550.385/.386: 550.343

Time Changes of Transfer Functions at Kakioka Related to Earthquake Occurrences (I)

By

YUKIZO SANO

Kakioka Magnetic Observatory

Abstract: A study on transfer functions at Kakioka has been carried out in order to investigate their interesting time changes related to neighbouring earthquake occurrences. Transfer functions for various period components have been obtained as frequently as possible since July, 1976 using the every minute sampling data by the optical pumping magnetometer system (KASMMER). A very fine resolution on analysis of the transfer functions is aimed by this study.

As a preliminary result of the study, it is found out from various analyses of the data during the period roughly from 1976 to 1978 that there may exist some precursory changes of the transfer functions related to large and near earthquakes. Such interesting results are clearly confirmed as "mean earthquake time changes" by statistical analyses of many remarkable earthquakes.

On the other hand, in individual cases, the time changes of transfer functions estimated by various running averages indicate so complicated features that it is difficult to regard all of them as a natural confident change, partly because of some error components. However, time changes likely to correlate with some remarkable earthquakes near Kakioka are to a certain degree confirmed in many cases. Besides, it is also found out that the transfer functions seem to have a complicated magnetic activity dependence and a certain systematic error component.

1. Introduction

It is well known that there exists a peculiar behaviour of the Z component of geomagnetic short period variations in many regions of the world. Such variations as anomalous Z geomagnetic variation are interpreted by electric currents induced in anomalously distributed electric conductors in the earth's surface and interior. In Japan, the following two anomalies are most famous and well investigated. The one is the central Japan anomaly found by Rikitake and his coworkers (1959). The other is the northeastern Japan anomaly found by Kato and others (1968). A number of other local anomalies have also been found. For example, Sasai (1967) investigated the so-called island effect on Oshima and Sasai

(1969) the peninsula effect on the Kii Peninsula. Also, Honkura (1972) investigated a similar geomagnetic variation anomaly on Miyake Island. Kuboki and Oshima (1966) analyzed anomalies at Japanese main stations and many other survey points, especially near Kakioka. Intensive observations and analyses of the anomaly are still under way.

The anomalous vertical component of the geomagnetic short period variation ΔZ is generally expressed with the horizontal components ΔH and ΔD by the following linear equation:

$$\Delta Z = A \cdot \Delta H + B \cdot \Delta D. \tag{1}$$

The coefficients A and B are constants peculiar to an observation point, being called CA transfer function (CA means conductivity anomaly and hereafter CA transfer function is denoted simply by T. function). As will be described in the next section, these T. functions are complex functions and have usually a frequency dependence. They are one of the characteristic constants which gives us information on the electric conductivity anomaly in the earth's interior.

The Kakioka Magnetic Observatory is located within the central Japan anomaly region. So, the various characteristics of the anomalous geomagnetic variation at Kakioka have been studied in relation to an electric conductivity anomaly and earthquake occurrence by researchers such as Yoshimatsu (1963), Kuboki and Oshima (1966), etc. And it is one of the most important and interesting problems in these studies whether or not there is any relation between a time change of the T. function and an earthquake occurrence. Recently, Yanagihara (1972) found an interesting secular change of T. function at Tokyo (1897—1912) and Kakioka (1913—1973) closely related to the Kanto earthquake (M=7.8). Yanagihara and Nagano (1976) also reported that some conspicuous time changes of the T. function for an 80 minute period component at Kakioka were confirmed in connection with fairly large earthquake occurrences. They mainly analyzed typical isolated bay disturbances with a period of 80 minutes. Shiraki and Yanagihara (1975) also studied a time change and frequency characteristics of T. functions at Kakioka in many magnetic storm disturbances. The calculation methods of T. functions in these studies (except in Yanagihara's study) are based on those invented by J. E. Everett and R. D. Hyndman (1967). The data used were scaling values of the bar-magnet variometer's magnetograms which had more or less scaling errors and poor resolutions not only in value but also in time.

The present author has analyzed T. functions at Kakioka using the technique of the Fourier analysis and the least square method for a number of geomagnetic disturbances. The data used, which are much more precise than the scaling value data of the magnetograms, are the following. The Kakioka Magnetic Observatory has been observing the geomagnetic field by four optical pumping magnetometers of the Kasmmer system, the details of which havc been reported by Yanagihara et al. (1976). The Kasmmer system supplies us with utilizable digital data such as the every minute sampling, the every 3-second sampling and the hourly mean values. The every minute sampling data are used in the present study. The main purpose of the present study is to confirm various time changes of T. functions at Kakioka with much finer resolution than the study by Yanagihara and Nagano. This is very interesting for the earthquake prediction study. Meanwhile, using the same Kasmmer's data Shiraki (1977) has also analyzed T. functions by a different method of the power spectral analysis, secular changes of which are continuously monitored by their monthly mean values.

In this paper, the author will report on some interesting results on the time changes of T. functions at Kakioka related to some large earthquake occurrences in the vicinity of Kakioka not only in the case of individual events but also with reference to the statistical features of many earthquakes.

2. Transfer functions and data analyses

2.1 Transfer functions

The anomalous Z component of short period geomagnetic variations ΔZ is connected with the horizontal components ΔH and ΔD by the formula (1) as mentioned in the preceding section. In this relation it is supposed that there is no external part to the Z component. As the A and B T. functions are usually complex functions, the formula (1) is written as follows:

$$\Delta Z=(A_u+iA_v)\Delta H+(B_u+iB_v)\Delta D \tag{2}$$

where the subscripts u and v are the real (in-phase) part and the imaginary (out-of-phase) part of the T. functions respectively. Three components ΔZ, ΔH, and ΔD of the geomagnetic variations are also complex functions and are written by the sine and cosine parts of Fourier transforms for respective identical period components as follows:

$$\left.\begin{aligned}\Delta Z&=\Delta Z_u+i\Delta Z_v\\ \Delta H&=\Delta H_u+i\Delta H_v\\ \Delta D&=\Delta D_u+i\Delta D_v,\end{aligned}\right\} \tag{3}$$

where the subscripts u and v mean also the real part (=cosine term) and the imaginary part (=sine term). The complex T. functions A and B are given by Everett and Hyndman (1967) as follows:

$$\left.\begin{aligned} A&=(\bar{H}D\cdot\bar{D}Z-\bar{D}D\cdot\bar{H}Z)/(\bar{H}H\cdot\bar{D}D-\bar{D}H\cdot\bar{H}D)\\ B&=(\bar{D}H\cdot\bar{H}Z-\bar{H}H\cdot\bar{D}Z)/(\bar{H}H\cdot\bar{D}D-\bar{D}H\cdot\bar{H}D)\end{aligned}\right\} \quad (4)$$

where $\bar{H}H$, $\bar{D}H$, etc. are summations of $(\Delta H_u - i\Delta H_v)(\Delta H_u + i\Delta H_v)$, $(\Delta D_u - i\Delta D_v)(\Delta H_u + i\Delta H_v)$, etc., respectively for a number of geomagnetic variations with the same period component.

2.2 Primary data analyses

The T. function analyses in the present study are applied to the nine period components of 5, 10, 20, 30, 60, 90, 120, 180 and 240 minutes. In these analyses, the digital data of every minute sampling recorded in a magnetic disk are used, which have such preciseness and resolution at 0.1 nT in absolute value and perfect simultaneity in sampling time of three components.

