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Geoelectric Characteristics of Mito, Kakioka, Aizu and Numazu Regions Revealed by the Analysis of the Geoelectric Field Variations with BAYTAP-G
— an evaluation of BAYTAP-G as a means of an analysis of the geoelectric field —

by

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Abstract

With the use of BAYTAP-G, the author analized low-frequency geoelectric field variations observed using telecommunication facilities near Mito, Aizu and Numazu and with the conventional method at Kakioka. Focusing attention on the amplitude factor of the frequency response, the amplitude of the tidal component and minimum ABIC-value, the author discussed what were derived by this analysis to evaluate BAYTAP-G as a means of an analysis of the geoelectric field. The apparent resistivity derived by the above factor made prominent the contrast between the three regions (Mito, Kakioka and Numazu) and Aizu region. The amplitude of the tidal component also showed a similar distinct contrast between the three regions and Aizu region. The author confirmed that the minimum ABIC-value well correlates with the geomagnetic activity, suggesting that induced component can not be completely separated in this study. By the use of the third (Z-)component of the geomagnetic field, the minimum ABIC-value is lowered greatly in winter and little in summer season. This seasonal variation of the role of the Z-component of the geomagnetic field which is lead by a characteristic seasonal variation of the amplitude factor could not be geophysically interpreted in this study. The minimum ABIC-value is further lowered by the use of the advanced associated data of the geomagnetic field.

1. Introduction

In the previous paper (OZIMA *et al.*, 1989; MORI *et al.*, 1993), we reported that we analized our data of the geoelectric field variations with BAYTAP-G (ISHIGURO *et al.*, 1984). With this program, the observed geoelectric field variations were separated into four components: 1) tidal component, 2) response to the associated data, 3) trend, and 4) irregular component. By the use of the geomagnetic data for associated data, we can obtain the electromagnetically induced component as the response to the geomagnetic variations. This induced component is well known to be by far the predominant variation of the geoelectric field variations. With this method, owing to the separation of the induced component, the anomalous changes in the geoelectric field which might be related with the tectonic activities can be precisely detected. For this purpose, of course, we need fairly stable and noiseless digital data of both the geoelectric and geomagnetic field variations over a long time. In addition to the improvement in the detectability of the anomalous changes in the crustal self-potential which may be found in the trend and/or the irregular component, analysis of the geoelectric field variations with BAYTAP-G gives us other information. That is, i) the amplitude factor (the ratio of the frequency response(induced geoelectric field) to the geomagnetic field) and the phase shift of the frequency response, ii) the amplitude and the phase of the constituents of the tidal component, and iii) ABIC-values (Akaike, 1980).

With the use of the facilities of the Nippon Telegraph and Telephone Company:NTT (the length of the base-line is 20 to 30 km) at Mito and Numazu regions (Fig. 1), we have observed the geoelectric field variations since 1985. At Mito region, we have obtained so highly stable and noiseless digital one-minute values of the geoelectric field variations (*e.g.*, Mori, 1987), but the observation at Mito region was terminated in August, 1989. The data obtained at Mito region throughout this interval were used in this study. At Numazu region, however, considerable amount of cultural noise is contaminated (*e.g.*, Takayama, 1989). The observation at Numazu region was continued until July, 1996, but the data during the interval listed in Table 1 were used in this study. Similarly as ours, Kinoshita *et al.* (1989) have started observation of the geoelectric field variations with the use of the facilities of NTT at several regions in Japan in 1987. Of them, the data at Aizu region for the interval listed in Table 1 were provided for this study. The observation stations at Aizu region are also shown in Fig. 1. At Kakioka Magnetic Observatory (KAK in Fig. 1), fairly noiseless digital one-minute values of the geoelectric field variations have been obtained from Jan., 1987 to Jan., 1988 with the conventional method with the base-line EW:1.2 km and NS:0.9 km). In order to have a quick-look of the quality of the data, examples of the original one-minute values concerned in this study are shown in Fig. 2. One observation-line of which direction is close to E-W from each region was selected for this study. Table 1 is the list of the distance, the direction and the time-interval of the four base-lines of which data the author analized and reports here.

Recently, in April, 1996, the Kakioka Magnetic Observatory including the author has finished the construction of a geomagnetic and geoelectric observation system at Awajishima. We have just started analizing the geoelectric data at Awajishima using BAYTAP-G. Therefore, the author felt that

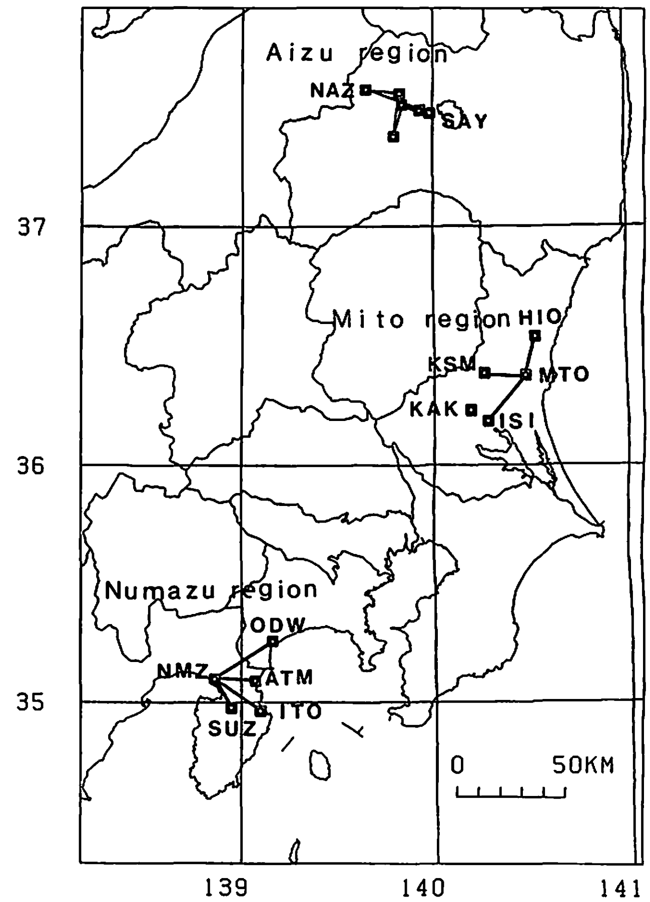


Fig. 1 Observation networks for the geoelectric field, and Kakioka Magnetic Observatory. The thick straight line between observation points shows the base-line of the geoelectric observation with NTT facilities. Details of the observation points are given in Mori (1987) and Kinoshita, *et al.* (1989). Mito region — MTO:Mito, KSM:Kasama, ISI:Ishioka, HIO:Hitachiohta. Numazu region — NMZ:Numazu, ATM:Atami, ITO:Ito, SUZ:Shuzenji, ODW:Odawara. Aizu region — NAZ:Nishiaizu, SAY:Seaburiyama. Names of the other four points are not shown in this figure. AIZ 1CH in Table 1=NAZ-SAY. Kakioka region — KAK:Kakioka Magnetic Observatory

Table 1 Description of the observation lines concerned in this study and the interval of data which were analized in this study.

region	base-line	distance(km)	direction	interval
Mito*	KSM-MTO	19.0	N 93 °E	1985 Mar.–1989 Aug.
Kakioka**	KAK EW	1.2	N 85 °E	1987 Jan.–1988 Jan.
Aizu*	AIZ 1CH	31.8	N110 °E	1987 Sep.–1988 Oct.
Numazu*	NMZ-ATM	18.9	N 92 °E	1985 Sep.–1990 Aug.

* using NTT facilities, ** using conventional method

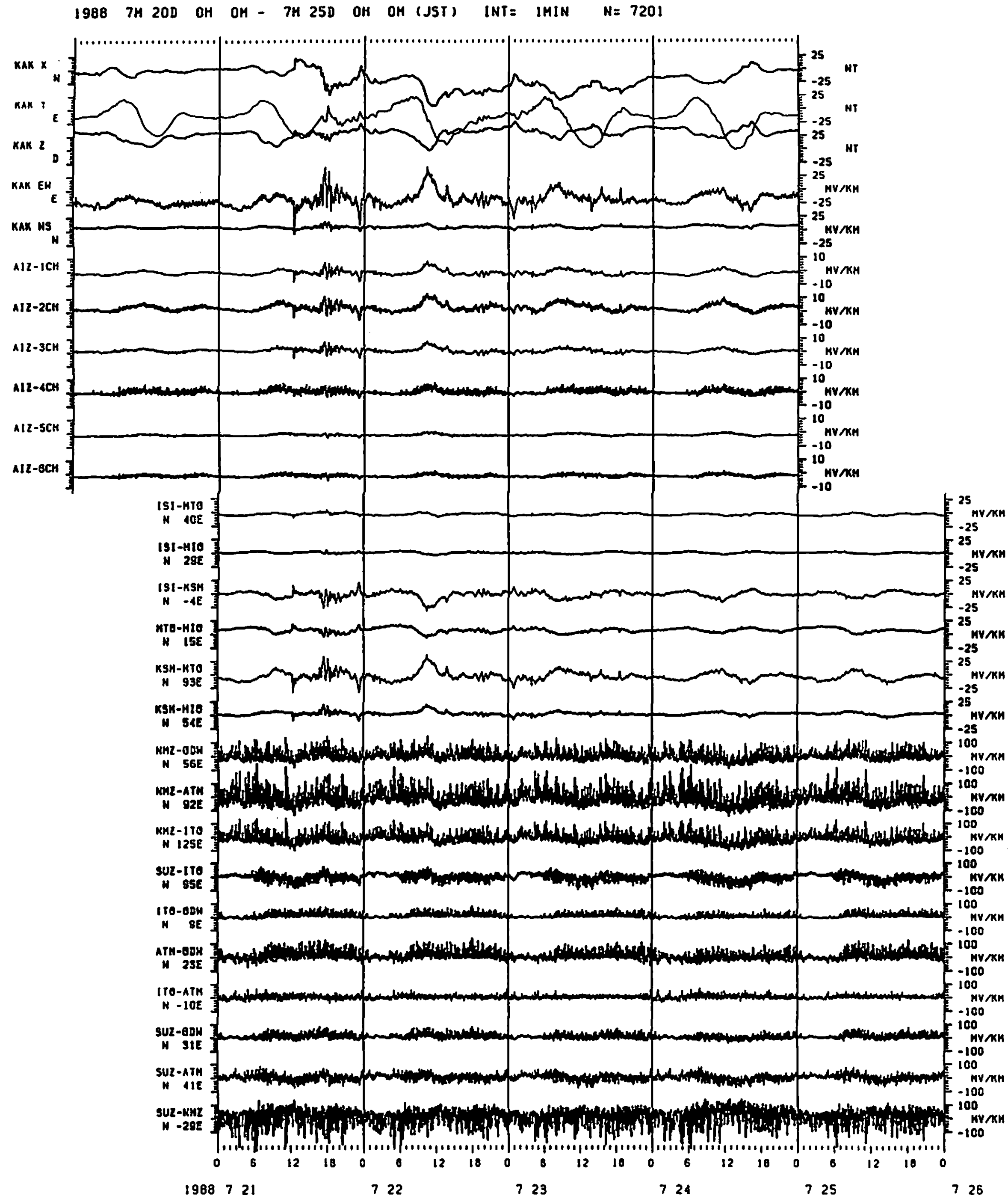


Fig. 2 Examples of the plot of the original one-minute values of the data.

it is her duty to publish a paper in Memoirs of the Kakioka Magnetic Observatory on the experienced knowledge which she had obtained in the course of the analysis of the geoelectric data at Mito, Numazu, Aizu and Kakioka with BAYTAP-G, hoping that this paper would benefit the younger colleagues at the Kakioka Magnetic Observatory.

In this paper, the author intended to evaluate how BAYTAP-G works as a means of the analysis of the geoelectric field variations and will report the results of the analysis of these data using BAYTAP-G with special reference to i) the time-variation of the amplitude factors of the frequency response, ii) that of the amplitude of the tidal constituents, iii) that of the ABIC-values, iv) geoelectric differences between these four regions (Mito, Kakioka, Aizu and Numazu). In this study, the author dealt with the hourly mean values derived from the one-minute values for both the geomagnetic and the geoelectric fields. Therefore, this study is not adaptable for quick phenomena. The geomagnetic field observed at Kakioka Magnetic Observatory (which is located about 30 km SW of Mito) were used for associated data for those four regions. Every successive 744 hourly mean values (corresponding to 31 days) of the observed data for the interval listed in Table 1 were analized. As the quality of the data at Mito region is the best, the author reports the results of the analysis mainly of KSM-MTO.

