Relationships between strong geomagnetic storms and electric grid failures in Poland using the geoelectric field as a GIC proxy during the first half of the Solar Cycle 24

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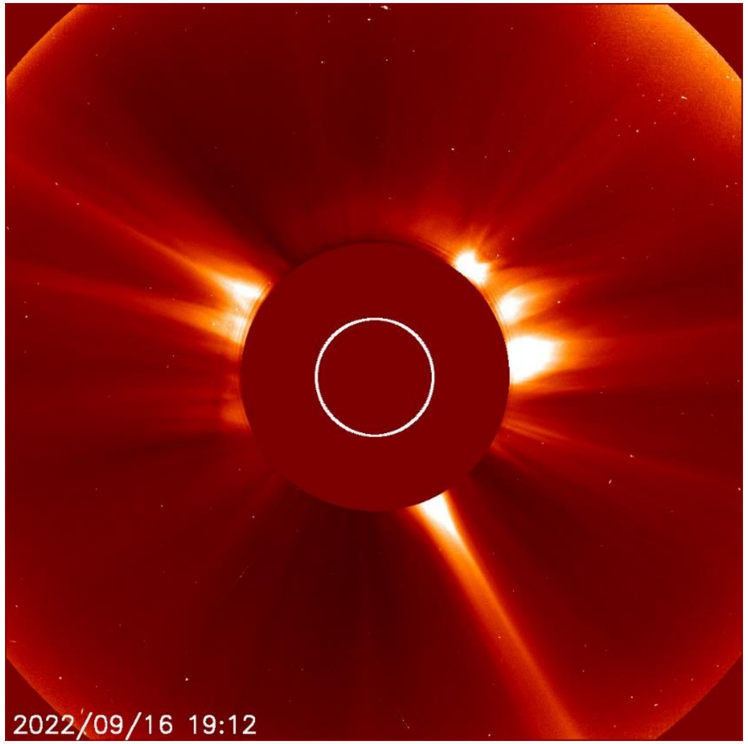
Outline

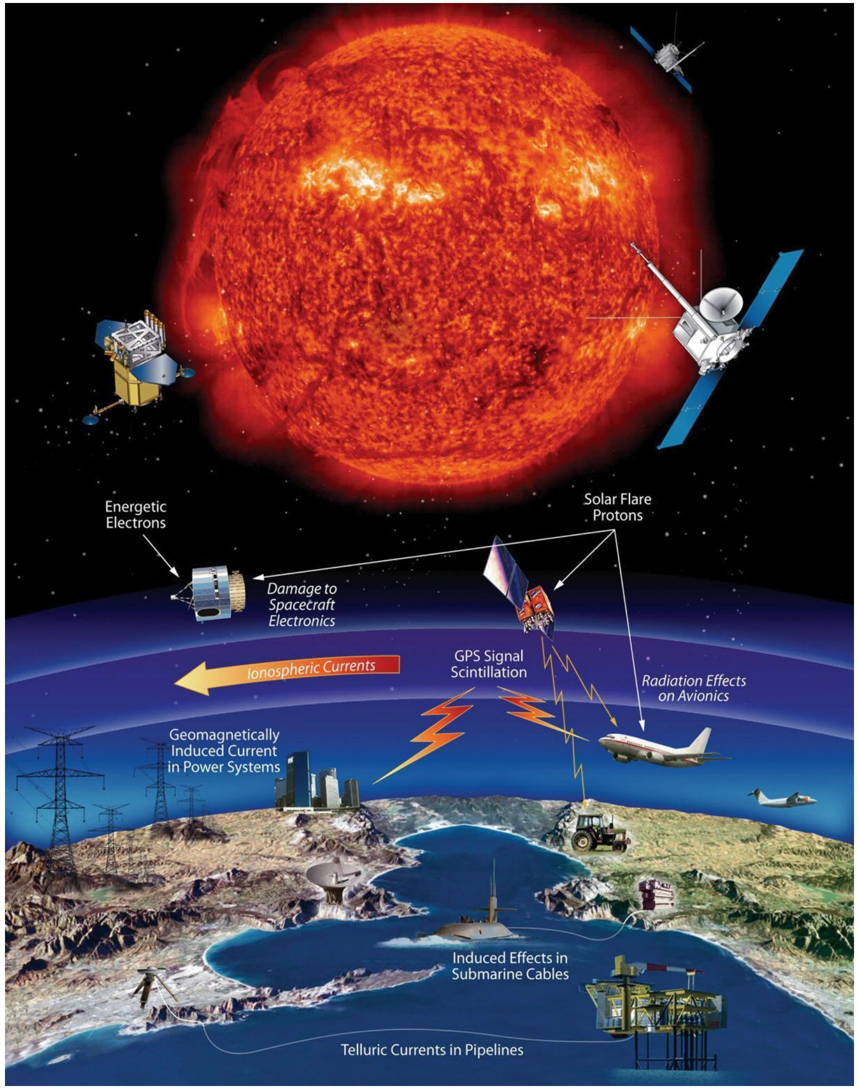
Space weather effects: GIC

EGFs in Poland

EGF during geomagnetic storms

Summary





www.nasa.gov

Motivation

The subject of our studies are intense geomagnetic storms (Dst < -100nT) observed during the first half of the Solar Cycle 24 . These type of geomagnetic storms appeared only a few times. They were primarily associated with southwardly directed heliospheric magnetic field Bz and preceded by halo or partial halo coronal mass ejecta. Using various methods, such as self-organizing maps, statistical and superposed epoch analysis, we show that during and right after intense geomagnetic storms there is a growth in the number of transmission line failures. We also look at the temporal changes in the number of failures during 2010-2014 and find that the growing linear tendency of the occurrence of electrical grid failures is possibly related to solar activity. Finally, we compare these results with the geoelectric field calculated for the region of Poland using one-dimensional layered conductivity Earth model.

