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7. *Geomagnetic Noises and Detectability of Seismo-magnetic Effect (1).*

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Summary

Geomagnetic total intensity values at various stations in the central part of Japan are examined with the intention of investigating into the accuracy of mutual comparison. The data from stations in the Matsushiro area lead to a conclusion that simple difference values are distributed with a standard deviation slightly smaller than 2γ on quiet days. Use of a mixing technique is suggested for making accidental noises small.

A detailed examination of the data from Kanozan and Oshima, 81 km distant from one another, suggests usefulness of a weighted difference technique which leads to a standard deviation smaller than 2γ.

Similar study on the data from two stations on Oshima Island brings out an extremely noisy example. No practicable way of correcting the data to an extent cited above is found.

1. Introduction

Detection of geomagnetic changes associated with an earthquake has recently been drawing much attention of seismologists and geomagneticians. Since the introduction of proton precession magnetometer to field observation, it has become possible to make an accurate observation of the earth's magnetic field without being bothered by drift of base-line values which used to be a serious problem in actual observation by the classical method. The accuracy of observation by a proton precession magnetometer being $\pm 1\gamma$, it seemed easy to compare the total intensities of the geomagnetic field between two stations at a moderate distance with an accuracy of the same magnitude.

It turned out by recent studies,[1,2] however, that geomagnetic changes at stations in a relatively small area such as that in central Japan are substantially different from one another. It is therefore made clear that simple differences between the total intensity values simultaneously observed at two stations are not necessarily free from non-local geomagnetic changes. Detectability of a seismo-magetic change, if any, is thus subject to a certain limit which is probably different from place to place.

Stacey and Westcott,[1] who made use of about 33,000 sets of synchronized measurements with a 36 sec. interval, concluded that the difference values between two stations, 25 km apart, in England scattered around the mean values respectively with standard deviations 0.85γ and 0.21γ for the individual and 24-hour average values.

Rikitake[2] has shown that simple difference values in the instantaneous total intensity between stations in central Japan, the distances between them being 100–200 km, scatter around the mean value with a standard deviation of about 3γ. If we use the data taken at night-time only, the standard deviation becomes 2.5γ or thereabouts. Rikitake suggested the use of a weighted difference technique which bases on the fact that the total intensity values at a station are systematically larger or smaller than those at another station. The standard deviation for individual values becomes around 2γ when the weighted differences are used for the night-time dada. Rikitake also noticed that similar standard deviations for the simple differences between a station on main land and that on an island in Japan Sea exceeds 4γ.

In the light of these results, it is felt that some drastic improvement should be made for the comparison technique of the total intensity values taken at various stations in Japan, otherwise geomagnetic noises would be so large that a seismo-magnetic effect, which is likely to amount to only several gammas[3] in conceivable cases could be almost masked. There is a reason to believe that this kind of geomagnetic noise could be large in Japan because we have been observing an enormous anomaly in geomagnetic variations there.[4] Such an anomaly having been generally believed to be caused by some complicated distribution of the underground electrical conductivity, it is therefore unavoidable

1) F. D. STACEY and P. WESTCOTT, *Nature*, **206** (1965), 1209.
2) T. RIKITAKE, *Bull. Earthq. Res Inst.*, **44** (1966), 1041.
3) T. YUKUTAKE and H. TACHINAKA, *Bull. Earthq. Res. Inst.*, **45** (1967), 785.
4) T. RIKITAKE, *Geophys. Journ. Roy. Astr. Soc.*, **2** (1959), 276.

that geomagnetic variations widely vary from place to place even though the magnetic fields arising from outside the earth are distributed regularly over Japan.

The writers intend to investigate into the characteristics of the noises and, if possible, to eventually find a way by which we obtain a large signal-to-noise ratio for eliminating non-local changes. Since it is highly likely that the nature of the noises differs from place to place, it has been planned to examine geomagnetic data at every available occasion. In this paper will be reported the first work in this line.

The present paper will be divided into three parts. First of all the data in the Matsushiro area, where we have been experiencing a swarm activity of earthquakes from 1965 on and an array of proton precession magnetometers has been at work, will be examined as an example of comparison between relatively near stations. The data will also be compared to those at permanent observatories some 200 km distant. Secondly, the noises in the case of a comparison between the total intensity values at two permanent observatories, Kanozan and Oshima, will be thoroughly examined with an extensive set of data. Thirdly and lastly, an example of an extremely noisy case as found at two stations on Oshima Island, a small volcanic island about 100 km south of Tokyo, will be reported.

2. Data from the Matsushiro area

An extensive observation of changes in the geomagnetic field has been carried out by an array of proton precession magnetometers in the Matsushiro area,[5),6),7),8),9)] the location of which being indicated in Fig. 5. As can be seen in Fig. 1, magnetometers were operated by the Earthquake Research Instititute, Japan Meteorological Agency and Shinshu University at 6 stations within a distance of roughly 40 km. The usual way of observation was to make observations 6 times with a time-interval of 2 minutes commencing at 1 h 01 m local time. We denote the mean values of the 6 observations by $\overline{F}_N$, $\overline{F}_H$, $\overline{F}_M$, $\overline{F}_{SO}$, $\overline{F}_{KO}$, and $\overline{F}_{SA}$ which are available every day.