2. Results of the analyses

2.1 *Amplitude factor of the frequency response of KSM-MTO, KAK EW and AIZ 1CH derived using X(northward)- and Y(eastward)-component of the geomagnetic variations*

Fig. 3(a) and (b) show the time-variations of the amplitude factors at KSM-MTO for the X- and Y-component of the geomagnetic variations, respectively, for several typical periods for examples. As seen in the figures, there are fluctuations in these factors. The fluctuation relative to the value of the amplitude factor itself seems almost constant for all periods, *e.g.*, around 0.15 for the X-component. The origin of this fluctuation is inferred partly to be in the accuracy of the observed data. However, as seen in Fig. 3(a), on the whole, the amplitude factors for all periods at KSM-MTO for the X-component of the geomagnetic variations may be regarded to have been almost constant for these several years. On the other hand, as seen in Fig. 3(b), besides the fluctuations, a seasonal (biannual) variation in the amplitude factor for the Y-component of the geomagnetic variations in the medium period range ($T \cong 4 \sim 6$ hours) is dominant. However, generally, the variation of the amplitude factor for the Y-component of the geomagnetic variations for the whole period range may be regarded to have been stationary. Therefore, except for the seasonal variations, the electro-magnetic properties at this region has not suffered changes so much in these several years. The amplitude factors at KAK EW (Fig. 4) and at AIZ 1CH (not shown in the figure) show similar variations as those at KSM-MTO. As has been already mentioned, the data at Numazu region are very noisy, therefore, the author could not show the amplitude factors of the frequency response at NMZ-ATM.

In the case of KAK EW (Fig. 4), the value of the amplitude factor is about 1.5 times as large as that at KSM-MTO (Fig. 3). This is the reflection of a slight difference in the apparent resistivity between these two regions (Mito and Kakioka). On the other hand, in the case of AIZ 1CH, the value of the amplitude factor is small by one order of magnitude compared with that at KSM-MTO (see Table 4). This also should be the reflection of a large difference in the apparent resistivity between Mito and Aizu regions. These will be discussed further in *3.3*.

2.2 *Amplitude factor of the frequency response of KSM-MTO, KAK EW and AIZ 1CH derived using X-, Y-, and Z(downward)-component of the geomagnetic variations*

Fig. 5(a), (b) and (c) show the time-variation of the amplitude factors at KSM-MTO for the X-, Y-, and Z-component of the geomagnetic variations, respectively, for several typical periods for examples. The zigzag variation in the longer period range for the X-component and the seasonal variation for the medium period range for the Y-component is similar as those in the above case where the Z-component of the geomagnetic variations was not employed. The anomalous value of the amplitude factor for the X-component at March, 1989 is supposed to be an effect of the extra-ordinarily large magnetic storm at that interval. The time-variation of the amplitude factor for the Z-component of the geomagnetic variations in the longer period range is comparatively large and seems to be seasonal and also to be correlated somewhat with the geomagnetic activity which is shown in Fig. 6. That is, when the geomagnetic activity is high, the amplitude factor for the Z-component of the geomagnetic variations of the longer period range is comparatively large. As clearly shown in these figures, in the shorter period range, variations of the amplitude factors for the X-(Fig. 5(a)) and the Z-component of the geomagnetic variations (Fig. 5(c)) are much intensive and principally seasonal, and also they seem to be anti-correlated. The variation for the Z-component of the geomagnetic variations of the shorter period range also seems to be superimposed by a geomag-

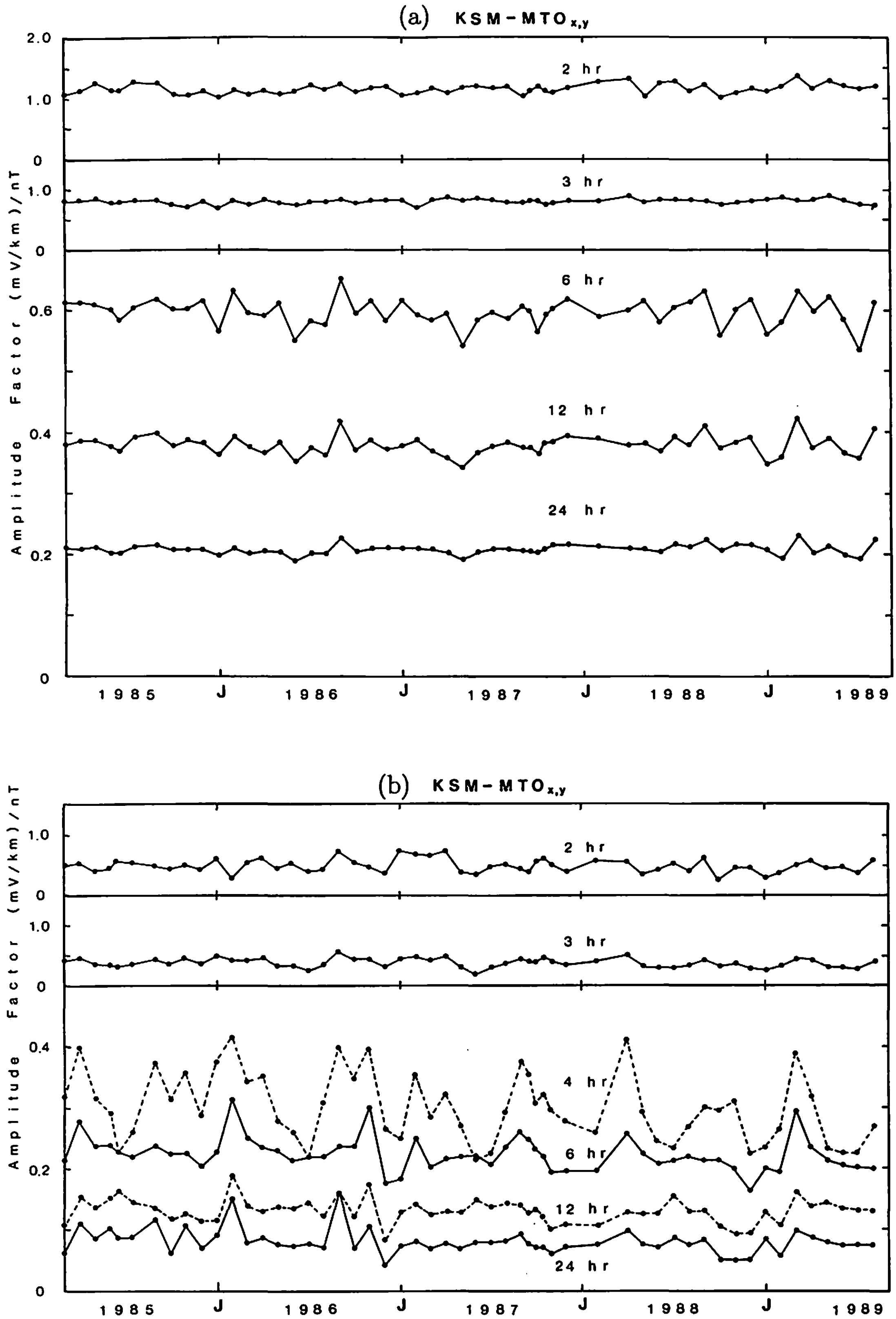


Fig. 3 Monthly variation of the amplitude factor of the geoelectric field at KSM-MTO for several typical periods. The X- and Y-component of the geomagnetic field were used as associated data. (a) For the X-component of the geomagnetic variations. (b) For the Y-component of the geomagnetic variations.

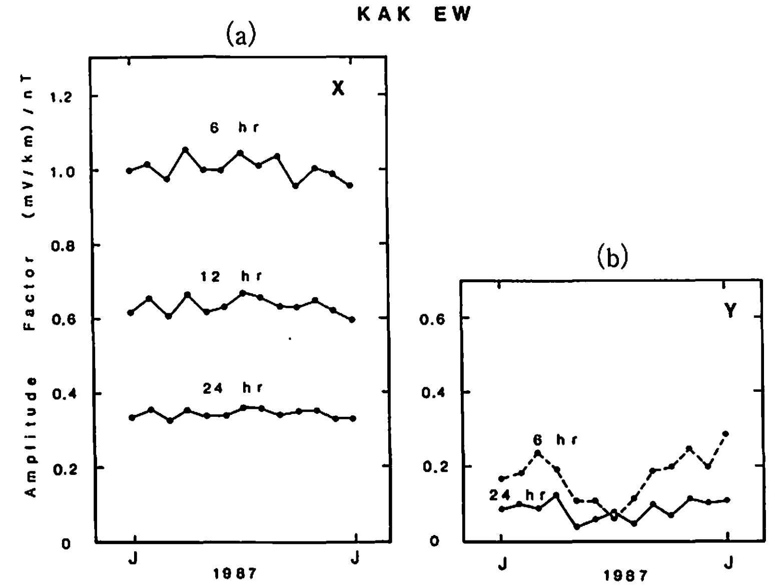


Fig. 4 Monthly variation of the amplitude factor of the geoelectric field at KAK EW for several typical periods. The X- and Y-component of the geomagnetic field at Kakioka were used as associated data. (a) For the X-component of the geomagnetic variations. (b) For the Y-component of the geomagnetic variations.

