Long- and short-term responses of the heliosphere-magnetosphere environment to solar activity variations

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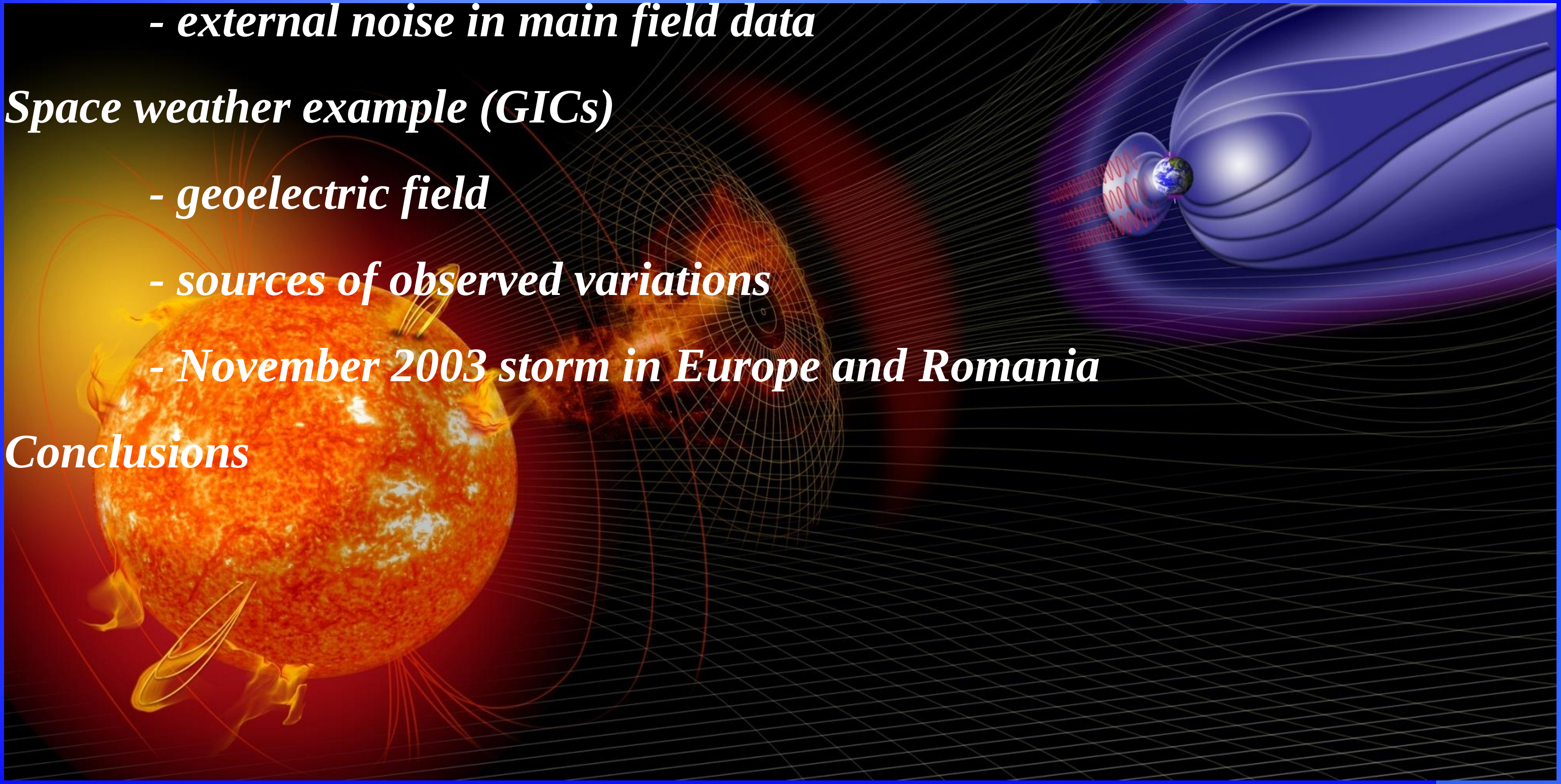
Outline

- *Definitions*
- *Space climate characterization*
    - *reconstruction back in time*
    - *external noise in main field data*
- *Space weather example (GICs)*
    - *geoelectric field*
    - *sources of observed variations*
    - *November 2003 storm in Europe and Romania*
- *Conclusions*



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.

Effects

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

Exposure of astronauts

Heart/mental conditions

We are interested in **Space climate**...

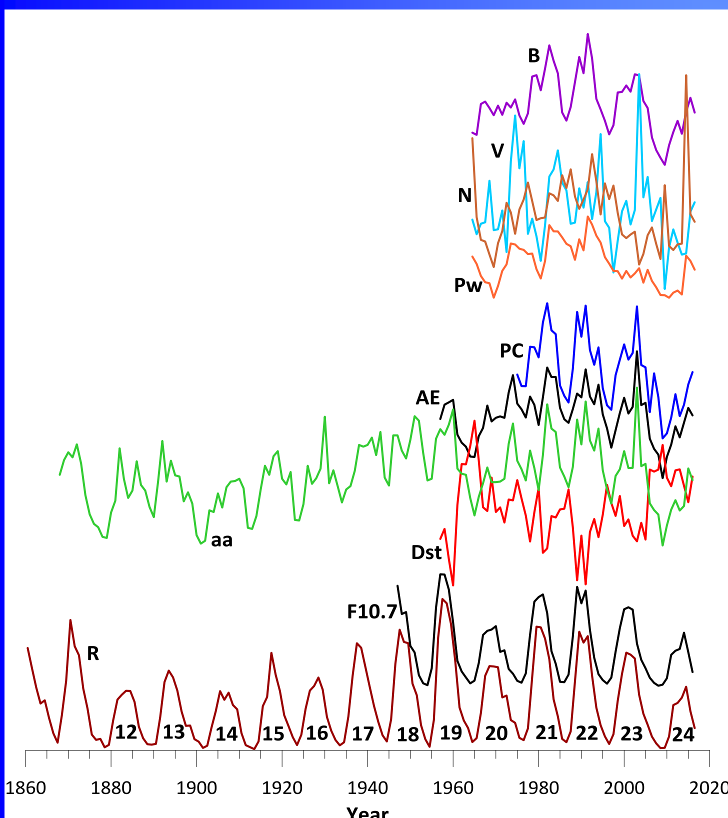
…the long-term change in the Sun, and its effects in the heliosphere and upon the Earth, including the atmosphere and climate.

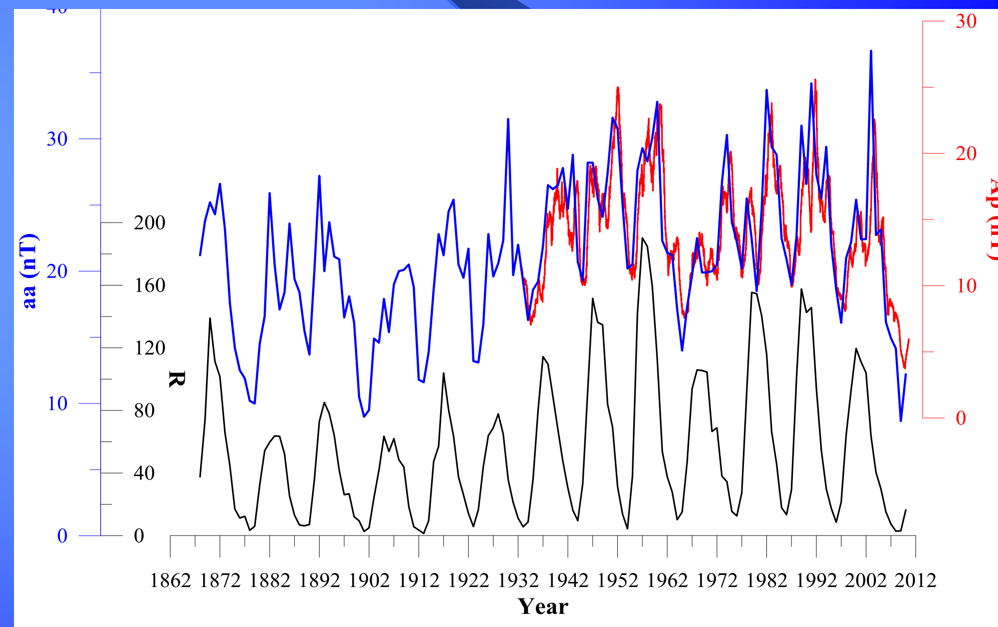
Information on Sun – Earth interaction

- space era: 1964

- the long geomagnetic time series recorded at geomagnetic observatories have provided means to characterize the Sun-Earth interaction at times prior to space era, via geomagnetic indices.

- no information prior to 1868; extended to 1830s (Svalgaard, AOGS 2014)





- looking for information from

- reconstructions

- 100-150 years long records from geomagnetic observatories

- the main field model gufm1 (1590-1990) (Jackson et al., 2000)

- looking for information from

- reconstructions

- 100-150 years long records from geomagnetic observatories

- the main field model gufm1 (1590-1990) (Jackson et al., 2000)

Reconstructions explicitly assume that one could extrapolate before 1964:

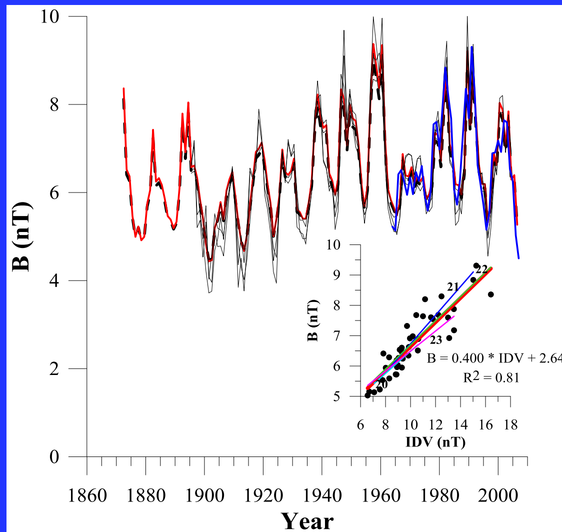
- the correlation between SW and HMF parameters and geomagnetic indices;
- the validity of the Parker spiral theory;
- the heliolatitudinal independence of the heliospheric magnetic flux from the Sun;
- the coupling function between the solar wind and the magnetosphere.

Reconstructions:

- linear correlations
- physical model + linear correlation

Reconstructions to 1870

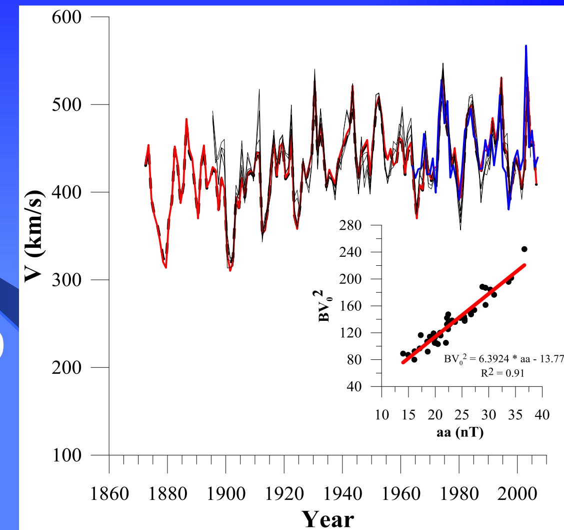
- based on correlations



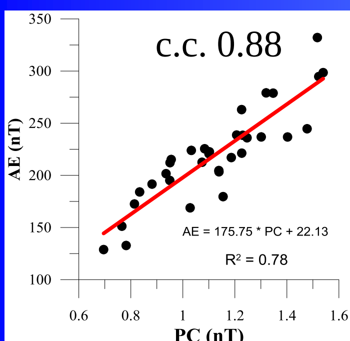
B~IDV

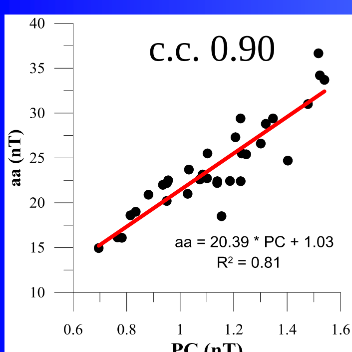
BV^2~IHV

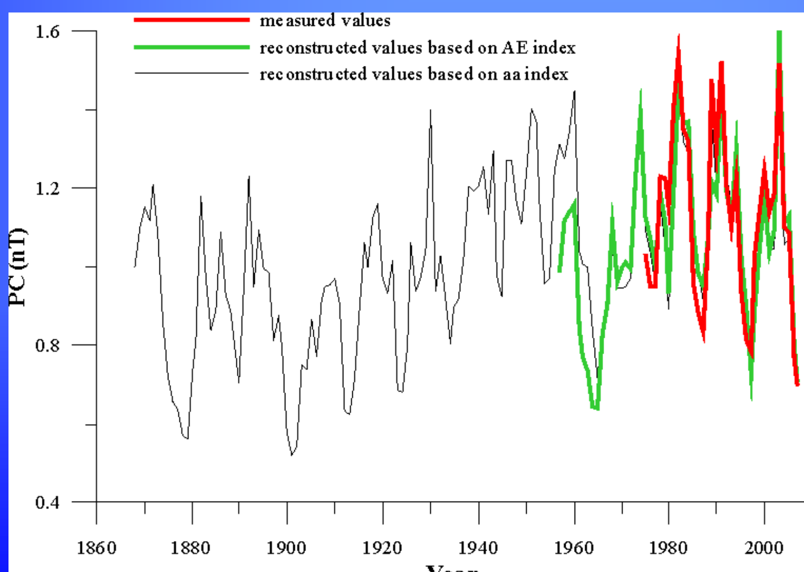
Svalgaard&Cliver (JGR2005, 2007)
Rouillard et al. (JGR2007)
Demetrescu et al. (ASR2010)



