ULF GEOMAGNETIC OBSERVATION AT PANAGJURISHTE, BULGARIA AS A TOOL FOR INVESTIGATION OF THE MAGNETOSPHERE-IONOSPHERE-LITHOSPHERE SYSTEM

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DOI: 10.34975/bgj-2020.43.8

Abstract. A tri-axial search-coil magnetometer system, a part of SEGMA Array (South European Geomagnetic Array), operates since 2003 at the Geomagnetic Observatory Panagjurishte, Bulgaria. It is designated to measure and collect data for the Earth's magnetic field variations, specific geomagnetic events and long-term study of ULF signals. These observations provide information on the dynamical processes in the Earth's magnetosphere, geomagnetic micro-pulsations, fluctuations and storms. Here, we obtained results related to three powerful geomagnetic storms recorded by the search-coil magnetometer during the years 2017-2018. Furthermore, we presented the dynamical spectra in the ULF range of each storm.

Key words: ULF variations, search-coil magnetometer, geomagnetic storm, Panagjurishte.

Introduction

The study of the ULF spectrum (0.001-10 Hz) of the Earth's magnetic field, its local fractal structures, spectral and polarization characteristics are important for the identification of the causes of the associated disturbances. In the last two decades, the analysis of the ULF spectrum of magnetic field is particularly relevant, as it is believed that ULF emissions are likely to be generated directly from the area of preparation of geodynamic processes (Fraser-Smith, 2009; Molchanov et al., 2011). In most of all reported cases of such emissions, recorded by ground-based measurements, these are signals that are not of lithospheric origin, but are related to the interaction of the solar wind with the Earth's magnetosphere. These processes, which have a magnetospheric origin, are recorded on the Earth and together with the ionospheric and local ones, form the electromagnetic noise at a given point of recording (McPherron, 2005). Signals of lithospheric origin are difficult to identify against the background of general electromagnetic noise. For this reason, different authors use different methods to analyze these ULF emissions, both classical and non-traditional: the direct search method (Ismaguilov et al., 2003; Kopytenko et al., 2001, 1993; Li et al., 2019, 2013; Prattes et al., 2011) polarization method, determination of principal components and singular spectral analysis (Serita et al., 2005), Power spectrum analysis, monofractal and multifractal analysis (Gotoh et al., 2003; Ida et al., 2012, 2005; Varotsos et al., 2009, 2003), DFA (detrended fluctuation analysis) (Chamati et al., 2011, 2009; Chamati, M., 2018; Chamati and Botev, 2019; Nenovski et al., 2013) and classical statistical methods (Fidani, 2019, 2018; Zhang et al., 2013).

The preparation of geodynamic processes in the lithosphere is not well understood from an electromagnetic point of view. To gain insight the variations of the magnetic field measured in the ground layer, a comprehensive study of the complex of physical phenomena arising in the preparation of geodynamic processes is necessary.

Geomagnetic variations

The geomagnetic variations can be generally classified as variations of external and internal origin. The time variations of external origins include two main types: regular and irregular. The regular variations are classified as daily (Solar-quiet and Lunar-magnetic) and long-term (Solar cycle). The irregular variations include pulsations, storms and substorms. The time variations of internal origins are mainly due to sources in deep interior of the Earth. They are known as long-term variations (secular, jerks) and generally occur on time scales longer than few years. The short-term variations originate in the sources external to the Earth and they occur in time scales less than one year. ULF pulsations (continues and irregular) and their manifestation in the Earth's magnetic field variations are important to the study dynamical processes in magnetosphere (Bleier et al., 2009; Li et al., 2013; McPherron, 2005; Prattes et al., 2011). Many studies suggest a lithospheric source of some of the short time variations that are lasting from few seconds to few days. The variations, recorded on the ground and related to anthropogenic activities, are also a part of the general geomagnetic noise.

