GEOMAGNETIC CONSIDERATIONS AT BEGINNING OF THE 25th SOLAR CYCLE

ASIMOPOLOS Laurențiu, ASIMOPOLOS Natalia-Silvia, ASIMOPOLOS Adrian-Aristide, BALEA Bogdan

Abstract. Based on the planetary geomagnetic indices in the 23rd and 24th Solar Cycles progression, which corresponds to the period 1996-2008 respectively, 2008-2020 we make some considerations at the beginning of 25th Solar Cycle. The most important event in this new solar cycle was the geomagnetic storm of May 12, 2021. Based on data from three geomagnetic observatories from INTERMAGNET, we performed Fourier and wavelet analyses. For this analysis of the geomagnetic data sampled at one minute, we used the North component of each observatory and comparison with physical parameters related with this geomagnetic storm, available on many sites. Also, we used wavelet coherence between observatories, both for the North and East geomagnetic components, for May 12, 2021.

Keywords: Solar Cycle, geomagnetic storm, planetary geomagnetic indices, wavelet analyses, Fourier analyses.

Rezumat. Considerații geomagnetice la începutul celui de-al 25-lea ciclu solar. Pe baza indicilor geomagnetici planetari din progresia ciclurilor solare 23 și 24, care corespunde perioadei 1996-2008, respectiv 2008-2020, am făcut câteva considerații la începutul celui de-al 25-lea ciclu solar. Cel mai important eveniment din acest nou ciclu solar a fost furtuna geomagnetică din 12 mai 2021. Pe baza datelor de la trei observatoare geomagnetice de la INTERMAGNET, am efectuat analize Fourier și wavelet. Pentru aceste analize ale datelor geomagnetice prelevate la un minut, am utilizat componenta nordică a fiecărui observator și comparația cu parametrii fizici legați de această furtună geomagnetică, din date disponibile. De asemenea, am folosit coerența wavelet între observatoare, atât pentru componenta geomagnetică nordică, cât și estică, în 12 mai 2021.

Cuvinte cheie: Ciclu Solar, furtuna geomagnetica, indici geomagnetici planetari, analize wavelet, analize Fourier.

INTRODUCTION

Experts from the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) discussed their analysis and predictions about the new solar cycle and how the coming upswing in space weather will impact our lives and technology on Earth, as well as astronauts in space. They announced that a solar minimum occurred in December 2019, marking the start of a new solar cycle. Scientists use sunspots to track solar cycle progress; the dark blotches on the Sun are the origins for giant explosions – such as solar flares or coronal mass ejections – which can spew light, energy, and solar material into space (https://science.nasa.gov/science-news/science-at-nasa/https://www.spaceweatherlive.com/en/solar-activity/solar-cycle.html, http://www.noaa.gov).

In order to understand the cycles of the Sun and determine the start of a new solar cycle, monthly data must be used on sunspots from the World Data Centre for the Sunspot Index and Long-term Solar Observations, located at the Royal Observatory of Belgium in Brussels, which tracks sunspots and pinpoints the solar cycle's highs and lows.

Space weather is caused by four main components: solar flares consisting of X-ray solar flashes, coronal mass ejections (CME's), high speed solar wind, and solar energetic particles, and refers to the effects that the Sun has on Earth and the planets of the solar system. A Coronal Mass Ejection (CME) is a massive cloud of hydrogen ions that is ejected from the surface of the Sun when the stored energy is suddenly released. The CME produces a cloud of high energy particles traveling at supersonic speeds (500-2000 km per second). When a CME is ejected towards Earth it reaches us within a day or two. The impact of the CME on the Earth causes a disturbance to the Earth's magnetic field.

The solar wind is a stream of charged particles ejected from the upper atmosphere of the Sun. It mostly consists of electrons and protons and varies in temperature and speed over time.

Solar Energetic Particles (SEPs) are high-energy charged particles originating from energised solar-flare sites or shock waves associated with CME's. SEPs consist of protons, electrons and heavy ions with energy ranging from a few tens of keV to GeV (the fastest particles can reach speed up to 80% of the speed of light). They are of particular interest and importance as they can endanger life in outer space.

CMEs and SEPs together generate magnetic disturbances and auroras, which are natural bright light displays seen in the vicinity of the magnetic poles of the southern and northern hemispheres. 'Aurora Borealis' refers to auroras found in the north, while 'Aurora Australis' are found in the south.

The Sun is a sphere of hot gas (plasma) with loop-like structures on the solar surface which are associated with the magnetic field of the Sun. When one of these loops becomes unstable, it breaks off from the surface of the Sun and creates a solar flare. The biggest flares can be hundreds of times the size of the Earth. Usually, solar flashes associated with solar flares are ranked based on their intensity five categories (A, B, C, M and X). A-class flashes are the weakest, while X-class flashes are the most energetic. Solar flares are seen by the photons (or light) released across the spectrum. X-rays are the primary wavelength monitored in the classification of solar flares. Flares also contribute to the acceleration of protons and other charged particles that may accompany a significant event.

The scientific aspects related to these phenomena are approached both from an astrophysical, geophysical (ASIMOPOLOS N. S., 2018; ASIMOPOLOS, 2012; BENOIT, 2012; CAMPBELL, 2003) and mathematical (https://www.mathworks.com, BOX et al., 2016; BISGAARD & KULAHCI, 2011) point of view in many works and data are available on the website http: //www.intermagnet.org.

23rd AND 24th SOLAR CYCLES PROGRESSION

The solar cycles show the cyclicity of solar magnetic activity. This is a nearly periodic (about 11-year) change in the Sun's activity measured in terms of variations in the number of observed sunspots on the solar surface. The following charts of the solar cycles are updated every month on site: https://www.spaceweatherlive.com/en/solar-activity/solar-cycle.html with the latest predictions. The observed values are initially temporary values that are replaced with the final data once it is available. The graph below, in figure 1, shows the number of days with a geomagnetic storm per year and how strong those storms were.

