AFCRL 293

THE AVERAGE MORPHOLOGY OF GEOMAGNETIC STORMS WITH SUDDEN COMMENCEMENT

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BOULDER, COLORADO

SCIENTIFIC REPORT NO. 32

CONTRACT AF19 (604)-2140

4 April 1961

Prepared for

Air Force Cambridge Research Laboratories
Air Research and Development Command
United States Air Force
Bedford, Massachusetts

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DER AKADEMIE DER WISSENSCHAFTEN IN GÖTTINGEN
MATHEMATISCH-PHYSIKALISCHE KLASSE
Sonderheft Nr. 4

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(BEOBACHTUNGEN ÜBER GEOPHYSIKALISCHE WIRKUNGEN DER SONNE UND DES MONDES, MITTEILUNG NR. 4)

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This research was supported by contracts made with the Geophysical Institute of the University of Alaska, by the Geophysics Research Directorate of the Air Force Cambridge Research Center.

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Vorgelegt in der Sitzung vom 11. Dezember 1959

Gesamtherstellung: Hubert & Co., Göttingen
7678

Abstract

This paper describes the average morphology of geomagnetic storms with sudden commencement. A numerical intensity index was assigned to each of 346 storms occurring in 1902—45. On the basis of these indices the storms were divided into three sets, of 136 weak, 136 moderate, and 74 great storms. Their morphology was studied separately. For weak storms records were analyzed from 26 magnetic observatories, ranging in geomagnetic latitude from 80° N to 48° S; and for moderate and great storms, from 19 observatories, 80° N to 1° S.

The storm-time variation Dst and the disturbance longitudinal inequality DS were determined for the first three storm days for different latitudes. The DS variation was obtained, and harmonically analyzed, for each of the first eight quarter-day intervals and for the succeeding three 8-hour intervals. New features of storm morphology during the first few hours of storm time were discovered: namely, that DS reaches its maximum in about two or three hours from the storm commencement, and that its phase rapidly changes during the first few storm hours. In other respects the results confirm those previously obtained by Chapman, and much extend them. At Huancayo, nearly on the magnetic equator, some features of the storm field are found to be abnormal.

Zusammenfassung

Diese Arbeit beschreibt die durchschnittliche Morphologie erdmagnetischer Stürme mit plötzlichem Anfang. Ein numerischer Intensitätsindex wurde jedem von 346 Stürmen zugeschrieben, die in den Jahren 1902—1945 auftraten. Auf der Grundlage dieser Indizes wurden die Stürme in drei Sätze eingeteilt: 136 schwache, 136 mäßige und 74 große Stürme. Ihre Morphologie wurde getrennt untersucht. Für schwache Stürme wurden die Ergebnisse von 26 magnetischen Observatorien analysiert, in geomagnetischen Breiten 80° N bis 48° S; für mäßige und große Stürme, von 19 Observatorien, zwischen 80° N und 1° S.

Die Sturmzeit-Variation Dst und die Störungs-Längen-Ungleichheit DS wurden bestimmt für die ersten drei Sturmtage für verschiedene Breiten. Die DS Variation wurde abgeleitet und harmonisch analysiert für jedes der ersten acht Vierteltages-Intervalle und für die folgenden drei Achtstunden-Intervalle. Neue Züge der Sturm-Morphologie während der allerersten Stunden Sturmzeit wurden entdeckt: nämlich, daß DS sein Maximum innerhalb etwa 2 oder 3 Stunden nach Sturmausbruch erreicht, und daß seine Phase während der ersten Sturmstunden sich schnell ändert. In anderen Beziehungen bestätigen die Ergebnisse die früheren Resultate Chapmans und ergänzen sie wesentlich. In Huancayo, nahezu auf dem magnetischen Äquator, ergeben sich einige Züge des Sturmfeldes als anomal.

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1. Introduction

Some geomagnetic storms begin gradually, with no clearly defined onset. Others begin suddenly, and simultaneously all over the earth to within a minute or so. The two kinds may respectively be called GC and SC storms (gradually commencing and suddenly commencing).

A typical storm, if it starts and ends in periods of magnetic calm, has a rather definite life cycle. Its evolution is a function of storm time (T), reckoned from the storm commencement. This is easily reckoned for SC storms, and for many GC storms also it can be estimated within an hour or so. The rate of evolution of a magnetic storm depends also on its intensity.

During a magnetic storm or lesser magnetic disturbance, an additional "disturbance" (or D) magnetic field is superposed on the otherwise existing field. The morphological study of a magnetic storm concerns the ascertainment, description and representation of this D field and its evolution during the life of the storm. It deals solely with the magnetic data from the commencement of the storm. Other (non-morphological) studies, not here discussed, relate to the time relations of magnetic storms, with respect to the season, the sunspot cycle, the solar rotation, aurorae, ionospheric and cosmic ray disturbances, and so on.

Some main features of magnetic storm morphology were recognized long ago by Broun (1861), Adams (1892) and others. An important pioneer morphological study was made by Moos (1910), mainly though not entirely on the basis of the Bombay records.

A more comprehensive analysis of storm morphology was made by Chapman (1918, 1927, 1935, 1952), in four papers that will here be referred to as C_1, C_2, C_3 and C_4. The papers $C_{1,2,3}$ are summarized in the treatise *Geomagnetism* (here referred to as GM), by Chapman and Bartels. The papers $C_{1,4}$ were based on (a) the data for a set of forty moderate SC storms of fairly uniform intensity, from 12 observatories in latitudes ranging from 6° S to 60° N, and (b) additional data from Bombay (19° N) and Pavlovsk (60° N) for two groups of storms twice and four times as intense. The papers $C_{2,3}$ were in addition based on data for polar and other observatories, for much less highly disturbed days. The forty moderate storms were drawn from the years 1902 to 1911, and were selected in 1916. The five-year interval 1911 to 1916 corresponds to the lag in the availability of the published data of some of the observatories.

Since 1911 more than three decades have gone by, during which many magnetic storms have been recorded by a growing number of observatories. In 1952 we decided to renew and extend the studies made in the papers C_{1-4}, using all the suitable observatory data then available, for as many SC storms as possible. The number of observatories that before 1902 published hourly magnetic values was judged to be too few for our purpose. In 1952 some of the observatories whose records we wished to use had not published their recent data. The outcome was that our study, using mainly the methods of papers $C_{1,4}$, is based on 346 SC storms (Table 1) that occurred during the 44 years 1902 to 1945; and we used data from 26 magnetic observatories (Table 2), whose latitudes ranged from 44° S to 80° N.

An important new feature of our work was the assignment of a numerical intensity index to each storm on the basis of data for each storm from many observatories. On the basis of these indices the 346 storms were divided into three *sets*, of weak, moderate and great storms. Each set was separately studied, and also seasonal subdivisions of each set. In nearly all respects the results confirm those obtained in the papers C, and greatly extend them. New features of storm morphology during the first few hours of storm time were discovered. At Huancayo, nearly on the magnetic equator, some features of the storm field were found to be abnormal.

Though this investigation is extensive, it does not adequately explore many important special aspects of average storm morphology in *high* geomagnetic*) latitudes. This is because there are so few observatories with many years of record, in gm latitudes above 60°. We used results from only four such observatories (of which only two provided 20 or more years' data). Four observatories in that region are far too few for the study of the average polar features of the storm field, which there is much more complex than anywhere else on the earth. As magnetic disturbance is most intense and irregular in high latitudes, more observatories than elsewhere, and more years' data at each, are desirable. The great deficiency in the magnetic observatory coverage of the polar caps can be met only by the establishment of 20 or more well distributed additional polar observatories, and their maintenance for two decades or more. The data they could supply are needed for study in conjunction with auroral, ionospheric, cosmic ray, rocket and satellite data. Without more polar magnetic observatories the full value cannot be gained from the highly expensive "space" observations of the outer gm field and the Van Allen radiation belts.

As our study was based on hourly values of the magnetic elements, it does not and cannot deal with the details of magnetic storms during the first hour of their life. The very worth-while study of those details requires reference to the magnetograms, of which in our work we made no systematic inspection.

The storms we have studied were recorded at many observatories whose data were not available to us. Some of these observatories have records over a still longer period than the one we considered. It would be of great value if the average storm morphology at these other observatories were studied, somewhat along the lines here followed, or as Yokouchi (1957, 1958) has done for Kakioka.

2. The selection of our 346 SC storms

Table 1 lists the 346 storms we selected. Its four columns A, B, C, D give (A) the serial number of the storm, (B) the date and (C) the time of its SC (to 0.1 hour, in universal or Greenwich time), and (D) its intensity index. The method by which these indices were assigned is described in § 4. No other classification of the storms was made. The storms (1902—11) whose dates are marked with an asterisk are the forty used in papers $C_{1,4}$.

In forming our list of SC storms we drew upon five sources:

(a) the list of storms and their times of commencement at the observatories of the U.S. Coast and Geodetic Survey, given in their publications;

(b) the descriptions of "principal magnetic storms" given in *Terrestrial Magnetism and Atmospheric Electricity*;

(c) a list given by Maunder (1904) of storms recorded up to 1903 at Greenwich;

(d) an extension of the list (c), covering the period 1874—1927, given in *Greenwich Photo-Heliographic Results*, 1927; and

*) In this paper gm will be used as a contraction for *geomagnetic*, and likewise gg for *geographic*.

Table 1

List of SC storms, 1902—45. (Forty storms used by Chapman in $C_{1,4}$ are marked with an asterisk.) (A) the serial number; (B) the date; (C) the time of SC in GMT; (D) the intensity index.

A	B	C	D
	1902		
1	April 10	9.6	31
2	*May 8	12.0	23
	1903		
3	*April 5	23.4	57
4	*August 25	22.9	24
5	*December 13	12.5	46
6	*December 30	3.2	37
	1904		
7	January 9	17.3	16
8	*April 17	16.3	42
9	June 6	4.7	12
10	June 15	16.5	50
11	July 6	20.9	20
12	*August 3	13.8	22
13	*September 24	19.5	27
	1905		
14	*January 3	23.7	24
15	January 5	9.9	21
16	*January 16	23.9	6
17	February 3	1.7	41
18	March 2	13.3	43
19	March 7	3.0	45
20	*April 1	1.2	44
21	*June 5	1.9	12
22	*July 5	21.6	30
23	*August 2	0.5	52
24	*November 12	8.1	47
25	November 15	15.3	72
26	*December 12	2.9	31
	1906		
27	*February 18	22.6	35
28	March 3	23.4	23
29	April 28	13.7	8
30	*May 13	20.7	41
31	*July 29	19.9	15
32	December 21	21.5	64
	1907		
33	*January 11	8.8	41
34	*January 14	19.6	13
35	February 7	8.1	50
36	February 9	14.2	66
37	*March 10	5.0	32
38	March 11	17.3	18
39	*March 21	13.4	24
40	*May 18	14.0	36
41	June 18	3.6	32
42	*July 10	14.4	34
43	*September 10	1.8	58
44	September 17	8.7	19
45	*October 13	7.7	41
46	*November 21	10.7	49
	1908		
47	February 22	12.2	26
48	August 8	7.7	32
49	*August 19	0.2	19
50	*August 21	8.6	12
51	September 11	7.9	84
52	September 28	9.2	97
53	*November 17	1.0	50
54	December 4	8.8	42
	1909		
55	January 29	22.6	31
56	*March 18	9.5	57
57	*March 26	12.3	40
58	May 14	4.9	101
59	*May 18	5.1	75
60	June 21	5.5	18
61	*September 21	11.3	34
62	September 25	8.5	156
63	*September 30	4.0	61
64	*October 23	0.0	45
	1910		
65	February 20	10.2	8
66	March 27	23.3	60
67	September 29	8.0	20
68	*October 19	7.2	50
	1911		
69	*March 20	0.8	33
70	*April 8	11.3	54
71	April 16	8.1	23
72	June 30	21.8	5
73	November 8	13.7	16
	1912		
74	September 17	14.0	13
	1913		
75	January 2	11.2	20
76	March 14	4.4	26
77	April 8	19.9	37
78	October 18	7.6	15
	1914		
79	January 4	20.0	8
80	April 6	8.1	43
81	June 25	2.0	8
82	July 5	1.4	32
83	November 26	17.7	27
	1915		
84	January 4	3.5	5
85	March 6	15.4	13
86	April 7	19.7	22
87	April 26	4.0	17
88	June 16	13.0	138
89	October 23	12.8	14
90	November 5	14.6	78
	1916		
91	January 11	4.0	38
92	February 1[illegible]	16.5	6
93	March 8	0.6	36
94	May 20	23.0	36
95	June 29	20.4	31
96	August 22	18.5	28
97	August 26	19.7	80
	1917		
98	January 4	5.0	96
99	February 14	5.0	35
100	April 25	14.4	16
101	May 16	5.7	12
102	May 25	9.1	15
103	June 9	0.1	2
104	June 24	13.7	14
105	July 2	3.7	10
106	August 9	4.2	75

Table 1 (continued)

A	B	C	D
	1917		
107	August 20	8.4	58
108	September 5	6.2	39
109	December 7	10.3	10
110	December 16	9.2	69
	1918		
111	January 12	4.0	14
112	January 28	14.8	29
113	February 5	6.8	28
114	March 7	21.2	80
115	April 10	20.9	46
116	April 29	21.3	48
117	June 9	23.1	68
118	August 15	15.8	46
119	September 21	4.3	24
120	November 29	13.3	40
121	December 25	3.8	59
	1919		
122	January 3	18.2	60
123	January 12	23.4	21
124	January 31	10.7	15
125	February 27	19.4	27
126	April 6	7.8	26
127	May 1	22.9	62
128	August 11	7.0	97
129	September 2	12.4	46
130	September 23	20.5	51
131	October 1	16.2	77
132	October 8	21.5	22
133	October 22	3.1	49
134	October 26	14.6	47
	1920		
135	March 4	11.6	97
136	March 13	12.9	14
137	March 22	9.2	193
138	May 13	0.3	47
139	September 22	2.3	19
140	November 26	12.9	32
141	December 4	5.0	2
142	December 25	10.1	55
	1921		
143	April 18	14.5	17
144	April 28	19.5	39
145	May 19	20.1	76
146	June 3	10.7	32
	1922		
147	January 30	23.5	32
148	March 14	7.1	1
149	December 9	21.9	0
	1923		
150	January 20	3.0	9
151	March 24	9.9	56
152	June 12	20.5	32
153	September 26	4.0	53
	1924		
154	January 29	5.4	51
155	March 29	3.6	16
156	April 6	8.2	8
157	April 24	21.6	15
158	May 21	6.0	52
159	June 9	14.2	57
160	June 18	7.0	18
161	July 9	5.4	3
162	July 20	16.6	8
163	August 4	1.1	8
164	September 4	5.7	17
165	December 11	22.9	6
	1925		
166	May 3	22.4	53
167	August 22	14.8	17
168	September 1	17.8	25
169	September 21	2.3	45
170	December 27	14.8	58
	1926		
171	January 3	22.4	0
172	January 22	15.6	46
173	January 26	16.3	107
174	February 10	5.8	30
175	February 23	16.4	97
176	March 5	10.1	44
177	March 17	21.1	21
178	April 14	14.1	134
179	April 21	10.3	28
180	May 3	21.2	48
181	June 1	11.2	68
182	September 14	8.8	50
183	October 13	19.4	81
184	October 24	6.4	38
	1927		
185	January 4	20.1	10
186	January 7	10.4	43
187	January 24	23.7	34
188	February 9	16.9	30
189	March 27	14.5	12
190	April 13	23.8	61
191	May 27	4.5	17
192	July 21	21.0	62
193	August 20	6.6	73
194	August 29	0.0	53
195	October 10	8.4	23
196	October 12	10.4	56
197	October 22	6.7	77
198	November 18	4.6	38
199	December 12	19.7	34
	1928		
200	February 12	7.3	12
201	May 5	2.8	12
202	May 10	12.2	39
203	May 27	14.8	88
204	July 2	8.5	13
205	July 7	23.5	105
206	August 4	17.1	30
207	August 25	22.6	47
208	September 7	13.8	65
209	September 24	16.4	22
210	October 18	7.4	68
211	October 24	17.8	36
212	November 11	17.0	17
	1929		
213	January 3	7.1	31
214	February 16	23.1	87
215	February 26	19.4	86
216	March 11	13.9	116
217	March 15	8.5	71
218	July 5	9.1	15
219	July 10	11.6	26
220	July 14	16.5	39
221	July 31	21.1	45
222	August 14	12.5	34
223	September 6	23.6	31
224	October 16	11.2	40
225	December 3	12.1	82
	1930		
226	January 3	8.1	22
227	May 4	23.9	46
228	June 15	10.5	28

Table 1 (continued)

A	B	C	D
	1930		
229	July 9	14.9	27
230	September 18	8.8	68
231	November 13	19.5	45
232	December 3	1.1	88
	1931		
233	February 13	9.0	16
234	June 1	15.5	37
235	June 26	15.0	17
236	July 23	3.4	17
	1932		
237	February 2	20.3	16
238	April 22	5.5	13
239	October 14	17.8	41
240	December 14	12.7	45
	1933		
241	February 19	10.0	39
242	April 30	16.5	56
243	May 29	6.5	14
244	July 23	9.7	26
245	September 8	21.4	61
	1934		
246	January 1	8.2	33
247	February 8	17.3	31
248	July 3	10.5	9
249	July 30	3.3	35
250	December 1	4.9	5
	1935		
251	January 27	14.8	21
252	May 1	12.8	36
253	July 7	21.1	31
254	August 19	5.4	17
255	September 23	1.6	51
256	October 24	6.7	38
257	November 29	3.9	8
258	December 24	19.6	15
	1936		
259	February 2	15.1	10
260	May 10	8.1	21
261	June 18	9.7	67
262	July 2	4.8	44
263	July 5	2.5	6
264	November 2	14.3	8
265	November 28	23.6	61
266	December 27	3.5	72
	1937		
267	January 27	8.6	50
268	February 2	23.1	60
269	February 18	19.1	1
270	March 26	20.9	36
271	March 31	3.3	59
272	April 24	12.0	72
273	April 25	15.8	38
274	April 26	17.9	48
275	April 27	19.0	47
276	May 4	16.9	62
277	June 4	14.4	63
278	June 13	8.7	6
279	June 27	2.8	7
280	July 19	12.9	34
281	August 1	21.8	74
282	August 22	3.1	78
283	September 10	17.9	45
284	September 30	13.8	62
285	October 3	11.3	58
286	October 7	5.3	82
287	October 9	6.6	5
	1938		
288	January 16	22.6	108
289	January 25	11.9	154
290	February 6	3.2	31
291	February 8	11.0	25
292	March 21	22.7	67
293	April 13	11.7	25
294	April 16	5.8	66
295	May 11	15.9	115
296	June 7	22.1	11
297	June 12	17.9	4
298	July 4	12.1	28
299	July 30	4.6	53
300	August 3	21.6	22
301	August 10	3.4	37
302	September 13	18.6	64
303	September 27	22.0	20
304	September 30	10.4	16
305	October 7	6.2	100
	1939		
306	February 5	19.8	59
307	February 24	17.1	126
308	March 27	17.6	60
309	April 17	1.9	91
310	April 24	17.6	15
311	May 5	20.7	56
312	June 14	0.1	57
313	July 4	14.1	60
314	July 21	10.0	3
315	August 12	1.7	72
316	August 22	0.7	126
317	September 2	21.7	25
318	October 13	2.1	112
	1940		
319	January 3	14.7	30
320	March 29	16.1	129
321	April 25	2.1	54
322	May 23	17.9	17
323	June 25	2.9	54
324	July 13	8.0	34
325	September 26	17.1	47
326	November 12	7.1	79
	1941		
327	March 1	3.9	187
328	April 24	7.3	50
329	June 13	3.7	24
330	July 4	3.7	184
331	August 4	1.5	37
332	September 18	4.2	179
333	October 31	3.7	87
334	December 1	6.0	67
	1942		
335	March 1	7.5	36
336	March 5	4.3	16
337	July 10	23.6	18
	1943		
338	March 29	18.6	45
	1944		
339	March 26	2.0	29
340	April 1	23.4	47
341	December 15	18.9	46
	1945		
342	March 27	20.6	10
343	April 1	5.0	34
344	April 11	7.5	39
345	October 23	23.7	26
346	December 13	12.7	82

(e) later reports of storms recorded at Greenwich, given by H. W. Newton in *The Observatory*[1]).

The forty storms used in papers $C_{1,4}$ were drawn from the above sources (a) and (b).

We adopted into our list all the storms of the period 1902—1945, from the sources (a) to (e), for which at least two observatories reported a sudden commencement with reasonable agreement as to its time.

When two or more SC storms followed in close succession—a phenomenon studied by Newton (1950)—each was included in our list as a separate storm.

We may have included a few weak disturbances hardly deserving to be called storms. We might have eliminated such cases if we had examined the magnetograms from several observatories. We might also have excluded some pairs of overlapping storms, to get "purer" results. This was not done. But a few such cases will not have materially affected our results.

3. The magnetic observatories

Table 2 (p. 13) lists the 26 magnetic observatories whose data we used. Its columns (a) to (n) begin by listing (a) the serial number and (b) the name of each observatory P. The next seven columns list particulars connected with the position of P on the earth: (c), (d) give the gm and gg[2]) latitudes; (e), (f) and (g) give its gg and gm east longitudes (the former in time units as well as in angle); (h) gives, to 0.1 hour, the daily mean difference between gm and standard local time, and (i) gives ψ, the angle, reckoned positively eastward, between the northward gg and gm meridian arcs through P—this angle is the magnetic declination that would correspond to the earth's centered dipole field; GM, pp. 645—6, may be consulted for more details concerning the items in columns (h) and (i). Column (k) gives the number of years of record available to us, in the period 1902—45. Columns (l), (m), (n) indicate the degree of completeness of the data provided by the observatory, for each set of storms, namely 136 weak, 136 moderate, and 74 great. For example, Godhavn provided records of 69 of the 136 weak storms. The main cause of missing data was that some observatories were not established until after 1902.

Twenty four of the 26 observatories were later combined into 8 groups, according to their gm latitude. The other two, Godhavn and Huancayo, may be regarded as forming single-member "groups". Thus there were 10 groups in all. They are indicated in Table 2, and in certain columns mean values are given for each group. In calculating the mean gm latitudes for groups 9 and 10, which include all the southern observatories except Huancayo, the separate latitudes were weighted according to the fractions given in column (l).

