INVESTIGATION OF THE ULF GEOMAGNETIC NOISE RECORDED ON MAY 1, 2020 AT PANAGJURISHTE GEOMAGNETIC OBSERVATORY

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Abstract. On May 1st, 2020, at the Geomagnetic Observatory in Panagjurishte, Bulgaria, the unusual ultra-low frequency (ULF) geomagnetic noise was recorded by a tri-axial (X, Y, and Z directions) induction magnetometer. The time series from April 1, 2020 till May 1, 2020 are examined. Applying the detrended fluctuation analysis (DFA), the DFA exponent is calculated for the time series along the three geomagnetic directions, and the results show an unusual decrease in values of the DFA exponent in time scales 10-180s and 10-900s that starts after April 29, 2020. Through Magnitude-Squared Coherence analysis, the correlation and phases between every two geomagnetic components are obtained for the time series on May 1, 2020, under very low geomagnetic activity levels. The high values of the coherence and phase full sync for the X and Z components are observed, in the time period 04:00–20:00 UTC, at a frequency range 0.125-0.25 mHz. The present study does not rule out that the considered disturbances have a lithospheric origin.

Key words: ULF geomagnetic variations, DFA analysis, Magnitude-Squared Coherence, Panagjurishte.

Introduction

ULF variations of the geomagnetic field are an integral part of studying the interrelationships in the magnetosphere, ionosphere, atmosphere, and lithosphere systems.

The National Geoinformation Center (NIGGG, BAS) (Miloshev et al., 2019) collects various types of geo-information data, which are linked with many natural phenomena for example the geomagnetic storms, sub-storms and ULF pulsations (Blagoveshchensky and Sergeeva, 2018; Borovsky, 2020; Chamati, 2020; Chamati and Andonov, 2021; Nose et al., 1998), lithospheric geodynamic processes (Aleksandrova et al., 2021;

Oynakov et al., 2021a, 2021b; Popova et al., 2021; Trifonova et al., 2021), geomagnetic field elements (Metodiev and Trifonova, 2020) the air quality, the climate and etc.

The interactions between the lithosphere and the magnetosphere systems are poorly investigated despite the numerous scientific studies in the field. An unsolved problem is whether there is a direct or indirect relationship between earthquakes and the disturbances/variations in the Earth's magnetic field. The main task here lies in separating the different types of disturbances based on their origin. In order to be able to give at least a partial answer to the question of the previously mentioned connections, a good knowledge of the subject area and systematic studies of different types of geo-parameters are required.

For example, many authors have conducted research on this topic, linking it with hard-to-explain peculiar geomagnetic field disturbances (Alperovich et al., 2003; Anagnostopoulos, 2021; Fraser-Smith, 2009; Gotoh et al., 2003; Nenovski et al., 2013), total electron content (TEC) in the ionosphere (Akhoondzadeh, 2012; Zhao and Hao, 2015), ground water level (He and Singh, 2019) and many other parameters.

Data set

A tri-axial induction magnetometer operates in the Geomagnetic Observatory Panagjurishte, Bulgaria (42.51N/24.18E) as part of an acquisition system that records original data sets for the ULF geomagnetic field variations associated with X (north-south), Y (east-west), and Z (down/vertical) directions. They are sampled at 100 Hz and organized in files with a duration of one hour. With the aid of software packages, it performs verifications on the data files and converts them into data files, sampled at 1 Hz.

The data sets for the values of the local *K* index (Metodiev, M. and Trifonova, P., 2021) were downloaded from: http://www.niggg.bas.bg/observatories-bg/geomagnetic-observatory-pag/%D0%BB%D0%BE%D0%BA%D0%B0%D0%BB%D0%BD%D0%B8-%D0%BA-%D0%B8%D0%BD%D0%B4%D0%B5%D0%BA%D1%81%D0%B8/

Methods

The detrended fluctuation analysis (DFA) (Peng et al., 1995) over the time series of geomagnetic field variations is applied. This method is very helpful for determining long-range correlations in time series over various time scales. Moreover, Wavelet coherence is used as a measure of correlation between two time series that contain data for geomagnetic field variations and is based on Matlab software.

