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47. *Local Difference in Variations of the Geomagnetic Total Intensity in Japan.*

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Summary

Geomagnetic total intensities (F) observed simultaneously with the same type of proton precession magnetometers at nine stations widely scattered over Japan are compared. The observations have been carried out cooperatively by a research group on earthquake prediction in Japan. During a period from July 1 to 31, 1968, the nine magnetometers have been carefully maintained so as to obtain homogeneous data. These data are analysed in this report.

The amplitude and phase of daily variation of the geomagnetic total intensity change considerably from day to day and from place to place. But examination of the data simultaneously observed shows that there are three different modes in the daily variation in the total intensity. We may define, on the basis of the modes thus found, three areas, i.e. the northeastern, central and southwestern parts of Japan.

The following conclusions are reached through the present work. Making use of simple differences in hourly mean values during the night-time between the stations, an anomalous local change in the geomagnetic field in most parts of Japan can be detected, if it occurs, with an accuracy of about 3γ in standard deviation. If weighted differences are used, the accuracy can be slightly improved, so that the standard deviation of comparision is estimated as about 2.5γ. The relative weight for a certain combination of stations is empirically determined. The standard deviation for weighted differences between the stations at a distance within 500km is smaller than that for simple differences by 1γ or so except for those under the influence of so-called "island-effect".

1. Introduction

A number of proton precession magnetometers have been set up at stations widely distributed over Japan since 1964. Supported by an earthquake prediction research project, the aim has been to observe very accurately geomagnetic secular variations in parts of Japan. In order to discuss the detectability of a seismo-magnetic effect, it is required to know how accurately the geomagnetic fields simultaneously observed at various stations can be compared with one another. A special observation project was planned by a geomagnetic research group, the members of which are from universities and governmental institutions, during a period from July 1 to 31, 1968. Nine magnetometers were maintained in as good a condition as possible during the period, so that large sets of geomagnetic total intensity values, which provide basic data for discussing possibilities of detecting a seismo-magnetic effect, were obtained.

In association with the occurrence of an earthquake, it is sometimes expected that a local change in the geomagnetic field may be caused by changes in the physical state of rocks around the epicenter. Should the electrical conductivity in the epicentral area also change, it would be expected that the behaviour of short-period variations, say geomagnetic bay or similar changes, may also change. Local anomalous changes in the geomagnetic field associated with earthquakes have been reported by many investigators in classical reports. But there are few observations that unquestionably confirmed the relation between geomagnetic changes and an earthquake occurrence.

In order to detect a local change in the geomagnetic field associated with a physical process within the earth's interior, it is necessary to eliminate non-local change originating from outside the earth from the observed data. The usual method of eliminating such non-local changes is to compare changes in the geomagnetic field at two or more stations. Supposing that total intensities F_A and F_B are simultaneously observed at stations A and B respectively, the time-change of the simple difference, $F_A - F_B$, is considered to indicate the local change at A or B provided the distance between A and B is not too large.

Fujita[1] reported that the error of eliminating non-local changes was estimated as 5γ or smaller for the first-order survery of the Geographical Survery Institute, where the average of hourly values observed during the period from 06h to 22h was used. In the case of the second-order survey in which the values of only four observations in an hour are made use of, the accuracy is considered to be 10γ or so.

The total intensity values observed by proton precession magnetometers was investigated by Stacey and Westcott[2] in East Anglia where

1) N. FUJITA, *Journ. Geod. Soc. Japan*, **11** (1965), 8.
2) F. D. STACEY and P. WESTCOTT, *Nature*, **206** (1965), 1209.

no outstanding conductivity anomaly within the earth had been found. They made use of about 33,000 sets of synchronized measurements with the interval of 36 seconds. The standard deviations of the difference in the total intensity between two stations, 25km apart, were 0.85γ and 0.21γ for the individual and 24-hour average values respectively.

Rikitake[3] investigated a possible way of eliminating non-local changes of the total intensity by making use of the data of proton magnetometers operated on the occasions of the Matsushiro Earthquake Swarm and Niigata Earthquake. He classified the data into night-time and day-time data and also into disturbed and undisturbed days. When the data were classified into disturbed and undisturbed days, the standard deviation of the difference between stations was not greatly different. In the case of making use of night-time data, the standard deviation was less than 3γ for comparing a single set of simultaneous observations in the central part of Japan. As to day-time data, the standard deviation was very large in comparison with that of night-time data. Rikitake made use of a weighted difference method, too. After multiplying the total intensity at a station by a certain factor, the difference between the multiplied value and the total intensity itself observed at another station was calculated. In this case the standard deviation became 2γ or smaller.

Rikitake et al.[4] analysed the data which was observed by proton magnetometers at several stations in the central part of Japan. From the night-time data on undisturbed days at Nomashi on Oshima Island and Kanozan, about 80km apart, the standard deviation amounting to 2.2γ for simple difference and 1.8γ for weighted difference were obtained. Between Nomashi and Senzu on Oshima Island, only 7km apart, the standard deviation on undisturbed days was estimated as 2γ. Daily variation of the total intensity was different systematically between the two stations. The difference seems likely to be caused by electric currents induced in the surrounding see-water by the external geomagnetic field change.

Many scientists have investigated underground electrical conductivity by analysing short-period geomagnetic variations such as bays. Especially, Central Japan Anomaly[5] and Northeastern Japan Anomaly[6] are notable in Japan. Even in the anomalous area, the following empirical relations between three geomagnetic components are found, $\Delta Z = A \cdot \Delta H$

3) T. Rikitake, *Bull. Earthq. Res. Inst.*, **44** (1966), 1041.

4) T. Rikitake et al., *Bull. Earthq. Res. Inst.*, **46** (1968), 1.

5) T. Rikitake, *Geophys. J.*, **2** (1959), 276.

6) Y. Kato, *Proc. the Symposium on Conductivity Anomaly in Japan held at Kakioka*, Dec. 6 and 7, 1967, 19.

$+B\cdot\Delta D$, where ΔZ, ΔH and ΔD are changes in the vertical, horizontal and magnetic east components, respectively. ΔH and ΔD are not so anomalous, but ΔZ is extremely anomalous over the Japan Island. The coefficients A and B take on peculiar values at each station, and they seem to be determined by the distribution of underground electrical counductivity and sea-water in the vicinity. Namely, if the electrical conductivity changes under the influence of some geophysical causes, it is expected that the coefficients A and B will also change.

For the daily variation which has a period longer than that of the above-mentioned short period variations, the form of the variation is most strongly affected by the path of the center of the equivalent overhead currents. It is well known that the center of the equivalent currents of S_q (Solar daily variation) passes over the vicinity of Japan[7], and that the path fluctuates from day to day. There is a remarkable phase shift of Z daily variation in Japan[8], but it cannot be attributed to the said path of the center of equivalent currents. It seems rather to be due to the local anomaly of the electrical conductivity in the earth.

To detect a local change which may be useful for earthquake prediction research, it will be more advantageous to make use of the three geomagnetic components than the use of total intensity only. But the base line value and the sensitivity of usual variometer, which is used generally to observe variations of each component, is not stable enough unless frequent absolute observations by an accurate magnetometer and the good maintenance of the instruments are conducted. On the other hand the proton precession magnetometer is free from drift and it is not difficult to observe the total intensity with an accuracy higher than 1γ. Although the total intensity seems to play an important role at the present stage of earthquake prediction research basing on local anomalous changes in the geomagnetic field, no thorough comparisons of natural

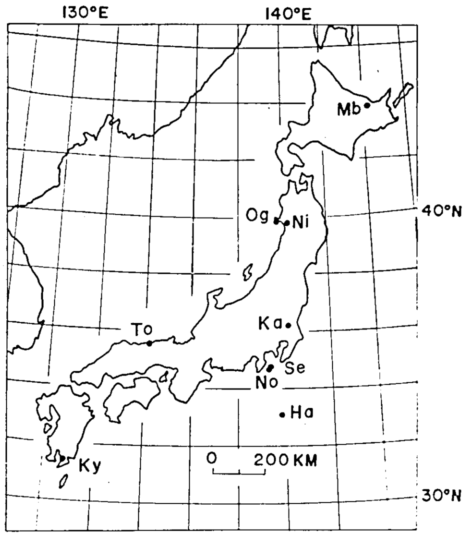

Fig. 1. Locations of stations

7) M. HASEGAWA, *Journ. Geophys. Res.*, **65** (1960), 1437.
8) T. RIKITAKE et al., *Bull. Earthq. Res. Inst.*, **34** (1956), 197.

Table 1. Locations of stations

Station	Abbreviation	Geographic		Geomagnetic	
		Longitude	Latitude	Longitude	Latitude
Memambetsu	Mb	144°12′	43°55′	208°4′	34°0′
Oga	Og	139 47	39 54	205 2	29 7
Nibetsu	Ni	140 16	39 48	205 6	29 6
Kakioka	Ka	140 11	36 14	206 0	26 0
Senzu	Se	139 25	34 47	205 4	24 5
Nomashi	No	139 22	34 44	205 4	24 6
Hachijo-jima	Ha	139 48	33 07	206 0	22 9
Tottori	To	134 14	35 31	200 7	24 9
Kanoya	Ky	130 53	31 25	198 1	20 5

variations in the total intensity between various stations in Japan have so far been performed.

Fig. 1 shows the locations of the stations at which the present cooperative observation has been carried out. The geographic and geomagnetic coordinates of these stations are tabulated in Table 1. The geomagnetic coordinates are calculated using the table produced by Kuboki[9].

We make use of the data of one-minute interval obtained by proton precession magnetometers except the data at Kanoya. The total intensity at Kanoya is calculated from the values of H and Z recoreded on an ordinary magnetogram. All through the paper, JST (Japanease Standard Time) is used except for the indicated cases.

2. Daily and short-period variations

2-1. *Three types in the daily variation*

Examining variation in F at every station during July, 1968, it was found that there were three types in the daily variations. One is that changing very regularly and almost in the same way at all the stations. The second type is characteristic in that the field variations of a certain group of stations take on a similar shape, but they are very different from other groups. The third type has a small disturbance modifying the normal mode and producing a wiggle on the record at some of the stations.

Fig. 2a is one of the first type variations obtained on July 30, 1968.

9) T. Kuboki, *Memoirs Kakioka Mag. Obser.*, **13** (1968), 63.

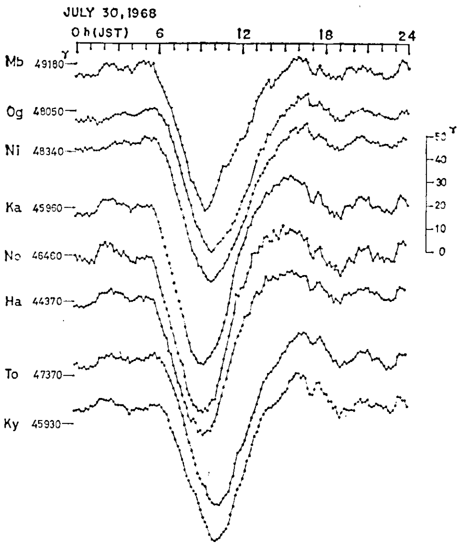

Fig. 2a. Daily variations of the total intensity on July 30.

