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Transfer Functions of Short-period Geomagnetic Variations (0.3 min. to 9.0 min.) at Kakioka

by

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Abstract

In this paper transfer functions of very short-period geomagnetic variations (0.3 min. to 9.0 min.) at Kakioka during the period from Jan. 1977 to Mar. 1979 have been analyzed. A real-time calculation method of such the transfer functions by the KASMMER system and some interesting results are described.

From the present analysis, it is found out that there is an interesting long term variation like a seasonal or annual variation in time change of Au and Bu transfer functions, particularly in the shorter-period components. While, in the present transfer functions not only a great random error component but also a great systematic one depending upon the former or the geomagnetic activity are recognizable.

1. Introduction

The concept of a geomagnetic or magnetotelluric transfer function is applied to the study of electrical induction in the earth's interior. These transfer functions at an observatory of the geomagnetic or magnetotelluric fields have been regarded as parameters which are essentially controlled by the electrical conductivity of the crust and upper mantle. In this paper the author will treat the geomagnetic transfer function and hereafter it is denoted simply by *T.* function. Much detailed descriptions on the *T.* function should be referred to the author's other paper (Sano, 1980) or others (*e.g.* Everett and Hyndman, 1967; who first presented the rigid calculation method of *T.* functions in complex form.).

T. functions for the geomagnetic variations of long-period components such as 10 min. to 180 min. and their time changes at Kakioka have been reported by Yoshimatsu (1963), Yanagihara *et al.* (1976), Shiraki *et al.* (1977) and the present author (1980) relating to earthquake occurrences near Kakioka. In the present study a real-time calculation method of *T.* functions for the shorter-period geomagnetic variation than in the above studies is presented and some interesting results obtained are discussed. Hereafter these *T.* functions are named short-period *T.'* function. Data used for the determinations of the short-period *T.* functions are from the KASMMER system, which is a main continuous observation system of the geomagnetic fields at the Kakioka Magnetic Observatory.

The short-period *T.* functions at Kakioka have been a little rigidly studied hitherto. Only Kuboki *et al.* (1966) and Yanagihara (1972) obtained such similar kinds of *T.* functions by a classical analysis method for rapid geomagnetic variations such as SSC, SI and pi phenomena with a periodicity of a few minutes. And Mori (1977) tried to analyze *T.* functions for pi and pc pulsations with periods from 10 sec to 500 sec by a rigid calculation method. Also the present author reported a preliminary results of this study (Sano, 1977).

2. Analysis method of short-period transfer functions

2.1. Real-time calculation method

The periods of the geomagnetic variations treated in this study are the following ten kinds.

Periods=0.3, 0.5, 0.75, 1.0, 1.5, 2.0, 3.0, 4.5, 6.0, and 9.0 minutes.

In order to calculate the short-period *T.* functions, 3-sec sampling data of the geomagnetic three components H, Z and D by the KASMMER system are used. The present calculation method is essentially the same as that for the long-period *T.* functions described in the other paper (Sano, 1980). As the 3-sec sampling data are not usually stored into any memory in the KASMMER system, the actual data processing in the present case is carried out at real-time by the following way.

The data processing is done by a minicomputer (H–10) which is connected on-line to the measuring system of the KASMMER's optical pumping magnetometers. Reading the data at every 3-seconds, the calculations of Fourier transforms of H, Z and D components are carried out successively for ten periods to be analyzed. This processing has been continued during an appointed interval of 9.0 min. from which a set of Fourier transforms are determined. And, this routine has been repeated successively ten times. Thereafter, the respective *T.* functions are calculated by the least square method of the complex function for the thus-obtained Fourier transforms and the data processed are immediately typed out. In addition to these calculations, standard deviations of the respective individual *T.* functions assessed in the least square method are also calculated. These processings are automatically continued until the computer receives a manual stop command.

Detailed Fourier transform processing is done in the following way. At first, the top values of three geomagnetic components in each interval (9.0 min.) are taken as their initial values and successive reading values are subtracted by these initial values. Now, as shown in Fig. 1 by a schematic diagram, let the above residual values be ΔH, ΔZ, and ΔD, respectively. These ΔH, ΔZ and ΔD variations generally include some non-cyclic changes like a straight line shown in the figure. Such a non-cyclic change of each component should be eliminated from the Fourier transform calculations.

