EVALUATION OF ELECTROMAGNETIC FIELD VARIATIONS FROM MONITORED DATA IN PLANETARY OBSERVATORIES

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Abstract. The Earth's electromagnetic field varies over time. Its changes have a large variety of both morphology and generation mechanisms, at the same time showing parallels with various geophysical and helio-physical phenomena. The correlation of these phenomena based on their physical substrate proved very useful to clarify several issues concerning field morphology. The geomagnetic field, as part of the Earth's electromagnetic field, is monitored in planetary observatories, from the INTERMAGNET network, with high-resolution and accurate triaxial magnetometers. In this paper we present the main types of variations exemplified through the data analysis from Surlari Geomagnetic Observatory (located at about 30 km North of Bucharest) for different time periods and acquisition rates. Geomagnetic data were analysed for the whole period of activity of the Observatory Surlari from 1943 to present. Thus, the data used for the study of the large periodicities of the geomagnetic field are presented as a series of hourly averages covering the period of analogic measured. We have highlighted, for long series of recordings for several solar cycles, 22-years and 11-years periodicities. Following the same procedures for the medium (multiannual) series, the annual, seasonal and monthly periodicities were highlighted. For shorter data series, we highlighted the diurnal, semi-diurnal (12-hour), 8-hour and even lower periodicities. For very short series with a high sampling rate and for some magnetotellurics records, we have highlighted various types of continuous pulsations (Pc1 - Pc5) and irregular pulsations (Pi1 - Pi2). Time - frequency analyses allow identify the frequency characteristics of the signal at a time. For this we chose a mobile window, moving along the signal from time t_0 to any position t_i, on temporal axis. The frequency content of each window was analysed, finally obtaining the frequency spectrum well localized in time.

Keywords: Earth's electromagnetic field, geomagnetic pulsations, geomagnetic storms, planetary observatories, INTERMAGNET network.

Rezumat. Evaluarea variaţiilor câmpului electromagnetic din datele monitorizate în observatoarele planetare. Câmpul electromagnetic al Pământului variază de-a lungul timpului. Schimbările sale au o mare varietate morfologică şi mecanisme de generare si prezintă paralelizari cu diverse fenomene geofizice şi heliofizice. Corelarea acestor fenomene pe baza substratului lor fizic s-a dovedit foarte utilă pentru a clarifica mai multe aspecte legate de morfologia câmpului. Câmpul geomagnetic, ca parte a câmpului electromagnetic al Pământului, este monitorizat în observatoarele planetare, din reţeaua INTERMAGNET, cu magnetometre triaxiale de înaltă rezoluţie şi de precizie. În această lucrare prezentăm principalele tipuri de variaţii exemplificate prin analiza datelor de la Observatorul Geomagnetic Surlari (situat la cca 30km la nord de Bucureşti), pentru diferite perioade de timp şi rate de achiziţie. Datele geomagnetice au fost analizate pentru întreaga perioadă de activitate a Observatorului Surlari din 1943 până în prezent. Astfel, datele utilizate pentru studiul periodicităţilor mari ale câmpului geomagnetic sunt prezentate ca o serie de medii orare care acoperă perioada măsurată analogic. Am evidenţiat, pentru serii lungi de înregistrări pentru mai multe cicluri solare, periodicităţi de 22 ani şi 11 ani. Urmând aceleaşi proceduri pentru seriile de înregistrări medii (multianuale), au fost evidenţiate periodicităţile anuale, sezoniere şi lunare. Pentru serii de date mai scurte, am evidenţiat periodicităţile diurne, semidiurne, de 8 ore şi chiar mai mici. Pentru serii foarte scurte cu o rată de eşantionare ridicată şi pentru câteva înregistrări magnetotelurice, am evidenţiat diferite tipuri de pulsaţii continue (Pc1 - Pc5) şi pulsaţii neregulate (Pi1-Pi2). Analizele de timp - frecvenţă permit identificarea caracteristicilor frecvenţei semnalului la un moment dat. Pentru aceasta am ales o fereastră mobilă, care se deplasează de-a lungul semnalului de la momentul t_0 la orice poziţie t_i, pe axa temporală. Am analizat conţinutul de frecvenţă al fiecărei ferestre, obţinând în final spectrul de frecvenţe bine localizat în timp.

Cuvinte cheie: câmpul electromagnetic al Pământului, pulsaţii geomagnetice, furtuni geomagnetice, observatoare planetare, reţeaua INTERMAGNET.

INTRODUCTION

The part of the geomagnetic field which has a simpler structure and determines its spatial distribution is mainly due to causes located inside the Earth, while that who diversify his morphology has external causes. The variation of the manifestations and of the space and time distribution of geomagnetic field have external causes.

Mechanisms from inside and outside the Earth are particularly important, from the core processes, which are responsible for producing the main field to the ionosphere and magnetosphere phenomena whose effects are the variations in geomagnetic disturbances.

