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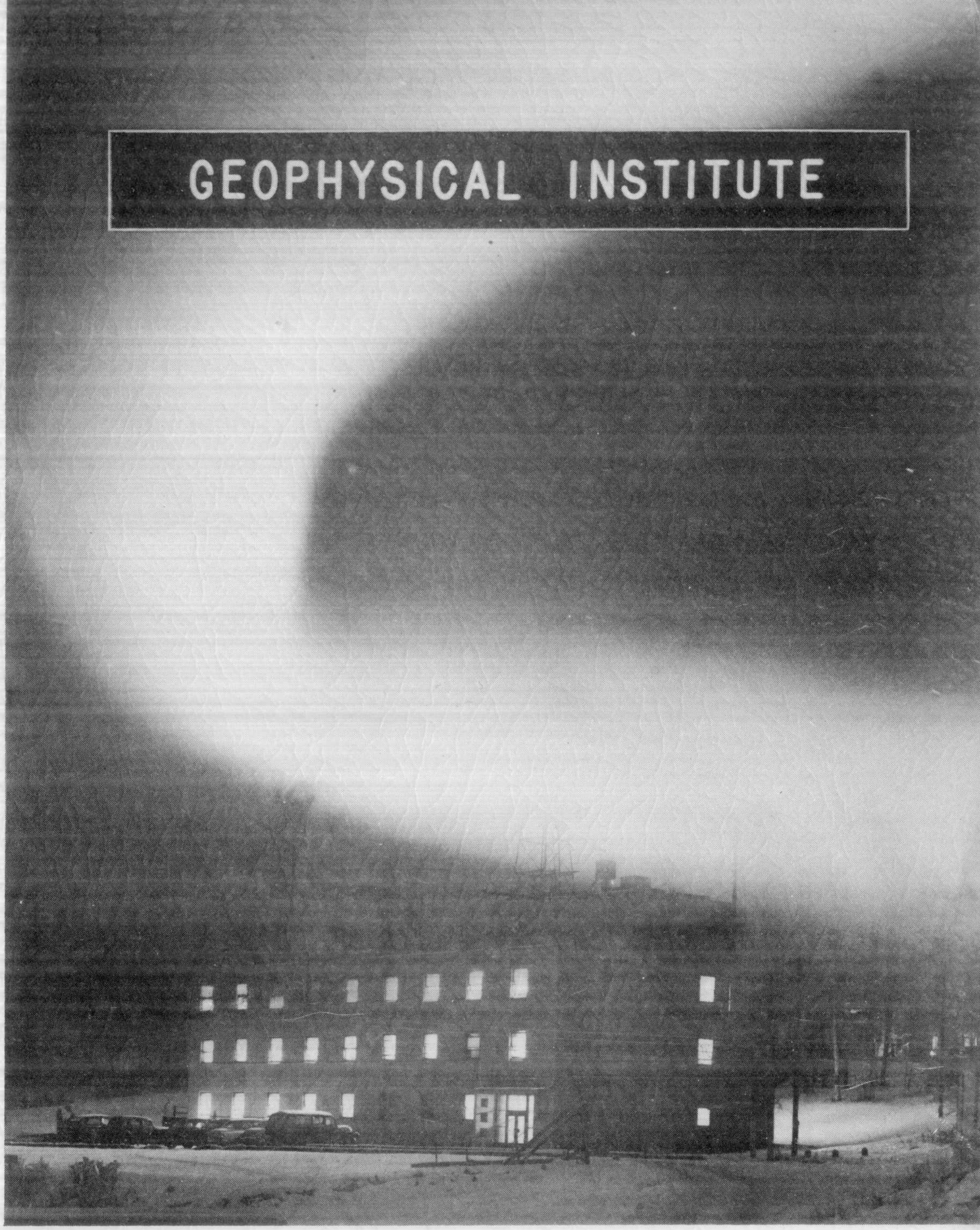

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A STUDY OF THE MORPHOLOGY OF MAGNETIC STORMS

MODERATE MAGNETIC STORMS

Final Report

AF 19(604)-1732

June 30, 1957

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

Some average characteristics are determined for 136 moderate magnetic storms with sudden commencements that occurred during the interval 1902-1945. The average storm field is resolved for different epochs of storm time st into Dst, independent of local time, that is, of longitude λ, relative to the sun, and into DS, that depends on λ. Part DS is expressed in terms of harmonic components with respect to λ, and like Dst, the amplitudes and phases of these components, are functions of st and of geomagnetic latitude. They are determined, for each of the three magnetic elements, declination, horizontal force, and vertical force, at eight geomagnetic latitudes ranging from 80°N to 1°S. In the first, and main harmonic component of DS, its variations with respect to storm time differs notably from that of Dst: its maximum is attained earlier and its decay is more rapid. The storm-time changes of the smaller harmonic components of DS have been less fully determined. The average characteristics of moderate storms are compared with those of weak storms.

1. INTRODUCTION

This paper is the second of a series, which describe new studies of the morphology of magnetic storms and of its dependence on their intensity. A previous paper[1] (hereafter referred to as FR-1, signifying Final Report 1) dealt with weak magnetic storms. The present paper discusses storms of moderate intensity, using the same methods as in FR-1; and a third paper will deal similarly with great magnetic storms. The Air Force Cambridge Research Center, Air Force and Development Command, has sponsored these investigations, under contract with the Geophysical Institute, College, Alaska.

The whole investigation is based on 346 suddenly commencing storms that occurred during the interval 1902-1945. The 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 maximum epoch of each storm (FR-1, 14-15). The intensity numbers were used to divide the storms into these groups: weak (136), moderate (136) and great (74). In each group, three seasonal sub-groups were formed (FR-1, 16); these sub-groups, for the 136 moderate storms considered here, included 46, 40, and 50 storms respectively, in the December solstitial months November-February (season d), the June solstitial months May-August (season j), and the equinoctial months March, April, September, October (season e).

The storm field is resolved into two parts: Dst, the storm-time variation, and DS, the disturbance longitudinal inequality* (FR-1, 34-40, 69-77). Consider the storm change Δ f in a magnetic element f at a station P on gm (geomagnetic) latitude θ at the 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 eastwards from the midnight meridian, is the local time at P measured in angle, as well as being a position-coordinate of P at the particular epoch. The average value of Δ f 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 difference 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 θ .

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; the number n of the day (1, 2, or 3) is added to the symbol, SD^n.

The previous paper, FR-1, gave determinations of Dst, DS and SD^n for the 136 weak storms there considered. In this paper, corresponding results for the 136 moderate storms are given, and compared with the former results. This is a first stage in the study of the dependence of

* In 1952, DS was named "disturbance local time variation." It now seems preferable to name it "disturbance longitudinal inequality." S. Chapman.

magnetic storm morphology on the storm intensity. The study will be completed by similar treatment of the 74 great storms.

The results of this comparative study are briefly compared with those of previous discussions of magnetic storm morphology and its dependence on storm intensity. In such investigations, begun by Moos[2], and continued by Chapman[3,4,5], the morphology was found to be substantially the same over a large range of intensity, but some important detailed changes dependent on intensity were noted. A general account of the subject is given in reference 6.

2. THE OBSERVATORIES

The observations used in this study are Nos. 1-19 in Table 1, FR-1, 11-12. Their geomagnetic latitudes range from 80°N to 1°S. These observatories are divided into eight groups, as shown in Table 1 of this report. The grouping is the same as for the weak storms, except that two southern groups, Nos. 9 and 10, are not included in this study.

The mean magnetic declination D for each group of observatories is given in column 5 of Table 1, and column 6 gives Ψ, the mean declination relative to the geomagnetic meridian; both D and Ψ are reckoned positive when eastward. Column 7 gives the mean difference in hours, averaged over the day, between geomagnetic and standard local time. The difference is small for the lower latitude groups, but for groups 1-4 is worth taking into account. This is done as regards DS and SD in

Table 1. The grouping of observatories according to geomagnetic latitudes θ ; corresponding values of D and ψ , the mean declination and the mean geomagnetic declination respectively, both reckoned positively eastward; corresponding values of t_g-t, the time (averaged over the day) by which geomagnetic time precedes local time.

Group number	Number of observatories	Observatories	Mean geomagnetic latitudes	D	ψ	D - ψ	t_g-t	Proportion of records available
1	1	Godhavn	80°	-56°.0	-17°.5	-38°.5	1ʰ.1	64/136
2	3	Tromsö, Sodankylä, Lerwick	65°	4.8	-27.0	31.8	1.6	182/408
3	4	Sitka, Eskdalemuir, Lovö, Rudo Skov	58°	1.9	-10.4	12.3	0.6	325/544
4	4	De Bilt, Greenwich, Val Joyeux, Cheltenham	52°	-10.5	-13.1	2.6	0.7	543/544
5	2	Ebro, Tucson	42°	1.2	- 2.5	3.7	0.1	176/272
6	2	Porto Rico, Kakioka	28°	- 4.8	2.7	- 7.5	-0.1	240/272
7	2	Honolulu, Zikawei	21°	3.4	7.3	- 3.9	-0.2	242/272
8	1	Huancayo	- 1°	7.4	1.3	6.1	0	60/136
	Total 19							1,846/2,584

the present discussion of moderate magnetic storms; that is to say, the time abcissae in graphs of DS and SD refer to mean solar time corrected for the difference given in column 7; this was not taken into account in FR-1.

The last column of Table 1 indicates the extent of the available storm data. For example, the one observatory in group 1 had records for 64 of the 136 storms; and the three observatories of group 2 had, in all, 182 records out of the 3 x 136 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.

3. THE STORM TIME VARIATIONS

3.1 Dst in the geomagnetic-north component Hgm.

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

Figs. 1 and 2 show the Dst variations in Hgm for the average weak storm and the average moderate 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 sudden commencement. The curves show the variations from four hours before to 72 hours after the sudden commencement. The force scale indicated

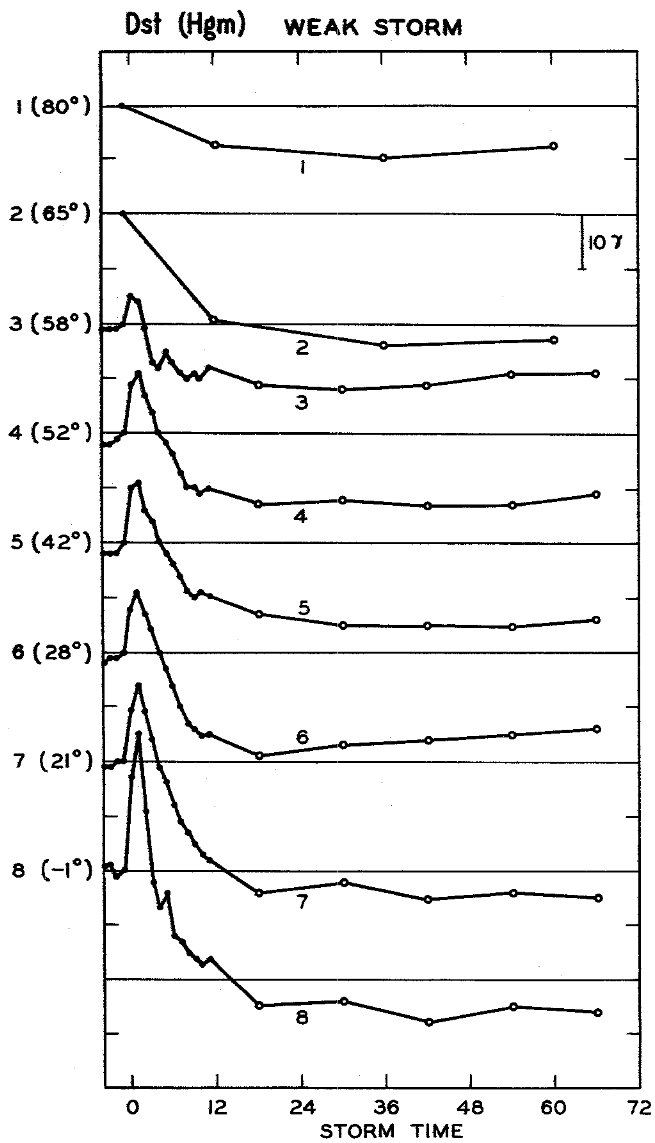


Fig. 1.

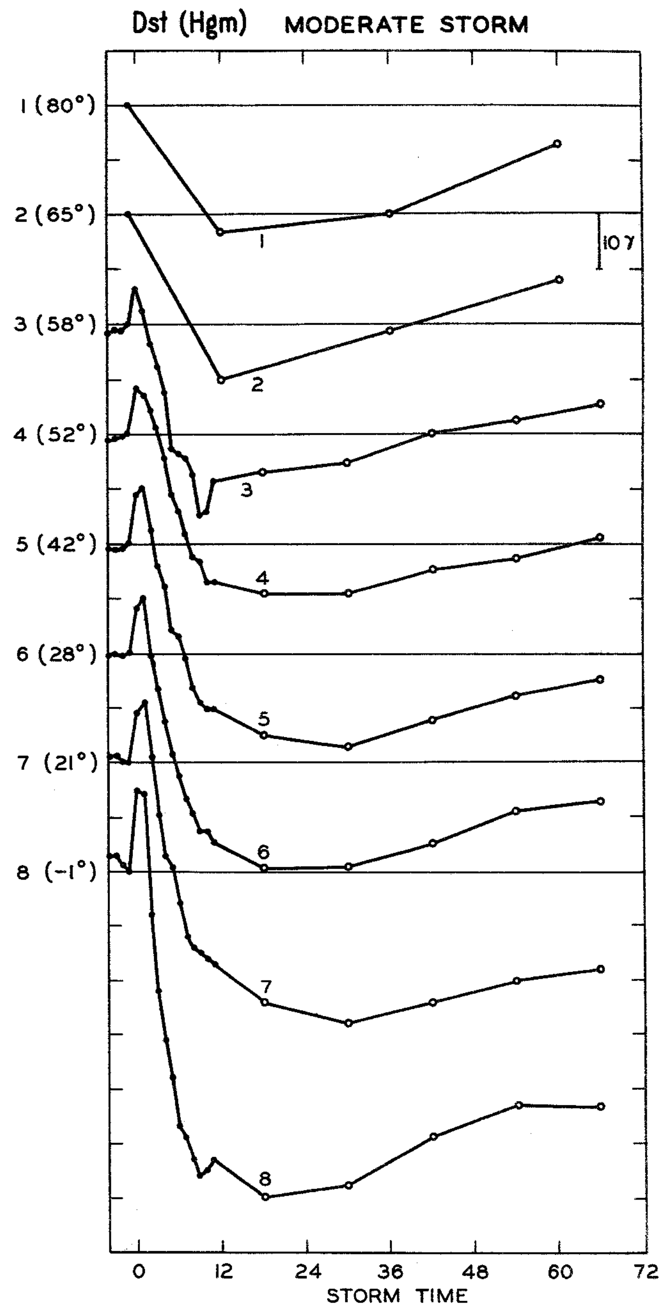


Fig. 2.

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.

is the same throughout both Figures. (Fig. 1 is part of Fig. 5, p. 43 of FR-1). In these figures, 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. 3, 4, 6, 7 in Sections 3.2 and 3.3.

For Dst in Hgm, the following differences are found between the average weak storm and the average moderate storm:

(1) The size of the initial phase in the average moderate storm is smaller than that in the average weak storm. This rather remarkable fact is shown by the maximum values of Dst (Hgm) during the initial phase of the two groups of storms, given in Table 2. It should be borne in mind that the data here used are hourly values (mostly hourly means), hence they do not give the absolute maximum values of the Dst changes in Hgm.

