A STUDY ON THE LONG TERM BEHAVIOR OF THE IMPEDANCE TENSOR AT NAGYCENK GEOPHYSICAL OBSERVATORY

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In the Observatory, a parallel monitoring and registration of geomagnetic and telluric variations has been carried on for more then fifty years. At the first approach we started to compare the spectral energy distribution of the minute mean value horizontal telluric and magnetic components of the last four years. The impedance tensors spectra have been calculated by using one day time intervals for the whole four years. Based on the plane wave assumption we expected some stable behavior of the transfer function. On the contrary certain periods has been found in the time variation of some spectral component. This appeared mostly in the phase of the tensor elements. Dominant spectral peaks have been shown at periods of 93 days and one year related to seasonal variation and the Earth orbiting respectively. So as to extend our examination on longer time interval, we started to digitize the analogue telluric and magnetic records we archived since 1962. We also propose to investigate the deviation of estimated apparent resistivity curves resulting from the above variation of the impedance tensor and to analyse the long term behavior of some magnetotelluric invariants.

Introduction

Magnetotelluric studies provide important contribution to our knowledge of the subsurface structures. Assuming that the resistivity horizontally homogeneous and the EM field variations are also homogenous at the characteristic scale size of the studied area the resistivity distribution can be derived directly from electric and magnetic field observation. The rate of the variation of horizontal electric and magnetic field at each frequency band is namely the impedance function. The apparent resistivity values obtained by this transfer function on different frequencies is related to the electrical resistivity in different depth below the surface. Longer period samples deeper structures. But the values of this transfer function depends on the underground conductivity distribution as well as on the geometry of the source. Thus the well-known magnetotelluric data processing and analysis results systematic error so called source effect. In most cases the plane wave assumption gives good approach (Cagniard 1953, Price 1953), but at high latitudes the auroral electrojet and at low latitudes (the magnetic equator) the equatorial electrojet causes such a distortion. This paper is a brief summary of our works focusing on the possible source effect in mid latitudes especially which can be shown based on the data of the Nagycenk Geophysical Observatory.

Geomagnetic and telluric data

The Széchenyi István Geophysical Obsevatory was founded in 1957. Since the beginning the observatory provides continuous earth current and geomagnetic observations with control of absolute measurements. The potential differences are measured in North-South and East-West directions with electrode spacing of 500 m and recorded with 1 sec and 10 sec sampling rate. Low polarization lead plate electrodes are buried about 2 m below the surface. Resolution of recording is 20000 mV/km/2^{14} bit. Geomagnetic variations are recorded by the ARGOS system which is developed by the Geomagnetism Group of British Geological Survey as a PC based automatic observatory equipped with triaxial fluxgate and proton magnetometer in DD/DI configuration. 10 second samples are used to provide minute values centered on the minute by means of a 7-point cosine filter. The resolution and dynamic range of the triaxial fluxgate and the proton magnetometer is 0.1 nT, $\pm$500 nT/$\pm$400 nT and 0.1 nT, 10000–90000 nT respectively.

The data recorded by the ARGOS system had been checked on before archiving and in cases of system failure the missing data has been rectified by means of the geomagnetic time serial measured by the backup system (DR02).

The observatory lies on a thick conductive sediment and is surrounded by a National Park preserving the site from far industrial noise and manmade activity. The selected interval is a four year period (2000–2003), which is in the ascending phase of the solar activity just after the minimum.

Data Processing

As mentioned above the geomagnetic data used in this work was free of gaps so no interpolation should be applied. Whereas the telluric time serial was not continuous, in cases of few minute long missing intervals spline interpolation seemed to provide reliable data. Unfortunately in the last days of June, 2000 we had a 2–3 day long system failure which was impossible to bridge accurately. Except that critical interval less than 100 data sample had been interpolated and none of the gaps was longer than 10 samples (100 seconds) in the subinterval processed used for further processing (1024 days from the date 01.04.2000). The telluric data should be presented with 1 minute sample rate for compatibility. This could be accomplished by means of the same type of digital filter which is applied on the raw 10 second sampled geomagnetic data. The recorded minute value time series of H, D, Z geomagnetic elements has been transformed to X, Y and Z components. To obtain the optimal temporal and spectral resolution of the impedance function we performed the processing on two different scaling. In the first approach the geomagnetic and the telluric data had been split into four-day pieces as basic elements of the whole dataset. As the ensuing data processing proved, this time resolution was not satisfactory for many reasons. Therefore the elementary unit of the time series considered to be one day long (1440 minute sample). These time segments have been processed by the method of J Verő (Verő 1972).