PC – AE
PC – aa







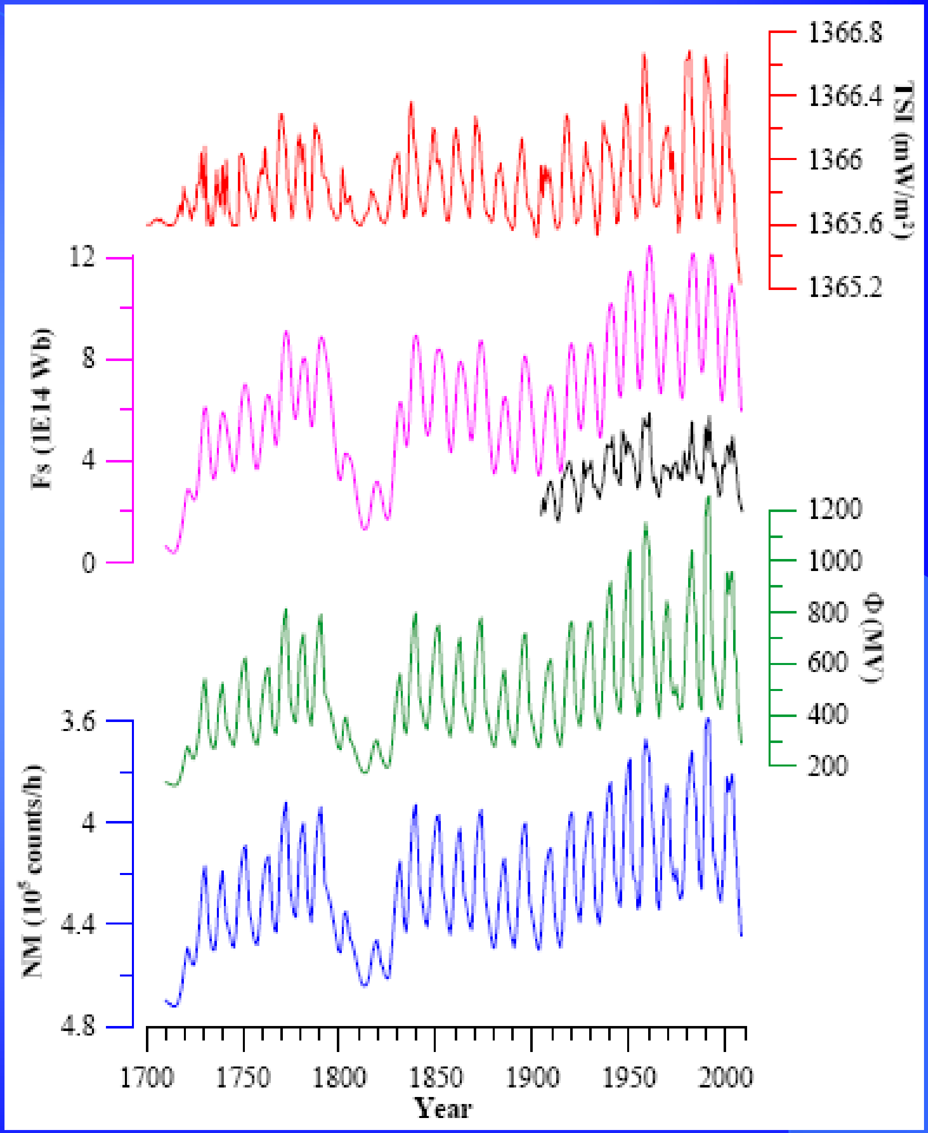
Reconstructions to 1700

- based on physical models + correlations (R)

TSI – model linking the solar radiative output with the contributing features of the photosphere (sunspots&faculae) *(Lean et al., 1995; Lean et al.,2000)*, or
with the solar surface magnetic flux *(Solanki et al., 2002; Krivova et al.,2007)*

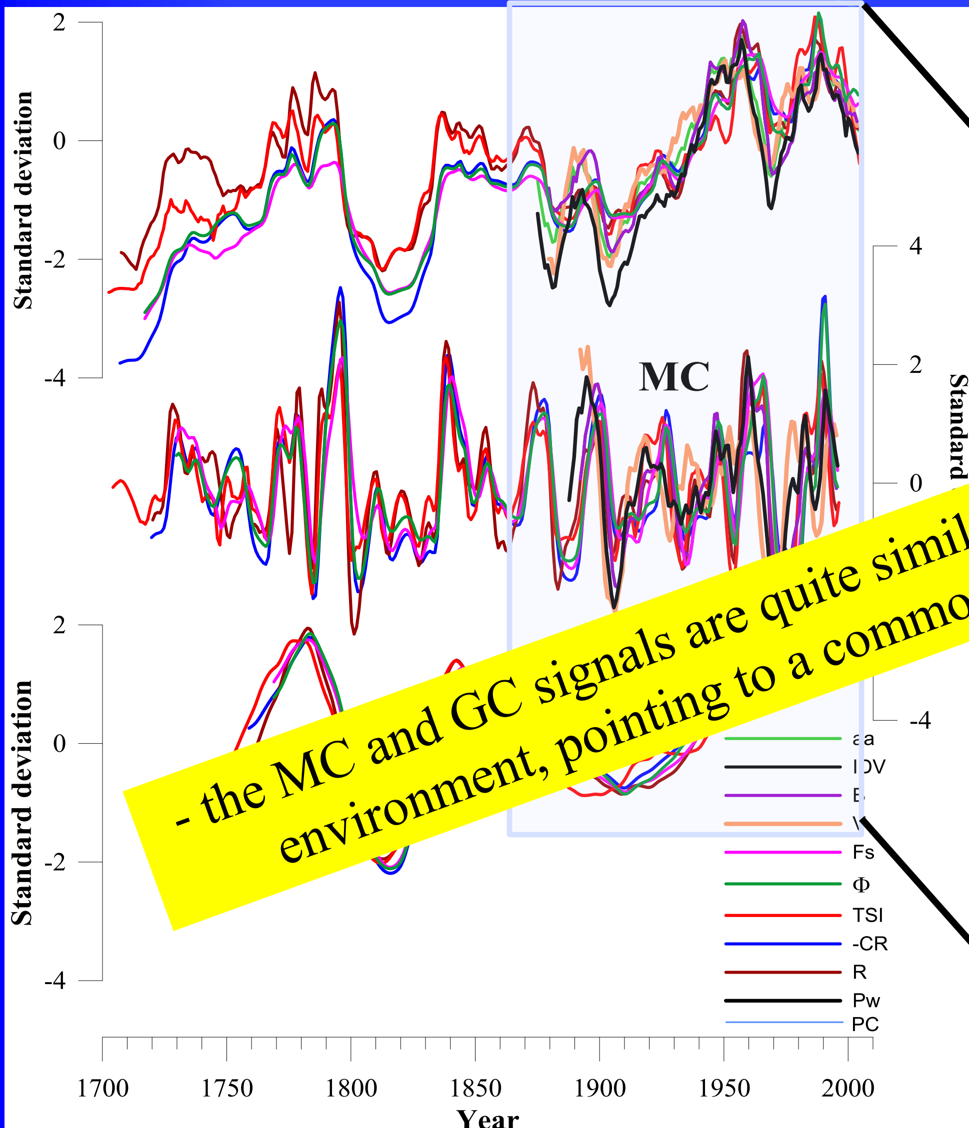
Fs – model using solar magnetograph data in the Potential Field Source Surface (PFSS) method *(Wang&Sheely, 1995; 2002)*
- model for the emergence and long-term evolution of the solar flux *(Solanki et al., 2000, 2002; Lean et al.,2002; Wang et al., 2005)*

GCR flux, Φ – reconstruction of the open flux from sunspot numbers *(Solanki et al., 2002)* in conjunction with a spherically symmetric model of the heliosphere *(Usoskin et al., 2002a)* to reconstruct the intensity of GCR at Earth *(Usoskin et al., 2002b)*