The field changes similarly at all the stations, having only one large depression between 9h and 11h JST. This type appeared most frequently in July. Daily variations of about 15 days of the month were of the first type. This type of variation has been considered to be the best for eliminating the external effect by taking simple differences between the stations and extracting the magnetic change originating from the interior. However, it was revealed that the simple differences thus computed do not completely eliminate the diurnal effect due to the electric currents flowing in the ionosphere.

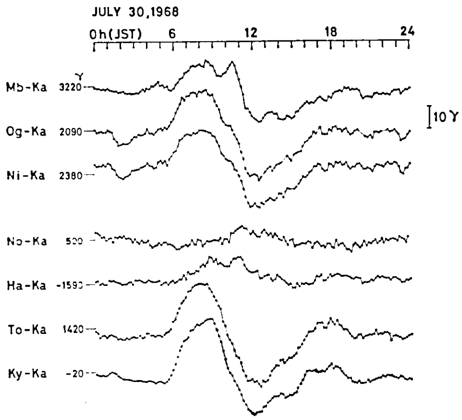

Fig. 2b. Daily variations of difference in the total intensity between each station and *Ka* on July 30.

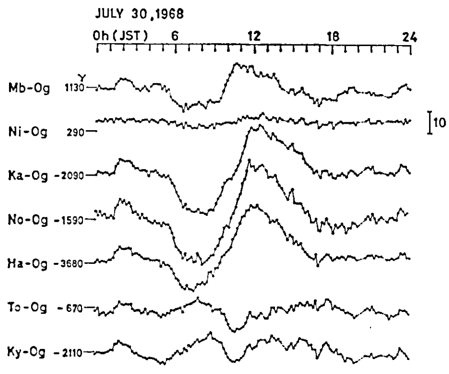

Fig. 2c. Daily variations of difference in the total intensity between each station and *Og* on July 30.

Figs. 2b and c show the differences between the stations when station *Ka* and station *Og* are taken as the reference respectively. Fig. 2b shows that the differences become considerably small for *No*−*Ka* and *Ha*−*Ka*, but for the other combinations there still remain fairly large diurnal changes. In Fig. 2c, the differences are also large except for those closely spaced stations, *Ni*−*Og*.

The daily variations on July 19 are typical of the second type. As in Fig. 3a, daily variation curves at the Pacific side of the central part of Japan (stations *Ka*, *Se*, *No* and *Ha*) are very different from those

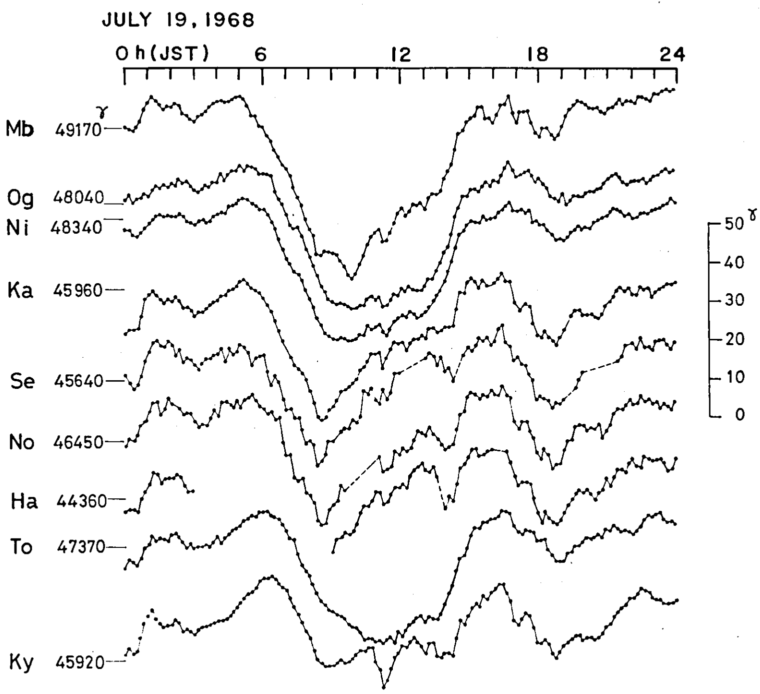

Fig. 3a. Daily variations of the total intensity on July 19.

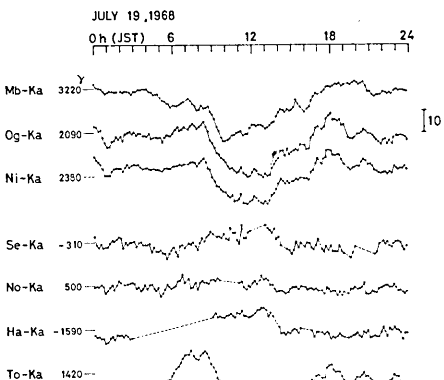

Fig. 3b. Daily variations of difference in the total intensity between each station and *Ka* on July 19.

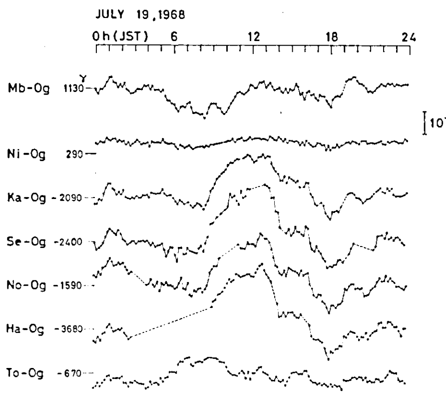

Fig. 3c. Daily variations of difference in the total intensity between each station and *Og* on July 19.

at the Japan Sea side. This type does not appear so frequently as the first type. Only six days were counted for the second type within the month examined. For this type the differences between the stations were also calculated and shown in Figs. 3b and c. They show the same features as in the case of the first type.

One of the third type variations took place on July 26. At all the stations south of *Ka*, disturbances of about four-hour duration are superposed on the maximum depression of normal daily variations in *F* as in Fig. 4.

An example of disturbed days is shown in Fig. 5a together with the differences between the stations in Figs. 5b and c. From these figures, it is clearly seen that the elimination of the external variations is much more difficult than in the case of the first and second type variations.

In order to investigate how the above three types of F variations are produced, magnetograms of three components (*H*, *D* and *Z*) at *Mb*, *Ka* and *Ky* were examined. The daily variations in the three components on July 30, 19 and 26 are shown in Figs. 6, 7 and 8.

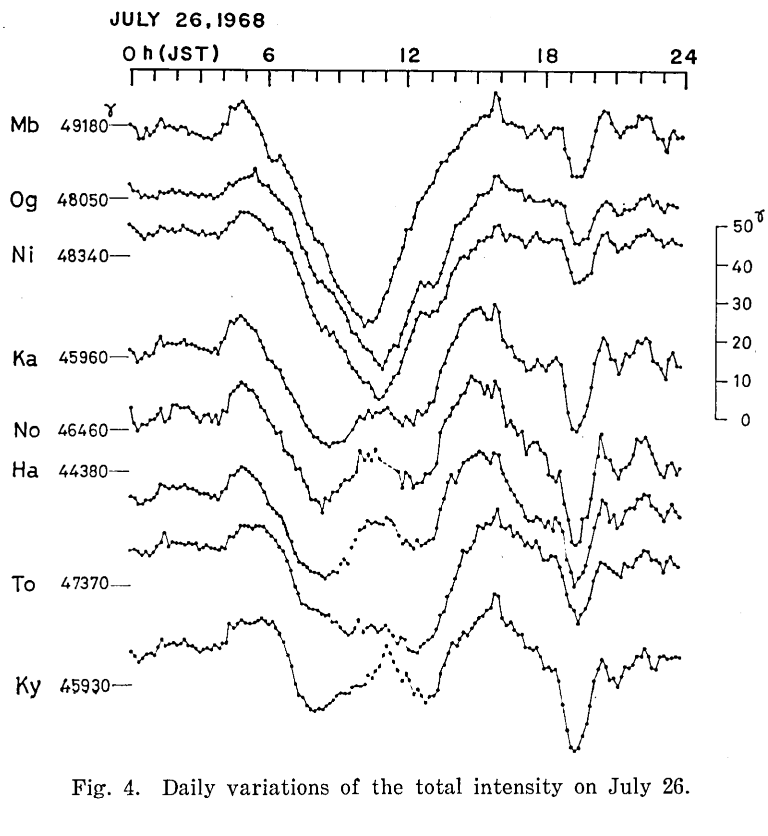

Fig. 4. Daily variations of the total intensity on July 26.

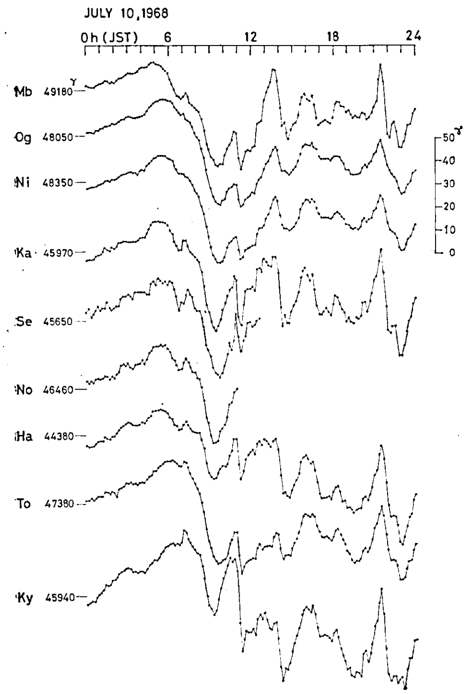

Fig. 5a. Daily variations of the total intensity on July 10.

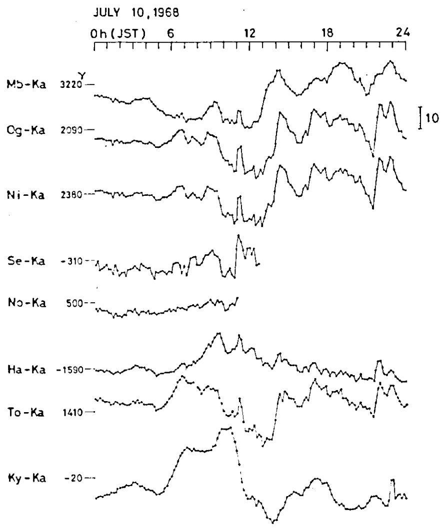

Fig. 5b. Daily variations of difference in the total intensity between each station and *Ka* on July 10.