The time difference in column (h) is small for the observatories in the lower latitudes, but is worth taking into account for groups 1 to 4.

The angles in columns (i), (j) were used in transforming the magnetic elements H, E to components along gm N and E (§ 8).

Fig. 1a shows the distribution of the observatories on a map drawn in gm co-ordinates. Fig. 1b shows their distribution in gm (A) and gg (B) latitude and longitude, by projection on the plane of the gm or gg equator: the southern observatories are shown by open circles, the northern ones by dots. The serial numbers are given alongside.

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[1]) After our work was well under way, the lists (c), (d), (e) were combined and discussed in the valuable publication *Sunspot and Geomagnetic Storm Data, derived from Greenwich Observations, 1874—1954*, (1955).

[2]) See the footnote on p. 8.

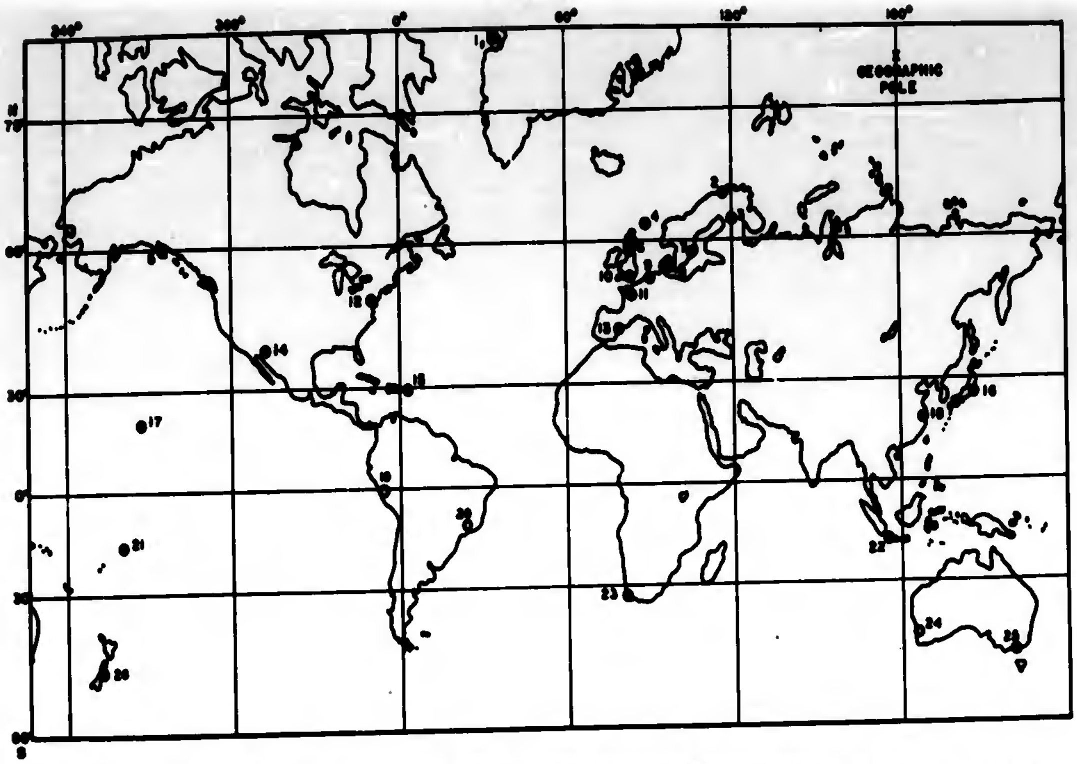


Figure 1a. See § 3. The distribution of the 26 magnetic observatories here used. The map is drawn in gm co-ordinates; the southern observatories are shown by open circles, and the northern ones by dots.

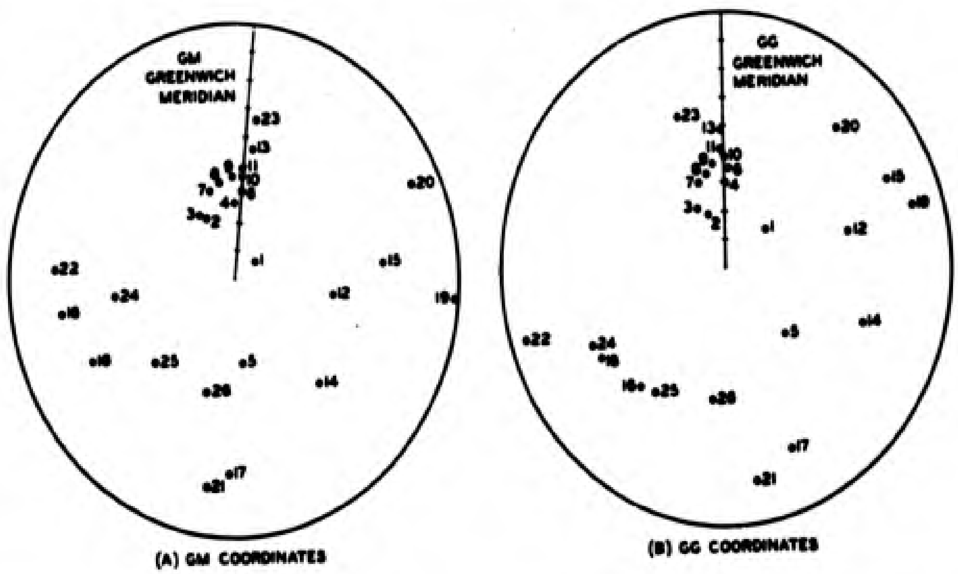


Figure 1b. See § 3. The distribution of the 26 magnetic observatories in gm (A) and gg (B) co-ordinates, shown by projection on the plane of the gm or gg equator; the southern observatories are shown by open circles, the northern ones by dots.

Notes relative to changes of location and name of certain observatories used in this work: 9, de Bilt, was replaced by Witteveen from 1938; 10, Greenwich, was replaced by Abinger after 1924; 11, Val Joyeux, was replaced by Chambon-la-Forêt after 1936; 15, Porto Rico, was at Vieques till 1924, and at San Juan after 1926; 18, Zikawei, was at Lukiapang from 1907 to 1933, and at Zo-Sè from 1934; 20, Vassouras, was at Rio de Janeiro till 1914; 22, Batavia, was replaced by Kuyper after 1928; 23 Cape Town, was replaced by Hermanus after 1941. In Table 2, in cases where an observatory had more than one location during the period 1902—1945, the mean location is given, but only one of the locations is named there.

Table 2

List of the 26 magnetic observatories here used. (a) the serial number; (b) the observatory; (c) and (d) the gm and gg latitudes; (e), (f) and (g) the gg and gm east longitudes (the former in time units as well as in angle); (h) the daily mean difference between gm and standard local time, reckoned positively when the former precedes the latter; (i) the angle, reckoned positively eastward, between the northward gg and gm meridian arcs through the observatory; (j) the magnetic declination (reckoned positively when eastward), the mean over the period of years here used; (k) the number of years of record available to us, in the period 1902—45; (l), (m) and (n) the degree of completeness of the data provided by the observatory, for each of the three sets of storms, namely 136 weak, 136 moderate, and 74 great, respectively.

		Latitude		Longitude							Proportion of available storms		
a	b	c gm °	d gg °	e gg °	f gg h	g gm °	h h	i °	j E dec. °	k yrs.	l ÷136	m ÷136	n ÷74
	Group 1												
1	Godhavn	80	69	307	20.5	33	1.1	—17.5	—56.0	20	69	64	50
	Group 2												
2	Tromsö	67	70	19	1.3	117	1.9	—30.8	—2.9	16	43	45	33
3	Sodankylä	64	67	27	1.8	120	1.6	—26.7	2.3	29	101	92	63
4	Lerwick	63	60	359	23.9	89	1.4	—23.6	—13.9	12	41	45	31
	(Mean	65									185/408	182/408	127/222)
	Group 3												
5	Sitka	60	57	225	15.0	275	—1.2	21.4	30.2	44	136	136	73
6	Eskdalemuir	59	55	357	23.8	83	1.1	—20.4	—15.8	25	88	75	43
7	Lovö	58	59	18	1.2	106	1.2	—22.1	— 2.0	18	51	54	41
8	Rude Skov	56	56	12	0.8	99	1.2	—20.6	— 5.0	19	56	60	46
	(Mean	58									331/544	325/544	203/296)
	Group 4												
9	De Bilt	54	52	6	0.4	90	0.9	—19.1	—10.5	44	136	135	74
10	Greenwich	54	51	0	0.0	84	1.0	—18.5	—13.4	44	136	136	69
11	Val Joyeux	51	48	2	0.1	84	0.8	—17.4	—12.1	44	136	136	74
12	Cheltenham	50	39	283	18.9	351	—0.1	2.4	— 6.1	44	136	136	74
	(Mean	52									544/544	543/544	291/296)
	Group 5												
13	Ebro, Tortosa	44	41	1	0.1	80	0.6	—15.0	—11.5	26	100	74	34
14	Tucson	40	32	249	16.6	312	—0.4	10.1	13.8	36	113	102	64
	(Mean	42									213/272	176/272	98/148)
	Group 6												
15	Porto Rico	30	18	294	19.6	4	0.1	—0.8	— 4.1	43	129	127	66
16	Kakioka	26	36	140	9.3	206	—0.2	6.2	— 5.5	37	113	113	63
	(Mean	28									242/272	240/272	129/148)
	Group 7												
17	Honolulu	21	21	202	13.5	267	—0.2	12.3	9.9	44	136	136	74
18	Zikawei	20	31	121	8.1	189	—0.1	2.2	— 3.1	35	111	106	58
	(Mean	21									247/272	242/272	132/148)

Table 2 (continued)

a	b	Latitude c gm °	Latitude d gg °	Longitude e gg °	Longitude f gg h	Longitude g gm °	h h	i °	j E dec. °	k yrs.	Proportion of available storms l ÷136	m ÷136	n ÷74
	Group 8												
19	Huancayo	— 1	—12	285	19.0	354	0.0	1.3	7.4	24	74/136	74/136	51/74
	Group 9												
20	Vassouras	—12	—23	316	21.1	24	—0.1	— 5.1	7.7	31	101		
21	Apia	—16	—14	188	12.5	260	0,2	11.7	10.6	25	72		
22	Batavia	—18	— 6	107	7.1	176	0.0	— 0.9	0.8	35	93		
23	Cape Town	—33	—34	19	1.3	80	—0.5	—13.7	—24.4	13	35		
	(Mean	—17 weighted according to the fractions in column (l).									301/544)		
	Group 10												
24	Watheroo	—42	—30	116	7.7	186	0.1	1.3	— 3.8	27	83		
25	Toolangi	—47	—38	146	9.7	221	0.4	9.5	8.3	10	38		
26	Christchurch	—48	—44	173	11.5	253	0.7	15.2	18.3	18	51		
	(Mean	—46									172/408)		
											2,378/3.536	1,846/2.584	1,081/1.406
											Σ 5,305/7,526		

See also the notes below Fig. 1, page 13.

4. The intensity indices for the storms

Over the major part of the earth the chief average feature of a magnetic storm is the decrease of the horizontal intensity H during the main phase (GM, Chapter 9). This was made the basis for the assignment of an intensity index to each storm.

Some previous lists of storms have grouped them according to their intensity, weak, moderate, great and very great—usually as recorded at a particular observatory. As far as we know, no general numerical intensity index has previously been assigned to storms on the basis of the records from several observatories.

The relative intensity of world-wide magnetic activity is internationally classified for periods of 3 Greenwich hours (the Kp indices) and for Greenwich days (the character figures C and A). The Kp indices are available for only part of the period here dealt with. We judged it necessary to devise a method of assigning intensity indices expressly adapted to our storms. To avoid undue labor we based it on the daily mean values m of H at the following observatories (Table 3) in middle and low latitudes. Some of these observatories gave the means for Greenwich days, others for local civil days (from midnight).

For each of these observatories the day that includes the storm SC is reckoned as day 0. The preceding days in reverse order are numbered —1, —2, . . ., and the succeeding days, 1, 2, . . . For each observatory the difference $m_{-1} - m_1$ for the storm was computed; the suffix indicates the day to which the daily mean m refers. The mean value of these differences, in gammas, for the observatories in Table 3, was taken as the provisional (and in most cases the actual) intensity index for the storm.

Table 3

The observatories used to determine the storm intensity index, and their gm and gg latitudes and longitudes.

Observatory	Latitude gm	Latitude gg	Longitude gm	Longitude gg
Cheltenham	50°	39°	351°	283°
Tucson	40	32	312	249
Porto Rico	30	18	3	294
Helwan	27	30	106	31
Honolulu	21	21	267	202
Zikawei	20	31	189	121
Alibag	10	19	144	73
Elizabethville	—13	—12	94	28
Batavia	—18	— 6	176	107
Cape Town	—33	—34	80	19

In nearly all cases this index was positive. A few weak storms gave negative indices, and for a few great storms the index seemed faulty. These cases were examined in more detail. The negative indices were found in some cases to be due to an after-effect of a disturbance shortly preceding the SC. In some other faulty indices the maximum of the main phase fell earlier or later than on the day 1 as here used. In these cases individual examination of m also for days —2, 0, 2 enabled more appropriate pre-storm and post-SC means to be determined. They gave revised intensity indices which in no case were negative.

Our procedure underestimated the main phase reduction of H—especially for the great storms, where the main phase maximum is attained during the first storm day. A different and better method of assigning indices would move some borderline storms from one of our sets to another. But our procedure sufficed for our purpose of dividing the storms into three sets of weak, moderate and great storms. These corresponded to the ranges of the intensity indices shown in column 2 of Table 4. Column 3 gives the mean index for each set, and for all the storms. Later columns give the number of storms in each set, and also their number (and mean index, written in brackets) in certain seasonal subdivisions of the sets. The seasons are the usual d, j and e groups of four months:

d: December solstitial group: November to February

j: June solstitial group: May to August

e: equinoctial group: March, April, September, October.

Table 4

Index ranges and numbers of weak, moderate and great storms; seasonal subdivisions and mean indices.

Set	Index range	Mean index	Number	Seasons: Solstices d	Seasons: Solstices j	Seasons: Equinox e
Weak	0 to 30	16	136	42 (15)	50 (16)	44 (18)
Moderate	31 to 60	44	136	46 (43)	40 (43)	50 (46)
Great	Over 60	91	74	37 (88)		37 (93)
All		43	346	215 (39)		131 (50)

The set of great storms, being the least numerous, was divided into only two seasons, solstitial (d and j) and equinoctial. To make the numbers in the seasonal subdivisions more uniform, some storms near the seasonal border-lines were transferred from one subdivision to another, namely six great storms from (d + j) to e, and eight moderate storms from e to j.

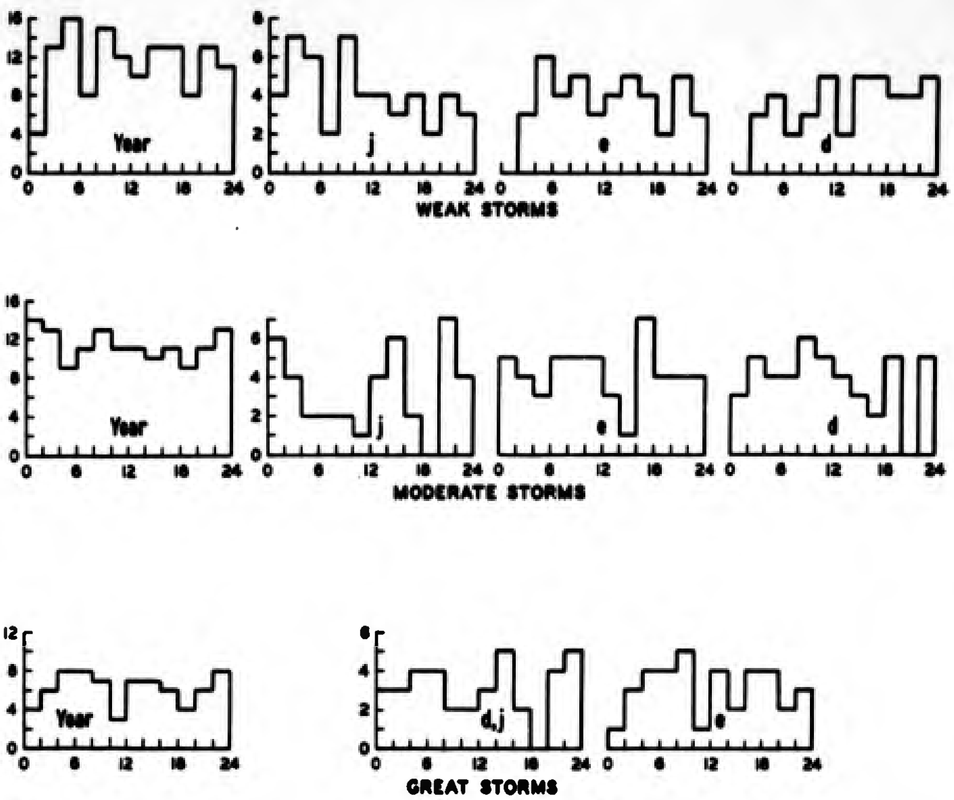


Figure 2. See below. The distribution of the SC times over the Greenwich day, for the three intensity sets and their seasonal subdivisions.

The forty moderate storms used in the papers $C_{1,4}$ (listed in C_4, page 482, and marked by asterisks in our Table 1) had a mean index number 37—a little less than that (44) for our set of moderate storms. Of the 40 storms, 25 are included in our moderate set, 13 (with indices ranging from 6 to 30) among our weak storms, and two (with indices 61 and 75) among our great set.

Fig. 2 shows the distribution of the SC times over the Greenwich day, for the three sets and their seasonal subdivisions. In all cases the distribution is fairly uniform, considering the number of storms included in each case.

Fig. 3 shows the year-to-year variations, through four sunspot cycles, of Nsc, the number of our SC storms in each year: of I, their mean intensity for each year: and of R, the annual mean sunspot number. The SC storms were most numerous near the sunspot maxima, but the mean storm intensity I had its maximum, in three of the four cycles, two or three years after sunspot maximum.

These relations are shown more clearly in Fig. 4, which graphs the averages of Nsc, I and R relative to sunspot epoch reckoned from sunspot minimum.

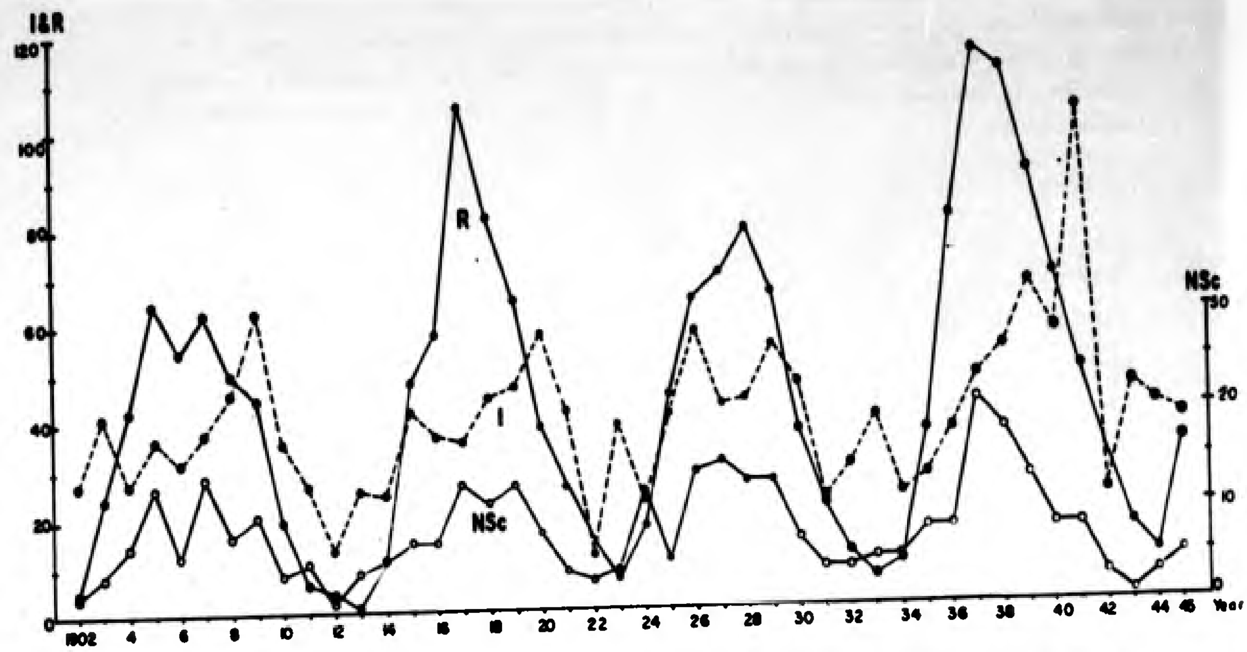


Figure 3. See p. 17. The number (Nsc) of our SC storms, their annual mean intensity (I), and the annual mean sunspot number (R), for the years 1902—45.

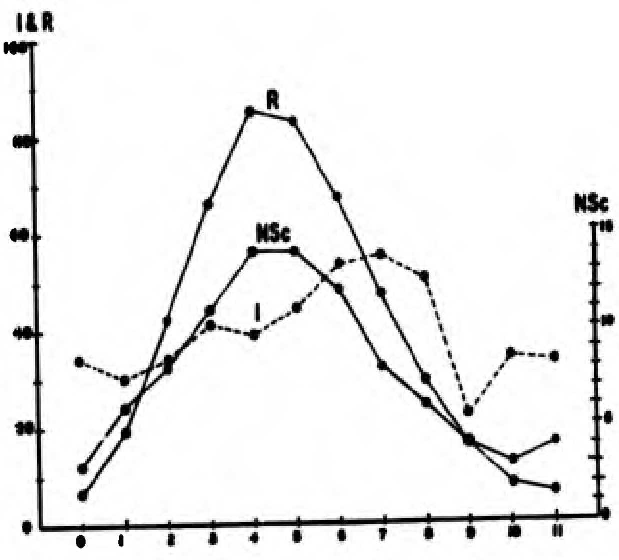


Figure 4. See p. 17. The number (Nsc) of our SC storms, their annual mean intensity (I), and the annual mean sunspot number (R): mean of the four solar cycles. Nsc, I, R are plotted relative to sunspot epoch reckoned from sunspot minimum.