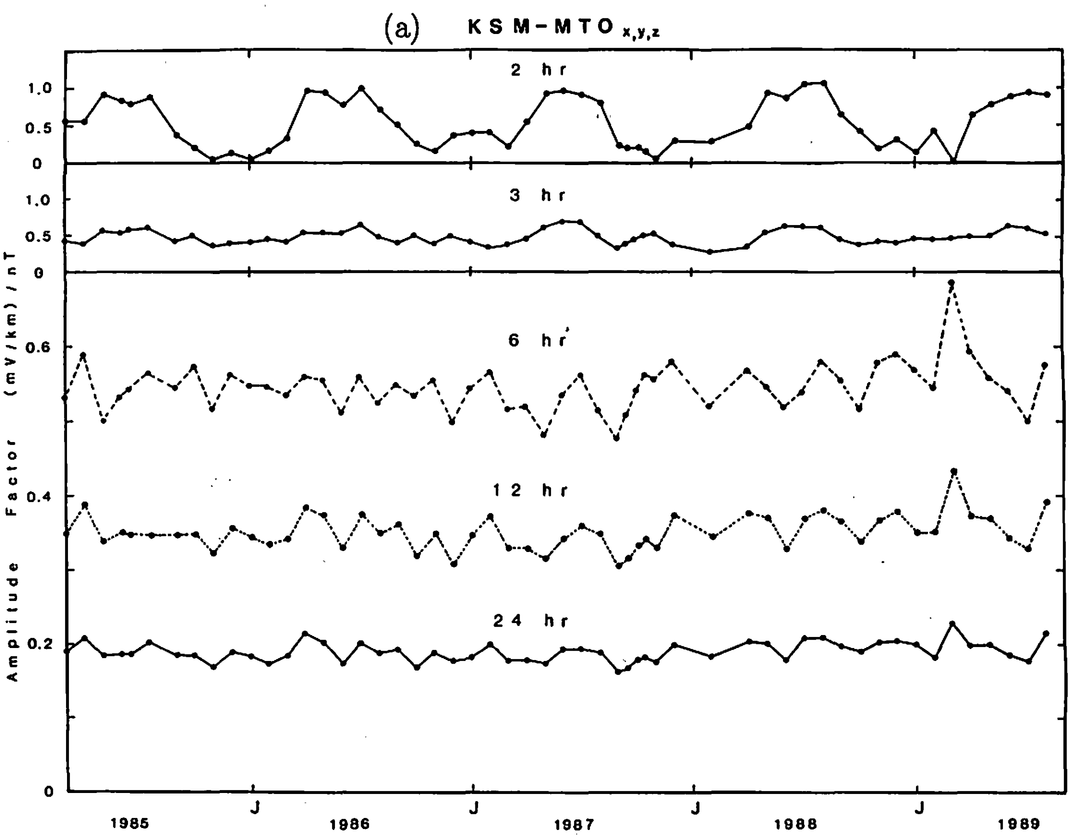
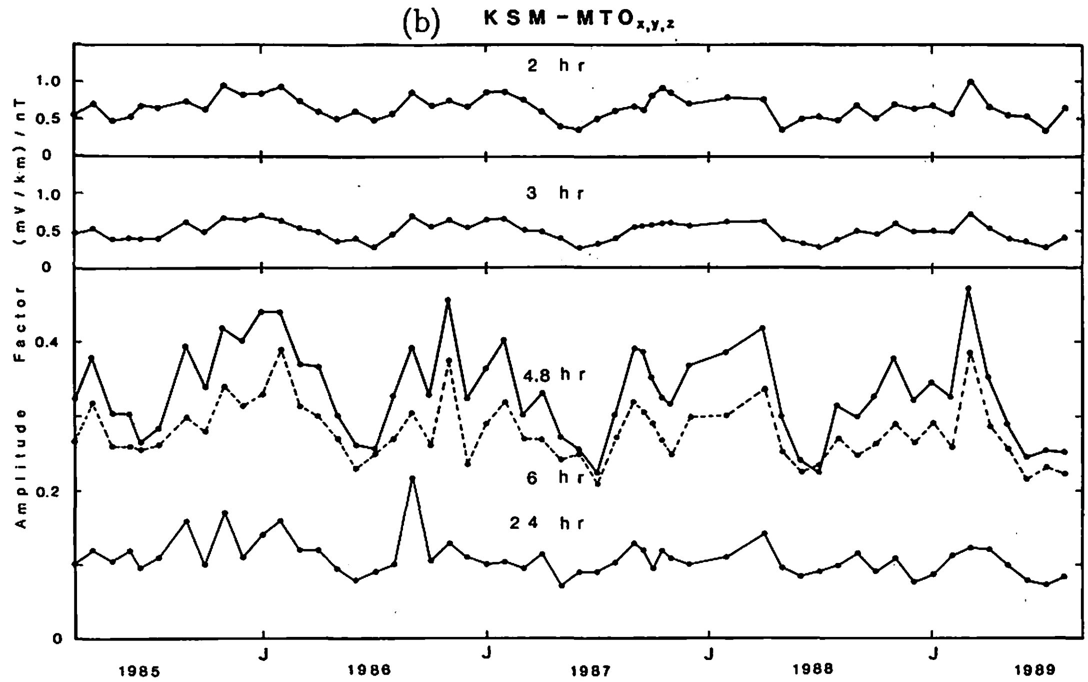
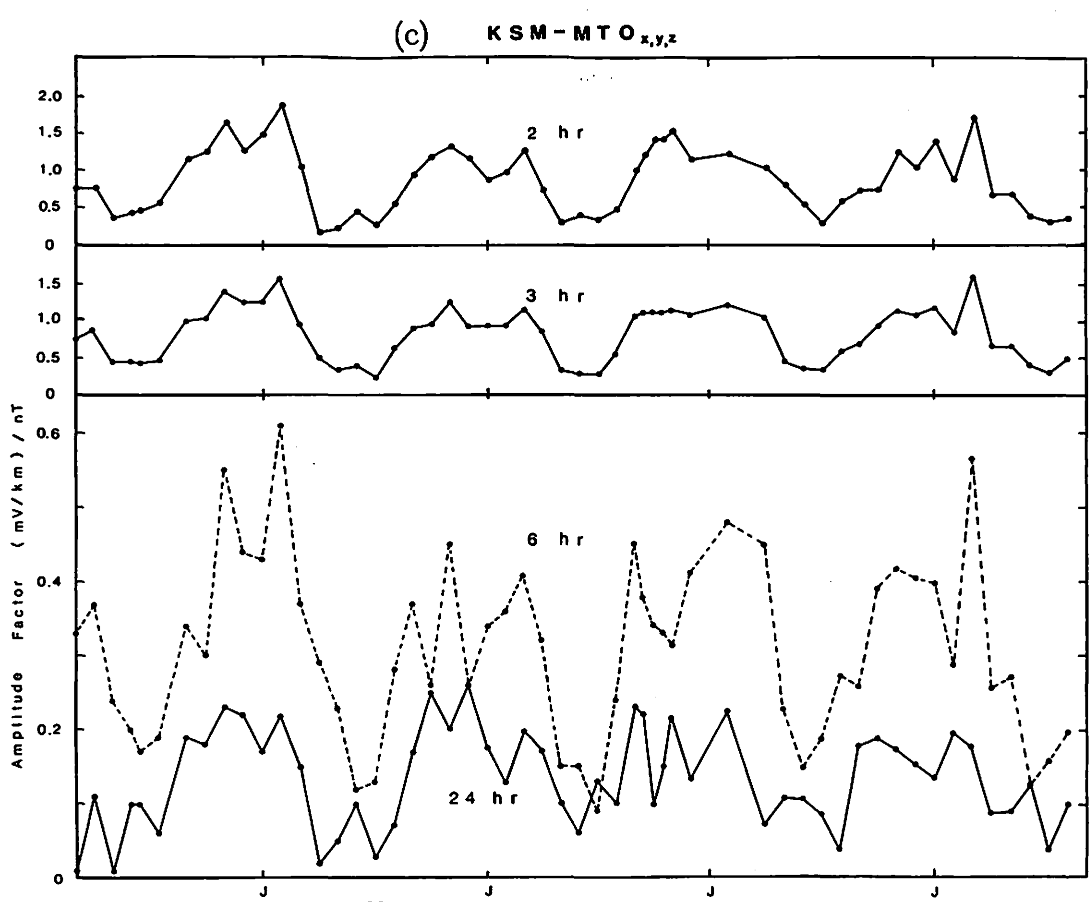


Fig. 5 Monthly variation of the amplitude factor of the geoelectric field at KSM-MTO for several typical periods. The X-, Y-, and Z-component of the geomagnetic field at Kakioka were used as associated data. (a) For the X-component of the geomagnetic variations. (b) For the Y-component of the geomagnetic variations. (c) For the Z-component of the geomagnetic variations.


(b) KSM - MTO$_{x,y,z}$
2 hr
3 hr
4.8 hr
6 hr
24 hr
Amplitude Factor (mV/km)/nT
1.0
0.5
0
0.4
0.2
J
1985
1986
1987
1988
1989


(c) KSM - MTO$_{x,y,z}$
2 hr
3 hr
6 hr
24 hr
Amplitude Factor (mV/km)/nT
2.0
1.5
1.0
0.5
0
0.6
0.4
0.2
J
1985
1986
1987
1988
1989

netic-activity-dependent component. The comparatively small seasonal variation for the Y-component for medium ~ short period range is in phase with that for the Z-component of the geomagnetic variations of all period range. For KAK EW and AIZ 1CH, similar results were obtained as shown in Fig. 7 and 8, respectively. From the same reason as in *2.1*, the author could not show the result of NMZ-ATM.

On the basis of the facts, i) that in the above

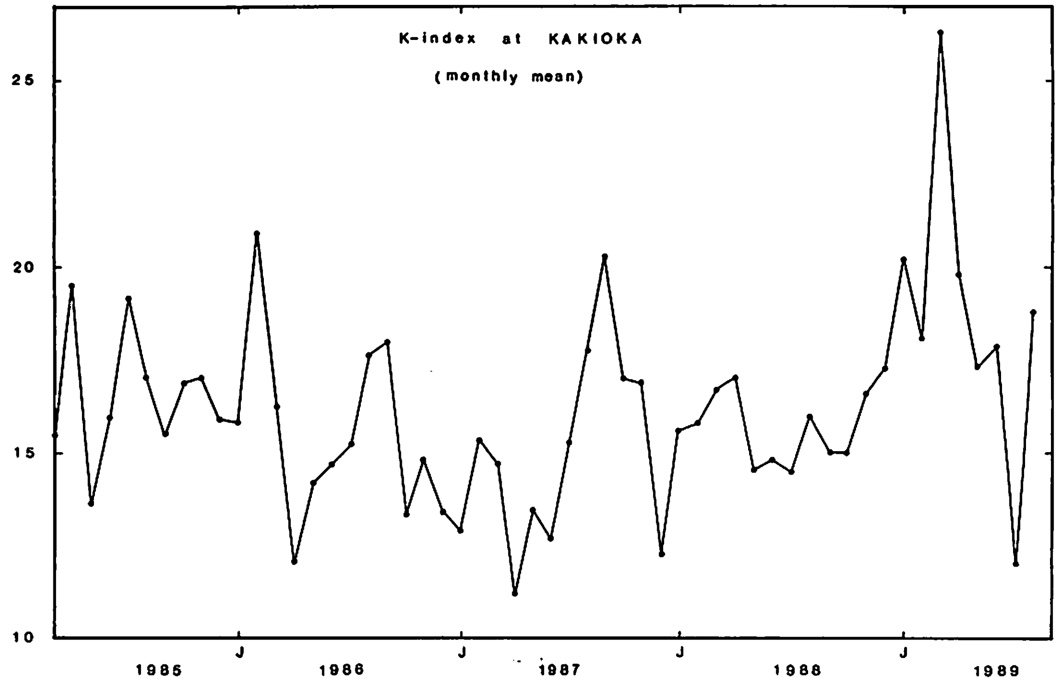


Fig. 6 Monthly mean value of the daily sum of the three-hour K-index at the Kakioka Magnetic Observatory.

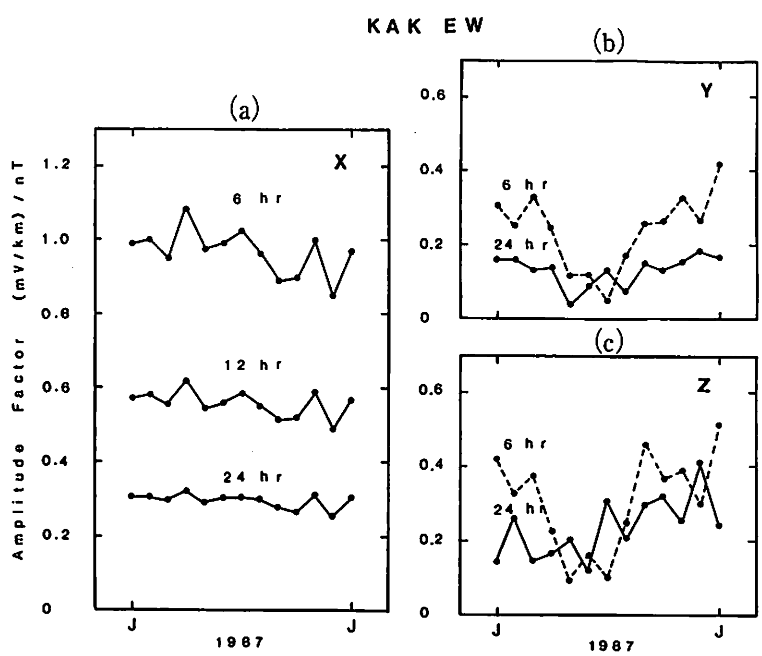


Fig. 7 Monthly variation of the amplitude factor of the geoelectric field at KAK EW for several typical periods. The X-, Y-, and Z-component of the geomagnetic field at Kakioka were used as associated data. (a) For the X-component of the geomagnetic variations. (b) For the Y-component of the geomagnetic variations. (c) For the Z-component of the geomagnetic variations.