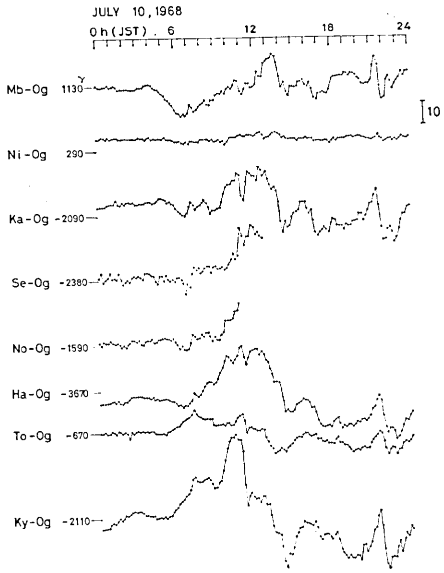

Fig. 5c. Daily variations of difference in the total intensity between each station and *Og* on July 10.

Estimating the center latitude of the overhead equivalent current system for the daily variation on the basis of Fig. 6, we see that the center passes the southern side of *Ky* on July 30, when the *F* daily variations are fairly uniform over Japan as it is seen in Fig. 2. We observe that the maximum decreases in the *H* component at *Mb*, *Ka* and *Ky* take place almost simultaneously. But those in the *Z* component at *Mb* and *Ka* occur about 80 minutes earlier than at *Ky*. It is almost certain, therefore, that the disagreement of the phase of daily variation in *F* between stations seems to be caused by the phase shift of *Z* component. A similar tendency is found for about 15 days of the month in addition to the day treated in the above.

On July 19 when the daily variation in F in the cetral area of Japan is very different from those in the area along the Japan Sea, the center of equivalent overhead currents passes near *Ka*. The phase of H component is nearly the same for the three stations. But the maximum decrease time of Z component is different from each other. The maximum decrease at *Mb* occurred about 80 minutes later than that at *Ka*. Meanwhile the maximum decrease at *Ky* lags about 90 minutes behind that at *Mb*. The F-curves near the maximum decrease time at *Og*, *Ni* and *To* are relatively flat in comparison with those at *Ka*, *Se*, *No* and *Ha*. This seems to be caused by the phase shift of H

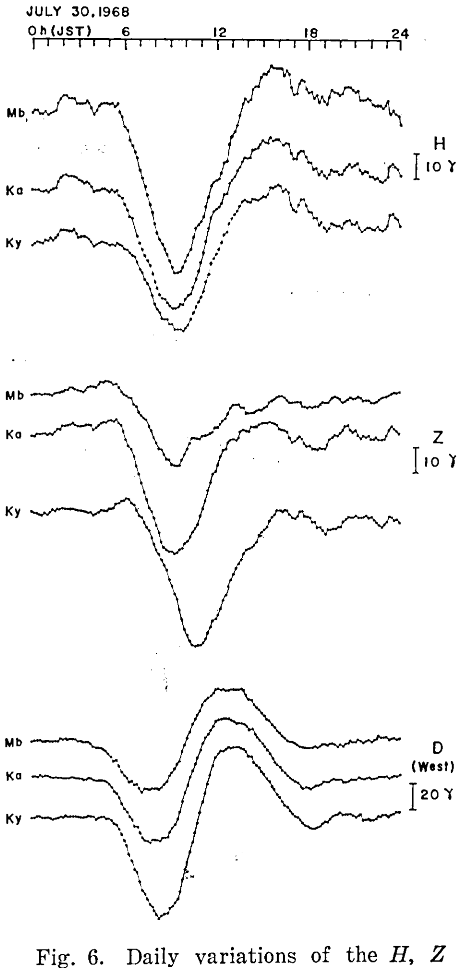

Fig. 6. Daily variations of the H, Z and D components at *Mb*, *Ka*, *Ky* on July 30.

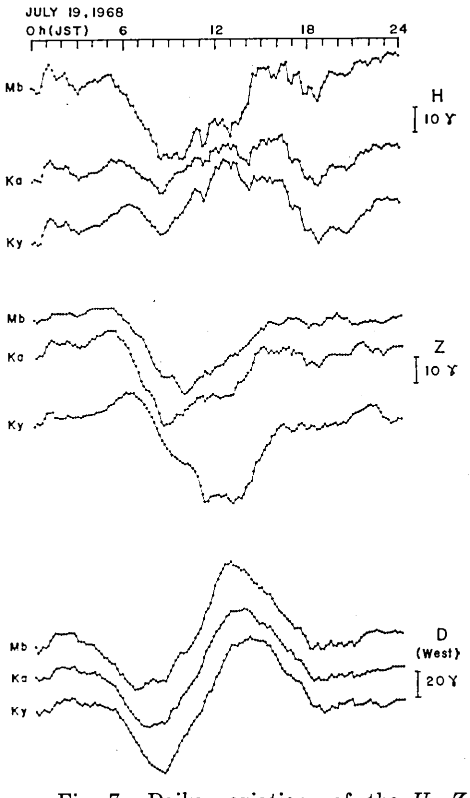

Fig. 7. Daily variations of the H, Z and D components *Mb*, *Ka*, *Ky* on July 19.

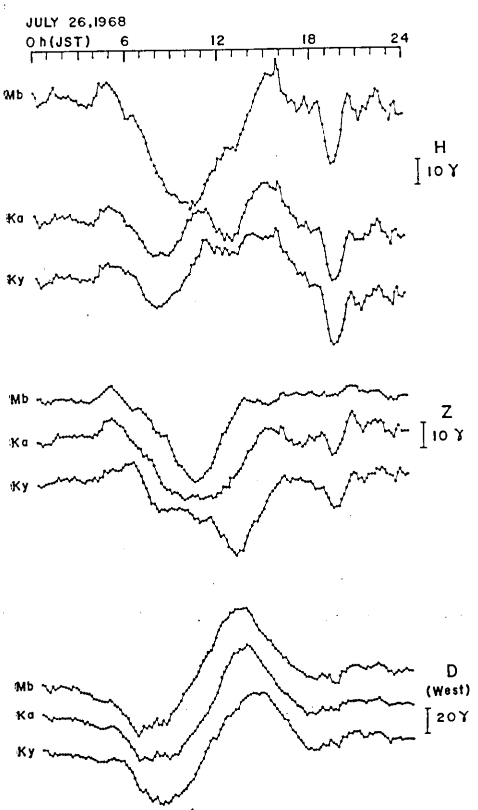

Fig. 8. Daily variations of the *H*, *Z* and *D* components at *Mb*, *Ka*, *Ky* on July 26.

and *Z* components at *Og*, *Ni* and *To*. For the other 5 days, we find a similar type of daily variation though their characteristics are not as clear as that on July 19.

On July 26, an additional positive change of *F* with a duration of about four hours appeared near the time of maximum decrease at stations on the southern side of *Ka* as is shown in Fig. 4. Looking at the daily variations of three components in Fig. 8, we see positive changes of *H* component between 08h and 13h at *Ka* and *Ky*. On the contrary, no change of that sort is observed at *Mb*. The reason why we observed such a complicated daily variation is not quite clear. It may be assumed either that the center of overhead equivalent currents of daily variation passes between *Ka* and *Ky* or that the center passes through the southern side of *Ky* and a short period variation of which the cause is not known is added to the normal daily variation only on the southern side of *Ka*.

2-2. *Amplitude and phase of daily variation*

General feature of the daily variation in *F* has been investigated qualitatively in the previous section. In this sub-section will be examined the amplitudes and phases of the daily variation at each station. The amplitude is defined by the range between the maximum value in the early morning and the minimum on the day considered. Meanwhile, the phase is represented here by the time of the minimum in *F*. When short period disturbances, such as a bay or si, are superposed on a daily variation around its maximum or minimum, the said amplitude or phase is measured so as to exclude the disturbances. If the disturbances are too intense or complicated, the amplitude and phase cannot be determined.

Table 2 shows the averaged value and standard deviation of the amplitude of daily variation in F for the month at each station. As shown in this table, the amplitude at each station has standard deviations ranging from 8 to 12γ. Table 3 shows those for the amplitude ratio at each station to *Ka* or *Og*. Table 4 shows those for the phase difference between each station and *Ka* or *Og*. When the phase of the heading station is advancing, the difference in the table is shown by a positive value. The upper parts of Tables 3 and 4 show the averaged values and the standard deviations for all the days for which the amplitude and the phase can be determined, while the lower parts show those obtained after omitting the four days of the first and second largest or smallest values.

Judging from the standard deviations of the amplitude ratio and the phase difference in Tables 3 and 4, stations *Ka*, *Se*, *No* and *Ha* seem to form one group, and stations *Mb*, *Og* and *Ni* another one. However, the geographical distribution of amplitude ratio and phase difference is rather irregular even if their extreme values are excluded. Therefore, it seems difficult to draw their contour lines all over Japan. Rikitake et al.[10] showed that the maximum decrease time of daly variation for

Table 2. Amplitude of daily variations in γ for the total intensity, July, 1968

	Mb	Og	Ni	Ka	Se	No	Ha	To	Ky
Monthly mean	45	47	45	46	38	44	37	43	40
Standard deviation	9.0	8.7	9.4	9.8	8.0	11.5	9.9	9.4	11.9

Table 3. Amplitude ratios of daily variations in the total intensity, July, 1968

		Mb	Og	Ni	Ka	Se	No	Ha	To	Ky
Average for all days	Amplitude ratio	1.01	1.04	1.00	1	0.88	0.95	0.80	0.98	0.92
	Standard deviation	0.23	0.18	0.18		0.08	0.09	0.09	0.13	0.20
	Amplitude ratio	0.96	1	0.98	0.99	0.89	0.97	0.80	0.95	0.88
	Standard deviation	0.12		0.04	0.15	0.14	0.19	0.16	0.17	0.33
Average for days excluding those of large deviations	Amplitude ratio	0.99	1.02	0.99	1	0.87	0.96	0.81	0.97	0.91
	Standard deviation	0.13	0.11	0.10		0.06	0.07	0.06	0.08	0.05
	Amplitude ratio	0.96	1	0.98	1.00	0.89	0.97	0.80	0.95	0.85
	Standard deviation	0.10		0.03	0.11	0.11	0.12	0.11	0.14	0.24

10) T. RIKITAKE et al., *ibid.*, 8).

Table 4. Phase differences in minutes of daily variations in the total intensity, July, 1968.
The value in ( ) is corrected for local time differences

		Mb	Og	Ni	Ka	Se	No	Ha	To	Ky
Average for all	Phase difference	(−30) −14m	(−41) −43	(−37) −37	0	(+ 1) − 2	(+ 6) + 3	(+ 5) + 3	(−25) −49	(− 5) −42
	Standard deviation	48	46	47		14	15	14	41	− 48
	Phase difference	(+12) 30	0	(+ 2) + 4	(+41) +43	(+60) +58	(+47) +45	(+51) +51	(+19) − 3	(+57) +31
	Standard deviation	29		6	46	37	46	49	49	70
Average for days excluding those of large deviation	Phase difference	(−35) −19	(−41) −43	(−37) −36	0	(+ 3) 0	(+ 5) + 2	(+ 4) + 2	(−20) −44	(0) −37
	Standard deviation	30	27	30		8	6	8	28	18
	Phase difference	(+10) +28	0	(+ 3) + 5	(+41) +43	(+59) +57	(+46) +44	(+49) +49	(+18) − 4	(+53) +27
	Standard deviation	16		5	27	32	22	22	37	46

the vertical component in the central part of Japan is earlier than at the other stations in Japan. The present investigation shows the same tendency for the total intensity as is shown in Table 4.

