Assesing geoelectric hazard over Romania during extreme geomagnetic storms in March 1989, November 2003 and May 2024

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Outline

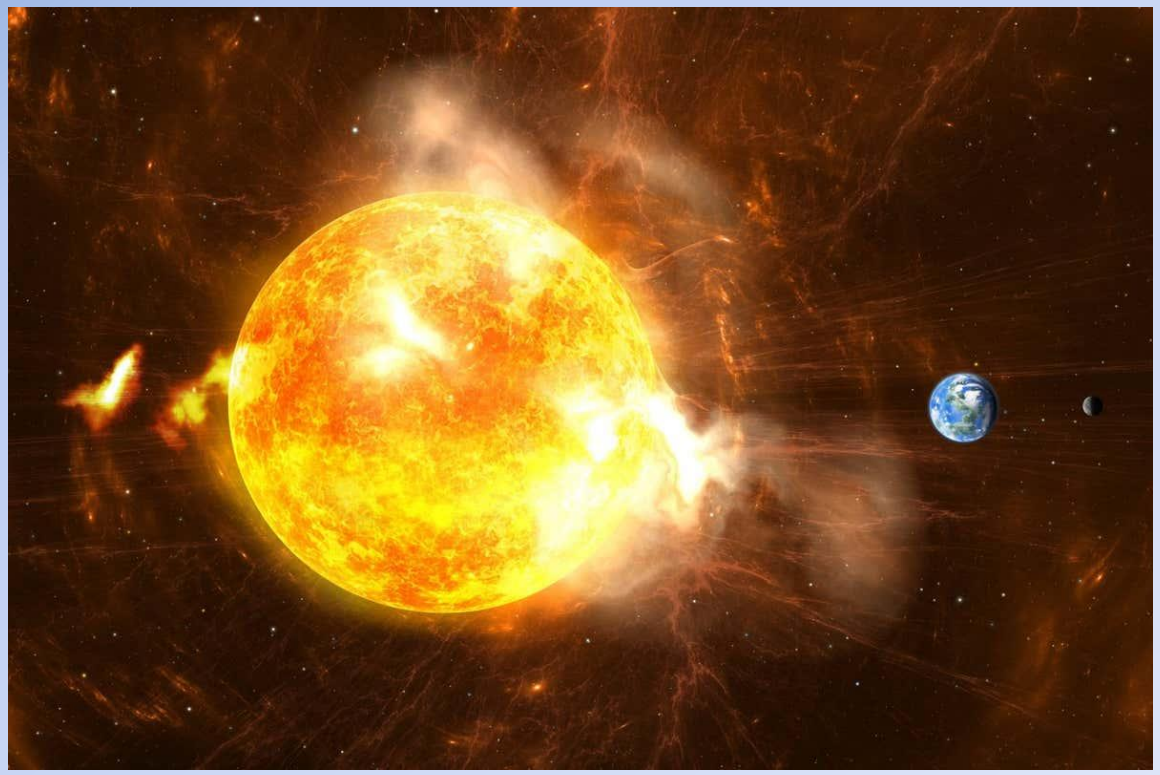
Extreme geomagnetic storms (superstorms)

Geomagnetic disturbance

Space weather hazard

- surface geoelectric field
- geoelectric hazard – Emax

Concluding remarks

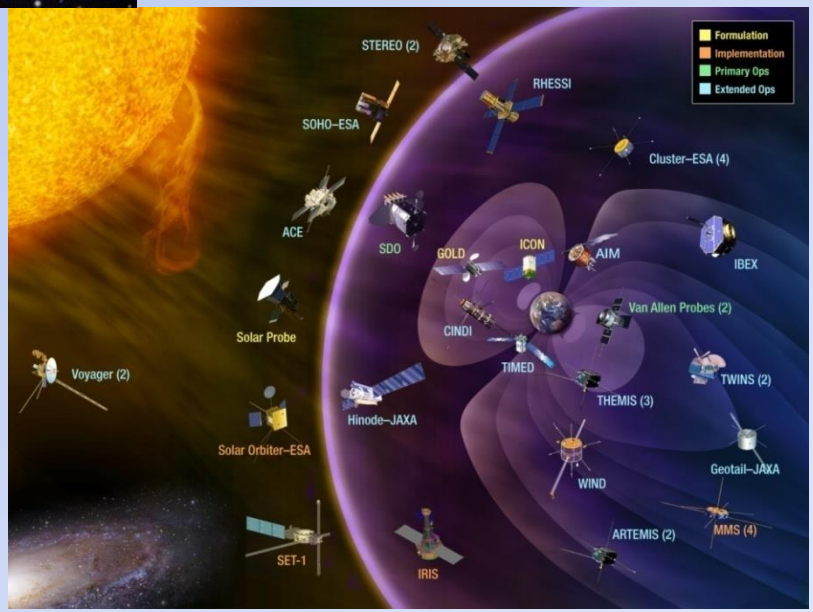


Sun-Earth system interaction



- interacting processes

- media space missions

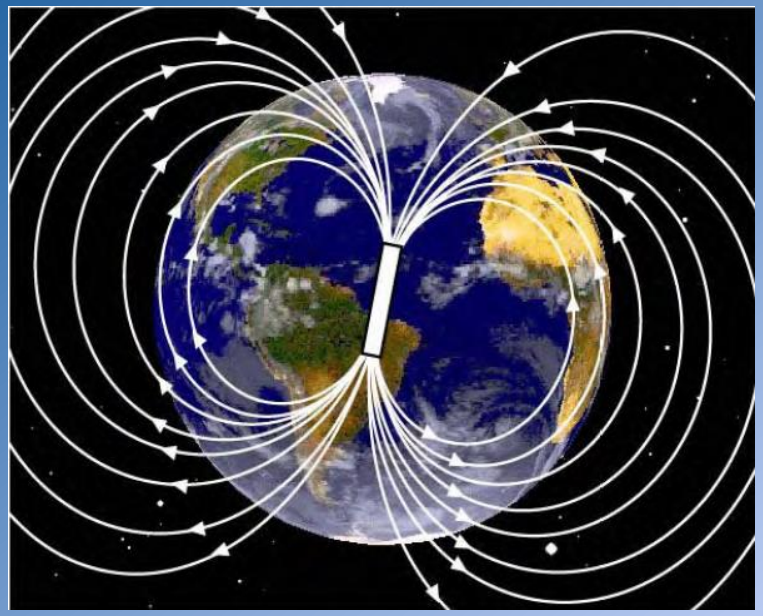


Sun-Earth system interaction

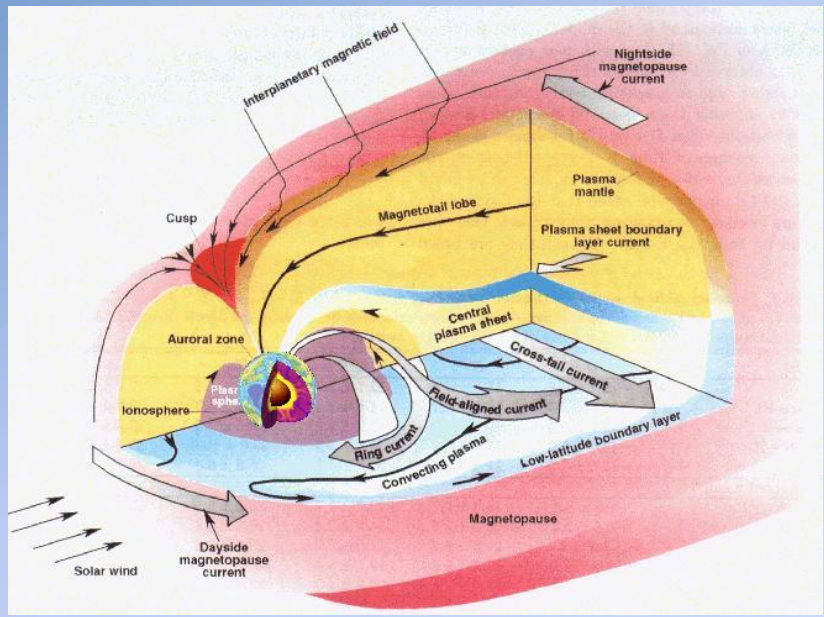


The Earth's magnetic field

"The Earth globe itself is a great magnet." William Gilbert, 1600 AD



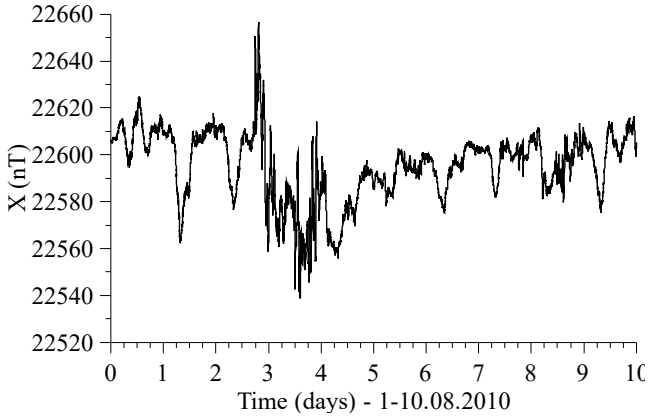
- internal field (95-98%), produced by a dynamo process in the outer core of the Earth

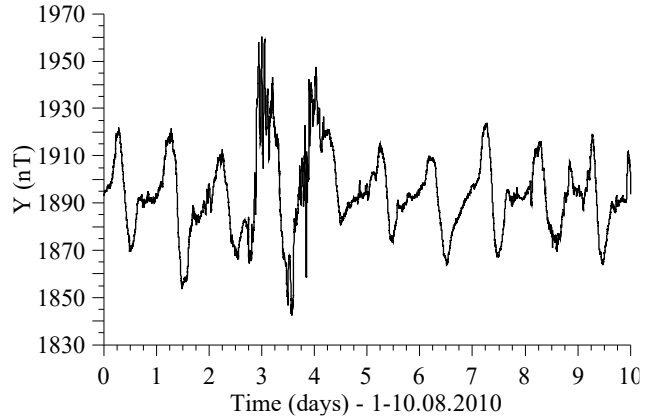


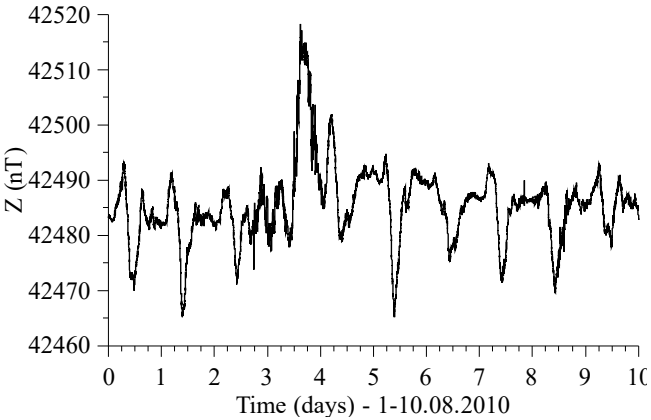
- external field, the effects of electric current systems in the magnetosphere and ionosphere, as a result of the interaction with SW and HMF

- navigation
- geophysical mapping, crust, ocean and mantle
- the exploration of the dynamics of the Earth's interior
- mineral exploration and risk mitigation
- solar-terrestrial relationships (ionosphere and magnetosphere)

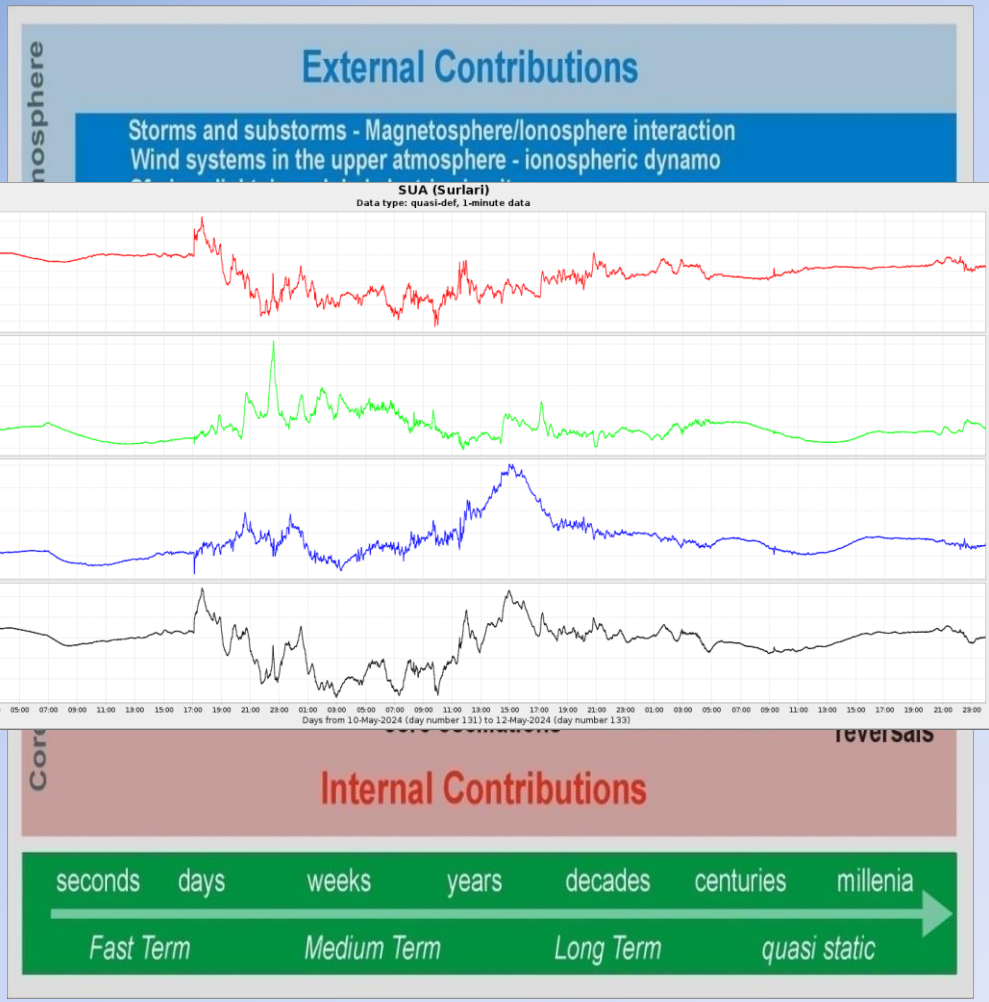
Sources and variations







Geomagnetic records (SUA)



