On the climate of the solar-terrestrial space

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Outline

Some definitions

Geomagnetic variability – geomagnetic indices

Review of instrumental data

Reconstructions

Space climate features

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

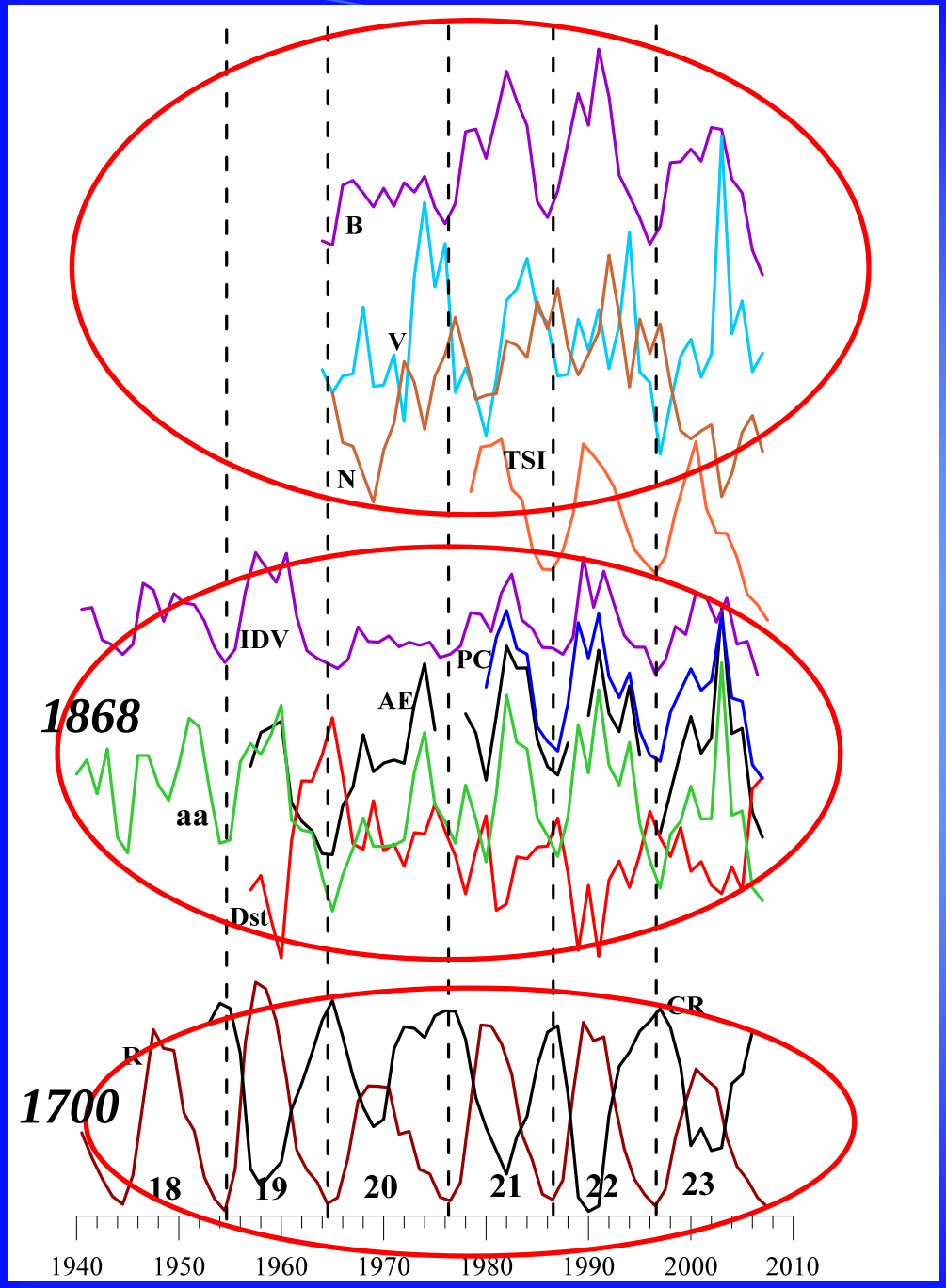
Disruption of
- satellite operations
- comunication
- navigation
- electric power grids on ground (GICs)
- hydrocarbon distribution grids

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.



Study data – annual means

- Heliosphere (1AU): B, V, N, Pw TSI, CR
- Magnetosphere: aa, IDV, IHV, AE, PC, Dst
- Sun: R

Space era - 1964

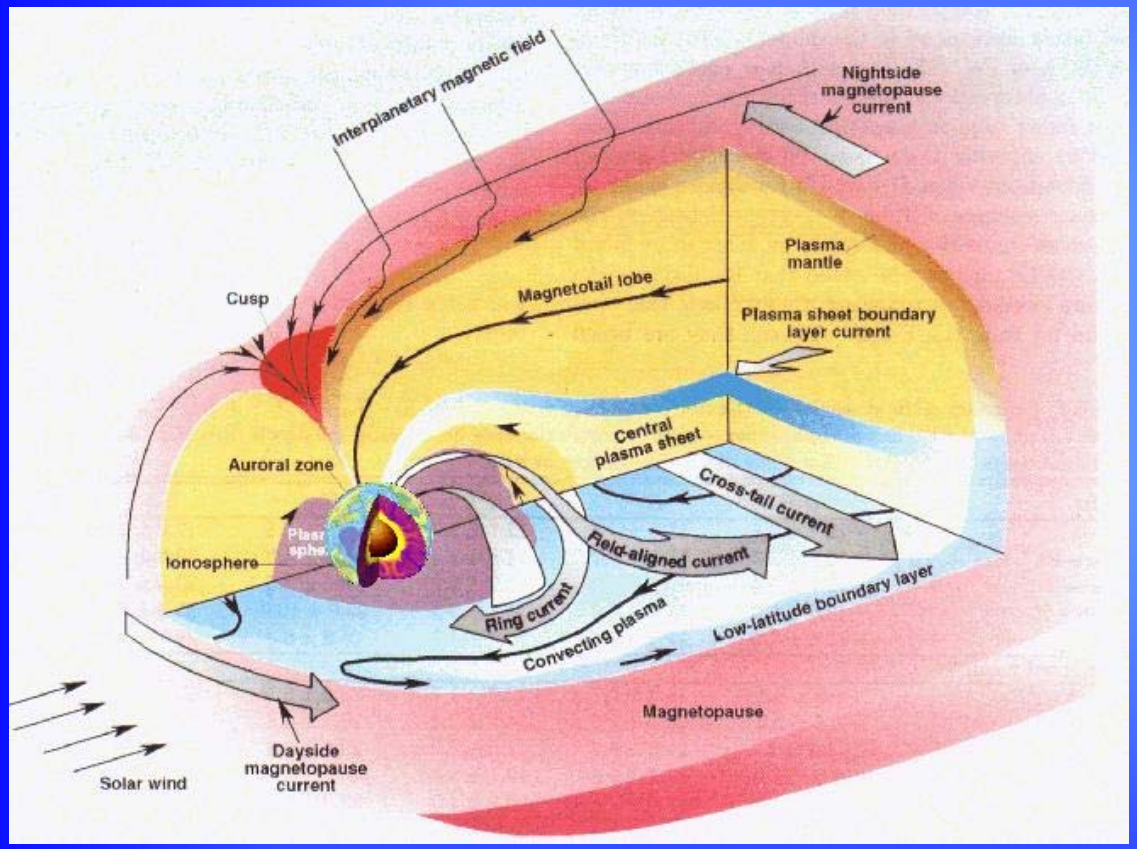
Reconstructions explicitly assume that one could extrapolate before 1964:

- 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.

