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Some Statistical Investigations of Geomagnetic Disturbances observed at Kakioka

By Yukio Yokouchi

概　要

柿岡にて観測された資料につき主として磁気擾乱における *Dst*, *SD*, 及 *Dm* についての統計調査を行つた。尚関連して統計された *Sq* 及 *Sd* についても述べた。

§ 1. Introduction

In the previous paper[1] the results of various statistical studies on the geomagnetic disturbances observed at Kakioka (36°14′N, 140°11′E) were reported for the period 1924–1951. Here, by the aid of the same material the following disturbances are calculated and investigated ; average storm-time variation (*Dst*) and disturbance daily variation (*SD*), from storm days in the period 1924–1951 for H, D and Z and also for H disturbance daily variation (*SD*) derived from diurnal variations of quiet days (*Sq*) and disturbed days (denoted here by *Sd*) and *Dm*, disturbed minus quiet days mean, in the period 1925–1951. Although the general aspect of the world-wide distributions of these variations have been studied by a number of writers, it seems yet to be needed to clearify the characteristics of these variations at any individual observatory as well as their changes in the long course of years. The present investigations are conducted for the purpose by using the data of more than twenty years long.

The data used are based on the annual reports of the Kakioka Magnetic Observatory[2] for the period 1924–1947 and the preliminary reports for the period 1948–1951. As the hourly values of quiet and disturbed days those of the international five quiet and five disturbed days are used respectively, but when there are missing records on some of these days the value of the other suitable days selected are substituted for them. The auther is much indebted to Dr. S. Imamiti's effort referring to the data for the quiet and disturbed days in 1925–1934.

§ 2. Progress of variations of the geomagnetic storms

In the previous paper, geomagnetic storms with sudden commencements (SC) are classified into the following three groups :

(a) : ordinary typical storm process is clearly seen, i. e. initial and main phases

are easily detectable on the records ;

(b) : the interval between the sudden commencement and the beginning of the main phases is longer than several hours regardless of activity of the interval ;

(c) : sudden commencements are followed by irregular variations of fairly long period, so that the beginning of the main and last phases are not easily detectable.

During 1924–1951, 398 SC–storms and 230 G-storms (storms with gradual commencement, each of which maximum range in H exceeds 70 γ) are observed, and the daily fre-

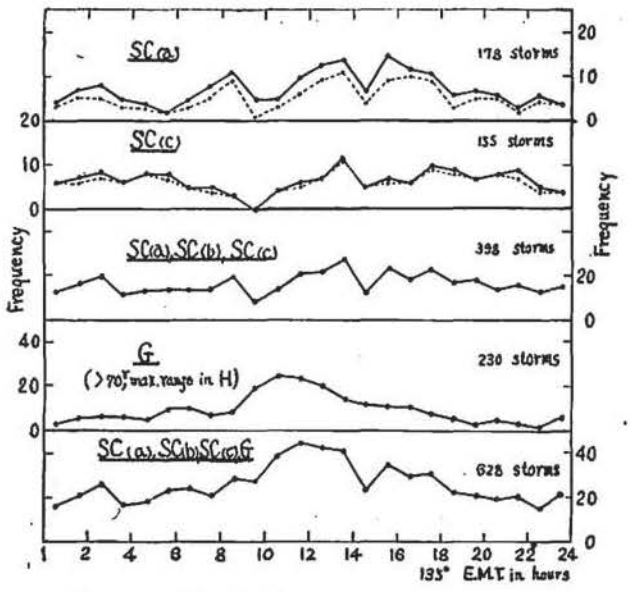

Fig. 1. Hourly frequency of occurrence of geomagnetic storms, 1924–1951, Kakioka.

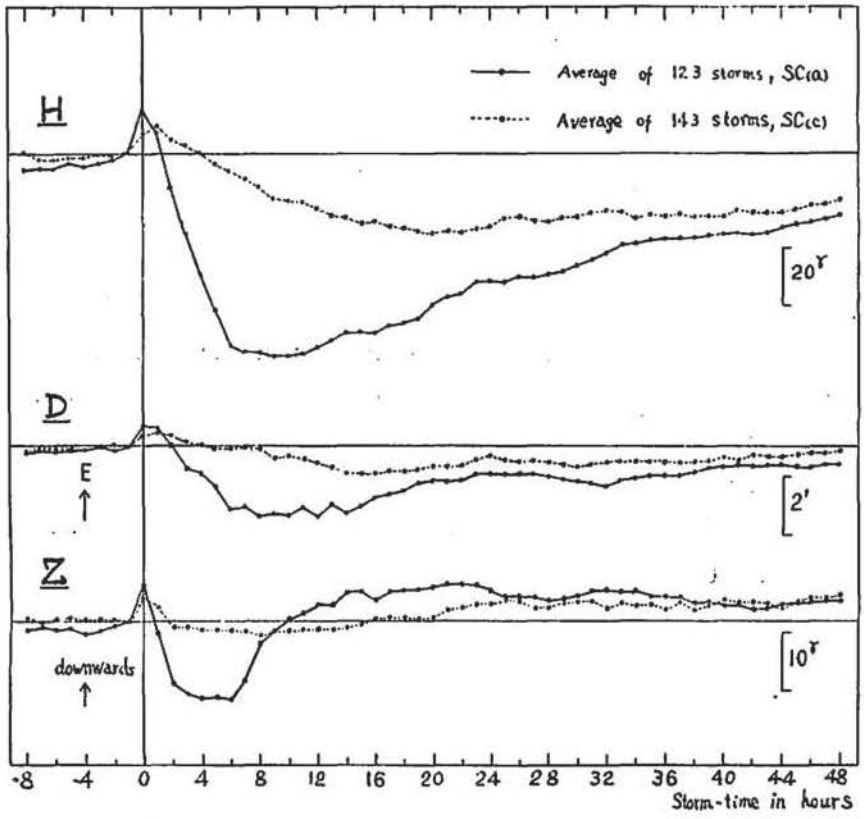

Fig. 2. Average storm-time variation (*Dst*), 1924–1951, Kakioka.

quencies of occurrence of each type of storms are shown in Fig. 1. The daily frequencies of occurrence of SC-storms were already described in the previous paper, and so it is remarked here that G-storms show the distinct diurnal change of occurrence with the maximum at about 11 h in local time.

In Fig. 2 and Table 1 are shown the two kinds of average storm-time variations (*Dst*) of H, D and Z for SC(a) group of 123 storms and SC (c) group of 143 storms, excluding the storms with missing records, those associating with other ones occurred in the first 48 hours after their commencements and also those with double main phases. The daily frequencies of occurrence of adopted storms are shown in Fig. 1 by the dotted lines. These *Dst*-curves are derived from the hourly values of storm days subtracted the quiet day mean variations of the corresponding months, respectively. All hourly values used are the momentary values, and then 0 h of *Dst* stands for the whole hour nearest to the time of sudden commencement. The ground levels given in Fig. 2 and Table 1 show the values at −1 h in storm-time, so the following values should be added to all values given in Fig. 2 and Table 1 when the levels are to be changed for 24 hours' mean values before commencements.

For SC(a) H : +4.2 γ,
D : +0.′15, Z : +1.6 γ
For SC(c) H : +0.7 γ,
D : −0.′05, Z : −0.6 γ

Referring to the distribution of magnitude of storms the frequencies spectrum for the maximum ranges of H-traces are shown in Fig. 3, of which means are 175 γ for SC(a) and 97 γ for SC(c), respectively.

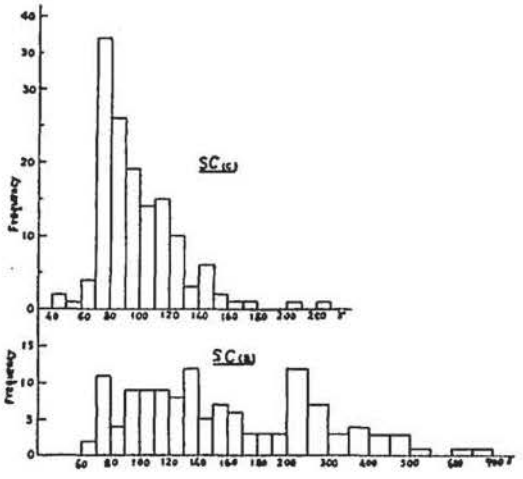

Fig. 3. Frequencies for specified successive intervals of maximum ranges of H of adopted storms, 1924-1951, Kakioka.

The first day's mean (storm-time 0–23 h) and the second day's mean (storm-time 24–47 h) after the commencement minus 24 hours' mean before the commencement of storm (*Dm*) are respectively given as follows.

SC(a)	first day	second day	SC(c)	first day	second day
H :	−47.2 γ	−26.6 γ		−14.4 γ	−19.6 γ
D :	−1.′28	−0.′72		−0.′41	−0.′49
Z :	+1.4 γ	+5.6 γ		−0.6 γ	+2.7 γ

D : positive if towards the East
Z : positive if vertically downwards

As for the value of *Dm* for H, the ratio of the second day to the first day

is 0.6 for SC(a) and 1.4 for SC(c), respectively. In this connection, the mean value of disturbed days minus quiet days for 1925–1951 is calculated as -25.3γ for H.