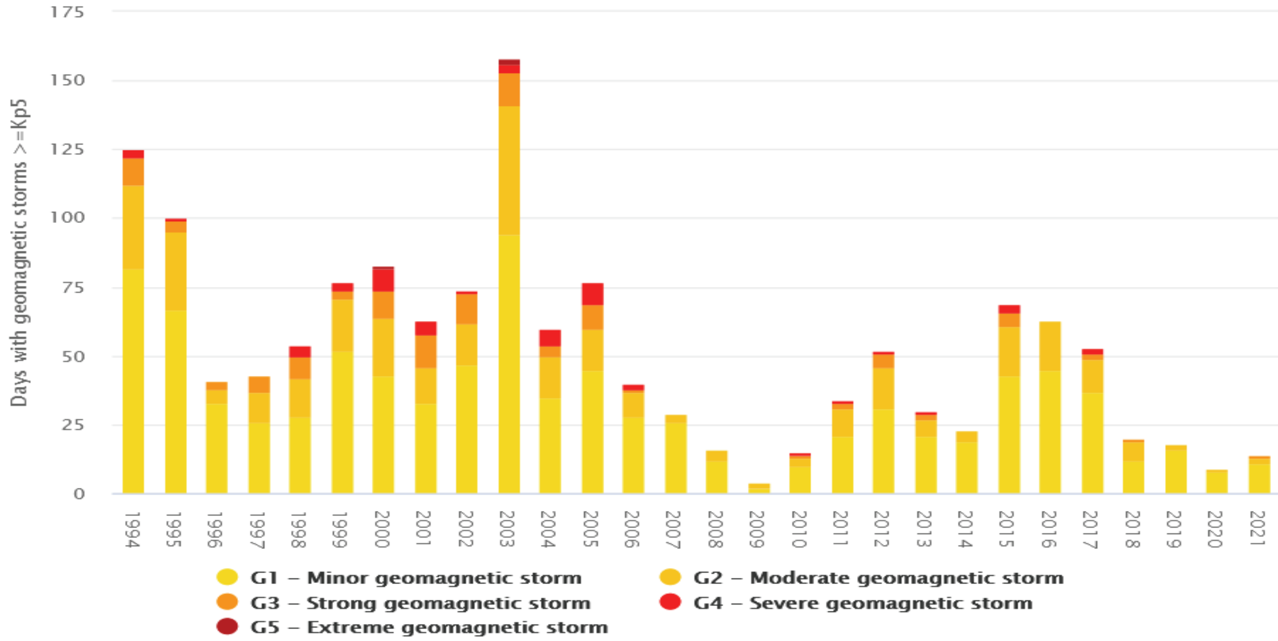

Figure 1. Days with geomagnetic storms per year (according to the finalized Kp-index of GFZ Potsdam).

Figure 2 shows the number of spotless days per year.

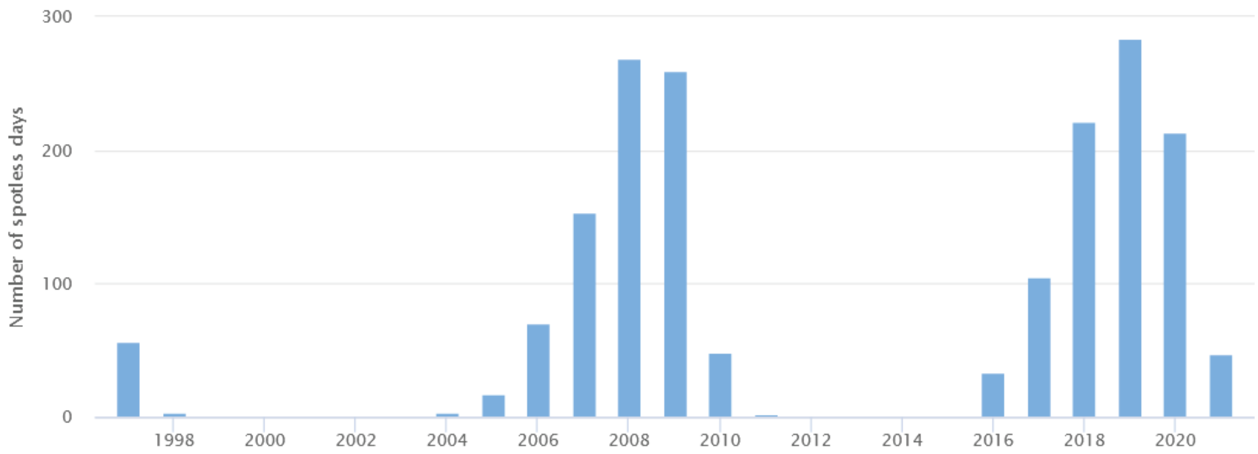

Figure 2. Number of spotless days per year.

During periods of low solar activity, the Sun can be devoid of any sunspots and thus be spotless. This is a frequent occurrence in the years around and during the solar minimum. The graph below shows how many days during a specific year the earth-facing side of the Sun had no sunspots.

Figure 3 presents the progression of the 23rd and 24th Solar Cycles and the predicted 25th Solar Cycle – for the F10.7cm Radio Flux.