Secondary, the respective periodic change parts are defined by fluctuations from the above-mentioned straight line which is estimated by a regression line and these periodic change parts are denoted by $\Delta H'$, $\Delta Z'$ and $\Delta D'$, respectively. They are expressed as follows:

$$\Delta H' = \Delta H - Ah \cdot t + Ch$$
$$\Delta Z' = \Delta Z - Az \cdot t + Cz$$
$$\Delta D' = \Delta D - Ad \cdot t + Cd,$$

where Ah, Az and Ad are the regression coefficients, and t is time series (3, 6,... 540 sec, corresponding to 1, 2, 3,...180 in 3-second data sampling series.). The constant terms of Ch, Cz and Cd are neglected in the actual data processing. Each Fourier transform of the periodic change parts above defined can be obtained by subtracting each Fourier transform of the second term from that of the first one in the above formulae. Besides, the calculations of regression coefficients are carried out in parallel with the Fourier transform calculations.

In this way, a set of T. functions of ten period components are successively obtained nearly at every 90 min. interval. This analysis is used to be done temporally on such day as some geomagnetic disturbances occur or are expected to occur. Consequently, during the periods analyzed effective geomagnetic disturbances do not always occur. In fact, sometimes very remarkable disturbances were missed to be analyzed, on the contrary, sometimes meaningless ones with a very small amplitude were analyzed during a long time.

2.2. Reliability of the present short-period transfer functions

As the present analysis is continuously done regardless that there are meaningful geomagnetic disturbances enough to be analyzed or not as previously mentioned, generally original individual T. functions thus obtained have much less reliability.

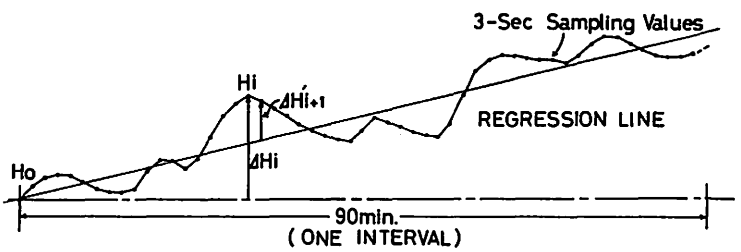


Fig. 1. Schematic diagram of a short-period geomagnetic variation and its non-cyclic change defined in the present study (expressed by H-component).

Table 1. Standard deviations of *Au* and *Bu* *T.* functions of short-period components. S.D. and S.D.′ are mean standard deviations of individual transfer functions in the least square calculation and standard deviations obtained from each dispersion of the whole transfer functions themselves.

Period (Min.)	Au		Bu	
	S. D.	S. D.′	S. D.	S. D.′
0.3	0.174	0.181	0.237	0.219
0.5	0.215	0.195	0.273	0.252
0.75	0.254	0.213	0.342	0.289
1.0	0.295	0.220	0.393	0.320
1.5	0.325	0.216	0.414	0.317
2.0	0.322	0.218	0.418	0.319
3.0	0.316	0.204	0.403	0.306
4.5	0.261	0.189	0.353	0.292
6.0	0.228	0.166	0.310	0.273
9.0	0.172	0.140	0.271	0.245

In Table 1 two kinds of standard deviations are given. The one (S.D.) is all mean of standard deviations (say, standard error) which are assessed for each individual *T.* function itself and the other (S.D.′) is the standard deviation estimated by each total dispersion of *T.* function values themselves adopted in statistics.

As can be easily understood from the two kinds of standard deviations given in Table 1, the raw individual *T.* functions show generally so low reliability that anything can be hardly discussed from almost all of them. It will be pointed out as a few possible reasons for the above great standard deviations that (1) there is not any selection of the geomagnetic disturbances during the operation of an analysis, (2) the resolution of 0.1 nT (the present measuring unit of the KASMMER system) is not sufficient in general to analyze the short-periodic disturbances with a very small amplitude (At least, a resolution of 0.01 nT will be required.) and (3) there are more or less some influences of artificial magnetic noises from the electric rail ways near Kakioka.