Measuring instrument and data set

On May 2003, as a part of South European Geomagnetic Array (Italy, Hungary, Bulgaria), at Geomagnetic Observatory Panagjurishte a three-axial search coil magnetometer was installed. Thanks to the cooperation between University of L'Aquila, Italy and National Institute of Geophysics, Geodesy and Geography, Bulgaria, the acquisition system and communication equipment were fully upgraded in 2016. The timing is provided via GPS. The station allows to conduct studies on the longitudinal propagation of ULF signal. It provides real time measurements at a sampling period of 0.01s. For the needs of our research we use filtered data at sampling period 1s. In Table1 basic characteristics of the induction magnetometer which is located at Panagjurishte Geomagnetic Observatory are presented.

Table 1. Characteristics of the induction magnetometer at Panagjurishte, Bulgaria

Characteristics of induction magnetometer at Panagjurishte, Bulgaria	
Frequency band:	5 mHz – 20 Hz
Sensitivity:	10 mV/nT – 100 mV/nT
Intrinsic noise:	0.05 pT/$\sqrt{(Hz)}$ at 1 Hz
Temperature drift:	0.001%/C
Linearity:	0.006%
Axes misalignment:	< 0.1 degrees
Output signal:	+/- 10 V (+/-1000 or 100 nT)
Dimensions:	80x80x80 cm
Power supply:	12 V
Current absorption:	300 mA
Thermal range:	-40 °C/+50°C

Table 2 presents the geographic and geomagnetic coordinates of the measuring instrument.

Table 2. Location of the measuring instrument

Station	**Geographic Coordinates**	**Corr. Geomagnetic Coordinates**	**L**
Panagjurishte, Bulgaria	42.51 N	37.02 N	1.6
COD: PAG	24.18 E	97.24 E	(Corrected geomagnetic coordinates (CGM) and L values refer to the year 2006 and altitude of 120 km and are computed from a geomagnetic field model provided by: http://modelweb.gsfc.nasa.gov/models/cgm)

Results

As a demonstration of some of the many opportunities that research of ULF geomagnetic spectrum provides, here are presented three different cases: two geomagnetic storms and the set of three subsequent days with high geomagnetic activity recorded at Geomagnetic Observatory Panagjurishte, Bulgaria. Case one: the geomagnetic storm that occurs on 27-28 May 2017. The K_p index reaches a value 6.5 for the hours between 22:00 (UT) on 27 of May and 03:00 (UT) on 28 of May 2017 according to the prognostic data information (calculated from data on the parameters of the solar wind) which is updated every day on the internet page of National Institute of Geophysics, Geodesy and Geography, Bulgaria (http://data.niggg.bas.bg/kp_for/kp_mod_bg.php). On Figure 1 a shape-preserving Piecewise cubic Hermite interpolation (PCHIP) of the

ULF signal for the X (north-south) component of the geomagnetic field variations, which allows to emphasize the changes in the signal that originally recorded at resolution 1s is presented. Here are clearly visible rising disturbances in the signal and it maxima in time interval 22:00 (UT) on 27 of May till 03:00 (UT) on 28 of May 2017. On Figure 2 the dynamic spectra of the ULF signal, its period scales and energy spectrum are presented. Disturbances are observed over all time scales between 1Hz and 1mHz as most of the energy of the process is concentrated within time scale 180-900 seconds during the storm.