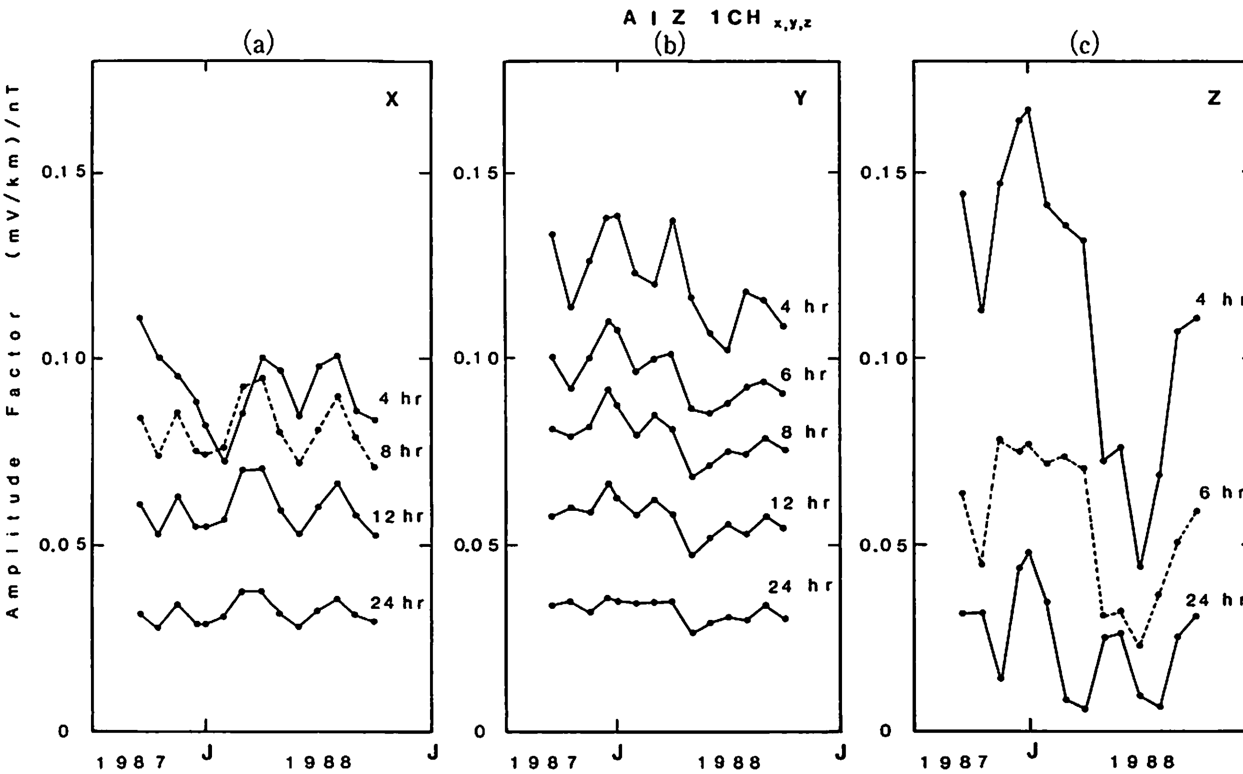


Fig. 8 Monthly variation of the amplitude factor of the geoelectric field at AIZ 1CH for several typical periods. The X-, Y-, and Z-component of the geomagnetic field were used as associated data. (a) For the X-component of the geomagnetic variations. (b) For the Y-component of the geomagnetic variations. (c) For the Z-component of the geomagnetic variations.

case where the Z-component of the geomagnetic field was not employed for associated data to which responses were taken, the amplitude factor for the X-component of the geomagnetic variations was almost constant with time even in the short period range, ii) that similar results as Fig. 4 were obtained for the data at AIZ 1CH of which locality is far away from the other three regions, and also iii) that the variation of the Z-component of the geomagnetic field is not thoroughly independent of the variations of the X- and Y-component, the author concludes that the intensive time-variation of the amplitude factors in this case does not indicate an actual time-variation in the electro-magnetic properties in these regions but is merely derived from the principle of BAYTAP-G so that the ABIC-value is totally minimized. That is, the values of these factors in this case no more mean information about the electric properties of the earth as expected in magneto-telluric method. This is discussed in *3.4*.

2.3 Minimum ABIC-values for KSM-MTO

Fig. 9 shows the time-variation of the minimum ABIC-value for each set of 31 days for the two cases, *i.e.*, (i) the Z-component of the geomagnetic variations was not included in the analysis, (ii) three components (X-, Y-, and Z-component) of the geomagnetic variations were adopted. The author found that the minimum ABIC-value for the case (i) is always larger than that for the case (ii) regardless of the value itself. This means that the role of the Z-component of the geomagnetic variations is significant in general for the reproduction of the induced geoelectric variations. As seen in Fig. 9 and Fig. 6, the minimum ABIC-value is clearly correlated with the geomagnetic activity. That is, in the more intensely disturbed interval, the larger the minimum ABIC-value is and this situation is not changed by the use of the Z-component of the geomagnetic variations. This correlation is a matter of course after the definition of ABIC-value. Still, the author likes to point out this fact in order to emphasize that this correlation indicates that the analysis of the geoelectric variations using hourly mean values with BAYTAP-G (employed here) cannot completely separate the induced geoelectric variations, especially at the magnetically disturbed intervals, and consequently comparatively large amplitude of the irregular component is left at the magnetically disturbed intervals as will be demonstrated below.

The difference between the two minimum ABIC-values for (i) and (ii), which may indicate a measure of the importance of the Z-component of the geomagnetic variations for the representation of the induced geoelectric variations, varies annually, as shown in Fig. 10. The difference is maximum in winter and minimum in summer, which being almost zero in July. This is qualitatively consistent with the fact that the variation of the amplitude factor for the Z-component of the geomagnetic variations is small in summer and large in winter for the whole period range, as indicated in Fig. 5(c).

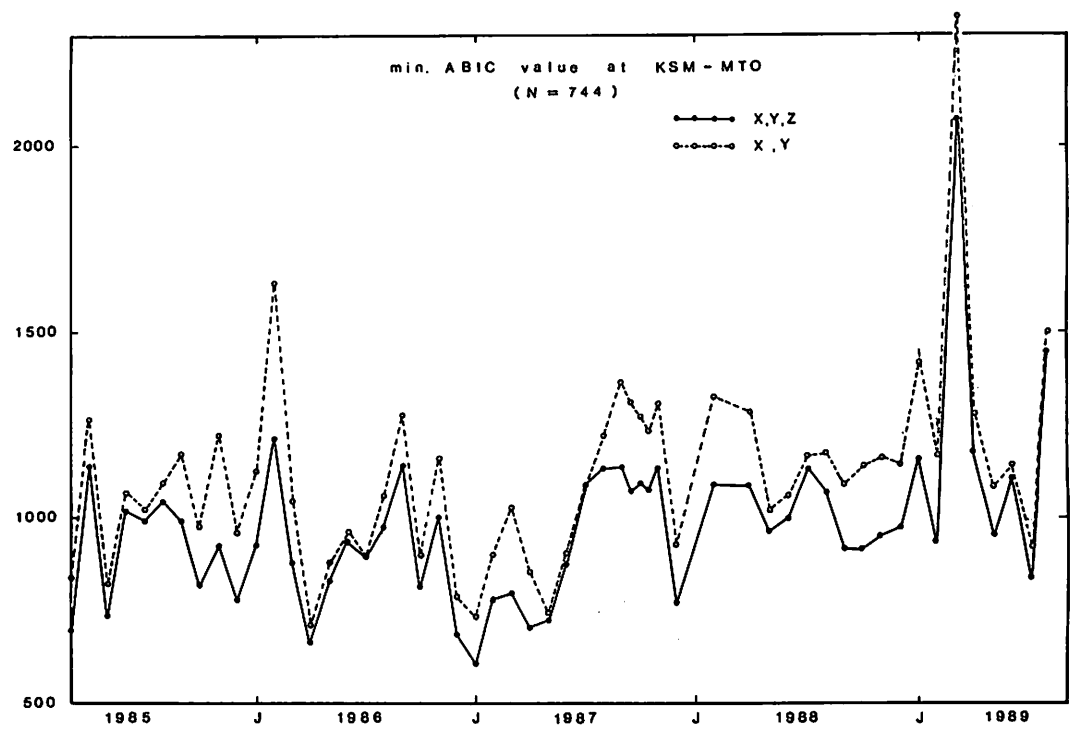


Fig. 9 Minimum ABIC values of the geoelectric field at KSM-MTO in the two cases where the Z-component of the geomagnetic field was not adopted and adopted as associated data.

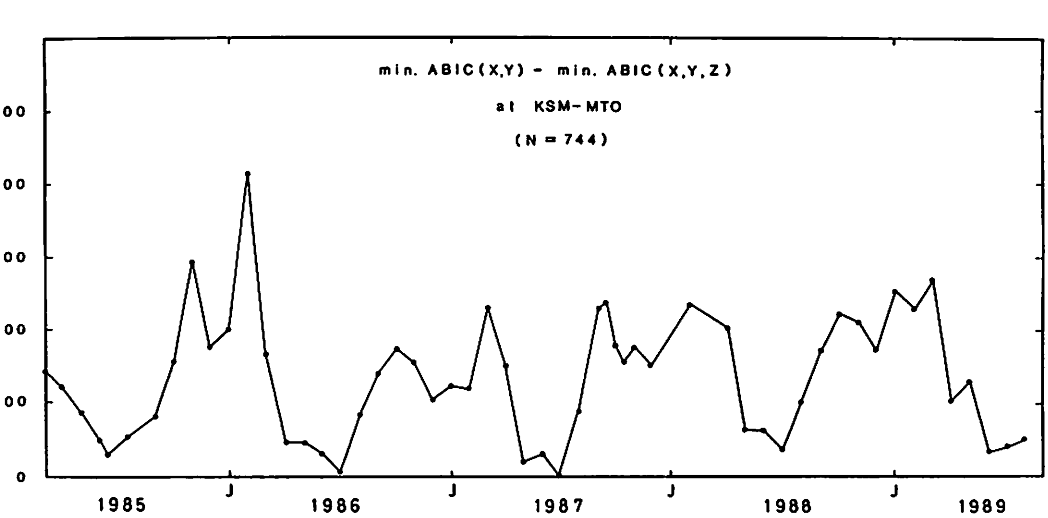


Fig. 10 The difference between the minimum ABIC values in the two cases.

2.4 Amplitude of the tidal component at KSM-MTO

Fig. 11 shows time-variation of the amplitude of the most predominant four constituents of the tidal component (O_1, $S_1{}^1$, M_2, $S_2{}^2$) in which the X- and Y-component of the geomagnetic variations were used as associated data. The amplitude of S_1 and S_2 varies greatly yearly, while that of O_1 and M_2 stays comparatively constant. Furthermore, the amplitude of S_1 and S_2 is anti-correlated with each other. That is, the amplitude of S_1/S_2 is small/large in summer and large/small in winter. In the case where the Z-component of the geomagnetic varia-

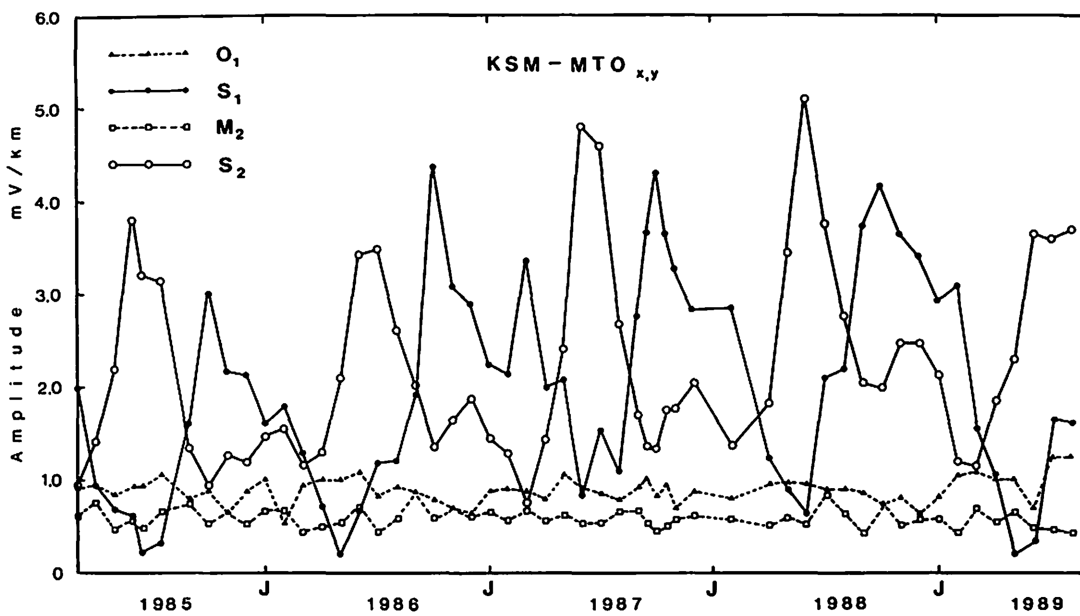


Fig. 11 Monthly variation of the amplitude of the tidal component of the geoelectric field at KSM-MTO for the four constituents. The X- and Y-component of the geomagnetic field were used as associated data.