Results and discussion

On May 1, 2020, the Geomagnetic Observatory in Panagjurishte recorded an unusual "noise" in ULF variations of the geomagnetic field (Figure 1). They are mainly manifested along the vertical direction, which starts at about 03 UTC and lasts almost until the end of the day.

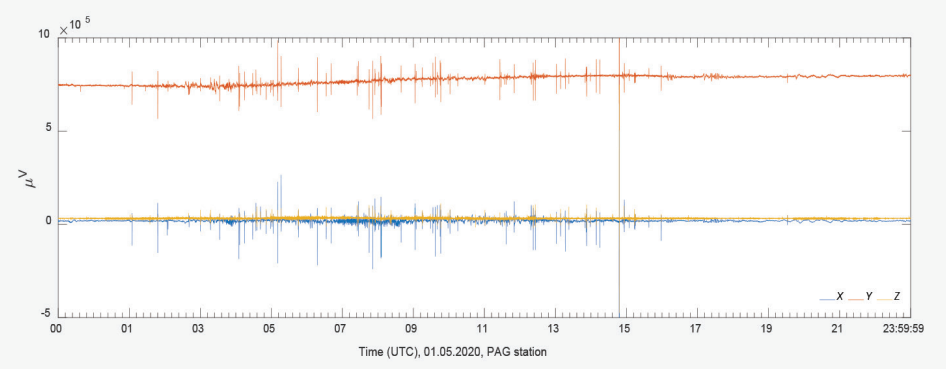

Figure 1. ULF variations along the X, the Y and the Z components on May 1, 2020.

Figure 2 shows the values of the local *K* index (Metodiev, M. and Trifonova, P., 2021) calculated for the Geomagnetic Observatory Panagjurishte on May 1, 2020. The values vary between 0 and 2, which indicate a very low level of geomagnetic activity. The values of the planetary K index have the same values.

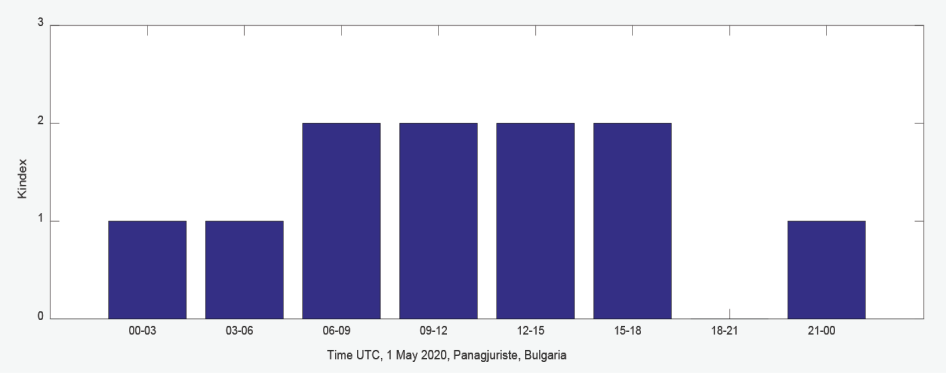

Figure 2. *K* index, May 1, 2020, Panagjurishte, Bulgaria

Next, the DFA is applied to a time series with recorded data along the three main directions (X, Y, and Z) of the ULF geomagnetic field variations. The analysis is performed for the time period April 1, 2020, to May 1, 2020. For each geomagnetic component, for the time scales 10-180s and 10-900s, the DFA exponent is calculated. The results are presented in Figure 3. On the first panel, the DFA exponent calculated for the Z component is shown. Comparison with values of DFA index for the X and the Y components pointed to a decrease of values of DFA exponent (Z component) after April 29, 2020. This decrease of the values indicates that correlations in time series weakened and its self-affinity is changed. The reasons for this decrease in DFA can be due to perturbations with sources in

the Earth's magnetosphere, ionosphere, lithosphere, or anthropogenic. The fact that they are predominantly observed in the vertical component of the magnetic field, these variations strengthens the hypothesis that the sources are most likely of either lithospheric, anthropogenic, or mixed origin. To shed some light on the issue of "noise" observed of the vertical component in the time series of data for May 1, 2020, the magnitude-squared coherence, as a measure of correlation between two signals based on wavelet analysis, was obtained.

