On the sources of the largest geomagnetic storms in solar cycles 23 and 24

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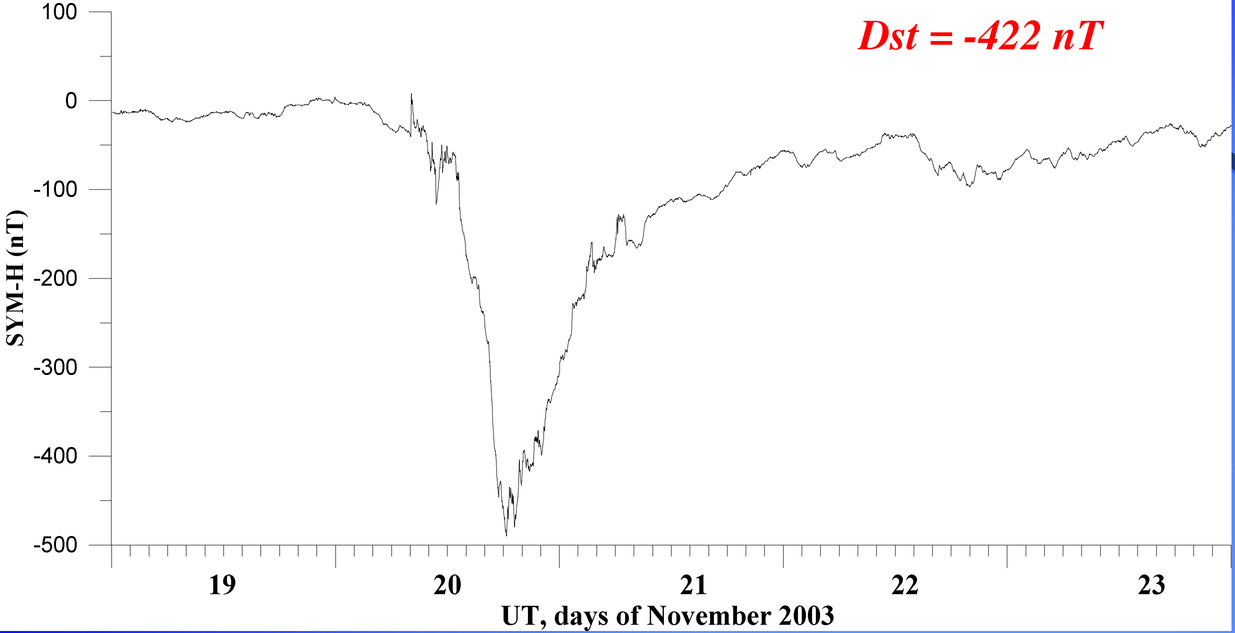
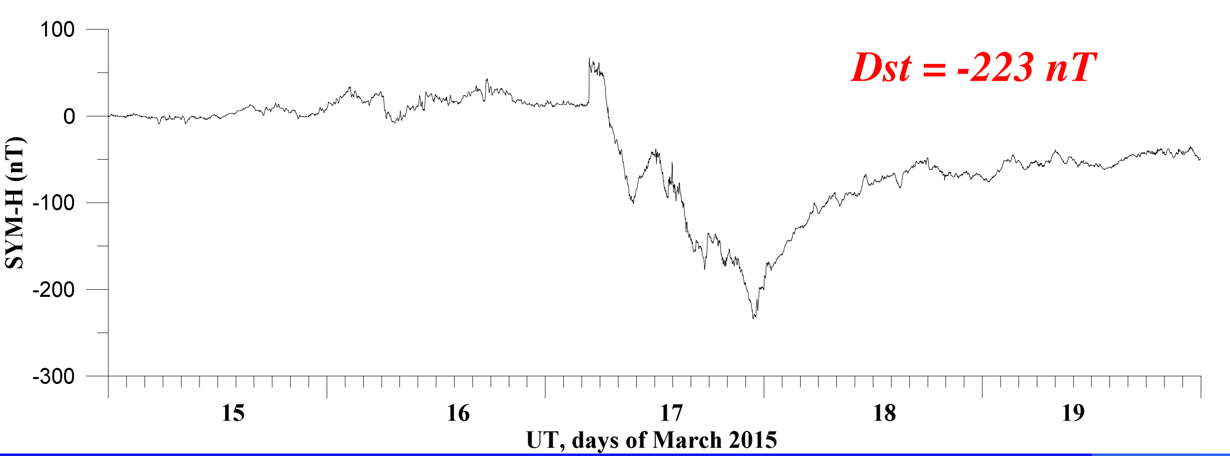
”If you have seen one storm, you have seen one storm”
Friedel et al., 2002

Largest geomagnetic storms in cycles 23, 24

November 2003



March 2015

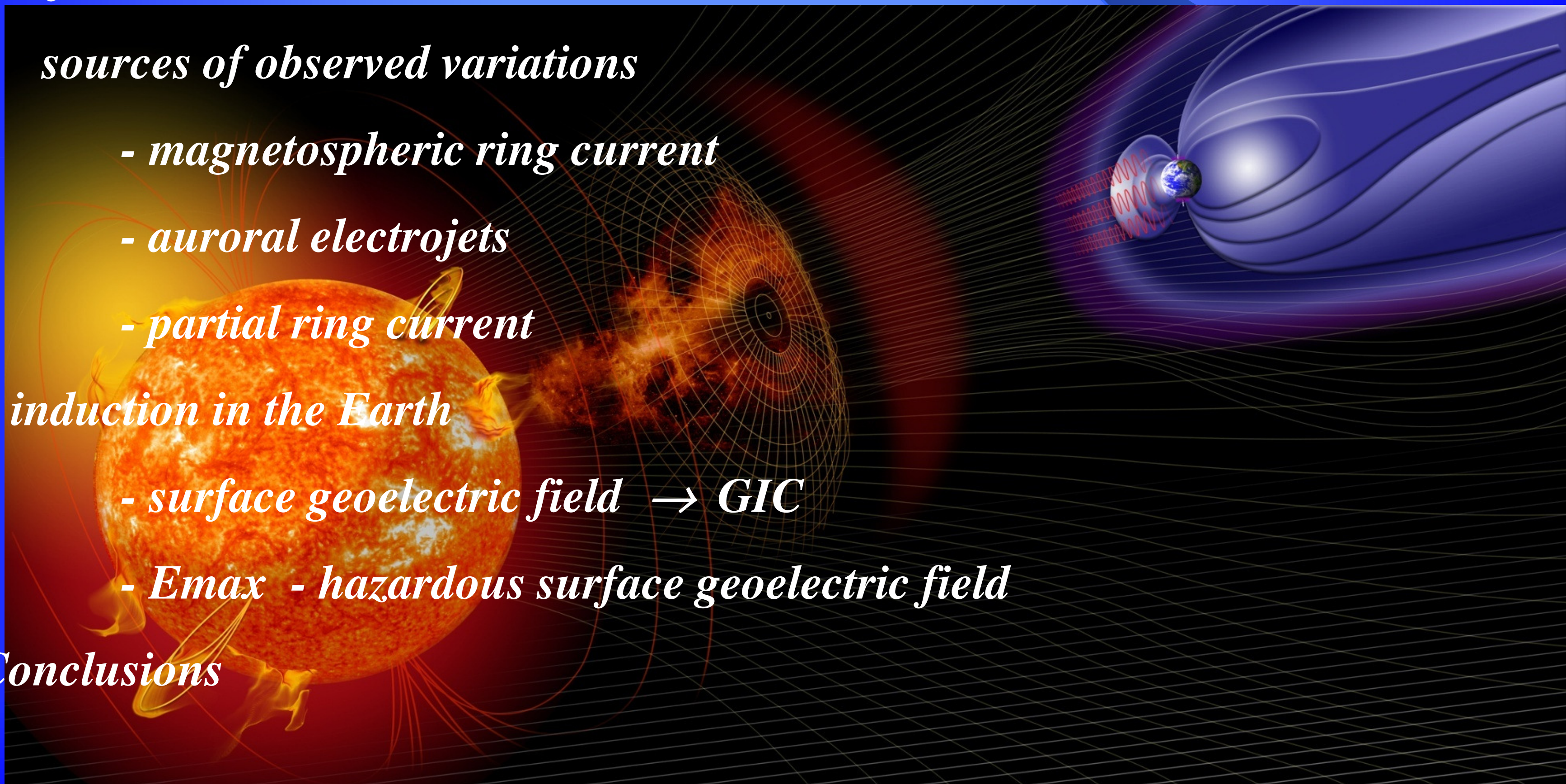


Outline

Data

- ***Geomagnetic disturbance at European observatories (Intermagnet)***
- ***Solar wind and geomagnetic indices data***