Table 2

The maximum values of Dst (Hgm) in the initial phase for the average weak storm and the average moderate storm. Unit: 1 gamma

gm. lat.	58°	52°	42°	28°	21°	-1°
Weak storm	5	11	11	11	14	25
Moderate storm	6	8	10	10	11	15

(2) The Dst (Hgm) reverses its sign (when measured from pre-storm level) notably earlier in the average moderate storm than in the average weak storm. The difference between this reversal time for the

weak storm and for the moderate storm is greatest near 28°, and decreases both equatorward and poleward. The storm time at which Hgm crosses its pre-storm level is given in Table 3.

Table 3

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

gm lat.	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
Difference	0.7	0.8	1.7	2.0	1.7	1.2

(3) The ratio of the maximum depression in Dst (Hgm) for the average moderate storm to that in the average weak storm does not vary with geomagnetic latitude. Values of the maximum depression in Dst (Hgm) at different latitudes for the average weak and moderate storms, and the ratios of this quantity for the moderate to that for the weak storm are given in Table 4.

Table 4

Maximum depression in Dst (Hgm) in the average weak storm and the average moderate storm. Unit: 1 gamma.

gm. lat.	80°	65°	58°	52°	42°	28°	21°	-1°
Weak storm	10	14	12	13	15	19	25	28
Moderate storm	23	30	(35)*	29	37	39	48	60
Moderate/Weak	2.3	2.1	(2.9)	2.2	2.5	2.1	1.9	2.1

* The curve for Group 3 in Fig. 2 suggests that this large value is due to irregular changes that were not averaged.

(4) The minimum in Dst (Hgm) is attained, and the recovery phase begins, notably earlier in the average moderate storm than in the average weak storm. In the average weak storm, Dst(Hgm) reaches its minimum about 1.5 days after the SC at geomagnetic latitudes 58° to 80°, and about 2 days after the SC in the lower latitudes. It remains near this minimum level throughout the third day of the storm. In the average moderate storm the corresponding time intervals are about 12 hours and 24 hours; Dst (Hgm) starts to recover towards the normal level on the second day of the moderate storm. The rate of recovery seems greater in and near the auroral zone than in the lower latitudes.

3.2 Dst in the geomagnetic-east component, Egm.

Figs. 3 and 4 show the Dst variations in the geomagnetic east component Egm, for the average weak storm and the average moderate storm, for the observatory groups/1 to 8. The time and force scales are the same as in Figs. 1 and 2. Except possibly for groups 1 and 2 the variations appear to be irregular and due to accidental variations not fully smoothed out. Hence, it appears that the Dst lines of magnetic force lie very nearly in planes through the geomagnetic axis.

This conclusion can be demonstrated in another way. Let ΔH, ΔE, ΔHgm, and ΔEgm denote the Dst departures in the magnetic and the geomagnetic north and east directions; let D and ψ denote the mean magnetic and geomagnetic declinations for a group of observatories

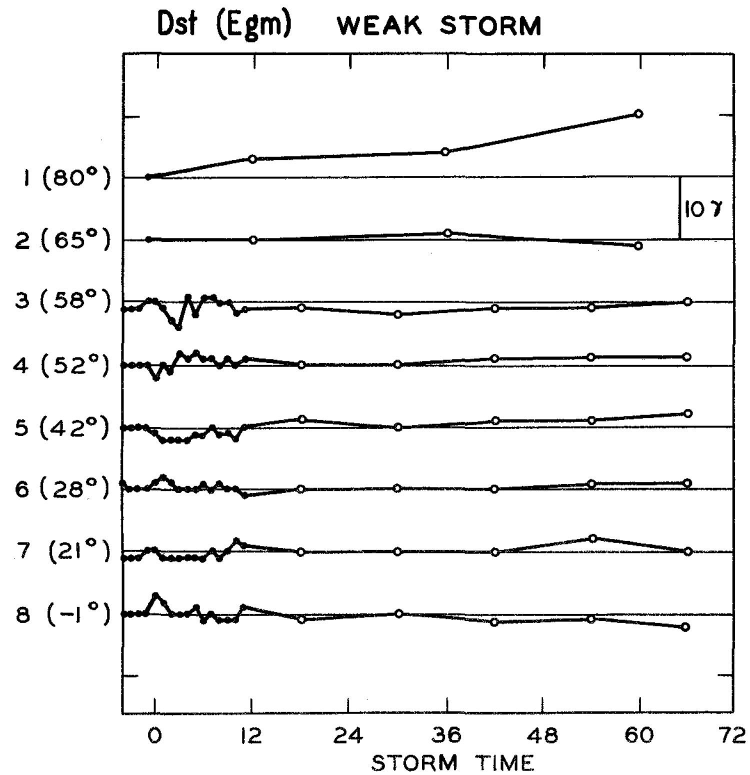


Fig. 3.

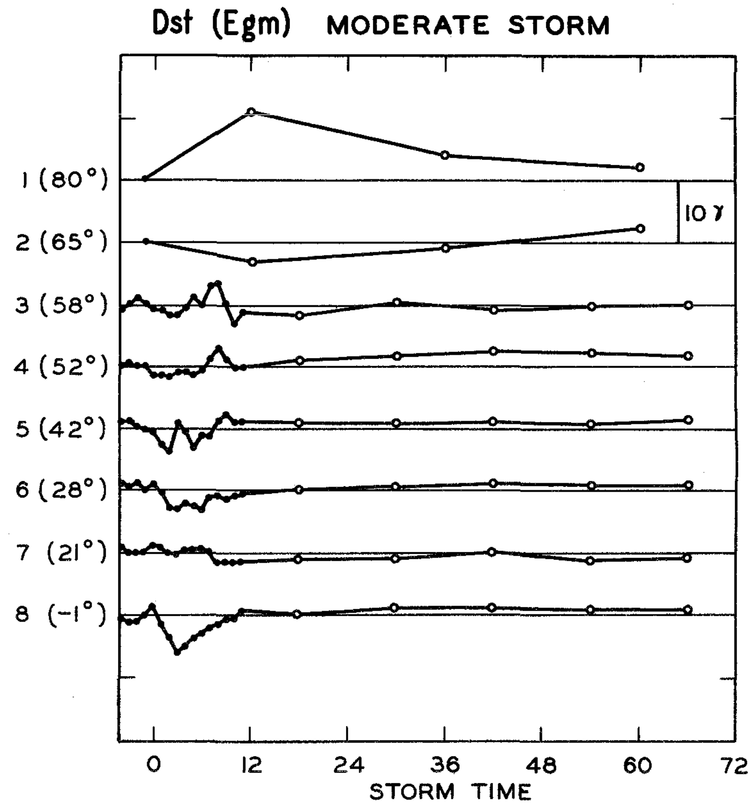


Fig. 4.

Figs. 3 and 4. Dst variations in the geomagnetic-east component, Egm, at different geomagnetic latitudes for the average weak and the average moderate storm.

as given in Table 1. Then,

$$\Delta E = \Delta E gm \cos(D-\Psi) - \Delta Hgm \sin(D-\Psi).$$

If Δ Egm is really zero, ΔE should be given by - ΔHgm $\sin(D-\Psi)$. Fig. 5 shows the "expected" graph of ΔE thus calculated, and also the graphs of the actual ΔE for the Dst field for the average moderate storm. The agreement seems good since the differences are small and irregular.

3.3 Dst in the vertical force

Figs. 6 and 7 show the Dst variations in the vertical force for the average weak storm and the average moderate storm: clearly they are much less than the Dst (Hgm) changes, and their sign is opposite. The recovery in this component appears to be slower than in the horizontal component.

4. THE DISTURBANCE DAILY VARIATIONS

In this paper and in the preceding paper on weak storms, 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,

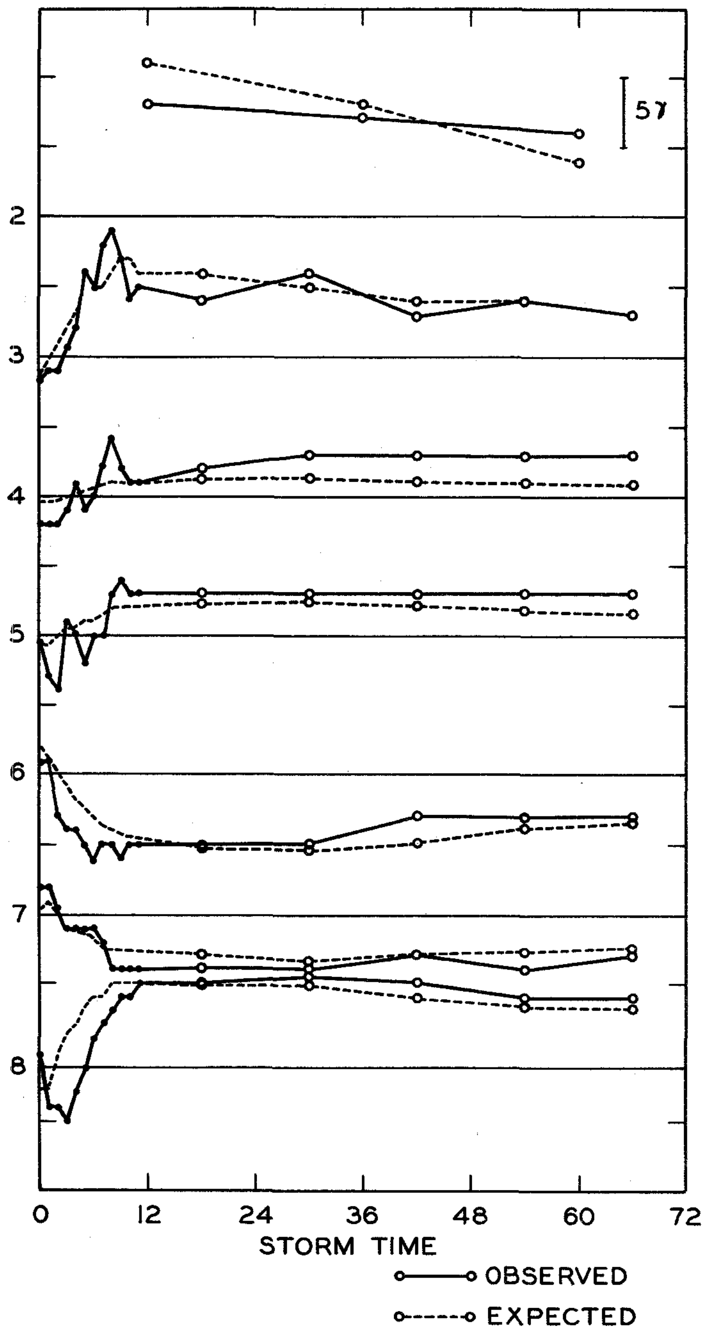


Fig. 5. The observed Dst variations in E and the semi-theoretically computed Dst variations in E by $\Delta E = -\Delta Hgm \sin (D - \Psi)$, where ΔHgm indicates changes in the geomagnetic-north component, and where D and Ψ represent the east declination and the geomagnetic east declination, reckoned in angle, respectively. From top downward, curves refer to the observatory-groups 2(65°), 3(58°), 4(52°), 5(42°), 6(28°), 7(21°), and 8(-1°), the numbers in parentheses indicating geomagnetic latitudes. Variations refer to the average moderate storm.

Figs. 6 and 7. Dst variations in the vertical force Z at different geomagnetic latitudes for the average <u>weak</u> and the average <u>moderate</u> storm. Z is measured positively toward nadir.

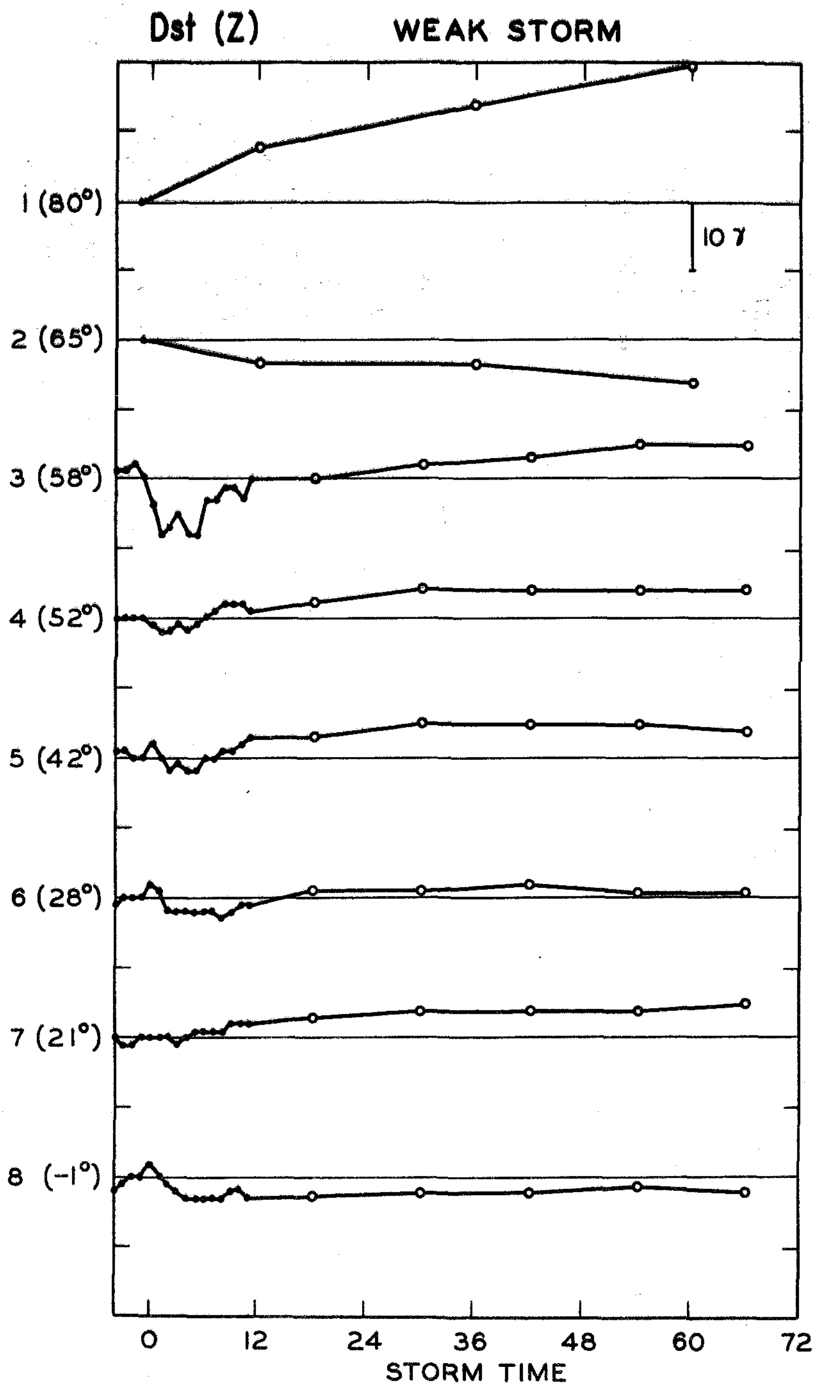
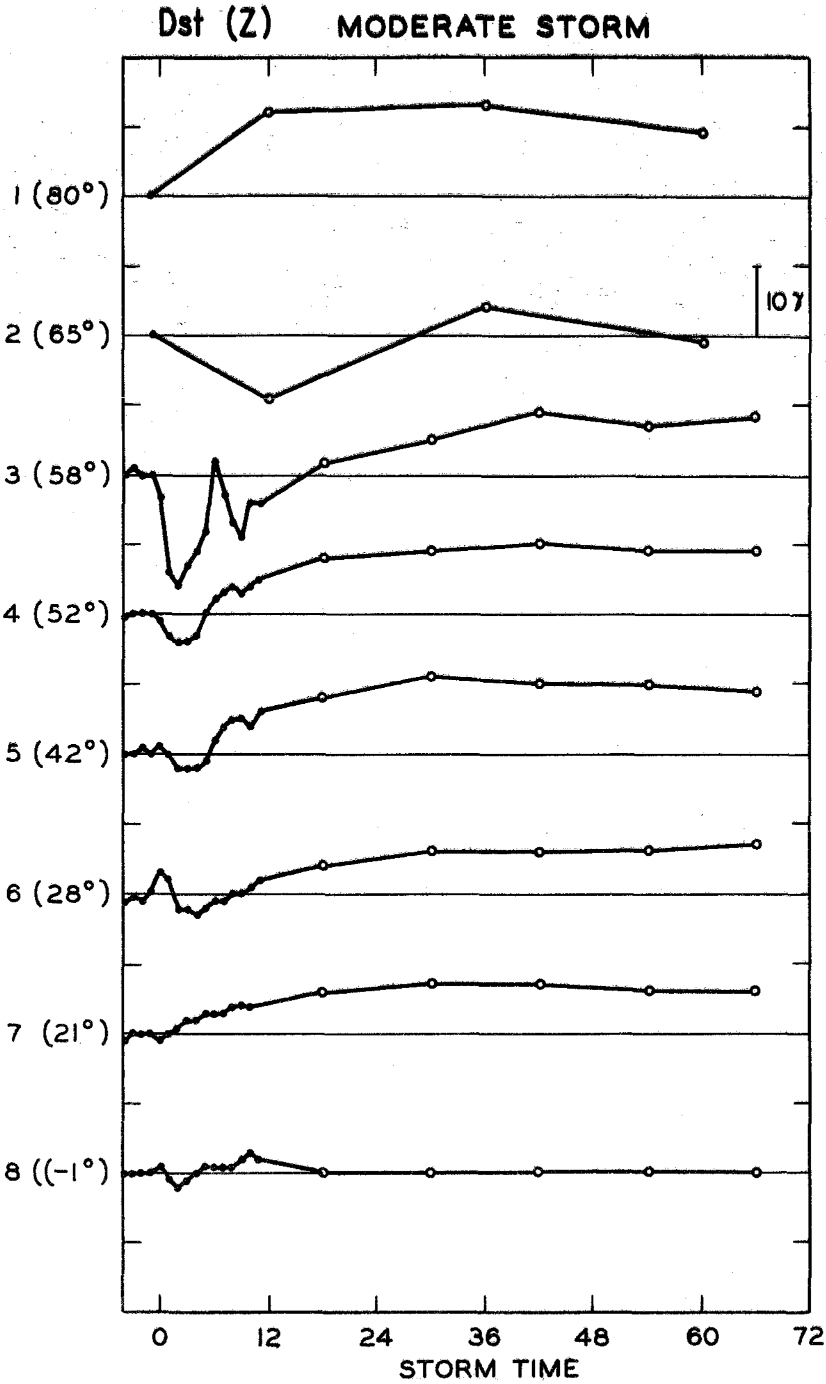