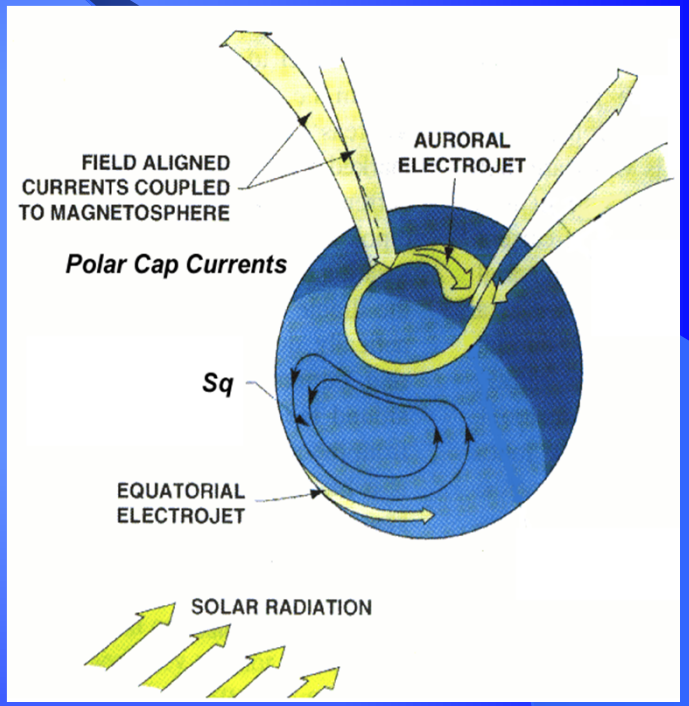
- linear correlations
- physical model + linear correlation

Geomagnetic activity- geomagnetic indices

- effects of electric current systems in the magnetosphere and ionosphere as a result of the interaction with the solar wind and the heliospheric magnetic field.



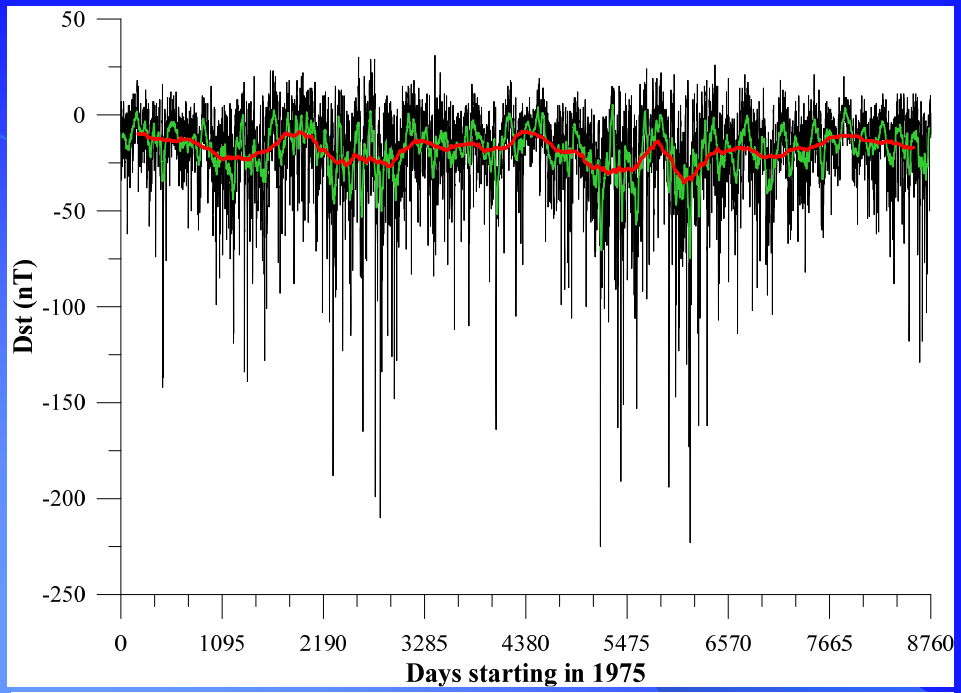
The magnetosphere



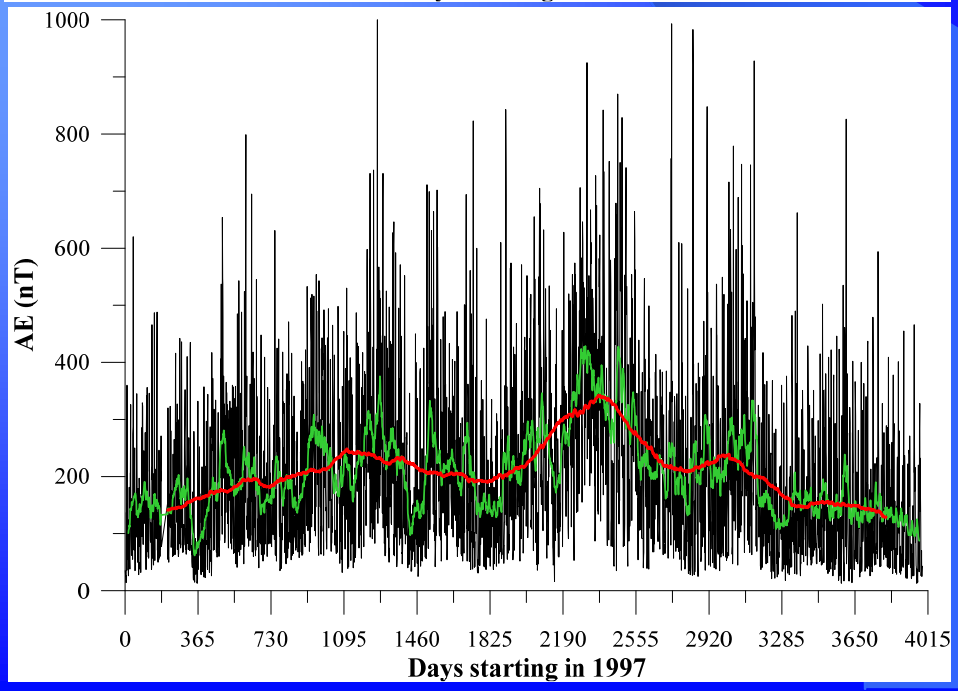
The ionosphere

Geomagnetic indices: Dst, AE

- Dst index (magnetospheric ring current) derived from geomagnetic variations in the horizontal component from 4 selected observatories relatively close to the equator (hourly values starting in 1957)



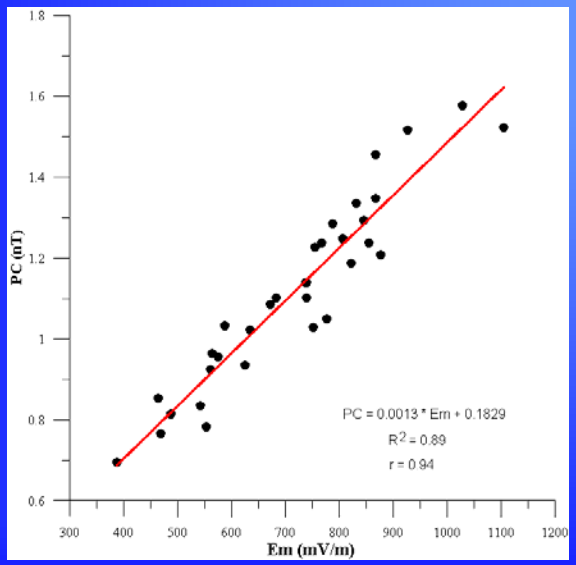
- AE index (auroral electrojet), derived from geomagnetic variations in the horizontal component from 12 selected observatories along the auroral zone in the northern hemisphere (hourly values starting in 1957)