The northern lights in Wegorzewo, Poland, 17.08.2022, 22:30, by Paweł Gajda

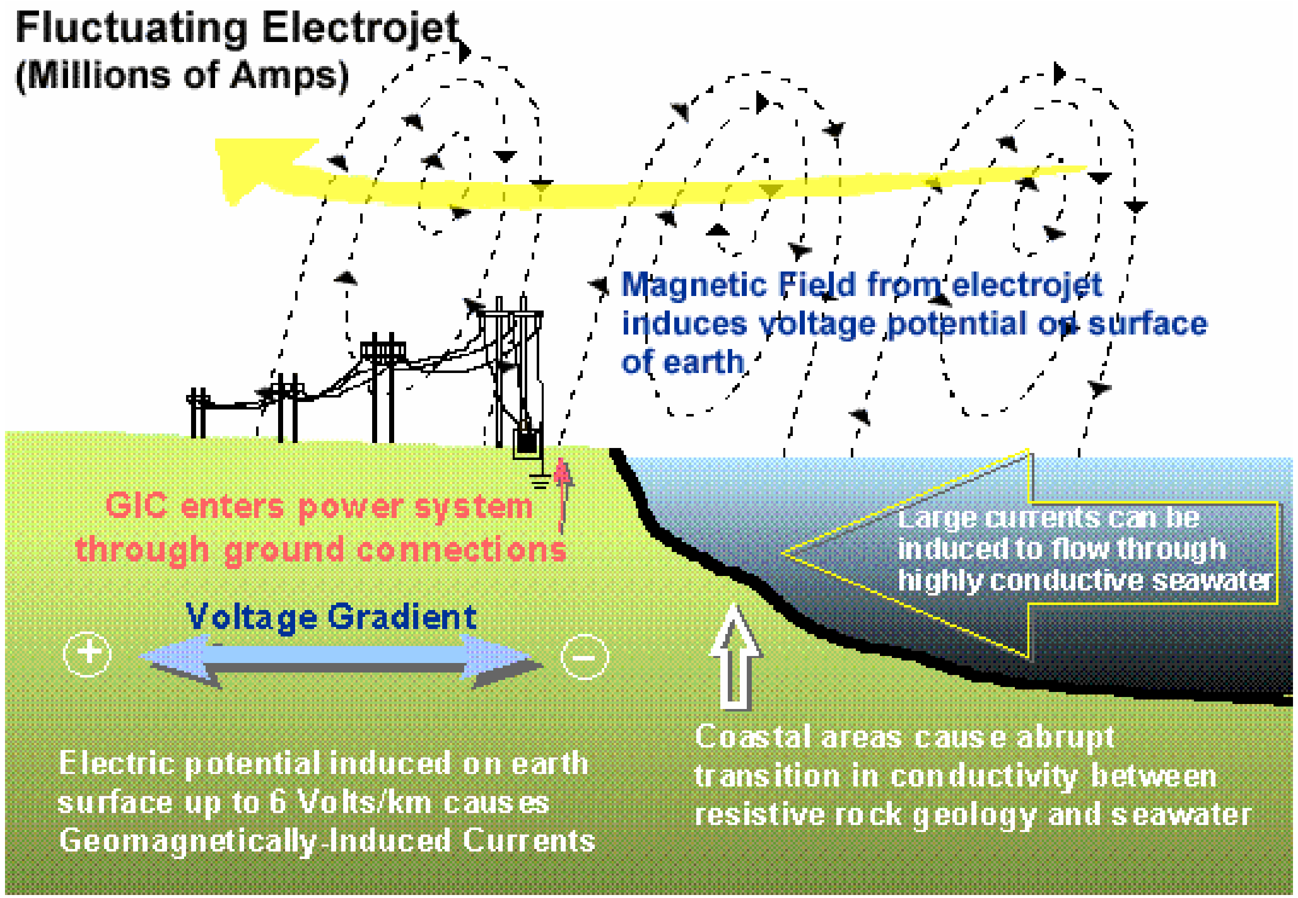
GIC

-electrical grids

- pipelines

-telecommunication cables

- railways

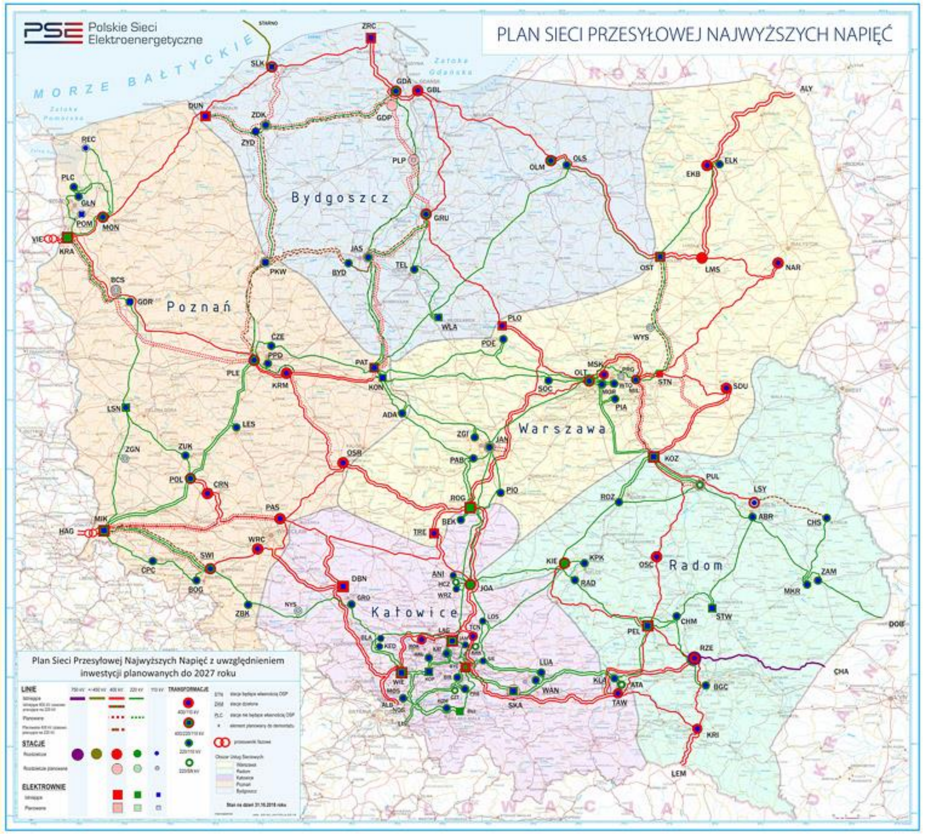


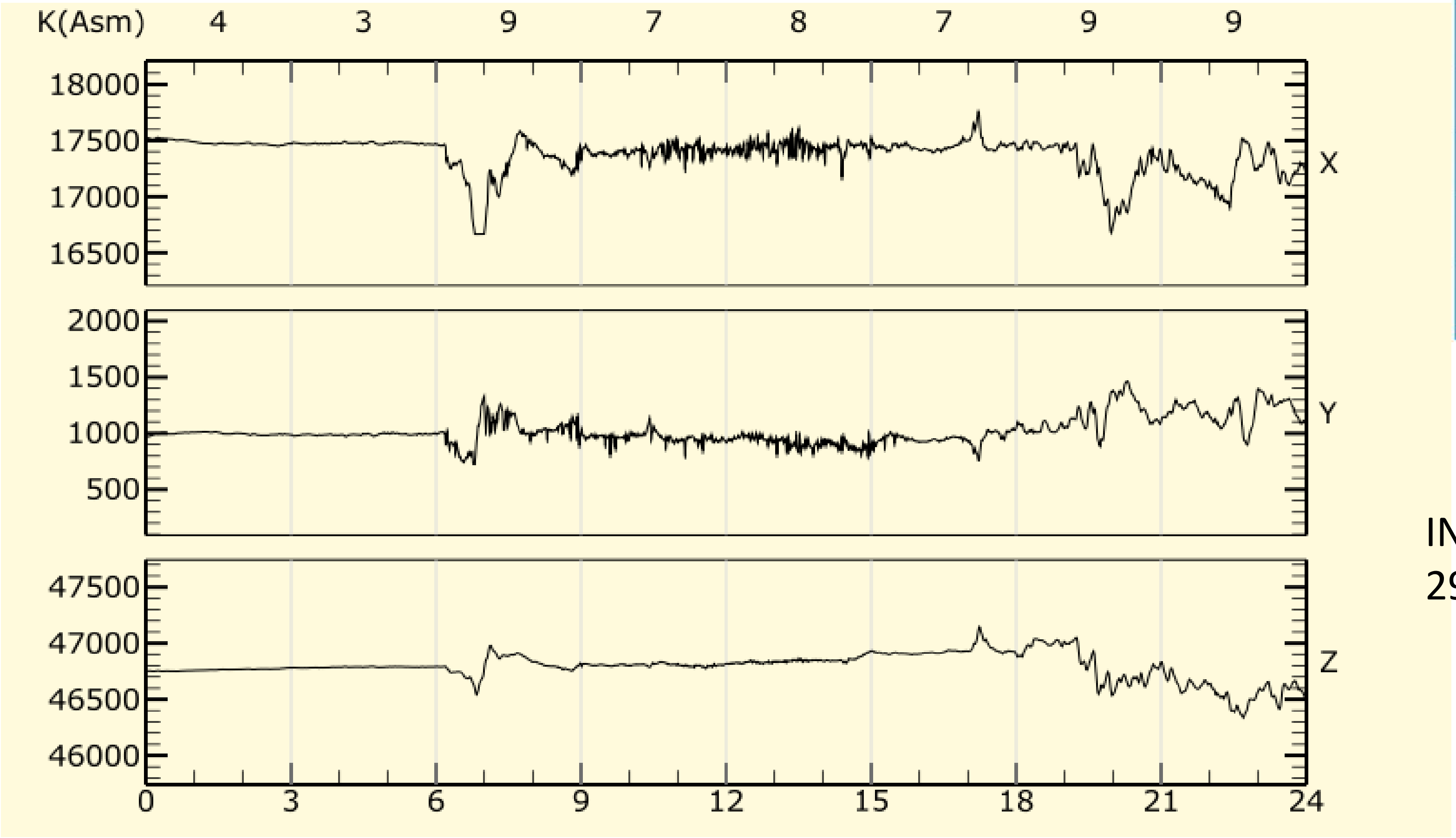
http://www.metatechcorp.com/

Malmö blackout, 30.10.2003

29.10.2003, 07:46 interrupted import from Poland to Sweden, 300 MW, SwePol Link

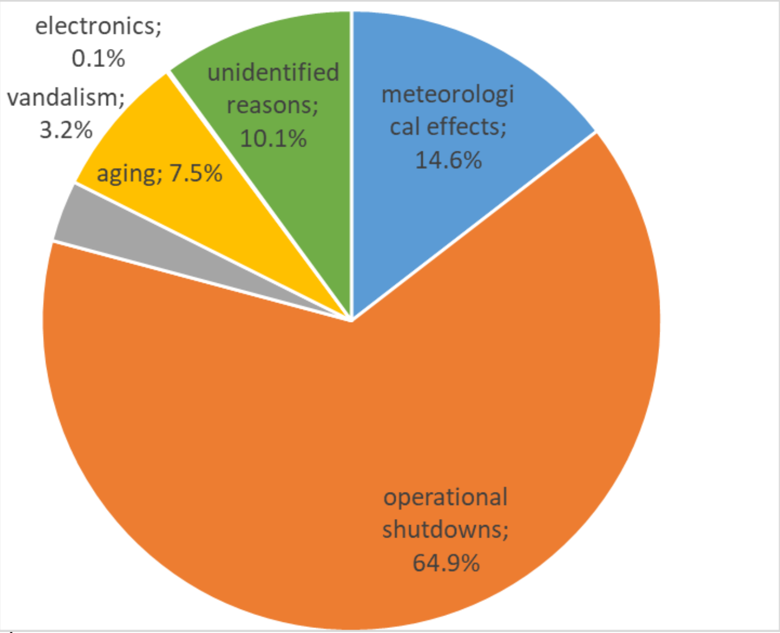
Pulkkinen et al., 2005

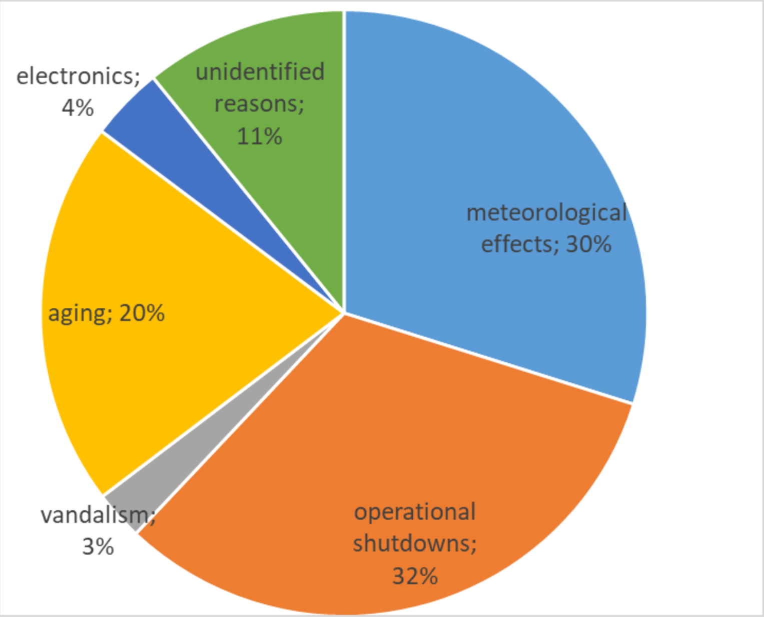




INTERMAGNET: Magnetogram, Hel, 29.10.2003

no.	reasons in 2014	main groups	number	%
1	storm		5195	17.2
2	ice& snow & rime		124	0.4
3	rime		197	0.7
4	rime& tree& branch		271	0.9
5	snow		154	0.5
6	snow& tree& branch		30	0.1
7	wind		1272	4.2
8	wind& tree& branch	A: meteorological effects	1761	5.8
		Total A	**9004**	**29.8**
9	protection devices		1065	3.5
10	switching		3800	12.6
11	planned breaks		3924	13.0
12	another operator		337	1.1
13	works of own brigades		38	0.1
14	open object		193	0.6
15	closed object		160	0.5
16	at the recipient		69	0.2
17	in order to save people		1	0.0
18	switching activities		6	0.0
19	assembly defects	B: operational shutdowns	110	0.4
		Total B	**9703**	**32.0**
20	charges, theft, disassembly		410	1.4
21	cutting down trees by other parties		132	0.4
22	fire		105	0.3
23	digging	C: vandalism	145	0.5
		Total C	**792**	**2.6**
24	aging		3135	10.4
25	local impairment of insulation	D: aging	3074	10.2
		Total D	**6209**	**20.6**
26	fuse		1	0.0
27	power system protection automation and telemechanics		1178	3.9
28	secondary circuits and power system protection automation	E: electronics devices	2	0.0
		Total E	**1181**	**3.91**
29	unidentified	**F: unidentified**	**3266**	**10.8**
		TOTAL	30155	100.0

