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Monitoring of Time Changes of Conductivity Anomaly Transfer Functions at Japanese Magnetic Observatory Network

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Abstract

The conductivity anomaly (CA) transfer functions at Japanese magnetic observatory network (Memambetsu, Kakioka, Matsuzaki, Omaezaki and kanoya) are calculated day by day in order to examine their time changes. The power spectral method is employed to calculate the transfer functions with periods of 120, 60, 30 ànd 10 minutes by utilizing all (1440) geomagnetic one-minute values in one day. Defining the error factor which indicates how adequate the Z variation is reproduced from linear combination of the H and D variations, we select adequate values of the transfer functions for their monthly means. As a result, the secular change of the 10-minute-period A_u's for Kakioka (-0.05/30years) is essentially consistent with its secular change for 1940-1970 obtained by Yanagihara and Nagano(1976). The 10-minute-period A_u's for Kanoya and for Memambetsu increase in contrast to that for Kakioka. Those for Matsuzaki and for Omaezaki have decreasing A_u's with annual change rates of about 0.02, although it is uncertain to conclude that these secular changes are natural because of contamination by noises.

Introduction

The CA(conductivity anomaly) transfer function (shortened as 'the transfer function' from now on) reflects electromagnetic underground structure [Everett and Hyndman, 1967; Honkura, 1972]. Its time change, thus, can be regarded to relate to change of the underground structures which cause an earthquake [Yanagihara and Nagano, 1976; Honkura,1979; Rikitake, 1979; Chen, 1981; Gong, 1985; Zhijia, 1989]. Yanagihara and Nagano (1976) analysed $\Delta Z/\Delta H$ of impulsive geomagnetic variations (si and ssc) from magnetograms (ΔZ and ΔH are jumps in the Z and H components, respectively) and found that the transfer functions at Kakioka changed in association with the Kanto earthquake (M

=7.8) occurred in 1923. Their result also indicates that $\Delta Z/\Delta H$ has been decreasing since 1940's with a rate of 0.1/30years. Stimulated by their results, a group of Kakioka Magnetic Observatory has been engaged in monitoring time change of the transfer functions [for example; Shiraki and Yanagihara, 1977, 1979; Shiraki,1980; Sano, 1980, 1982; Sano et al., 1982]. Shiraki (1980), analysing the geomagnetic one-minute data in 1976-1979 for Kakioka obtained that time change of the transfer functions is much affected by disturbances which are originated from the external atmosphere. Unfortunately, he couldn't confirm the secular change found by Yanagihara and Nagano (1976) owing to lack of sufficient amount of data. Sano (1980, 1982) and his group [for example, Sano et al., 1982] analysed the geomagnetic data of Kakioka, Memambetsu, Kanoya and Iwaki. They found correlation between time changes of the transfer functions and occurrence of earthquakes by a statistical method. However, this correlation might be apparent because the transfer functions and the earthquake occurrence have periods of about 27 days. This 27-day period is very near to the solar cycle. They also found that the transfer functions at separate stations sometimes have similar time changes.

Now we can utilize not only sufficient amount of geomagnetic one-minute data for Kakioka but also the one-minute data for other stations (Memambetsu, Matsuzaki, Omaezaki and Kanoya). Thus the present paper is written mainly in order to evaluate again the time change of the transfer functions by using the one-minute data at Japanese Magnetic Observatory Network.

Data and Analysing Method

The observatory network consists of Memambetsu, (MMB) , Kakioka (KAK) , Matsuzaki (MTZ), Omaezaki (OMZ) and Kanoya (KNY) as shown in Fig. 1. All stations produce geomagnetic one-minute data. KAK started continuous measurement of the one-miunte data in 1976. MMB and KNY did in 1985, in addition, we can utilize provisional data in 1982-1984 for KNY and 1984 for MMB when the fluxgate magnetometers were prepared for continuous measurement. MTZ in the Izu Peninsula and OMZ in the Tokai area were established in 1980 for technological development of monitoring geomagnetic variations associated with a large earthquake. Quality of data is perfectly controlled for KAK's data since 1976 as well as MMB's and KNY's ones since 1985. Others possibly contains abnormal values. The station of OMZ moved in 1984.

Fig. 1.

We make use of the power spectral method [Everett and Hyndman, 1967]. This is the same as that used by Shiraki (1980) . ΔZ of a geomagnetic variation is generally represented by ΔH and ΔD of the variations as

$$\Delta Z(\omega) \simeq A(\omega)\Delta H(\omega)+B(\omega)\Delta D(\omega), \quad (1)$$

where A and B are the conductivity anomaly transfer function. In addition, ω is a frequency. Both A and B are complex numbers depending on the frequency of the geomagnetic variation. Their real and imaginary parts are denoted with suffices u and v,

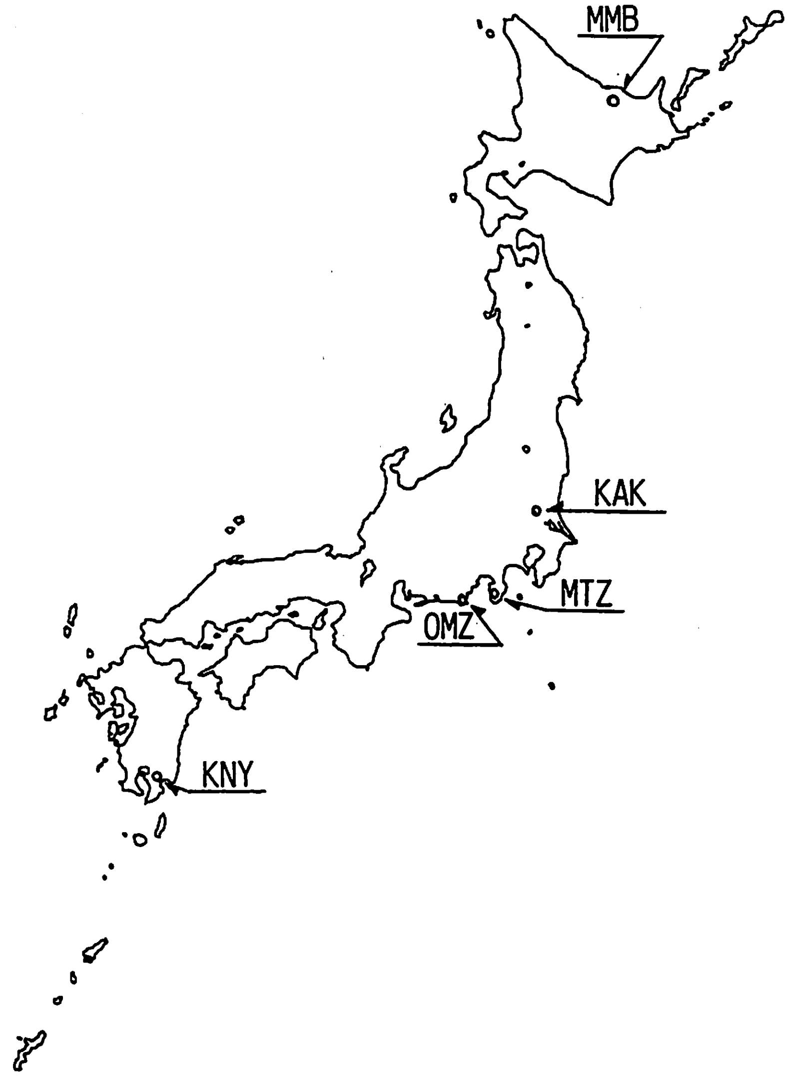

Figure 1 The observatory network. Longitude and latitude of each station are as follows: MMB: (43°55'N, 144°14'E); KAK(36°14'N, 140°11'E); MTZ: (34°44'N, 138°48'E); OMZ: (34° 37'N, 138°12'E); KNY (31°25'N, 130°53'E).

respectively. To calculate the transfer functions from the geomagnetic variations, we seek A and B which minimize $| \Delta Z - A \Delta H - B \Delta D |^2$. Operating this procedure, we get

$$A = (P_{DD}P_{ZH} - P_{DH}P_{ZD}) / (P_{HH}P_{DD} - P_{HD}P_{DH}), \tag{2}$$

and

$$B = (P_{HH}P_{ZD} - P_{HD}P_{ZH}) / (P_{HH}P_{DD} - P_{HD}P_{DH}), \tag{3}$$

were P_{XX} and P_{XY} are auto- and cross-power spectra, respectively.

We intend to monitor the natural time change of A and B. The quality of data cannot be expected to be always controlled perfectly. Further, even when the data are perfectly controlled, the transfer function may not always have the same value by the effect of limited precision of the digital values (say, the quantized noise) or by that of external geomagnetic disturbances as suggested by Shiraki (1980) and Sano (1982). To monitor how adequate ΔZ is represented by linear combination of ΔH and ΔD, we define the error factor denoted by $\varepsilon(\omega)$. This means sum of absolute value of the deviations ($|\Delta Z - A\Delta H - B\Delta D|^2$) normalized by $\Delta Z \Delta Z^*$.

$$\begin{aligned}\varepsilon(\omega)=1+&|A|^2 P_{HH}/P_{ZZ}+|B|^2 P_{DD}/P_{ZZ}\\&-AP_{ZH}/P_{ZZ}-BP_{ZD}/P_{ZZ}-A^*P_{HZ}/P_{ZZ}-B^*P_{DZ}/P_{ZZ}\\&+A^*BP_{HD}/P_{ZZ}+B^*AP_{DH}/P_{ZZ}.\end{aligned} \tag{4}$$

Results

We selected 4 periods of 120, 60, 30, 10 minutes for the present transfer function analysis. These periods are commonly used for the analysis by other scientists.

Day-to-day variations

Day-to-day variations of the transfer function, ε and ΣK of KAK in 1988 are shown in Fig. 2-(a) KAK, (b) MMB and (c) KNY. We can notice the following characteristics in these figures; 1) The fluctuation of the variation is the smallest for the transfer functions with the period of 30 minutes; 2) The fluctuation tends to be larger in summer (May to August) and smaller in winter (November to February); 3) ε (denoted as ERROR in the figures) tents to be larger when ΣK is smaller.

The transfer function associated with an earthquake with M = 7.0 is predicted to change by as small as 0.05 after Honkura (1979) who evaluated this amount by using a simple cylindrical model. Accordingly, we have to calculate the transfer function with the accuracy sufficiently smaller than 0.05. However, even when we utilize the power spectrum method, the fluctuation of the day-to-day variation of the transfer function is larger than 0.1 for almost all transfer functions at the three stations after Fig. 2. Since it may be impossible to predict an earthquake by using the daily value of the transfer function, we need to select adequate transfer functions and employ some time averages. Reduction of the fluctuations of the transfer functions is also important to prediction of a large earthquake with M=8 because we need to catch a precursory change associated with such a hazardous earthquake even when it occurs in a place distant from the network station.

For reference, day-to-day variations of the transfer functions for MTZ and for OMZ are shown in Fig. 3. As these observatories are unmanned ones, we cannot expect perfect control of data quality. Indeed, the transfer functions at both stations have several abnormal values. Additionally, it is clear that variations of the transfer functions with the period of 10 minutes are largest among all the transfer functions for both stations. This is partly resulted from artificial noises from electric railways running nearby. There are probably unidentified sources of the noises at MTZ (T. Yamamoto, personal communication, 1989).

ε-the transfer function relation

Bearing in mind that ε is a measure of the error of the transfer function, ε-the transfer function relations are examined in order to get a threshold value for the adequate values of the transfer functions. Figure 4 presents the transfer functions vs ε for all 5 stations. As for KAK, MMB and KNY, the threshold values are fixed as shown in Table 1. The transfer functions with ε smaller than these threshold values have smaller standard deviations and almost the same values against ε. Numbers of the transfer functions adopted for calculation of monthly means are sufficiently large.

Some componets of the transfer functions have a tendency against ε. When ε becomes larger, the value of the component becomes close to null. This tendency is clear when the value is apart from null like A_u's for KAK, for MTZ and for OMZ. On the other hand, we pointed out that ε and ΣK are anti-correlated each other. Therefore, the day with larger ε of the transfer function tends to have smaller amplitudes of D and H. Here, we only present the result on the relation between the transfer function and the amplitudes of horizontal components of geomagnetic variations (D and H). We need to consider the mechanism in the future.

Geomagnetic fields at OMZ and at MTZ are contaminated by artificial noises from electric railways running nearby. Some noises with an unidentified source affect geomagnetic data at MTZ (T. Yamamoto, peresonal communication, 1989). These noises mainly affect the transfer functions with the period of 10 minutes. Decrease in the 10-minute-period A_u might be resulted from these noises. Resultantly, we hardly get the threshold of ε for the A_u of this period. In the present study, we preliminary set the thresholds as 0.4 for MTZ and 0.1 for OMZ.

Monthly means

Monthly means of the transfer function with 95% confidence intervals are shown in Fig. 5 for all stations. All available values of the transfer functions are used for the monthly means in these figures. KAK and MMB seem to have no abnormal values in whole intervals. Besides, KNY has abnormal values before 1984. As for MTZ and OMZ, abnormal values are spotted in whole intervals. In particular, it seems that all monthly means of the transfer functions before 1984 for OMZ are of no use. As mentioned above, the transfer functions with the period of 10 minutes both for MTZ and for OMZ are affected by the

Table 1 Threshold values of ε

period	MMB	KAK	MTZ	OMZ	KNY
120	0.4	0.2	0.1	0.1	0.1
60	0.2667	0.1333	0.1	0.0667	0.1333
30	0.2	0.2	0.1	0.1	0.1
10	0.1333	0.2	0.4	0.1	0.1

noises and evidently they are fluctuated more than those with other periods.

The deviations of 95% confidence interval of the transfer functions with the period of 10 minutes for KAK show peculiar feature. They were larger in the beginning of the analysis interval and gradually decreasing as time goes till about 1983. We don't judge here whether this feature comes from some natural origins like the external disturbances or from change of quality of data.

Next, selecting the transfer function with ϵ smaller than the threshold value, we calculate monthly means and present results in Fig. 6. We calculate the monthly means when number of days employed are greater than 10 inclusive. There are no significant differences between the results in Fig. 5 and those in Fig. 6 for KAK except for the transfer functions with the period of 10 minutes. Some are excluded because of poor accuracy of the transfer functions in Fig. 6. As for MMB, there are no significant difference, either. So is the same for KNY except the transfer functions before 1984 (particularly for shorter periods). Fluctuations of the monthly means before 1984 are reduced by the selection. But even so, the transfer functions with the period 10 minutes have too many abnormal values to be utilized for further analysis. Several abnormal values also remain for the transfer functions with other longer periods. Thus, KNY's transfer functions before 1984 are omitted for further analysis in order to avoid contamination of the abnormal values because the quality of geomagnetic data are perfectly controlled after 1985. As a result, the selection of the transfer function with ϵ did not work out so well for KAK, MMB and KNY.

In the case of OMZ's transfer functions, fluctuations of monthly means become smaller for the selected ones. It is also evident that the month-to-month variations of the transfer functions before 1984 are larger than those after 1985. Bearing in mind that station of OMZ moved in 1984, we use the monthly means after 1985. MTZ's transfer functions have relatively more accurately determined in comparison to OMZ's except for those with the period of 10 minutes. The 30-minute-period A_v changes in the end of 1982. But we don't have any idea in the cause. Records of the borehole strainmeter near OMZ station don't show synchronous change in 1982-1983 [Japan Meteorological Agency, 1989].

Month-to-month variations

As noted previously, the transfer function should be obtained with the month-to-month fluctuation of the values less than 0.05. Only MMB's transfer functions can meet this requirement. As we don't know a short-term variation ($\simeq$ 1 month) in the underground structures, the month-to-month variation of the transfer functions don't seem to relate to the crustal activity. In this sense, monitoring of the transfer function may be applied to the long-term prediction of earthquakes.