Subjects



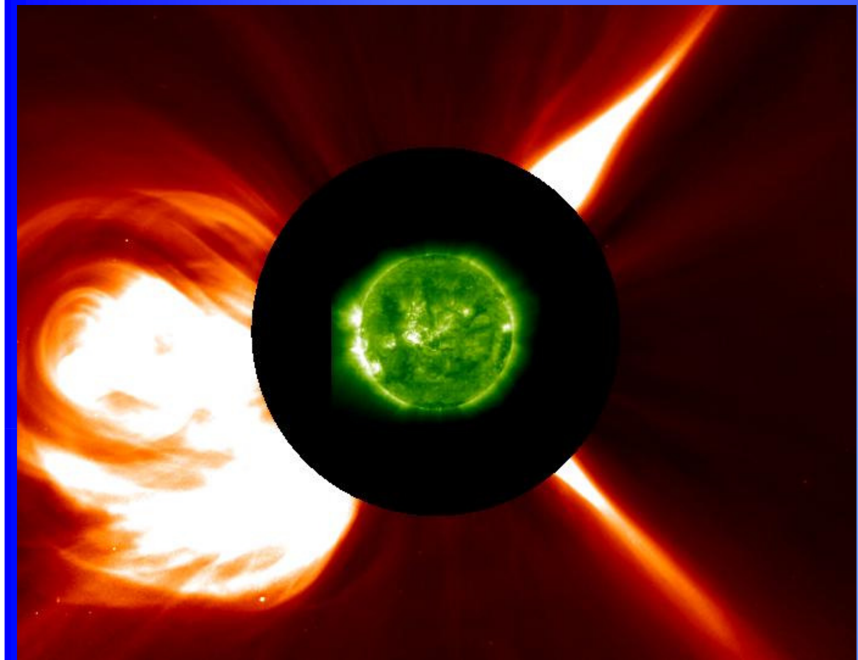
- ***sources of observed variations***
  - ***- magnetospheric ring current***
  - ***- auroral electrojets***
  - ***- partial ring current***
- ***induction in the Earth***
  - ***- surface geoelectric field → GIC***
  - ***- Emax - hazardous surface geoelectric field***

Conclusions

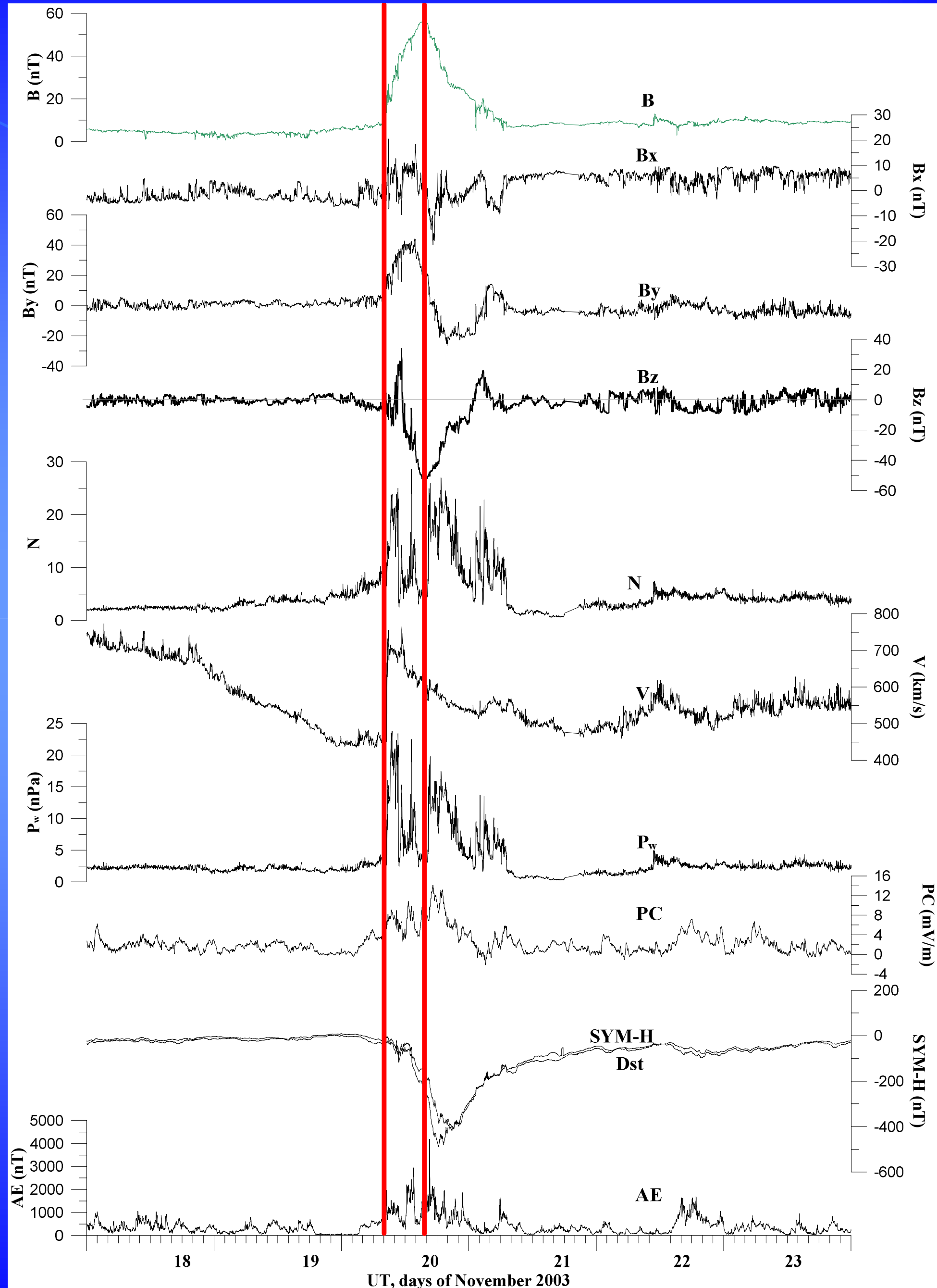
November 2003 storm

ICME

CME



November 18, 2003
10:24 UT



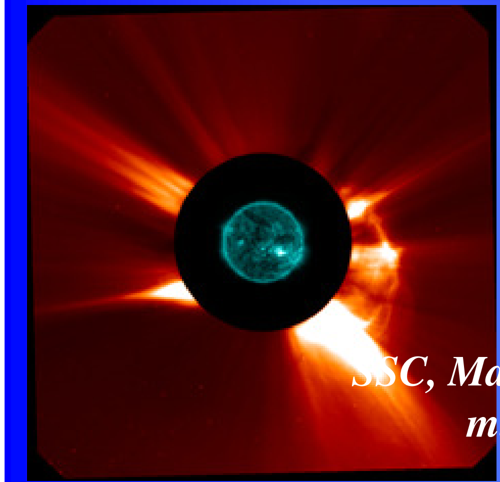
LASCO C2 image (jhelioviewer.org/)