The physical generation mechanism of the geomagnetic field of internal origin has been incompletely explained until now. Instead, the external field, although it has a higher morphological and phenomenological complexity, occurs as a result of a chain of physical processes framed in coherent explanatory concepts, largely verified by direct confrontation with reality.

Terrestrial magnetism has a determined spatial distribution and a characteristic temporal evolution. The dual variability of the geomagnetic field, with the place and time at which the observations are made, makes its space-time structure very complex.

The persistent part of the field, with a spatial distribution, corresponding in a first approximation to the field of a uniform magnetized sphere, has a slowly evolution in time, called secular variation. The transient geomagnetic field is represented by the calm and regular variations and by sudden and sporadic changes.

The two constituent parts of the geomagnetic field (the persistent emphasized by mediation for extended time and, respectively, transitional by momentary deviations from the mean) have different weights: the persistent, called the main geomagnetic field is over 90% of the total geomagnetic field, while the transient does not exceed 10% only during periods of extreme agitation of the field (geomagnetic storms).

The knowledge of the structure of the magnetosphere is based on the abundant data provided by satellite and land observations. The complicated problems of the structure of the magnetosphere and the nature of the geomagnetic variations have been largely dealt with in many publications and many authors: AKASOFU (1977), AKASOFU & CHAPMAN (1972), LYATSKY (1978), MATSUHITA (1975), MISHIN (1978), NISHIDA (1978), PUDOVKIN (1975, 1976) all in GEBBINS & HERRERO-BERVERA, 2007. Also, crustal magnetism is in relation with magnetics properties of geological formations (NICULESCU et al., 2012).

THE EARTH'S ELECTROMAGNETIC FIELD VARIATIONS

A simplified model for the magnetosphere and sources of the main variations is outlined in Fig. 1.

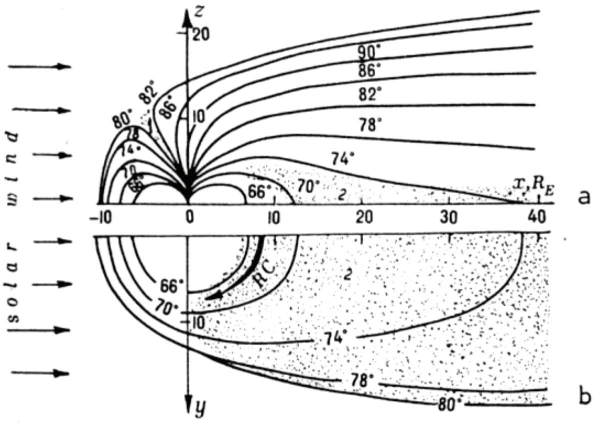


Figure 1. Structure of the magnetosphere (TRYGANENKO & PUDOVKIN, 1975 in GEBBINS & HERRERO-BERVERA, 2007). a - meridian section; b - equatorial section.

The outer boundary of the magnetosphere, called magnetopause, is formed in the region where the geomagnetic field can stop the compressive forces exerted by the solar wind (solar plasma flow).

Moving around the magnetosphere, the solar wind gathers plasma and deforms the geomagnetic field lines from the periphery of the magnetosphere. Plasma moves back to Earth and to Sun along the peripheral area of the magnetosphere, this movement being called magnetospheric convection.

Due to high plasma conductivity, the electric field is closed at zero in the solar wind coordinate system. The solar wind has a Vsw speed relative to the Earth-linked coordinate system and thus induces the electric field in the latter.

The characteristic wind speed is about 300-400 km/s, and the Interplanetary Magnetic Field (IMF) increases with 3-5 nT, which gives the magnitude of Em of the order of 0.5-1 mV/m. Incorporating the southern face of the magnetosphere, the potential difference of 70 kV (Mishin 1978 in CONSTABLE CATHERINE – 2005) or even 300 kV (Nishidda 1978 in CONSTABLE CATHERINE – 2005) is reached. The effect of this electric field is an important cause of magnetospheric convection.