Several examples of geomagnetic variations analyzed in the present study are shown in Fig. 1. Those shown in the first part are the smallest selected for the present analysis. The others are of moderate magnitude. A short periodic geomagnetic variation to be analyzed is deduced here by eliminating simply a non-cyclic change part which is defined as shown in the figure by the broken straight line from the initial point to the last one of each event. In general, diurnal variation (S_q-field) and Dst-like variations are considered unwanted variation components for the T. function study, because they have a somewhat larger external Z component. This means that these variations do not satisfy the formula (2) in the

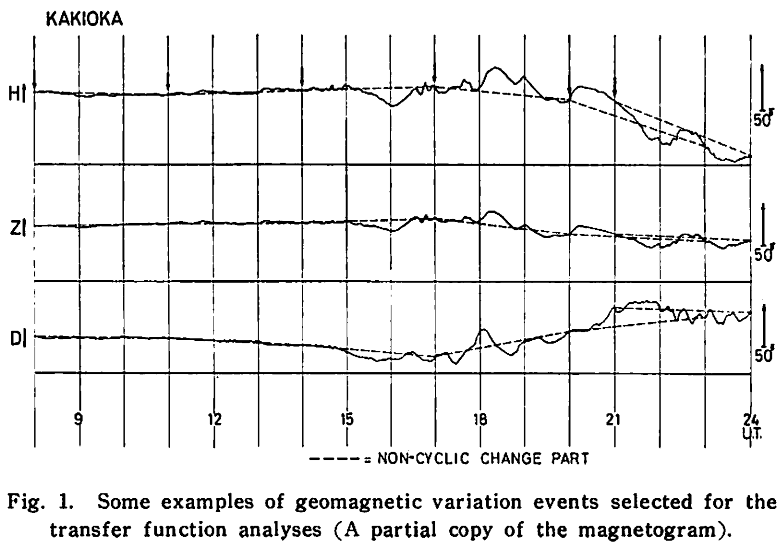


Fig. 1. Some examples of geomagnetic variation events selected for the transfer function analyses (A partial copy of the magnetogram).

preceding section. So, much attention has been paid to the selection of analyzed events so that the selected geomagnetic variations may not contain large S_q-field variations and Dst-like variations or contain them as little as possible. Geomagnetic disturbances analyzed in the present study are selected usually with a duration of 3 hours (180 minutes).

Next, Fourier transforms of three components for the nine periods are calculated from the above reduced periodic change parts of every event selected, and T. functions of the nine period components are obtained according to the formula (4) of the least square method. In order to determine a set of T. functions, usually ten geomagnetic disturbance events are used. In addition to the above calculation, an accuracy of each individual T. function is estimated by a standard deviation assessed in the least square method. This standard deviation is equal to the 68 % confidence interval of individual T. function.

Generally, about ten geomagnetic disturbance events are selected from a few days during a weakly disturbed period ($K=1, 2$) and from only one day or one day and a half during a stormy or disturbed period ($K>3$). This leads to a quite finer sampling rate of T. functions. In Yanagihara and Nagano's and other studies using the scaling value data of the magnetograms as introduced in the preceding section, only a few sets of T. functions have been obtained from the period of a month or a few months.

2.3 Secondary data analyses

As will be discussed in a later section, the reliability of the T. functions thus obtained from the primary data analyses is not generally so high as original T. functions whose reliable time changes can be clearly estimated. Namely, as useful Fourier transform data are not always obtained from all of the analyzed events and all the period components in the primary analyses, so reliable T. functions are not always obtained from these primary Fourier transform data without any selection. For the primary analyses are carried out including small geomagnetic disturbances in order to get as fine a time resolution as possible in the T. function study.

Even if the geomagnetic disturbances are considerably intense, all of the T. functions are not always obtained reliably. Because geomagnetic disturbances do not have always effectively all the period components concerned in the present analyses.

It is impossible or will lead to a mistake to discuss some time changes of the T. functions only from the primary raw data. Therefore, certain kinds of secondary data analyses are required to improve their reliability or to estimate their reliable time changes. In the present study the following secondary analyses have been tried for that purpose.

For the data in 1976 new T. functions for several period components are recalculated from new groups of relatively reliable Fourier transforms selected by omitting some unsuitable ones (about 30 %∼50 %) having a very small amplitude in comparison with the others or an exceptionally deviating value of $\Delta Z_u/\Delta H_u$ (when, $\Delta D_u \leq \Delta H_u$) from each mean value of A_u T. functions. The reliability of the new T. functions thus obtained turns out fairly higher than that of the primary data (Refer to the section 5.). For the other data in 1977 and 1978 such secondary analyses have not been done yet. As an alternative secondary analysis to the above, various kinds of running average methods are applied for the entire data of present concern. In these cases, to reduce contributions from unreliable data having a very large standard deviation, various kinds of weighted running averages are tried together with simple running ones.

Several interesting results of these secondary analyses will be presented in the next section.

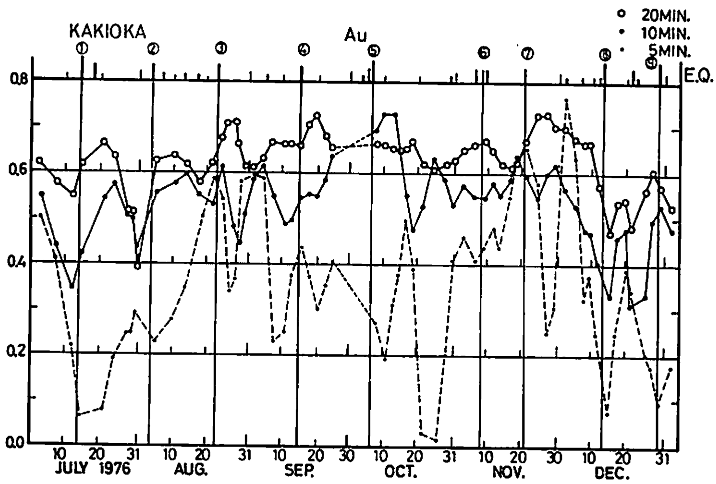
2.4 Statistical data analyses

Though a relatively high reliability of T. functions can be attained by the secondary analyses, it is not yet sufficient for discussing time changes of T. functions related to earthquake occurrences without any suspicion of error components. Hence, as the next step various statistical data analyses using a superposed epoch method for some remarkable earthquakes are carried out. This analysis method is quite similar to the well known method which is applied to the determination of mean Dst variation for many magnetic storms. We call a time change of T. function obtained by this statistical analysis as "an earthquake time change". By these statistical analyses it is confirmed that mean earthquake time changes obtained indicate typically an earthquake precursor change. These interesting results will be presented in section 4.

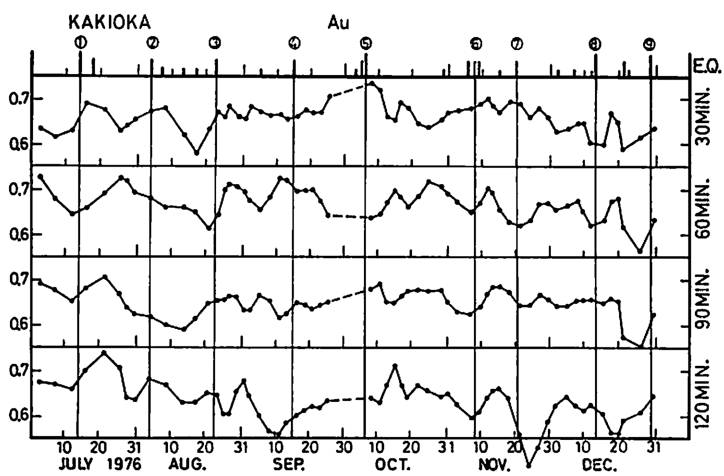
3. Time changes of transfer functions estimated in individual cases

3.1 Time changes of A_u T. functions during the latter half of 1976

Some preliminary results on A_u T. functions in 1976 are shown in Fig. 2. Fig. 2(a) shows A_u T. functions of periods of 5, 10 and 20 minutes and Fig. 2(b) shows those of periods of 30, 60, 90 and 120 minutes. The plotted values are not perfectly raw data from the primary analyses, but each of them is a weighted



(a) 5, 10, and 20 min. period components.



