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HOMOGENEITY OF MAGNETIC VARIATIONS AROUND THE NURMIJÄRVI OBSERVATORY

by

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Abstract

Geomagnetic variations were recorded at four temporary stations around the Nurmijärvi Geophysical Observatory for two weeks in June 1982. The stations were about 30 km from the observatory. The purpose was to study the spatial homogeneity of magnetic variations observed at Nurmijärvi, *i.e.* to find out whether there are local induction effects in the recordings of Nurmijärvi. Analysis of the data showed that the variations were practically homogeneous for periods ranging from 300 s to 2000 s. A regional induction effect is, however, indicated. A procedure to estimate the induced and external Z-variations is also presented.

1. *Introduction*

A geomagnetic variation observed on the earth's surface is affected primarily by magnetospheric and ionospheric sources and secondarily by currents and charges induced in the earth. In the secondary part we can further distinguish local effects from large-scale induction.

A Polish-Finnish induction study was begun in 1982 to obtain information on the spatial homogeneity of magnetic variations recorded at the Nurmijärvi Geophysical Observatory in southern Finland (60°30′34″N, 24°39′20″E). In other words, the purpose of the study was to find out whether local induction ~~effects~~ occur at Nurmijärvi, which would be important to be taken into account when data from the observatory are used. The eventual aim of a larger project, whose first part is discussed in this paper, will be to develop a method of separating the different contributions to magnetic variations. This method should be easier to be used in practice than that of SIEBERT and KERTZ (1957) in which a local field is separated into external (*i.e.* primary) and internal (*i.e.* secondary or induced) parts by integrating around the point of observation (see also WEAVER, 1964).

In the present work, geomagnetic variations were recorded at four stations around Nurmijärvi after first test-running the instruments at the observatory. The point at issue will be to find out whether the differences between magnetic variation data collected at different stations exceeded the instrumental differences obtained from the recordings during the period of tests. In this case, local induction effects are indicated. The possible existence of an induction effect in a larger scale, *i.e.* a regional effect, will be studied by determining the transfer functions and induction vectors of the stations. In this connection we will also present a method of estimating the induced and external contributions in the vertical magnetic variation at Nurmijärvi.

2. *Testing of the instruments at Nurmijärvi*

In the measurements we used four Polish TPMs (torsion photoelectric magnetometers) (MARIANIUK, 1977). They were first installed in four houses at the Nurmijärvi Observatory to record magnetic variations for about a week. Synoptic recordings gave data enabling the accuracy of the recording system to be estimated and possible sources of error to be detected.

Only analog recorders were mainly used during the testing period, and all analysis of the testing data was based on their recordings. Owing to non-linearities of the chart recorders the data were less accurate than those given by digital recordings. The speeds of the analog recorders were about 60 mm/h. Scale values were determined daily by a typical electromagnetic method. The results are shown in Table 1. As usual, X, Y and Z denote the north, east and vertical components of the geomagnetic field, respectively.

To check the scale value determinations of the TPM recordings, interaction between components and orientation of the sensors, we developed a special procedure based on the comparison of these data with the digital flux-gate recording at the

Table 1. Scale values of analog recorders of the TPMs in the four houses at the Nurmijärvi Observatory during the tests.

House	nT/mm		
	X	Y	Z
1	2.11 ± 0.05	2.05 ± 0.05	2.02 ± 0.03
2	2.02 ± 0.08	1.98 ± 0.05	2.02 ± 0.04
3	2.06 ± 0.04	2.08 ± 0.03	2.03 ± 0.06
4	2.00 ± 0.06	2.02 ± 0.04	2.01 ± 0.06

observatory. For this purpose we selected certain events with high magnetic activity. An example is shown in Fig. 1. We assumed the relation between recorded components to be

$$\begin{bmatrix} \Delta X_i \\ \Delta Y_i \\ \Delta Z_i \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \begin{bmatrix} \Delta X_i^N \\ \Delta Y_i^N \\ \Delta Z_i^N \end{bmatrix} \tag{1}$$

where

ΔX_i^N, ΔY_i^N, ΔZ_i^N are time series according to the observatory flux-gate data,

ΔX_i, ΔY_i, ΔZ_i are time series obtained with a TPM in a recording house,

and $i = 1, \ldots, \tilde{N}$, $\tilde{N}$ is the number of points in the data series.