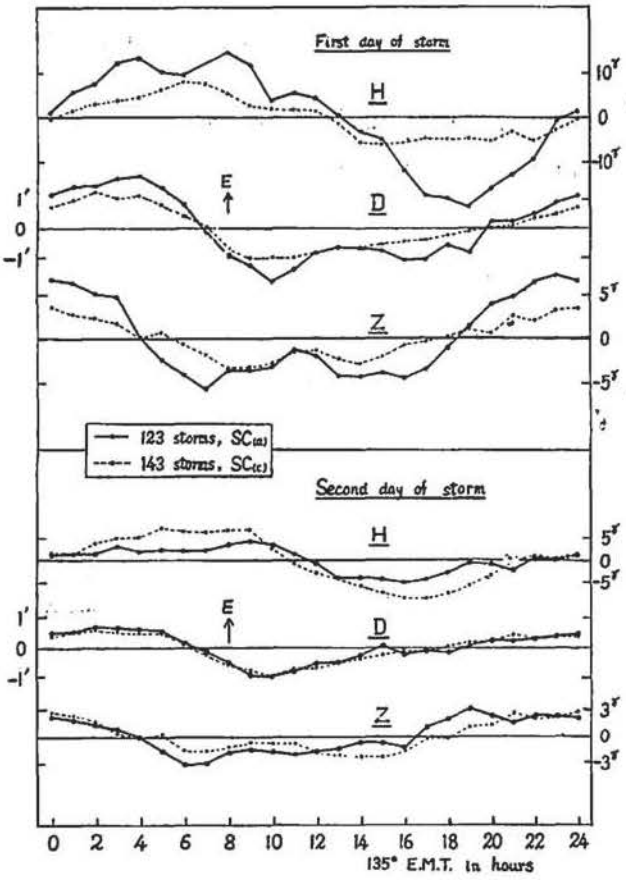

Fig. 4. Disturbance daily variation on storm day (*SD*), 1924–1951, Kakioka.

The mean disturbance daily variations (*SD*) for the 1st day and 2nd day derived from the series of *Dsts* arranged for each local time of occurrence, and shown in Fig. 4 and Table 2. Their harmonic amplitudes and phase angles are given in Table 3. The amplitude cn and phase angle θ_n of the Fourier series are given by $\Sigma c_n \sin(nt+\theta_n)$, where t is reckoned from the 135° E. M. midnight. As regards to the amplitude of *SD*-variation, there is seen a great decrease from the 1st day to the 2nd day for SC(a), but is not so for SC(c), that is, as for the value of harmonic amplitude c_1 for H the ratio of the 2nd day to the 1st day is 0.2 for SC(a) and 1.2 for SC(c), respectively.

It is noted here that the general character of the curve of *Dst* is in similar tendency for the two groups, SC(a) and SC(c), but the former shows a larger amplitude and an earlier process of changes than the latter. There is no fundamental difference between the *Dst*-variations obtained here and those recorded at several middle or low latitude stations so far as the H-trace is concerned. The D-trace has a similar tendency to the H-trace, though it should be considered that the difference between the direction of geomagnetic axis of north pole (ψ) and the declination (D) at Kakioka is about 12° or 13°, and so about 20% of variation of H-trace ought to take a role as D-trace. On the other hand, the Z-trace shows a particular change during the first several hours, which is quite different from that illustrated in the usual text book. Such a special type of Z-variation may be due to a special condition of the distribution of electrical conductivity in the earth's interior, such as suggested by T. Rikitake and others[3]. The difference between SC(a) and SC(c) in

regard to the general tendency of *Dst* and *SD* may correspond to the Chapman's result[4] regarding to that between 'Great' and 'Moderate' storms.

§ 3. Changes of monthly and annual means of *Dm*

The daily mean values of disturbed days as well as of all days, subtracted those of quiet days, (*Dm*), are shown respectively in Fig. 5 and Table 4 for each month. B. Cynk[5] has studied the seasonal change of *Dm* in detail from the world-wide data, and we have also from the present results at Kakioka a distinct seasonal change with two maxima in equinoxes and two minima in June and Dec.–Jan., annual mean of *Dm* being -26.5γ for disturbed days and -9.9γ for all days.

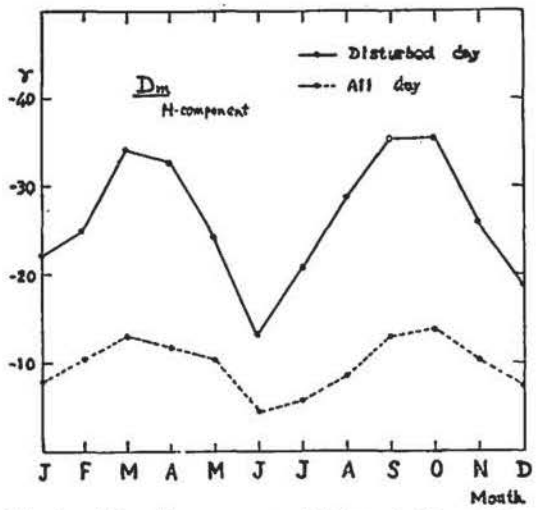

Fig. 5. Monthly means of *Dm* of H, 1925–1951, Kakioka.
Full line : disturbed day minus quiet day mean.
Dotted line : all day minus quiet day mean.

Annual values of *Dm* during 1925–1955 are shown in Fig. 6 and Table 5, and it will be seen from the figure that there is an obious correspondence between the variations of the relative sunspot number and *Dm*, though the degree of it is different for different sunspot cycles.

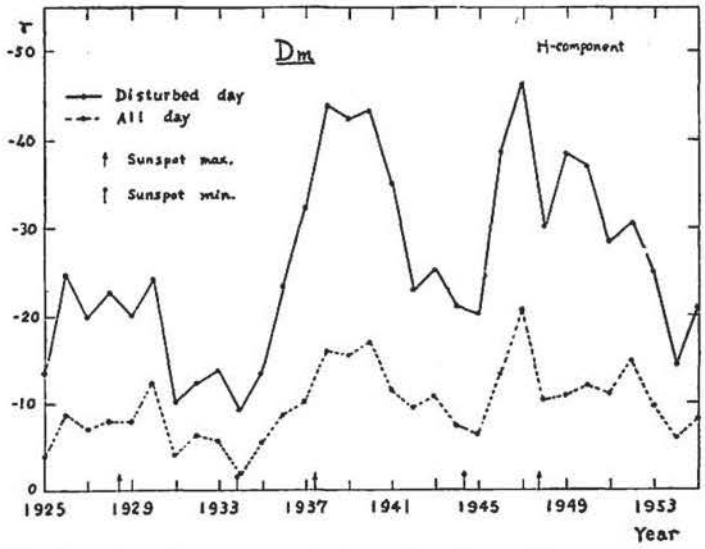

Fig. 6. Annual means of *Dm* in H, 1925–1955, Kakioka.
Full line : disturbed day minus quiet day mean.
Dotted line : all day minus quiet day mean.

§ 4. Seasonal change and year to year change of *SD* and *Sq* for H

Although we have a detailed description of *Sq* by S. Imamiti[6] and something about *Sq*, *Sd* and *SD* by T. Yumura[7] regarding the data at Kakioka, in the present paper their harmonic analysises for each month and each year in the period 1924–1951 are principally investigated for H-component.

Monthly and seasonal means of *Sq*, *Sd* and *SD*, and also the results of harmonic analysises for them are shown in Fig. 7–13 and Table 6–9. As regards to seasonal changes of harmonic amplitudes and phase angles of diurnal variations of

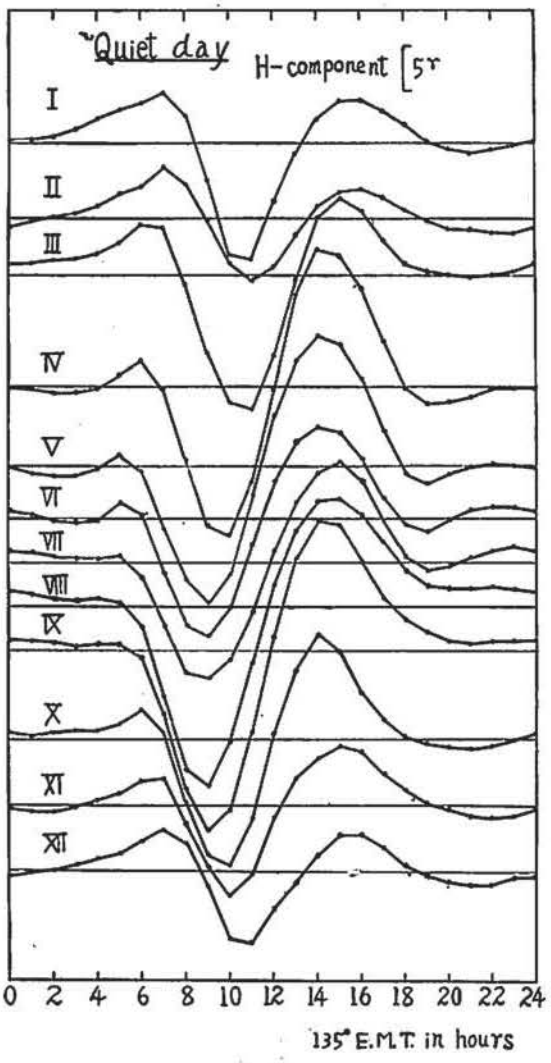

Fig. 7. Diurnal variation of geomagnetic horizontal intensity, quiet day, 1925–1951, Kakioka.

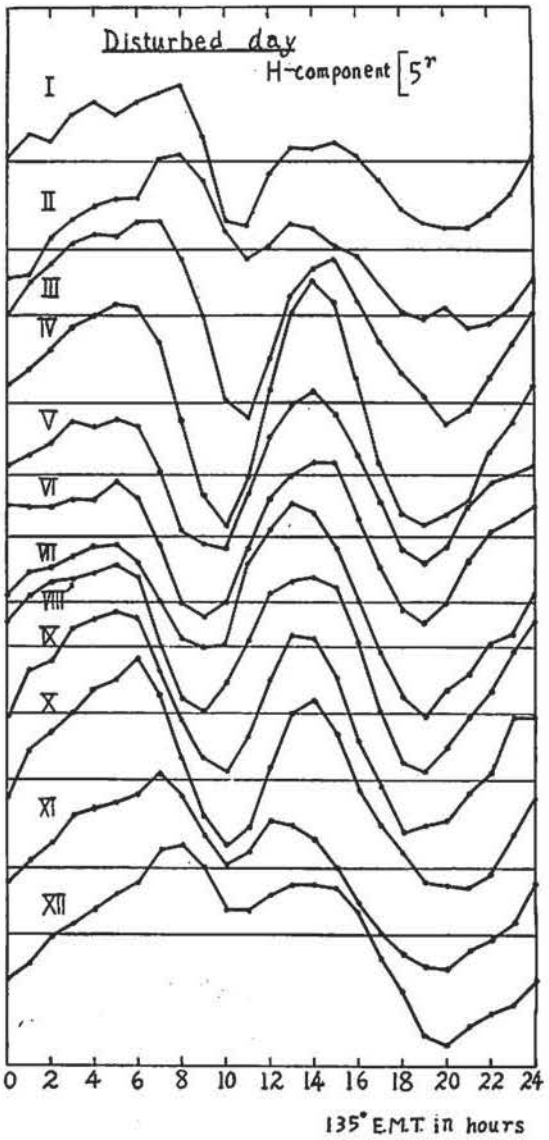

Fig. 8. Diurnal variation of geomagnetic horizontal intensity, disturbed day, 1925–1951, Kakioka.