Intensity of geomagnetic storm

- the disturbance storm-time geomagnetic index, Dst -

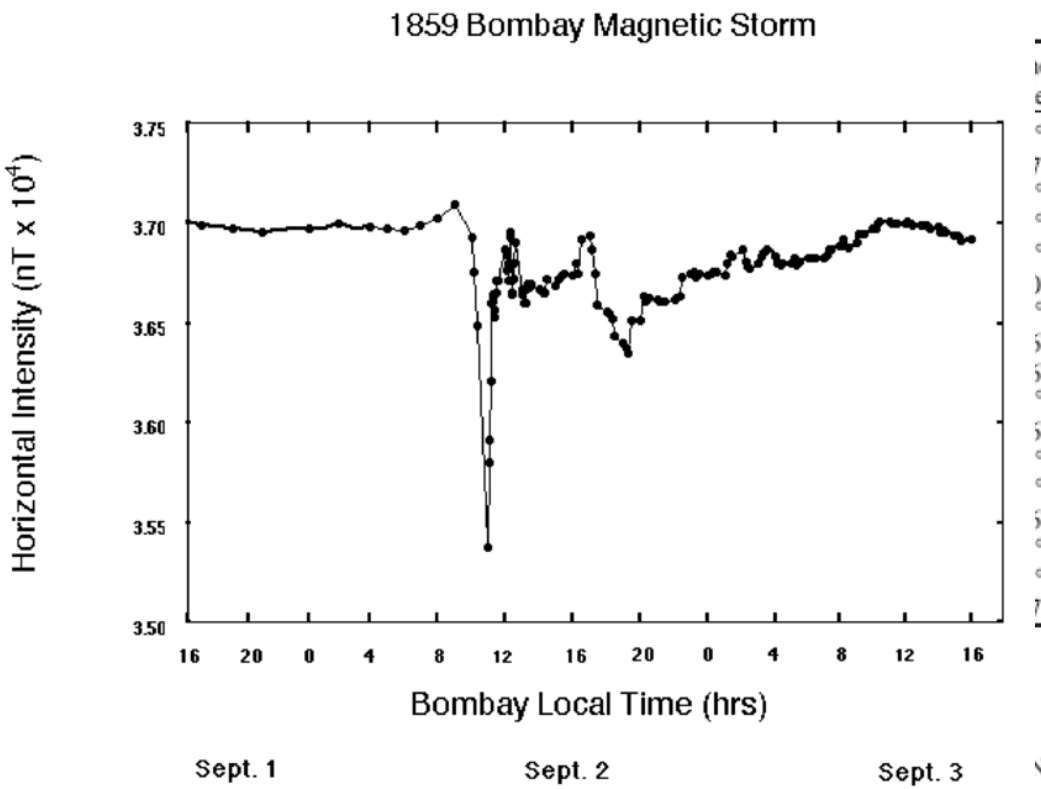
- small -30 nT < Dst < -50 nT
- moderate -50 nT < Dst < -100 nT
- large -100 nT < Dst < -150 nT
- major (severe) Dst < -150 nT
- superstorms Dst < -500 nT

Extreme geomagnetic storms (superstorms)

Table 1. Chronologic

Storm	Year
1	1859
2	1859
3	1872
4	1882
5	1903
6	1909
7	1921
8	1928
9	1938
10	1957
11	1958
12	1989

[a]The list includes the
[b]The values recorded
[c]Saturation of the inst
[d]H range is defined as
[e]Geomagnetic coordin



Geomagnetic[e] Longitude E
142.7°
82.5°
142.7°
142.7°
142.7°
82.8°
142.7°
96.2°
96.2°
142.7°
96.2°
142.7°
142.7°
96.2°
142.7°
142.7°
205.1°

NGDC site).

39 superstorms (1957-2018) Meng et al., 2019

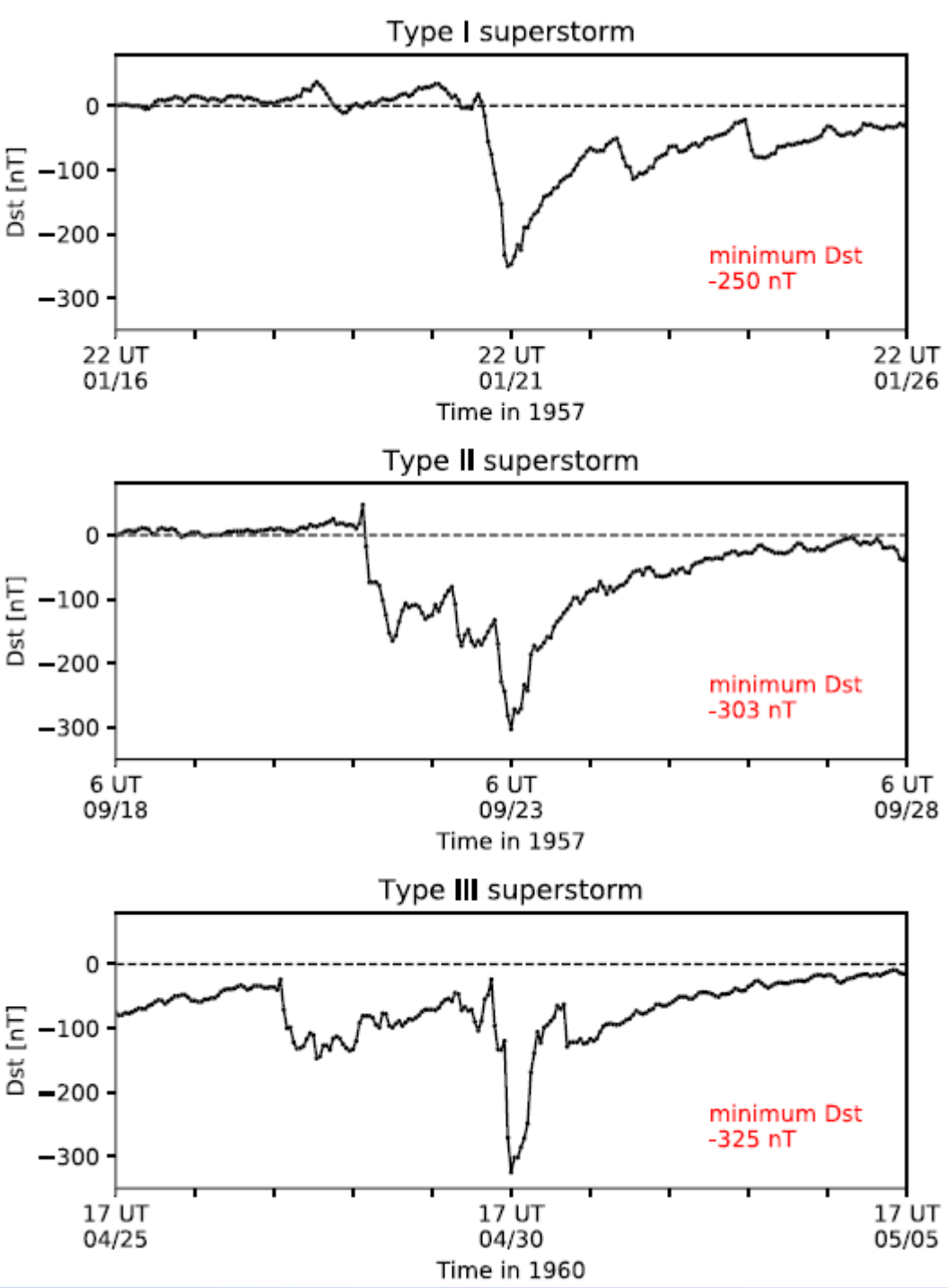
Table 1
Geomagnetic Storms With Dst ≤−250 nT (Superstorms) Ranked by the Minimum Dst, 1957–2018

1	2	3	4	5	6	7	8
Solar cycle	Dst_{min} time (yyyy-mm-dd UT)	Dst_{min} (nT)	SYM-H_{min}/time (nT)/(mm-dd UT)	SI^*/time (nT)/(mm-dd UT)	Type	Interplanetary Cause	Associated solar flare Class/location/active region[a] (Reference)
SC22	1989-03-14 01:30	−589	−720/03-14 00:46	56/03-13 01:31	III	Unknown	X4.5[b]/N31E22/5395 (Allen et al., 1989)
SC19	1959-07-15 19:30	−429			II	Unknown	X6.2[b]/N17E04/5265 (Cliver & Crooker, 1993)
SC19	1957-09-13 10:30	−427			II	Unknown	X4.0[b]/N12W02/4134 (Cliver & Crooker, 1993)
SC19	1958-02-11 11:30	−426			III	Unknown	M4.8[b]/S12W14/4400 (Cliver & Crooker, 1993]
SC23	2003-11-20 20:30	−422	−490/11-20 18:17	49/11-20 08:06	III	sheath[c]+MC[d] *Bz*-	M3.9/S01E16/10501 (Gopalswamy, Yashiro, Michalek, et al., 2005]
SC20	1967-05-26 04:30	−387			II	Unknown	X6.2[b]/N29E25/8818 (Cliver & Crooker, 1993)
SC23	2001-03-31 08:30	−387	−437/03-31 08:06	129/03-31 01:00	I	sheath+MC *Bz*-	X1.7/N20W19/9393 (Srivastava & Venkatakrishman, 2002; Wang et al., 2003)
SC23	2003-10-30 22:30	−383	−432/10-30 22:55	76/10-30 20:08	III	Sheath	X10.0/S15W02/10486 (Gopalswamy, Yashiro, Liu, et al., 2005)
SC23	2004-11-08 06:30	−374	−394/11-08 05:55	92/11-07 19:20	I	sheath+MC *Bz*-	M9.3/N09E05/10696 (Trichtchenko et al., 2007)
SC22	1991-11-09 01:30	−354	−402/11-09 01:32	49/11-08 13:15	I	Unknown	M4.7[b]/S14W20/6906 (possible DSF[e]) (Cliver et al., 2009)
SC23	2003-10-30 00:30	−353	−391/10-30 01:48	81/10-29 06:14	III	sheath+MC *Bz*-	X17.2/S16E08/10486 (Gopalswamy, Yashiro, Liu, et al., 2005; Tsurutani et al., 2005)
SC19	1960-11-13 09:30	−339			II	Unknown	X4.0[b]/N28E12/5925 (Cliver & Crooker, 1993)
SC19	1958-07-08 22:30	−330			II	Unknown	X4.0[b]/N25W08/4634 (Cliver & Crooker, 1993)
SC19	1960-04-01 18:30	−327			III	Unknown	X2.6[b]/N12E11/5615 (Cliver & Crooker, 1993)
SC19	1960-04-30 17:30	−325			III	Unknown	M7.4[b]/N14W21/5642 (Cliver & Crooker, 1993)
SC21	1982-07-14 01:30	−325	−436/07-14 01:24	60/07-13 16:22	II	Likely sheath+MC	X7.1[b]/N11E37/3804 (Cliver & Crooker, 1993)
SC19	1957-09-05 03:30	−324			III	Unknown	M7.4[b]/N23W30/4124 (Haurwitz, 1962)
SC21	1981-04-13 06:30	−311	−343/04-13 07:09	120/04-12 23:20[f]	II	PICME[g]+sheath	X2.5[b]/N07W35/3025 (Cliver & Crooker, 1993)
SC21	1986-02-09 00:30	−307	−379/02-09 00:35	178/02-08 21:00	II	Unknown	X1.7[b]/S04W06/4711 (Garcia & Dryer, 1987; Tsurutani et al., 1992)
SC19	1957-09-23 07:30	−303			II	Unknown	M7.4[b]/N10W06/4152 (Cliver & Crooker, 1993)
SC19	1958-09-04 22:30	−302			II	Unknown	M1.3[b]/S08E84/4741 (possible DSF; Cliver & Crooker, 1993)
SC23	2000-07-16 00:30	−301	−347/07-15 21:54	93/07-15 15:04	II	MC *Bz*-	X5.7/N22W07/9077 (Tsurutani et al., 2005)
SC22	1991-03-25 00:30	−298	−337/03-25 03:41	118/03-24 03:55	II	Unknown	X9.4[b]/S26E28/6555 (Smart & Shea, 1996)
SC23	2001-11-06 00:30	−292	−320/11-06 04:06	88/11-06 01:54	II	PICME+sheath	X1.0/N06W18/9684 (Khan et al., 2014)
SC21	1982-09-06 11:30	−289	−265/09-06 11:44	66/09-05 22:53	III	Unknown	M6.4[b]/N10E36/3886 (Cliver & Crooker, 1993)
SC22	1992-05-10 14:30	−288	−363/05-10 14:15	81/05-09 20:02	II	Likely sheath+MC	M7.4[b]/S26E08/7154
SC23	2000-04-07 00:30	−288	−320/04-07 00:09	46/04-06 16:45	III	Sheath	C9.7/N15W66/8933 (Huttunen et al., 2002; Jadav et al., 2005)
SC19	1960-10-07 00:30	−287			III	Unknown	possible DSF (Cliver & Crooker, 1993)
SC20	1970-03-08 22:30	−284			III	Sheath	M5.1[b]/S11E09/10614 (Formisano, 1973)
SC22	1990-04-10 18:30	−281	−311/04-10 16:38	41/04-09 08:46	II	Unknown	M1.5[b]/N24E29/6007 (Cliver & Crooker, 1993)
SC19	1961-10-28 18:30	−272			II	Unknown	possible DSF (Cliver & Crooker, 1993)
SC23	2001-04-11 23:30	−271	−280/04-11 23:57	26/04-11 15:53	III	Sheath	X2.3/S23W09/9415 (Wang et al., 2003)
SC22	1989-10-21 16:30	−268	−337/10-21 11:32	18/10-20 09:19	III	Likely sheath+MC	X13.0[b]/S27E10/5747 (Cliver & Crooker, 1993)
SC22	1989-11-17 22:30	−266	−325/11-17 21:06	71/11-17 09:28	III	Unknown	X3.2[b]/N11W26/5786 (Cliver & Crooker, 1993)
SC23	2004-11-10 10:30	−263	−282/11-10 09:31	46/11-09 18:51	III	sheath+MC *Bz*+	X2.0/N09W17/10696 (Trichtchenko et al., 2007)
SC19	1957-03-02 07:30	−255			II	Unknown	M3.1[b]/N18W35/3863 (Cliver & Crooker, 1993)
SC22	1989-09-19 04:30	−255	−292/09-19 05:23	37/09-18 10:31	I	Unknown	M2.3[b]/N20E22/5687 (Cliver & Crooker, 1993)
SC22	1991-10-29 07:30	−254	−284/10-29 08:02	51/10-28 11:03	III	sheath+MC *Bz*+	X6.1[b]/S13E15/6891
SC19	1957-01-21 22:30	−250			I	Unknown	C8.8[b]/S30W18/3820 (Cliver & Crooker, 1993)