In any case, in order to discuss some reliable and natural behaviours of the *T.* functions, it is quite necessary to average a great number of *T.* functions for a day or a few days, or a month. Furthermore, some unreliable data showing a greatly deviating values from its general mean value or having an exceptionally large standard deviation (S.D.) should be omitted from the averaging procedure. And as for the averaging, a weighted mean method is used to reduce erratic contributions of unreliable data. The reciprocal of the standard deviation (S.D.) is used as a weight in the weighted mean.

3. Results of the present analyses

As be well known, the four *Au*, *Bu*, *Av* and *Bv* *T.* functions are expressed by the following equation,

$$\Delta Z = (Au + i \cdot Av)\Delta H + (Bu + i \cdot Bv)\Delta D,$$

where ΔZ, ΔH and ΔD are short-periodic variations of the respective geomagnetic fields. *Au* and *Bu* are the real term (in-phase) and *Av* and *Bv* are the imaginary (out-of-phase), respectively. In this paper some interesting results concerned with *Au* and *Bu* *T.* functions are presented.

3.1. *Temporal time changes of mean transfer functions for a day or a few days*

Operations of the present analysis have been carried out temporally or randomly

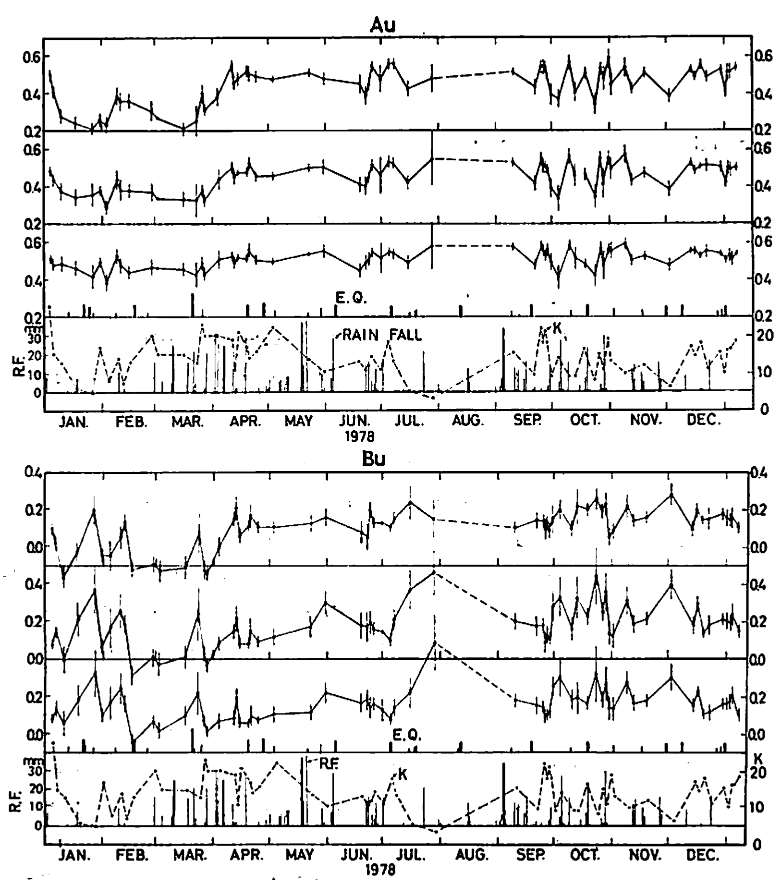


Fig. 2. Mean transfer functions of three sub-bands for a day or a few days in 1978. The error bars are the 95% confidence interval. Remarkable earthquakes, daily sum of K-index (K) and daily total rainfall at Kakioka are also shown at the bottom of each panel.

during the period from Jan. 1977 to Mar. 1979. From this period about 130 sets of mean *T*. functions for a day or a few days are obtained. These mean *T*. functions are further averaged for three sub-period bands. These bands are called short-, middle- and long-period bands and they consist of the following period components:

Short-period band (S.P.)=0.3, 0.5, 0.75, 1.0 and 1.5 minutes

Middle-period band (M.P.)=1.0, 1.5, 2.0, 3.0 and 4.5 minutes

Long-period band (L.P.)=2.0, 3.0, 4.5, 6.0 and 9.0 minutes.