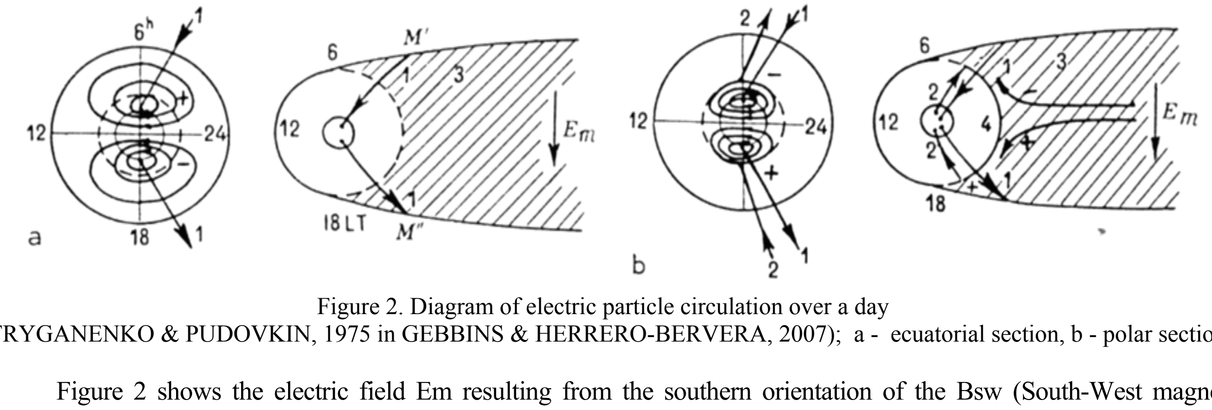


Figure 2. Diagram of electric particle circulation over a day (TRYGANENKO & PUDOVKIN, 1975 in GEBBINS & HERRERO-BERVERA, 2007); a - ecuatorial section, b - polar section.

Figure 2 shows the electric field Em resulting from the southern orientation of the Bsw (South-West magnetic induction orientation). In the magnetosphere queue, the combined effect of the Earth and the geomagnetic field directed from the Earth to the southern part of the equatorial plane and towards the Earth in the north part results in the compaction of charged particles from the equatorial plane and their displacement to Earth. An increase in the Bz (vertically magnetic induction orientation) component when approaching the Earth favours the acceleration of the particles, the positive tasks - the protons being rejected towards the meridian of the evening and the negative charges towards the morning. Thus, the electrical polarization of the inner portion of the plasma jet known as the Alfven layer occurs. Figures 3 and 4 show two representative schemes for the main source areas of the magnetosphere for different types of observed phenomena as well as the main components of the magnetosphere current systems.

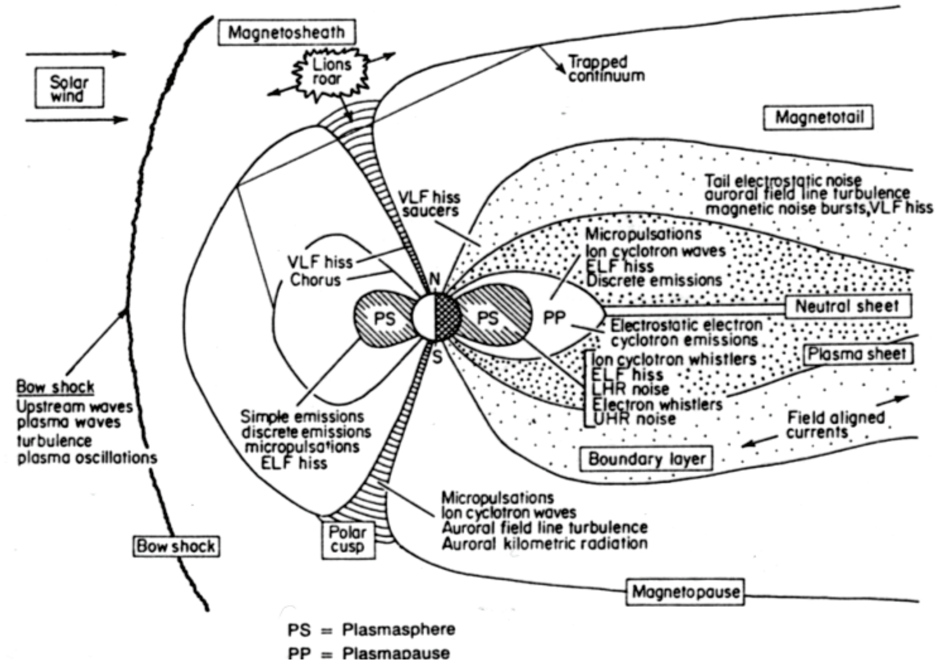


Figure 3. The main source areas in the magnetosphere for different types of observed phenomena (SHAWAN, 1979 in GEBBINS & HERRERO-BERVERA, 2007).

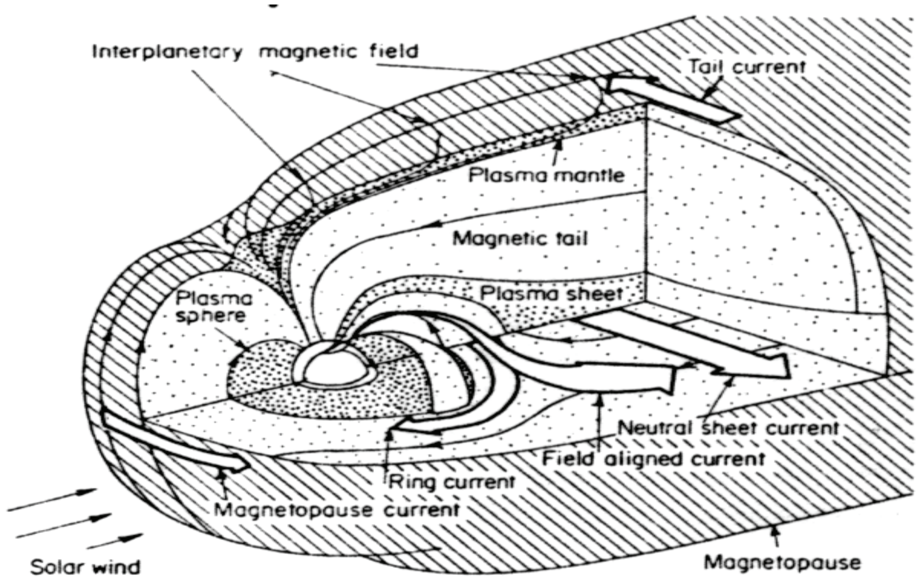


Figure 4. The main components of magnetospheric current systems. The earth and the atmosphere are represented by the two small spheres in the center of the figure. (POTEMRA, 1984 in GEBBINS & HERRERO-BERVERA, 2007).