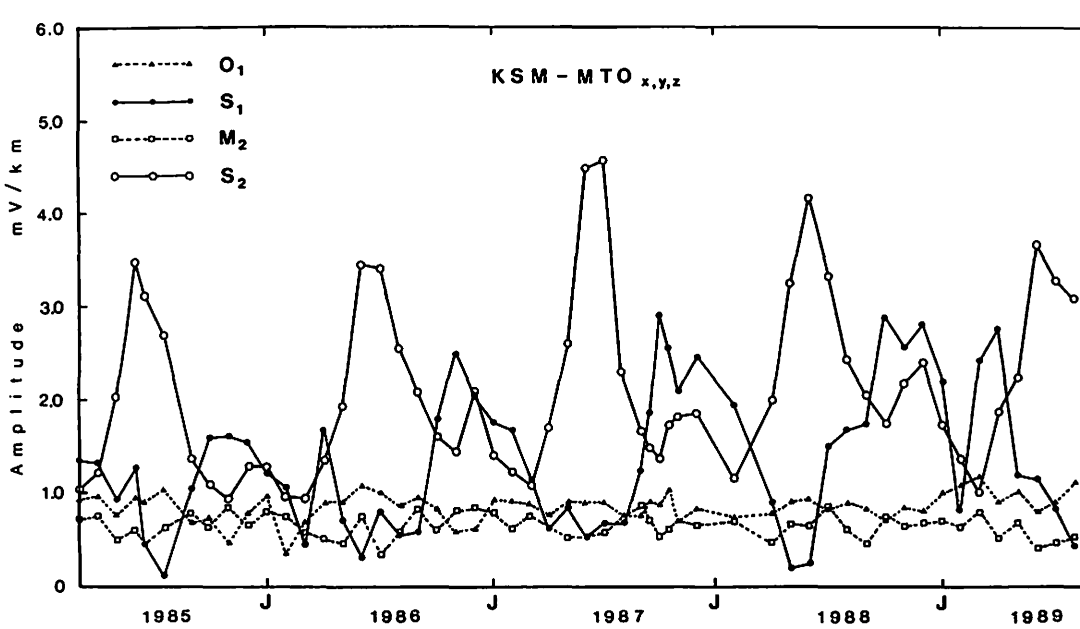


Fig. 12 Monthly variation of the amplitude of the tidal component of the geoelectric field at KSM-MTO for the four constituents. The X-, Y-, and Z-component of the geomagnetic field were used as associated data.

[1] P_1 and K_1 are included

[2] K_2 is included

tions is added to the associated data, except for S_1, the amplitude is almost same as those in the case where the Z-component of the geomagnetic variations is not used, while that of S_1 is greatly different as shown in Fig. 11 and Fig. 12. That is, owing to the addition of the Z-component of the geomagnetic variations for the estimation of the induced electric field, considerable amplitude of the tidal component of the period of 24 hours is reduced. As will be seen from the fact that the time-variation of the reduced one is similar to that of the amplitude factor of the Z-component of the geomagnetic variations of period of 24 hours (Fig. 5(c)), the reduced portion of the tidal component of the period of 24 hours should have been brought to the induced component by the Z-component of the geomagnetic variations. This fact implies that using BAYTAP-G, it may practically be difficult to separate thoroughly the tidal component from the induced one for the variation of the periods of S_n ($n=1,2,3,\ldots$), because these periods of S_n are contained in both the geomagnetic variations and the tide.

In principle, there could be two factors which cause the real tidal component of the geoelectric field, *i.e.*, i) earth-tide, ii) ocean-tide. Therefore, if we assume that the effect of the geomagnetic variations were completely separated in this analysis as a response (induced) component, 'the tidal components (S_1, S_2, O_1, M_2)' in Fig. 11 and/or Fig. 12 could be regarded to be due to the earth-tide and/or the ocean-tide. As has been pointed out by MORI (1989), S_1 is not contained in the ocean-tide. Therefore, the fact that the significant amplitude of 'S_1' exists in the tidal component of the geoelectric field as shown in Fig. 11 and/or Fig. 12 implies one possibility that 'S_1' thus obtained may be originated from the earth-tide. The other possibility is that as S_1, K_1 and P_1 were not separated in this analysis, the amplitude of 'S_1' thus obtained could be attributed to K_1 and/or P_1. As K_1 and P_1 are contained in both the ocean-tide and the earth-tide, the tidal component, 'S_1', in this case can not be identified whether it is of the ocean-tide or of the earth-tide origin. However, as I already mentioned, the above assumption is not valid in this study. Therefore, these arguments on the origin of the tidal component 'S_1' would not be significant.

3. Discussions

3.1 *Efficiency of the advanced associated data*

As shown in ISHIGURO *et al.* (1984), BAYTAP-G admits to use up to three kinds of associated data of which time is restricted to present to past. Accordingly, only the previous associated data are used usually as in this paper. As has been already mentioned (OZIMA *et al.*, 1989), the ABIC-value is greatly lowered by the use of the Z-component besides X- and Y-component of the geomagnetic variations as associated data. By modifying the usage of BAYTAP-G, the author tried to use the advanced associated data as well as the previous data, and found that the ABIC-value was further lowered. This was expected from Mori's method (OZIMA *et al.*, 1989) which uses both the previous and the advanced associated data for the estimation of the induced component. In Table 2, an example of the ABIC-values for a magnetically disturbed (March, 1989) and a magnetically quiet (April, 1989) intervals is shown. As can be seen in this Table, in more disturbed interval, the larger advanced number is needed to minimize ABIC-value. In Fig. 13, it is visualized how the irregular component is decreased by the use of the advanced associated data for the same interval as those in Table 2. One possible interpretation for the fact that the advanced value of the geomagnetic field has significant role on the estimation of the present value of the induced component of the geoelectric field would be that the influence of the variation in the earth-current on that of the geomagnetic variations is significant in this case.

3.2 *Comparison of the tidal component at Aizu region with those at Kakioka and Mito region*

In order to examine the effect of the sea on the geoelectric field variations, the author tried to compare the tidal component at Mito and Kakioka regions which are located comparatively close to the seashore with that at Aizu region which is located at inland. In Table 3, the amplitude of the four constituents (S_1(including P_1 and K_1), S_2 (including K_2), O_1, M_2) of the tidal component for the four regions are listed. In these cases, the three (X-, Y-, and Z-) components of the geomagnetic variations at Kakioka were used as associated data. The amplitude of S_1 and S_2 varies with time as has

Table 2 An example of the ABIC values at KSM-MTO for various combinations of lag numbers for the magnetically disturbed and quiet intervals, respectively. The underlined numbers are the minimum values.

March, 1989(magnetically disturbed). N=744

Associated Data	Lag number to the future(hr)	Lag number to the past(hr) 5	6	7	8
(X,Y)	0	2396	2392	2349	2367
(X,Y,Z)	0	2098	2077	2095	
	1	1704	1675	1694	
	2	1693	1663	1675	
	3	1693	1661	1667	
	4	1681	1658	1667	
	5	1685	1668	1674	

April, 1989(magnetically quiet). N=744

Associated Data	Lag number to the future(hr)	Lag number to the past(hr) 5	6	7	8
(X,Y)	0	1312	1290	1280	1286
(X,Y,Z)	0	1188	1175	1190	
	1	1045	1038	1057	
	2	1052	1050	1068	
	3	1061	1061	1079	
	4	1070	1074	1091	
	5	1089	1095	1112	

been shown in Fig. 11 and Fig. 12, therefore, the maximum and minimum values are listed in this table. The amplitude of the 'S_1' and 'S_2' at Numazu region is extraordinarily large. This is because the large amplitude of the cultural noises at Numazu region is mostly periodic (mainly period of 24 and 12 hours), consequently they are delivered to the 'tidal component'. Accordingly, for Numazu region, it is difficult to estimate the value of the amplitude of the constituents of the ***real*** tidal component. Therefore, the amplitude of O_1 and M_2 of NMZ-ATM in Table 3 is left in blank and Numazu region was excluded from the discussion here.

As shown in Table 3, the 'S_1' and 'S_2' at AIZ 1CH are exceptionally small compared with those at KSM-MTO and KAK EW. As we have mentioned in *2.4*, these periods are predominant in both the geomagnetic and geoelectric variations and the tide, therefore, we would be safe not to discuss here about these differences between KSM-MTO, KAK EW and AIZ 1CH.

As Mori (1989) has shown, M_2 is faintly and O_1 is not contained in the geomagnetic field, while both are characteristically predominant in the ocean-tide. Therefore, the amplitude of O_1 and M_2 in the tidal component may give a measure of the influence of the ocean-tide to the geoelectric variations. As shown in Table 3, the amplitude of O_1 and M_2 at Aizu region is small by one order of magnitude compared with that at Kakioka and Mito region. However, this difference may not be attributed simply to the difference in the distance of the each region from the seashore, but should be explained as follows. As the induced component is almost separated in this analysis by the use of the geomagnetic variations as associated data, and also O_1 and M_2 is practically not contained in the geomagnetic variations, the origin of the tidal component (O_1 and M_2) left here in the geoelectic variations should be regarded as not induction but conduction. This geoelectric variation of conduction-origin (tidal component (O_1 and M_2) in this case) is related with the earth-resistivity, *i.e.*, it is expected to become small where the earth-resistivity is small. The fact that the amplitude of the tidal component (O_1 and M_2) at Aizu region is comparatively small than those in other three regions harmonizes with the contrast in the ap-

(a)

