KIEL-UP • DOI: 10.38072/2748-3150/p14

Signs of geoeffective space weather events in cosmic rays during the first half of the solar cycle 24

Agnieszka Gil [1,2], Renata Modzelewska [1], Szczepan Moskwa [3], Agnieszka Siluszyk [1], Marek Siluszyk [1,4], Anna Wawrzaszek [2], Anna Wawrzynczak [5,6]

Correspondence

[1] Institute of Mathematics, Siedlce University of Natural Sciences and Humanities, Poland, gila@uph.edu.pl
[2] Space Research Centre, Polish Academy of Sciences, Warsaw, Poland, agil@cbk.waw.pl
[3] AGH University of Science and Technology, Krakow, Poland
[4] Military University of Aviation, Deblin, Poland
[5] Institute of Computer Sciences, Siedlce University of Natural Sciences and Humanities, Poland
[6] National Centre for Nuclear Research, Otwock, Poland

Keywords

Forbush decreases; transmission lines failures; geomagnetic storms; space weather effects

Abstract

Solar originating events are continually evident in galactic cosmic ray (GCR) flux registered at the ground by neutron monitors. We analyze time intervals of sporadic Forbush decreases (Fd) observed by neutron monitors (NM) during the first half of solar cycle 24. We consider NMs data, as well as, solar, heliospheric and geomagnetic activity parameters, around those periods, using different mathematical tools. Subsequently, an impact of space weather phenomena on energy infrastructure is well known, in the further step we consider logs from one of the Polish transmission lines operators during the time intervals of Fds. Based on the data from the Institute of Meteorology and Water Management-Polish National Research Institute we exclude from the analysis the weather-related failures. We found that the increase in the superposed averaged number of failures appears around Forbush decreases.

1. Introduction

The influence of space phenomena on functioning satellites systems (European Galileo, American GPS, Russian GLONASS and others) and space probes, communication systems, on astronauts, as well as crew and frequent passengers of aircraft, or ground energetic electrical systems and even on climate, make the understanding of the solar-terrestrial links an imperative matter (e.g. Wang et al. 2016). Variability of the Sun, continuously measured from 16th century, affects the Earth in a number of ways, depending on the level of solar activity. During the solar maximum transient phenomena as solar flares and coronal mass ejections are very frequent, leading to an increase in the injection, acceleration, and transport of solar energetic particles. Short and medium-term changes in the Sun have been identified as the cause of severe geomagnetic disturbances. A strong magnetic storm affects the normal operation of ground located electronic and electrical systems and causes damages of satellites and its equipment. These phenomena reinforce each other during the maximum of solar activity (e.g. Kudela 2009; Gopalswamy 2016; Pulkkinen 2017, and references therein). There are signatures that solar storms evolving to geomagnetic storms affect transmission lines in Poland (Gil et al. 2019, 2020a).

KIEL-UP • DOI: 10.38072/2748-3150/p14

In this context, the stream of particles of galactic cosmic ray (GCR) constantly reaching the Earth is a unique available source of information on the state of interplanetary space. In addition, terrestrial apparatus used to measure the GCR particle stream is not exposed to the influence of sudden processes on the Sun and interplanetary space and most importantly, GCR particles carry information about the global conditions prevailing in the heliosphere, and not just at one particular point, as in the case with in situ measurements made by space probes. The GCR particle flow is/was measured using various space probes, such as Voyager 1 and 2, Ulysses, ACE / CRIS, Pamela, etc., as well as unmanned balloon flights and ground detectors: neutron monitors (NMs) and muon telescopes (MTs). The global network of NMs is a unique 'instrument' for observing GCR particles in the energy range from ~ 0.5 GeV to ~ 50 GeV, continuously 'scanning' the entire sky. Because NMs are located at different latitudes, they provide information about the energy spectrum of the GCR, and this in turn gives information about the size of the heliosphere in which the cosmic rays at a given moment are modulated by the Sun. Thanks to the Neutron Monitor Data Base (NMDB), the realtime monitoring of space weather is possible (e.g. Grigoryev et al. 2019), predicting geomagnetic field disturbances with estimated preceding time from a few hours up to 1.5 days (Starodubtsev et al. 2019).