H-component it is seen from the figures (Fig. 11–12) that : For c_1 of Sq, it is greater in summer and smaller in winter in general view, containing maximum value in August and minimum one in February, and θ_1 of Sq remains almost constant during April–November and smaller values during December–March. For c_2 and c_3 of Sq there are two maxima around April and September and predominant low values in winter, and for θ_2 and θ_3 of Sq there are greater in summer and smaller in winter, respectively. For c_1 of SD there is a predominant maximum in September and a secondary one in April and two minima in January and July. θ_1 of SD is greater in summer and smaller in winter, except the smaller value in July.

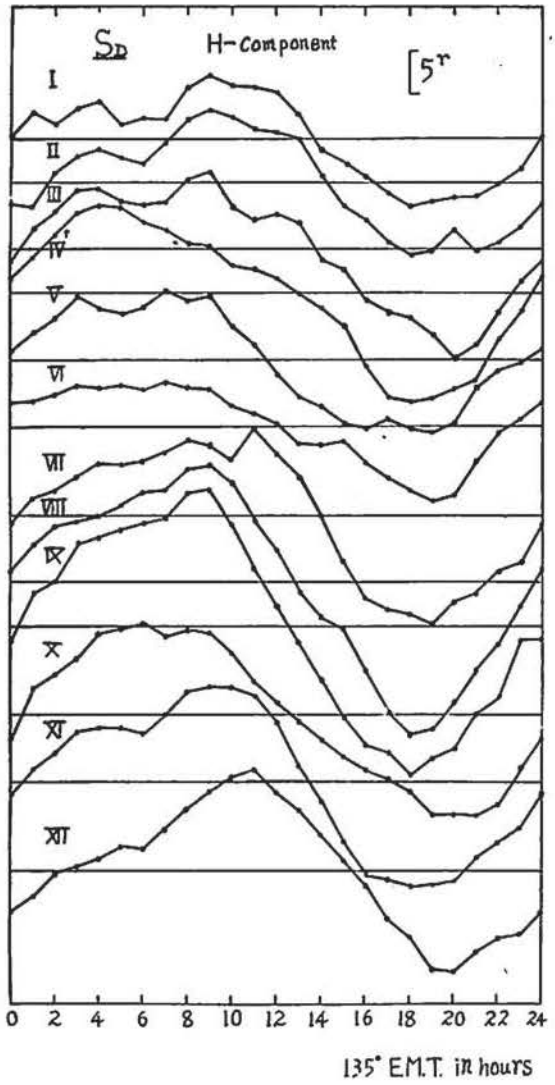

Fig. 9. SD-variation of geomagnetic horizontal intensity, disturbed day minus quiet day, 1925–1951, Kakioka.

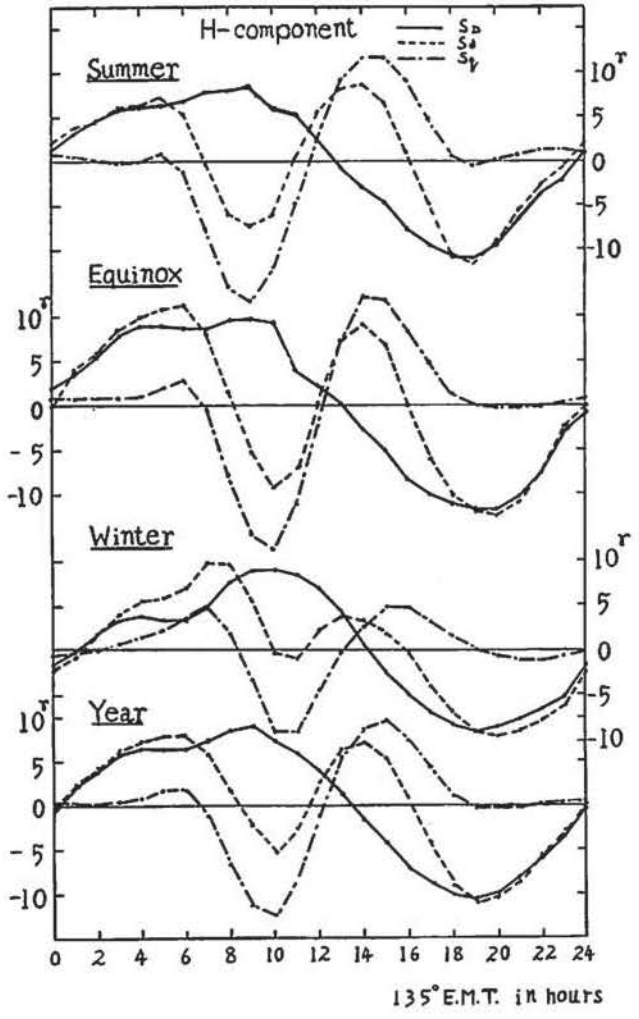

Fig. 10. Diurnal variation of geomagnetic horizontal intensity, quiet day, disturbed day, and disturbed day minus quiet day (SD) 1925–1951, Kakioka.

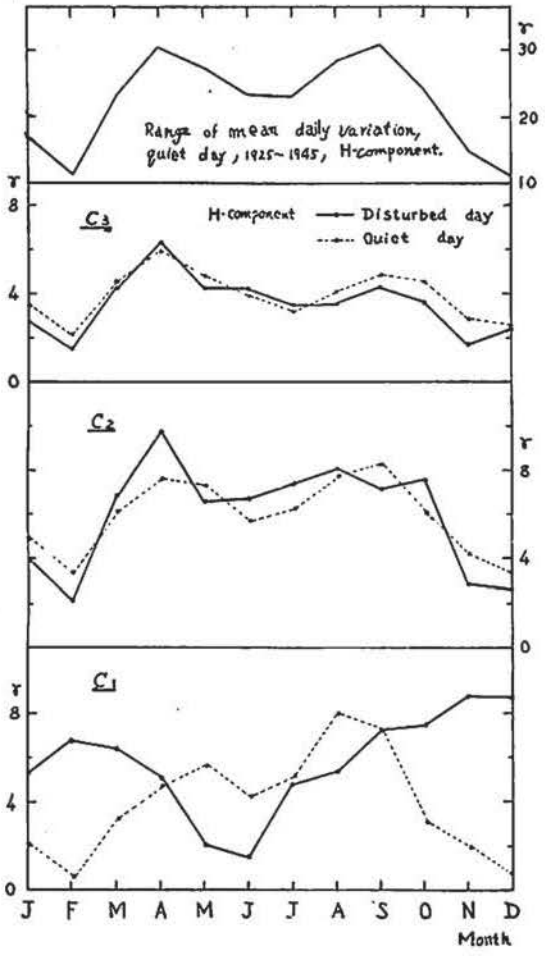

Fig. 11. Harmonic amplitudes c_1, c_2 and c_3 of diurnal variation of H, quiet and disturbed day, 1925–1951, Kakioka.

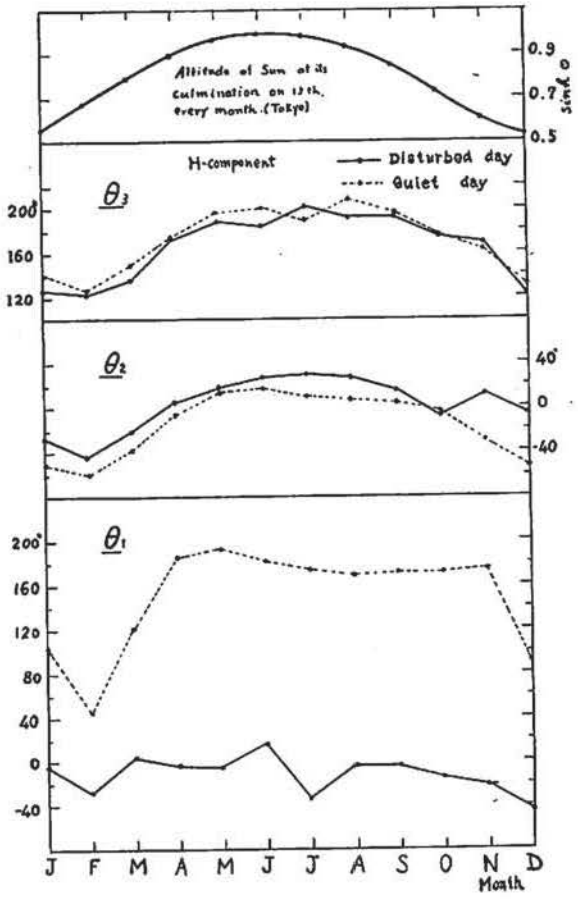

Fig. 12. Harmonic phase angles θ_1, θ_2 and θ_3 of diurnal variation of H, quiet day and disturbed day, 1925–1951, Kakioka.

