THE GEOMAGNETIC STORM ON NOVEMBER 3-4, 2021: SPECTRAL CHARACTERISTICS IN ULF RANGE AT MID LATITUDES

M. Chamati

National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, ul. Acad. G. Bonchev, bl 3, Sofia1113, Bulgaria, e-mail: mchamati@geophys.bas.bg

DOI: 10.34975/bgj-2022.45.1

Abstract. The geomagnetic storm class G3 was recorded on November 3–4, 2021 on the ground-based magnetometers. Using time series of the data corresponding to the horizontal geomagnetic component, the spectral characteristics in the ULF range for the data collected at Panagjurishte (Bulgaria) and Conrad (Austria) observatories are obtained. To obtain the degree of correlation between the X and the Y components at both stations the coherence analysis is used. It was found that the X components have a very high degree of correlation for the entire studied period in the frequency range 0.03125–16 mHz and are fully synchronous in phase. The Y components have significant differences in phase and values of coherence for different frequency ranges. The dynamic spectra depict similar behavior along the X and Y components during the storm. The geomagnetic variations at both observatories were affected at different time scales. The main difference is that the spectral characteristics appear on time scales 200–400s, where disturbances appear simultaneously along the X component at Panagjurishte and along the Y component at Conrad.

Key words: ULF geomagnetic variations, storm, spectral analysis, coherence.

Introduction

The geomagnetic storm is a disturbance of the Earth's magnetosphere caused mostly by solar wind (fully ionized plasma) blow shock and rarely by direct links between the Sun's magnetic field and the Earth's magnetic field. The Earth's magnetic field is measured by satellite and ground-based equipment. These natural phenomena are widely studied during the last few decades (Lakhina and Tsurutani, 2016). Their spectral characteristics, the impact on the ionosphere (Blagoveshchensky and Sergeeva, 2018; Dahal et al., 2022), the electromagnetic pulsations during the storms (Chamati, M., 2018; Marin et al., 2014) as well as a solar wind properties (Borovsky, 2020) are of particular interest. The large-scale spatial structure of the solar wind are studied (J. Borovsky and Denton, 2006; J. E. Borovsky and Denton, 2006). Alteration (lasting a few seconds) in the direction of the interplanetary magnetic field and accompanied by sudden changes in the velocity vector of the solar-wind plasma are also investigated (Gosling et al., 2011, 2009; McComas et al., 1998). Statistical analysis of the latitudinal distributions of the horizontal geomagnetic variations for period of three years are performed (Watermann and Gleisner, 2009).

Data set

A tri-axial induction magnetometer operates at the Geomagnetic Observatory Panagjurishte (PAG), Bulgaria (42.51N/24.18E) as part of the 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 into data files with a duration of one hour. With the aid of software packages, it performs timely verifications of the data files and converts them into data files, sampled at 1 Hz.

The flux-gate magnetometer that operates at Conrad Observatory (WIC), Austria, is a part of the International Real-time Magnetic Observatory Network (INTERMAGNET). Its coordinates are 47.93N/15.86E. The provided data are sampled at 1s along the three directions (X, Y, and Z).

The data set for the values of the local *K* index (Metodiev, M. and Trifonova, P., 2021) was 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/

The data set for the values of the global K index was taken from: https://www.spaceweatherlive.com/en/archive/2021/11/03/kp.html

Methods

The spectral analysis is performed on the basis of the Wavelet Morlet analysis. Wavelet coherence is used as a measure of the correlation between two time series that contain data for geomagnetic field variations and is based on Matlab software.

Results and discussion

On November 3–4, 2021, the geomagnetic storm class G3 due to the coronal mass ejection (CME) on the sun arrived on Earth around 19:30 UTC. The value of the solar wind speed increased from 500 km/s to 750 km/s, according to OMNIWeb (https://omniweb.gsfc.nasa.gov/form/dx1.html). On Figure 1, the records of the geomagnetic field variations along the X and Y directions from different types of magnetometers located at mid-latitudes—Panagjurishte, Bulgaria, and Conrad Observatory, Austria—are presented.