2. Forbush decreases

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. However, they are more likely to occur in the 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 (Forbush 1937). The usual amplitude (maximum 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' energy of 10 GeV (e.g. Wawrzynczak & Alania 2010, 2005). Using these Fds characteristics, we have listed the sporadic Fds in the years 2010-2014. We have compared the times of appearance of Fds with electrical grids failures using the superimposed epoch analysis.

Superposed epoch analysis is a method reviling relationships between the analysed time series (Chree 1913). Denton et al. (2005), 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 the phase of the solar cycle. Liemohn et al. (2008) studied magnetic storms features, as their occurrence time or strength. Gil et al. (2019) had 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.

KIEL-UP • DOI: 10.38072/2748-3150/p14

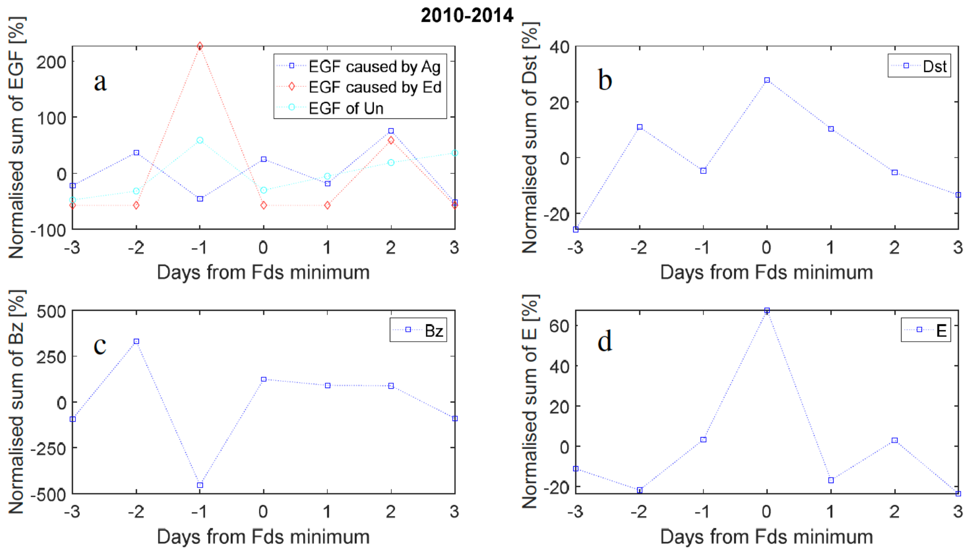

Figure 1: The superposed averaged values of (a) electrical grids failures number (caused by the aging, electronic devices breakdowns and having unknown reasons), (b) Dst-index changes, (c) Bz component of the HMF, and (d) geoelectric field E, with a key time connected to the minimum time of Forbush decreases.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

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 a particular type, for details see Gil et al. 2020a) 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 200% 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 all three groups of EGF.

3. Case study-failures during the 'Battle of Grunwald day'

We analyze the geomagnetic storm which happened on July 15 of 2012 in the 602 anniversary of the famous Polish Battle of Grunwald. Thus we propose the name for this event 'Battle of Grunwald day' (Gil et al. 2020b). According to the NOAA scale, it was a G3 geomagnetic storm with the Bz heliospheric magnetic field component dropping to -20 nT, Dst index -139 nT, AE index to 1368 nT and Ap index 132 nT. It was preceded by the solar flare of X1.4 class on 12 of July. This geomagnetic storm was accompanied by the fast halo coronal mass ejection at 16:48:05UT on 12 of July-the first C2 appearance, with the sky plane speed 885 km/s and peak speed 1415 km/s (Gopalswamy et al. 2016, 2014). This geomagnetic storm was classified as the fourth of the strongest geomagnetic storms from the solar cycle (SC) 24. During this storm, the Fd was registered.

The interplanetary fast forward shock was registered on 14 July at 17:39:09 UT (www.cfa.harvard.edu, last accessed April 8, 2021). The consequences of the disturbances in the heliosphere are also seen