5) T. RIKITAKE et al., *Bull. Earthq. Res. Inst.*, **44** (1966), 363.
6) T. RIKITAKE et al., *Bull. Earthq. Res. Inst.*, **44** (1966), 409.
7) T. RIKITAKE et al., *Bull. Earthq. Res. Inst.*, **44** (1966), 1335.
8) T. RIKITAKE et al., *Bull. Earthq. Res. Inst.*, **44** (1966), 1735.
9) T. RIKITAKE et al., *Bull. Earthq. Res. Inst.*, **45** (1967), 395.

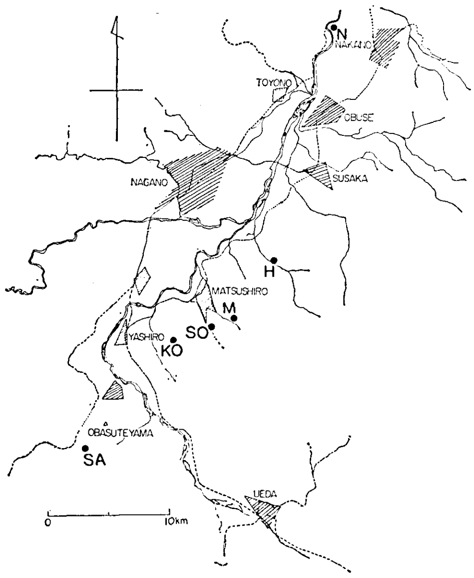

Fig. 1. Proton precession magnetometer array in the Matsushiro area.

Although the seismic activity was so high in the 1966 summer that a clear-cut geomagnetic change associated with it was observed,[9] we do not think that any definite geomagnetic effect took place towards the end of that year and later. In order to investigate into geomagnetic noises over the Matsushiro area, we therefore selected a period from Dec. 1, 1966 to Feb. 28, 1967.

The whole days are classified into three groups. Group A contains data for days magnetically very quiet at the observation time, Group B is for days slightly disturbed (preceded geomagnetic bays do not completely end by the observation time), and Group C is for disturbed days for which the observations are made definitely in the course of geomagnetic bays or similar changes. Groups A, B, and C contain 42, 17 and 17 days respectively.

2-1. Dispersion of the difference values

Picking up pairs of stations, simple differences in the mean geomagnetic total intensity between them are made. Since similar data for the same period are available from two permanent observatories, Kanozan and Oshima, they are also involved in the present study. The mean values from these observatories are respectively denoted by $\overline{F}_K$ and $\overline{F}_O$.

In Table 1 are given the standard deviations for each pair of stations separately for A, B and C groups. The histograms for all the pairs are shown for Groups A and C respectively in Figs. 2a and 2b. From the table and figures, it is apparent that the dispersion of difference values is small for magnetically quiet days, i.e. the standard deviations amount to 2γ or smaller for combinations of stations in the Matsushiro area and 2.5γ or thereabouts for combinations of those stations and Kanozan and Oshima which are more than 200 km distant

Table 1. Standard deviations in γ for the simple difference values for all the combinations of stations as classified into A (quiet), B (intermediate) and C (disturbed) groups.

Combination	Standard deviation (γ)			Distance between stations (km)
	A	*B*	*C*	
M—N	1.9	2.1	2.3	26
M—H	1.6	1.9	2.7	6
M—KO	1.7	1.5	3.1	7
M—SA	1.7	2.5	1.6	16
M—SO	2.1	1.8	1.4	2.5
M—K	2.3	3.9	5.9	242
M—O	2.3	3.2	4.6	227
N—H	1.7	2.1	2.1	20
N—KO	1.7	2.3	3.5	33
N—SA	1.8	2.6	3.5	41
N—SO	1.9	2.3	2.8	28
N—K	2.3	3.7	5.9	250
N—O	2.2	3.3	4.8	235
H—KO	1.4	1.8	3.8	12
H—SA	1.3	1.8	2.9	22
H—SO	1.8	1.7	3.1	12
H—K	2.3	2.7	5.8	245
H—O	1.8	2.2	4.7	230
KO—SA	1.8	1.9	1.7	10
KO—SO	2.3	1.1	2.4	5
KO—K	2.6	3.0	5.3	243
KO—O	2.0	2.5	3.6	230
SA—SO	2.1	1.1	1.4	14
SA—K	2.0	2.2	2.9	245
SA—O	1.8	1.9	1.9	230
SO—K	2.7	2.6	5.7	242
SO—O	2.8	2.0	4.1	227
K—O	2.3	2.0	2.6	81

from the Matsushiro area. But the standard deviations become larger and scattered when the frequency distributions on disturbed days are considered. It is remarkable that the standard deviations for such days exceed 5γ for the difference values between stations in the Matsushiro area and Kanozan and Oshima. The situation can be clearly observed in Figs. 2a and 2b in which we see that the histograms become extreme-