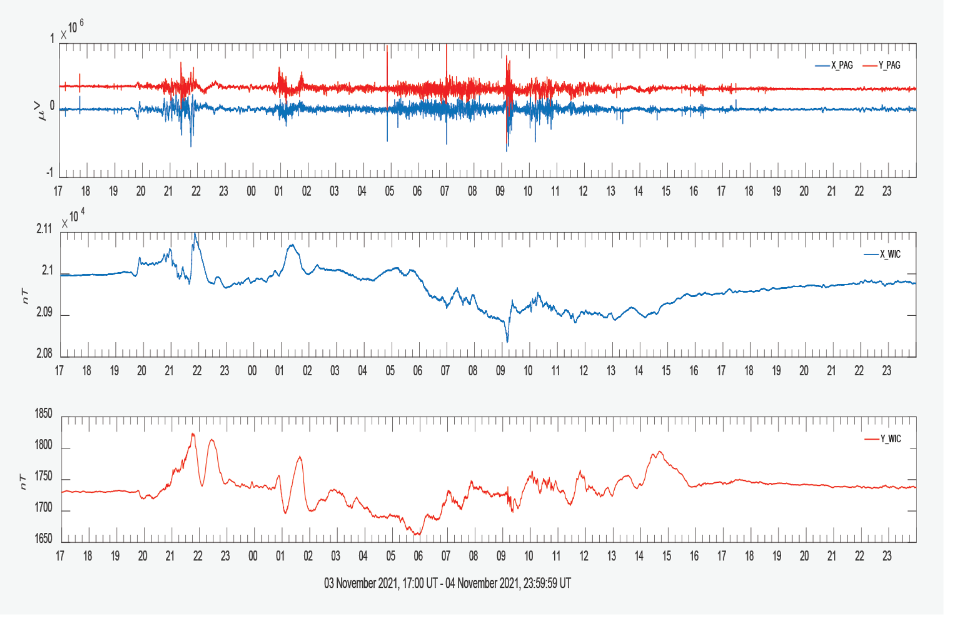

Figure 1. Geomagnetic variations along the X and the Y components on November 3-4, 2021, PAG (Bulgaria) and WIC (Austria) stations.

Figure 2 shows the values of the global *Kp* index on the top panel (https://www.spaceweatherlive.com/en/archive/2021/11/04/kp.html) and the local *K* index values on the bottom panel (Metodiev, M. and Trifonova, P., 2021) calculated for the Geomagnetic Observatory Panagjurishte on November 3–4, 2021.

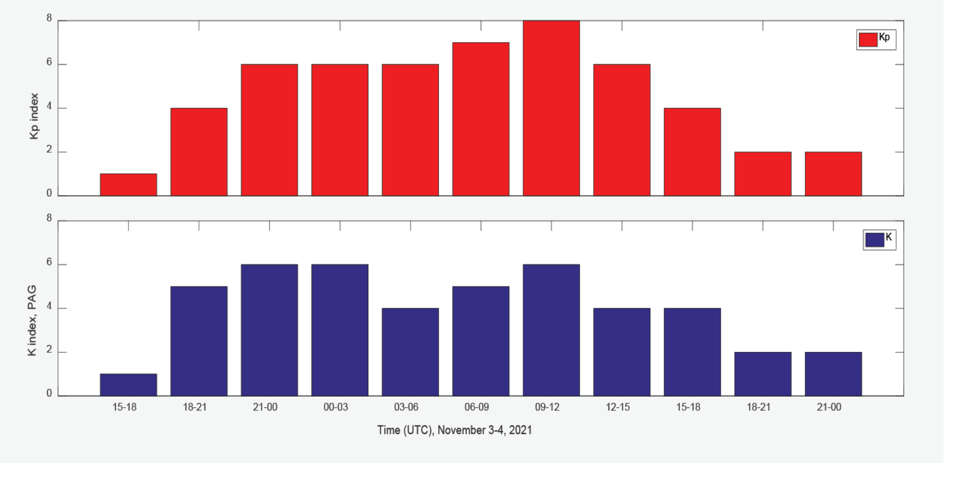

Figure 2. *Kp* and *K* index (PAG), November 3-4, 2021

The Kp index reached 8 - an extremely high value on November 4, 2021 in the time interval 09-12 UTC. During the same time, the K index at Panagjurishte was 6. The local K index values at WIC station are not available, but according to the interactive geomagnetic activity map provided by the INTERMAGNET web site, the local geomagnetic index in the vicinity of Austria stations is very close to that calculated at PAG station.

