Long-term variations of the parameters of the slow solar wind from geomagnetic data

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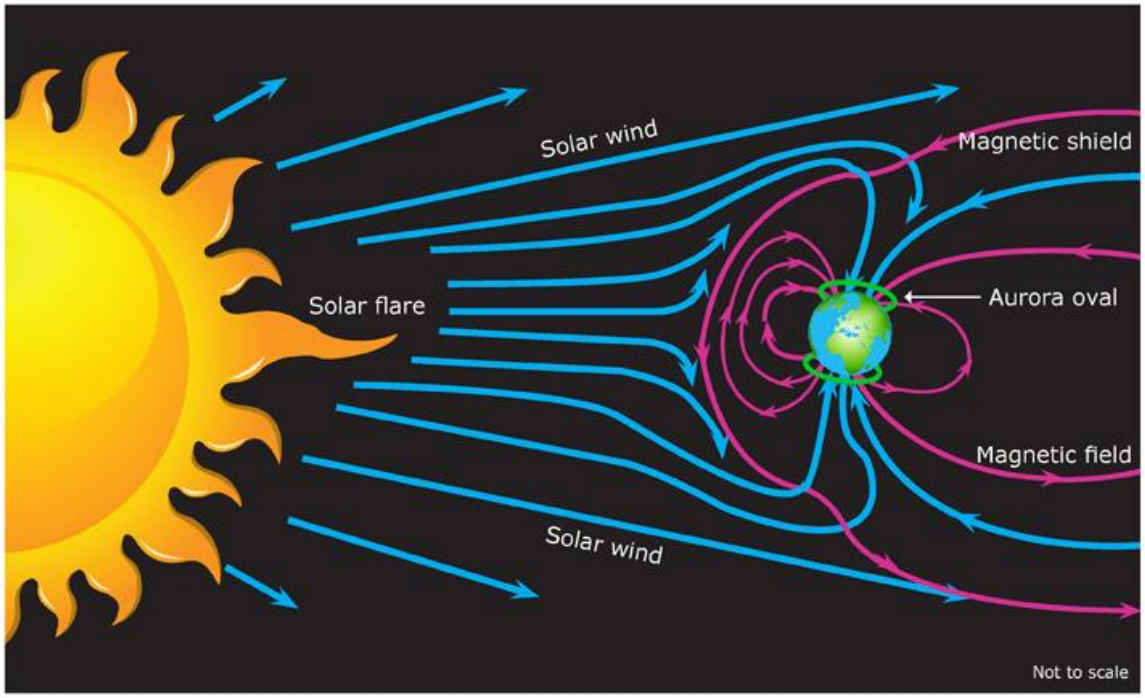
The idea to use geomagnetic activity indices to reconstruct solar wind parameters is not new

The Earth's magnetosphere reacts to the solar wind variations causing disturbances in the Earth's magnetic field – geomagnetic activity



Different geomagnetic indices: sensitive to different solar wind parameters

Geomagnetic index	Function of	$B\,V^{\alpha}$	Proponents
IDV; [D_{st}<0]; u	B	$\alpha = 0$	Svalgaard & Cliver; Love; Bartels
m	$B\,V^{0.5}$	$\alpha = 0.5$	Lockwood et al.
PCP	$B\,V$	$\alpha = 1$	Le Sager & Svalgaard
IHV	$B\,V^{2}$	$\alpha = 2$	Svalgaard & Cliver
am, aa; ap	$B\,V^{2}$	$\alpha = 2$	Mayaud; Bartels

Clilverd and Svalgaard, AGU2008

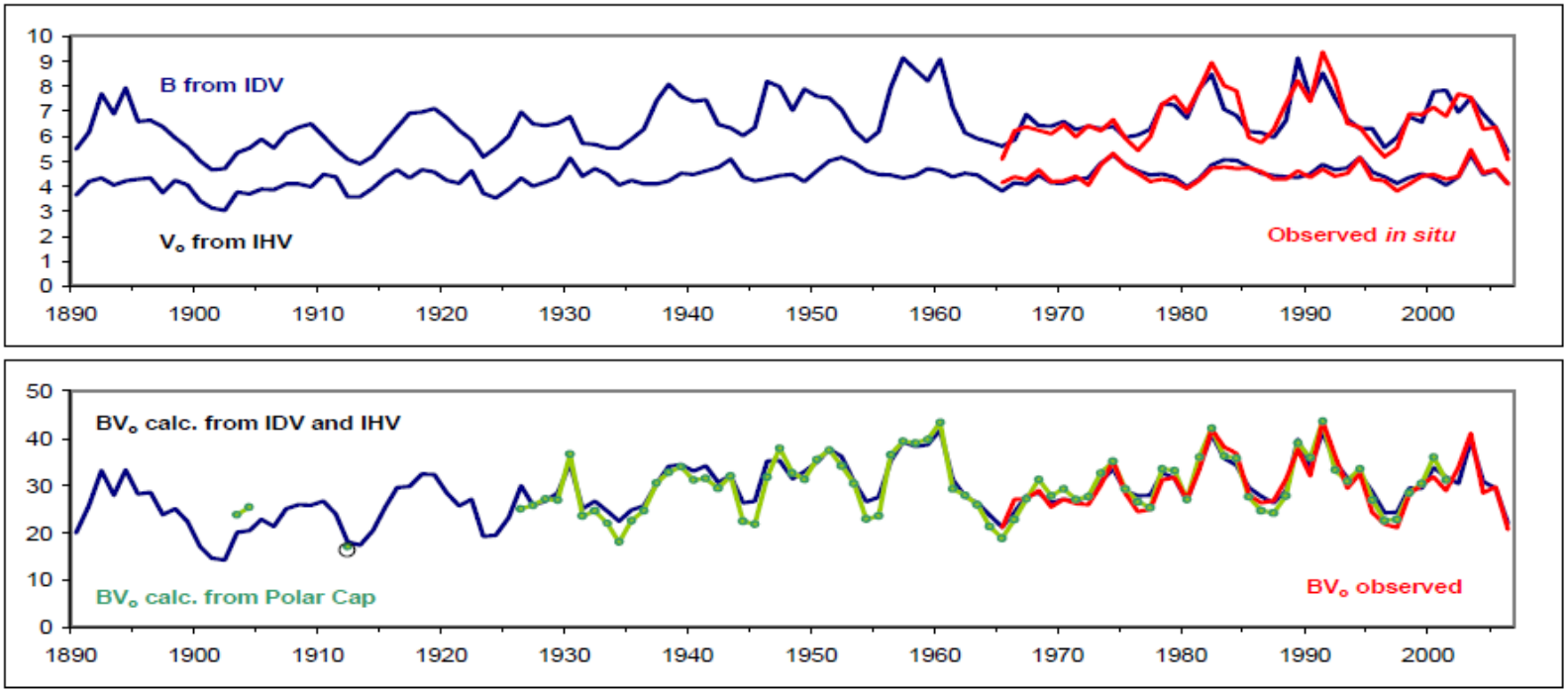
Reconstructions of *B* and *V*

We now have three independent ways of estimating solar wind and IMF parameters:

An Over-determined System:

1. The *IHV*-index, estimating BV^2
2. The *IDV*-index, estimating B
3. Polar Cap Potential index, estimating BV

These indices are readily computed from simple hourly means (or values) for which we have measurements stretching back well into the 19th century. We can thus estimate $V = \sqrt{[(BV^2) / B]}$ and use that value to calculate BV for comparison with the estimated BV.