The 19 greatest storms, with indices 100 or more, are as follows, in descending order of their indices:

Serial number	Storm index	Date
137	193	March 22, 1920
327	187	March 1, 1941
330	184	July 4, 1941
332	179	September 18, 1941
62	156	September 25, 1909
289	154	January 25, 1938
88	138	June 16, 1915
178	134	April 14, 1926
320	129	March 29, 1940
307	126	February 24, 1939
316	126	August 22, 1939
216	116	March 11, 1929
295	115	May 11, 1938
318	112	October 13, 1939
288	108	January 16, 1938
173	107	January 26, 1926
205	105	July 7, 1928
58	101	May 14, 1909
305	100	October 7, 1938

5. The magnetic variations Sq, Dst, DS and SD

The geomagnetic field undergoes two kinds of daily variation, with periods of a solar day and a lunar day: these are denoted by S and L. When S is derived from days that magnetically are truly quiet, it is denoted by Sq. When derived from all days or from disturbed days (over a given period, such as a month) it is denoted by Sa and Sd. It is found that Sa — Sq and Sd — Sq are daily variations of similar type; Sd — Sq has the greater amplitude; and the type differs from that of Sq. This difference variation is called the disturbance daily variation, and is denoted by SD. Usually Sq and Sd are derived from the five international quiet and disturbed days in each calendar month. In high latitudes SD is much greater than in low, and S derived from the international quiet days generally appears to contain an appreciable SD part. An idealized definition of Sq is: the daily magnetic variation characteristic of days when the ionosphere is everywhere ionized only by solar ultraviolet radiation.

Except at such stations as Huancayo, where Sq and L in the horizontal force H are abnormally great, L is insignificant compared with the magnetic storm variations. It was completely ignored in our investigation.

The magnetic storm (or D) variations at any station P (in latitude θ), that are added during a storm to the otherwise existing magnetic variations there, are resolved into two parts, denoted by Dst and SD. At the storm time T, reckoned from the storm commencement, let λ denote the longitude of P measured eastwards from the midnight meridian; λ is the local time of P, and may be reckoned in angle or time units. Let df denote the disturbance change in the magnetic element f at P at storm time T. The average value of df, round the parallel of latitude θ, at time T, is denoted by Dst(f, T).

It is a function of T (and of θ), and is called the storm time variation at latitude θ. The difference $df - Dst(f, T)$ is denoted by DS (f, T, λ), indicating that it is a function of both T and λ. In paper C_4, DS was named the *disturbance local time variation*, but it now seems preferable to name it the *disturbance longitudinal inequality*. As a function of λ, DS (f, T, λ) can be analyzed into its harmonic components; the coefficients are functions of T and θ.

As we do not have data for many magnetic observatories ranged round any one parallel of latitude, we cannot well determine DS for individual storms. It is determined from the average of a number of storms of similar intensity, in which, at any storm time T, an observatory has different local-time longitudes λ.

The variation DS, regarded as a function of λ, and averaged with respect to storm time T over each of the first, second, third, . . . storm days, is equivalent to SD, the disturbance daily variation, for those days. These special cases will be denoted by SD^n, where $n = 1, 2, 3, \ldots$ The m-th harmonic component of DS or SD will be denoted by DS_m or SD_m.

For the variations Sq, D, Dst, DS, SD in any particular element, such as horizontal force H, east declination E (in force units) and vertical force Z, the element may be indicated by adding its symbol: e.g., Sq (H), Dst (H).

6. The method of analysis

The material for this investigation consisted of tables of hourly values of the magnetic elements from our different observatories. The values were either instantaneous, or hourly means. They referred to local or standard time. The detailed differences of treatment applicable to these different cases need not be described here.

The sequences of these hourly values during our magnetic storms indicated the variations under study. They had to be selected and transcribed and then analyzed in several ways. In the transcription the hourly values themselves were not copied: instead the hour-to-hour differences were used. This had two advantages: more often than not, the differences were smaller numbers than the hourly values, and, more important, their use avoided complications arising from missing hourly values, in forming means. At a convenient later stage in the work, our various derived sequences of differences were re-converted into sequences of hourly values measured from chosen appropriate levels. For data without missing values the results are identical with those that would be obtained using hourly values.

For each storm and observatory the hourly value whose epoch was closest to the SC time was treated as being at storm time $T = 0$. As storm SCs are distributed approximately uniformly over the day, the mean epoch for a set of such chosen hourly values will be close to $T = 0$, although some of these hourly values, within half an hour after the true SC times, will be influenced by the storm to some extent.

For each storm we used 76 hourly values for each element at each observatory, in the form of hour-to-hour differences $(-4) - (-3)$, $(-3) - (-2)$, . . ., $(70) - (71)$, where (m) denotes the value for hour m of storm time. These 75 differences will be denoted by $d_{-3}, d_{-2}, \ldots, d_{71}$. Thus a few pre-storm hours, and the first *three* storm days, were used (in the papers $C_{1,4}$ only the first *two* storm days were used).

A "section of data" will here signify the sequences d_m for a particular element, observatory, and seasonal subdivision of one of the three sets of storms. For each section of the data a series of related sheets Sq, A, B, C and D was prepared.

If data had been available or used for each element and observatory for all the storms, the sections of the data would have numbered 624, namely 3 (elements) $\times$ 26 (observatories) × 8 (the number of seasonal subdivisions of the sets of storms—cf. Table 4). As the data for the seven southern observatories 20—26 were used only for the weak storms, there were actually 519 sections of the data.

Consider a section of the data that contained n storms. These, and the calendar months in which they began, may be supposed numbered in date order, $s = 1$ to $s = n$.

6.1 *The Sq sheet* for this section of the data records the mean Sq variation for each of the n calendar months, derived, where available, from the five international quiet days in each—and otherwise from local quiet days or from all days. The sheet has 24 columns, marked 0 to 23, in which were entered the hour-to-hour differences (0) — (1), (1) — (2), . . ., (23) — (24). Wherever available, the Sq variations uncorrected for the non-cyclic change were used. If two storms, s and $s + 1$, began in the same month, the entries in row $s + 1$ would be the same as in row s. Means were computed for each column and entered in row $n + 1$.

6.2 *The A sheets* have 75 columns, headed —3 to 71. Its row s contains in these columns the hour-to-hour differences d_m for the storm s. Missing hourly values in the original material would leave some blank spaces on the A sheet.

6.3 *The B sheets* have 24 columns and n rows, numbered as on the Sq sheet. The entries in each row s were the same as in row s of the Sq sheet, but in general they were not in the same columns. If the SC time for storm s was at the Sq sheet hour h, the entries in row s of the B sheet began with the entry in row s and column h of the Sq sheet; successive entries followed, from columns $h + 1$, $h + 2$, . . ., 23 of the Sq sheet; they continued with those from columns 0, 1, . . ., $h - 1$.

6.4 *The C sheets (giving mean Dst)*. These sheets have 75 columns and n rows, which were numbered as on sheet A. Let x denote any column number, and [x] the number from 0 to 23 that differs from x, if at all, by an integral multiple of 24. The sheet C entry in row s, column x was the difference between the corresponding entry on sheet A, and the entry in row s and column [x] of sheet B. Means were formed for each column and entered in row $n + 1$. The sequence in row $n + 1$, given on an hour-to-hour difference basis, was re-converted into hourly values by successive addition. The series of 75 values so obtained is the Dst variation for storm time —3h to 71h, reckoned from the level for storm time —4h. This series was re-calculated from the level for storm time —1h; the resultant sequence was entered in row $n + 2$. Suitable checks on the arithmetic were applied at this and other stages of our analysis.

The entries in row $n + 2$ represent the average Dst variation, that is, the total variation freed from the mean Sq variation, supposing this to continue unchanged throughout magnetically disturbed periods; the DS variation is taken to be averaged out by combining sequences for many storms. If the contribution from L is ignored (and except in H at Huancayo it is intrinsically small and almost completely removed in the means), row $n + 2$ corresponds to the average storm variation Dst. The entries in each row s give the combined Dst and DS variation, together with the irregular variations, in storm s: on an hour-to-hour difference basis.

6.5 *Eleven sheets D_r (giving DS)* were next prepared, each with s rows and 24 columns (0 to 23). Each sheet D_r contained entries from sheet C, for the hours of one interval r, where r has values from 1 to 11, of the 3 storm days. The intervals 1 to 8 were for successive 6-hour intervals, covering the first two storm days; the intervals 9 to 11 were of 8 hours, completing the third storm day. On each row of the first 8 sheets D_r there were 6 entries, and on the remaining sheets D_r, 8 entries—all for the corresponding intervals of storm time on sheet C, in columns 0 to 71. For example, on the sheet D_1 the entries were those from the columns 0 to 5 of sheet C. The other spaces in the rows of the sheets D were blank; missing values in the original data sometimes added other blank spaces on the sheets D. The entries on sheet D were made according to their *local time*. For example, if storm 1 began at local hour h, the first entry on row 1 of sheet C would be placed in column h of row 1 of sheet D.

The mean for each column on each sheet D was then formed, and entered in row n + 1. These means were summed; the sum was in general not zero. Their mean (the sum divided by 24) was subtracted from each entry in row n + 1. The differences, entered in row n + 2, gave the mean DS variation on the hour-to-hour difference basis. The sequence was then re-converted into that of hourly values by successively adding the differences starting from the first column (corresponding to local time 0 h); the resultant sequence, giving a variation reckoned from the level for local time 23 h, was re-calculated from the mean of the 24 values by subtracting the latter from each value. The sequence so obtained was entered in row n + 3, which gave the mean DS variation for the interval r of storm time.

For the element H and the first interval, this procedure was slightly changed—the entries were those of the columns 0 to 5 of the sheet C, less the mean for each column, given in row n + 1. This was to eliminate the rapid Dst(H) variation during the first six storm hours. In the later intervals the Dst variation was smaller and more uniform, and its influence in the determination of DS was removed in the change from row n + 1 to row n + 2. This refinement of method was not used for the H data of the observatories 1 to 4, in the highest latitudes. This was because there the irregular variations much exceed Dst, even during the first six storm hours.

7. Combination of the results

The above procedure gave Dst (row n + 2 of the sheets C) for each section of the data—that is, for each element and observatory and seasonal subdivision of the three sets of storms of different intensities. Likewise the D sheets (row n + 3) gave DS for each section of the data, for 11 intervals of storm time.

This represents a considerable subdivision of our extensive material. The Dst and DS sequences showed irregularities, because accidental features of individual storms were not fully averaged out. Hence some corresponding sequences were grouped together, to give better averaging and reduced irregularities.

(a) The seasonal sequences were suitably combined, to give annual mean sequences.

(b) Some observatories were grouped together, and their sequences combined, as indicated in Table 2. The observatories of Godhavn and Huancayo were alone in their respective gm latitudes. Their sequences, and those of the eight groups of observatories, gave Dst and DS for ten gm latitudes (for weak storms: for moderate and great storms, for eight gm latitudes, as the southern observatories were not used in that part of our investigation).

(c) For the two highest latitudes (Godhavn and Group 2), where DS is exceptionally great, and exceeds Dst, the Dst variation (from the initial value at storm time T = 0) was averaged over the first, second and third storm days, to obtain results less affected by DS and the irregular variations. For these latitudes an attempt was made to determine DS first and then to determine Dst after removing the average DS. But this procedure did not improve the results; hence it is not discussed here further.

(d) For the other latitudes, Dst was averaged over each of the last five half-days: the hourly values were retained only for the first 12 hours of storm time.

(e) The DS variations for the first four intervals r (§ 6.5), comprising the first storm day, were combined to give SD^1 (§ 5). Similarly SD^2 and SD^3 sequences were formed from the DS sequences for the second four and last three intervals r.

8. Conversion of the Dst results for H and E to geomagnetic N and E

It has been shown by van Bemmelen (1895, 1897) (with reference to the after-disturbance effect, but not to storms) that the Dst field lines lie nearly in gm meridian planes. To bring out this feature, the Dst sequences were converted, before combining the observatories, from the local magnetic north (H) and east (declination) to gm north and east; the angle of conversion is $\psi - D$ (columns i, j of Table 2). Except for the observatories in groups 1 to 3 this angle is small and the conversion is unimportant. Even for groups 1 to 3, Dst(H) is little altered, but Dst (E) is materially changed.

The DS and SD results were not converted in this way.

9. The storm-time variations Dst; scale differences in the diagrams

Graphs of the Dst variations from row n + 2 of the sheets C (§ 6.4) are given in Figures 5 (for Hgm), 6 (for Egm) and 7 (for Z). Each Figure has 3 panels, for the storms of different intensities, A (weak), B (moderate), C (great). The abscissae refer to storm time, from —4 h to 71 h; on the average, 0 h coincides with the SC time. Hourly points are shown by dots from —4 h to 11 h; the later half-day means are shown by small circles. No smoothing was applied to the sequences on the rows n + 2 of the C sheets (§ 6.4).

In Figures 5 to 7 and some later ones, the force scale is not the same for all groups: some of the high latitude graphs are shown on a contracted scale. To draw instant attention to these scale differences, small black rectangles are given alongside the graphs: in each case the height corresponds to 10 gammas in Figures 5, 6, 7, and to 50 gammas in Fig. 27, and the width to 12 h. Thus a reduced scale is indicated by a rectangle of diminished height. For example, in Fig. 5, the force scale in panel C (for great storms) is contracted (about twofold) as compared with panels A, B. In other diagrams, as in Fig. 8, a scale change is indicated by a number (the scale contraction factor) enclosed in a circle.

Only panel A has graphs for the observatory groups 9, 10, as their data were used only for weak storms.

9.1 *The variation Dst(Hgm)*, shown in Fig. 5, is first an increase, followed by a larger decrease, and afterwards by a slow recovery towards normal. The graphs for Godhavn and group 2 do not show the first phase, because only the daily mean points are plotted; in their latitudes the irregular variations are so great that the available number of magnetic storms does not suffice to give reliable hourly or bihourly means for Dst (see § 7, (c)).

Some numerical characteristics of Dst (Hgm) in the first phase of a storm are listed in Tables 5 and 6. Table 5 gives the maximum increase of Hgm in the first phase, for the different latitudes and sets of storms. The values given must be less than the true maxima, because the use of hourly values in this investigation inevitably introduces some smoothing, especially of the fairly rapid variations during that phase.

The increase is most for the great storms: there is little systematic difference between the values for the weak and moderate storms—except at Huancayo. There, for all intensities, the increase is abnormally great. This matter is further discussed in § 16.

Table 5

Maximum Dst(Hgm) in the first phase, in different latitudes, for weak, moderate and great storms. Unit: 1 gamma.

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

Table 6 lists the storm times at which, in different latitudes, and for storms of different intensities, Hgm returns to its pre-storm value, on its way towards the decrease that marks the main phase of the storm. It is not easy to assign probable errors to these times, and to assess the reliability of any apparent variation of the time with respect to gm latitudes. But the shorter time for the more intense storms is probably a valid result, and might be expected in view of the undoubted similar intensity-dependence of the time of maximum of the main phase, that is, of the epoch when Dst (Hgm) attains its minimum value. This time is near 18h for the average great storm; for the average moderate storm it is between 24h and 30h; for the average weak storm the epoch is uncertain—Dst (Hgm) remains near its minimum level throughout the second and third days, and at the end of the third day it is not clear whether the recovery phase has begun.

The recovery phase of Dst(H) and of DS is further discussed in § 15.

Table 6

Approximate storm times at which in different latitudes Dst(Hgm) crosses its pre-storm level, in weak, moderate and great storms. Unit: 1 hour.

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

Table 7 gives the magnitude of the decrease of H at the maximum of the main phase of a storm, for each intensity set, and in eight gm latitudes. It gives also the ratios of these magnitudes, moderate/weak and great/moderate. These ratios are less reliable for Godhavn and latitude 65° than for the other latitudes, because the former are derived only from daily means. The overall mean ratio great/moderate, 2.2, differs little from the ratio of their mean intensity indices (91/44 or 2.07: Table 3). But the latter ratio (44/16, or 2.75) for moderate/weak exceeds the mean ratio 2.1 given in Table 7.

Table 7

Magnitude of the decrease of Dst(Hgm) in the main phase, in different latitudes, for weak, moderate and great storms (unit: 1 gamma) and their ratios.

Observatory group	1	2	3	4	5	6	7	8	
Mean gm latitude	80°	65°	58°	52°	42°	28°	21°	—1°	
Weak storms	10	14	12	13	15	19	25	28	
Moderate storms	23	30	28	29	37	39	48	60	
Great storms	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

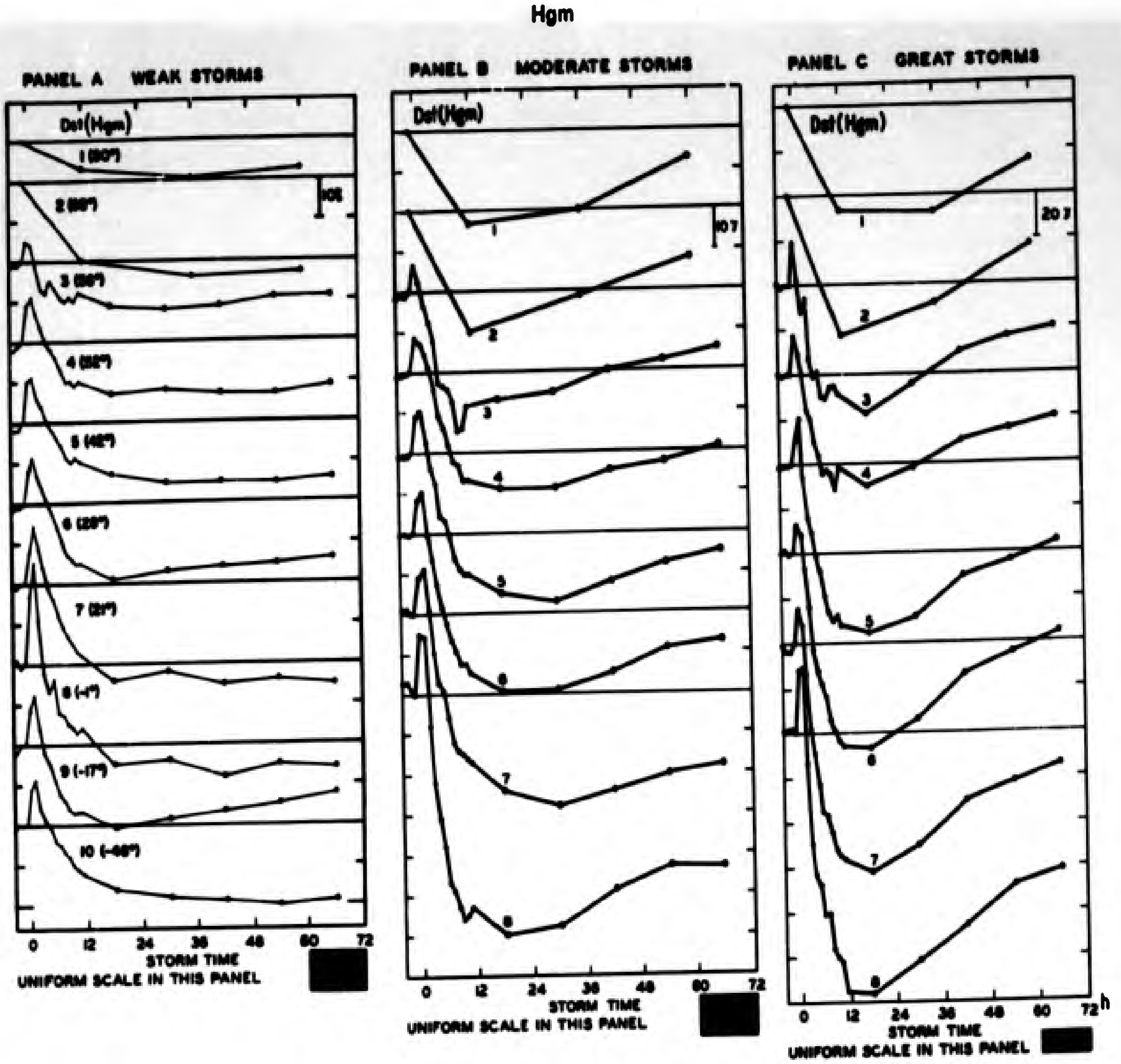


Figure 5. See p. 23. The variation Dst in the geomagnetic north component Hgm. The abscissae refer to storm time. Hourly points from —4 h to 11 h are shown by dots, and the later half-day means by small circles. For 80° and 65° (graphs 1 and 2) circles refer to daily means. In the black rectangles at the foot of each panel the height corresponds to 10 gammas and the width to 12 hours.