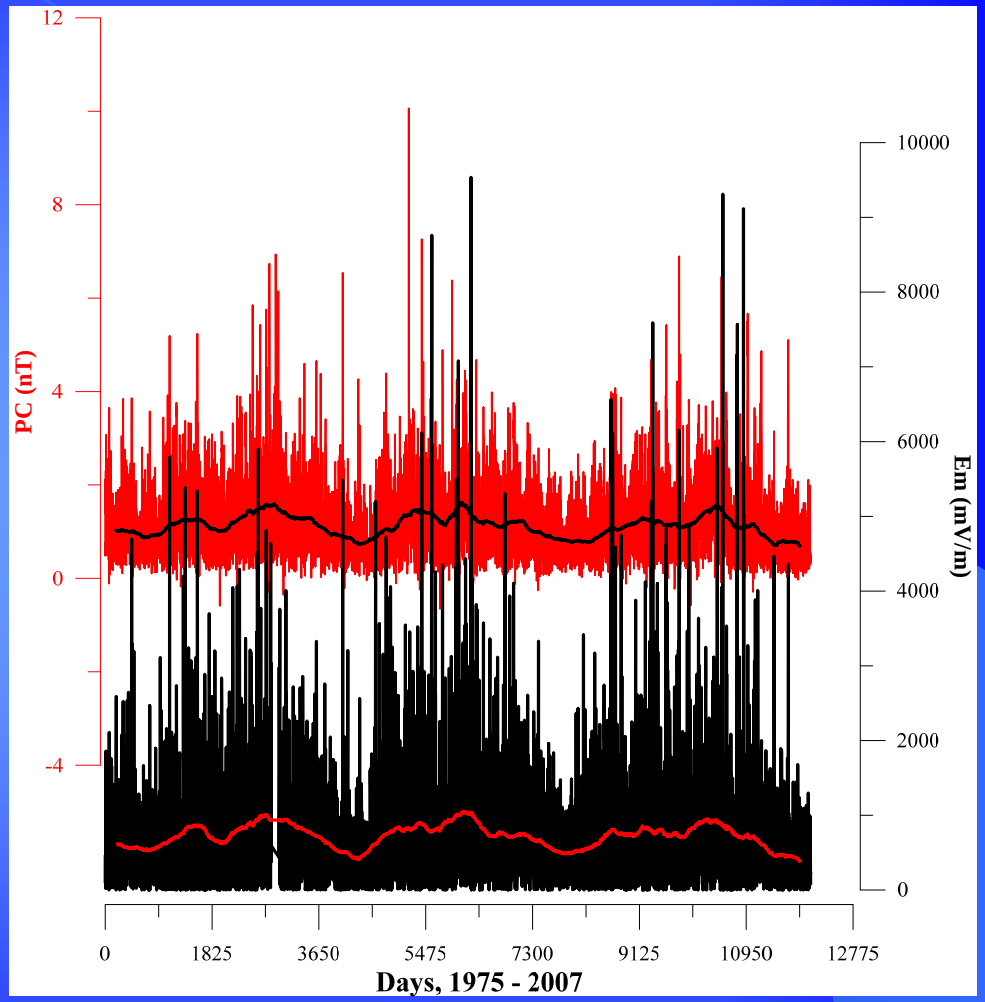


Geomagnetic indices: PC

- PC index (Polar Cap magnetic activity generated by the geoeffective interplanetary electric field Em (fifteen-minute index starting in 1975)

$$PC \sim Em = Vsw * B_T * \sin(q/2) * \sin(q/2)$$
$$q = \arccos(Bz/B_T)$$

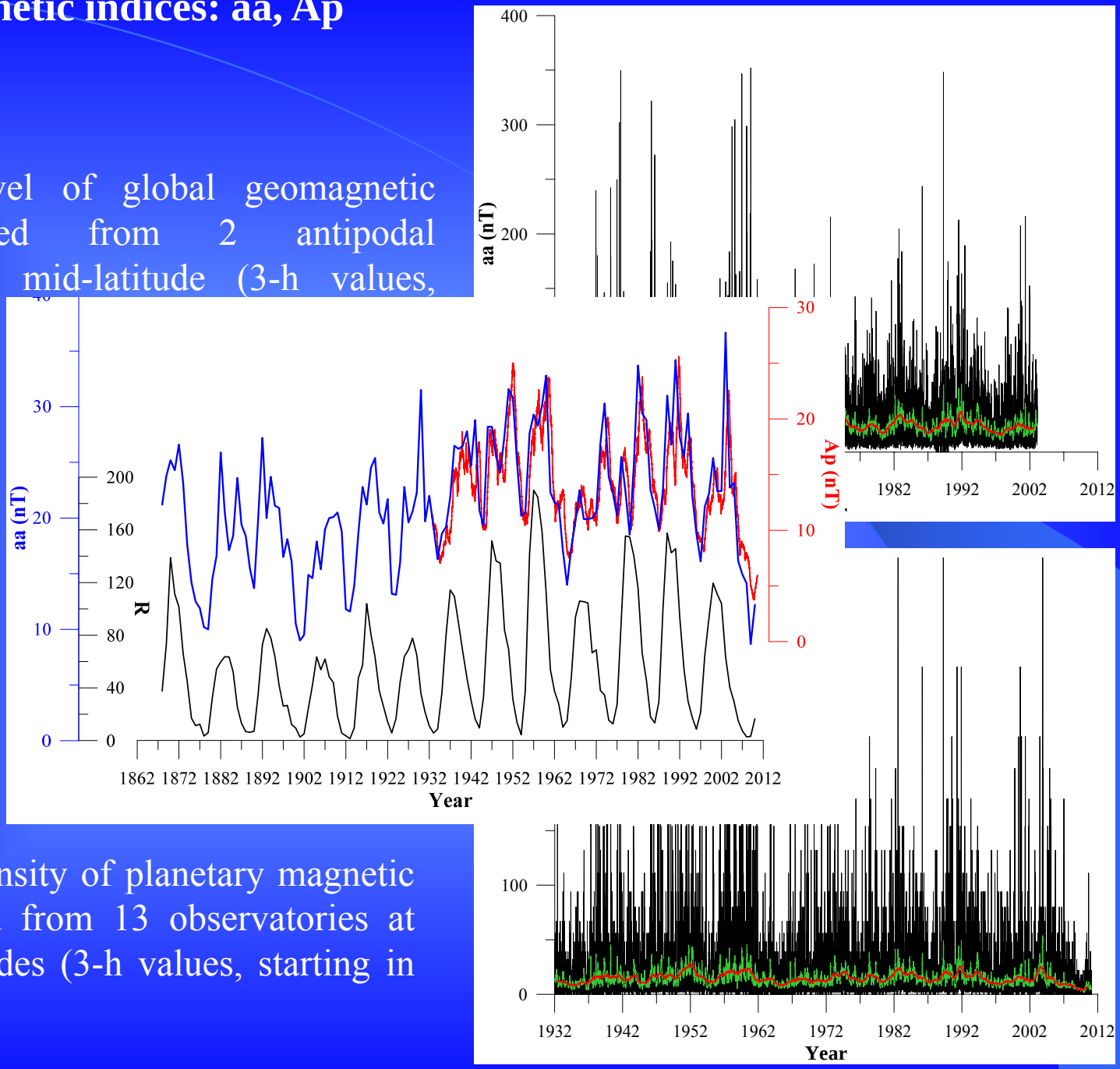




Dst, AE, PC affect the geomagnetic activity at local scale

Geomagnetic indices: aa, Ap

- aa index (level of global geomagnetic activity) derived from 2 antipodal observatories at mid-latitude (3-h values, starting in 1868)