Dst (Z)
WEAK STORM
1 (80°)
10 γ
2 (65°)
3 (58°)
4 (52°)
5 (42°)
6 (28°)
7 (21°)
8 (-1°)
0
12
24
36
48
60
72
STORM TIME

Fig. 6.



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. 7

and SD^3, respectively. *

Figs. 8-13 show such SD variations, together with the average solar quiet daily variations, Sq, derived by taking the average of the mean daily changes 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. 8, 10, 12 refer to weak storms, and (for Sq) to the months in which they occurred; they give graphs for two southern groups of observatories, not included in Figs. 9, 11, 13.

The time scale is the same throughout these figures, but for some of the observatory groups, especially in the higher geomagnetic latitudes (also for Sq(H) at Huancayo, group 8), the force scales are contracted. This should be carefully noted when considering these diagrams. The force scales for the Sq graphs also differ from diagram to diagram.

These diagrams resemble those previously given by Chapman[3,4], which are reproduced in Geomagnetism (Ch. IX, Figs. 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 here given.

* It is recommended that subscript i, as in SD_i, be reversed for the i-th harmonic component of SD. However, in FR-1 and also in Figs. 8, 9, 10, 11, 12, and 13 in this report, this notation was not used. Instead, SD for the first, second and third days were denoted by SD_1, SD_2, and SD_3, respectively. According to the system of notation recommended here, these symbols should be replaced by SD^I, SD^2, and SD^3, respectively.

WEAK STORM

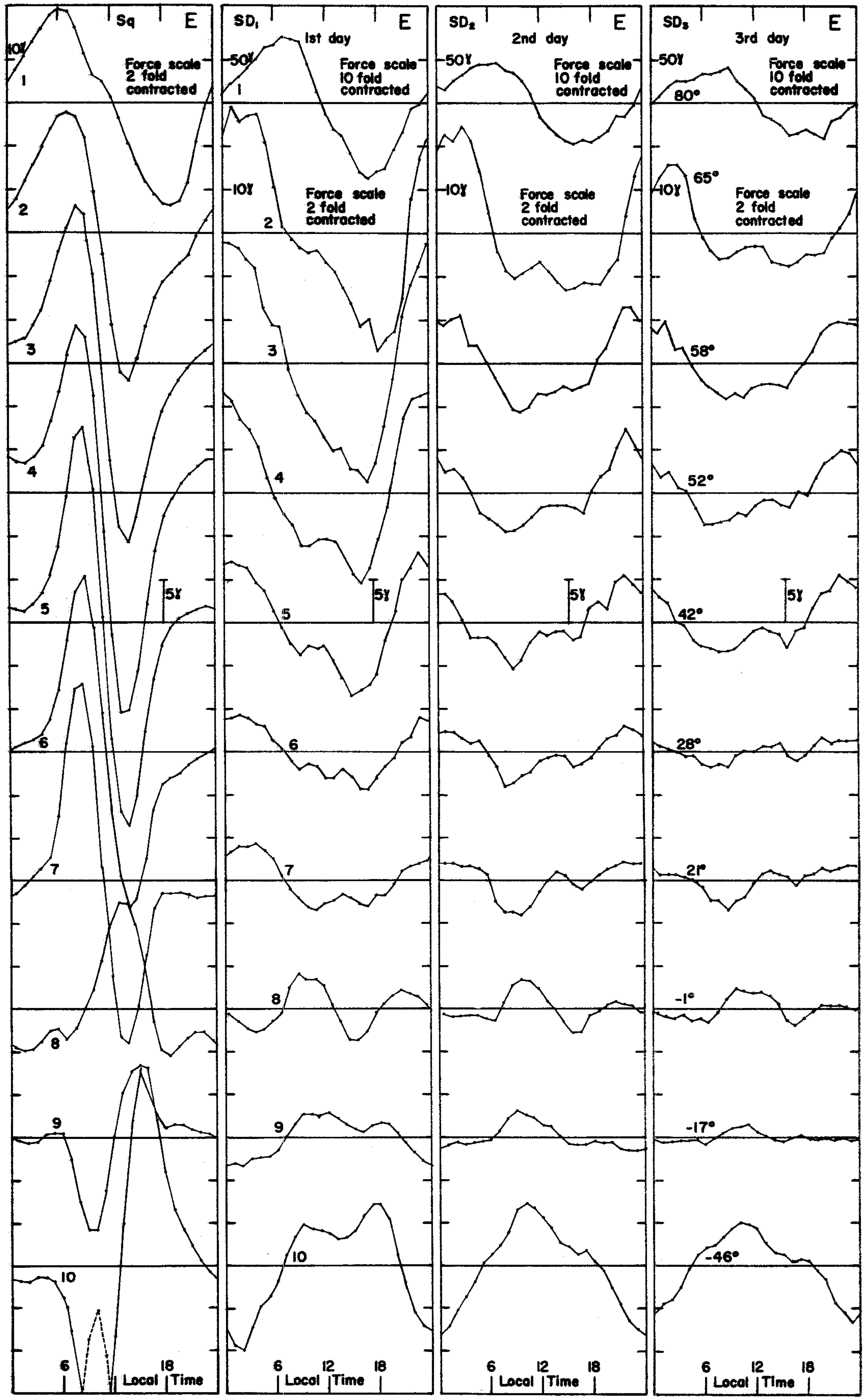


Fig. 8. Sq and SD in the east declination E measured in the force unit at different geomagnetic latitudes for the average <u>weak</u> storm. The three columns for SD, i.e., the second, third and fourth from the left, refer to the first, second, and third days of the storm, respectively.

MODERATE STORM

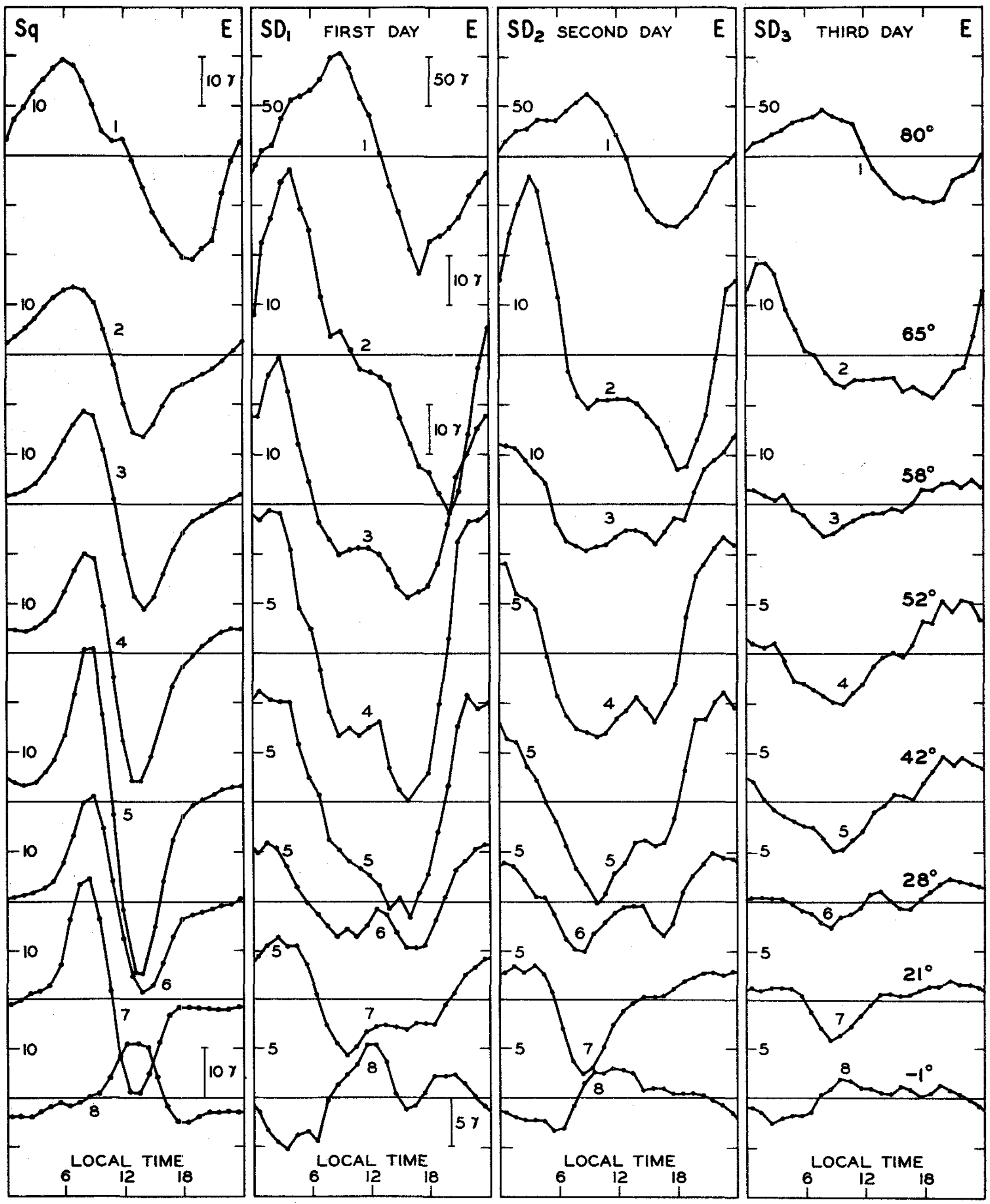


Fig. 9. Sq and SD in the east declination E measured in the force unit at different geomagnetic latitudes for the average moderate storm. The three columns for SD, i.e., the second, third, and fourth from the left, refer to the first, second, third days of the storm respectively.

WEAK STORM

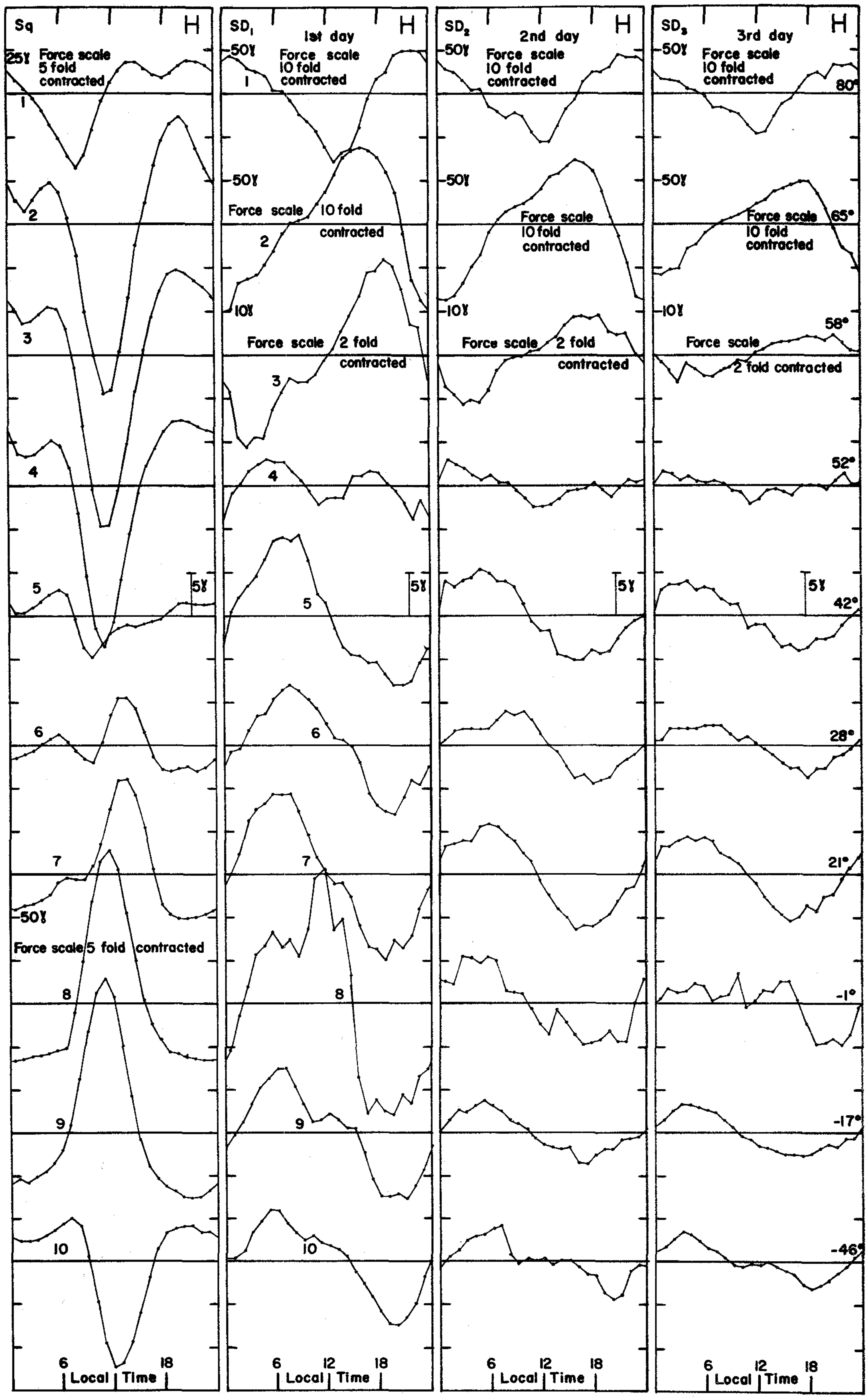


Fig. 10. Sq and SD in the horizontal force H at different geomagnetic latitudes for the average weak storm. The three columns for SD, i.e., the second, third, and fourth from the left, refer to the first, second, and third days of the storm, respectively.

