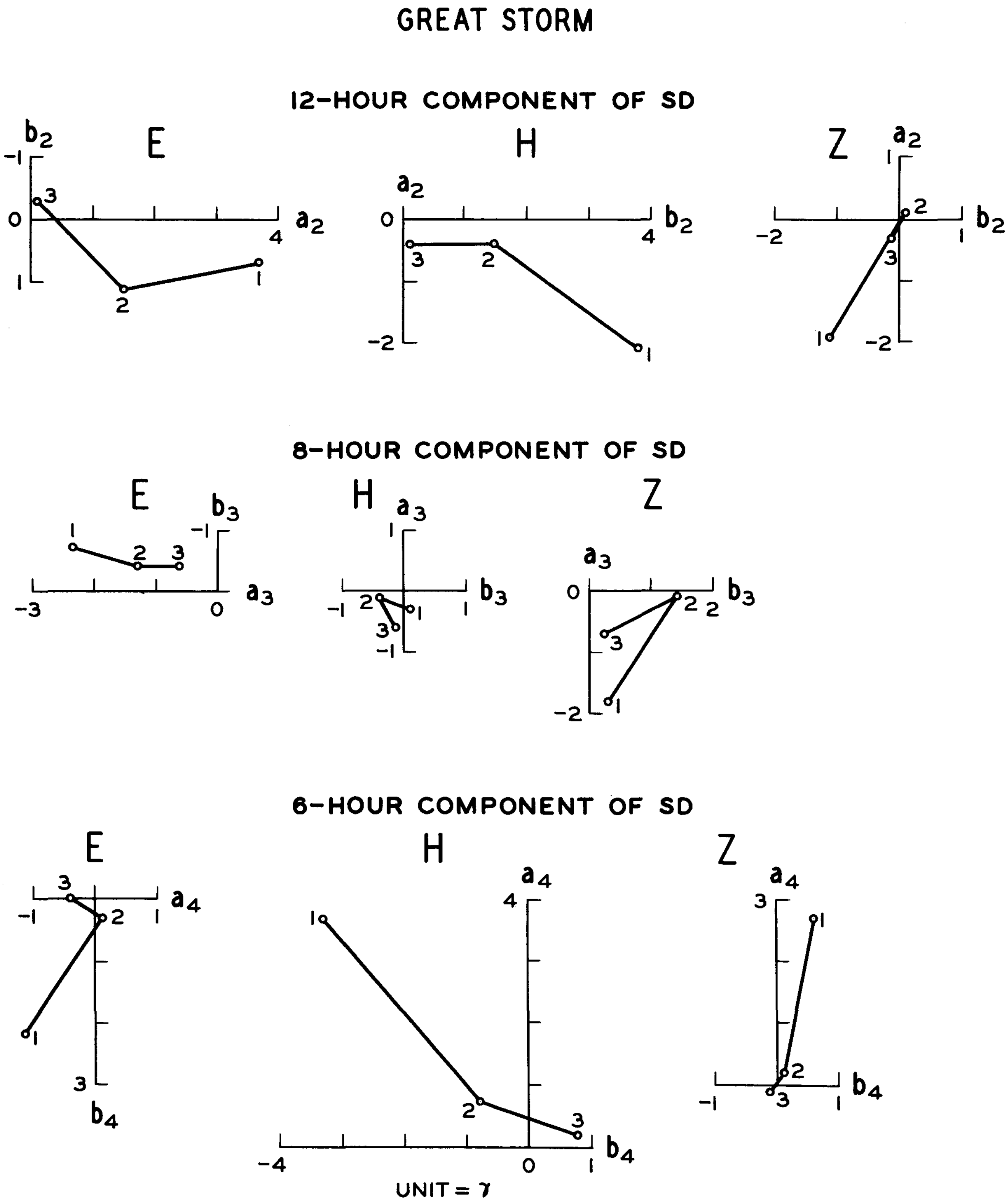


Fig. 29. Harmonic dials for SD_2, SD_3, and SD_4, for H, E, and Z for the average <u>great</u> storm; mean of the observatory-groups 4(52°), 5(42°), 6(28°), and 7(21°). The three dial points refer to the first, second, and third days of the storm.