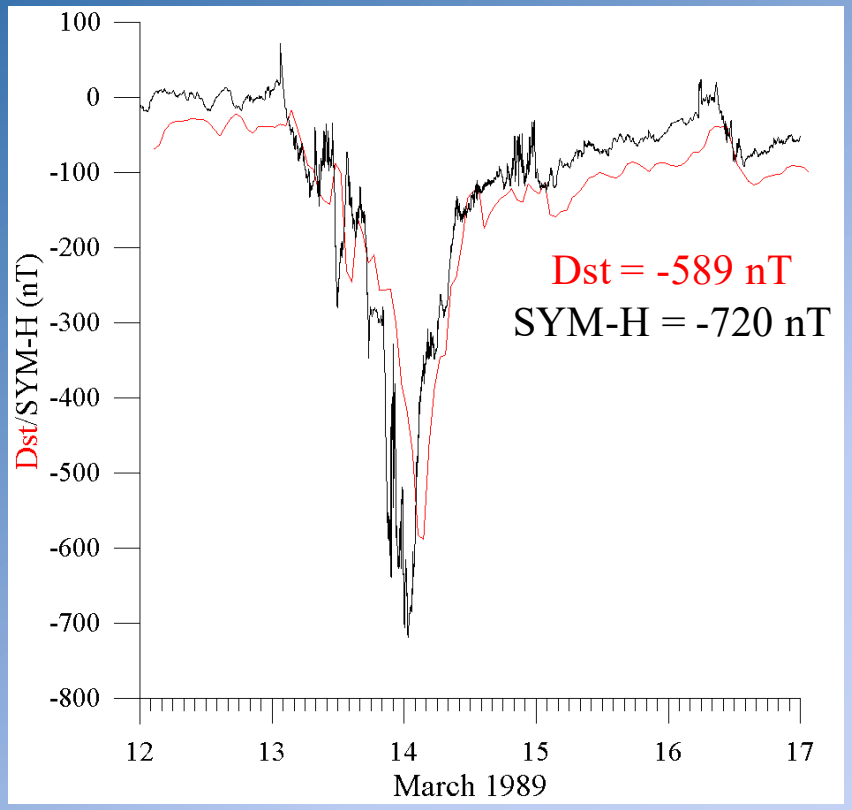
[a]Calcium Plage Area numbering before 1981 and NOAA Active Region numbering afterward. [b]Unconfirmed flare. [c]Sheath preceding an ICME. [d]Magnetic cloud. [e]Disappearing solar filament. [f]Ambiguous SI^+. [g]Preceding ICME.

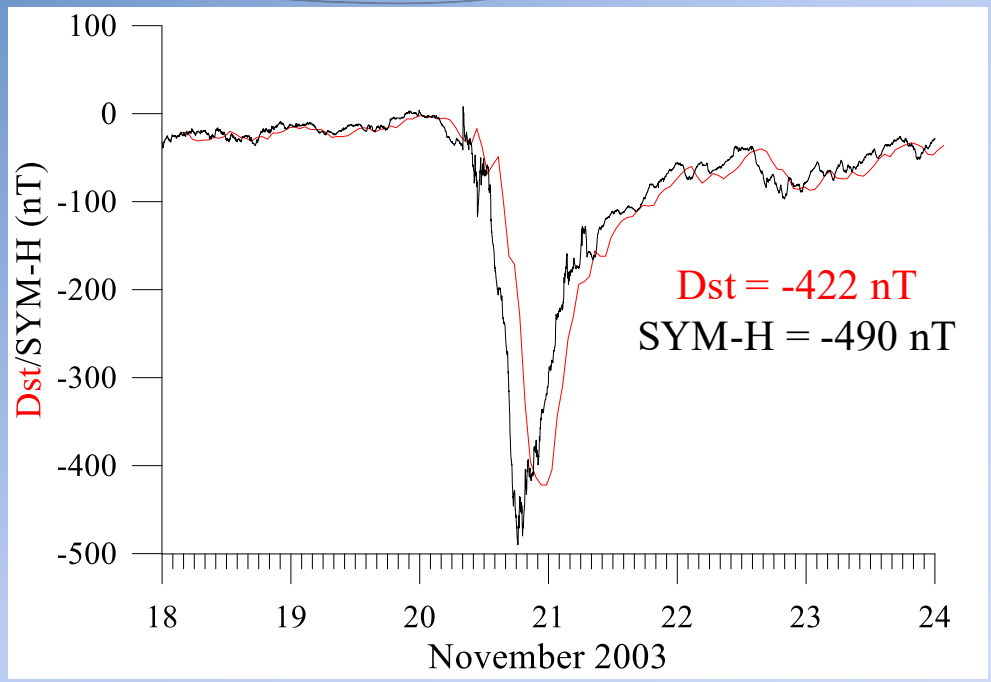
39 superstorms (1957-2018) Meng et al., 2019

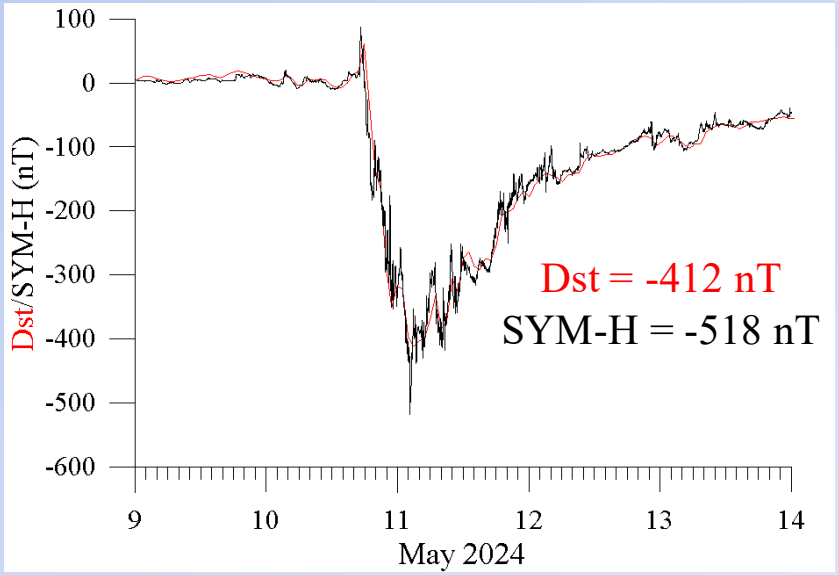
- Dst decreases from a positive value to its maximum negative value
- Dst decreases from a positive value and has one or more dips before it reaches the maximum negative value
- Dst remains negative for more than 72h prior to the time of the Dst minimum



Geomagnetic superstorms
- March 1989, November 2003 and May 2024 -





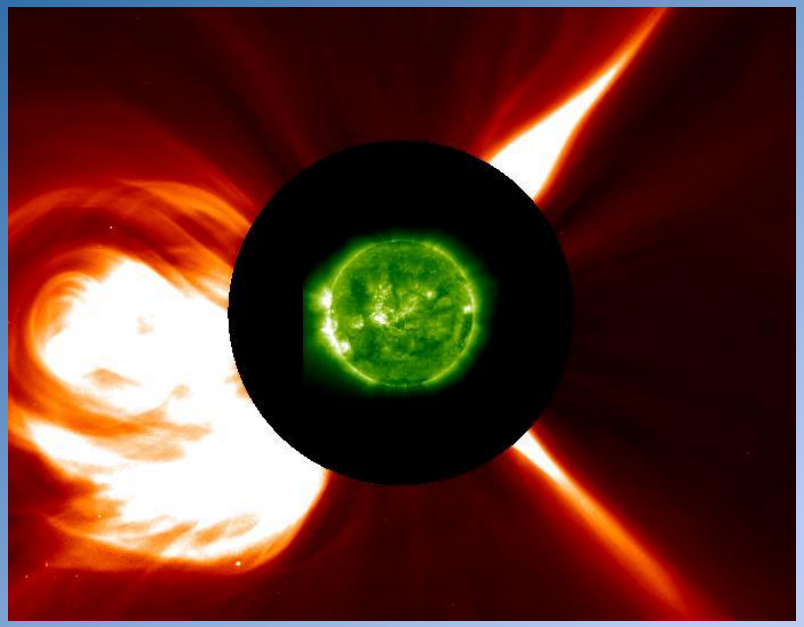


(https://wdc.kugi.kyoto-u.ac.jp/)

