Long-term variations in the geomagnetic field. Any connection to the solar activity?

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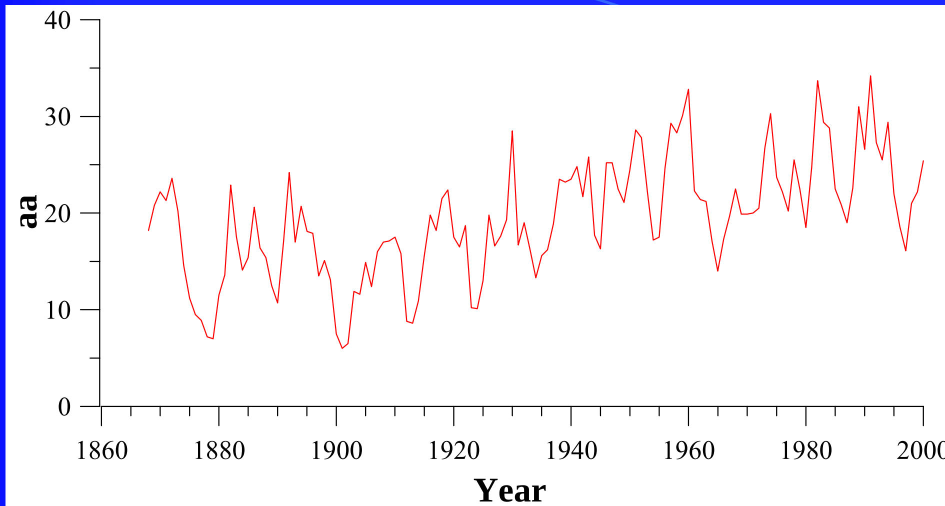
Outline

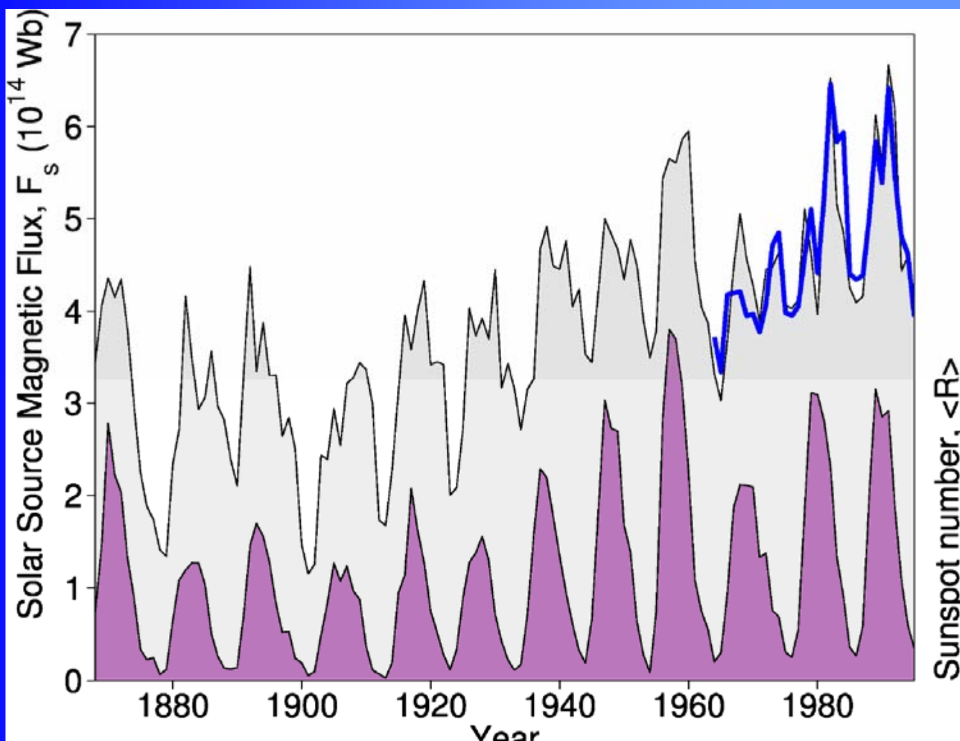
Introduction

External variations and solar activity

Main field

- measurements
  secular variation
- modelling
- field at core surface
- 150 – 100 years of observatory data
- possible connections to the solar activity



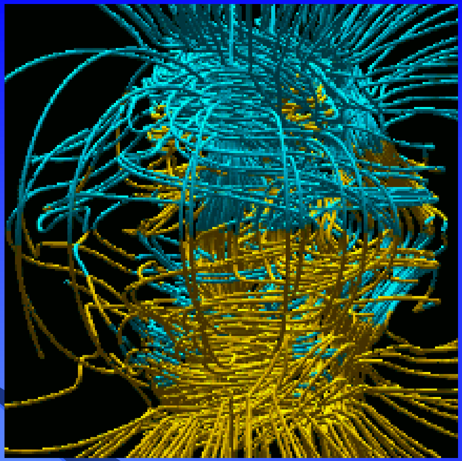


Geomagnetic and solar activity

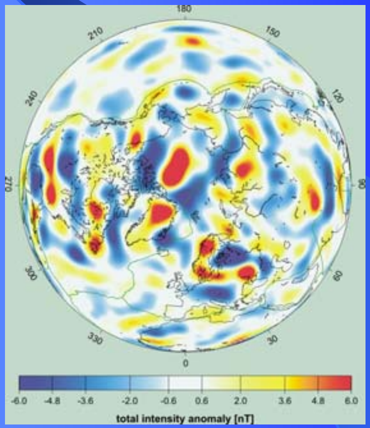
The relationship between the solar activity and short-term variations in the geomagnetic field has been known for a long time. As a matter of fact, the study of geomagnetic phenomena such as geomagnetic storms and substorms, bays and pulsations, together with astronomical observations and studies, made possible the advancement of solar and magnetospheric physics and the development of the solar-terrestrial science.

Lockwood et al., 1999

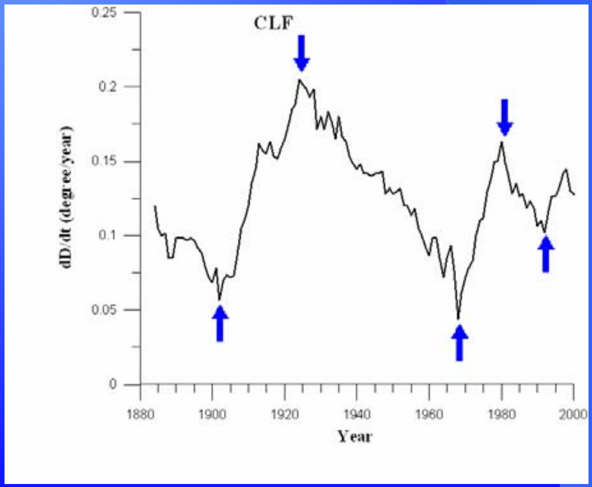
However, 95-98% of the observed geomagnetic field has internal sources, being mainly produced by a dynamo process in the outer core of the Earth (the main geomagnetic field)



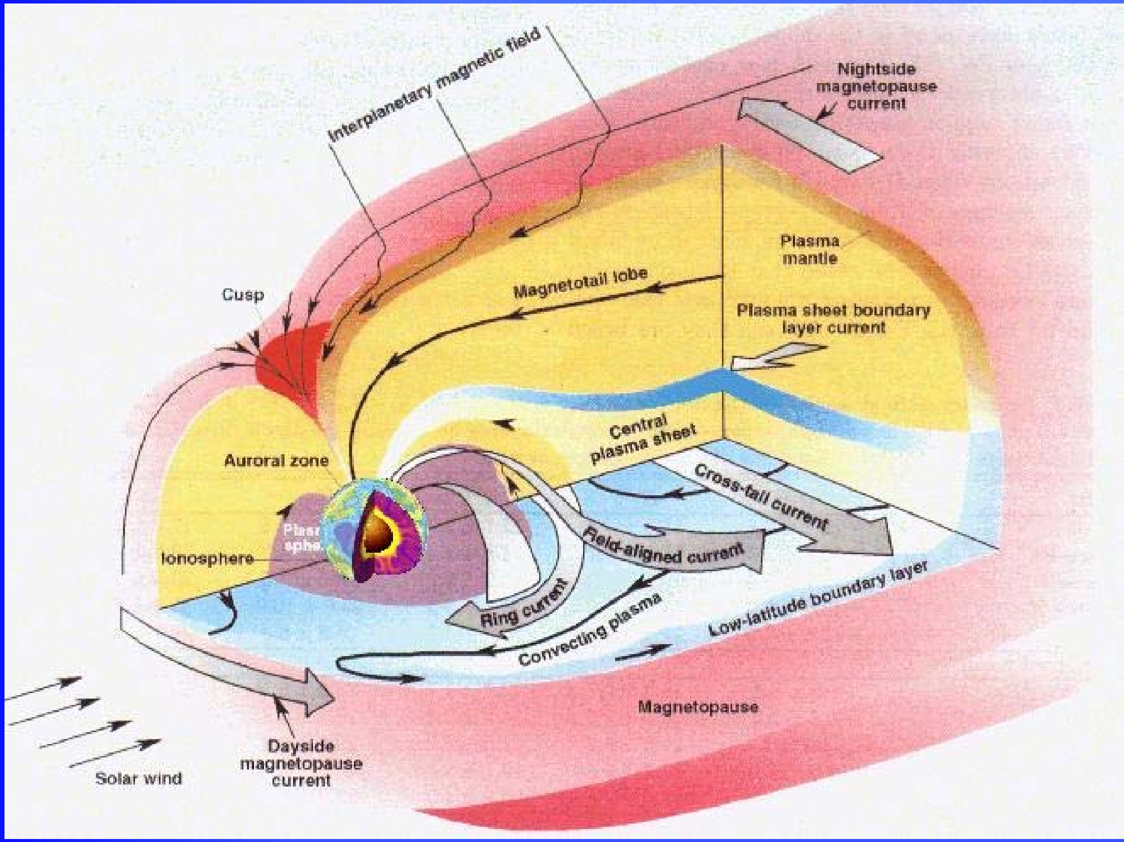
and by magnetic rocks in the lithosphere (the lithospheric field).

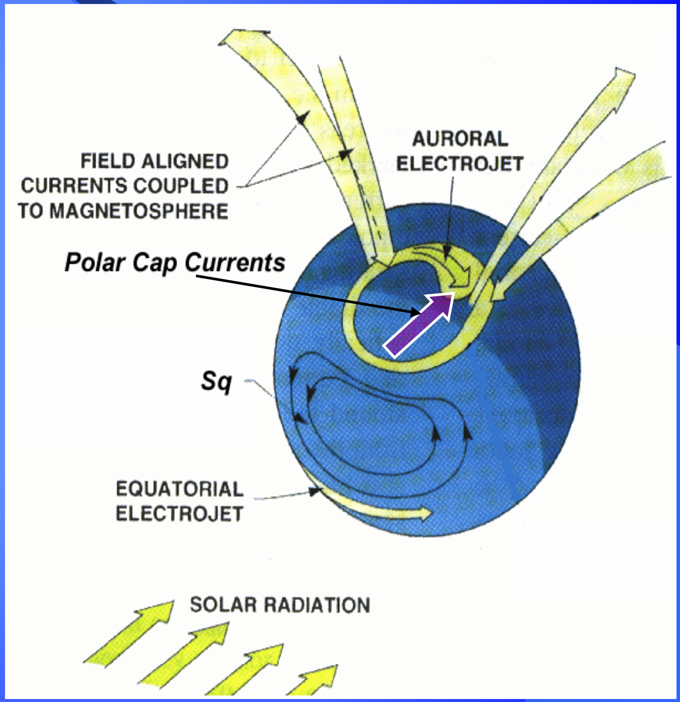


The time evolution of the main field is currently believed to be characterized by intervals of constant secular variation interrupted by episodes of sudden (1-3 years) steps in the secular acceleration, called geomagnetic jerks, produced in the Earth's outer core.