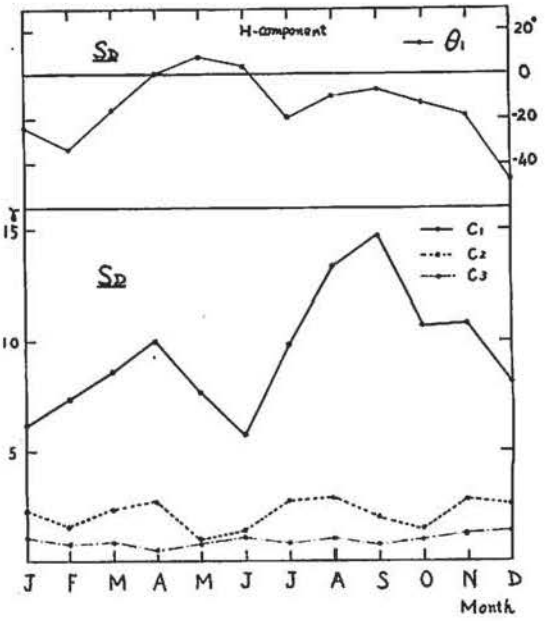

Fig. 13. Harmonic amplitudes c_1, c_2 and c_3 and phase angle θ_1 of SD-variation of H, disturbed day minus quiet day, 1925–1951, Kakioka.

The harmonic amplitudes and phase angles for the yearly mean diurnal variations *Sq*, *Sd* and *SD* are shown in Fig. 14–18 and given in Table 10–11. c_1, c_2 and c_3 of *Sq* all show almost a similar tendency of changes, which corresponds to that of the sunspot variation, though their magnitudes decrease slowly from year to year. θ_1, θ_2 and θ_3 of *Sq* all remain almost constant throughout period, if irregular fluctuations are ignored. c_1 of *SD* is fairly similar with that of solar variation for the period from 1925 to about 1934, but clearly not so from about 1935, increasing thereafter from year to year with some irregularities. The annual values of θ_1 of *SD* is about $-15°$, averaging some irregularities contained.

§ 5 Conclusion

The following facts are concluded from this investigation.

(1) The frequency of occurrence of G–storms shows a diurnal variation with the maximum around 11 h in local time.

(2) *Dst*–curve obtained for H–component shows a similar tendency of changes with the results of other middle or low latitude stations.

(3) *Dst*–curves of the declination shows a similar tendency of variation with H–trace, and it may be considered almost as the effect of D–ψ.

(4) *Dst*–curve of Z shows a particular change during the first several hours and it may be due to some special distribution of electrical conductivity within the earth's interior.

(5) The seasonal change of *Dm* has two maxima in equinoxes and two minima in June and Dec.–Jan.

(6) The year to year change of *Dm* corresponds to that of the solar variation, but the magnitude differs for each sunspot cycle.

(7) The seasonal change of c_1 of *SD* shows a predominant maximum in September and a secondary one in April and two minima in January and July.

(8) The year to year change

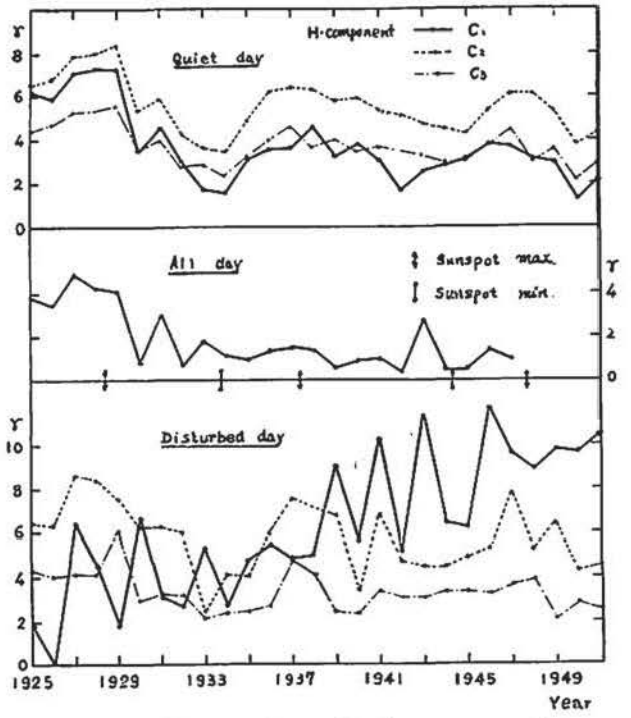

Fig. 14. Harmonic amplitudes c_1, c_2 and c_3 of diurnal variation of H, quiet day and disturbed day; 1925–1951, Kakioka.

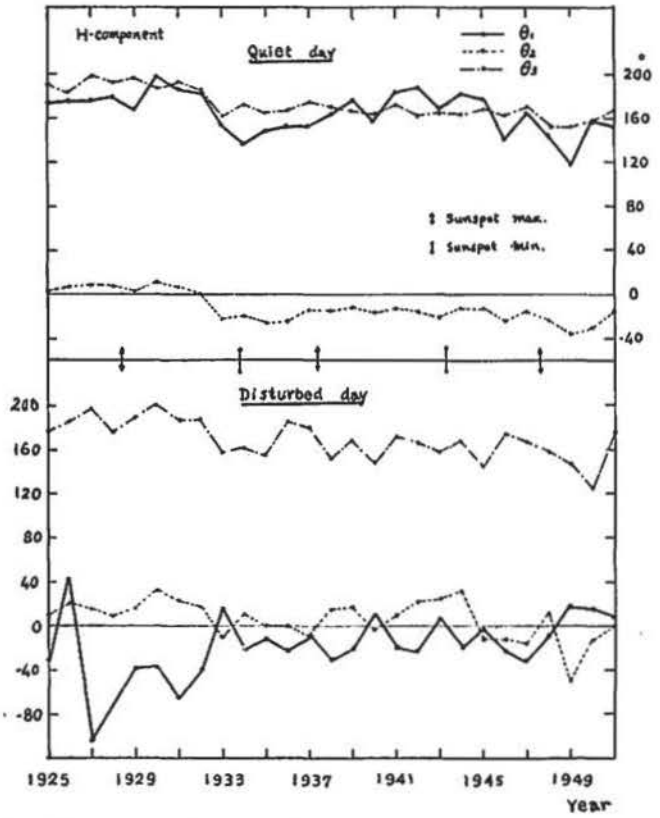

Fig. 15. Harmonic phase angles θ_1, θ_2 and θ_3 of diurnal variation of H, quiet day and disturbed day, 1925-1951, Kakioka.

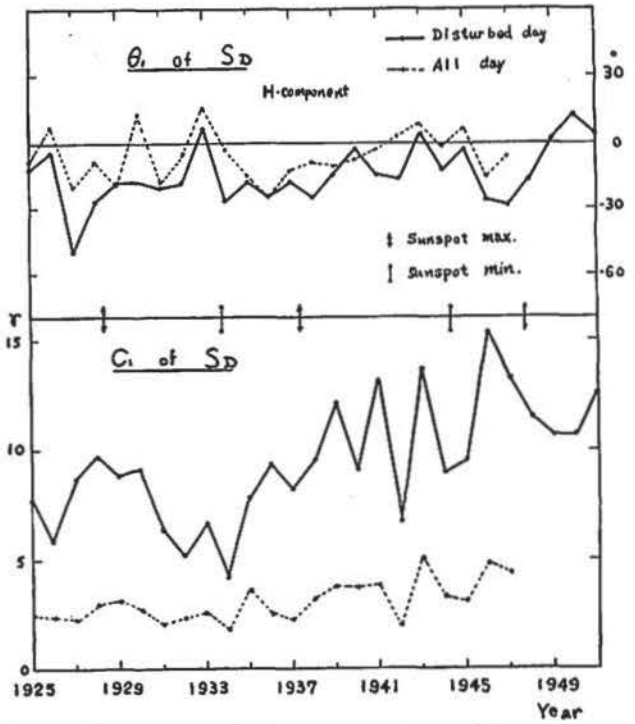

Fig. 16. Harmonic amplitude c_1 and phase angle θ_1 of *SD*-variation of H, disturbed day minus quiet day and all day minus quiet day, 1925-1951, Kakioka.

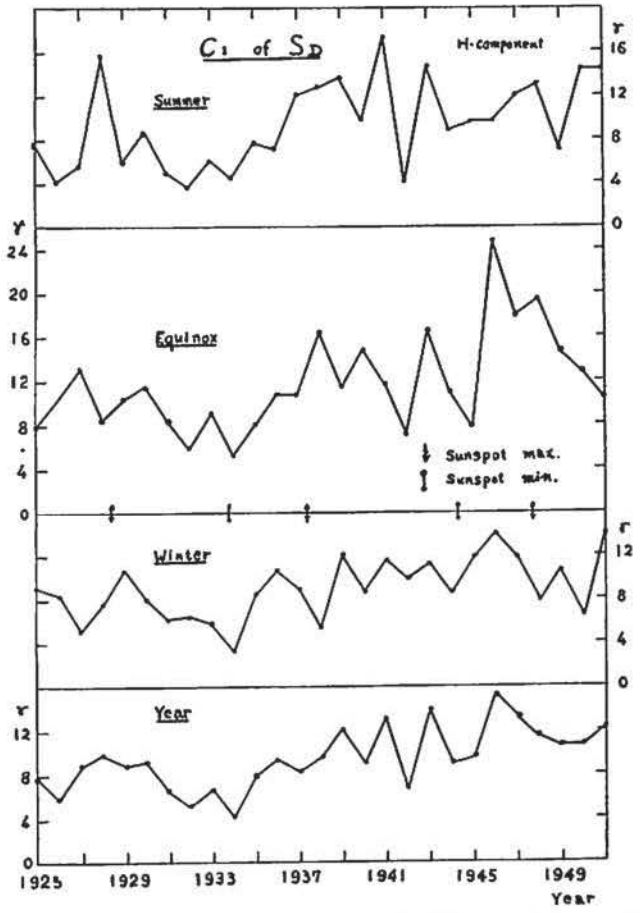

Fig. 17. Harmonic amplitude c_1 of SD-variation of H. disturbed day minus quiet day, 1925–1951, Kakioka.

