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Signatures of geoeffective space weather events in cosmic rays during the ascending phase of the solar cycle 24

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Abstract:
Solar originating events are continually evident in galactic cosmic ray (GCR) flux registered at the ground by neutron monitors and in situ by space probes. We analyze time intervals of sporadic Forbush decreases (Fd) during the ascending phase of solar cycle 24. We consider cosmic rays flux, as well as, solar, heliospheric and geomagnetic activity parameters, around these periods, using different mathematical tools. Moreover, for this epoch of solar activity we compute geoelectric field for the Poland's region using a 1-D layered conductivity Earth model. Against the background of the above-mentioned parameters, we analyze the number of failures in southern Poland transmission lines. Our results reveal the increase in the superposed averaged number of failures around the appearance of solar transients visible in the GCR flux, suggesting their potential coupling.

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1. Introduction

European space weather definition states that "*Space weather is the physical and phenomenological state of natural space environments. The associated discipline aims, through observation, monitoring, analysis and modelling, at understanding and predicting the state of the sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them; and also at forecasting and nowcasting the possible impacts on biological and technological systems*" [1].
Space weather effects may be very pleasing to the eyes, generating beautiful aurora. Unfortunately, they can also have negative impacts, for instance, on electrical and electronic equipment. This is why we need to learn increasingly about the mechanisms, features, and origins of space weather events using, among others, various mathematical tools.
In many countries, the space weather issue is a part of national security policy. The White House document published in March 2019 entitled '*National Space Weather Strategy And Action Plan*' being the product of the Space Weather Operations, Research, and Mitigation Working Group, Space Weather, Security, and Hazards Subcommittee, Committee On Homeland and National Security of the National Science & Technology Council states: "*The National Science and Technology Council (NSTC), through the Space Weather Operations, Research, and Mitigation (SWORM) Working Group, has led the coordination of Federal activities to enhance American preparedness for and resilience to the effects of space weather. This National Space Weather Strategy and Action Plan provides strategic direction, identifies key actions, and calls for continued coordination across space weather and critical infrastructure stakeholders to promote American leadership in research, technology, and innovation. Through the NSTC, I am committed to coordinating the implementation of this Strategy and Action Plan across executive branch departments and agencies to build a space-weather-ready Nation*" [2].
The National Oceanic and Atmospheric Administration (NOAA) introduced Space Weather Scales as a means of informing the society about the space weather situation and their potential impacts on people and various systems. These scales pronounce the environmental instabilities for: geomagnetic storms, radio blackouts, and solar radiation storms. The scales list possible effects and display how often such events may happen. They also provide a detailed measure of the intensity of the physical reasons [3].
One of the space weather impact aspects, namely, on electrical networks, was extensively studied not only in North America [4, 5] and Scandinavia [6–8], but also in Europe: in United Kingdom [9], Spain [10], Greece [11], Italy [12, 13], Austria [14], the Czech Republic [15, 16], and finally, by us, in Poland [17–20].

2. Results

For the maxima and near maxima epochs of solar activity after the powerful coronal mass ejecta and solar flares, there are observed short period disturbances (shock waves, magnetic clouds etc.) in the interplanetary space with the drastically massive range changes of the solar wind velocity, density and the components of the IMF. As a rule, the powerful disturbances in the interplanetary space go along with the short period decreases (called Forbush decreases, Fds) of the GCR intensity. The classical, sporadic Fds appear randomly in time, rarely without any regularity, increasing its frequency in ascending and descending phases of the solar sunspot cycle. They are characterized by the rapid decrease in the GCR intensity during one-two days (as observed on Earth) followed by its gradual recovery in 5–7 days [21]. The usual amplitude (minimal GCR intensity reduction with respect to the GCR intensity in the Fds onset in %) of the Fds is about 5-20% for the GCR particles' relative energy of 10 GV (e.g., [22, 23]). Using these Fds characteristics, we have listed the sporadic Fds in the years 2010-2014. We have faced Fds occurrence against the number of electrical grids failures using the superimposed epoch analysis. Superposed epoch analysis is a method reviling relationships between the analysed time series [24]. [25] investigating the correlation of the geomagnetic storm phase with a temporal variation of plasma found at geosynchronous orbit, showed that one of the crucial factors for the plasma sheet density is phase of the solar cycle. We [17] have shown that the increase in the superposed averaged number of electrical grids failures (EGF) appears around one day after the fast halo CME occurrence, on the day of sudden storm commencement (SSC), as well as around zero-day or the day after when the Kp index was greater or equal 5.