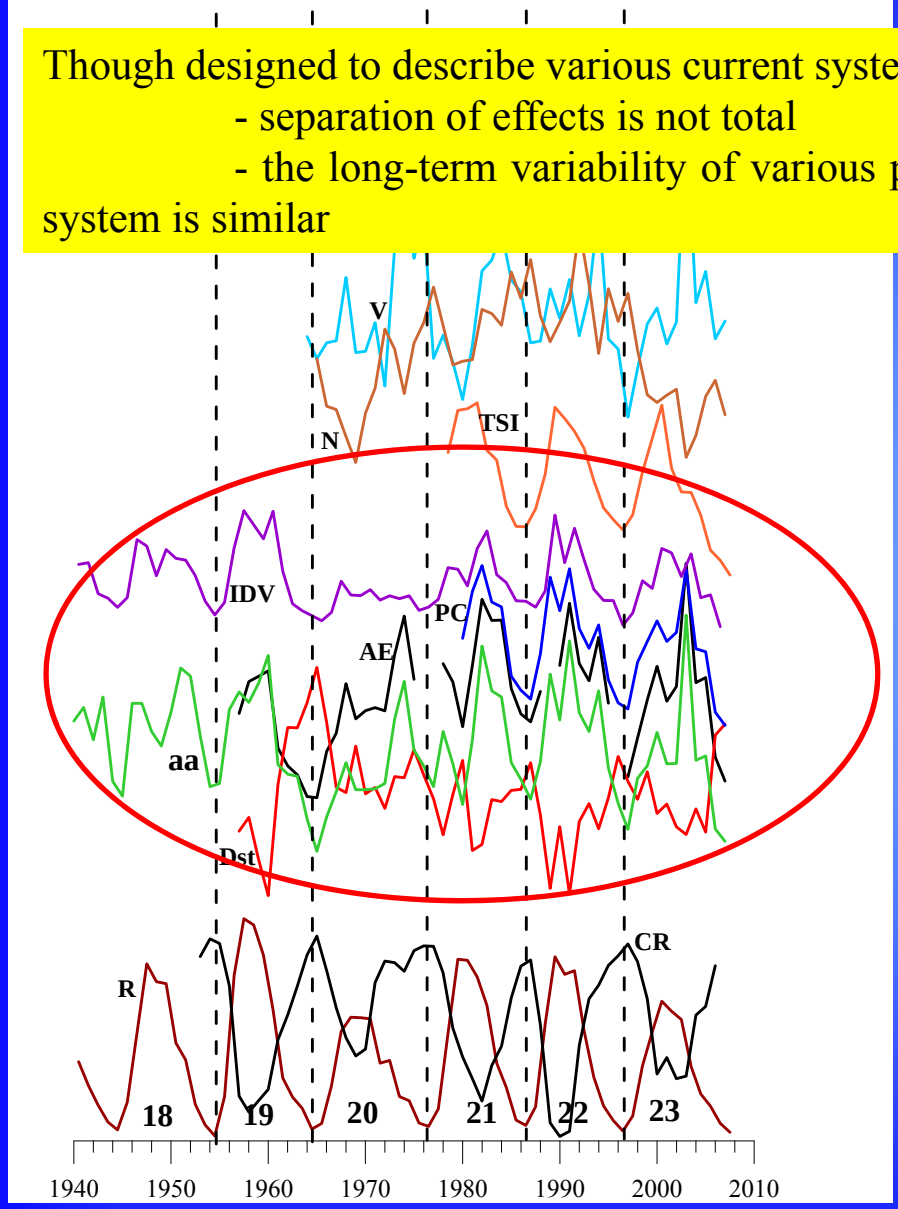
- Ap index (intensity of planetary magnetic activity) derived from 13 observatories at subauroral latitudes (3-h values, starting in 1932)

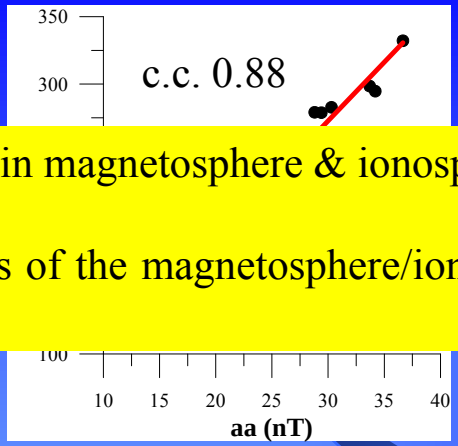
Long-term geomagnetic variability

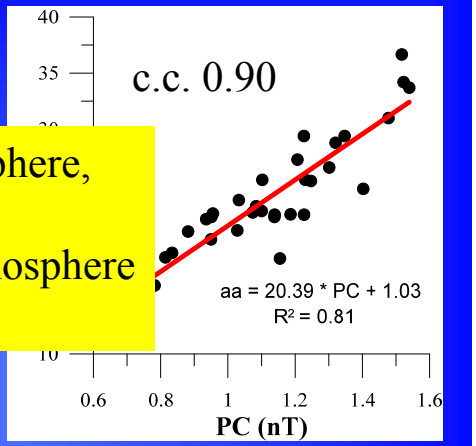
Interannual scale

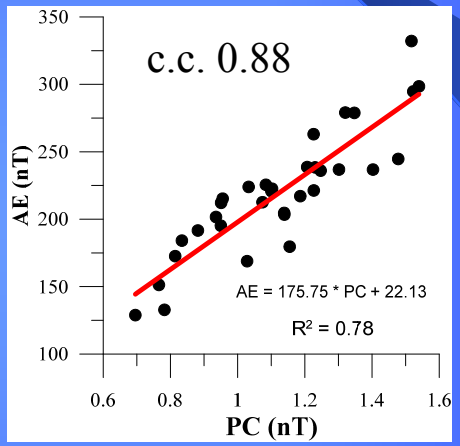
Though designed to describe various current systems in magnetosphere & ionosphere,

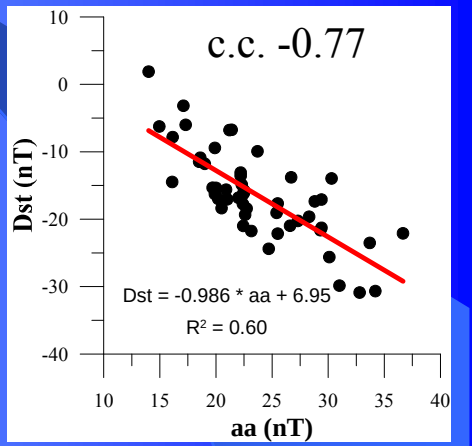
- separation of effects is not total
- the long-term variability of various parts of the magnetosphere/ionosphere system is similar