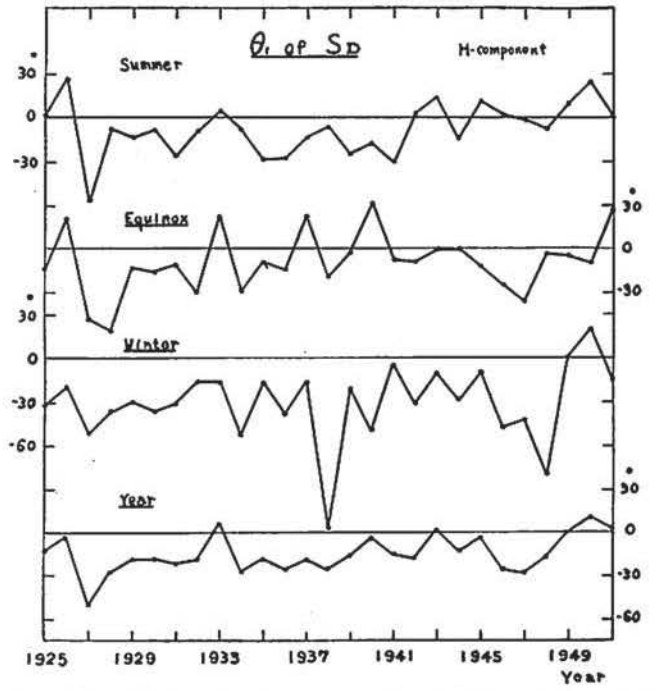

Fig. 18. Harmonic phase angle θ_1 of SD-variation of H, disturbed day minus quiet day, 1925–1951, Kakioka.

of c_1 of SD shows a similar tendency with that of the solar variation during 1925–1934, but does not so thereafer, increasing the magnitude from year to year with some irregularities.

Although we have various kinds of the changes of annual means for the geomagnetic data at Kakioka, their correspondencies to sunspot variations are different each other, and precise investigations of these changes will be remained as a feature task. The variations are shown in Fig. 19 in the benefit of inspection.

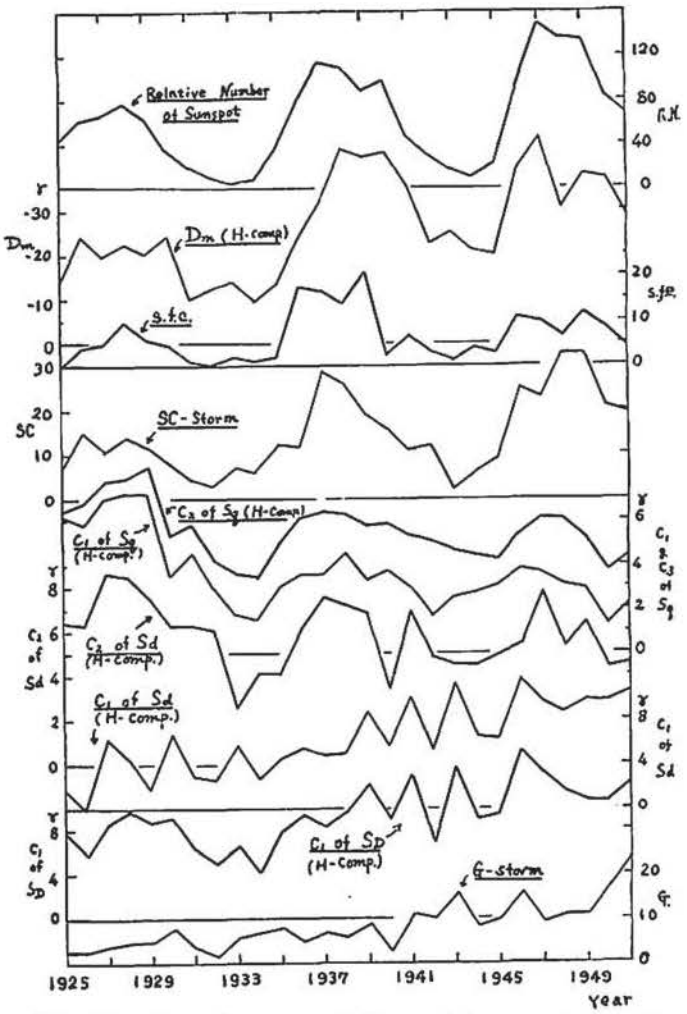

Fig. 19. Annual means of D_m and harmonic amplitude c_1 and c_2 of S_q, c_1 and c_2 of S_d, c_1 of SD, yearly sums of numbers of occurrences of s. f. e. and SC- and G-storms at Kakioka and annual means of relative number of sunspot.

Acknowledgement

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Table 1. Average storm-time variations of geomagnetic storms (*Dst*), 1924-1951, Kakioka.

123 storms for SC(a), 143 storms for SC(c)

unit : H : γ, D : ′, Z : γ

Storm-time		-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	H	0.0	15.1	7.6	-10.4	-26.7	-40.4	-52.9	-65.4	-67.6	-67.8	-69.2	-69.2	-68.4	-65.9	-63.6	-60.6	-60.2	-60.8	-58.5	-57.7	-55.9	-51.6	-48.9	-47.5	-43.3
SC (a)	D	0.00	0.74	0.66	0.07	-0.75	-0.86	-1.35	-2.12	-1.99	-2.33	-2.25	-2.28	-1.99	-2.37	-1.93	-2.21	-2.02	-1.69	-1.60	-1.48	-1.24	-1.18	-1.19	-1.14	-0.91
	Z	0.0	6.8	-1.9	-10.6	-12.3	-13.1	-12.9	-13.3	-10.2	-3.9	-1.9	0.3	1.3	3.1	3.0	5.1	5.2	4.0	5.2	5.5	5.6	6.1	6.6	6.8	6.5
	H	0.0	7.5	9.4	4.9	3.3	0.2	-3.2	-5.1	-8.0	-10.8	-14.9	-15.7	-16.1	-18.0	-20.8	-21.8	-23.6	-23.3	-24.6	-25.5	-26.4	-26.8	-26.1	-26.5	-24.9
SC (c)	D	0.00	0.40	0.50	0.38	0.18	0.07	-0.06	-0.04	0.00	-0.04	-0.39	-0.31	-0.39	-0.57	-0.67	-0.87	-0.90	-0.89	-0.87	-0.79	-0.77	-0.69	-0.65	-0.61	-0.44
	Z	0.0	4.2	2.6	-1.0	-0.9	-1.3	-1.3	-1.6	-1.9	-2.5	-2.9	-1.6	-1.5	-1.4	-1.5	-1.0	-0.5	0.7	0.7	0.7	0.6	0.9	2.0	2.2	3.0

hours

Storm-time		24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
	H	-43.2	-44.0	-41-8	-42.0	-40.6	-39.9	-37.5	-35.7	-33.5	-30.9	-30.3	-29.4	-28.6	-28.8	-28.4	-27.7	-27.1	-26.7	-27.4	-26.7	-24.7	-23.5	-22.8	-21.7	-20.3
SC (a)	D	-0.92	-0.93	-0.90	-0.95	-0.99	-1.11	-1.17	-12.0	-1.33	-1.13	-1.01	-0.99	-0.96	-0.98	-0.88	-0.71	-0.67	-0.60	-0.62	-0.63	-0.59	-0.64	-0.70	-0.62	-0.59
	Z	5.8	4.3	4.5	4.3	3.7	4.0	4.8	5.5	5.8	5.5	5.4	4.6	4.3	4.2	3.4	3.7	3.1	3.1	2.4	2.7	3.0	3.5	3.2	3.7	3.9
	H	-24.8	-22.0	-2.11	-22.8	-22.7	-21.8	-20.9	-19.7	-19.4	-19.5	-21.8	-20.9	-21.4	-20.3	-21.4	-21.2	-21.3	-19.7	-19.9	-20.2	-19.9	-19.1	-17.2	-16.8	-15.7
SC (c)	D	-0.33	-0.45	-0.45	-0.45	-0.55	-0.59	-0.65	-0.59	-0.55	-0.48	-0.52	-0.48	-0.51	-0.51	-0.49	-0.49	-0.34	-0.50	-0.27	-0.28	-0.38	-0.26	-0.24	-0.23	-0.18
	Z	3.1	4.1	3.5	2.5	2.6	3.2	3.5	3.8	2.7	3.3	2.9	3.0	2.3	3.4	2.1	2.9	3.9	3.3	3.5	3.1	2.7	3.8	4.6	4.2	4.8

D : positive if towards the East

Z : positive if vertically downwards

Table 2. Disturbance daily variations on storm-days (*SD*), 1924-1951, Kakioka.