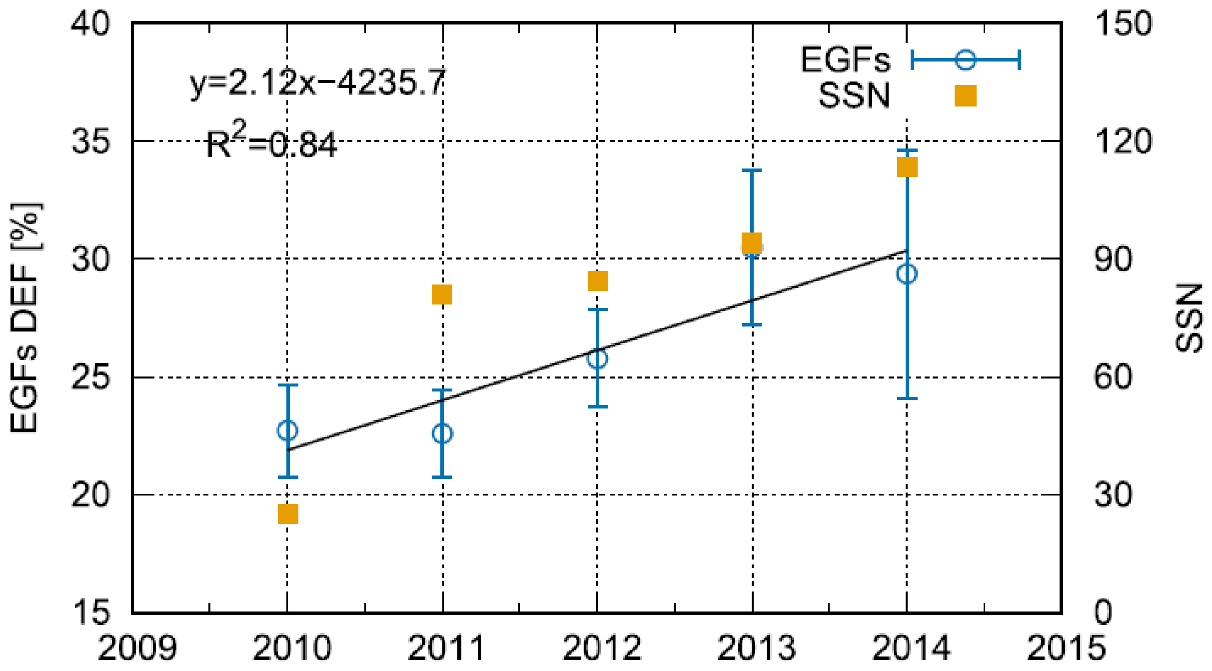




Six general clusters of the electrical grids failures' causes in 2010 (left) and 2014 (right)

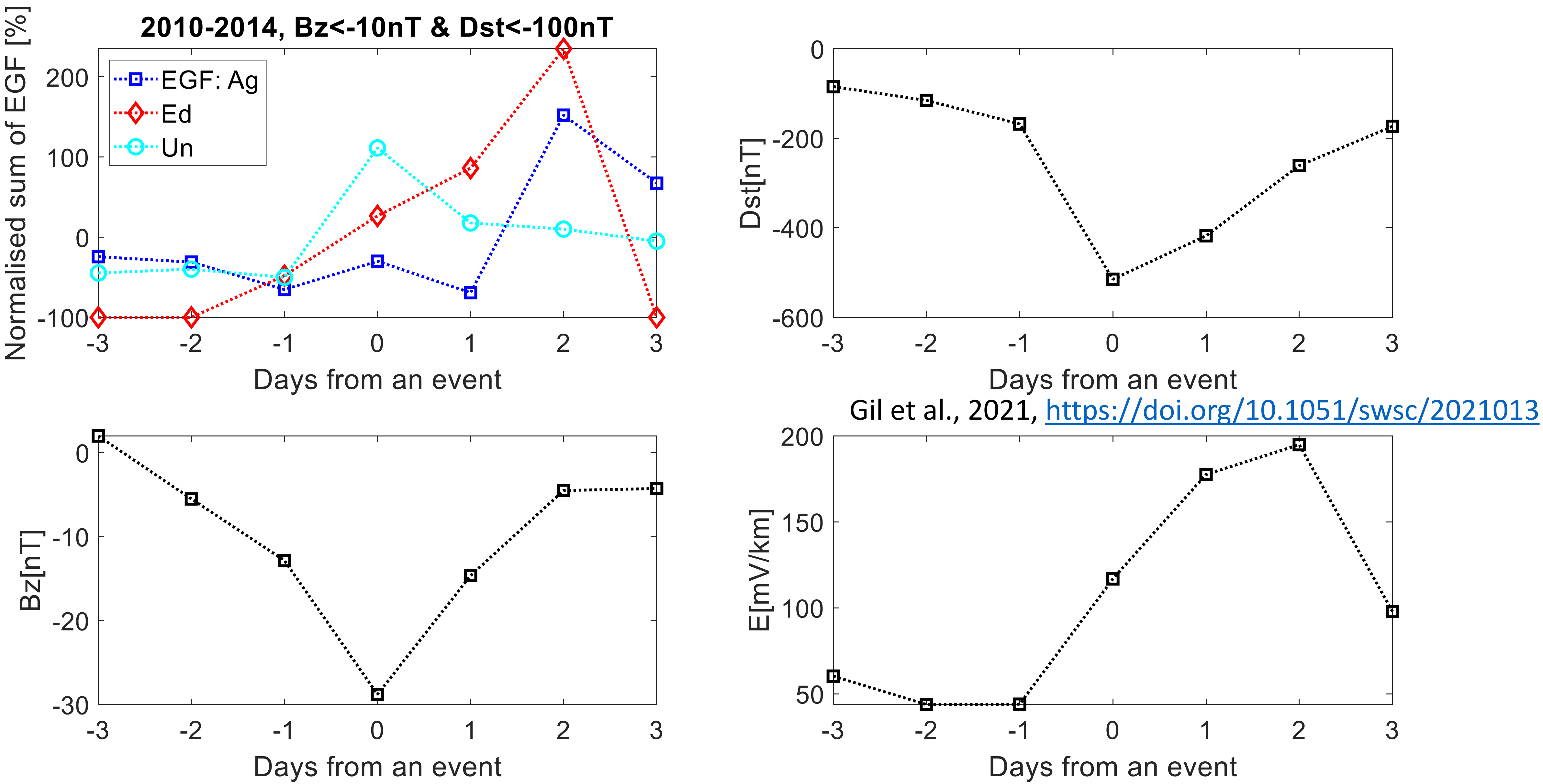
Gil i in., 2019a

https://doi.org/10.1186/s13362-019-0064-9



Linear regression of the annual percentage rate of EGFs from three groups which might be of solar origin in 01.2010–07.2014 (circles, left axis) and yearly changes of SSN (squares, right axis).