We define the so called zero days as a key time, among the data of minimum phase of the Forbush decreases. Next, we extract subsets of data of EGFs in South Poland in January 2010- July 2014 (of particular type, for details see [18]) 3 days before and after each key time. Subsequently, we superpose all extracted subsets of failures synchronizing all zero days. Our results are shown in Figure 1a. To visualise the overall situation in the Earth vicinity we perform the Chree analysis for the same days using the data of geomagnetic Dst-index [nT] (Figure 1b), heliospheric magnetic southward component Bz[nT] (Figure 1c) and computed geoelectric field, E [mV/km] (Figure 1d). Details of $E = \sqrt{E_X^2 + E_Y^2}$ computations are given below. Figure 1 shows that the day before the Fd minimum phase there was a double growth in the EGF connected to the electronic devices, which was a day after the ~ 350 % increase in the Bz value. Two days after the Fds minima there was ~ 100 % growth in the all three groups of EGF.

We use also ML methods, such as self-organizing maps, which are a sort of artificial neural network trained with unsupervised learning [26]. Figures 2-3 display samples of our results, showing that during the Grunwald Battle Storm the EGFs caused by the aging of infrastructure elements (Figure 2) and EGF having unknown reasons (Figure 3) are in the same neutron as SWd and other solar wind properties are closely located (the blue hexagons represent neurons, and the red lines show which particular neurons are connected).

3. Summary

Analysis of each individual geoeffective event in the framework of transmission lines failures can be a clue in revealing a collective characteristic of the state of the near heliosphere, ionosphere, geomagnetosphere, which may contribute to the number of failures increase.

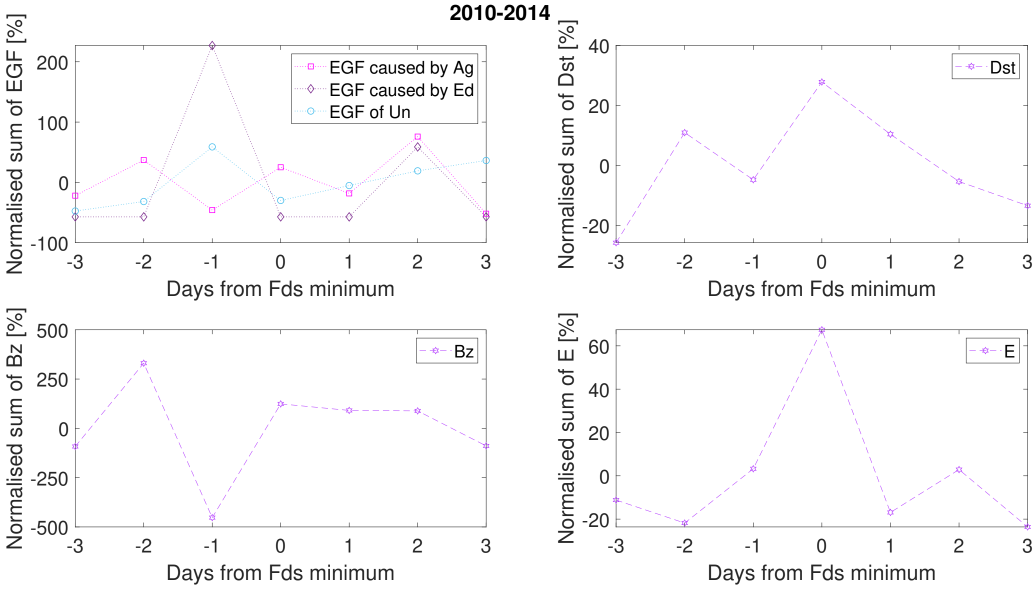

Figure 1: The superposed averaged values of (a) electrical grids failures number (caused by the aging, electronic devices breakdowns and having unknown reasons), (b) Dst-index changes, (c) Bz component of the HMF and (d) geoelectric field E, with a key time connected to the minimum time of Forbush decreases. The value of 0 on the Y axis denotes normalized average value around Fds