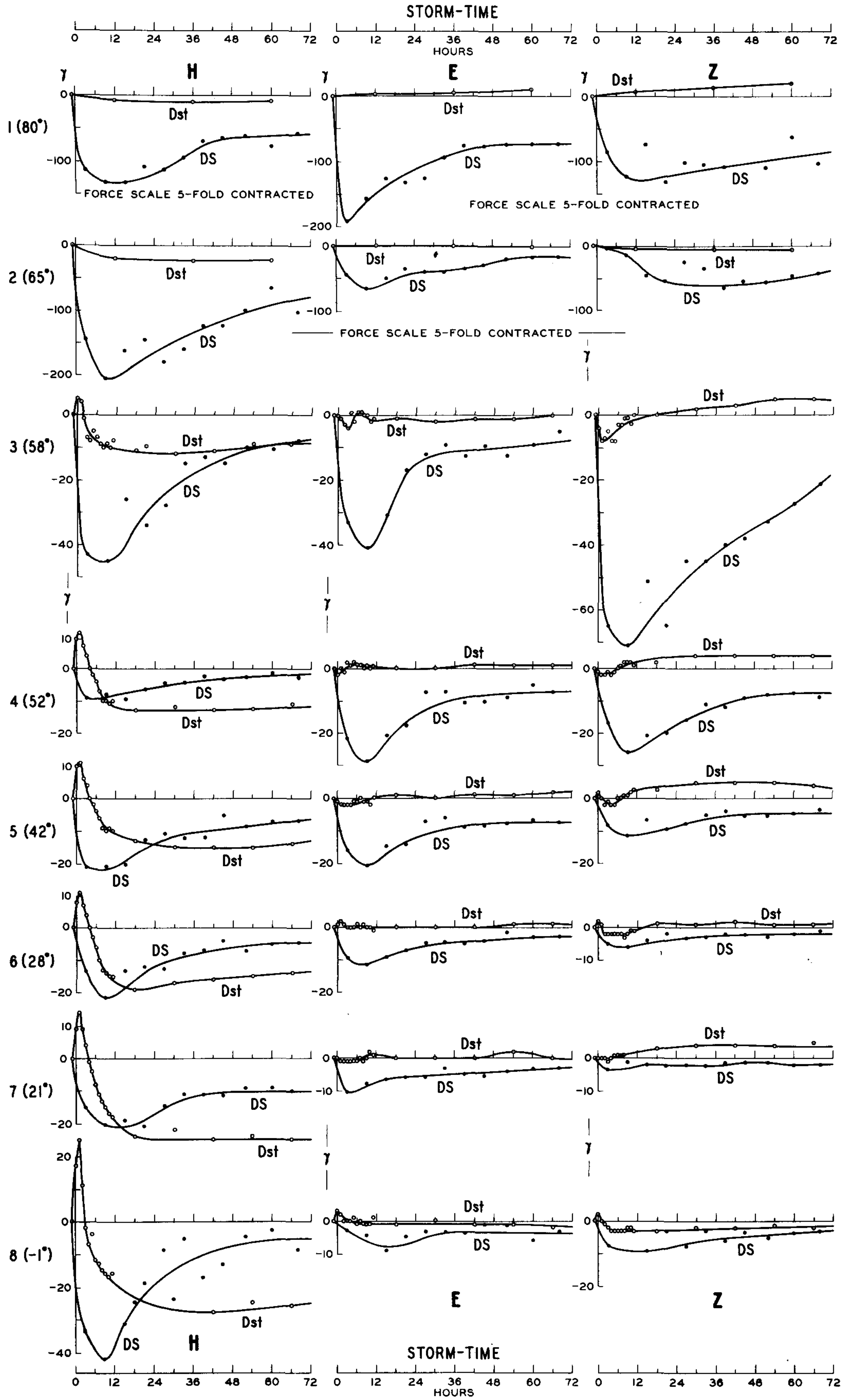


Fig. 30. Dst variations and the ranges (with negative sign) of the first harmonic component of DS, $(-2c_1)$, for H, E, and Z, plotted against storm time, for the average <u>weak</u> storm, for different geomagnetic latitudes.