Let us here briefly present correlation coefficients of variations of the transfer function for two separate stations (MMB-KAK, KNY-KAK). Table 2 gives the coefficients for the daily value, for the monthly means of all daily values and for the monthly means of selected daily values. We can see that the variations in the monthly means are generally correlated. Therefore, in the standpoint of the earthquake prediction, we cannot use the individual value of the monthly mean because their variations don't relate to a local change. Although

Table 2 Correlation coefficients of the transfer functions in 1988

period		MMB-KAK			KNY-KAK		
		1)	2)	3)	1)	2)	3)
120	A_u	0.170	-0.145	0.341	0.132	0.131	0.536
	B_u	0.203	0.402	-0.001	0.004	-0.062	-0.191
	A_v	0.336	0.422	0.353	-0.009	0.345	0.083
	B_v	0.427	0.560	0.461	0.479	0.565	0.572
60	A_u	0.190	0.189	0.446	0.074	0.355	0.431
	B_u	0.197	0.428	0.336	0.064	0.001	-0.069
	A_v	0.293	0.729	0.730	-0.088	0.519	0.549
	B_v	0.174	0.159	0.192	0.267	0.516	0.221
30	A_u	0.140	0.217	0.397	0.249	0.200	0.242
	B_u	0.226	0.282	0.126	0.057	0.140	0.158
	A_v	0.236	0.696	0.633	0.247	0.557	0.525
	B_v	0.191	0.230	0.313	0.234	0.313	0.407
10	A_u	0.034	-0.400	-0.192	-0.035	-0.129	0.022
	B_u	-0.052	0.055	0.152	0.143	0.199	0.253
	A_v	0.178	0.118	0.312	0.029	0.068	0.176
	B_v	0.071	0.264	0.368	0.125	-0.384	-0.207

1) Daily value, 2) monthly mean from all daily values, 3) monthly means from selected daily values

the daily values have smaller correlation coefficients, the larger fluctuations prevent them from being applied to the prediction. Anyway, the transfer function is not adequate for the short-term prediction.

Next, seasonal variation of the transfer function is shown in Figs. 7 and 8. Data from KAK, MMB and KNY are employed here. The monthly means from all and selected daily values are used for Figs. 7 and 8, respectively. As noticed by previous scientists [Shiraki, 1980; Sano, 1982], the transfer function has seasonal variations in both cases. Thus, even we select the daily values of the transfer functions, the effect of the external disturbance still remains.

Annual change rates of the transfer functions

Let us calculate time change rate of each transfer function by using the monthly means of selected data. Results are listed in Table 3 in the unit of year^{-1} along with relevant standard deviations. we don't consider standard deviation of the individual monthly mean value in calculation of the annual change rate. The data used are 1976-1988 for KAK, 1981-1988 for MTZ, 1984-1988 for MMB and 1985-1988 for OMZ and for KNY. Although KNY and MTZ have data before 1984, they are excluded from the analysis because the relevant transfer functions are determined less accurately. In the following discussion, we consider only the annual change rates written in bold face because they definitely indicate increase or decrease in the secular chages.

At first, let us consider the time change rate for KAK, MMB and KNY. AfterYanagihara and Nagano (1976), the transfer function of KAK has been decreasing since 1940's at the rate of 0.1 per 30 years. As their analysis was concerned on only A_u of a shorter period (like a rising period of ssc and si), the 10-minute-period A_u is mainly

Table 3 Time change rates of the transfer functions per year ($x10^{-4}$). The rate which is twice as large as its deviation or more is written in bold face.

period		MMB	KAK	MTZ	OMZ	KNY
120	A_u	**31.5±10.8**	-5.8±3.1	**15.1± 4.5**	**-66.7± 12.8**	27.6±17.8
	B_u	-2.8± 9.6	0.8±2.8	**-17.7± 5.9**	**85.4± 19.9**	-33.7±20.4
	A_v	-32.9±18.0	-2.1±3.2	**-28.9± 5.0**	-14.9± 12.3	9.9±12.8
	B_v	-23.7±13.6	**9.4±4.4**	**-19.0± 6.8**	**40.4± 17.5**	**-99.2±23.2**
60	A_u	7.3± 5.1	**-10.0±2.3**	-0.1± 4.2	**-25.6± 9.3**	**17.6± 8.7**
	B_u	3.4± 3.9	3.3±1.9	**-23.0± 6.1**	**45.2± 22.5**	-3.6±12.5
	A_v	3.9± 7.8	1.1±2.4	**-38.5± 5.8**	**-22.7± 8.6**	-7.7± 5.8
	B_v	-1.1± 5.4	2.3±2.0	6.6± 5.6	21.1± 11.4	-6.2±11.3
30	A_u	3.0± 3.2	**-6.7±1.1**	-2.1± 7.1	**-57.8± 7.9**	**23.9± 5.8**
	B_u	-3.1± 3.3	-0.4±1.5	**-35.9± 8.8**	**75.3± 20.9**	-6.0±11.8
	A_v	4.4± 4.2	**-6.8±1.6**	**-95.6±10.6**	**-56.9± 8.9**	-5.7± 4.4
	B_v	-0.2± 2.6	0.0±1.4	-3.8± 6.8	-4.1± 11.9	**-14.0± 6.3**
10	A_u	**9.5± 3.5**	**-16.8±2.0**	**-221.2±24.5**	**-288.1±122.0**	**17.1± 5.2**
	B_u	**-10.7± 2.9**	**-17.6±3.3**	**-165.8±42.0**	18.8± 64.2	**-14.6± 6.7**
	A_v	2.5± 2.8	4.3±2.5	**-190.8±19.0**	**-168.6± 26.2**	-8.5± 4.5
	B_v	0.2± 1.9	1.3±3.0	-31.3±24.0	-42.9± 51.5	-1.6± 6.1

concerned here. The time change rate in Table 3, $-1.68x10^{-3}$/year (-0.05/30 years), is about the half of the result of Yanagihara and Nagano (1976), but has the same sense as their result. Bearing in mind that their result on the secular change rate possibly contains errors due to primitive analysis of the transfer functions, this discrepancy may have no sense. Thus, we conclude that decrease in A_u after 1940 still continues. In contrast to KAK's result, it is evident that the 10-minute-period A_u's for MMB and for KNY increase in magnitude. As KAK's annual change rate of the 10-minute-period A_u is $(-12.1\pm7.6)x10^{-4}$ for the intereval of 1985-1988, the difference of analysing interval cannot explain the opposite sense of A_u's change rate.

Generally, the transfer functions of MTZ and of OMZ change with time change rates larger than those of other stations do. In particular, the 10-minute-period A_u's are decreasing remarkably for both stations. These change rates up to 0.1/5 years are comparable to the change rates for KAK before the Kanto earthquake after Yanagihara and Nagano (1976). However, as the transfer functions of MTZ and of OMZ are determined less accurately than those of other stations are, we need to treat them carefully. Bearing in mind that MTZ's and OMZ's data are contaminated by the noises which reduce the accuracy of calculation of the transfer functions with shorter periods, we need another clue to conclude that these remarkable changes of the transfer functions are associated with accumulation of the crustal stress which causes an earthquake.

Discussion

As a large earthquake is predicted to occur in the near future in the Tokai area, MTZ's and OMZ's transfer functions are primarily important. However, because there are the noises which hide natural changes of the transfer functions, our results presented in Table

3 should be doubted at first. We strongly need to check them by the data from other station located in Tokai area.

The 10-minute-period A_u for KAK has the tendency which is consistent with the result of Yanagihara and Nagano (1976). After them, the decreasing A_u means accumulation of the crustal stress in the southern Kanto area. Besides of this, we found increasing A_u's with the period of 10-minutes for MMB and KNY. We need to continue monitoring the time change in the future. In addition, it is important to make a model which can explain the secular variations.

The present paper deals with preliminary results of time change of the transfer function. We need to improve the analysis method for definite conclusion for it. As for points of improvement, the followings are important;

1) To examine the transfer function by using only night-time data (for example, 00h-04h LT). This treatment may reduce significantly the transfer function's noises from electric railways felt at MTZ and at OMZ. In addition, Sq variation with the significant Z component may contaminate the time change of the transfer functions. As Sq variations depends on the season (larger in summer and smaller in winter) the fluctuations in the daily values of the transfer functions in Fig. 2, may resulted from the Sq's seasonal variation. Therefore, it may be important to take this improvement.

2) To calculate the time change rate of the transfer function and its standard deviation by considering standard deviations of the monthly mean value.

3) To set the threshold value of ε by more sophisticated method such as investigation on the standard deviation of the transfer functions with ε smaller than the threshold.

Conclusion

By using geomagnetic one-minute data at MMB, KAK, MTZ, OMZ and KNY, the conductivity anomaly transfer functions are calculated day by day. After investigating time change of the transfer functions, the following results are preliminarily obtained. But all of the results should be checked again with the improved methods and with data from other stations.

1) The 10-minute-period A_u for KAK is decreasing with annual change rate of $1.6\text{x}10^{-3}$. This is consistent continuation of the result of Yanagihara and Nagano (1976).

2) The 10-minute-period A_u's for MMB and for KNY are increasing in magnitude.

3) The 10-minute-period A_u's for MTZ and for OMZ have significantly large decreases in magnitude. These amount as that of KAK before the Kanto earthquake according to Yanagihara and Nagano (1976).

The last conclusion needs further confirmation by other methods. To do this, for example, the night-time data should be exclusively used for the analysis. In addition, the data from other stations in the Tokai area are essentially necessary for the confirmation.

Acknowledgement

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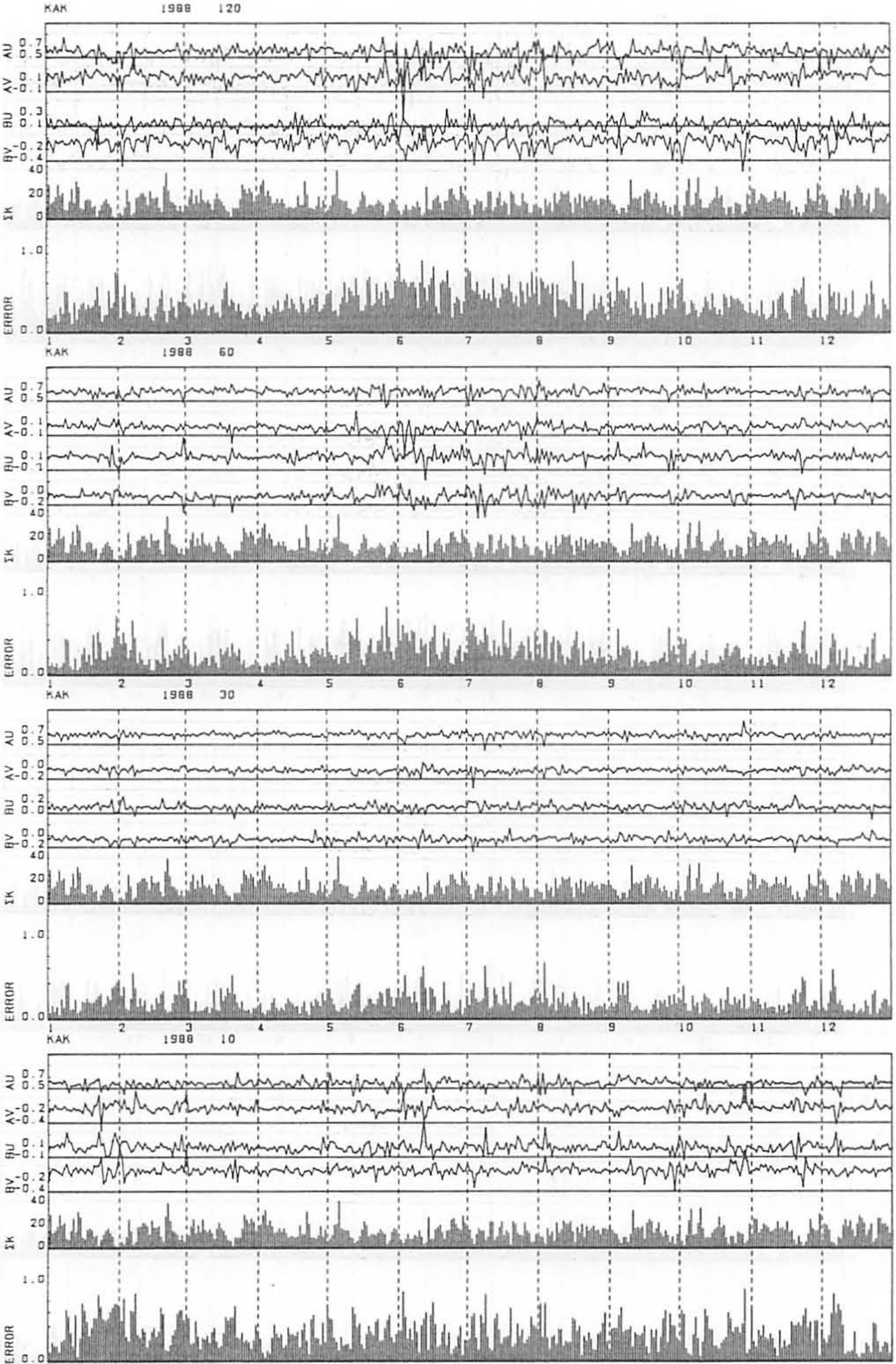
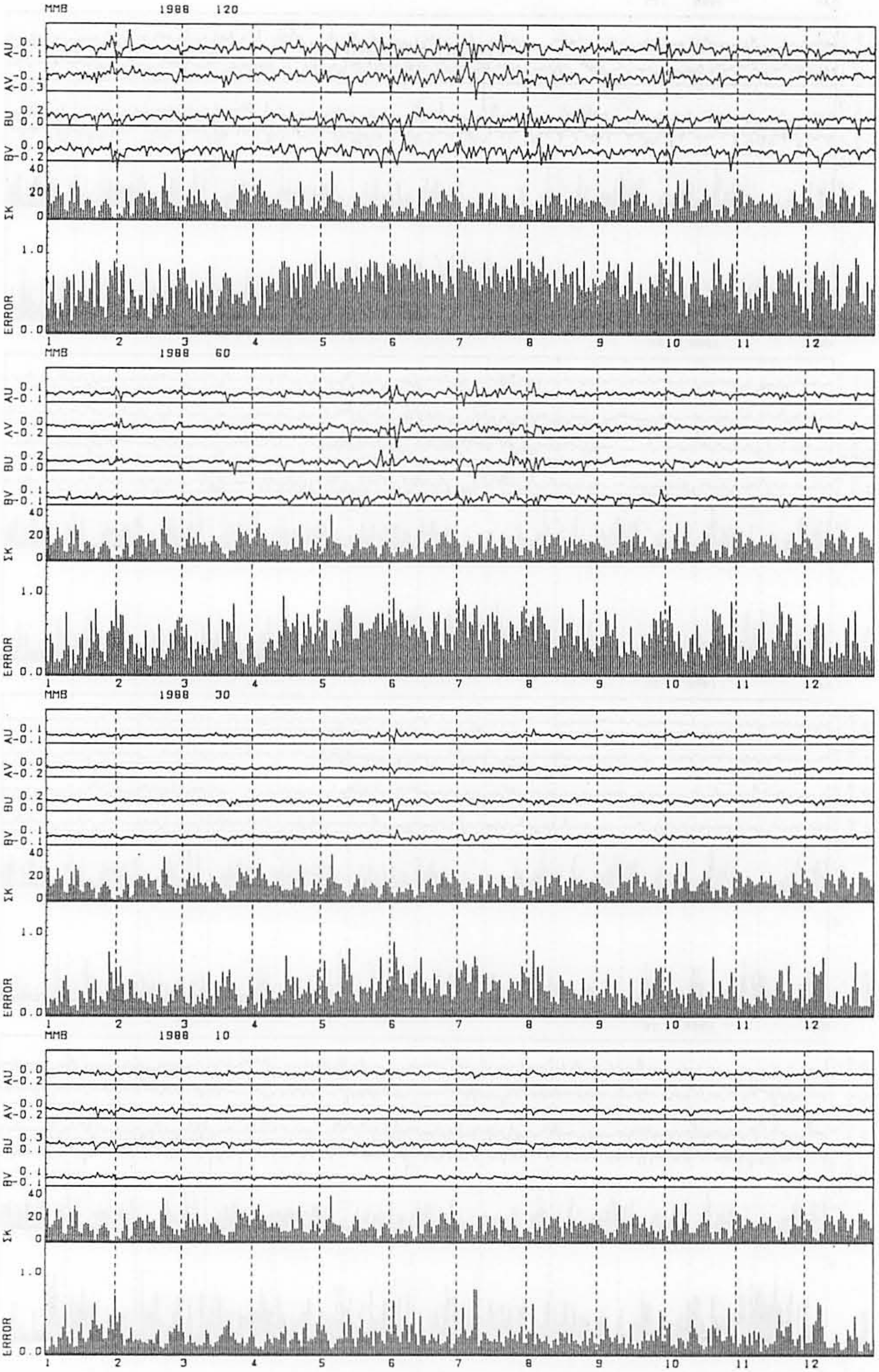
(Figures 2—8 are appended in the following pages.)