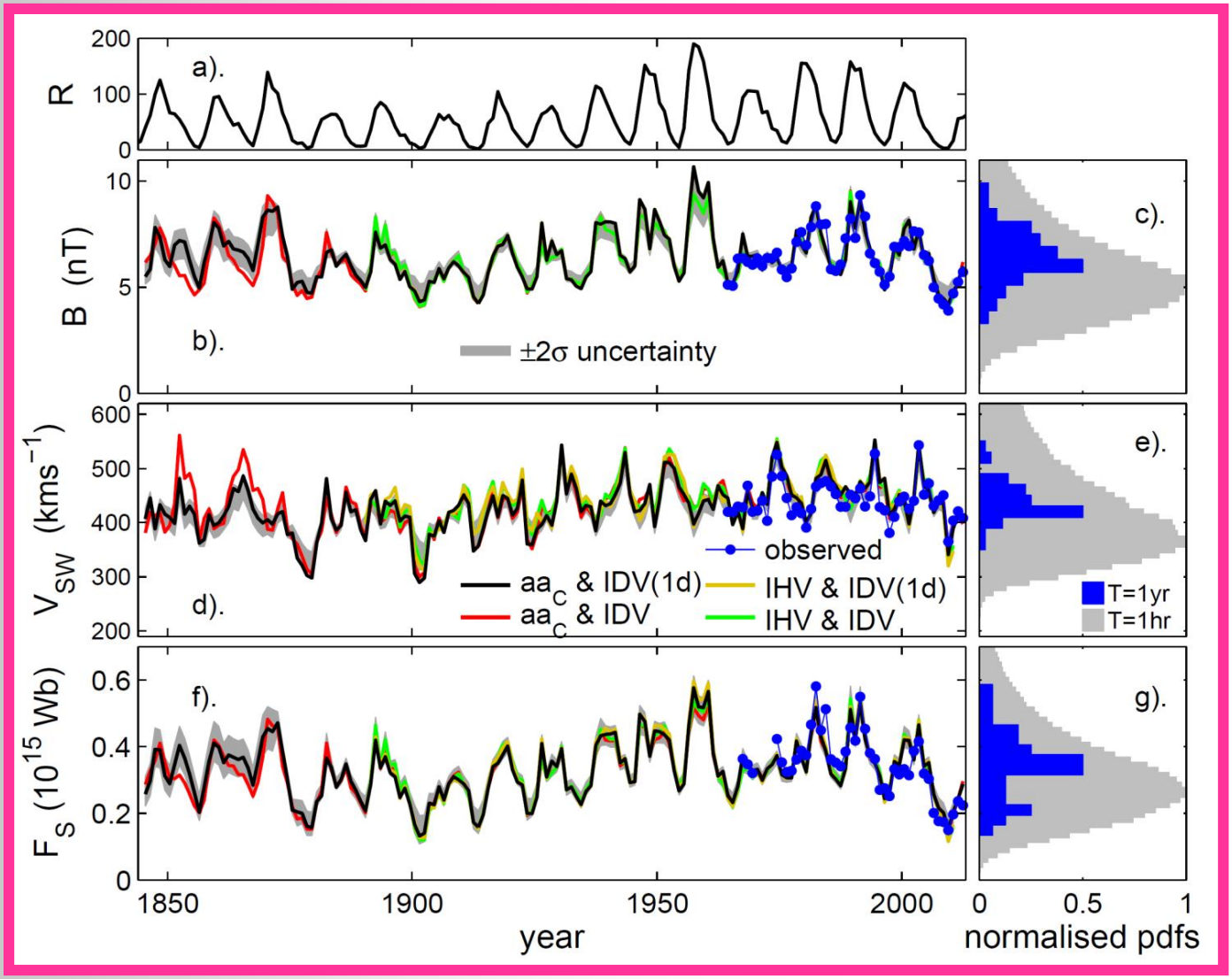
Svalgaard, 2008

Geomagnetic Reconstructions

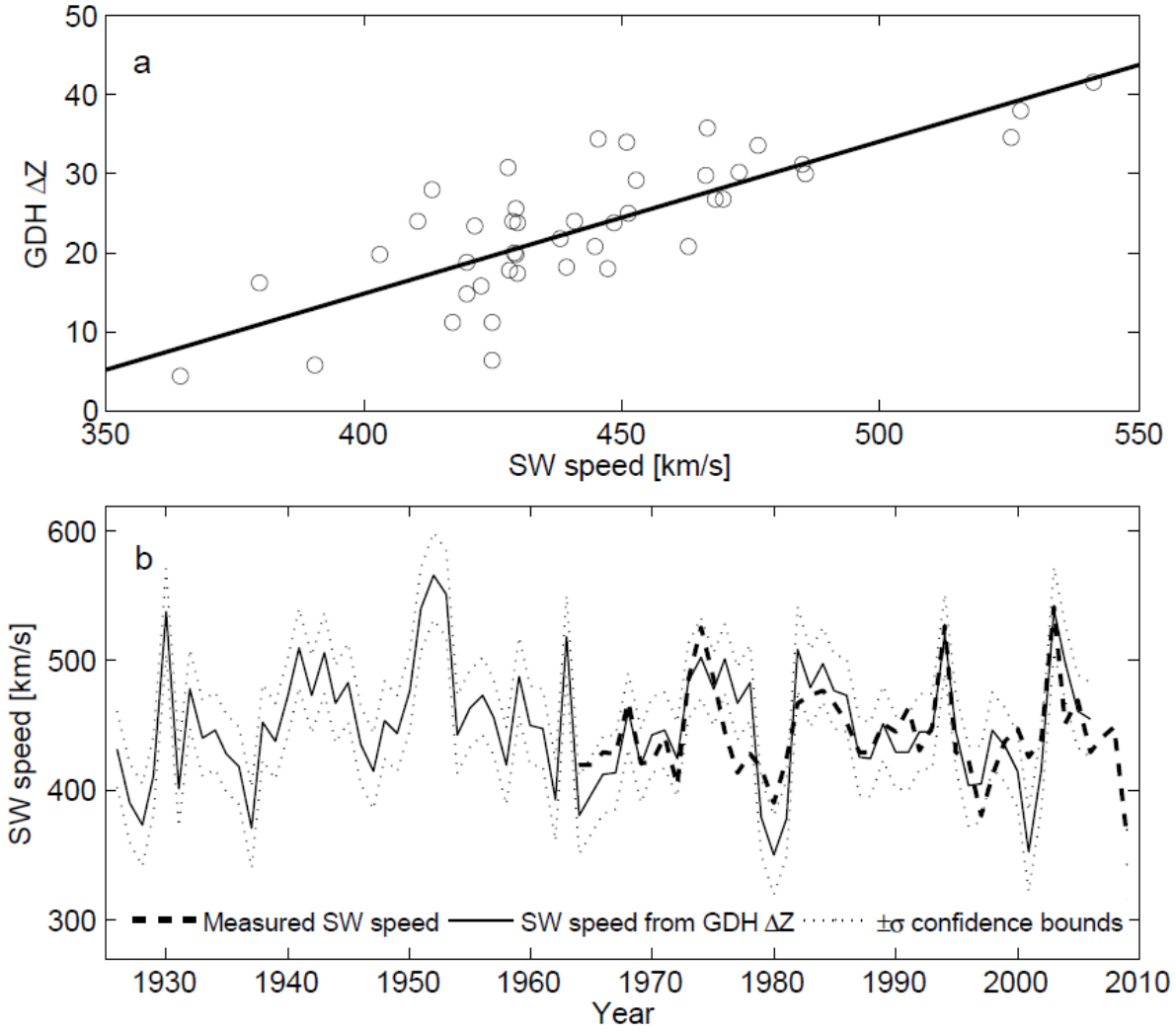
of near-Earth IMF, B, solar wind speed, V_{SW}, and the Open Solar Flux (OSF), F_S