SSC, November 20, 2003
8:12 UT

March 17, 2015 storm

Kataoka et al., GRL 2015; Gopalswamy, 2015

Sheath - Magnetic Cloud - HSS scenario

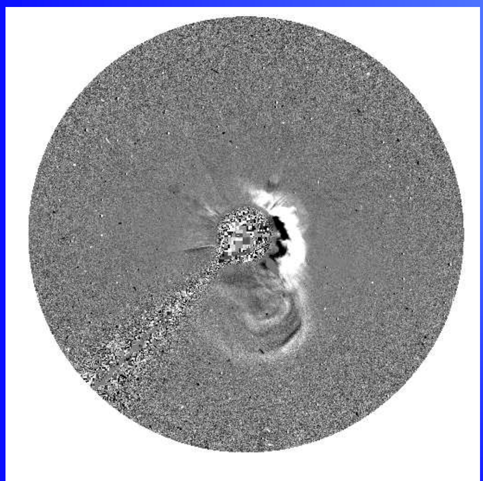


March 15, 2015
C9.1 flare 02:13 UT
CME 02:00 UT

SSC, March 17, 2015, 04:01 UT
min Dst = -223 nT

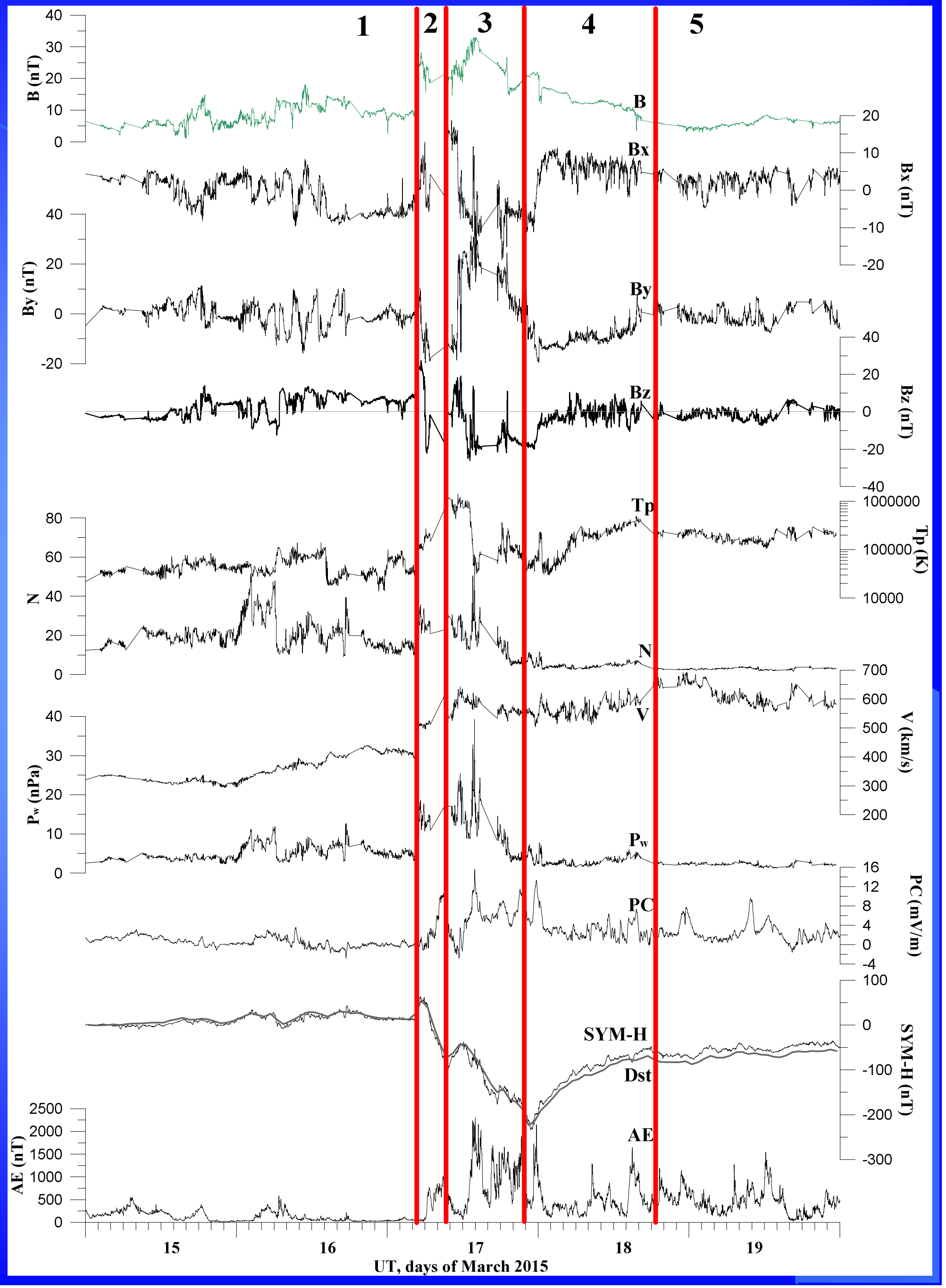
Liu et al., ApJL 2015

Sheath - ejecta - ejecta - HSS scenario

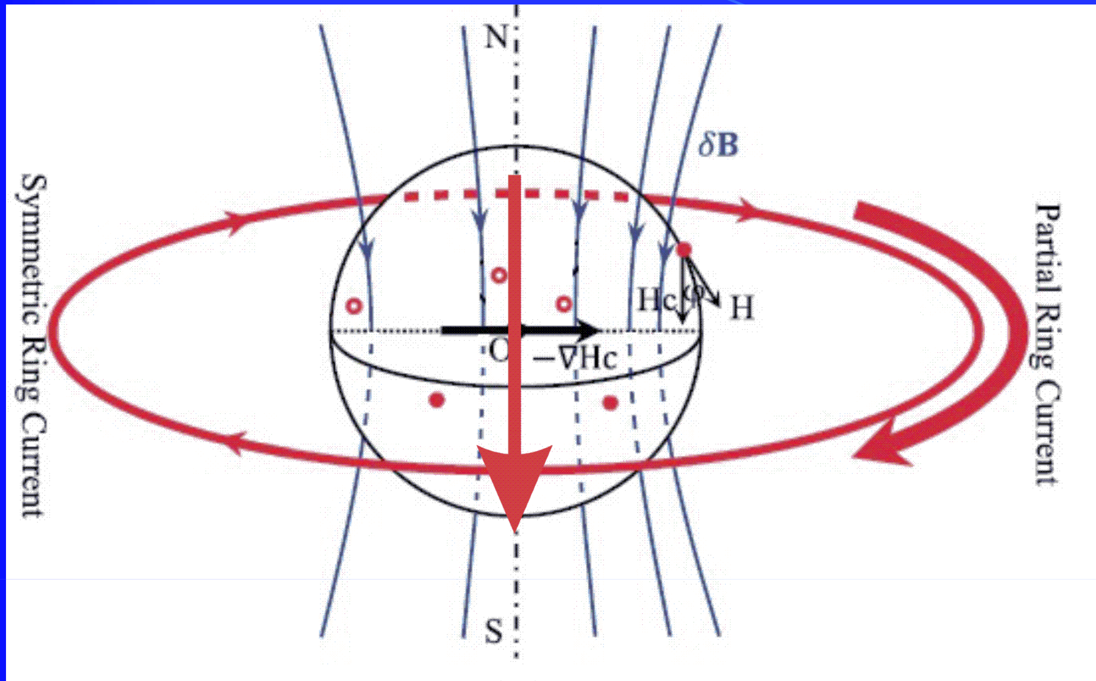


March 14, 2015
C2.6 flare 11:55 UT
CME1

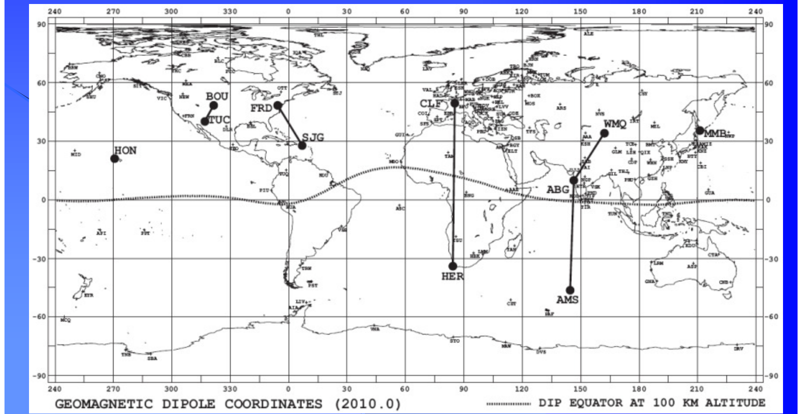
March 15, 2015
C9.1 flare 02:13 UT
CME2 02:00 UT



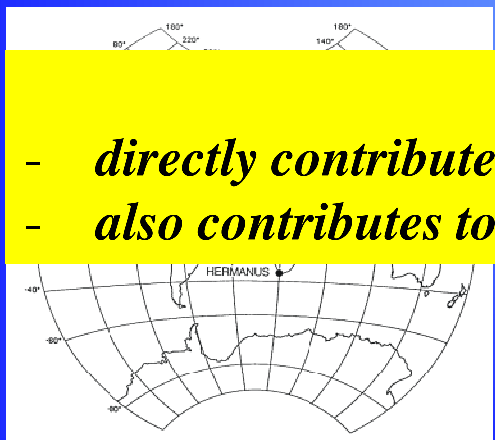
Ring current and geomagnetic indices (SYM, ASY)



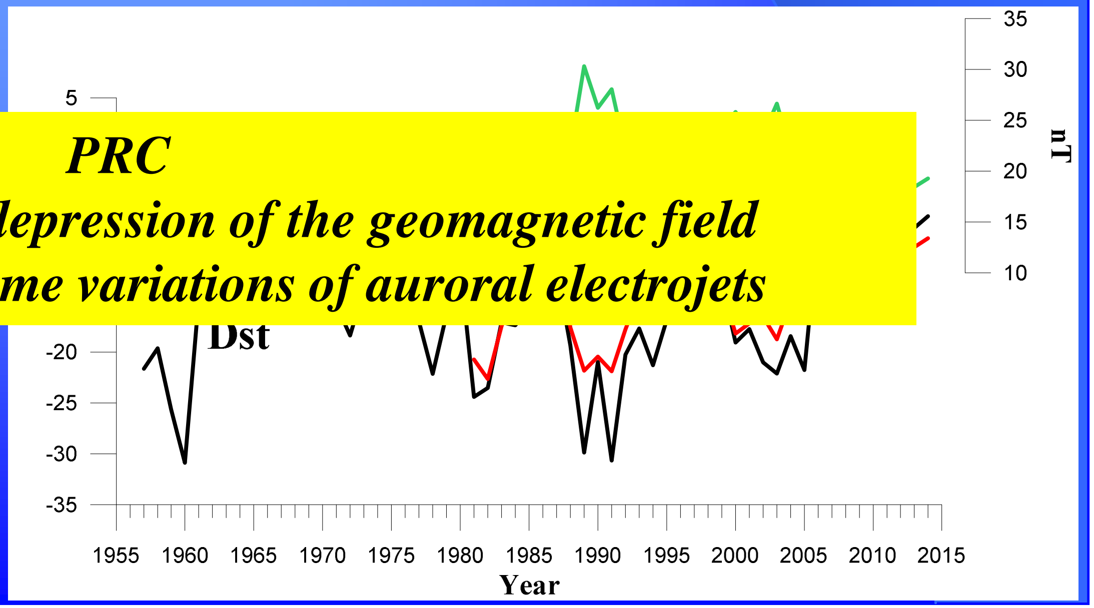
adapted from Shen et al. (2015)



Iyemori (1990); http://wdc.kugi.kyoto-u.ac.jp/



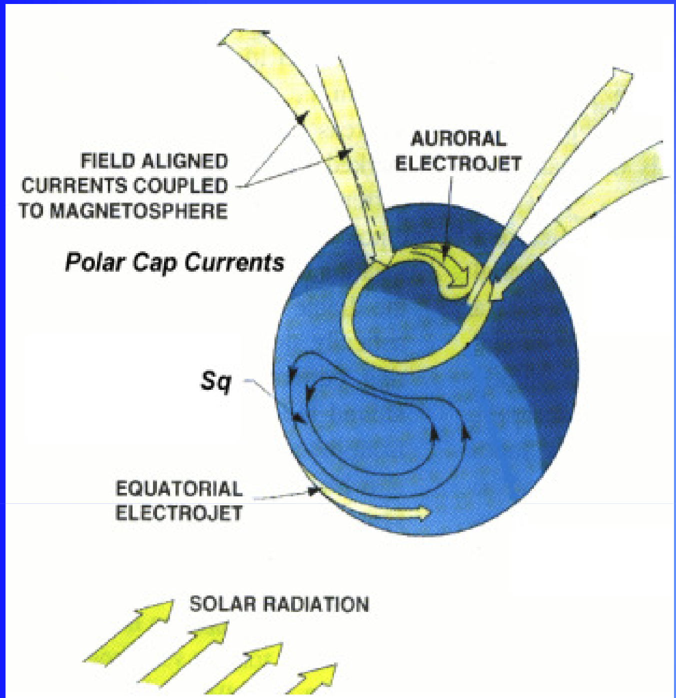
Sugiura (1964); http://wdc.kugi.kyoto-u.ac.jp/