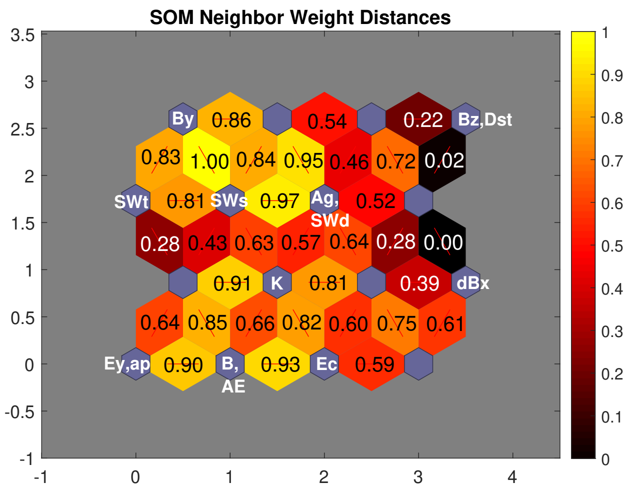

Figure 2: SOM neighbor weight distances with weight values of connections between neighboring neurons for the case when only failures caused by the aging are incorporated into the computations, around the strong geomagnetic storm on 15 July 2012. Colors from black to yellow display the weight values of the connections between neighboring neurons

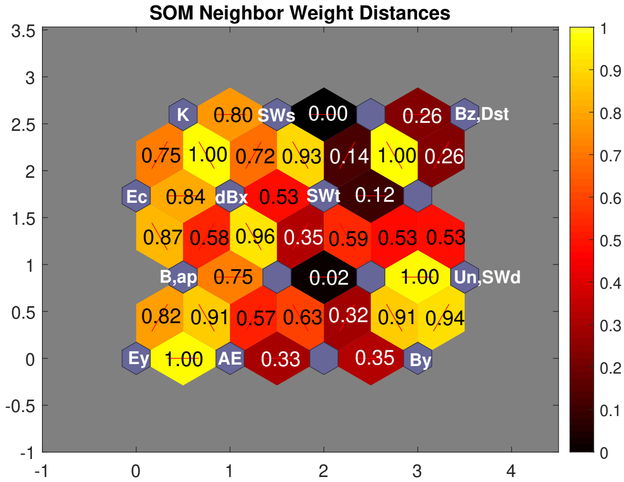

Figure 3: As in Figure 2, for the case when only failures having unknown reasons are incorporated into consideration, around the strong geomagnetic storm on 15 July 2012

References

[1] *http://www.senmes.es/pub/03COST724 – Short.pdf*

[2] *https://aerospace.org/sites/default/files/2019 – 03/Natl%20Space%20Weather%20Strategy%20Mar19.pdf*

[3] *https://www.swpc.noaa.gov/noaa – scales – explanation*

[4] *Schrijver C.J., R. Dobbins, W. Murtagh, S.M. Petrinec* Assessing the impact of space weather on the electric power grid based on insurance claims for industrial electrical equipment. Space Weather **12** (2014) 487–498

[5] *Boteler D.H., Pirjola R.J., Nevanlinna H.* The effects of geomagnetic disturbances on electrical systems at the Earth's surface. Advances in Space Research **22** (1998) 17–27

[6] *Viljanen A., Pirjola R.J.* Statistics on geomagnetically-induced currents in the Finnish 400 kV power system based on recordings of geomagnetic variations. Journal of Geomagnetism and Geoelectricity **41** (1989) 411–420

[7] *Pulkkinen A., E. Bernabeu, J. Eichner, A. Viljanen, C. Ngwira* Regional-scale high-latitude extreme geoelectric fields pertaining to geomagnetically induced currents. Earth, Planets and Space **67** (2015) 1–8

[8] *Viljanen A., R. Pirjola, E. Prácser, J. Katkalov, M. Wik* Regional-scale high-latitude extreme geoelectric fields pertaining to geomagnetically induced currents. Journal of Space Weather and Space Climate **4** (2014) A09

[9] *Oughton E. J., M. Hapgood, G. S. Richardson, C. D. Beggan, A. W. P. Thomson, M. Gibbs, C. Burnett, C. T. Gaunt, M. Trichas, R. Dada, R. B. Horne* A Risk Assessment Framework for the Socioeconomic Impacts of Electricity Transmission Infrastructure Failure Due to Space Weather: An Application to the United Kingdom. Risk Analysis **39** (2019) 5