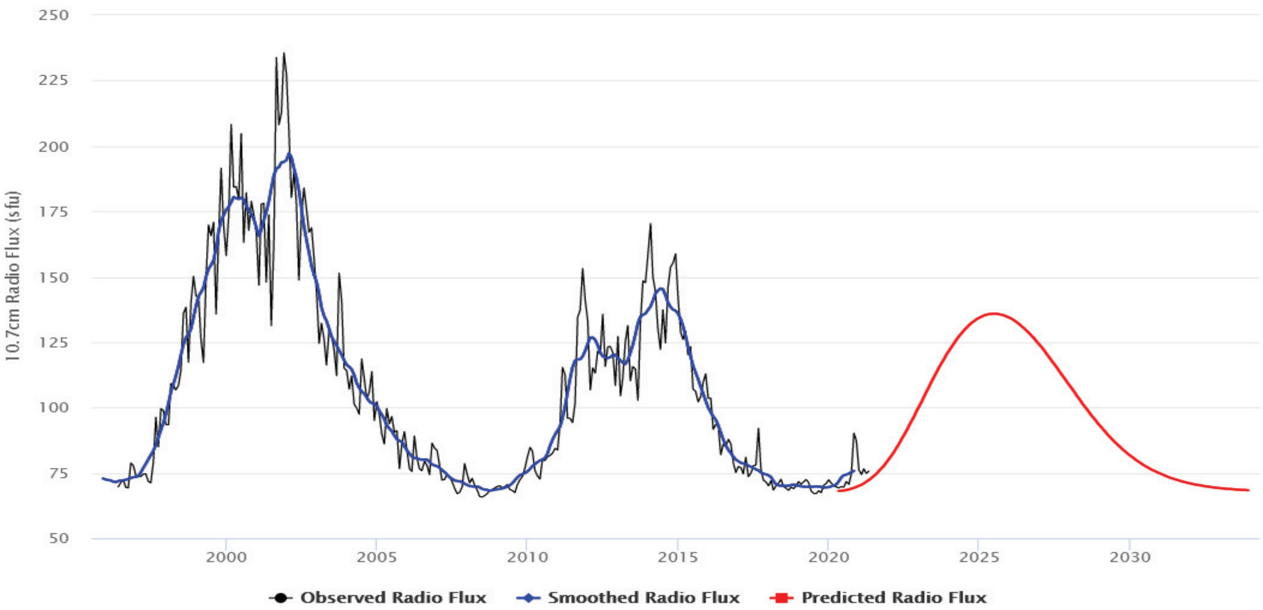

Figure 3. Solar Cycle progression – F10.7 cm Radio Flux.

Figure 4 presents the 23rd and 24th Solar Cycles progression and the predicted 25th Solar Cycle – for sunspot number.

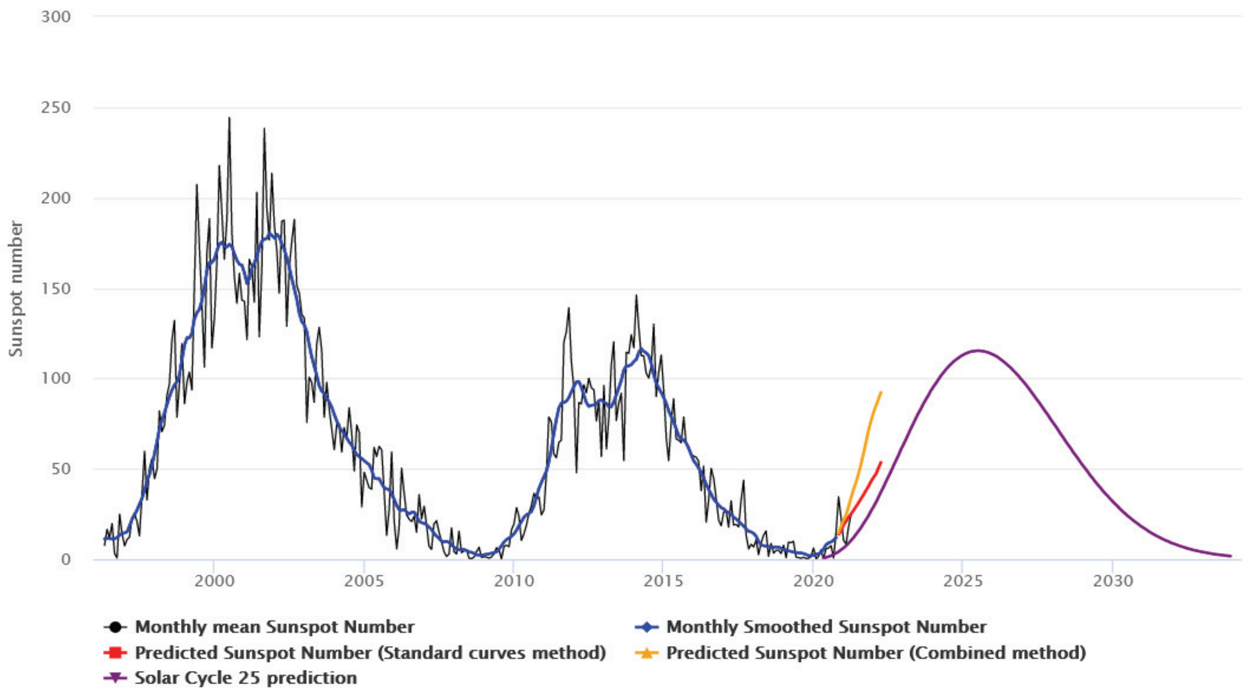

Figure 4. Solar Cycle progression – Sunspot number.

GEOMAGNETIC STORM FROM THE BEGINNING OF the 25th SOLAR CYCLE

The physical parameters of geomagnetic storm from May 12, 2021 are shown in the following figures: the number of C, M and X-class solar flares that were produced during past month together with the sunspot number of each day (Fig. 5), Kp-index (Fig. 6), the speed of the solar wind (Fig. 7), the density of the solar wind (Fig. 8), the total magnetic field (Bt) of the solar wind (Fig. 9) and the vertical magnetic field (Bz) of the solar wind (Fig. 10).