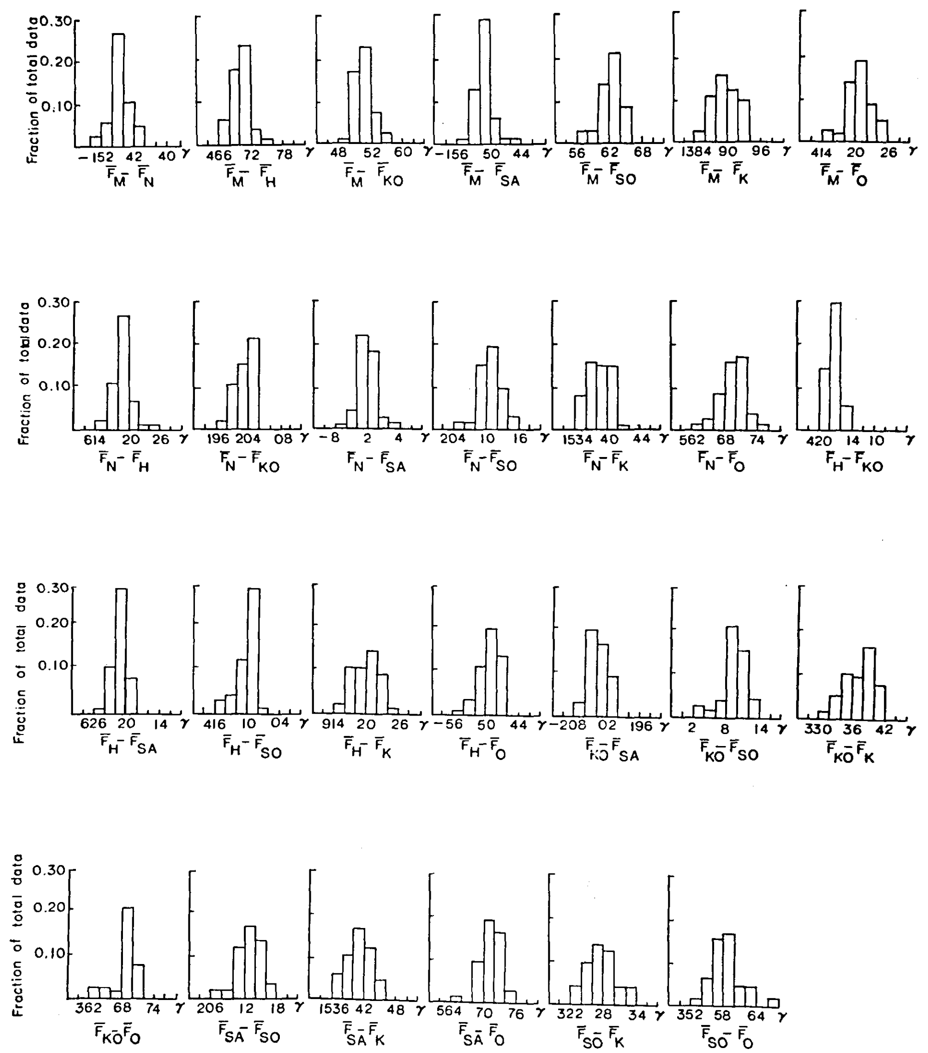

Fig. 2a. Histograms for the simple differences between all the pairs of stations for Group A (quiet days).

ly flat for disturbed days in the combinations of distant stations.

In the previous paper,[2] one of the writers (T.R.) has reached a conclusion that night-time simple differences between Station M and Stations K or O could involve a standard deviation amounting to 2.6γ or so for undisturbed days. The conclusion seems to fit in with the result of the present study which bases on a set of more homogeneous