The middle-period band is superposed partially upon the period components of the other bands.

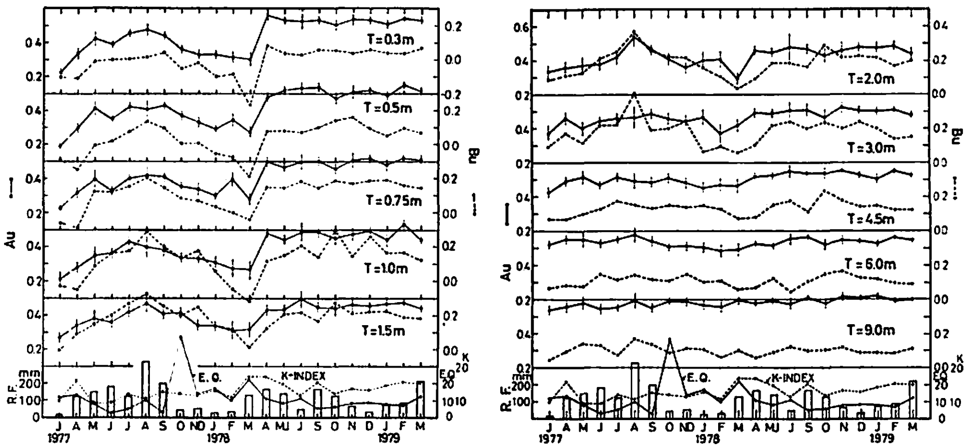
In Fig. 2 *Au* and *Bu* mean *T*. functions of these three bands during the year of 1978 are shown, respectively. At the lower part of each panel, main felt earthquakes, daily rainfalls and daily sums of K-index at Kakioka are also shown for the reference' sake. The earthquakes are indicated by the fat bars, whose length is proportional to its degree of the Japanese intensity scale of earthquake at Kakioka.

As can be seen in the figure all kinds of *T*. functions show quite conspicuous and complicated changes. Particularly, the *T*. functions of *Bu* or the short-period band in both cases are so. Although several possible relations between decreasing changes and earthquake occurrences seem to be recognizable, it is uncertain whether they are similar kinds of earthquake precursory changes to those reported in the other paper (Sano, 1980) or merely accidental features due to some error origins. While, somewhat close relations will be seen or suggested between the *T*. function changes and the geomagnetic activity change. This will be discussed again in latter sub-section.

3.2. *Long term changes of monthly mean T. functions*

In addition to the above mentioned changes of *T*. functions, a large long term change like a seasonal or annual variation can be seen in each band. In order to discuss a much more reliable time change of each *T*. function and to clarify the detailed feature in the long term change, further certain kinds of averaging need. For this purpose monthly mean (or sum) values of *T*. functions and the other elements are calculated.

In Fig. 3 are shown these monthly mean values of *Au* and *Bu T*. functions of the respective period components. The panel (a) is of the shorter-period components and the panel (b) is of the longer-period ones. Monthly sums of main felt earthquakes (E.Q.) and rainfalls (R.F.), and monthly mean of daily sum of K-index (K-index) are presented in the bottom of each panel. The occurrence frequency of an earthquake is experimentally defined by a weight of $e^{(M-3.0)}$, where M is the magnitude of earthquake. The error bars only shown for *Au T*. functions are the 95% confidence interval. In general, the error bars of *Bu T*. functions are slightly



(a) Shorter-period components (b) Longer-period components

Fig. 3. Monthly means of *Au* and *Bu* transfer functions during the period from Jan. 1977 to Mar. 1979. Monthly mean of daily sum of K-index and monthly summation of earthquake occurrence frequency and monthly total rainfall are shown together at the bottom of each panel.

larger than those of *Au T.* functions.

From the figure it can be clearly found that both *Au* and *Bu T.* functions in each period component show conspicuous long term changes and they are well resemble in change manner to one another. Namely, the long term changes of the shorter-period *T.* functions are well characterized likely that each of them shows a annual variation with a maximum in summer and a minimum in winter in 1977, and in Apr. 1978 a sudden increasing change occur, thereafter the long term change almost disappears. On the other hand, the changes in the longer-period bands are very small, particularly in the case of 9.0 min. period band, any significant change cannot be seen. In this way, it should be noted that the shorter the period, the larger the above discussed long term change becomes.