MODERATE STORM

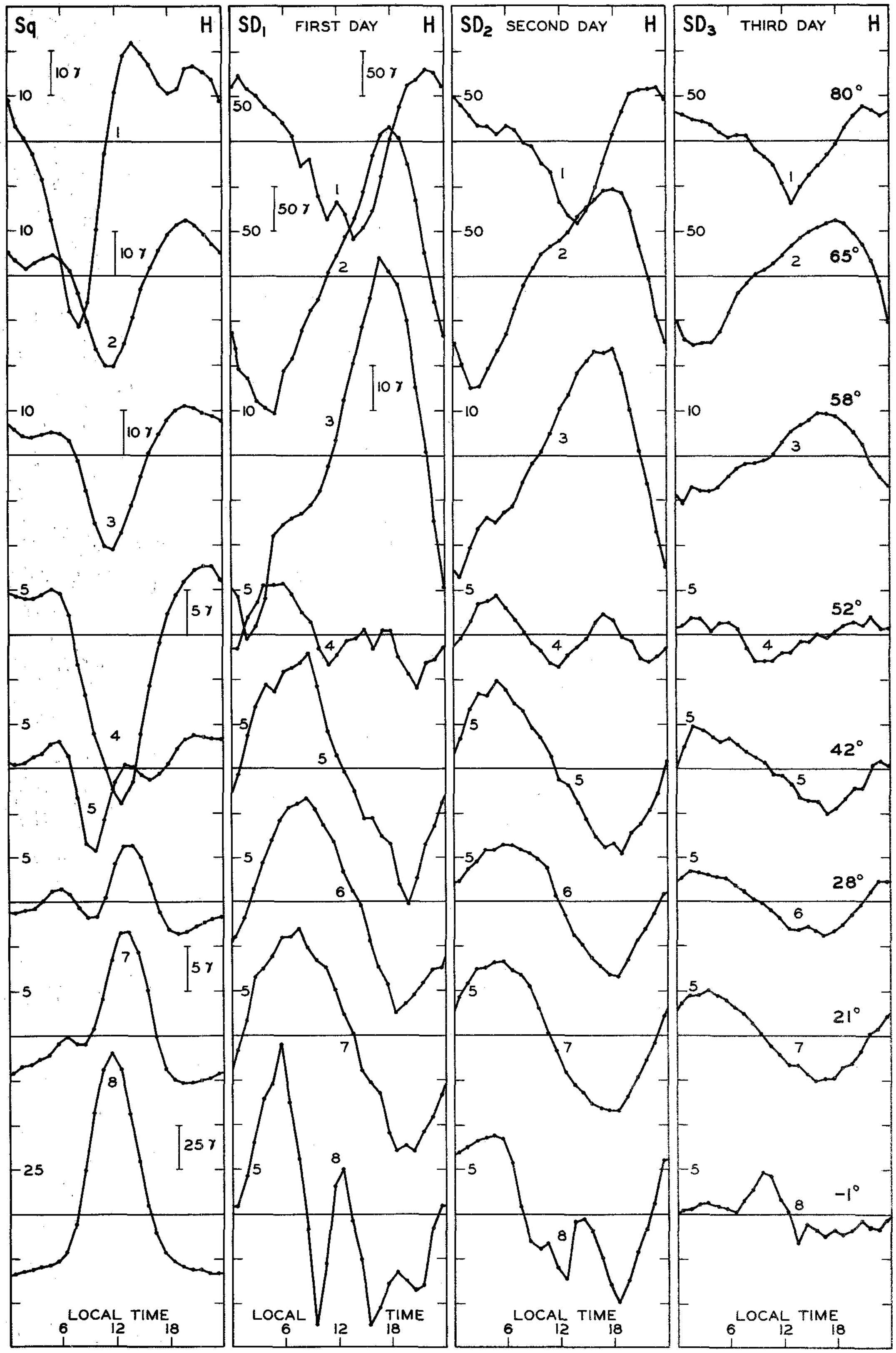


Fig. 11. Sq and SD in the horizontal force H at different geomagnetic latitudes for the average moderate storm. The three columns for SD, i.e., the second, third and fourth from the left, refer to the first, second, and third days of the storm, respectively.

WEAK STORM

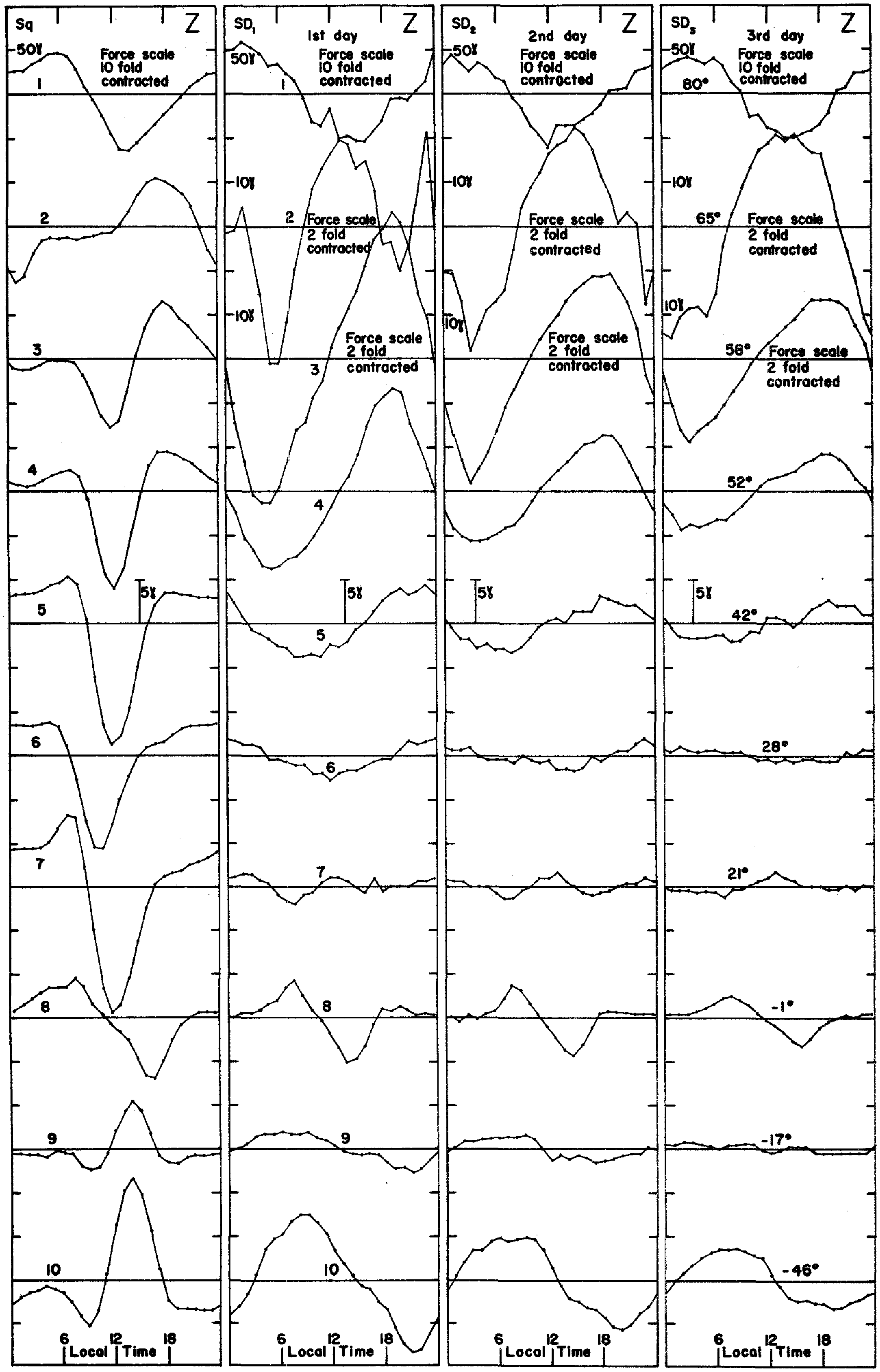


Fig. 12. Sq and SD in the vertical force Z at different geomagnetic latitudes for the average weak storm, Z being measured positively toward nadir. The three columns for SD, i.e., the second, third and fourth from the left, refer to the first, second and third days of the storm, respectively.

MODERATE STORM

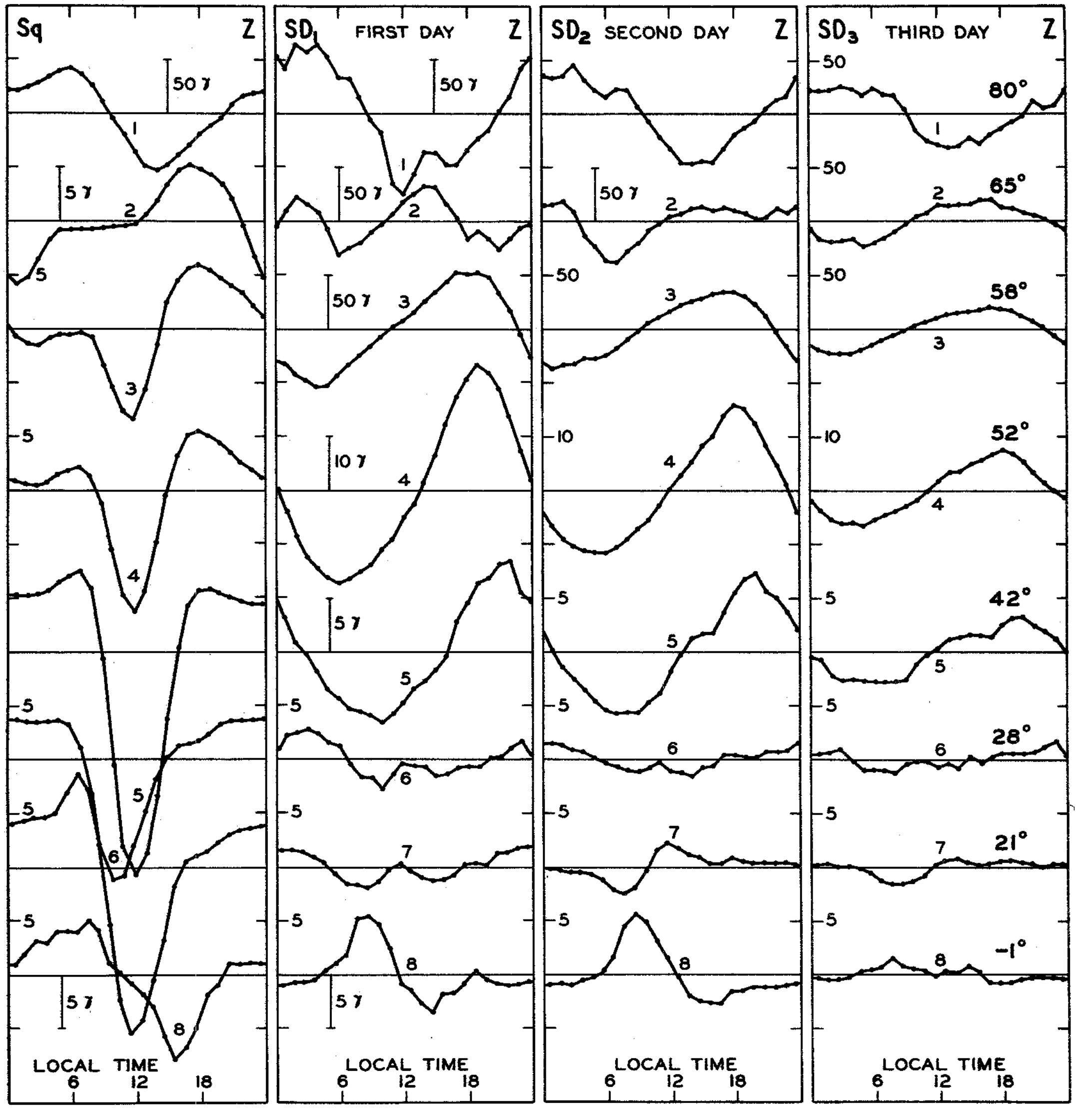


Fig. 13. Sq and SD in the vertical force Z at different geomagnetic latitudes for the average moderate storm, Z being measured positively toward nadir. The three columns for SD, i.e., the second, third and fourth from the left, refer to the first, second and third days of the storm, respectively.

Figs. 10, 11, for the element H show that the SD curves are reversed on crossing a certain "focal" latitude, not far north of 52°. The curves for this latitude are, in some cases, transitional between those for more northerly and southerly latitudes. There is some indication that the focal latitude is slightly higher on the first storm day than on the second and third. There seems to be no marked change of the focal latitude from the weak to the moderate storms.

The amplitudes of SD for the weak and the moderate storms are compared in Section 6.

5. THE FIRST 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:

$$\sum_n (a_n \cos n\lambda_s + b_n \sin n\lambda_s)$$

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

where a_n, b_n and c_n are in gamma and σ_n in degrees for all three elements; λ_s is measured eastward from the midnight meridian. The harmonic coefficients and phases for the 11 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 eight observatory groups are presented in Table 5.

Table 5. Harmonic data for the first component of DS in E, H, and Z, measured in gamma, for the average moderate 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 reckoned from the midnight meridian.

Group 1 (80°). Godhavn.