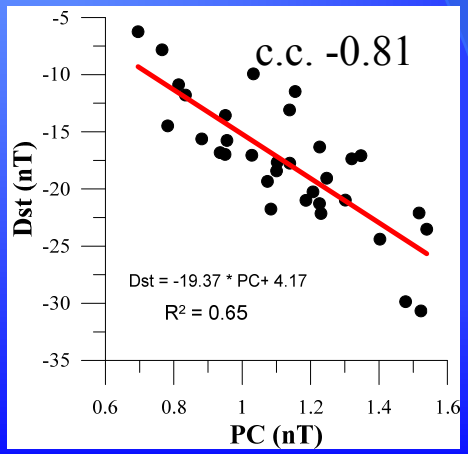




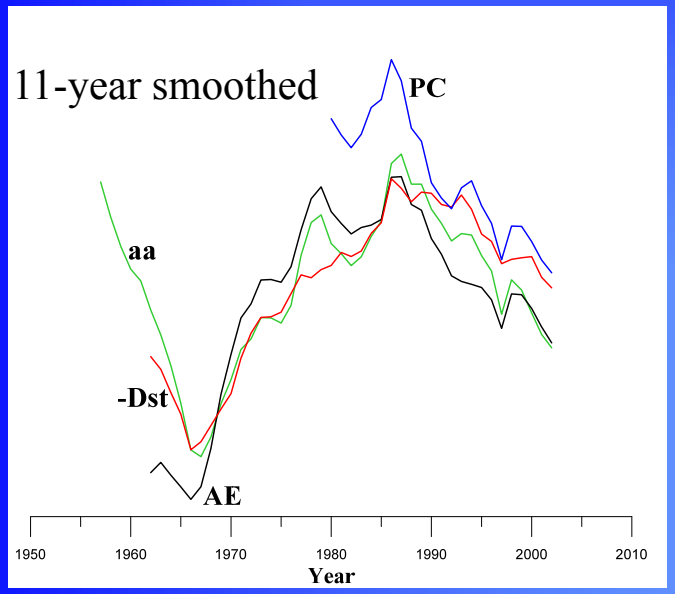


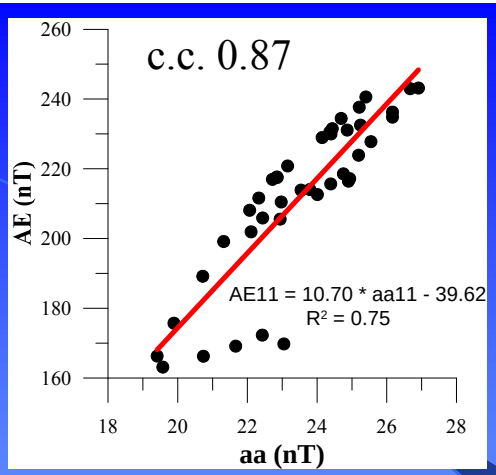


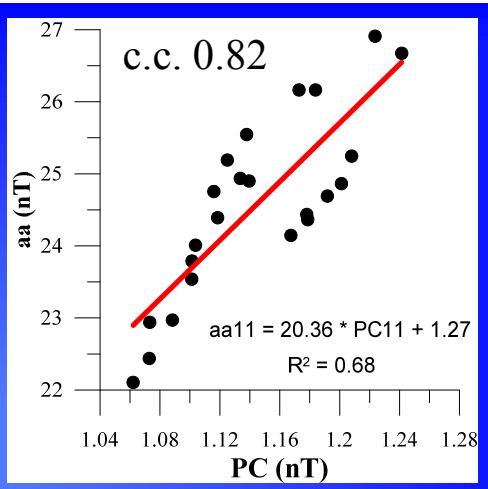


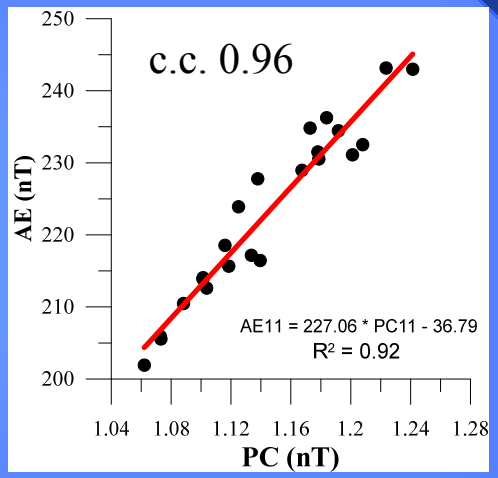


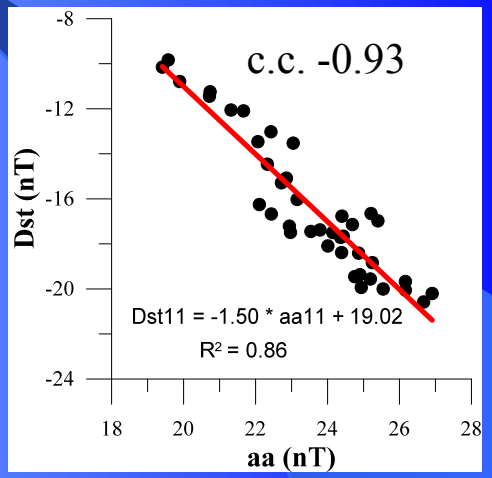
Long-term geomagnetic variability
Interdecadal scale

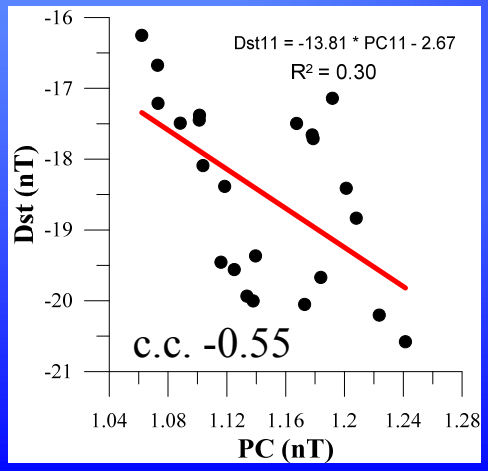










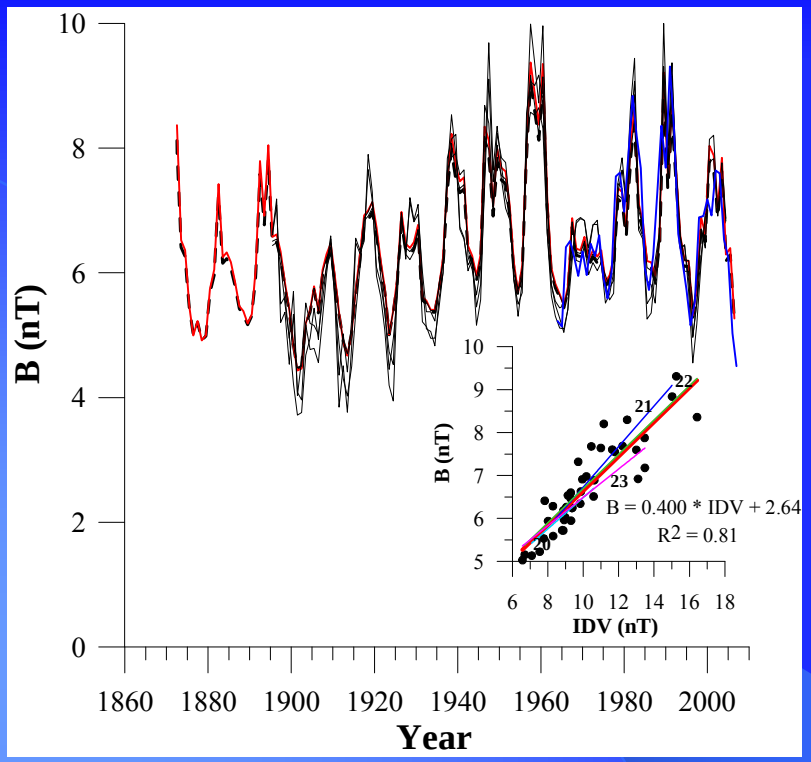


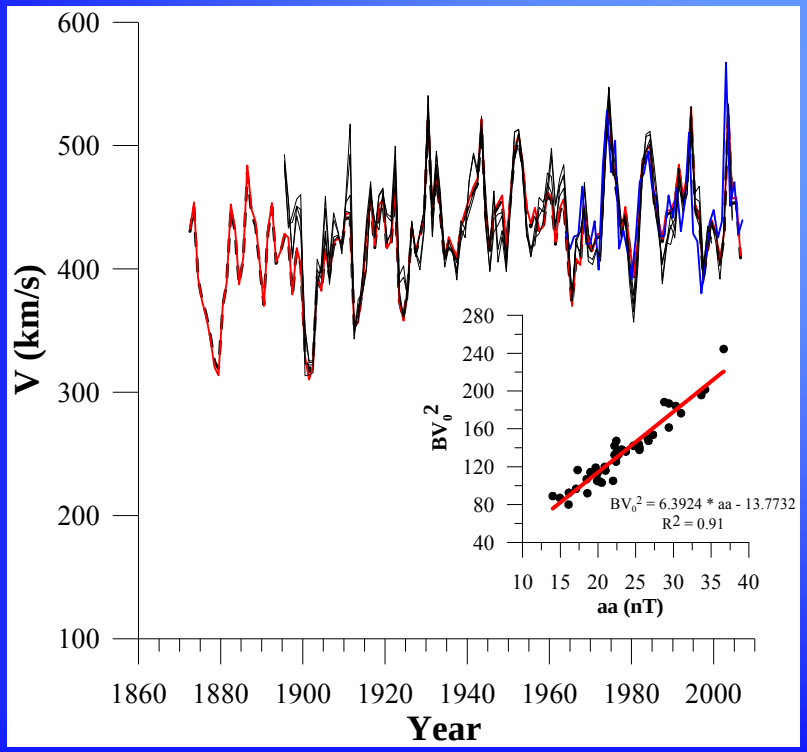
- the geomagnetic indices correlate well with each other at interannual time scales and the correlation generally improves if the solar cycle effect is removed