Solar causes of the largest geomagnetic storm

November 20, 2003 storm

CME



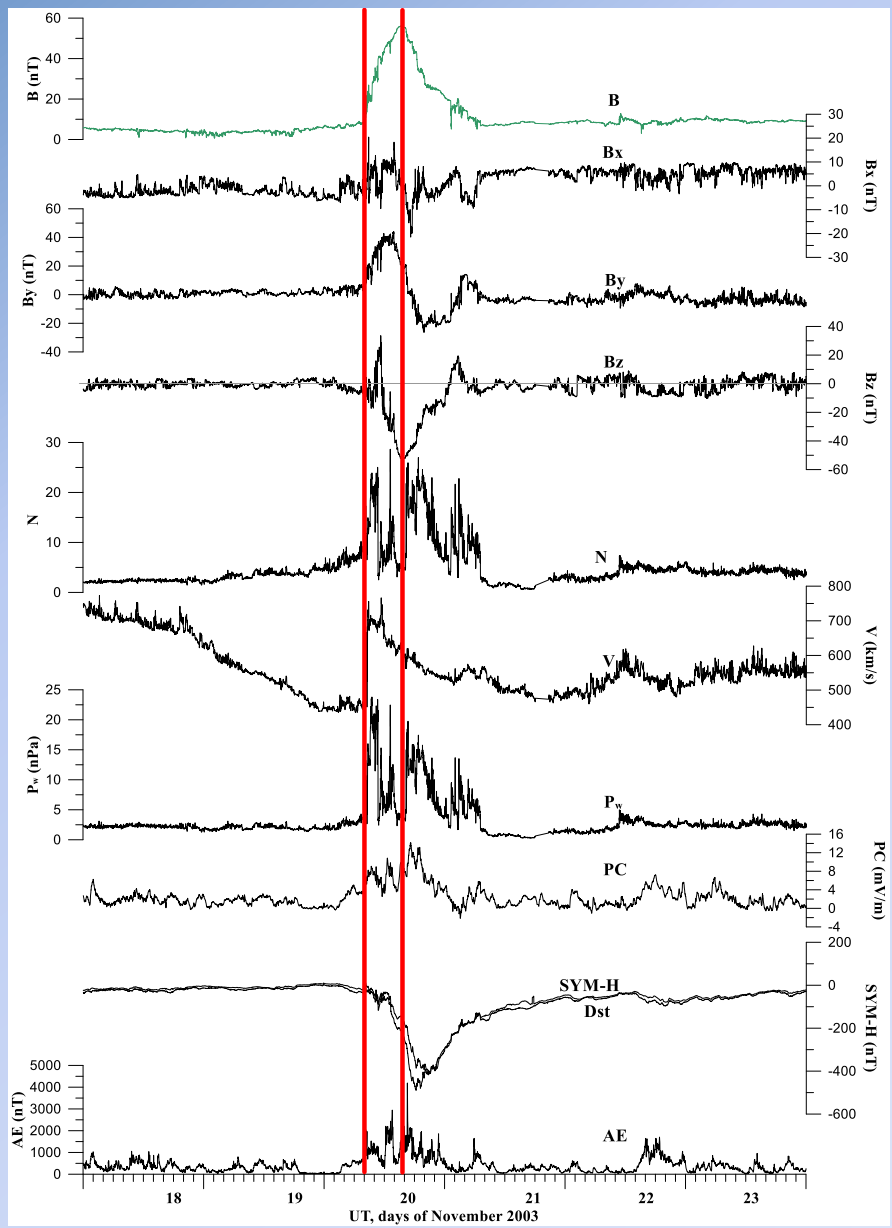
November 18, 2003
10:24 UT

GOES
LASCO C2 image (jhelioviewer.org/)

Solar eruption November 18, 2003, 8:12 UT

SSC, November 20, 2003, 8:03 UT
min Dst = -422nT

Solar wind and interplanetary parameters

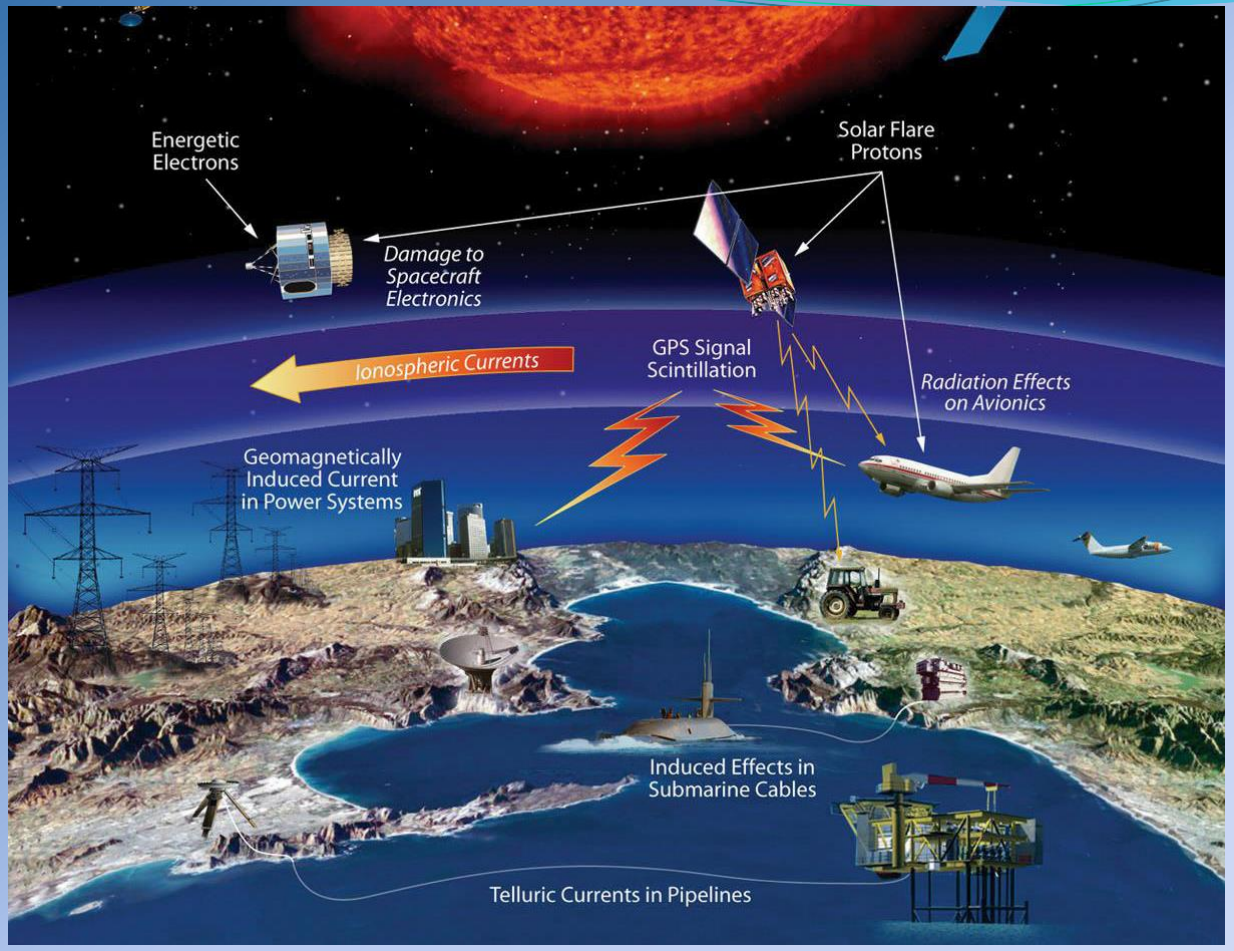


www.omniwebdata

Space weather...

...refers to conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health.

Geomagnetic storms - space weather hazard



Disruption

- satellite operations comunication
- navigation
- electric power grids on ground (GICs)
- hydrocarbon distribution grids

Space weather hazard (GICs)

Induction in the Earth

Variable external magnetic field

↓

Telluric currents

↓

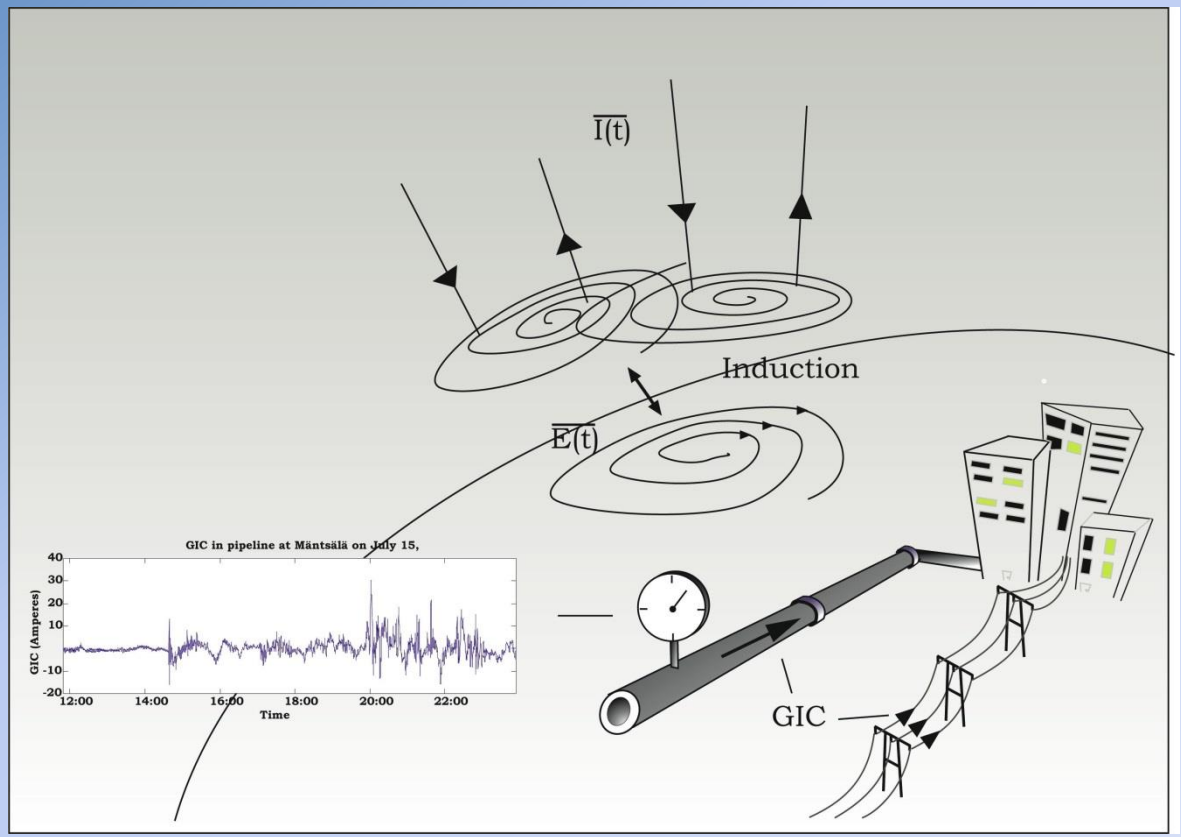
Secondary magnetic field

↓

Surface electric field

↓

Electric currents (GICs)



Surface geoelectric field

Plane wave model

Viljanen & Pirjola, 1989

$$E_x(\omega) = \frac{Z(\omega)}{\mu_0} B_y(\omega), E_y(\omega) = \frac{Z(\omega)}{\mu_0} B_x(\omega)$$

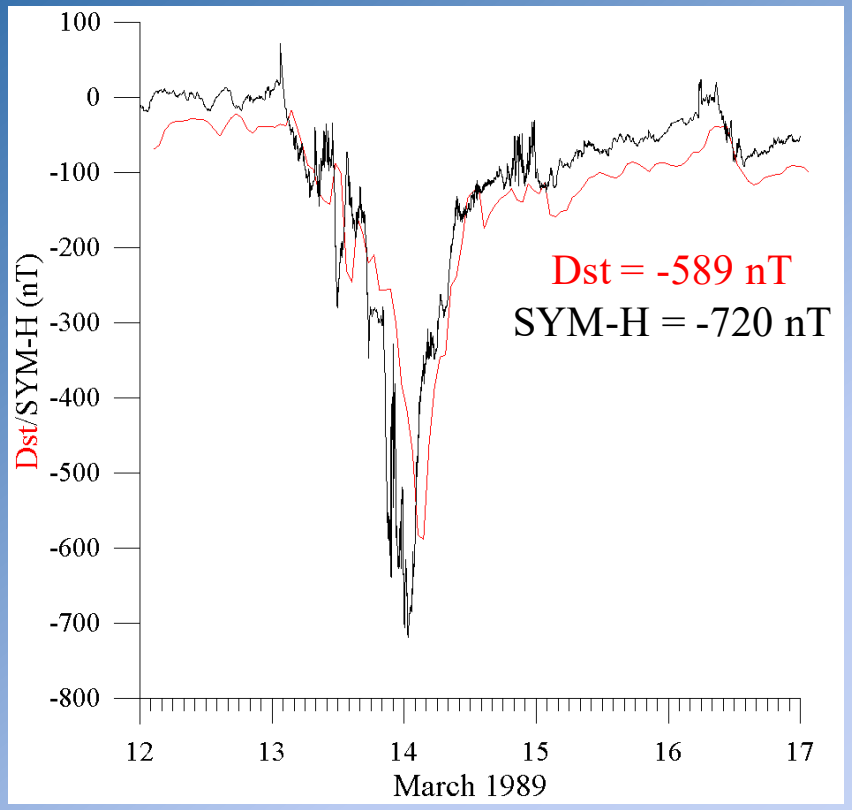
$$E_y(t) = -\frac{1}{\sqrt{\pi \mu_0 \sigma}} \int_{-\infty}^{t} \frac{g_x(u)}{\sqrt{t-u}} du$$