Interval	a_1	b_1	c_1	σ_1	
					E
1	-83.7	89.3	122.4	317°	
2	1.2	113.8	113.8	1	
3	-12.3	71.9	72.9	350	
4	6.6	76.2	76.5	5	
5	0.1	68.0	68.0	0	
6	-11.0	82.1	82.8	352	
7	6.0	55.5	55.8	6	
8	-15.6	29.8	33.6	332	
9	- 7.7	54.0	54.5	352	
10	1.9	41.1	41.1	3	
11	- 8.3	41.4	42.2	349	
					H
1	85.3	69.3	109.9	51°	
2	94.7	0.9	94.7	89	
3	83.3	-12.3	84.2	98	
4	69.3	-14.8	70.9	102	
5	92.2	10.2	92.8	84	
6	45.8	5.7	46.2	83	
7	52.3	14.3	54.2	75	
8	39.8	- 1.5	39.8	92	
9	37.6	4.5	37.9	83	
10	37.7	- 4.5	38.0	97	
11	35.8	22.4	42.2	58	
					Z
1	35.5	85.8	92.8	22°	
2	63.2	-21.1	66.6	108	
3	44.3	42.9	61.7	46	
4	47.1	38.6	60.9	51	
5	38.7	30.9	49.5	51	
6	31.5	24.1	39.7	53	
7	30.5	16.9	34.9	61	
8	19.3	35.5	40.4	29	
9	9.8	15.8	18.6	32	
10	30.9	32.3	44.7	44	
11	21.2	7.1	22.4	72	

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

Interval	a_1	b_1	c_1	σ_1
				E
1	-12.8	18.4	22.4	325°
2	14.0	37.8	40.3	20
3	15.3	27.4	31.4	29
4	8.3	17.1	19.0	26
5	13.7	20.6	24.7	34
6	20.7	16.3	26.3	38
7	5.9	14.9	16.0	22
8	14.5	5.2	15.4	20
9	9.8	6.8	11.9	35
10	- 1.3	- 0.7	1.5	242
11	12.4	9.1	15.4	54
				H
1	52.9	-127.3	137.9	157°
2	-71.8	-149.0	165.4	206
3	-61.8	-153.8	165.8	202
4	-88.7	- 98.6	132.7	222
5	-61.9	-104.1	121.1	211
6	-87.3	- 88.5	124.3	225
7	-43.5	- 66.9	79.8	213
8	-43.4	- 58.7	73.0	216
9	-43.3	- 47.8	64.5	222
10	-21.6	- 49.7	54.2	204
11	-36.5	- 64.8	74.4	209
				Z
1	-10.7	-12.4	16.4	221°
2	12.7	5.3	13.8	67
3	-17.2	-14.7	22.6	229
4	-15.3	4.0	15.8	285
5	30.9	2.3	31.0	86
6	8.3	-24.5	25.9	161
7	- 0.4	-16.0	16.0	181
8	-15.1	-27.9	31.7	208
9	- 5.0	-16.3	17.1	197
10	-17.2	-14.7	22.6	229
11	-10.8	-19.2	22.0	209

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

Interval	a_1	b_1	c_1	σ_1	
					E
1	1.7	22.3	22.4	4°	
2	27.1	16.9	31.9	58	
3	21.7	3.8	22.0	80	
4	16.4	- 1.3	16.3	95	
5	15.8	5.8	16.8	70	
6	9.4	2.1	9.6	77	
7	10.0	- 3.3	10.5	108	
8	5.8	- 3.1	6.6	118	
9	5.5	- 2.2	5.9	112	
10	1.6	- 2.8	3.2	150	
11	4.4	- 2.3	5.0	118	
					H
1	16.2	-34.9	38.5	155°	
2	-31.3	-37.7	49.0	220	
3	-15.5	-23.9	28.5	213	
4	-27.7	-26.8	38.6	226	
5	-18.5	-27.8	33.4	214	
6	-20.7	-19.8	28.7	226	
7	-12.7	-12.1	17.5	226	
8	- 5.6	- 6.4	8.5	221	
9	- 8.3	- 7.6	11.3	228	
10	- 1.9	- 6.2	6.5	197	
11	- 4.6	- 7.7	9.0	211	
1	19.9	-41.8	46.3	155°	
2	-29.3	-63.3	69.8	205	
3	-19.7	-44.2	48.4	204	
4	-24.6	-41.0	47.8	211	
5	-24.1	-45.7	51.7	208	
6	-29.0	-27.9	40.2	226	
7	-19.3	-16.9	25.7	229	
8	- 7.5	-21.2	22.5	199	
9	-14.9	-19.8	24.8	217	
10	- 9.1	-15.0	17.5	211	
11	-10.6	-17.3	20.3	212	

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

Interval	a_1	b_1	c_1	ϵ_1
				E
1	3.2	15.8	16.1	11°
2	24.3	6.6	25.2	75
3	18.1	- 2.3	18.2	97
4	7.8	- 1.6	8.0	102
5	13.3	1.2	13.4	85
6	10.3	- 0.9	10.3	95
7	8.8	- 4.1	9.7	115
8	5.8	- 2.6	6.4	114
9	3.2	- 3.3	4.6	136
10	3.6	- 3.2	4.8	132
11	3.4	- 2.8	4.4	129
				H
1	0.7	0.0	0.7	90°
2	-2.3	4.6	5.1	333
3	-0.5	5.2	5.2	355
4	1.0	3.0	3.2	18
5	0.6	0.8	1.0	37
6	0.2	- 0.3	0.4	146
7	0.8	0.4	0.9	63
8	0.8	3.8	3.9	12
9	3.5	- 0.3	3.5	95
10	1.2	- 1.3	1.8	137
11	0.9	0.8	1.2	48
				Z
1	14.3	- 9.8	17.3	124°
2	1.8	-22.9	23.0	175
3	1.9	-21.7	21.8	95
4	- 0.6	-20.2	20.2	182
5	- 1.9	-19.0	19.1	186
6	- 2.2	-12.5	12.7	190
7	- 2.5	-11.5	11.8	192
8	0.8	- 8.9	8.9	175
9	- 2.6	- 7.4	7.8	199
10	- 1.1	- 5.8	5.9	191
11	- 1.0	- 5.6	5.7	190

Group 5 (42°). Ebro, Tucson.

Interval	a_1	b_1	c_1	ε_1
				E
1	- 0.1	14.3	14.3	0°
2	16.3	3.8	16.7	77
3	16.0	2.1	16.1	83
4	9.4	- 3.3	10.0	109
5	12.3	0.0	12.3	90
6	8.3	- 4.0	9.2	116
7	8.1	- 2.3	8.4	106
8	6.9	- 1.9	7.2	105
9	2.8	- 3.6	4.6	142
10	3.3	- 3.6	4.9	137
11	2.5	- 1.6	3.0	123
				H
1	- 6.1	3.5	7.0	300°
2	- 7.8	15.4	17.3	333
3	- 1.9	15.3	15.4	353
4	1.2	12.0	12.1	6
5	1.6	14.8	14.9	6
6	3.2	7.2	7.9	24
7	- 1.3	8.1	8.2	351
8	- 0.8	6.0	6.1	352
9	2.7	5.3	5.9	27
10	1.1	2.6	2.8	23
11	0.9	4.1	4.2	12
				Z
1	6.3	1.4	6.5	77°
2	5.8	- 6.8	8.9	140
3	4.8	- 5.4	7.2	138
4	3.5	- 7.3	8.1	154
5	4.2	- 6.5	7.7	147
6	2.9	- 7.9	8.4	160
7	0.8	- 5.2	5.3	171
8	1.7	- 2.9	3.4	150
9	0.2	- 3.7	3.7	177
10	-0.3	- 3.3	3.3	185
11	-0.3	- 1.8	1.8	189

Group 6 (28°). San Juan, Kakioka.

E

Interval	a_1	b_1	c_1	σ_1
1	0.8	7.3	7.3	6°
2	10.0	1.0	10.1	84
3	5.1	-1.5	5.3	106
4	1.7	-1.5	2.3	131
5	8.3	0.0	8.3	90
6	1.8	-4.0	4.4	156
7	2.5	0.5	2.5	79
8	2.2	-0.3	2.2	98
9	1.6	-0.9	1.8	119
10	0.8	-1.7	1.9	155
11	1.1	-0.7	1.3	122

H

Interval	a_1	b_1	c_1	σ_1
1	-12.1	2.3	12.3	281°
2	-10.5	12.5	16.3	320
3	- 4.2	12.8	13.5	342
4	- 0.1	9.3	9.3	359
5	- 0.6	8.1	8.1	356
6	- 0.6	7.6	7.6	355
7	0.3	8.2	8.2	2
8	0.1	5.8	5.8	1
9	2.3	3.5	4.2	33
10	2.3	3.4	4.1	34
11	2.2	1.3	2.6	59

Z

Interval	a_1	b_1	c_1	σ_1
1	0.8	2.1	2.2	21°
2	3.1	1.7	3.5	61
3	1.9	-1.3	2.3	124
4	1.2	-0.2	1.2	99
5	0.6	-0.3	0.7	117
6	1.9	0.1	1.9	87
7	1.6	0.8	1.8	63
8	1.0	-0.8	1.3	129
9	1.4	-1.0	1.7	126
10	0.3	-0.3	0.4	135
11	-0.1	-0.8	0.8	187

Group 7 (21°). Honolulu, Zikawei.

E

Interval	a_1	b_1	c_1	γ_1
1	- 0.5	6.6	6.6	356°
2	8.5	4.1	9.4	64
3	6.2	-0.3	6.2	93
4	4.5	-1.7	4.8	339
5	7.2	-1.3	7.3	350
6	4.4	-2.4	5.0	331
7	2.5	-2.9	3.8	139
8	1.5	0.4	1.6	75
9	3.0	-1.7	3.4	330
10	1.4	-1.4	2.0	45
11	1.9	-0.3	1.9	99

H

Interval	a_1	b_1	c_1	γ_1
1	-15.9	3.7	16.3	283°
2	- 4.6	18.9	19.4	346
3	- 3.2	11.1	11.6	344
4	2.4	10.3	10.6	13
5	- 1.0	11.3	11.3	355
6	3.2	9.7	10.2	18
7	3.1	8.1	5.1	37
8	1.3	5.2	5.4	14
9	2.6	4.8	5.5	28
10	2.1	4.4	4.9	26
11	2.1	4.3	4.8	26

Z

Interval	a_1	b_1	c_1	γ_1
1	2.2	-0.3	2.2	98°
2	1.8	0.7	1.9	69
3	0.9	-1.0	1.3	138
4	1.3	-0.2	1.3	99
5	0.4	-2.7	2.7	172
6	-0.7	-2.0	2.1	199
7	-1.3	-0.7	1.5	242
8	0.1	0.8	0.8	7
9	0.5	-1.2	1.3	157
10	-0.2	-0.7	0.7	196
11	0.3	-0.8	0.9	159

Group 8 (-1°). Huancayo.

E

Interval	a_1	b_1	c_1	ϵ_1
1	-3.5	-3.6	5.0	224°
2	2.1	-3.0	3.7	145
3	-3.2	-1.8	3.7	241
4	-3.4	-0.6	3.5	260
5	-0.8	-2.0	2.2	202
6	-2.5	-1.7	3.0	236
7	-1.7	-0.7	1.8	248
8	-2.5	-1.3	2.8	243
9	-2.5	-1.3	2.8	243
10	-2.4	0.1	2.4	272
11	2.1	-1.8	2.8	131

H

Interval	a_1	b_1	c_1	ϵ_1
1	-9.7	-2.2	9.9	257°
2	-3.3	0.8	3.4	284
3	2.0	12.0	12.2	9
4	17.3	21.4	27.5	39
5	3.2	7.6	8.2	23
6	7.0	9.8	12.0	36
7	-1.3	4.1	4.3	342
8	6.3	3.2	7.1	63
9	-1.8	0.6	1.9	72
10	-2.3	4.7	5.2	334
11	1.7	1.4	2.2	51

Z

Interval	a_1	b_1	c_1	ϵ_1
1	-2.3	0.3	2.3	277°
2	-3.0	2.7	4.0	312
3	0.0	6.1	6.1	0
4	1.5	-1.3	2.0	131
5	-1.1	2.8	3.0	339
6	-1.5	1.4	2.1	313
7	-2.1	2.2	3.0	316
8	-1.8	2.3	2.9	322
9	-0.2	1.3	1.3	351
10	-0.1	-0.5	0.5	191
11	-1.6	0.9	1.8	299

Figs. 14-17 consist of sets of harmonic dials. Figs. 14 and 16 refer to weak storms, Figs. 15 and 17 to moderate storms. In each pair the earlier figure refers to the four higher latitude groups of observatories, and the later figure refers to the lower latitudes. Each dial shows a connected set of 11 dial points for the first harmonic of DS, at the 11 epochs of storm time from 3 to 45 hours at 6-hour intervals, and then at 52, 60 and 68 hours. To accomodate 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 with storm time in all latitudes: the changes are systematic except in the cases where 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 dial-grams for the weak and moderate storms are essentially of the same character, if irregular changes are ignored. It is uncertain whether the phase change with storm time is more rapid for moderate than for weak storms.

The irregular dial-gram for H near the magnetic equator (Group 8) is noteworthy. 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. When this abnormal enhancement is superposed upon the normal change characteristic in low latitudes, the

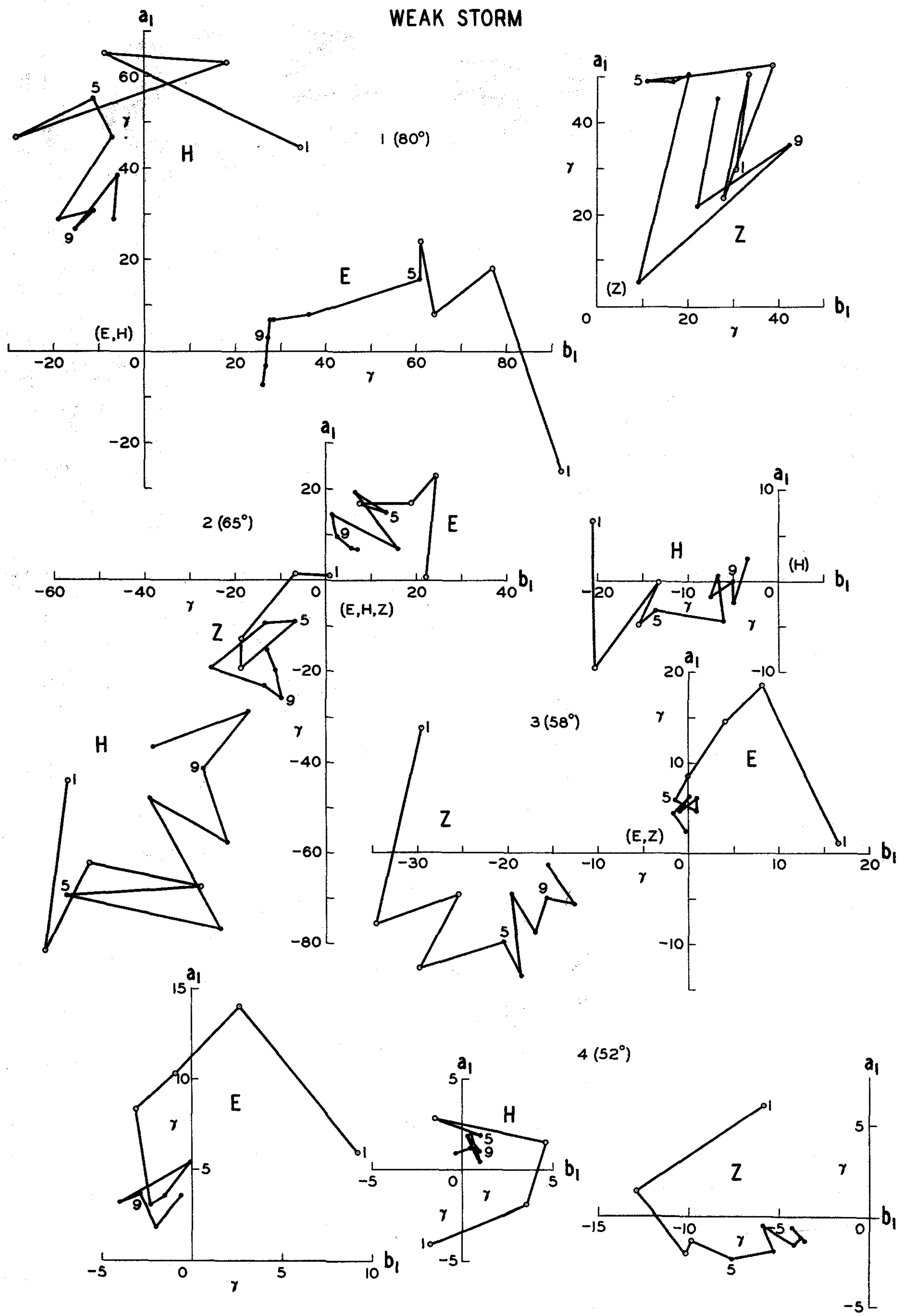


Fig. 14. Harmonic dials for the first component of DS in H, E, and Z for the average weak storm for the observatory-groups 1(80°), 2(65°), 3(58°), and 4(52°), the numbers in parentheses being geomagnetic latitudes. The eleven points refer to the eight 6-hour intervals and the following three 8-hour intervals.