The main geomagnetic field and the transient geomagnetic field can be evaluated by spherical harmonic analysis. Spherical functions are characterized by two remarkable properties:

- possibility to represent a certain distribution of values, no matter how complicated, on a sphere;

- their character of harmonic functions, satisfying the Laplace equation, which must undergo a field values derived from a potential.

Transitory part of geomagnetic field, represented by variation phenomena in a large range of periods, offers information both on external causes of the field with extensions in ionosphere and magnetosphere, as well as on internal ones, tightly connected to globe inner structure, anomalies in the distribution of electric properties in the crust, geodynamic processes in the mantle or convection phenomena in outer core.

The transient changes in the geomagnetic field are highlighted by continuous records of items made in magnetic observatories. On the one hand, periods of "quiet magnetic", characterized by slow variations, regular and predictable of the geomagnetic components recorded, quasi-sinusoidal looking can be distinguished on the obtained magnetograms, and on the other hand, periods of "magnetic agitation", when the field presents deviations with an irregular distribution in time, with unequal amplitudes of the elements in relation to periods of magnetic quiet.

The external component of the geomagnetic field may present periodic variations (dependent on the position of the Sun and Moon relative to the meridian of the place) and aperiodic variations associated with increasing or reducing of solar activity at a certain moment.

In terms of how vary daily records of geomagnetic field elements to an observatory, the days can be classified into two categories:

- quiet magnetic days;
- disturbed magnetic days.

An extreme case of perturbation is a magnetic storm. Except the storm days in the records of the magnetic observatories can observe certain regularities of the daily variations.

The main part is the solar daily variation (S), with a 24-hour period and a lunar variation (L) with small amplitude (lunar daily variation) with a period of about 25 hours. Disturbance variation (D) is additional field which appears in disturbed or stormy days. S and D are relatively easy to recognize in the record, but to determine the variation produced by moon requires processing of long data sets.

Beside the statistical and spectral analyses, an important role at the beginning of a morphological study of the electromagnetic field is played by the visual analysis of analog magnetograms, which can easily highlight aperiodic magnetic events with very different morphology. For this reason it is useful to preserve the observatories' magnetograms. Several amplitude features allow the individualization of these events in several characteristic and standardized types (sudden impulses - and sudden storms commenced - Ssc, chromosphere eruptions - SFE, bays - b and pulsations) reflecting external causes related to different areas of the magnetosphere.

Thus, sudden jumps (SI), with a low nT amplitude, of the geomagnetic components are produced by a sudden change of solar wind pressure on the magnetosphere boundary (at a distance of about 10 Earth radii). When there is a rapid change of the magnetic field, with a few tens of nT or nT, precedes a geomagnetic storm (Ssc impulses), the magnetosphere is compressed and pushed to the Earth. Chromosphere eruptions (SFE) are caused by a sudden increase in solar UV and X radiation that ionizes the upper atmosphere and intensify the electrical currents. Magnetic bays (b) are a consequence of increasing of the polar electro-jets at night.

Continuous pulsations (Pc) of low-frequency are generated mainly by magneto-hydrodynamic instabilities of the contact between the solar wind and magneto - break. Many pulsations from the medium frequency band are caused by the instability proton - cyclotron in the solar wind. The continued pulsation of high frequency is mainly due to the ion - cyclotron instability in the magnetosphere where the energy of instability comes from anisotropic perturbations of the energetic protons.

Irregular pulsations (Pi) are generated by transient phenomena such as sudden impulses from the solar wind. The study of continuous pulsations Pc provide information about the near-Earth plasma, and the investigation of long-term changes of these pulses, in observatories is important for the study of plasma regions.

From the trend of the diurnal averages of geomagnetic components within a longer time (multiannual) overlapping oscillations representing large and small deviations from the monthly mean can be seen over a slow annual variation (secular variation). These deviations are more pronounced during equinox, because of the particular position of the Earth's magnetic dipole axis relative to the main direction of corpuscular solar radiation flow, their pressure on the magnetosphere is stronger, and the particle density penetrating the magneto-break (and concentrated in belts van Allen radiation) is higher.