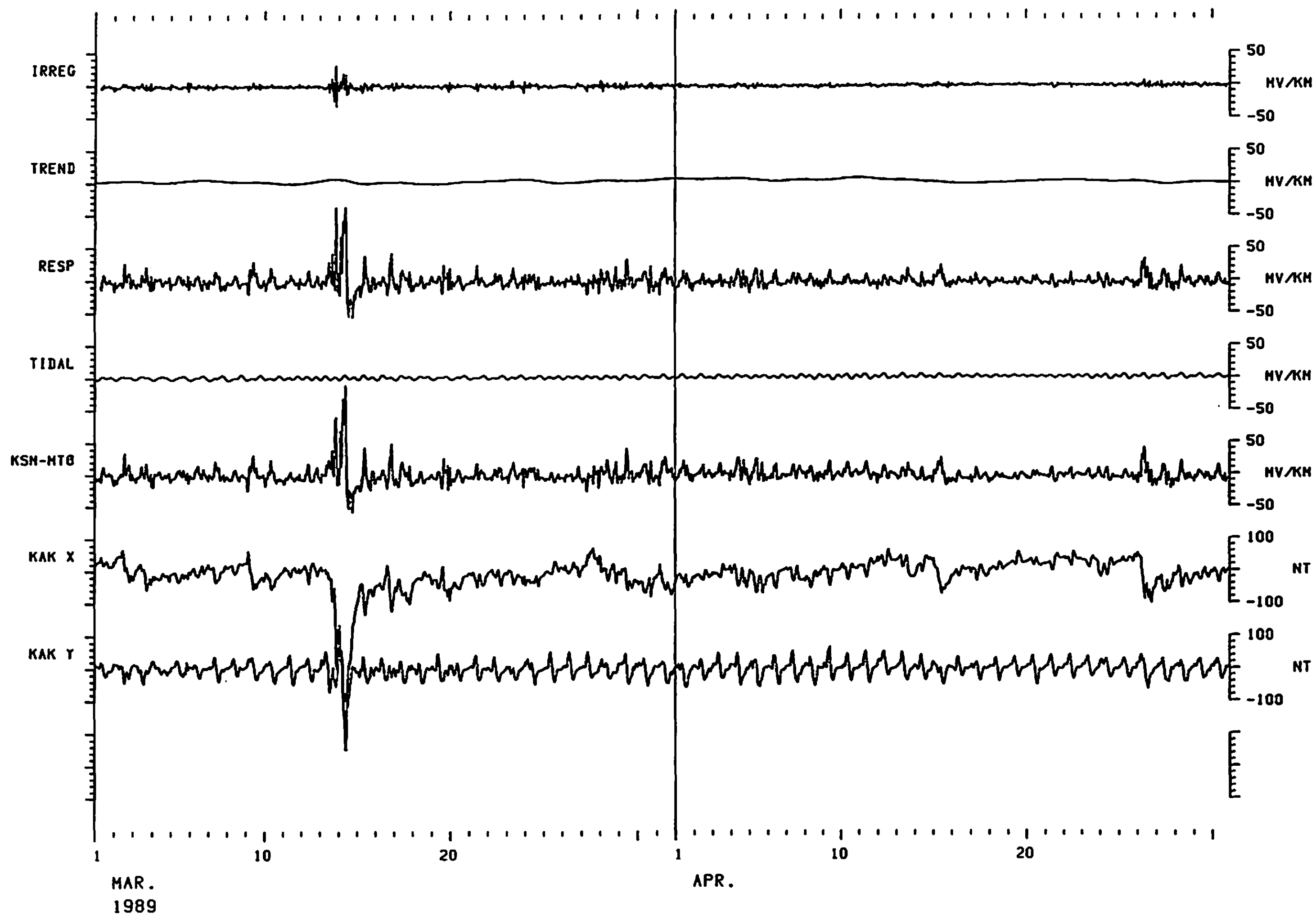
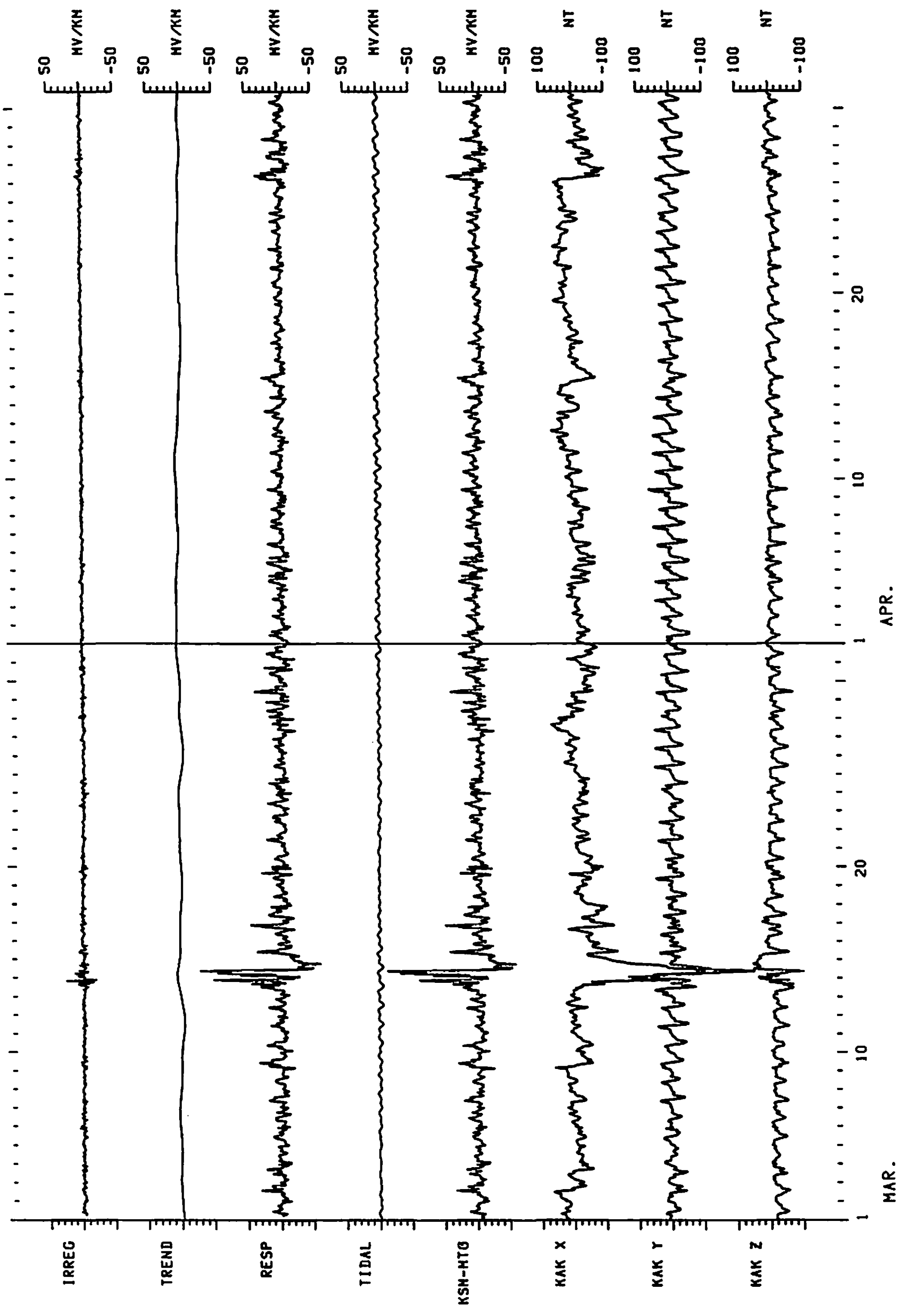
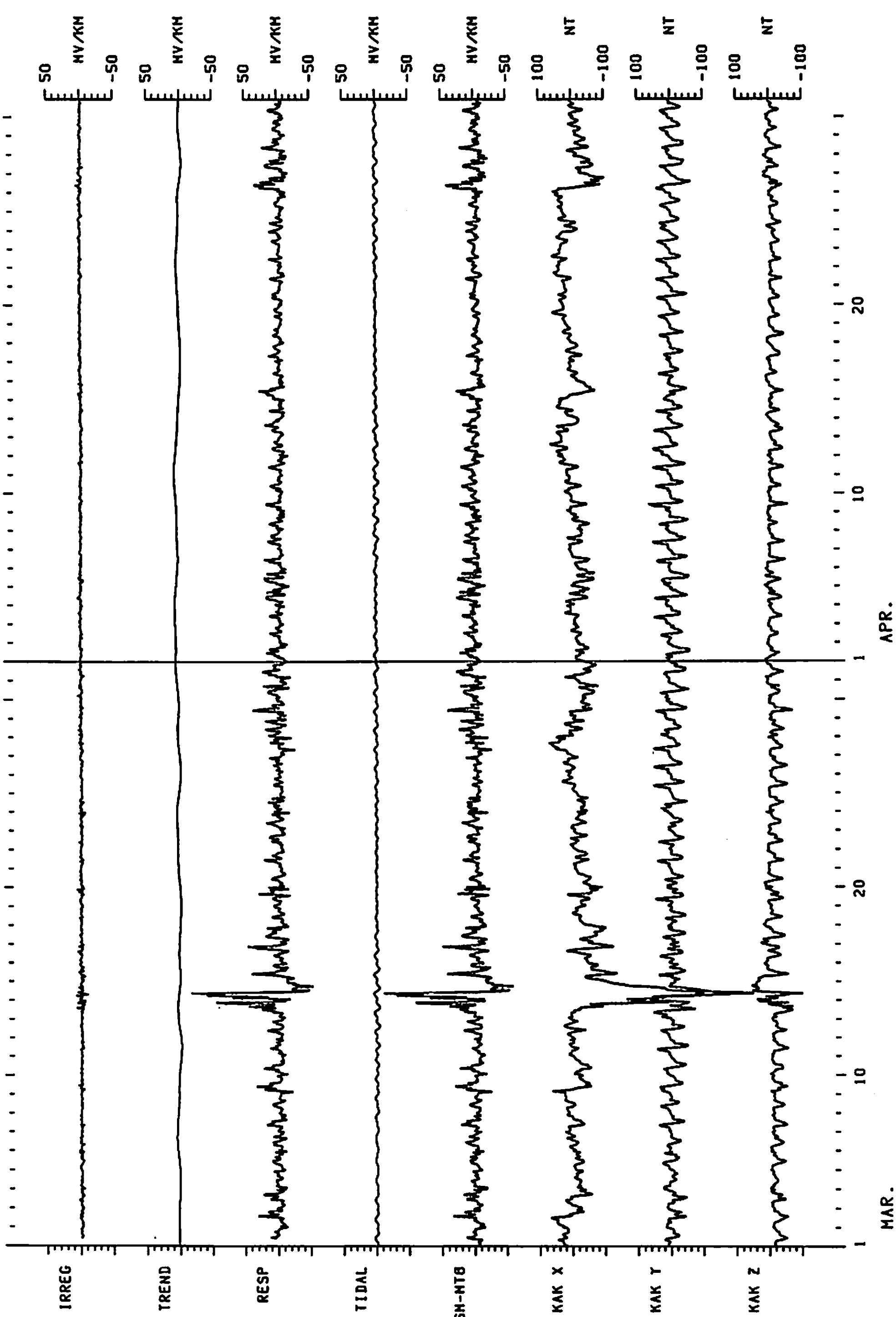


Fig. 13 Separation of the geoelectric variations at KSM-MTO into four components, *i.e.*, irregular component, trend, tidal component, and response. (a) Lagged data of the X- and Y-component of the geomagnetic field were used. (b) Lagged data of the X-, Y-, and Z-component of the geomagnetic field were used. (c) Both advanced and lagged data of the X-, Y-, and Z-component of the geomagnetic field were used as associated data.

(b)


IRREG
TREND
RESP
TIDAL
KSH-MTO
KAK X
KAK Y
KAK Z
50
MV/KM
-50
100
NT
-100
MAR.
1989
APR.
1
10
20

(c)


IRREG
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1989
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APR.

Table 3 Amplitude of the tidal component of the four observation lines. The large amplitude of S_1 and S_2 for NMZ-ATM is due to the periodic large noises.

Observation Line	Amplitude of the Tidal Component (mV/km) $S_1(P_1, S_1, K_1)$	$S_2(S_2, K_2)$	O_1	M_2
KSM-MTO	0.2 ~ 2.9	1.0 ~ 4.6	0.9	0.7
KAK EW	0.3 ~ 3.5	1.7 ~ 7.2	1.4	0.6
NMZ-ATM	6 ~ 31	4 ~ 20		
AIZ 1CH	0.04 ~ 0.54	0.08 ~ 0.62	0.17	0.18

parent resistivity within these four regions as shown below. Consequently, in this case, the effect of the ocean-tide on the geoelectric variations could not be derived just from the amplitude of the tidal component.

3.3 Homogeneous earth model and apparent resistivity

If we assume a homogeneous earth, the ratio, $|E/H|$ should be simply proportional to the inverse of the square root of the period, T. That is,

$$|E/H| \propto (1/T)^{1/2},$$

where E and H is the geoelectric and geomagnetic field, respectively, both fields being orthogonal to each other. This ratio, $|E/H|$ may be regarded as the similar property as the amplitude factor for the X- and Y-component of the geomagnetic variations derived by the analysis with BAYTAP-G. TAKAYAMA and MORI (1987) reported that the predominant direction of the variation of the geoelectric field at Mito region is in NW-SE and an induction by the Y-component as well as by the X-component of the geomagnetic variation existed in the geoelectric variations at KSM-MTO of which direction is almost in E-W. This implies that the electro-magnetic structure at this region is heterogeneous and/or anisotropic. Similar result as TAKAYAMA and MORI (1987) was obtained in this study. Fig. 14 shows some examples of the amplitude factor at KSM-MTO for the X- and Y-component of the geomagnetic field in relation with $(1/T)^{1/2}$ for three intervals of January to March, 1990. It can be seen from this figure that the amplitude factor is not proportional to $(1/T)^{1/2}$ for the whole period range but is proportional only for the period range of about 3 to 12 hours for the

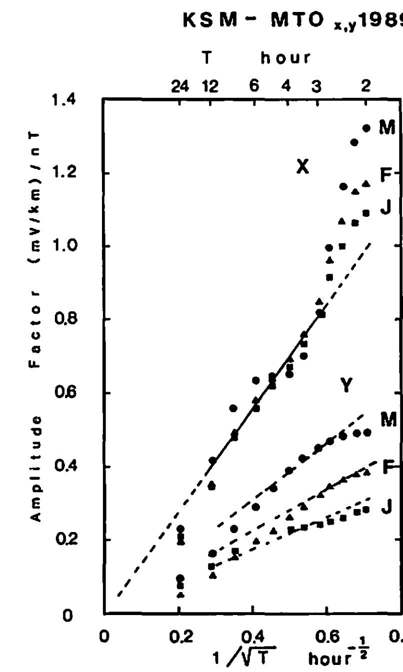

Fig. 14 Amplitude factors at KSM-MTO for the X- and Y-component of the geomagnetic variations with respect to $(1/T)^{1/2}$ or T for the intervals of January (square), February (triangle), and March (circle), 1989. T:period (hour).

X-component of the geomagnetic variations. The amplitude factor for the Y-component of the geomagnetic field is not also proportional to $(1/T)^{1/2}$ and changes by month-to-month for the whole period range. These facts indicate that the homogeneous earth model is not applicable to this region and are consistent with the result by TAKAYAMA and MORI (1987).

TAKAYAMA (1992) has reported impedance tensors for periods of 5.3 to 1920 minutes with the use of the magneto-telluric method at Mito region using the same geoelectric and geomagnetic data as those in this report. The author simply derived Cagniard's apparent resistivity, $\rho\,(\Omega\cdot m)$ from the relation, $\rho = 0.2\ T\,|E/H|^2$, using the average

Table 4 Amplitude factor and apparent resistivity at Mito, Kakioka, Numazu, and Aizu regions for the period of 86400 and 21600 sec (24 and 6 hours).