The sources of the external variations of the geomagnetic field are to be found in the magnetosphere and ionosphere. They result from the interaction of the solar wind with the magnetosphere and of the solar radiation with the upper atmosphere.





Geomagnetic indices to quantify long-term external field variations (1)

- Geomagnetic activity:

aa – (Mayaud, 1972; 1980)

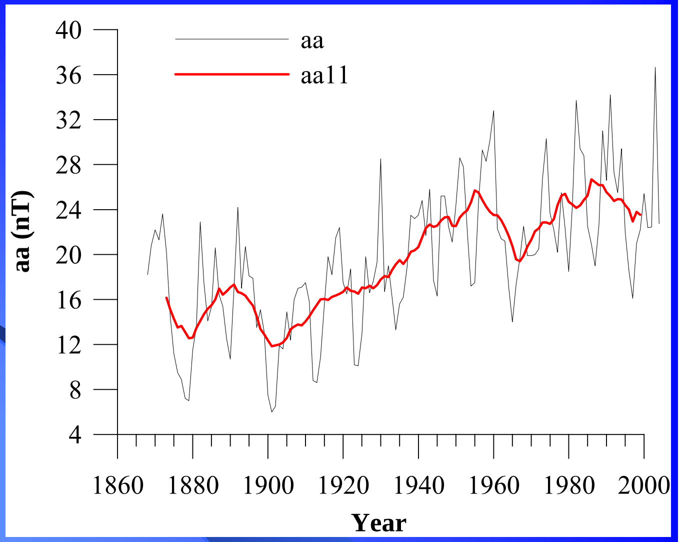
- widely used to depict long-term variations of the geomagnetic activity;
- long-term similarity between aa and R in terms of 11-year running averages (Feynman & Crooker, 1978; Feynman, 1982; Silver, 1992; Cliver et al., 1998*)*
- heliospheric conditions at 1 AU (IMF strength, SW speed & density) account for the upward drift in the 20th century (Stamper et al., 1997)
- calibration problems – (Svalgaard et al., 2004)

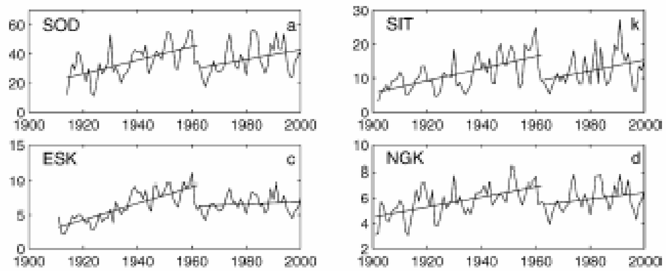
IHV – (Svalgaard et al., 2004) to avoid calibration problems.

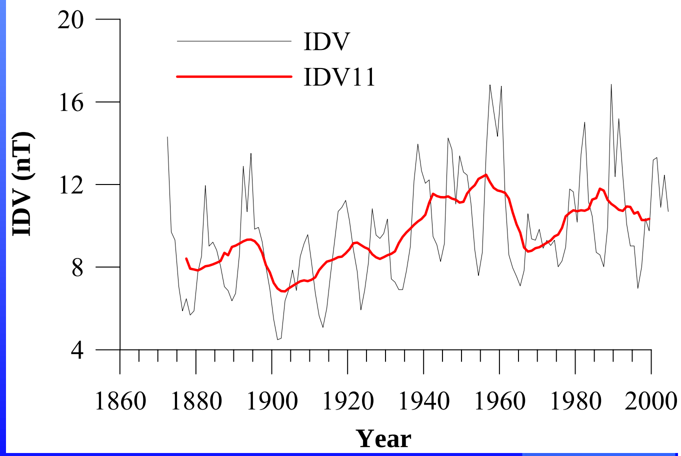
- Mursula et al., 2004 and Mursula & Martini, 2005 - latitudinal dependence, corrections of early data

IDV – (Svalgaard & Cliver, 2004) – controlled by the IMF strength

Ah – (Mursula & Martini, this symposium)



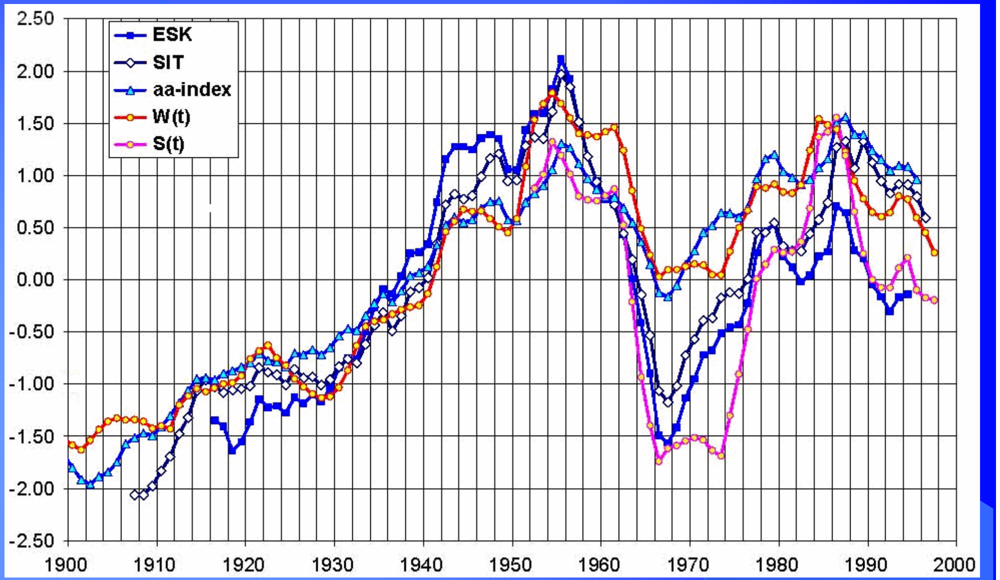




Geomagnetic indices to quantify long-term external field variations (2)

- Solar quiet daily variation Sq

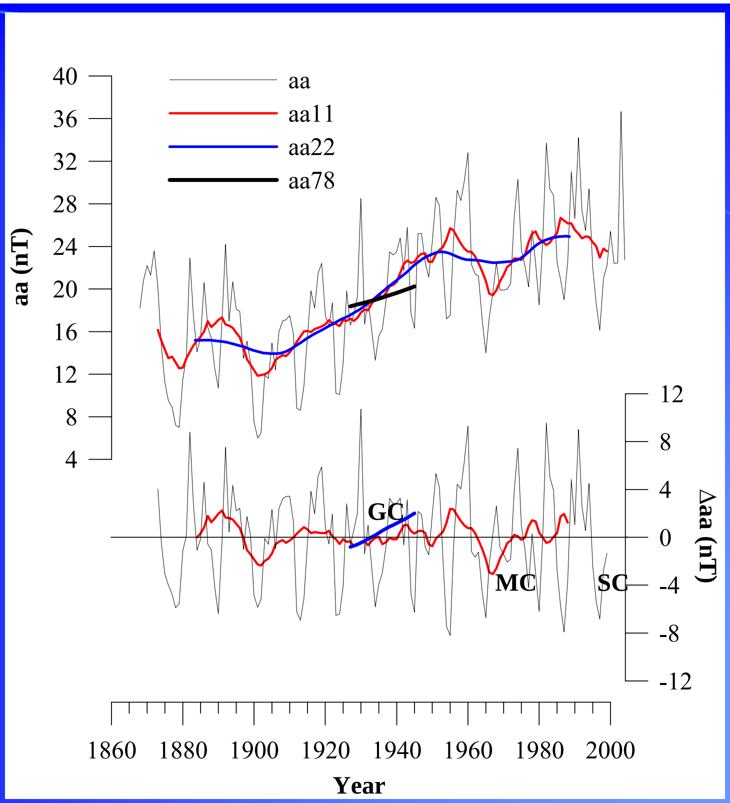
x, y, z, r – (Le Mouël et al., 2005)
controlled by the solar UV radiation