The main phases of data process are as follows:

1. *Separation of signals with different periods*

   The task is completed by a convolution type filter truncated with a Hanning window. The filter functions are the following:

   $$F(t) = \frac{1}{2\pi t}\left(\sin\frac{2\pi t}{p_1} - \sin\frac{2\pi t}{p_2}\right)\left(\cos\frac{2\pi t}{T} + 1\right) \quad F(0) = \frac{2d}{p_1} - \frac{2d}{p_1}$$

   for the in-phase component.

   $$G(t) = \frac{1}{2\pi t}\left(\cos\frac{2\pi t}{p_1} - \cos\frac{2\pi t}{p_2}\right)\left(\cos\frac{2\pi t}{T} + 1\right) \quad G(0) = 0$$

   for the out-phase component.

   p_1 – lower period limit, p_2 – upper period limit, d – digitization interval.

   The estimations have been processed on periods with relation quotients of 1.1.

2. *Selection of information that can be used for the determination of the tensor*

   Randomly appearing leakage currents, digitization errors or simply a temporary disappearance of certain period bands may produce a decrease in coherency. Such intervals must be excluded from further processing. The selection is based on coherence analysis between cross-channels. In the further processing the coherence threshold has been set to 0.8.

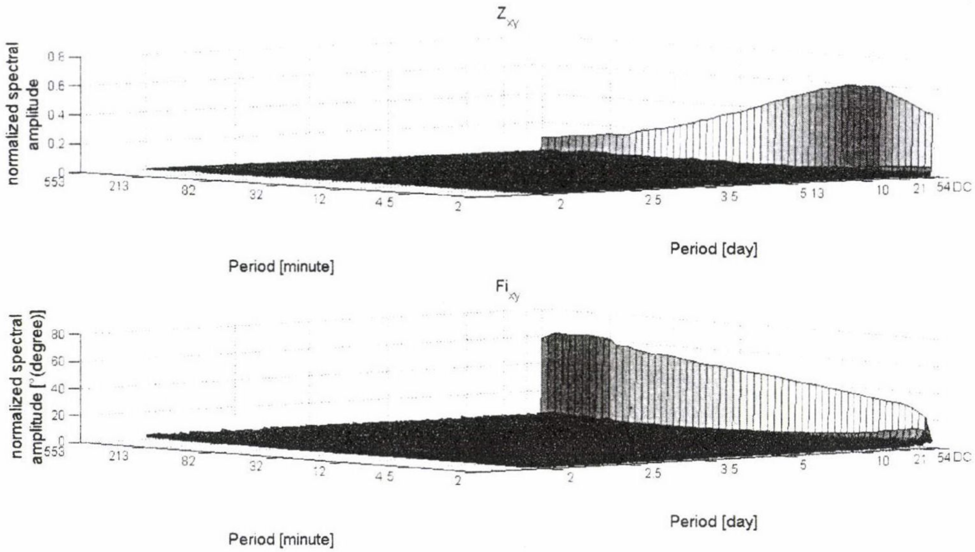

Fig. 1. Spectral components of long term variation of the modulus and phase of Z_{xy} impedance tensor element

3. *Computation of the elements of the impedance tensor*

The detailed description of method used for the computation of the impedance tensor elements can be found by Verő (1972). The formulas are the following:

$$Z_{xx} = \frac{|E_x|}{|H_x|} \frac{\mathrm{Coh}(E_x, H_x) - \mathrm{Coh}(E_x, H_y)\mathrm{Coh}(H_y, H_x)}{1 - |\mathrm{Coh}(H_x, H_y)|^2}$$

$$Z_{xy} = \frac{|E_x|}{|H_y|} \frac{\mathrm{Coh}(E_x, H_y) - \mathrm{Coh}(E_x, H_x)\mathrm{Coh}(H_x, H_y)}{1 - |\mathrm{Coh}(H_x, H_y)|^2}$$

$$Z_{yx} = \frac{|E_y|}{|H_x|} \frac{\mathrm{Coh}(E_y, H_x) - \mathrm{Coh}(E_y, H_y)\mathrm{Coh}(H_y, H_x)}{1 - |\mathrm{Coh}(H_x, H_y)|^2}$$

$$Z_{yy} = \frac{|E_y|}{|H_y|} \frac{\mathrm{Coh}(E_y, H_y) - \mathrm{Coh}(E_y, H_x)\mathrm{Coh}(H_x, H_y)}{1 - |\mathrm{Coh}(H_x, H_y)|^2}$$

4. *Spectral analysis of impedance elements*

The long term variation of each impedance element at each frequency has been examined through Fourier-decomposition. The transformation has been carried out on both modulus and phase of the elements. The results of Z_{xy} element are displayed on Fig. 1.