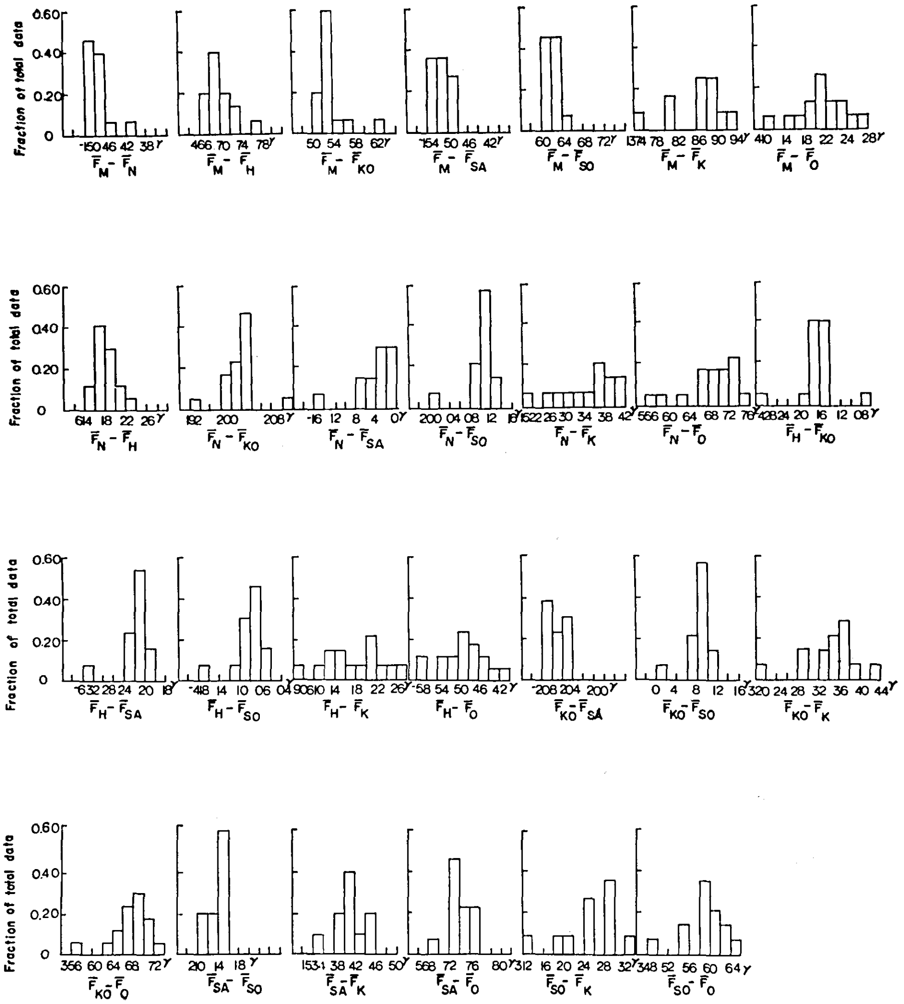

Fig. 2b. Histograms for the simple differences between all the pairs of stations for Group *C* (disturbed days).

data than the previous ones. Before this study, the writers wondered if a comparison between the geomagnetic field intensities at relatively close stations such as those in the Matsushiro area could be made with an accuracy less than 1γ. Contrary to expectation, however, the present work makes it clear that, even in such a narrow area, the geomagnetic field does not fluctuate uniformly. Consequently, the standard deviation for disturbed days is considerably larger than that for quiet days.

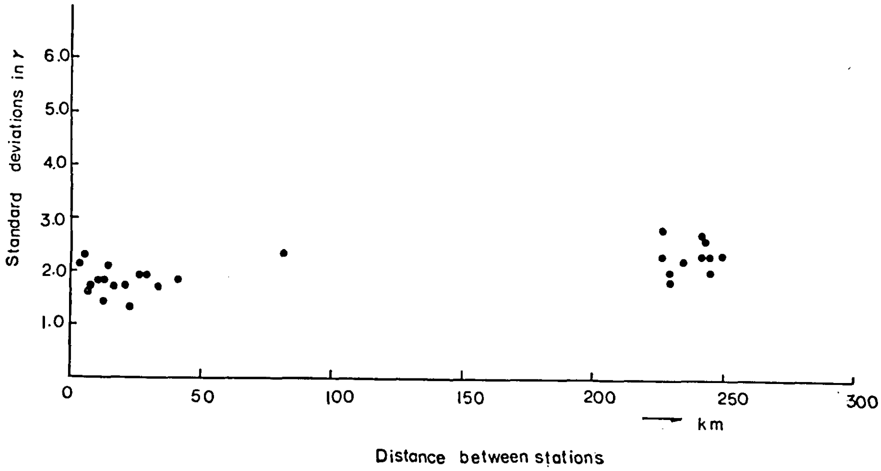

Fig. 3a. Standard deviation versus distance relation for quiet days.

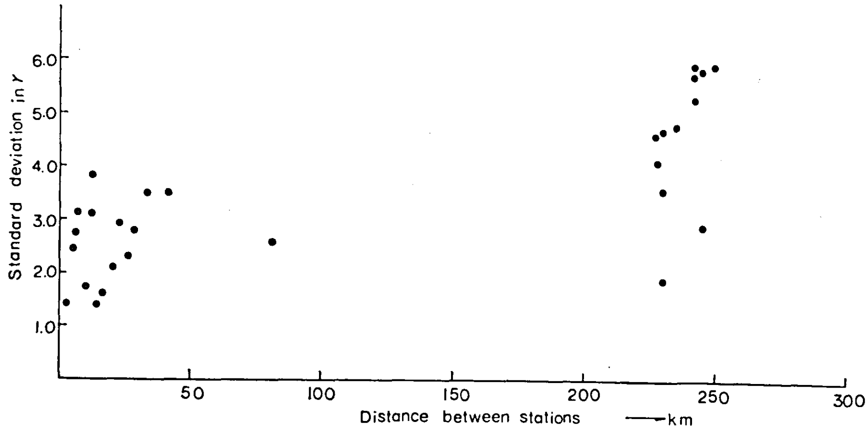

Fig. 3b. Standard deviation versus distance relation for disturbed days.

Figs. 3a and 3b indicate how the standard deviations change with the distance between stations for quiet and disturbed days. In spite of a great scatter of plotted points in the figures, we still observe an increase in the standard deviation with the distance. Such an increase is considerable for the data on disturbed days.

2-2. Possible application of mixing technique

Most likely the differences in the geomagnetic field between stations in such a narrow area as the present one would be caused by differences in the electromagnetic induction effect within the earth. No exact reason why we observe such differences of extremely local character has been known. Rikitake et al.[10] reported on a great gradient of geomagnetic change as observed by a rubidium magnetometer with two sensing heads set on the summit of Mt. Minakamiyama, the centre of the Matsushiro seismic activity, with a distance of about 100 m. The gradient, which is dependent on rapidity of geomagnetic change, is incredibly large sometimes amounting to a few per cent of the original change for geomagnetic bays.

In addition to the above effect, there should certainly be the influence of noisy magnetic fields produced by stray electric currents from the railways which are mostly operated by d.c. in this part of Japan. Although the observations are made during the midnight period when the effect is thought to be the smallest, it is still likely that night-trains are running somewhere far away from the observation points. The magnetic noises of this origin would certainly differ from station to station, so that it might be possible to lessen noises by mixing the observed results at each station of the magnetometer array. Such a mixing would also be useful for making the influence of local induction effect smaller.