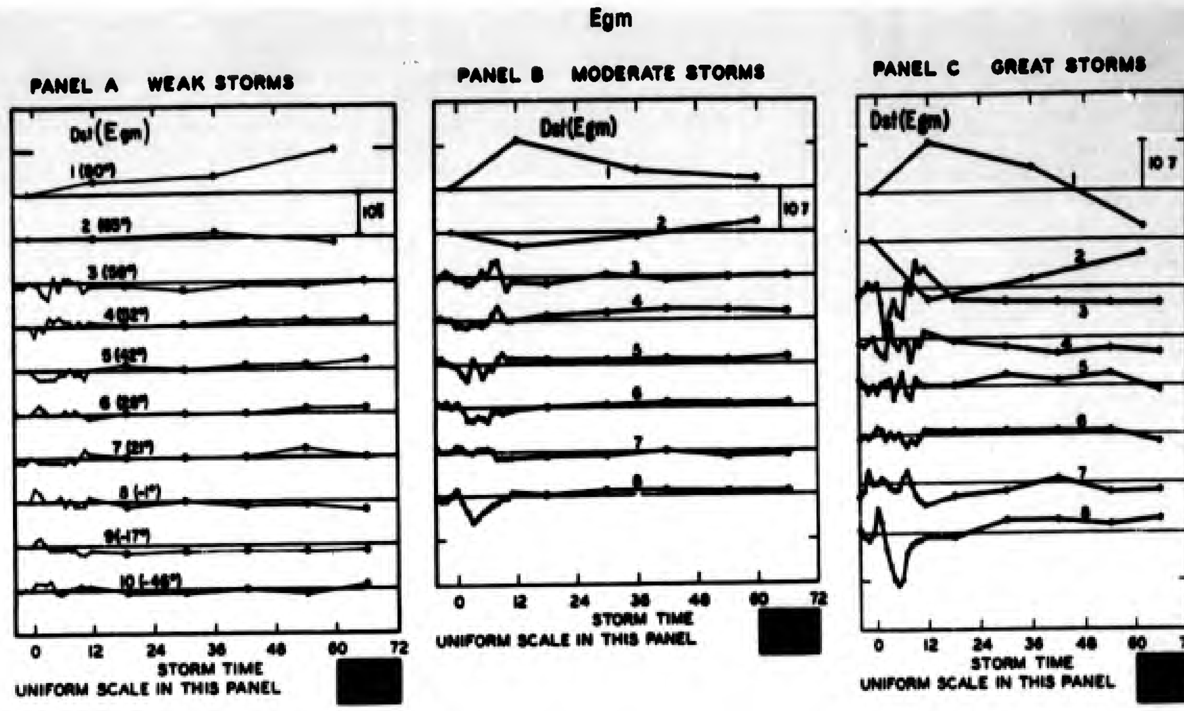


Figure 6. See p. 23 and below. The variation Dst in the geomagnetic east component Egm. The abscissae refer to storm time. Hourly points from —4 h to 11 h are shown by dots; the later half-day means by small circles. For 80° and 65° (graphs 1 and 2) circles refer to daily means. In the black rectangles at the foot of each panel the height corresponds to 10 gammas and the width to 12 hours.

9.2 *The variation Dst (Egm)* is shown by Fig. 6 to be small except in high latitudes. The irregularities in the graphs show that the accidental storm variations are incompletely cancelled out. Comparison of Fig. 6 with Fig. 5 shows that, at least over the greater part of the earth, the lines of force of the Dst field lie in gm meridian planes. At Godhavn Dst (Egm) seem to be systematically eastward in storms of all intensities. Also Dst (Egm) may be westward in latitude 65°. But these may only be consequences of the sparseness of the stations and their data. If Dst(E) were symmetrical around the gm axis, whether eastward or westward, it would imply that $\oint \mathbf{H} \cdot d\mathbf{s}$ round the circle of gm latitude differed from zero, and that there were electric currents crossing the earth's surface, of completely unlikely magnitude.

9.3 *The variation Dst(Z)* shown by Fig. 7 is much less than Dst(H) in all latitudes except at Godhavn (note the 2½-fold scale contraction for the Godhavn graph for great storms). The recovery in Dst(Z) seems to be notably slower than in Dst(H).

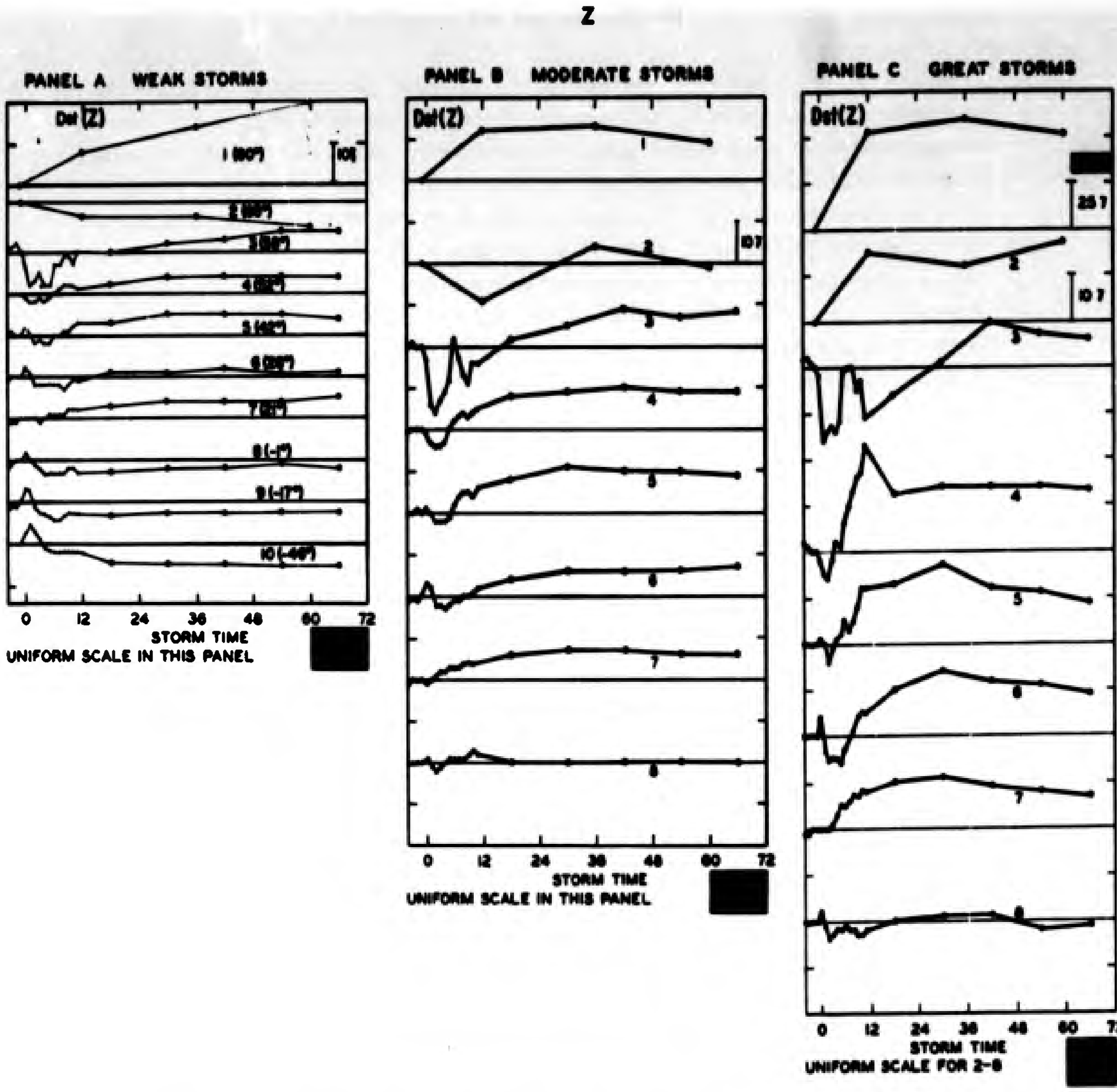


Figure 7. See pp. 23, 26. The variation Dst in the vertical force Z. The abscissae refer to storm time. Hourly points from —4 h to 11 h are shown by dots; the later half-day means by small circles. For 80° and 65° (graphs 1 and 2) circles refer to daily means. In the black rectangles at the foot of each panel and alongside the graph 1 in panel C the height corresponds to 10 gammas and the width to 12 hours.

10. The Sq and SD variations

Figs. 8, 9, 10 illustrate Sq and SD^n ($n = 1, 2, 3$) for the elements H, E, Z. The Sq variations are those given by the Sq sheets (§ 6.1), for the set of weak storms; those for the moderate and great storms gave, not surprisingly, essentially the same results. In each Figure the first panel illustrates Sq. Then follow three sets of three panels each; each set gives SD^n ($n = 1, 2, 3$) for the first three storm days, for one of the three intensity-sets of storms, in the order weak, moderate, great. The force-scale is uniform except where otherwise indicated—by a number enclosed in a circle (cf. § 9). The abscissae for Sq refer to standard local time, those for SD refer to gm local time. The mean difference between gm and standard local time is given for each observatory in column (h) of Table 2. It is small for the lower latitude observatories, but for the observatories 1 to 5 it is worth taking into account.

The Sq graph for Godhavn is omitted because it was clear that, as given by the Sq sheet (§ 6.1) it consisted partly of SD. Thus, even when magnetically quiet conditions exist in the lower latitudes, the ionosphere at Godhavn still seems to be affected by the D field—the ionosphere is not ionized only by solar ultraviolet light (§ 5).

10.1 *Sq and SD in the horizontal force H*. From Fig. 8 it is immediately evident that SD on the three storm days has a constant type and decreasing range; its type differs considerably from that of Sq. The Sq variation is greatest during the day hours: for SD the variation at night is comparable with that by day. The SD variation is mainly diurnal, the first harmonic being clearly predominant: this is not the case for Sq. Both variations are approximately symmetrical with respect to the equator, and are reversed at certain "focal" latitudes. For Sq this latitude is between 42° (graph 5) and 28° (graph 6); for SD it is between 58° (graph 3) and 52° (graph 4)—nearer to the latter—for weak and moderate storms; for great storms the focal latitude may be a little to the south of 52° during the first two storm days. Unlike Sq, SD increases greatly towards auroral latitudes, but seems to decrease again towards the pole.

Over the latitude range 42° to 21° (graphs 5 to 7) SD(H) is constant in type, but it becomes less regular near the equator. Graphs 8 to 10 show that both Sq and SD preserve their type as the equator is crossed.

At Huancayo Sq(H) is abnormally large, but SD(H) appears normal, except that its range seems to decrease from the first to the third storm day more rapidly than elsewhere, in weak storms.

The Huancayo graphs (8) for SD^1 for weak and moderate storms have a secondary maximum near noon, as if Sq were enhanced during such storms; if this were so, the enhancement would (according to our procedure) be superposed on SD.

H

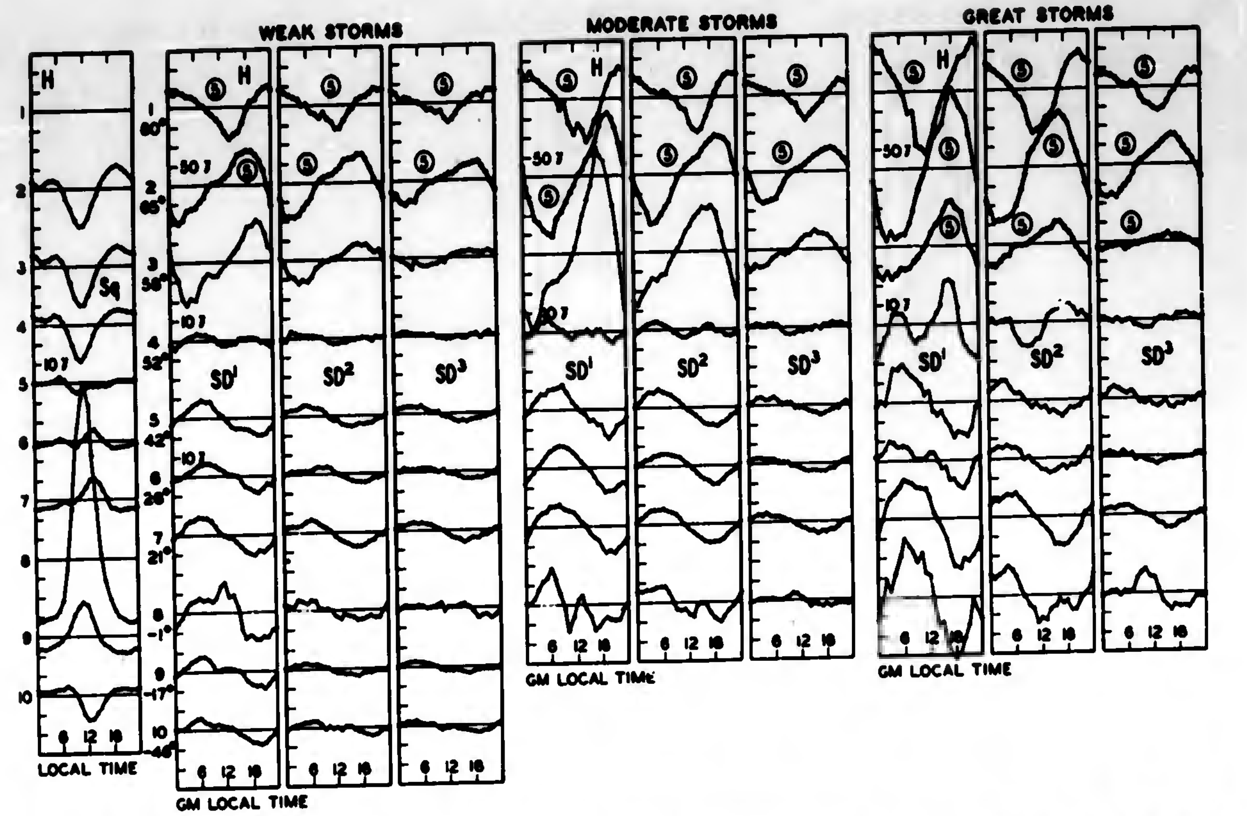


Figure 8. See p. 28. Sq and SD in the horizontal force H (*not* the geomagnetic north component Hgm). The first panel illustrates Sq; the following three sets (of three panels each) refer to the three intensity sets, in the order weak, moderate and great; each set gives SD^n ($n = 1, 2, 3$) for the first three storm days. The force scale is uniform except where otherwise indicated by a number (the scale contraction factor) enclosed in a circle. The abscissae for Sq refer to standard local time; those for SD refer to gm local time.

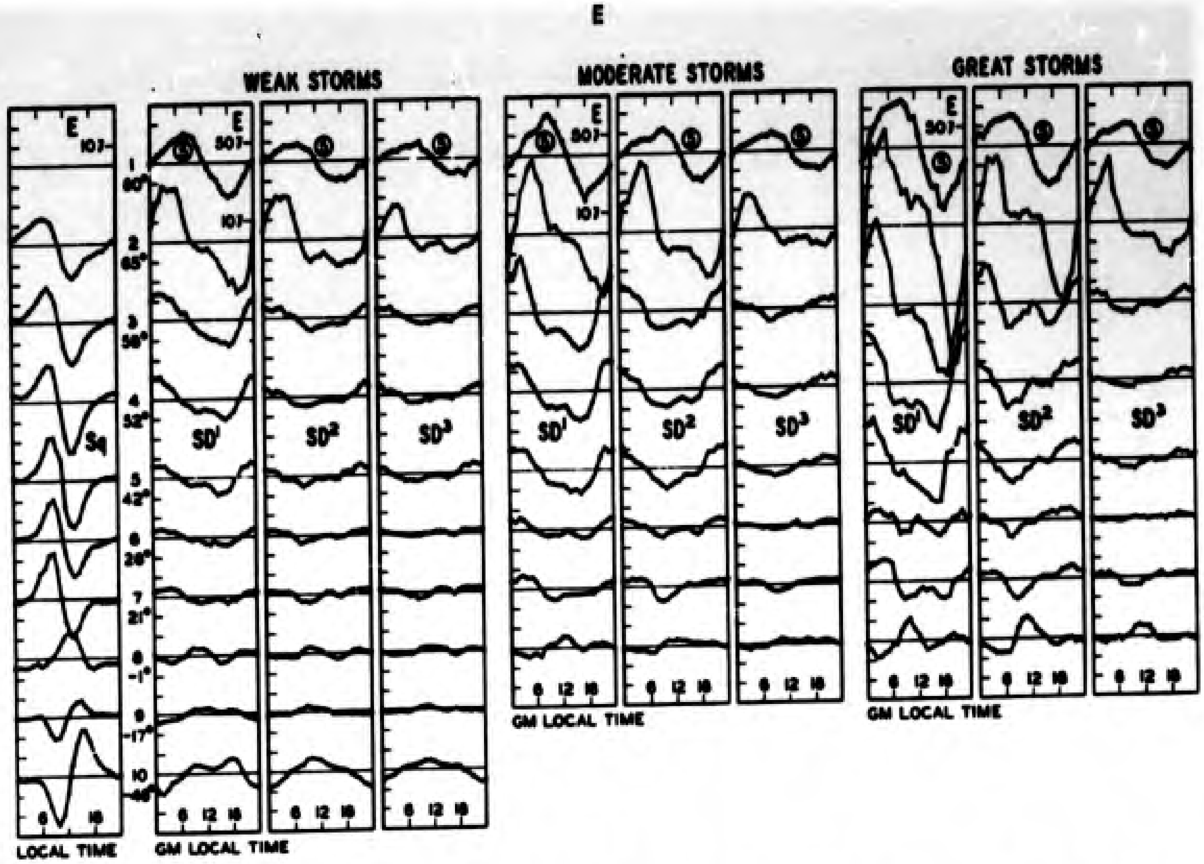


Figure 9. See §§ 10 and 10.2 below. Sq and SD in declination E (*not* the geomagnetic east component Egm). The first panel shows Sq; the following three sets (of three panels each) refer to the three intensity sets, in the order weak, moderate and great; each set gives SD^n (n = 1, 2, 3) for the first three storm days. The force scale is uniform except where otherwise indicated by a number (the scale contraction factor) enclosed in a circle. The abscissae for Sq refer to standard local time, those for SD to gm local time.

10.2 *Sq and SD in declination E.* In type, Sq(E) is constant, and its phase is uniform, from latitude 65° (graph 2) to 21° (graph 7); the phase is reversed on crossing the equator. Similar remarks apply to SD(E). At Huancayo (graph 8) Sq(E) is peculiar, and not merely transitional in character; SD(E) seems to be of southern rather than transitional character. Unlike Sq(E), SD(E) increases greatly towards auroral latitudes, and the increase continues up to gm latitude 80° (graph 1), with approximately constant phase.

As with SD(H), SD(E) does not show any marked enhancement, as Sq does, in the day hours.

10.3 *Sq and SD in the vertical force Z.* Between gm latitudes 58° (graph 3) and —46° (graph 10) Sq(Z) preserves a constant type, reversed on crossing the equator. Similar remarks apply to SD(Z), but its amplitude (unlike that of Sq) increases rapidly towards 65° (graph 2), and is reversed on crossing to within the auroral cap (graph 1). On the first day of great storms the reversal occurs at a lower gm latitude, below 65°.

Like SD(H) and SD(E), SD(Z) proceeds at a similar rate by night as by day, unlike Sq(Z). As in H and E, SD in Z is quite different from Sq in type and distribution.

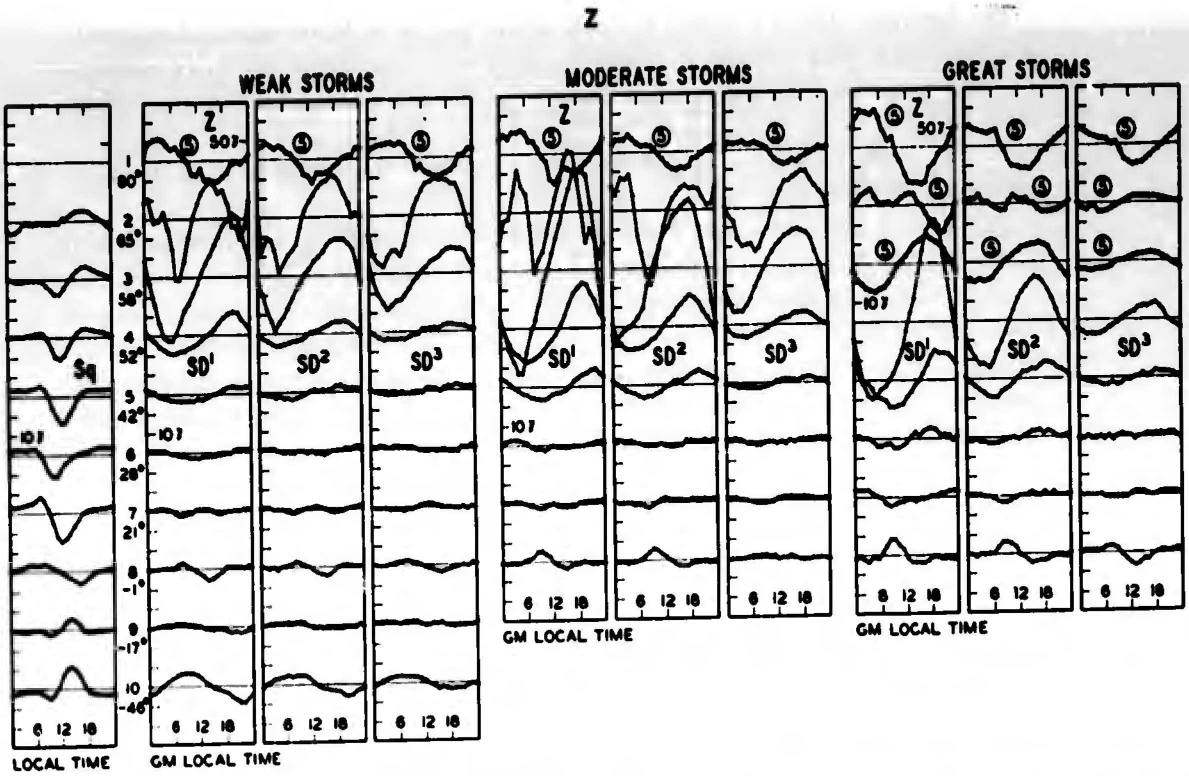


Figure 10. See §§ 10 and 10.3 p. 30. Sq and SD in the vertical force Z. The first panel shows Sq; the following three sets (of three panels each) refer to the three intensity sets, in the order weak, moderate and great; each set gives SD^n (n = 1, 2, 3) for the first three storm days. The force scale is uniform except where otherwise indicated by a number (the scale contraction factor) enclosed in a circle. The abscissae for Sq refer to standard local time, and those for SD to gm local time.

11. Vectograms of Sq and SD

The difference between Sq and SD is illustrated still more clearly by their vectograms. The complete Sq or SD vectogram is a time-marked three-dimensional curve, traced out by the end of the corresponding field vector drawn from a fixed origin. At many stations the variations of the vectogram are greater in the horizontal plane than along the vertical, and then it is most convenient to deal only with the horizontal projection of the vectogram, determined only by the H and E variations.

Figs. 11—16 show such horizontal vectograms for Sq and SD for Godhavn and for latitudes 65° (Fig. 11), 58° (Fig. 12), 52° (Fig. 13), 42° (Fig. 14), 28° (Fig. 15), 21°, —1°, —17° and —46° (the last four in Fig. 16). Except for Godhavn (§ 10), each diagram gives one Sq vectogram, from the Sq sheet (§ 6.1) for weak storms, and three sets of three SD diagrams, for SD^1, SD^2, SD^3 for weak, moderate and great storms; for each latitude the scale is the same for all the vectograms. (In Figs. 14 and 16, Sq and SD vectograms for weak storms only are shown.)