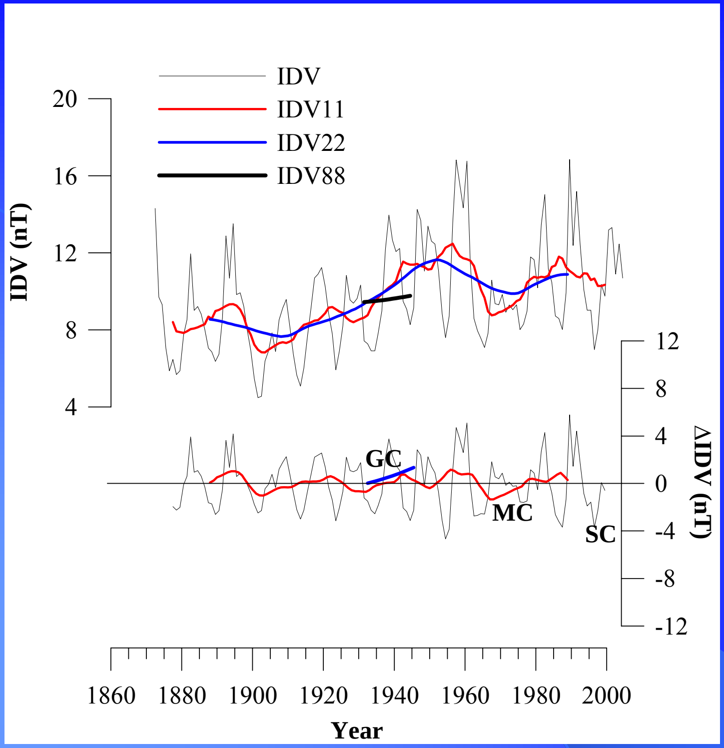


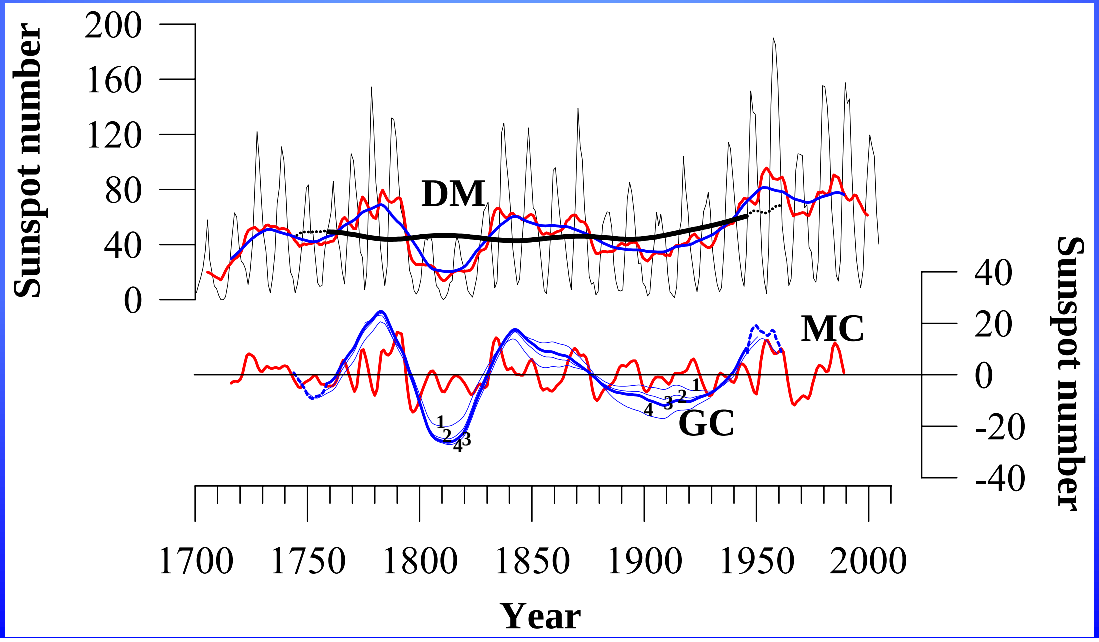
● in terms of 11-year averages – similarity with aa and R – "overall trend of the geomagnetic field"

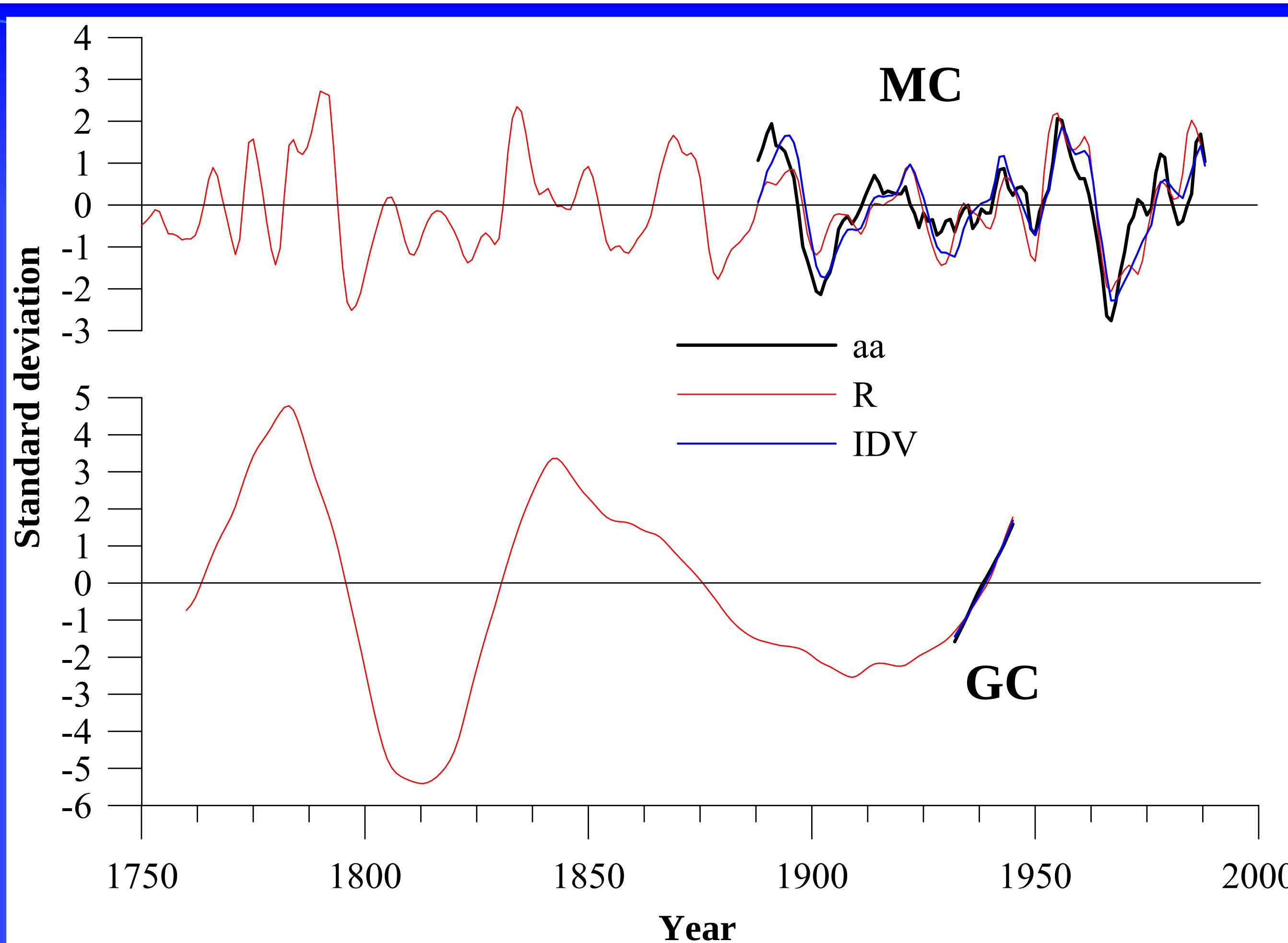
● both EM radiation and corpuscular flux in the vicinity of the Earth are subject to the same time variations on the time-scale considered.

A common trend is present also at longer time-scales:
- 22-year
- "secular", "80-90 year", Gleissberg cycle

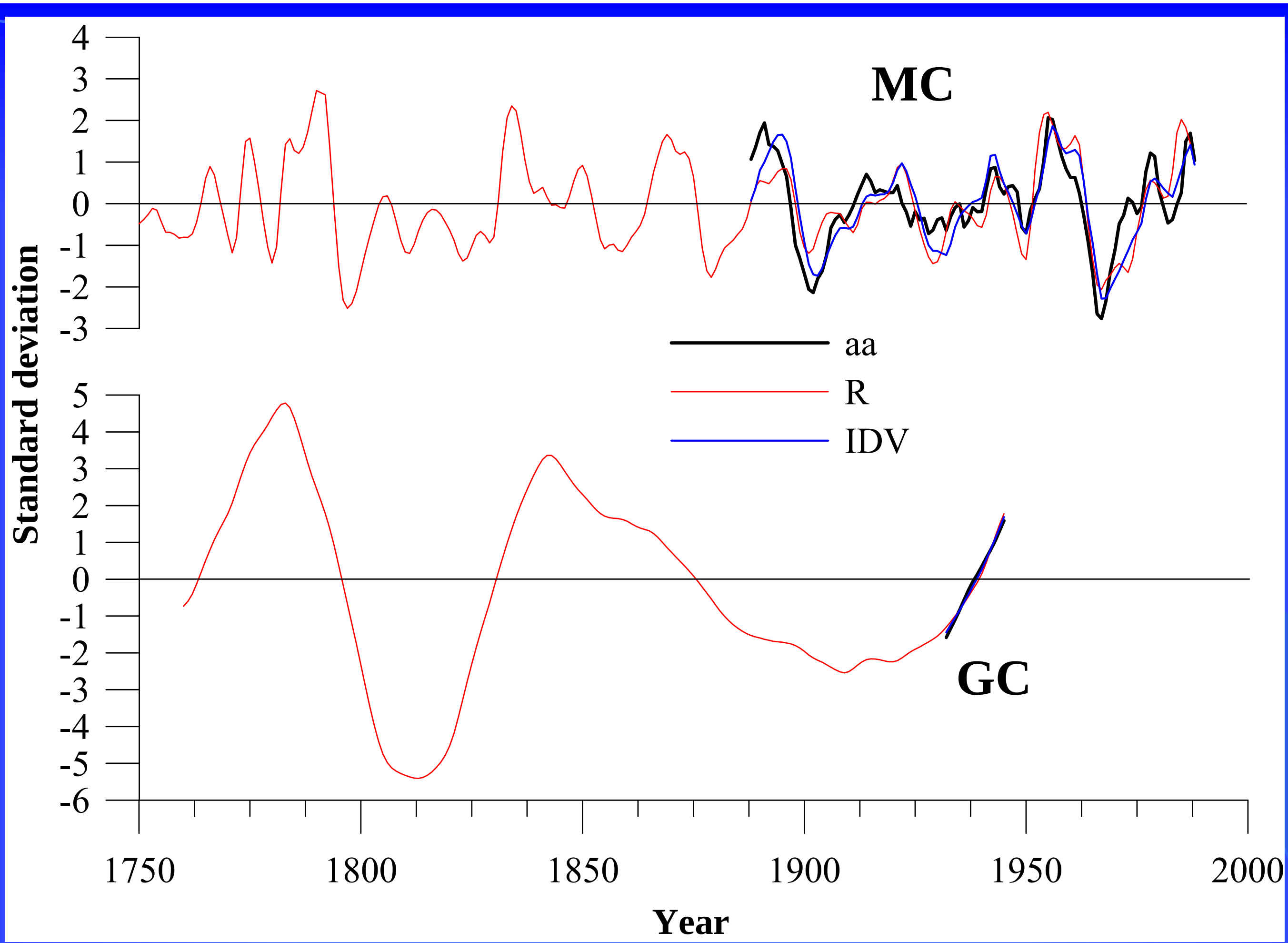

aa
aa11
aa22
aa78
aa (nT)
Δaa (nT)
GC
MC
SC
Year


IDV
IDV11
IDV22
IDV88
IDV (nT)
ΔIDV (nT)
GC
MC
SC
Year


Sunspot number
DM
MC
GC
Year



reduced to their mean over the common interval and scaled with their standard deviation as unit



At both the 22-year scale and the GC scale

-the coronal source field - as reflected by general heliospheric conditions at 1 AU – aa, IHV