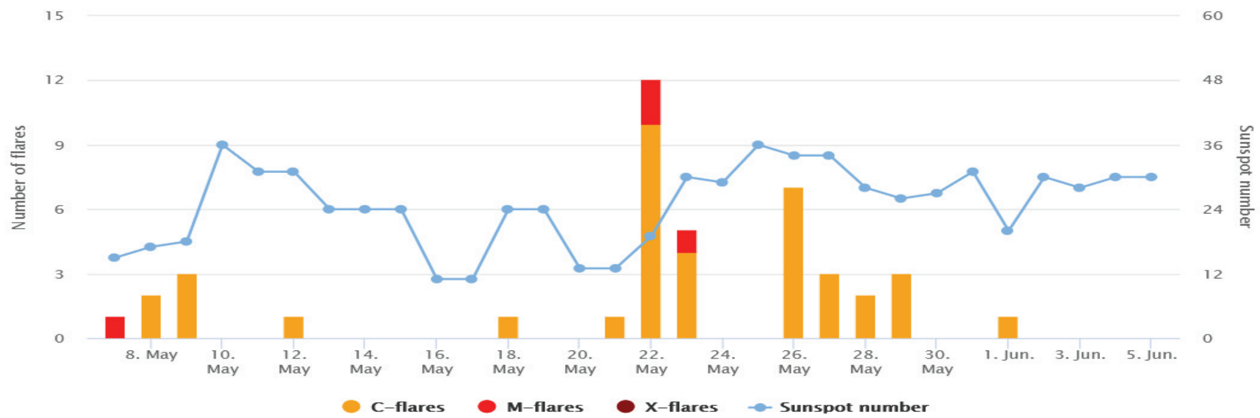

Figure 5. Number of C, M, X – class flares and sunspot number in period May 7 – June 5, 2021.

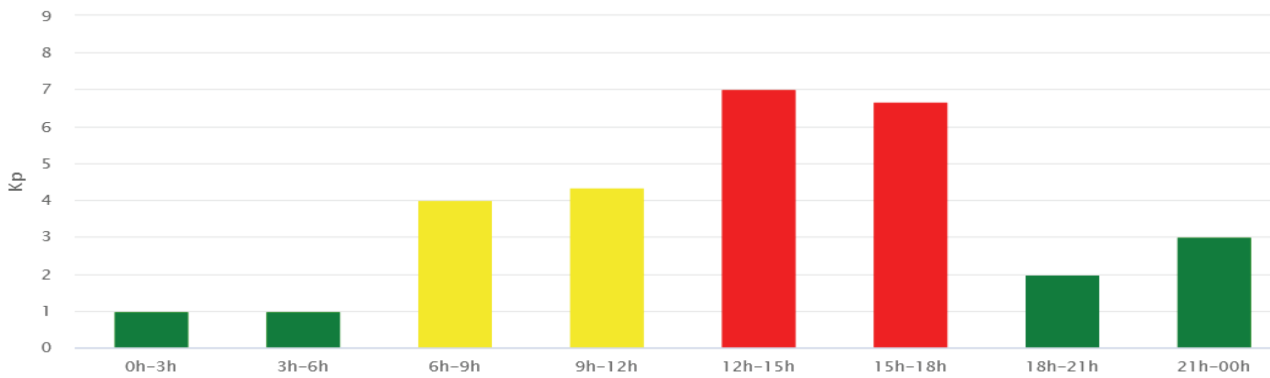

Figure 6. GFZ Potsdam official Kp-index of Wednesday, 12 May 2021.

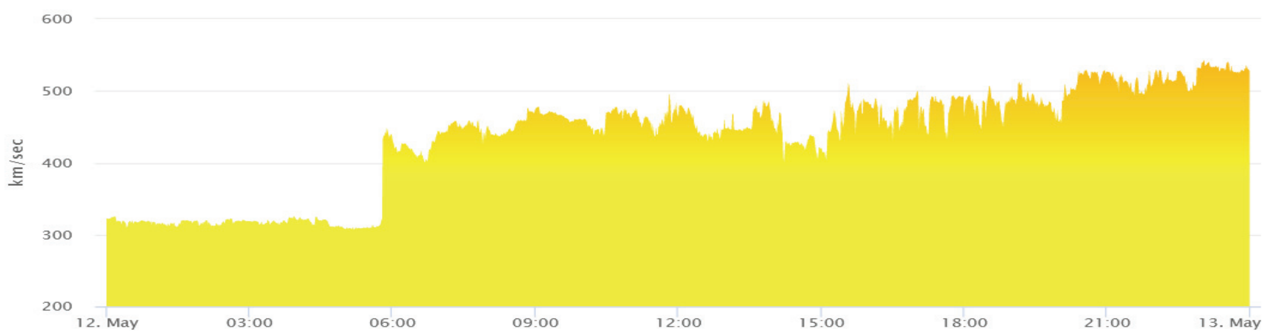

Figure 7. Solar wind (Speed) of Wednesday, 12 May 2021 (from NOAA SWPC - SpaceWheatherLive.com).

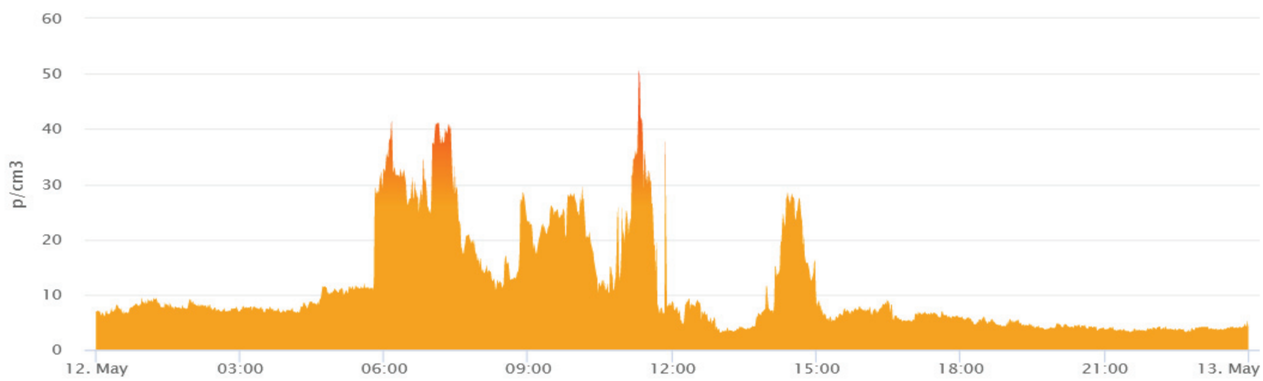

Figure 8. Solar wind (Density) of Wednesday, 12 May 2021 (from NOAA SWPC - SpaceWheatherLive.com).