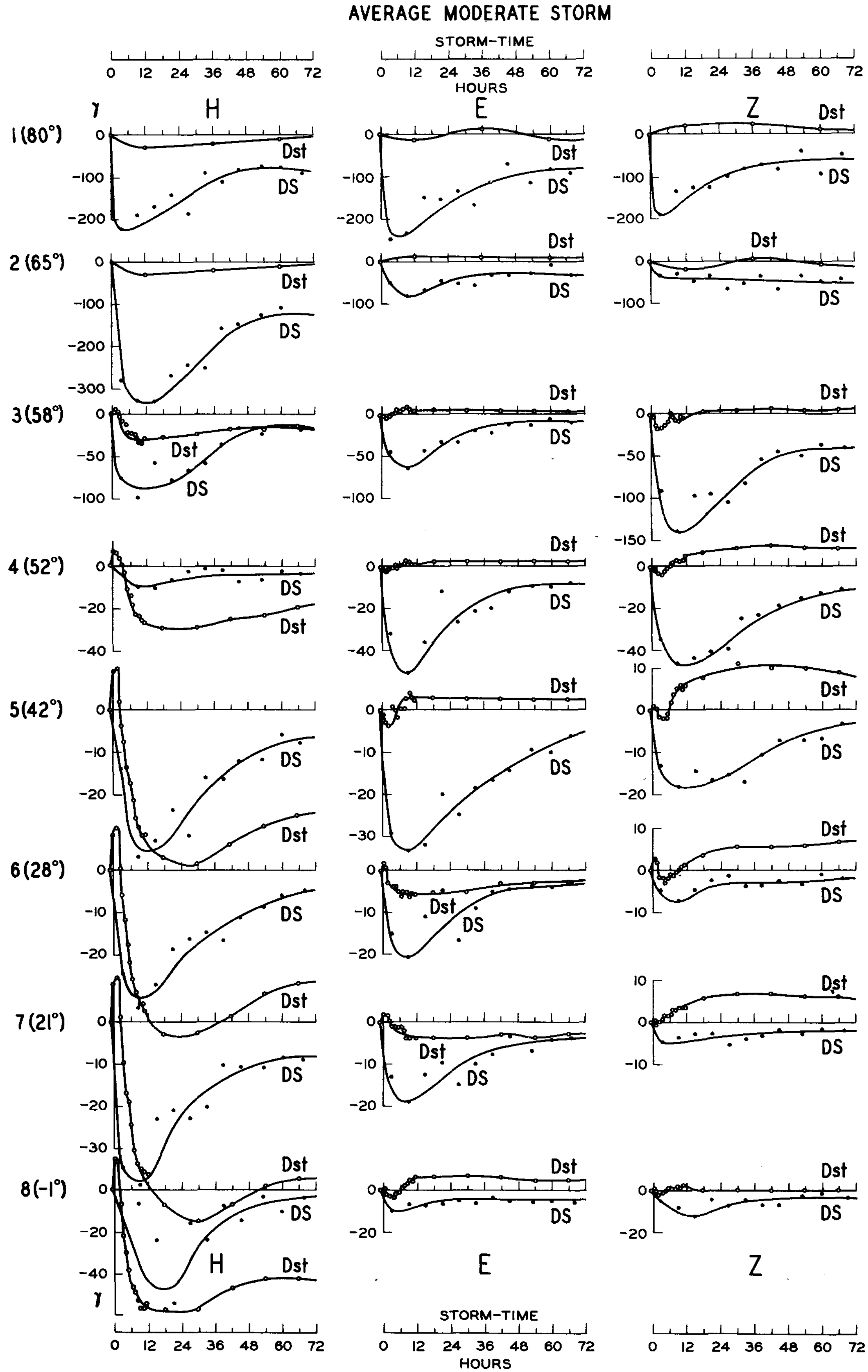


Fig. 31. Dst variations and the ranges (with negative sign) of the first harmonic component of DS, $(-2c_1)$, for H, E, and Z, plotted against storm time, for the average moderate storm, for different geomagnetic latitudes.

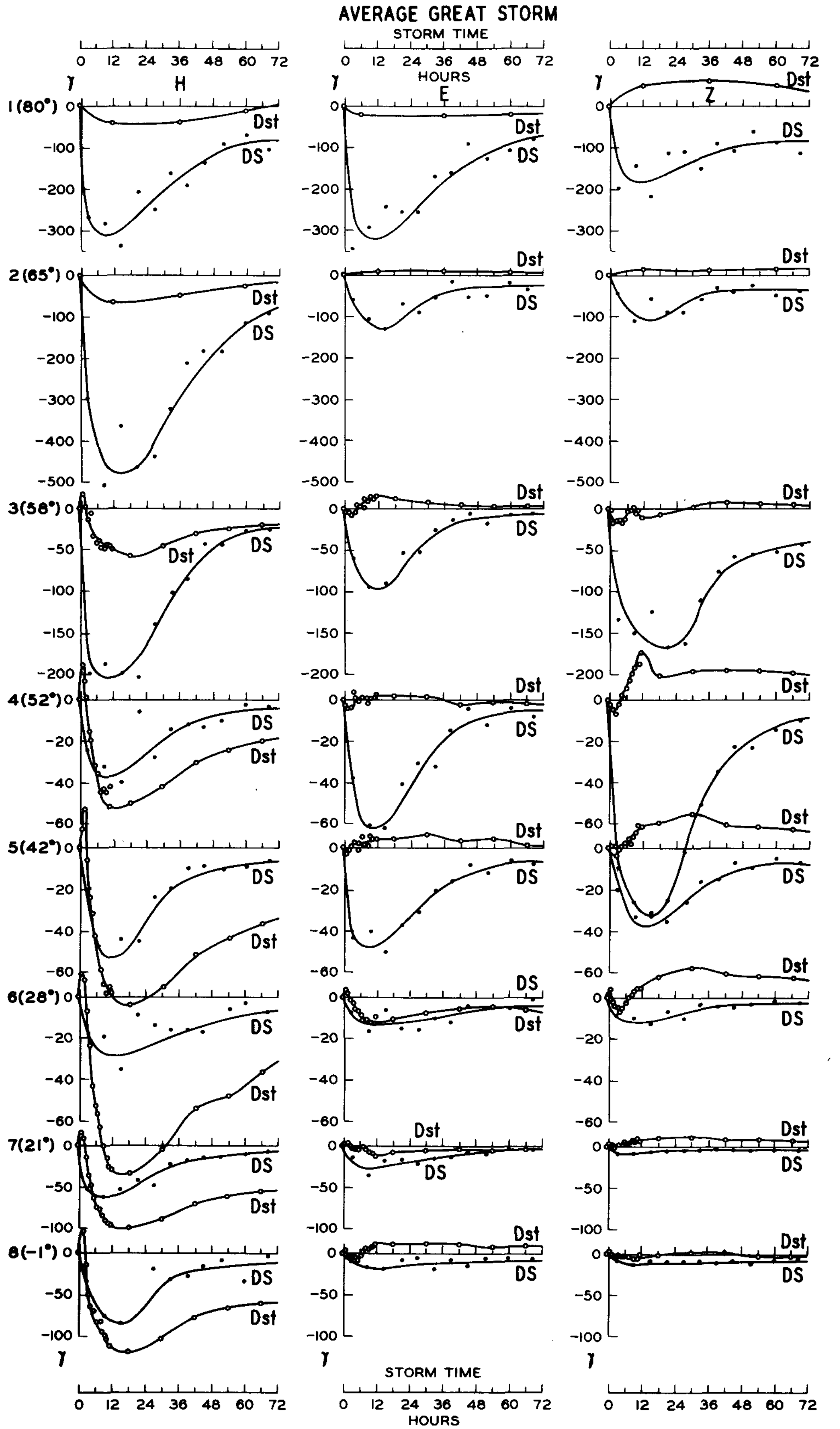


Fig. 32. Dst variations and the ranges (with negative sign) of the first harmonic component of DS, $(-2c_1)$, for H, E, and Z, plotted against storm time, for the average great storm, for different geomagnetic latitudes.

scale for groups 5 through 7 is the same; the scale is contracted 2-fold for groups 4 and 8, 5-fold for groups 3, and 10-fold for groups 1 and 2. In Fig. 32 the force scale used for groups 4 through 6 is the same, and is contracted 2.5-fold for groups 3, 7, and 8, 5-fold for groups 1 and 2.