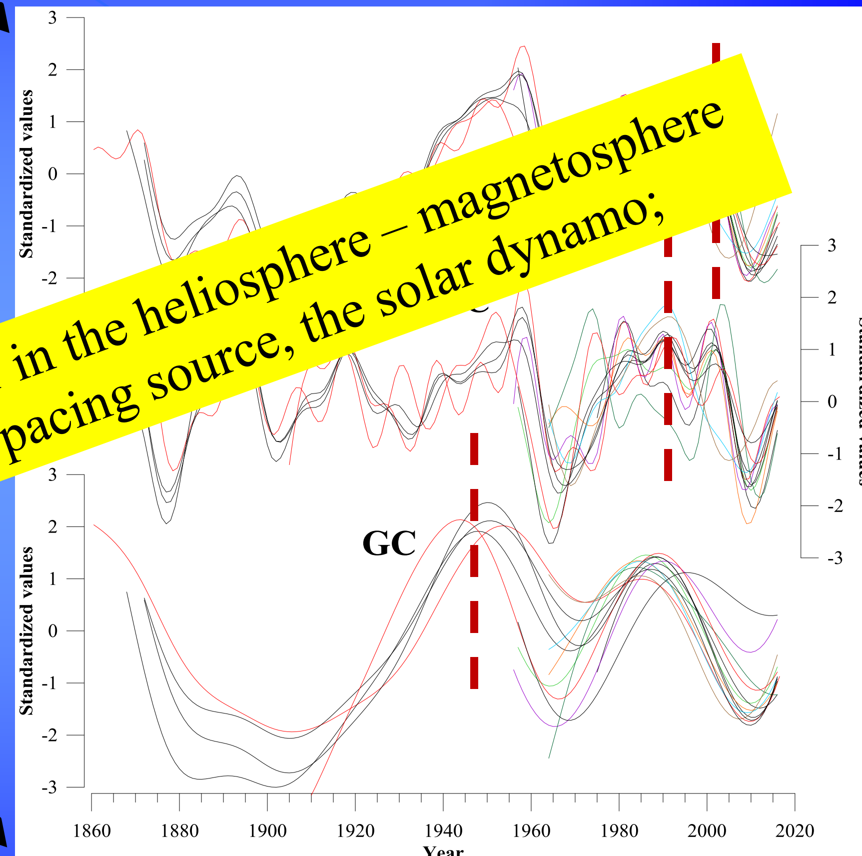


The solar-heliospheric-magnetospheric environment

Trends in data / interdecadal and centennial constituents



Extension to present

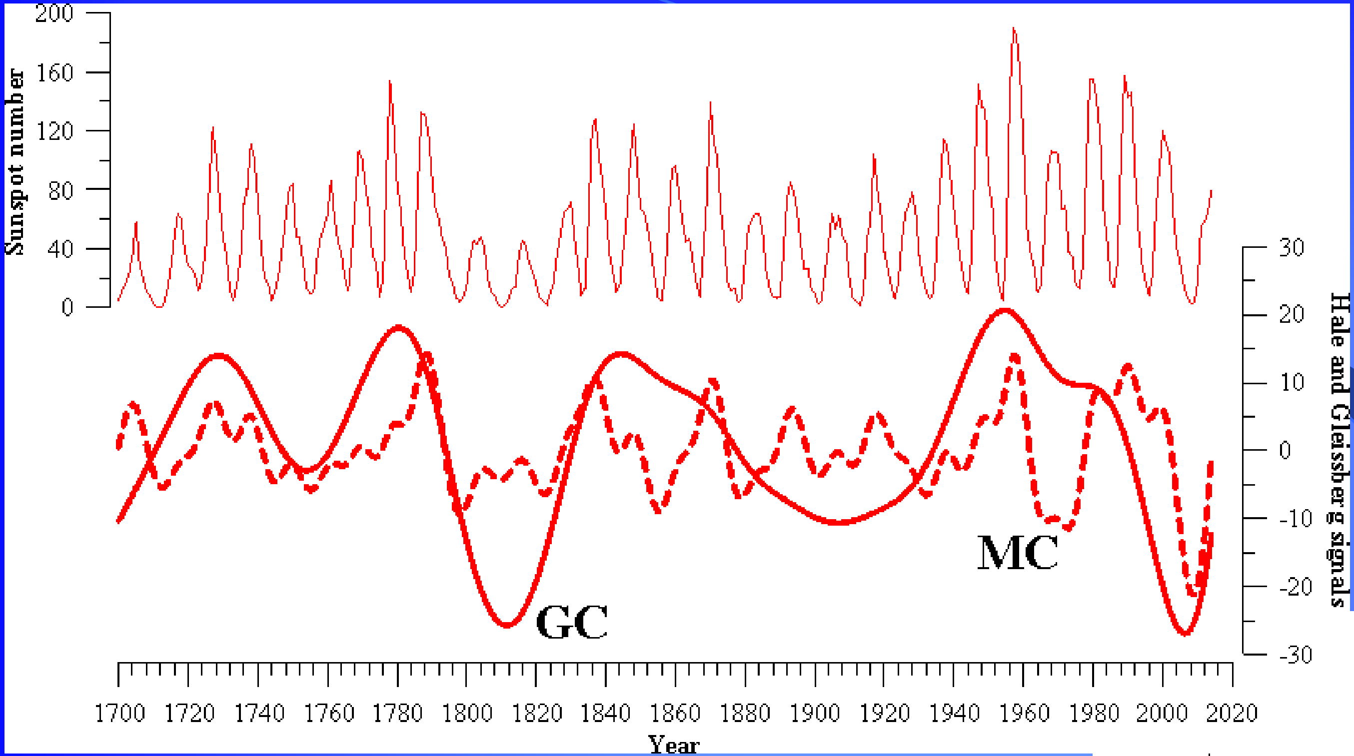


- the MC and GC signals are quite similar in the heliosphere – magnetosphere environment, pointing to a common pacing source, the solar dynamo;

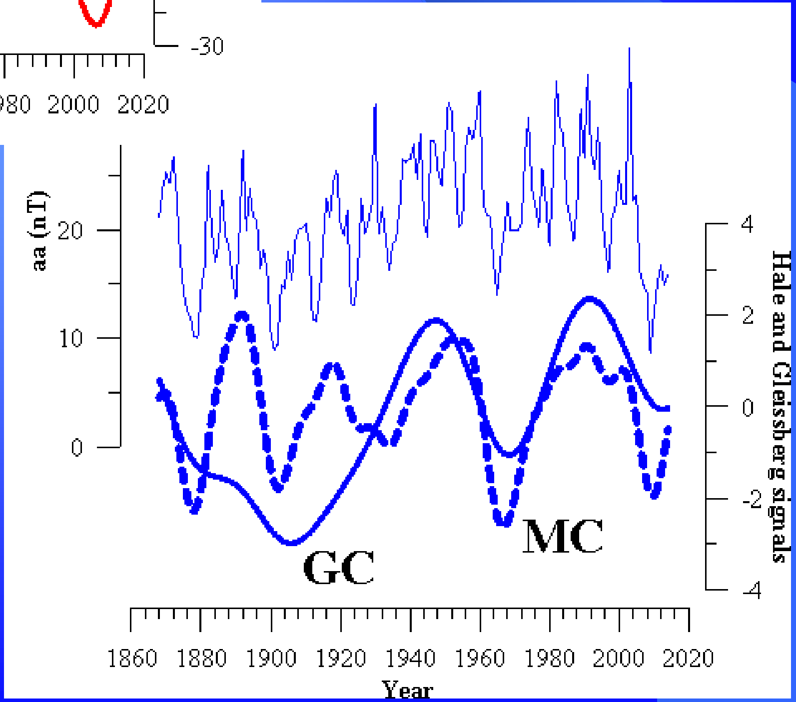
Curves are reduced to their means over the common time interval and scaled with their standard deviations about the mean as a unit

Demetrescu&Dobrica, JGR 2008
Demetrescu et al., ASR 2010
Dobrica&Demtrescu, RRG 2021

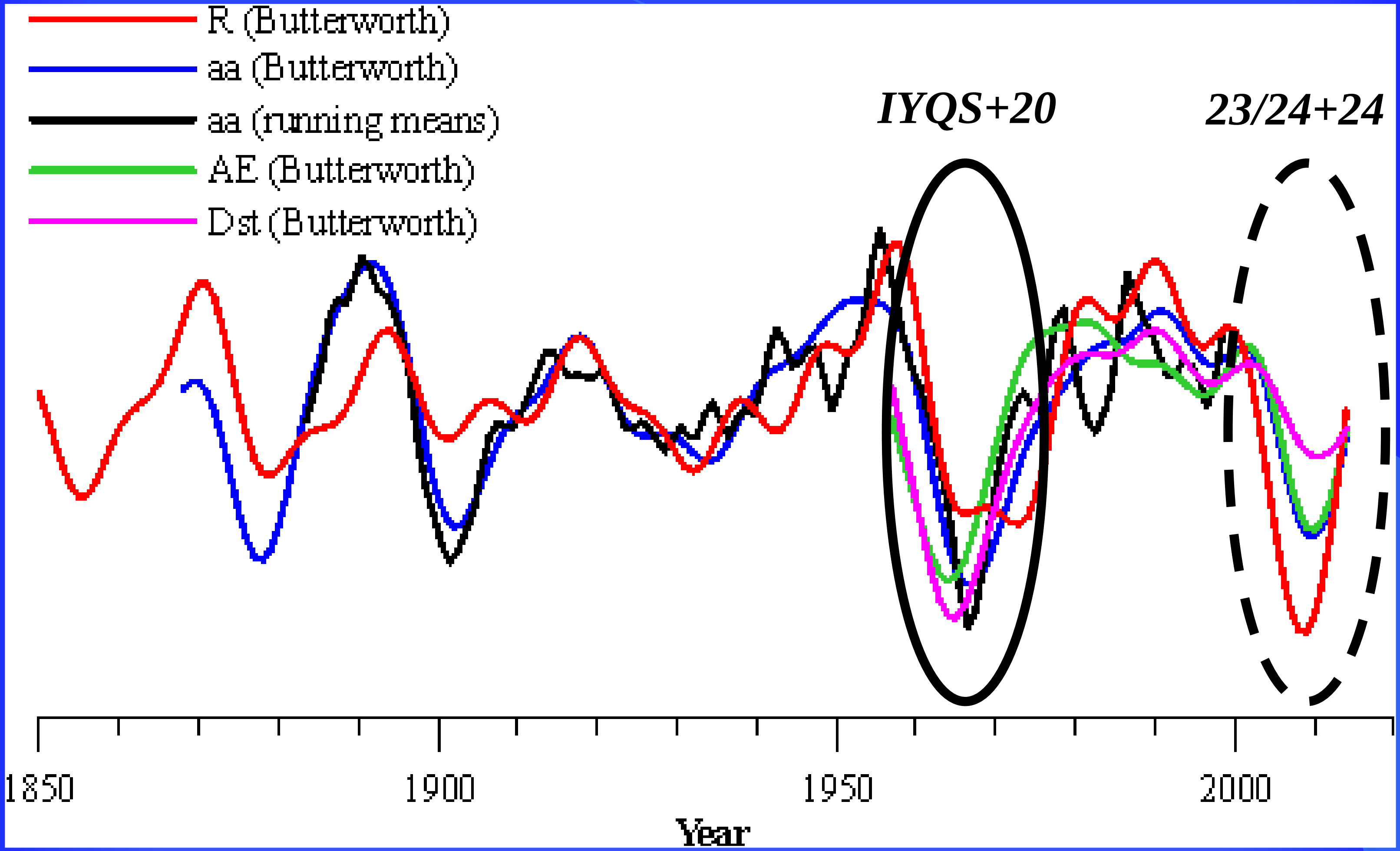
Magnetic (MC) and Gleissberg (GC) signals in R and aa



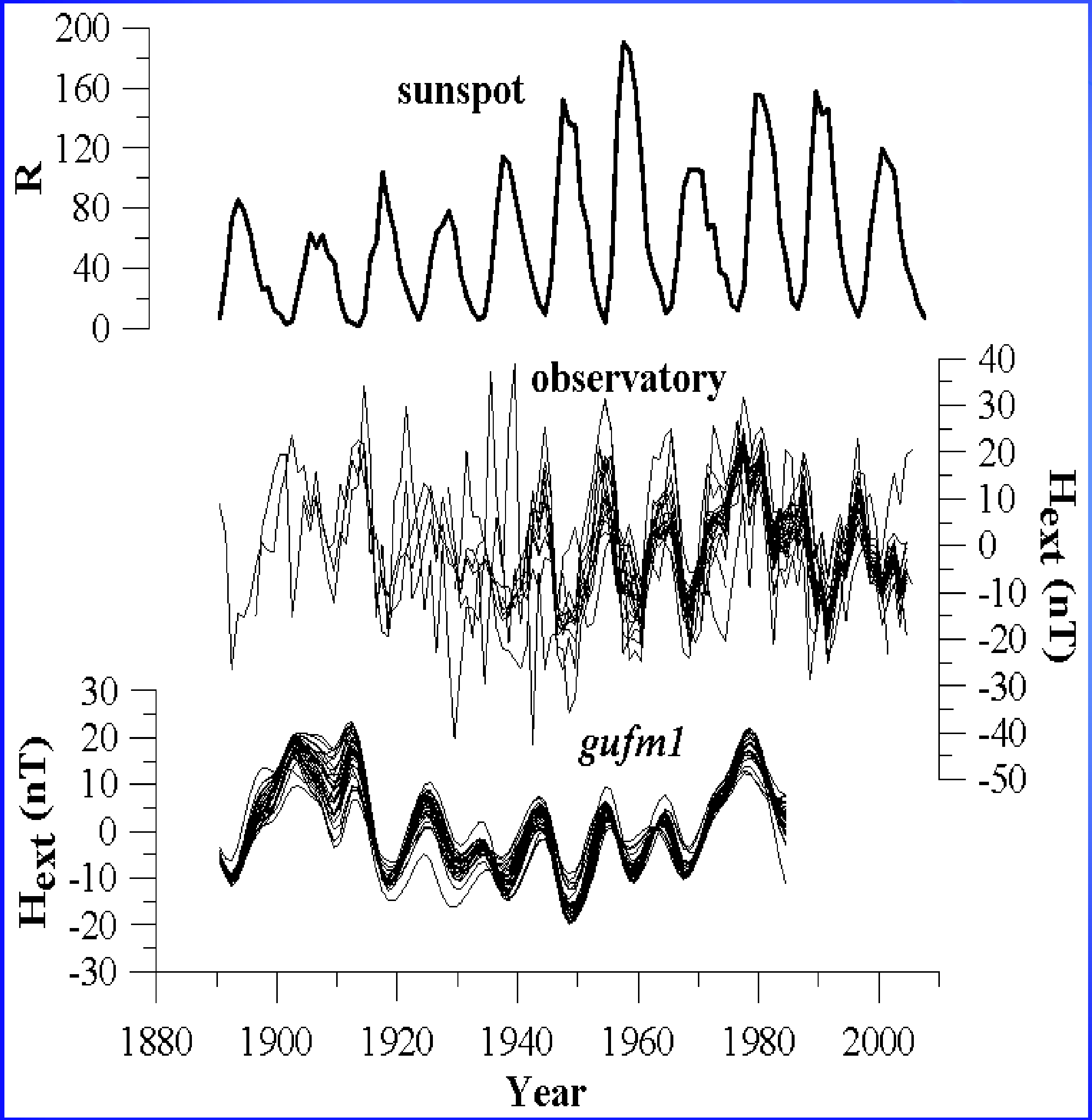
- superposed minima in MC and GC signals for both IYQS + next cycle 20 and the last deep minimum 23/24 + next cycle 24