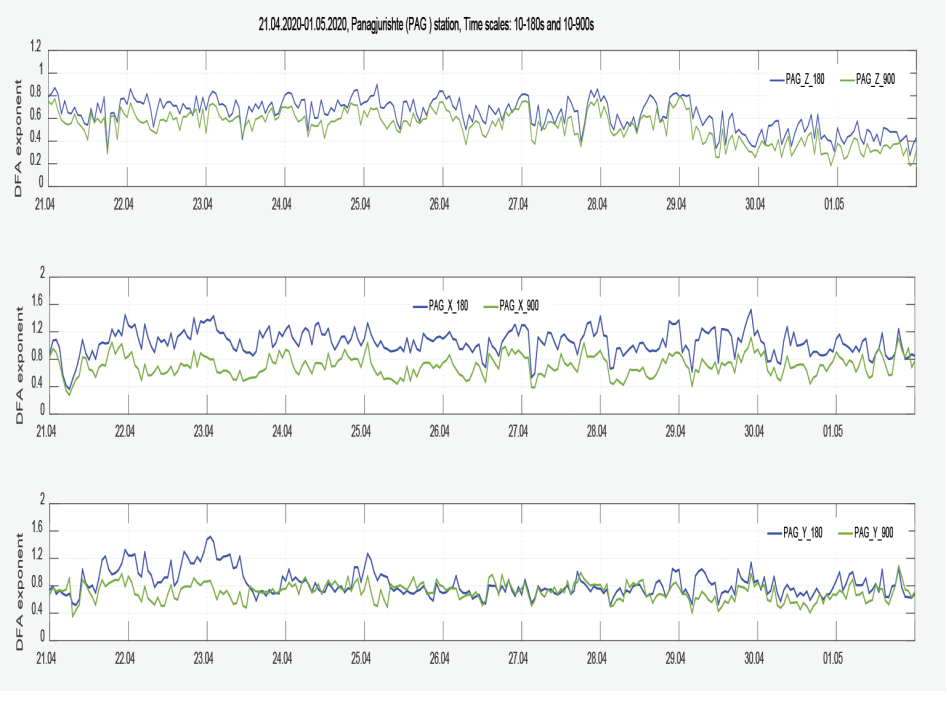

Figure 3. The DFA exponent calculated in time scales 10-180s and 10-900s for the Z, X and Y components, Panagjurishte, 21.04.2020-01.05.2020

Figure 4 shows the changes in magnitude-scored coherence between X and Z directions for May 1, 2020. The coherence has values ranging from 0 to 1 and covers wide ranges of frequencies from 0.015625 mHz to 512 mHz. Figures 5 and 6 show the coherence for the (X, Y) and (Y, Z) components for the same frequency band. With black arrows, the phases are marked. Figure 4 depicts four interesting facts, which is not observed on Figures 5 and 6. Indeed,

1 - High coherence values close to 0.9 in the time interval 04-20 UTC. This one time interval can be divided into three subintervals: 04–11 UTC, 11–15 UTC, and 15-20 UTC.

2 - The coherence's first subinterval has values around 0.9 and covers the frequency range 0.125-0.25 mHz. The black arrows show that the phases of the geomagnetic "noise" along the X and Y directions are different.
3 - full synchronization in phases is observed in the second subinterval after about 11 UTC, but only at 0.125 mHz. For the frequency interval of 0.25–0.5 mHz, the coherence is close to 0.
4 - The phases of geomagnetic "noise" along the X and Z components reach full synchronization at 0.125-0.25 mHz in the third subinterval (after 15 UTC).