At 80°, well inside the auroral zone, and at 65°, near the zone of maximum auroral frequencies (67°), DS predominates greatly over Dst. At 80°, DS in H and E are of comparable size; whereas at 65°, H is the predominant component of DS.

DS(H) decreases greatly from 65° to 58°, but DS(Z) increases from the former to the latter latitude. This is because the electric currents responsible for DS flow in a narrow belt, in the east-west direction, to the north of 58° and not far from 65° latitude; these electric currents are called the auroral electro-jets.

At 58°, though Dst is still small compared with DS, it begins to show the characteristics that mark it throughout moderate and low latitudes. These remarks refer to all of the three intensity groups.

In the average weak storm and the average moderate storm, the maximum of DS(Z) at 58°, is greater than the maxima of DS(H) and DS(E), and it decreases rather rapidly with decreasing latitude; at 52° it is reduced to roughly one-third the maximum DS(Z) at 58°, and is comparable with DS(E). In the average great storm the maximum DS(H) at 58° is still, though only slightly, greater than the maximum DS(Z) there, and DS(Z) does not decrease from 58° to 52° so rapidly as in the weak and moderate storms; at 52° the maximum DS(Z) is roughly two-thirds the corresponding quantity at 58°. This feature may be interpreted as being an indication that the magnetic effect of the auroral electro-jets extends farther to the south in the average great storm than in the weaker storms; this may be either due to a displacement of the auroral electro-jets in great storms to more southerly latitudes than their position in weaker storms, or due to a broadening of their width in great storms.

With decreasing latitude, Dst(H) and DS(H) increase to maxima near the equator (except that DS(H) is rather small at 28° for the average great storm); DS(E), Dst(Z), and DS(Z) diminish, to be reversed on crossing the equator.

As Chapman showed[6], the storm-time course of the DS part of the storm field differs greatly from that of the Dst part. The main difference is that DS attains its maximum earlier, and decays more rapidly. This difference was shown for the mean of 40 storms of moderate intensity, using data from eight observatories ranging in geomagnetic latitude from 50°N to 18°S. The curves for the observatory-groups 4 to 8 in Figs. 30, 31, 32, confirm this conclusion for the groups of weak, moderate, and great storms.

In order to investigate this important difference between the storm-time course of Dst and DS on a quantitative basis, these variations in H are averaged over the observatory-groups 5, 6, and 7. Fig. 33 shows such averages, i.e. Dst(H) and $-2C_1$ in DS(H) for the average weak storm, the average moderate storm, and the average great storm. The storm time and the absolute value of minimum Dst and of maximum DS, and the half decay time, defined as the time from the minimum, or maximum, to half its value, are given in Table 8.

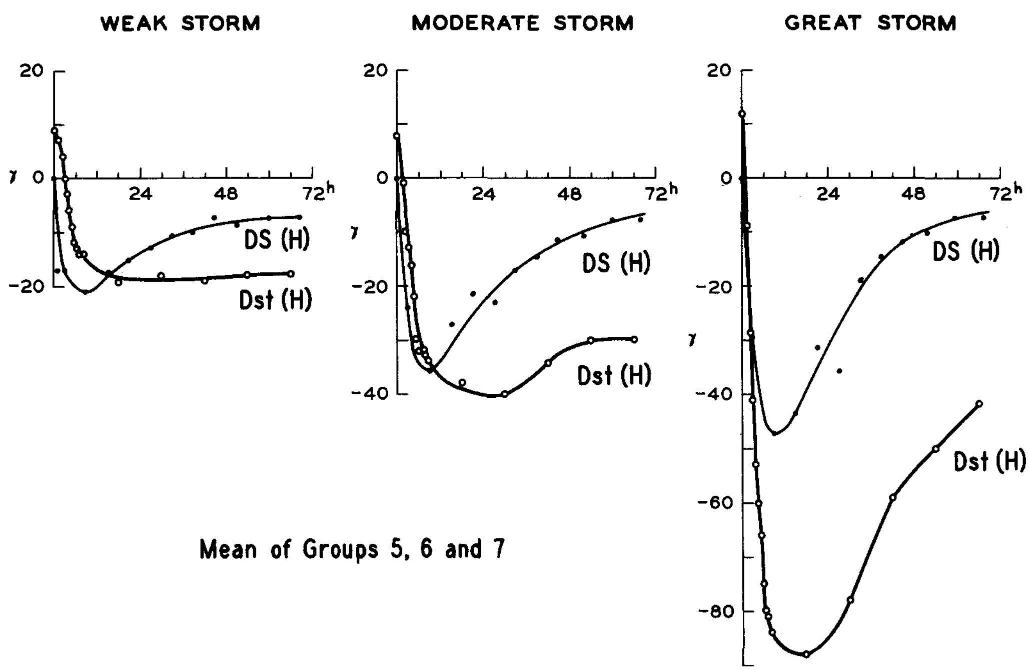


Fig. 33. Dst(H) and the range (with negative sign) of the first harmonic component of DS(H), $-2c_1$, plotted against storm time for the mean of the observatory-groups 5, 6, and 7, for the average <u>weak</u> storm, the average <u>moderate</u> storm, and the average <u>great</u> storm.