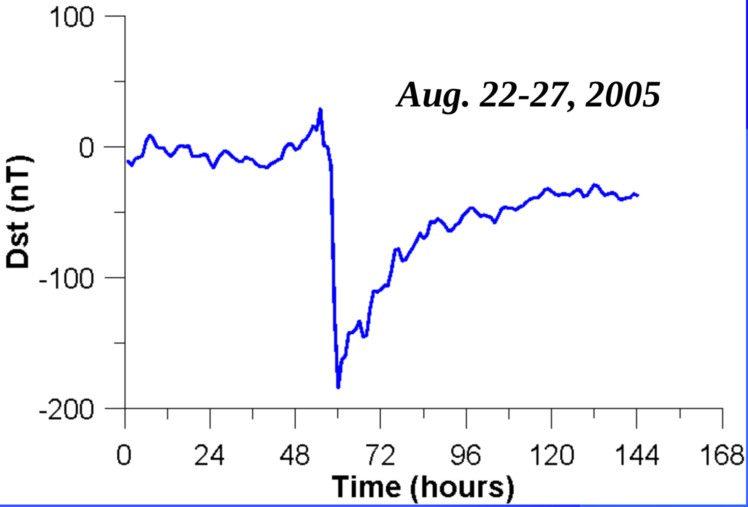
MC signature in solar and geomagnetic activity parameters



External, solar-cycle-related effects in observatory data and in gufm1 model



Annual means contain a residual, not averaged out disturbance field. Not accounted for, it leaks into main field models



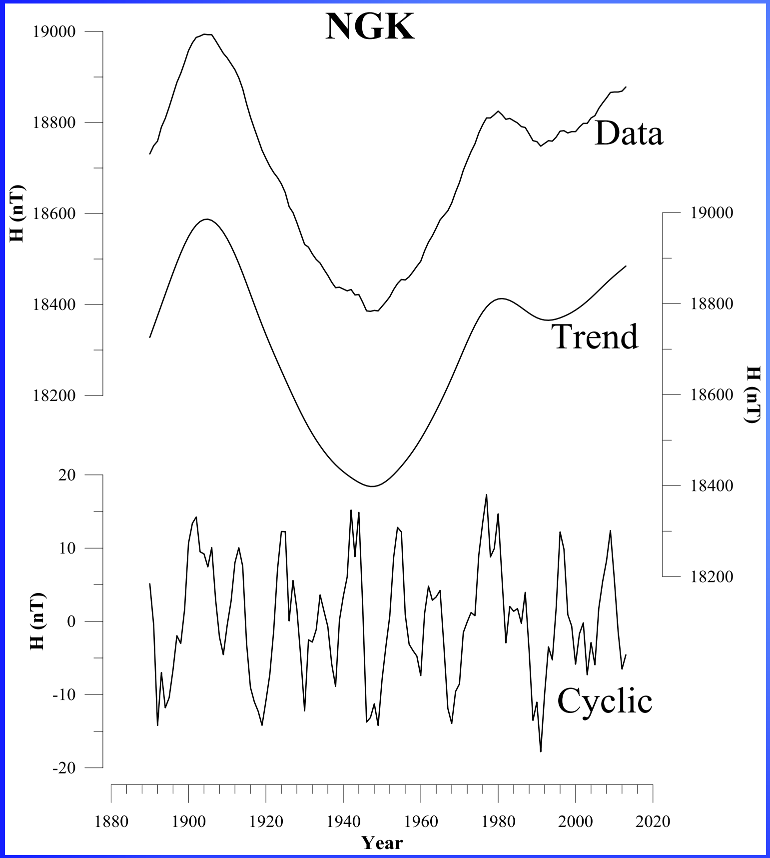
The external signal is anticorrelated with solar activity

Information back in time – observatory era
~1850 – present

Data —*HP filter*→ *Trend + cyclic*

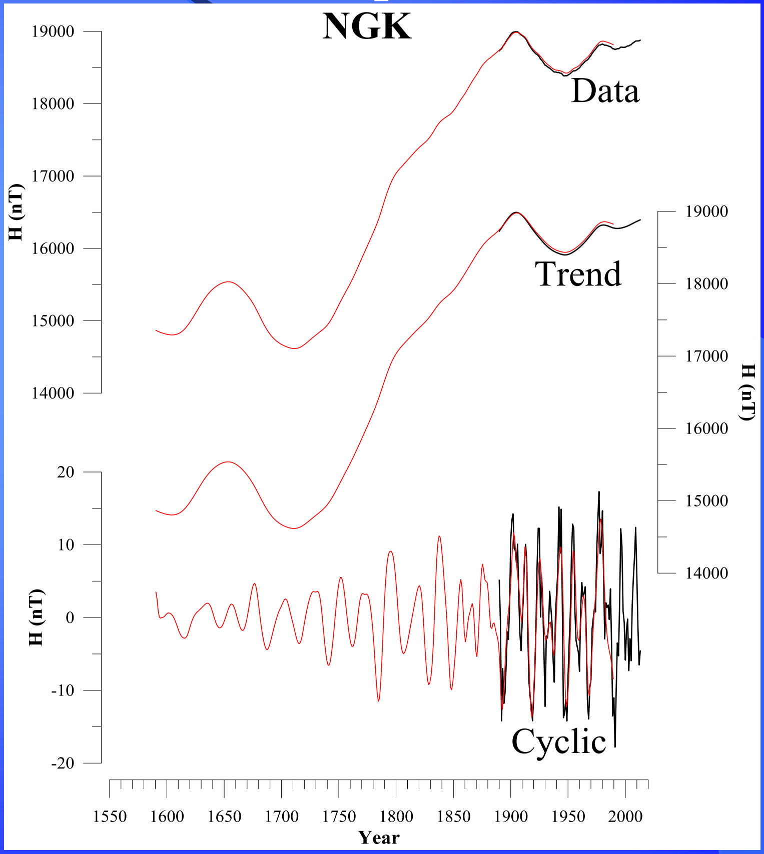
Hodrick&Prescott (1997)

~1850 – present



H

1590 - present



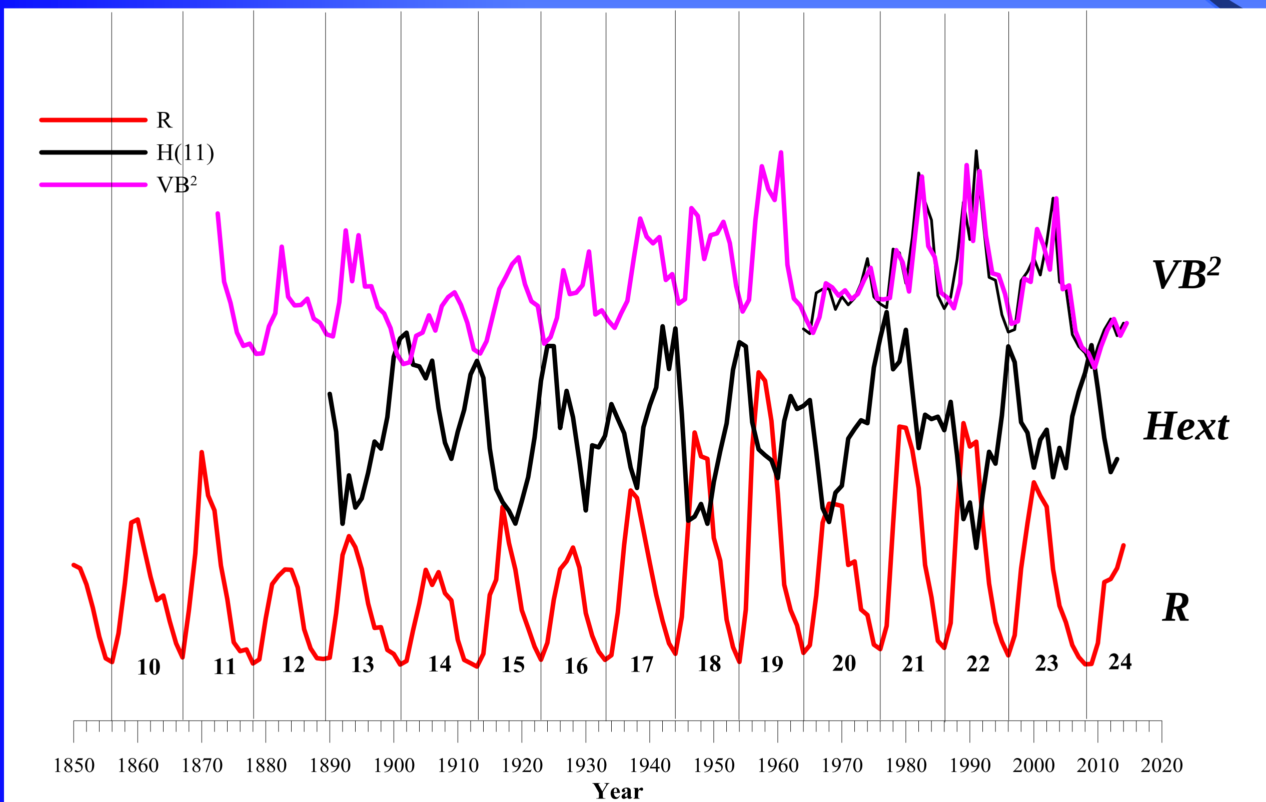
gufm1 - Jackson et al. (2000), 1590-1990, based on:
- prior to 1850: D&I measured during sea voyages
- after 1850: observatory and satellite data

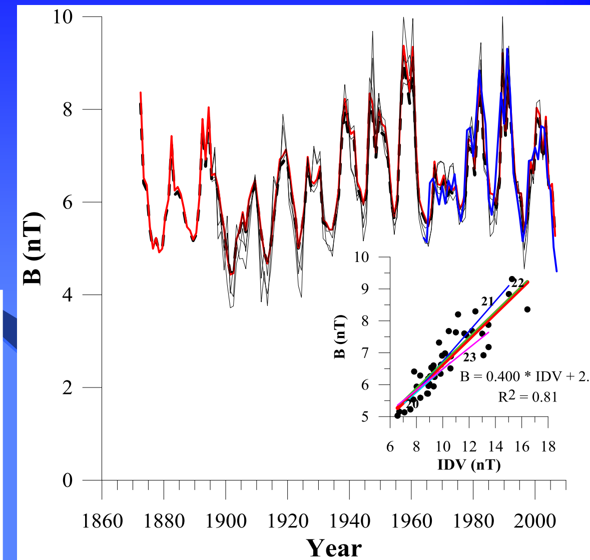
Information back in time – observatory era, ~1850 - present