(a)

Figure 2 Day-to-day variation of the transfer functions in 1988 for (a) KAK, (b) MMB and (c) KNY. The periods of the transfer functions are 10, 30, 60 and 120 minutes. ε (denoted as ERROR in the figures) and ΣK of KAK are also shown in the lower lines.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MMB 1988 60
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AV 0.0 -0.2
BU 0.2 0.0
BV 0.1 -0.1
ΣK 40 20 0
ERROR 1.0 0.0
1 2 3 4 5 6 7 8 9 10 11 12
MMB 1988 30
AU 0.1 -0.1
AV 0.0 -0.2
BU 0.2 0.0
BV 0.1 -0.1
ΣK 40 20 0
ERROR 1.0 0.0
1 2 3 4 5 6 7 8 9 10 11 12
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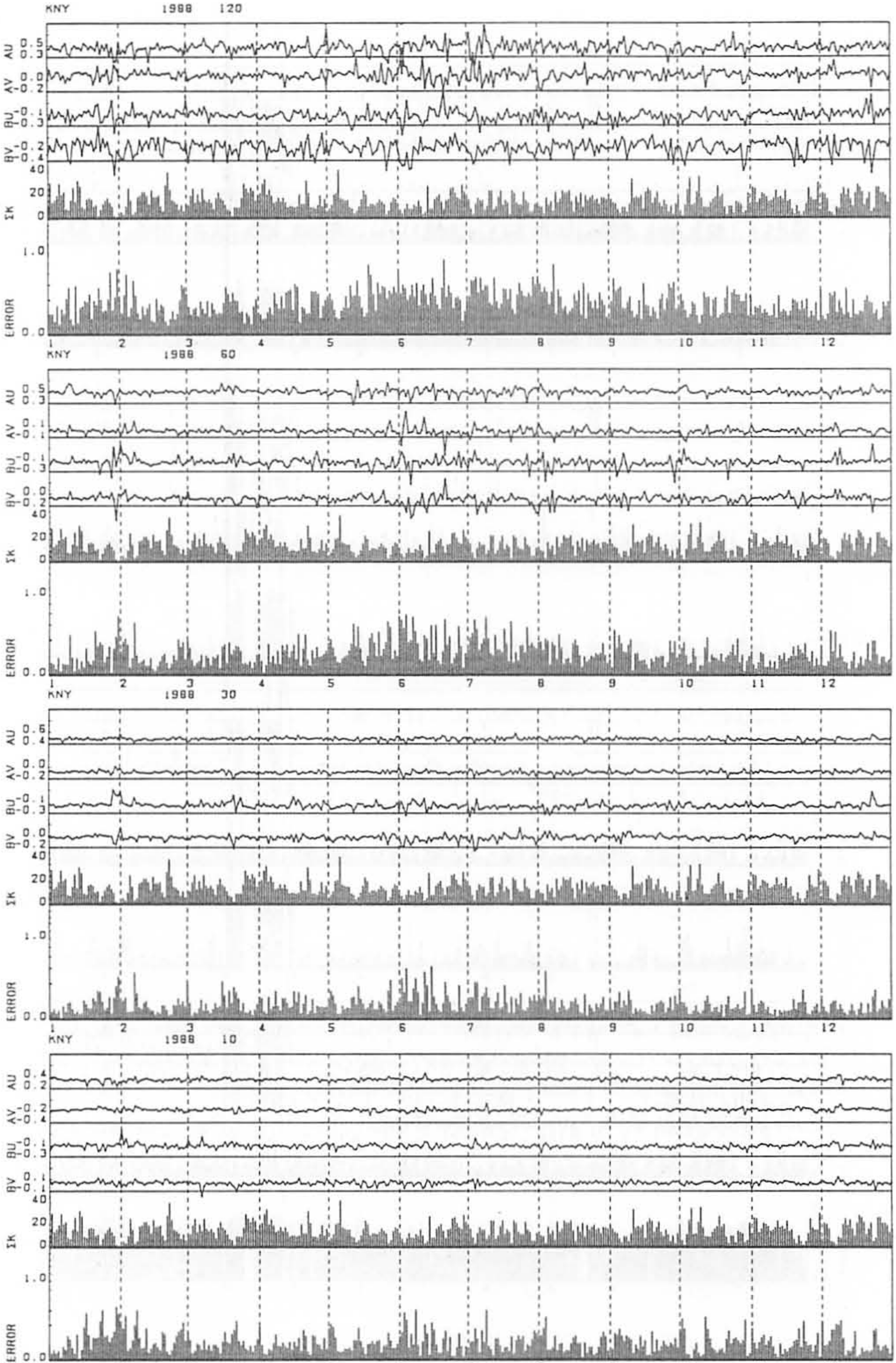
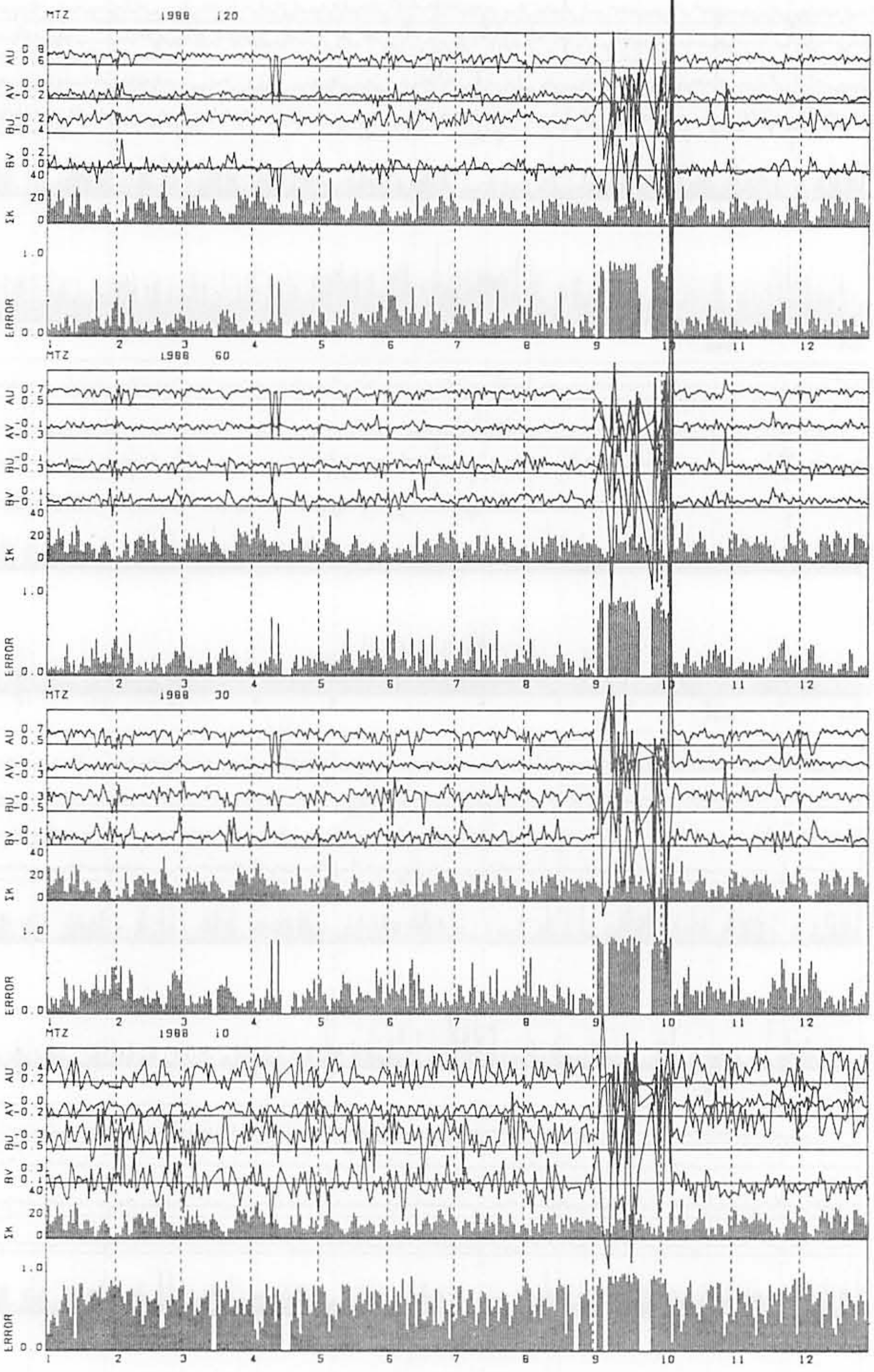
ΣK 40 20 0
ERROR 1.0 0.0
1 2 3 4 5 6 7 8 9 10 11 12

(b)

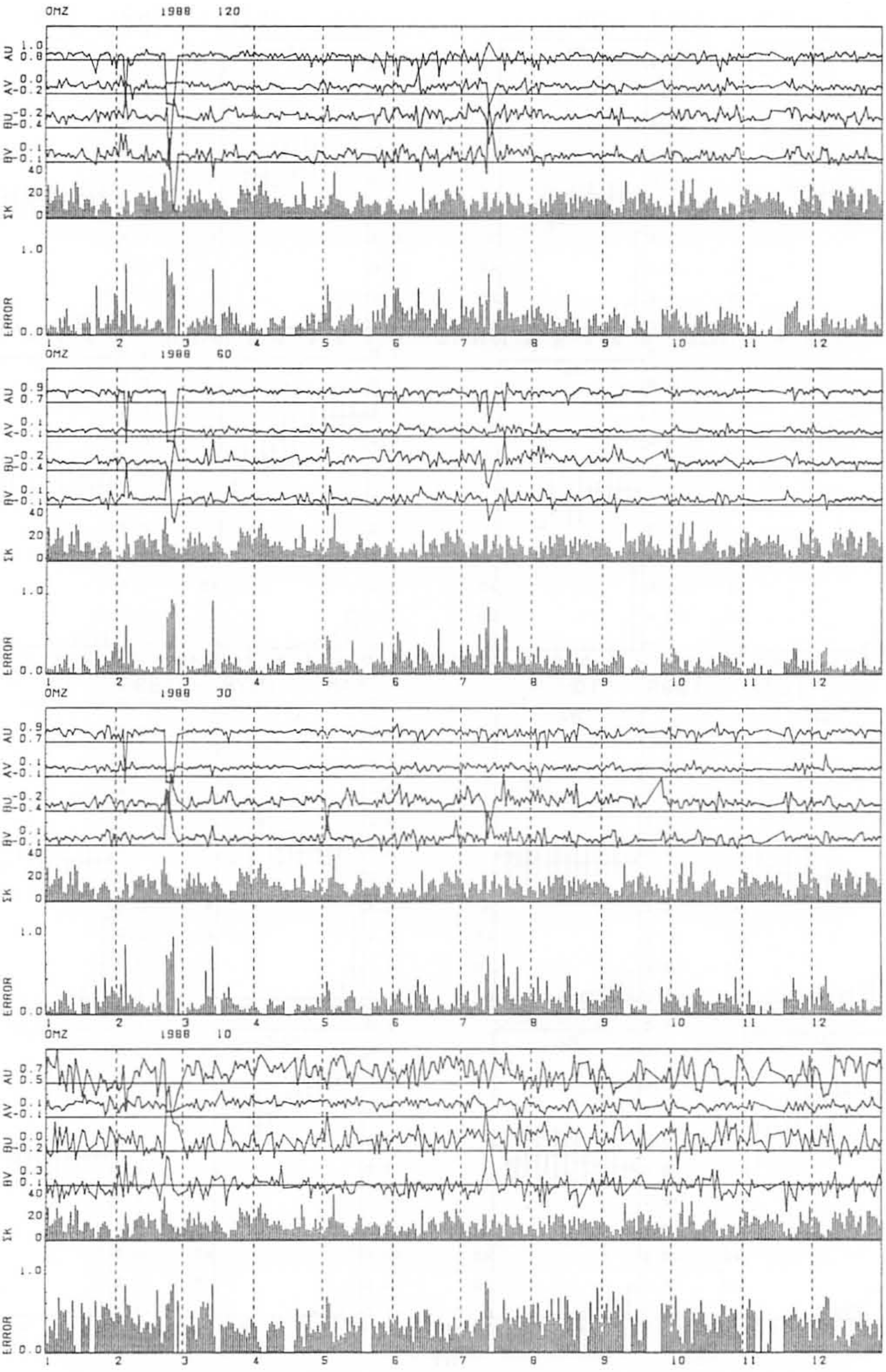

KNY 1988 120
KNY 1988 60
KNY 1988 30
KNY 1988 10
AU
AV
BU
BV
ΣK
ERROR
1 2 3 4 5 6 7 8 9 10 11 12

(c)

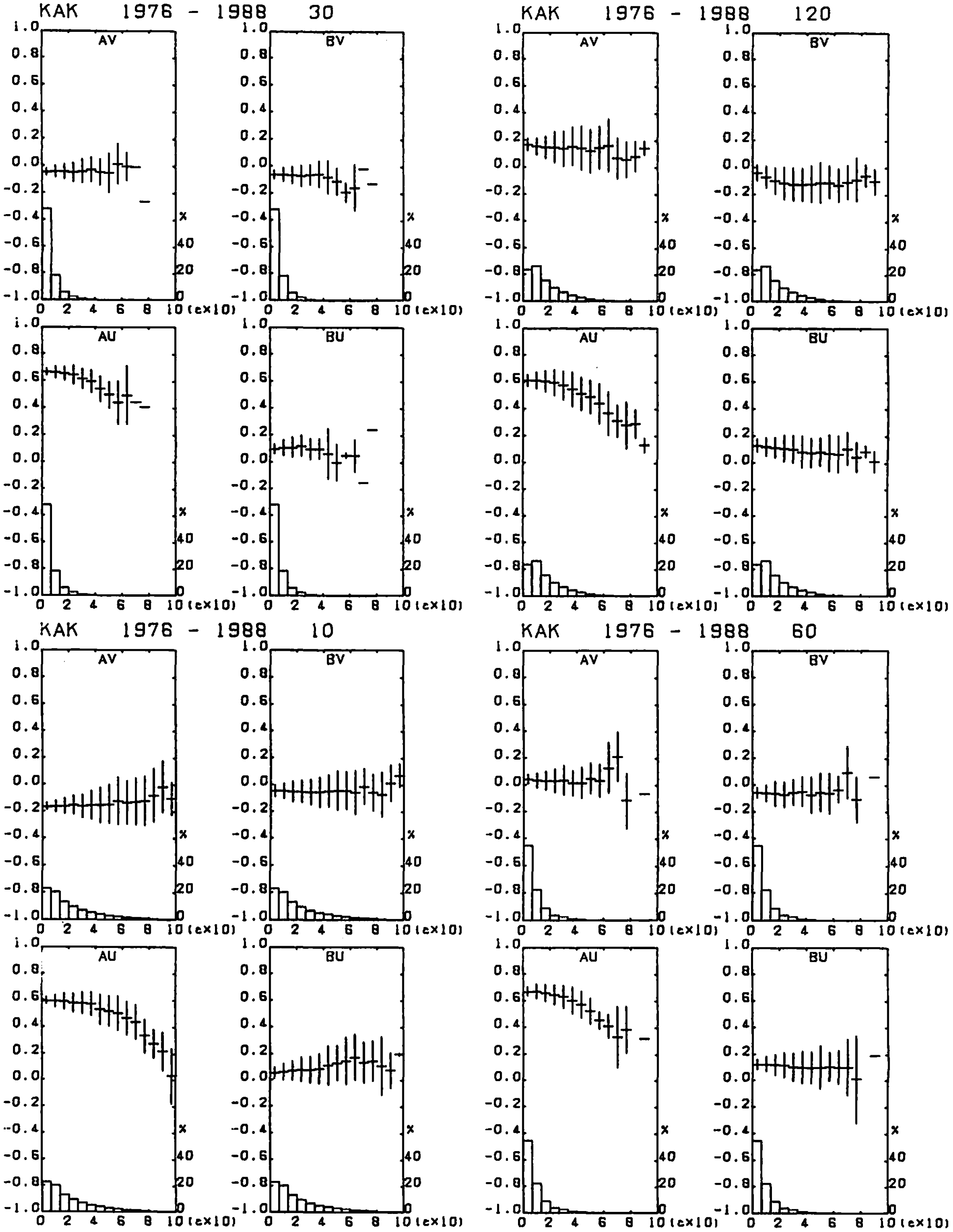


(a)

Figure 3 Day-to-day variation of the transfer functions for (a) MTZ and (b) OMZ in 1988. Presentation is the same as that Fig. 2. MTZ's abnormal transfer functions in September relate to not natural changes but some artificial noises due to instrumental malfunction and/or man-made disturbances.