The directions of local magnetic N and E, and of gm and gg N, are indicated separately. The force-scale is marked on the local magnetic N axis, or indicated by a black rectangle. For each vectogram the line is drawn heavier for the day half (6 h to 18 h) than for the night half.

In all cases the vectograms show the decrease of SD from the first to the third storm day, with little change of type.

The SD vectograms for Godhavn (80° gm) are nearly circular; the horizontal force vector rotates clockwise. Those for latitude 65° are strikingly different; they are thin, and extend along a direction lying between gm and gg N. This direction is approximately perpendicular to the auroral zone. From this form of the vectogram it is inferred that SD is produced by a nearly overhead laterally limited current flowing along the zone, with direction and magnitude that change with local time. Such a narrow current is called an *electrojet*—in this case, the auroral electrojet.

The Sq vectogram for this latitude (65°) is nearly circular, and shows no influence of the electrojet. Its range is much smaller than that of SD, even on the third day of weak storms. Unlike the SD vectograms, most of it is described during the half day centered at noon.

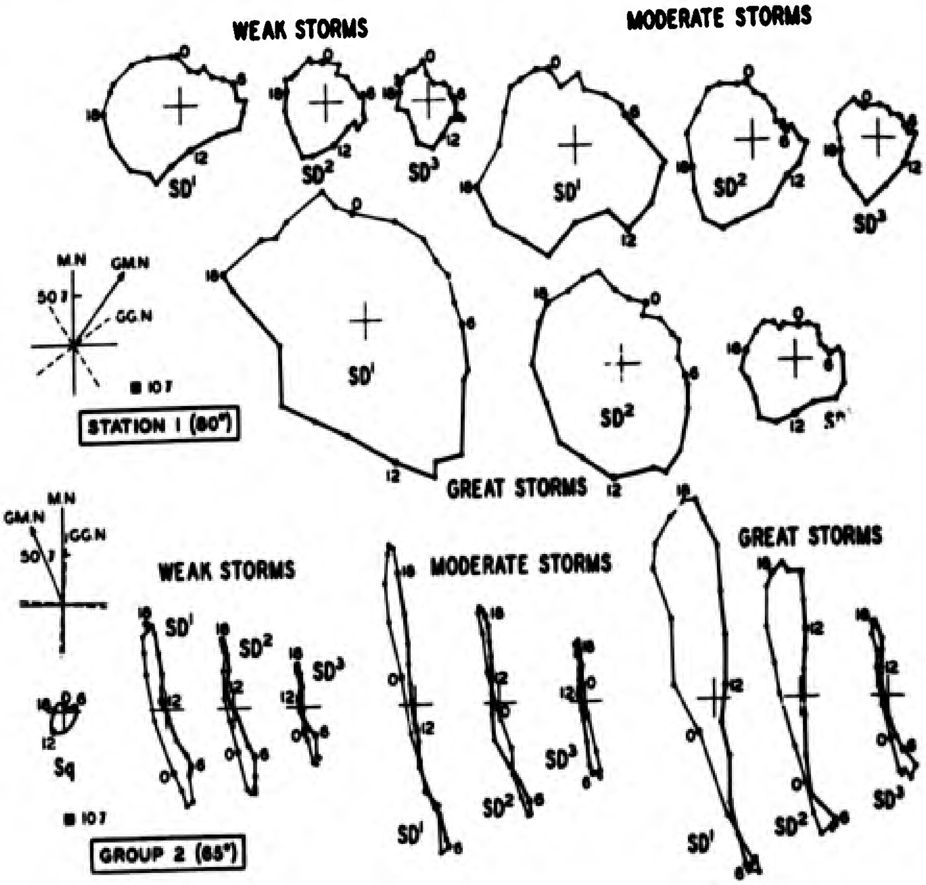


Figure 11. See above. The horizontal vectograms of SD for Godhavn (80°) and those of Sq and SD for gm latitude 65°. The three SD sets (of three vectograms each) refer to the three intensity sets, weak, moderate and great; each set gives vectograms of SD^n (n = 1, 2, 3) for the first three storm days. The directions of local magnetic, and gg, N and E, and of gm N are indicated. The force scale is the same for all the vectograms, and is marked on the local magnetic N axis, or indicated by a black rectangle. The numbers in the Sq vectogram refer to standard local time, and those in the SD vectograms to gm local time.

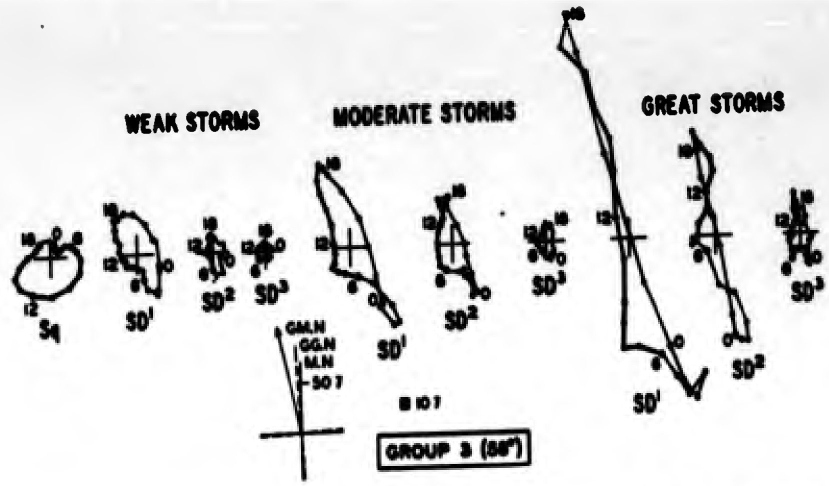
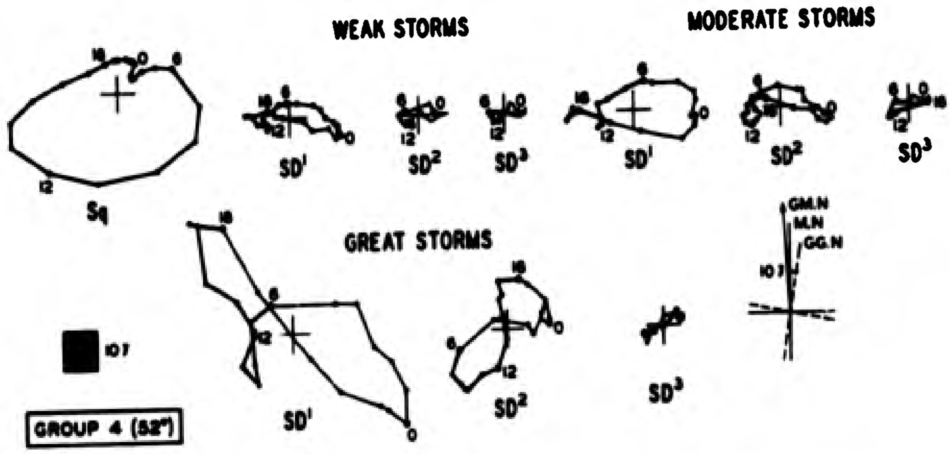


Figure 12 (above) and 13 (below). See below. Horizontal vectograms of Sq and SD^n (n = 1, 2, 3 for the first, second and third storm days). Fig. 12 refers to group 3 (gm lat. 58°) and Fig. 13 to group 4 (52°), separately for weak, moderate and great storms. The directions of local magnetic and gg N and E, and of gm N, are indicated. The force scales are different in Figure 12 and Figure 13, but are the same for all the vectograms in each of these two sets; they are marked on the local magnetic N axis, or indicated by a black rectangle. The numbers beside the Sq vectograms refer to standard local time, and those beside the SD vectograms to gm local time.



At gm latitude 58° (Fig. 12) the Sq vectogram is similar in shape to that in Fig. 11, but larger. For weak storms the SD diagrams are more nearly oval than in Fig. 11, but with increasing storm intensity they become elongated, more resembling those of Fig. 11—at least during the first two storm days. This is taken to indicate that the N auroral zone draws southward as the storm intensity increases. The SD vectograms are described in the clockwise sense during weak and moderate storms.

Six degrees further south (52° gm) the size of the Sq vectogram (allowing for the change of scale) is little altered (Fig. 13), but it is more elongated in the E—W direction. The SD vectograms also are elongated in that direction, though on the first day of a great storm there is some tendency to revert to the auroral SD type. The size of the SD vectograms is much less than for latitude 58°. Their narrowness in the N—S direction corresponds to the nearness to the SD focal latitude, except in great storms, when the focus moves southward, like the zone. During weak and moderate storms the SD vectograms are described anticlockwise, indicating that the focus lies to the N: during great storms the vectograms have two loops, described in opposite senses. The decline of SD from the first to the third storm day is most marked for the great storms.

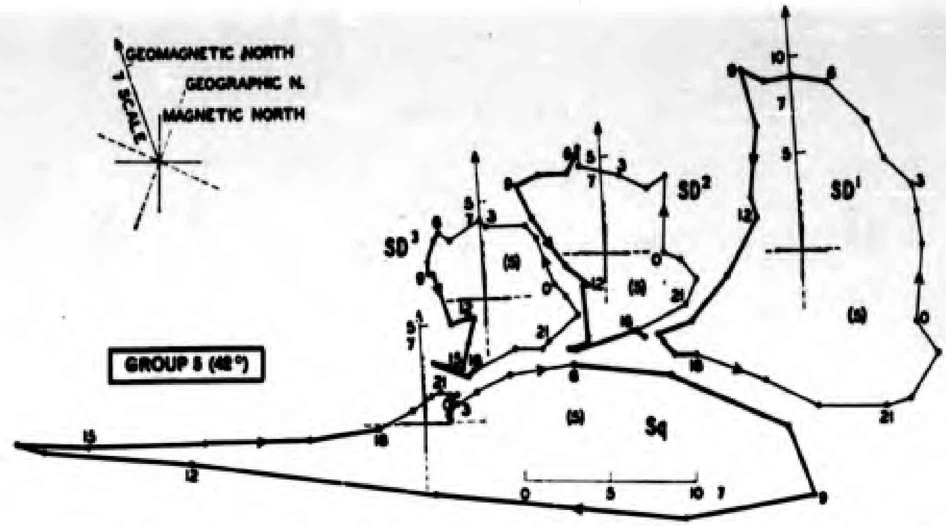
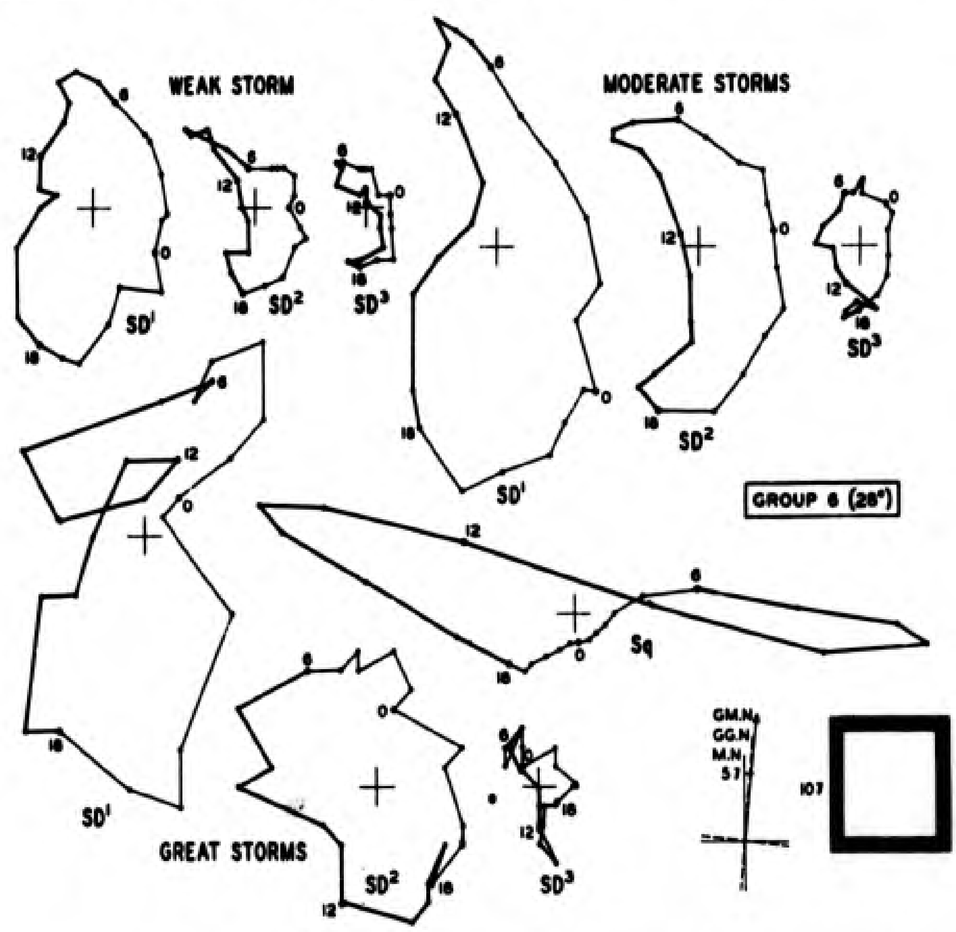


Figure 14 (above) and 15 (below). See below. Horizontal vectograms of Sq and SDⁿ (n = 1, 2, 3 for the first three storm days). Fig. 14 refers to group 5 (gm lat. 42°) for weak storms only; Fig. 15 refers to group 6 (28°), separately for weak, moderate and great storms. The directions of local magnetic and gg N and E, and of gm N, are indicated in each vectogram as in Figs. 11—13. The force scales are slightly different in Figure 14 and Figure 15, but are the same for all the vectograms in each of these sets; they are marked on the local magnetic N axis, and in Figure 15 it is also indicated by a black (open) rectangle. The numbers beside the vectograms refer to standard local time in the Sq vectograms, and also in those for SD in Fig. 14; in Fig. 15 those for SD refer to gm local time.



At latitude 42° (Fig. 14) the Sq diagram has become still flatter, though still described clockwise, as in higher latitudes: the Sq focus is nearer. The distance from the SD focus is increased, and the SD diagrams (shown only for weak storms) are more nearly circular;

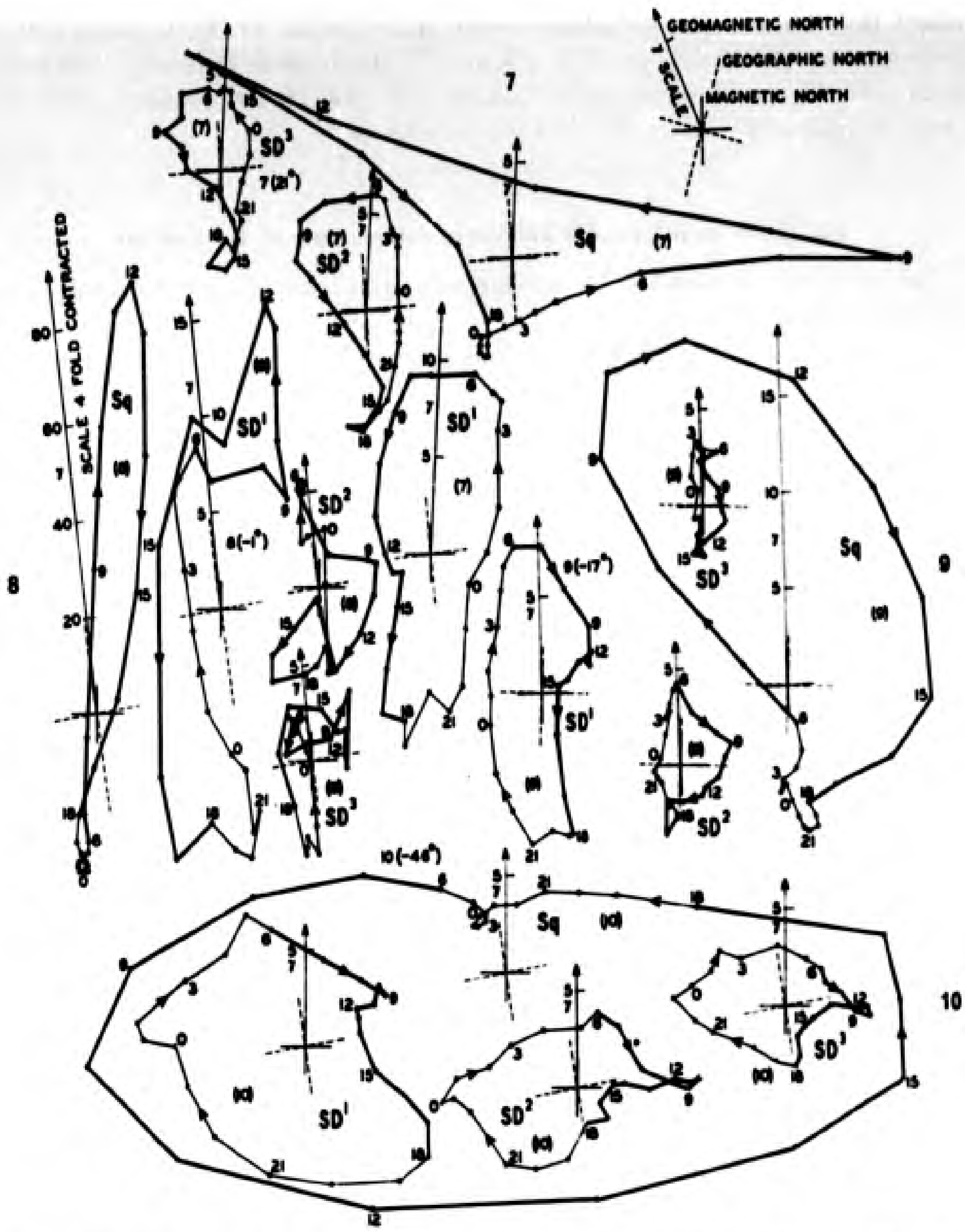


Fig. 16. See below. Horizontal vectograms of Sq and SD^n ($n = 1, 2, 3$ for the first three storm days) for weak storms, for groups 7, 8, 9 and 10 (gm lats. 21°, —1°, —17° and —46°). The various N and E directions are indicated as in Figs. 11—13, 15. The force scales are indicated on each gm N axis; they are all the same except that the Huancayo Sq diagram is reduced fourfold. The numbers beside the vectograms all refer to standard local time.

their sense of description remains anticlockwise. The SD change is rather greater by night than by day, and (in weak storms) less than in Sq.

At latitude 28° (Fig. 15) the Sq vectogram is looped: the Sq focus is near. The SD vectograms are still smaller relative to Sq.

At 21° latitude (Fig. 16) the Sq vectogram is described in the anticlockwise sense, and is still narrow along the meridian. The SD vectograms, on the contrary, are elongated in that direction, and their course is about equal by day and by night. At Huancayo (—1°) (Fig. 16) the Sq vectogram is abnormally large in the meridian direction (indicating, in association with other evidence, the near presence of the daytime equatorial electrojet). The SD vectograms do not share this enhancement. In the southern hemisphere the SD vectograms for latitude —17° (Fig. 16) resemble those for N latitude 21°, except that their sense is reversed (clockwise): this is because SD(E), but not SD(H), is reversed on crossing the equator. But Sq at —17° differs rather surprisingly from that at 21°. The Sq and SD vectograms for latitude —46° (Fig. 16) are reasonably similar to those for latitude 42°, except for their reversal of sense.

12. The first and second harmonic components of DS and SD

The DS variations obtained on the sheets D_r (§ 6.5) were harmonically analyzed, according to the formulae:

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

or

$$\sum_n c_n \sin (n\lambda_s + \sigma_n).$$

Here λ_s denotes local time, or longitude relative to the sun, measured eastward from the midnight meridian. For moderate and great storms (but not for weak storms) a correction for the difference between gm and standard local time (Table 2, column h) was applied to the phase angle σ_n. The factors a_n, b_n, c_n were expressed in gammas.

Table 8 (pp. 50—51) gives the values of a_1, b_1 thus calculated. To obtain a first broad view of these results, those for the 4 or 3 intervals r of each storm day were combined, to give the corresponding harmonic coefficients of SD^1, SD^2 and SD^3. Also, to examine whether the higher harmonics (3rd and 4th) have any importance, they also were calculated for each of the three storm days, from the combined SD sequences for the 10 observatories of groups 4 to 7 (latitudes 54° to 20° gm). They were found to be very lsmall and irregular, and are not given or further considered here (see the note on p. 53).

The first harmonic of DS (and therefore also of SD) is predominant at all latitudes, in all three elements, and at all storm times.

Harmonic components of a daily variation can conveniently be indicated graphically by harmonic dials. One dial serves for one frequency. Here only the first and second frequencies, of 24 and 12 hours period, are considered. The dial position of a point indicates by its co-ordinates the factors a_n, b_n. By its distance from the origin it indicates c_n. By its direction from the origin it indicates the phase σ_n, reckoned anticlockwise from the rightward horizontal direction. Further, if the dial is regarded as the face of a clock recording the time by n circuits of its hour hand each day, the direction of the dial point from the origin indicates the time(s) of maximum. For the first and second harmonics the dial must be regarded as the face of a 24-hour clock or of an ordinary 12-hour clock.

Figs. 17 and 18 give harmonic dials respectively for the first and the second harmonic of the combined SD for groups 4 to 7, mean gm latitude 36°. Dial points are given for SD^1, SD^2, and SD^3, and the successive points are connected. The SD(H) dial points are given relative to the usual directions (as shown) of the dial axes. To illustrate the degree of similarity of the progression of SD(E) and SD(H), in amplitude and phase, from the first to the third day of a storm, the SD(E) dial points are shown relative to dial axes turned clockwise through 90°, relative to those for SD(H). The SD(Z) dial points are shown relative to dial axes rotated through 180°. Arrowed arcs, a quadrant for E and a semicircle for Z, show the rotations needed to bring the dial axes for these SD(E) and SD(Z) *dialgrams* into the usual directions.