The finding of these significant features in the short-period *T.* functions is one of the most meaningful and interesting results in the present study. The origin of these changes are not well understood at the present stage. The changes are not closely related to the geomagnetic activity change, but seem to be slightly related to the total rainfall or the earthquake occurrence frequency. Accordingly, it is possibly inferred that they are produced by some internal source origins rather than external ones. Of course, it is hardly considered that they are merely accidental results by some error origins. If these interpretations are true, the characteristics in the *T.* function changes may be easy to be understood by a reflection of electrical conductivity changes at an upper part of the earth's interior.

Meanwhile, it should be noted that there are some great differences in time change manner and absolute value of the shorter-period *T.* functions between the periods preceding and following the sudden increasing change in Apr. 1978. This is quite strange and it is quite unknown what happened in Apr. 1978 in the earth's interior.

3.3. Systematic error components in time change of T. functions

In this sub-section a systematic error component of *T.* functions is discussed with relation to the standard deviations (S.D.) or the geomagnetic activity. In Fig. 4 are shown *Au* and *Bu* mean S.D. dependences of four sub-period bands. These bands are denoted by ①, ②, ③ and ④ in the figure and they consist of the following period components:

①=0.3 and 0.5 minutes
②=0.75, 1.0 and 1.5 minutes
③=2.0, 3.0 and 4.5 minutes
④=6.0 and 9.0 minutes.

The respective *T.* functions in each band are classified into 27 groups according to their standard deviation values which are divided into 27 sub-ranges uniformly except the last one. And mean values of *T.* functions and standard deviations within each group and sub-range are obtained, respectively. Fig. 4 shows changes of the former mean values as a function of the mean standard deviation. The error bars are the 95% confidence interval.

From the figure it is clearly confirmed that almost all of the *T.* functions change greatly and somewhat systematically depending upon their standard deviations. These

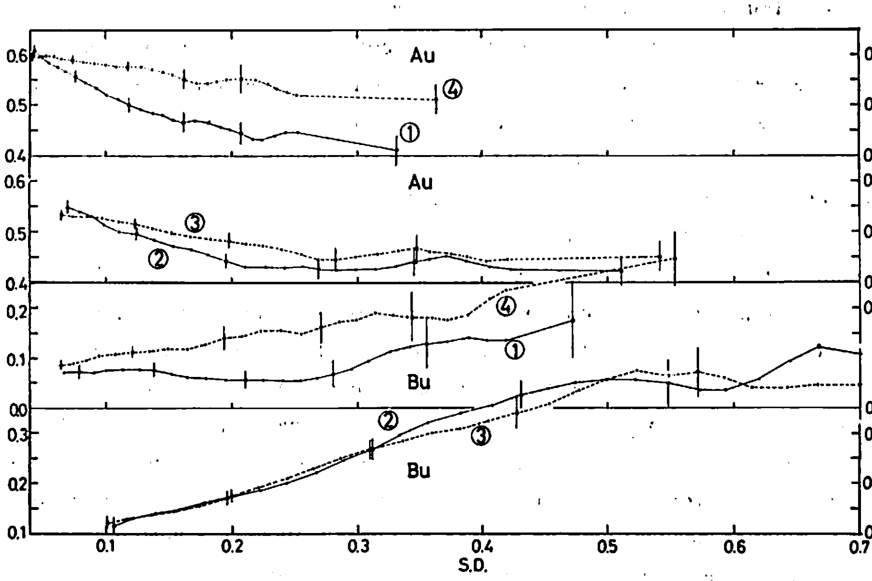


Fig. 4. Mean standard deviation dependences (systematic error components) of *Au* and *Bu* transfer functions of four sub-bands.

changes are regarded as a systematic error component or an S.D. dependence. The sense of the S.D. dependence is opposite between *Au* and *Bu* *T*. functions in general feature. It is very notable that in general rather small S.D. dependences can be seen at the side of the larger S.D. than at the side of the smaller one, as if each value of *T*. functions reaches at a constant level respectively.