PRC

- ***directly contributes to the depression of the geomagnetic field***
- ***also contributes to storm-time variations of auroral electrojets***

Auroral electrojet and geomagnetic indices (AE, AU, AL)

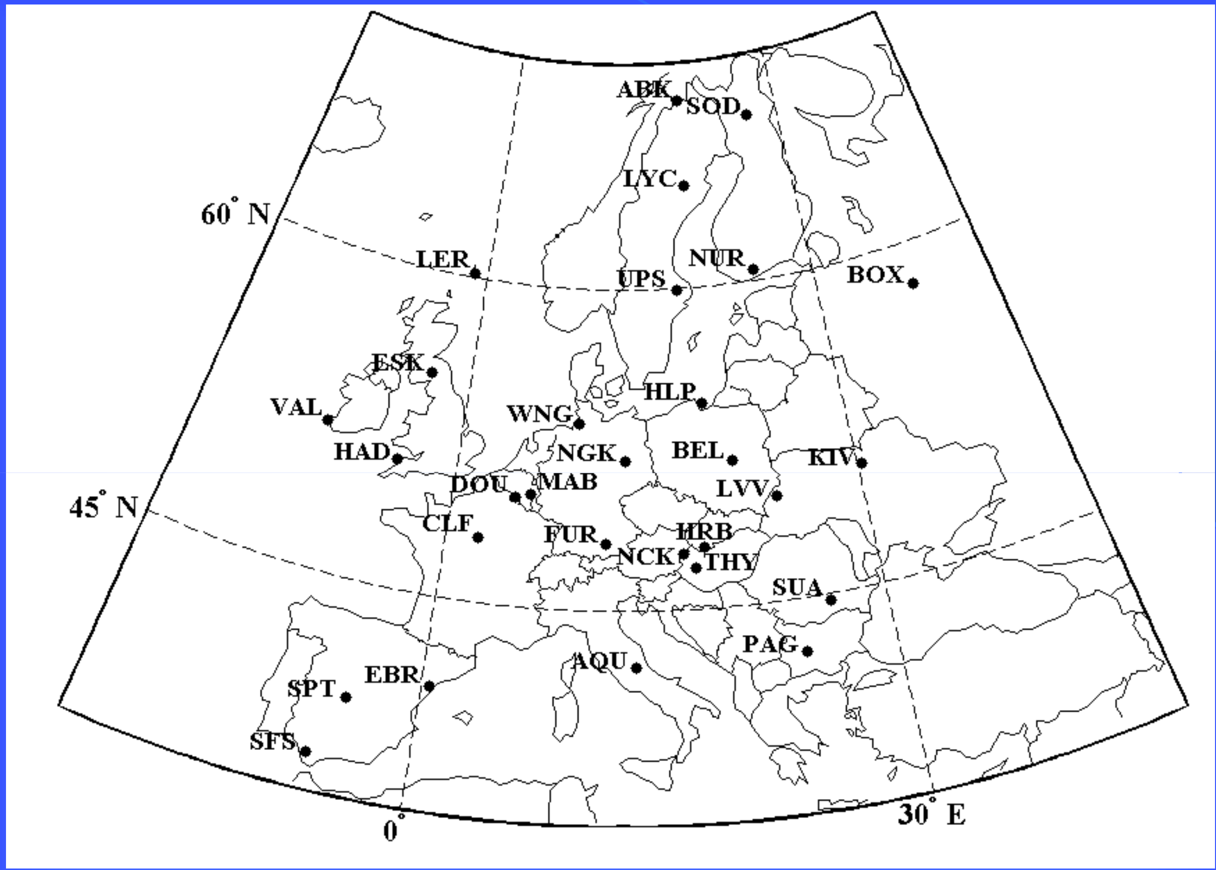


- to monitor the magnetic signature of the eastward and westward auroral electrojets in the Northern hemisphere.

- AE indices (auroral electrojets), derived from geomagnetic variations in the horizontal component from 12 selected observatories along the auroral zone in the northern hemisphere (starting in 1957). AU, Al, AE, AO.