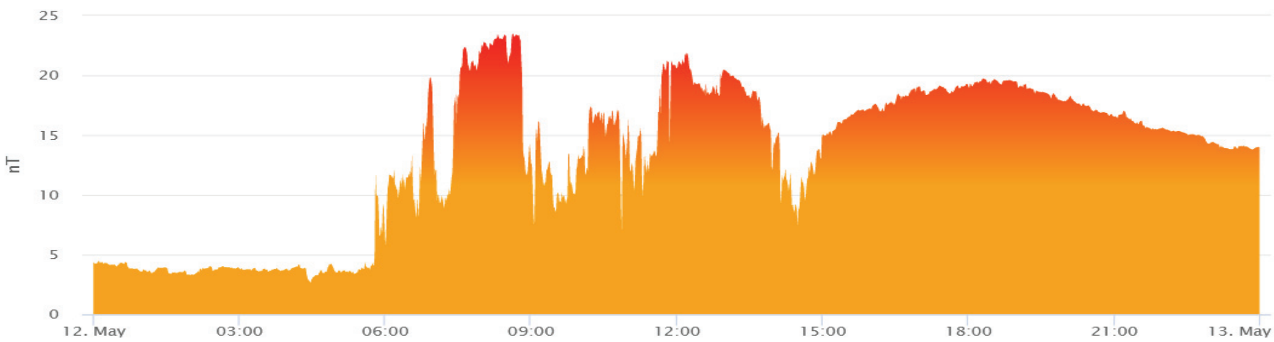

Figure 9. Solar wind, Interplanetary Magnetic Field (IMF) (Bt), of Wednesday, 12 May 2021
(from NOAA SWPC - SpaceWheatherLive.com).

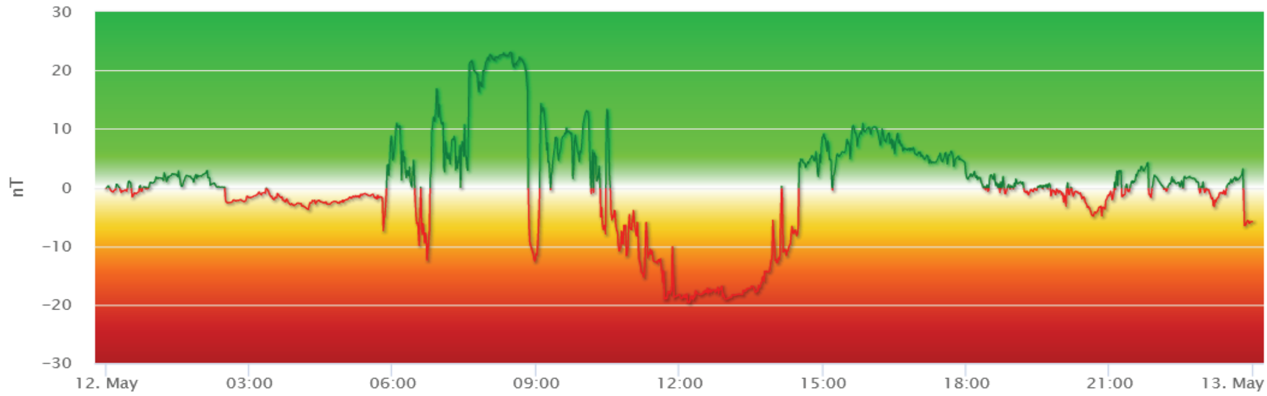

Figure 10. Solar wind, Interplanetary Magnetic Field (IMF) (Bz), of Wednesday, 12 May 2021
(from NOAA SWPC - SpaceWheatherLive.com).

Figures 11a and 11b shows the analysed geomagnetic data, sampled at 1 minute, from the Surlari Observatory, for May 12, 2021, the most recent geomagnetic storm. In top-down order we find: the geomagnetic signal recorded on the North direction, absolute coefficients for the level 5th wavelet transform with the db5 function in MATLAB, spectral analysis of North geomagnetic field and wavelet analyses.

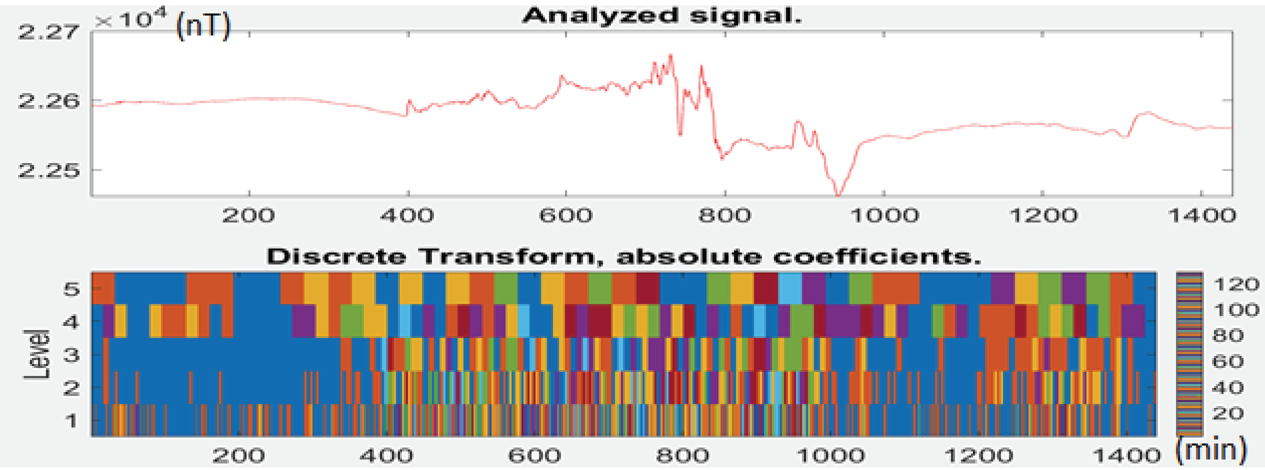

Figure 11a. The North component of the geomagnetic field, from the Surlari Observatory and absolute coefficients for the level 5th wavelet transform with the db5, for May 12, 2021.