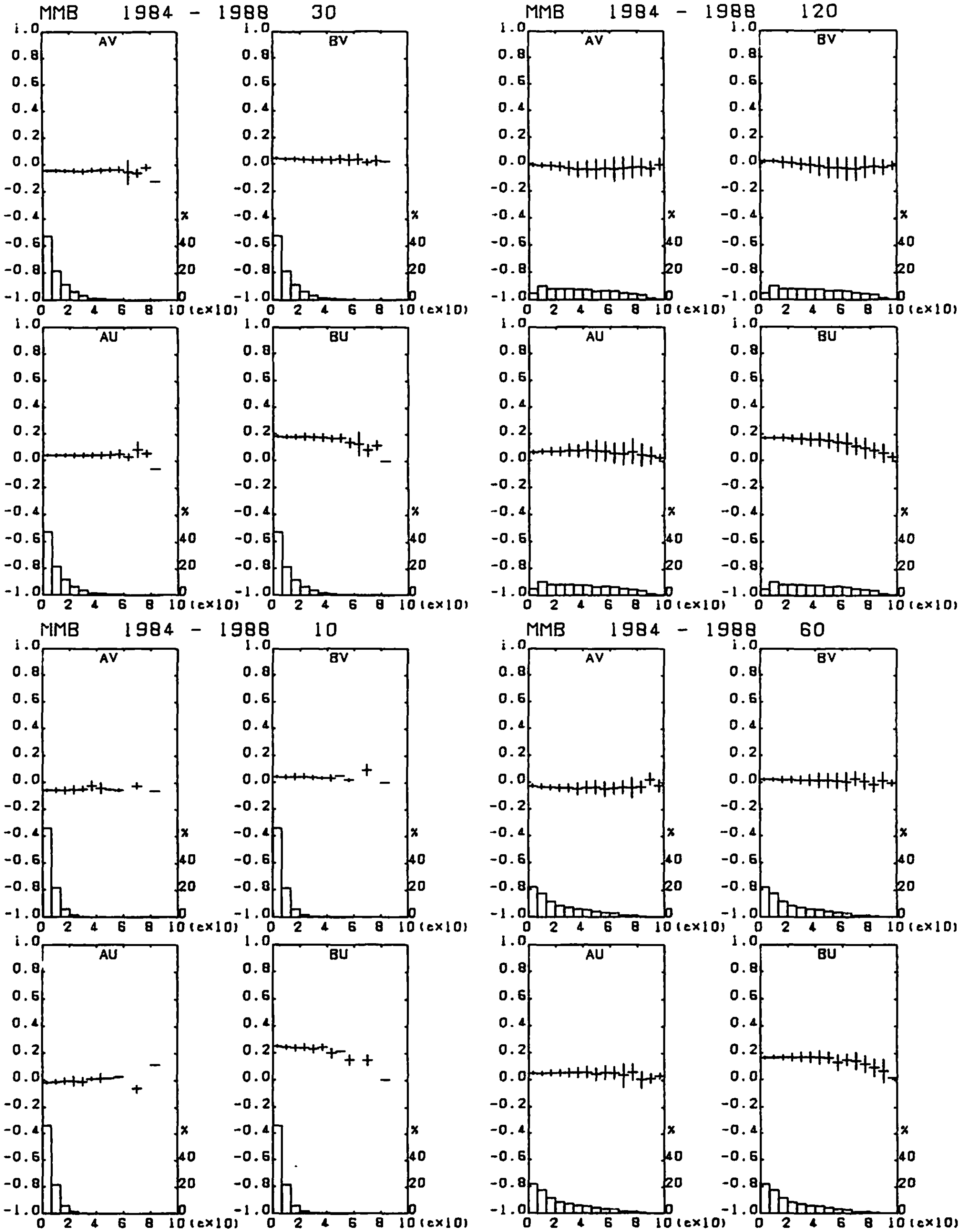

OMZ 1988 120
AU 1.0 0.8
AV 0.0 -0.2
BU -0.2 -0.4
BV 0.1 -0.1
ΣK 40 20 0
ERROR 1.0 0.0
OMZ 1988 60
AU 0.9 0.7
AV 0.1 -0.1
BU -0.2 -0.4
BV 0.1 -0.1
ΣK 40 20 0
ERROR 1.0 0.0
OMZ 1988 30
AU 0.9 0.7
AV 0.1 -0.1
BU -0.2 -0.4
BV 0.1 -0.1
ΣK 40 20 0
ERROR 1.0 0.0
OMZ 1988 10
AU 0.7 0.5
AV 0.1 -0.1
BU 0.0 -0.2
BV 0.3 0.1
ΣK 40 20 0
ERROR 1.0 0.0
1 2 3 4 5 6 7 8 9 10 11 12

(b)

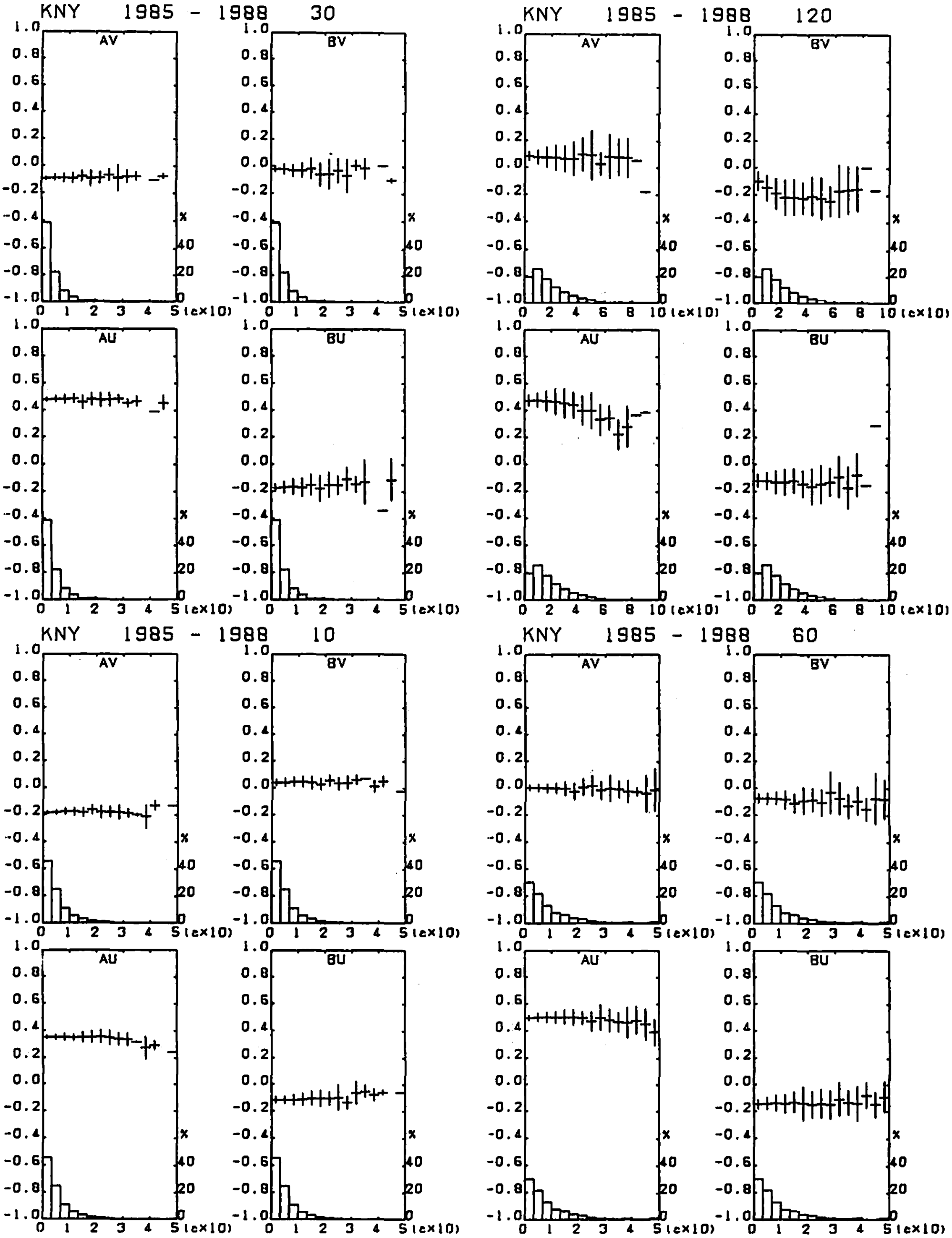


(a)

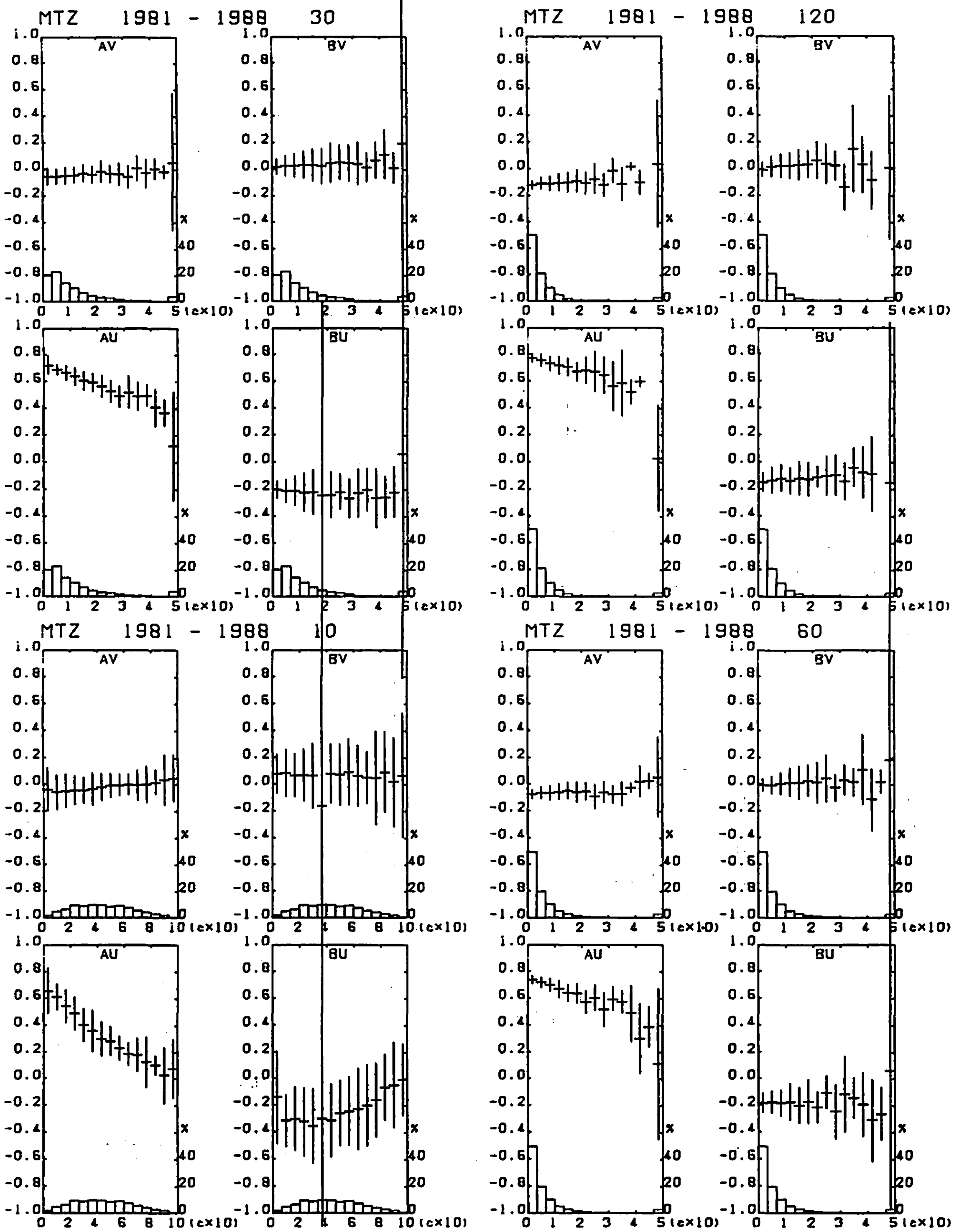
Figure 4 Relations between ε and values of the transfer functions for (a) KAK, (b) MMB, (c) KNY, (d) MTZ and (e) OMZ. The periods are 10, 30, 60 and 120 minutes. Error bars in the figures indicate standard deviations. Rectangles in the lower part of each figure shows occurrences in the unit of percent.