- Sunspot number, R
- near-Earth IMF, B
- near-Earth solar wind speed, V_{SW}
- Open Solar Flux (OSF)

(from Lockwood et al., Annales Geophys, 2014)



Reconstruction of V from the vertical component in a high-lat station



Mursula et al., 2015

These are reconstructions of the variations of the ***average*** solar wind.
What about its different components?

the solar wind has 3 components corresponding to 3 components of geomagnetic activity:

- slow solar wind
- high speed solar wind streams
- coronal mass ejections

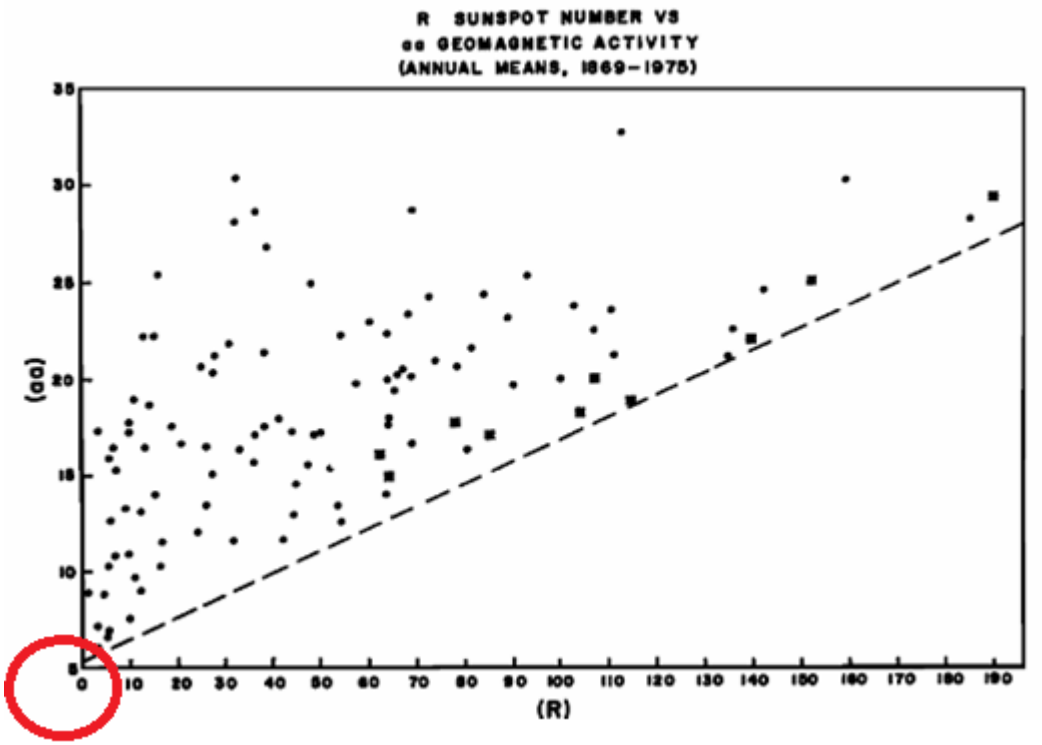
Feynman (1982): sunspot- and non sunspot-related geomagnetic activity

$$aa_R = a + b*R$$

the minimum geomagnetic activity at a given number of sunspots = geomagnetic activity due to sunspot-related solar activity

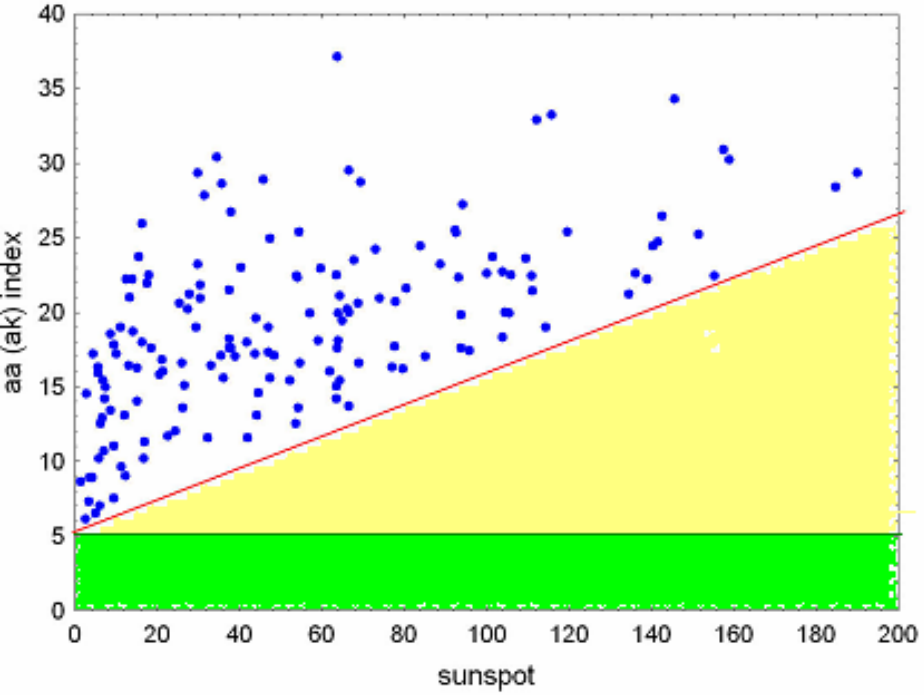
$$aa_P = aa - aa_R$$

geomagnetic activity due to non-sunspot-related solar activity



(Feynman, 1982)