Observation Line	E/H $(mV/km/nT)$		ρ $(\Omega \cdot m)$	
	T = 24 hr	T = 6 hr	T = 24 hr	T = 6 hr
KSM-MTO	0.22	0.60	850	1600
KAK EW	0.34	1.0	2000	4300
NMZ-ATM	0.45	0.88	3500	3300
AIZ 1CH	0.034	0.10	20	43

values of the amplitude factor for the X-component of the geomagnetic variations as $|E/H|$ for the periods of $T=86400$ and 21600 sec. The values are listed in Table 4. The apparent resistivity thus obtained at Mito region showed similar values as those by TAKAYAMA (1992). The author confirmed that the predominant direction of the variation of the geoelectric field at Aizu region is similar to that at Mito region. The amplitude factor and the apparent resistivity at AIZ 1CH differ distinctly from those at other three regions, which are almost similar to each other.

YANAGIHARA and YOKOUCHI (1965) and YANAGIHARA (1965) have reported in detail the geoelectric characteristics at Kakioka, comparing them with data at the eastern area of Kanto-plain near Kakioka. The result shown in Table 4 that the apparent resistivities obtained in this study at Mito and Numazu regions are close to that at Kakioka implies that the geoelectric situations of these two regions are similar to that at Kakioka. On the other hand, the apparent resistivity at Aizu region distinctly differs from and about 1/100 as small as that at Kakioka. This is consistent with the result that the amplitude of the tidal component at Aizu region is small by about one order of magnitude compared with those at other three regions.

As hourly values of the geoelectric variations were used as the inducing field in this study with BAYTAP-G, we are concerned here with the period of more than two ~ a few hours. Taking into account this large period, apparent resistivity thus obtained here could be regarded not to be controlled by the electric fine-structure near the surface, and the actual skin-depth of the electromagnetic field discussed here could be estimated to be more than a few tens kilometers. As already mentioned, at Aizu region the apparent resistivity thus obtained is distinctly low, *i.e.*, 20 to 50 $\Omega \cdot m$. This could be interpreted in such a way that the actual resistivity around a few tens kilometers depth at Aizu region is possibly low, rather than we interpret to be due to the geology of Aizu-basin which consists of sediments. The possibility of the existence of the low-resistivity deep layer at Aizu region reminds us of the two-dimensional models of resistivity in north-eastern and central Japan proposed by OGAWA (1987) and UTADA *et al.* (1986), respectively, which suggesting the existence of a conductor in lower crust whose depth ranges from 20 to 30 km.

3.4 Seasonal-variation of the amplitude factors of the frequency response when the three components of the geomagnetic field were adopted as associated data

As already have been shown in Fig. 5, when the Z-component of the geomagnetic variations is added to the associated data to which response is taken, the amplitude factors display considerably large seasonal variation in the shorter period range, *i.e.*, the amplitude factor for the X-/Z-component of the geomagnetic variations becomes small/large in winter and large/small in summer season. This variation is characteristic in the very short period range. In order to indicate the detailed feature of the anti-correlation of the two amplitude factors, those with respect to $(1/T)^{1/2}$ in the two cases (where the Z-component of the geomagnetic variations was used and was not used) are compared in Fig. 15 and 16 for the intervals of March and July, 1987, for examples, respectively. These figures and Fig. 14 distinctly show that when the Z-component of the geomagnetic variations was not used, the amplitude factor for the X-component of the geomagnetic variations does not so much vary seasonally or by month-to-month in the period range of about 3 to 12 hours, while that for the

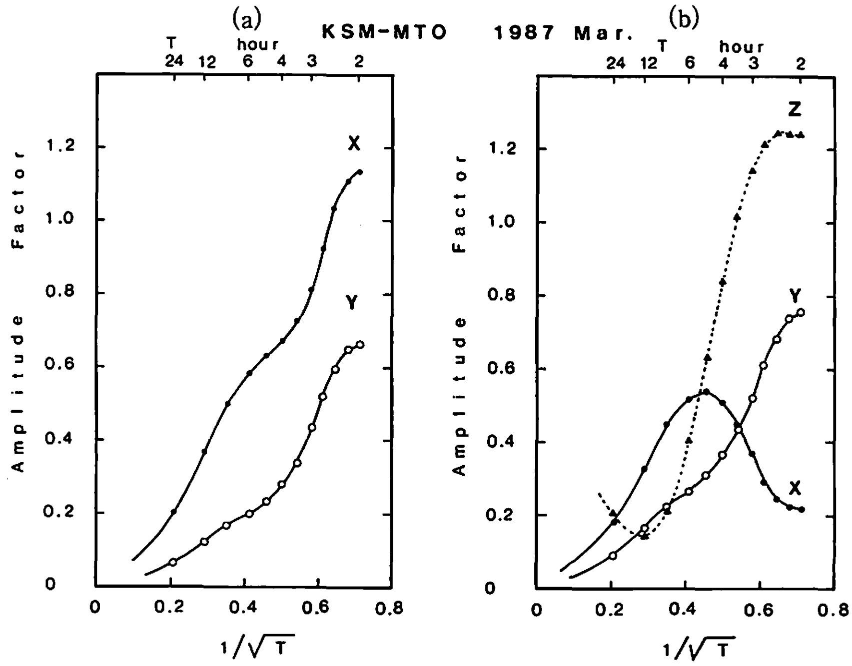

Fig. 15 An example of the amplitude factor at KSM-MTO with respect to $(1/T)^{1/2}$ or T in March, 1987. Solid circle:For the X-component of the geomagnetic variations, Hollow circle:For the Y-component of the geomagnetic variations, Triangle:For the Z-component of the geomagnetic variations. (a) The Z-component of the geomagnetic field was not adopted. (b) The Z-component of the geomagnetic field was adopted as one of the associated data.

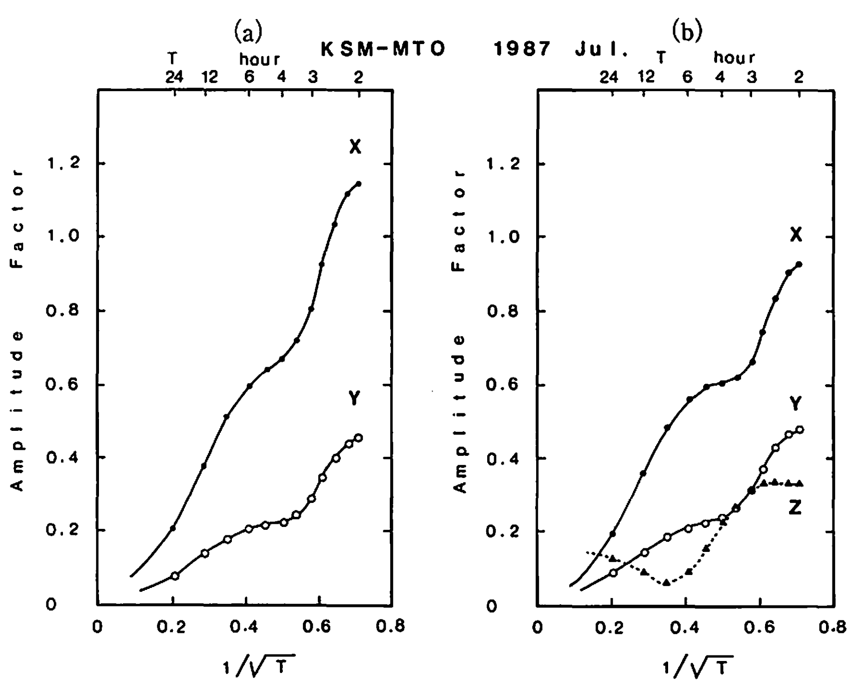

Fig. 16 Similar representation of the amplitude factor in July, 1987.

Y-component of the geomagnetic variations does display such variations regardless of the use of the Z-component of the geomagnetic variations. By the joining of the Z-component of the geomagnetic variations, in March (winter), the amplitude factor for the X-component of the geomagnetic variations is drastically lowered in the shorter period range, being maximum around T=5~6 hours. In such an interval, contrary to the above mentioned behaviour, the amplitude factor for the Z-component of the geomagnetic variations becomes large in the shorter period range. On the other hand, in July (summer), the effect of the Z-component of the geomagnetic variations to the amplitude factor for the X-component of the geomagnetic variations and also the value of the amplitude factor for the Z-component of the geomagnetic variations itself are small. Fig. 15 and 16 also show that the amplitude factor for the Y-component of the geomagnetic variations is not so sensitively affected by the use of the Z-component at all seasons, but its sense of the seasonal variations is same as that of the Z-component of the geomagnetic variations in the shorter period range.

These characteristic behaviour shown in Fig. 15 and 16 (also in Fig. 5) could be interpreted as a result of the familiar fact that the three components of the geomagnetic variations are not completely independent with each other. Fig. 15 and 16 imply that the coherency between the X- and Z-component of the geomagnetic variations is large in winter season at shorter period range. Moreover, it is suggested that especially in winter season at shorter period range, the coherency of the geoelectric variations to the Z-component of the geomagnetic variations is larger rather than that to the X-component of the geomangetic variations.

In order to support the above arguments, the author tried to examine coherencies between the geoelectric variations and the three components of the geomagnetic variations, and also between the Z-component and the other two components of the geomagnetic variations. Fig. 17(a) shows the partial coherencies of the geoelectric field variations at KSM-MTO to each X- and Y-component of the geomagnetic field for an interval of March, 1987. In the case of the additional use of the Z-component of the geomagnetic field variations, those to each X-, Y- and Z-component of the geomagnetic field variations are also shown in Fig. 17(b). Similarly as Fig. 17, the partial coherencies for another interval of July, 1987 in the two cases are shown in Fig. 18(a) and (b). Fig. 19 shows the partial coherencies of the Z-component of the geomagnetic variations at Kakioka to each X- and Y-component of the geomagnetic variations for the same intervals as those in Fig. 17 and 18 (Ozima, 1995). These results in Fig. 17, 18 and 19 seem on

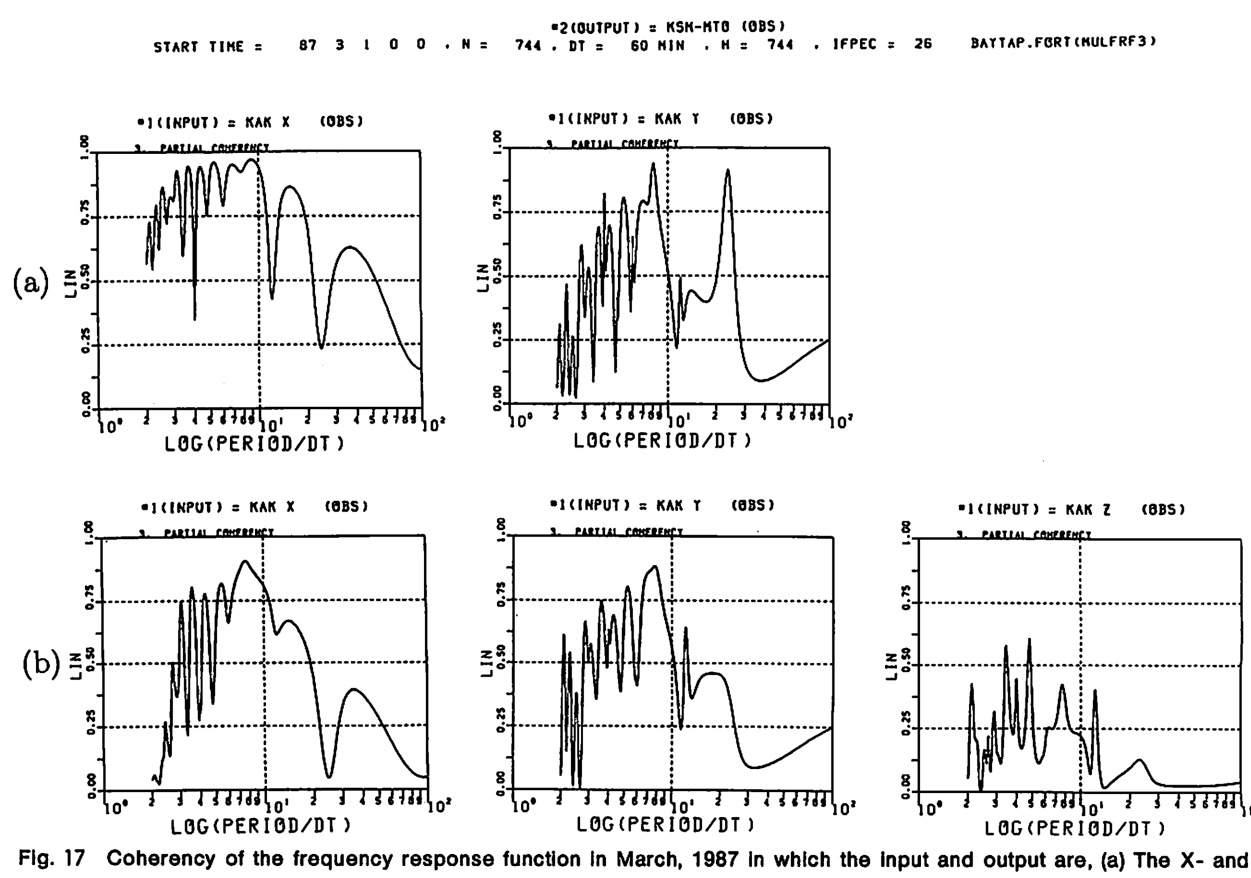

Fig. 17 Coherency of the frequency response function in March, 1987 in which the input and output are, (a) The X- and Y-components of the geomagnetic field at Kakioka, and the geoelectric variations at KSM-MTO. (b) The X-, Y- and Z-components of the geomagnetic field at Kakioka, and the geoelectric variations at KSM-MTO.