123 storms for SC(a), 143 storms for SC(c)

unit ; H : γ, D : ′, Z : γ 135° E.M.T. in hours

	Hour		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
SC (a)	1st day	H	5.9	7.5	12.5	13.6	10.4	9.7	12.1	14.6	11.9	3.7	5.4	4.4	0.5	-3.3	-4.6	-12.0	-17.4	-17.9	-20.0	-16.0	-12.7	-9.3	-0.7	1.2
		D	1.39	1.40	1.68	1.78	1.39	0.89	-0.11	-0.93	-1.25	-1.81	-1.41	-0.76	-0.62	-0.63	-0.74	-1.06	-1.04	-0.54	-0.77	0.21	0.23	0.51	0.91	1.17
		Z	6.4	5.0	4.9	0.4	-2.4	-4.0	-5.8	-3.6	-3.6	-3.3	-1.1	-1.9	-4.1	-4.2	-3.9	-4.5	-3.5	-0.9	1.5	4.0	4.9	6.6	7.2	6.6
	2nd day	H	1.8	1.3	3.2	2.0	2.2	2.0	2.1	3.7	4.2	3.3	1.2	-0.8	-4.0	-3.8	-4.4	-5.1	-4.3	-2.7	-0.5	-0.9	-2.2	0.4	0.3	1.0
		D	0.54	0.67	0.65	0.61	0.58	0.15	-0.12	-0.49	-0.92	-0.95	-0.78	-0.49	-0.48	-0.25	0.04	-0.20	-0.11	-0.15	0.08	0.22	0.24	0.33	0.41	0.47
		Z	1.8	1.2	0.6	-0.2	-1.6	-3.3	-3.0	-1.9	-1.4	-1.7	-2.0	-1.7	-1.4	-0.6	-0.7	-1.2	1.1	1.9	3.1	2.3	1.6	2.4	2.3	2.1
SC (c)	1st day	H	1.7	3.0	3.7	4.4	6.0	7.9	7.3	5.2	2.8	1.9	2.0	1.7	-1.1	-5.3	-5.9	-5.3	-4.7	-4.8	-4.5	-5.3	-3.1	-5.1	-2.9	-0.3
		D	0.93	1.22	1.04	1.14	0.80	0.43	0.04	-0.70	-1.03	-1.01	-1.01	-0.78	-0.63	-0.58	-0.55	-0.44	-0.38	-0.25	-0.09	0.01	0.12	0.40	0.54	0.73
		Z	2.7	2.4	1.9	0.1	0.7	-0.5	-1.7	-3.2	-3.3	-2.8	-1.5	-1.4	-2.2	-2.9	-2.0	-0.6	-0.1	0.4	1.1	0.6	2.7	1.7	3.4	3.5
	2nd day	H	1.4	4.0	5.1	5.3	7.4	6.7	6.2	7.0	6.8	2.7	-0.9	-3.0	-4.3	-6.0	-7.3	-8.3	-8.4	-7.6	-5.9	-3.3	0.0	1.1	0.5	1.8
		D	0.53	0.65	0.53	0.46	0.52	0.17	-0.25	-0.58	-0.78	-0.93	-0.71	-0.65	-0.51	-0.33	-0.20	-0.09	-0.11	0.05	0.19	0.27	0.47	0.33	0.43	0.43
		Z	2.4	1.7	0.4	-0.2	0.1	-1.6	-1.6	-1.2	-0.6	-0.8	-0.9	-1.9	-2.0	-2.4	-2.4	-1.7	-0.3	-0.1	1.1	1.4	2.6	2.0	2.1	2.7

D : positive if towards the East

Z : positive if vertically downwards

Table 3. Harmonic analysys of *SD*-variations of geomagnetic storms, 1924-1951, Kakioka. unit ; H : γ, D : ′, Z : γ

			Amplitude				Phase angle(°)			
			c_1	c_2	c_3	c_4	θ_1	θ_2	θ_3	θ_4
SC (a)	1st day	H	14.8	3.4	1.0	1.1	355	58	135	304
		D	1.37	0.38	0.33	0.09	67	6	221	58
		Z	5.4	2.6	1.1	0.3	100	108	311	270
	2nd day	H	3.5	1.6	1.0	0.1	16	176	354	270
		D	0.60	0.29	0.15	0.02	88	346	208	27
		Z	2.5	0.4	0.6	0.2	130	124	351	333
SC(c)	1st day	H	6.1	0.4	0.5	1.0	359	124	307	73
		D	0.93	0.36	0.13	0.05	73	351	231	11
		Z	2.7	0.4	0.5	0.6	100	64	22	121
	2nd day	H	7.2	1.8	0.5	0.8	17	186	180	270
		D	0.63	0.22	0.11	0.01	86	333	225	45
		Z	2.1	0.8	0.4	0.1	98	150	346	180

D : positive if towards the East
Z : positive if vertically downwards
$c_n \sin(nt+\theta_n)$, where t is the time from 135° E. M. midnight.

Table 4. Monthly values of *Dm* for H, 1925-1951, Kakioka. unit : γ

	Disturbed days minus quiet days	All days minus quiet days
Jan.	-22.2	-7.8
Feb.	-25.0	-10.4
Mar.	-34.3	-13.2
Apr.	-32.9	-11.9
May	-24.4	-10.5
June	-13.3	-4.7
July	-20.7	-5.9
Aug.	-28.9	-8.6
Sep.	-35.5	-13.2
Oct.	-35.7	-14.0
Nov.	-26.2	-10.5
Dec.	-19.4	-8.0
Winter	-23.1	-9.2
Equinox	-34.7	-13.1
Summer	-21.8	-7.4
Year	-26.5	-9.9

Table 5. Annual values of *Dm* for H, Kakioka. unit : γ

Year	Disturbed days minus quiet days	All days minus quiet days	Year	Disturbed days minus quiet days	All days minus quiet days
1925	-13.2	-4.0	1943	-25.5	-10.9
1926	-24.9	-9.0	1944	-21.1	-7.6
1927	-19.9	-7.2	1945	-20.2	-6.7
1928	-22.8	-8.2	1946	-39.0	-13.5
1929	-20.1	-8.1	1947	-46.4	-21.1
1930	-24.5	-12.6	1948	-30.2	-10.5
1931	-10.2	-4.1	1949	-38.7	-10.9
1932	-12.5	-6.6	1950	-37.3	-12.0
1933	-13.8	-5.9	1951	-28.6	-11.3
1934	-9.2	-2.0	1952	-30.8	-15.0
1935	-13.6	-5.6	1953	-25.1	-9.8
1936	-23.8	-8.9	1954	-14.5	-6.2
1937	-32.4	-10.2	1955	-21.1	-8.3
1938	-44.1	-16.2	1927-29	-20.9	-7.8
1939	-42.6	-15.7	1936-38	-33.4	-11.8
1940	-43.4	-17.2	1946-48	-38.5	-15.0
1941	-35.1	-11.6	1932-34	-11.8	-4.8
1942	-22.9	-9.7	1943-45	-22.3	-8.4

In 1948-1955, provisional values are used.

Table 6. Diurnal variations of geomagnetic horizontal intensity, quiet days (S_q), 1925-1951, Kakioka.

unit : γ 135° E.M.T. in hours

Month \ Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan.	0.3	0.7	1.8	2.6	3.7	4.5	5.7	3.1	-4.4	-12.9	-13.3	-6.7	-1.2	2.7	4.7	4.9	3.8	2.2	0.1	-0.8	-1.1	-0.7	-0.1	0.2
Feb.	-0.4	0.1	0.4	1.3	2.6	3.5	5.6	3.7	-0.5	-5.4	-7.2	-5.6	-2.0	1.4	3.0	3.4	2.3	0.9	-0.4	-1.3	-1.4	-1.6	-1.8	-1.0
Mar.	1.4	1.6	1.8	2.4	3.5	5.6	5.4	-1.1	-9.0	-14.5	-15.2	-9.3	-0.8	6.4	8.7	7.3	4.0	1.3	0.4	-0.1	-0.3	-0.2	0.3	1.4
Apr.	-0.3	-0.7	-0.7	-0.3	1.2	2.8	-0.4	-8.4	-16.0	-17.1	-11.0	-0.4	10.1	15.4	14.9	11.0	5.0	-0.3	-2.0	-1.9	-1.2	-0.4	-0.2	-0.1
May	-0.9	-1.2	-1.1	-0.5	1.2	-0.6	-7.2	-13.1	-15.6	-12.4	-3.9	5.6	11.9	14.6	13.8	9.8	3.7	-1.0	-2.1	-1.0	-0.4	0.0	0.0	-0.2
June	0.5	-0.2	-0.5	-0.2	1.6	0.1	-6.2	-12.1	-13.4	-10.1	-3.0	4.1	8.8	10.4	9.7	6.6	2.3	-1.0	-1.6	-0.1	1.0	1.3	1.3	0.9
July	1.1	0.7	0.5	0.3	0.7	-1.7	-7.3	-12.7	-13.2	-11.1	-5.6	1.3	6.8	10.1	11.5	9.2	4.8	0.5	-1.0	-0.5	0.5	1.4	1.8	1.3
Ang.	1.4	0.9	0.6	0.9	0.5	-2.4	-10.2	-18.5	-20.5	-15.4	-6.5	2.2	8.5	11.8	12.0	10.4	7.2	4.0	2.3	2.0	2.0	2.2	2.0	1.6
Sep.	1.1	0.9	0.5	0.7	0.6	-0.9	-7.3	-15.6	-20.5	-18.1	-9.2	1.5	10.6	14.6	14.1	10.1	6.0	3.5	2.2	1.4	0.9	1.3	1.2	1.3
Oct.	0.4	0.9	1.0	1.0	1.7	3.3	0.6	-7.2	-13.2	-14.4	-9.1	0.2	8.4	11.9	10.0	5.3	2.1	0.2	-0.5	-0.9	-1.0	-0.8	-0.1	0.7
Nov.	-0.8	-0.9	-0.2	0.5	1.2	2.7	3.0	-2.2	-7.1	-10.2	-8.0	-1.5	3.1	5.4	6.8	6.1	3.5	1.8	0.2	-0.5	-1.1	-1.4	-1.2	-0.4
Dec.	-0.3	0.0	0.6	1.4	1.9	3.5	4.8	3.2	-1.6	-7.6	-8.3	-4.3	-1.3	1.7	4.1	4.2	2.7	0.8	-0.4	-1.2	-1.5	-1.5	-0.8	-0.6
Winter	-0.3	0.0	0.6	1.5	2.4	3.5	4.8	1.9	-3.4	-9.1	-9.2	-4.5	-0.3	2.8	4.7	4.7	3.1	1.4	-0.1	-0.9	-1.3	-1.3	-0.9	-0.5
Equinox	0.6	0.6	0.6	0.9	1.7	2.6	-0.5	-8.2	-14.8	-16.2	-11.1	-2.2	7.0	12.0	11.9	8.4	4.3	1.1	0.0	-0.4	-0.4	-0.1	0.2	0.8
Summer	0.5	0.0	-0.1	0.0	1.0	-1.2	-7.8	-14.1	-15.8	-12.2	-4.9	3.3	9.0	11.8	11.8	9.0	4.5	0.6	-0.6	0.1	0.8	1.2	1.3	0.9
Year	0.3	0.2	0.4	0.8	1.7	1.7	-1.2	-6.8	-11.3	-12.5	-8.4	-1.1	5.2	8.8	9.5	7.4	3.9	1.0	-0.3	-0.4	-0.3	0.0	0.2	0.4