In spite of the short distance between *Se* and *No* on Oshima Island, 7 km only, the difference in the mean amplitude amounts to several per cent as is shown in Table 2. It is in agreement with the result by Rikitake et al.[4] that the amplitude at *No* is larger than at *Se*. As pointed out by them, the major parts of such an anomaly on an island may be caused by the magnetic field produced by electric currents induced in the sea surrounding the island. This shows that the elimination of non-local geomagnetic changes must be extremely difficult for the data from an island station.

Although the individual phase represented by the time of the minimum in F changes remarkably between 08h and 13h local time, some classifications may be possible as to the distribution of its difference for the data during July, 1968. The following 5 classes are found, where the differences of less than 30 minutes in local time are neglected.

(1) No phase difference ; 4 days
(2) (*Ka, Se, No, Ha*) : (*Mb, Og, Ni, To*) ; 9 days
(3) (*Ka, Se, No, Ha, To*) : (*Mb, Og, Ni*) ; 5 days
(4) Phase lag only at *To* ; 2 days
(5) The others ; 4 days

As to the remaining 7 days the phase cannot be determined because of considerable disturbances. In the cases (2) and (3), the phase of the station in a bracket is the same and the left advances more than 30 minutes. One of the days in (5) is contrary to (3). The phase at *Ky* is rather similar to that at *To* though only few data have been examined for this combination of stations.

The classification indicates that the stations may be divided into the following three groups. *Mb*, *Og* and *Ni* are the first, *Ka*, *Se*, *No* and *Ha* are the second, and *To* and *Ky* are the third. This is exactly the same as the result from the standard deviation. Considering these facts, it may be said that the daily variation in *F* in Japan can be classified roughly into three types each representing the northeastern, central and southwestern part of Japan, respectively.

The amplitude and phase of daily variation in *F* seem likely to be affected most seriously by the position of the center of overhead equivalent currents which undergoes considerable fluctuations from day to day. Although the writers tried to estimate the center path of the current systems from three component magnetograms at *Mb*, *Ka* and *Ky* during July, 1968 and to clarify the relation between the center position and the form, the amplitude or the phase of daily variation in *F*, no definite conclusion had been reached. But it seems likely that the phase differences become small all over Japan when the center passes over the southern side of Japan.

2-3. *Short period variation*

Examples of short-period variation of the total intensity are shown in Figs. 5 and 9, which are plotted by using ten-minute mean values and every one-minute values, respectively. As is clear in Fig. 5a, amplitudes of disturbance with durations from 1 to 3 hours at *Og*, *Ni* and *To* are smaller than those at other stations.

Rikitake[11] studied the distribution of the horizontal component of geomagnetic bay and similar changes in Japan. According to his study, the ratio of the change in the horizontal component (ΔH) at *Mb* to that at *Ka* is 1.49, and the differences in ΔH between the stations in Honshu and Kyushu are not greater than 20%. However, changes in the vertical component (ΔZ) is very dissimilar in Japan, and $\Delta Z/\Delta H$ changes from -1.0 to 1.2.[12),13),14),15),16)] $\Delta Z/\Delta D$ (ΔD: change in the magnetic east component) is much smaller than $\Delta Z/\Delta H$ at most stations. It has also been reported that the phase of ΔH differs from that of ΔZ at *To*[13] and

11) T. RIKITAKE, *J. Geomag. Geoelec.* **17** (1965), 95.
12) Y. KATO, *ibid.*, 6).
13) T. KUBOKI and H. OSHIMA, *Memoirs Kakioka Mag. Obser,, Supplementary* **2** (1966), 1.
14) Y. SASAI, *Bull. Earthq. Res. Inst.*, **45** (1967), 137.

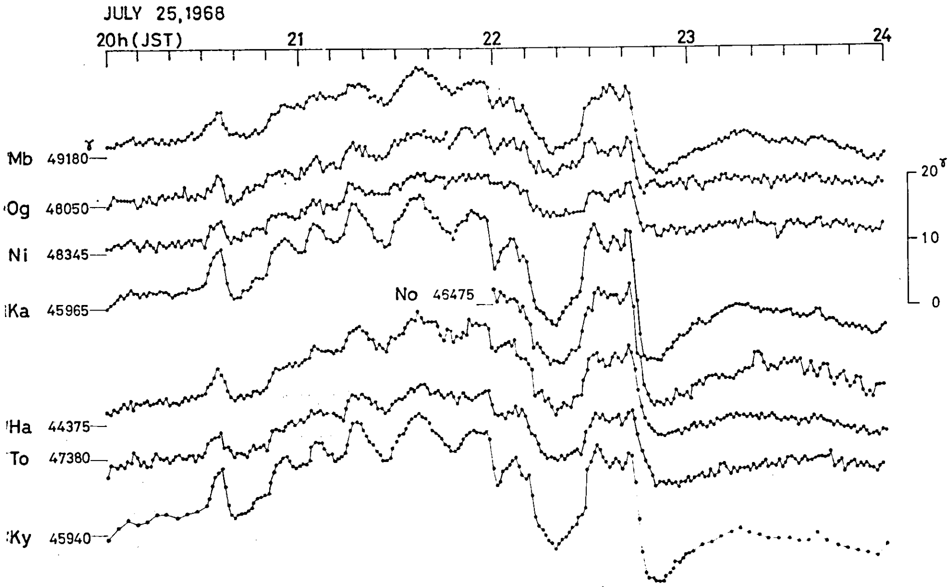

Fig. 9. Short-period fluctuations of the total intensity on July 25.

other stations near the coast of Japan Sea, while ΔZ is, to a high degree of approximation, in phase with ΔH at stations in the Central Japan Anomaly area.

Because changes in the total intensity (ΔF) depend on both ΔH and ΔZ, the amplitude of ΔF is controlled largely by $\Delta Z/\Delta H$, and the form of the variation may depend on the phase of ΔH and ΔZ and/or the value of $\Delta Z/\Delta D$. As seen in Figs. 5b and 5c, short-period variations in F are distributed in a complicated way. Fig. 9 also manifests the variability of amplitude of short-period variation with the duration from 10 to 30 minutes from station to station.

3. Fluctuations of hourly mean of the total intensity

In section 2, it has been mentioned that daily variation in F changes remarkably from day to day and from place to place. It should also be stressed that day-time values of F suffer severe fluctuations. On the other hand, fluctuations of night-time value are considerably smaller. In this section, the writers will investigate fluctuations in the total intensity separately for day-time and night-time values on the basis of the data

15) J. MIYAKOSHI, *Proc. the Symposium on Conductivity Anomaly in Japan held at Tottori*, Nov. 28 and 29, 1968.

16) S. UTASHIRO et al., *Proc. the Symposium on Conductivity Anomaly in Japan held at Tottori*, Nov. 28 and 29, 1968.

taken during the observation period. The night-time value is represented by the mean of observed values with one-minute interval from 00h to 01h, while the day-time one is that from 09h to 10h.

Figs. 10 and 11 show fluctuations of night values and their dif-

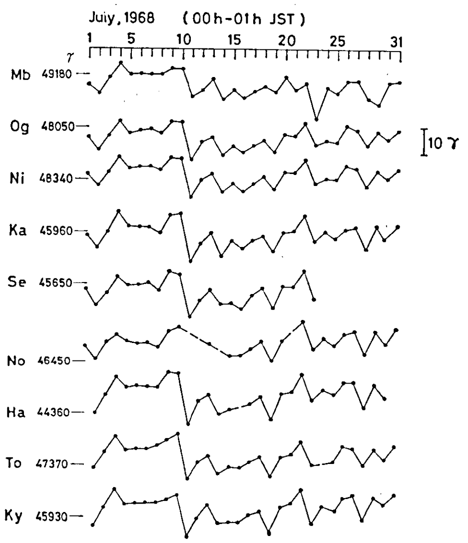

Fig. 10. Fluctuations of hourly mean value from 00h to 01h of the total intensity during July, 1968.

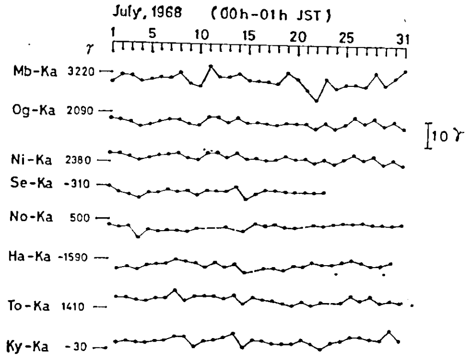

Fig. 11. Differences in the hourly mean value from 00h to 01h between each station and *Ka*.

ferences between each station and *Ka*, respectively, during July, 1968. The fluctuation of the hourly mean value is smaller than 20γ at all the stations. The fluctuation of the difference between each station and *Ka* seems to be insignificantly small though it becomes a little larger as the distance increases.

Fluctuations of hourly mean value for the hour from 09h to 10h at each station and thier differences between each station and *Ka* are shown in Figs. 12 and 13, respectively. The fluctuation of the day-time value is several times as large as that of the night value. The difference between each station and *Ka* also fluctuates in a wide range.

Standard deviations of the difference value for all the combinations of station are shown in Table 5. The standard deviation ranges from 0.5 to 3.1γ for the night-time value and from 1.2 to 12.3γ for the day-time value, respectively. This indicates that use of the data in the night-time is much better than that of the data in the day-time for getting accurate elimination of non-local geomagnetic change.