TABLE 8. The storm-time course of Dst(H) and DS(H) for the mean of the observatory-groups 5, 6, and 7, for the average weak storm, the average moderate storm, and the average great storm.

(i) Storm-time of minimum Dst(H) and maximum DS_1(H)

	Weak Storm	Moderate Storm	Great Storm
Dst(H)	33(18 to 48)^h	30^h	18^h
DS(H)	9	9	9

(ii) Minimum Dst(H) and maximum DS_1(H). Unit: gamma

	Weak Storm	Moderate Storm	Great Storm
Dst(H)	19(1.0)	40(2.1)	88(4.6)
$2C_1$ for DS(H)	20(1.0)	36(1.8)	48(2.4)

The number in parentheses in each entry is the ratio of the value in the entry to that for the average weak storm in the same variation.

(iii) Time for the decay from minimum Dst(H) to half the minimum, and the corresponding time from maximum DS(H) to half the maximum.

	Weak Storm	Moderate Storm	Great Storm
Dst(H)	> 3 days	> 3 days	45 hours
$2C_1$ for DS(H)	24 hours	24 hours	24 hours

DS has risen to a considerable fraction of its maximum intensity at the time of the transition (when Dst(H) is zero) from the initial to the main phase of the storm. DS(H) attains its maximum at about 9^h of storm time, and decays to half the maximum in about 24 hours from the time of maximum, in all the three intensity groups. This contrasts strongly with the behavior of Dst. In the average weak storm, Dst(H) is near its minimum from 18^h to 48^h of storm time, the center of this interval being about 33^h; minimum Dst(H) is about 30^h for the average moderate storm, and 18^h for the average great storm.

The subsequent decay intervals to half the minimum for the average weak storm and the average moderate storm, cannot be deduced from Fig. 33, because this half decay is not accomplished within the first three storm days. But in the middle of the sixth half-day, the recovery of Dst(H) is only a few per cent for the average weak storm, and is about 25 per cent for the average moderate storm. For the average great storm the half decay time is about 45 hours. These remarks apply to moderate and low latitudes. At higher latitudes, the smaller magnitudes of Dst and the greater irregularities in DS make such estimates difficult and doubtful.

The values of minimum Dst(H) for the mean of the observatory-groups 5, 6, and 7, are 19, 40 and 88 gamma for the weak, moderate, and great storms, respectively (Table 8); the ratios of minimum Dst(H) for the moderate and great storms to that for the weak storms are 2.1 and 4.6 respectively. The values of maximum DS(H), as measured by $2C_1$, for the mean of the same observatory-groups, are 20, 36, and 48 gamma for the weak, moderate, and great storms, respectively. The ratios of the values for the moderate, and great storms to that for the weak storm are 1.8 and 2.4. Thus the range of DS(H) in moderate and low latitudes does not increase proportionately with the maximum diminuation in Dst(H).

8. SEASONAL VARIATIONS IN Dst.

8.1 Seasonal variation in Dst(H); season d and season j.

Fig. 34 shows Dst(H) for season d (December solstice) and season j (June solstice), at different latitudes, for the weak storms and the moderate storm. In the figure the force scale is the same for all the graphs, and time abscissae refer to storm time -1^h to 72^h.

For group 4(52°), the initial phase of Dst(H) for the weak storms for season d is appreciably smaller in magnitude, and shorter in duration, than that for season j; Dst(H) for season d crosses the pre-storm level about 4 hours earlier than does Dst(H) for season j. Dst(H) for this group appears to attain its minimum much earlier in season d than in season j. The corresponding curves for the same group for moderate storms show similar characteristics; the difference in the reversal time there is about 3 hours.

For group 10, mean geomagnetic latitude -46°, the above characteristics are reversed; that is, at this southern latitude the initial phase of Dst(H) is smaller and shorter in season j than in season d, and Dst attains its minimum considerably earlier in season j than in season d.

This difference in Dst(H) between season d and season j is not clear in the graphs for the other observatory-groups for the weak storms. However, this seasonal variation is remarkably shown in all the curves for the moderate storms. The seasonal effect is small in low latitudes and increases toward 58°. It is reversed on crossing the magnetic equator, but the seasonal variation in the initial phase is rather obscured in the graph for -43° latitude, mean of Watheroo, Toolangi, and Christchurch.

The great storms are divided into two season groups, equinoctial and solstitial; hence it is not possible to study these seasonal variations with them without further re-grouping the storms in the solstitial season into two sub-groups, season d and season j. This is not done in this paper.