GEOMAGNETIC DATA FROM SURLARI OBSERVATORY

Thus, the data used for the study of large periodicities of the geomagnetic field are presented as a series of hourly averages covering the period 1.01.1958-31.12.2006. These data were downloaded in the WDC format from the ftp site of the World Data Center for Geomagnetism from Kyoto. These were calculated annually based on final data both from analogue magnetograms and digital recordings (ASIMOPOLOS et al., 2010, 2012a, 2012b).

To study the diurnal variations, non-periodic variations (geomagnetic storms, phenomena SSC or SFE) were used as several minute averages for the entire period in which digital recordings were made in Surlari Observatory.

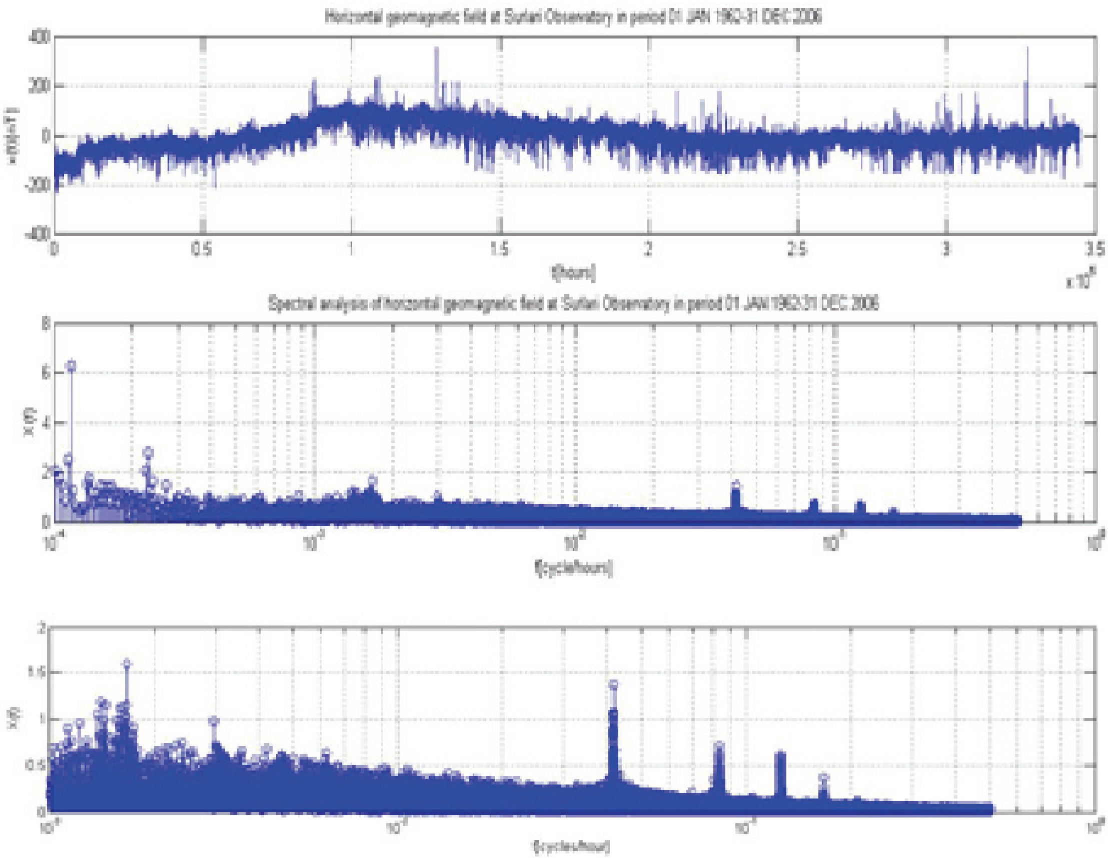
In order to study periodic phenomena with higher frequencies, we used gross values of the records of geomagnetic field components made with a sampling rate of 2 Hz, generally covering periods up to 24 hours.

The first processing was performed on a series of hourly values, based on final data and recorded during 1.01.1958-31.12.2006 in Șurlari geomagnetic observatory, with a major disruption in data acquisition in both years 1960 and 1961. Because of the existence of the disruption, the recorded values were treated separately for the intervals 1958-1959 and respectively 1962-2006.

We will illustrate, in the following, the spectral processing of the data acquired between 01.01.1962 and 31.12.2006, providing a long information series, almost continuous (about four solar cycles) as a series of values hourly average calculated annually based on final data.

At the latitude of the Surlari Observatory the horizontal component H has the highest degree of disturbance, reaching its variation amplitude of about 400 nT as shown in Fig. 5.

The first stage of the data processing (using WON et. al., 2004, www.matworks.com) is the linearization process. After applying linearization characteristic equations for each component is obtained extracting of the secular variation of the geomagnetic field component and is preserved the effect of external geomagnetic field.



A)

B)

C)

Figure 5. A) Diference between horizontal geomagnetic component and the linear trend, for Surlari Observatory for the period 1.01. 1962 - 31.12. 2006, based on hourly averages read from magnetograms; B) Spectral analysis for frequency range between 10^{-4} and 0.5 cycles / hour; C) Spectral analysis for frequency range between 10^{-3} and 0.5 cycles / hour.