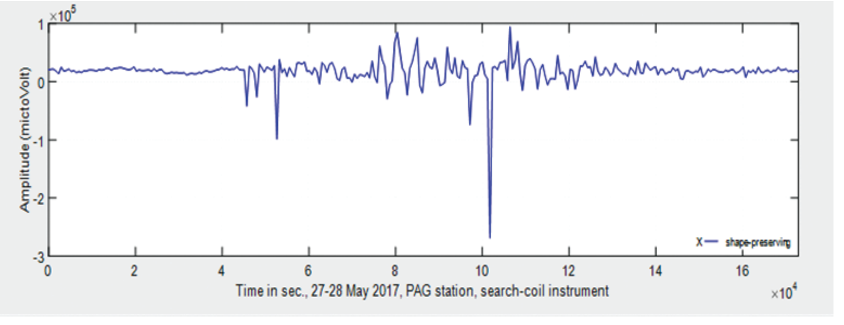

Fig. 1. Shape-preserved signal in seconds, 27-28 May 2017, X component

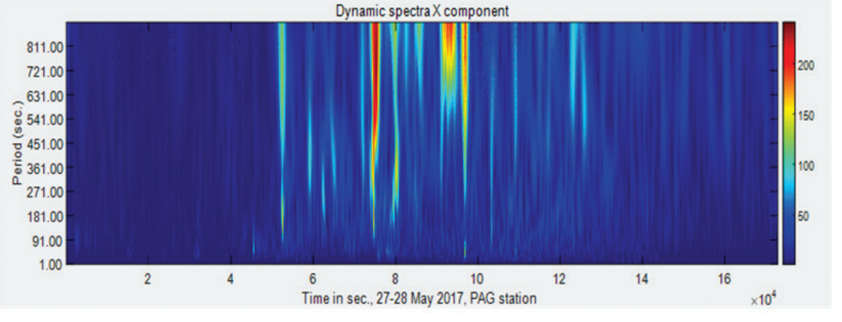

Fig. 2. Dynamic spectra, X component, 27-28 May 2017, PAG station, time in seconds.

Case two: the powerful geomagnetic storm which occurred at 7-8 September 2017. It begins about 23:00 (UT) and about 02:00 (UT) Dstmin = −142 nT (Blagoveshchensky and Sergeeva, 2018). During the storm at the Geomagnetic Observatory Panagjurishte the local K index reaches the value 7. The shape preserved signal for the X component of geomagnetic field variations is presented on Figure 3 and its dynamic spectra are presented on Figure 4 (Fig.4 is previously presented in (Chamati, M., 2018)). Here are observed powerful disturbances, including continuous ULF pulsations, during the whole period in all time scales. These storms are studied in detail in (Chamati, M., 2018).