The difference in Dst between the season d storms and season j storms as described above, implies that the Dst field is not symmetrical with respect to the magnetic equator in the solstitial seasons. A theoretical

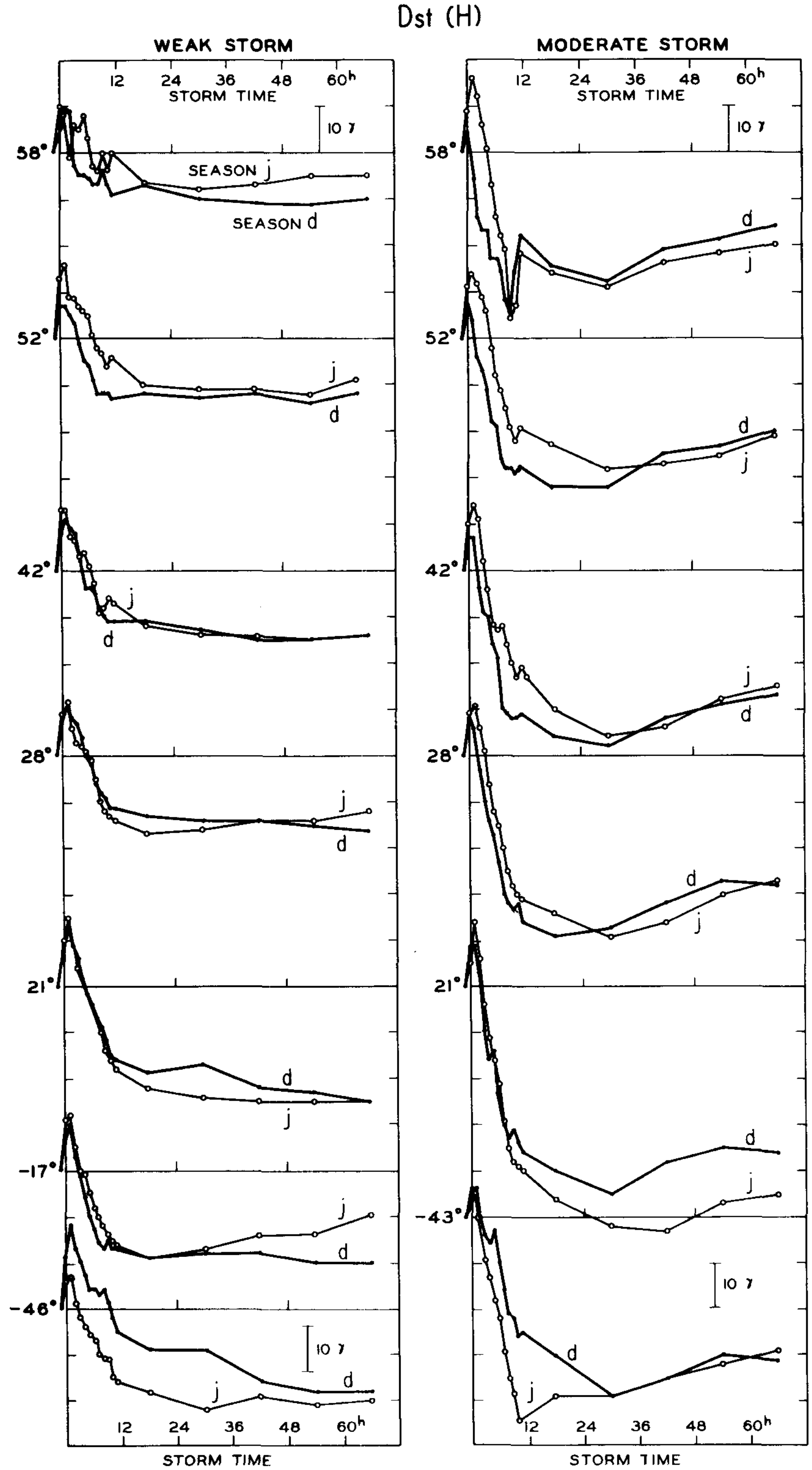


Fig. 34. Dst(H) in season d and season j, at different geomagnetic latitudes, for weak storms and moderate storms.