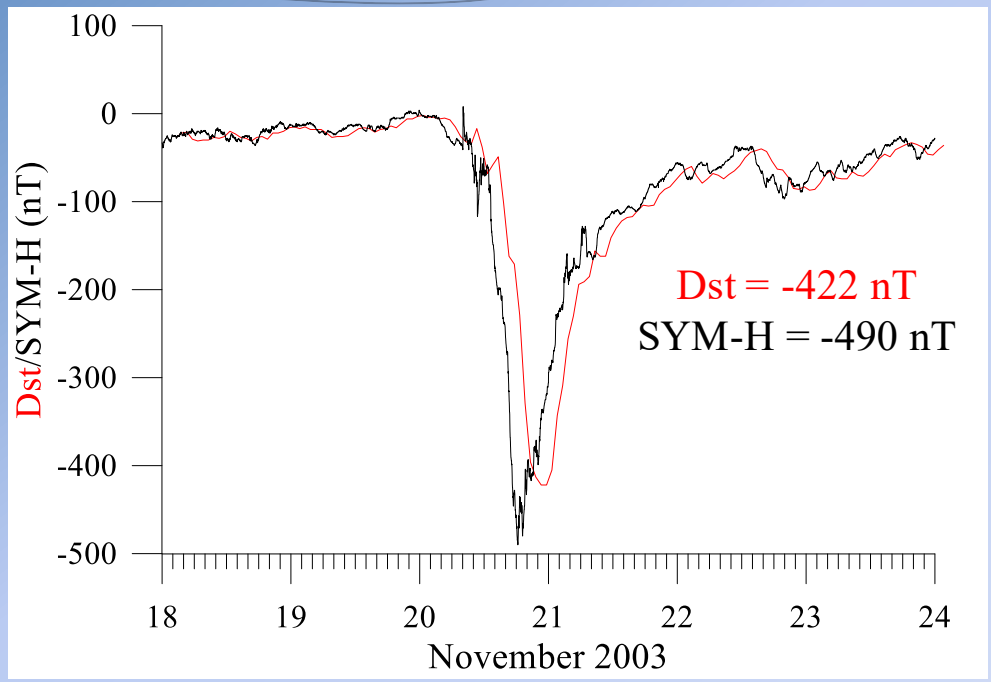
$$E(T_N) = \frac{2}{\sqrt{\pi \mu_0 \sigma}} (R_{N-1} - R_N - \sqrt{M} b_{N-M})$$

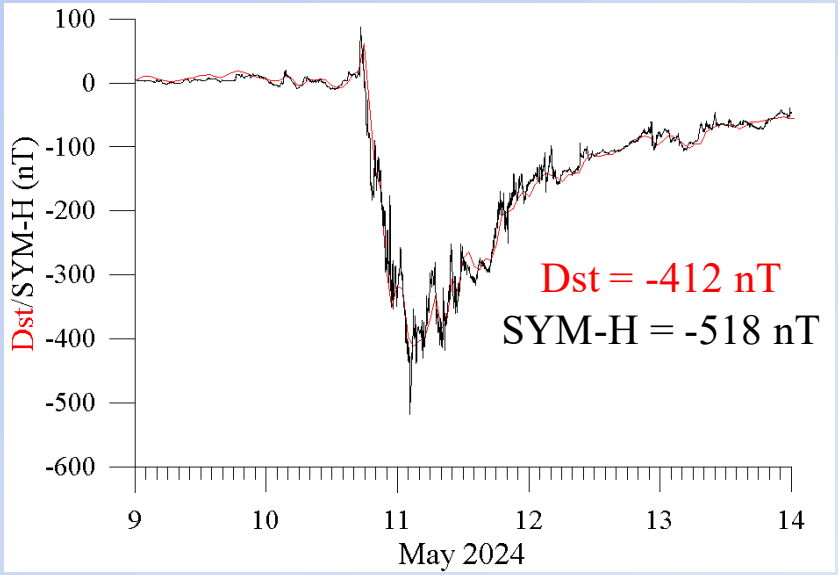
$$R_N = \sum_{n=N-M+1}^{N} b_n \sqrt{N-n+1}$$

$$E(T_N) = \sqrt{E_x^2 + E_y^2}$$

Geomagnetic superstorms
- March 1989, November 2003 and May 2024 -

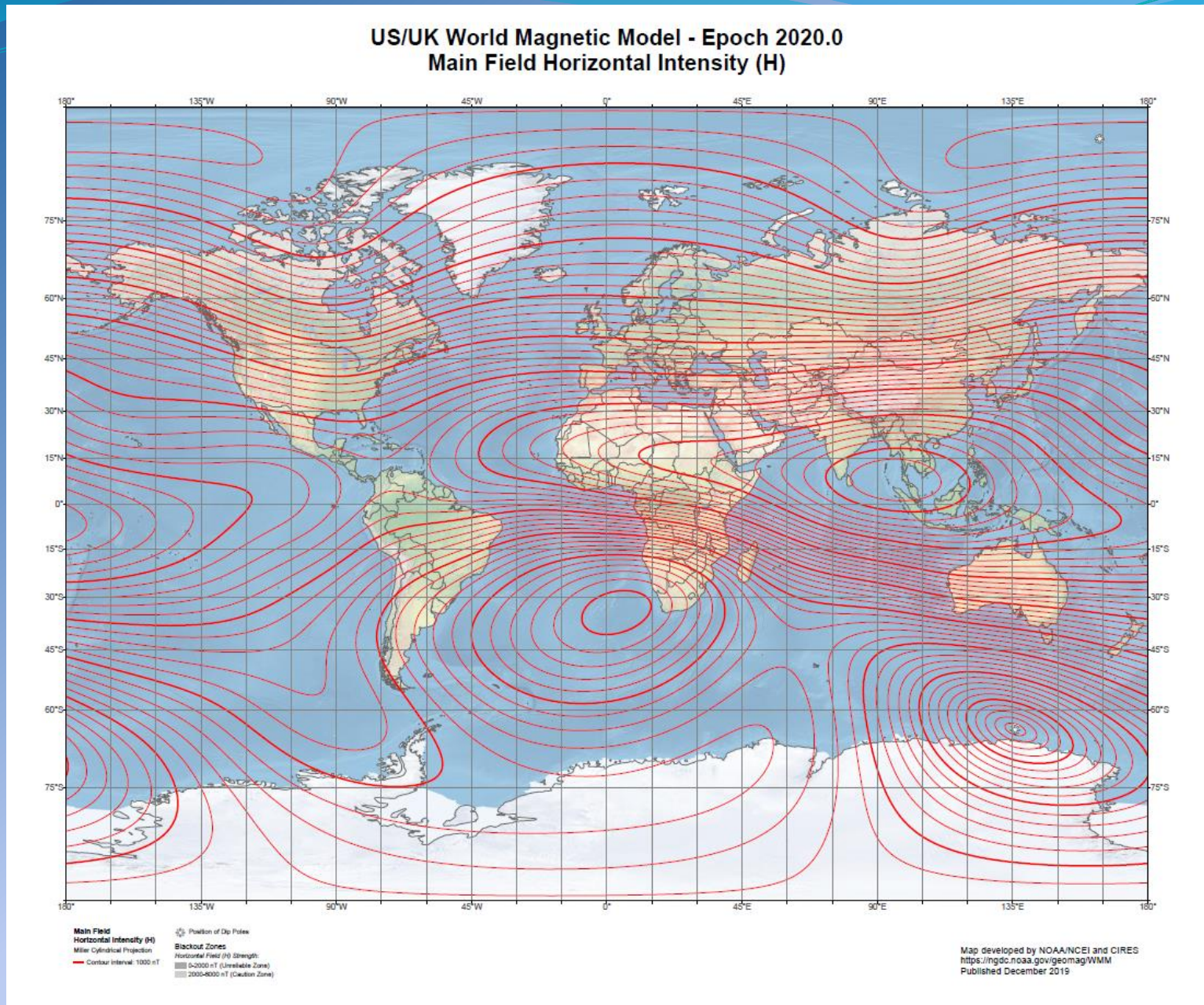






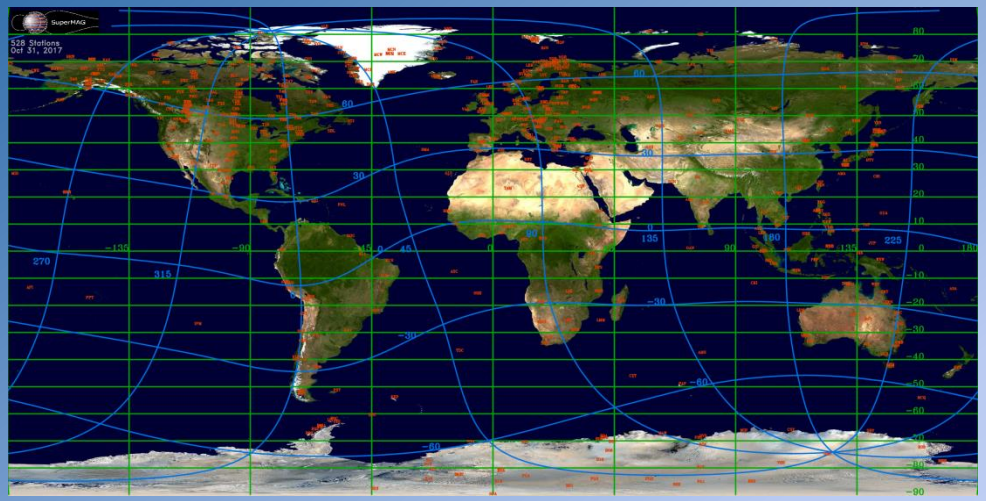
(https://wdc.kugi.kyoto-u.ac.jp/)

Geomagnetic disturbance

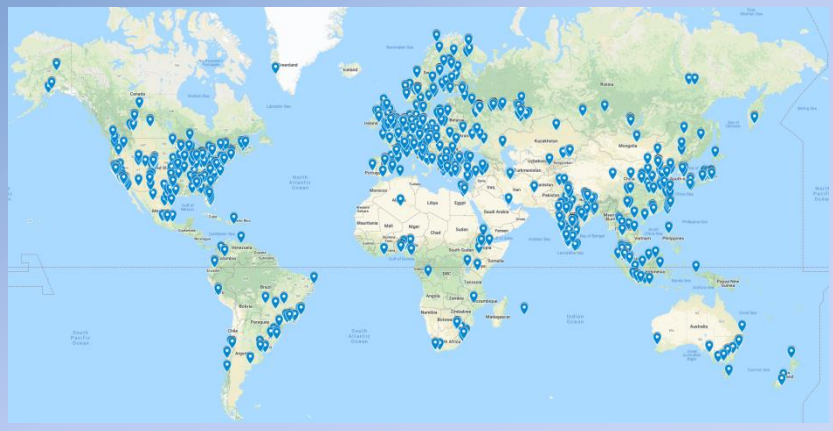


SuperMAG: a worldwide collaboration of organizations and national agencies that currently operate more than 300 ground based magnetometers;

Funded by NSF, NASA and ESA;



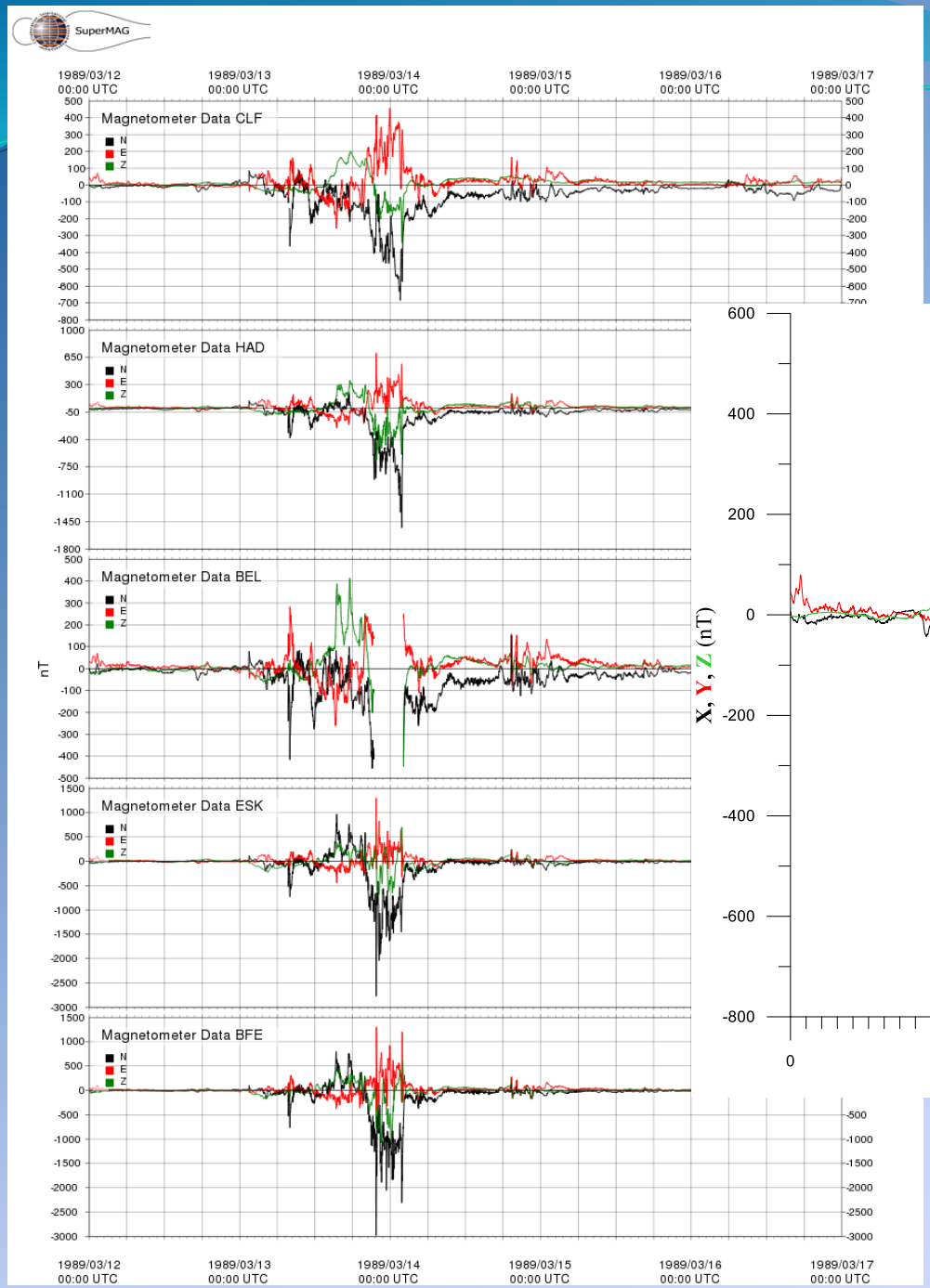
https://supermag.jhuapl.edu/info/img/SuperMAG_Earth_GEO.png