In the hope of testing the mixing technique, we calculate the deviations of the observed values from the mean value for each quiet day at a station. The histograms for such deviations are illustrated in Fig. 4 for respective stations. The standard deviations of these distributions are estimated as shown in Table 2. The average of these 6 distributions is also calculated, its histogram being included in Fig. 4 and its standard deviation being given in Table 2, too. It is then noticed that the standard deviations become somewhat smaller, so that the influence of any accidental noise at one of the stations becomes unimportant by making use of the mixing technique. Although no dramatic improvement for eliminating noises to the geomagnetic field observation is possible in the present study which bases on a rather scanty set of data, it would certainly be worthy of making use of the mixing technique as suggested here in comparing the geomagnetic fields between two areas moderately separated. The writers suggest possible use of an array station formed by a number of proton precession magnetometers placed at satellite points with distances of a few kilometers with one another for representing an instantaneous geomagnetic total

10) T. RIKITAKE et al., *Bull. Earthq. Res. Inst.*, **45** (1967), 919.

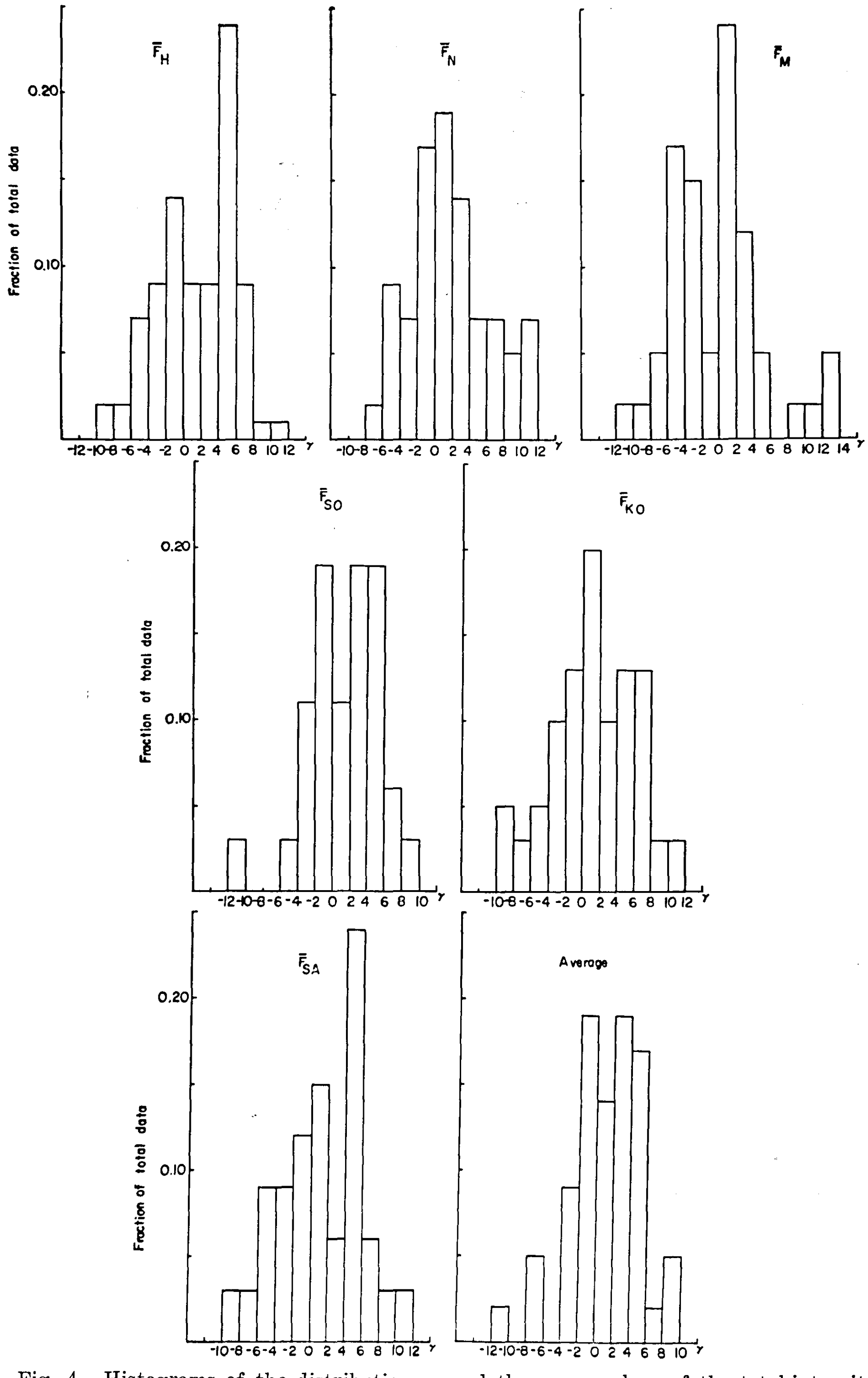

Fig. 4. Histograms of the distribution around the mean values of the total intensity of the geomagnetic field at the six stations in the Matsushiro area. The average distribution is also shown.

Table 2. Standard deviations in γ for the deviations from the mean values for the 6 stations and the average of them.

Station	Standard deviation
N	5.0
M	4.7
H	6.2
SO	4.7
KO	5.0
SA	6.0
Average	4.4

intensity at the centre of the array although many trials should be made in the future in establishing the best system of observation by an array station.