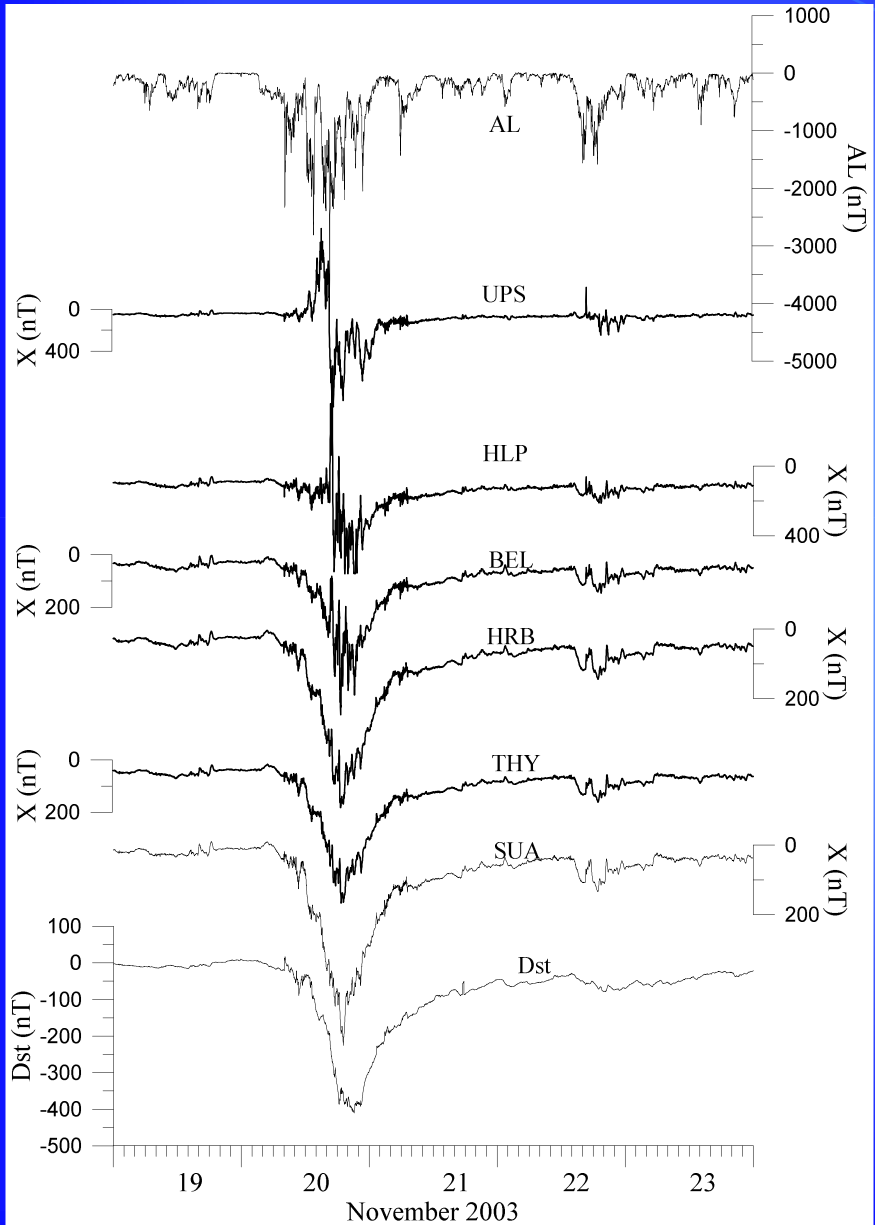
http://wdc.kugi.kyoto-u.ac.jp/aedir/

European geomagnetic observatories

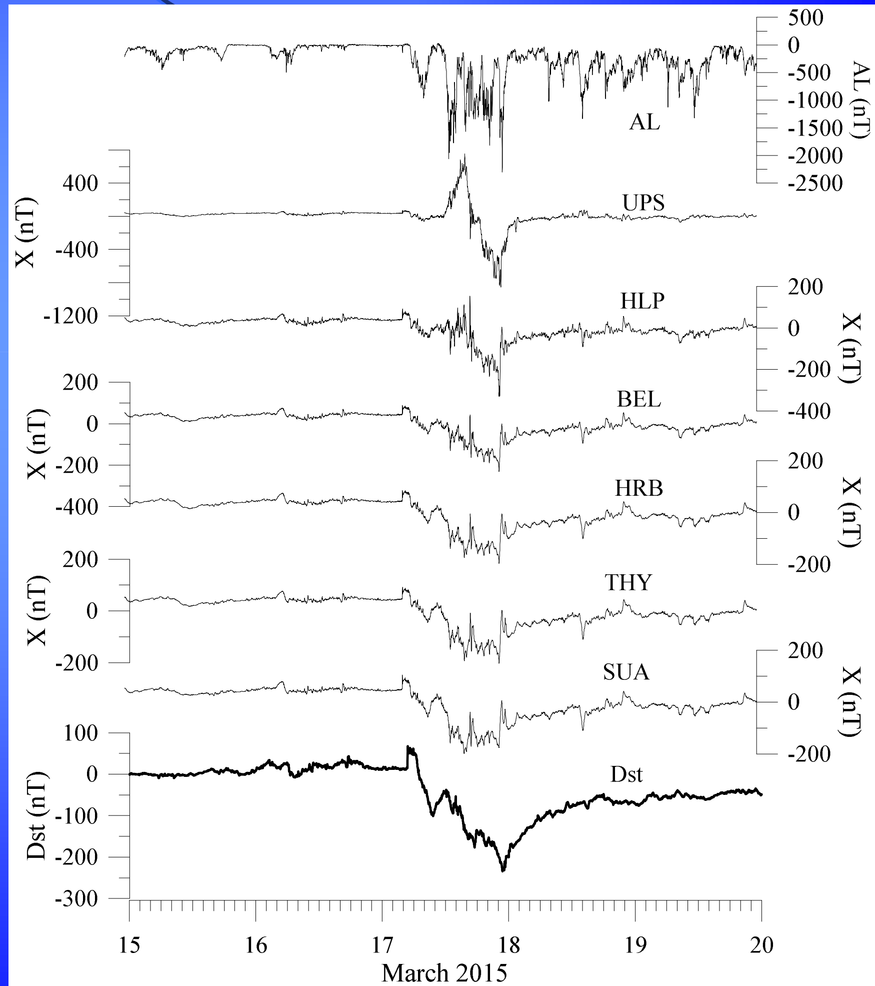


Geomagnetic disturbance

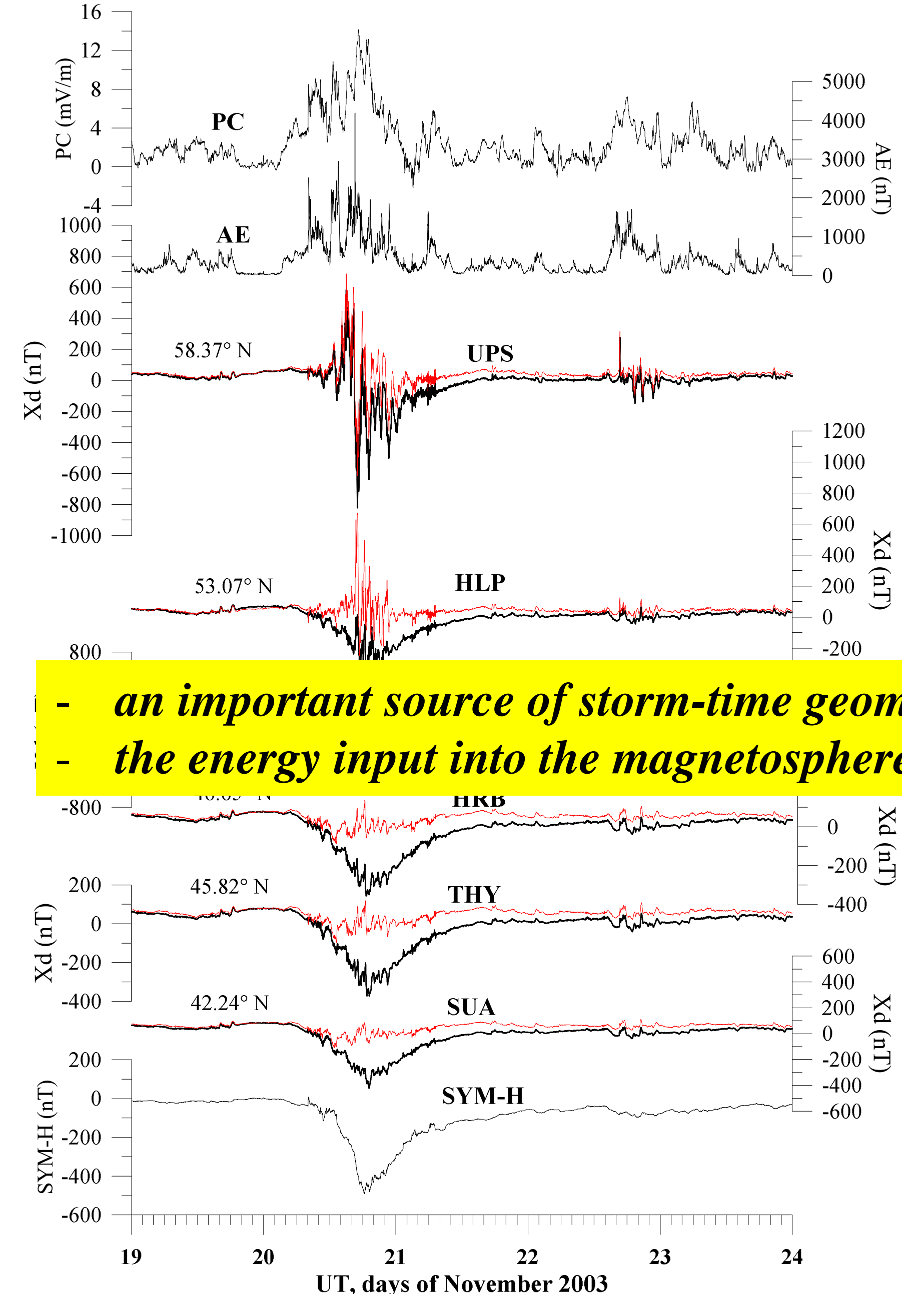
November 2003 storm
~105°E

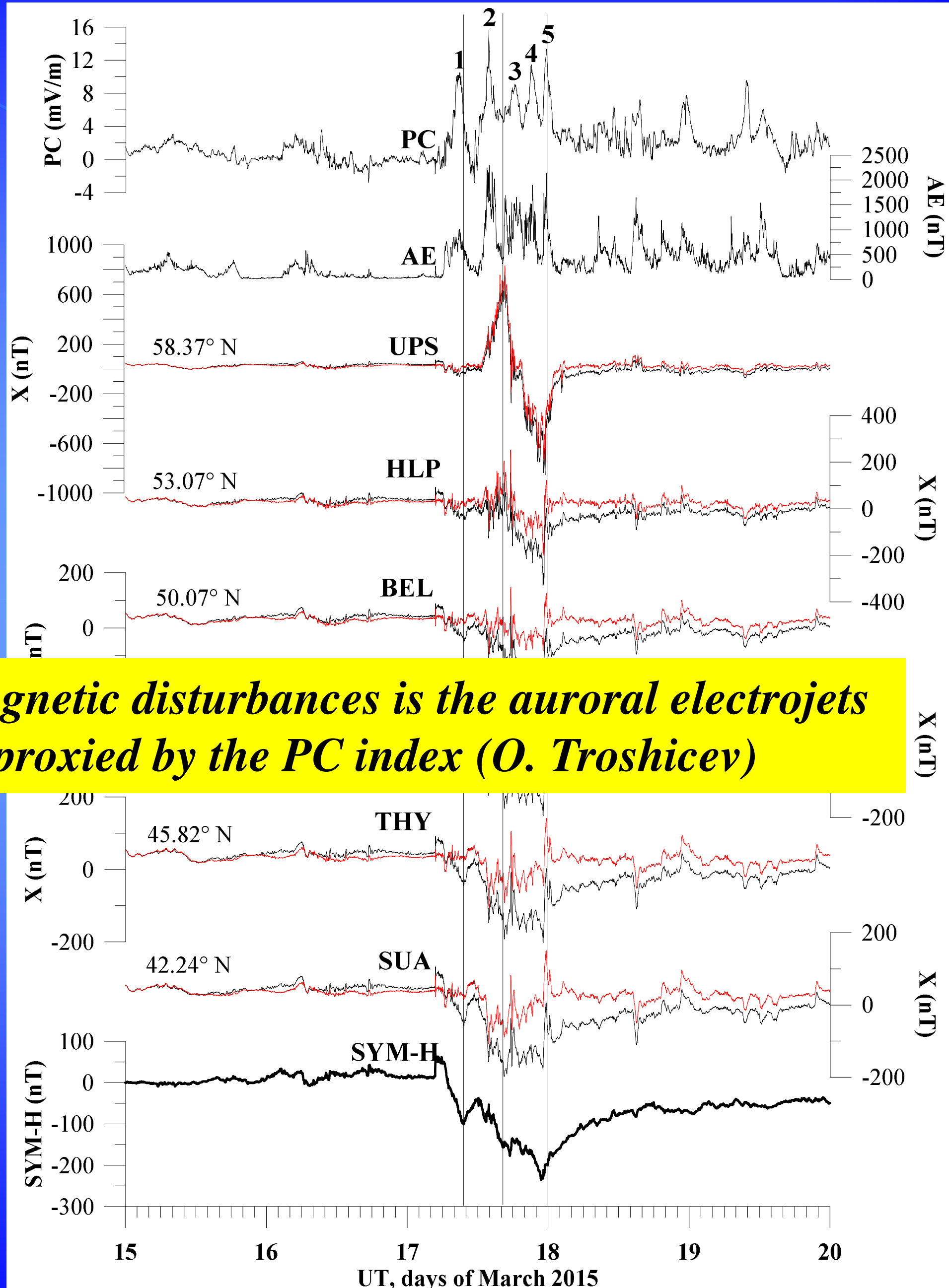


March 2015 storm
~105°E



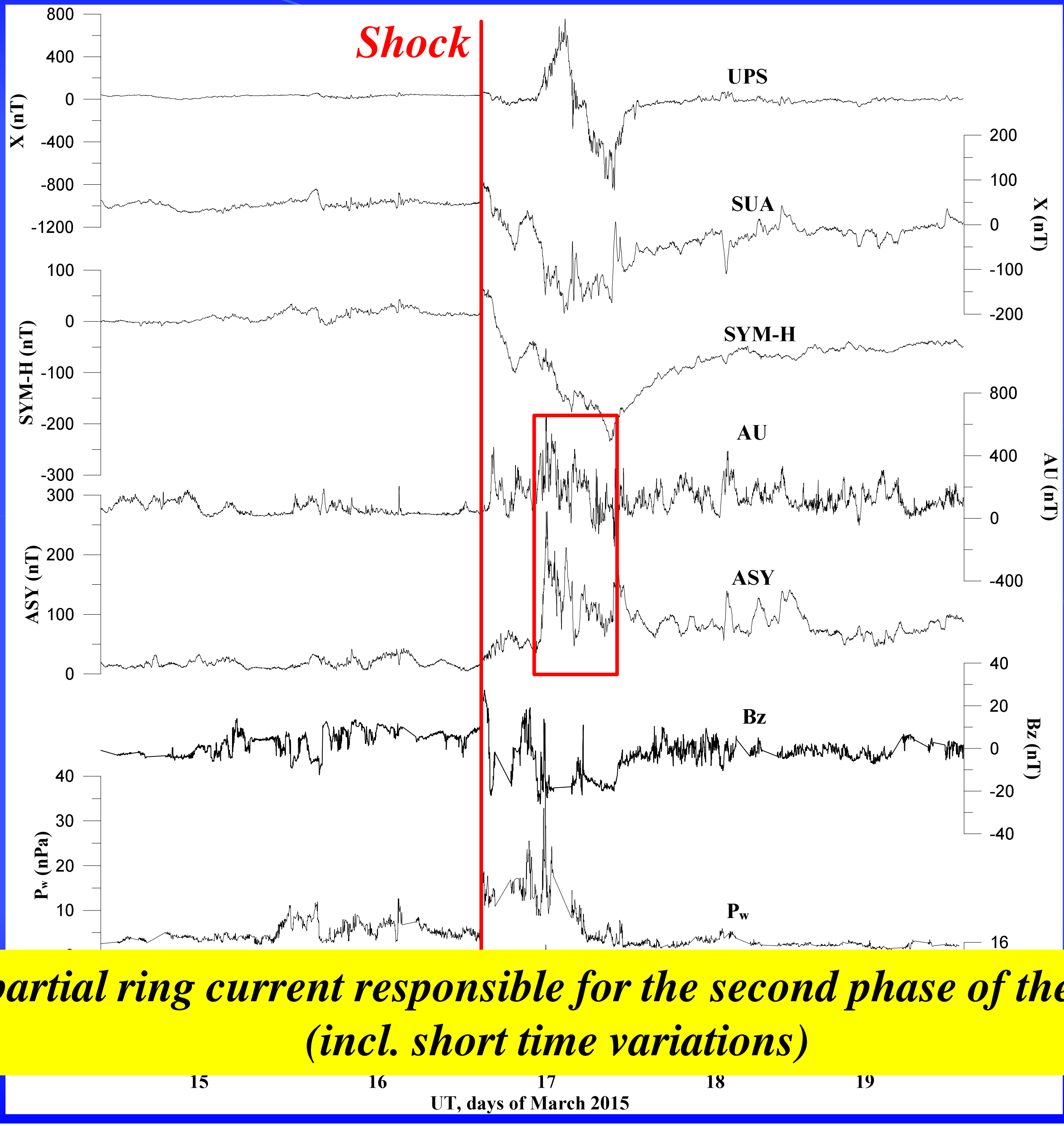
*Geomagnetic disturbance -Dst*cosθ*





- ***an important source of storm-time geomagnetic disturbances is the auroral electrojets***
- ***the energy input into the magnetosphere proxied by the PC index (O. Troshicev)***

Geomagnetic disturbance



- ***partial ring current responsible for the second phase of the storm (incl. short time variations)***