B~IDV

BV^2~IHV

Horizontal component ; $\varepsilon \sim VB^2$





Svalgaard&Cliver (JGR2005, 2007)
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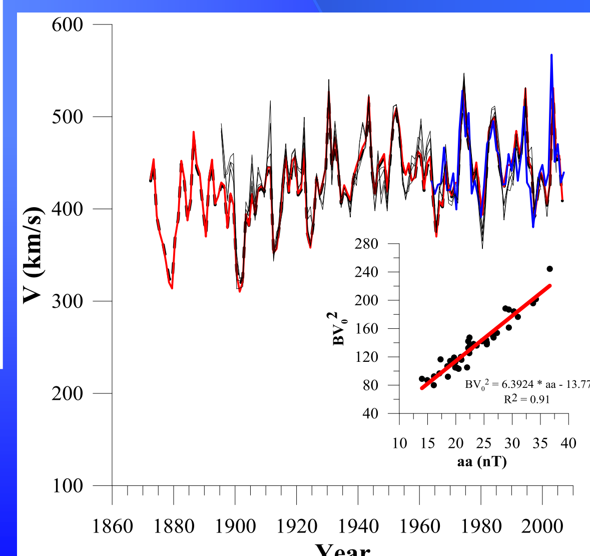
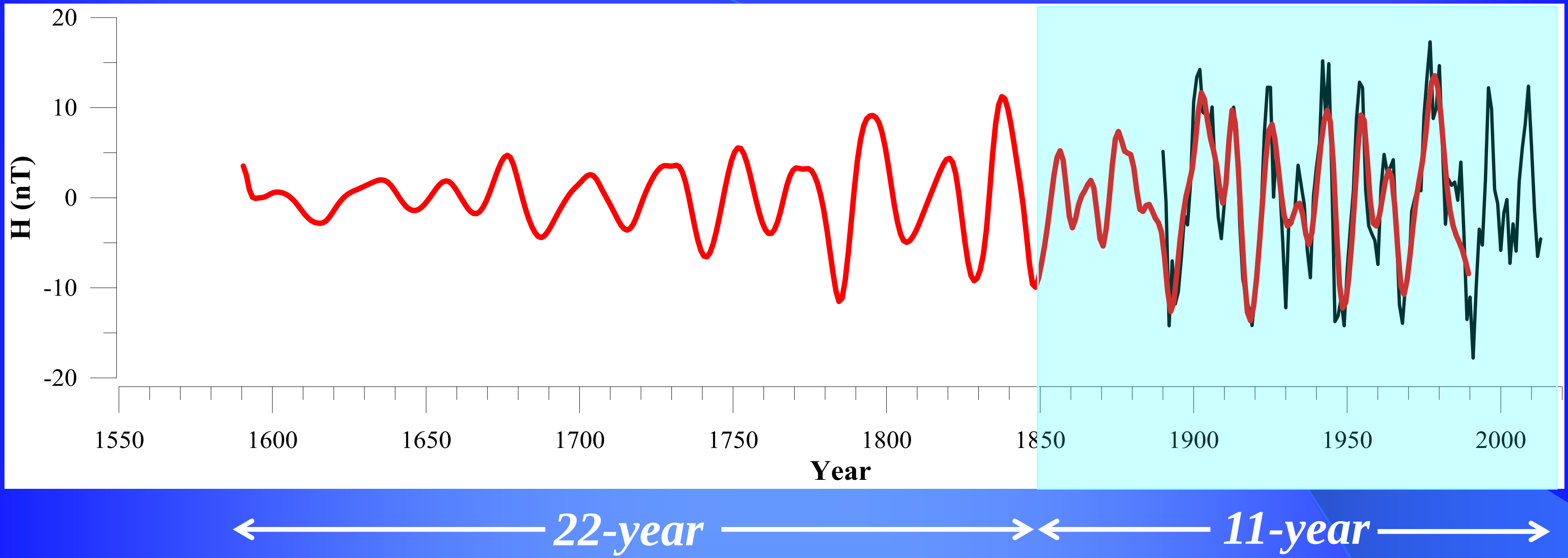
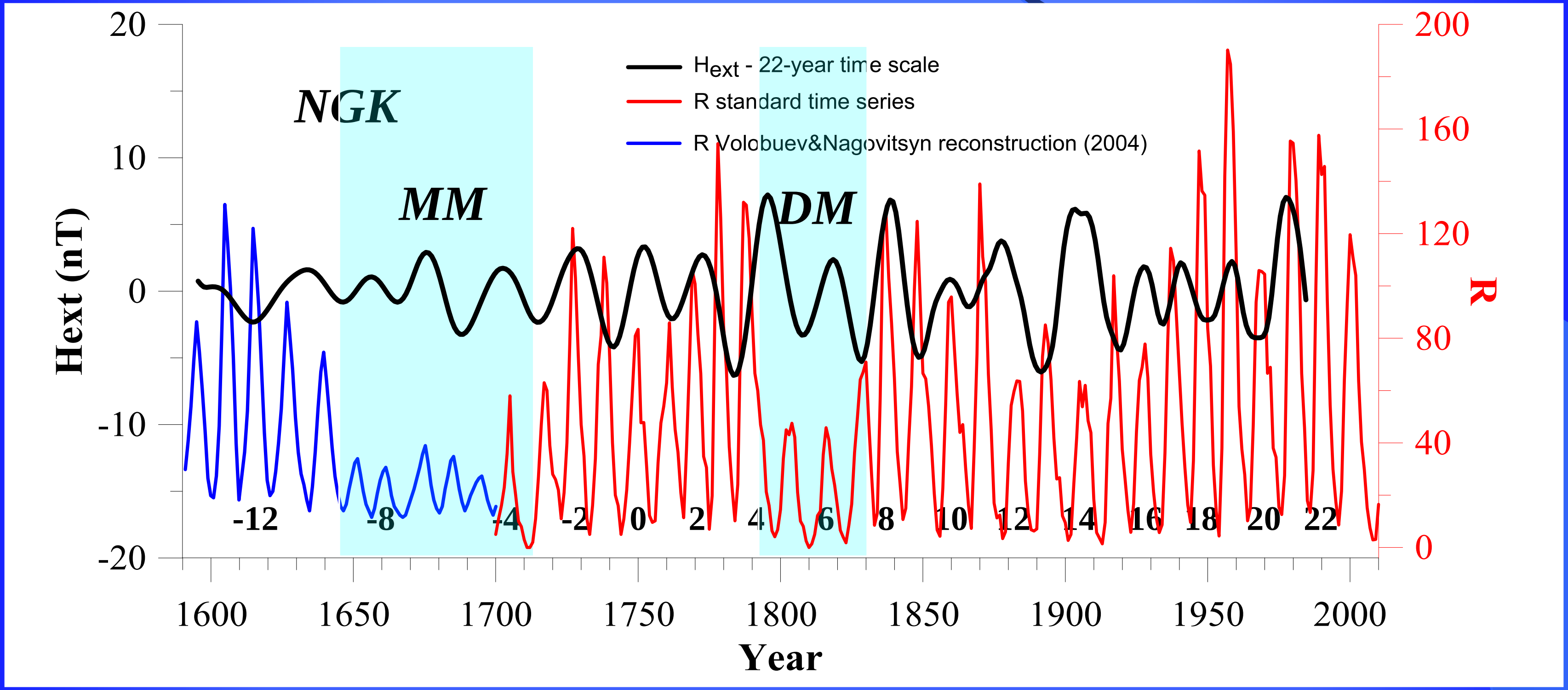


Information back in time – gufm1 main field model, 1590 - present



Information back in time – gufm1 main field model, 1590 - present

The 22-year time scale



- there is geomagnetic activity during MM and DM

Space weather example (GICs)

Variable external magnetic field

↓

Telluric currents

↓

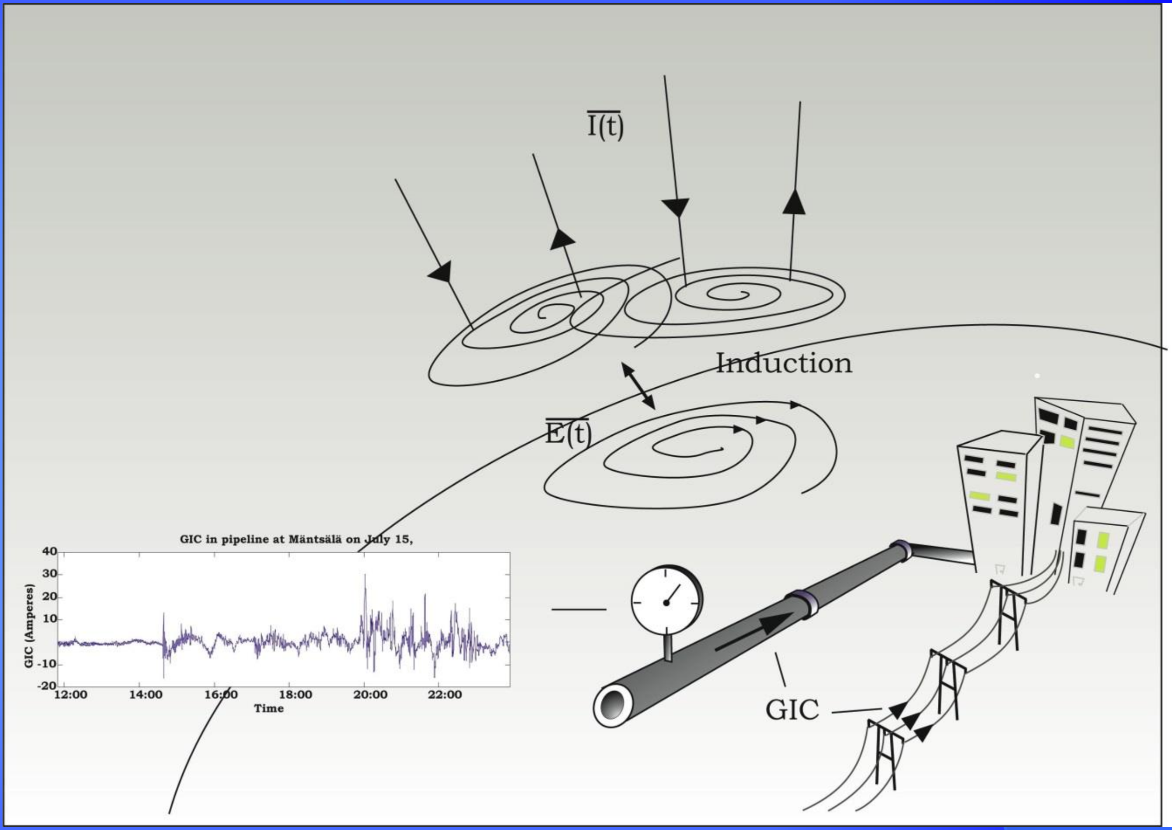
Secondary magnetic field

↓

Surface electric field

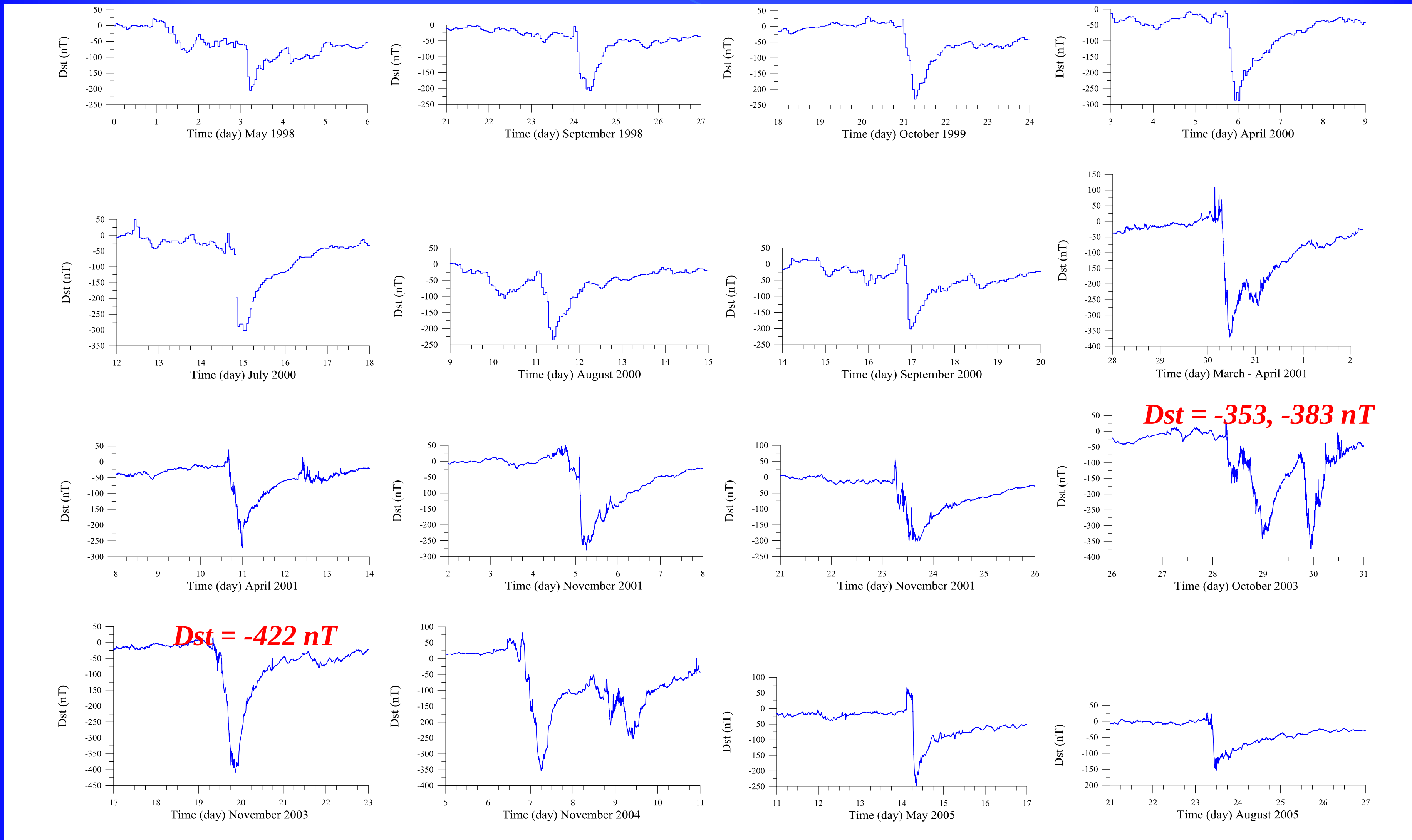
↓

Electric currents (GICs)