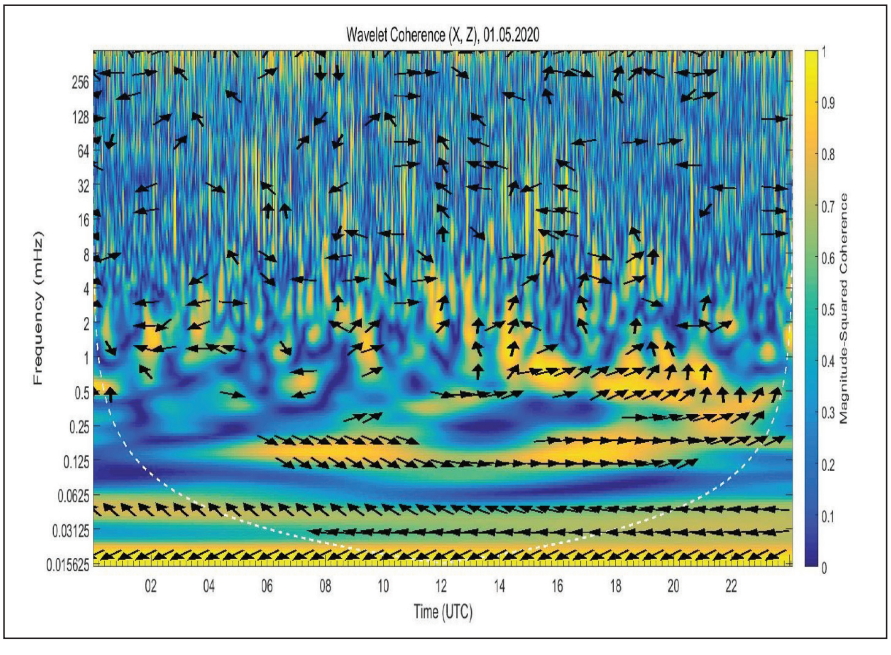

Figure 4. May1, 2020, PAG station, X and Z components

The reasons of this unusual geomagnetic noise, recorded along the vertical (Z) component might have different sources. Here, any simultaneous disturbances, recorded along the three geomagnetic directions at frequency interval 0.125-0.25 mHz, are not observed and this makes the possibility that they have a magnetospheric origin unlikely. From the lithospheric point of view, the one earthquake was recorded at this day. It occurred at 11:01:39 UTC on May 1, 2020 and has a magnitude of Mw=4.6, a depth of 18 km, and an intensity of Io/Imax=5.5. The epicenter has geographic coordinates 42.23N/24.87E, and its distance from Panagjurishte Geomagnetic Observatory is about 65 km in east-southeast direction. The unusual perturbations observed in the vertical component coincide well with the time the earthquake occurred. The facts that have been discussed cannot rule out the possibility that the cause of the disturbances on the Z component could be the preparation of the earthquake or that the observed effects are a co-seismic effect.