Gil et al., 2021;
https://doi.org/10.1051/swsc/2021013



% above normalised sum of daily EGFs (a), averaged over the number of events (b) Dst-index[nT], (c) Bz[nT] component of HMF and (d) computed geoelectric field E[mV/km], for years 2010-2014 in the case when: Dst < -100 nT and Bz < -10 nT

Transfer Function - 1D model

Earth conductivity varies in all directions, but the greatest variation is with depth

Layered Conductivity Model

N layers, each specified by conductivity (σ_n) and thickness (l_n)

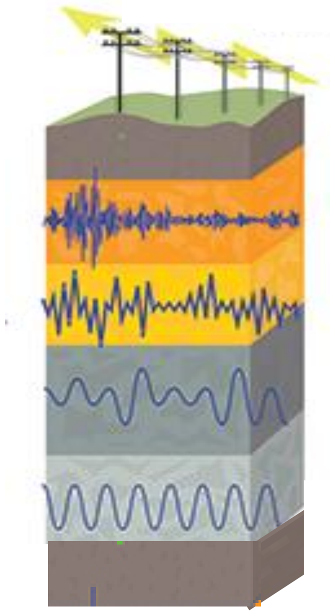
$$K_n = \eta_n \frac{K_{n+1}(1 + e^{-2k_n l_n}) + \eta_n(1 - e^{-2k_n l_n})}{K_{n+1}(1 - e^{-2k_n l_n}) + \eta_n(1 + e^{-2k_n l_n})}$$

$$\eta_n = \frac{i2\pi f}{k_n}$$

$$k_n = \sqrt{i2\pi f \mu_0 \sigma_n}$$

$$\mu_0 = 4\pi 10^{-7} \mathrm{H}^{-1}\mathrm{m}$$

$$K_N = \sqrt{\frac{i2\pi f}{\mu_0 \sigma_N}}$$



$$B(t)$$

↓

$$F\{B(t)\}$$

↓

$$K(f)$$

↓

$$E(t) = F^{-1}[K(f)\,F\{B(t)\}]$$

[Boteler, D., 2012; Boteler and Pirjola, 2019]