Table 5. Standard deviations in γ for the simple and the weighted differences in the mean value for periods 00h–01h (night-time hourly mean value), 00h 30m–00h 40m (10-min. mean value) and 09h–10h (day-time hourly mean value)

Combination	Distance (km)	Standard deviation (γ)				
		$00^h - 01^h$		$00^h30^m - 00^h40^m$	$09^h - 10^h$	
		Simple difference	Weighted difference	Simple difference	Simple difference	Weighted difference
Og - Ni	44	0.5	0.5(Og - 0.97 Ni) 0.5(Ni - 1.01 Og)	0.6	1.2	1.2(Og - 0.97 Ni) 1.2(Ni - 0.97 Og)
Mb - Ni	542	1.8	1.6(Mb - 0.78 Ni) 1.8(Ni - 1.01 Mb)	1.9	7.1	5.4(Ni - 0.63 Mb) 7.1(Mb - 1.09 Ni)
Mb - Og	574	1.9	1.7(Mb - 0.78 Og) 1.9(Og - 0.97 Mb)	2.0	7.0	5.5(Og - 0.61 Mb) 7.0(Mb - 1.03 Og)
Se - No	7.5	1.4	1.2(No - 0.85 Se) 1.3(Se - 1.05 No)	1.7	1.9	1.2(No - 0.86 Se) 1.3(Se - 1.57 No)
Ka - Se	175	1.2	1.1(Se - 0.92 Ka) 1.2(Ka - 1.03 Se)	2.1	2.5	2.2(Ka - 0.96 Se) 2.2(Se - 0.97 Ka)
Ka - No	182	1.8	1.7(No - 0.86 Ka) 1.8(Ka - 0.94 No)	1.9	3.3	3.2(Ka - 0.91 No) 3.3(No - 1.00 Ka)
No - Ha	183	1.9	1.4(No - 0.74 Ha) 1.8(Ha - 1.15 No)	1.9	3.9	2.8(No - 0.98 Ha) 2.8(Ha - 0.97 No)
Se - Ha	187	1.4	1.0(Se - 0.82 Ha) 1.2(Ha - 1.16 Se)	2.0	3.3	2.6(Se - 0.80 Ha) 3.1(Ha - 1.13 Se)
Ka - Ha	346	1.5	1.3(Ka - 0.85 Ha) 1.4(Ha - 1.08 Ka)	1.9	4.5	4.2(Ka - 0.91 Ha) 4.3(Ha - 0.96 Ka)
To - Ky	547	1.5	1.1(To - 0.83 Ky) 1.3(Ky - 1.11 To)	1.7	5.8	5.0(To - 0.77 Ky) 5.8(Ky - 1.02 To)
Og - To	694	1.0	0.9(Og - 0.87 To) 1.0(To - 1.09 Og)	1.1	5.7	5.2(Og - 0.80 To) 5.5(To - 0.88 Og)
Ni - To	730	1.0	0.9(Ni - 0.88 To) 1.0(To - 1.07 Ni)	1.1	6.6	6.0(Ni - 0.74 To) 6.5(To - 0.86 Ni)
Og - Ky	1240	1.6	1.2(Og - 0.77 Ky) 1.5(Ky - 1.17 Og)	2.1	8.6	7.0(Og - 0.53 Ky) 8.6(Ky - 1.00 Og)
To - Mb	1267	2.3	1.8(Mb - 0.69 To) 2.3(To - 1.07 Mb)	3.5	11.4	8.5(To - 0.48 Mb) 10.2(Mb - 0.68 To)
Ni - Ky	1274	1.8	1.4(Ni - 0.78 Ky) 1.7(Ky - 1.12 Ni)	2.2	8.9	7.3(Ni - 0.53 Ky) 8.9(Ky - 1.00 Ni)
Ky - Mb	1815	3.0	2.2(Mb - 0.60 Ky) 2.9(Ky - 1.08 Mb)	3.4	12.0	10.7(Ky - 0.48 Mb) 10.9(Mb - 0.50 Ky)
Og - Ka	416	1.4	1.0(Og - 0.82 Ka) 1.1(Ka - 1.15 Og)	1.7	6.2	5.3(Og - 0.68 Ka) 6.2(Ka - 1.01 Og)
Ni - Ka	419	1.2	0.9(Ni - 0.84 Ka) 1.1(Ka - 1.13 Ni)	1.7	6.3	5.4(Ni - 0.71 Ka) 6.3(Ka - 0.97 Ni)
Og - Se	576	1.1	0.9(Og - 0.86 Se) 1.1(Se - 1.10 Og)	1.5	7.0	5.0(Og - 0.39 Se) 6.8(Se - 0.73 Og)
Og - No	581	1.8	1.7(Og - 0.79 No) 1.8(No - 0.97 Og)	2.3	8.8	6.9(Og - 0.48 No) 8.8(No - 0.77 Og)
Ni - Se	585	1.2	1.1(Ni - 0.88 Se) 1.2(Se - 1.05 Ni)	1.5	6.5	5.4(Ni - 0.52 Se) 5.9(Se - 0.62 Ni)
Ni - No	591	2.2	2.0(Ni - 0.78 No) 2.1(No - 0.90 Ni)	2.5	8.8	7.2(Ni - 0.50 No) 8.6(No - 0.72 Ni)
Og - Ha	758	1.7	0.9(Og - 0.72 Ha) 1.3(Ha - 1.30 Og)	1.8	9.4	7.3(Og - 0.52 Ha) 9.2(Ha - 0.82 Og)
Ni - Ha	764	1.8	1.1(Ni - 0.73 Ha) 1.4(Ha - 1.26 Ni)	2.0	9.4	7.5(Ni - 0.53 Ha) 9.1(Ha - 0.79 Ni)
Ka - Mb	913	2.5	1.7(Mb - 0.65 Ka) 2.3(Ka - 1.15 Mb)	2.5	10.3	8.8(Ka - 0.57 Mb) 9.7(Mb - 0.70 Ka)
Se - Mb	1091	2.6	2.1(Mb - 0.65 Se) 2.6(Se - 1.06 Mb)	3.0	9.7	8.3(Se - 0.35 Mb) 8.9(Mb - 0.50 Se)
No - Mb	1097	3.1	2.6(Mb - 0.54 No) 3.0(No - 0.74 Mb)	3.7	12.3	9.9(No - 0.38 Mb) 11.3(Mb - 0.49 No)
Ha - Mb	1250	3.1	2.0(Mb - 0.54 Ha) 3.1(Ha - 1.22 Mb)	3.6	12.2	10.7(Ha - 0.44 Mb) 11.2(Mb - 0.49 Ha)
No - To	474	2.0	1.9(No - 0.85 To) 2.0(To - 0.99 No)	2.1	7.6	6.4(To - 0.62 No) 7.6(No - 0.88 To)
Se - To	478	1.5	1.5(Se - 0.95 To) 1.5(To - 0.95 Se)	2.0	5.6	4.0(To - 0.52 Se) 5.6(Se - 1.00 To)
Ka - To	541	1.3	1.2(Ka - 1.02 To) 1.2(To - 0.91 Ka)	1.5	6.4	5.7(To - 0.75 Ka) 6.4(Ka - 0.93 To)
To - Ha	575	1.3	1.0(To - 0.82 Ha) 1.2(Ha - 1.15 To)	1.4	7.4	6.5(To - 0.72 Ha) 7.4(Ha - 0.91 To)
Ha - Ky	860	1.4	1.3(Ky - 0.89 Ha) 1.4(Ha - 1.03 Ky)	1.5	7.8	7.3(Ha - 0.77 Ky) 7.5(Ky - 0.83 Ha)
No - Ky	871	1.9	1.6(No - 0.78 Ky) 1.9(Ky - 1.06 No)	1.9	7.3	7.1(Ky - 0.75 No) 7.3(No - 0.79 Ky)
Se - Ky	877	1.3	1.2(Se - 0.90 Ky) 1.2(Ky - 1.04 Se)	1.8	7.2	6.3(Se - 0.60 Ky) 6.7(Ky - 0.67 Se)
Ka - Ky	1009	1.7	1.6(Ka - 0.90 Ky) 1.6(Ky - 0.99 Ka)	2.1	7.6	7.1(Ka - 0.74 Ky) 7.5(Ky - 0.84 Ka)

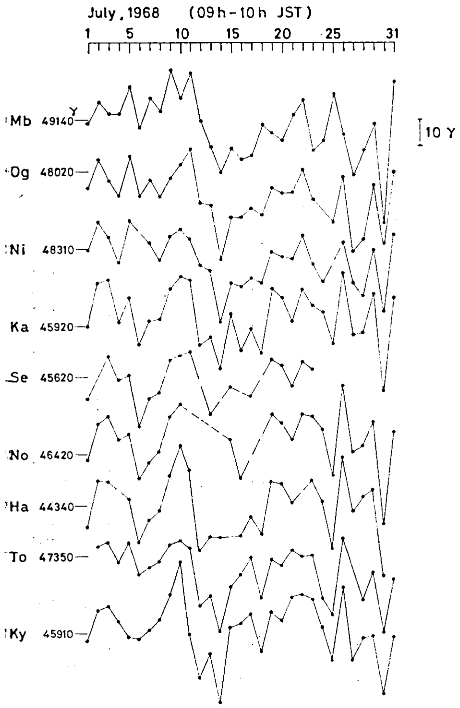

Fig. 12. Fluctuations of hourly mean value from 09h to 10h of the total intensity during July, 1968.

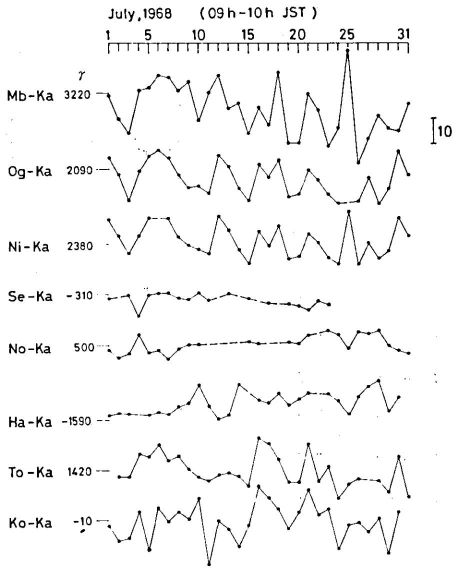

Fig. 13. Differences in the hourly mean value from 09h to 10h between each station and *Ka*.

Fig. 14 shows how the standard deviation changes with the distance between stations. Roughly speaking, it increases in proportion to the distance. Especially the increasing rate of the day-time value is very large.

Fig. 15 shows relations of the hourly mean values between two stations for all the combinations. All the relations shown in Fig. 15 can be classified roughly into the following three cases.

(1) Both the night-time and day-time values are found nearly on the same line (for examples, *Ni* versus *Og* and *Se* versus *No*).

(2) The night-time and day-time values seem to be distributed on two separate lines (for example, *Ha* versus *Ka*).

(3) The night-time values seem to have a linear relation, but no linear relation is held for the day-time values (for examples, *Mb* versus *Ha* and *Ky* versus *Mb*).

As a whole, the night-time values hold linearity almost always between two stations. On the other hand, the day-time values show similar linearity for some combinations but not always.