A normal least-square procedure was used to calculate the unknown coefficients C_{jk} and their mean square errors.

The results of the calculation are given in Table 2. From this it can be seen that the errors of scale value determination were lower than 5 % and that interactions between the components were within the limit of accuracy, because the non-diagonal elements of matrix C were below 5 %.

We then made some statistical calculations: we computed the standard deviations between the TPM recordings in the houses and the flux-gate recording, and the coefficients of correlation. The results of the computations are shown in Table 3.

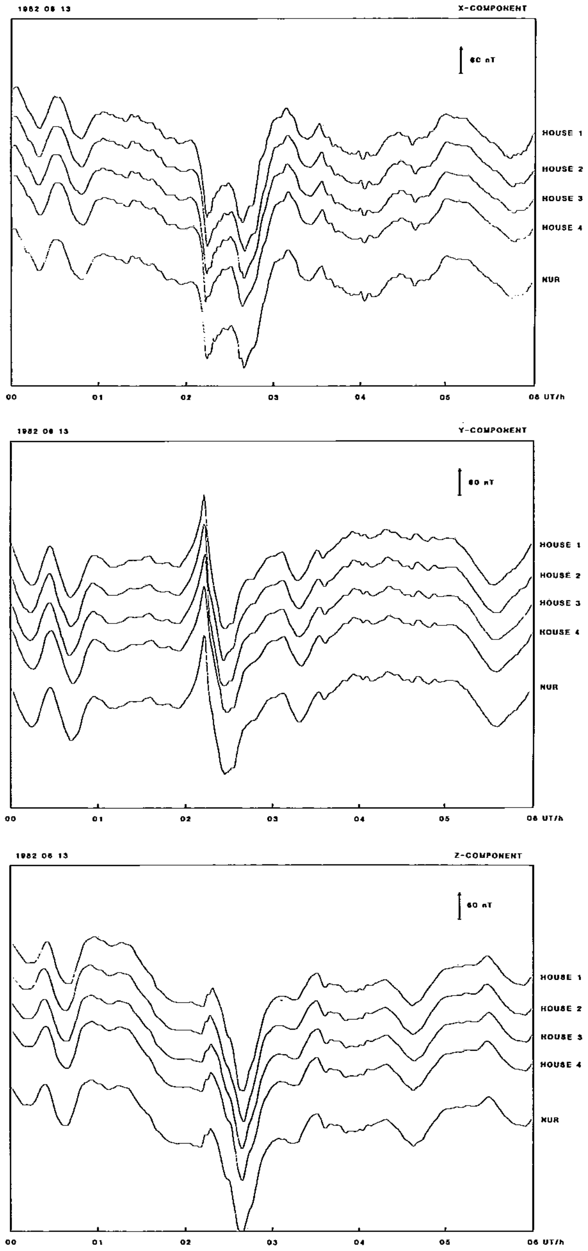

Fig. 1. TPM recordings in the four houses at the Nurmijärvi Observatory in a six-hour period on 13 June 1982, during the tests. The curves are based on values digitized from analog recordings. Also shown are simultaneous digital data obtained with a flux-gate magnetometer at the observatory. All the curves have arbitrary base lines.

Table 2. Elements of matrix C between TPM recordings in each house and the flux-gate recording at the Nurmijärvi Observatory during the tests.

House 1			House 2			House 3			House 4		
0.981	−0.002	0.038	0.998	0.021	0.013	1.014	0.053	0.017	1.011	0.012	0.037
±0.010	±0.008	±0.009	±0.005	±0.004	±0.005	±0.005	±0.004	±0.004	±0.010	±0.009	±0.009
0.003	0.997	0.015	0.037	1.039	−0.013	0.009	1.030	0.006	0.001	1.015	0.034
±0.007	±0.006	±0.006	±0.008	±0.007	±0.007	±0.005	±0.004	±0.005	±0.007	±0.006	±0.007
0.016	0.000	1.049	0.001	0.029	1.023	0.013	0.010	1.054	0.008	0.018	1.010
±0.006	±0.005	±0.006	±0.008	±0.006	±0.007	±0.003	±0.003	±0.003	±0.005	±0.004	±0.004

Table 3. Statistical calculations for the testing at the Nurmijärvi Observatory. The TPM recordings in the four houses are compared to the flux-gate recording. The standard deviation is given in nT.