(b) 30, 60, 90 and 120 min. period components.

Fig. 2. Individual time changes (A_u) of several period components estimated by a three-term running average for the period from July to December in 1976. The thick bars (E.Q.) indicate earthquakes felt at Kakioka. The nine ones marked by a vertical line are specially analyzed in the present study.

(1 : 2 : 1) running average for three successive T. functions. In the upper part of each figure, earthquakes (E. Q.) felt at Kakioka are indicated by the thick bars and the nine specially referred to are marked by vertical lines. (The length of the thick bar is proportional to the earthquake intensity at Kakioka. The largest one is intensity 4 in the Japanese scale.) The nine earthquakes have magnitudes 4.0—6.0.

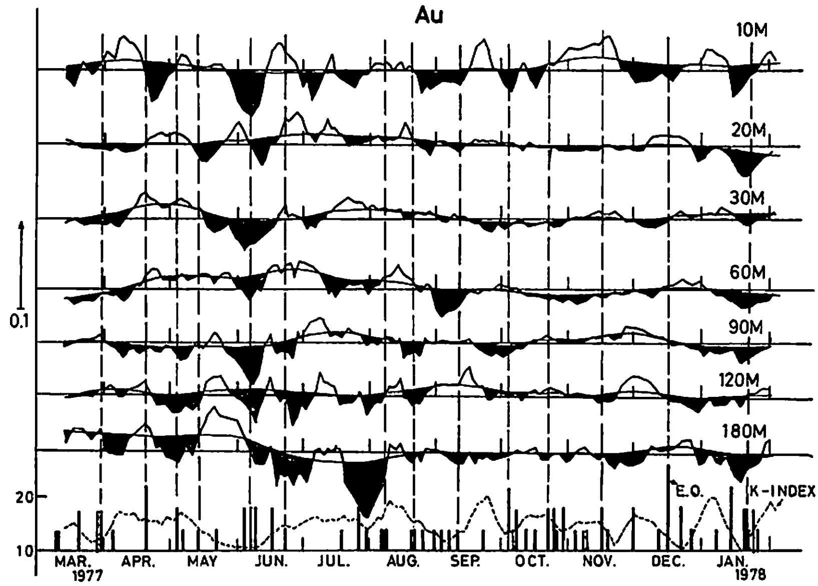
From the figure it is evident that very conspicuous and frequent changes in every T. function can be seen, especially in Fig. 2(a). Some of them seem to show some parallelism in all of the period components, though their shapes and magnitudes are more or less different from each other. It is not certain whether all the above-mentioned changes are natural behaviour or not, but to some extent certain that some error components are included within the changes. Especially, the change of the 5 minute period component is so large and irregular that a great part of it may be accidentally due to a great error, for A_u mean standard deviation (error) for it is about 0.15, i. e. two or three times greater than those for the other period components. Therefore, that of the 5 minute period component is excluded from the present study together with that of the 240 minute period component.

If we look again at the figures much more carefully, it may be found out that the time changes shown seem to have some relationships with earthquake occurrences. Namely, it is very interesting to note that decreasing changes seem to occur before or about the days of the earthquake occurrences marked by the vertical lines in most of the A_u T. functions. At least in the author's opinion, this suggests something like the probability that there exist some time changes of the T. functions related to earthquake occurrences at Kakioka.

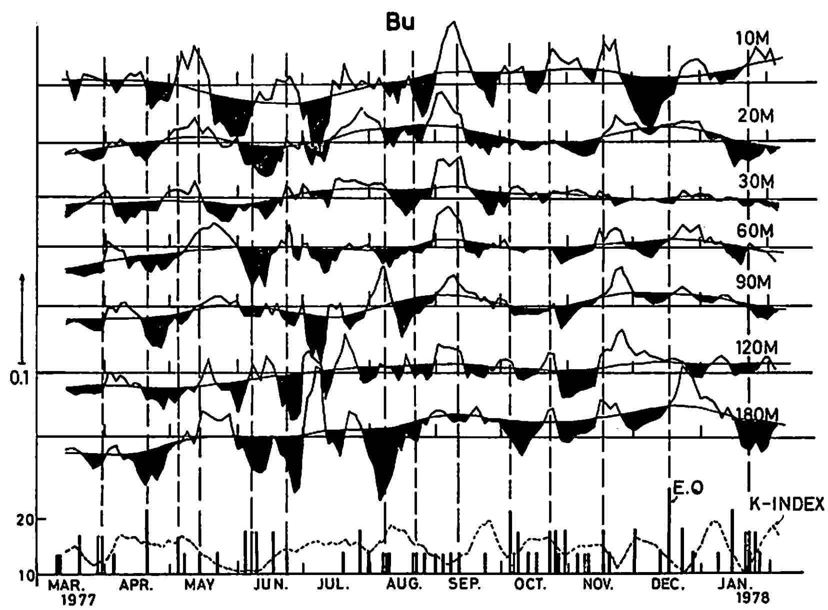
3.2 Time changes of A_u and B_u transfer functions during the period from Mar. 1977 to Jan. 1978

128 sets of T. functions have been obtained from the period from Mar. 1977, to Jan. 1978, in the primary analyses. As mentioned in the preceding section, it is difficult to find out their confident behaviour of time changes directly from the above primary data. In order to estimate such behaviour, five-term or more simple and weighted running averages are calculated.

Fig. 3 shows some results thus obtained on A_u and B_u T. functions for 1977. They are the respective time changes estimated by a five-term weighted running average. As for the weight in the running average, the reciprocal of standard deviation corresponding to the individual T. function is used in the present case.



(a) A_u transfer functions.



(b) B_u transfer functions.

Fig. 3. Individual time changes of A_u and B_u transfer functions estimated by a five-term running average for the period from Mar. 1977 to Jan. 1978. The thick bars (E.Q.) indicate earthquakes felt at Kakioka, their length being proportional to the intensity of earthquake by the Japanese scale. The 14 earthquakes marked by a broken line are specially taken up in the present analyses.

Table 1. List of the earthquakes treated in this paper from Mar. 1977 to Jan. 1978.

No.	Date		Time(J.S.T.)			Location	Magn.	Dist.	Depth
1	1977	Mar.	30th	08h	45m	central Ibaraki Pref.	4.4	7km	70km
2	〃	Apr.	19	15	15	coast of Ibaraki Pref.	5.1	48	60
3	〃	May	3	21	54	nortern Chiba Pref.	4.3	57	80
4	〃	〃	13	19	27	central Chiba Pref.	4.4	74	70
5	〃	Jun.	4	08	27	nortern Tokyo Bay	4.6	60	80
6	〃	〃	22	16	11	E off Chiba Pref.	5.0	93	40
7	〃	Aug.	8	08	24	SW Ibaraki Pref.	3.8	16	70
8	〃	〃	21	00	26	〃	4.1	29	70
9	〃	Sep.	11	08	10	off Ibaraki Pref.	4.3	120	40
10	〃	Oct.	5	00	39	SW Ibaraki Pref.	5.4	32	60
11	〃	〃	22	20	58	off Ibaraki Pref.	4.9	111	40
12	〃	Nov.	16	23	58	southern Ibaraki Pref.	4.6	28	90
13	〃	Dec.	17	00	10	off Ibaraki Pref.	5.6	102	40
14	1978	Jan.	21	11	17	central Ibaraki Pref.	4.1	3	80

Each curve indicates the 124 respective running average values plotted by an X-Y plotter. On the other hand, each smoothed curve is a long term (seasonal ?) variation according to eye-estimation. In these figures similar running averages of $\overline{\sum K}$ (K-index) and main earthquakes felt at Kakioka also are shown, where $\overline{\sum K}$ is mean $\sum K$ (daily sum of K-index) for the period (or days) from which about ten events of geomagnetic disturbance are selected to determine a set of T. functions, meaning roughly a degree of magnitude of the geomagnetic disturbances analyzed. The earthquakes marked by vertical lines are those with magnitudes larger than 3.8. Further details are given in Table 1.