MMB 1984 - 1988 30
MMB 1984 - 1988 120
MMB 1984 - 1988 10
MMB 1984 - 1988 60
AV
BV
AU
BU
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
%
40
20
0
0 2 4 6 8 10 (e×10)

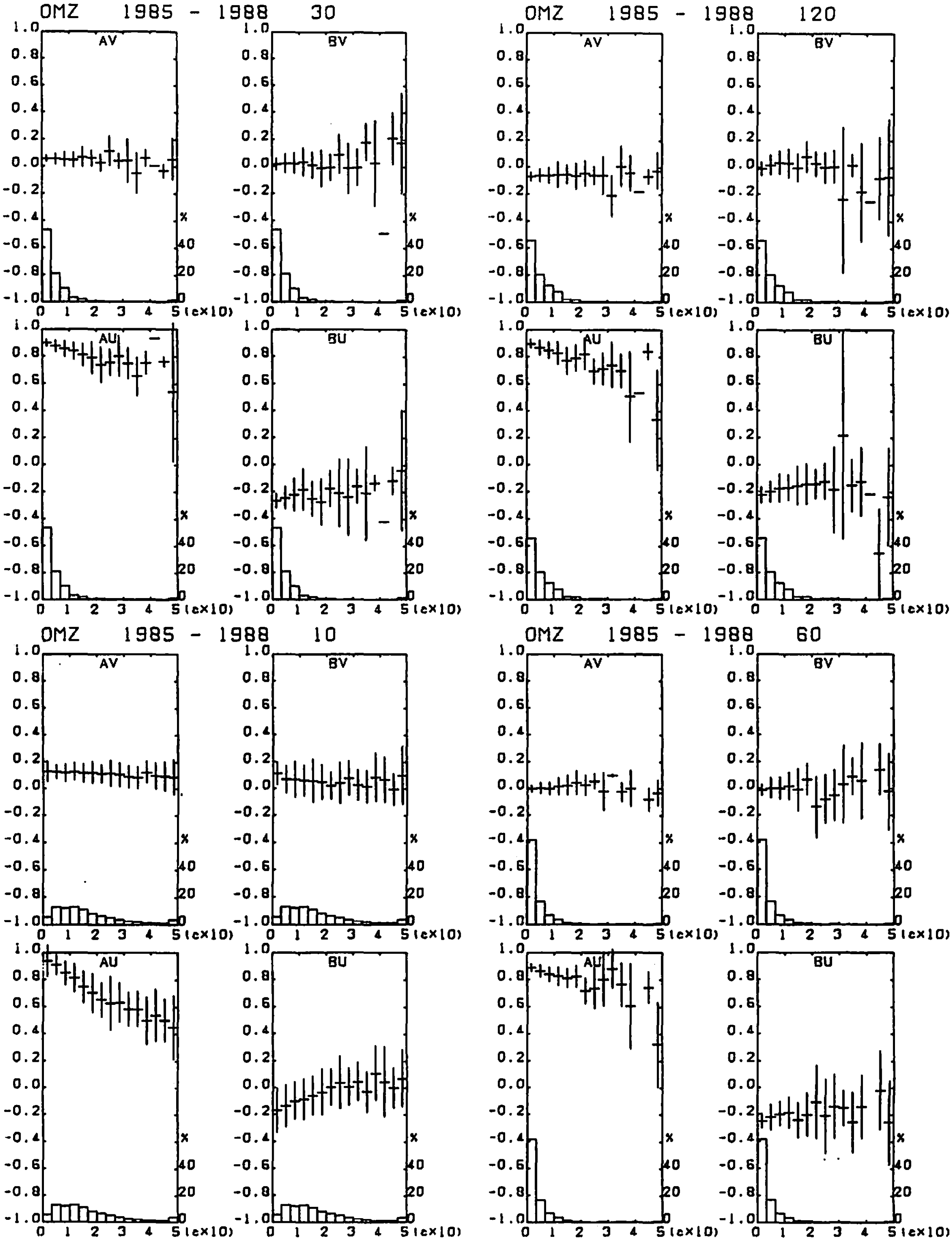
(b)


KNY 1985 - 1988 30
KNY 1985 - 1988 120
KNY 1985 - 1988 10
KNY 1985 - 1988 60
AV
BV
AU
BU
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
%
40
20
0
0 1 2 3 4 5 (×10)
0 2 4 6 8 10 (×10)

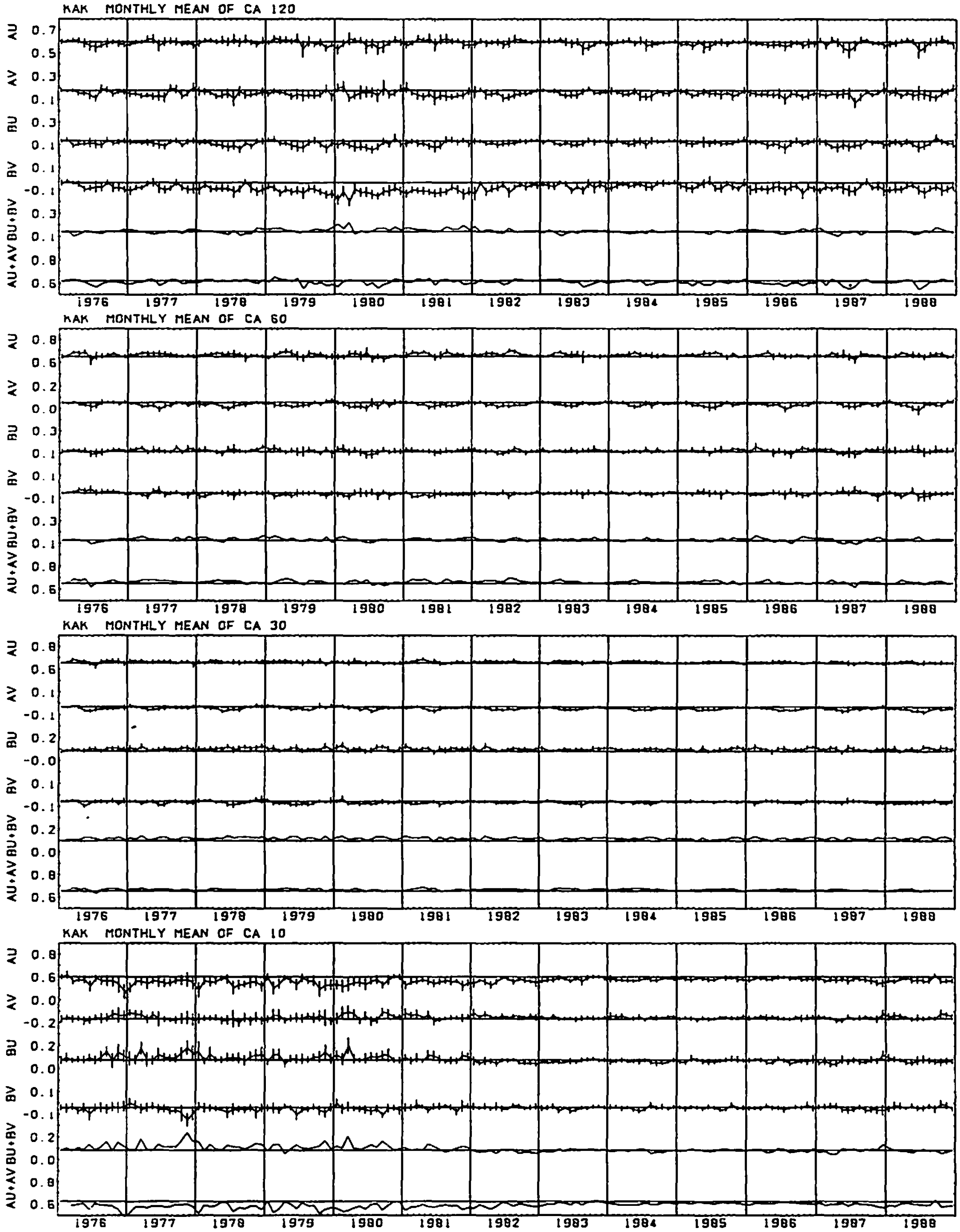
(c)


MTZ 1981 - 1988 30
MTZ 1981 - 1988 120
MTZ 1981 - 1988 10
MTZ 1981 - 1988 60
AV
BV
AU
BU
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
x
40
20
0
0 1 2 3 4 5 (×10)
0 2 4 6 8 10 (×10)

(d)

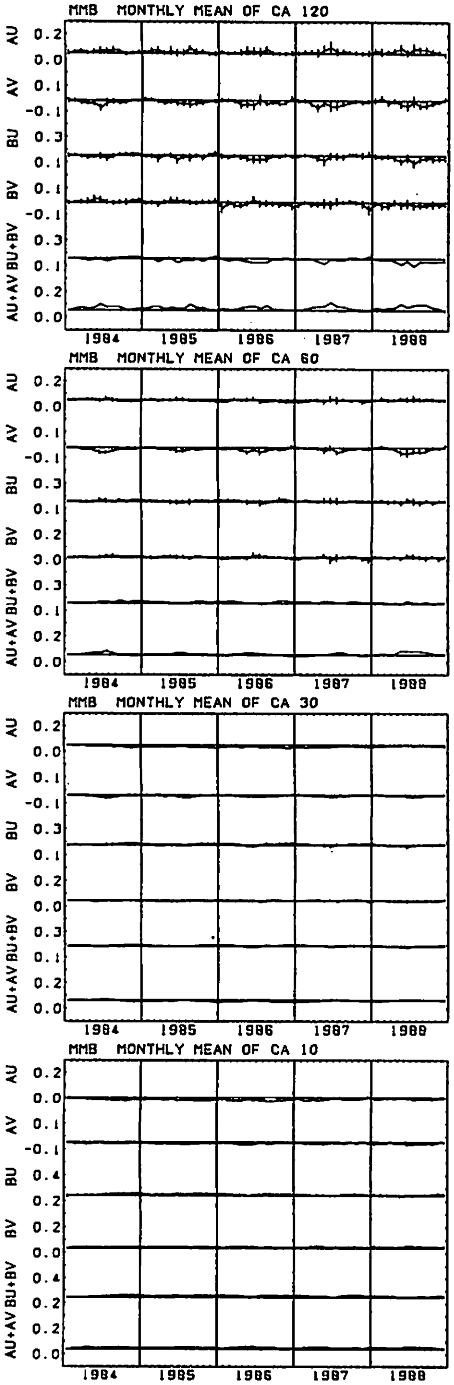

OMZ 1985 - 1988 30
OMZ 1985 - 1988 120
OMZ 1985 - 1988 10
OMZ 1985 - 1988 60
AV
BV
AU
BU
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
%
40
20
0
0 1 2 3 4 5 (e×10)

(e)

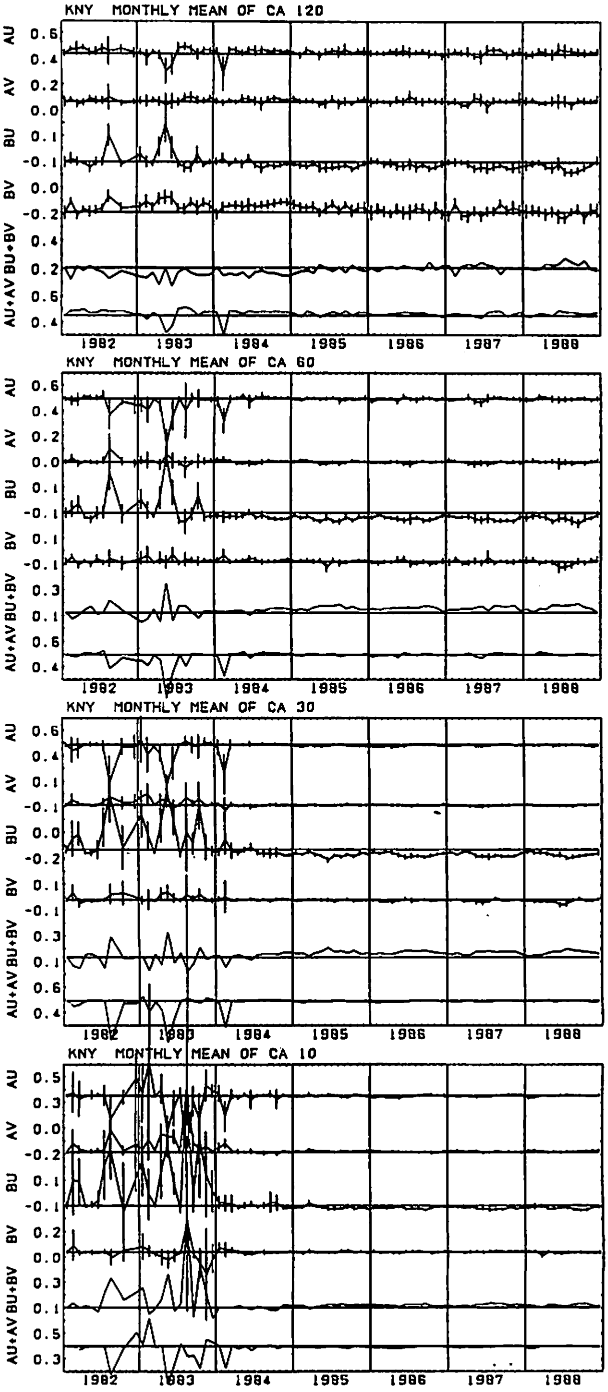


(a)

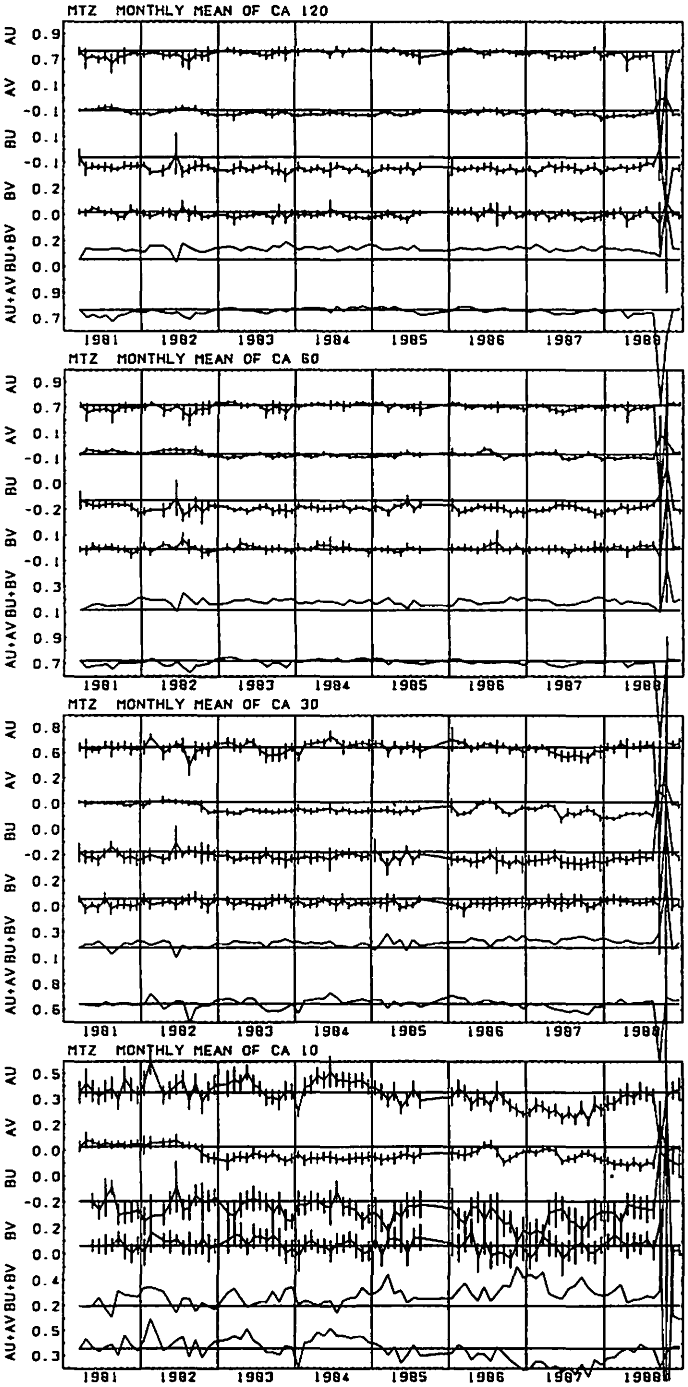
Figure 5 Month-to-month variations of the transfer function for (a) KAK, (b) MMB, (c) KNY, (d) MTZ and (e) OMZ. A_u+A_v and B_u+B_v mean respectively $(A_u^2+A_v^2)^{1/2}$ and $(B_u^2+B_v^2)^{1/2}$. Each error bars in the figure means 95% confidence interval. Monthly mean values are calculated by using all available daily values of the transfer functions.