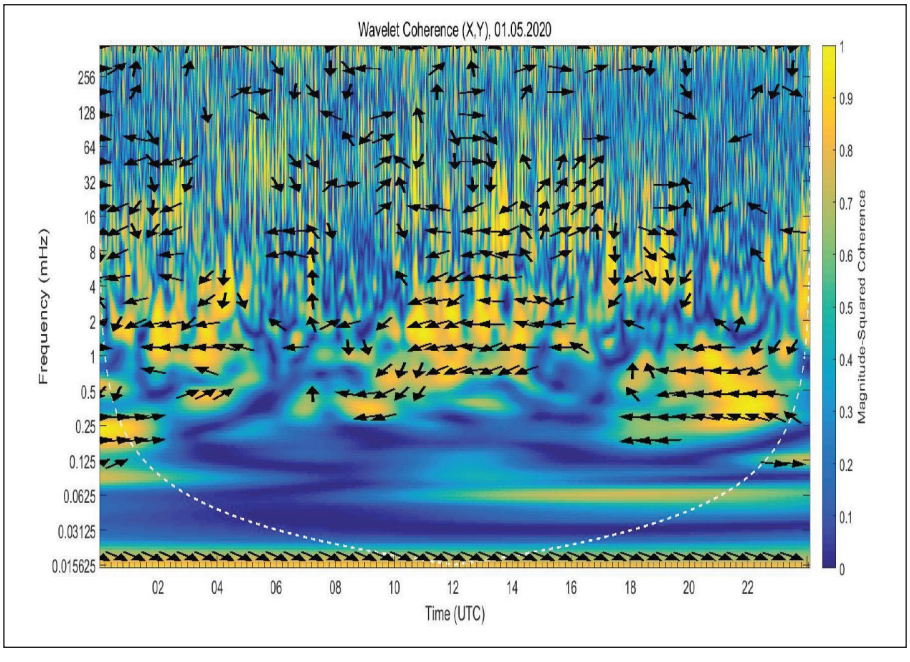

Figure 5. May1, 2020, PAG station, X and Y components

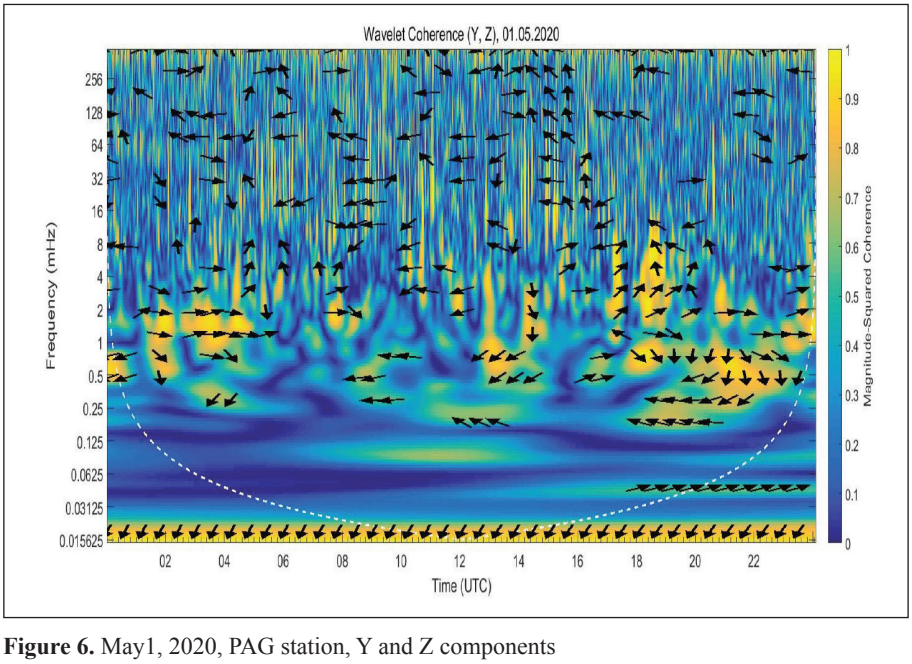

Figure 6. May1, 2020, PAG station, Y and Z components

Conclusions

On May 1, 2020, an unusual geomagnetic "noise" along the vertical (Z) component was recorded at the Geomagnetic Observatory Panagjurishte. The detrended fluctuation analysis and wavelet magnitude-squared coherence are performed, and the low levels of local and global geomagnetic activities are discussed. The specific decrease in the DFA index values calculated for the Z component in time scales 10-180 s and 10-900 s is obtained after April 29, 2020. The coherence wavelet analysis shows that on May 1, 2020, a high level of coherence between X and Z components was observed between 04 and 20 UTC. The phases of these two directions are going to differ initially, but after 11 UTC they are going to be fully synchronized. As this disturbance doesn't appear to be in the horizontal direction, it is possibly not of magnetospheric origin. The vertical direction of the disturbance cannot rule out the possibility that the cause of the disturbances on the Z component could be the preparation of the earthquake or that the observed effects are a co-seismic effect.

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Изследване на ULF геомагнитен шум, записан на 1 май 2020 г. в Геомагнитна обсерватория „Панагюрище“

М. Шамати

Резюме. На 1 май 2020 г. в геомагнитната обсерватория в Панагюрище, България, необичаен геомагнитен шум на свръх-ниска честота (ULF) е записан от трикомпонентен (X, Y и Z) индукционен магнитометър. Анализирани са времевите редове от данни за периода 1 април - 1 май 2020 г. Прилагайки флуктуационен анализ с елиминиране на тренда (DFA) е изчислена DFA експонентата за времевия ред за трите геомагнитни посоки. Резултатите показват необичайно намаляване на стойностите на DFA експонентата във времевите скали 10-180s и 10-900s, което започва след 29 април 2020 г. Изчислени и определени са кохерентността и фазите на геомагнитния шум посредством Wavelet анализ, за всеки две магнитни направления, при условията на ниска геомагнитна активност. Високи стойности на кохерентност (около 0.9) в часовия интервал 04:00–20:00 UTC и пълен фазов синхрон без отместване във фазите (11:00-20:00 UTC) между компонентите X и Z се наблюдават на 1 май 2020 г., в честотния диапазон 0,125-0,25 mHz. Въз основа на извършения анализ за наблюдаваните и анализирани смущения, не може да се изключи възможността те да произхождат от литосферен източник.