As can be seen in the figures, all of the A_u and B_u T. functions show also very frequent and complicated short period variations in their time changes. Some of them amount as much as ± 0.05 or more. Although errors are not shown in the figures, they are on average about ± 0.02 to ± 0.03 in standard error. So, not all of the above mentioned variations may be natural and confident time changes. And from these results it is on the whole impossible to conclude that some definite relations between the time changes and earthquake occurrences can be clearly found out, because of the so frequent occurrences of both phenomena. However, many time changes seem to correlate with remarkable earthquakes. More often than not, some decreasing changes (like the blackened parts in the figures) seem to occur some time before or at about remarkable earthquake occurrences. These features are on the whole similar to those shown in Fig. 2.

On the other hand, some possible correlations or dependences seem to be recognized between the time changes of the T. functions and the K-index variation. This characteristic will be examined in detail in a later section.

4. Some results of statistical data analyses

4.1 Various mean earthquake time changes for various groups of transfer functions

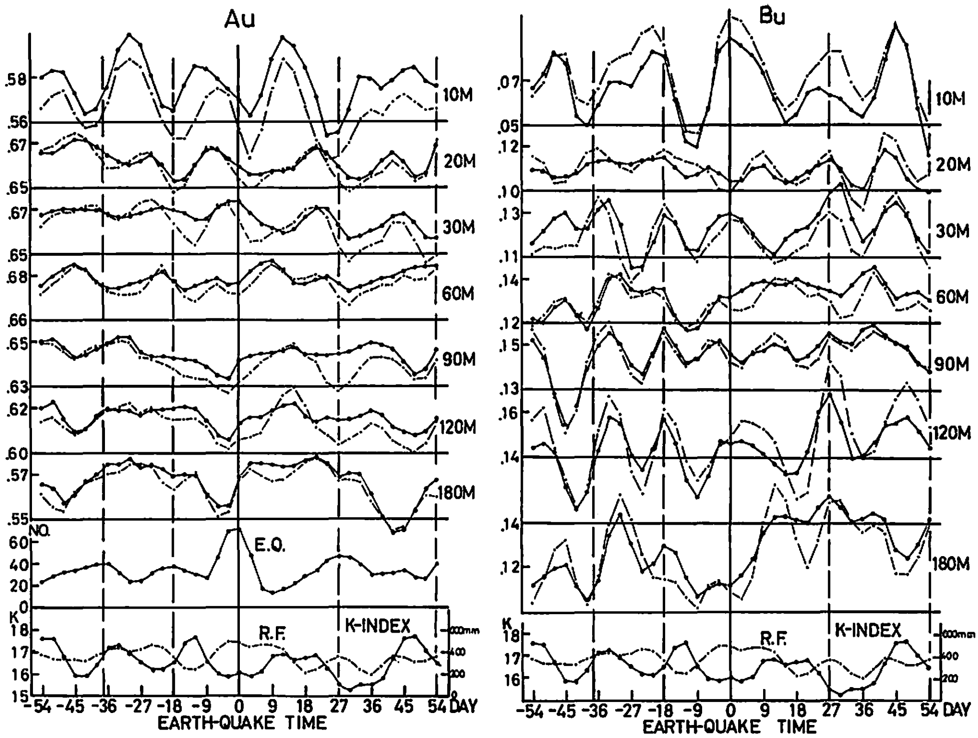
a) Superposed earthquake time changes of each period component

In the preceding section, the time changes of A_u and B_u T. functions have been presented and some relations with earthquake occurrences have roughly and qualitatively been discussed. In order to lead up to a much more confident and quantitative discussion, various kinds of statistical correlation analyses are carried out.

First, mean earthquake time changes of every period component are obtained by the following superposed epoch method. For many remarkable earthquakes each period of ± 60 days, the center of which is the day of an earthquake occurrence, is divided into 39 half-overlapping sub-periods with each interval of six days. (Successive two sub-periods are superposed by half of the respective sub-period (three days).) Here, the earthquake time is taken as -57, -54, …… 0, …… $+54$, $+57$ (day) corresponding to the respective sub-periods. The T. functions belonging to each sub-period are simply averaged or averaged with a weight of the reciprocal of the standard deviation as similar to the weighted running average in the preceding section. Furthermore, the averages thus obtained are smoothed by three-term running averages.

Two representative results obtained from the data of 1977 are shown in Fig. 4. They are mean earthquake time changes of A_u and B_u of each period component superposed for the 14 earthquakes given in Table 1. Those shown by the full line curves are of the weighted average and those by broken ones are of the simple average, respectively. At the bottom of each figure, the similarly superposed occurrence frequency of earthquakes felt at Kakioka (weighted by the degree of the Japanese earthquake intensity scale), the K-index and total rainfall are also shown. The five vertical lines (full or broken) show each peak of the earthquake occurrence frequency (That is to say, a seismic activity).

As can be seen in the figures, the mean earthquake time changes show to some extent regular and periodic behaviour. They seem to correlate to a few peaks of the earthquake occurrence frequency with similar relations to those suggested in individual cases. At least, the relations between time changes of



(a) A_u transfer functions (b) B_u transfer functions

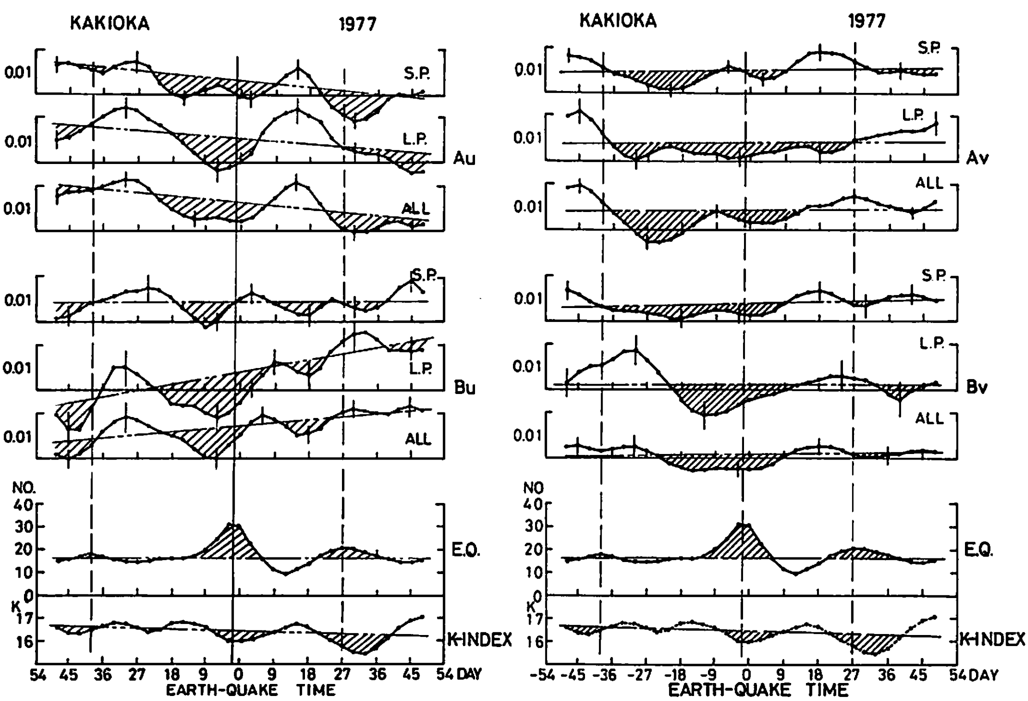
Fig. 4. Respective mean earthquake time changes of A_u and B_u transfer functions superposed with 14 remarkable earthquakes in 1977. The full and broken lines are of the weighted and simple averages, respectively. (E.Q. = Earthquake occurrence frequency; K-INDEX = Magnetic activity; R.F. = Total rainfall).

the T. functions and near earthquake occurrences suggested in the preceding section are somewhat confirmed by these analyses. These features can be found rather clearly in the case of A_u T. functions in Fig. 4(a). However, such good proportionality as is expected between amplitudes of the time change and the earthquake occurrence frequency is hardly found.