MMB MONTHLY MEAN OF CA 120
MMB MONTHLY MEAN OF CA 60
MMB MONTHLY MEAN OF CA 30
MMB MONTHLY MEAN OF CA 10
AU
AV
BU
BV
AU+AV
BU+BV
1984
1985
1986
1987
1988

(b)


KNY MONTHLY MEAN OF CA 120
KNY MONTHLY MEAN OF CA 60
KNY MONTHLY MEAN OF CA 30
KNY MONTHLY MEAN OF CA 10
AU
AV
BU
BV
AU+AV
BU+BV
1982
1983
1984
1985
1986
1987
1988

(c)



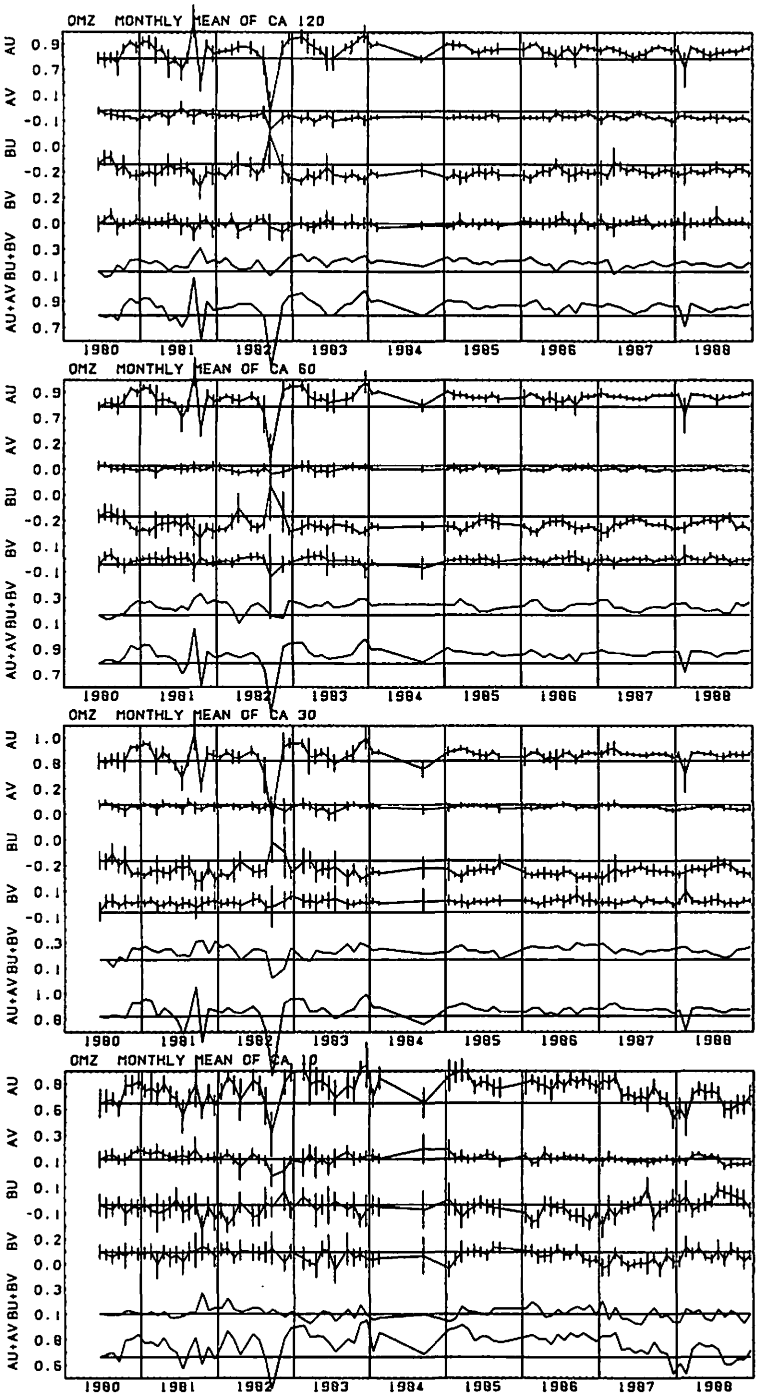
MTZ MONTHLY MEAN OF CA 120

MTZ MONTHLY MEAN OF CA 60

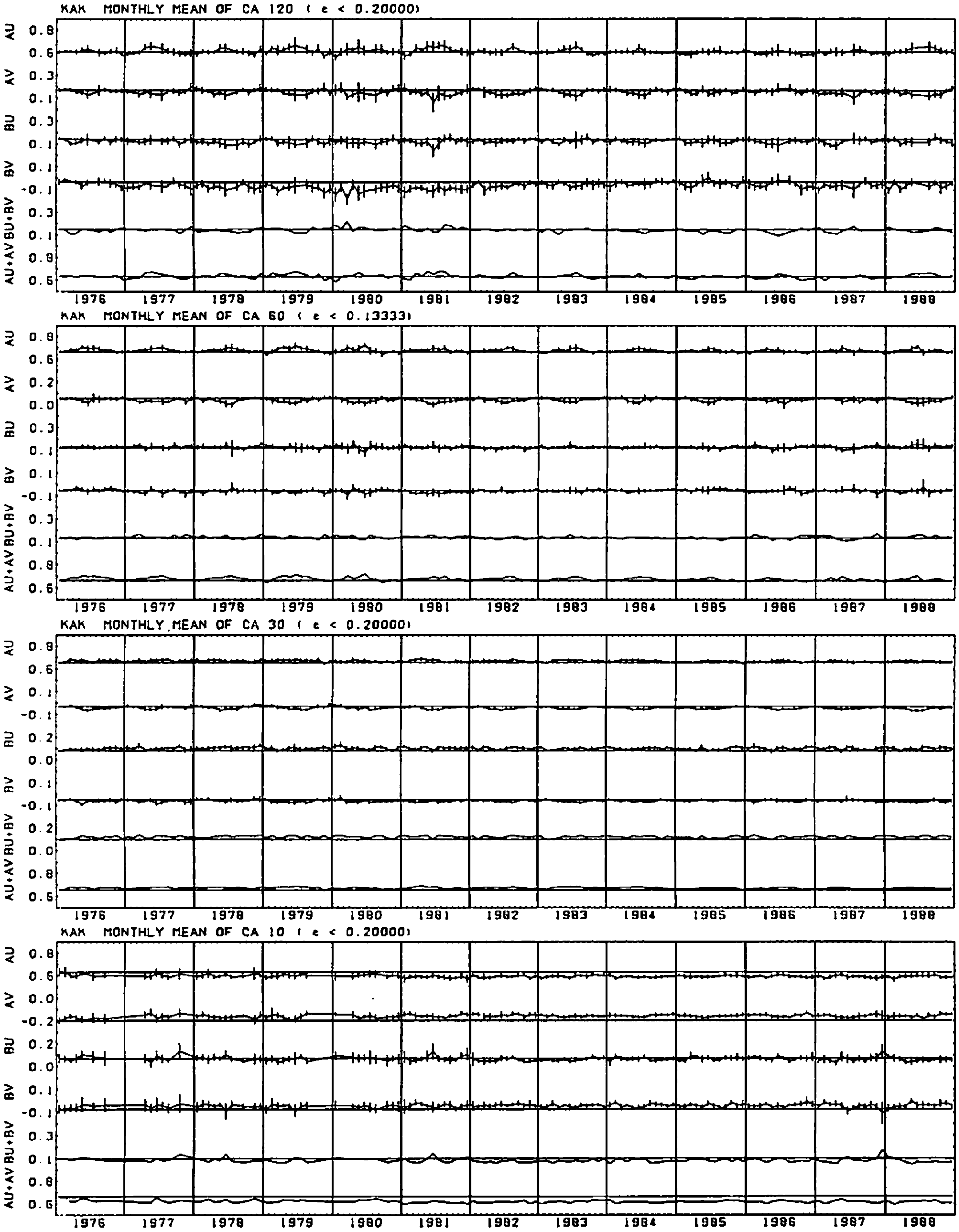
MTZ MONTHLY MEAN OF CA 30

MTZ MONTHLY MEAN OF CA 10

(d)

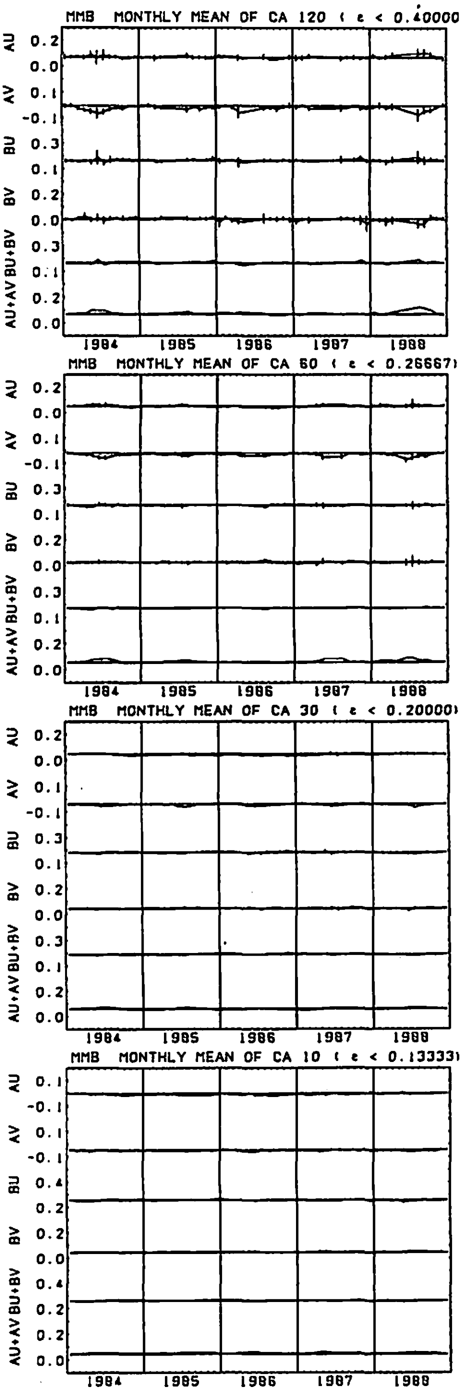

OMZ MONTHLY MEAN OF CA 120
OMZ MONTHLY MEAN OF CA 60
OMZ MONTHLY MEAN OF CA 30
OMZ MONTHLY MEAN OF CA 10
AU
AV
BU
BV
AU+AV
BU+BV
0.9
0.7
0.1
-0.1
0.0
-0.2
0.2
0.0
0.3
0.1
0.9
0.7
1.0
0.8
0.8
0.6
1980
1981
1982
1983
1984
1985
1986
1987
1988

(e)



(a)

Figure 6 Month-to-month variations of the transfer functions for (a) KAK, (b) MMB, (c) KNY, (d) MTZ and (e) OMZ. $A_u + A_v$ and $B_u + B_v$ mean respectively $(A_u^2 + A_v^2)^{1/2}$ and $(B_u^2 + B_v^2)^{1/2}$. Each error bars in the figure means 95% confidence interval. Monthly mean values are calculated by using the transfer functions with ε less than the threshold shown in Table 1.

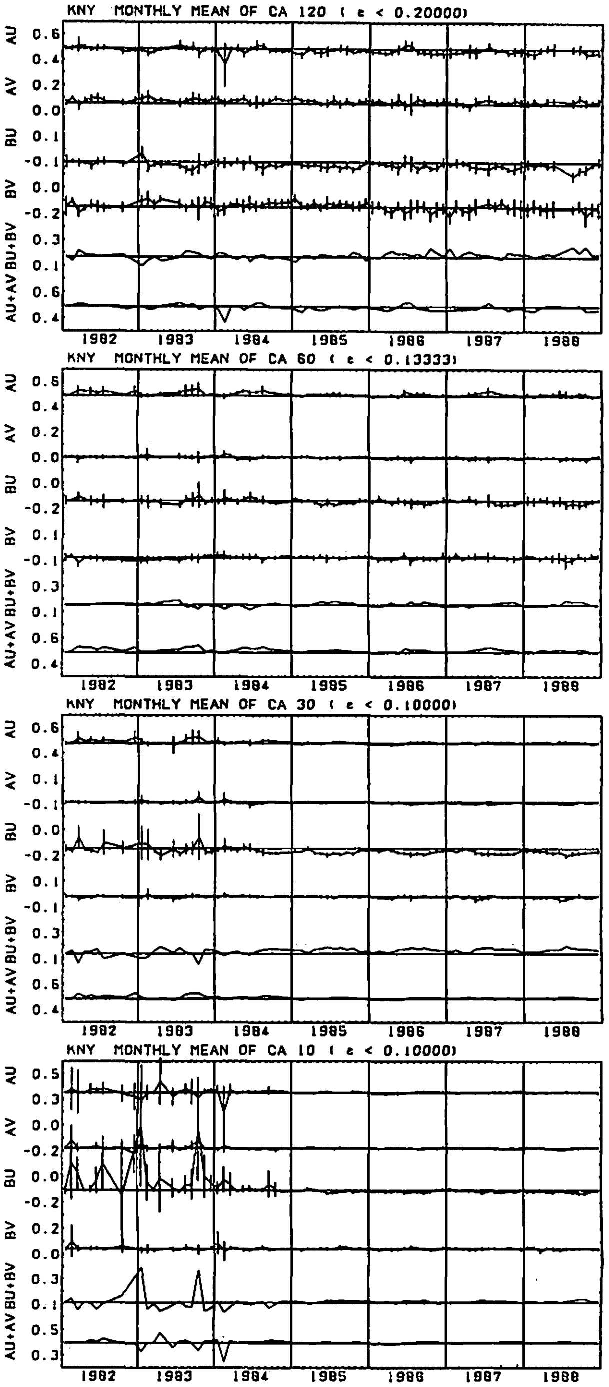

MMB MONTHLY MEAN OF CA 120 (ε < 0.40000

MMB MONTHLY MEAN OF CA 60 (ε < 0.26667)

MMB MONTHLY MEAN OF CA 30 (ε < 0.20000)

MMB MONTHLY MEAN OF CA 10 (ε < 0.13333)

(b)

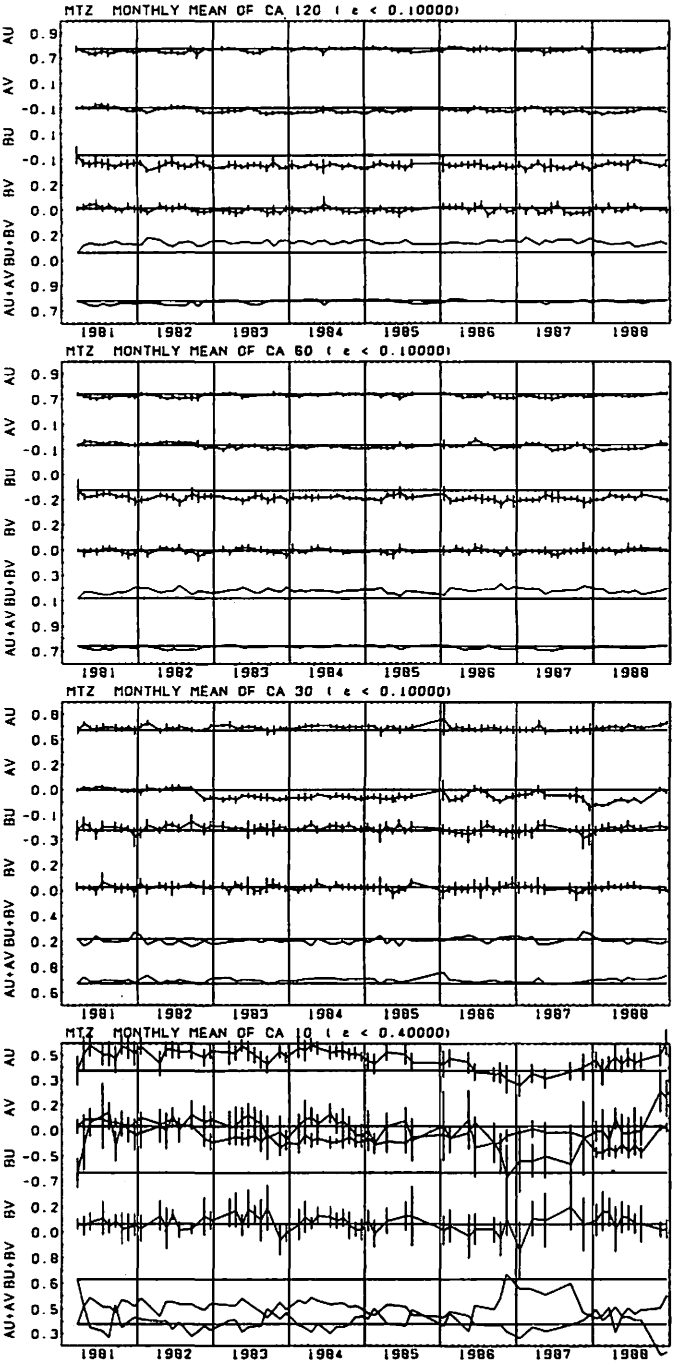

KNY MONTHLY MEAN OF CA 120 (ε < 0.20000)

KNY MONTHLY MEAN OF CA 60 (ε < 0.13333)