Table 7. Diurnal variations of geomagnetic horizontal intensity, disturbed days (*Sd*), 1925-1951, Kakioka.

unit : γ 135° E. M. T. in hours

Month \ Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan.	3.3	2.3	5.3	6.8	5.3	6.9	7.9	8.7	2.7	-6.9	-7.4	-1.3	1.5	1.4	2.1	0.6	-2.3	-5.5	-7.1	-7.6	-7.8	-6.1	-3.7	0.5
Feb.	-3.0	1.4	3.5	5.0	5.6	5.8	10.3	10.9	7.8	2.1	-1.1	0.3	3.0	2.4	0.4	-0.7	-4.3	-7.1	-8.1	-6.7	-9.1	-8.5	-6.9	-3.3
Mar.	3.9	5.9	8.4	9.2	9.0	10.7	10.8	6.5	-0.3	-9.7	-11.7	-5.3	2.3	5.2	6.4	1.6	-3.2	-6.6	-9.3	-12.5	-11.0	-7.2	-3.3	0.1
Apr.	3.9	6.2	8.6	9.8	11.2	10.9	6.9	-2.5	-10.5	-13.8	-8.3	1.4	10.2	13.9	11.4	2.8	-6.6	-12.5	-13.8	-12.5	-11.0	-5.5	-2.1	2.0
May	2.2	3.5	6.0	5.3	6.4	5.4	0.5	-6.4	-8.3	-8.5	-2.2	4.2	7.7	9.3	6.8	2.2	-3.0	-8.6	-10.2	-8.2	-3.5	-1.0	-0.1	1.0
June	3.4	3.4	4.1	4.1	6.2	4.2	-1.2	-7.8	-9.3	-7.8	-1.5	4.4	6.8	8.2	8.1	2.5	-3.6	-8.4	-10.0	-7.8	-3.0	0.5	1.9	3.5
July	3.3	3.8	5.1	6.3	6.5	4.5	0.1	-4.1	-5.1	-4.8	4.4	8.3	11.2	10.2	6.2	0.0	-5.7	-10.6	-13.1	-10.0	-8.2	-4.8	-3.6	0.7
Aug.	5.6	7.4	7.6	8.4	9.3	7.8	0.3	-5.9	-7.4	-4.1	0.5	5.8	7.4	7.6	6.6	0.3	-7.5	-13.2	-14.2	-11.5	-8.0	-5.1	-0.8	2.9
Sep.	4.8	5.9	9.5	10.6	11.5	10.6	4.9	-0.7	-5.1	-6.7	-2.8	3.6	8.6	8.4	3.8	-3.5	-8.4	-13.5	-12.8	-12.4	-9.2	-6.9	-0.5	-0.4
Oct.	3.5	5.5	7.5	10.1	11.4	13.7	9.5	2.3	-4.2	-7.6	-5.5	1.5	7.5	9.1	5.1	-1.1	-5.3	-8.4	-11.7	-12.0	-12.4	-10.9	-6.2	-2.0
Nov.	0.8	2.6	5.8	6.7	7.4	8.3	10.7	8.1	3.7	0.4	1.9	5.4	4.9	3.3	0.0	-4.3	-7.5	-9.9	-11.2	-11.5	-9.4	-8.1	-6.2	-1.7
Dec.	-3.3	-0.2	1.1	2.9	4.6	6.0	9.7	10.2	7.5	2.9	2.9	4.5	5.6	5.6	5.2	2.4	-2.9	-6.8	-11.7	-12.7	-10.6	-9.1	-8.1	-5.2
Winter	-0.6	1.6	4.0	5.4	5.7	6.7	9.7	9.5	5.3	-0.4	-1.0	2.2	3.8	3.1	1.8	-0.5	-4.3	-7.3	-9.5	-9.7	-9.2	-8.0	-6.2	-2.3
Equinox	4.0	5.8	8.5	9.9	10.7	11.4	8.0	1.3	-5.1	-9.3	-7.1	0.2	7.1	9.1	6.7	0.0	-5.9	-10.3	-11.9	-12.4	-10.9	-7.7	-2.9	0.0
Summer	3.6	4.5	5.7	6.1	7.1	5.5	-0.1	-6.1	-7.5	-6.3	0.3	5.6	8.2	8.8	6.9	1.2	-5.0	-10.3	-11.9	-9.4	-5.7	-2.6	-0.7	2.0
Year	2.4	4.0	6.1	7.2	7.9	7.9	5.9	1.6	-2.4	-5.3	-2.6	2.7	6.4	7.0	5.1	0.2	-5.0	-9.3	-11.1	-10.4	-8.6	-6.1	-3.3	-0.1

Table 8. Diurnal variations of geomagnetic horizontal intensity, disturbed days minus quiet days (*SD*), 1925–1951, Kakioka.

unit : γ 135° E.M.T. in hours

Month \ Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan.	3.0	1.6	3.5	4.2	1.6	2.4	2.2	5.6	7.1	6.0	5.9	5.4	2.7	-1.3	-2.6	-4.3	-6.1	-7.7	-7.2	-6.8	-6.7	-5.4	-3.6	0.3
Feb.	-2.6	1.3	3.1	3.7	3.0	2.3	4.7	7.2	8.3	7.5	6.1	5.9	5.0	1.0	-2.6	-4.1	-6.6	-8.0	-7.7	-5.4	-7.7	-6.9	-5.1	-2.4
Mar.	2.5	4.3	6.6	6.8	5.5	5.1	5.4	7.6	8.7	4.8	3.5	4.0	3.1	-1.2	-2.3	-5.7	-7.2	-7.9	-9.7	-12.4	-10.7	-7.0	-3.6	-1.3
Apr.	4.1	6.8	9.2	10.0	9.9	8.0	7.2	5.9	5.4	3.2	2.6	1.7	0.0	-1.6	-3.6	-8.3	-11.7	-12.3	-11.9	-10.7	-9.9	-5.2	-2.0	2.0
May	3.0	4.6	7.0	5.7	5.1	5.9	7.6	6.6	7.2	3.8	1.6	-1.5	-4.3	-5.4	-7.1	-7.7	-6.8	-7.7	-8.2	-7.2	-3.2	-1.1	-0.2	1.1
June	2.9	3.6	4.6	4.3	4.6	4.1	5.0	4.3	4.1	2.3	1.5	0.3	-2.0	-2.2	-1.6	-4.1	-5.9	-7.4	-8.4	-7.7	-4.0	-0.8	0.6	2.6
July	2.1	3.0	4.5	5.9	5.7	6.1	7.3	8.5	8.0	6.2	9.9	6.9	4.3	0.0	-5.4	-9.3	-10.6	-11.2	-12.2	-9.6	-8.8	-6.3	-5.5	-0.7
Aug.	4.2	6.5	7.0	7.5	8.8	10.2	10.5	12.6	13.1	11.3	7.0	3.6	-1.1	-4.2	-5.4	-10.1	-14.7	-17.2	-16.5	-13.5	-10.0	-7.3	-2.8	1.3
Sep.	3.8	5.1	9.1	10.0	11.0	11.6	12.3	15.0	15.5	11.5	6.5	2.2	-1.9	-6.1	-10.2	-13.5	-14.3	-16.9	-14.9	-13.7	-10.0	-8.1	-1.6	-1.6
Oct.	3.1	4.6	6.5	9.1	9.7	10.4	8.9	9.5	9.0	6.9	3.6	1.3	-0.9	-2.8	-4.9	-6.4	-7.4	-8.6	-11.2	-11.1	-11.4	-10.1	-6.1	-2.7
Nov.	1.7	3.4	5.9	6.1	6.1	5.5	7.6	10.2	10.7	10.6	9.8	6.8	1.7	-2.2	-6.9	-10.5	-11.1	-11.8	-11.5	-11.1	-8.4	-6.8	-5.1	-1.4
Dec.	-3.0	-0.2	0.5	1.5	2.7	2.5	4.9	7.0	9.1	10.5	11.2	8.8	6.9	3.9	1.1	-1.8	-5.6	-7.6	-11.3	-11.5	-9.1	-7.6	-7.3	-4.6
Winter	-0.3	1.6	3.4	3.9	3.3	3.2	4.9	7.6	8.7	8.7	8.2	6.7	4.1	0.3	-2.9	-5.2	-7.4	-8.7	-9.4	-8.8	-7.9	-6.7	-5.3	-1.8
Equinox	3.4	5.2	7.9	9.0	9.0	8.8	8.5	9.5	9.7	6.9	4.0	2.4	0.1	-2.9	-5.2	-8.4	-10.2	-11.4	-11.9	-12.0	-10.5	-7.6	-3.1	-0.8
Summer	3.1	4.5	5.8	6.1	6.1	6.7	7.7	8.0	8.3	5.9	5.2	2.3	-0.8	-3.0	-4.9	-7.8	-9.5	-10.9	-11.3	-9.5	-6.5	-3.8	-2.0	1.1
Year	2.1	3.8	5.7	6.4	6.2	6.2	7.1	8.4	8.9	7.2	5.8	3.8	1.2	-1.8	-4.4	-7.2	-8.9	-10.3	-10.8	-10.0	-8.3	-6.1	-3.5	-0.5

Table 9 Harmonic analysis of mean diurnal variations of geomagnetic horizontal intensity, 1925-1951, Kakioka.