Actually, geomagnetic activity has three components



$$aa = aa_R + aa_P$$

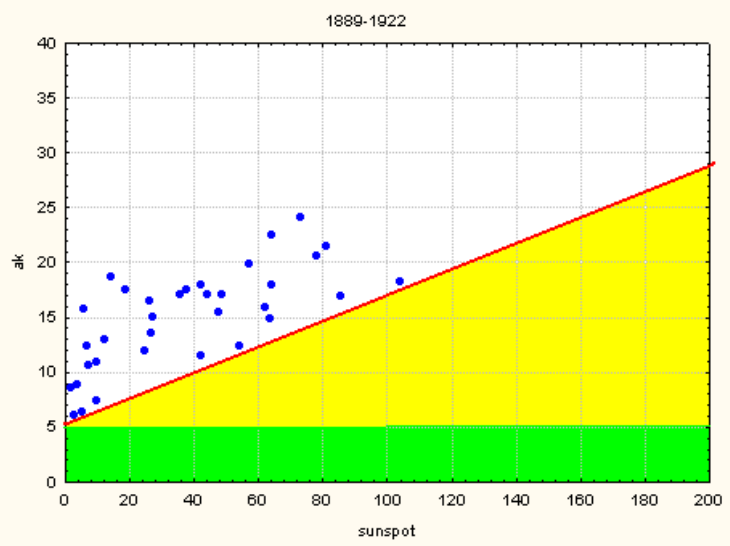
$$aa_R = a + b*R$$

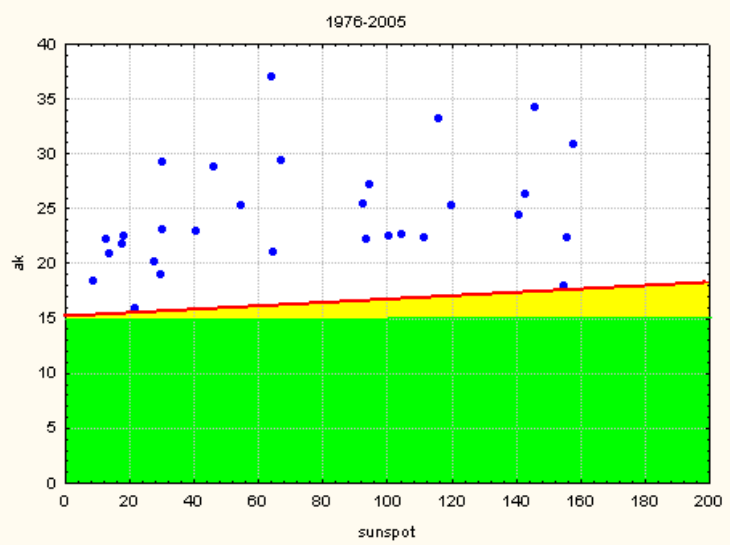
$$aa_R = aa_{min} + aa_T$$

$$aa = aa_{min} + aa_T + aa_P$$

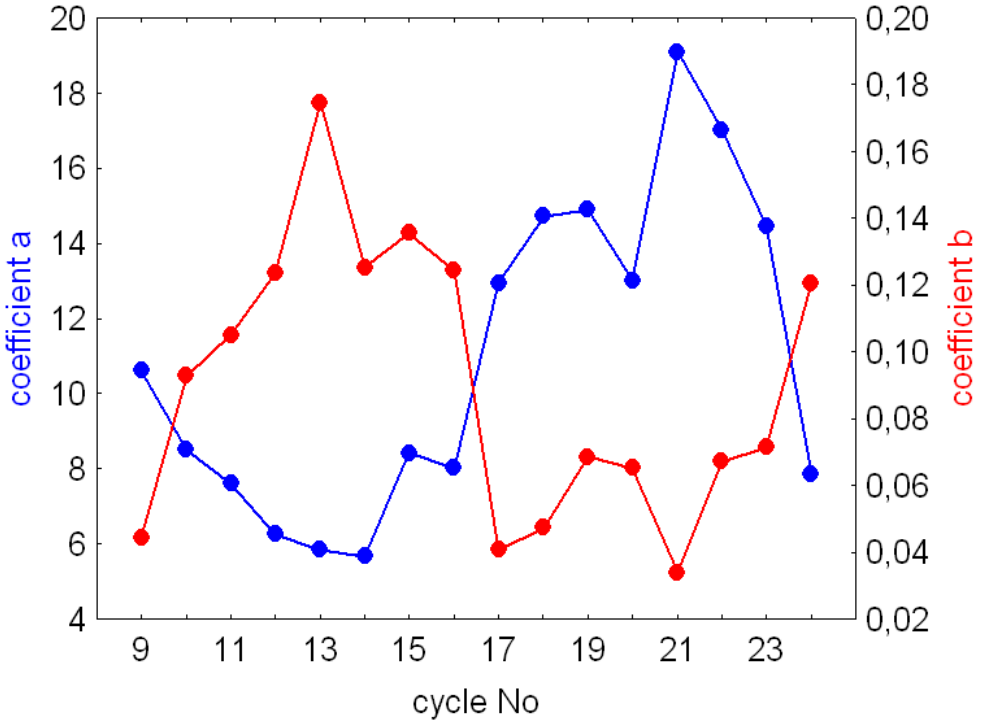
- aa_{min} - “floor” in geomagnetic activity (slow solar wind)
- aa_T – geomagnetic activity due to sunspot-related solar activity (CMEs)
- b – sensitivity of geomagnetic activity to sunspot-related solar activity
- aa_P – due to non sunspot-related solar activity (HSS)

The three components of geomagnetic activity are different in different periods



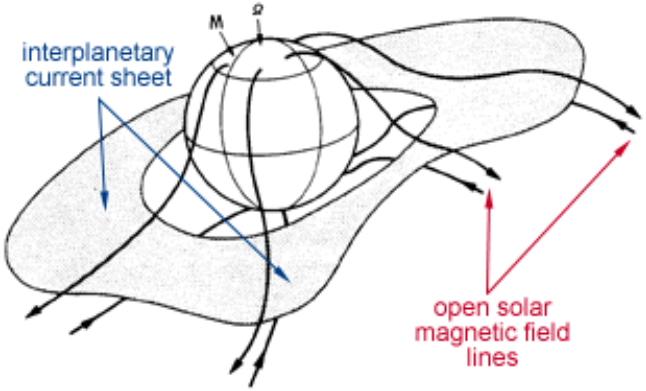


and have long-term cyclic variations



What determines the geomagnetic activity "floor"?

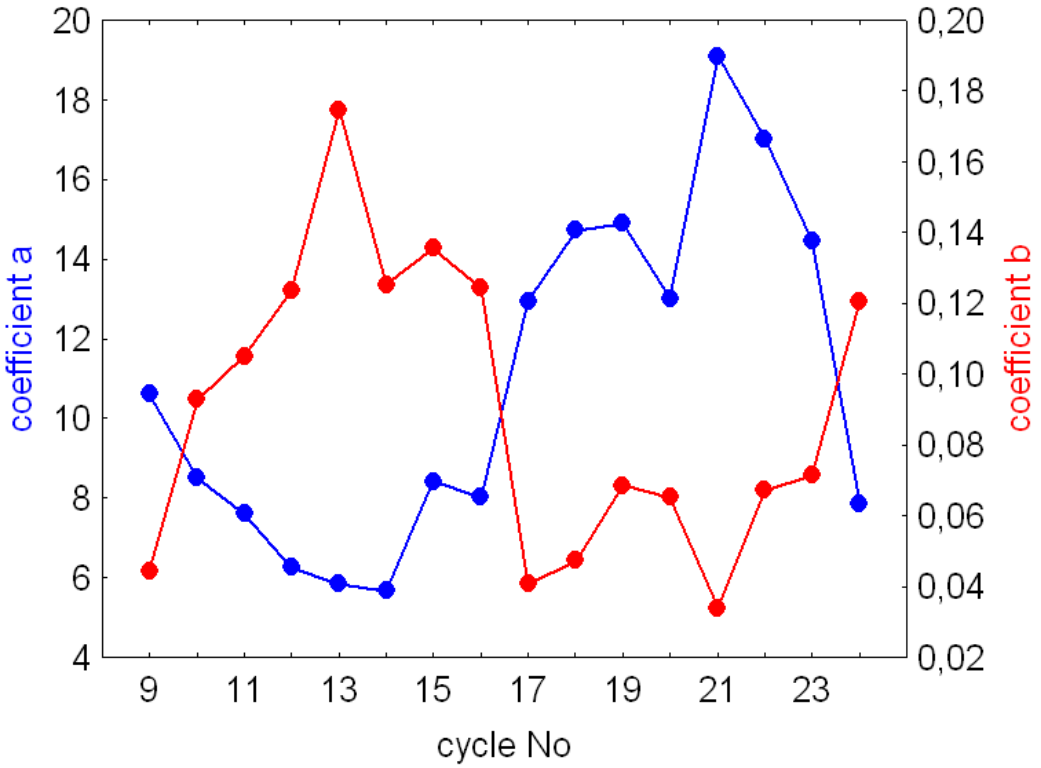
- This is the lowest possible geomagnetic activity in the absence of any CMEs and HSS
- Caused by the slow solar wind which continuously bathes the Earth
- The source of the slow solar wind is the streamer belt