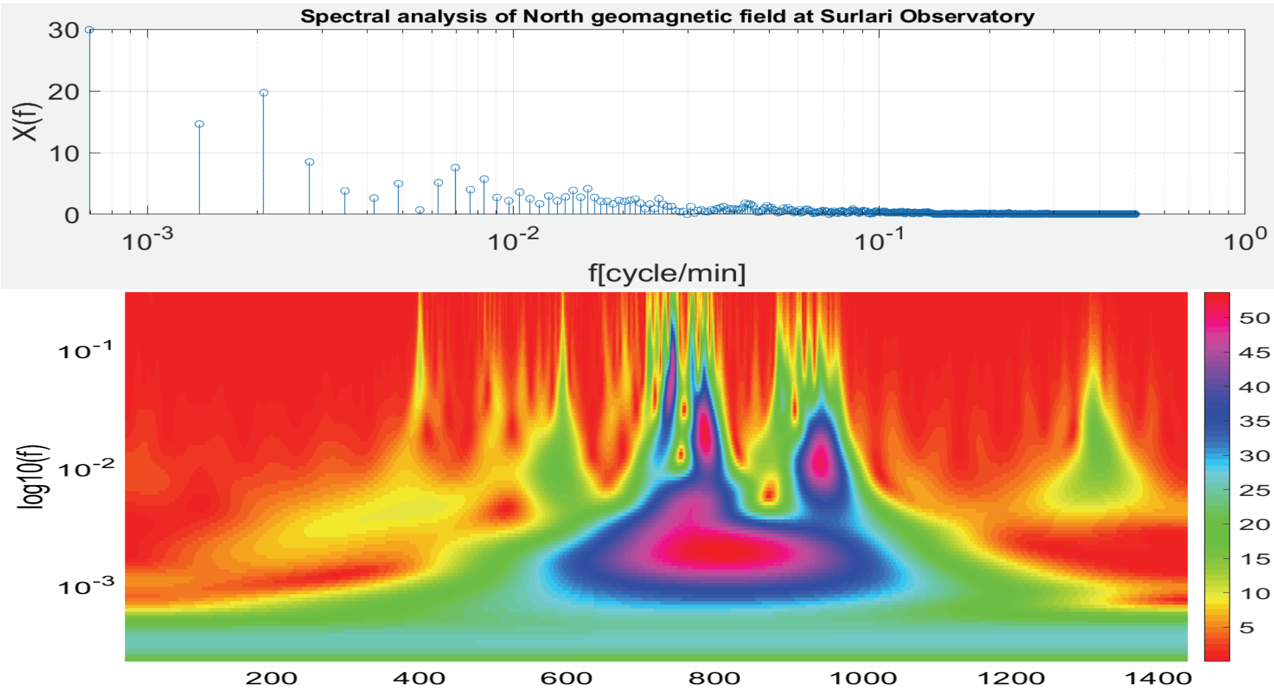

Figure 11b. Spectral and wavelet analyses for North component of geomagnetic field, from Surlari Observatory, for May 12, 2021.

Figures 12 and 13 shows the analysed geomagnetic data, sampled at 1 minute, from the Honolulu Observatory (Fig. 12) and the Uppsala Observatory (Fig. 13), for May 12, 2021. Each of these two figures comprises 3 images, in top-down order: the geomagnetic signal recorded on the North direction, the spectral analysis of the North geomagnetic field and wavelet analyses for the 5th level with the db5 function in MATLAB.