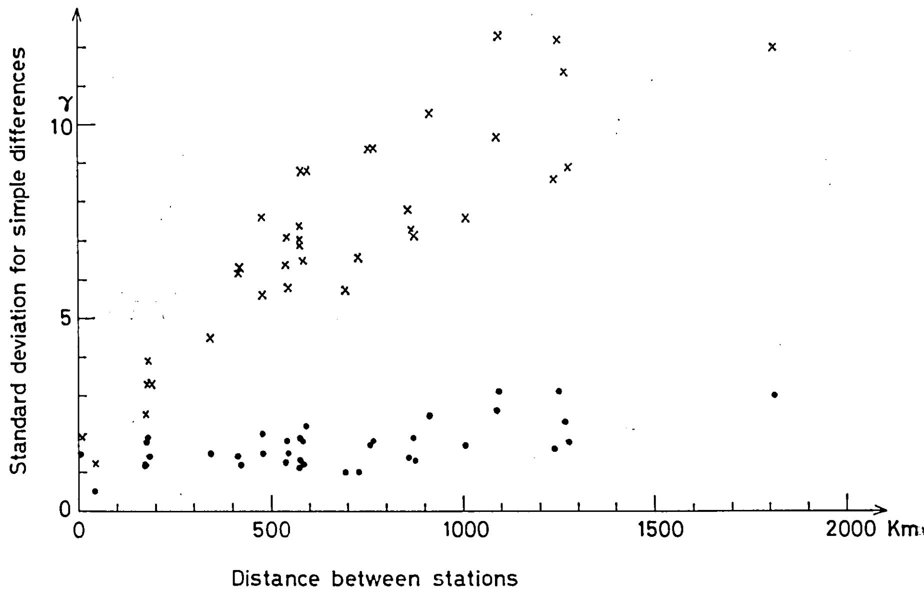

Fig. 14. Relation between standard deviation and distance.
●: hourly mean value from 00h to 01h.
×: hourly mean value from 09h to 10h.

As amplitude ratio of total intensity fluctuation at a station to that at other ones is not always 1, we will investigate in the following how the accuracy of elimination of non-local geomagnetic changes can be improved by using weighted difference instead of simple differences between two stations. Linear relations $F_A = aF_B + b$ or $F_B = a'F_A + b'$ are assumed between F_A and F_B which are observed as hourly mean values of total intensity at stations A and B, respectively. The coefficients a and a' are determined by the least square method. Standard deviations for weighted differences $F_A - aF_B$ and $F_B - a'F_A$ are calculated for all the combinations of stations. The standard deviations and the coefficients a and a' for the above day-time and night-time hourly mean values are shown in Table 5. By using the weighted difference instead of the simple difference, the standard deviation is reduced to a value smaller than 2.6γ for the night-time value even for combinations of widely separated stations in Japan. The improvement amount to as much as 50% at the most. As to the day-time data standard deviations are reduced also by using weighted differences. However, the reduced values are much greater yet than those for simple differences of night-time values.

Standard deviations for ten-minute mean values from 00h 30m to

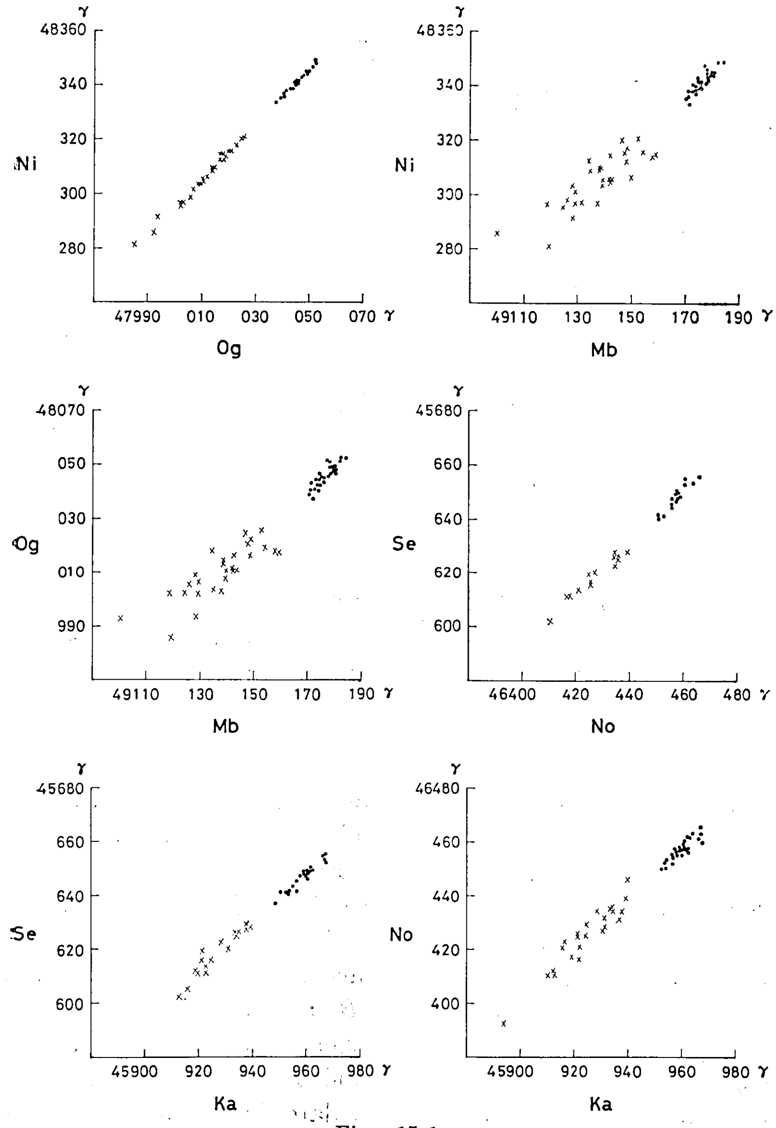

Fig. 15-1

Fig. 15. Correlations between hourly mean values for pairs of stations.
●: hourly mean value from 00h to 01h.
×: hourly mean value from 09h to 10h.

00h 40m are calculated in order to compare them with those for hourly mean values. As shown in Table 5, some of them are little larger than those for the hourly mean values from 00h to 01h, and there are also much larger ones. Such differences seem to be largely affected by local

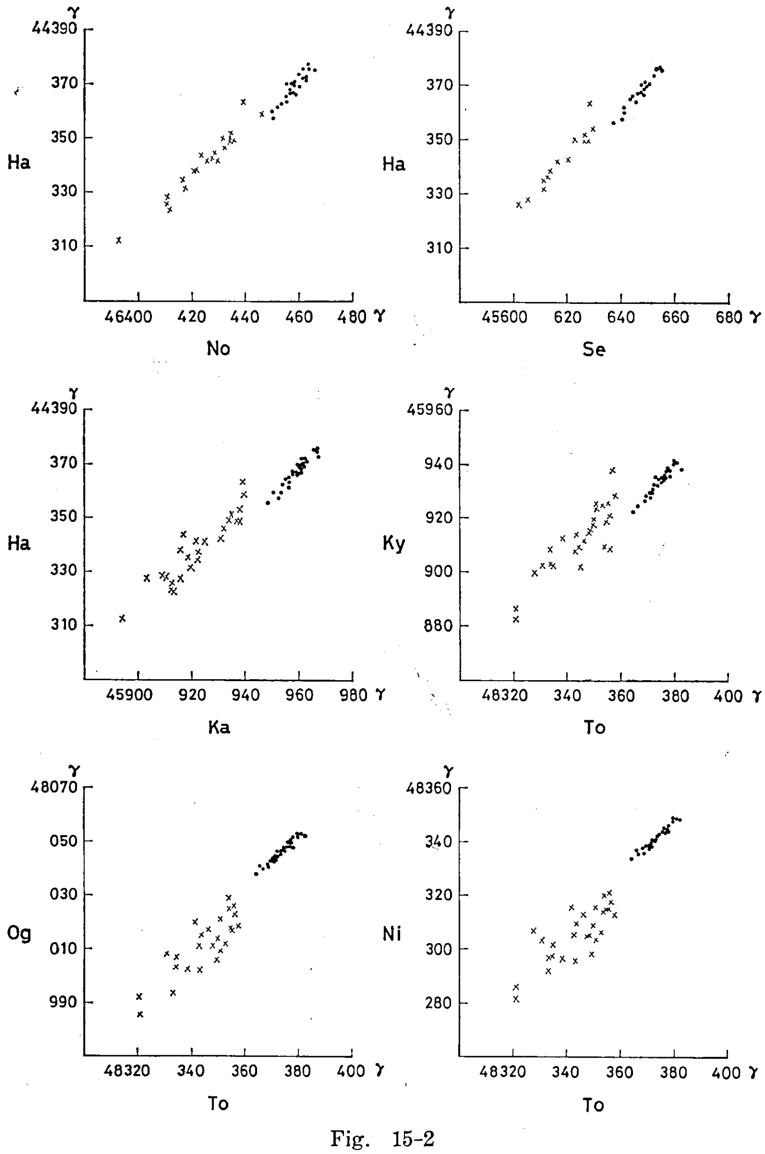

Fig. 15-2

differences in the vertical component for geomagnetic bays or similar changes.

4. Daily mean

In the last section, it has been shown that the use of hourly mean value in the night-time from 00h to 01h provides data for comparison

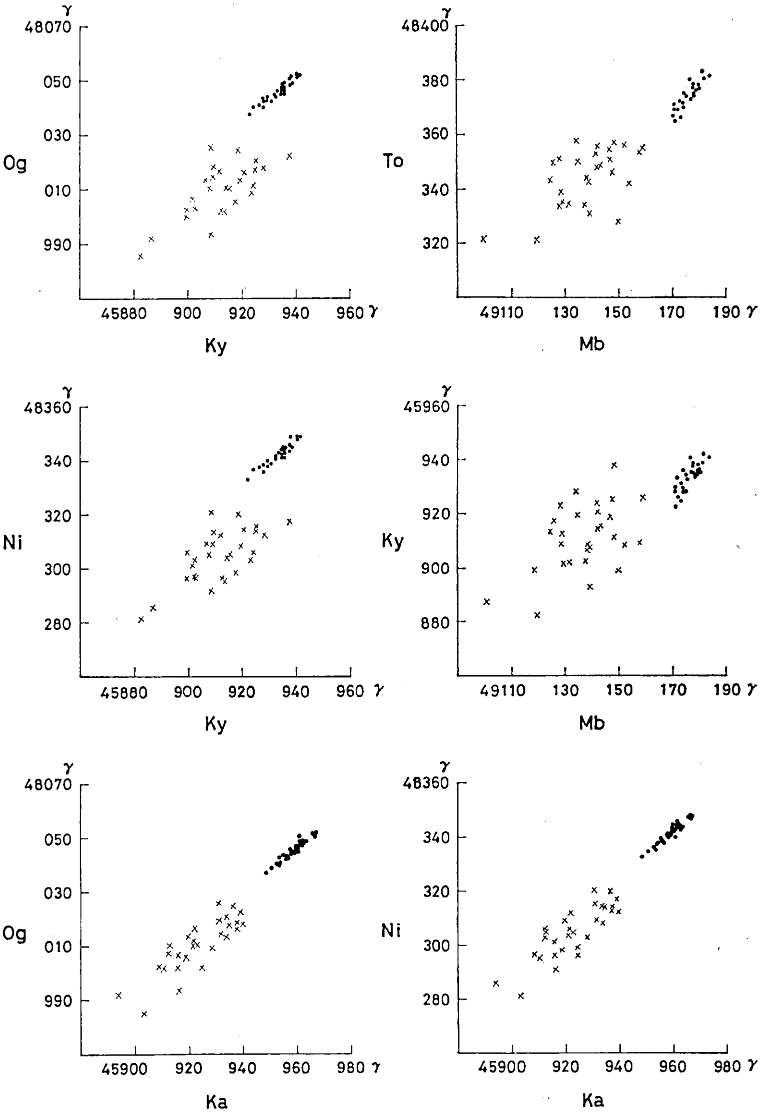

Fig. 15-3

between total intensity values at two stations with standard deviations smaller than 2.6γ for Japanese stations provided the weighted difference method is applied. Since, however, daily mean values have often been used for comparing the geomagnetic field at two observation points, it would also be of interest to see how the daily mean values including both the day-time and night-time data fluctuate.