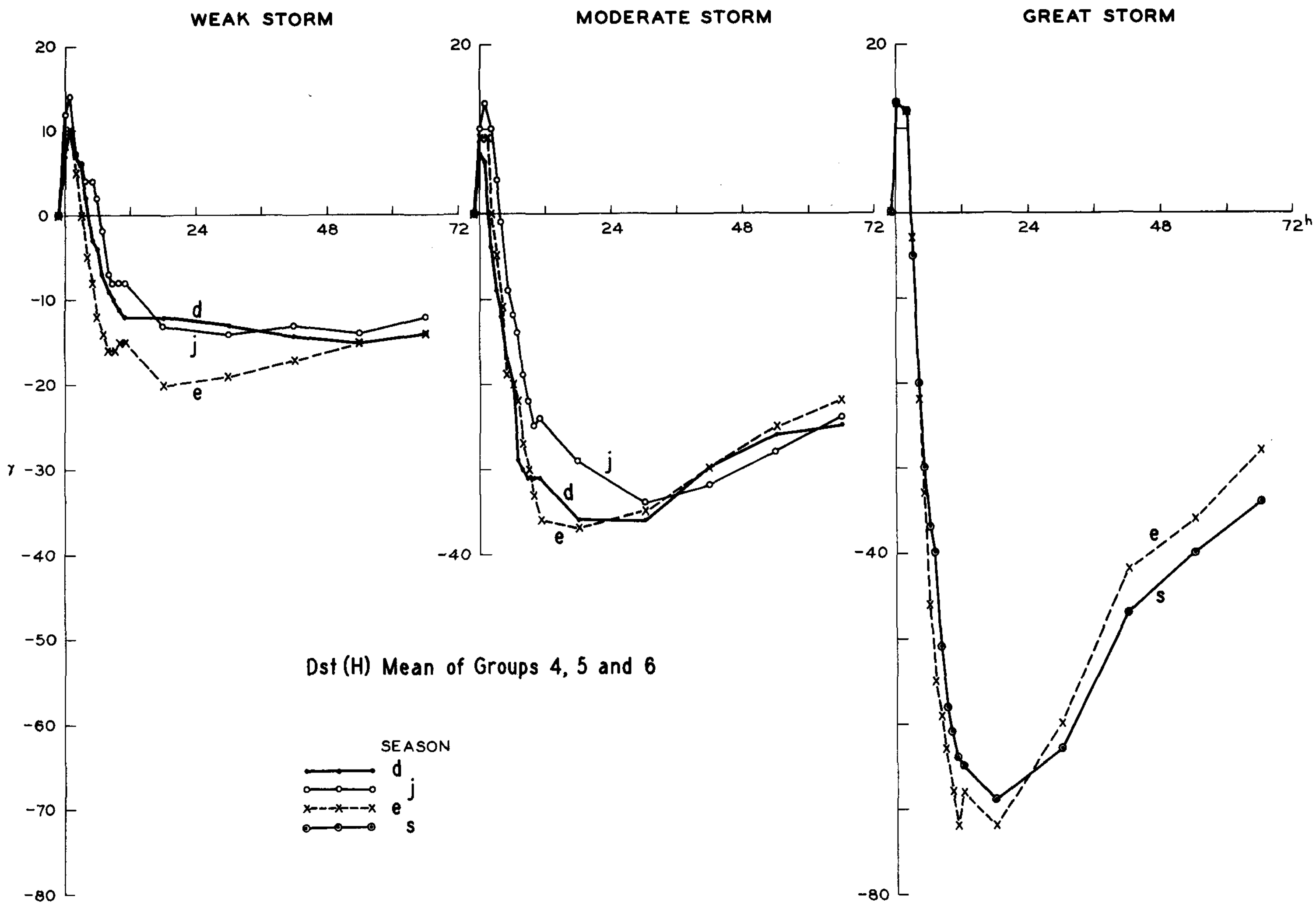


Fig. 35. Dst(H) in season d, season j, and season e, for the mean of the observatory-groups 4, 5, and 6, for <u>weak</u> storms and <u>moderate</u> storms, and Dst(H) in season s and season e, for the mean of the same observatory-groups, for <u>great</u> storms.

interpretation of this remarkable characteristic of the Dst field is of great interest; in this respect a separate detailed study of the subject is now being undertaken.

8.2 Seasonal variation in Dst(H); season e and season s.

Fig. 35 shows Dst(H) for the mean of the observatory-groups 4, 5, and 6, for the weak, moderate, and great storms for the three seasons. In the graphs for the weak and moderate storms, dots represent the values based on the data for season d, circles those for season j, and crosses those for season e; in the graph for the great storms circles, each with a dot inside, refer to the data for season s (season d and season j combined), and crosses to those for season e.

The curves for season d and season j for the weak storms and the moderate storms show the seasonal variations discussed in Section 8.1, for the mean of the observatory-groups 4, 5, and 6.

In the group of weak storms, those which occurred in season e appear more intense than those in season d and season j. This seasonal difference is not so obvious for the groups of moderate and great storms. However, in these latter groups, the minimum of Dst(H) in season e appears slightly smaller (its absolute value greater), and its recovery earlier, than in the average of season d and season j.

9. SEASONAL VARIATIONS IN DS

Fig. 36 shows the mean ranges of DS in the first four quarter-day intervals (the first day of the storm), for season d, season j, and season e, for weak and moderate storms, and for season s and season e for great storms. There appear to be no notable seasonal variations in the range of DS in low to moderate latitudes.