Reconstructions to 1870

- **based on correlations: B-IDV**
  BV^2-aa

- 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



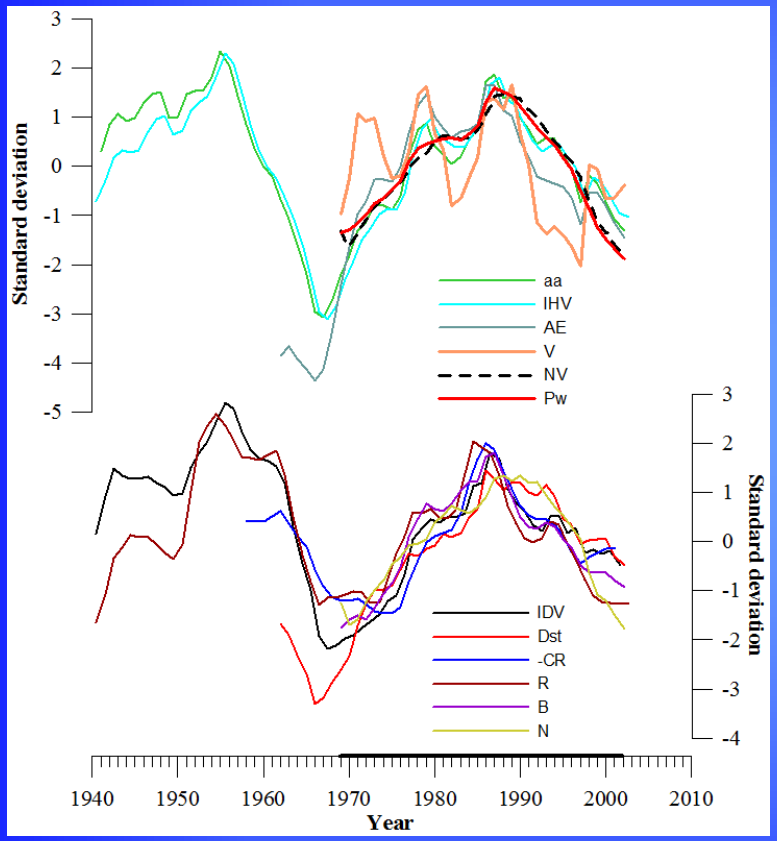


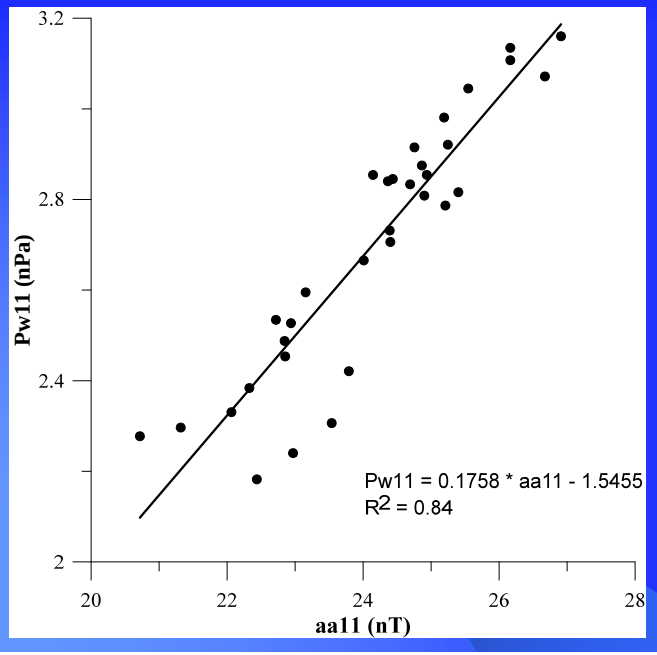
Svalgaard&Cliver (JGR2005)
Rouillard et al., (JGR2007)
Svalgaard&Cliver (JGR2007)
Demetrescu&Dobrica (ASR2010)

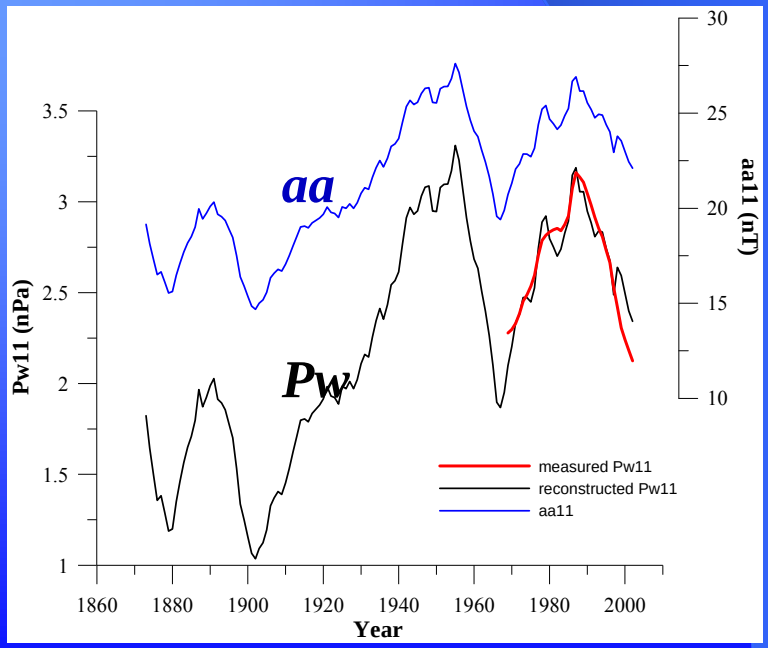
Reconstructions to 1870

- **based on correlations: Pw - aa**

In terms of 11-year averages







Dobrica et al., Sun&Geosphere 2012

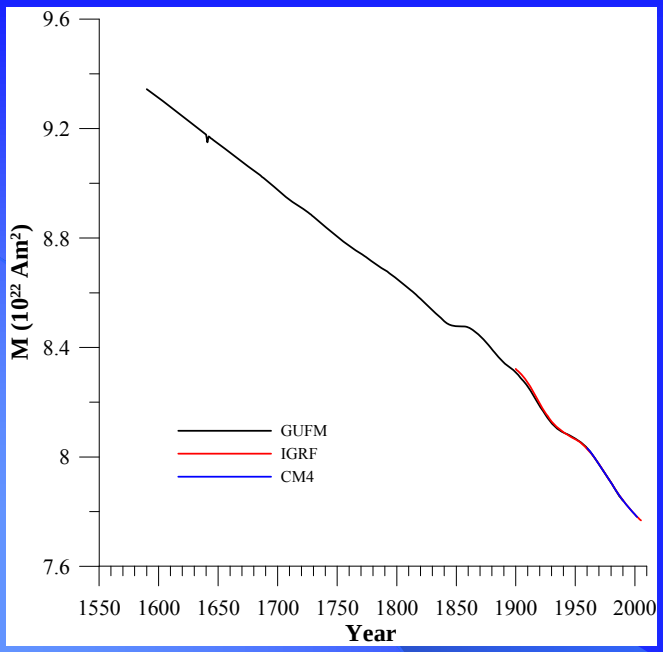
Reconstructions to 1870

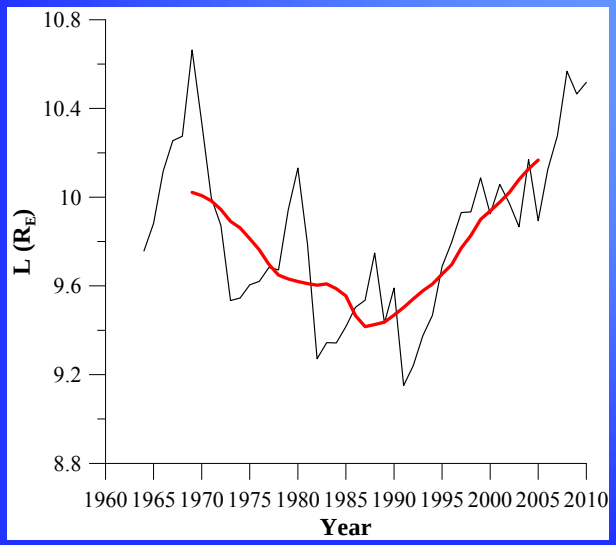
- **based on correlations: Pw - aa**

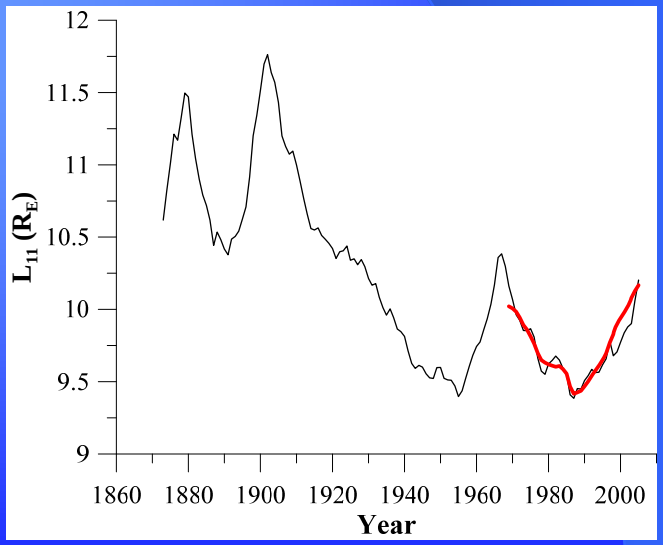
Standoff distance of the dayside magnetopause (L)

$$L = k\left(\mu_o M^2 / P_w\right)^{1/6}$$

M - the magnetic moment of the Earth's dipole
Pw - the dynamic pressure of the solar wind at magnetopause
μo - the permeability of the vacuum
k - constant