On the other hand, it is also impossible from these results to find a clear relation between the T. functions and the K-index or the rainfall, but it should be noted that both the K-index and the rainfall seem to show rather similar periodic variations. From these facts we see the possibility that some of their effects upon the T. function changes seem to modify somewhat the earthquake time changes in amplitude and in phase, especially in the case of the K-index, as will be again discussed in a later section. The rainfall is a factor which is considered to relate more or less to the electric conductivity change in the upper part of the earth's interior, namely to a change of T. function. But in the present analyses no quantitative relations with the time changes of T. function are found out. In conclusion, no earthquake time changes so clear as to be unmistakable are found out from these analyses yet, but it is further suggested with much higher possibility from these statistical analyses that there may be time changes of the T. functions at Kakioka related to earthquake occurrence near that place.

b) Various kinds of mean of mean earthquake time changes

Next, in order to confirm furthermore confident earthquake time changes, various kinds of mean of mean earthquake time changes are obtained for various groups of the T. functions, and each of them is smoothed by the five-term running average. Also the earthquake occurrence frequency and K-index activity are



(a) A_u and B_u transfer functions (b) A_V and B_V transfer functions

Fig. 5. Respective averages of mean earthquake time changes for the shorter period component (S.P.), the longer period compnent (L.P.) and all of A_u, A_V, B_V and B_u transfer functions in 1977. (E.Q. = Superposed earthquake occurrence frequency; K-INDEX = Mean magnetic activity)

smoothed by the same running average method. The above-mentioned groups of T. functions, for example, are of the shorter period components (S.P.) of 10, 20, 30 and 60 minutes, of the longer period ones (L. P.) of 90, 120 and 180 minutes, of all A_u, A_v, B_u, B_v, etc.

In Fig. 5 are shown respective mean earthquake time changes of the shorter period components, of the longer period ones and of all period ones (ALL) for each T. function for the data of 1977. The error bars in the figures show standard errors. The mean changes of the earthquake occurrence frequency (E. Q.) and the K-index are shown at bottom of each figure. In Fig. 6 are shown further average earthquake time changes for the groups of all the shorter period components, of all the longer ones, of all the real T. functions, of all the imaginary ones and of all of the T. functions.

As can be seen in the figures, the earthquake time changes seem to become more and more clear in features by the above step-by-step averagings. The major change corresponding to the maximum earthquake occurrence frequency at the middle in the final result of all averages (Fig. 6) indicates clearly such a confident earthquake time change as gradual decreasing before the the central peak of the earthquake occurrence frequency (Say, the major earthquake occurences) and

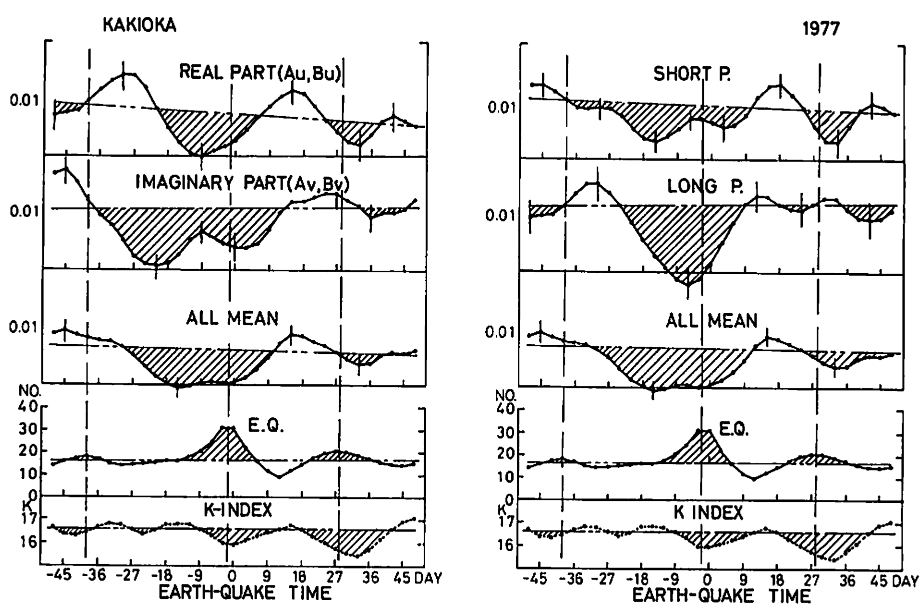


Fig. 6. Final result of mean earthquake time changes of transfer functions averaged for 14 remarkable earthquakes likely to show a clear precursor of the earthquake occurrences in 1977.

thereafter rather abruptly increasing or recovering. Such gradual decreasing seems to begin 30 or more days before the major earthquake occurrence peak and its range amounts to as much as 0.004. Though this range is smaller by about one order than those for the changes previously pointed out in individual cases, that change is accepted as a reliable earthquake time change of the T. function at Kakioka with 95 % or more confidence. The minor decreasing changes corresponding to the secondary peaks of the earthquake occurrence frequency seem to be recognizable. Thus these changes, at least the major ones, may be safely regarded as a precursory change of the T. function at Kakioka related to near earthquake occurrences. As for the partial mean earthquake time changes, those for the real parts and the longer period components show better and more reasonable features in time change as an earthquake precursor than the others. Especially so is the latter one; its range of the major change is the largest amounting to 0.008. But it is doubtful whether this is a general feature or an accidental result.

It is highly interesting to note that the above estimated earthquake time changes have good resemblance in features to the well-known secular change of A T. function found by Yanagihara (1972). However, of course, their time scales and magnitudes of changes are greatly different. This difference may be rather reasonable, considering great difference between the magnitudes of the earhquakes dealt with in the present analysis ($M=4.6$ in average) and that in Yanagihara's study ($M=7.8$). Because an expected time duration (T) of earthquake precursor is a function of the magnitude of earthquake (like $\log_{10} T=0.7\ M-1.83$, where T=days, after Rikitake (1976)).

On the other hand, the same analyses have been carried out for the data of the period from Jan. to Dec. 1978. From this period 228 sets of T. functions have been obtained, which is much more than in the previous period (1977). Here, only the final results of mean earthquake time changes are shown in Fig. 7 in the same manner as in Fig. 6. In this case ten earthquakes are taken up, their details given in Table 2. Comparing the final results for both periods (Fig. 6 and Fig. 7), their general features on the mean earthquake time change are quite consistient with each other, though the mean magnetic activity variations (K-index) in both cases are rather different.

Consequently, it is further emphasised from the above fact that so-called earthquake time changes of T. functions found in the present analyses are not a unreliable change by an effect of the magnetic activity, an error component or others, but they are surely an earthquake precursor as discussed previously.