Induction in the Earth

Space weather hazard (GICs)

Variable external magnetic field

↓

Telluric currents

↓

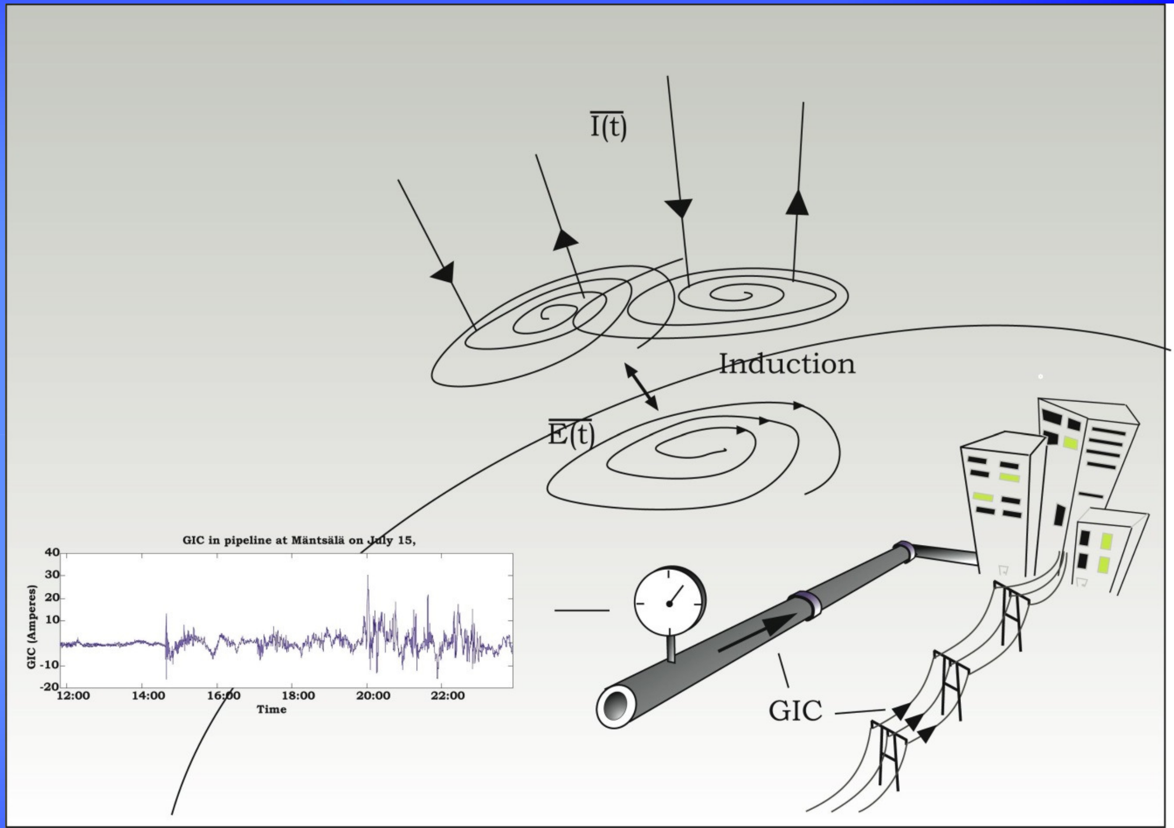
Secondary magnetic field

↓

Surface electric field

↓

Electric currents (GICs)



http://en.wikipedia.org/

Surface geoelectric field

Plane wave model

Viljanen & Pirjola, 1989

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

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

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

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

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

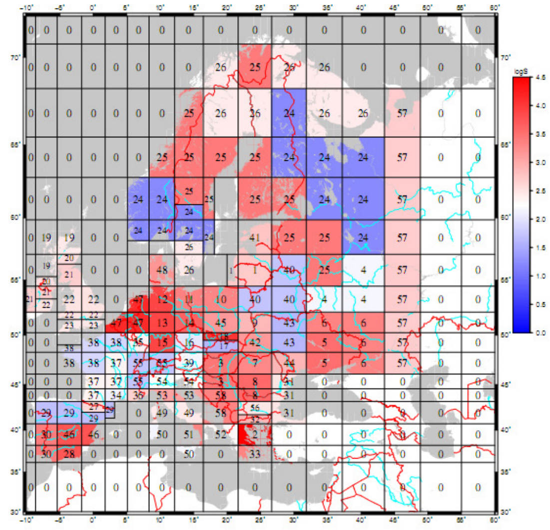
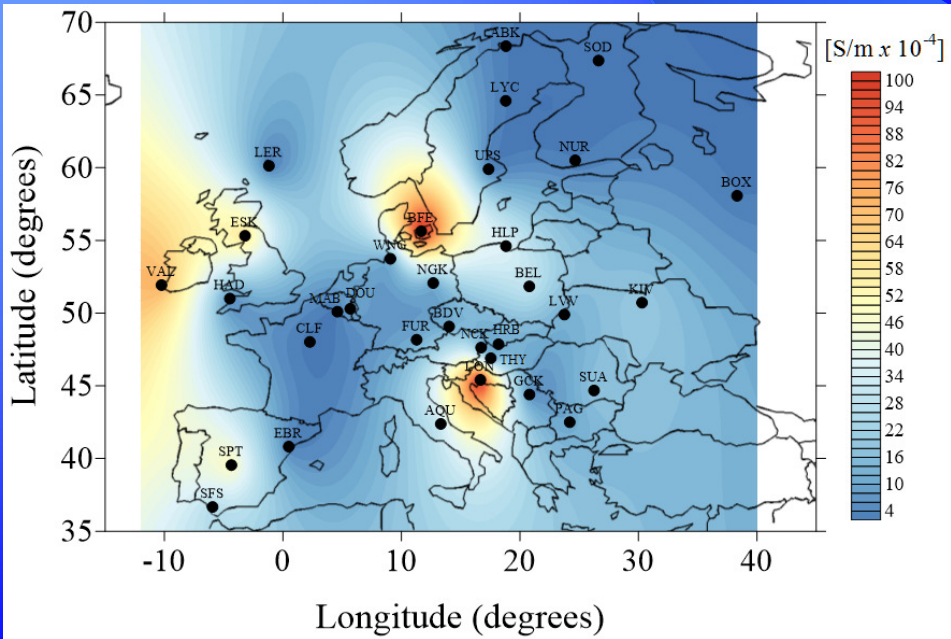