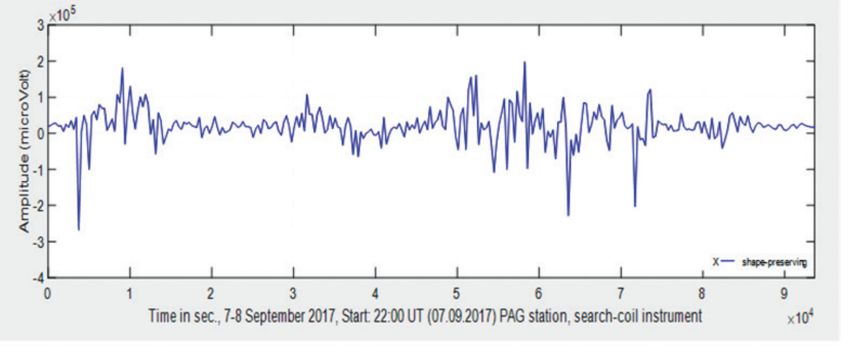

Fig. 3. Shape-preserved signal in seconds, 7-8 September 2017, X component

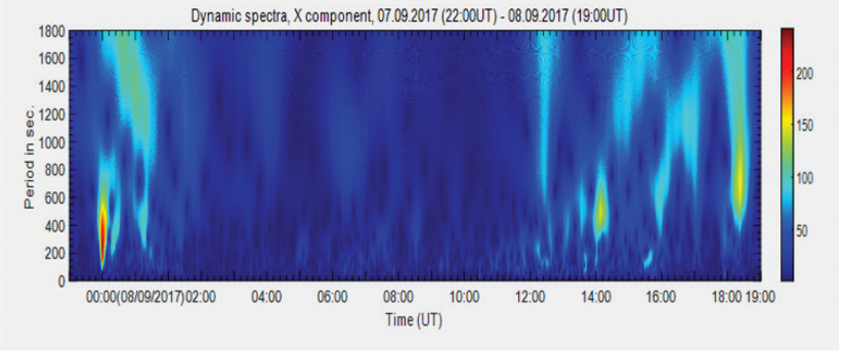

Fig. 4. Dynamic spectra X component, 7-8 September 2017, PAG station

Case three: the geomagnetic storm that occurs at 26 August 2018. During the morning hours at same day, Dst index reaches the value -169nT at high latitudes (Kleimenova et al., 2019). Here are recorded and observed geomagnetic disturbances and pulsations which appear in time period 25-27 August 2018. Figure 5 presents shape-preserved signal in seconds for the X component of geomagnetic field variation at PAG station. The disturbances with high amplitudes are clearly visible at 26 August 2018. The calculated K_p index varies between 4 and 6.5 for the hours between 19:00 (UT) at 25 August and 22:00 (UT) at 27 August 2018 (http://data.niggg.bas.bg/kp_for/kp_mod_bg.php). The K_p value is 7.

Figure 6 depicts dynamic spectra obtained for the X component. Relatively lower-energy disturbances are observed in the ULF spectrum of geomagnetic field variations at Panagjurishte, Bulgaria than high geomagnetic latitudes. Its maxima appear during the storm at 26 August 2018 with periods 450-900sec. For the other time scales the signal is significantly disturbed. Detrended fluctuation analysis (DFA) (Peng et al., 1995) is applied to data for X, Y and Z components for the time period 25-27 August. The DFA