KIEL-UP • DOI: 10.38072/2748-3150/p14

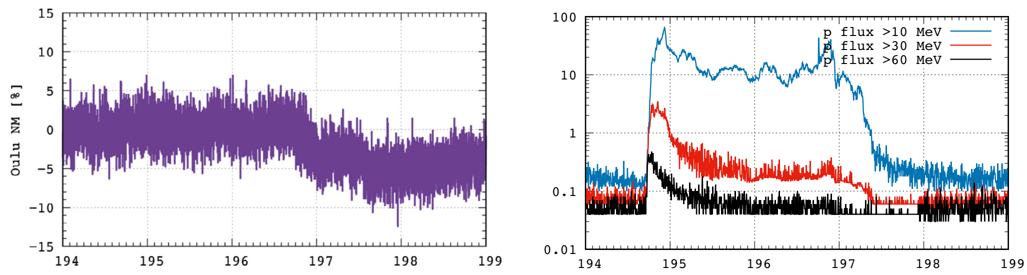

Figure 2: (a) Galactic cosmic ray intensity by Oulu neutron monitor in [%] with 1-minute resolution, (b) 5-minute integrated proton flux from OMNI, for 12-16 July 2012, DOY 194-198

in the cosmic ray flux variability. Figure 2 presents the cosmic ray proton fluxes measured in situ (figure 2b) and by Oulu neutron monitor (NM; figure 2a) for 12 – 16 July 2012.

Figure 2b shows the significant growth of proton flux on 12 July 2012 (DOY194) as a consequence of the solar flare. At 06:00 UT on 14 July 2012 (DOY196), the subsequent peak is seen in the integral proton flux > 10 MeV/n. Starting on 15 July 2012 (DOY 197), due to the CME passage, the depression in cosmic ray flux variability was observed. This decrease in cosmic ray intensity was also recorded by ground neutron monitors up to ~10- 15 GeV as confirmed by Oulu NM (figure 2a) for which the maximum depression rate was ~12%.

The evolution of this CME in the Earth vicinity simulated by Community Coordinated Modeling Center (CCMC) using ENLIL Model (Odstrcil, Smith, & Dryer 1996) of the dynamical 3-dimensional heliospheric conditions is shown in figure 3 (this CCMC animation of CMEs can be found in http://helioweather.net/archive/2012/07/, last accessed April 8, 2021). Figure 3b illustrates the interplanetary conditions measured and modeled: the solar wind radial velocity Vr, the proton density N and temperature T, as well as the heliospheric magnetic field strength |B| showing their rapid growth during the studied event.

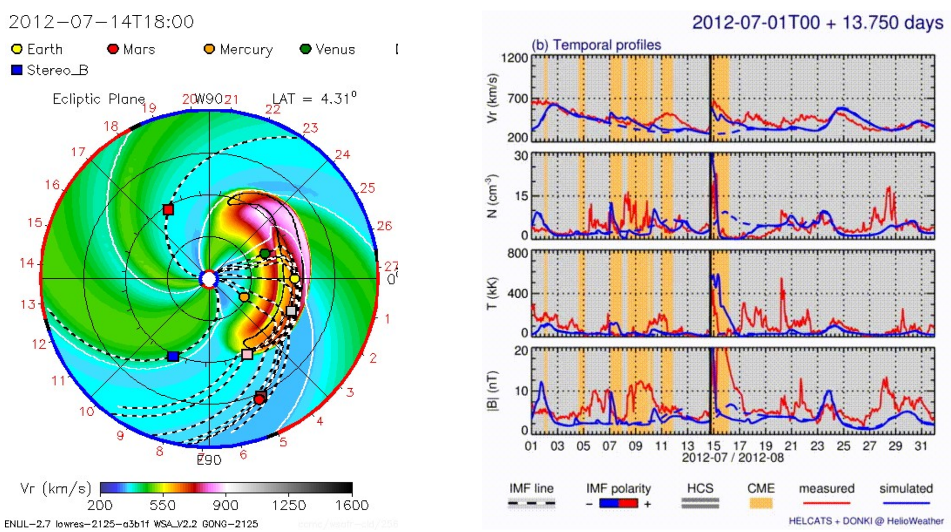

Figure 3: (a) Solar wind radial velocity contour plots in the ecliptic planes on 14 July 2012 at 18 UT, and (b) time profiles of the solar wind radial velocity Vr, proton density N and temperature T, the heliospheric magnetic field strength |B| for July 2012 with the black vertical line on 15 July 2012 at 0 UT (http://helioweather.net/archive/2012/07/vel3e1.html, ccmc.gsfc.nasa.gov, last accessed April 8, 2021)"

KIEL-UP • DOI: 10.38072/2748-3150/p14

The above-described situation was mirrored in the behaviour of Earth's magnetosphere. The dissipation processes in the CME-driven shocks (e.g., Reames et al. 1996) compressed geomagnetosphere and there appeared on July 14, 2012 at 18:09 the sudden storm commencement (SSC, http://www.obsebre.es, last accessed April 15, 2021). Firm compression of the magnetosphere, related to the above-mentioned CME arrival and passage, was detected. It was clearly visible in the horizontal B_X (N-S direction) and B_Y (E-W) geomagnetic field components measured in Belsk observatory, which served as basic data for computations of the geoelectric field with the induced surface geoelectric field according to the methodology introduced by Boteler (1994) and later developed (Boteler 2013).