Date and time		House 1			House 2			House 3			House 4		
		X	*Y*	*Z*	*X*	*Y*	*Z*	*X*	*Y*	*Z*	*X*	*Y*	*Z*
1982 06 13	Standard deviation	6.33	5.12	4.25	3.78	4.83	4.36	4.51	3.86	4.61	4.92	5.46	3.56
00.00–06.00UT	Correlation	0.995	0.995	0.998	0.998	0.995	0.998	0.998	0.997	0.999	0.997	0.993	0.999

3. *Measurements around Nurmijärvi*

Fig. 6 shows the stations in Mäntsälä (MAN), Janakkala (JAN), Nummi-Pusula (NUM) and Kirkkonummi (KIR) at which geomagnetic variations were recorded from 15 to 28 June 1982. They lay in four different directions and at distance of 30 km from the Nurmijärvi Observatory (NUR).

As indicated above, the stations were equipped with TPMs. The sensors were located under cover on the ground at each station. The covers were used to diminish the effects of temperature changes and to protect the instruments.

Data were collected in analog and digital form. The analog recording speeds were usually about 60 mm/h, and the sensitivities were approximately 2 nT/mm (*cf.* Table 1). The digital sampling interval was 10 s at all stations to start with, but it had soon to be changed to 20 s at Nummi-Pusula and Kirkkonummi because of practical reasons in the data collection. The analog recordings cover practically the whole period of measurements, but a lot of digital data are missing. So analog results also had to be used in the data treatment.

Digital 10 s values for the analysis were collected at Nurmijärvi by the flux-gate magnetometer at the same time.

4. *Statistical analysis of the variations*

From the data collected at the stations around Nurmijärvi we selected certain events with higher activity. We found five such events during the period. Two examples are shown in Figures 2 and 3. Part of the analysis was made using data digitized from analog recordings (*cf.* Section 3).

Looking at the selected events, we can see that the TPM recordings at the four stations and the Nurmijärvi flux-gate recording were very similar. Nevertheless we calculated statistical parameters between the TPM recordings and the flux-gate recording as we did for the testing data (Section 2). We deducted the linear trend from the data to avoid any effect of temperature changes. The results of this calculation are presented in Table 4. They show that the standard deviations were several nT. The magnitude of the standard deviation for an event depends strongly on the amplitude of the geomagnetic variation during the event. So this amplitude must be taken into account in each standard deviation. In the events considered here, the mean amplitude of variation was about 100 nT; in the testing it was larger: about 300 nT. This increased the standard deviations of the testing data as compared to those of the station data.

On comparing the standard deviations given in Tables 3 and 4 it can be deduced that the differences were due mainly to the accuracy of the data. Taking into