As a reasonable fact, it will be expected that the standard deviations correlate well negatively with the geomagnetic activity, that is to say, the amplitude of the short-periodic geomagnetic disturbance, although its details are not shown in this paper. Consequently, it is considered that the S.D. dependences are nearly equivalent to respective geomagnetic activity dependences, but, of course, the sense of the correlation is opposite.

In Fig. 5 some correlations between the mean *T*. functions of the short-period band as discussed in sub-section 3.1 and the geomagnetic activity (mean ΣK) are presented for both the cases of *Au* and *Bu* *T*. functions, respectively. Three kinds of plots indicated by the marks o, ● and × are of the respective epochs shown in the figure. As all plots spread quite widely, each correlation is not so high, but there is certainly a geomagnetic activity dependence in each plot, being approximately consistent with that expected from the S.D. dependence.

These S.D. and geomagnetic activity dependences are regarded as that they are not essential features in the geomagnetic natural variations at Kakioka, but mainly due to some error origins whose details are quite unknown. To a certain extent, however, this fact can be inferred from the reasons pointed out in sub-section 2.1 as concerns the reliability of the *T*. functions.

In any case, it should be noted that the temporal changes of *T*. functions shown in Fig. 2 are more or less affected by the above S.D. dependence or the geomagnetic

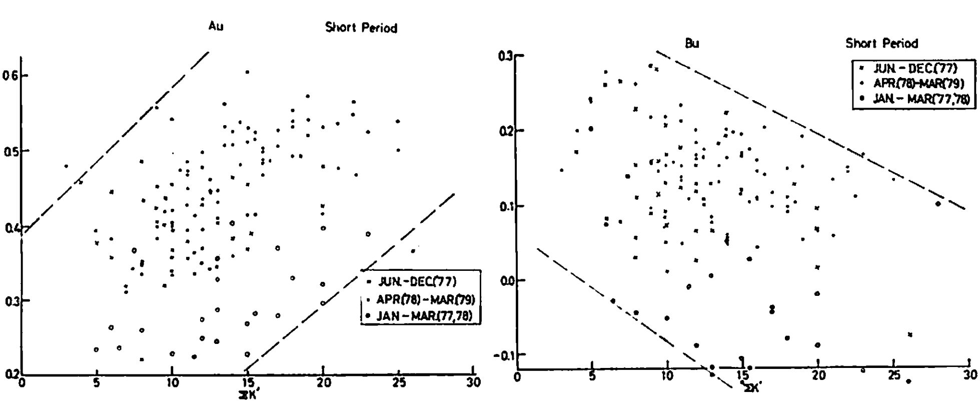


Fig. 5. Correlations of mean transfer functions for a day or a few days with the geomagnetic activity (mean ΣK) in the case of S.P. band (0.3 min. to 1.5 min.). The left and right panels are for the *Au*'s and *Bu*'s, respectively.

activity one. This means that the effect of such the dependences can not be sufficiently averaged out for the mean of a day or a few days, even if the present weighted mean method is used. While, the changes of monthly means shown in Fig. 3 are regarded as natural features in which the S.D. dependence or other error components are considerably well eliminated. Because both the changes of *Au* and *Bu* *T.* functions are quite resemble to each other in sense and amplitude. These features will be never caused by the S.D. dependence or other errors.

3.4. A few other characteristics of the short-period transfer functions

(a) Period characteristics of the T. functions and their standard deviations

Period dependent features of the short-period *T.* functions and their standard deviations are shown in Fig. 6. The upper frame of Fig. 6 shows all means of the respective *T.* functions averaged for the entire data used herein and their data numbers (N). The lower frame shows such means of the standard deviations (S.D.) and the other standard deviations (S.D.′), respectively. They are plotted against the period.