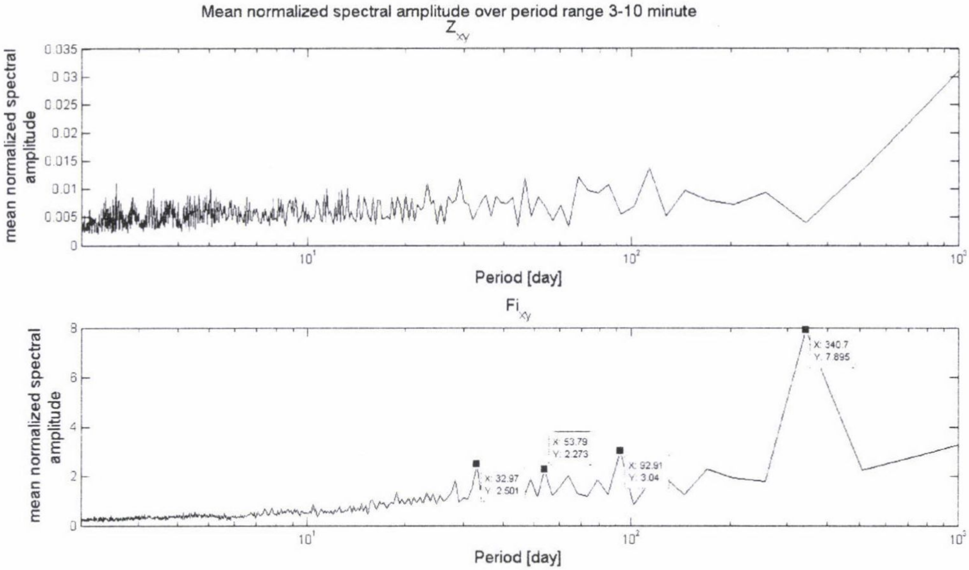

Fig. 2. Mean spectral amplitude of the Z_{xy} and φxy variation in the range 3–10 minutes

On Fig. 1 no significant Fourier component can be recognised beside the DC in the whole periodrange of 2 min–8 hours. However, the detailed examination of the behavior of the period range 3–10 minutes results some peaks in the long term spectra, fee Fig. 2 Some of them can be associated with well known processes like the annual (340 days), the seasonal (93 days) and the 2nd harmonic of the Carrington period (54 days). The clear Carrington period doesnt produce significant peak and the Lunar cycle doesnt appear either. A 33 day component also appears which can hardly be explained, although the same spectral component has been recognized in the statistical analysis of the CME ejection of the Northern hemisphere of the Sun. (The 340 day long component can be identified as annual variation, the 15 day difference is an artifact because the applied Fourier-window was set to 1024 days, less then 3 years.) Note that no such components can be recognized on the spectra of $|Z_{xy}|$.

To clarify how the peaks come, spectral analysis of H and E field polarization has been carried out, see Fig. 3, Fig. 4.

Note that the peaks of the spectral decomposition of φxy can be obtained as the peaks that appear on the polarization pattern of the H but is not present in the E polarization variation, namely the annual and seasonal components. Detailed