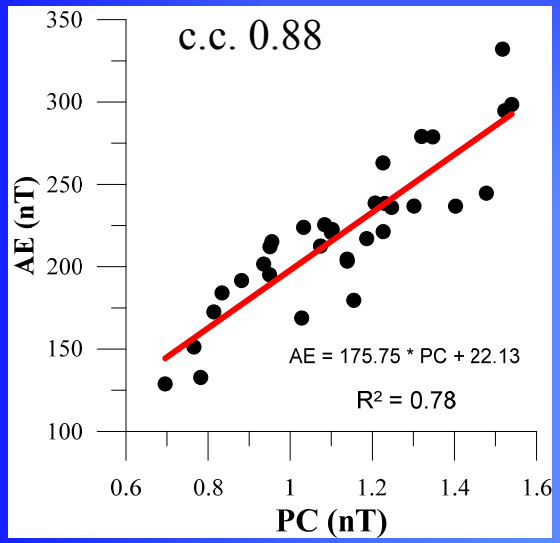


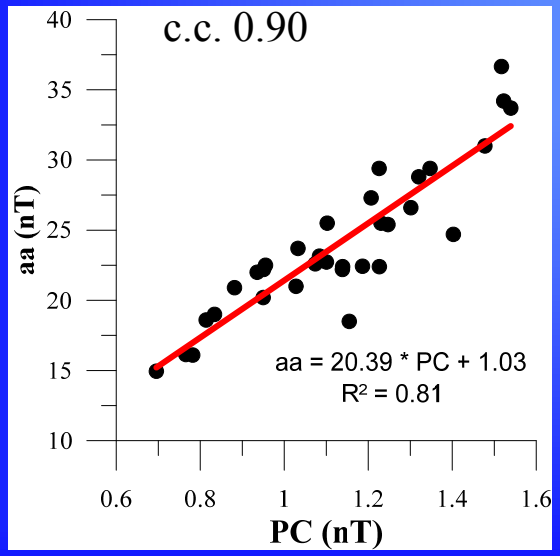


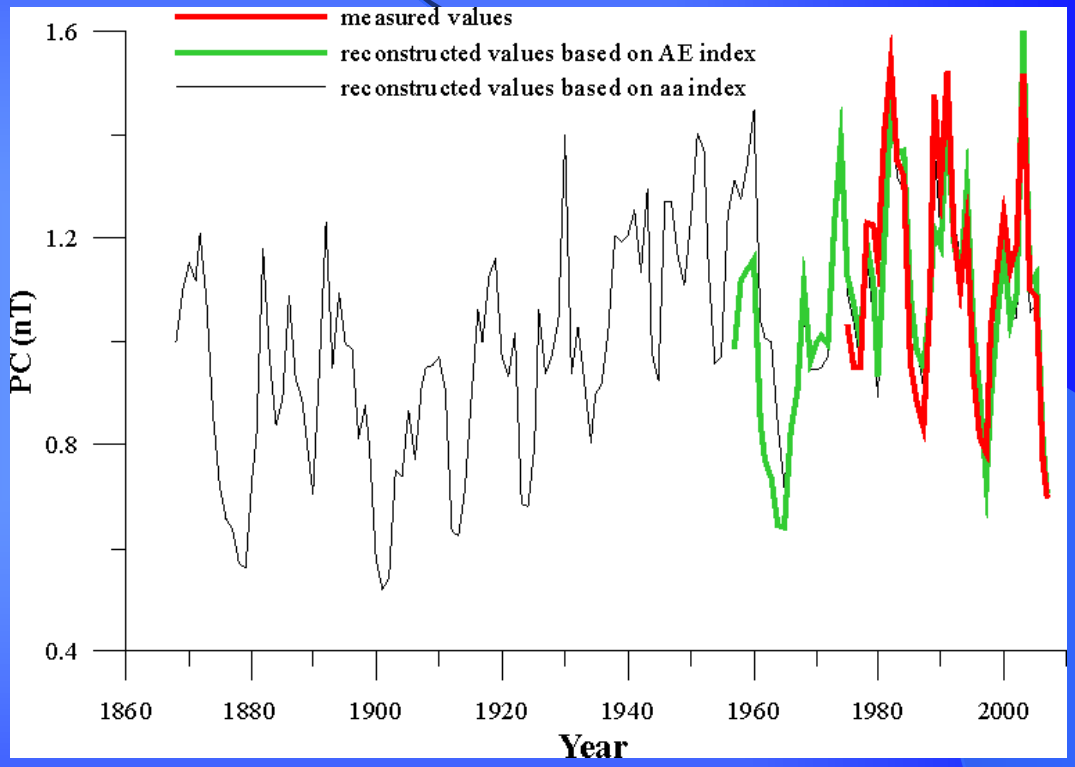
Dobrica et al., Sun&Geosphere 2012

Reconstructions to 1870

- based on correlations: PC – AE
  PC – aa







Reconstructions to 1700

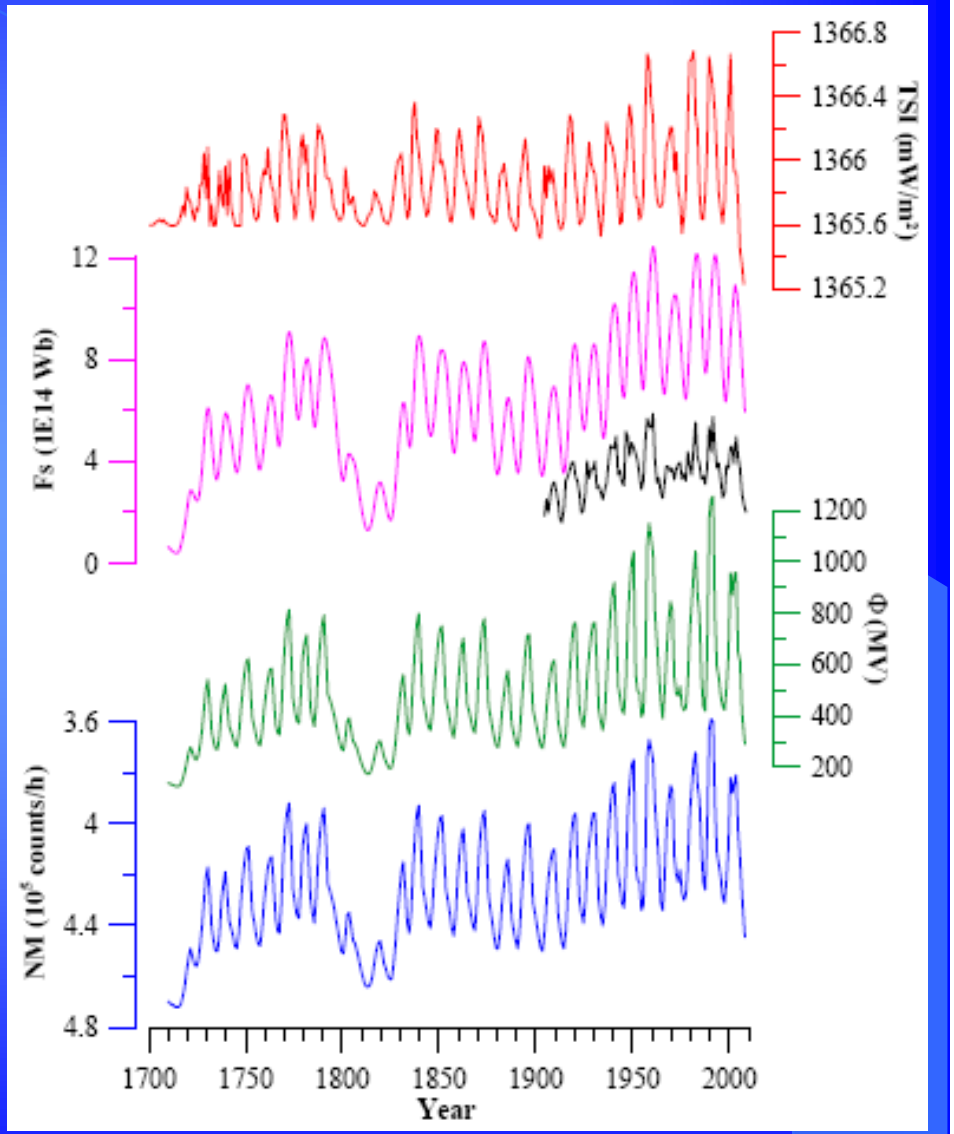
- based on physical models + correlations (R)