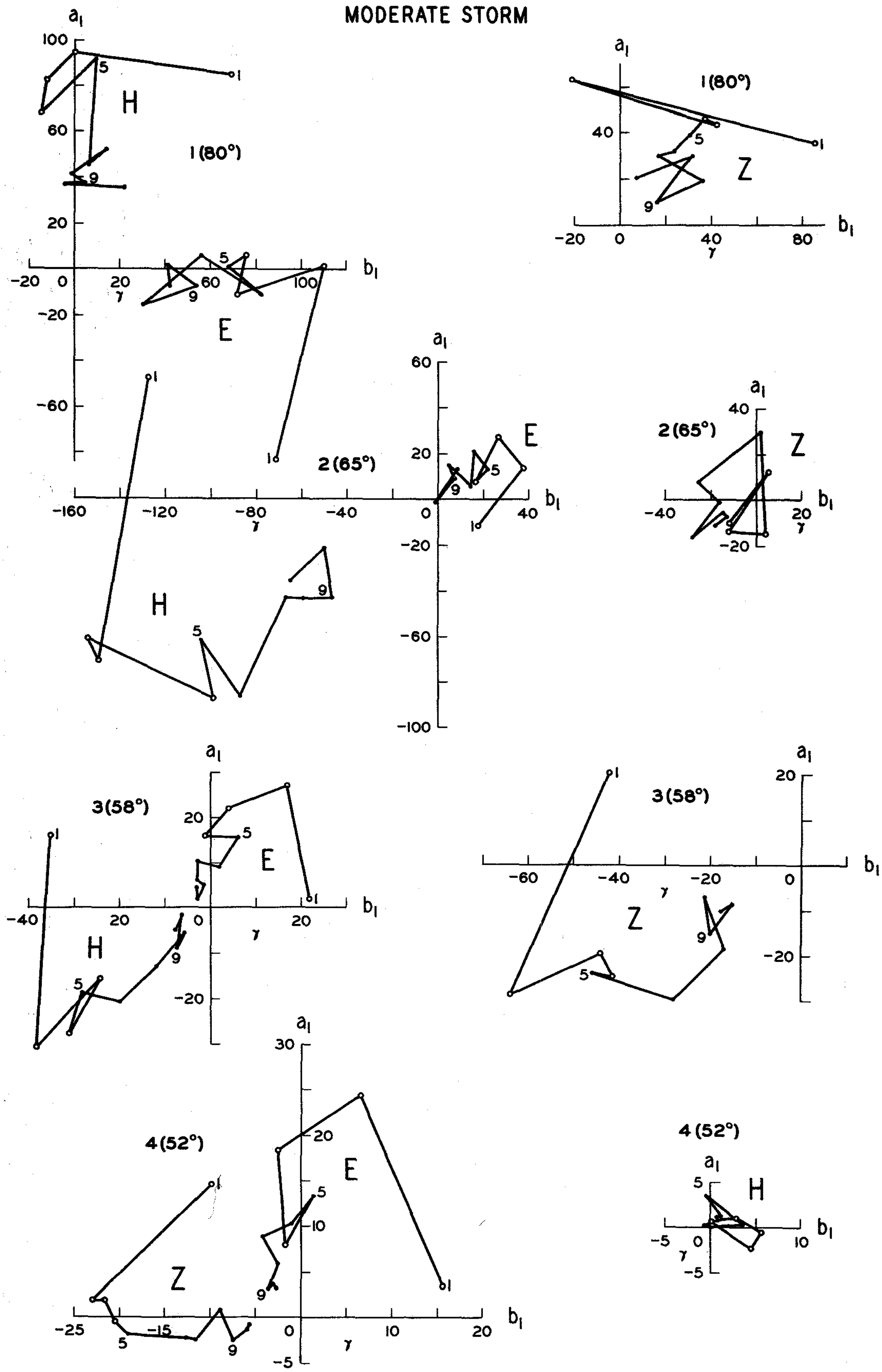


Fig. 15. Harmonic dials for the first component of DS in H, E, and Z for the average moderate storm for the observatory-groups 1(80°), 2(65°), 3(58°), and 4(52°), the numbers in parentheses being geomagnetic latitudes. The eleven points refer to the eleven intervals as in Fig. 14.

WEAK STORM

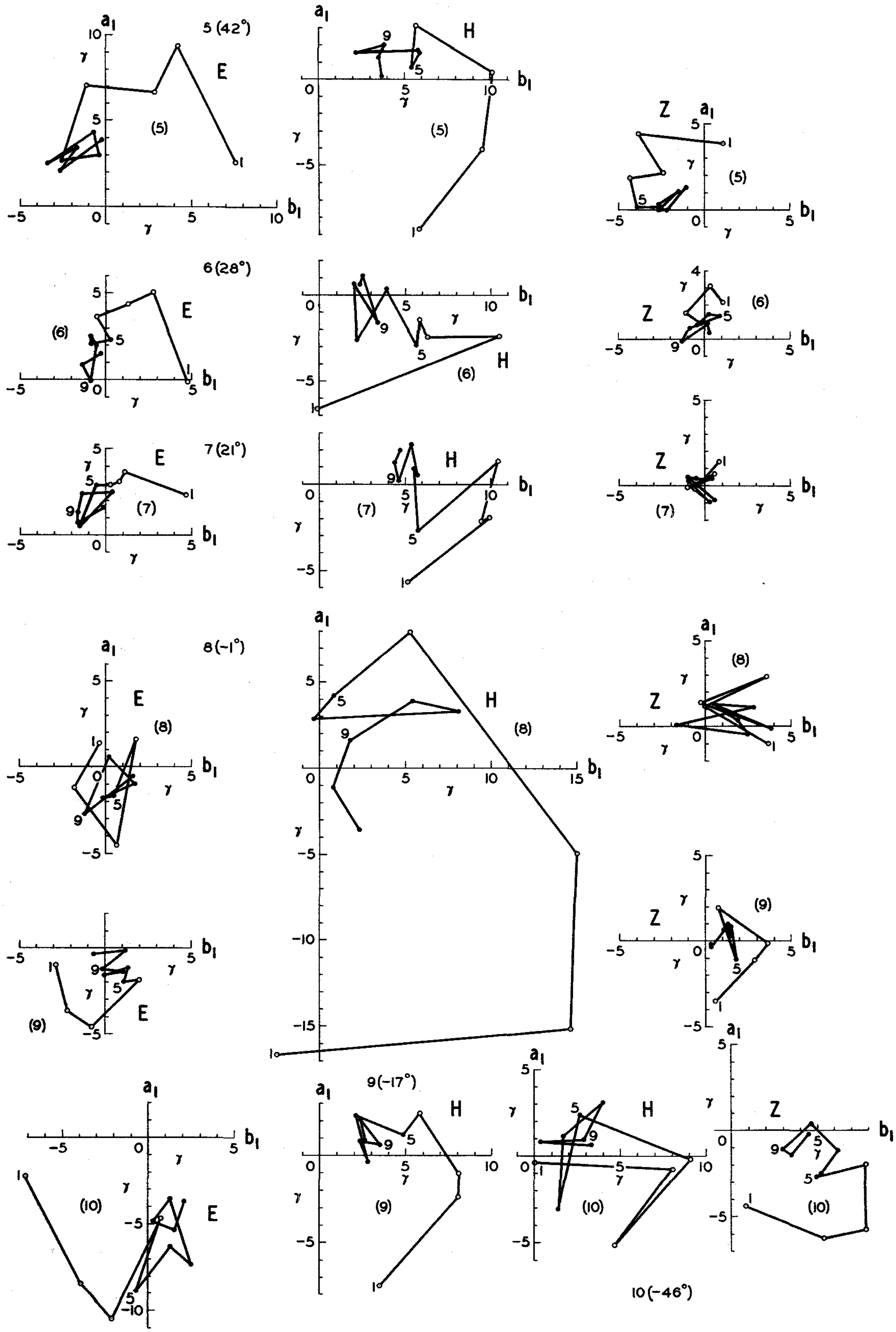


Fig. 16. Harmonic dials for the first component of DS in H, E, and Z for the average weak storm for the observatory-groups 5(42°), 6(28°), 7(21°), 8(-1°), 9(-17°), and 10(-46°); here the numbers in parentheses are geomagnetic latitudes, negative sign indicating southern latitude. The eleven points refer to the first eight 6-hour intervals and the following three 8-hour intervals.

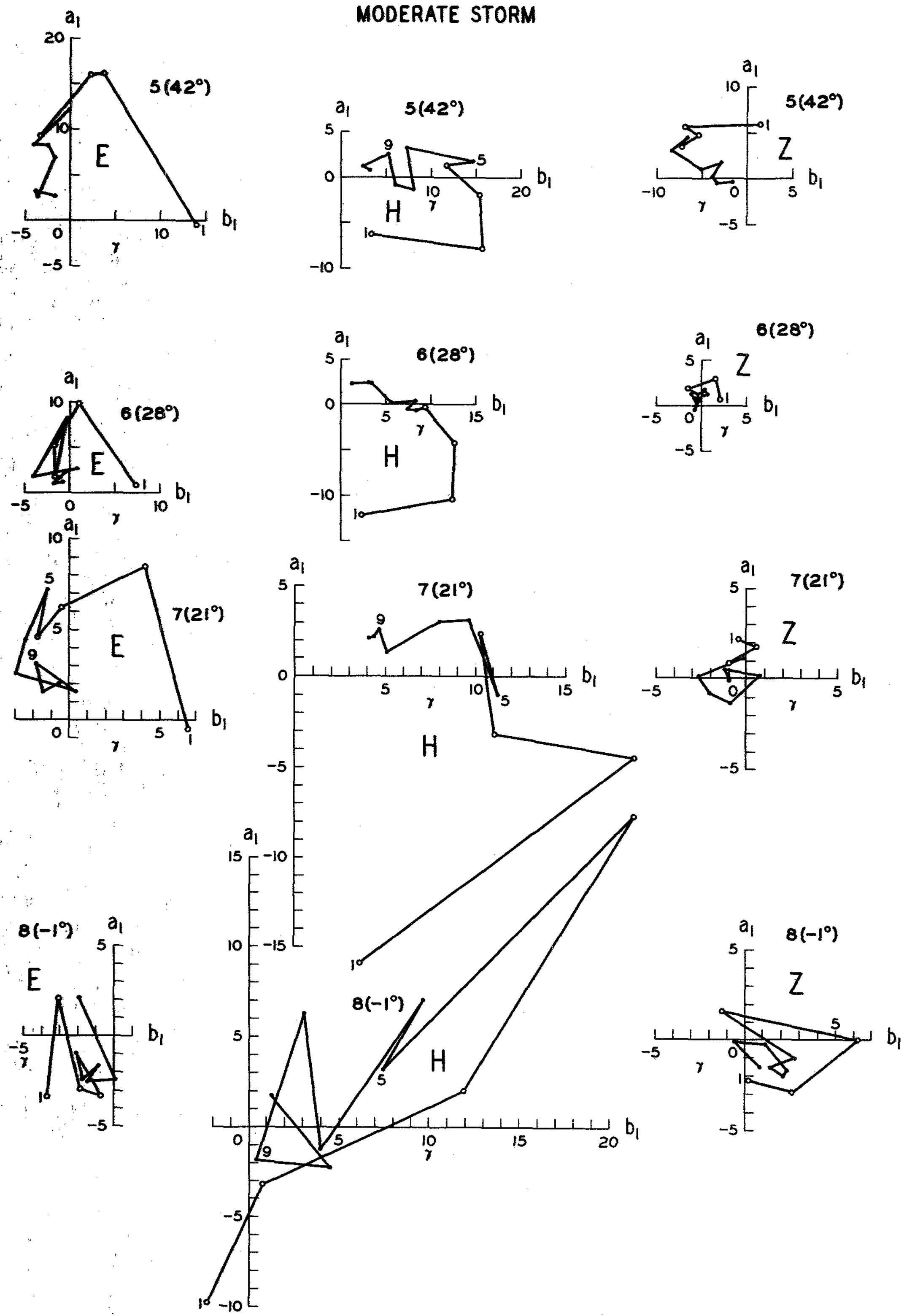


Fig. 17. Harmonic dials for the first component of DS in H, E, and Z for the average moderate storm for the observatory-groups 5(42°), 6(28°), 7(21°), and 8(-1°); here the numbers in parentheses are geomagnetic latitudes, negative sign indicating southern latitude. The eleven points refer to the eleven intervals as in Fig. 16.

resultant variation is complex. The amplitude of the first component may be considerably suppressed, and the higher harmonics may become appreciably greater than those in the normal DS in low latitudes.

In the harmonic dials for the observatory groups 5(42°), 6(28°), and 7(21°) in Figs. 16 and 17, changes in the second and third days are small and of magnitudes comparable with the irregularities. Hence the systematic changes may be brought out more clearly if all-day means are taken for the second and third days. Thus, 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 resultant coefficients are further averaged over the observatory groups 5, 6, and 7; they are given in Table 6. The harmonic dials so obtained for E, H, and Z for the weak and moderate storms are shown in Fig. 18. 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. 18 are given in Table 6. The comparison of the phase angles δ_1 for the weak and moderate storms in Table 6 shows remarkable agreement between them: the largest discrepancy is only 18°.