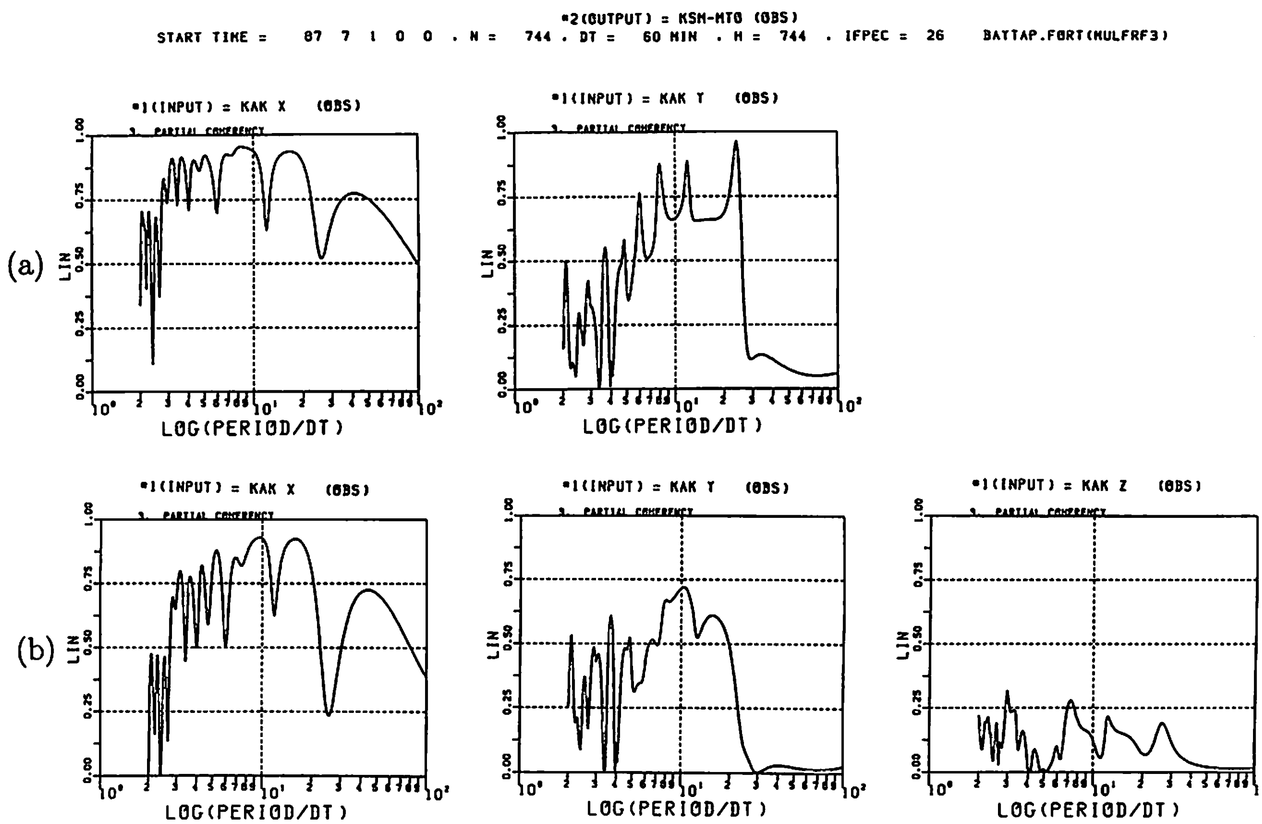

Fig. 18 Coherency of the frequency response function in July, 1987 in which the input and output are, (a) The X- and Y-components of the geomagnetic field at Kakioka, and the geoelectric variations at KSM-MTO. (b) The X-, Y- and Z-components of the geomagnetic field at Kakioka, and the geoelectric variations at KSM-MTO.

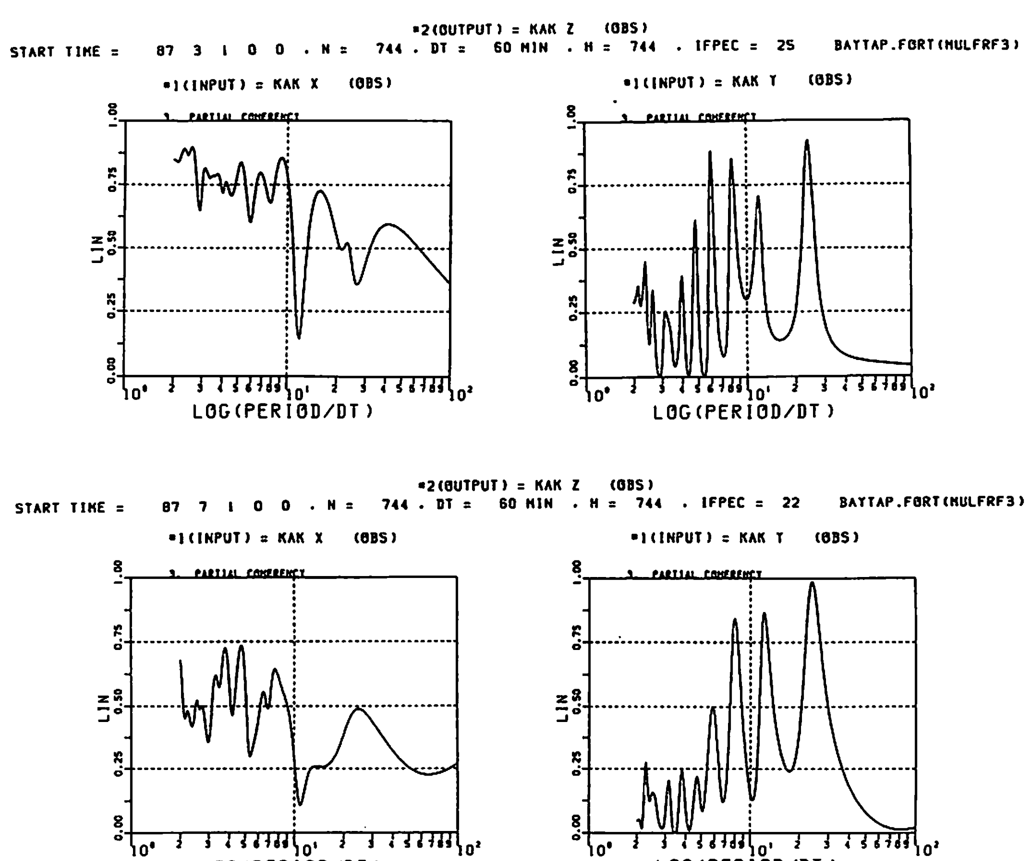

Fig. 19 Coherency of the frequency response function in March(upper) and July(lower), 1987 in which the input and output are the X- and Y-components, and the Z-component of the geomagnetic field at Kakioka.

the whole to support the above arguments on the characteristic behaviour of the seasonal variations of the amplitude factors.

This characteristic behaviour of the amplitude factor was observed at Mito, Kakioka and Aizu regions as shown in Fig. 5, 7 and 8, and supposedly at Numazu region. The origin of this characteristic behaviour of the amplitude factor obtained in this study, as well as that of the seasonal variations in the coherency within the three components of the geomagnetic variations could not be interpreted on the basis of geophysics in this study. However, it could be essentially related with the characteristics of the geomagnetic variations at Kakioka of which geomagnetic data were used as associated data for the four regions throughout this study. The author has tried to separate the purely independent component included in the Z-component from the X- and Y-component of the geomagnetic variations using BAYTAP-G, but this separation turned out not to be useful to acquire any geophysical interpretation. Further, with relation to this problem, the author has examined the transfer functions using hourly values of the geomagnetic variations at Kakioka (Ozima, 1995). Again, this was not fruitful. Finally, the author would like to leave this unsolved problem to the future.

Acknowledgements

We are grateful to NTT at Mito and Numazu who kindly provided us with the facilities for our study. We are much indebted to many staffs of the Kakioka Magnetic Observatory for collecting data at Mito region. The author thanks Dr. M. Kinoshita who kindly provided us with the geoelectric data at Aizu region. The author also thanks Mr. H. Takayama for his critical readings the manuscript and giving the author valuable comments. Thanks are also due to a referee, Mr. T. Yamamoto for his critical and helpful comments. The author would like to express her gratitude to Dr. T. Mori for his encouragement throughout this study.

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BAYTAP-G を用いた地電流データの解析から判った，水戸・柿岡・会津・沼津地域の地電流特性 —地電流データの解析手法としての BAYTAP-G の評価—

小嶋美都子

(1997年12月26日受付，1998年 2 月20日改訂)

概　　要

BAYTAP-G を用いて，水戸，柿岡，会津，沼津地域の地電位変動データを解析した．柿岡以外のデータはすべて，NTT の施設を利用した超長基線観測値である．解析した 4 地域の地電流データ，参照観測値として用いた柿岡地磁気観測所の地磁気のデータとも，毎時平均値を用いて月毎（N＝744）に解析を行った．BAYTAP-G を用いると，地電流の変動は，地磁気変動による誘導成分，潮汐成分，ゆっくりした変動（トレンド），残差（irregular component）の 4 成分に分解することが出来るが，これまでは主として，いかに効率よく 4 成分の分解が出来るか，いかにして効率よく微小な地電流の異常変化を検出出来るかについて検討し，それらについての結果はすでにいくつかの論文にして発表済みである．当論文においては，BAYTAP-G による解析の結果得られる，誘導成分の amplitude factor，潮汐成分の振幅，及び最低 ABIC 値に着目し，この解析により何が判るか，問題点として何が残るか等を検討した．周期別誘導成分の amplitude factor（振幅係数）から求めた各地域の見かけ比抵抗の値は，水戸・柿岡・沼津の 3 地域と会津地域との間で大きなコントラストを示した．潮汐成分の振幅も，見かけ比抵抗値でみられたと同じ地域差を示した．各解析期間（1 ヶ月）中の最低 ABIC 値は，その期間の地磁気活動度に非常に良く対応していることを改めて示した．このことは，ここで用いた方法では，特に，地磁気の荒れた期間には，誘導成分を完全には分離することが出来ないことを示唆している．また，地磁気誘導成分を計算する際に，地磁気X－，Y－成分の他に，Z－成分も用いると，最低 ABIC 値は，冬季にはかなり下がるが，夏期においては，Z－成分の使用の影響はほとんど最低 ABIC 値には現れない．このような，地電流の地磁気変動による誘導成分への，地磁気Z－成分の役割の季節変化は，共通して用いた柿岡における地磁気変動そのものの特性によるものであろうと考えられるが，実際に何故この様な季節変化が起きるかについて明確な説明はできなかった．更に，最低 ABIC 値は，参照観測値の地磁気の値として，過去の値と共に，未来の値（advanced associated data）をも用いることにより，劇的に低下することが判明した．

付記：当論文原稿は，筆者が調査課に所属していた1991年にはほぼ骨格ができあがっていたが，その後筆者が観測課を経て技術課に所属するに従い，余裕がなくなり未完のまま放置されていた．また，誘導成分への地磁気Z－成分変動の役割の季節変化を物理的に明快に説明することが出来なかったことも，放置された原因の一つである．しかし，この様な現象が存在することは事実として認めざるを得ない．1996年より当所が淡路島で観測している電磁気データの，BAYTAP-G を用いた解析の着手に際し，これまでに筆者が水戸地域等の地電流データの BAYTAP-G を用いた解析の結果得た知見を埋もれさせずに，未解決の問題は問題として，論文として残しておくべきであろうと考え，筆者の定年退職前に，とりあえずまとめたものである．