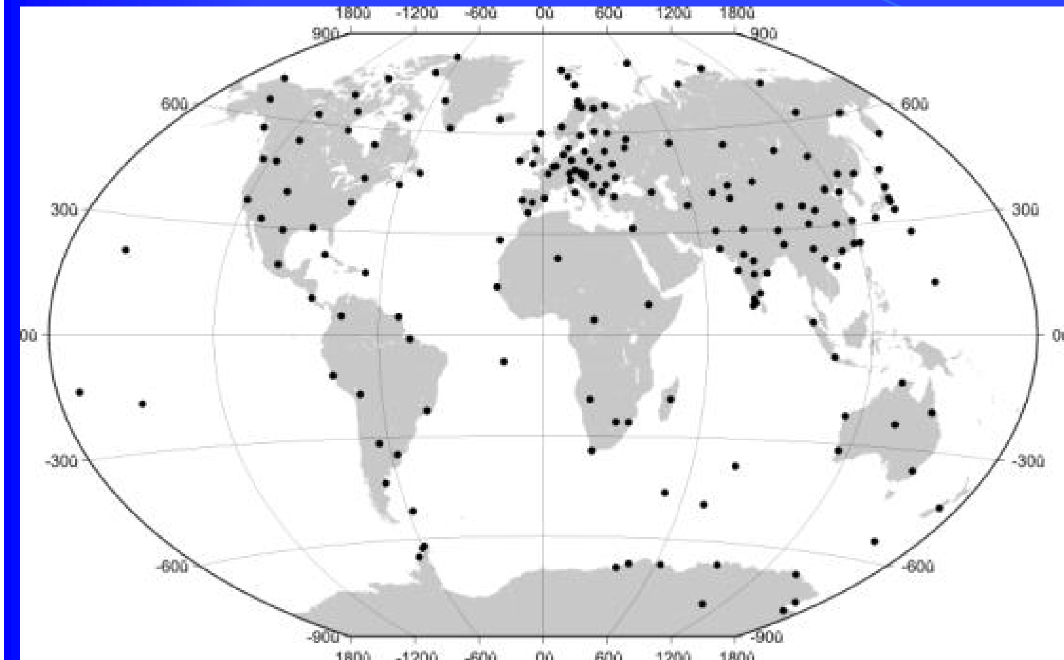
- as reflected by the IMF strength at 1 AU – IDV

- the photospheric magnetic field – R

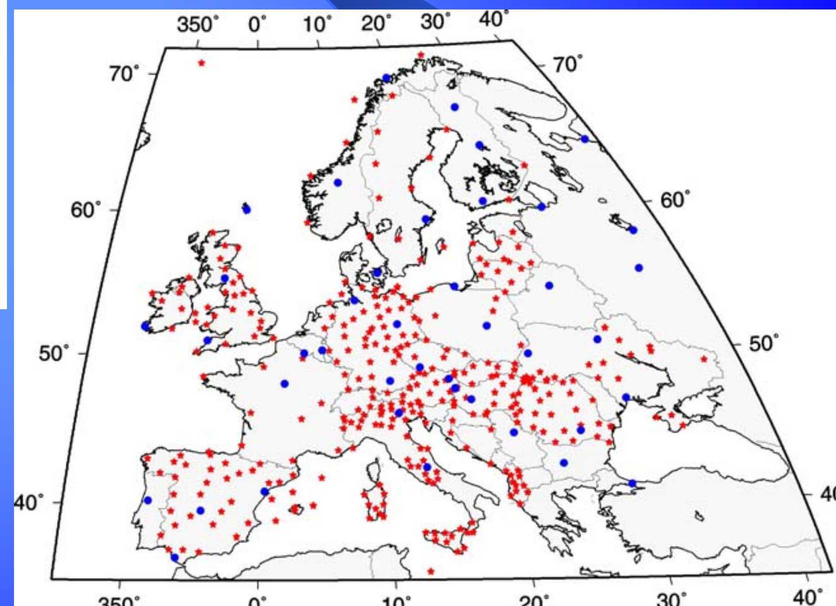
- the solar radiative output – x, y, z, r, S

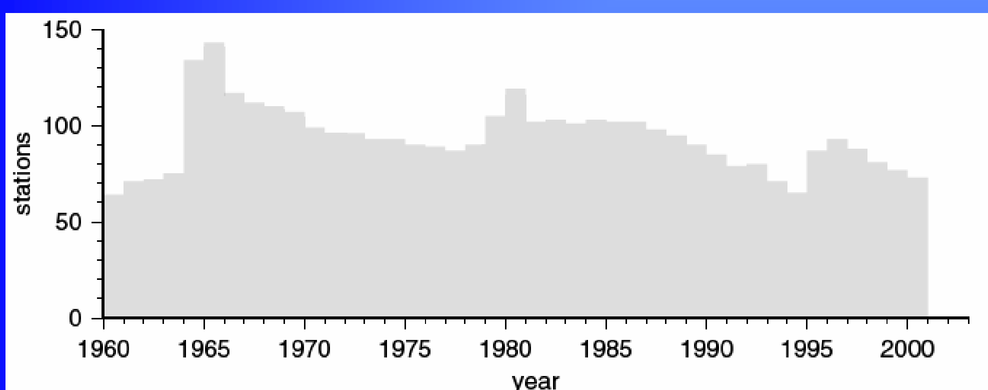
have a similar behaviour, being subject to similar long-term variations caused by processes developing in the Sun

Ground-based measurements



Historical measurements: 16th century
Observatory measurements: 1846
Repeat stations