Figure 2: Conductance map of Europe, upper 80 km

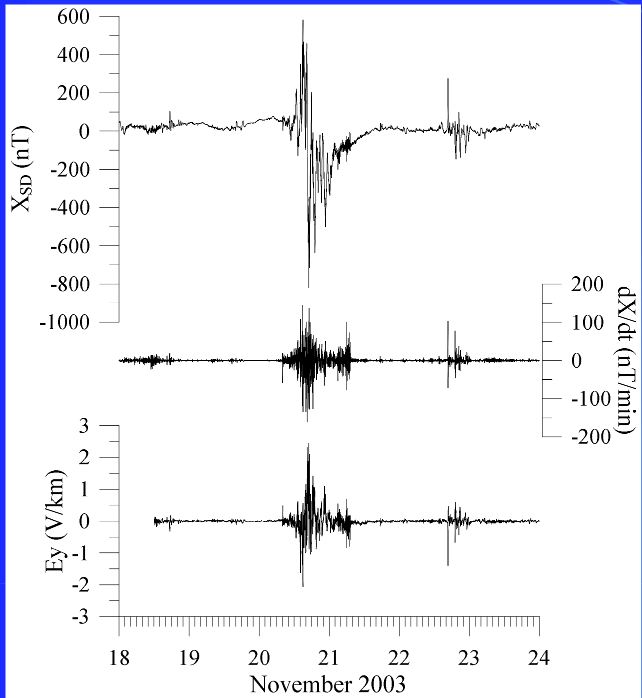
MT model of Adam et al. (2002)