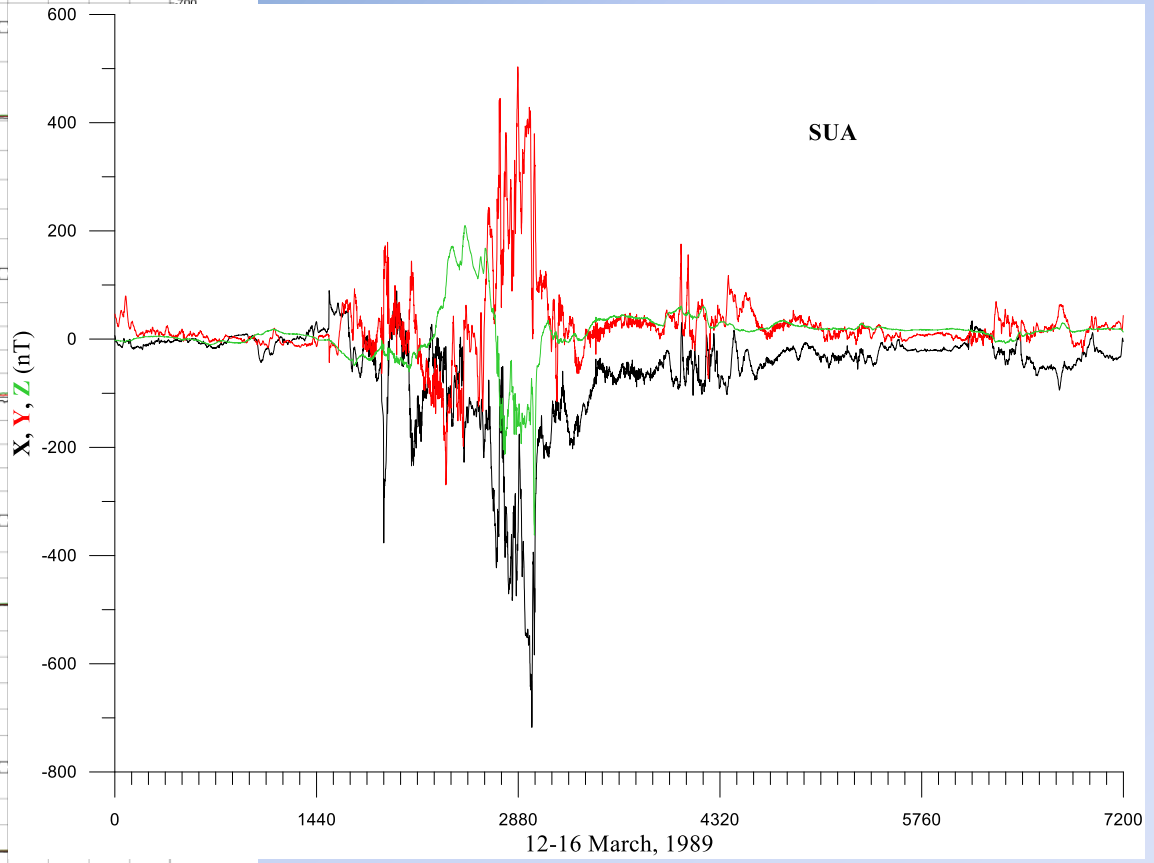
https://supermag.jhuapl.edu/info/

Contributors

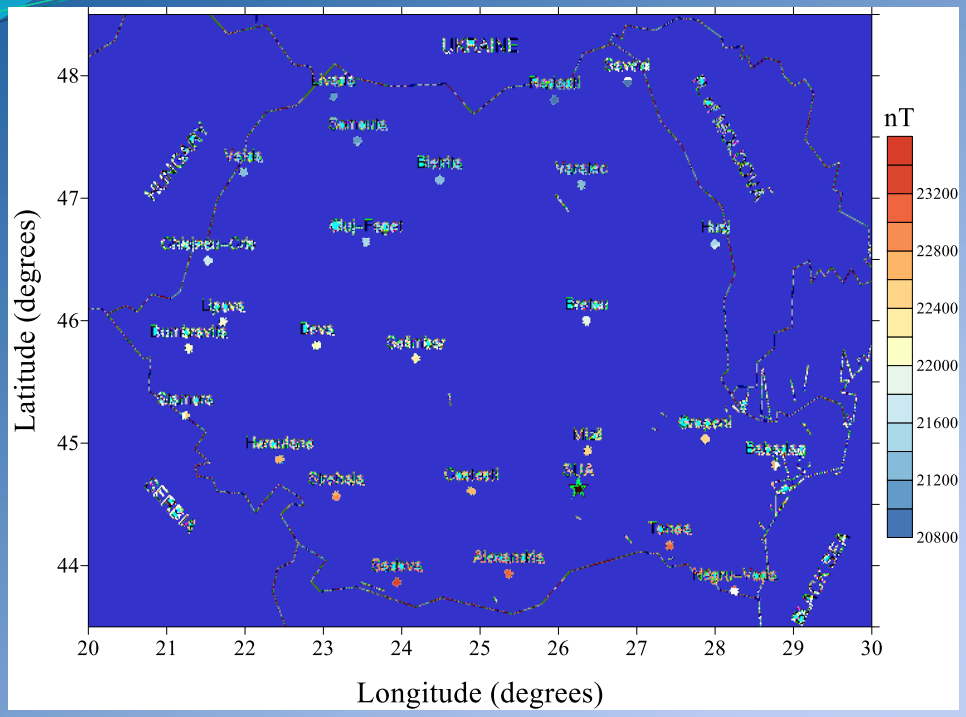




$$X_{SUA} = X_{CLF} * \cos \theta_{SUA} / \cos \theta_{CLF}$$

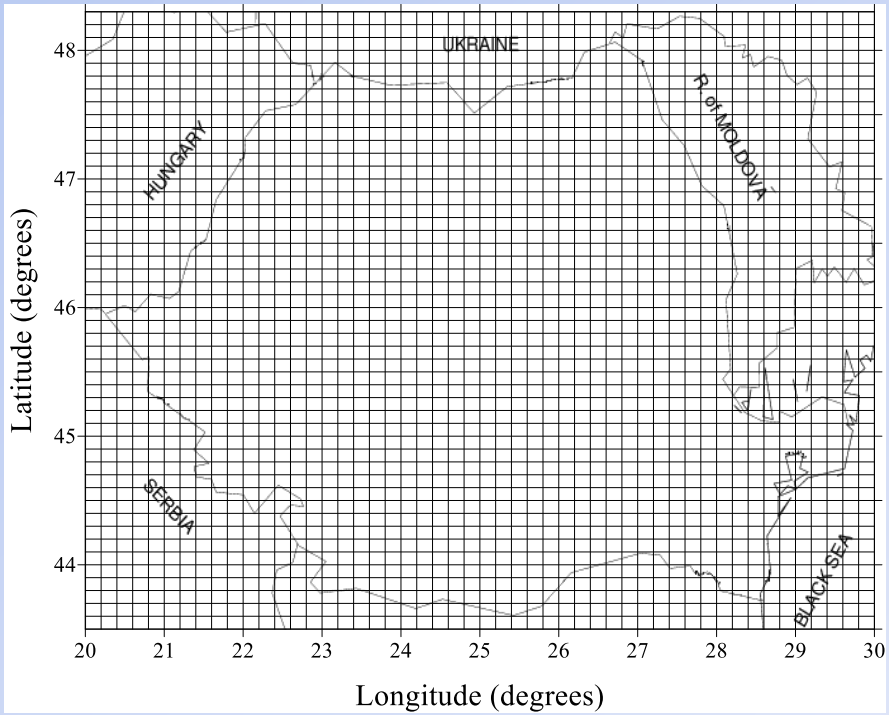


Geomagnetic data over Romania



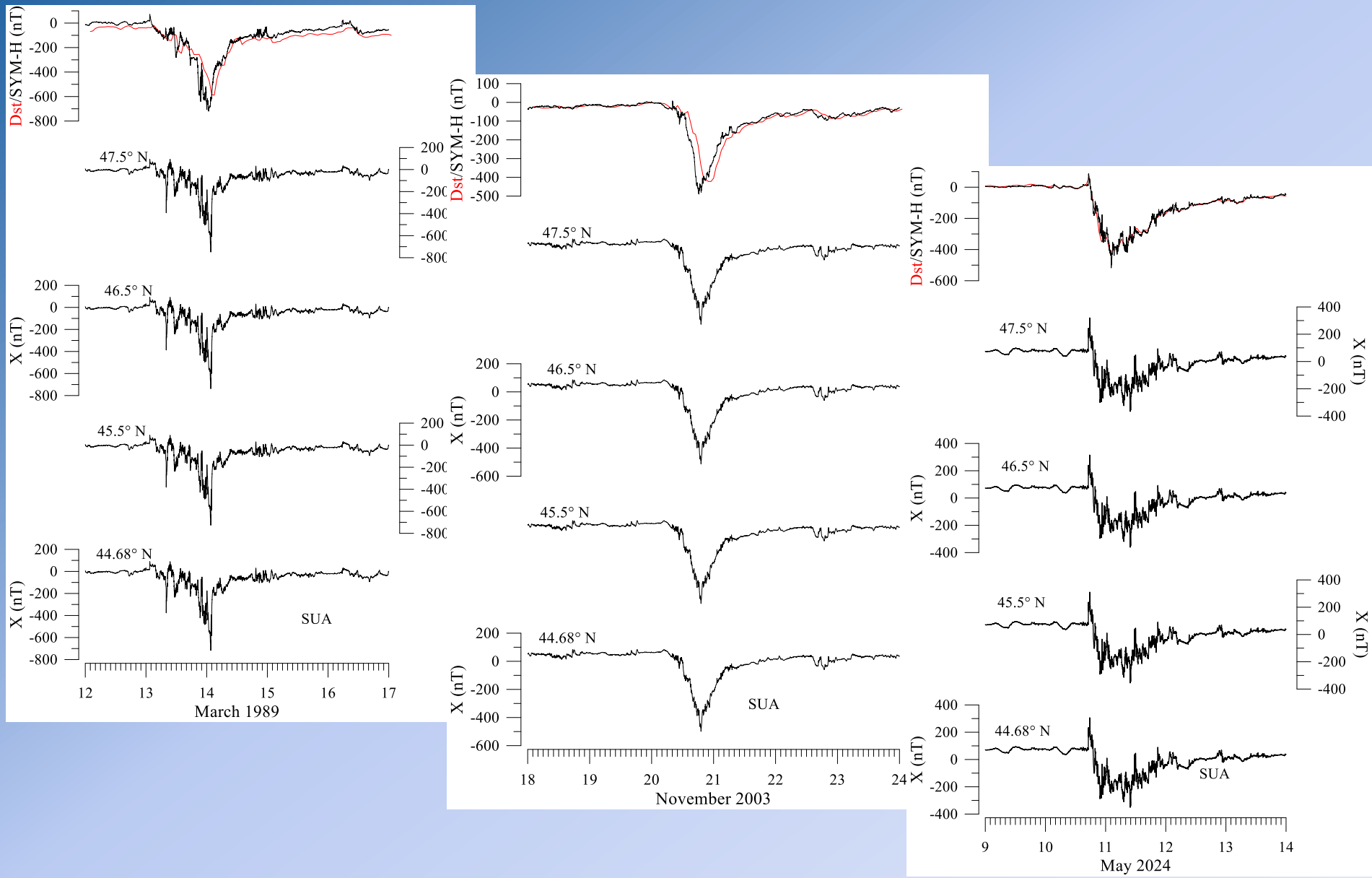
$$X_d = X_{SUA} * \cos\theta / \cos\theta_{SUA}$$