Conductivity models

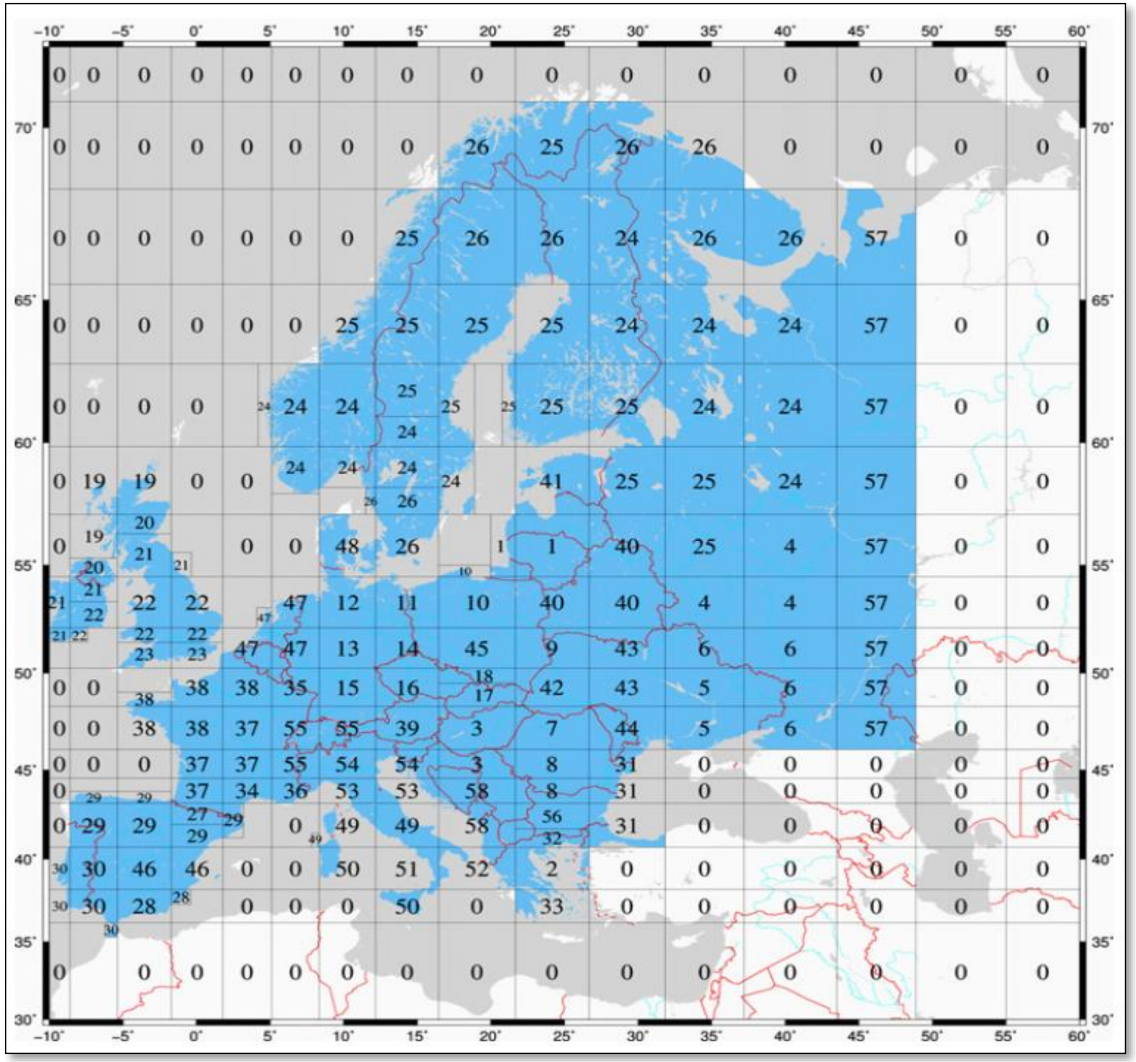


Figure: 1D resistivity models in Europe

Number of layers

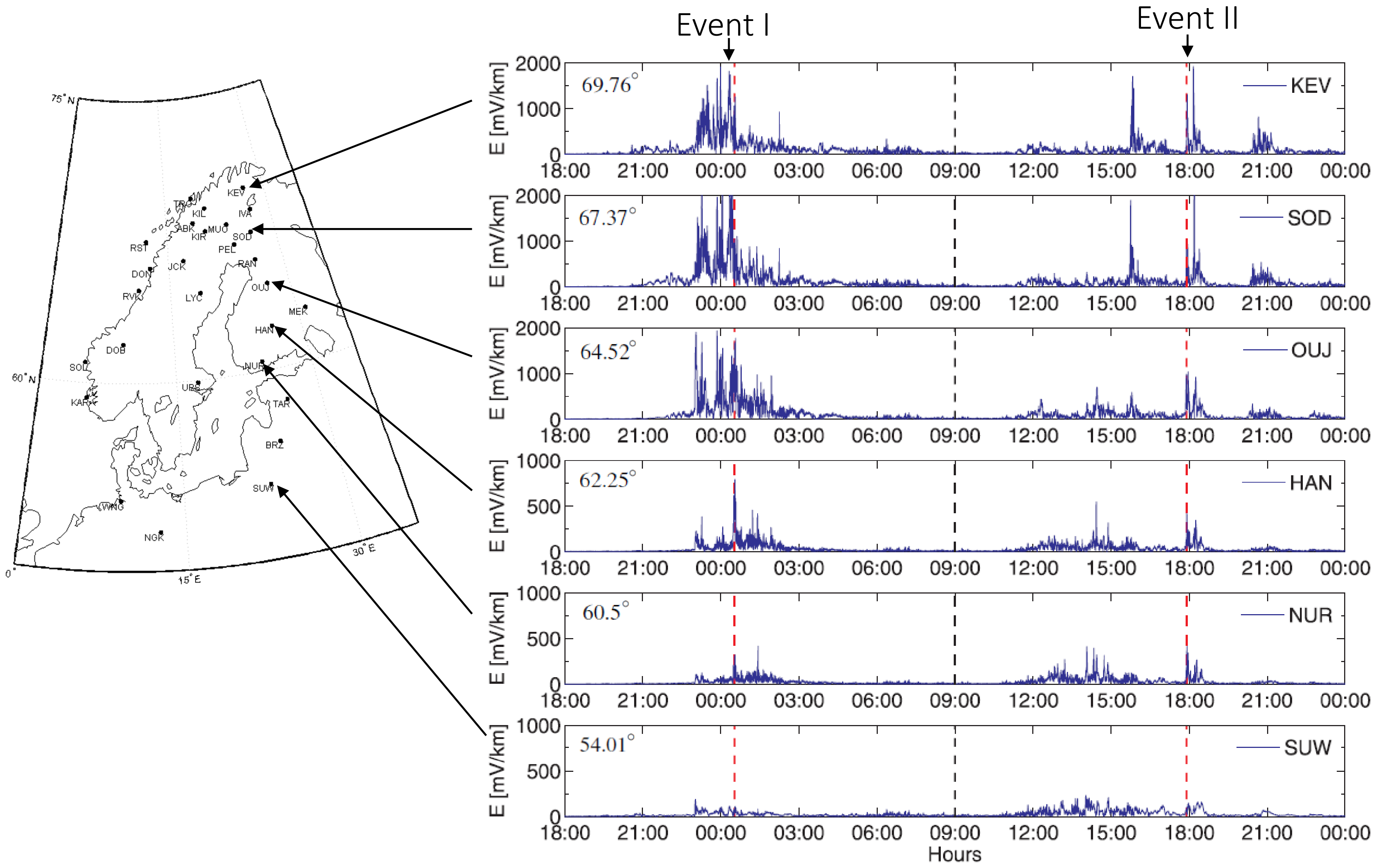
Conductivity (σ=1/ρ)

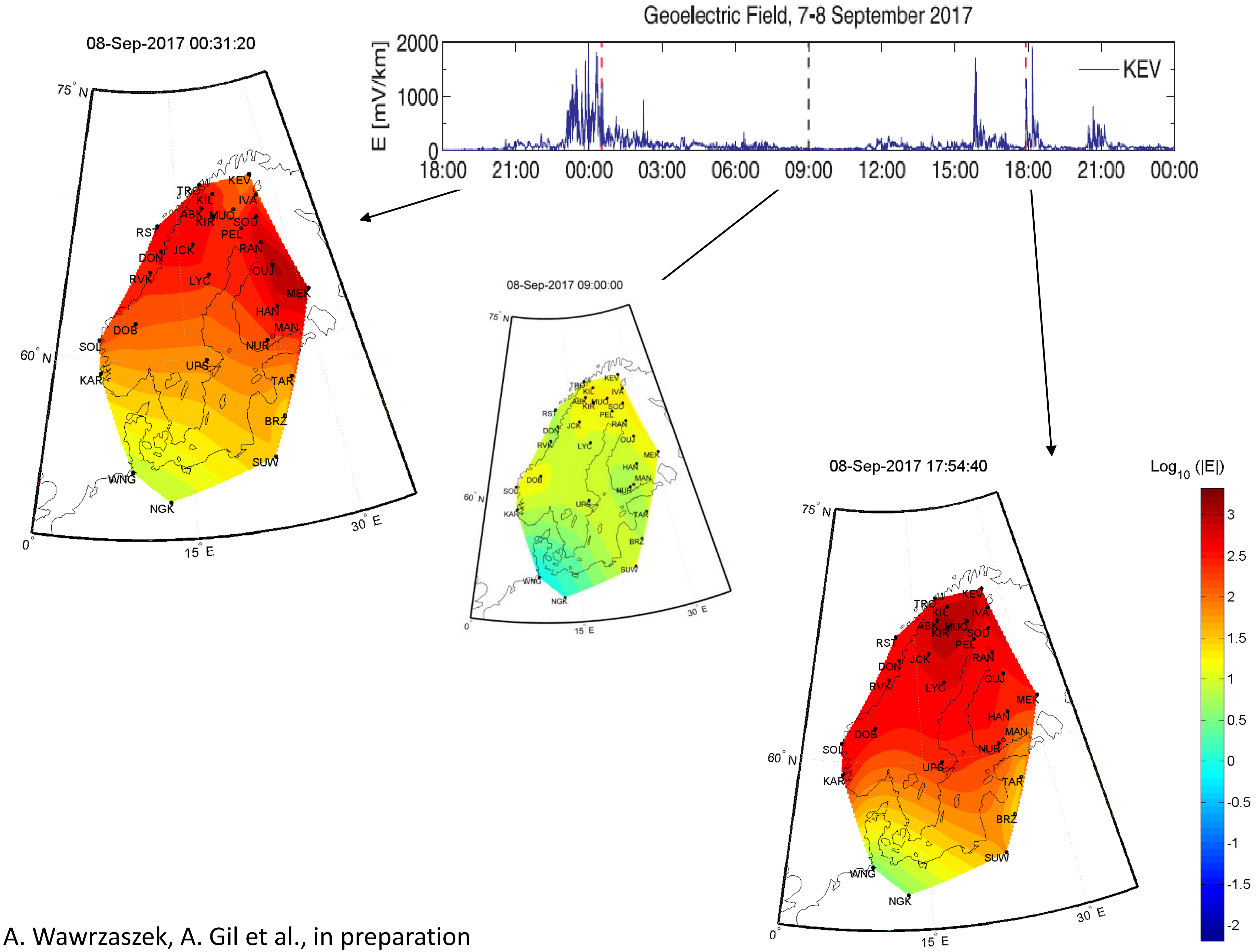
Thickness (l=d)

Layer	ρ Ωm	d km	ρ Ωm	d km
	Model 1		Model 2	
1	40.00	0.40	20.00	0.10
2	3.00	1.30	170.00	4.00
3	2000.00	140.00	65.00	11.90
4	118.00	170.00	17.00	50.00
5	15.00		0.20	
	Model 3		Model 12	
1	5.00	3.00	1.00	4.00
2	1000.00	57.00	200.00	4.00
3	10.00		0.50	1.50
4			200.00	2.00
5			1000.00	100.00
6			10.00	