For all three recorded components an upward trend is observed for the whole period. This trend represents the secular variation of the analysed components. Declination D and vertical component Z have variations with smaller amplitudes at latitude of Surlari Observatory. These variations are generally masked by the strong tendency of increasing values of these two components. Increasing trend is the dominant feature of these components.

Comparing sunspot number variation with linearized graphics components H, D and Z of the geomagnetic field can be seen overlapping periods of enhanced solar activity with periods of increasing amplitude variations of the geomagnetic field components.

The following figures exemplify the evolution graphs for the horizontal component, declination and vertical component for both the original data and after the removal of the linear trend.

A Gaussian distribution can be observed for the horizontal component H, whose upward trend is more pronounced (Fig. 6).

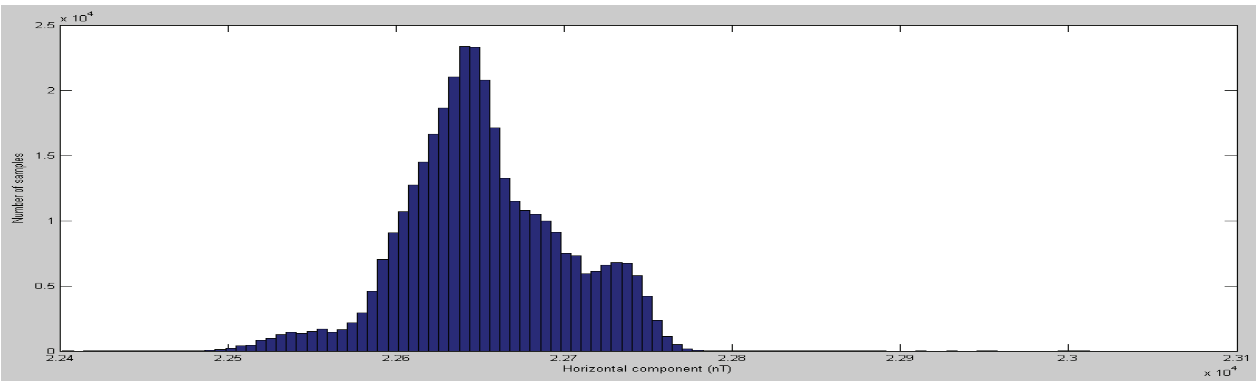


Figure 6. Histogram of horizontal component for year period 1962-2006.

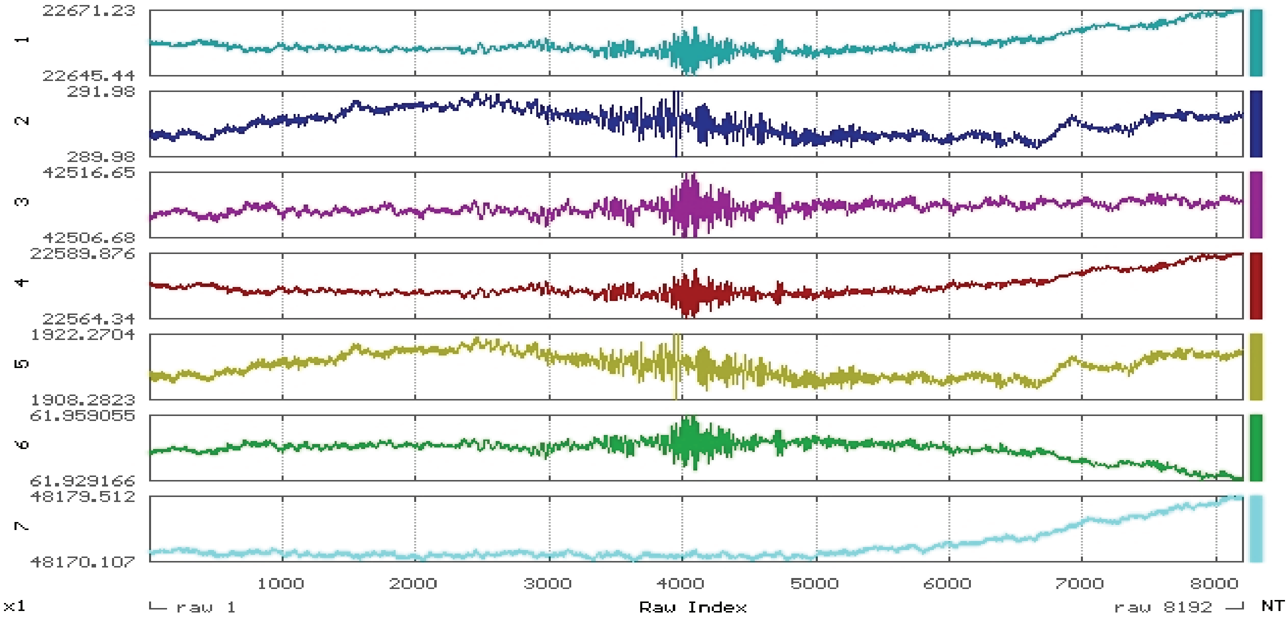


Figure 7. Graphical representation of the representative pulsations on 11.03.2011, in time interval 06:05:04 to 07:13:20 recorded at Şurlari Observatory. In this figure: 1 - horizontal geomagnetic component H, 2 – declination D, 3- vertical geomagnetic component Hz, 4-geomagnetic component Hx on the North direction, 5 – geomagnetic component Hy on the East direction, 6 – inclination I, 7 - total geomagnetic field F. The abscissa shows the number of samples with sampling rate of 0.5 seconds. In the y-axis components 1, 3, 4, 5 and 7 are given in nT, component 2 is given in minutes and component 6 is given in degrees.