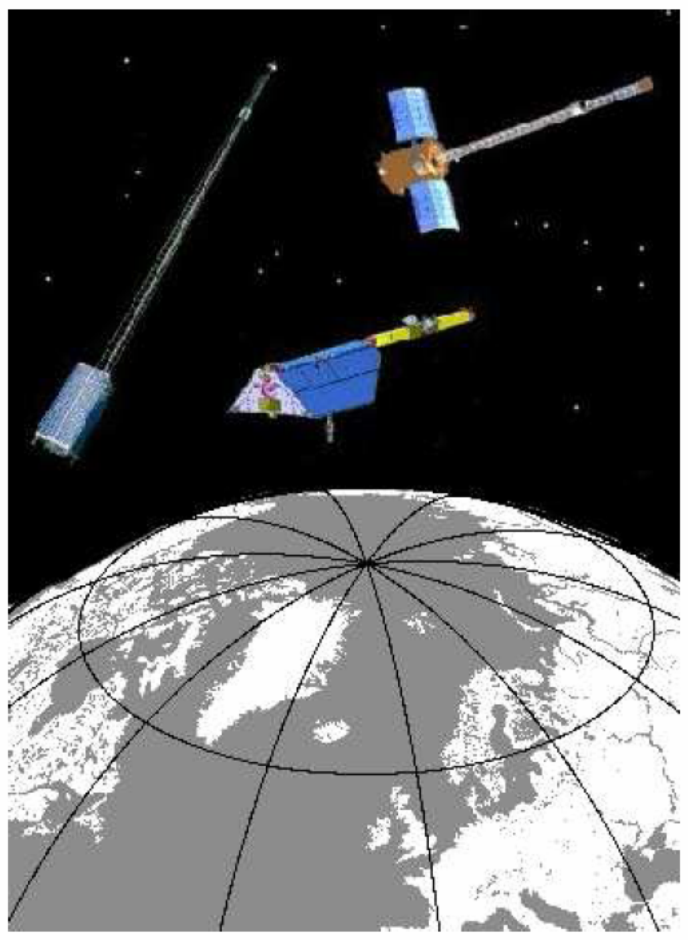


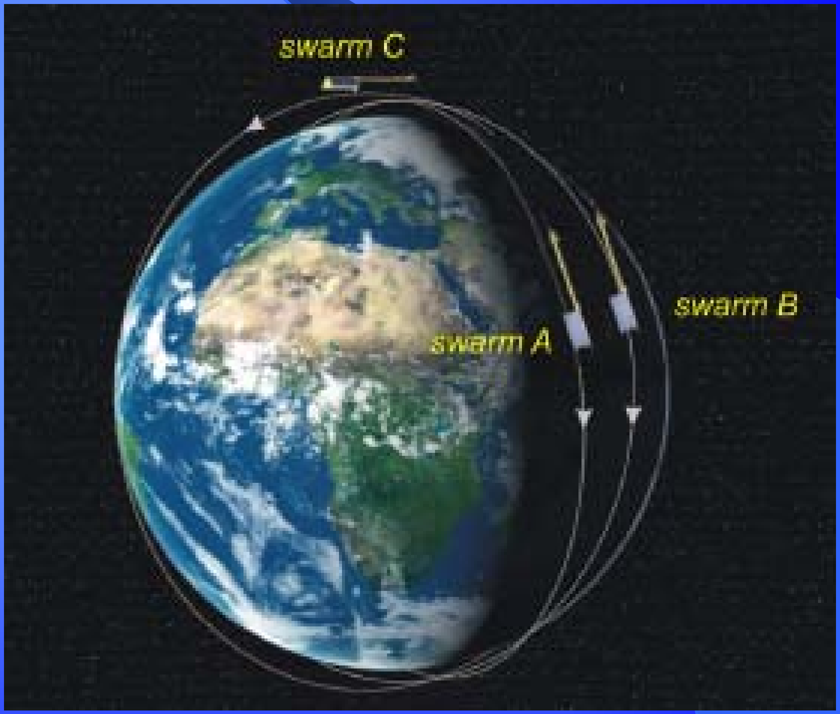


Satellite missions

Early: POGO, MAGSAT – 1980
Contemporary: Oersted, CHAMP, SAC-C

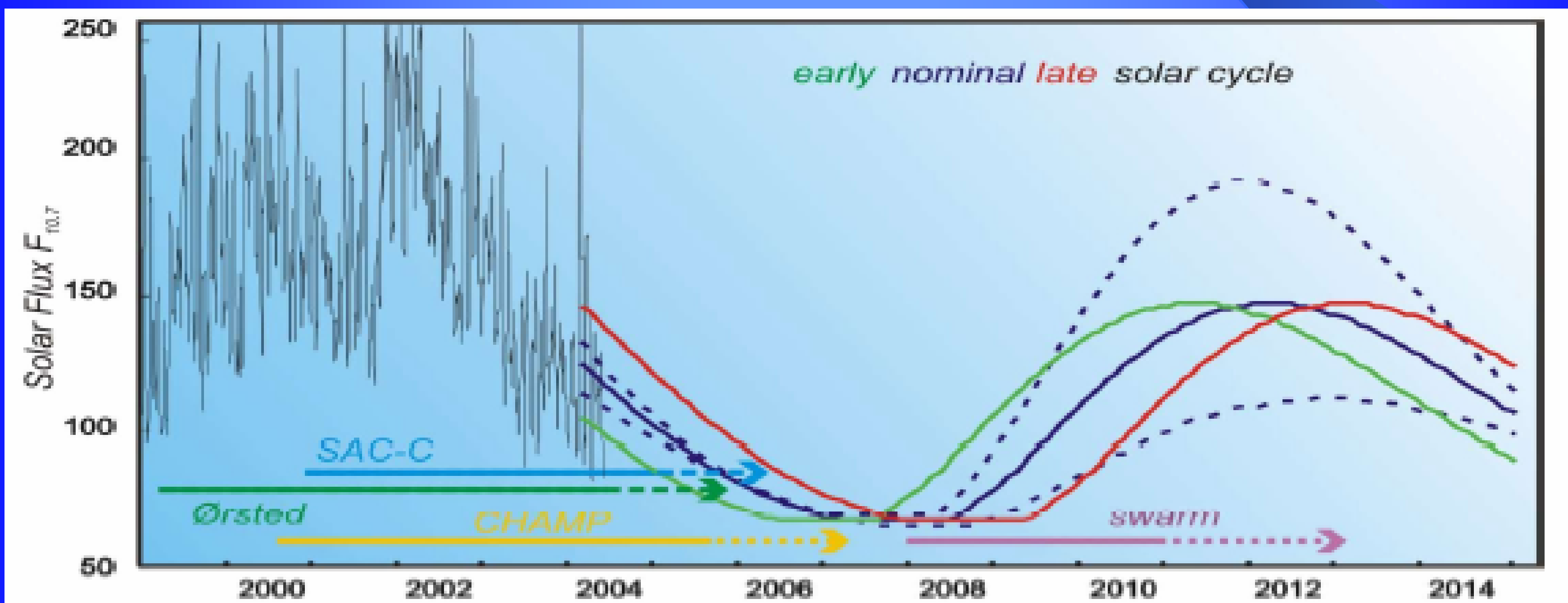
Future: SWARM

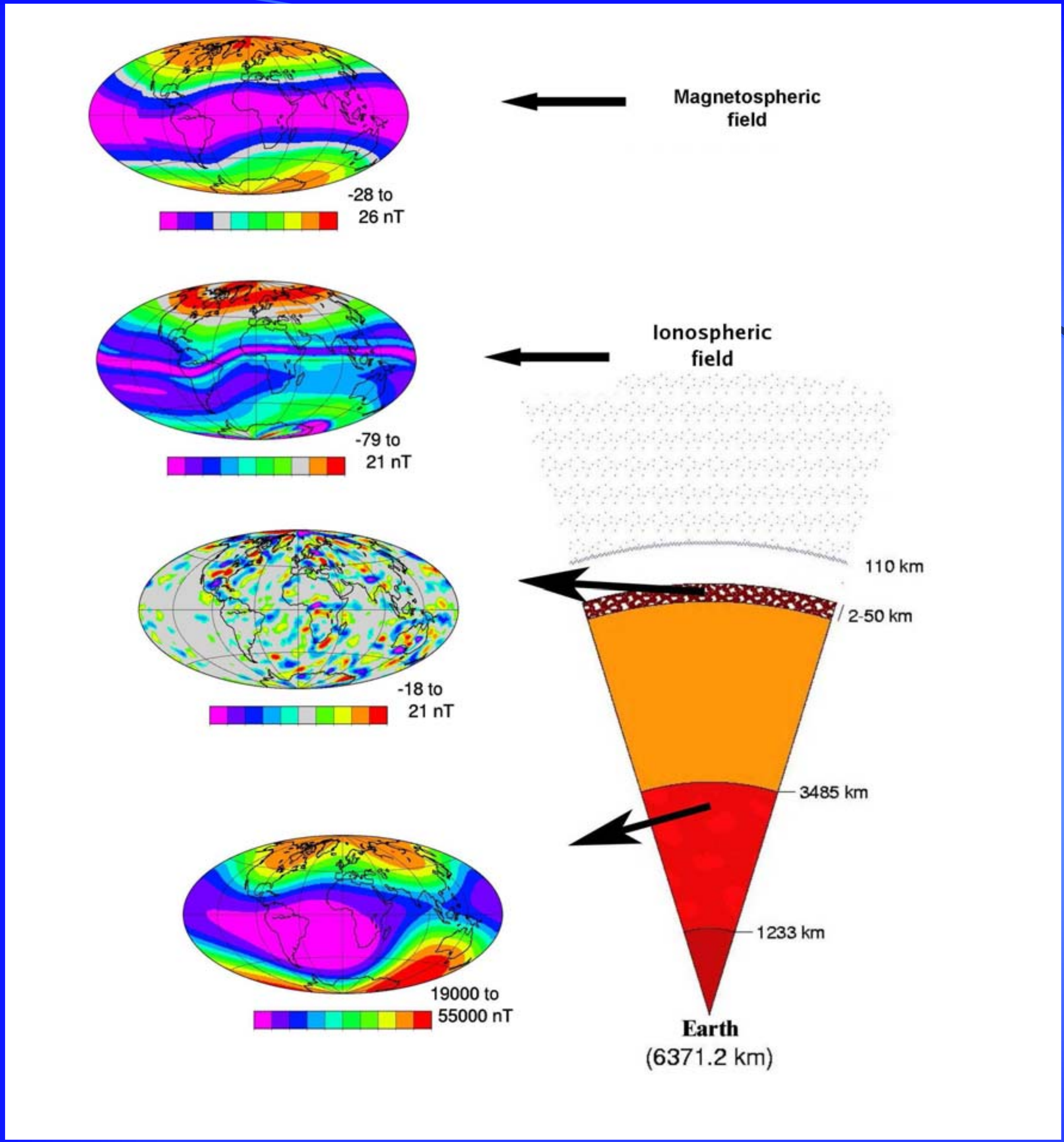




International Decade of Geopotential Research, IUGG (IAGA & IAG), 1999

Mission (Country)	2000	2002	2004	2006	2008	2010	2012
Oersted (DK)							
CHAMP (GER)							
SAC-C (ARG/USA/DK)							
GRACE (USA/GER)							
GOCE (ESA)							
Swarm (ESA)							
	Absolute magnetics with precise attitude determination						
	Gravity static and time variable						
	Combination of absolute magnetics and gravity						