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)*

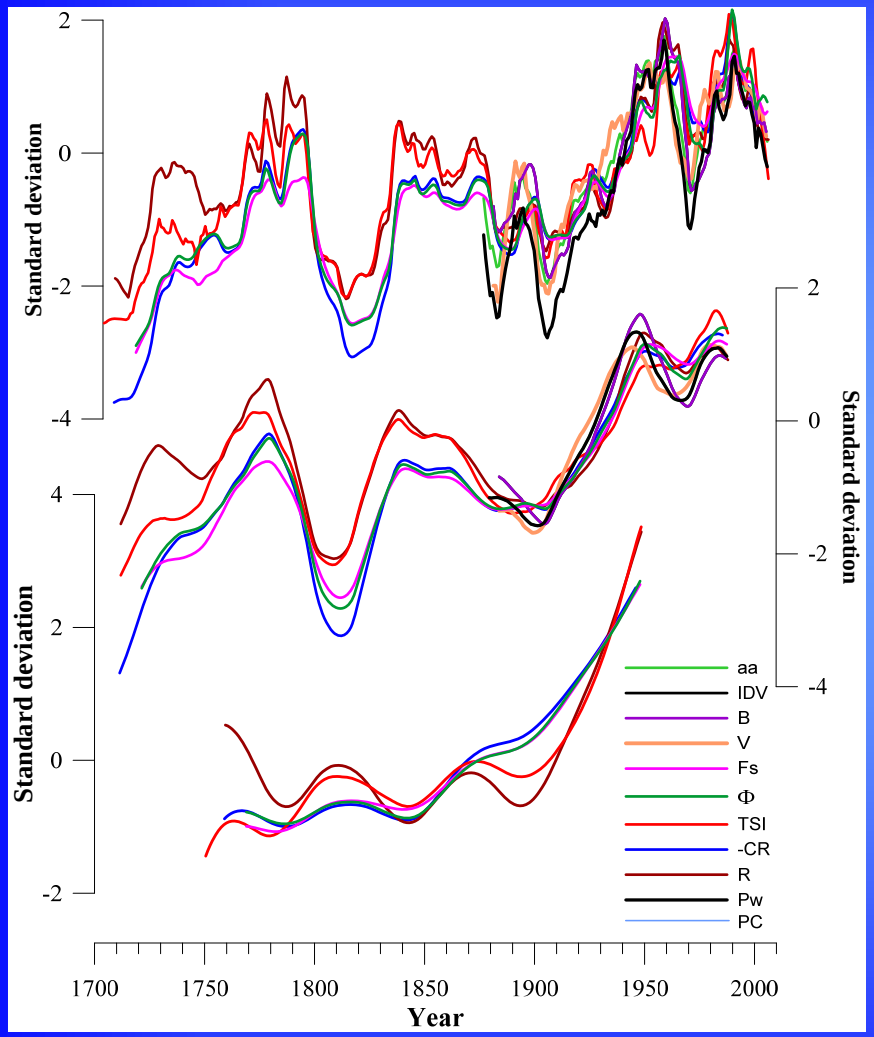
GCR flux, Φ – reconstruction of the open flux from sunspot numbers *(Solanki et al., 2002)* in conjunction with a spherically symmetric model of the heliosphere *(Usoskin et al., 2002a)* to reconstruct the intensity of GCR at Earth *(Usoskin et al., 2002b)*



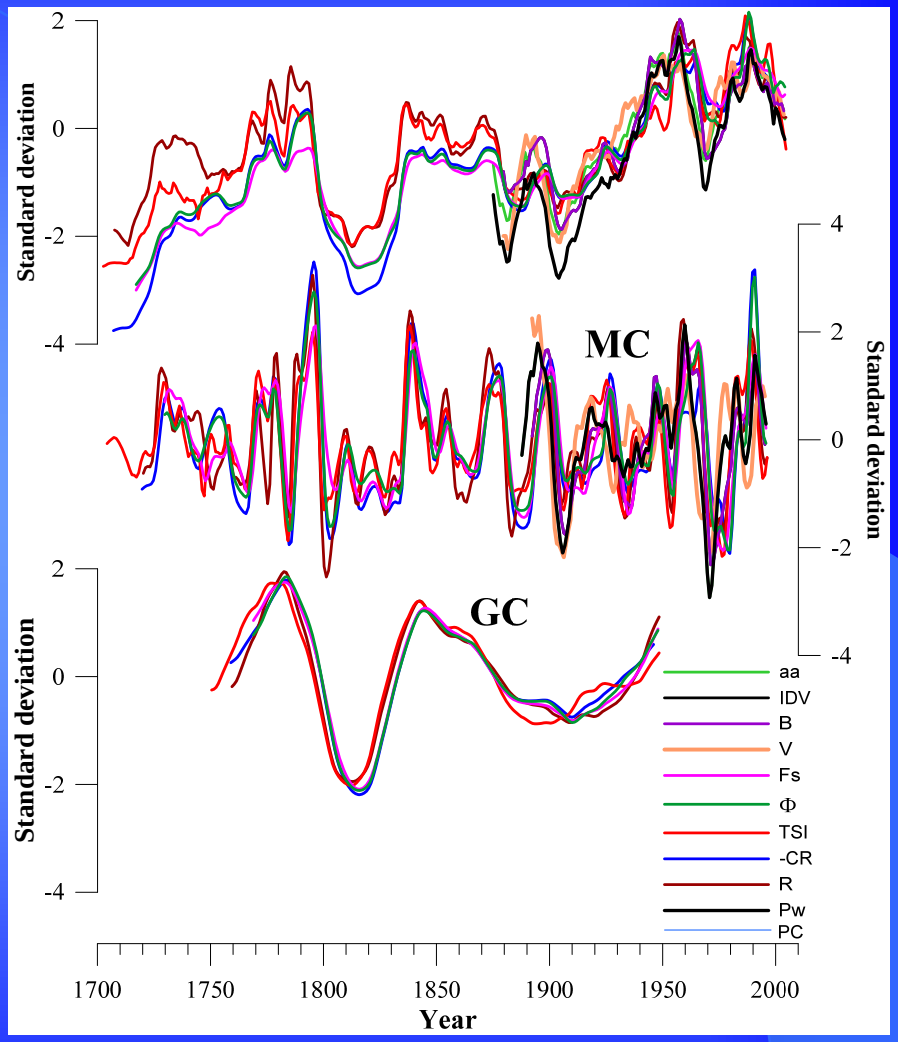
The solar-heliospheric-magnetospheric environment

Trends in data (interdecadal and centennial)

Standardized 11, 22 and ~88-year running averages



Signature of the Hale and Gleissberg cycles



Demetrescu&Dobrica, JGR 2008
Demetrescu et al., ASR 2010

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

Conclusions

- V, B, PC (indirectly Em), Pw, L were reconstructed prior to space era;

- signatures of the magnetic (Hale) cycle and of the Gleissberg cycle of the solar activity have been evidenced in the HMF, in the SW speed, in the dynamical pressure of the SW at magnetopause, in the TSI, in the open solar magnetic flux, in the GCR flux and in the geomagnetic activity;

- the long-discussed centennial increase of geomagnetic activity and the doubling of solar open flux in the twentieth century, defined in terms of 11-year averages of geomagnetic indices and, respectively, F_S, have been shown to be the result of the superposition of the MC and GC signatures in the data;

- when scaled by the standard deviation from the average value for the common interval covered by the data, the MC and GC signals are quite similar in the heliosphere – magnetosphere environment, pointing to a common pacing source, the solar dynamo;

- the results contribute to better defining the space climate concept.