0.1 x 0.1 degree network

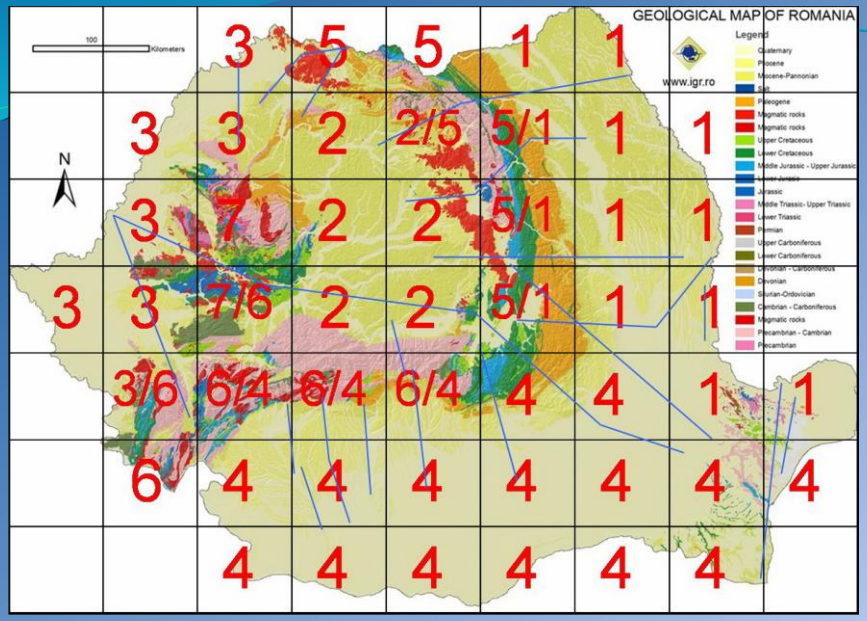


Geomagnetic disturbance over Romania

$$X_d = X_{SUA} * \cos\theta / \cos\theta_{SUA}$$

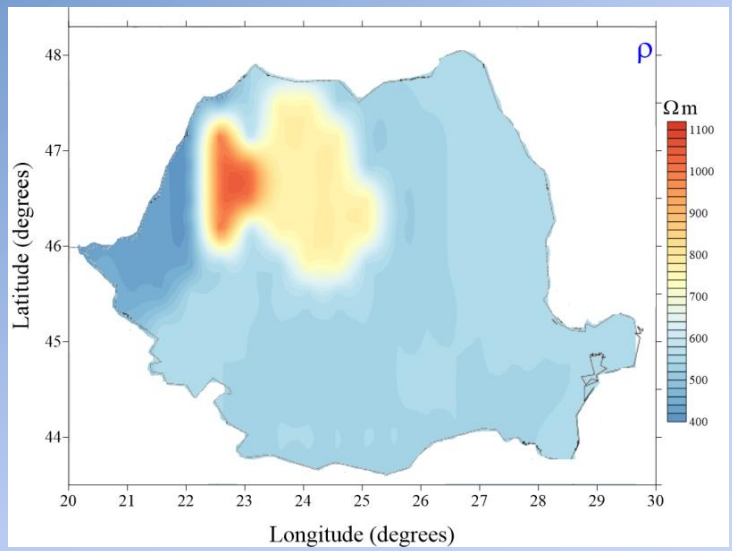


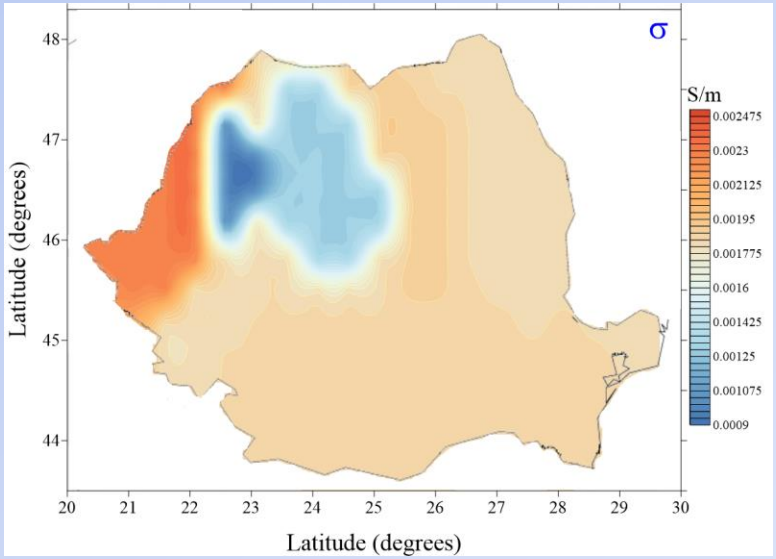
Electric structure of the Romanian underground



Tectonic unit
East European Platform + Scythian Platform + Carpathian Foredeep + North-Dobrogean Orogen
Transylvanian Depression
Pannonian Depression
Moesian Platform
East Carpathians
South Carpathians
Apuseni Mountains

Tectonic unit	Resistivity (ρ) [Ω m = VmA^{-1}]	Conductivity (σ) x 10^{-4} [S/m = AV^{-1}m^{-1}]	Resistance (R) [Ω = VA^{-1}]
East European Platform + Scythian Platform + Carpathian Foredeep + North-Dobrogean Orogen	544	18,4	95200
Transylvanian Depression	772	12,96	62525
Pannonian Depression	439	22,8	26320
Moesian Platform	540	18,5	70200
East Carpathians	528	18,9	90840
South Carpathians	549	18,2	70300
Apuseni Mountains	1009	9,9	80685

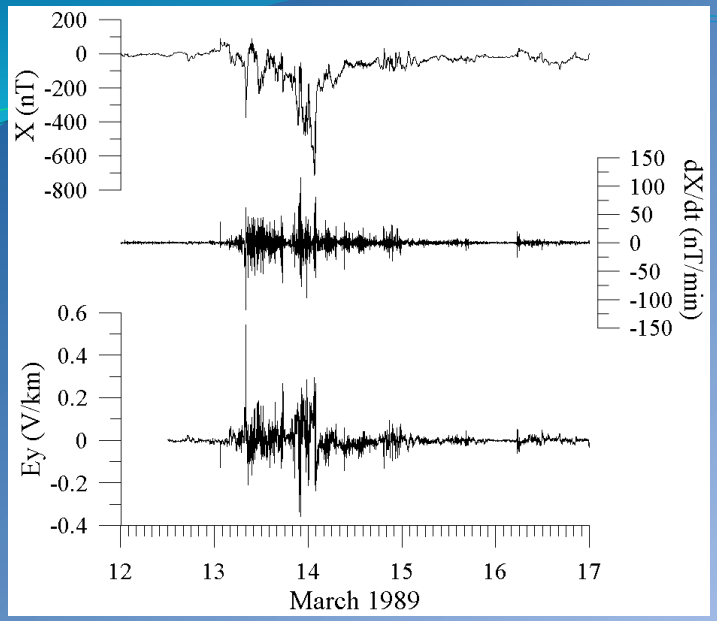


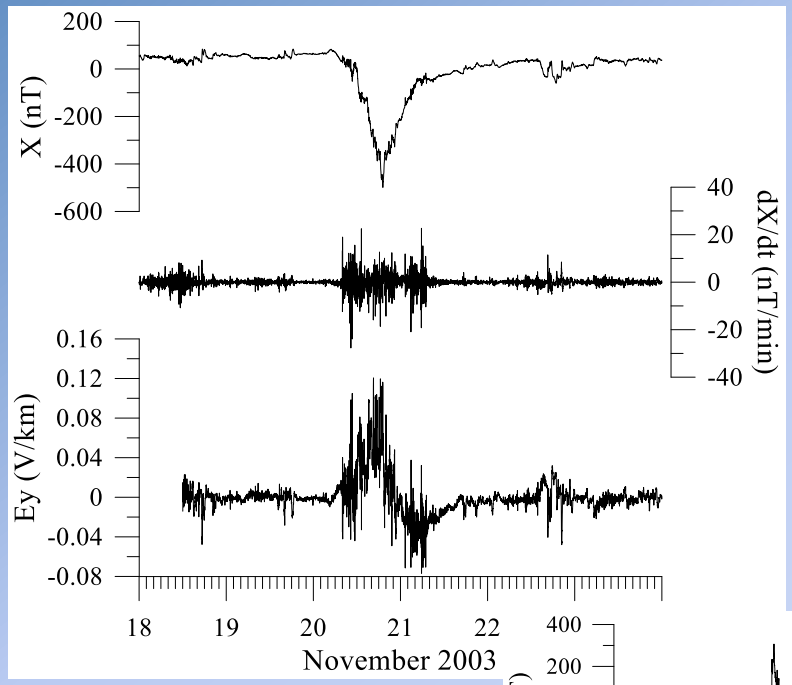


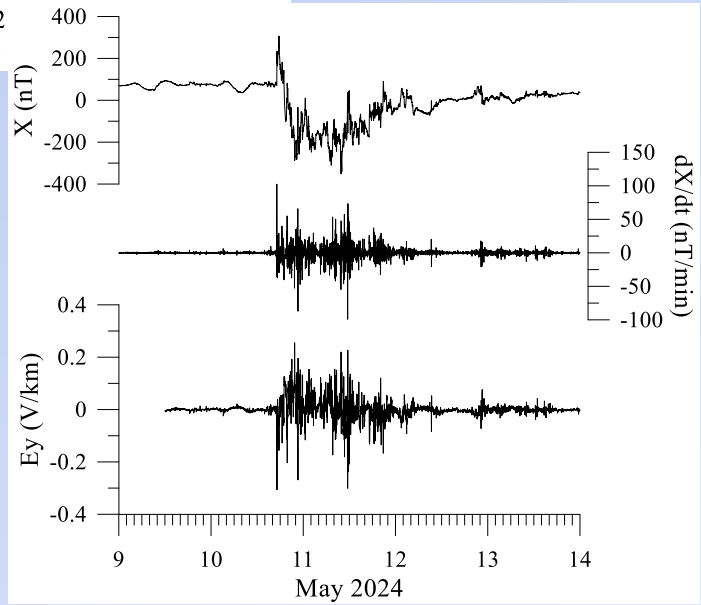
Stanica et al. (RRG, 2016)

Surface geoelectric field

SUA

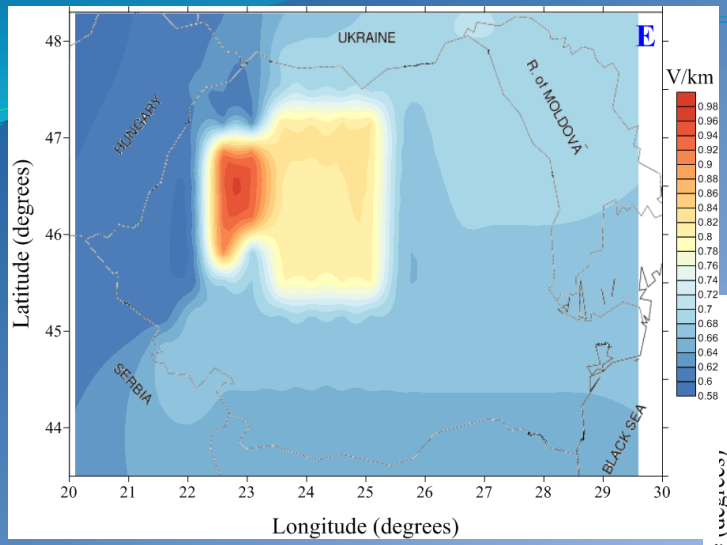




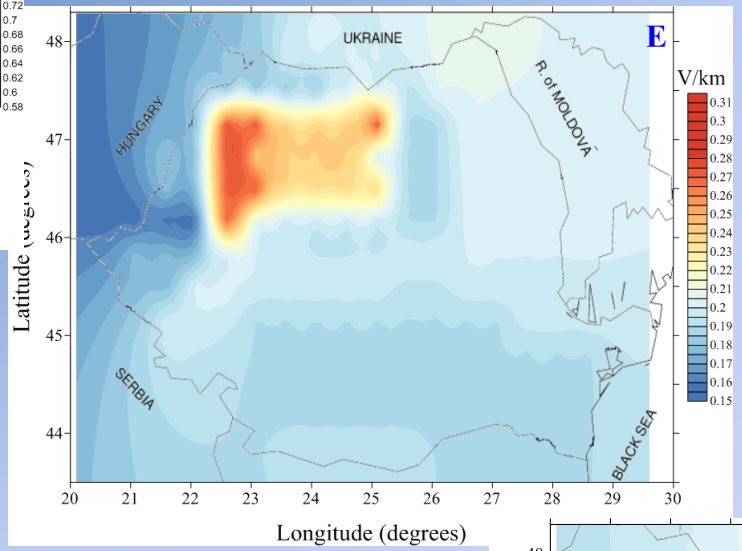


- the amplitude of geoelectric field depends on the morphology rather than the amplitude of the disturbance