Similar systematic changes in the first harmonic component of SD, from the first to the third storm day, are evident (Fig. 17) in all three elements, and in all three intensity sets of storms. The second harmonic is smaller than the first, but the storm-time changes in it, shown by Fig. 18, may be real; they will not be further considered here. The first harmonic shows not only a decreasing amplitude, but also an increasing phase angle, as storm time proceeds. The change of phase implies an earlier time of maximum.

Figure 17. See § 12, p. 36. The harmonic dials for the first harmonic component of SD in H, E, Z, for weak, moderate and great storms. The dial points 1, 2, 3 refer to SD on the first, second and third storm days. The SD(E) dial points are shown relative to dial axes turned clockwise through 90°, relative to those for SD(H). The SD(Z) dial points are shown relative to dial axes rotated through 180°. Arrowed arcs show the rotations needed to bring the dial axes for the SD(E) and SD(Z) dialgrams into the usual directions. The dials refer to the combined SD for observatory groups 4 to 7, mean gm latitude 36°.

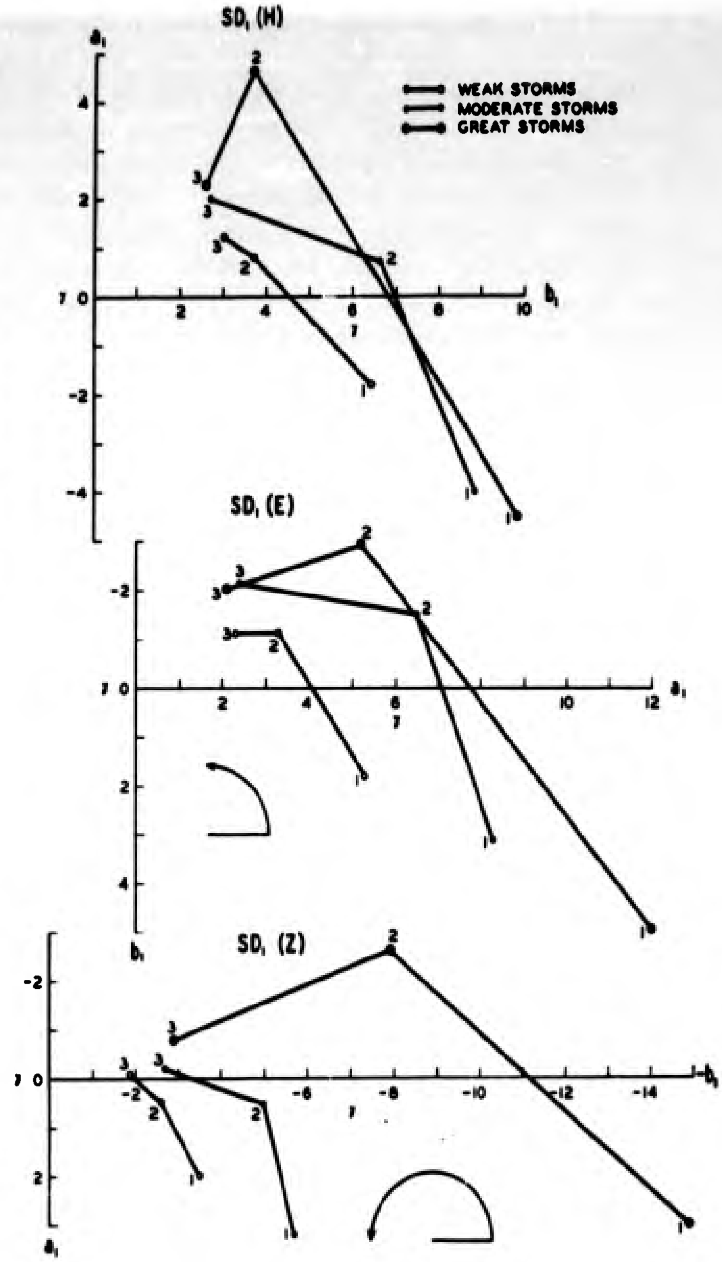
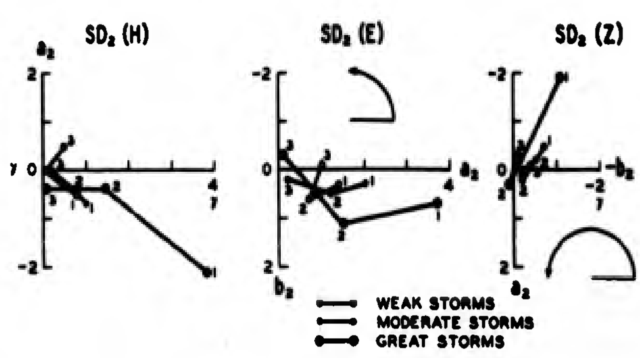


Figure 18. See § 12, p. 36. The harmonic dials for the second harmonic component of SD in H, E, Z, for weak, moderate and great storms. The dial points 1, 2, 3 refer to SD on the first, second and third storm days. The SD(E) dial points are shown relative to dial axes rotated through 90°, relative to those for SD(H). The SD(Z) dial points are shown relative to dial axes rotated through 180°. Arrowed arcs show the rotations needed to bring the dial axes for the SD(E) and SD(Z) dialgrams into the usual directions. The dials refer to the combined SD for observatory groups 4 to 7, mean gm latitude 36°.



13. The first harmonic component of DS in different latitudes

The DS coefficients in Table 8, for the 11 intervals of storm time, and for the small groups of observatories, are naturally more affected by accidental errors than are the condensed results illustrated in Figs. 17 and 18. Even so, it is of much interest to examine more closely how DS varies with the storm time, and in different latitudes.

To reduce the accidental error in this part of our analysis, we combined the DS results from all the storm intensities. The DS coefficients for the higher storm intensities were reduced by appropriate factors, determined from the data themselves, so as to give, in combination with the coefficients derived from weak storms, values representative of such storms.

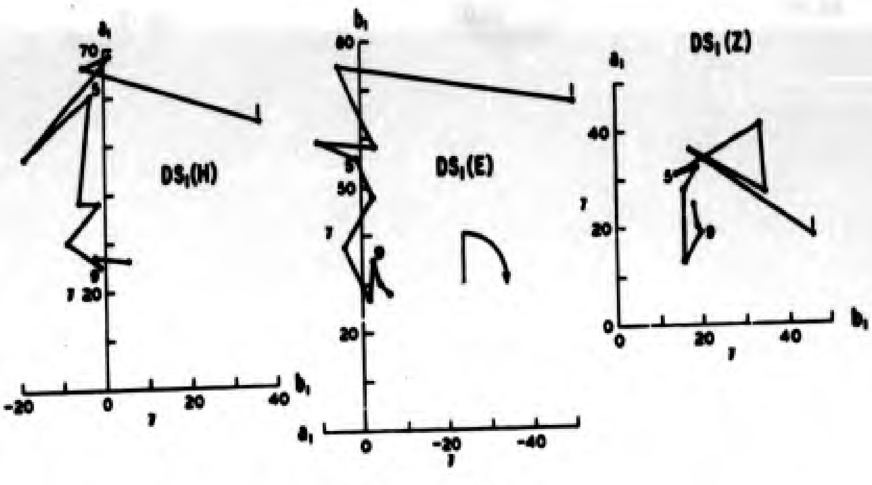
For Godhavn and latitude 65° the reduction factors were $\frac{2}{3}$ (moderate storms) and $\frac{1}{3}$ (great storms). For latitudes 58° and 52° the factors were $\frac{1}{2}$ and $\frac{1}{3}$. For Huancayo (latitude —1°) they were 1 and $\frac{1}{2}$. The weak storm results for the two southern groups (9, 10, mean latitude —32°) were combined, and results for moderate and great storms were not included.

It might appear more satisfactory to combine the results for the three storm intensities in the same proportions for all latitudes. But DS does not vary with storm intensity in the same way in all latitudes, nor at all storm times. The different factors for reduction to weak storm intensity illustrate the varying dependency of DS on storm intensity in different latitudes. The object here is to obtain results for the storm time variation of DS, appropriate to weak storm intensity, with reduced accidental error, by using all or nearly all of our storm data.

The results are illustrated in Figs. 19—24, by harmonic dials; some of those for E and Z are rotated in the way described in § 12.

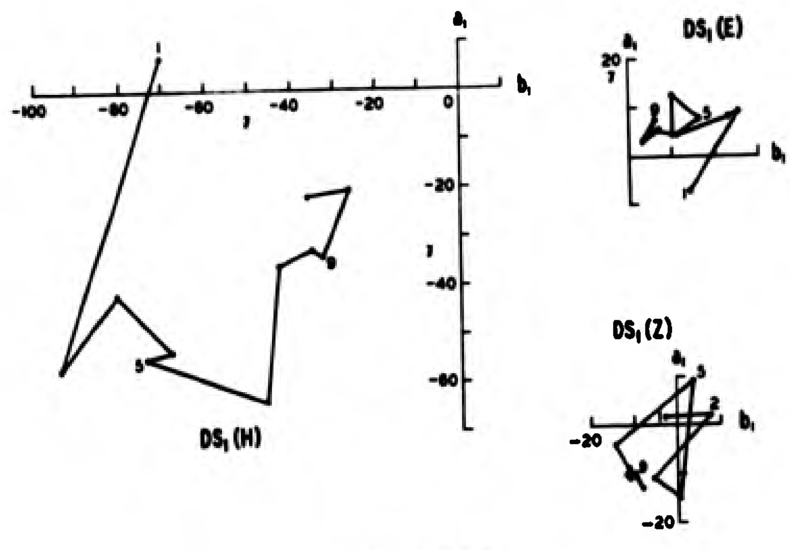
All the dials confirm the indication of Figs. 17 and 18, that there is a systematic storm-time change of DS_1 in phase and amplitude. The changes are greatest during the first half-day.

Fig. 19, for Godhavn (80°), indicates a rapid large change of phase of DS, in both H and E, during the first twelve hours of storm time.

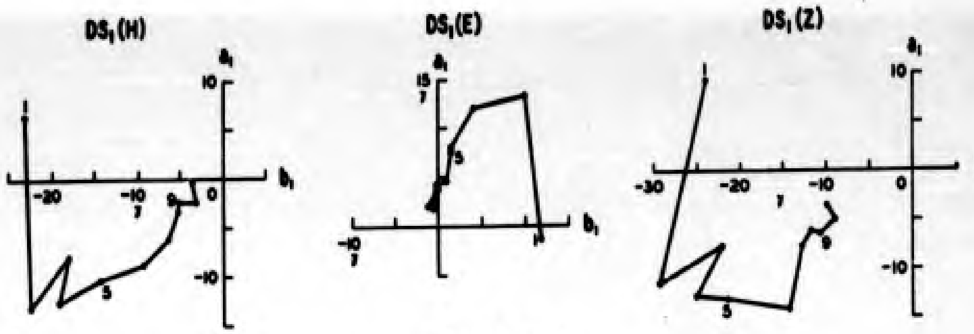


STATION I (80°)

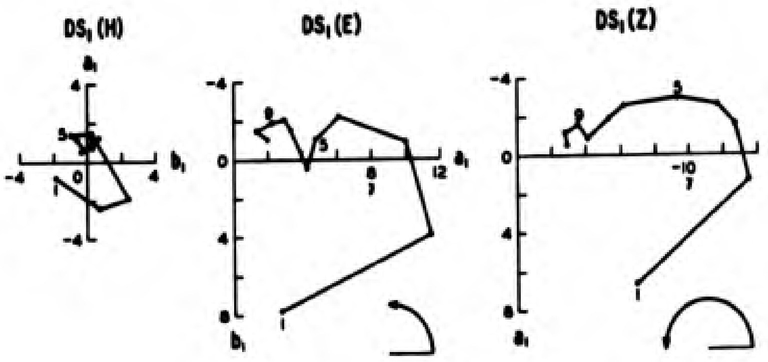
Figure 19 (above) and 20 (below). See § 13, p. 38. Harmonic dials for the first harmonic component of DS in H, E, Z, for Godhavn (Fig. 19) and for the three observatories of group 2 (mean gm lat. 65°). The dials are appropriate to weak storm intensity; the data for moderate and great storms are combined with those for weak storms, with reduction factors [illegible] and [illegible] respectively. In Fig. 19 the SD(E) dial is turned anticlockwise through 90° from its usual orientation; the arrowed arc shows the rotation needed to restore this orientation. The dial points 1—8 refer to the first eight 6-hour intervals of storm time; the dial points 9—11 refer to the three 8-hour intervals of the third storm day.



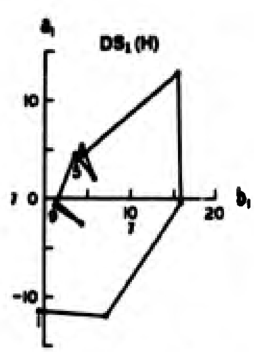
GROUP 2 (65°)



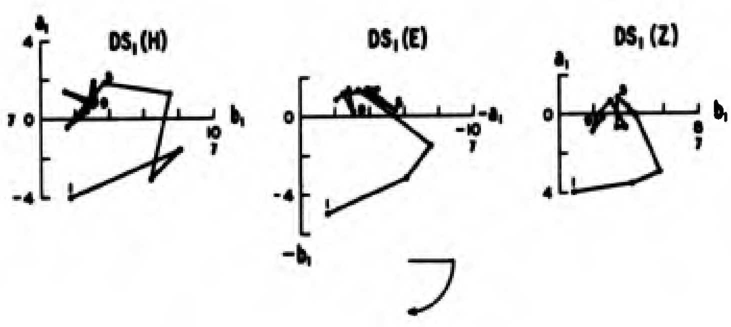
GROUP 3 (58°)



GROUP 4 (52°)



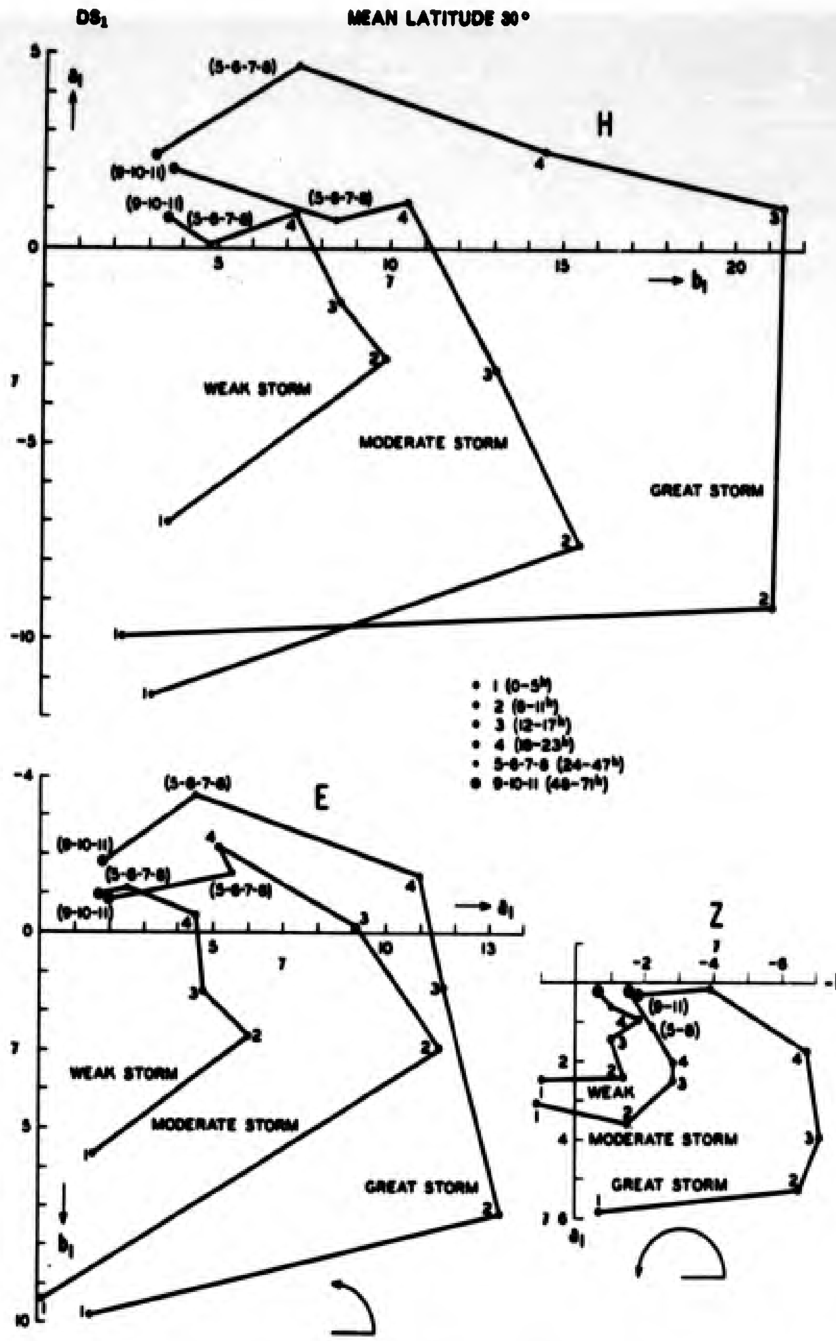
STATION 8 (−1°)



GROUPS 9 and 10 (—32°)

Figures 21 (top) and 22 (middle) and (below) 23 (left) and 24 (right). See § 13, p. 38. Harmonic dials for the first harmonic component of DS in H, E, Z (in Fig. 23, for H only). The dials are appropriate to weak storm intensity; in Figs. 21, 22, 23 data for moderate and great storms are combined with those for weak storms with reduction factors ½ and ⅓ (Figs. 21, 22) or 1 and ½ (Fig. 23) respectively. Fig. 21 (top) refers to the four observatories of group 3 (mean gm lat. 58°), Fig. 22 to the four observatories of group 4 (52°), Fig. 23 to Huancayo (—1°), Fig. 24 to the other seven southern observatories, groups 9, 10 (—32°). In Figs. 22, 24 the DS(E) dials have been turned through 90° (clockwise in Fig. 22, anticlockwise in Fig. 24); in Fig. 22 the DS(Z) dial has been turned through 180°; arrowed arcs show the rotations needed to restore the usual orientations. The dial points 1—8 refer to the first eight 6-hour intervals of storm time; the dial points 9—11 refer to the three 8-hour intervals of the third storm day.

Figure 25. See § 13.1. The harmonic dials for the first harmonic component of DS in H, E, Z, for weak, moderate and great storms: from observatories between the DS focal latitude and the equator (mean gm latitude 30°). The DS(E) dial points are shown relative to dial axes turned clockwise through 90°, relative to those for DS(H). The DS(Z) dial points are shown relative to dial axes rotated through 180°. Arrowed arcs show the rotations needed to bring the dial axes for DS(E) and DS(Z) into the usual directions. The dial points 1—8 refer to the first 6-hour intervals, and the dial points 9—11 to the following three 8-hour intervals.



For group 4, for a latitude near the DS focus, the DS(H) dial vectors are all small. For Huancayo (Fig. 23) the DS vectors are rather irregular, and only the DS(H) dial is shown.

The harmonic dials for the mean of the seven southern observatories (mean latitude —32°) are shown in Fig. 24. They are derived only from weak storms.

13.1 *DS for different storm intensities: between its focal latitude and the equator.* Fig. 25 shows the course of the DS variation, in the three elements, and for the three intensity sets of storms, for a mean latitude between the SD focus and the equator. It is obtained by combining the DS_1 harmonic coefficients for the 6 observatories of the groups 5, 6 and 7 (latitudes from 44° to 20°, mean 30°), and also combining the DS_1 coefficients for the intervals 5 to 8 (covering the second storm day) and 9 to 11 (for the third day). The E and Z dials are rotated clockwise by 90° and 180° respectively.

In all three elements the regularity of change of amplitude and phase is evident. The change is greatest during the first twelve hours or so. The phase changes are essentially similar in all three elements, for all three intensities.

14. DS in the first six storm hours

In C_4 the harmonic coefficients a_1 and b_1 for DS, were determined for the first four individual hours of the average storm. In that paper the analysis was based on the records for 40 storms and for 8 observatories; hence the average number of values contributing to each local hour was $40 \times 8/24$ or about 13.

In this paper we determined DS_1, in H and E, for each of the six hours in the first quarter-day interval of weak, moderate and great storms, separately. This was done by adding the six entries in sheet D_1 (§ 6.5) separately for storm hours 0 to 5, and by applying the same method as was described in § 6.5. The observatories used in this analysis were the same as in § 13.1: six in number, in latitudes from 44° to 20°, mean 30° gm. The average number of entries contributing for each local hour (or λ_s) was 29 (702/24), 27 (658/24) and 15 (359/24), for weak, moderate and great storms, respectively.

Fig. 26 shows the harmonic dials for H and E, in the 24-hour component of DS, thus determined; those for E are rotated clockwise through 90°. The dial points 0 to 5 refer to the first six hours. Those corresponding to the succeeding three quarter-day intervals and to the second and third days are also plotted; they are the same as in Fig. 25. In each dial the point for the mean of the first six hours (dial point 1 in Fig. 25) is indicated by a cross circled and connected by broken lines to the point referring to the second quarter-day interval. The origin of the dials refers to hour —1, the epoch that is supposed to be unaffected by the storms. This last remark also applies to all the harmonic dials mentioned in §§ 13, 13.1.

In both H and E the greatest change in amplitude and phase occurs in the first six hours. The small amplitudes for the mean of this interval, as shown by the dial points 1 in Fig. 25, are due to the rapid changes in phase during the interval.

The dialgram for great storms shows that at 2 hours storm time, DS_1 in both H and E, has a phase opposite to that for the second and third storm days. The figures for weak and moderate storms show a similar phase reversal, though not quite so complete, between the early storm hours and the later storm days.

In C_4 these large initial amplitudes and phase changes of DS_1 were not found; but the independent evidence provided by the six dials in Fig. 26 clearly establishes the existence of these phenomena.