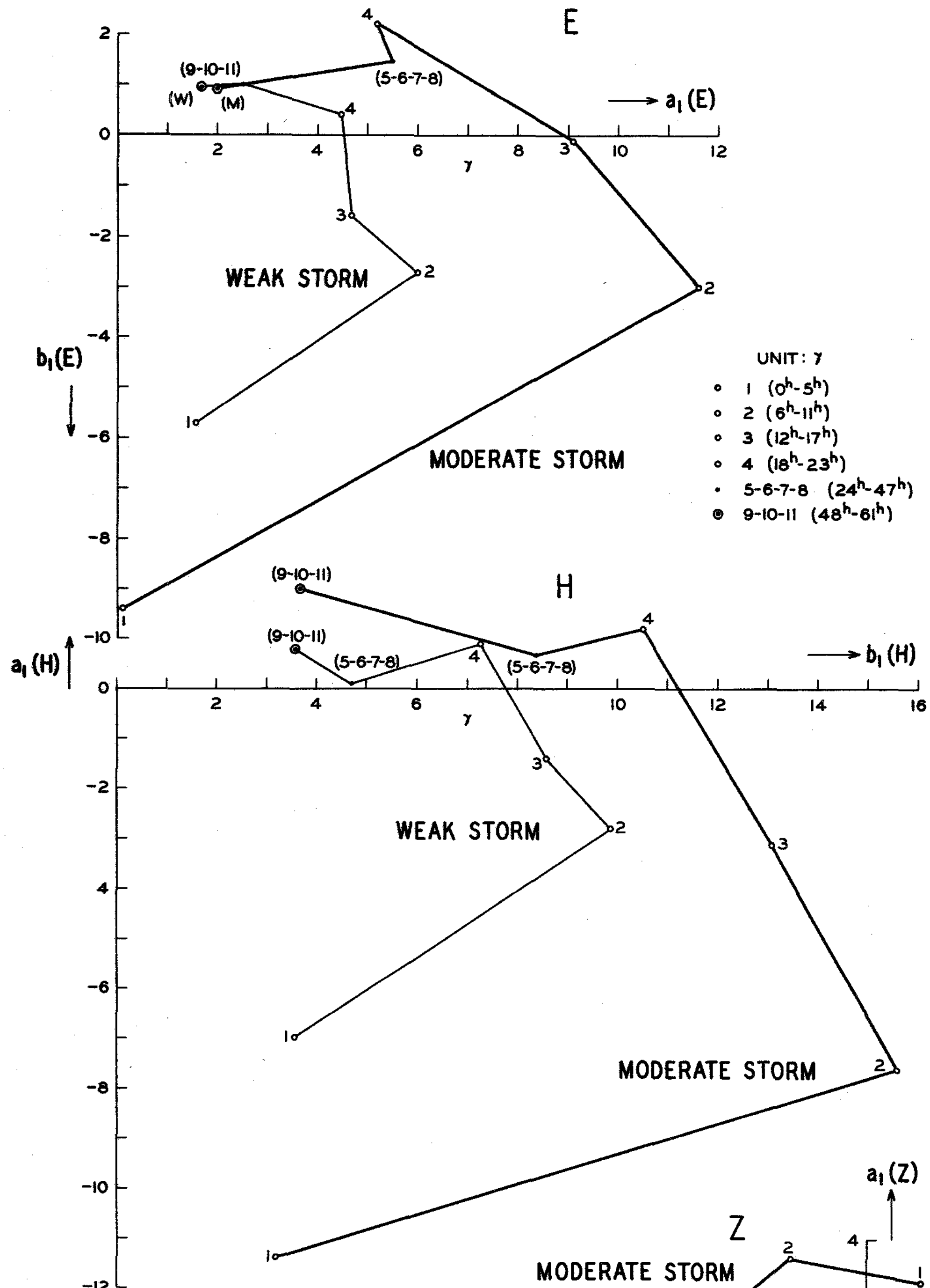
Fig. 18 summarizes the characteristics of the DS variations in the three elements for the average moderate and the average weak storm for geomagnetic latitudes 20° to 40°. From the harmonic dials in Fig. 18 it is possible to determine for these latitudes the statistical averages of the amplitudes and phases of DS in E, H, and Z for any given moment

Table 6. Harmonic data for the first component of the DS variations in E, H, and Z, for the average weak and the average moderate 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 nidnight 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 ($0^h - 5^h$), ($6^h - 11^h$), ($12^h - 17^h$), and ($18^h - 23^h$), respectively, and intervals 5-8 and 9-11 to the second and third day, respectively.

	Interval	Weak Storm		Moderate Storm		Weak Storm		Moderate Storm	
E		a_1	b_1	a_1	b_1	c_1	σ_1	c_1	σ_1
	1	1.6	5.7	0.1	9.4	5.9	16°	9.4	1°
	2	6.0	2.7	11.6	3.0	6.6	66	12.0	75
	3	4.7	1.6	9.1	0.1	5.0	71	9.1	89
	4	4.5	-0.4	5.2	-2.2	4.5	95	5.6	113
	5-8								
	5-8	2.5	-1.0	5.5	-1.5	2.7	112	5.7	105
	9-11	1.7	-0.9	2.0	-0.9	1.9	118	2.2	114
H									
	1	-7.0	3.6	-11.4	3.2	7.9	-63	11.8	-74
	2	-2.8	9.9	- 7.6	15.6	10.3	-16	17.4	-26
	3	-1.4	8.6	- 3.1	13.1	8.7	- 9	13.5	-13
	4	0.9	7.3	1.2	10.5	7.4	7	10.6	7
	5-8	0.1	4.7	0.7	8.4	4.7	1	8.4	5
	9-11	0.8	3.6	2.0	3.7	3.7	13	4.2	28
Z									
	1	2.5	1.0	3.1	1.1	2.7	68	3.3	70
	2	2.4	-1.4	3.6	-1.5	2.8	120	3.9	113
	3	1.4	-1.0	2.5	-2.8	1.7	126	3.8	138
	4	0.9	-1.8	2.0	-2.8	2.0	153	3.4	144
	5-8	0.5	-1.0	1.1	-2.2	1.1	153	2.5	153
	9-11	0.2	-0.6	0.2	-1.5	0.6	162	1.5	172



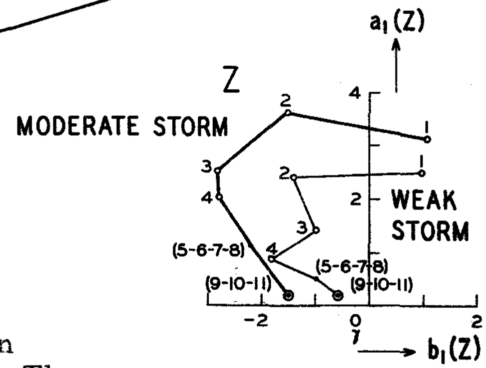


Fig. 18. Harmonic dials for the first component of DS in H, E, and Z for the average weak and the average moderate storm; mean of the observatory-groups 5(42°), 6(28°), and 7(21°), the numbers in parentheses being geomagnetic latitudes. The dial points 1 to 4 refer to the first four 6-hour intervals (in the first day), and the points marked by (5, 6, 7, 8) and those by (9, 10, 11) refer to the second and third day, respectively. The harmonic dial for E is rotated clockwise through 90°.

of storm time, or for any storm phase, in a magnetic storm within the range of storm intensity considered here, i.e. weak to moderate. Similar harmonic dials will later be derived for the group of great storms.

6. THE HIGHER HARMONIC COMPONENTS OF DS AND SD

It is of great interest to examine the higher harmonic components of DS and SD. 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 are shown in Fig. 19. In Fig. 19, the eleven dial points for each element refer to the same eleven epochs of storm time as in Figs. 14-17. The second component is clearly much smaller than the first.

To eliminate irregular variations, the dial points in Fig. 19 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. Such harmonic dials are shown in the upper part of Fig. 20. 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 Fig. 20. These higher harmonics are still smaller. The numerical data for the harmonic dials in Fig. 20 are given in Table 7, together with the corresponding data for the average weak storm.

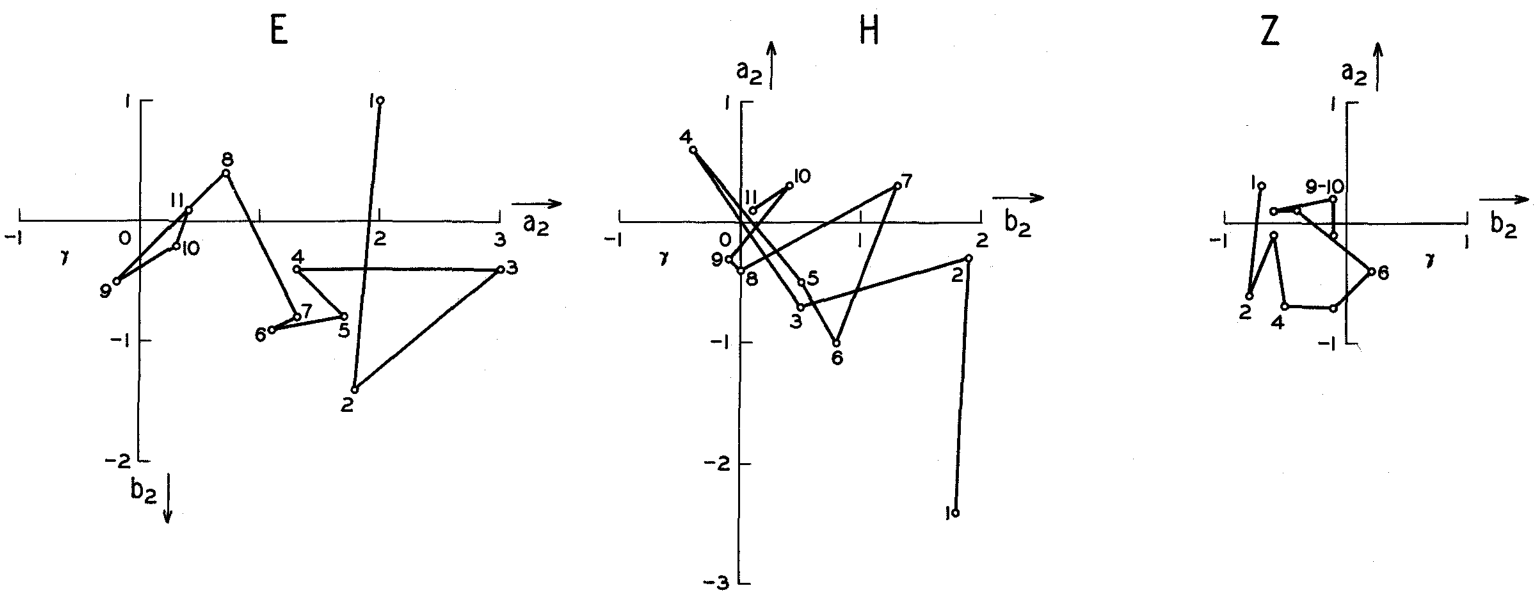


Fig. 19. Harmonic dials for the second component of DS in H, E, and Z for the average moderate storm; mean of the observatory-groups 4(52°), 5(42°), 6(28°), and 7(21°), the numbers in parentheses being geomagnetic latitudes. The eleven dial points refer to the first eight 6-hour intervals (in the first and second days) and the following three 8-hour intervals (in the third day).

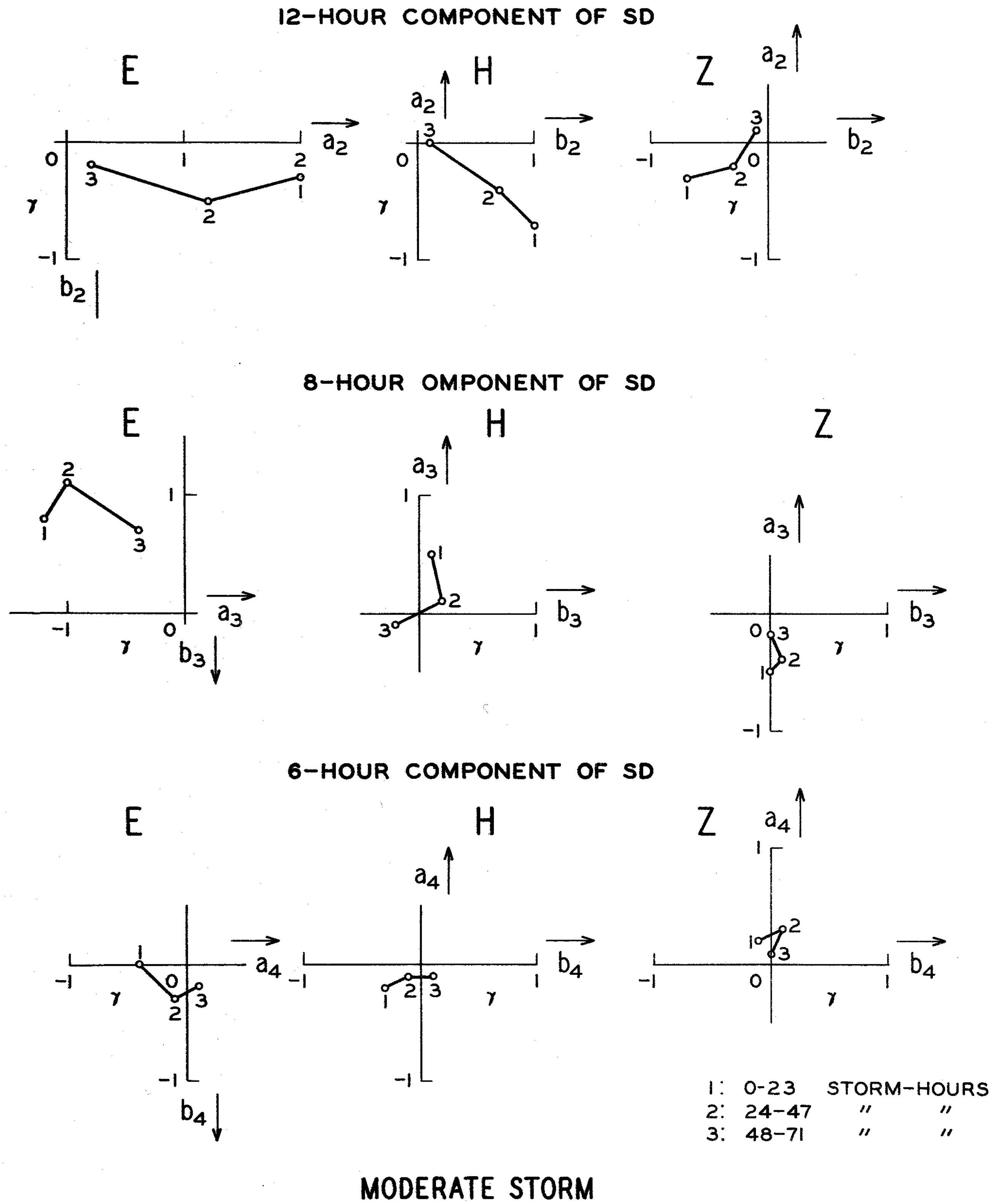


Fig. 20. Harmonic dials for SD^1, SD^2, and SD^3, for H, E, and Z for the average moderate storm; mean of the observatory-groups 4(52°), 5(42°), 6(28°), and 7(21°). The three dial points refer to the first, second, and third days of the storm.