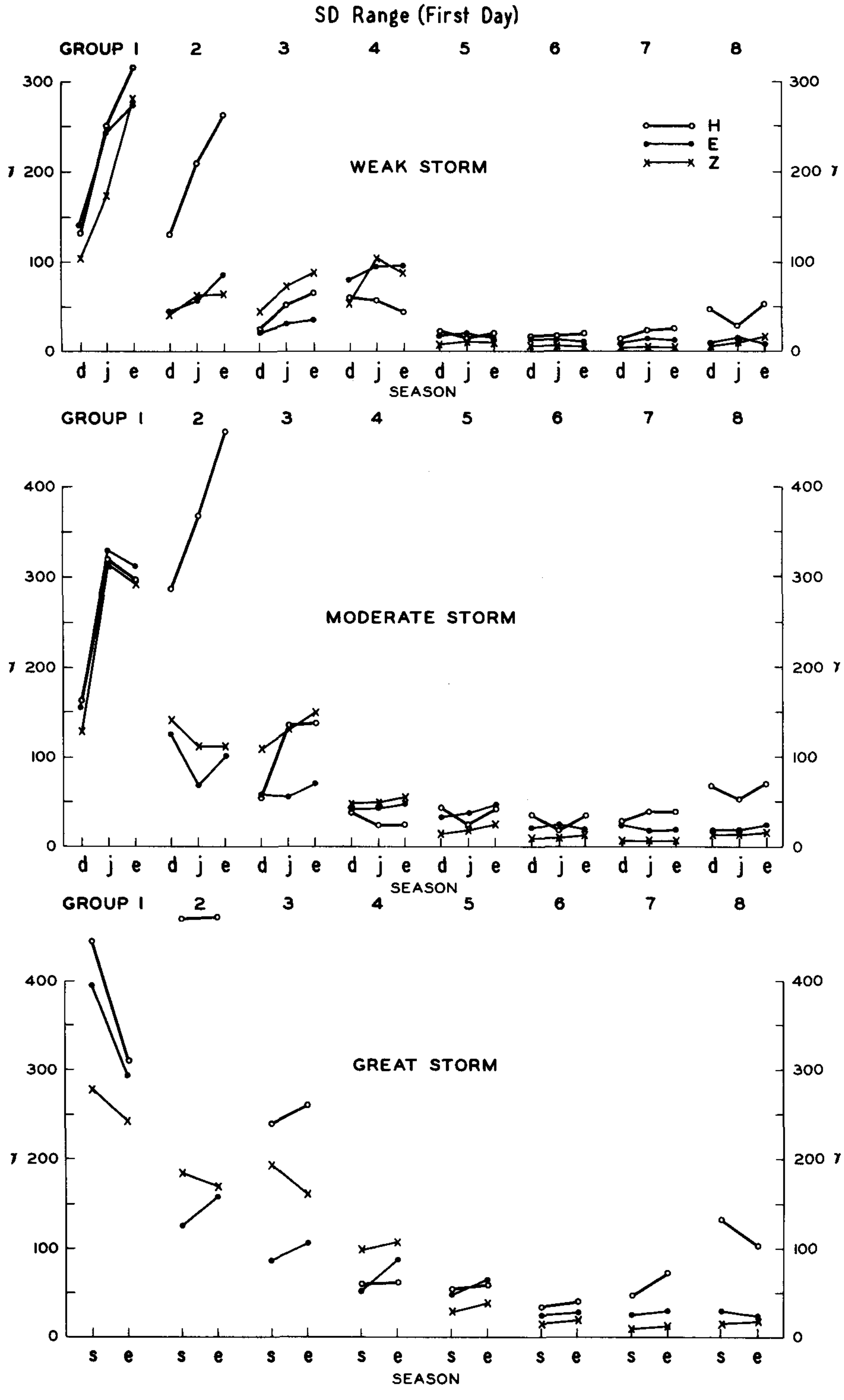


Fig. 36. Ranges in SD in H, E, and Z, in the first day of the storm, for the observatory-groups 1-8; season d, season j, and season e, for <u>weak</u> and <u>moderate</u> storms, and season s and season e for <u>great</u> storms.

For group 2, at 65°, the range of DS in H is greatest in season e and smallest in season d for the weak and moderate storms; hence it is greater in season e than in the mean of season d and season j. But it is nearly the same in season s and in season e for the great storms.

For group 1, at 80°, the range of DS in season d is less than those in season j and season e for the weak and moderate storms; it is greater in season e than for the mean of season e and season j for these groups of storms. For the great storms, however, the range of DS is greater in season s than in season e.

10. CONCLUSION

(1) The existence of the (positive) initial phase in H is confirmed with certainty in all three intensity groups at geomagnetic latitude 58°: mean of Sitka (60°), Eskdalemuir (59°), Lovö (58°), and Rude Skov (56°). It is not yet known whether Dst(H) has a positive phase in latitudes higher than 60°.

(2) The size of the initial phase in Dst(H) in low to moderate latitudes is nearly the same in the three intensity groups. This is rather surprising, because the size of the main phase in the same variation increases by a factor of about 2 from the average weak to the average moderate storm, and by the same factor from the average moderate storm to the average great storm.

(3) The greater the storm intensity, the earlier the time of reversal in Dst(H) (when measured from pre-storm level). Likewise the greater the storm intensity, the earlier is the time of the minimum of Dst(H), and the more rapid is its recovery.

(4) The latitude of the SD-foci is near 52°. There is some indication that this focal latitude is lower in the first storm-day in the average great

storm than in the same day in the average weak storm and in the average moderate storm. A more detailed study is needed to determine how the focal latitude varies with storm time in storms of different intensities.

(5) The phase of the first component of DS changes systematically with storm time in all the three intensity groups. The main change appears to be completed within twelve hours or so from the storm commencement. The phase of DS is essentially the same for the average weak storm, the average moderate storm, and the average great storm.

(6) The higher harmonic components in DS and SD in low and moderate latitudes have smaller amplitudes than the first component.

(7) The storm-time courses of Dst and DS are quite different; DS attains its maximum activity, and begins to recover, much earlier than Dst. The storm time of maximum DS and the rate of recovery do not seem to depend on the storm intensity, in contrast to a strong dependence on the intensity of the storm-time course in Dst.

(8) The Dst field appears to be asymmetrical with respect to the geomagnetic equator in season d and season j. In moderate latitudes in the northern hemisphere the initial (positive) phase of Dst(H) is greater in size and longer in duration in season j than in season d, and the main phase of Dst(H) develops more slowly in season j than in season d. These relative characteristics are reversed in the southern hemisphere; that is, the initial phase is greater and longer in season d than in season j, and the main phase develops more slowly in season d than in season j.

It is as yet uncertain whether or not there are any significant seasonal variations in Dst in the higher latitudes.

(9) There are no notable seasonal variations in DS in low and moderate latitudes. More studies are needed to determine seasonal variations in DS in the polar regions.

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