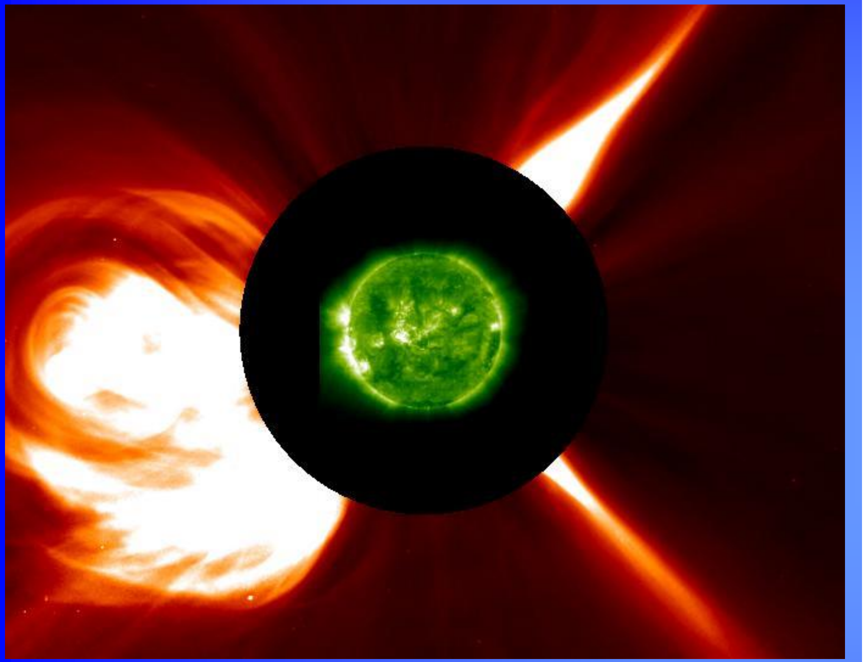
http://en.wikipedia.org/

Intense (Dst<-150 nT) storms – cycle 23



November 2003 storm

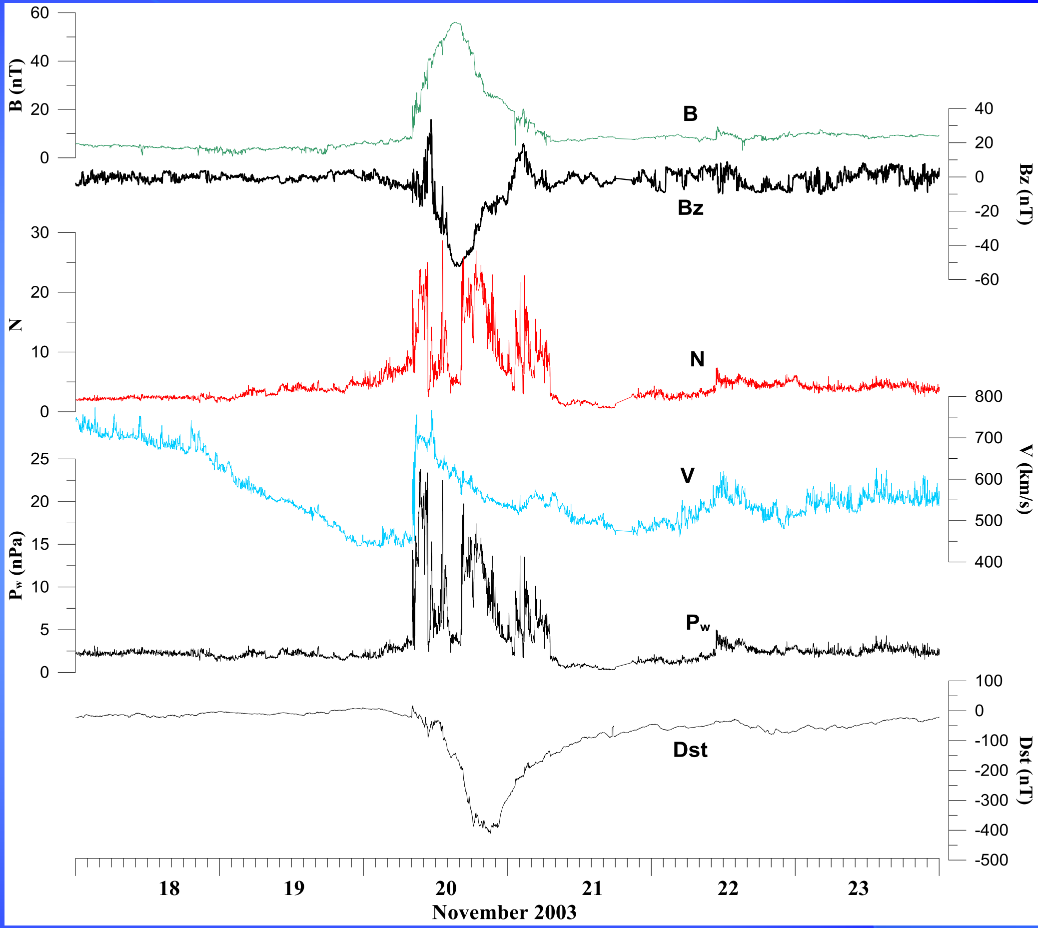
CME



November 18, 2003
10:24 UT

GOES
LASCO C2 image (jhelioviewer.org/)

ICME



www.omniwebdata

Solar eruption November 18, 2003, 8:12 UT

SSC, November 20, 2003
8:03 UT

Surface geoelectric field (1)

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

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

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

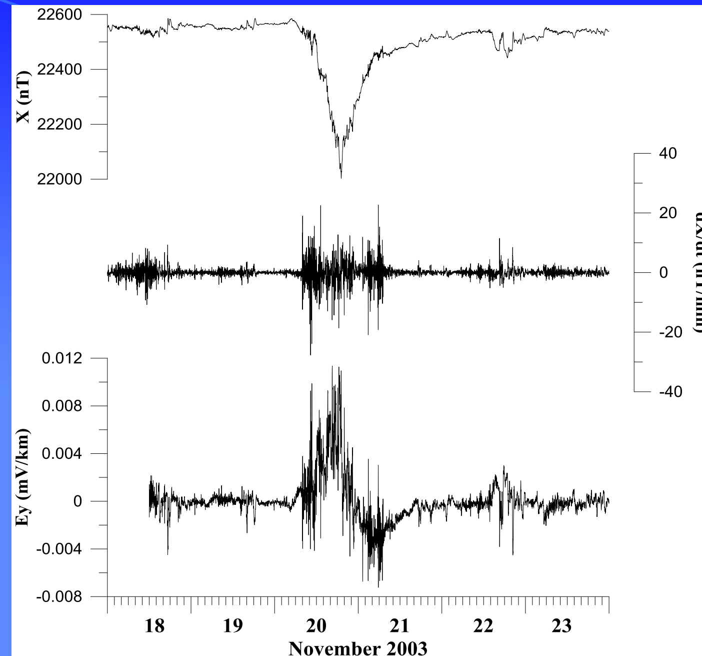
$$R_N = \sum_{n=N-M+1}^{N} b_n \sqrt{N-n+1}$$

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

Viljanen & Pirjola, 1989

www.eurisgic.eu

SUA



Intermagnet observatories

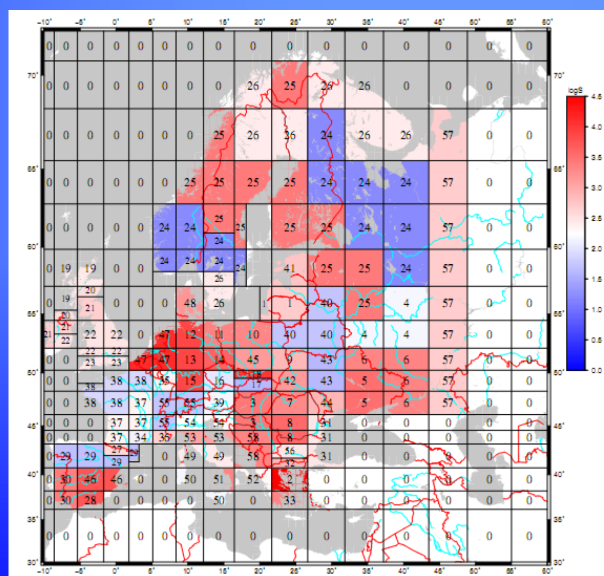
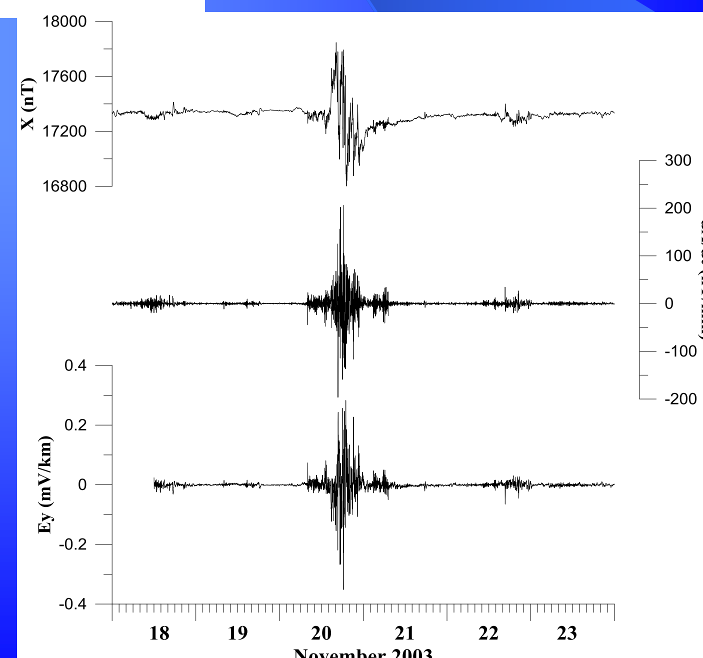


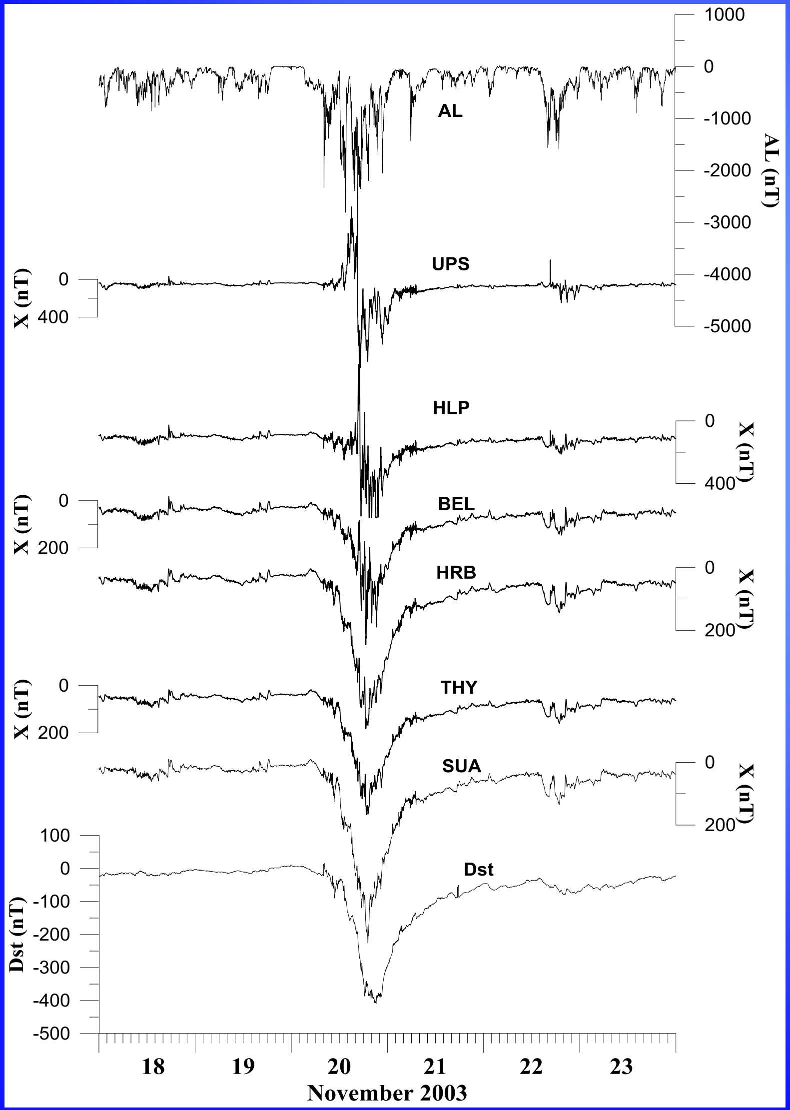
Figure 2: Conductance map of Europe, upper 80 km