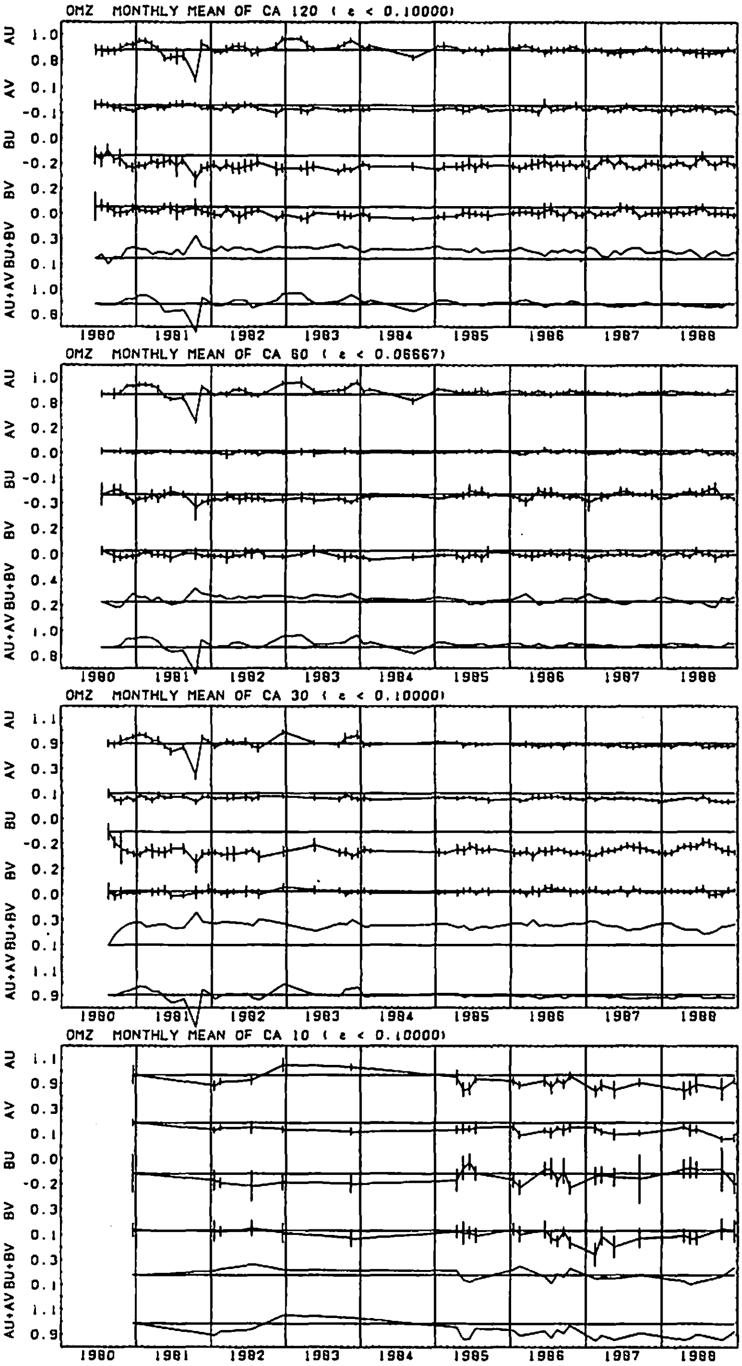
KNY MONTHLY MEAN OF CA 30 (ε < 0.10000)

KNY MONTHLY MEAN OF CA 10 (ε < 0.10000)

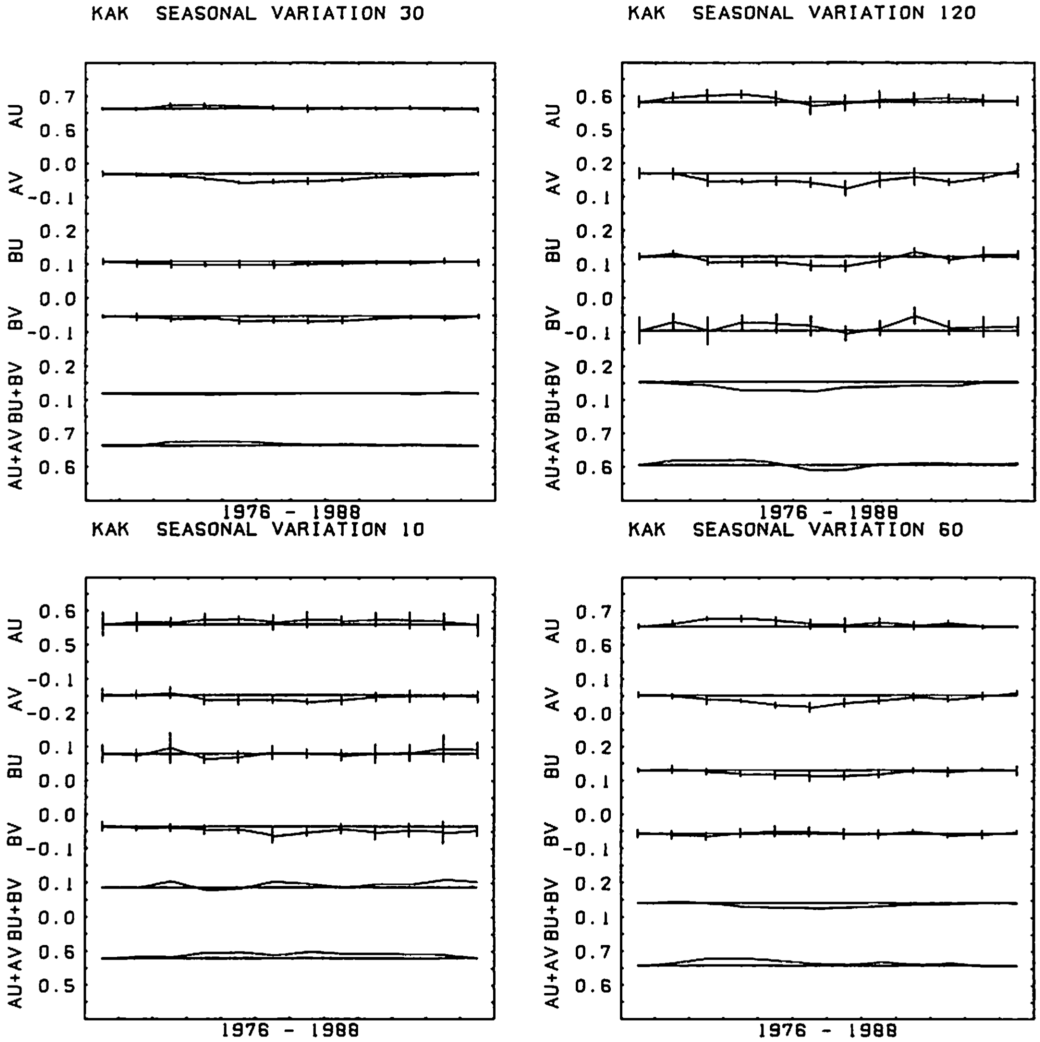
(c)


MTZ MONTHLY MEAN OF CA 120 (ε < 0.10000)
AU 0.9 0.7
AV 0.1 -0.1
BU 0.1 -0.1
BV 0.2 0.0
AU+AV BU+BV 0.2 0.0 0.9 0.7
1981 1982 1983 1984 1985 1986 1987 1988
MTZ MONTHLY MEAN OF CA 60 (ε < 0.10000)
AU 0.9 0.7
AV 0.1 -0.1
BU 0.0 -0.2
BV 0.2 0.0
AU+AV BU+BV 0.3 0.1 0.9 0.7
1981 1982 1983 1984 1985 1986 1987 1988
MTZ MONTHLY MEAN OF CA 30 (ε < 0.10000)
AU 0.8 0.6
AV 0.2 0.0
BU -0.1 -0.3
BV 0.2 0.0
AU+AV BU+BV 0.4 0.2 0.8 0.6
1981 1982 1983 1984 1985 1986 1987 1988
MTZ MONTHLY MEAN OF CA 10 (ε < 0.40000)
AU 0.5 0.3
AV 0.2 0.0
BU -0.5 -0.7
BV 0.2 0.0
AU+AV BU+BV 0.8 0.6 0.5 0.3
1981 1982 1983 1984 1985 1986 1987 1988

(d)

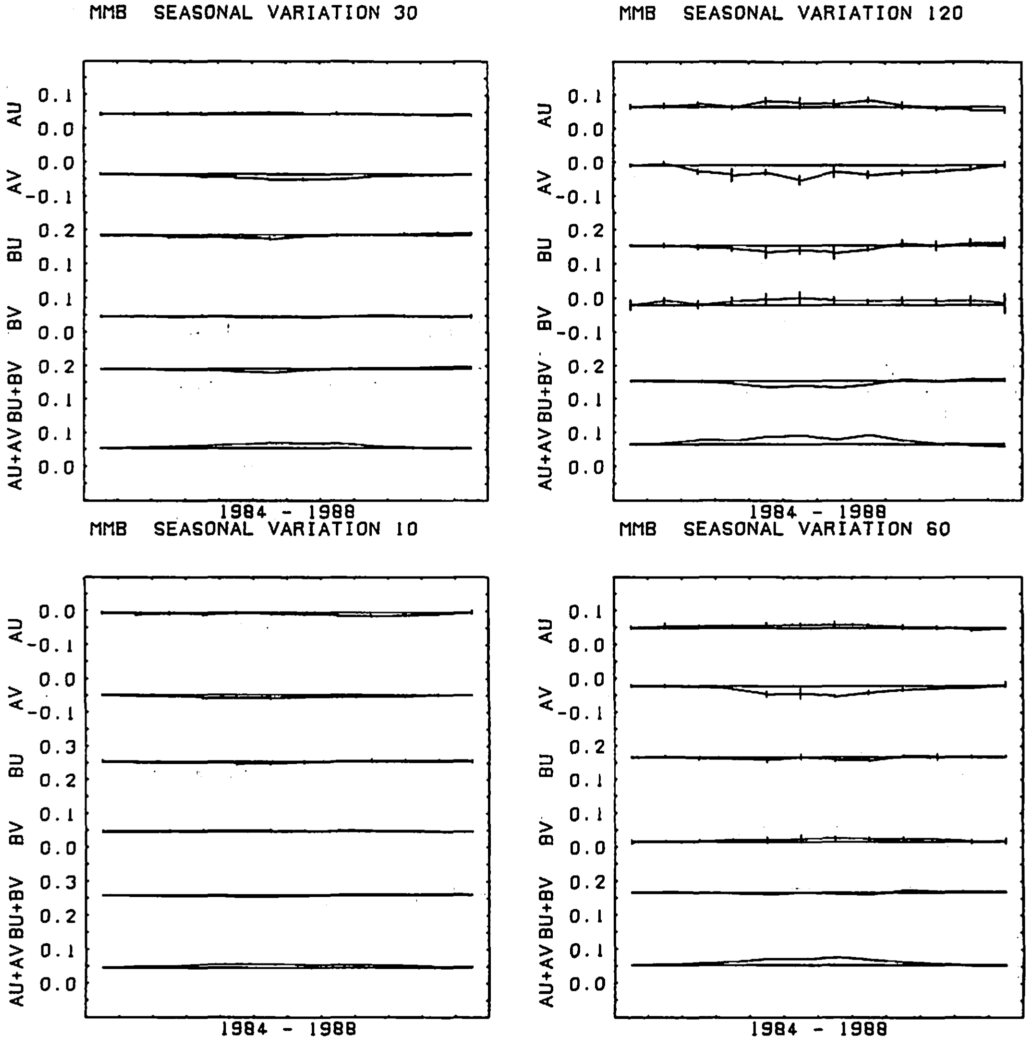

OMZ MONTHLY MEAN OF CA 120 (ε < 0.10000)
AU 1.0 0.8
AV 0.1 -0.1
BU 0.0 -0.2
BV 0.2 0.0
BU+BV 0.3 0.1
AU+AV 1.0 0.8
OMZ MONTHLY MEAN OF CA 60 (ε < 0.06667)
AU 1.0 0.8
AV 0.2 0.0
BU -0.1 -0.3
BV 0.2 0.0
BU+BV 0.4 0.2
AU+AV 1.0 0.8
OMZ MONTHLY MEAN OF CA 30 (ε < 0.10000)
AU 1.1 0.9
AV 0.3 0.1
BU 0.0 -0.2
BV 0.2 0.0
BU+BV 0.3 0.1
AU+AV 1.1 0.9
OMZ MONTHLY MEAN OF CA 10 (ε < 0.10000)
AU 1.1 0.9
AV 0.3 0.1
BU 0.0 -0.2
BV 0.3 0.1
BU+BV 0.3 0.1
AU+AV 1.1 0.9
1980 1981 1982 1983 1984 1985 1986 1987 1988

(e)

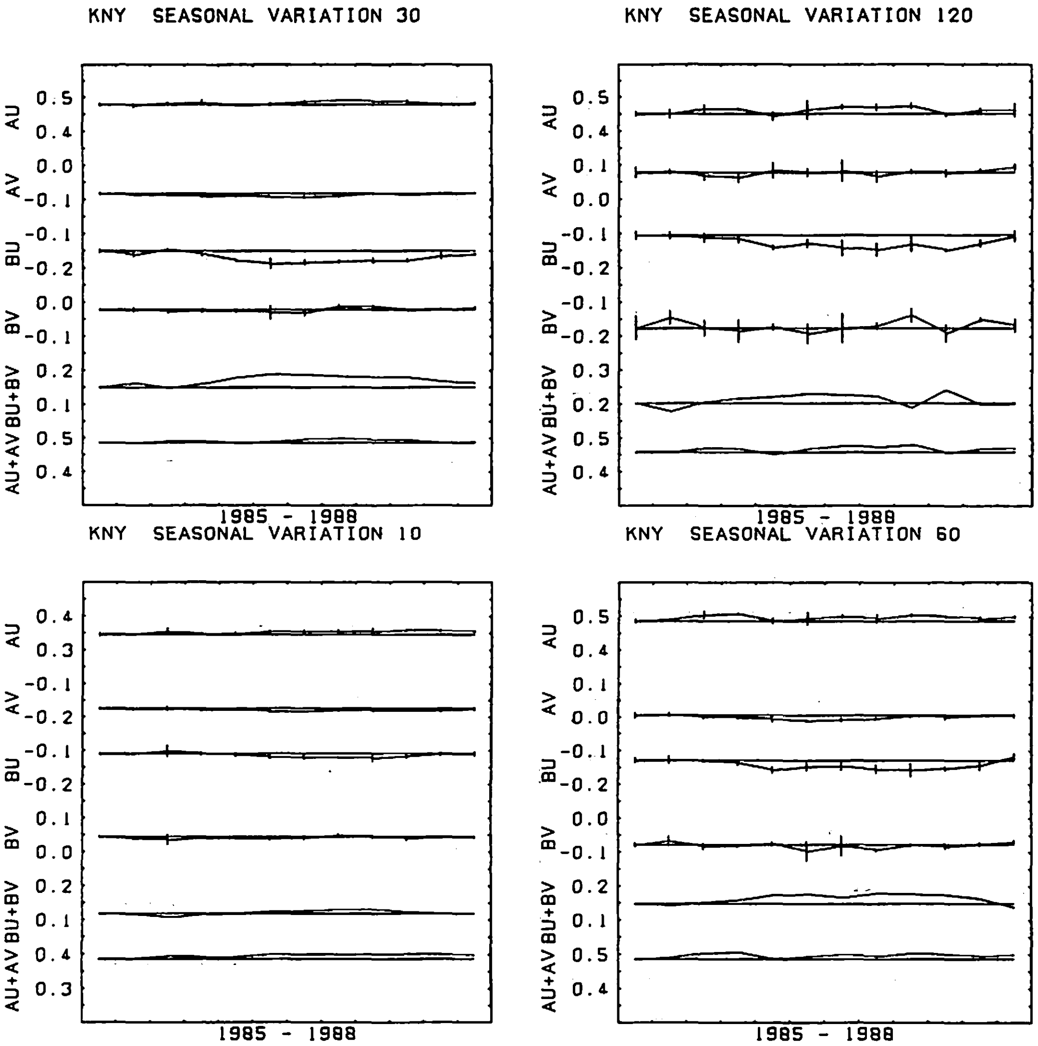


(a)