3. Comparison between instantaneous values of the geomagnetic total intensity at Kanozan and Oshima

Kanozan Geodetic Observatory of the Geographical Survey Institute and Oshima Magnetic Observatory of the Earthquake Research Institute have been equipped with a proton precession magnetometer for the past few years. The data from these permanent observatories will without doubt provide an excellent set of data for studying geomagnetic noises and the limit of comparing instantaneous geomagnetic total intensity values between the two stations. The locations of the observatories are shown in Fig. 5.

Following the observation system as described in the last section, we will use 6 measurements at about one o'clock local time each day. 1462 pairs of simultaneous measurements are available during an 8 month's period since December, 1966. Of these, 794 pairs are assigned to A, 299 to B and 439 to C groups as classified according to the degree of geomagnetic disturbance in the last section.

The histograms of simple differences are shown in Figs. 6a, 6b and 6c respectively for A, B and C groups, while the standard deviations are calculated as shown in Table 3.

As was first pointed out by Rikitake et al.,[5] it has been noticed that the total intensity values at Kanozan (F_K) are always larger than those at Oshima (F_O) in such a way that the ratio F_O/F_K is approxi-

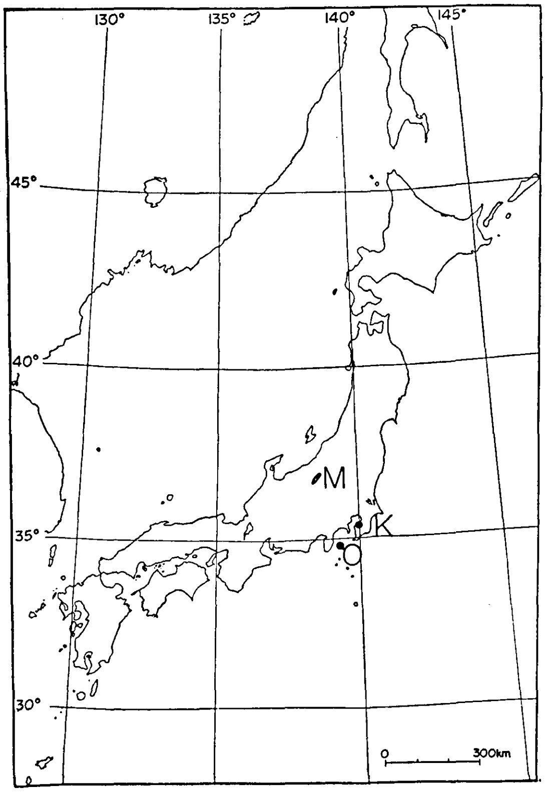

Fig. 5. The locations of stations. M: Matsushiro area, K: Kanozan Geodetic Observatory and O: Oshima Magnetic Observatory.

Table 3. Standard deviations in γ for the simple difference values and the weighted difference values.

Classification	Standard deviation
A (quiet)	2.2
B (intermediate)	2.6
C (disturbed)	3.0
Weighted difference for *A*	1.8

mately a constant. From the present data on quiet days, the proportional constant α is determined as 0.942. The histogram for $F_O-\alpha F_K$ on quiet days which is called the weighted difference is illustrated in Fig. 6d and the standard deviation for it is given in the last row of

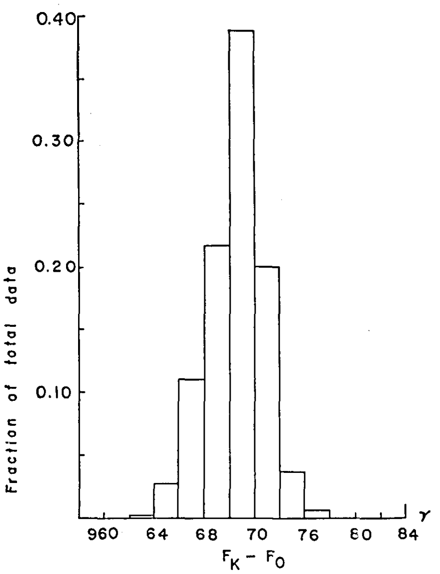

Fig. 6a. Histogram of $F_K—F_O$ for Group *A* (quiet days).

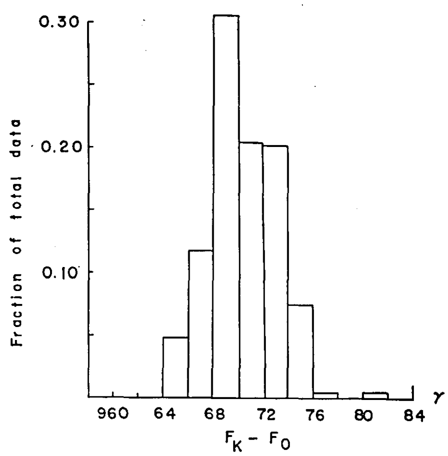

Fig. 6b. Histogram of $F_K—F_O$ for Group *B* (intermediate days).

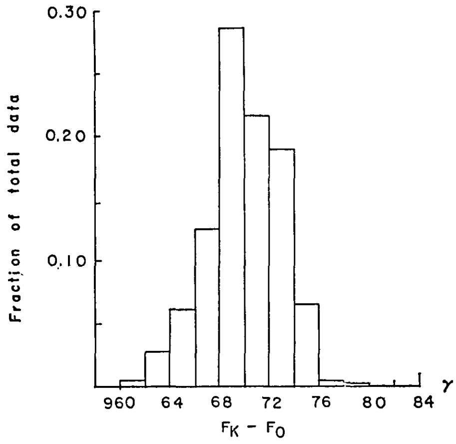

Fig. 6c. Histogram of $F_K—F_O$ for Group *C* (disturbed days).