In section 2-2, we have described that F daily variation can be

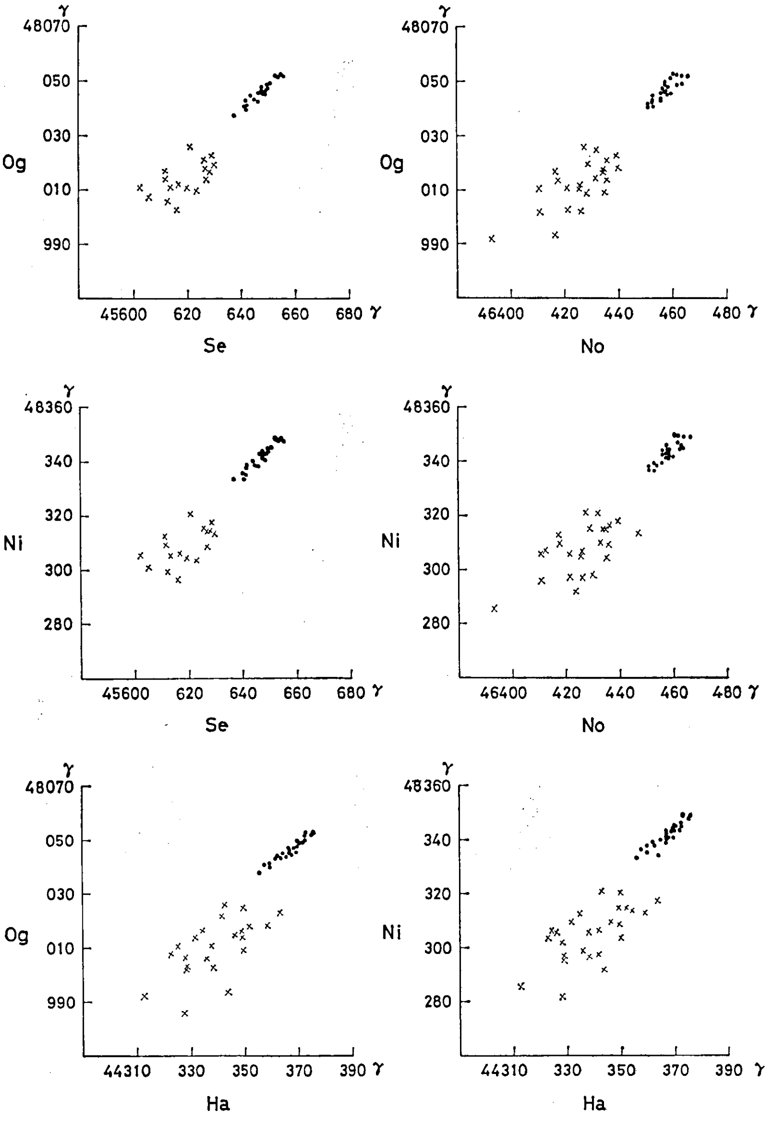

Fig. 15-4

classified roughly into three types which are found in the three areas, the northeastern, central and southwestern parts of Japan, respectively. Here, *Og*, *Ka* and *To* are selected as the representatives of the respective area. And *Ka* and *No* are taken as an example of the pair in the same area.

Fig. 16 shows fluctuations of the daily mean value at *Og*, *Ka*, *No* and *To*, and those of the difference for the pairs of *Og-Ka*, *Og-To*, *Ka-To*

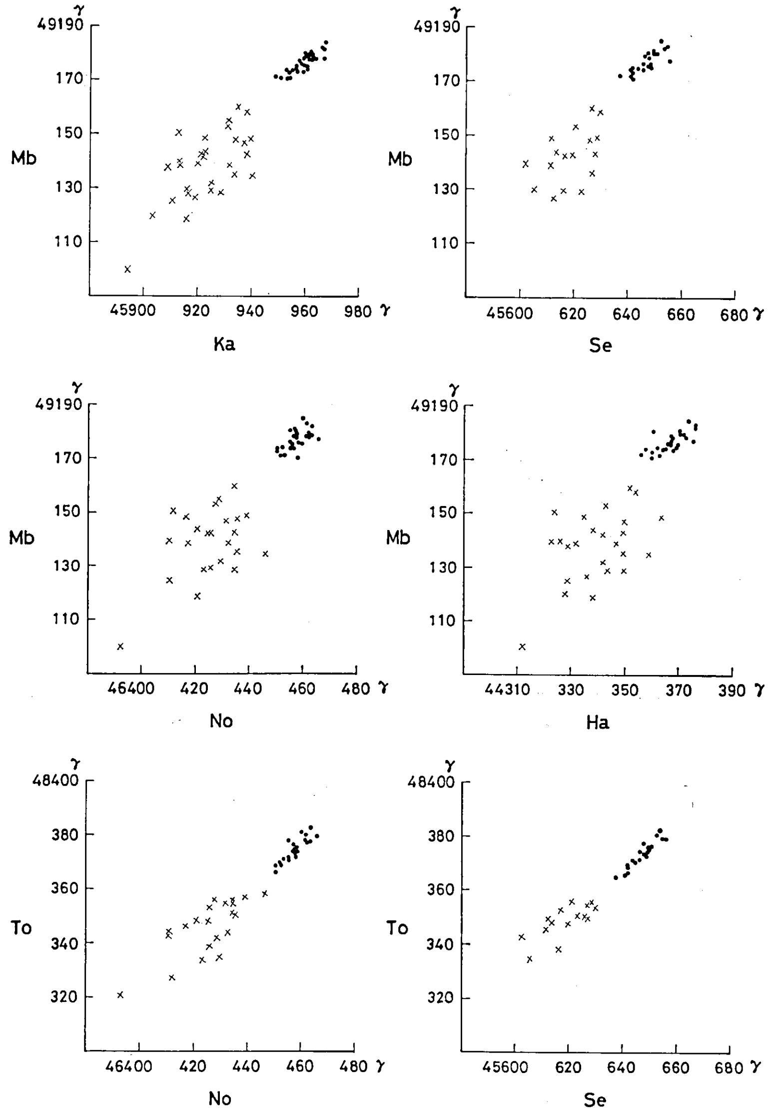

Fig. 15-5

and *No-Ka*. Those of the hourly mean value from 00h to 01h and the daily sum of *K*-index (Σk) at Kokioka are shown also in the same figure. ΣK is thought to represent the general feature of geomagnetic disturbance during the month. The daily mean value is generally 5-10γ smaller than the hourly mean value from 00h to 01h at each station. Fig. 17 shows the relations of daily mean value between two stations for the four combinations. The daily mean values seem to be correlated

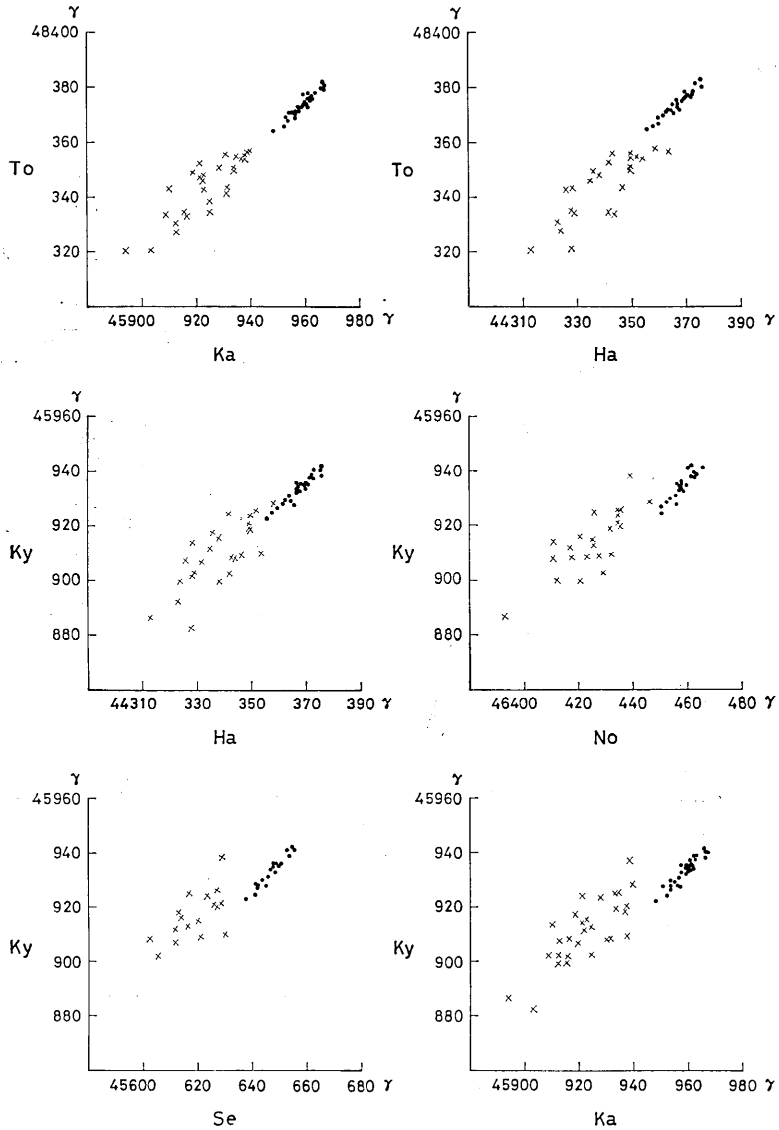

Fig. 15-6

approximately linearly to each other in a manner similar to that of the hourly mean values from 00h to 01h.

Standard deviations for simple difference of the daily mean value and for the simple and weighted differences of the hourly mean value are give in Table 6. As the number of days for which daily mean values are obtained at *No* is smaller than those at the others, the statistical accuracy may be low at *No*. The standard deviation of the simple difference

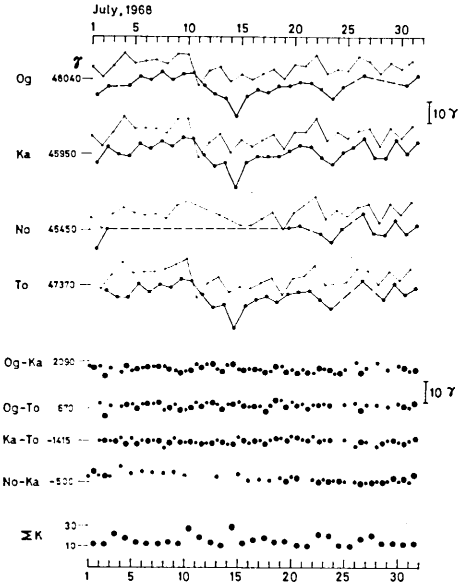

Fig. 16. Fluctuations of daily mean value and hourly mean value. The larger circles show daily mean values, while smaller ones hourly mean values from 00h to 01h.