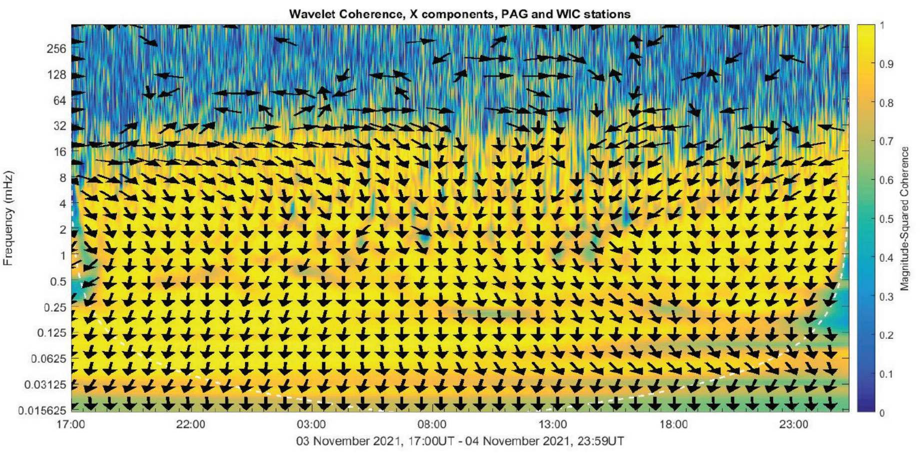

Figure 3. Wavelet coherence, X components (PAG and WIC stations), November 3-4, 2021

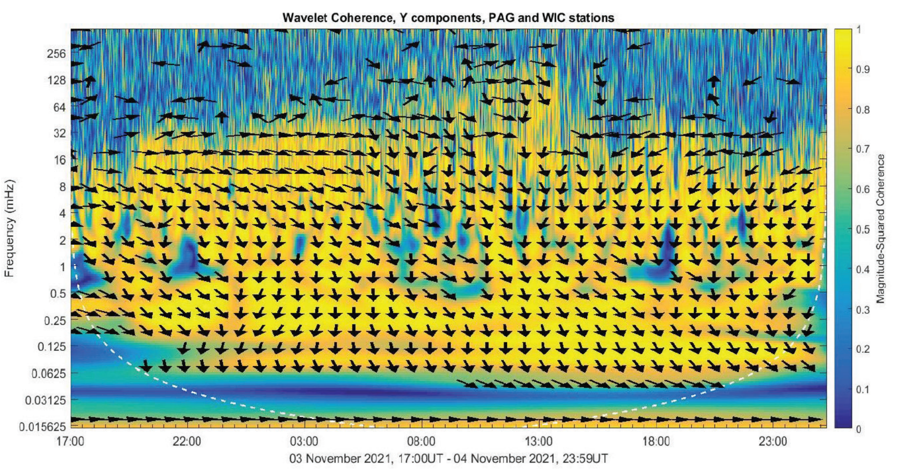

Figure 4. Wavelet coherence, Y components (PAG and WIC stations), November 3-4, 2021

On Figures 3 and 4, the wavelet coherence is obtained as a measure of the correlation between the X components of the two stations (PAG and WIC) along with the Y components. As it is clearly visible, the X components of the two geomagnetic stations have coherence values in the frequency range 0.03125–16 mHz that vary between 0.8 and 1. With black arrows, the direction of the phases is presented. It is fully synced without offset at most frequency ranges. For the Y components (Figure 4), the coherence values differ from those of the X components and remain the same with frequency ranges of 0.25–0.5 mHz and 4–16 mHz, but the phases during the analyzed days are not synced at high frequency ranges. This means that the intensity of the disturbance is, as usual, greater in the north-south direction.