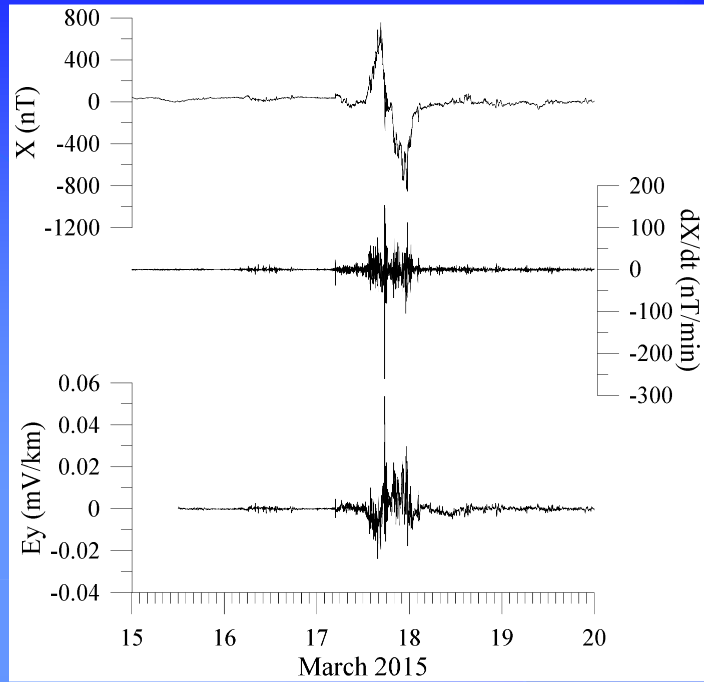


Surface geoelectric field

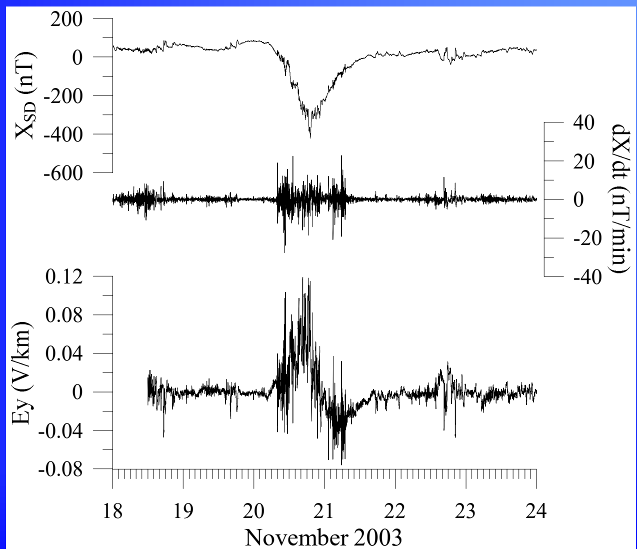
November 2003

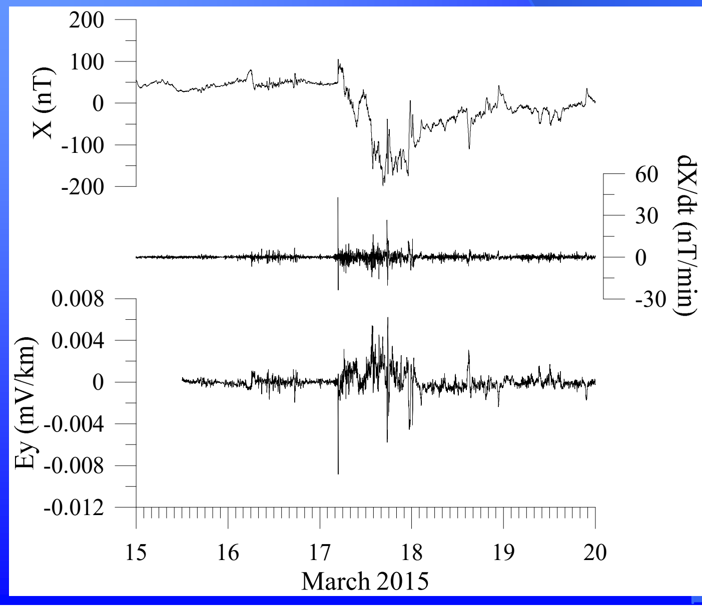
March 2015





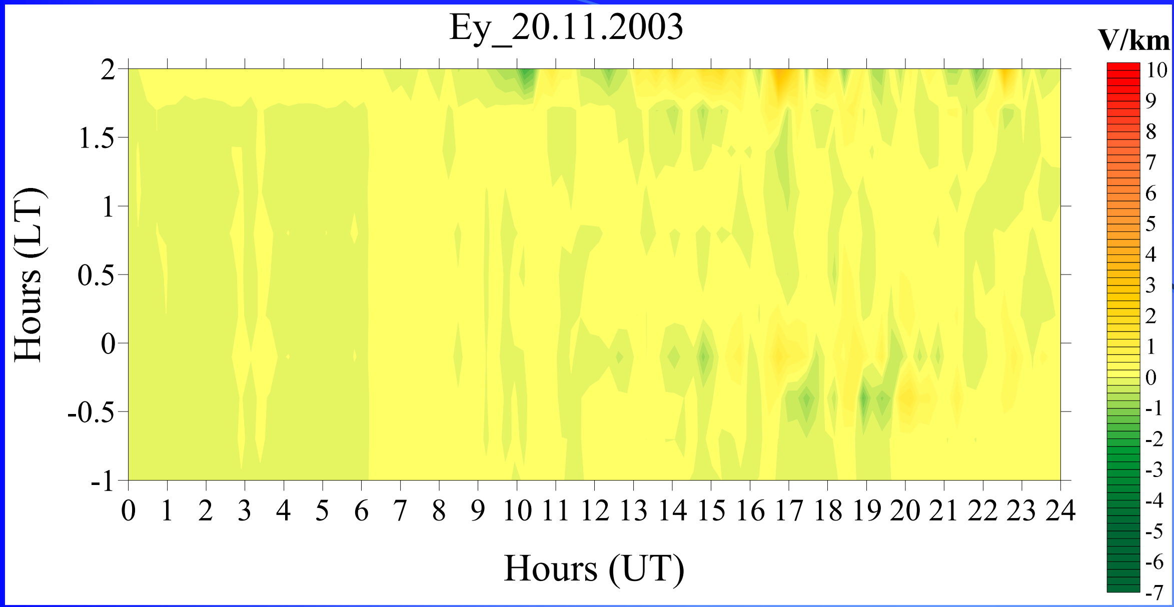
UPS

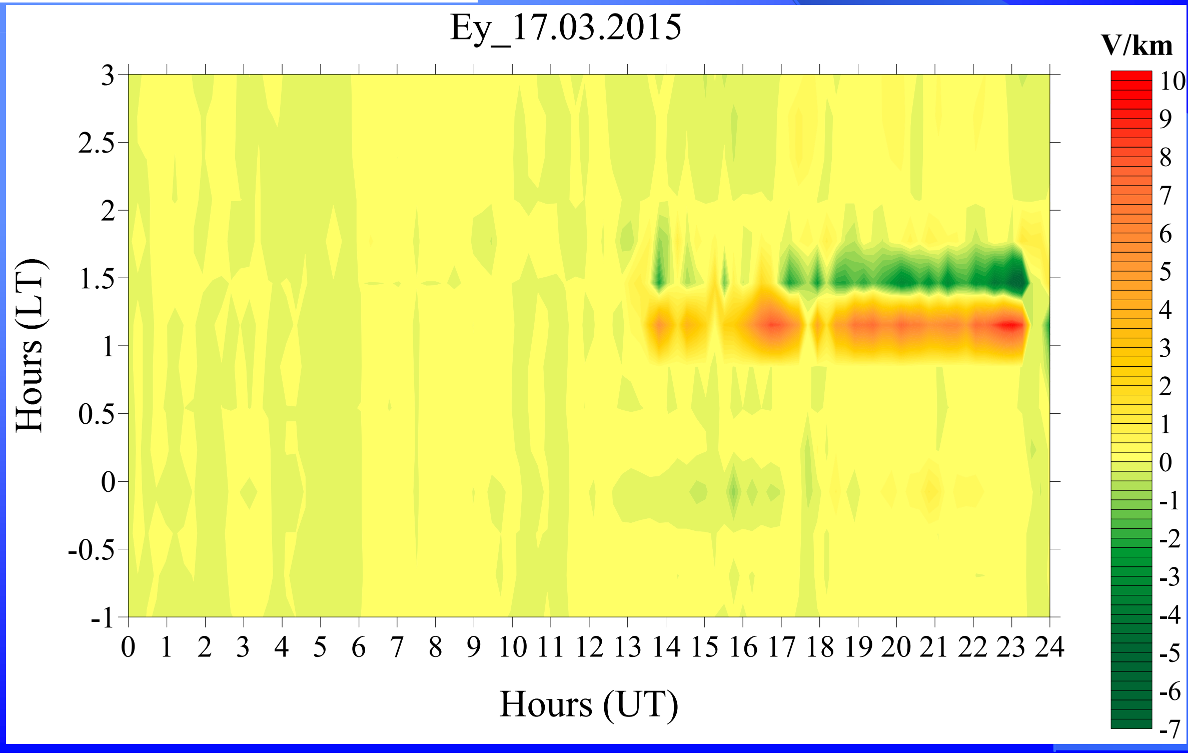




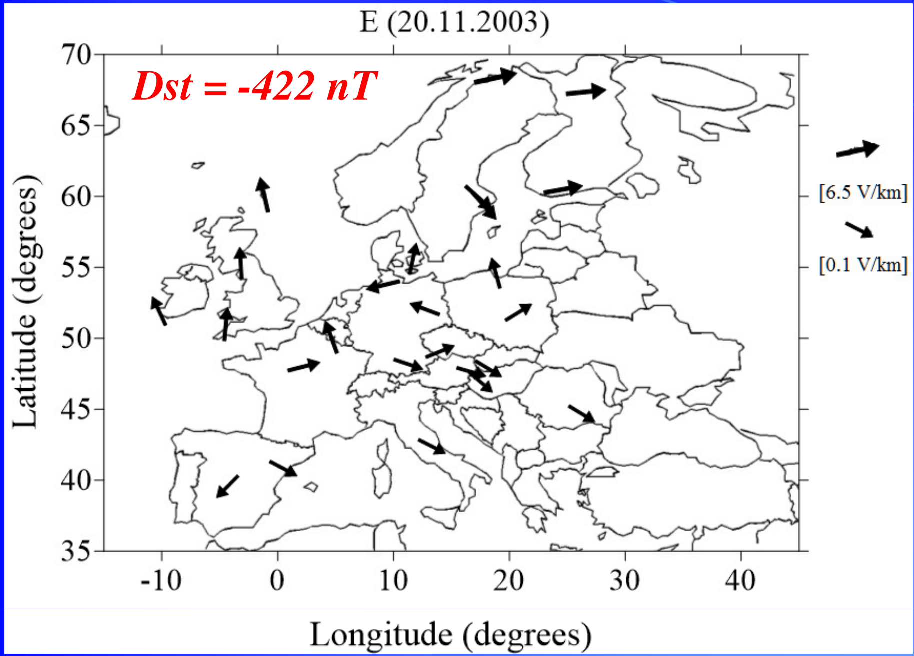
SUA

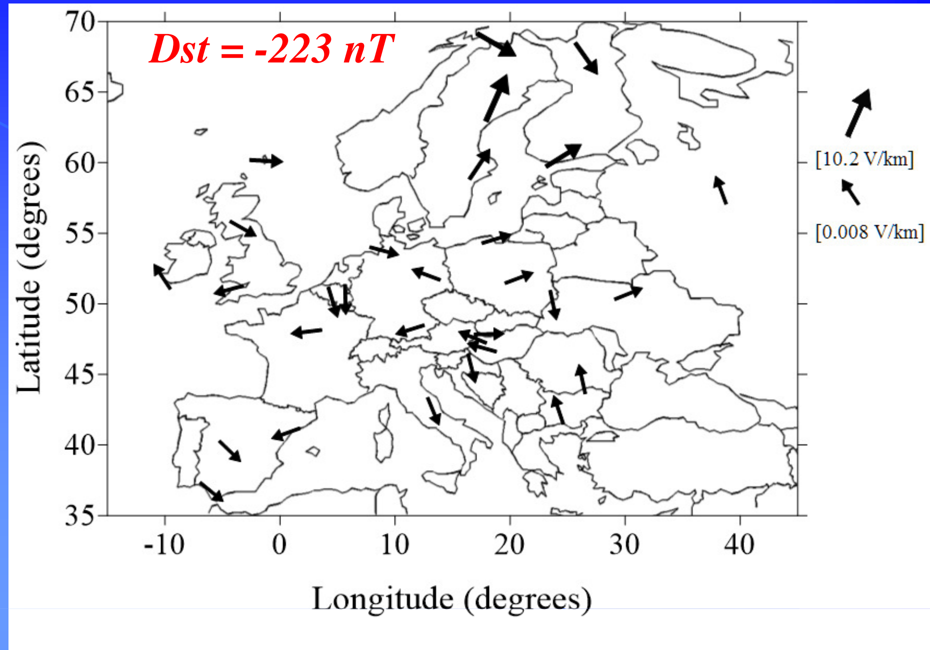
Surface geoelectric field – synoptic view



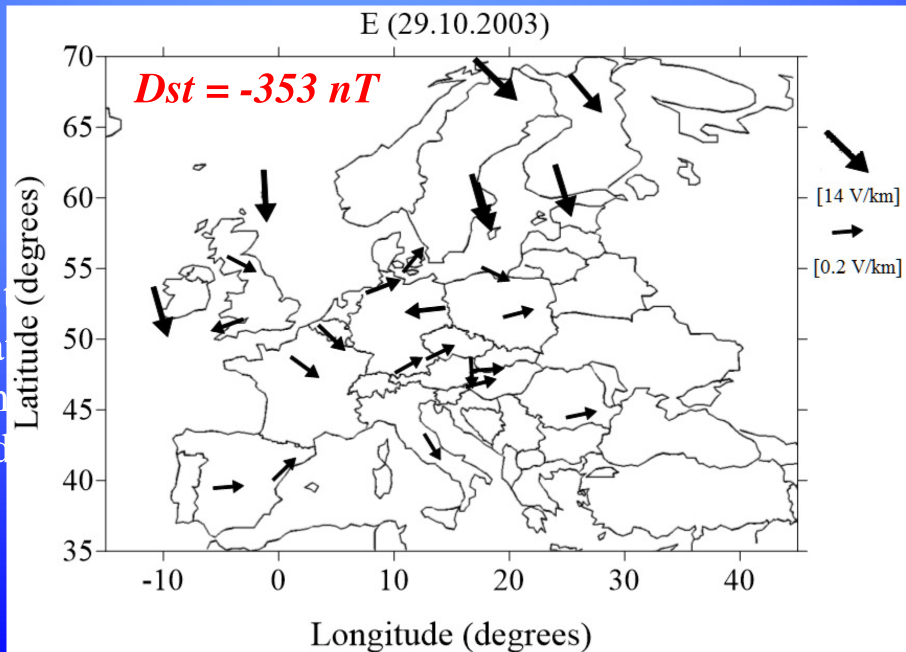


Surface geoelectric field – Emax





E max value is not reached at t
observatories and its orienta
moment of the storm developm
magnitude – arrows centered
observatory location



Conclusions

- *the amplitude and morphology of the geomagnetic disturbance is a result of the evolution of the two main direct sources of the geomagnetic activity: the magnetospheric ring current & the auroral ionospheric electrojets, to which we add the dual contribution of the partial ring current;*
- *storms differ from each other primarily because of interacting solar wind conditions and state of magnetosphere;*
- *the disturbance in X is 2-3 times larger at northern latitudes than at mid&southern latitudes; the geoelectric hazard (GICs) is significant above the 50ºN (S) geomagnetic latitude;*
- *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. Probable cause: local electric structure of the underground;*
- *future work: look at local effects, explore the role of magnetopause currents, and investigate contribution from the partial ring current.*