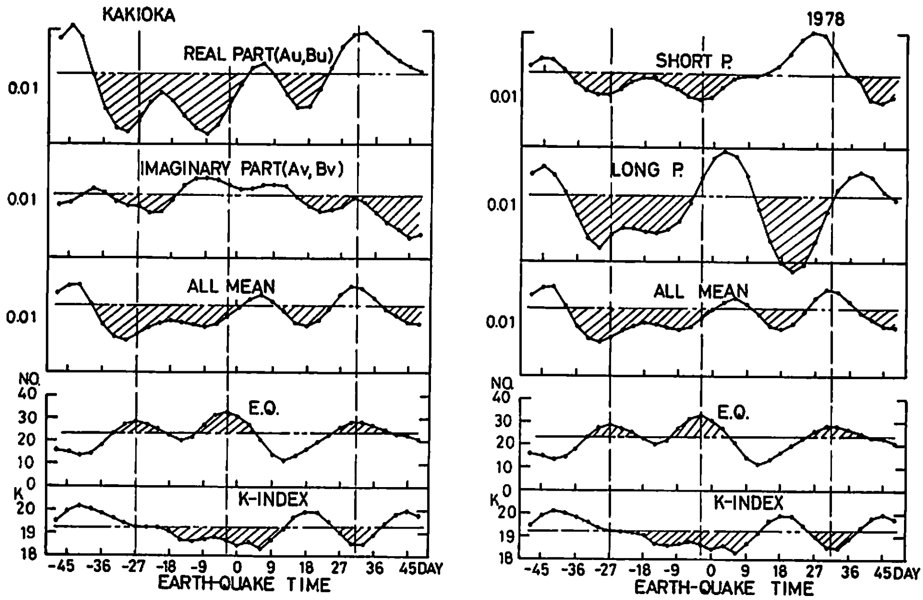


Fig. 7. Final result of mean earthquake time changes of transfer functions averaged for 10 remarkable earthquakes also likely to show a clear precursor of the earthquake occurrences in 1978.

Table 2. List of the earthquakes treated in this paper from Feb. to Nov. in 1978.

No.	Date		Time(J.S.T.)			Location	Magn.	Dist.	Depth
1	1978	Feb.	17th	21 h	51 m	SW Ibaraki Pref.	4.3	27 km	60 km
2	〃	Mar.	20	19	24	〃	5.5	30	60
3	〃	Apr.	19	19	48	coast of Ibaraki Pref.	4.3	56	50
4	〃	May.	26	03	18	east Tokyo	4.2	76	50
5	〃	Jun.	5	21	17	SW Ibaraki Pref.	4.2	25	40
6	〃	Jul.	18	13	07	〃	3.7	30	50
7	〃	Aug.	13	05	48	〃	4.1	31	60
8	〃	Sep.	9	21	00	off Fukushima Pref.	4.5	140	40
9	〃	Oct.	19	19	07	Northern Chiba Pref.	4.2	49	50
10	〃	Nov.	2	20	02	SW Ibaraki Pref.	3.8	12	60

Besides, in these cases a rather good proportionality between the earthquake time changes and the earthquake occurrence frequency changes can be found (including the secondary changes). Concerning the detailed features, however, some modifications perhaps mainly due to some effects of the magnetic activity variations seem to be considered. The minor precursory changes show more or less different relations in phase (possibly also in amplitude) with the earthquake

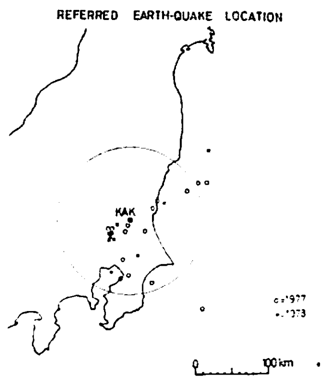


Fig. 8. Locations of the epicenters of the earthquakes in 1977 and 1978 taken up for the present analyses.

occurrence frequency changes from those of the major ones, for example, as can be seen at the changes corresponding to the last peaks of the earthquake occurrence frequency (about 27 days) in both figures.

In addition, the locations of the epicenters of the earthquakes treated in these analyses are shown in Fig. 8. As seen in the figure they distribute randomly over a large region from off Fukushima Pref. to off Chiba Pref. It is an important question whether there was good reason in the selection of the earthquakes in question. In future studies, a more reasonable selection of earthquakes will be nccessary in analysing earthquakes data in detail.

4.2 Some correlation analyses between the transfer functions and the magnetic activity or the standard deviations

a) Correlations between the transfer functions and the magnetic activity

It has already been suggested in the discussions above that some parts of time change of T. functions seem to correlate with the magnetic activity (K-index). This fact is statistically examined in this sub-section. The examinations have been carried out in the following ways.

First, coefficients of linear correlation between the T. functions and the $\overline{\sum K}$ (K-index) are calculated for each data (data No.$=$338) of the entire respective T. functions obtained during the period from Mar. 1977 to Dec. 1978. Secondly, for the same data the $\overline{\sum K}$'s are divided into about 19 classes according to thier degrees, and the corresponding T. functions belonging to each class are averaged and smoothed by the three-term running average. The results thus obtained on each period component are shown in Fig. 9. The respective coefficients of correla-

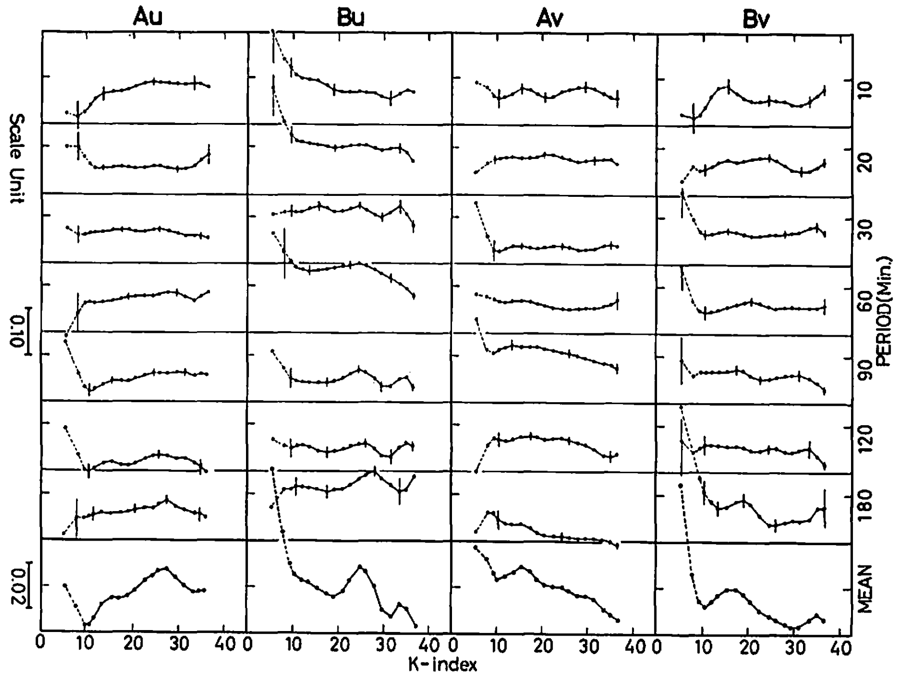


Fig. 9. Geomagnetic activity dependences on changes of the transfer functions obtained from the data (338) from Mar. 1977 to Dec. 1978.

Table 3. Coefficients of correlation between the transfer functions and the magnetic activity (K-index) for the data (338) from Mar. 1977 to Dec. 1978.

Period	A_u	B_u	A_v	B_v
10 min.	**0.166**	**−0.130**	0.027	0.004
20	−0.054	**−0.122**	0.015	0.061
30	0.070	−0.007	−0.017	−0.039
60	**0.126**	−0.060	**−0.106**	0.046
90	**0.116**	0.025	−0.072	0.057
120	0.063	0.060	−0.017	−0.038
180	0.076	0.060	**−0.131**	**−0.180**
Mean	0.071	−0.034	−0.043	−0.013

tion are given in Table 3. The bold-faced values are those over the 95% confidence limit (about 0.1).