unit ; amplitude : γ, phase angle : degree

Month	Quiet days								Disturbed days								Disturbed days—Quiet days, *SD*							
	Amplitude				Phase angle				Amplitude				Phase angle				Amplitude				Phase angle			
	c_1	c_2	c_3	c_4	θ_1	θ_2	θ_3	θ_4	c_1	c_2	c_3	c_4	θ_1	θ_2	θ_3	θ_4	c_1	c_2	c_3	c_4	θ_1	θ_2	θ_3	θ_4
Jan.	2.2	5.0	3.6		103	309	141		5.3	3.9	2.8		357	334	128		6.2	2.3	1.1		337	83	355	
Feb.	0.7	3.4	2.3		45	299	126		6.8	2.1	1.5		331	317	122		7.4	1.6	0.8		326	90	315	
Mar.	3.3	6.2	4.6		121	321	147		6.5	6.9	4.3		4	340	136		8.6	2.3	0.9		343	41	32	
Apr.	4.8	7.7	6.0		184	354	172		5.2	9.9	6.4		357	6	174		10.0	2.7	0.5		0	39	202	
May	5.7	7.4	4.9		193	13	195		2.1	6.6	4.3		355	18	189		7.7	1.0	0.8		8	151	50	
June	4.3	5.7	4.0		180	16	200		1.5	6.7	4.3		16	27	185		5.7	1.4	1.1		4	69	112	
July	5.2	6.3	3.3		172	9	189		4.8	7.4	3.5		327	30	202		9.8	2.7	0.8		340	88	277	
Aug.	8.0	7.7	4.1		167	6	208		5.4	8.1	3.6		356	26	193		13.4	2.9	1.1		351	102	80	
Sep.	7.4	8.3	4.9		170	3	195		7.3	7.2	4.3		357	15	192		14.7	2.0	0.8		353	135	40	
Oct.	3.1	6.1	4.6		171	354	175		7.5	7.6	3.7		346	353	175		10.7	1.5	1.0		347	344	29	
Nov.	2.0	4.2	2.9		174	330	162		8.8	2.9	1.7		339	12	170		10.8	2.8	1.3		342	107	328	
Dec.	0.7	3.4	2.6		90	306	130		8.8	2.7	2.4		315	354	123		8.1	2.6	1.4		312	76	14	
Winter	1.0	4.0	2.8	1.2	119	311	141	355	7.4	2.7	2.0	1.4	333	345	123	343	8.2	2.2	0.9	0.3	329	90	339	270
Equinox	4.4	6.8	4.8	1.8	166	349	174	19	6.6	7.7	4.4	1.7	356	359	169	13	10.9	1.5	0.6	0.3	352	42	45	270
Summer	5.7	6.8	4.1	0.9	177	11	198	96	3.3	7.2	3.9	0.5	348	25	192	112	9.1	1.8	0.5	0.4	354	96	79	256
Year	3.6	5.4	3.6	1.0	168	349	175	29	5.7	5.7	3.2	0.9	345	8	171	13	9.2	1.7	0.5	0.2	345	80	11	270

$cn\sin(nt+\theta_n)$, where t is the time from 135° E.M. midnight.

Table 10. Harmonic analysis of mean diurnal variations of geomagnetic horizontal intensity, 1925-1951, Kakioka.

unit ; amplitude : γ, phase angle : degree

Year	Quiet days						Disturbed days						Disturbed days—Quiet days (SD)					
	Amplitude			Phase angle			Amplitude			Phase angle			Amplitude			Phase angle		
	c_1	c_2	c_3	θ_1	θ_2	θ_3	c_1	c_2	c_3	θ_1	θ_2	θ_3	c_1	c_2	c_3	θ_1	θ_2	θ_3
1925	6.2	6.5	4.4	174	4	192	1.8	6.5	4.4	326	11	178	7.9	0.9	1.1	348	96	95
1926	5.9	6.8	4.7	175	7	184	0.1	6.4	4.1	45	22	186	5.9	1.8	0.6	356	119	351
1927	7.1	7.9	5.3	177	9	199	6.5	8.7	4.2	257	16	198	8.7	1.3	1.1	310	61	22
1928	7.3	8.0	5.4	180	7	194	4.6	8.5	4.2	289	9	177	9.8	0.6	1.8	333	39	57
1929	7.3	8.4	5.6	167	3	196	1.8	7.6	6.1	322	17	191	8.9	2.1	0.7	342	122	146
1930	3.5	5.4	3.6	198	12	189	6.7	6.3	3.0	323	34	201	9.2	2.6	0.9	342	92	32
1931	4.6	5.9	4.0	186	7	193	3.1	6.3	3.3	295	23	189	6.4	1.7	0.7	339	93	34
1932	3.0	4.3	2.8	182	1	186	2.7	6.1	3.2	318	18	189	5.2	2.3	0.4	341	48	207
1933	1.8	3.7	2.9	154	338	162	5.4	2.5	2.2	17	349	158	6.7	1.3	0.8	7	135	353
1934	1.6	3.5	2.4	137	340	173	2.7	4.2	2.4	340	12	162	4.2	2.2	0.5	333	69	90
1935	3.1	5.0	3.2	149	334	165	4.8	4.1	2.5	349	359	157	7.9	2.1	0.8	342	93	14
1936	3.6	6.2	4.0	152	335	167	5.5	6.2	2.8	338	1	186	9.4	2.8	1.3	335	77	331
1937	3.6	6.4	4.6	152	345	174	4.9	7.6	4.8	351	352	181	8.3	1.5	0.6	342	28	252
1938	4.6	6.3	3.7	163	344	171	5.0	7.2	4.2	327	15	153	9.5	3.7	1.3	335	77	90
1939	3.3	5.8	4.0	176	348	168	9.1	6.9	2.5	339	18	169	12.2	3.4	1.4	344	75	348
1940	3.8	5.9	3.5	157	343	164	5.7	3.4	2.4	10	357	147	9.1	2.7	1.4	357	146	78
1941	3.1	5.4	3.7	184	347	172	10.3	6.9	3.4	340	9	173	13.2	2.8	0.3	345	57	288
1942	1.7	5.1	3.5	187	345	162	5.2	4.8	3.1	336	24	167	6.7	3.2	0.5	343	99	307
1943	2.6	4.7	3.3	169	340	165	11.4	4.5	3.1	6	25	159	13.8	3.5	0.4	3	95	34
1944	2.8	4.5	3.0	182	347	163	6.5	4.5	3.4	340	33	168	9.0	3.6	0.4	347	100	207
1945	3.1	4.3	3.0	176	348	168	6.3	5.0	3.4	357	350	146	9.5	0.7	1.3	357	0	86
1946	3.8	5.4	3.8	141	335	162	11.7	5.4	3.3	338	349	175	15.4	1.4	0.9	334	73	288
1947	3.7	6.1	4.5	165	344	171	9.7	7.9	3.7	327	345	169	13.3	1.8	0.8	332	347	0
1948	3.1	6.1	3.0	144	338	153	8.9	5.3	3.9	349	13	159	11.5	3.1	0.9	343	83	180
1949	3.0	5.3	3.6	116	323	152	9.8	6.5	2.2	17	310	149	10.7	1.3	1.5	1	309	337
1950	1.3	3.8	2.2	157	330	156	9.7	4.4	2.9	16	348	126	10.7	1.4	1.4	12	45	78
1951	2.2	4.4	2.9	153	343	168	10.6	4.6	2.6	9	0	178	12.5	1.4	0.5	3	73	292
1925-51	3.6	5.4	3.6	168	349	175	5.7	5.7	3.2	345	8	171	9.2	1.7	0.5	345	80	11
1927-29	7.2	8.0	5.4	174	6	196	3.9	8.2	4.8	277	14	189	8.8	1.1	1.0	329	90	58
1936-38	4.0	6.3	4.2	157	342	170	5.1	6.9	3.9	338	3	170	9.0	2.5	0.3	337	69	0
1946-48	3.4	4.7	3.1	150	335	165	10.0	4.3	3.2	338	352	158	13.5	2.3	0.4	336	93	90
1932-34	2.0	3.8	2.7	163	348	174	3.2	4.2	2.5	353	10	171	5.2	1.7	0.1	350	73	45
1943-45	2.8	5.3	3.8	176	347	163	7.9	6.1	3.6	357	11	167	10.7	1.5	0.3	357	58	288

$cn\sin(nt+\theta_n)$, where t is the time from 135° E.M. midnight.

Table 11. Harmonic analysis of mean diurnal variations of geomagnetic horizontal intensity, disturbed days minus quiet days (*SD*), 1925-1951, Kakioka.

unit ; c : γ, θ : degree

Year	Amplitude, c_1			Phase angle, θ_1			Year	Amplitude, c_1			Phase angle, θ_1		
	W	E	S	W	E	S		W	E	S	W	E	S
1925	9.0	7.8	7.7	329	346	2	1942	9.8	7.0	4.1	330	352	3
1926	8.4	10.3	4.2	341	23	27	1943	11.2	16.5	14.6	350	1	15
1927	5.1	13.1	5.6	309	312	303	1944	8.3	10.8	8.8	331	0	346
1928	7.4	8.4	15.6	324	304	353	1945	11.7	7.7	9.5	351	349	12
1929	10.6	10.3	5.9	334	348	347	1946	14.1	24.9	9.6	313	335	3
1930	7.9	11.4	8.7	325	345	352	1947	11.9	17.9	11.9	318	324	359
1931	6.1	8.3	5.0	330	349	334	1948	7.8	19.7	13.0	280	356	353
1932	6.4	5.8	3.7	345	330	351	1949	10.7	14.6	7.1	2	356	10
1933	5.8	9.1	6.1	345	23	5	1950	6.6	12.8	14.4	21	351	26
1934	3.3	5.3	4.4	308	331	352	1951	14.0	10.4	14.4	346	26	2
1935	8.2	8.1	7.7	343	351	331	1925-51	8.2	10.9	9.1	329	352	354
1936	10.6	10.8	7.2	322	346	333							
1937	9.0	10.7	12.0	345	24	347	1927-29	8.4	9.9	8.5	324	322	332
1938	5.4	16.5	12.8	242	341	354	1936-38	7.2	12.1	10.6	293	344	336
1939	12.0	11.4	13.6	341	357	336	1946-48	10.9	20.3	11.5	307	358	358
1940	8.6	14.8	9.7	311	33	343	1932-34	5.0	6.0	4.7	338	351	358
1941	11.5	11.7	17.2	356	354	330	1943-45	10.3	11.6	10.7	345	358	6

W : Winter, E : Equinox, S : Summer