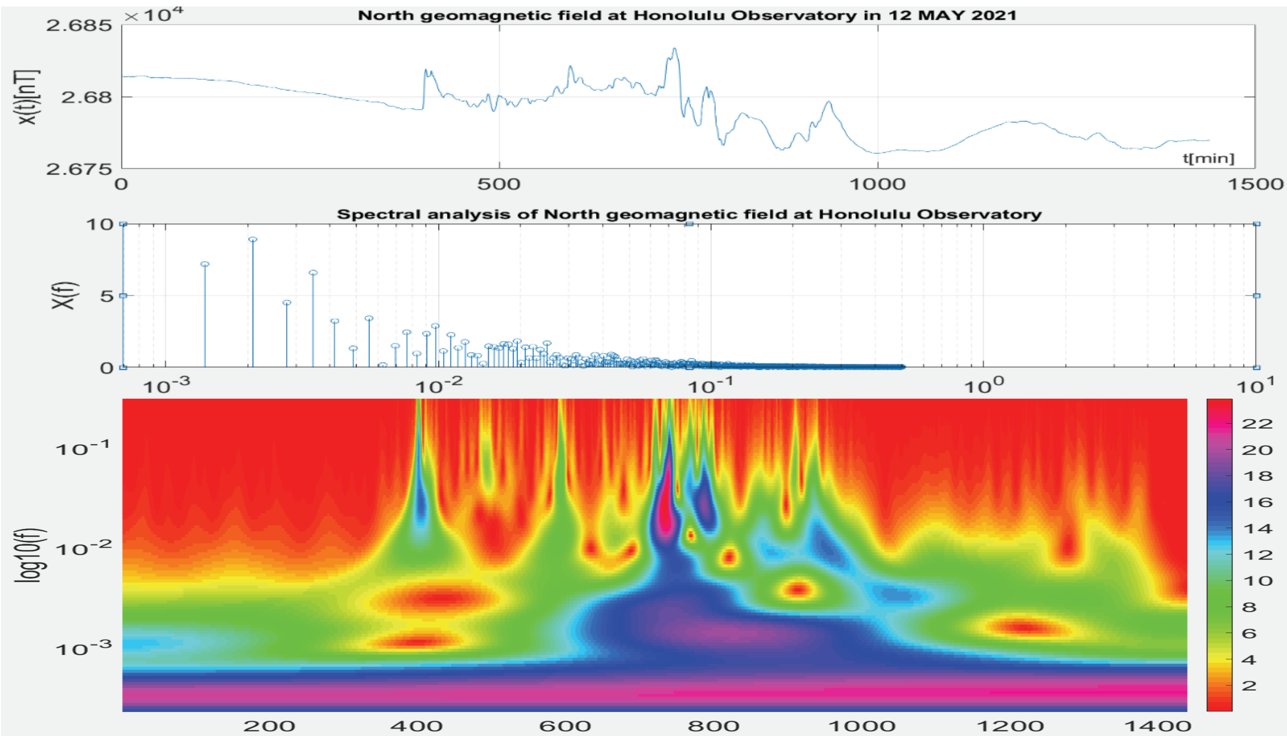

Figure 12. Spectral and wavelet analyses from data of the Honolulu Observatory for May 12, 2021.

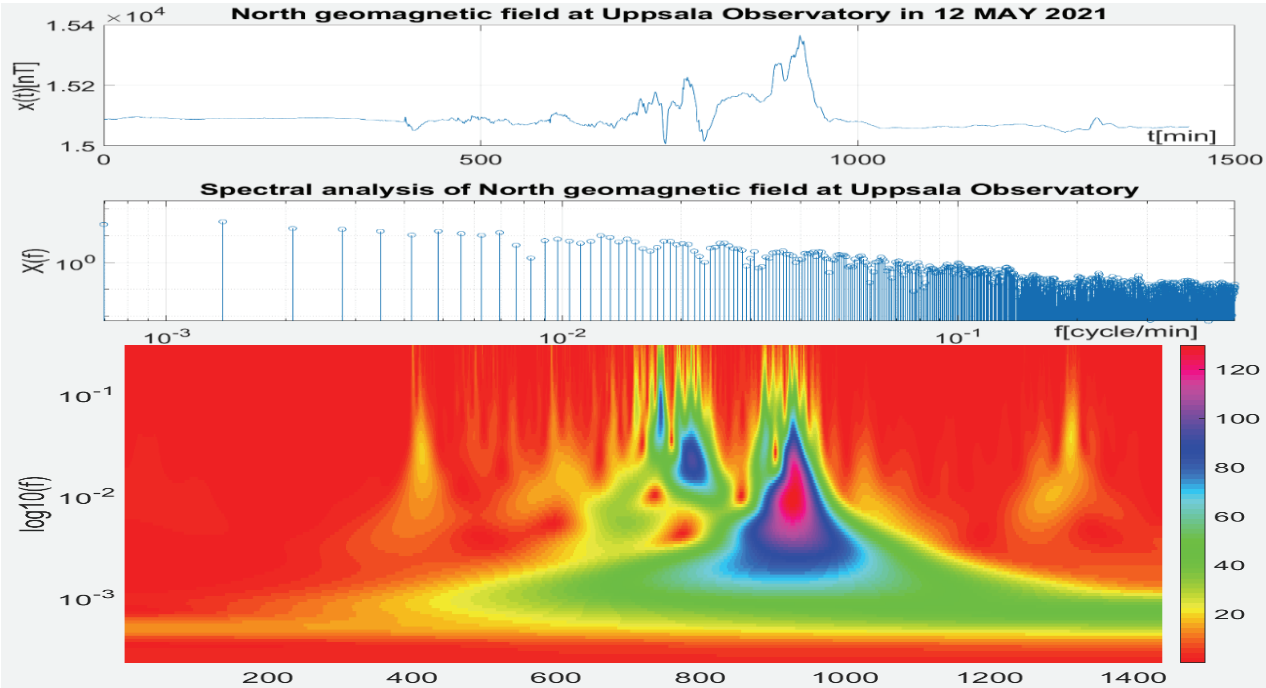

Figure 13. Spectral and wavelet analyses from data of Uppsala Observatory for May 12, 2021.

Also, we performed wavelet coherence (Fig. 14) between the Surlari and Uppsala observatories, for May 12, 2021.