The features of the correlations (or dependence) shown in the figure are so complicated that few definite characteristic features are found out. They do not seem to show generally a simple linear correlation or dependence. All of the coefficients of correlation show very low values; about three quarters of them are less than the limit of 95% confidence as given in the table. They might not be a natural feature but a mere accidental result due to some random errors. It seems, however, safe to say that the mean correlation for the whole period components of A_u T. function is positive while the others are rather negative, as shown at the bottom of each figure and table. And this means that the effects of the magnetic activity on time change of the T. function can be considerably removed or cancelled by averaging for all kinds of T. functions. It may be because of this fact that the earthquake time changes for all kinds of the T. functions shown in the previous section were quite reasonable as the earthquake precursor.

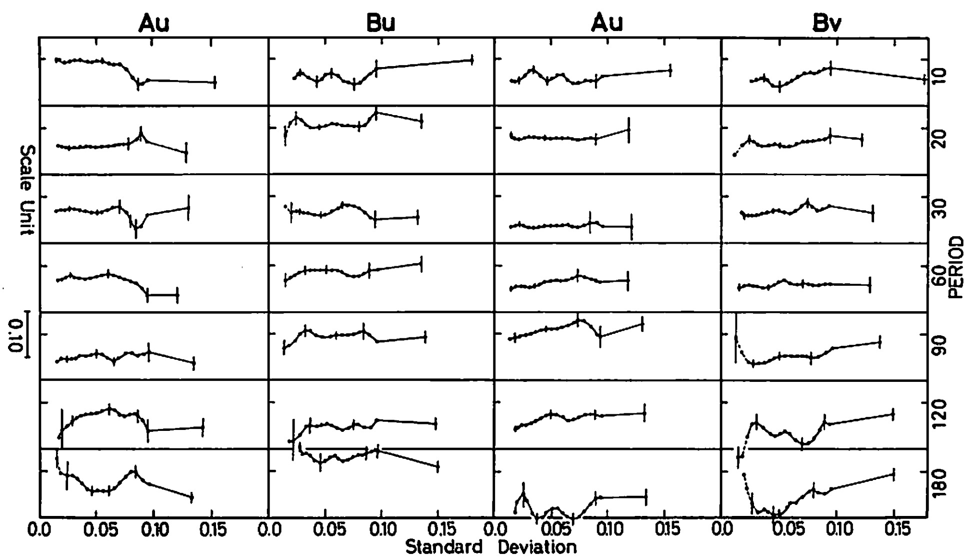


Fig. 10. Standard deviation dependences on changes of the transfer functions obtained from the data for the same period as shown in Fig. 9.

Table 4. Coefficients of correlation between the transfer functions and the standard deviations from the same data as in Table 3.

Period	A_u	B_u	A_v	B_v
10 min.	−0.270	0.185	0.078	−0.004
20	−0.054	−0.054	0.041	−0.007
30	−0.134	−0.045	0.033	0.004
60	−0.164	0.189	0.059	0.089
90	−0.101	0.041	0.193	0.230
120	−0.110	0.019	−0.073	0.239
180	−0.089	−0.174	0.083	0.319
Mean	−0.132	0.018	0.059	0.124

Table 5. Coefficients of correlation between the magnetic activity and the standard deviations for the same data as in Table 3.

Period	A_u	B_u	A_v	B_v
10	−0.478	−0.516	−0.474	−0.534
20	−0.385	−0.369	−0.413	−0.499
30	−0.370	−0.454	−0.401	−0.504
60	−0.297	−0.348	−0.360	−0.338
90	−0.345	−0.311	−0.335	−0.341
120	−0.354	−0.340	−0.330	−0.355
180	−0.334	−0.310	−0.353	−0.281
Mean	−0.378	−0.378	−0.385	−0.407

Then, if there really are some relationships between the T. functions and the magnetic activity, an external origin of the geomagnetic disturbances mainly contributed by Dst-like variations or S_q-field variation is to be supposed as possible causes of them. But their details have not been analyzed or known up to now. As this is one of the important points in the characteristics of the T. functions, a detailed analysis of it is urgently needed.

b) Correlations between the transfer functions and their standard deviations

Similar correlation analyses between the T. functions and their standard deviations are carried out. Some results are shown in Fig. 10 and Table 4 in the same manner as in the previous cases.

These correlations show on the whole a slightly higher degree in comparison with those for the K-index, though they also do not present very clear features. The present correlations may be due to similar effects to those suggested in the case of the magnetic activity dependences. For other correlations between the standard deviations and the K-index are much higher than the above two kinds of correlations as the coefficients given in Table 5 will show.

In this way, it is inferred that the time changes of T. functions estimated in the present study may contain more or less parts correlating with K-index or the standard deviations. Therefore, when a possible time change of the T. functions related to an earthquake occurrence is detected, it is highly neccessary to pay great attention to such magnetic activity or standard deviation dependences, as well as to reliability in estimation of T. functions, as will be discussed in the next section.

5. Reliability of the transfer functions in the present analyses

The reliability of the T. functions obtained in the present analyses can be estimated from two kinds of standard deviations. One is the standard deviation

Table 6. Standard deviations of various groups for the data from Jul. to Dec. 1976.

Unit$=10^{-3}$

Period min.	group	A_u S.D.	A_u T.F.	B_u S.D.	B_u T.F.	A_v S.D.	A_v T.F.	B_v S.D.	B_v T.F.	No.
30	A	58(55)	664	88(71)	120	57(46)	42	96(64)	50	41
	B	32(32)	669	43(46)	100	33(28)	35	47(28)	52	22
	C	57(55)	644	65(43)	112	56(27)	56	66(27)	47	11
	D	25(24)	678	49(49)	90	31(23)	37	51(23)	61	13
60	A	56(44)	667	70(35)	122	49(44)	−45	72(44)	56	41
	B	26(20)	673	40(26)	125	26(20)	−57	41(20)	45	20
	C	36(29)	671	49(40)	125	44(23)	−57	50(23)	45	11
	D	26(36)	669	43(30)	134	24(30)	−47	43(30)	52	10
90	A	49(47)	651	82(56)	171	52(58)	−106	84(58)	26	41
	B	26(19)	653	43(51)	157	30(45)	−115	46(45)	24	23
	C	35(46)	653	47(41)	131	42(47)	−132	53(47)	5	11
	D	25(29)	656	42(46)	167	29(33)	−98	47(33)	29	13
120	A	60(58)	635	95(96)	153	57(56)	−164	89(85)	7	41
	B	29(32)	628	47(49)	161	33(31)	−160	44(30)	4	21
	C	38(30)	625	48(37)	125	37(46)	−167	50(31)	−16	11
	D	34(55)	615	50(74)	161	40(44)	−163	49(76)	33	14

of individual T. function obtained in the least square method as already mentioned. The other one is a standard deviation obtained from the whole dissipation of respective T. functions themselves. Herefter the former and the latter will be called I-type and II-type standard deviations, respectively. Here, an error in the calculation of Fourier transforms is ignored, though it is contained within the standard deviations.

Several kinds of mean I-type standard deviations of 30, 60, 90 and 120 minute period components, which are obtained from a small amount of data during half of the year 1976, are given in Table 6. The groups denoted by A, B, C and D are based on the following classification of the geomagnetic disturbance events analyzed. A and B are for all events in the primary analyses and for some (about 50%) events selected out of all events in the secondary analyses, respectively. C and D are for the events with their occurrence time between 14h and 22h LT (during afternoon to late evening) and between 22h and 06h LT (during midnight to early morning) out of the selected events, respectively. The values given within the brackets in Table 6 are the II-type standard deviations. Also, for reference, mean values (T.F.) of the T. functions for each group are given in the same table.

Table 7. Mean standard deviations for the data in the primary analyses during the period from Mar. 1977 to Dec. 1978.