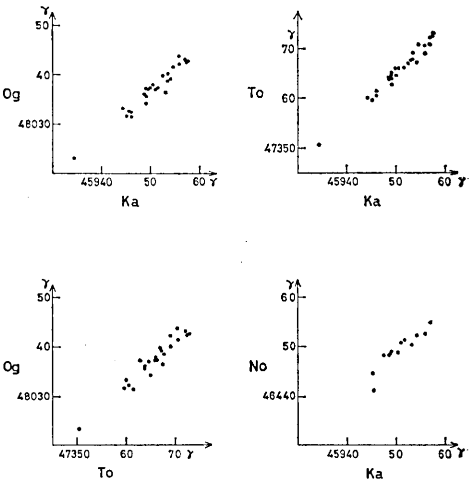

Fig. 17. Correlations between daily mean values for 4 pairs of stations.

Table 6. Standard deviations γ for the daily mean and night-time hourly mean value

Combination	Distance (km)	Standard deviation		
		00^h—24^h	00^h—01^h	
		Simple diff.	Simple diff.	Weighted diff.
Og — Ka	416	1.3	1.4	1.0
Og — To	694	1.4	1.0	0.9
Ka — To	541	0.9	1.3	1.2
Ka — No	182	1.5	1.8	1.7

of the daily mean value for the pair *No-Ka* is 1.5γ, which is the largest among the pairs considered, in spite of the smallest distance. This seems to be due not only to scanty data but also to the effect of induced electric currents in the sea surrounding *No*.

As seen in Table 6, the standard deviation of the daily mean value is not largely different from those of the hourly mean value. But it is interesting to note that the former is smaller than the latter for *Og-Ka* and *Ka-To*, while the situation is reversed for *Og-To*. The reason for such a difference in standard deviations seems to be ascribed to the geomagnetic variation anomaly. Short-period variations of the Z component at *Ka* are greatly different from those at the other two stations, *To* and *Og*. Hourly mean values are more influenced by the short-period variation than daily mean values, so that, for pairs including *Ka*, the standard deviation for daily mean values would be smaller than that for hourly mean values. On the other hand, for the pair *Og-To*, the latitude difference seems to play an important role and so the standard deviation for daily mean value could be larger than that for hourly mean values. The latitude differences for *Ka-To*, *Ka-Og* and *To-Og* are 43′, 3°40′ and 4°23′ respectively. As far as the present result is concerned, there is a tendency that the standard deviation of difference in daily mean value increases not with the distance but with the latitude difference between stations.

5. Daily variation of differences in the total intensity between two stations for a number of combinations of station

It has been studied in the foregoing sections that the fluctuation of differences in the total intensity between two stations is relatively small for data taken during the period from 00h to 01h although that for the period from 09h to 10h indicates an extremely large amplitude. In order to compare the total intensity at a station to that at another station, it has been suggested to make use of midnight values. It is of interest, however, to see to what extent the difference in the total intensity fluctuates for other hours of a day. Only four stations, *Og*, *Ka*, *To* and *No*, are used for the present study.

Differences in hourly mean value between two stations for combinations of *Og*, *Ka*, *To* and *No* are calculated and shown in Fig. 18. The dots show the monthly means of the difference in hourly mean value at respective hours between the indicated stations. Their standard deviations are shown by thick vertical lines. The thin lines indicate the range over which difference values are distributed. Then the top and bottom of the thin line indicate the maximum and minimum of the difference at the respective hour. Fig. 19 shows similar figures when we omit the period for which magnetic disturbances are considerable. The excluded hours, amounting to 97 hours, occupy 13% of the total.

It is observed that remarkably long vertical thin lines in the nighttime in Fig. 18, such as 22h for *Og-Ka* or 01h for *Og-To*, disappear in Fig. 19. It is concluded, therefore, that use of data taken during magnetic disturbances give rise to scattered values. In the day-time, the

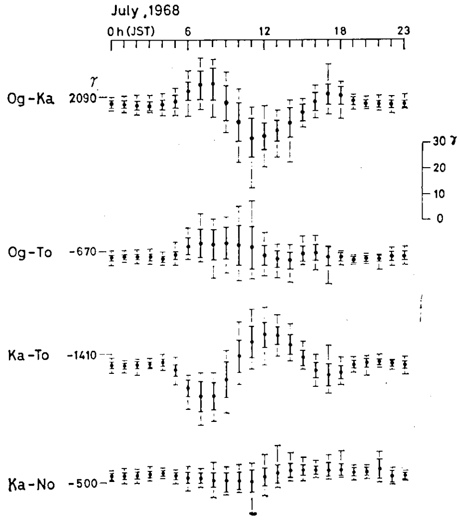

Fig. 18. Average daily variation of the difference in the total intensity during July, 1968. The dots, shorter thick lines and longer thin lines show the monthly mean values their standard deviations and maximum ranges, respectively.

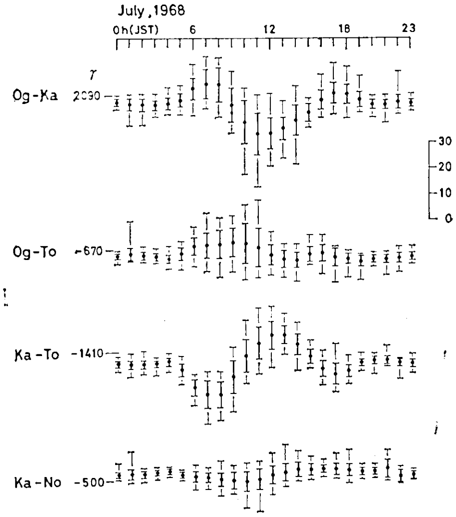

Fig. 19. Average daily variation of the difference in the total intensity as calculated from data from which those for disturbed periods are omitted. The dots, shorter thick lines and longer thin lines show the monthly mean values, their standard deviations and maximum ranges, respectively.

effect of disturbance cannot be found because the daily variation is large and variable. As is shown in Fig. 19, ranges of the difference which are indicated by thin vertical lines are smaller than 7γ in the night-time from 19h to 04h except for two cases of 21h for *Ka-No* and 04h for *Og-Ka*. It is likely, therefore, that the use of any hourly mean value in the night-time will bring about a statistical result similar to that of data from 00h to 01h as far as the difference is concerned. On the other hand, those in the day-time from 04h to 19h are from 20γ to 30γ even if disturbed hours are excluded.

Although only a few stations are considered in this section, the above result will be common for all stations. It is expected that the statistical result described in section 3 for the hourly mean value from 00h to 01h can be approximately extended to all the night hours from 19h to 04h.

6. Conclusions

Analysing the total intensity data taken at nine observatories covering Japan, it is found that the daily variation in F changes remarkably from day to day and from place to place even in such a narrow area as Japan. However, there exists a tendency that forms of variation at the stations situated along the Japan Sea are different from those at the stations in the central part of Japan. This seems to be caused by the difference in the underground electrical conductivity.

Although the phase and amplitude of daily variation are different from station to station over Japan as a whole, standard deviations of the amplitude ratio and phase difference are not so large if those in each of the following three areas are concerned, i. e. the northeastern, central and southwestern parts of Japan. It is doubtless that the daily variation is affected seriously by the path of the overhead current system. However, it seems likely that the daily variation is controlled by some unidentified causes probably including the underground electrical conductivity distribution.

The standard deviation of simple difference of hourly mean values from 00h to 01h amounts to about 3γ even for the most distant case for which the distance between two stations is about 1800km. If the distance is 500km or so, it is reduced to about 2γ. These values will indicate the accuracy when they are used for detecting a local geomagnetic change. As to the ten-minute mean value in the night-time, standard deviations are almost the same as those of the hourly mean value provided the vertical component of short-period variation is not so different between stations concerned. Those of the daily mean values are smaller than those of the night-time hourly mean value for pairs of stations of which the latitude difference is small. On the other hand, the standard deviation for daily mean is larger than that for night-time hourly mean for stations which are subjected to a large geomagnetic variation anomaly. The standard deviation of the hourly mean value in the day-time is very large. It is larger than 5γ when the distance is larger than several hundred kilometers.

If the weighted difference is used instead of simple difference, the standard deviation of hourly mean value in the night-time can be made as small as 2.6γ or less. If the distance between two stations amounts to a few hundred kilometers or smaller, the standard deviation becomes much smaller. The standard deviation for simple difference is slightly larger, say 3γ or so. For the day-time data similar improvement can be achieved when the weighted difference is used, but even in this case the standard deviation is much greater than that for the night-time simple difference.

It is concluded that, if the weighted difference of hourly mean value in undisturbed night-time is used, the standard deviation is reduced to 1γ or so for a pair of stations of which distance is less than 500km provided that the island effect is excluded.

To improve further the accuracy of eliminating non-local geomagnetic changes, proper account should be taken of daily variation, magnetic storm and the like although the writers have no concrete idea about how to achieve this at the moment. Probably it would be most important to carry out measurements at more stations for improving the accuracy.

Acknowledgments

The writers would like to express their thanks to Prof. T. Rikitake for his constant guidance and encouragement. They also wish to thank Dr. K. Yanagihara and Dr. T. Yukutake who eagerly gave us advice and suggestions. Our thanks are also due to the members of the C. A. group who conducted the magnetic observation and permitted the writers to use the data. Acknowledgment is due to Mr. Y. Sasai for his kind assistance in compiling the computer program.

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47. 日本における地磁気全磁力変化の地域差

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地震予知研究計画の一環として，地磁気永年変化精密観測のためのプロトン磁力計が各地に設置された．この磁力計を用いて磁気嵐や日変化などの非局地的磁場変化を日本全土についてどの程度除去できるかを調べた．解析に使用した記録は1968年7月の1ヶ月間で，この期間地震予知地磁気グループではプロトン磁力計の保守に万全を期した．

まず，全磁力日変化について調べた．その振巾や位相は各地で大きく異り，日本全体にわたってcontourを描くことはむずかしいが，日本を大略東北日本，中央日本および西南日本の3ブロックに分類した各ブロック内では地点間の振巾比や位相差の分散は小さくなる．

次に，各地点の全磁力値を比較したが，夜間(19h～04h)の1時間平均値を用いると，観測点間の距離が1800 km以内のときは2地点間の差の単純差の標準偏差は約3γ以内，重価差の場合は約2.5γ以内になる．地点差の日変化が大きく変動するため日中の値を比較すると標準偏差は非常に大きくなる．離島効果の影響を受けていると思われる観測点を除くと500 km以内で夜間値，重価差の標準偏差が1γ前後になることが期待される．