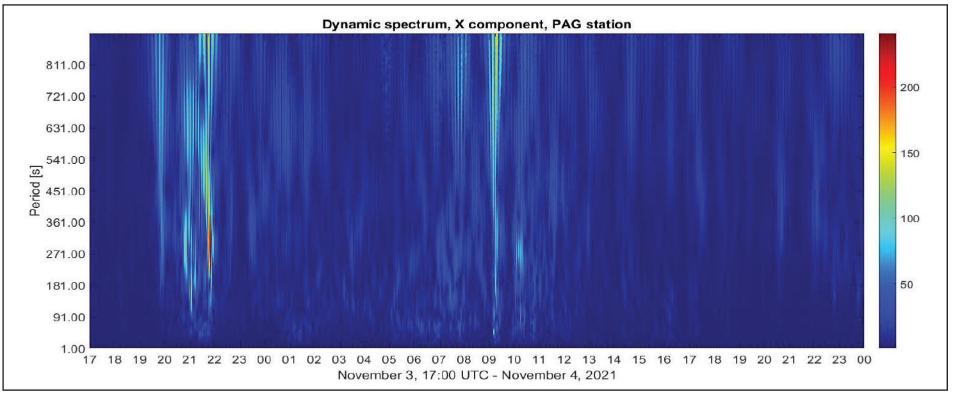

Figure 5. Dynamic spectrum, X component, PAG station, November 3-4, 2021

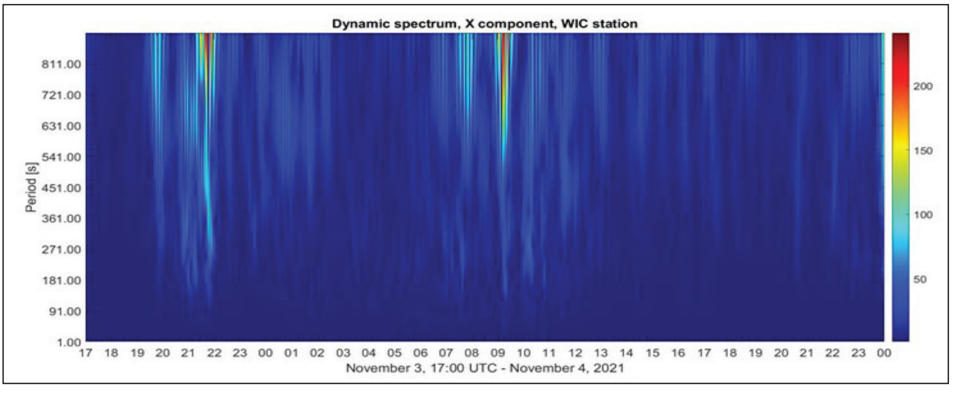

Figure 6. Dynamic spectrum, X component, WIC station, November 3-4, 2021

Figures 5 and 6 depict the dynamic spectra for the X components for the two stations—PAG and WIC. Their spectra are calculated for time scales of 1-900s or frequency ranges of 1 mHz-1 Hz, which correspond to ULF geomagnetic pulsation periods. Time series from the PAG and WIC stations are detrended from linear trends and then analyzed. On the two figures simultaneously, it is visible that the solar wind reached the Earth at about 19:30 UTC on November 3, 2021, when the largest in intensity disturbance is observed. For the PAG station they cover all investigated periods/frequencies, but for the WIC station disturbances appears in the period range 180-900s. The time of appearance is the same for both stations, and they are simultaneous with changes in the K and Kp indexes. At Panagjurishte Observatory at about 22:00 UTC powerful disturbances with periods varying in 200-400s (Pc5 range) are recorded. The differences are probably due to the use of different types of measuring instruments or weaker penetration of disturbance from the north direction.