Smith et al. (1978)

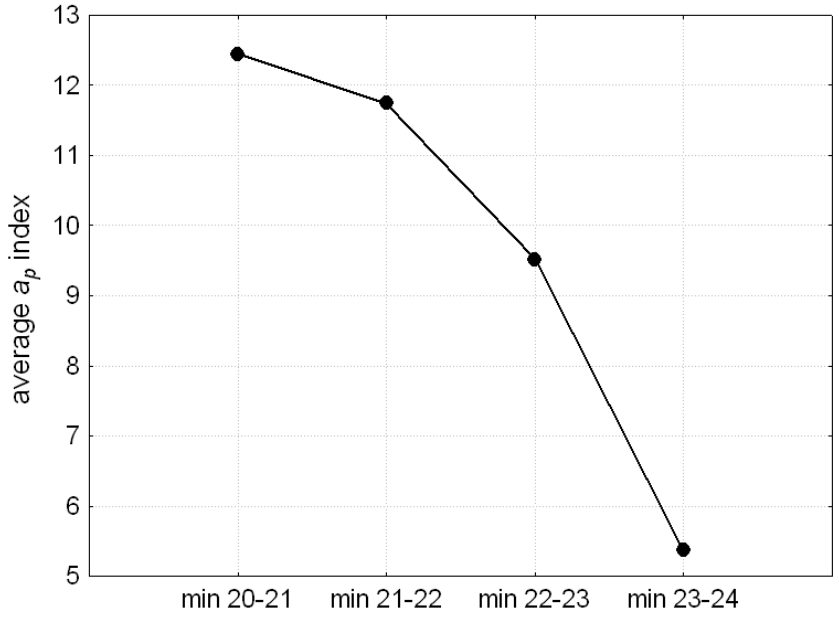
The solar streamer belt's projection in the interplanetary space is the heliospheric current sheet

The geomagnetic activity “floor” decreasing in the last 4 sunspot minima



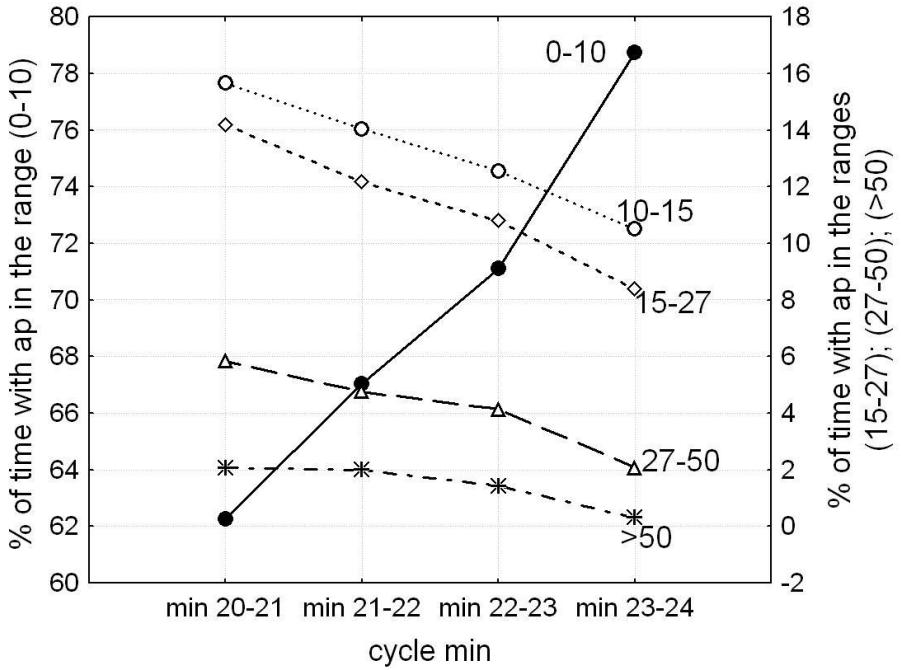
The overall geomagnetic activity also decreasing in the last 4 sunspot minima

average ap index



Increasing fraction of time with very low ap

Decreasing duration of intervals with high and even moderate ap

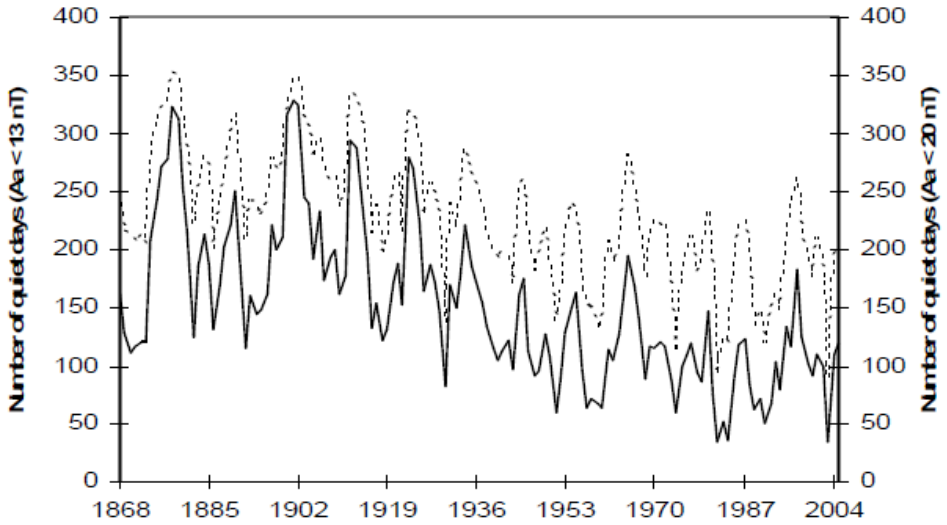


Possible reasons for the variable geomagnetic activity in sunspot minimum

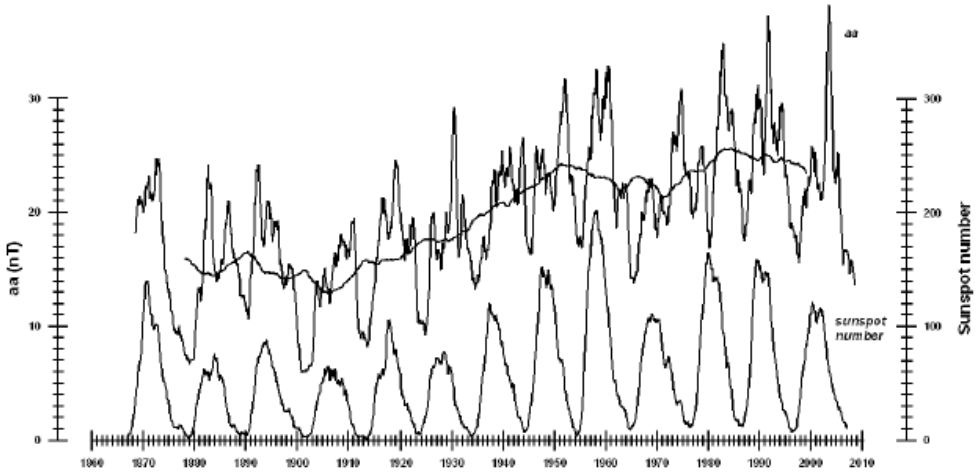
- Varying thickness of the heliospheric current sheet
- Varying parameters of the slow solar wind in the heliosheet
- Varying number and/or parameters of HSS and CMEs