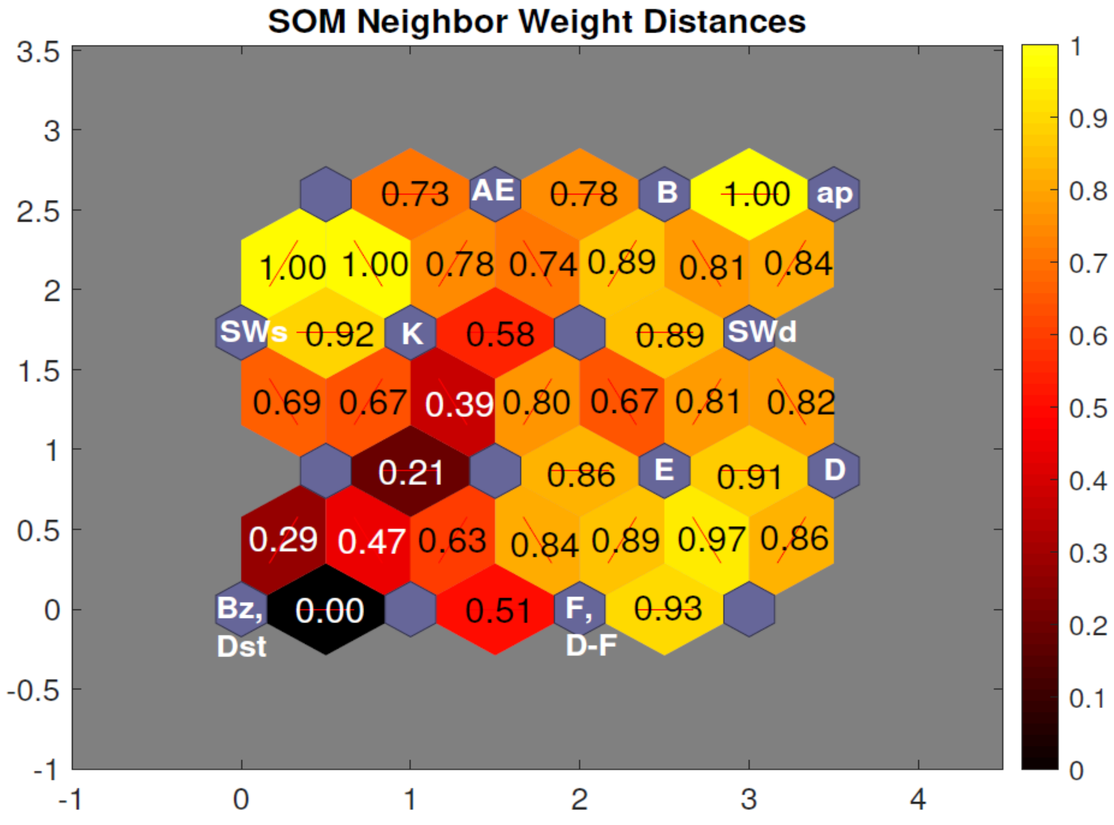
Adam et al., EURISGIC, FP7, 2012

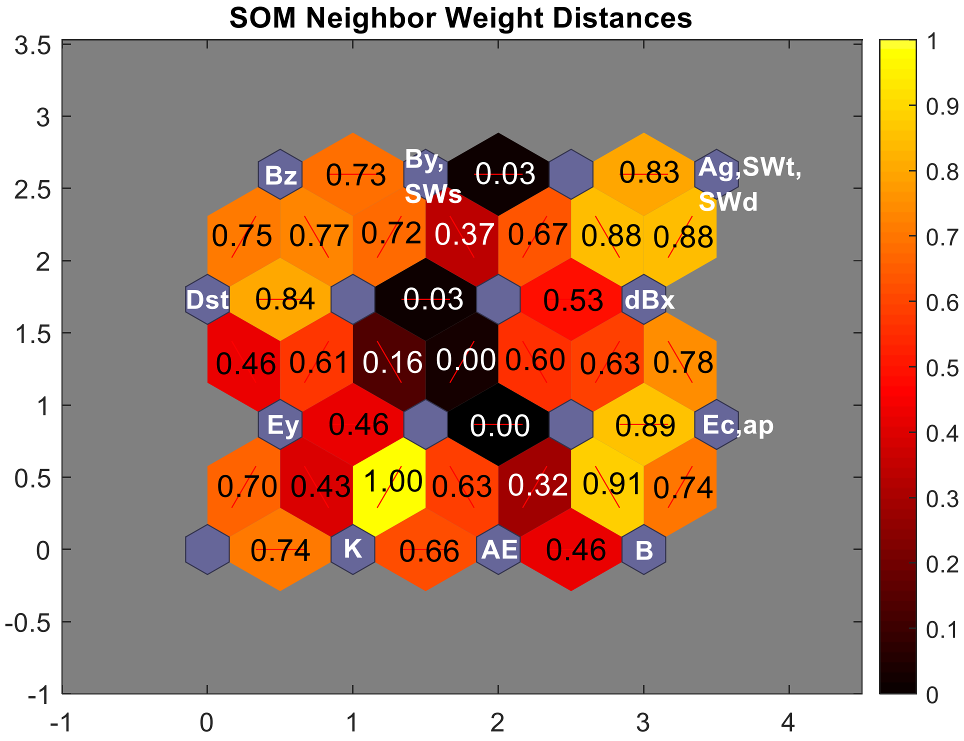
Geoelectric field computation





A. Wawrzaszek, A. Gil et al., in preparation

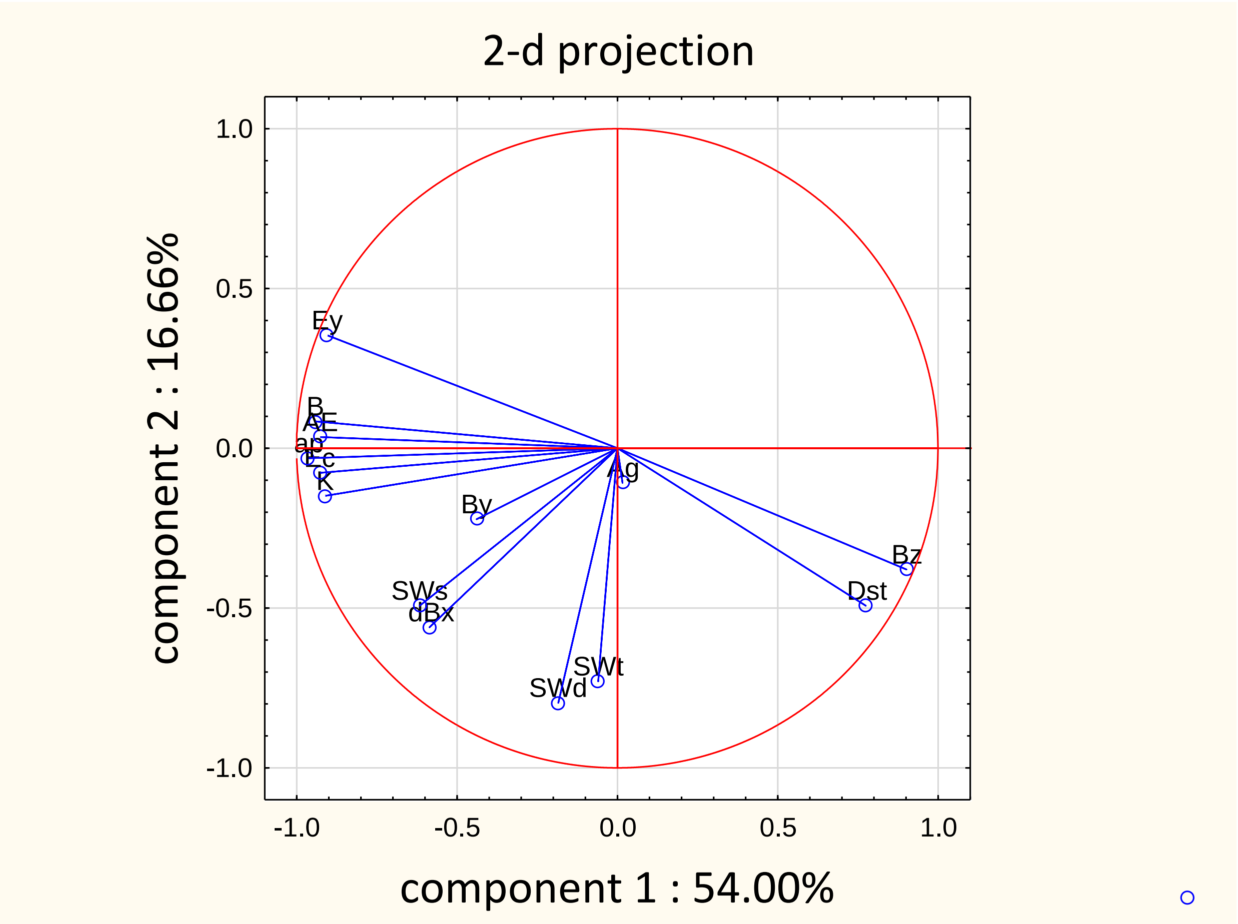


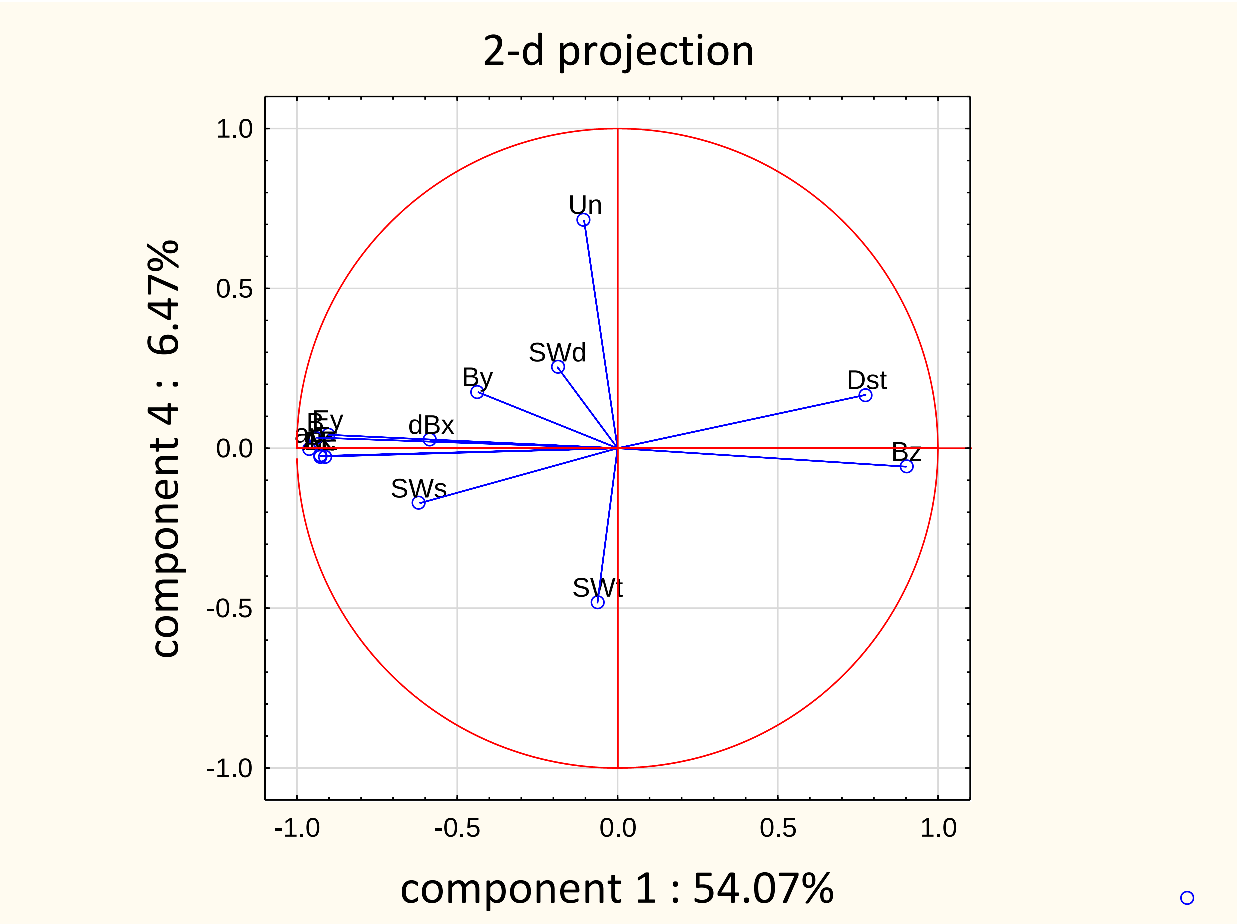


Gil et al., 2022, in preparation

SOM neighbor weight distances with weight values of connections between neighboring neurons for data without delay for the intense geomagnetic storm, 15.07.2012. The blue hexagons represent neurons, and the red lines show which particular neurons are connected. Colors from black to yellow display the weight values of the connection between neighboring neurons

Gil et al., 2021;
https://doi.org/10.1051/swsc/2021013





PCA biplot for the case when only failures caused by the aging (a), having unknown reasons (b) are incorporated into analysis, around the intense geomagnetic storm on 15 July 2012

Gil et al., 2022, in preparation

Summary

- In order to get a full picture of space weather events and effects we need diverse instruments and various observations , both in situ and on the ground
- We find that the yearly average number of transmission lines failures (which might be of solar origin) in the South Poland show a rising trend. Thus, it can be an indication of solar cycle phase dependency.
- The presented rapid growth of the number of electrical grids failures coincides in time (mostly with some delay) with an increase of geomagnetic activity mirrored in the increase of geoelectric field disturbances reflected in GICs. This suggests a link to the space weather effects.
- SW parameters turn out to have a substantial impact on the registered failures from the distinguished three groups

Thank you!

Acknowledgements

This work was partially supported by the Polish National Science Centre, grant number 2016/22/E/HS5/00406