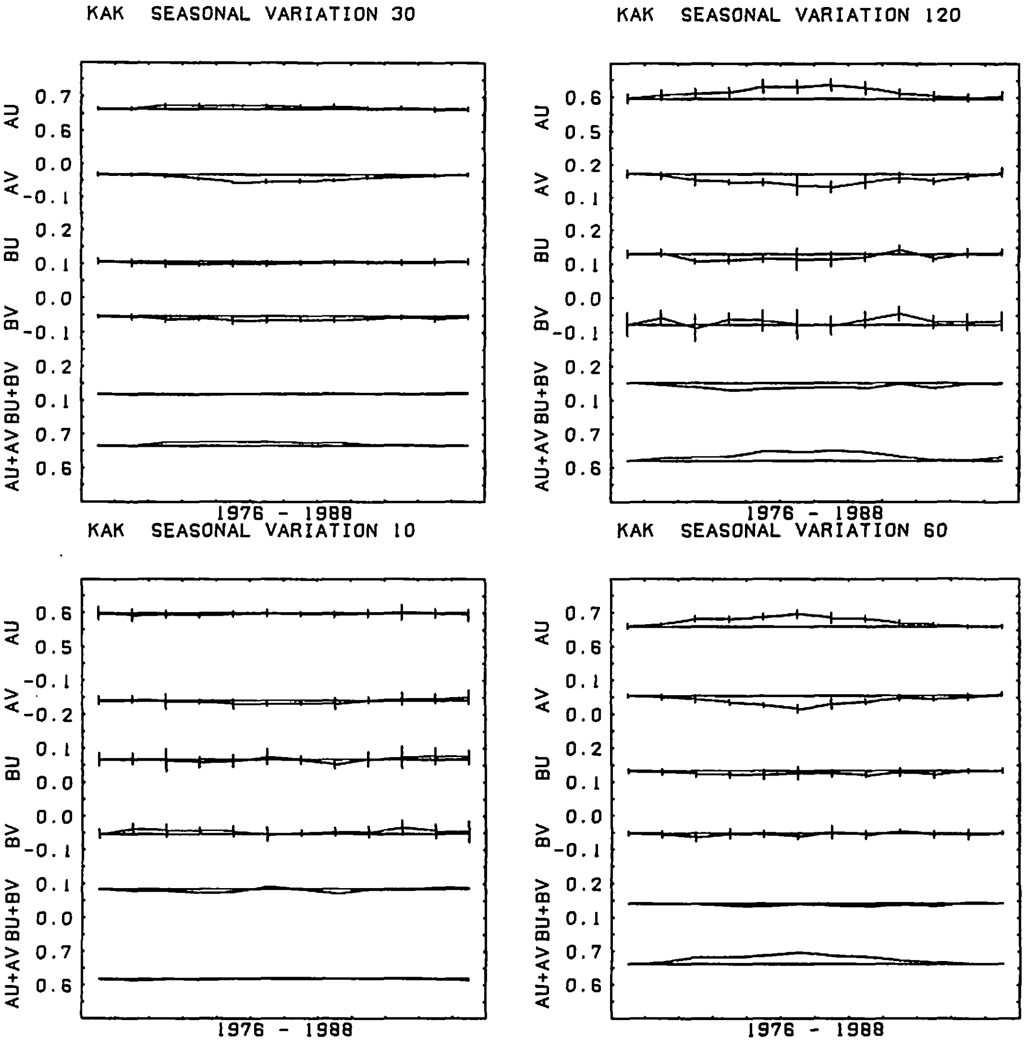
Figure 7 Seasonal variations of the transfer functions for (a) KAK, (b) MMB and (c) KNY. Monthly means from all daily values are used in these figures. Numerals in the lowest part of each figure indicates the interval employed. Au+Av and Bu+Bv mean respectively $(A_u^2+A_v^2)^{1/2}$ and $(B_u^2+B_v^2)^{1/2}$.


MMB SEASONAL VARIATION 30
AU
AV
BU
BV
AU+AV BU+BV
0.1
0.0
0.0
-0.1
0.2
0.1
0.1
0.0
0.2
0.1
0.1
0.0
1984 - 1988
MMB SEASONAL VARIATION 120
AU
AV
BU
BV
AU+AV BU+BV
0.1
0.0
0.0
-0.1
0.2
0.1
0.0
-0.1
0.2
0.1
0.1
0.0
1984 - 1988
MMB SEASONAL VARIATION 10
AU
AV
BU
BV
AU+AV BU+BV
0.0
-0.1
0.0
-0.1
0.3
0.2
0.1
0.0
0.3
0.2
0.1
0.0
1984 - 1988
MMB SEASONAL VARIATION 60
AU
AV
BU
BV
AU+AV BU+BV
0.1
0.0
0.0
-0.1
0.2
0.1
0.1
0.0
0.2
0.1
0.1
0.0
1984 - 1988

(b)

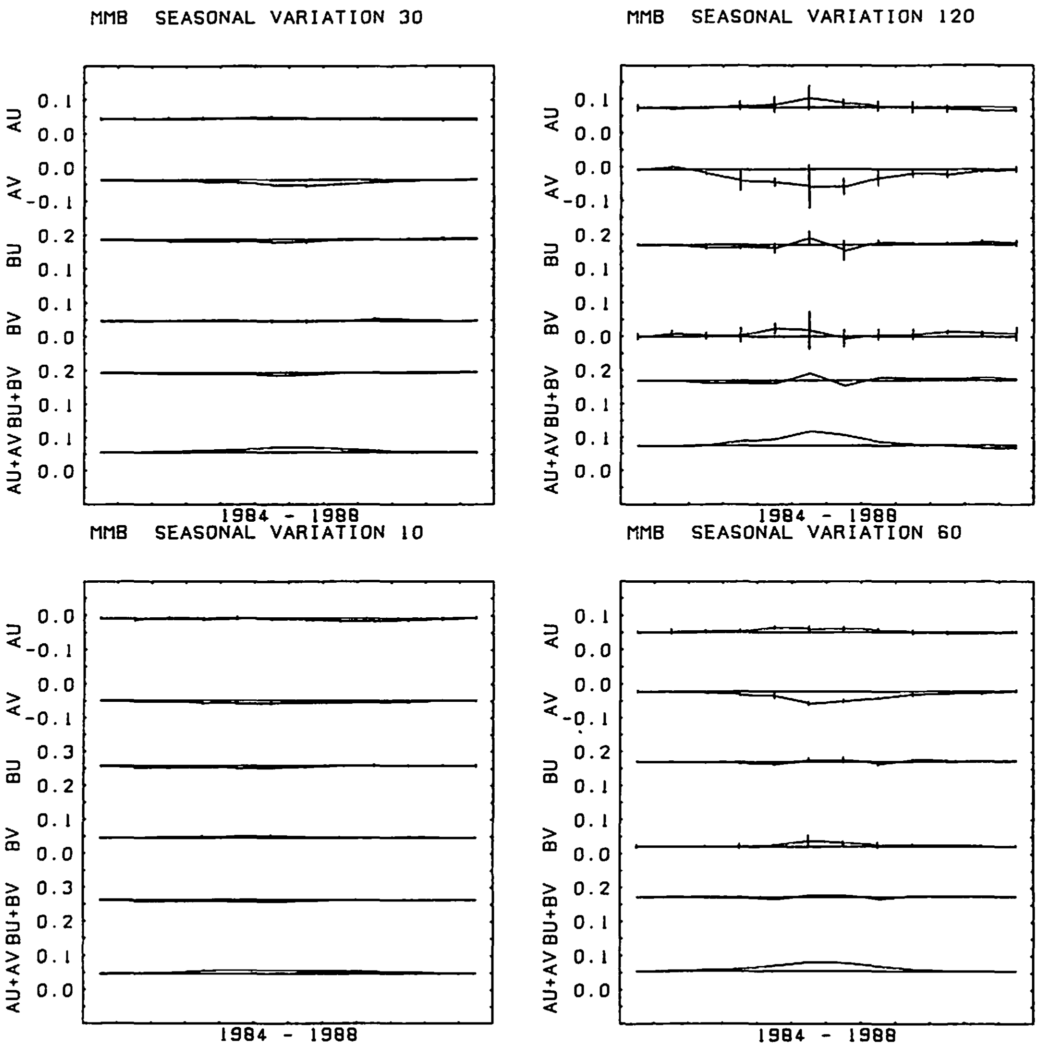

KNY SEASONAL VARIATION 30
AU
0.5
0.4
AV
0.0
-0.1
BU
-0.1
-0.2
BV
0.0
-0.1
AU+AV BU+BV
0.2
0.1
0.5
0.4
1985 - 1988
KNY SEASONAL VARIATION 120
AU
0.5
0.4
AV
0.1
0.0
BU
-0.1
-0.2
BV
-0.1
-0.2
AU+AV BU+BV
0.3
0.2
0.5
0.4
1985 - 1988
KNY SEASONAL VARIATION 10
AU
0.4
0.3
AV
-0.1
-0.2
BU
-0.1
-0.2
BV
0.1
0.0
AU+AV BU+BV
0.2
0.1
0.4
0.3
1985 - 1988
KNY SEASONAL VARIATION 60
AU
0.5
0.4
AV
0.1
0.0
BU
-0.1
-0.2
BV
0.0
-0.1
AU+AV BU+BV
0.2
0.1
0.5
0.4
1985 - 1988

(c)

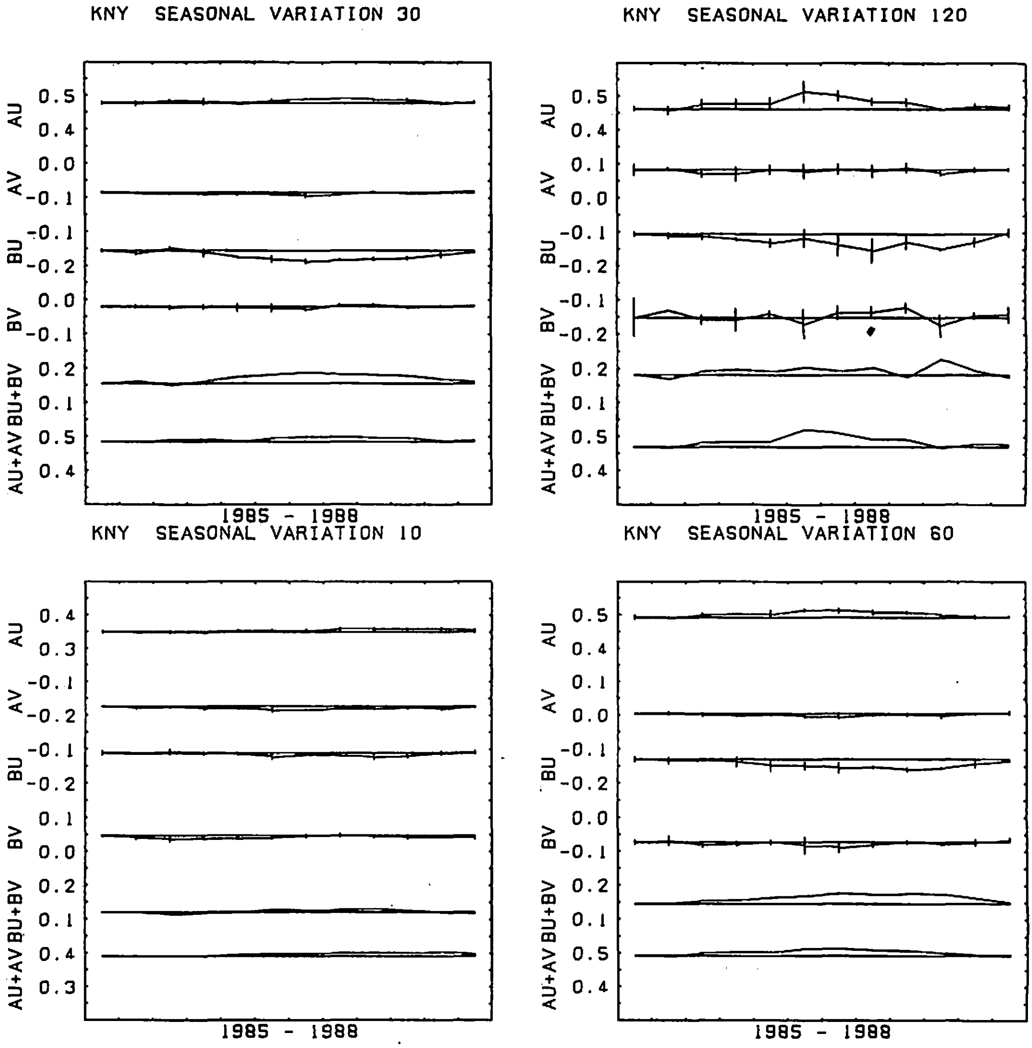


(a)

Figure 8 Seasonal variations of the transfer functions for (a) KAK, (b) MMB and (c) KNY. Monthly means from selected daily values are used in these figures. $A_u + A_v$ and $B_u + B_v$ mean respectively $(A_u^2 + A_v^2)^{1/2}$ and $(B_u^2 + B_v^2)^{1/2}$.


MMB SEASONAL VARIATION 30
MMB SEASONAL VARIATION 120
MMB SEASONAL VARIATION 10
MMB SEASONAL VARIATION 60
AU
AV
BU
BV
AU+AV
BU+BV
0.1
0.0
-0.1
0.2
0.3
1984 - 1988

(b)


KNY SEASONAL VARIATION 30
AU
AV
BU
BV
AU+AV
BU+BV
0.5
0.4
0.0
-0.1
-0.1
-0.2
0.0
-0.1
0.2
0.1
0.5
0.4
1985 - 1988
KNY SEASONAL VARIATION 120
AU
AV
BU
BV
AU+AV
BU+BV
0.5
0.4
0.1
0.0
-0.1
-0.2
-0.1
-0.2
0.2
0.1
0.5
0.4
1985 - 1988
KNY SEASONAL VARIATION 10
AU
AV
BU
BV
AU+AV
BU+BV
0.4
0.3
-0.1
-0.2
-0.1
-0.2
0.1
0.0
0.2
0.1
0.4
0.3
1985 - 1988
KNY SEASONAL VARIATION 60
AU
AV
BU
BV
AU+AV
BU+BV
0.5
0.4
0.1
0.0
-0.1
-0.2
0.0
-0.1
0.2
0.1
0.5
0.4
1985 - 1988

(c)

日本の地磁気観測所網における電気伝導度異常変換関数の時間変化の監視

藤田　茂

概　要

女満別，柿岡，松崎，御前崎，鹿屋で構成される地磁気観測所網における電気伝導度異常変換関数の時間変化を調べた．解析には地磁気毎分値を使用し，パワースペクトル法により 120，60，30，10分周期の変換関数の計算を行った．さらに各日の変換関数に対する誤差を計算し，決定精度の良い物のみを経年変化の解析に使用した．柿岡に対しては1976-1988年，松崎は1981-1988年，女満別は1984-1988年，鹿屋と御前崎は1985-1988年のデータを用いて時間変化率を計算した結果，以下のようなことがわかった．

1）　柿岡の10分周期 A_u は30年につき0.05程度の割合で減少している．この傾向はYanagihara and Nagano(1976)の結果と比較してやや小さいが，基本的には一致している．

2）　女満別・鹿屋の10分周期の A_u は柿岡と対照的に増加している．

3）　松崎と御前崎の10分周期の A_u は顕著な減少傾向を示す．その量は Yanagihara and Nagano(1976)の解析による関東地震の前に柿岡で観測された変換関数の変化量に匹敵する．但しこの結果は松崎と御前崎のデータが特に短周期側で電車等による擾乱の影響を受けているために，他の東海地域の地点のデータを解析する等，さらに詳しい調査による確認が必要である．

ここで行った解析は，擾乱の多い昼間のデータも含む全日のデータを使用していることや，変換関数の各月平均値の分散を考慮していない等まだ改良の余地がある．