The annual number of geomagnetically “quiet” and “very quiet” days is determined by the time the Earth spends in slow solar wing from the equatorial streamer belt

(*Simon and Legrand, 1987*)



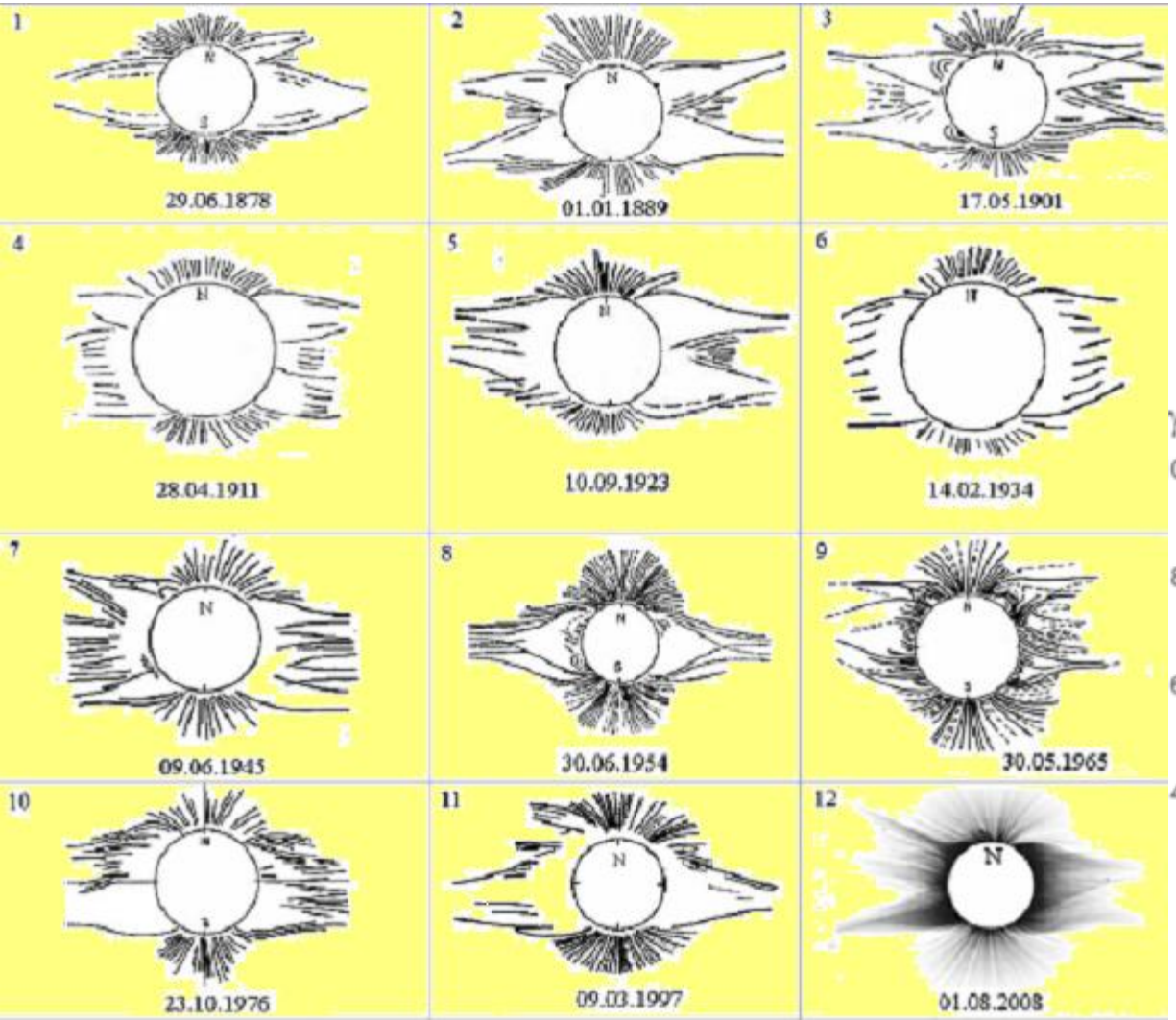
Annual number of quiet and very quiet days

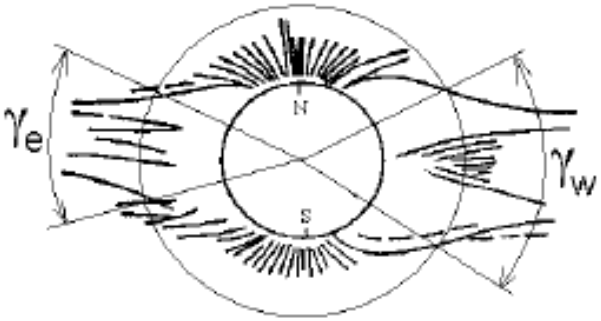


Average geomagnetic activity

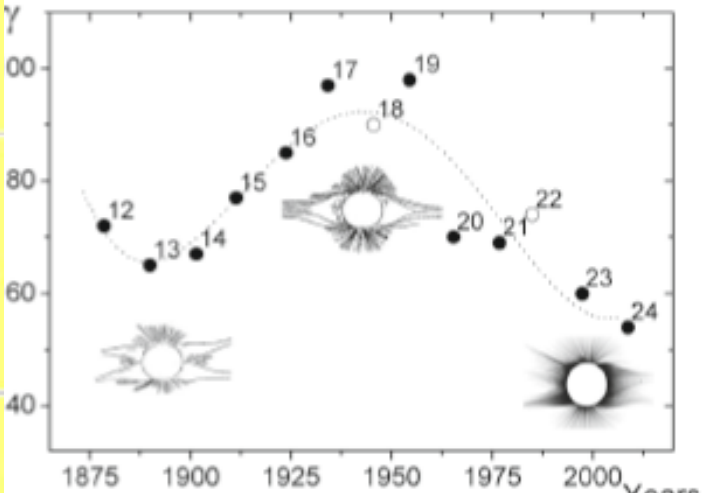
(Ouattara et al., 2009)