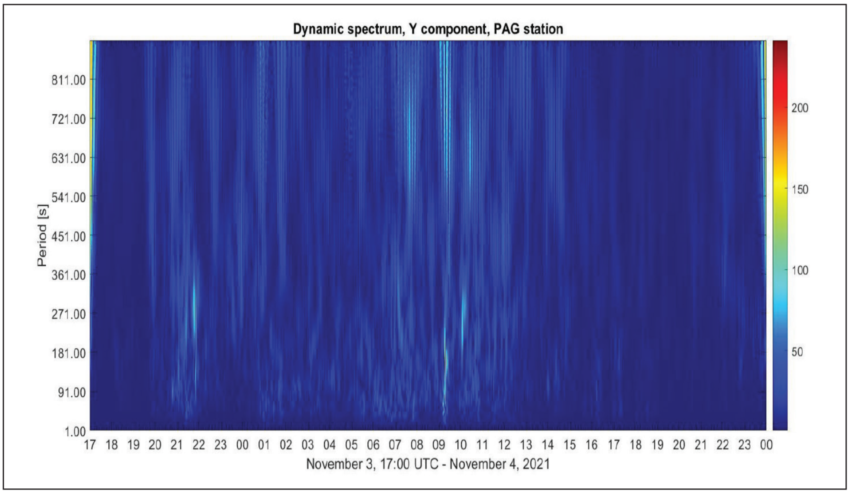

Figure 7. Dynamic spectrum, Y component, PAG station, November 3-4, 2021

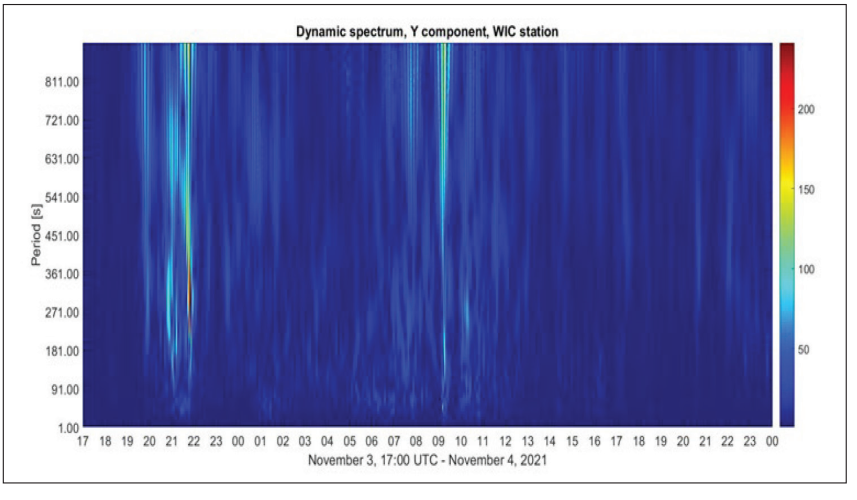

Figure 8. Dynamic spectrum, Y component, WIC station, November 3-4, 2021

Figures 7 and 8 present the dynamic spectra obtained for the Y components for the analyzed geomagnetic stations.

While, both stations show some similarities, they displayed discrepancies as well. The disturbances recorded at WIC (Figure 8) are stronger than at PAG (Figure 7). At time scales 200–400 (Pc5 range), disturbances similar to those observed at PAG station along the X component, also appear along the Y component at WIC station at the same time.

That may be due to the fact that at geographic latitude 47.93N, the penetration of the disturbance along the direction east-west is more pronounced than at latitude 42.51N.

Conclusions

On November 3–4, 2021, the geomagnetic storm class G3 disturbed the Earth's magnetosphere and was recorded from the magnetometers located at the ground-based observatories. The series of data for the geomagnetic field variations along the X and the Y directions recorded in PAG and WIC observatories are analyzed. Wavelet coherence analysis shows full synchronization in the phases and values of coherence in the frequency range 0.03125–16 mHz between the X directions of the two stations and differences along the Y components that are expressed in phase offset and partial synchronization across frequency ranges and time of appearing. The obtained dynamic spectra for the X and Y components show simultaneous disturbances in time scales ranging from 1-900s, which correspond to K and Kp index values. The main difference between the spectra of the stations is that the powerful disturbance in time scale 200-400s (Pc5 range) is observed in PAG station along X direction, but not in WIC station along X direction. This can be seen at WIC station along the Y axis. These discrepancies for the different components of the two stations may be due both to the use of different types of instruments which measure geomagnetic field variations and also to the different penetration of the disturbance at different latitudes.

Acknowledgments. This work is supported by Contract No D01-404/18.12.2020 (Project "National Geoinformation Center (NGIC)" financed by the National Roadmap for Scientific Infrastructure 2017-2023. The results presented in this paper rely on data collected at magnetic observatories. We thank the national institutes that support them and INTERMAGNET for promoting high standards of magnetic observatory practice (www.intermagnet.org).