Unit=10^{-3}

Period min.	Group	A_u S.D.	A_u T.F.	B_u S.D.	B_u T.F.	A_v S.D.	A_v T.F.	B_v S.D.	B_v T.F.	No.
10	A	104(109)	569	147(138)	86	106(106)	168	145(126)	58	338
20	〃	55 (59)	659	75 (75)	108	52 (53)	79	71 (72)	69	〃
30	〃	52 (60)	668	72 (73)	115	51 (57)	36	69 (65)	68	〃
60	〃	58 (66)	670	75 (83)	140	56 (60)	−36	73 (83)	60	〃
90	〃	71 (75)	645	90 (91)	149	71 (76)	−85	93 (97)	63	〃
120	〃	81 (90)	616	107(105)	148	75 (92)	−132	104(111)	52	〃
180	〃	92(100)	560	129(131)	115	94(116)	−174	126(142)	78	〃

On the other hand, in Table 7 standard deviations (only group A) etc. for the whole of the primary T. functions obtained from the period from Mar. 1977 to Dec. 1978 are given in the same manner as in Table 6. (Those of the other groups have not been obtained yet.)

In these tables, it should first be noted that the reliabilities of the respective T. functions in the present study are not so high, especially in the 10 min. and 180 min. period components, that no confident time changes can be easily estimated from the individual raw T. functions, and that all of the respective two type standard deviations are nearly equal in value. These facts mean that the T. functions discussed in the present study contain some large error components and in order to estimate their confident time changes, various kinds of averaging and statistical treatments carried out throughout the present study are highly necessary. In general, the standard deviations for the real T. functions are considerably smaller than those of the imaginary ones. This depends upon general differences of the geomagnetic disturbance powers as between the H and the D components.

Even though the results given in Table 6 are obtained from a very small number of data, they suggest another very important feature. Namely, the standard deviations of the group C are much larger than those of the group D. And the differences become greater and greater in the shorter period components. These are perhaps caused by some effects of S_q diurnal variation or others. These characteristics are interesting as some local time dependencies of T. functions and must be analyzed in detail for a much larger number of data.

As concerns the mean values of T. function, no confident difference among the respective four groups seems to be found. In other words, this may mean that no confident difference can be detected from the present result, even if more or less meaningful differences may exist, because of the smallness of the number of data.

6. Concluding remarks

In this paper, the author has reported the analysis method of T. function at Kakioka using Kasmmer's data and some preliminary results mainly on the time change of T. function related to earthquake occurrences. A few important results are summarized as follows;

(1) Very frequent and conspicuous time changes are found throughout the whole period analyzed and some of them seem to correlate with large and near earthquake occurrences in rather many cases, though it is pretty difficult to identify them with confidence because of so frequent occurrences of both phenomena.

(2) From statistical analyses, confident mean earthquake time changes are clearly confirmed as a precursor change related to remarkable earthquake occurrences.

(3) There seem to be some complicated dependences of the magnetic activity or the standard deviation (individual reliability of T. function).

These results are not definite conclusions and a few questions remain about not only the above conclusions but also the present analysis method itself. For example, a few important questions are whether or not the feature of the time change is different for different locations of epicenters and whether or not the feature is different among the four kinds of T. functions or among the respective period components. The present analyses have been carried out almost ignoring such questions. In fact, greater or smaller differences among the earthquake time changes for different T. functions can be seen in the present results (e.g., Figs. 5, 6 and 7), and their details have been described briefly in this paper. It is little known whether these complicated features are essential or not. This is an important problem to be solved on the basis of a much larger number of data.

As introduced in the first section, Shiraki (1977) has been carrying out analyses of day to day T. functions at Kakioka by the different method of spectral analysis for monitoring their much more long-term secular variations. It will be interesting and important to compare the author's data with Shiraki's and to see whether the present results are confirmed by Shiraki's. This comparison is under way. Its results will be reported in near future together with further results of the present analyses.

Acknowledgments: The present author would like to express his thanks to Dr. M. Kawamura, Director of the Kakioka Magnetic Observatory, for his valuable advice and encouragement.

References

Everett, J. E. and R. D. Hyndman (1970): Geomagnetic variations and electrical conductivity structure in western Australia. Phys. Earth Planet Interiors, 1, 24–34.

Honkura, Y. (1972): Geomagnetic variation anomaly on Miyake-jima island. J. G. G., 23, 3, 4, 307–333.

Kato, Y. (1968): Northeastern Japan anomaly of the upper mantle. Proc. Conductivity Anomaly Symp., Earthq. Res. Inst., Univ. Tokyo, 19–31.

Kuboki, T. and H. Oshima (1966): The anomaly of geomagnetic variation in Japan (part 3). Memo. Kakioka Mag. Obs., 12, 127–198.

Rikitake, T. (1959): The anomalous behaviour of geomagnetic variations of short period in Japan and its relation of the subterranean structure. The 9th Report. Bull. Earthq. Res. Inst., Univ. Tokyo, 37, 545–570.

Rikitake, T. (1976): Earthquake prediction. Vol. 9, Developments in Solid Earth Geophysics, Elsevier.

Sasai, Y. (1967): Spatial dependence of short period geomagnetic fluctuations on Oshima Island. 1, Bull. Earthq. Res. Inst. Univ. Tokyo, 45, 137–157.

Sasai, Y. (1969): Geomagnetic variation anomaly in the central part of Japan. Proc. Conductivity Anomaly Symp., Earthq. Res. Inst., Univ. Tokyo, 2, 43–55.

Shiraki, M. and K. Yanagihara (1975): Transfer functions at Kakioka. Memo. Kakioka Mag. Obs., 16, 143–155.

Shiraki, M. (1977): Monitoring of the time changes of CA transfer functions at Kakioka. J. Geod. Soc. Japan, 23, 3, 135–139, (in Japanese).

Yanagihara, K. (1972): Secular variation of the electrical conductivity anomaly in the central part of Japan. Memo. Kakioka Mag. Obs., 15, 1–11.

Yanagihara, K. and T. Nagano (1976): Time change of transfer function in the central Japan anomaly of conductivity with special reference to earthquake occurrences. J.G.G., 28, 157–163.

Yanagihara, K., M. Kawamura, Y. Sano and T. Kuboki (1973): New standard magnetic observation system of Kakioka (KASMMER). Memo. Kakioka Mag. Obs., 36, 4, 218–281.

Yoshimatsu, T. (1963): Result of geomagnetic routine observations and earthquakes. Memo. Kakioka Mag. Obs., 11, 71–83.

地震発生に関連した変換函数の時間的変化（I）

佐 野 幸 三

（地磁気観測所）

柿岡地磁気観測所では KASMMER システムの完成により，精度の高い地磁気毎分値の利用が可能になった．そこで1976年6月頃より，このデータを用いた多くの周期成分の CA 変換函数の定常的な解析を行ってきている．これは柿岡の CA 変換函数を常時監視し，地震等に関連したその時間的変化特性を詳細に研究しようとするものである．この報文では現在までにえられた概略次のような興味ある解析結果について報告する．

比較的小規模（M=4～6）な地震に対しても，その前兆現象的な CA 変換函数の変化が，個々の多くの事例からある程度見い出された．このことはさらに，解析期間に発生した比較的大規模な多くの地震についての重ね合せ統計平均の“地震時間変化”から十分に裏付られた．これらの結果は1976, 1977，1978年の各期間について，ほぼ矛盾のない同様な結果が求められており，まずは間違いのない事実だと思われる．

他方，柿岡の CA 変換函数の時間的変化の中には，地磁気活動度（K-指数）に依存する部分もあるらしいこともわかった．これらは各周期成分，CA 変換函数の種類などで特性が異なるようで，複雑な様相を示している．これらの特性は単なる誤差要因によって起こされたものとも考えられ，その詳細はまだ良くわからない．

Manuscript received 2 October 1979