Geoelectric hazard - Emax

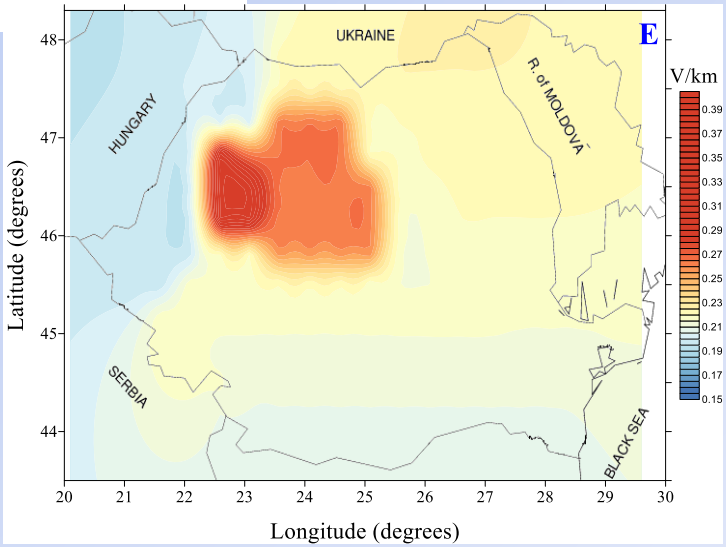


March 1989
Dst = -589 nT



November 2003
Dst = -422 nT

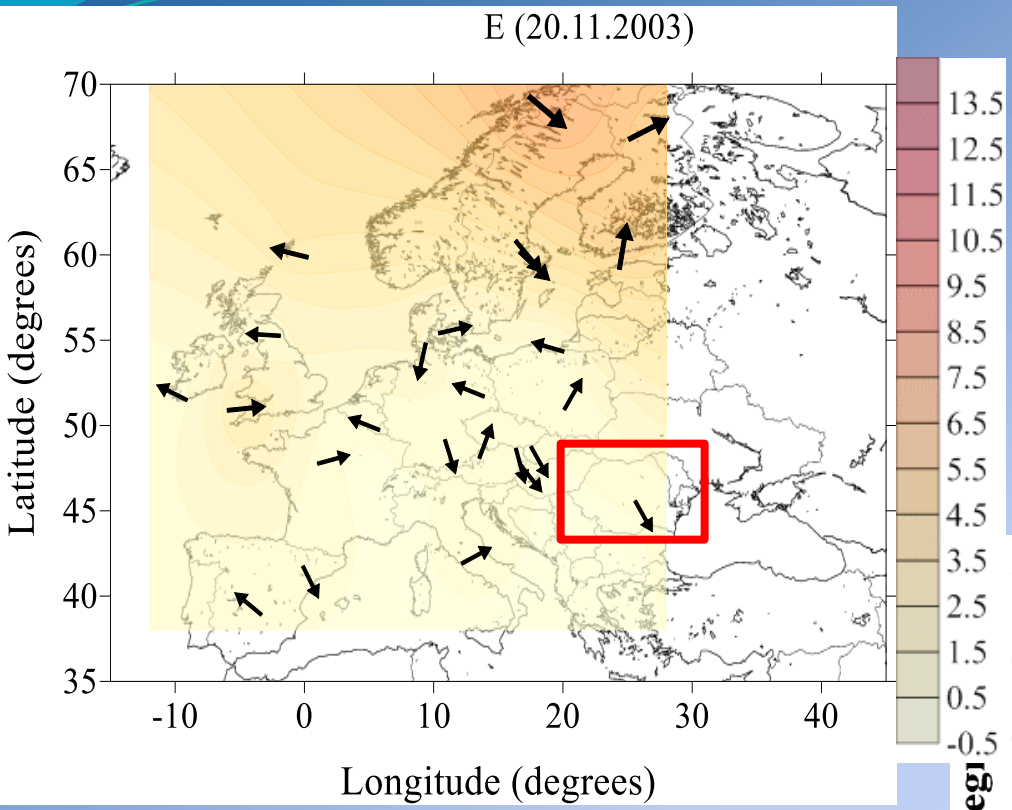
- the geoelectric hazard, in terms of Emax, in case of the March 1989 superstorm, is about three and, respectively, two times higher than in case of the November 2003 and May 2024 superstorms



May 2024
Dst = -412 nT

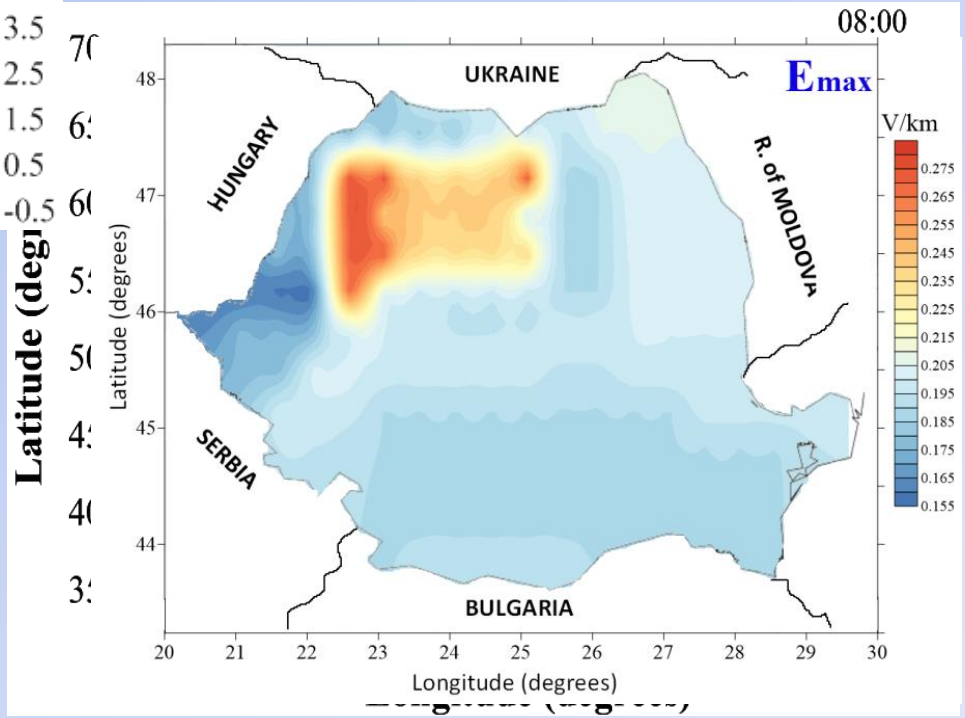
Geoelectric hazard (Emax) at regional and local scales

November 2003 storm



Dobrica et al. (2016)

E max value is not reached at the same moment at all observatories and its orientation depends on that moment of the storm development. Field direction and magnitude – arrows centered on the geomagnetic observatory location



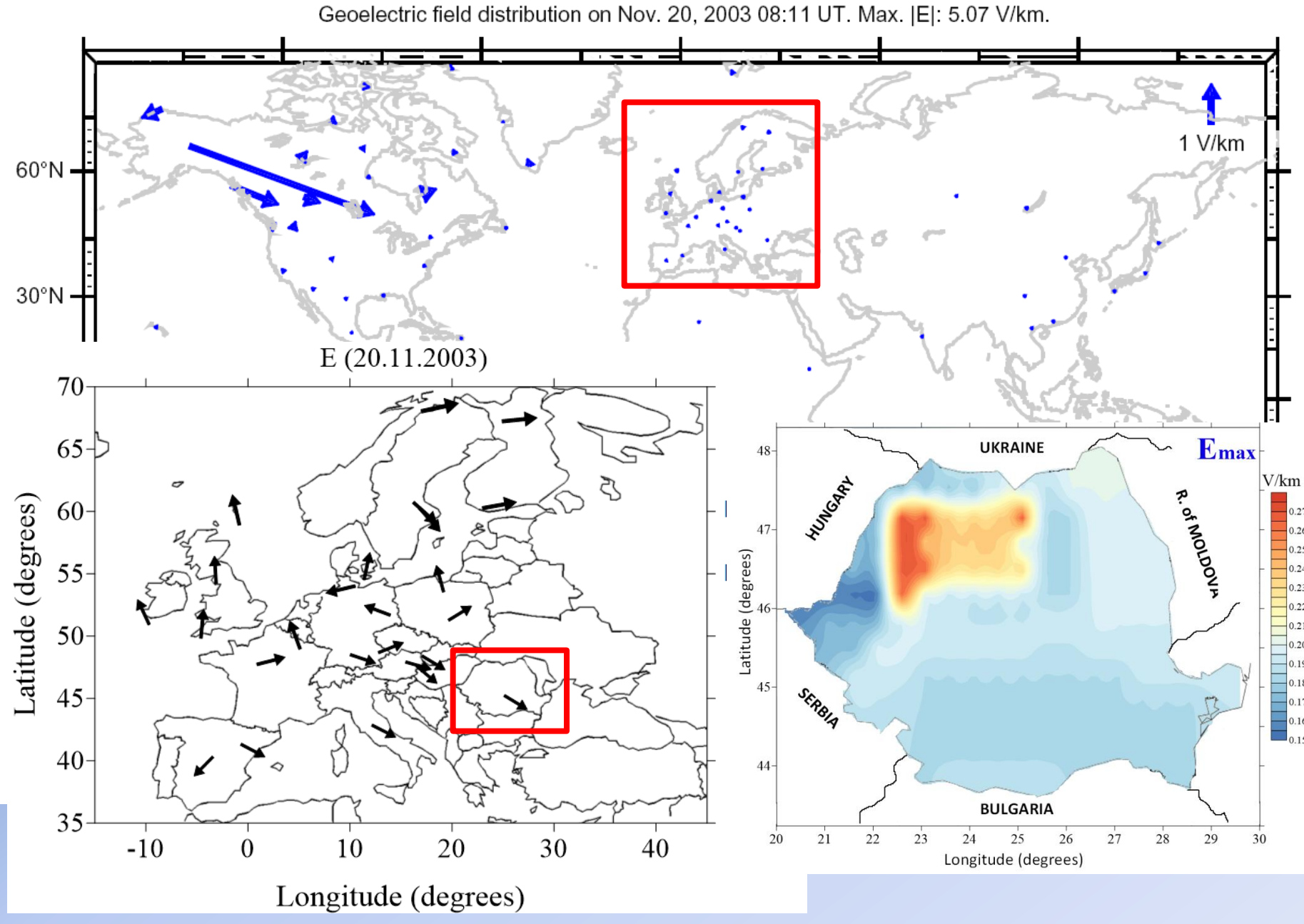

Geoelectric field distribution on Nov. 20, 2003 08:11 UT. Max. |E|: 5.07 V/km.
60°N
30°N
1 V/km
E (20.11.2003)
Latitude (degrees)
Longitude (degrees)
70
65
60
55
50
45
40
35
-10
0
10
20
30
40
UKRAINE
HUNGARY
R. of MOLDOVA
SERBIA
BULGARIA
Emax
V/km
0.275
0.265
0.255
0.245
0.235
0.225
0.215
0.205
0.195
0.185
0.175
0.165
0.155
48
47
46
45
44
20
21
22
23
24
25
26
27
28
29
30
Latitude (degrees)
Longitude (degrees)

Table 1 Examples of Extreme GIC Effects on Ground Systems Within the Last 80 Years

Date	Associated Effects/Impacts
March 24, 1940	Power circuit disturbances in North America. Earliest publicly reported impact on power grids (Davidson, 1940; McNish, 1940).
February 11, 1958	Blown AC power supply fuses for Finnish telecommunications cable system; Fire damage to telegraph equipment (Nevanlinna et al., 2001; Wik et al., 2009).
November 13, 1960	30 Swedish high-voltage power network line breakers tripped (Wik et al., 2009).
August 4, 1972	Communications cable system outage in mid-western United States (Boteler and Jansen van Beek, 1999).
July 13–14, 1982	Transformers and lines tripped in the Swedish high-voltage power system; Railway traffic light anomalies; Effects on telecommunications (Wik et al., 2009).
March 13–14, 1989	Hydro-Quebec blackout; New York transformer damage; Railway track anomalies (Boteler, 2001b; Bolduc, 2002; Eroshenko et al., 2010).
March 24, 1991	GIC > 100 A measured in Finland; 220 kV lines and a transformer tripped (Viljanen et al., 1999; Wik et al., 2009).
November 9, 1991	220 kV line tripping; Large pipe-to-soil voltages in an oil pipeline (Wik et al., 2009).
April 6, 2000	Largest GIC on Swedish transformer; False railway track occupations/blockages (Wik et al., 2009; Eroshenko et al., 2010).
November 6, 2001	Railway automatic system failure (Eroshenko et al., 2010).
October 29–30, 2003	Malmö blackout; Excessive transformer heating; Triggered emergency procedures at nuclear power plants in Canada and Northeastern United States; Reported damaged to high-voltage transformers in South Africa; Railway automatic system failure (Pulkkinen et al., 2005; Wik et al., 2009; Gaunt and Coetzee, 2007; Eroshenko et al., 2010).
November 20, 2003	Railway automatic system failure (Eroshenko et al., 2010).
November 8, 2004	Transformer GIC exceeding 100 A measured in southern Sweden (Wik et al., 2009).
May 14, 2005	Railway automatic system failure (Eroshenko et al., 2010).

Concluding remarks

- storms differ from each other primarily because of interacting solar wind conditions and state of magnetosphere;
- the disturbance in X of about hundreds of nT, over Romanian territory, in case of the superstorms, might be entirely given by the magnetospheric ring current contribution;
- the amplitude of geoelectric field depends on the morphology rather than the amplitude of the disturbance;
- the maximum value of geoelectric field in case of November 2003 superstorm is of the order of tenth of V/km, while in case of March 1989 superstorm is of the order of V/km;
- the geoelectric hazard (GICs) is to be taken into account even at mid latitudes.


Thank you!