We note the existence of the pulsations with different amplitudes and frequencies for the first six components. On the seventh component (total field F), these pulsations do not occur because they have a phase shift and through synthesis of the three perpendicular components (north, east and vertical) these pulsations disappear.

To explain better we selected a relevant detail for morphology pulsations.

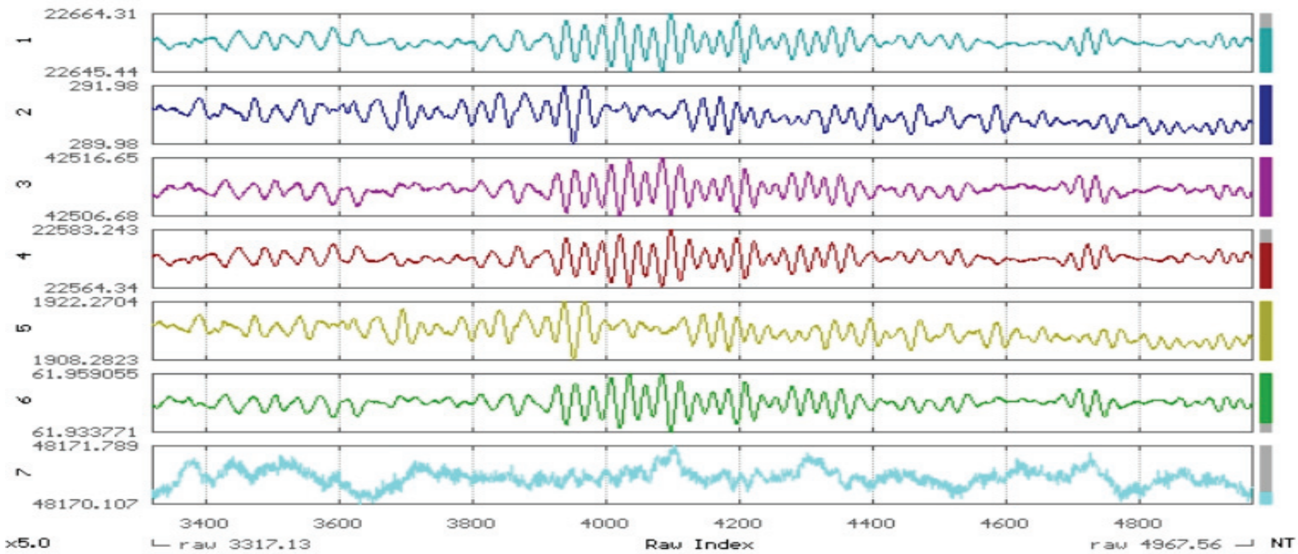


Figure 8. An detail of 1600 samples (800 seconds). Curves (1-7) have the same physical significance as in Fig. 7.

We performed a Fourier analysis to view the predominant frequencies for each geomagnetic component and can be distinguished frequencies in the range 0.02 Hz - 0.1 Hz, so in this example pulsations have periods between 10 and 50 seconds, fits in Pc3 and Pc4 categories.

We can show a variation of amplitudes for different geomagnetic components. Thus, the horizontal components were recorded amplitudes up to 20-22 nT, while the vertical component amplitudes of 10-12 nT occurred. Total geomagnetic field amplitudes were observed only 1-2 nT.

Predominant frequencies of these pulsations were different depending on the analyzed component.

We selected a sequence of 8192 samples (2^{13}), the horizontal and vertical components, which conducted to parametric spectrum (Figs. 9 and 10).