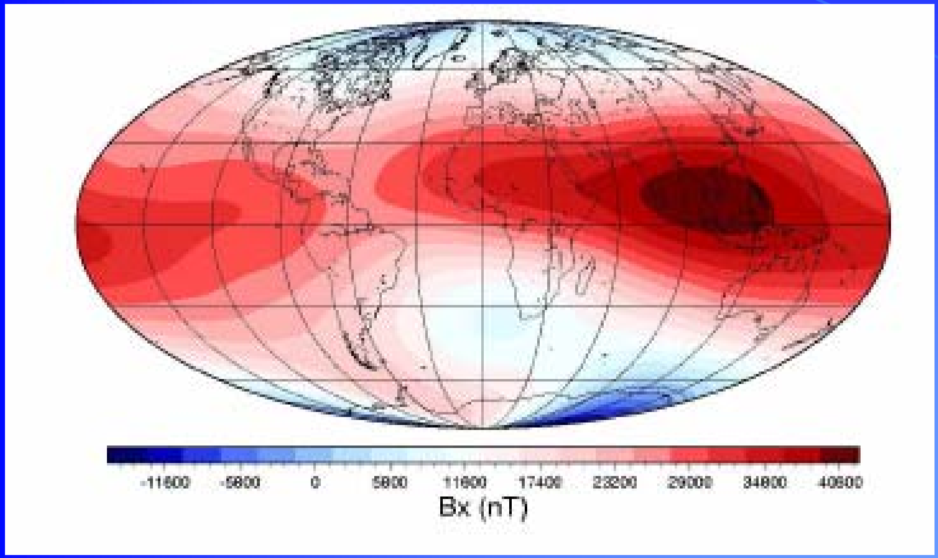


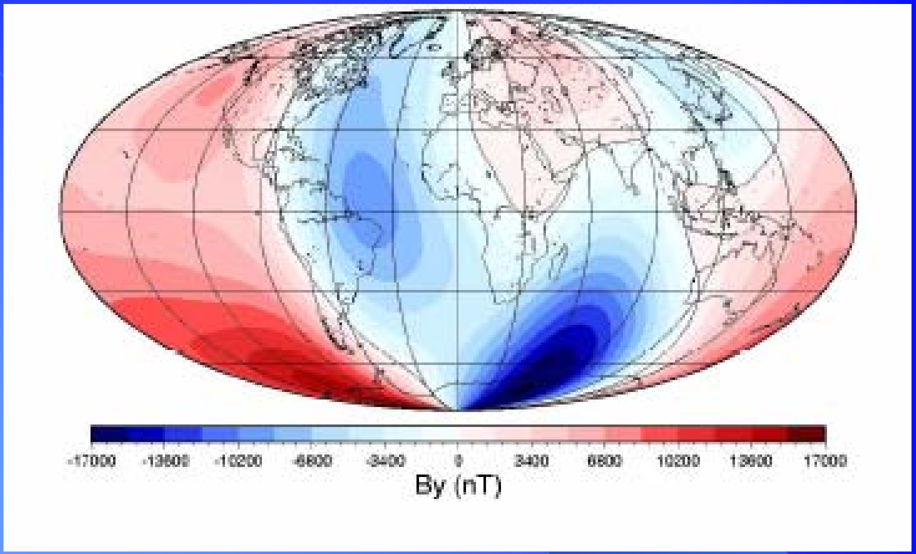
Comprehensive modelling

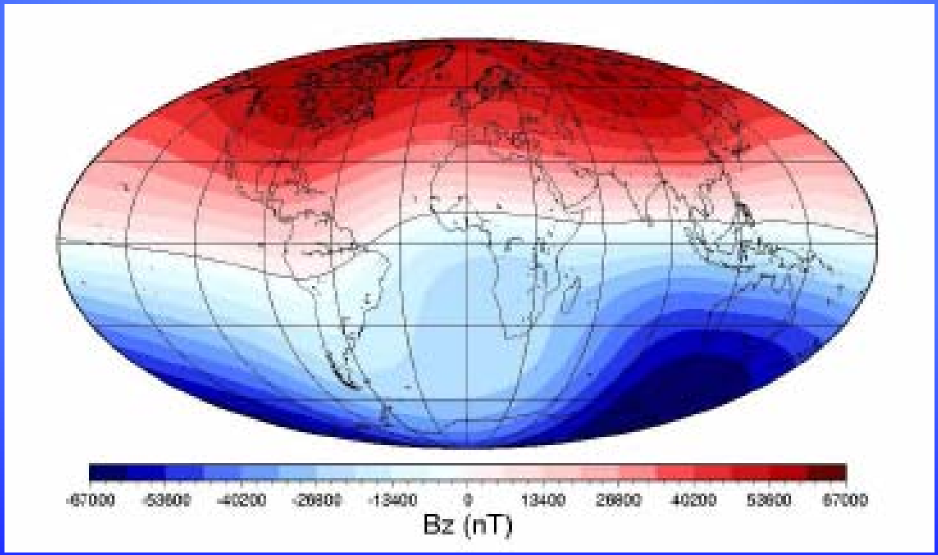
Sabaka et al., 2004

Dominant magnetic fields and their associated source regions
Altitude: 400 km

Main field components



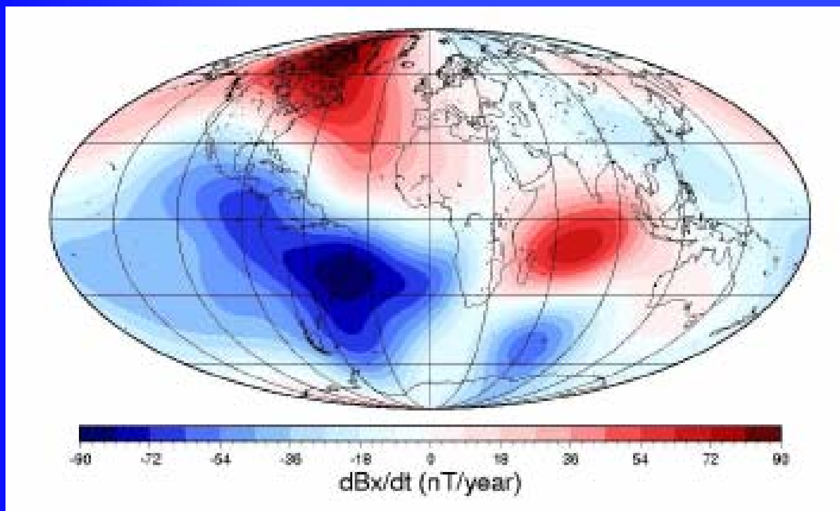


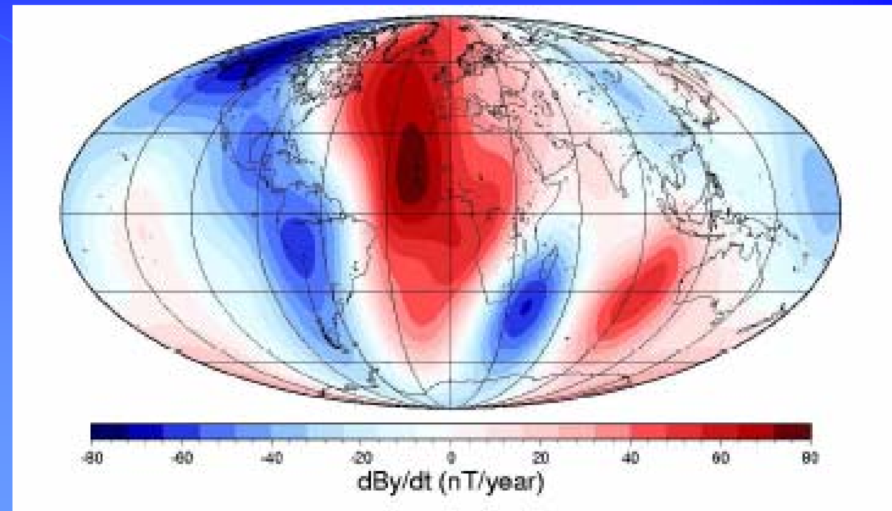


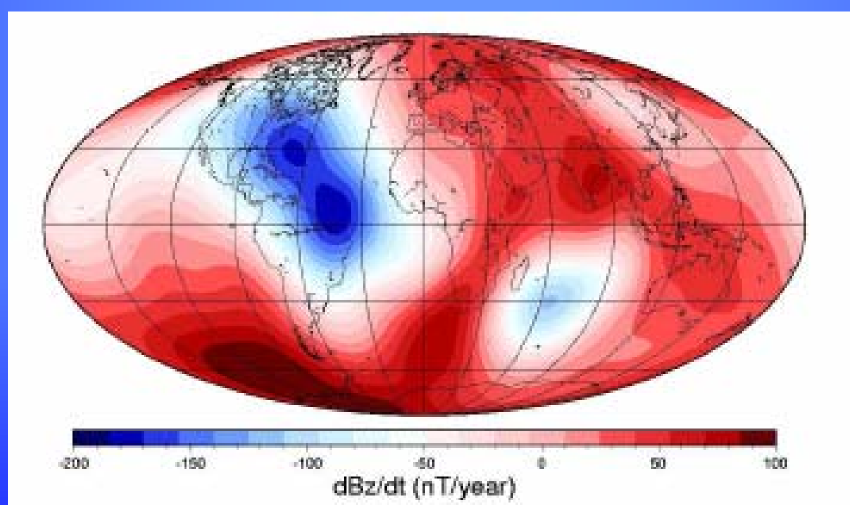
Earth’s surface. Epoch 2001

Olsen et al., 2002

Secular variation







Earth’s surface. Epoch 2001

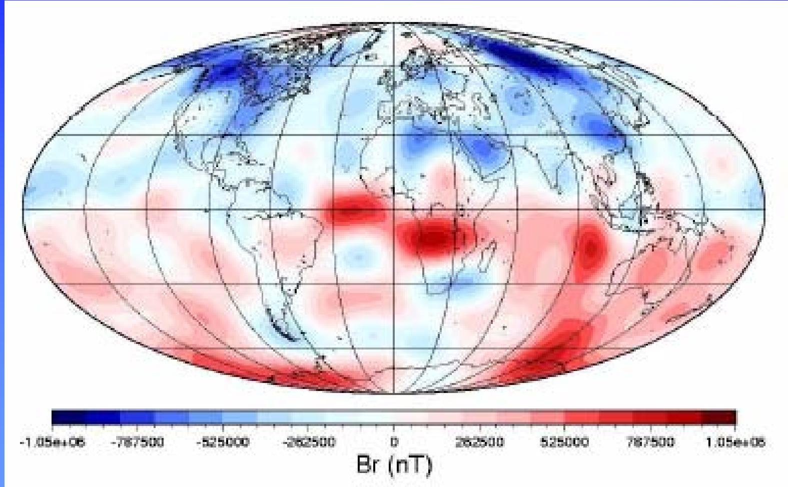
Olsen et al., 2002

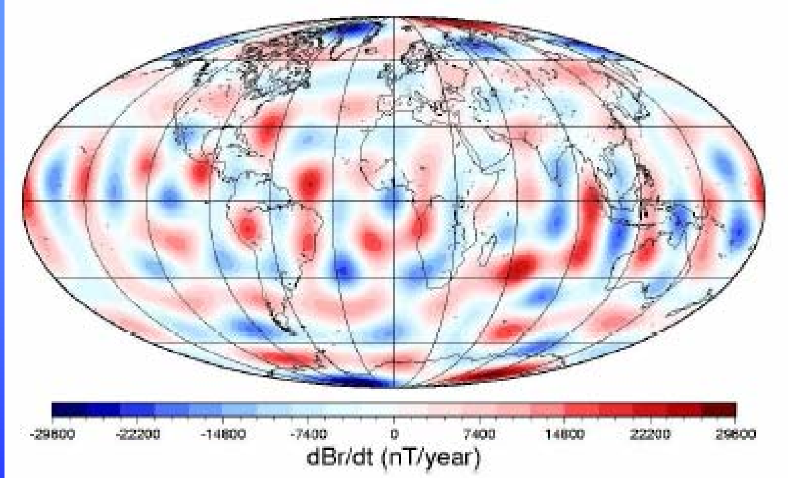
Radial field at the core surface (1)

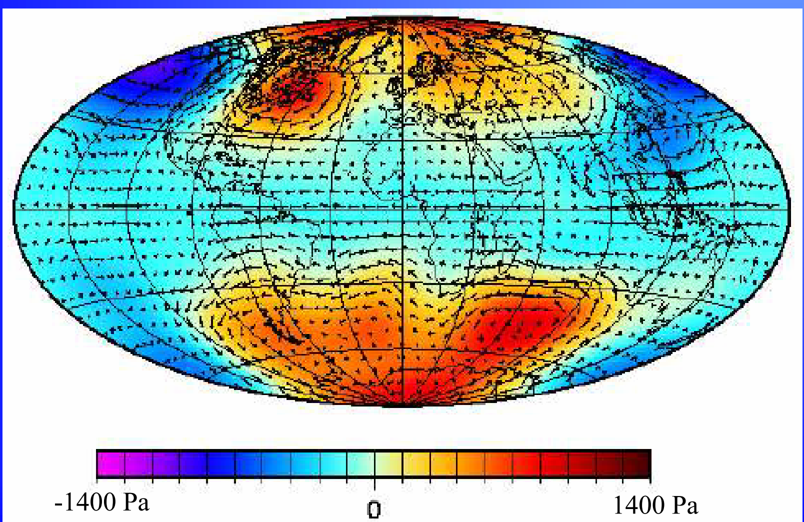
Downward continuation to the core-mantle boundary

Under certain assumptions
- large-scale flow
- frozen-in flux approximation
- flow - steady
  - tangentially geostrophic
  - purely toroidal

Br and dBr/dt can be used to derive the flow at the top of the core







Mandea & Purucker, 2006

Radial field at the core surface (2)

400 years of data into value – time dependent field models (Jackson et al, 2000)

Residual field

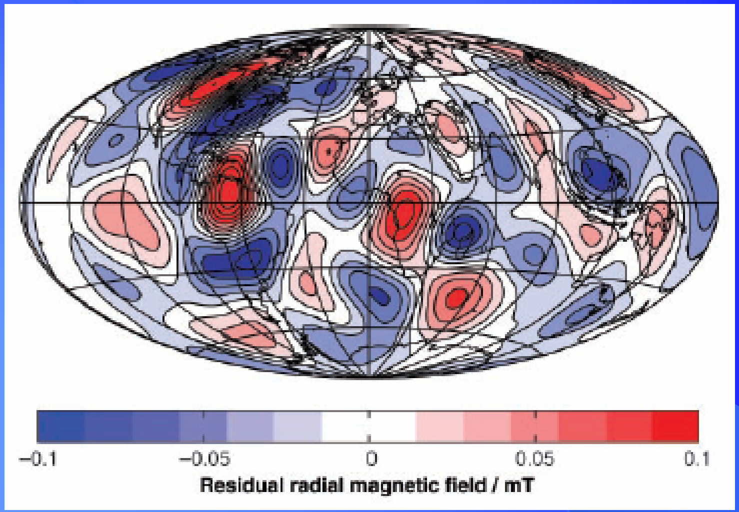
• non axysymmetric radial magnetic field

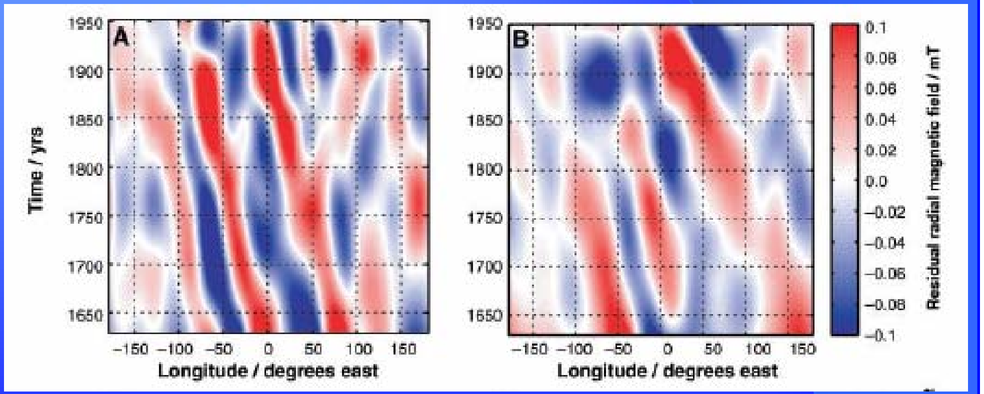
• varies on time shorther than the 400-year historical record

- dynamic field morphology rapidly evolving over the 400 years
- series of high-amplitude flux foci moving westward in the equatorial region, most obvious under the Atlantic hemisphere
- at the equator the period of the zonal motion is 270 years
- two different mechanisms:

• bulk fluid motions at the surface of the outer core that advects magnetic field features (westward equatorial jet)

• propagation of magnetohydrodynamic waves driven by either convective or magnetic instability





Finlay & Jackson, 2003

Time dependent flows can explain almost all secular variation and can even resolve rapid features as geomagnetic jerks, but

not necessarily represent true core flows

Independent test in favour:

- decadal variations in the length of the day are due to exchange of angular momentum between fluid core and solid mantle
- declination measurements – correlation with variations of LOD
- such exchanges should excite torsional oscillations in the Earth’s core (motions constant on cylinders) – Braginsky
- D. Jault – such cylinders should be observable in the surface flows Yes, for the 20th century

Torsional oscillations can explain the geomagnetic jerks – Bloxham, 2002

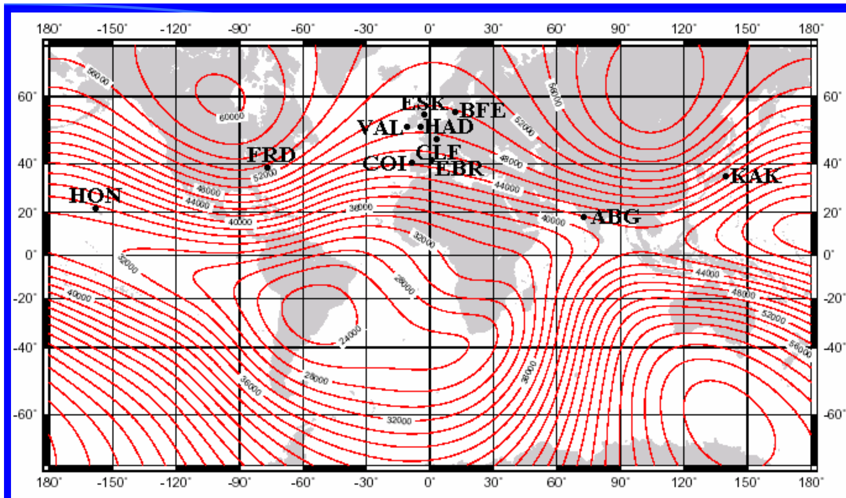
What about the question in the title?

The first “yes” came in 2004/2005 (AGU/EGU) from G. Legaut & D. Jault

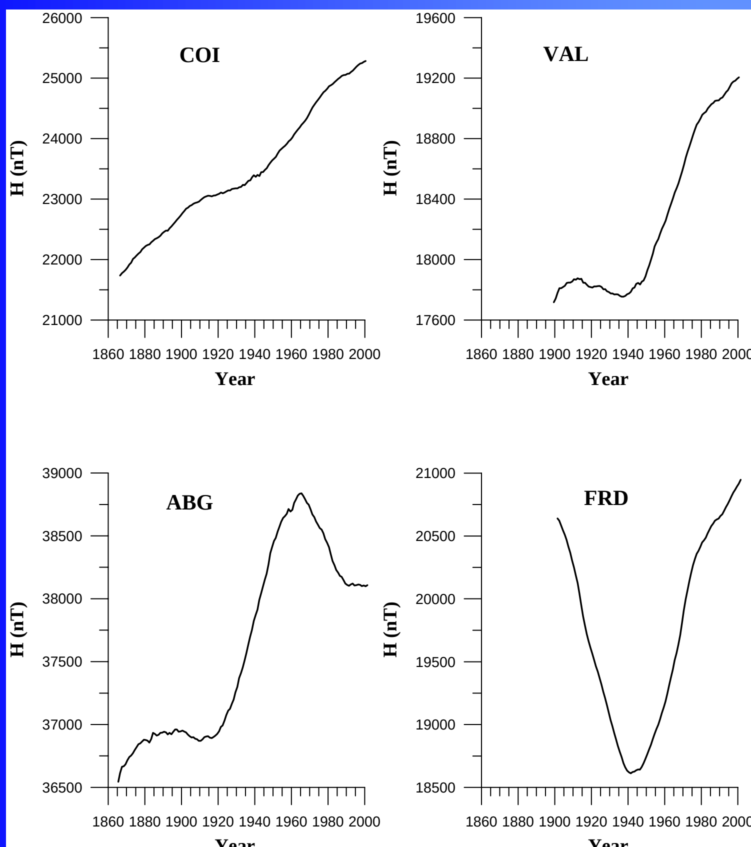
Depending on the electrical conductivity of the Earth's mantle, more or less intense electrical currents are induced in a thin layer at the top of the Earth's core by variations of the magnetic field of external origin. The induced electrical currents can excite Alfvén waves which propagate inward and interact with core motions producing the main geomagnetic field.

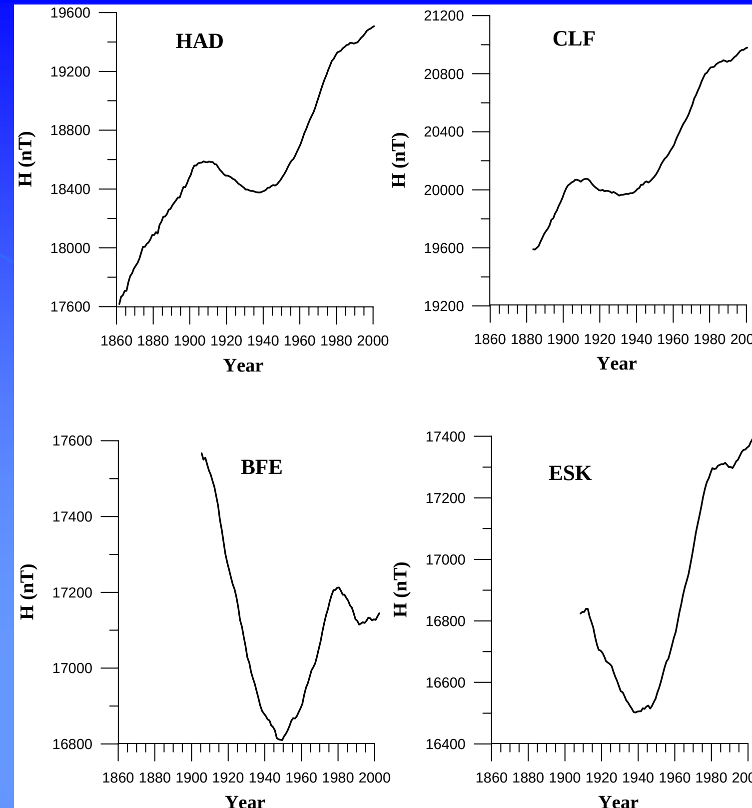
Conclusion: part of the secular variation may have an external origin. Proven possible in case of the 11-year solar cycle.

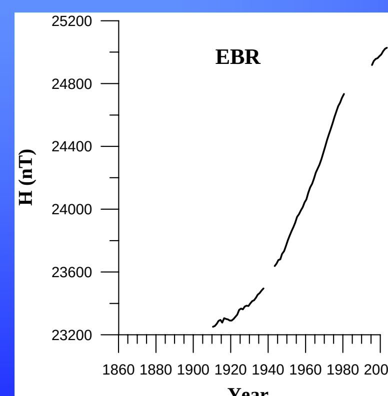
What long time-series of observatory data can tell us about the question in the title?

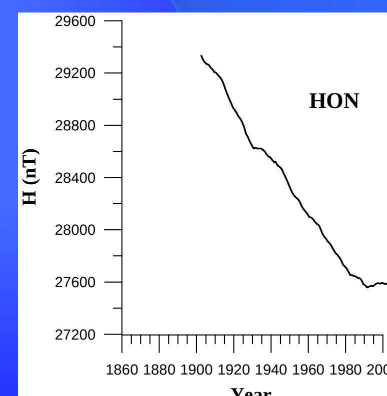


Background from http://www.geomag.bgs.ac.uk/mercator.html

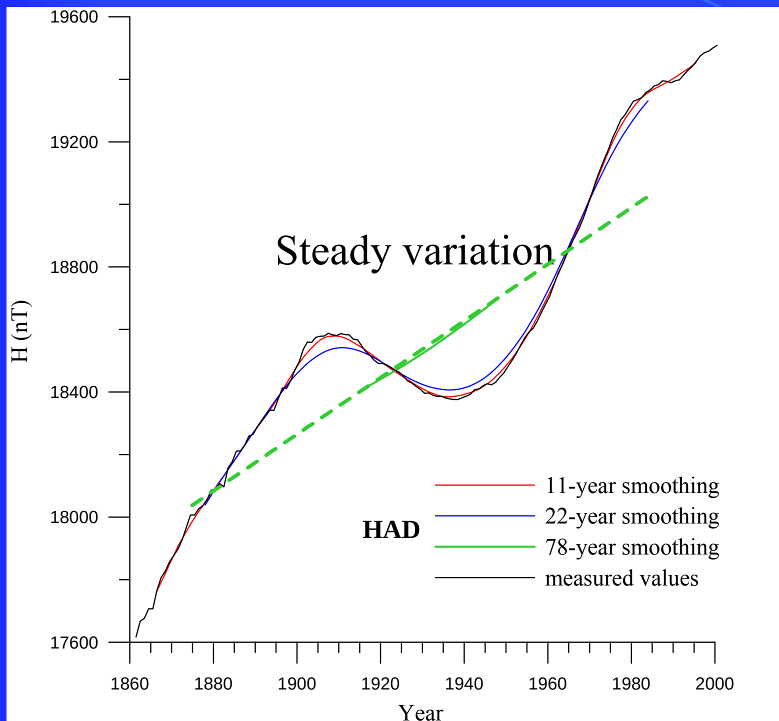




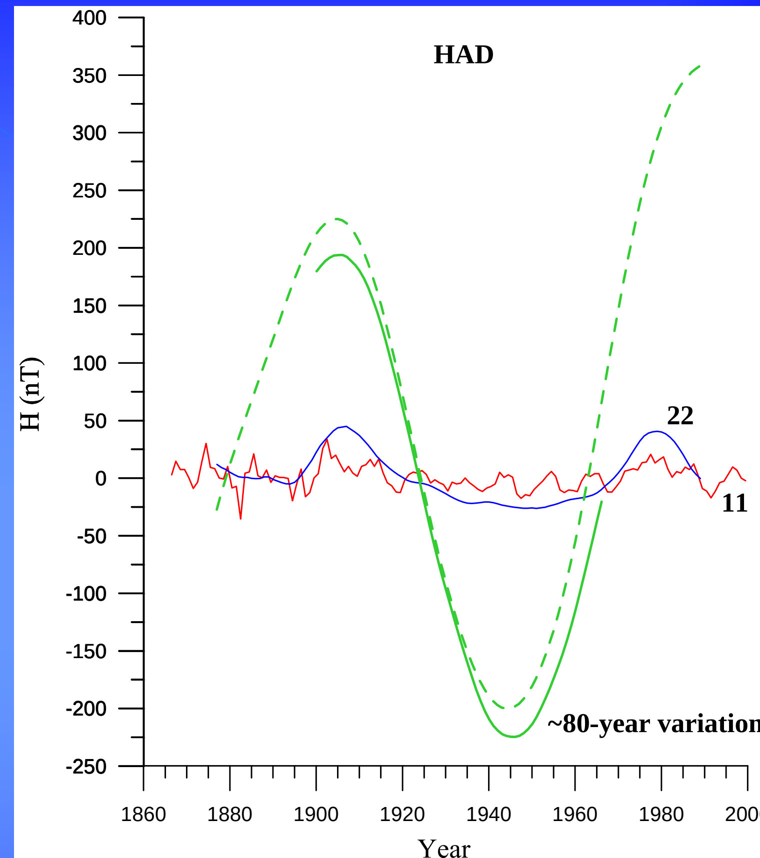




Example of data treatment

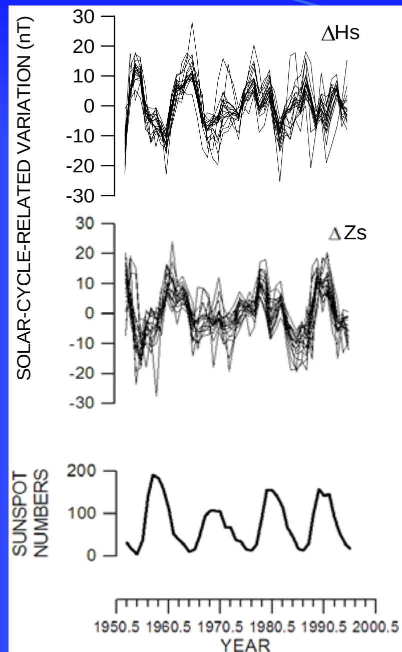


Successive filtering out of the sunspot cycle signature, which is not completely averaged out in the annual mean, of a 22-year variation, and of a ~80-year variation present in the time series of observatory annual means, by running averages with 11-, 22- and 78-year windows respectively, results in a so called "steady variation" (full green line). The dashed green line – extrapolation of the steady variation.