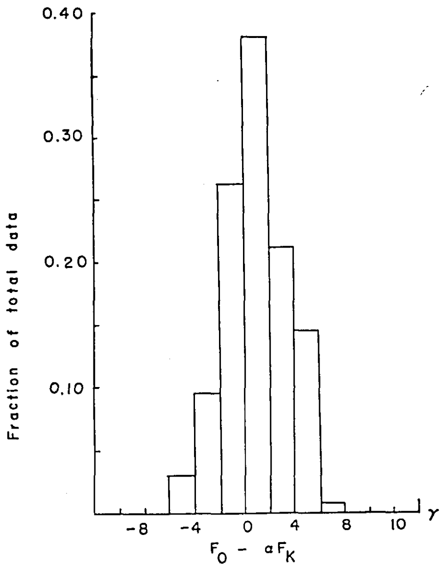

Fig. 6d. Histogram of the weighted difference ($F_O—\alpha F_K$) for Group *A*.

Table 3.

It is observed in the table that the standard deviation is drastically improved by adopting the weighted difference technique. The reason why we observe a great difference in changes in the total intensity values amounting to as much as 6 per cent between the two observatories only 81 km distant from one another has not been well understood. But the influence of local distribution of electrical conductivity around the stations may well be considerable as will be seen in the following section.

4. Comparison between instantaneous values of the geomagnetic total intensity at two stations on Oshima Island

Two sets of digitalized proton precession magnetometer[11] have been operated on Oshima Island, a volcanic island about 100 km south of Tokyo. The magnetometers were constructed under a 5-year plan for earthquake prediction research. They are constructed so as to print the digitalized total intensity values every one minute, punch them on a paper-tape and record them in an analogue form. A simple computer, by which the differences between synchronized punched data can easily be produced, is also prepared.

The magnetometers have been at work since 1966 at the Oshima Magnetic Observatory on the west coast of the island and at the Oshima Tsunami Observatory on the north-east coast. The former is a permanent observatory originally planned for detecting geomagnetic changes related to the volcanic activity. In Fig. 7 is shown the locations of the two observation points.

In spite of the small distance between the two stations, only 7 km say, the differences in the geomagnetic total intensity between the two stations turned out to be astonishingly large and scattered. Fig. 8a is a histogram of the differences between F_{SE} (Tsunami Observatory) and F_O (Magnetic Observatory), the latter having been used as the standard value on Oshima Island in the previous studies, on Jan. 5, 1967, a very quiet day of which $\sum K=2$. Even on such a quiet day, it is noticeable that the difference values, the number of which is only 1418 because of miscountings, are distributed in a range of 12γ with a standard deviation of 1.9γ. It is also seen that the distribution slightly deviates

11) Geomagnetic Group for Earthquake Prediction Research, *Bull. Earthq. Res. Inst.*, **44** (1966), 1167.

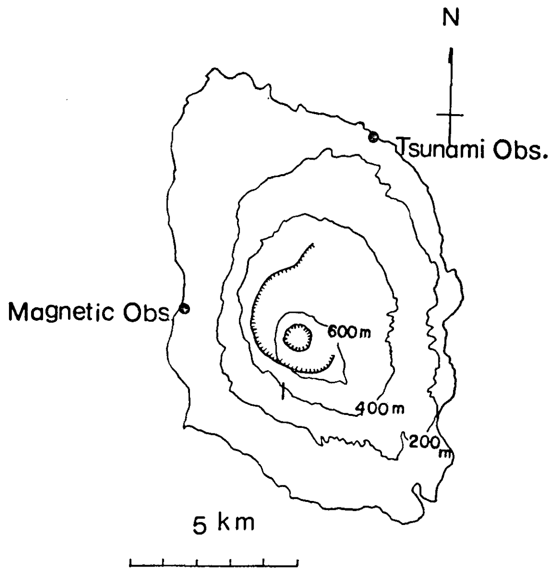

Fig. 7. Two stations on Oshima Island.

from a Gaussian one. Close examination of the data makes it clear that such an asymmetric distribution is caused by the fact that changes in F_O are larger than those in F_{SE} when the S_q (solar daily) variation tends to be larger at about midday period.

In contrast to the data on a quiet day, a similar histogram on Jan. 8, 1967 which is characterized by a moderate magnetic storm with $\sum K=29$ is shown in Fig. 8b. It is astonishing that the difference values are scattered in a range of 31γ and so the standard deviation amounts to a value as large as 5.7γ. Taking the small distance between the two stations into account, it should be noted that geomagnetic noises to comparing the geomagnetic total intensity values are extremely large in this case.

One of the writers (Y.S.),[12] who made a variometric work on the island, found that the vertical component of geomagnetic changes of short period varies from place to place. Reversals in sign of the vertical component between northern and southern stations have been found there.

The major parts of such an anomaly on an island could be caused by the magnetic field produced by electric currents in the sea surround-

12) Y. SASAI, *Bull. Earthq. Res. Inst.*, **45** (1967), 137.