References

Borovsky, J., Denton, M., 2006. Differences between CME-driven storms and CIR-driven storms. Journal of Geophysical Research 111. https://doi.org/10.1029/2005JA011447

Borovsky, J. E., 2020. What magnetospheric and ionospheric researchers should know about the solar wind. Journal of Atmospheric and Solar-Terrestrial Physics 204, 105271. https://doi.org/10.1016/j.jastp.2020.105271

Borovsky, J. E., Denton, M. H., 2006. Effect of plasmaspheric drainage plumes on solar-wind/magnetosphere coupling. Geophysical Research Letters 33. https://doi.org/10.1029/2006GL026519

Chamati, M., 2018. Geomagnetic disturbances observed at Panagyuriste (PAG) station, Bulgaria on 7-8th of September 2017 during the geomagnetic storm., in: Proceedings of the IX National Geophysical Conference. Presented at the IX National Geophysical Conference, Sofia, Bulgaria, pp. 10–16.

Gosling, J. T., McComas, D. J., Roberts, D. A., Skoug, R. M., 2009. A ONE-SIDED ASPECT OF ALFVENIC FLUCTUATIONS IN THE SOLAR WIND. ApJ 695, L213. https://doi.org/10.1088/0004-637X/695/2/L213

Gosling, J. T., Tian, H., Phan, T. D., 2011. PULSED ALFVÉN WAVES IN THE SOLAR WIND. ApJL 737, L35. https://doi.org/10.1088/2041-8205/737/2/L35

Lakhina, G. S., Tsurutani, B. T., 2016. Geomagnetic storms: historical perspective to modern view. Geoscience Letters 3, 5. https://doi.org/10.1186/s40562-016-0037-4

Marin, J., Pilipenko, V., Kozyreva, O., Stepanova, M., Engebretson, M., Vega, P., Zesta, E., 2014. Global Pc5 pulsations during strong magnetic storms: excitation mechanisms and equatorward expansion. Ann. Geophys. 32, 319–331. https://doi.org/10.5194/angeo-32-319-2014

McComas, D. J., Bame, S. J., Barker, P., Feldman, W. C., Phillips, J. L., Riley, P., Griffee, J. W., 1998. Solar Wind Electron Proton Alpha Monitor (SWEPAM) for the Advanced Composition Explorer. Space Science Reviews 86, 563–612. https://doi.org/10.1023/A:1005040232597

Metodiev, M., Trifonova, P., 2021. Local geomagnetic K- indices calculated at PAG observatory since 2007. National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences. https://doi.org/10.34975/ctlg-2021.k-ind.v.1.

Watermann, J., Gleisner, H., 2009. Geomagnetic variations and their time derivatives during geomagnetic storms at different levels of intensity. Acta Geophys. 57, 197–208. https://doi.org/10.2478/s11600-008-0045-7

Геомагнитната буря от 3-4 ноември 2021: спектрални характеристики в ултра-нискочестотен диапазон, получени за средни географски ширини.

М. Шамати

Резюме. Геомагнитната буря от клас G3 е регистрирана на 3-4 ноември 2021 г. от наземни магнитометри. Използвайки времеви редове от данни за хоризонталните геомагнитни компоненти, са получени спектралните характеристики в ULF диапазона за обсерваториите Панагюрище, България, и Конрад, Австрия. За получаване на степента на корелация между X компонентите и Y компонентите на двете станции, е приложен кохерентен анализ на базата на уейвлет трансформация. От него се установява, че X компонентите на двете станции имат много висока степен на корелация за целия изследван период в честотния диапазон 0.03125–16 mHz и са напълно синхронни по фази. Y компонентите имат значителни разлики във фазата и стойностите на кохерентност за различните честотни диапазони. Динамичните спектри изобразяват подобно поведение по X и Y компонентите по време на бурята. Геомагнитните вариации, записани в двете обсерватории, са засегнати в различни времеви скали. Наблюдава се едновременна поява на смущение по X компонента в Панагюрище и по Y компонента в Конрад обсерваторията във времевите скали 200–400 секунди.