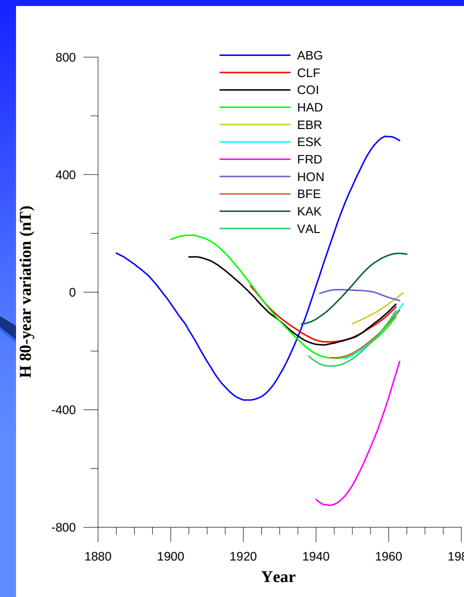


The 11- (red), 22- (blue) and ~80-year (green) variations extracted from data. Dashed green line-extrapolated ~80-year variation

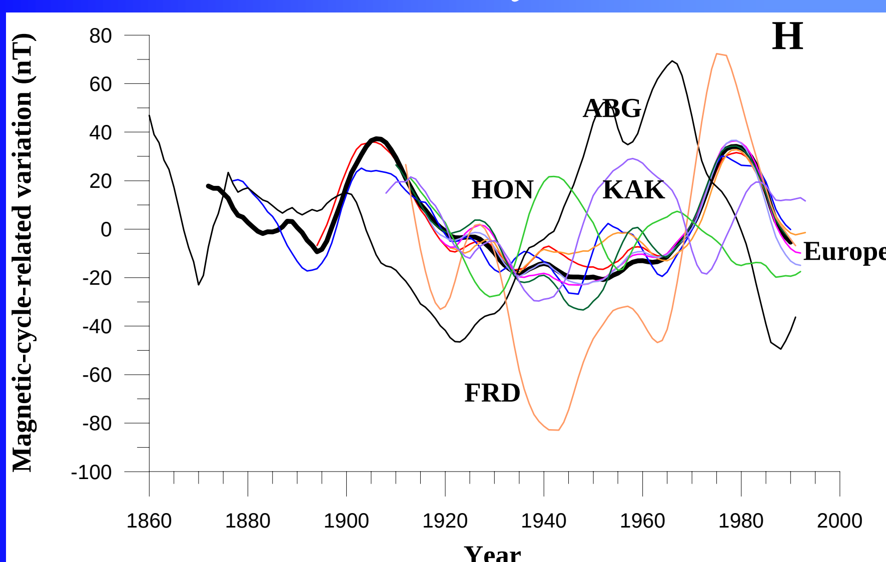
The extracted 11-year variation

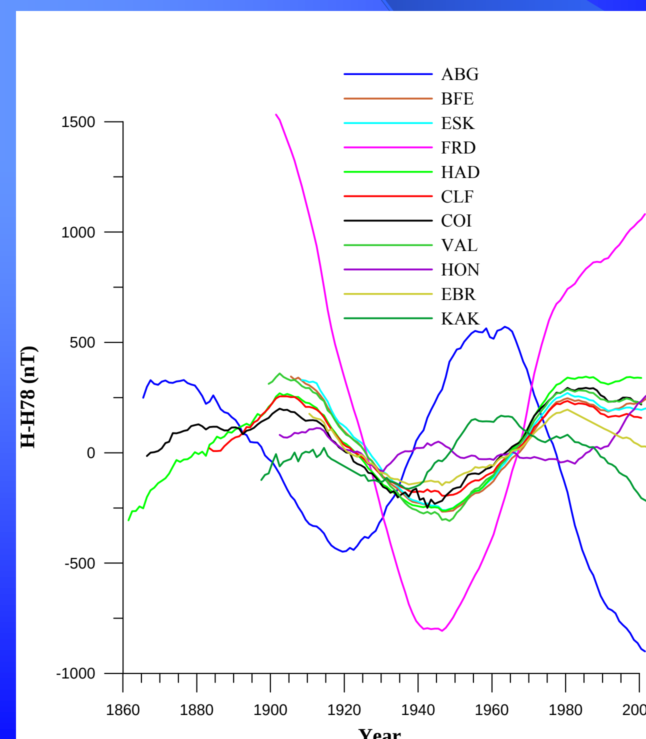


The extracted ~80-year variation



The extracted 22-year variation



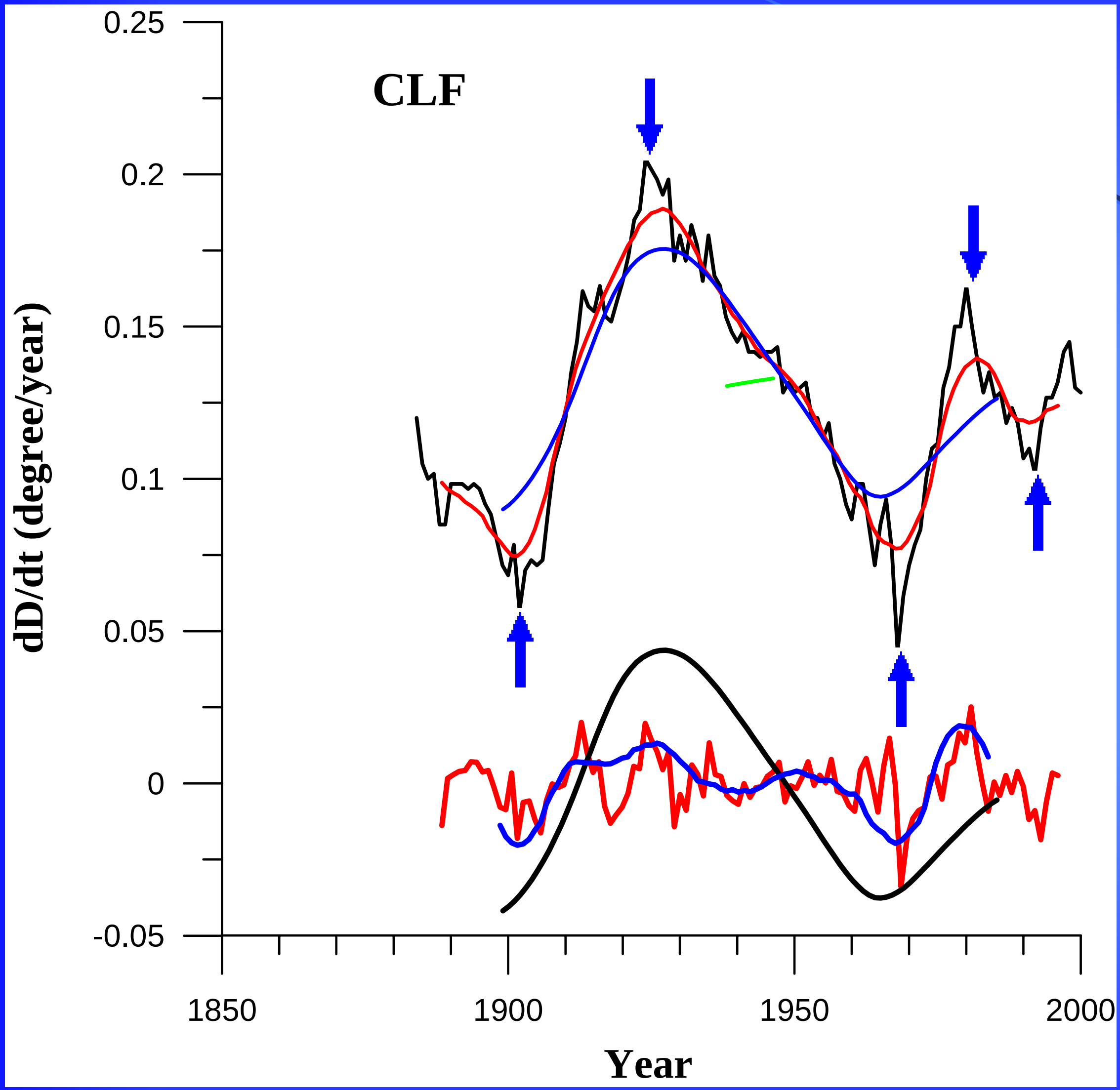


- while the 11-year variation is clearly related to the solar activity, the larger amplitude of the 22-year and of the ~80-year variations (40-100 nT and, respectively, 5-600 nT peak to trough as compared to 20-40 nT) points to a core source;

- however, this source might be controlled somehow by longer cycles in solar activity (22-year and Gleissberg cycles). A direct action of the solar activity on the geodynamo seems to be possible (Legaut & Jault, 2004/2005);

- a quantitative approach is needed to decide if the solar activity is pacing the geodynamo (sensu Legaut & Jault) at frequencies of 1/22 year $^{-1}$ and of ~1/80 year^{-1}.

The time derivative of declination



- is used to show the presence of jerks in the variation of the geomagnetic field

- the time derivative of the three components (in terms of the present analysis) of the declination is plotted as well

- the jerks appear to result from the superposition of the 11-year solar-cycle-related variation on the 22- and ~80-year variations. The time of occurrence, the duration and the amplitude depend on how the three types of variation combine to give the observed one.

Conclusions

- The question in the title:
Long-term variations in the geomagnetic field. Any connection to the solar activity?

- has a first "yes" answer from the interaction of the geodynamo with Alfvén waves excited by 11-year external variations.

- developments might appear, related to longer term external variations (22-year and GC). A quantitative approach is needed to decide if the solar activity is pacing the geodynamo (sensu Legaut & Jault) at frequencies of 1/22 $year^{-1}$ and of ~1/80 $year^{-1}$.