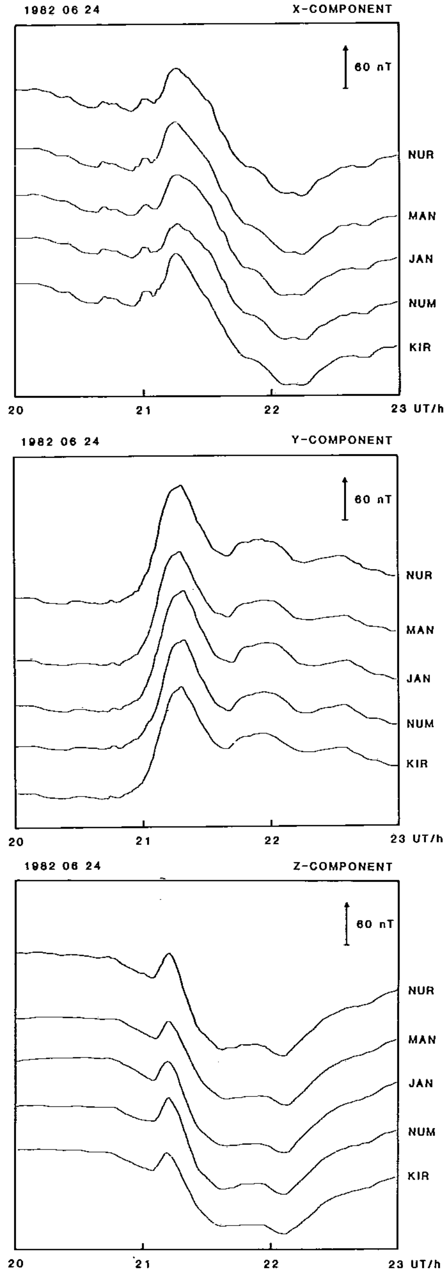

Fig. 2. Simultaneous TPM recordings at the four stations (Mäntsälä, Janakkala, Nummi-Pusula and Kirkkonummi) and flux-gate recording at the Nurmijärvi Observatory in a three-hour period on 24 June 1982. The curves are based on digital or digitized values. All the curves have arbitrary base lines.

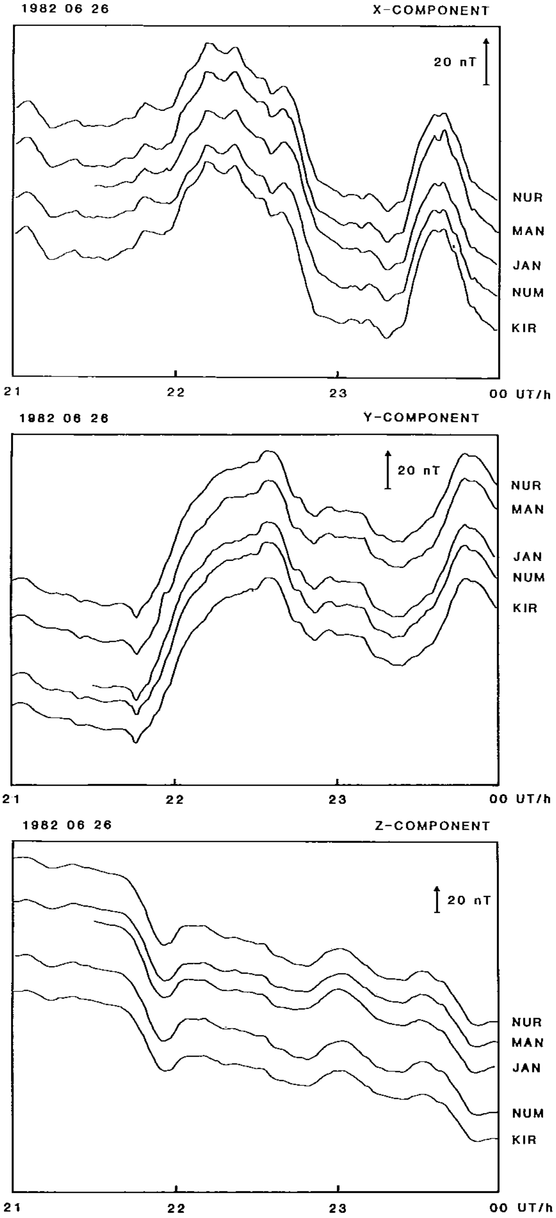

Fig. 3. Simultaneous TPM recordings at the four stations (Mäntsälä, Janakkala, Nummi-Pusula and Kirkkonummi) and flux-gate recording at the Nurmijärvi Observatory in a three-hour period on 26 June 1982. All the curves are based on digital recordings, and have arbitrary base lines.

Table 4. Statistical calculations for the measurements around Nurmijärvi. The TPM recordings at the four stations are compared to the flux-gate recording at the Nurmijärvi Observatory. The standard deviations are given in nT.