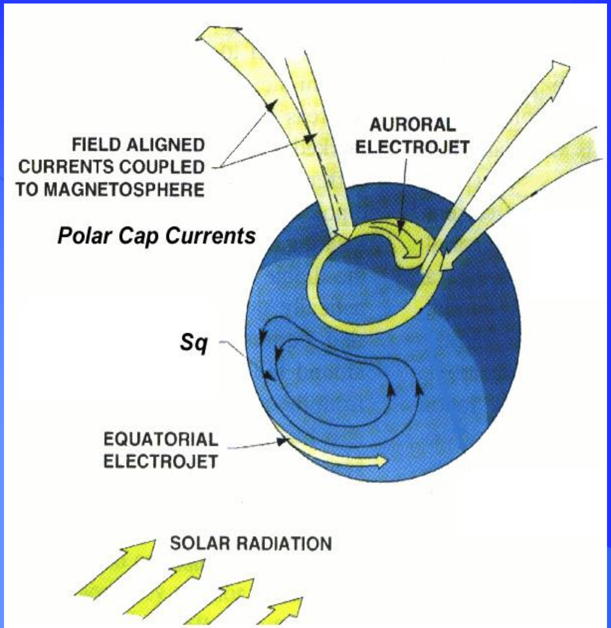
ESK

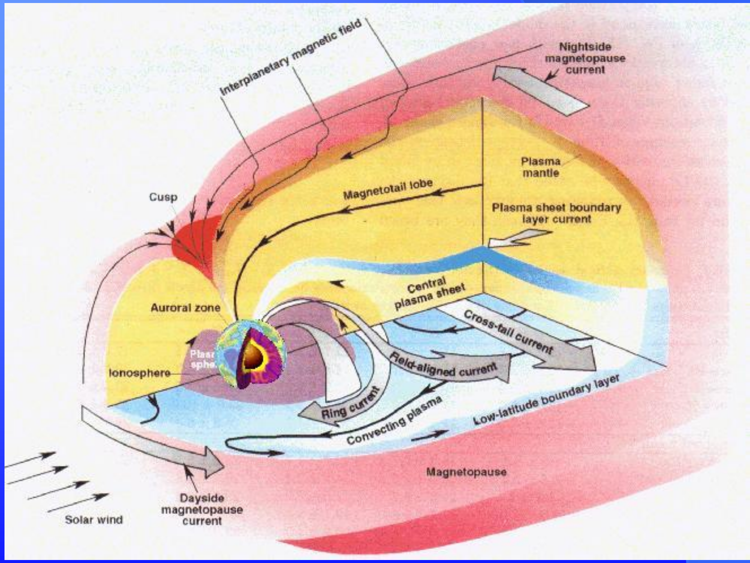


Sources of geomagnetic disturbance (1)

November 2003 storm
~105°E

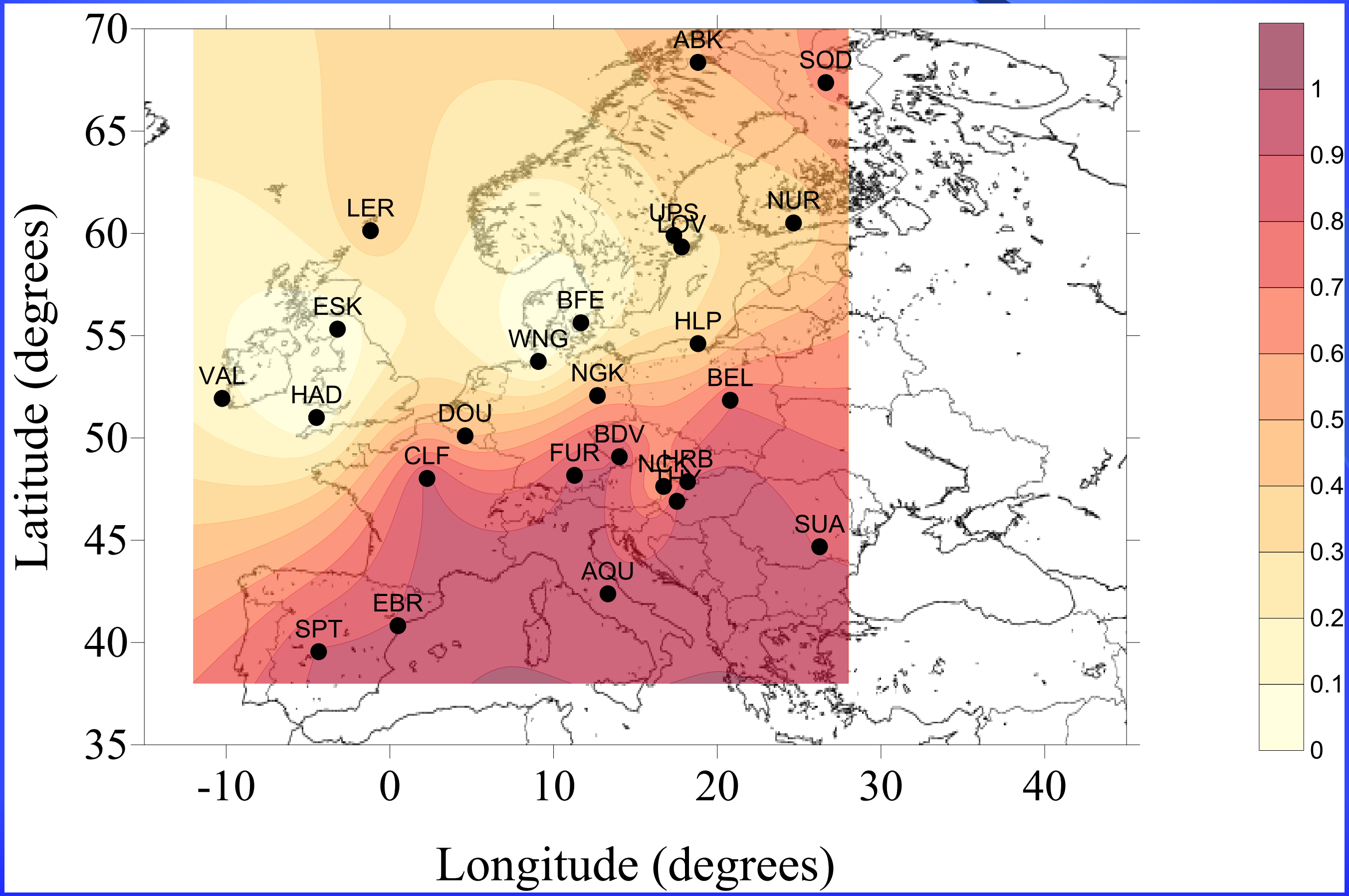






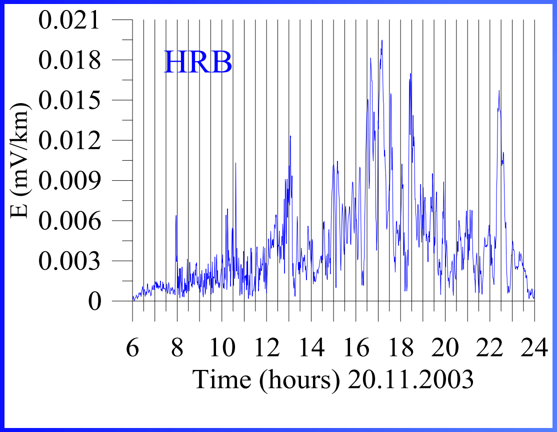
Sources of geomagnetic disturbance (2)