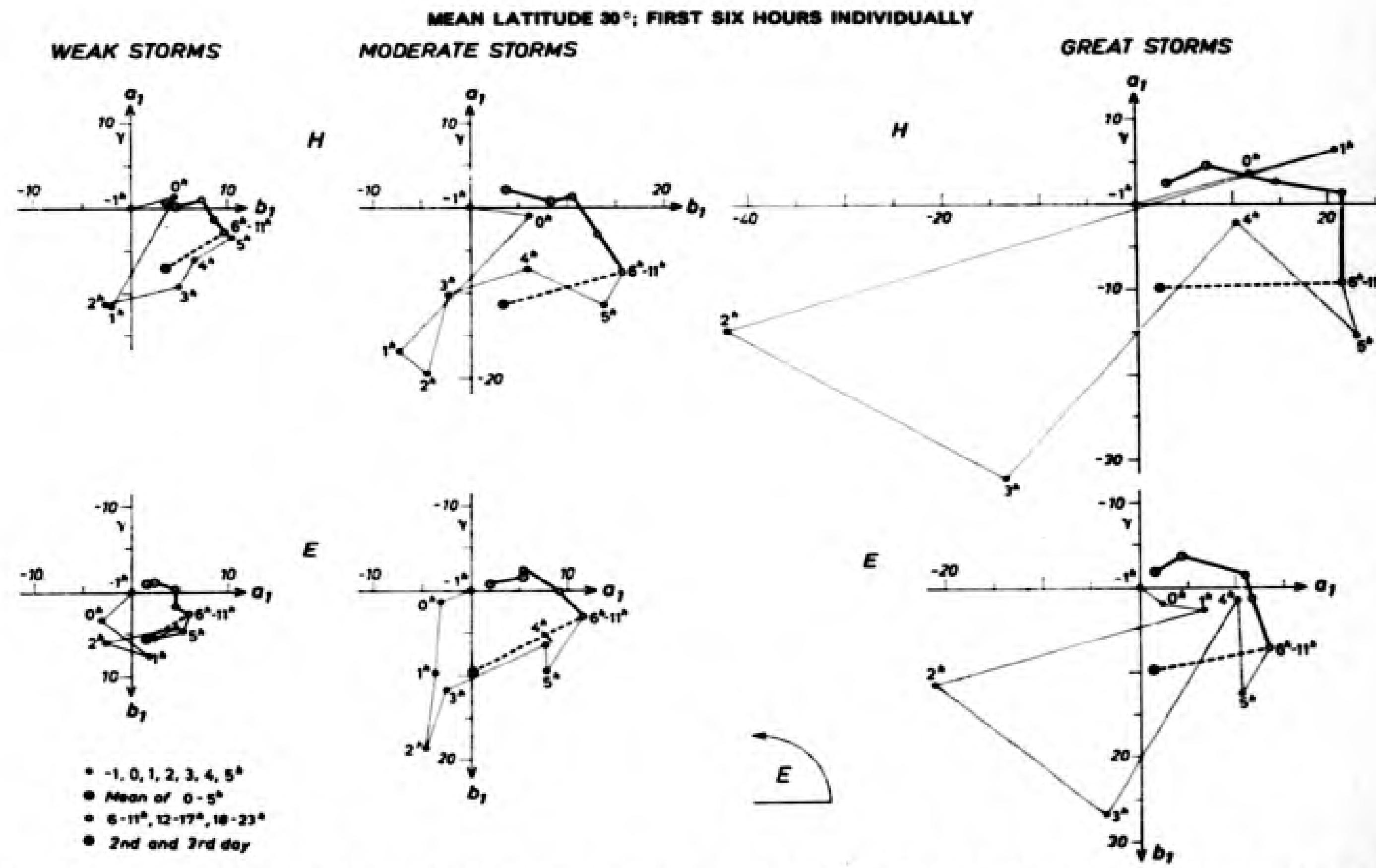


Figure 26. See § 14. The harmonic dials for the first harmonic component of DS in H and E, for the first six storm hours and for the later intervals, for the weak and moderate and great storm intensities: mean of groups 5, 6 and 7, mean gm latitude 30°. The DS(E) dial points are shown relative to dial axes rotated clockwise through 90°, relative to those for DS(H). The arrowed arc shows the rotation needed to bring the dial axes for DS(E) into the usual directions. The indicated storm hours refer to one-hour intervals centered thereat. The mean of the first six hours, shown by a cross enclosed in a circle, and the dial points for the later intervals are the same as in Fig. 25.

15. A comparison of the Dst and DS_1 changes

Fig. 27 illustrates the different rates of evolution of Dst and of the range ($2c_1$) of DS_1 during the first three days of magnetic storms. It shows graphs of Dst by full lines, and of DS_1 by broken lines, for the three elements, and for weak, moderate and great storms. Merely for ease of comparison, the ranges are plotted with negative sign, because Dst(H), the chief storm-time variation, is mainly negative. The scale of the graphs for the three highest latitudes is contracted 2-fold, as shown by the black rectangles (§ 9).

At 80°, well inside the auroral zone, and at 65°, near the zone, DS greatly predominates over Dst. At 65° latitude, DS(H) greatly exceeds DS(E), because of the proximity of the auroral zone and its electrojet.

The graphs for the great storms suggest that the electrojet at such times approaches the latitudes of group 3 (58°); DS(Z) is large at 52° during great storms.

At 58°, though Dst is still small compared with DS, it begins to show the characteristics that mark it throughout middle and low latitudes.

At still lower latitudes Dst(H) and DS(H) rise to maxima at the equator, while in E and Z they decrease, to be reversed on crossing to the southern hemisphere.

As shown in C_4, the amplitude or range of DS varies with storm time very differently from Dst. The main difference is that DS attains its maximum earlier, and dies away more rapidly. The phase changes that accompany these changes of amplitude are not shown in Fig. 27. Our work establishes that these changes, found in C_4 to characterize moderate storms, are shown also by weak and great storms. In addition, new facts regarding the rapid changes of DS during the earliest storm hours are here found (Figs. 26) from the study of the three groups of storms.

Fig. 28 shows DS(H) and Dst(H) for the mean of the 6 observatories of groups 5, 6, and 7 (mean latitude 30°), for weak, moderate and great storms: they supplement Fig. 26, which shows also the phase changes of DS. For the three intensities of storms, Fig. 28 indicates that in these latitudes the maximum ranges ($2c_1$) of DS(H) are nearly the same as the maximum decrease in Dst(H).

The time in which DS(H) later decreases to half its maximum amplitude is about 30 hours, 27 hours and 12 hours, for weak, moderate and great storms, respectively. The corresponding time for Dst(H) for weak and moderate storms is longer than 3 days, and consequently our work does not determine it. By the middle of the third day (storm time 60 hours) the recovery of Dst(H) is only a few per cent for weak storms, and about 25 per cent for moderate storms. For our great storms the time for half recovery is about 45 hours. These remarks apply to middle and low latitudes. In higher latitudes the small magnitude of Dst and the greater irregularities in DS make such estimates difficult and doubtful.

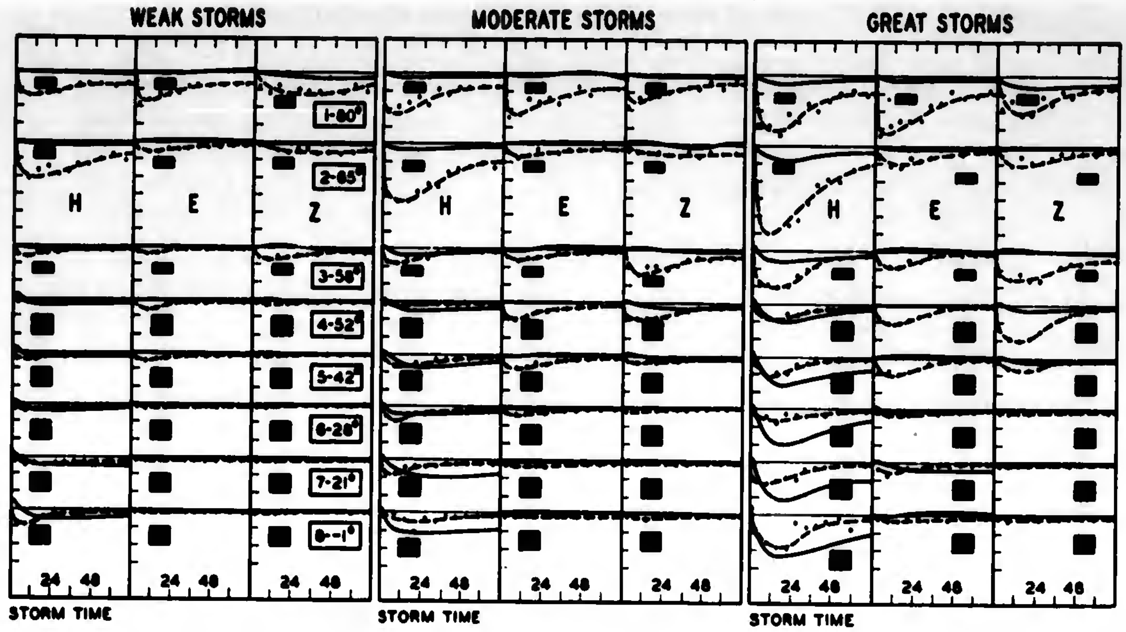


Figure 27. See § 15. Illustrating the different rates of evolution of Dst and of the range ($2c_1$) of DS_1 during the first three days of weak, moderate and great storms. Dst graphs are shown by full lines, and DS_1 by broken lines. For ease of comparison the ranges are plotted with negative sign. The force scale of the graphs for the three highest latitudes is contracted 2-fold. In all graphs the height of the black rectangles corresponds to 50 gammas and the width to 12 hours.

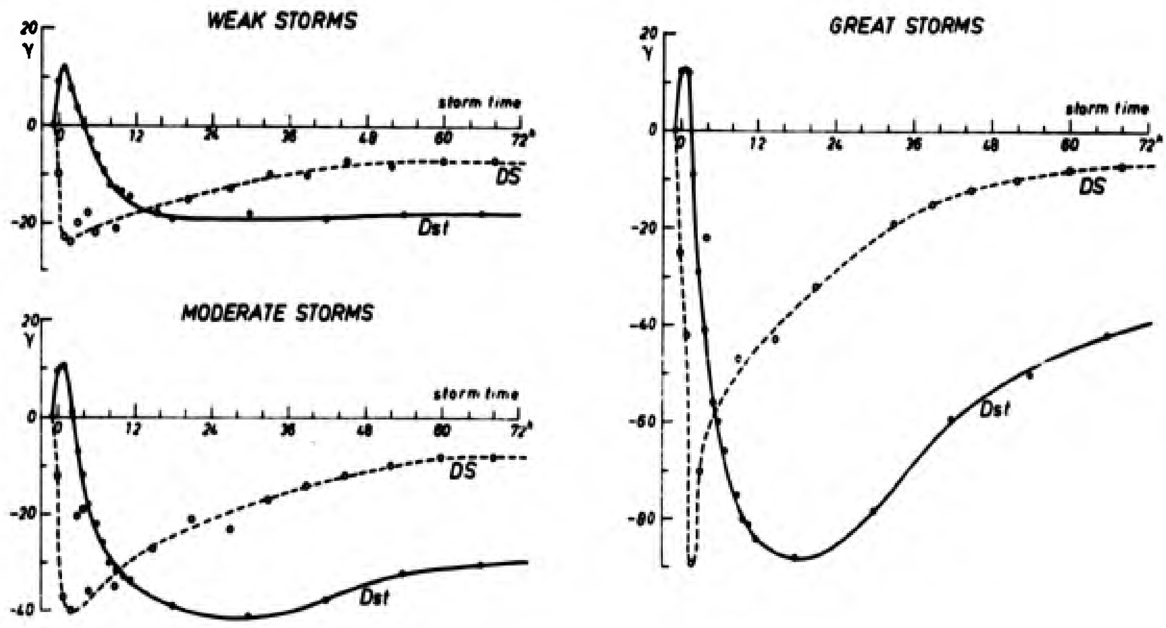


Figure 28. See § 15. A comparison of the rates of evolution of Dst(H) and the range ($2c_1$) of DS_1(H), during the first three days of weak, moderate and great storms: mean of groups 5, 6 and 7, mean gm latitude 30°. Dst curves are drawn with full lines, and those for DS with broken lines.

16. The storm variations near the geomagnetic equator

The Huancayo magnetic observatory was established in 1922, by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. This led to the surprising discovery that there Sq(H) is considerably enhanced. Subsequent investigations have shown that this enhancement is confined to a narrow belt of latitude, and that Huancayo is near the center of the belt. The existence of such an enhancement has since been demonstrated in other longitudes. The enhancement is ascribed to the presence of an eastward (equatorial) electrojet over Huancayo, during some of the daytime hours. Moreover Sqa(H), the augmentation of Sq(H) during solar flares, is enhanced like Sq(H). Later Bartels (1936) found that at Huancayo L(H), the lunar daily variation, is relatively even more enhanced than Sq(H). One of us (Chapman 1951) suggested that the D field does not share this enhancement. Our results confirm this suggestion as regards SD and the main phase of Dst. But several authors have independently shown that during its first phase the storm field is enhanced at Huancayo. Ferraro and Unthank in 1951, and later independently Sugiura in 1953, showed that the amplitudes of sudden storm commencements are enhanced at Huancayo during the hours of sunlight. Vestine in 1953 drew attention to a similar enhancement of Dst(H) during the first storm phase (cf. also Vestine and Forbush 1955).

Fig. 29 shows the mean amplitude (in H) of the Huancayo SCs of 180 storms (74 weak, 60 moderate, 46 great) for each of six 4-hour intervals of local time. It shows a maximum enhancement at or near noon.

Fig. 30, for Huancayo, shows the actual difference in the total storm variation, Dst + DS, between storms commencing during the hours of sunlight (6 h — 18 h) and those commencing during the hours of darkness (18 h—6 h). It shows such total variations for weak and moderate storms. In Fig. 30 the hourly mean point for 0 h is replaced by the mean amplitude of the SC. However, for comparison the combined day and night mean hourly value for 0 h is also shown, and is connected to the point for 1h by dotted lines. The daytime enhancement of the first phase is evident.

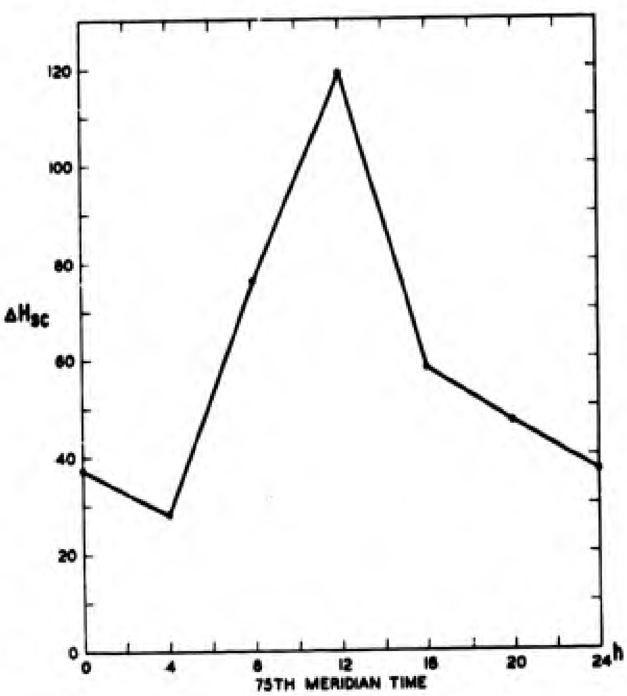


Figure 29. The mean amplitude (in H) of the Huancayo SCs of 180 storms (74 weak, 60 moderate, 46 great) for each of six 4-hour intervals of local time.

By definition Dst is the total field averaged over all longitudes around each latitude circle; the residual variation is DS. Hence if the enhancement of the total field, or part of it, is not uniform around the latitude circle, DS is necessarily influenced. Thus it is, in principle, not possible to speak of the abnormality in Dst and DS separately. However, the large irregularities at Huancayo make it difficult to determine the regular changes in DS. It is still uncertain whether or not DS at Huancayo differs systematically from that for adjacent low latitudes.

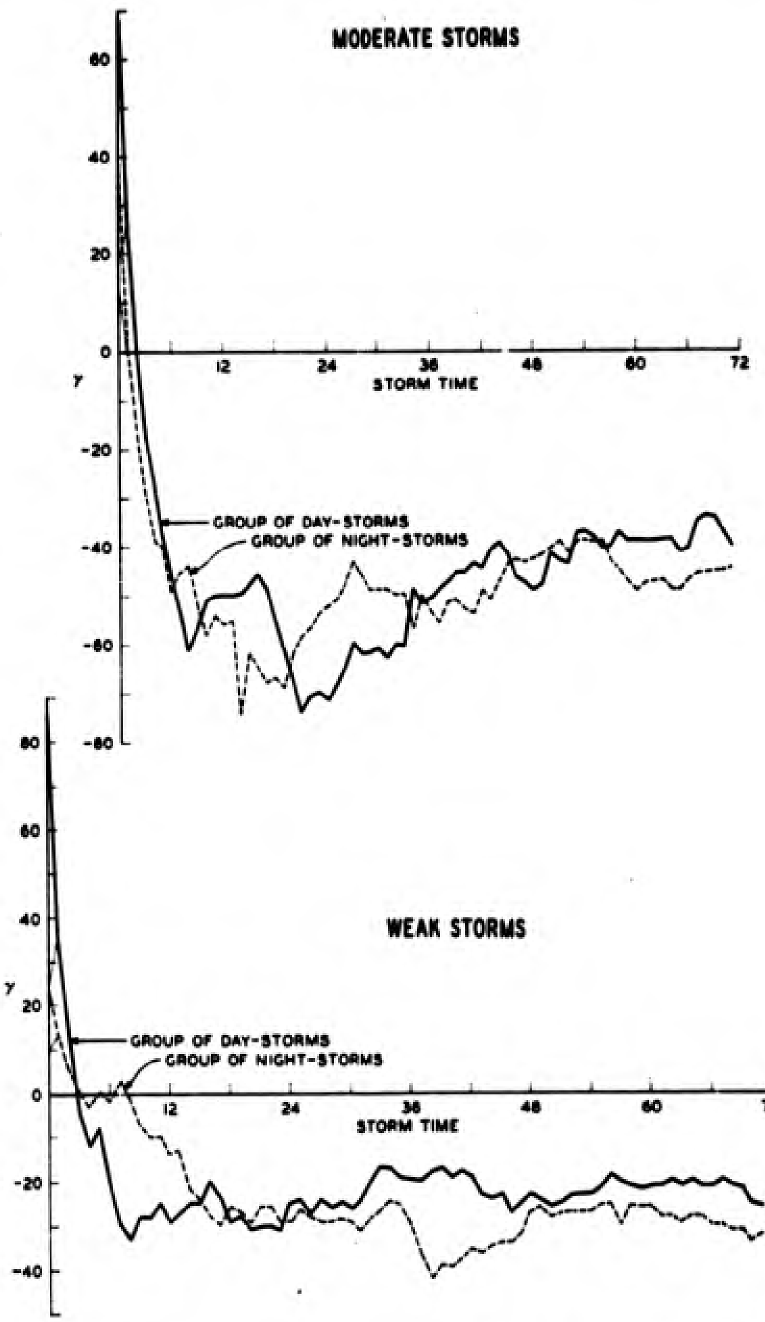


Figure 30. See § 16. Illustrating the daytime enhancement at Huancayo of the first phase of the storm field. The total storm variation, Dst + DS, during the first three days, is shown by full lines for storms commencing during the hours of sunlight (6h—18h), and by broken lines for those commencing during the hours of darkness (18 h—6 h). The lower Figure refers to 74 weak, and the upper one to 60 moderate storms. The mean hourly value for 0 h is replaced by the mean amplitude of the SCs of the storm in each set. For comparison the mean hourly value for 0 h is also shown, and is connected to the point for 1 h by dotted lines.

In contrast to the Huancayo abnormality in the variations Sq, L, SC and the first phase of magnetic storms, the disturbance daily variation, SD, and the daily mean, Dm, are normal (Chapman 1951). The nature of the irregular changes, Di, has not yet been investigated.

17. Conclusions

A new numerical intensity index was assigned to each of the 346 storms analyzed in this study. The index was based on the maximum decrease in H in the main phase, averaged over moderate and low latitudes (§ 4; the indices are listed in Table 1).

The variation Dst(Hgm) is first an increase, followed by a greater decrease, and later by a slow recovery towards normal (Fig. 5). The initial increase is greatest for the great storms; but there is little systematic difference between its values for the weak and moderate storms. The sudden commencement and the increase in the first phase are abnormally enhanced at Huancayo during the daytime (§ 16, Figs. 29, 30).

The SD variations are essentially the same in type throughout the three storm days and for all three storm intensities (Figs. 8—16). The Sq variation is greatest during the day hours, whereas in SD the variation at night is comparable with that by day. The focal latitude for Sq is between 42° and 28°; for SD it is near 52°.

The vectograms of SD for gm latitude 58° (Fig. 12) indicate that the north auroral zone draws southward as the storm intensity increases. The SD(H) graphs for great storms for gm latitude 52° (Fig. 8) indicate that the SD focal latitude moves slightly to the south of 52° during the first two days of great storms.

The harmonic dials of the 24-hour component of DS (Figs. 19—25) show systematic changes in both amplitude and phase; the main changes occur during the first half-day (§§ 13, 13.1). The DS_1 harmonic dials for the mean of six observatories between the north focal latitude and the equator, shown in Fig. 25, summarize the variation of DS_1 with storm time in these latitudes; the phase changes are essentially similar in all three elements, for all three intensities (§ 13.1).

The first harmonic coefficients of DS(H, E), combined for these six observatories (mean gm latitude 30°), were determined separately for each of the first six storm hours (§ 14). Fig. 26 shows a phase reversal, both in H and E, between the early storm hours and the later storm days.

DS_1 in these latitudes attains its maximum at about two hours from the storm commencement in all three intensities, but its rate of recovery is greater, the greater the storm intensity (Fig. 28). In Dst the epochs of both the maximum activity and the recovery phase become earlier with increasing storm intensity, but they are much delayed in comparison with DS_1 (§§ 9.1, 15; Figs. 5, 27, 28).

Though the material used in this work is extensive, the storm morphology derived from it for high latitudes is not enough to enable reliable current systems to be drawn for the polar regions.