Date and time		Mäntsälä			Janakkala			Nummi-Pusula			Kirkkonummi		
		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1982 06 19	Standard deviation	1.26	1.06	1.65	1.99	2.01	1.90	1.44	–	1.08	1.99	1.50	6.60
18.00–20.00UT	Correlation	0.998	0.996	0.998	0.996	0.989	0.998	0.996	–	0.999	0.993	0.993	0.972
1982 06 19	Standard deviation	2.34	2.74	3.10	2.77	–	4.53	1.64	1.83	4.08	–	–	–
21.00–24.00UT	Correlation	0.997	0.987	0.999	0.996	–	0.998	0.999	0.996	0.999	–	–	–
1982 06 24	Standard deviation	2.51	4.20	8.97	2.92	2.10	5.47	3.61	5.66	7.24	3.55	3.50	10.01
20.00–23.00UT	Correlation	0.999	0.996	0.991	0.999	0.999	0.995	0.998	0.997	0.995	0.998	0.997	0.995
1982 06 26	Standard deviation	1.54	2.35	6.57	3.91	3.12	2.64	1.44	1.31	–	2.42	2.10	5.26
21.00–24.00UT	Correlation	0.997	0.998	0.995	0.986	0.994	0.999	0.998	0.999	–	0.994	0.997	0.997
1982 06 27	Standard deviation	3.08	2.28	3.02	3.28	2.08	3.67	3.77	2.78	–	4.12	1.94	4.06
00.00–06.00UT	Correlation	0.991	0.997	0.996	0.989	0.997	0.994	0.985	0.995	–	0.990	0.998	0.997

account all possible sources of errors, accuracy of recordings and digitization errors, we could assume that only differences bigger than 10 % were meaningful. Such a difference was only observed once: at Kirkkonummi, in the vertical component.

5. *Calculation of transfer functions*

From the previous section it can be concluded that no local induction effect is observable in the surroundings of the Nurmijärvi Observatory. This conclusion is valid for a variation with a period between 300 s and 2000 s.

There is a possibility that local induction effects exist for other periods. Further, we cannot exclude the effect in a regional scale, *i.e.* the induction effects vary in a larger spatial scale than the distances between the stations. To check on this and other possibilities, we calculated a bivariate transfer function basing on WIELĄDEK and ERNST (1977).

The bivariate transfer function ($(A(\omega), B(\omega))$) is defined by the formula:

$$Z_{ind}(\omega) = A(\omega)X(\omega) + B(\omega)Y(\omega) \tag{2}$$

where $Z_{ind}(\omega)$ is the Fourier transform of the induced vertical magnetic variation, and $X(\omega)$ and $Y(\omega)$ are the Fourier transforms of the total (*i.e.* induced plus external) horizontal magnetic variation components. The formula is based on the assumption that the external variation field can be represented by the horizontal components only, *i.e.* the external vertical variation Z_{ext} is zero. This assumption, which means that the left-hand side of formula (2) equals the Fourier transform $Z(\omega)$ of the total Z-variation, is generally valid in middle latitudes.

However in the case of data from Nurmijärvi (geomagnetic latitude about 58°), the transfer function should contain three components, and instead of equation (2) we have:

$$Z_{ind}(\omega) = A'(\omega)X(\omega) + B'(\omega)Y(\omega) + C'(\omega)Z(\omega) \tag{3}$$

(see *e.g.* BERDICHEVSKY and ZHDANOV, 1984, p. 151). But unfortunately, we cannot use this formula, because our recordings concerned only total components. This is the reason that we had to use a two-component transfer function determined from equation (2) with $Z_{ind}(\omega) = Z(\omega)$. Such a procedure is acceptable when the distribution of the external Z-variations has a random character as can be seen by adding a noise $\eta(\omega)$ to formula (3) and rewriting it in the form:

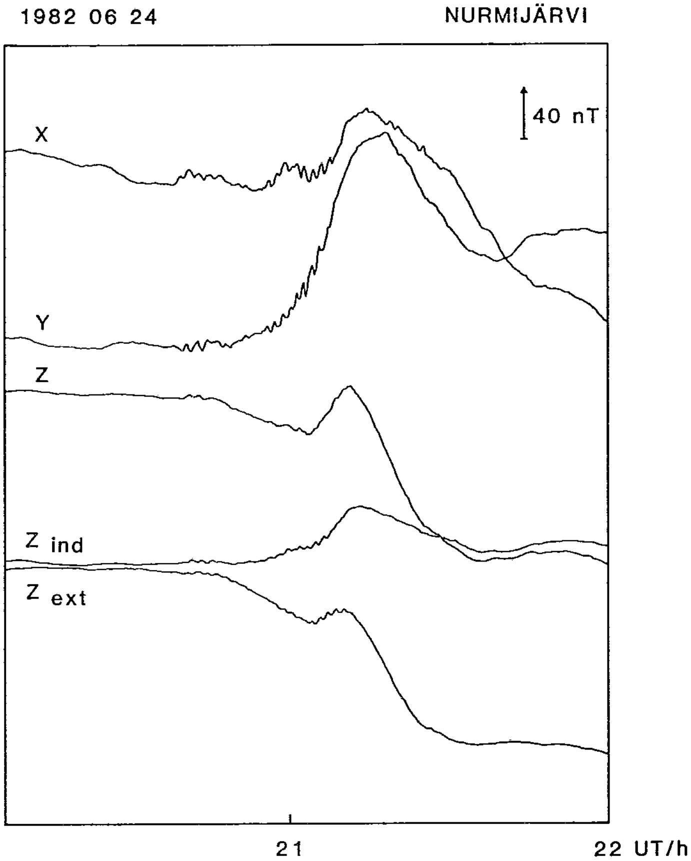

Fig. 4. Components X, Y and Z recorded at the Nurmijärvi Observatory for about two hours on 24 June 1982. Also shown are the calculated components Z_{ind} and Z_{ext}; Z_{ind} was obtained by convoluting the computed impulse responses with the horizontal variation components X and Y, and $Z_{ext} = Z - Z_{ind}$.

$$Z(\omega) + \eta'(\omega) = A(\omega)X(\omega) + B(\omega)Y(\omega) \tag{4}$$

where

$$\eta'(\omega) = \frac{\eta(\omega) - Z_{ext}(\omega)}{1 - C'(\omega)} ,$$

$$A(\omega) = \frac{A'(\omega)}{1 - C'(\omega)}$$

and

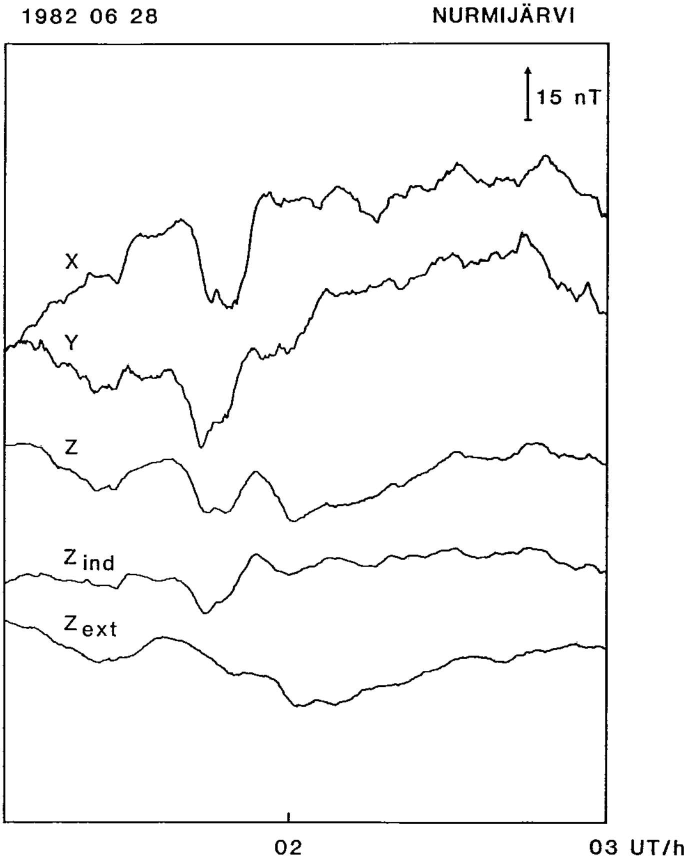

Fig. 5. Similar to Fig. 4, but applying to 28 June 1982.

$$B(\omega) = \frac{B'(\omega)}{1 - C'(\omega)}$$

We used a two-step procedure in our computations: first we calculated the transfer function $(A(\omega), B(\omega))$ using all events (approx. 40), and after that we computed the so-called predicted vertical variation component Z_{pre} (in time domain) by convoluting the impulse responses with the horizontal variation components.