Both period dependent features of *Au* and *Bu* *T.* functions are very significant. They show such different dependences as the *Au*'s is roughly a *U*-type, on the contrary, the *Bu*'s is a fine inverted *U*-type. The present results are in general consistent with those reported by Kuboki *et al.* (1966). These period characteristics of the short-period *T.* functions are very interesting together with those of the long-period ones

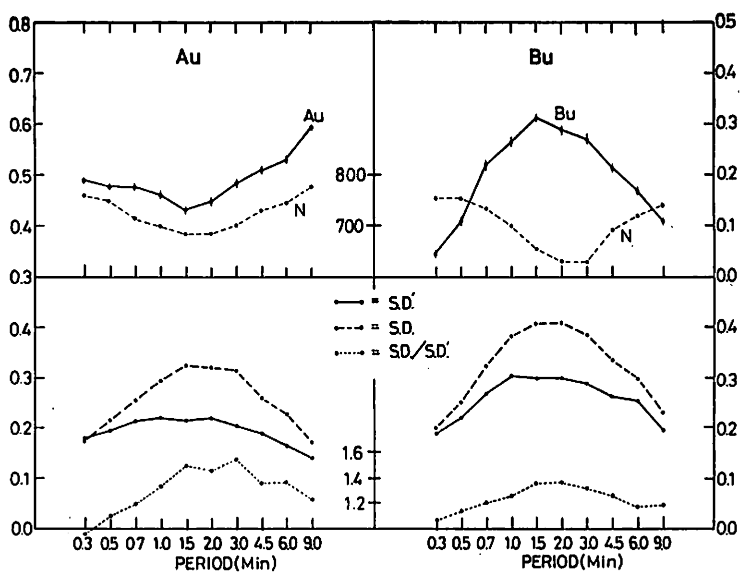


Fig. 6. Period characteristics of *Au* and *Bu* transfer functions and their standard deviations. The error bars are the 95% confidence interval.

reported in the other paper (Sano, 1980).

As for the standard deviation, it is very notable that the mean standard deviation of the period of 1.5 or 2.0 minutes in each case is the largest, and the shorter or the longer the period, the smaller the mean standard deviation becomes. These period dependences are hardly expected or caused from the calculation method. Hence, an existence of some predominant noise components mainly due to the artificial magnetic disturbances in such the middle period band may be recalled from the above fact in the standard deviations, though their details are unknown.

Meanwhile, the standard deviations of *Bu T.* functions are somewhat larger than those of *Au*'s. And it should be noted that the mean S.D. is generally larger than the S.D.′ in almost all cases. This means that S.D. is fairly over-estimated in the present analysis. Besides, the number of data adopted is inversely proportional to the mean value of S.D.

(b) Local time dependence of Au T. functions

C. W. Anderson *et al.* (1978) reported that significant local time dependences of induction vector (Parkinson vector) at high latitude stations from 54° to 65° were found for almost the same short-period geomagnetic variations as the present ones. It is very interesting whether or not there are similar local time dependences at Kakioka where is located at lower latitudes than the aboves. From a result of brief analysis, a certain kind of weak local time dependence is also found at Kakioka. Namely, in Fig. 7 are shown mean local time dependences of the present *Au T.* functions of five sub-bands and the entire band which are averaged for the data of 1978. Since the determinations of *T.* functions have been little done at day time (10h to 14h *LT*), such times of day are omitted from the statistics. The error bars show the 68% confidence interval except the 95% one for all mean plot.

Roughly speaking, all of the local time dependences, at least, except the third one, show such a change as having a maximum value around mid-night, rather significant and rapid decreasing at the morning side, and slight and gradual decreasing at the evening side. This manner can be most clearly confirmed from the all mean at the bottom of the figure. The decreasing changes from the mid-night to the morning are reliable with an about 95% confidence in average.

The above mentioned results have some portions resemble to the local time dependence reported by C. W. Anderson *et al.* (1978). It is, however, little known whether or not the present local time dependence at Kakioka can be understood by the same origins as an external source origin which was interpretated at high latitude stations by C. W. Anderson *et al.* Besides, there may be a possibility that the present one is caused by some error source origins. In any case, this matter is one of the most interesting problems on the time change of *T.* functions.