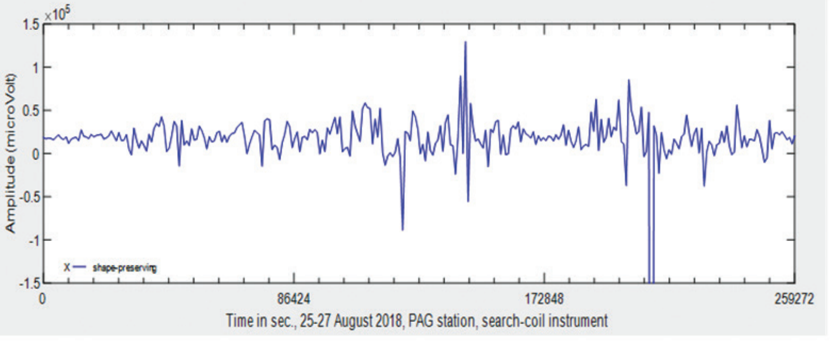

Fig. 5. Shape-preserved signal in seconds, 25-27 August 2018, X-component

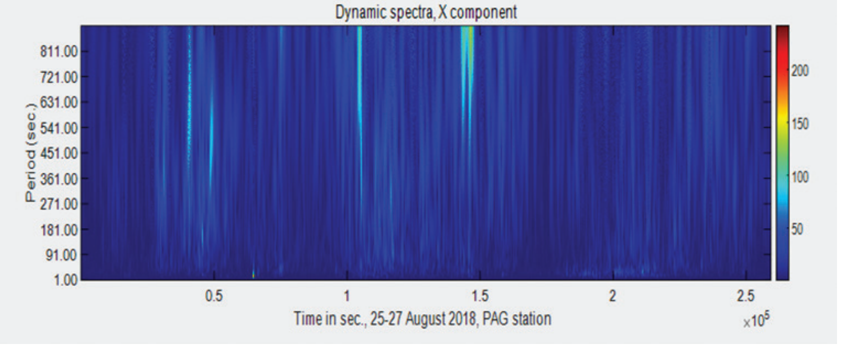

Fig. 6. Dynamic spectra X component, 25-27 August 2018, PAG station

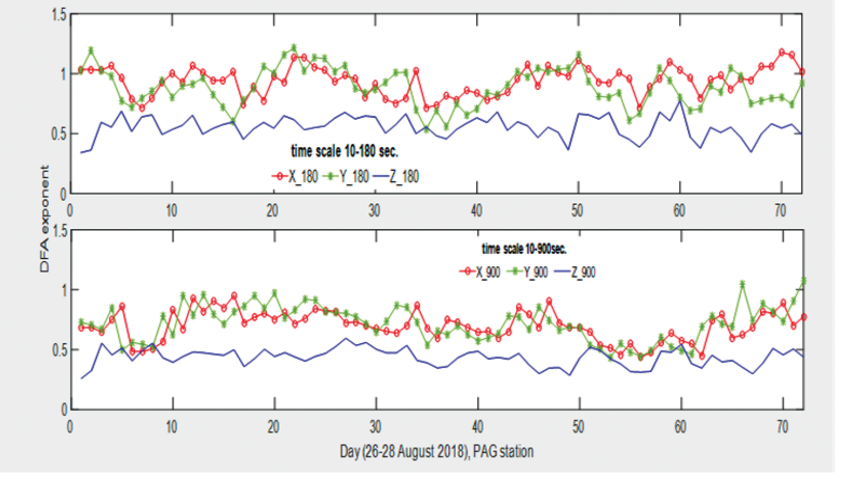

Fig. 7. DFA exponent, X, Y, Z components in time scales (10-180 sec) - top panel and (10-900sec) - bottom panel

exponent is calculated for two time scales: 10-180 sec and 10-900 sec. for each geomagnetic component. The behavior of the DFA exponent is presented on Figure 7. The time scale 10-180 sec. shows enhanced dynamic and unstable changes in the behavior of the DFA exponent compared to time scale 10-900 sec.

Conclusion

Using the data for the X component of the geomagnetic field variations, collected by the search-coil magnetometer at Panagjurishte, Bulgaria, we investigate three significant and powerful geomagnetic storms during 2017-2018. These storms have occurred at 27-28 May 2017, 7-8 September 2018 and 26 August 2018. For the first one we found that during the storm most of the energy of the process is concentrated in the time scale 180-900 seconds and all of the analyzed time scales are disturbed. For the second one powerful disturbances, including continuous ULF pulsations are observed, during the whole presented time period in all time scales. The third storm provides information that lower-energy disturbances are observed in the ULF spectrum of geomagnetic field variations at Panagjurishte, Bulgaria than high geomagnetic latitudes. The maxima of ULF spectra appear in the time scale 450-900 sec. DFA analysis shows that scaling exponent has enhanced dynamic and unstable changes in its behavior in time scale 10-180 sec. compared to time scale 10-900 sec.

Acknowledgments. This work is supported by Contract No D01-282/17.12.2019 (Project “National Geoinformation Center (NGIC)” financed by the National Roadmap for Scientific Infrastructure 2017-2023.

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Наблюдения в ULF спектъра на земното магнитно поле в Панагюрище, България, като инструмент за изследване на системата магнитосфера-йоносфера-литосфера

М. Шамати

Резюме. В геомагнитна обсерватория „Панагюрище", като част от магнитометричната мрежа SEGMA (South European Geomagnetic Array), от 2003 година оперира трикомпонентен индукционен магнитометър – единствен по рода си у нас. Тази система регистрира вариациите на земното магнитно поле в ULF спектъра и предоставя полезна информация за динамичните процеси в магнитосферата на Земята, микропулсации, флуктуации, геомагнини бури и специфични магнитосферни-йоносферни-литосферни събития. Получени са резултати, свързани с три геомагнитни бури за периода 2017-2018 година, които отразяват локалните смущения в геомагнитното поле. Представени са динамичните спектри в ULF диапазон за всяко едно събитие и са определени времевите скали на смущенията.