[10] *Torta J. M., L. Serrano, J. R. Regué, A. M. Sánchez, E. Roldán* Geomagnetically induced currents in a power grid of northeastern Spain. Space Weather **10** (2012) S06002

[11] *Zois J. P.* Solar activity and transformer failures in the Greek national electric grid. Journal of Space Weather and Space Climate **3** (2013) A32

[12] *Tozzi R., P. De Michelis, I. Coco, F. Giannattasio* A preliminary risk assessment of geomagnetically induced currents over the Italian territory. Space Weather **17** (2019) 46–58

[13] *Piersanti M., P. De Michelis, D. Del Moro, R. Tozzi, M. Pezzopane, G. Consolini, M.F. Marcucci, M. Laurenza, S. Di Matteo, A. Pignalberi, V. Quattrociocchi, P. Diego* From the Sun to Earth: effects of the 25 August 2018 geomagnetic storm. Ann. Geophys. **38** (2020) 703–724

[14] *Bailey R. L., T. S. Halbedl, I. Schattauer, G. Achleitner, R. Leonhardt* Validating GIC Models With Measurements in Austria: Evaluation of Accuracy and Sensitivity to Input Parameters. Space Weather **16** (2018) 887–902

[15] *Výbošt'oková T., and M. Švanda* mmediate and delayed responses of power lines and transformers in the Czech electric power grid to geomagnetic storms. Space Weather **17** (2019) 1208–1218

[16] *Švanda M., D. Mourenas, K. Žertová, T. Výbošt'oková* Immediate and delayed responses of power lines and transformers in the Czech electric power grid to geomagnetic storms. Journal of Space Weather and Space Climate **10** (2020) 26

[17] *Gil A., R. Modzelewska, Sz. Moskwa, A. Siluszyk, M. Siluszyk, A. Wawrzynczak, S. Zakrzewska* Does time series analysis confirms the relationship between space weather effects and the failures of electrical grids in South Poland? Journal of Mathematics in Industry **9** (2019) 7

[18] *Gil A., R. Modzelewska, Sz. Moskwa, A. Siluszyk, M. Siluszyk, A. Wawrzynczak, M. Pozoga, S. Domijanski* Transmission Lines in Poland and Space Weather Effects Energies **13** (2020) 2359

[19] *Gil A., R. Modzelewska, Sz. Moskwa, A. Siluszyk, M. Siluszyk, A. Wawrzynczak, M. Pozoga, L. Tomasik* The Solar Event of 14-15 July 2012 and Its Geoeffectiveness. Sol Phys **295** (2020) 135

[20] *Gil A., Berendt-Marchel M, Modzelewska R, Moskwa S, Siluszyk A, Siluszyk M., Tomasik L., Wawrzaszek A., Wawrzynczak A.* Evaluating the relationship betweenstrong geomagnetic storms and electric grid failures in Poland using the geoelectric field as a GIC proxy. Journal of Space Weather and Space Climate **11** (2021) 30

PoS(ICRC2021)1266

[21] *Forbush S.E.* On the Effects in Cosmic-Ray Intensity Observed During the Recent Magnetic Storm. Phys. Rev. **51** (1937) 1108

[22] *Wawrzynczak A., Alania M.V.* Modeling and data analysis of a Forbush decrease. Advances in Space Research **45** (2010) 622

[23] *Wawrzynczak A., Alania M.V.* Peculiarities of galactic cosmic ray Forbush effects during October November 2003. Advances in Space Research **35** (2005) 682

[24] *Chree C.* Some Phenomena of Sunspots and of Terrestrial Magnetism at Kew Observatory. Philosophical Transactions of the Royal Society of London. Series A, Containing Papers of a Mathematical or Physical Character **212** (1913) 75–116

[25] *Denton M. H., M. F. Thomsen, H. Korth, S. Lynch, J. C. Zhang, M. W. Liemohn* Bulk plasma properties at geosynchronous orbit. Journal of Geophysical Research **110** (2005) A07223

[26] *Kohonen T.* The self-organizing map. Proceedings of the IEEE **78** (1990) 1464–1480