18. Acknowledgements

The authors acknowledge the continuous interest and support of Dr. C. T. Elvey, the Director of the Geophysical Institute of the University of Alaska. The authors are indebted to Dr. M. A. Tuve, the Director of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, for his assistance in obtaining several necessary records. They are also indebted to the Director of the U.S. Coast and Geodetic Survey, to Professor J. Coulomb of the Institut de Physique du Globe, Paris, and to Sir H. Spencer Jones, formerly Astronomer Royal, for making unpublished data available to them. One of the authors (M. S.) was supported by the John Simon Guggenheim Memorial Foundation of New York while drafting this paper at the Cavendish Laboratory, Cambridge, England; he wishes to thank Dr. J. A. Ratcliffe and his colleagues for the hospitality extended to him during his stay there.

The laborious numerical work involved in this study was done by Marcia Green, Jeanne Hume, Sandra Fuller, and other computers; the diagrams were drawn by D. C. Wilder; to them the authors wish to express their appreciation, and also to Mr. H. Kurth, Göttingen, for his assistance in preparing some of the diagrams.

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	1958	ibid., 8, (2), 13—32

Table 8

Harmonic data for the first component of DS in H, E and Z, in the eleven intervals of storm time (§ 6.5), for weak, moderate and great storms. Intervals 1 to 8 refer to the first eight quarter-day intervals, and 9 to 11 to the succeeding three eight-hour intervals of storm time. DS is expressed as $\sum_n (a_n \cos n\lambda_s + b_n \sin n\lambda_s)$, where λ_s denotes local time, or longitude relative to the sun, measured eastward from the midnight meridian, and where a_n and b_n are expressed in gammas. For moderate and great storms (but not for weak storms) a correction for the difference between gm and standard local time (Table 2, column h) was applied in the analysis.

Int.	Weak Storms						Moderate Storms						Great Storms					
	H		E		Z		H		E		Z		H		E		Z	
	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1
Group 1 (80°). Godhavn																		
1	44.7	34.8	-26.3	91.8	30.0	30.9	85.3	69.3	-83.7	89.3	35.5	85.8	122.9	54.5	-138.4	102.3	0.1	98.4
2	65.8	-8.8	18.0	76.9	50.8	33.8	94.7	0.9	1.2	113.8	63.2	-21.1	142.4	-11.7	-8.0	144.8	30.6	65.1
3	64.3	16.4	8.0	63.8	23.6	27.9	83.3	-12.3	-12.3	71.9	44.3	42.9	171.0	-7.0	-18.1	121.4	54.0	94.6
4	47.2	-27.9	23.7	61.4	52.5	38.8	69.3	-14.8	6.6	76.2	47.1	38.6	99.2	-35.5	-3.3	127.6	75.3	74.8
5	55.5	-11.3	15.7	60.9	49.1	11.2	92.2	10.2	0.1	68.0	38.7	30.9	126.3	-12.3	-28.8	125.2	37.4	40.3
6	46.5	-9.5	8.0	46.3	49.1	16.8	45.8	5.7	-11.0	82.1	31.5	24.1	78.8	-23.9	18.3	83.0	58.0	48.8
7	29.8	-18.3	6.8	38.5	50.4	20.3	52.3	14.3	6.0	55.5	30.5	16.9	98.0	8.4	-0.8	79.2	28.6	33.7
8	30.6	-11.1	6.8	38.3	5.6	9.3	39.8	-1.5	-15.6	29.8	19.3	35.5	65.0	-26.1	-5.2	45.8	43.2	31.1
9	26.4	-15.2	2.9	37.4	35.6	42.5	37.6	4.5	-7.7	54.0	9.8	15.8	45.7	18.8	-13.9	61.2	26.9	13.0
10	38.3	-6.0	-3.3	36.8	22.0	22.2	37.7	-4.5	1.9	41.1	30.9	32.3	36.9	-1.3	-16.8	49.2	33.8	24.6
11	28.8	-6.7	-7.6	36.3	45.6	26.3	35.8	22.4	-8.3	41.4	21.2	7.1	51.0	17.3	-7.2	39.8	33.0	46.8
Group 2 (65°). Sodankylä, Tromsö, Lerwick																		
1	-44.1	-57.1	0.4	22.2	1.1	0.9	52.9	-127.3	-12.8	18.4	-10.7	-12.4	59.7	-137.3	-27.1	13.2	21.5	-3.4
2	-81.8	-62.3	23.0	24.5	1.4	-6.7	-71.8	-149.0	14.0	37.8	12.7	5.3	-81.4	-240.3	-12.5	51.8	-7.6	54.3
3	-62.2	-52.2	16.8	18.9	-12.8	-18.9	-61.8	-153.8	15.3	27.4	-17.2	-14.7	-47.3	-175.9	-4.8	64.1	-17.3	22.9
4	-67.9	-27.8	16.6	7.5	-19.5	-18.9	-88.7	-98.6	8.3	17.1	-15.3	4.0	-68.0	-220.9	-17.6	29.5	-30.8	34.8
5	-69.4	-57.6	15.1	13.6	-9.4	-6.4	-61.9	-104.1	13.7	20.6	30.9	2.3	-107.0	-191.3	-0.3	44.6	32.7	33.9
6	-76.3	-23.5	19.4	6.5	-9.3	-13.8	-87.3	-88.5	20.7	16.3	8.3	-24.5	-116.0	-111.2	8.8	27.2	-14.1	-27.8
7	-47.9	-39.2	6.8	16.0	-19.2	-25.8	-43.5	-66.9	5.9	14.9	-0.4	-16.0	-63.9	-85.9	0.8	9.5	-16.1	6.1
8	-58.0	-22.1	14.3	1.5	-23.3	-13.6	-43.4	-58.7	14.5	5.2	-15.1	-27.9	-26.0	-89.3	-15.3	19.2	-12.8	17.1
9	-41.7	-27.1	9.9	2.3	-26.0	-9.9	-43.3	-47.8	9.8	6.8	-5.0	-16.3	-64.9	-78.5	11.2	22.3	-0.6	-15.2
10	-28.8	-17.1	6.9	5.6	-19.9	-11.4	-21.6	-49.7	-1.3	-0.7	-17.2	-14.7	-36.7	-58.8	4.9	8.9	-2.8	-24.7
11	-36.2	-38.1	6.6	6.4	-15.4	-13.4	-36.5	-64.8	12.4	9.1	-10.8	-19.2	-13.0	-53.7	4.4	16.0	-16.3	-12.1

Table 8 (continued)

Int.	Weak Storms						Moderate Storms						Great Storms					
	H		E		Z		H		E		Z		H		E		Z	
	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1
Group 3 (58°). Sitka, Eskdalemuir, Lovö, Rude Skov																		
1	6.6	—20.6	1.1	16.5	13.8	—29.4	16.2	—34.9	1.7	22.3	19.9	—41.8	32.6	—94.8	—15.8	24.2	12.8	—65.6
2	—9.6	—20.4	18.8	8.1	— 7.8	—34.5	—31.3	—37.7	27.1	16.9	—29.3	—63.3	—42.0	—84.2	23.7	40.5	—36.3	—65.6
3	—0.1	—13.1	14.7	4.1	— 4.5	—25.3	—15.5	—23.9	21.7	3.8	—19.7	—44.2	—47.3	—87.0	33.0	19.7	—26.6	—55.5
4	—4.9	—15.3	8.6	0.0	—12.7	—29.7	—27.7	—26.8	16.4	— 1.3	—24.6	—41.0	—56.8	—86.0	22.0	14.4	—30.0	—74.3
5	—3.2	—13.6	6.0	— 1.4	— 9.9	—20.2	—18.5	—27.8	15.8	5.8	—24.1	—45.7	—54.5	—45.3	24.8	8.0	—51.7	—62.3
6	—4.3	— 6.1	4.7	1.0	—13.3	—18.4	—20.7	—19.8	9.4	2.1	—29.0	—27.9	—36.1	—36.3	13.5	2.1	—45.3	—30.5
7	0.7	— 6.6	6.1	1.0	— 4.5	—19.5	—12.7	—12.1	10.0	— 3.3	—19.3	—16.9	—38.3	—19.7	6.2	— 1.0	—26.8	—27.8
8	—1.8	— 7.5	4.8	— 1.0	— 8.8	—16.9	— 5.6	— 6.4	5.8	— 3.1	— 7.5	—21.2	—16.8	—13.5	— 1.9	1.3	—18.3	—22.8
9	—0.1	— 5.0	6.2	0.1	— 4.9	—15.7	— 8.3	— 7.6	5.5	— 2.2	—14.9	—19.8	— 7.9	—20.4	9.9	0.1	—18.4	—21.4
10	—2.4	— 4.9	4.4	— 1.2	— 5.7	—12.6	— 1.9	— 6.2	1.6	— 2.8	— 9.1	—15.0	—11.7	— 3.9	2.3	— 3.9	—15.7	—20.6
11	2.4	— 3.3	2.5	— 0.3	— 1.4	—15.3	— 4.6	— 7.7	4.4	— 2.3	—10.6	—17.3	— 3.2	—11.9	3.4	— 1.3	—10.5	—18.3
Group 4 (52°). De Bilt, Greenwich, Cheltenham, Val Joyeux																		
1	—4.1	—1.8	5.9	9.2	6.1	— 5.8	0.7	0.0	3.2	15.8	14.3	— 9.8	2.7	—11.5	2.7	18.8	20.6	—29.8
2	—1.9	3.5	14.0	2.7	1.4	—12.9	—2.3	4.6	24.3	6.6	1.8	—22.9	—11.1	—11.3	25.0	17.7	5.1	—48.5
3	1.5	4.6	10.3	—0.9	—2.0	—10.2	—0.5	5.2	18.1	— 2.3	1.9	—21.7	—20.3	— 0.9	31.2	— 1.6	—10.3	—50.8
4	2.8	—1.5	8.3	—3.1	—1.3	— 9.8	1.0	3.0	7.8	— 1.6	—0.6	—20.2	2.6	2.1	19.0	— 8.0	—17.7	—45.3
5	1.9	1.0	3.0	—2.3	—2.4	— 7.6	0.6	0.8	13.3	1.2	—1.9	—19.0	5.2	—12.8	15.2	— 3.9	—15.5	—33.4
6	2.0	0.5	3.5	—1.5	—1.9	— 5.3	0.2	—0.3	10.3	— 0.9	—2.2	—12.5	3.5	— 6.2	12.8	9.3	—13.9	—21.2
7	0.4	1.0	5.4	—0.1	—0.5	— 5.9	0.8	0.4	8.8	— 4.1	—2.5	—11.5	2.8	— 5.4	1.0	— 7.3	—10.7	—13.6
8	1.8	0.4	3.2	—4.0	—1.6	— 4.2	0.8	3.8	5.8	— 2.6	0.8	— 8.9	5.3	— 3.8	0.0	— 1.9	— 3.7	—10.8
9	1.0	0.8	3.6	—2.9	—1.2	— 3.8	3.5	—0.3	3.2	— 3.3	—2.6	— 7.4	3.5	3.7	5.5	— 2.3	— 5.9	— 9.8
10	0.9	—0.3	1.8	—2.0	—1.3	— 3.6	1.2	—1.3	3.6	— 3.2	—1.1	— 5.8	0.6	— 1.0	1.0	— 1.5	— 4.5	— 5.4
11	1.2	0.5	3.5	—0.6	—0.6	— 4.3	0.9	0.8	3.4	— 2.8	—1.0	— 5.6	1.6	— 0.1	2.4	— 3.4	— 1.4	— 4.9
Group 5 (42°). Ebro, Tucson.																		
1	—8.7	5.8	2.6	7.6	3.9	1.1	—6.1	3.5	— 0.1	14.3	6.3	1.4	— 8.3	— 5.6	8.8	19.6	9.7	— 1.8
2	—4.1	9.5	9.3	4.2	4.4	—3.8	—7.8	15.4	16.3	3.8	5.8	—6.8	—12.7	27.3	18.3	7.8	10.4	—12.8
3	0.4	10.1	6.7	2.8	2.1	—2.4	—1.9	15.3	16.0	2.1	4.8	—5.4	— 2.0	21.8	25.2	1.4	9.1	—12.5
4	2.7	5.7	7.0	—1.1	1.8	—4.3	1.2	12.0	9.4	—3.3	3.5	—7.3	11.4	19.6	17.2	— 6.8	5.7	—16.8
5	0.6	5.4	2.7	—2.5	0.2	—3.9	1.6	14.8	12.3	0.0	4.2	—6.5	3.3	11.3	13.8	— 6.6	1.5	—12.7
6	1.5	5.9	3.0	—0.3	0.2	—2.5	3.2	7.2	8.3	—4.0	2.9	—7.9	5.3	7.8	7.0	— 7.8	1.1	— 7.9
7	1.6	5.8	4.3	—0.7	1.1	—1.5	—1.3	8.1	8.1	—2.3	0.8	—5.2	4.1	2.8	3.7	— 7.0	— 2.2	— 7.0
8	1.5	2.2	2.5	—3.4	0.2	—2.7	—0.8	6.0	6.9	—1.9	1.7	—2.9	4.1	1.8	0.1	— 3.8	0.3	— 3.4
9	1.9	3.8	3.4	—1.7	0.1	—2.6	2.7	5.3	2.8	—3.6	0.2	—3.7	3.3	4.2	5.3	— 2.3	1.6	— 4.2
10	1.2	3.5	2.1	—2.6	0.0	—2.2	1.1	2.6	3.3	—3.6	—0.3	—3.3	2.2	4.1	1.0	— 2.7	— 0.3	— 2.3
11	0.1	3.6	3.8	—0.2	1.4	—1.2	0.9	4.1	2.5	—1.6	—0.3	—1.8	1.3	2.5	2.6	— 2.8	0.6	— 3.2

Table 8 (continued)

Int.	Weak Storms						Moderate Storms						Great Storms					
	H		E		Z		H		E		Z		H		E		Z	
	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1
Group 6 (28°). San Juan, Kakioka																		
1	-6.7	-0.2	-0.1	4.8	2.2	1.1	-12.1	2.3	0.8	7.3	0.8	2.1	3.8	8.0	0.0	3.3	3.8	-2.6
2	-2.4	10.5	5.1	2.8	3.1	0.3	-10.5	12.5	10.0	1.0	3.1	1.7	-7.3	5.7	8.3	2.5	1.5	-4.8
3	-2.4	6.3	4.4	1.3	1.5	-1.1	-4.2	12.8	5.1	-1.5	1.9	-1.3	5.8	16.8	0.9	2.7	0.6	-5.8
4	-1.5	5.8	3.7	-0.5	0.9	-0.2	-0.1	9.3	1.7	-1.5	1.2	-0.2	-2.7	3.6	7.4	0.7	-2.6	-2.2
5	-2.9	5.6	2.3	0.3	1.3	0.9	-0.6	8.1	8.3	0.0	0.6	-0.3	-0.1	6.8	3.4	7.1	-1.0	-4.7
6	0.3	3.9	2.1	-0.8	1.4	0.3	-0.6	7.6	1.8	-4.0	1.9	0.1	5.9	5.7	3.9	-3.4	-0.5	-1.3
7	-2.7	2.2	2.5	-0.8	0.8	-0.3	0.3	8.2	2.5	0.5	1.6	0.8	7.4	2.7	2.2	-5.4	0.5	-1.9
8	0.7	2.0	2.0	-0.5	0.7	-0.9	0.1	5.8	2.2	-0.3	1.0	-0.8	5.2	3.5	0.0	-2.0	-1.3	-1.8
9	-1.6	3.4	-0.1	-0.9	-0.2	1.3	2.3	3.5	1.6	-0.9	1.4	-1.0	3.0	0.4	-0.6	-2.6	-1.4	-0.6
10	1.1	2.5	0.8	-1.3	1.0	0.2	2.3	3.4	0.8	-1.7	0.3	-0.3	0.5	1.2	0.9	-2.3	0.4	-0.6
11	0.6	2.3	1.5	-0.2	0.4	0.3	2.2	1.3	1.1	-0.7	-0.1	-0.8	2.8	2.3	-0.4	0.3	0.5	-0.8
Group 7 (21°). Honolulu, Zikawei																		
1	-5.7	5.1	2.3	4.7	1.4	0.9	-15.9	3.7	-0.5	6.6	2.2	-0.3	-25.0	4.4	-4.3	6.4	4.3	2.3
2	-1.9	9.9	3.7	1.1	-0.2	-0.6	-4.6	18.9	8.5	4.1	1.8	0.7	-7.3	30.6	13.6	11.2	4.0	-1.9
3	-2.2	9.4	3.1	0.8	0.7	0.6	-3.2	11.1	6.2	-0.3	0.9	-1.0	-0.4	25.5	9.0	0.1	1.9	-3.0
4	1.4	10.4	2.9	0.3	-0.1	-1.0	2.4	10.3	4.5	-1.7	1.3	-0.2	-1.0	20.3	8.3	2.0	2.4	-1.1
5	2.7	6.7	2.9	-0.5	-0.8	0.6	-1.0	11.3	7.2	-1.3	0.4	-2.7	6.5	24.2	9.8	-3.1	1.2	-2.8
6	0.9	5.5	0.5	-1.5	0.5	-1.0	3.2	9.7	4.4	-2.4	-0.7	-2.0	4.5	9.9	4.9	-5.0	0.3	-2.1
7	0.6	5.6	2.5	0.4	0.4	-0.5	3.1	8.1	2.5	-2.9	-1.3	-0.7	3.0	8.5	2.7	-4.8	1.3	-0.8
8	2.3	5.3	2.4	-1.4	0.4	0.4	1.3	5.2	1.5	0.4	0.1	0.8	6.6	2.9	2.7	-0.8	1.3	-0.5
9	0.2	4.6	1.3	-1.6	-0.2	-0.6	2.6	4.8	3.0	-1.7	0.5	-1.2	2.3	6.2	3.9	-2.8	0.3	-1.8
10	1.3	4.4	0.7	-1.6	0.5	-0.9	2.1	4.4	1.4	-1.4	-0.2	-0.7	4.3	3.4	1.8	-0.6	0.0	-1.7
11	2.0	4.7	1.6	-0.1	-0.9	0.3	2,1	4.3	1.9	-0.3	0.3	-0.8	1.8	4.1	1.4	-0.5	1.2	0.5
Group 8 (-1°). Huancayo																		
1	-16.7	-2.5	1.4	-0.3	-1.0	3.7	-9.7	-2.2	-3.5	-3.6	-2.3	0.3	-15.5	6.2	1.0	-4.6	-2.6	-1.3
2	-15.1	14.7	-1.2	-1.8	1.1	0.0	-3.3	0.8	2.1	-3.0	-3.0	2.7	-35.2	13.3	-7.6	-1.8	-2.6	5.7
3	-4.9	15.0	-4.5	0.7	2.9	3.6	2.0	12.0	-3.2	-1.8	0.0	6.1	4.1	40.5	-8.0	-0.1	1.5	3.8
4	7.9	5.3	1.6	1.8	1.4	-0.2	17.3	21.4	-3.4	-0.6	1.5	-1.3	26.9	39.5	-1.4	3.8	-2.9	2.9
5	4.2	0.8	-1.6	0.5	-0.1	3.9	3.2	7.6	-0.8	-2.0	-1.1	2.8	7.8	5.8	-1.9	0.3	0.3	4.5
6	2.8	-0.3	-1.8	-0.1	1.3	0.5	7.0	9.8	-2.5	-1.7	-1.5	1.4	14.0	6.3	-8.8	-1.2	-3.9	1.8
7	3.3	8.1	-0.9	1.7	1.1	2.9	-1.3	4.1	-1.7	-0.7	-2.1	2.2	7.7	11.1	-1.6	4.1	0.1	5.1
8	3.9	5.4	0.7	0.2	0.1	-1.7	6.3	3.2	-2.5	-1.3	-1.8	2.3	6.0	4.9	-6.8	-1.8	-0.1	3.4
9	1.6	1.8	0.0	-0.8	-0.4	2.5	-1.8	0.6	-2.5	-1.3	-0.2	1.3	-2.2	3.7	-2.8	0.5	4.4	3.0
10	-1.1	0.8	-2.7	-1.2	0.3	1.9	-2.3	4.7	-2.4	0.1	-0.1	-0.5	-7.3	14.6	-2.3	1.8	3.3	0.0
11	-3.6	2.3	-0.5	1.6	1.2	0.7	1.7	1.4	2.1	-1.8	-1.6	0.9	0.3	0.3	-2.4	0.4	1.1	2.8

Table 8 (continued)

Int.	Weak Storms						Moderate Storms						Great Storms					
	H		E		Z		H		E		Z		H		E		Z	
	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1	a_1	b_1
Group 9 (—17°). Rio de Janeiro, Apia, Batavia, Cape Town																		
1	—7.5	3.5	—1.0	—2.8	—3.5	0.6												
2	—2.4	8.1	—3.7	—2.2	—1.1	2.9												
3	—1.1	8.1	—4.6	—0.8	—0.1	3.6												
4	2.4	5.8	—1.9	2.0	1.9	0.8												
5	1.2	4.8	—2.0	1.1	—1.1	1.8												
6	2.3	2.1	—1.2	1.3	0.8	1.5												
7	—0.4	2.8	—1.6	0.0	0.1	1.4												
8	0.8	2.4	—1.4	1.1	1.0	1.4												
9	0.6	3.5	—1.3	—0.2	0.7	1.2												
10	2.1	2.4	—0.2	1.2	—0.3	0.3												
11	0.8	2.5	—0.3	—0.6	—0.2	0.4												
Group 10 (—46°). Watheroo, Toolangi, Christchurch																		
1	—0.4	0.0	— 2.2	—7.1	—4.4	0.8												
2	—0.8	8.1	— 8.5	—3.9	—6.3	5.4												
3	—5.2	4.7	—10.5	—2.1	—5.9	7.8												
4	0.2	9.1	— 4.7	0.8	—2.0	7.8												
5	2.4	2.6	— 8.9	—0.7	2.7	4.9												
6	—3.1	1.3	— 6.3	1.3	—2.5	5.2												
7	1.2	2.7	— 7.3	2.5	—1.2	6.2												
8	3.1	4.0	— 3.6	1.3	0.4	4.6												
9	0.9	2.9	— 4.8	0.3	—1.1	3.0												
10	0.8	0.3	— 5.3	1.6	—1.4	3.5												
11	0.6	3.4	— 3.7	2.2	—0.2	4.5												

The coefficients of the first four harmonic components of the combined SD for the 10 observatories of groups 4 to 7 are given in Table 7, p. 41, in the Final Report, Contract AF 19 (604)—2163, Geophysical Institute, College, Alaska, August 1958.