Confirmation from solar eclipse observations

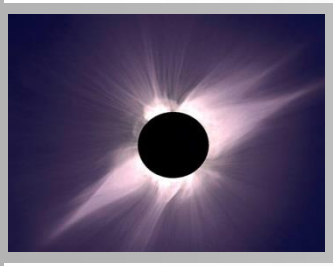




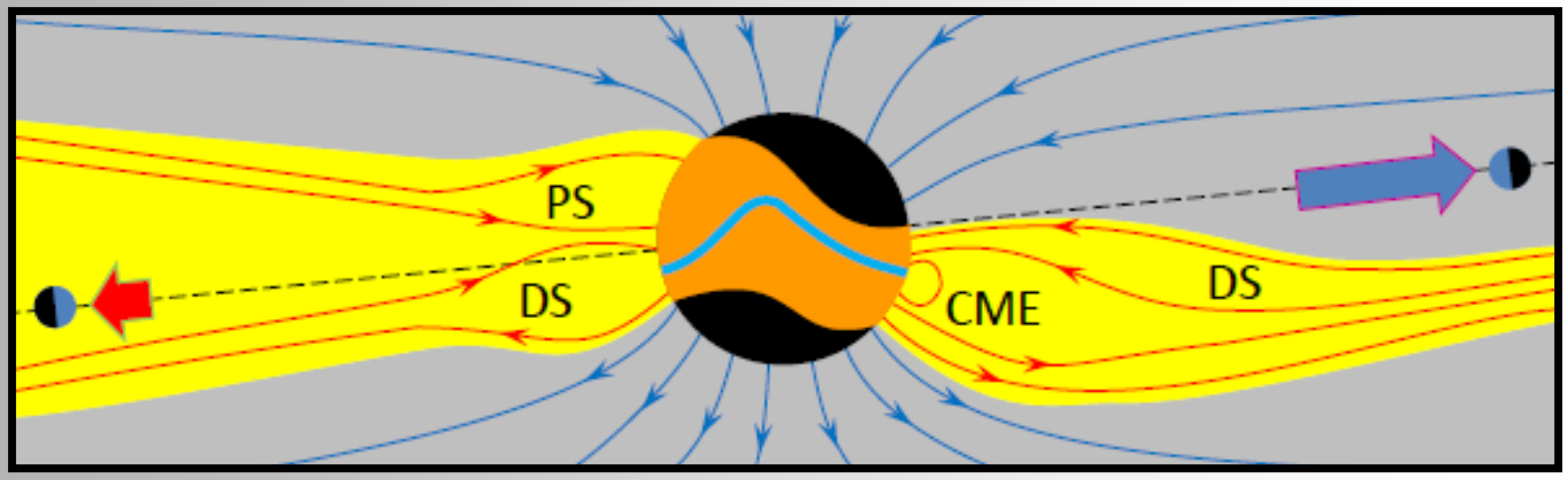
$$\gamma = 180 - (\gamma_W + \gamma_E).$$



Tlatov (2010)

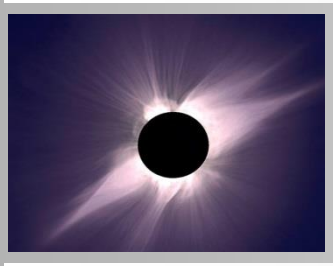


Solar wind speed at Earth and the streamer belt width: concept



- streamer belt comprises dipole streamers (DS) and pseudostreamers (PS) and is filled with slow solar wind
- during the solar cycle streamer belt width varies
- thinnest around sunspot minimum so Earth spends more time solar in continuous fast solar wind of polar coronal holes
- We infer it was thicker when solar activity was low so Earth remained almost continuously in slow solar wind

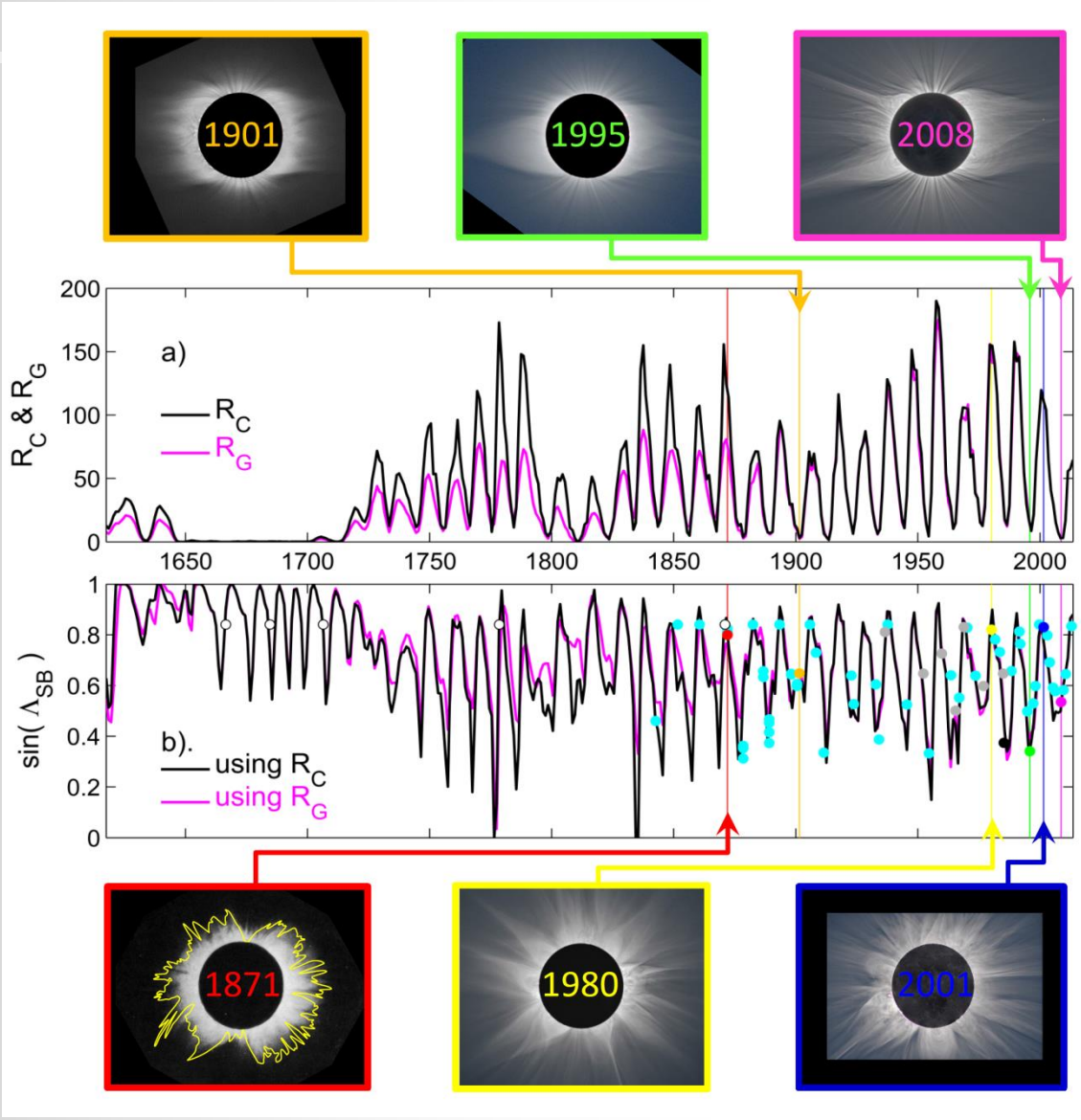
Lockwood et al., 2014



Model results: streamer belt width since the Maunder minimum

- Lower panel shows streamer belt width modelled for corrected sunspot number composite R_C (in black) and group sunspot number R_C (in mauve)

Lockwood et al., 2014



Question:

Is the streamer belt width the factor and is it the only factor determining the geomagnetic activity in sunspot minimum?