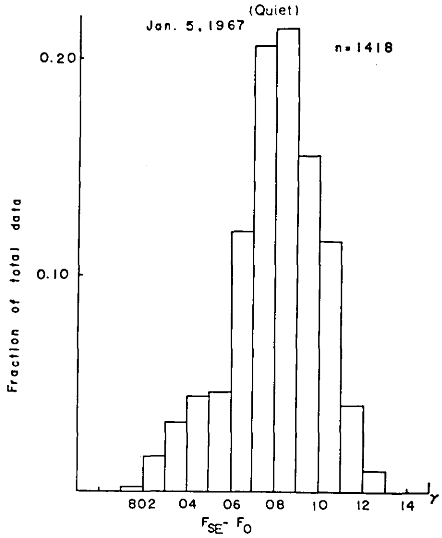

Fig. 8a. Histogram of $F_{SE}-F_O$ on Jan. 5, 1967, a very quiet day.

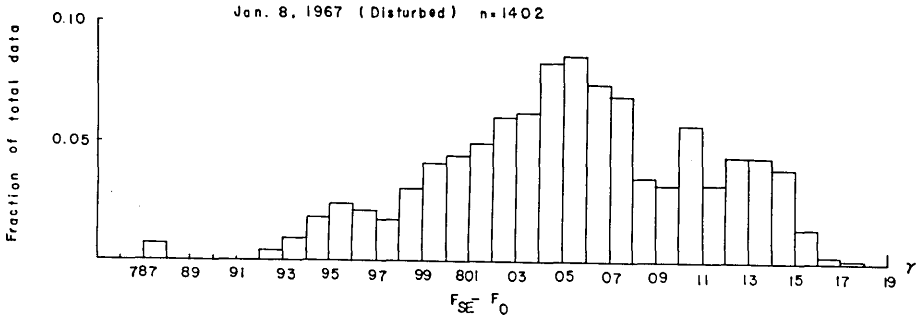

Fig. 8b. Histogram of $F_{SE}-F_O$ on Jan. 8, 1967, a moderately disturbed day.

ing the island induced by the inducing field arising outside the earth although a possibility that some contribution could be made by the underground distribution of electrical conductivity cannot be ruled out.

In the light of the above results, it would be difficult to make a comparison of the geomagnetic field between stations on an island with an accuracy similar to that at inland stations. Sasai's unpublished work[13] proved, however, that the Oshima Magnetic Observatory is fortunately situated at a place where the influence of the induced magnetic field is very small.

13) Y. SASAI, To be published in the *Bull. Earthq. Res. Inst.*

5. Conclusions

The present work leads us to conclude the following points:

(1) Comparison of the geomagnetic total intensity values at midnight period can be made with a standard deviation slightly smaller than 2γ between stations in the central area of Japan provided the distances between them do not exceed 50 km.

(2) The accuracy of comparison becomes low when the distances increase. For a combination of stations, the distance between them exceeding 200 km, it is difficult to have a standard deviation smaller than 2.5γ.

(3) The conclusions in (1) and (2) are reached for data on quiet days. If we make use of data on disturbed days, the standard deviation becomes substantially large.

(4) Improvement of signal-to-noise ratio will be possible by mixing data observed by an array of proton precession magnetometers spread within an area of several square kilometers.

(5) When the distance between stations exceeds 50 km, a weighted difference technique can be successfully applied. As far as the data which the writers dealt with is concerned, the limit of the method is slightly smaller than 2γ in standard deviation.

(6) Accurate comparison between stations among which island stations are involved is extremely difficult. No practicable way of correcting data would easily be found.

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7. 地震に伴なう地磁気変化に対する磁気雑音 (1)

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2カ所の観測点におけるプロトン磁力計の観測値を比較する場合に，単純な差を作るだけでは，観測点付近の地下構造および人工的雑音のために，地震に伴なう地磁気変化を精度よく検出することがむずかしい．このような雑音は地域ごとにことなっていると思われるので，筆者らは日本全土についてこの種雑音の特性を明らかにすることを目的としている．

本報においては，まず松代地震地域に展開された6つの磁力計の観測値を用いて，各観測点の全磁力値がどの程度の精度で比較できるかを調べた．地方時1時1分から2分毎に行なわれた6つの

測定値の平均値を用いると，磁気的に静穏な日の資料によれば，1.8 γ 程度の標準偏差で，観測点間距離が 40 km 以下の観測点についての比較ができることがわかった．

各観測点の観測値を混合する場合には，雑音を若干軽減することのできることがわかったが，このような array 方式の観測は今後の課題である．

つぎに，鹿野山と伊豆大島の2固定観測所の観測値を使用して，両観測所の瞬間値は静穏日深夜については，単純差で 2.2 γ また重価差で 1.8 γ の標準偏差が得られた．観測所間距離は 81 km である．

伊豆大島の地磁気観測所と津波観測所には地震予知研究計画によって製作されたプロトン磁力計が設置され，毎分の測定が行なわれている．静穏日については 2 γ 程度の標準偏差が求められるが，地磁気日変化が2観測所において系統的にことなることが判明した．観測点間距離はわずか 7 km であるが，主として海水中の誘導電流によってこのような差があらわれるものと考えられる．磁気的に乱れた日は標準偏差が 5 γ 以上に達し，離島での観測値をとりあつかう場合には，雑音除去がいちじるしく困難であることがわかった．