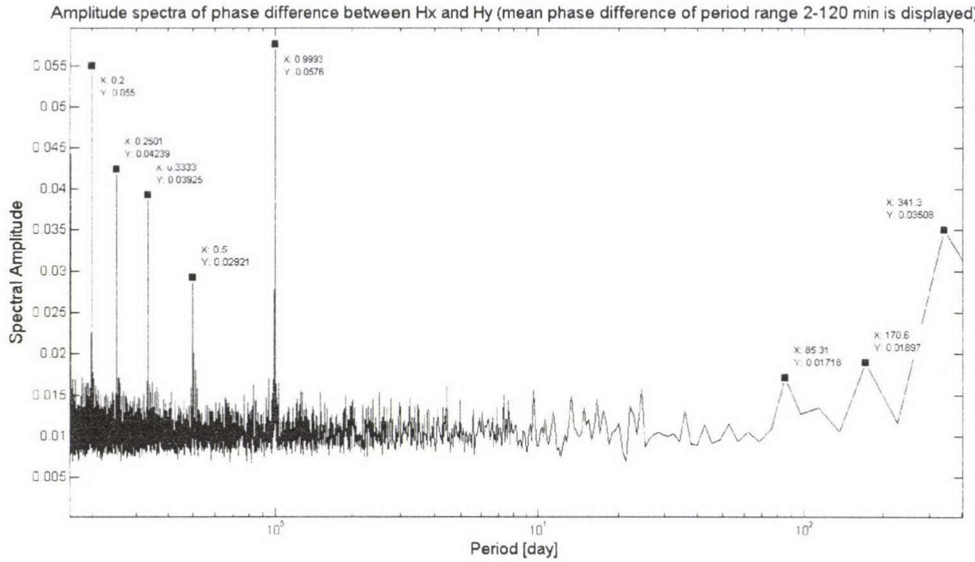

Fig. 3. Periodicity in the polarization pattern of horizontal geomagnetic field

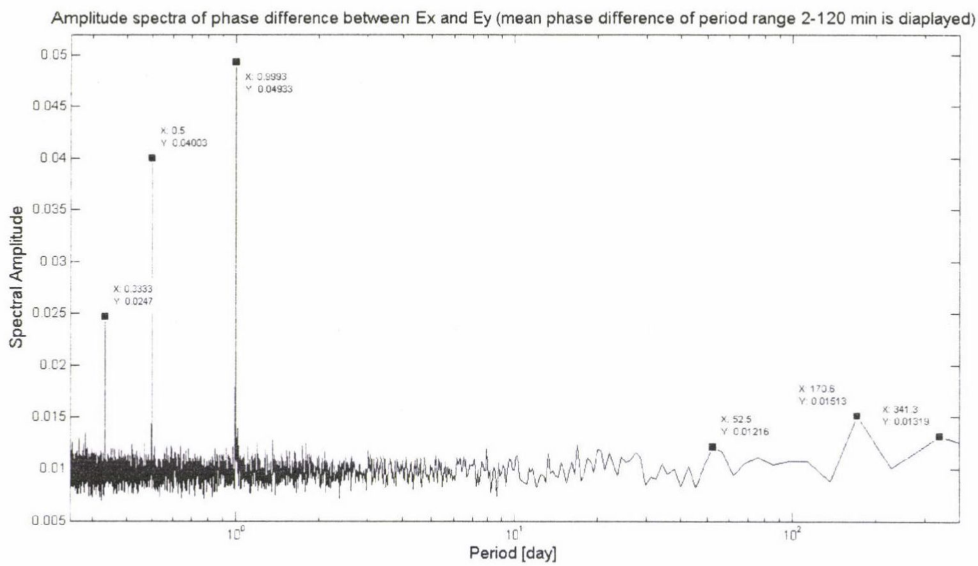

Fig. 4. Periodicity in the polarization pattern of the telluric field

analysis of long term periodicities has been carried out at each frequency which φxy has been calculated, but no subrange shows different behavior then the mean shown above. (The figures of recognized periodicities dont match on Fig. 2 and

Fig. 3 because the applied Fourier window is different.) Further examination of the long term behavior of the impedance tensor is in progress to clarify the physical processes and the coupling between the well known periods and the long term behavior of the impedance tensor. Detailed analysis of Z on more extended time interval is also proposed. The digitization of earlier analogue registrations is already set up.

Acknowledgement

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References

Cagniard L 1953: Basic theory of the magneto-telluric method of geophysical prospecting. *Geophysics*, 18, 605–635.

Wait J 1953: On the relation between telluric currents and the Earths magnetic field. *Geophysics*, 18, 281–289.

Mareschal M 1986: Modelling of natural sources of magnetospheric origin in the interpretation of regional induction studies: A review. *Surv. of Geophys.*, 8, 261–300.

Pirjola R 1992: On magnetotelluric source effects coused by an auroral electrojet system. *Radio Science*, 27, 463–468.

Price A T 1962: The theory of magnetotelluric methods when the source field is considered. *J. Geoph. Res.*, 67, 1907–1918.

Verő J 1972: On the determination of the magnetotelluric impedance tensor. *Acta Geod. Geoph. Mont. Hung.*, 7, 333–351.