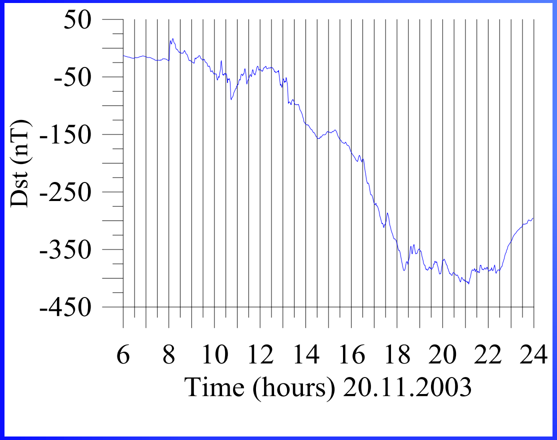
Ring current contribution

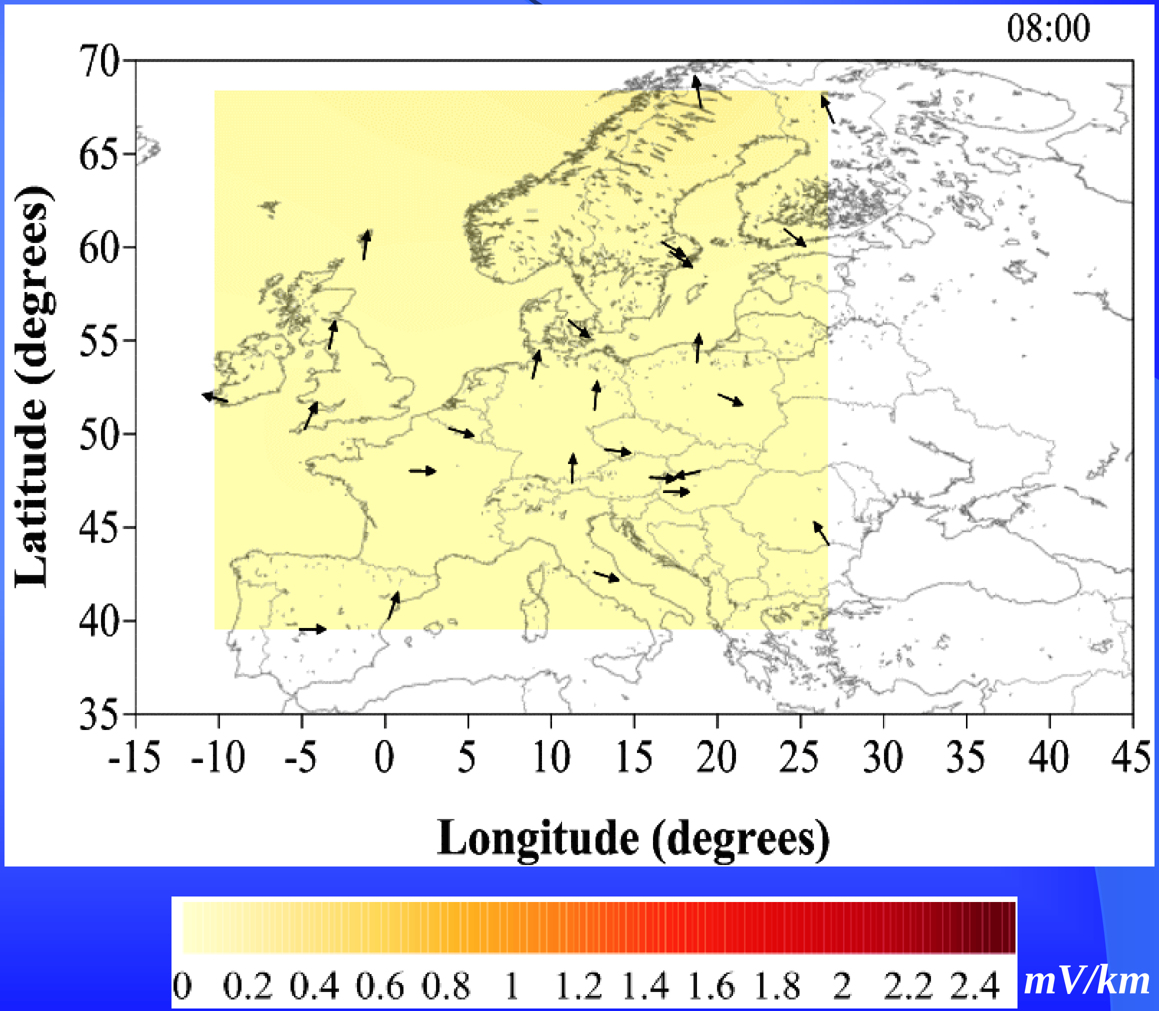


Geoelectric field evolution

Initial & main phase – November 2003 storm

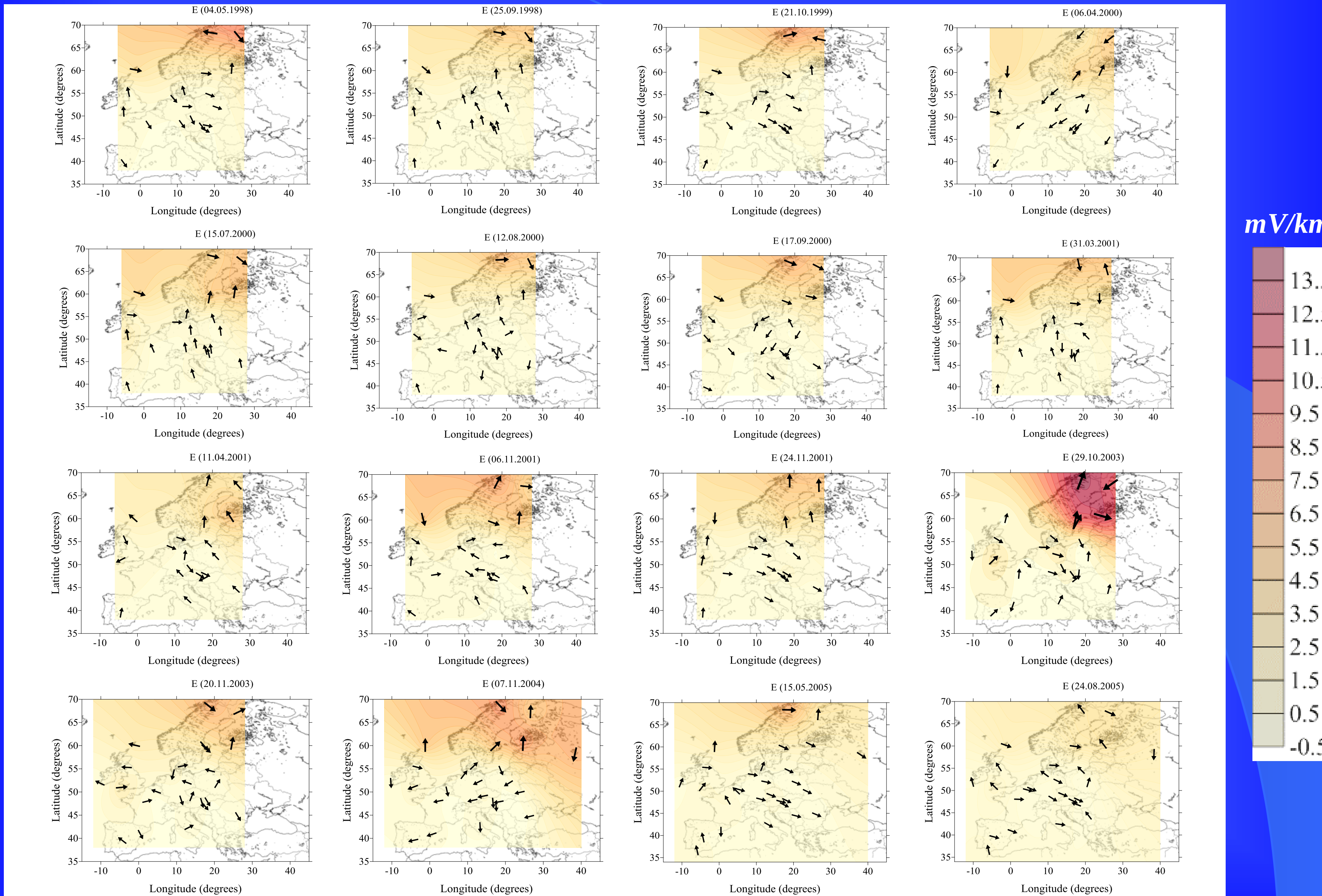






Toward GIC hazard assessment

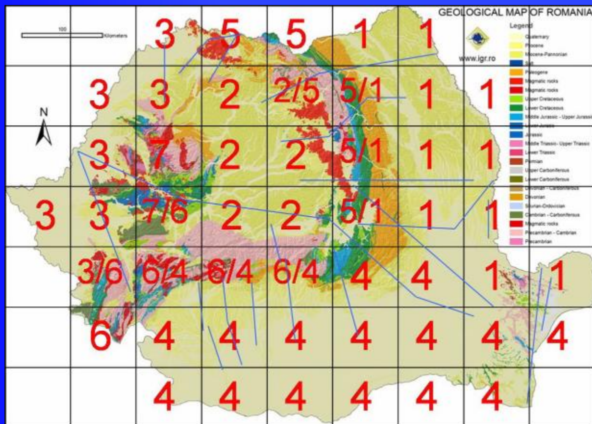
Emax maps



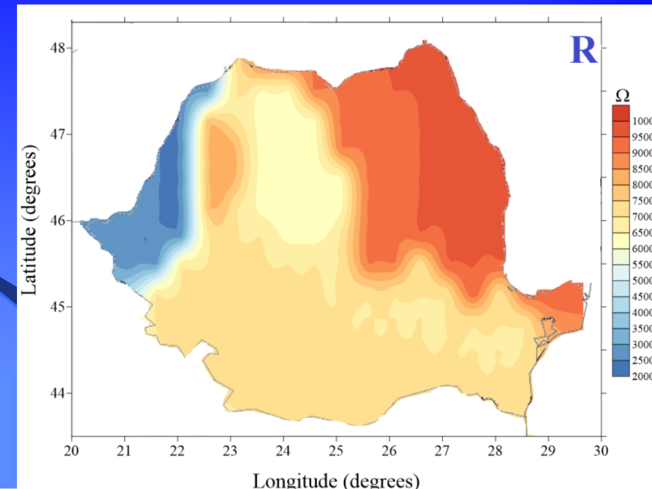
Dobrica et al., SG 2016

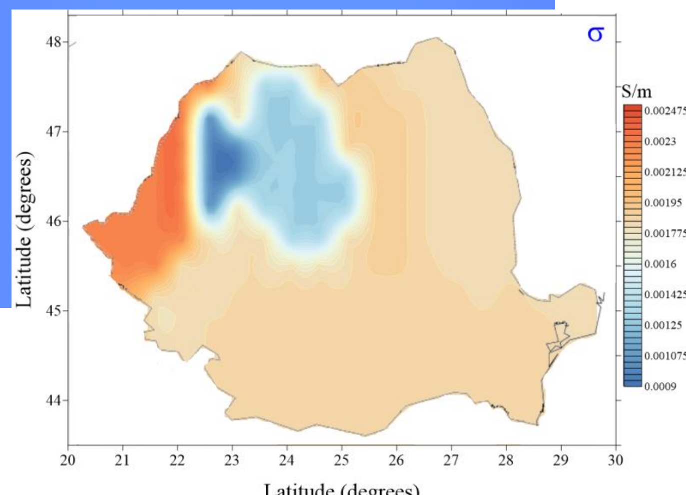
Toward GICs hazard assessement – Romania

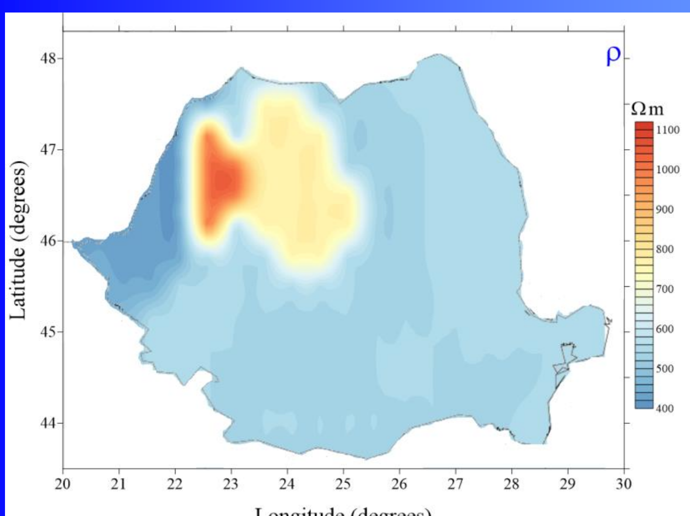
Earth conductivity parameters – MT data



Geological map of Romania (after IGR) with the MT geotransects (blue lines) and square cells, numbered from 1 to 7, corresponding to the 1-D MT lithospheric models





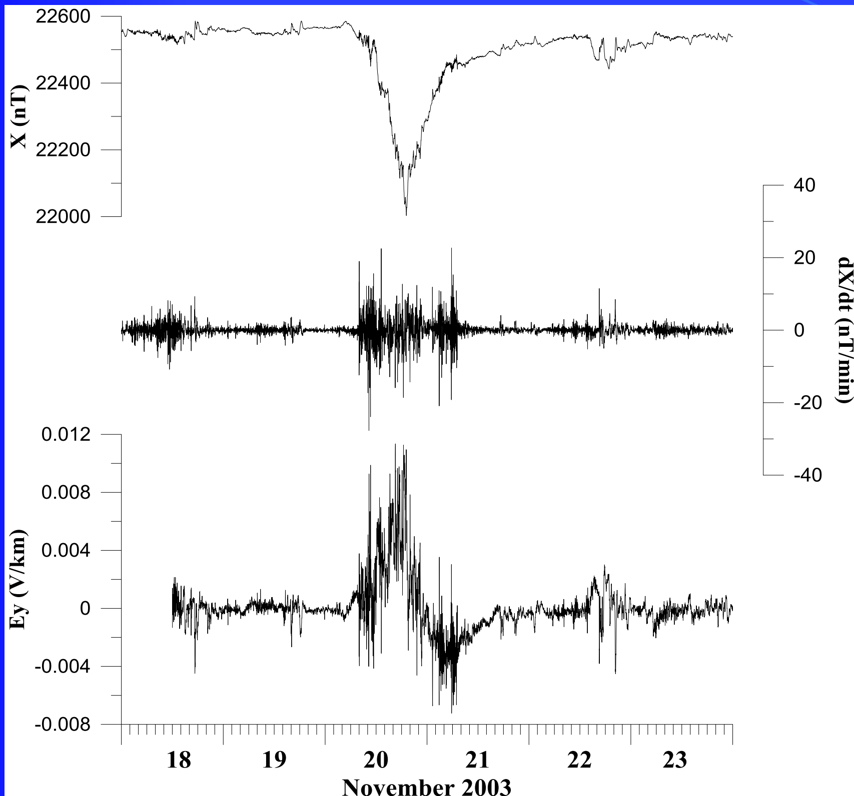


Tectonic unit
East European Platform + Scythian Platform + Carpathian Foredeep + North-Dobrogean Orogen
Transylvanian Depression
Pannonian Depression
Moesian Platform
East Carpathians
South Carpathians
Apuseni Mountains

Stanica et al. (RRG, 2016)

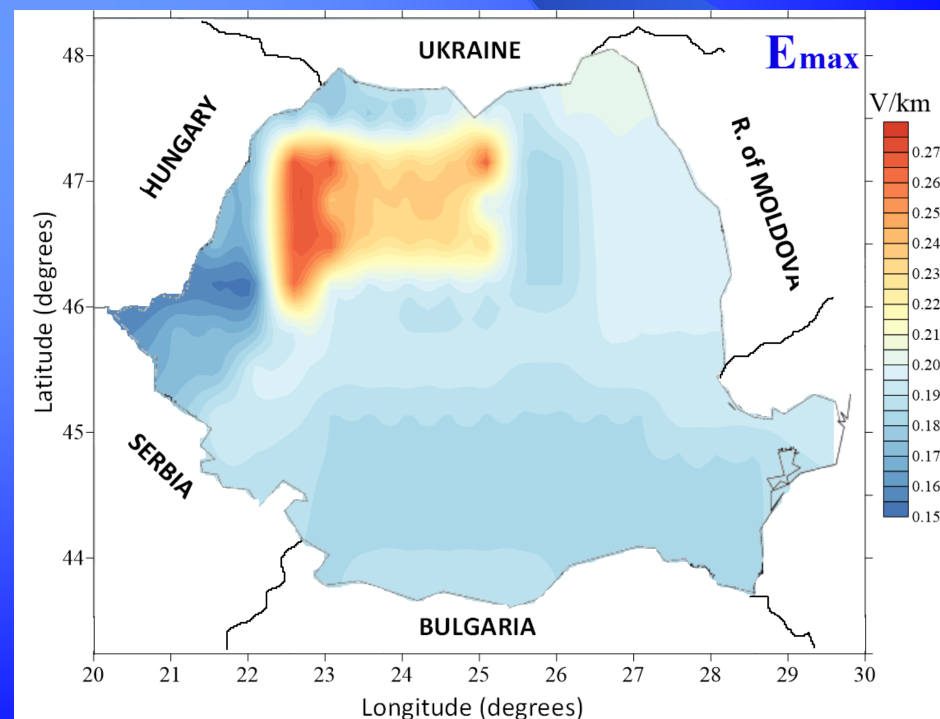
Toward GICs hazard assessement – Romania

Example geomagnetic storm of Nov 2003



- data from Surlari geomagnetic observatory

- Emax distribution



Dobrica et al. (RRG, 2016)

Conclusions

- *the MC and GC signals are quite similar in the heliosphere – magnetosphere environment, pointing to a common pacing source, the solar dynamo;*
- *information on space climate could be retrieved for the last 400 years using data from geomagnetic observatories and main field models;*
- *during the geomagnetic storm, effects of auroral electrojets superimpose at all latitudes on the disturbance created by the magetospheric ring current;*
- *the amplitude of the geoelectric field produced by magnetic variations is of the order of hundreths of mV/km in case of SUA (45°N), and of 1-2 mV/km in case of UPS (60°N);*
- *the maximum E value is not reached at the same moment at all observatories and its orientation depends on that moment of the storm development;*
- *future work: look at local effects and explore the role of magnetopause currents;*
- *the present approach concerns only the geophysical problem of GIC hazard. Engineering solutions are the next step.*