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
SD(H)	1	-1.8	6.4	-0.5	0.8	0.3	-0.3	-1.3	0.1
	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
SD(E)	1	5.3	1.8	1.4	0.3	-0.7	-0.5	0.4	-0.2
	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
SD(Z)	1	2.0	-3.5	0.1	-0.2	-0.2	-0.2	0.6	0.2
	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
SD(H)	1	-4.0	8.8	-0.7	1.0	0.5	0.1	-0.2	-0.3
	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
SD(E)	1	8.3	3.1	2.0	0.3	-1.2	-0.8	-0.4	0.0
	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
SD(Z)	1	3.2	-5.7	-0.3	-0.7	-0.5	0.0	0.2	-0.1
	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

7. COMPARISON OF Dst AND DS

Figs. 21 and 22, the former for weak and the latter for moderate storms, enable the storm-time course of the Dst and DS variations to be compared, in the three magnetic elements and for different magnetic latitudes. The measure of DS used is $2c_1$, the range of the first harmonic component of DS, or rather $-2c_1$, so that the DS curves more resemble Dst(H), which is mainly negative. The values computed from the observational data are shown by circles (for Dst) and dots (for DS); smooth curves are drawn between them. Each curve shows the variation throughout the first three storm days. In Fig. 21 the force scale is the same for the observatory group 3-8 (gm. lats. -1° to 58°); for groups 1 and 2, the scale is contracted 5-fold. In Fig. 22, the force scale used for group 5-7 is the same (it is rather more open than the scale used in Fig. 21 for the same groups); this scale is contracted 2-fold for groups 4 and 8, 5-fold for group 3, and 10-fold for groups 1 and 2.

At 80°, well inside the auroral zone, DS predominates greatly over Dst. It is greatest in E and least in Z, though the proportionate differences between the three elements are small. For the weak storms, $2c_1$ for DS(E) rises to 190 γ, for moderate storms to 240 γ.

At 65°, near the zone of maximum auroral frequencies, (67°), DS(H) predominates, with a maximum range 200 γ (weak storms), 360γ (moderate storms)— decidedly greater than for E and Z. As at 80°, Dst is small compared with DS.

AVERAGE WEAK STORM

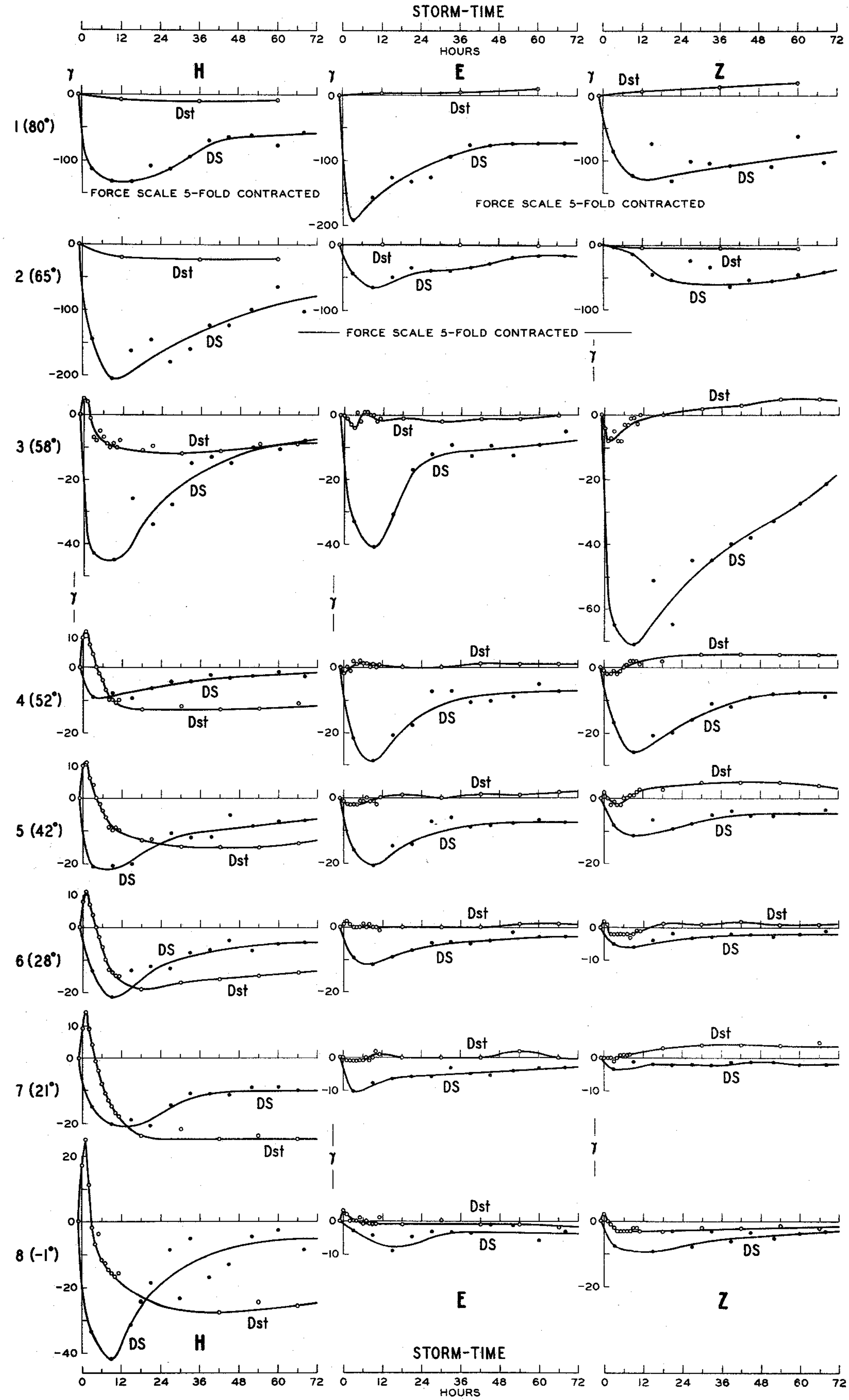


Fig. 21. Dst variations and the ranges in the first component of DS, $(2c_1)$, for H, E, and Z plotted against storm time, for the average weak storm for different geomagnetic latitudes.

AVERAGE MODERATE STORM

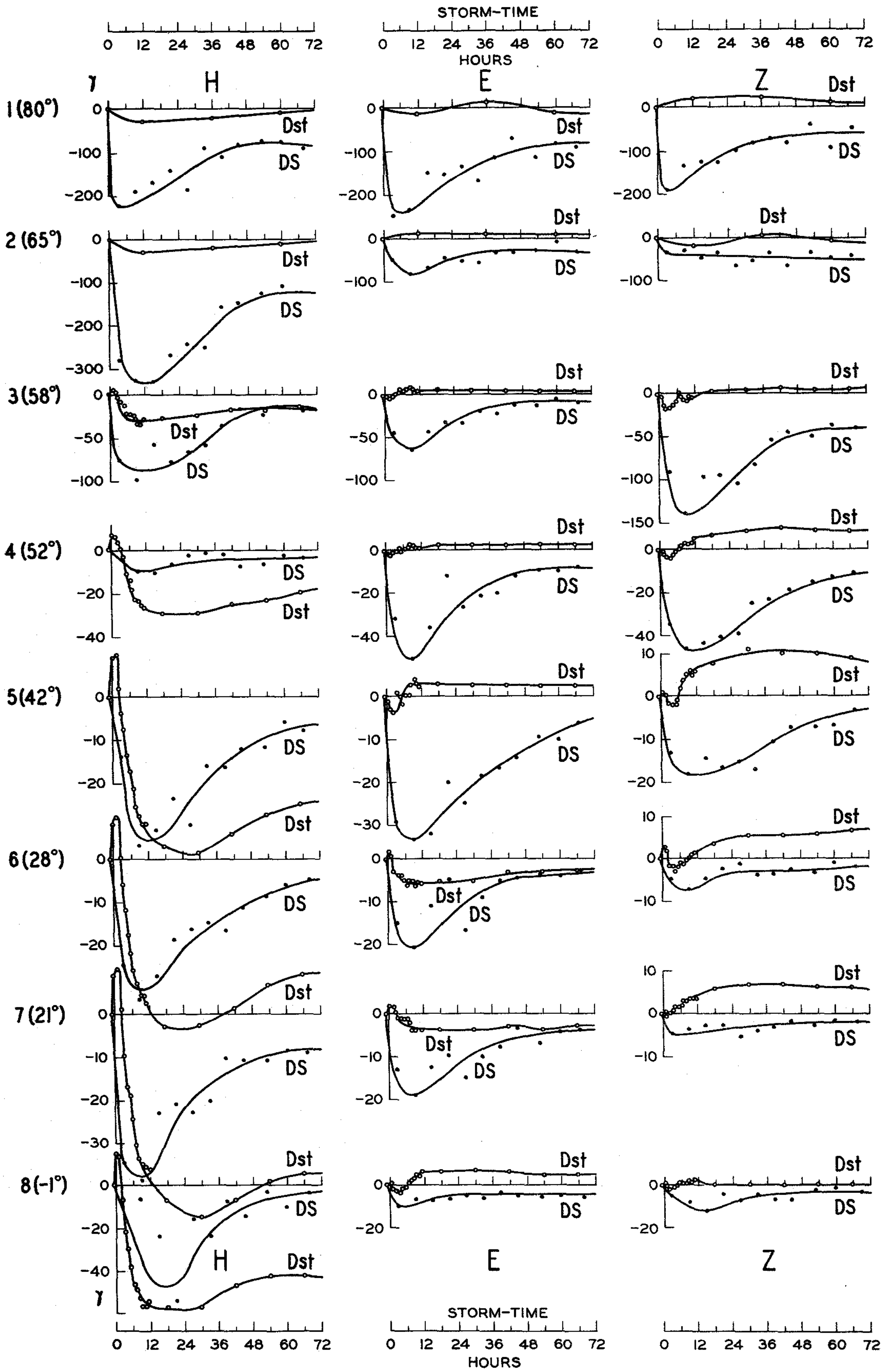


Fig. 22. Dst variations and the ranges in the first component of DS, ($2c_1$), for H, E, and Z, plotted against storm time, for the average moderate storm for different geomagnetic latitudes.

From 65° to 58° DS(H) decreases greatly, but DS(Z) does not. Indeed, for moderate storms it shows a marked increase. This implies that the electric currents responsible for DS flow (eastward and westward) to the north of 58°, and not far from 65° latitude. From Figs. 21 and 22 alone, the latitude of the electric currents cannot be determined more definitely.

At 58°, though Dst is still small compared with DS (especially in Z), it begins to show the characteristics that mark it throughout middle and low latitudes - small and reverse in Z as compared with H, and negligible in Egm.

At 52°, the greatest variations are DS(E) and DS(Z). In H, Dst becomes greater than DS. The smallness of DS(H) compared with DS(E) and DS(Z) implies that the foci of the DS current circuits are near 52°.

At 42°, Dst (H), DS(H), and DS(E) approach equality. At 28° DS(E) is less than DS(H), and for moderate (but not for weak) storms, Dst(H) exceeds DS(H). With further decrease of latitude, Dst(H) and DS(H) increase to maxima at or near the equator; but DS(E), Dst(Z), and DS(Z) diminish, to be reversed on crossing the equator.

The above remarks concern the magnitudes of Dst and DS as a whole, at different latitudes and in different elements. The storm-time course of their changes is next considered.

As Chapman showed[5], the storm-time course of the DS part of the D 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 gm latitude from 50°N to 18°S.

The curves for the observatory groups 4 to 8 in Figs. 21 and 22 confirm this conclusion, on the basis of much more data. They show also that it is valid for weak storms, despite the considerable difference between their storm-time development and that of moderate storms.

In both weak and moderate storms, 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. The maximum of DS is attained at about 9^h or 12^h (storm time) both in weak storms and moderate storms. Because DS is determined less accurately than Dst, it is not yet possible to estimate any difference there may be between the times of maximum DS for the two classes of storm. The subsequent decay of DS seems, surprisingly, to be more rapid for weak than for moderate storms; the decay time from maximum DS(H) to half the maximum is about 18 hours for weak storms, and about 24 hours for moderate storms. This contrasts strongly with the behavior of Dst. In the main phase, the storm hour of maximum development is about 36 for the weak storms and 26 to 27 for the moderate storms. The subsequent decay intervals to half the maximum cannot be deduced from Fig. 21, 22, because this half decay is not accomplished within the first three storm days. But in the middle of the sixth half-day, the recovery Dst(H) is only a few per cent for weak storms; for moderate storms it is about 25 per cent. These remarks apply to middle and low latitudes. At higher latitudes, the smaller magnitudes of Dst make such estimates difficult and doubtful.

The maximum diminution in Dst(H) is about 48 gamma at 21° latitude in the average moderate storm. It is about 25 gamma at the same latitude in the average weak storm. Thus, the Dst-field of the average moderate storm is 1.9 times the corresponding field in the average weak storm. The maximum range in DS(H) at this latitude is 38 gamma in the average moderate storm, and 20 gamma in the average weak storm. Thus, the average range in DS(H) at its maximum activity is slightly less than the maximum Dst(H) in both weak and moderate storms, and the moderate storm is nearly twice as intense as the average weak storm (on the present classification of storms) both in DS(H) and Dst(H). At 65°, the ratio is somewhat less - about 1.7, as measured with respect to DS(H).

Thus, the intensity of the auroral zone current and of the polar cap current increase less than proportionately as the intensity of the Dst-field in the lower latitudes increases. This feature will be investigated further for great storms.

8. CONCLUSION

8.1 The intensity index of magnetic storms

In this series of studies the morphology of magnetic storms, a new storm intensity index is defined. The maximum deviation of Dst(H) from the pre-storm level in low and middle latitudes is used as a measure for the storm intensity. The index is here called the class number.

The average class number of the 136 weak storms investigated in FR-1 is 16 (15 for season d, 16 for seasons j and e). The mean Dst(H) at its most active phase is 16 gamma between geomagnetic latitudes 28° and 42°. The average class number of the 136 moderate storms studied in this paper is 44 (43 for the seasons d and j and 46 for season e). The mean Dst(H) at its maximum is 44 gamma between geomagnetic latitudes 21° and 28°. Thus the class number successfully represents the maximum depression of Dst(H) in middle latitudes.

8.2 The Dst variations

The existence of the (positive) initial phase in H is confirmed with certainty for both average weak and average moderate storms 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°.

The size of the initial phase in Dst(H) is not proportional to the storm intensity. In low and moderate latitudes, it is less for the average moderate storm than for the average weak storm.

The Dst(H) reverses its sign (when measured from pre-storm level) notably earlier in the average moderate than in the average weak storm. Likewise the minimum in Dst(H) is attained, and the recovery phase begins, much earlier in the average moderate than in the average weak storm.

The direction of the Dst-field, in its initial and main phases, lies in planes that contain the geomagnetic axis. This is here demonstrated in more detail than hitherto.

8.3 The DS and SD variations

The latitude of the SD-foci is near 52°. As yet, no change in this latitude has been determined as the storm intensity increased from weak to moderate.

The phase of the first component of DS changes systematically with storm time in both average weak and average moderate storms. The main change appears to be completed within twelve hours or so from the sudden commencement. The phase of DS is essentially the same for the average weak and the average moderate storm.

The higher harmonic components in DS and SD in low and moderate latitudes have smaller amplitudes than the first component. The higher harmonic components in high latitudes will be further studied later. In this connection, Cain and Chapman[7] have recently shown that the second harmonic component of SD for Sitka, as derived from the daily variations on disturbed days, undergoes a systematic change with the degree of disturbance, and that the size, relative to the first component, is greater at Sitka than is found in this paper for the lower latitudes.

8.4 Future plans

The characteristics of the average weak storm and those of the average moderate storm are compared in this report. The investigation of the group of great storms is now being undertaken. When this latter study is completed, the morphology of magnetic storms will have been determined in detail for three different intensities, weak, moderate, and great. The next stop will be the discussion of the seasonal change in the morphology. A further step will be the synthesis of the results in the form of current systems, whose dependence on storm time, storm intensity, and season will be considered. The abnormality of the disturbance field at the geomagnetic equator will also be discussed.

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