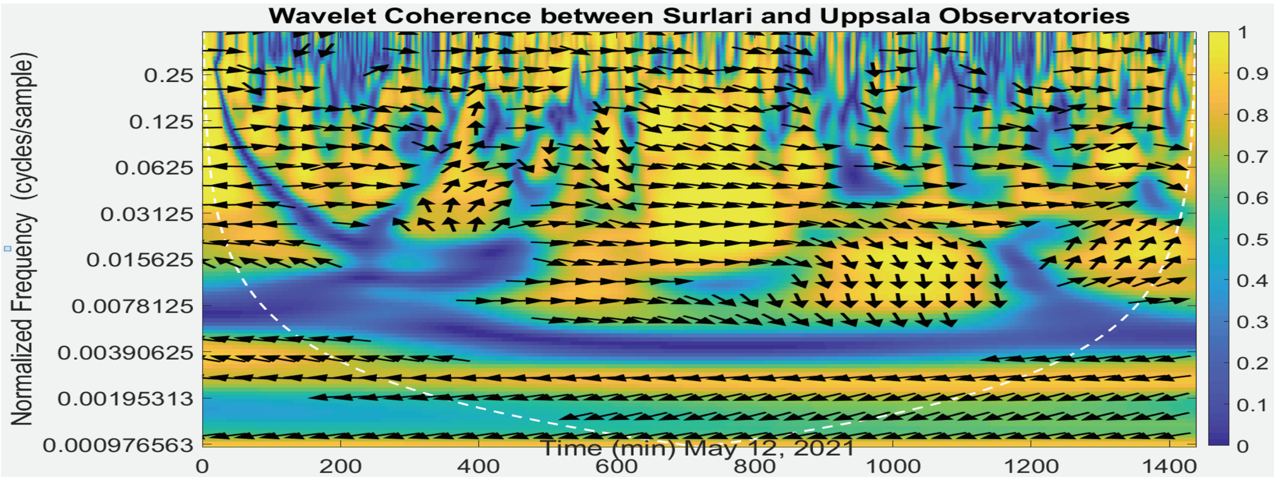

Figure 14. Wavelet coherence between Surlari and Uppsala Observatories, for North geomagnetic component, for May 12, 2021.

CONCLUSIONS

The start of solar cycle 25 was determined retrospectively. This statement of new solar cycle may not occur less than 7 months after the minimum in order to discard the possibility of a double trough.

When the start of cycle 25 was announced, a large number of spotless days that were included in cycle 24 was transferred to cycle 25.

From the beginning of the 25th Solar Cycle, the most important geomagnetic event was a storm dated May 12, 2021, with index Kp = 7. From the magnetic data sampled at 1 minute for three planetary observatories – Surlari (Romania), Uppsala (Sweden) and Honolulu (United States) – we performed spectral analysis and wavelet analysis for the northern component (most sensitive to major geomagnetic disturbances) of the geomagnetic field. We also performed wavelet coherence between these observatories.

From comparisons between the speed and density of solar wind with the analysed geomagnetic data from three observatories we can see a very good corelation between them, as well as wavelet coherence between geomagnetic data.

While the Fourier transform cannot show which of the harmonic components is present at a time in the geomagnetic data series, the wavelet analysis gives us information in the form of a three-dimensional graph (time, frequency, amplitude) or a two-dimensional shape, when the amplitude is encoded by colour intensity levels. A first step in the wavelet analysis is the Short Time Fourier Transform, applied successively with different narrow windows, for the best accuracy of time location. Increasing the window improves the resolution in frequency but decreases the resolution in time.

The wavelet transform is one of the ways of representing the signals in the multi-resolution analysis where the analysed geomagnetic signal is described by a sequence of approximations that contain more and more information. Each level of approximation contains on the one hand all the information available at the previous level plus an additional detail component.

Two modalities to statistical forecast some geomagnetic events can be: Auto-Regressive Integrated Moving Average and Machine Learning (Jupyter Notebook) procedures can be used for a large database.

ACKNOWLEDGEMENT

We thank the national institutes that support geomagnetic observatories and INTERMAGNET for promoting high standards and practice of them. Also, we thank for the support provided by the Ministry of Research for financing of the project “The realization of 3D geological / geophysical models for the characterization of some areas of economic and scientific interest in Romania”, with Contract no. 28N / 2019 and project No. 16PCCDI/2018 „Institutional capacities and services for research, monitoring and forecasting of risks in extra-atmospheric space”, within PNCDIII.

REFERENCES

ASIMOPOLOS N. S. & ASIMOPOLOS L. 2018. Study on the high-intensity geomagnetic storm from march 2015, based on terrestrial and satellite data, Micro and Nano Tehnologies & Space Tehnologies & Planetary Science. *Issue 6.1*, SGEM 2018. DOI: 10.5593/sgem2018/6.1. **18**: 593-600.

ASIMOPOLOS L., SĂNDULESCU A. M., ASIMOPOLOS N. S., NICULICI E. 2012. *Analysis of data from Surlari National Geomagnetic Observatory*. Edit. Ars Docendi. București. 96 pp.

BOX G. E. P., JENKINS G. M., REINSEL G. C., LJUNG G. M. 2016. *Time series analysis - Forecasting and Control*. Fifth Edition. John Wiley & Sons. Hoboken. New Jersey. 709 pp.

BENOIT S. L. 2012. INTERMAGNET *Technical reference manual - Version 4.6*. Murchison House West Mains Road. Edinburgh. EH9 3LA UK. 100 pp.

BISGAARD S. & KULAHCI M. 2011. *Time series analysis and forecasting by example*. John Wiley & Sons. Hoboken. New Jersey. 382 pp.

CAMPBELL W. H. 2003. *Introduction to Geomagnetic Fields*. Cambridge University Press. 350 pp.

***. https://science.nasa.gov/science-news/science-at-nasa/ (accessed February 24, 2021).

***. https://www.spaceweatherlive.com/en/solar-activity/solar-cycle.html (accessed February 28, 2021).

***. https://www.intermagnet.org/ (accessed February 22, 2021).

***. http://www.noaa.gov (accessed February 14, 2021).

***. https://www.mathworks.com (accessed February 24, 2021).

Asimopolos Laurențiu
Geological Institute of Romania
1st Caransebeş Street, 012271 - Bucharest, Romania.
E-mail: laurentiu.asimopolos@igr.ro, asimopolos@gmail.com

Asimopolos Natalia-Silvia
Geological Institute of Romania
1st Caransebeş Street, 012271 - Bucharest, Romania.
E-mail: natalia.asimopolos@igr.ro, asi_nata@yahoo.com

Asimopolos Adrian Aristide
University POLITEHNICA of Bucharest
Faculty of Transports, 313 Splaiul Independentei, 060042 - Bucharest, Romania.
E-mail: adrian.asimopolos@gmail.com

Balea Bogdan-Valeriu
Geological Institute of Romania
1st Caransebeş Street, 012271 - Bucharest, Romania.
E-mail: natalia.asimopolos@igr.ro, asi_nata@yahoo.com

Received: March 15, 2021
Accepted: August 26, 2021