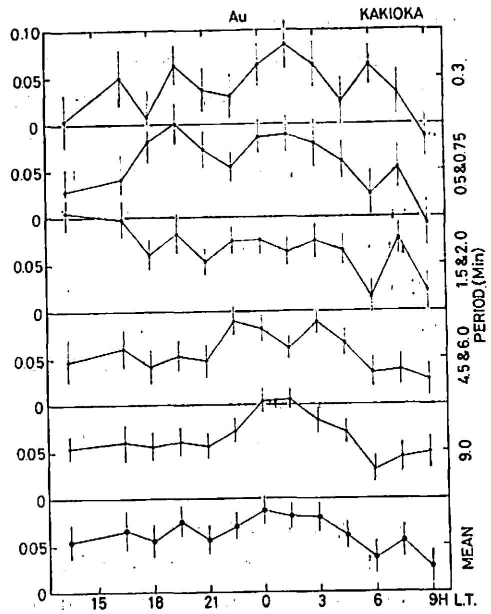


Fig. 7. Local time dependences for various groups of *Au* transfer functions. The error bars are the 68% confidence interval except the 95% one in all mean.

4. Concluding remarks

In this paper the real-time calculation method of the short-period *T.* functions at Kakioka by the KASMMER system and many interesting results obtained from the analyses of the data during the period from Jan. 1977 to Apr. 1979 have been presented. Though some of the present results are somewhat questionable, the following ones which are considerably believable are obtained:

(1) The *T.* functions in the shorter-period components within the period band treated herein indicate significant long term changes like a seasonal or annual variation especially in 1977. Such features are quite resemble between *Au* and *Bu* *T.* functions.

(2) The *T.* functions have substantial period characteristics, particularly in the case of *Bu* *T.* function.

(3) Some local time dependences in change of *T.* functions are found.

(4) Even mean *T.* functions for a day or a few days have a fairly great random error and a systematic error depending upon the former or the geomagnetic activity. It is, however, possible to discuss meaningful time changes from monthly mean *T.* functions (mean of about ten mean *T.* functions for a day or a few days).

In conclusion, in order to attain much more reliable *T.* functions, the present analysis method has many difficult problems to be improved. For example, they are to analyze only effective geomagnetic disturbances by using an off-line system, to improve the resolution of the digital data from 0.1 nT to at least 0.01 nT, to avoid artifitial disturbances as much as possible from the analysis, to analyze much more frequently and so on. These are still in consideration.

The short-period *T.* functions are one of the most useful means to get informations of electrical conductivity anomaly in the upper part of the earth's interior which are closely related to earthquake occurrences there. More detailed and reliable analysis is highly desired. Besides, though this paper has reported only the results on the *Au* and *Bu T.* functions, those on the *Av* and *Bv*'s should be reported, these analyses being in preparation.

Acknowledgements

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柿岡における地磁気短周期 (0.3 min.～9.0 min.) 変化の変換函数

佐 野 幸 三

概 要

柿岡における Kasmmer システムの毎秒計測値を用いた地磁気短周期 (0.3 min.～9.0 min.) 変化の変換函数実時間解析法およびその 2, 3 の解析結果について報告する。

解析期間は Jan. 1977～Mar. 1979 で，今回の解析結果で最っとも注目すべきことは，このような短周期変換函数の時間的変化の中に，顕著な長周期変動が認められたことである。この変化は短い周期成分の変換函数になるほど卓越するという明瞭な傾向があり，またこれらの時間変化特性は Au と Bu 変換函数で全く良い一致を示している。これらの変化は地震発生（活動度）や雨量とある程度の相関性が見られ，また後述する地磁気活動度依存性とは無関係と考えられるので，それらは主として地球内部に起因する変化であると推定される。

しかしながら，今回の解析法には磁場計測の分解能が 0.1 nT では十分ではないこと（地磁気短周期変化振幅は一般に小さい。），また有効な地磁気変化があるなしにかかわらずの実時間連続解析であるというようないろいろな問題があり，個々に求められた変換函数は極めて大きな誤差（バラツキ）を持っている。さらに，その誤差に依存したかなり大きな系統誤差も認められ，これはまた地磁気活動度依存性とも考えられるもので，有意な地下に原因する変換函数の同定はそれほど容易ではない。

この系統誤差（地磁気活動度依存性）は Au と Bu 変換函数でセンスが反対である。したがって，前述の変換函数の長期的変化は，少なくともこのような効果によるものではないと結論される。むろん，これらの変化の他に大きな短周期的変化も多く見られるが，それらについては外部要因・誤差要因によるものもかなり多いと考えられ，それらの判別はなかなか困難である。