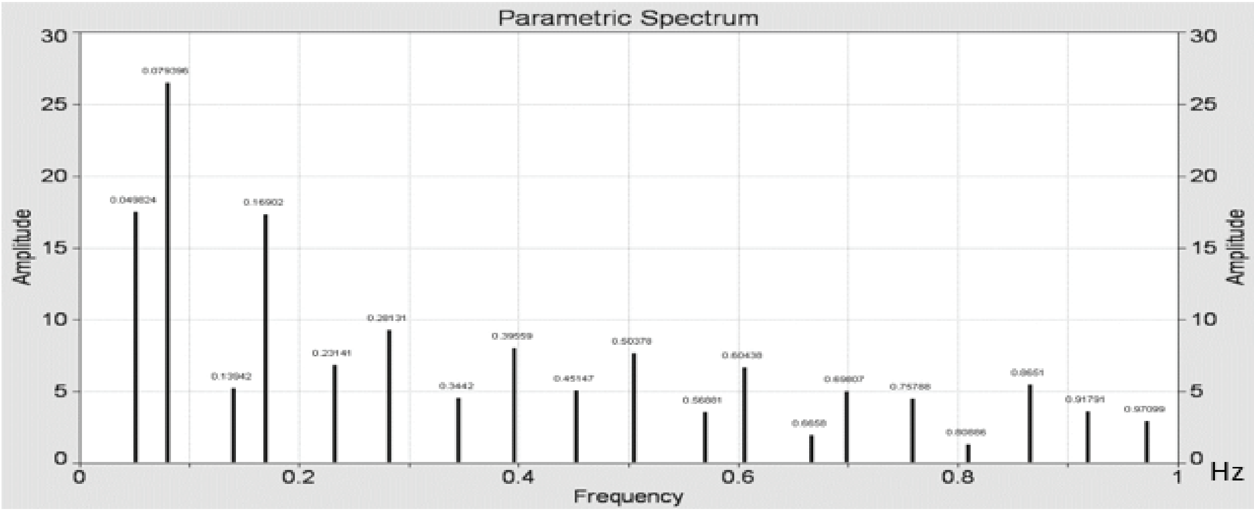


Figure 9. Parametric spectrum for horizontal geomagnetic field (H).

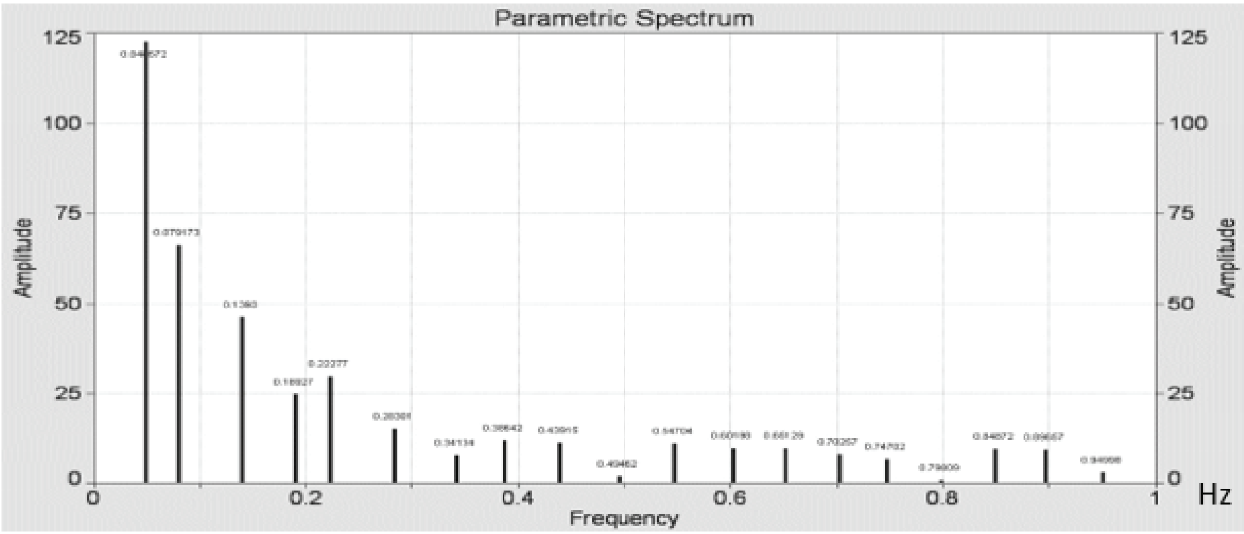


Figure 10. Parametric spectrum for vertical geomagnetic field (Hz).

CONCLUSIONS

Were reviewed the scanned analogic magnetograms recorded in the Surlary Observatory, identifying two types of even\: calm and disturbed variation.

From the whole set of data resulting from the processing of the records geomagnetic field components, several time series were selected with different sampling rates, to be subject to statistical and spectral studies.

Sampling rates were chosen based on the maximum resolution of the acquisition systems, data processing mode and the length of the analysed time series.

For the magnetograms recorded during the period 1943-1999 the maximum temporary resolution that can be achieved is 3 minutes, but because standardized processing requires processing of minute averages or hourly averages of these records, we used hourly average of the values of components recorded.

These data were downloaded in the WDC format from the ftp site of the World Data Centre for Geomagnetism from Kyoto. These were calculated annually based on final data both from analogy between magnetograms and digital recordings.

Digital recordings made between 1999 and February 2009, with a sampling rate of 0.2 Hz, and between March 2009 and to date, the sampling rate was 2 Hz for components D, H and Z and 0.2 Hz for scalar value of the total field F.

To study the diurnal variations, non-periodic variations (geomagnetic storms, phenomena SSC or SFE) were used as several minute averages for the entire period of digital recordings.

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