It seems clear that in events in which the difference $Z - Z_{pre}$ is small (in time domain) the external Z-variation Z_{ext} is small so that Z_{pre} can be considered equal to the induced one, *i.e.* $Z_{pre} = Z_{ind}$. This further means that the difference $Z - Z_{pre}$ should be interpreted as Z_{ext}. However in the last conclusion, it must be kept in

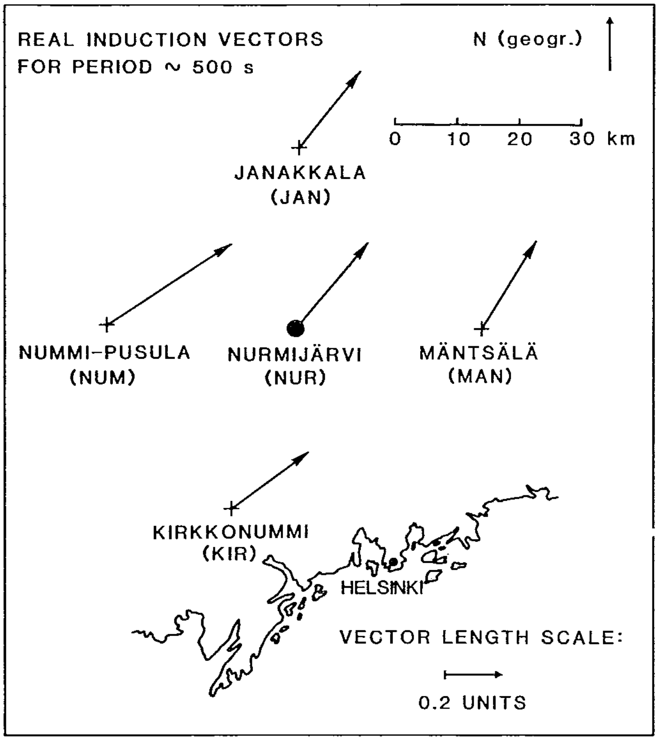

Fig. 6. Real induction vectors at the stations Mäntsälä, Janakkala, Nummi-Pusula and Kirkkonummi, and at the Nurmijärvi Observatory, for a period of about 500 s.

mind that Z_{ext} was assumed to be small, *i.e.* equal to the order of the accuracy of the interpretations.

Transfer function calculations described above are illustrated in Figures 4 and 5, in which the calculated Z-variation Z_{pre} is directly denoted by Z_{ind} and $Z_{ext} = Z - Z_{pre}$. The geomagnetic (real) induction vectors are shown in Fig. 6 for a period of about 500 s. Here we use the convention that the arrows point to the direction away from a good conductor, *i.e.* they are not reversed. In agreement with the results obtained in Section 4, the lengths and directions of the induction vectors of different places are very similar. Since the length of the vectors is about 0.4 units, we can conclude that the recordings of magnetic variations at the Nurmijärvi Observatory are influenced by induction in the earth. However, this induction effect has no local character but a regional one.

6. *Conclusions*

The observatories, which create a global network, are located in different geological units. Some of them established near an ocean coast or see-land contact record a strong induction effect. But also at a land observatory this effect can be large. From the point of view of users it seems important to know how big and how homogeneous this induction effect is.

We have tried to establish a simple procedure for computing the induction effect at the Nurmijärvi Observatory in Finland. We also developed a new method for the selection of data which we can also use for the estimation of the induced and external contributions to Z-variations.

From this study we can say that the spatial distribution of the magnetic field variations for periods of 300 s to 2000 s is generally homogeneous at Nurmijärvi. But on the other hand, several tens of percents of the variation amplitude, at least in the vertical component, is due to the induction effect. The scale length of the anomaly is larger than the dimensions of our array. The users of the data should be aware of this fact. We believe that each observatory should have knowledge of the homogeneity of magnetic field variations around it. We proposed a simple procedure for collecting data and for their analysis.

We believe that a bigger array with more stations should be used and some more accurate procedure of the separation of the total variation into internal and external parts should be developed later.

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