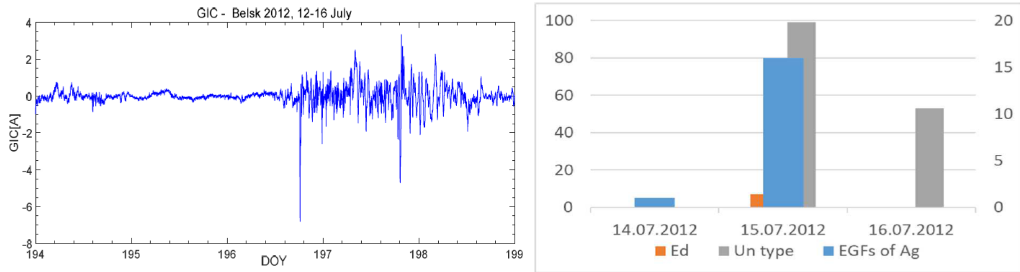

Figure: 4 (a) Computed geomagnetically induced currents (1-min resolution) for 12-16 July 2012, DOY 194-198, (b) electrical grids failures (1-h resolution), for 14-16 July 2012, DOY 196-198.

We applied the layered Earth model with resistivity according to Adam et al. (2012). Computations of the geomagnetically induced currents GIC presented in figure 4a were done by formula with $GIC = a \cdot E_x + b \cdot E_y$ (a, b) = (−62.3,133.2) Akm/V, following Wik et al. (2008). We can observe strong fluctuations in the computed GIC during the presented event.

Around that time in Polish electric transmission lines infrastructure, there was observed significant growth of the number of failures (figure 4b), which reasons might be of solar origin, namely, caused by the aging, electronic devices breakdowns and having unknown reasons (a detailed description can be found in Gil et al. 2020a). The appearance of some delay between the EGFs increase and solar disturbances in the Earth's vicinity is discussed in Švanda et al. 2020, Gil et al. 2019, and Zois 2013.

4. 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.

Acknowledgments

Data of cosmic rays are from OULU station (http://cosmicrays.oulu.fi). Data of geomagnetic field components are from Belsk observatory, the part of INTERMAGNET (http://rtbel.igf.edu.pl), heliospheric data are from OMNI (https://omniweb.gsfc.nasa.gov). The ENLIL simulation results have been provided by the Community Coordinated Modeling Center at Goddard Space Flight Center (http://ccmc.gsfc.nasa.gov). The ENLIL Model was developed by Dusan Odstrcil, now at the George Mason University - Space Weather Lab and NASA/GSFC - Space Weather Lab. We acknowledge the financial support by the Polish National Science Centre, grant no. 2016/22/E/HS5/00406.

KIEL-UP • DOI: 10.38072/2748-3150/p14

References

Adam, A., Pracser, E., Wesztergom, V., 2012, Acta Geod. Geophys. Hung., 47, 377, DOI: https://dx.doi.org/10.1556/ageod.47.2012.4.1

Boteler, D.H., 2013, IEEE Power & Energy Society General Meeting, Vancouver, BC, 2013, 1-5. DOI: https://dx.doi.org/10.1109/PESMG.2013.6672717

Boteler, D. H., 1994, IEEE Trans. Magn., 30, 172, DOI: https://dx.doi.org/10.1109/20.312255

Chree, C., 1913, Philosophical Transactions of the Royal Society of London. Series A, Containing Papers of a Mathematical or Physical Character, 212, 75

Denton, M. H., Thomsen, M. F., Korth, H., et al. 2005, J. of Geophysical Research, 110, A07223, DOI: https://dx.doi.org/10.1029/2004JA010861

Gil, A., Modzelewska, R., Moskwa, Sz., et al. 2020a, Energies, 13, 2359, DOI: https://dx.doi.org/10.3390/en13092359

Gil, A., Modzelewska, R., Moskwa, Sz., et al. 2020b, Solar Physics, 295, 135, DOI: https://dx.doi.org/10.1007/s11207-020-01703-2

Gil, A., Modzelewska, R., Moskwa, Sz., et al. 2019, Journal of Mathematics in Industry, 9, 7, DOI: https://dx.doi.org/10.1186/s13362-019-0064-9

Forbush, S. E., 1937, Phys. Rev., 51, 1108–1109

Gopalswamy, N., Yashiro, S., Thakur, N., et al. 2016, Ap. J., 833 2, article id. 216, DOI: https://dx.doi.org/10.3847/1538-4357/833/2/216

Gopalswamy, N., 2016, Geoscience Letters, 3, article id.8, DOI: https://dx.doi.org/10.1186/s40562-016-0039-2

Gopalswamy, N., Xie, H., Akiyama, S., et al. 2014, Earth, Planets and Space, 66 104, DOI: https://dx.doi.org/10.1186/1880-5981-66-104

Grigoryev, V. G., Starodubtsev, S. A., Gololobov, P. Yu., 2019, Solar-terrestrial physics, 5, 3, 93

Kudela, K., 2009, Acta Phys. Slovaca, 59, 537

Liemohn, M. W., Zhang, J.-C., Thomsen, M. F., et al. 2008, Geophysical Research Letter, 35, L06S06, DOI: https://dx.doi.org/10.1029/2007GL031717

Odstrcil, D., Smith, Z., Dryer M., 1996, Geophys. Res. Lett. 23, Issue 18, 2521, DOI: https://dx.doi.org/10.1029/96GL00159

Pulkkinen, A., Bernabeu, E., Thomson, A., et al. 2017, Space Weather, 15, 7, 828, DOI: https://dx.doi.org/10.1002/2016SW001501

Reames, D. V., Barbier, L. M., Ng, C. K., 1996, Astrophysical Journal, 466, 473-486, DOI: https://dx.doi.org/10.1086/177525

Starodubtsev, S. A., Grigoryev, V. G., Gololobov, P. Yu., 2019, Journal of Physics. Conference Series, 1181, 012011, DOI: https://dx.doi.org/10.1088/1742-6596/1181/1/012011

Švanda, M., Mourenas, D., Žertová, K., et al. 2020, J. Space Weather Space Clim., 10, 26 DOI: https://dx.doi.org/10.1051/swsc/2020025

Wang Ch., Rosen, I. G., Tsurutani, B. T., et al. 2016, J. Space Weather Space Clim., Volume 6, A5, DOI: https://dx.doi.org/10.1051/swsc/2015046

Wawrzynczak, A., Alania M. V., 2010, Advanced in Space Research, 45, 5, 622-631, DOI: https://dx.doi.org/10.1016/j.asr.2009.09.005

Wawrzynczak, A., Alania M. V., 2005, Advanced in Space Research, 35, 682-686, DOI: https://dx.doi.org/10.1016/j.asr.2004.12.055

Wik, M., Viljanen, A., Pirjola, R., et al. 2008, Space Weather, 6, 7, DOI: https://dx.doi.org/10.1029/2007SW000343

Zois, J. P., 2013, J. Space Weather and Space Climate, 3, A32, DOI: https://dx.doi.org/10.1051/swsc/2013055

Questions and answers

Rolf Bütikofer: How can we use this result for spwx purposes?
Answer: This work still needs to be continued, but in a future it could be used in practice: transmission lines operators, who would gain knowledge about the increased risk of small power grids failures, which would be associated with the upcoming geomagnetic storm, could organize more energy-rescue-teams at that time, which would have resulted in the shortening the duration of these minor breakdowns, and thus reducing the costs related to non-delivered electricity.

Ludwig Klein: Are there comparisons with countries at comparable latitudes as to the occurrence of failures?
Answer: There are paper showing even more south countries than Poland, e.g. Czech Republic (e.g. Švanda et al. 2020, DOI: https://dx.doi.org/10.1051/swsc/2020025), Greece (e.g., Zois 2013, DOI: https://dx.doi.org/10.1051/swsc/2013055) or Italy (e.g. Tozzi 2019, DOI: https://dx.doi.org/10.1029/2018SW002065).