Other possible sources of the geomagnetic floor variability

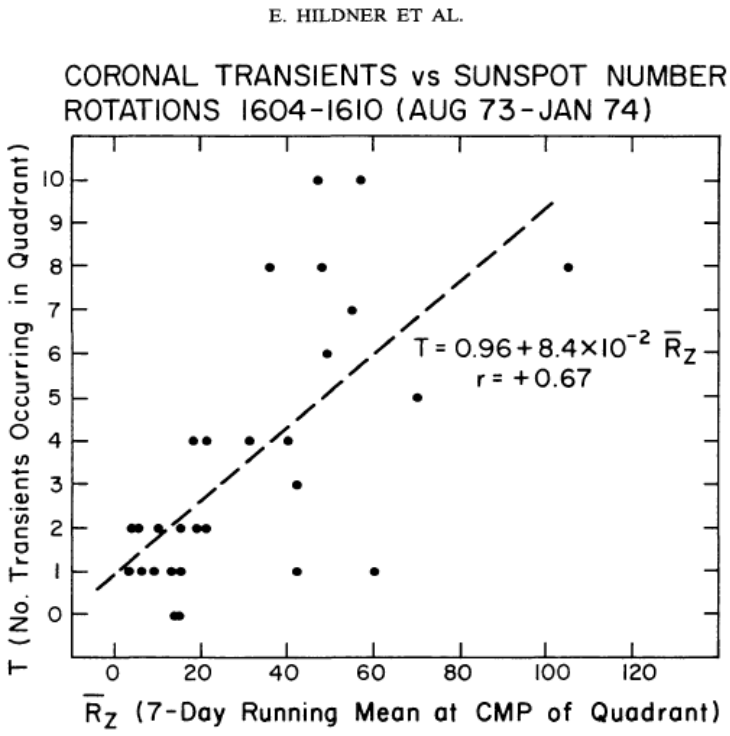
- variations of the number and/or parameters of coronal mass ejections and/or high speed solar wind streams

- variations of the parameters of the slow solar wind from the heliospheric current sheet

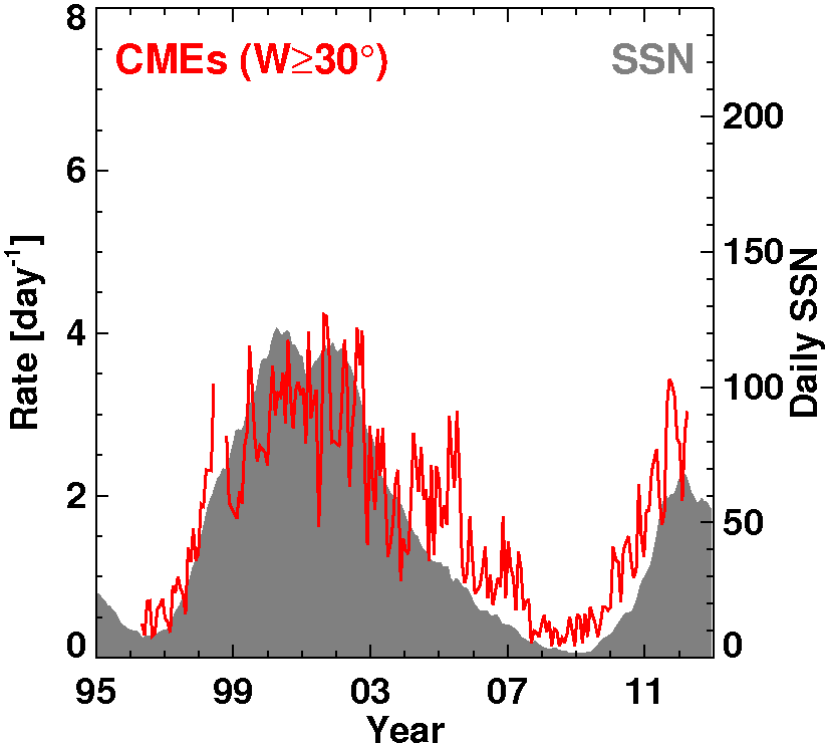
We study the last 4 minima for which there are *in situ* measurements

- ± 12 months around sunspot minimum
- Identify times when the Earth is under the influence of CMEs and HSS
- CME: low T, low plasma β, high B
- HSS: jump in V, high V, high T, low N
- Slow solar wind: no CME, no HSS, V<450 km/s

Possible effects of the number and/or parameters of CMEs



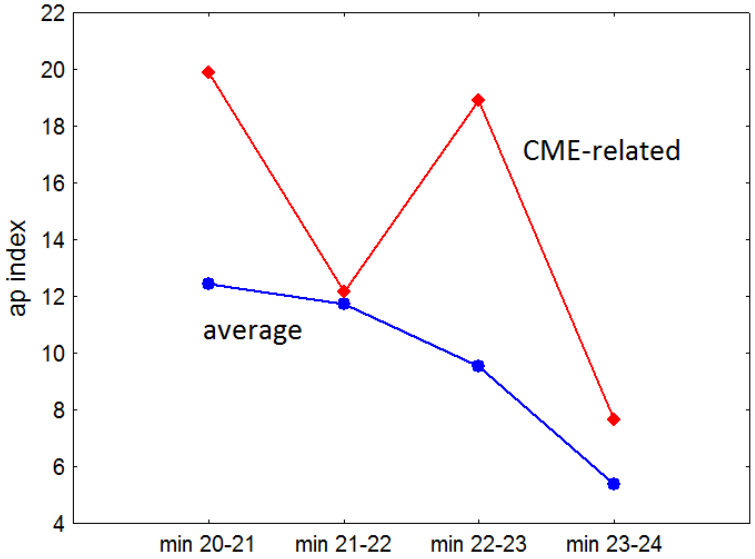
Hildner et al. (1976) - Skylab



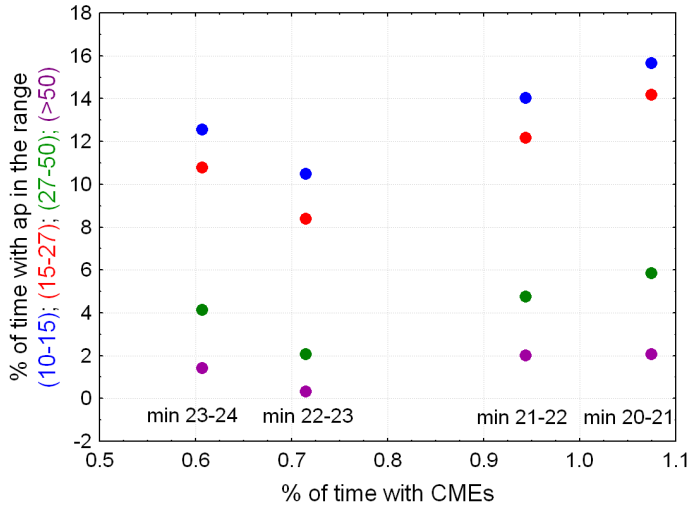
Gopalswamy (2012) - SOHO

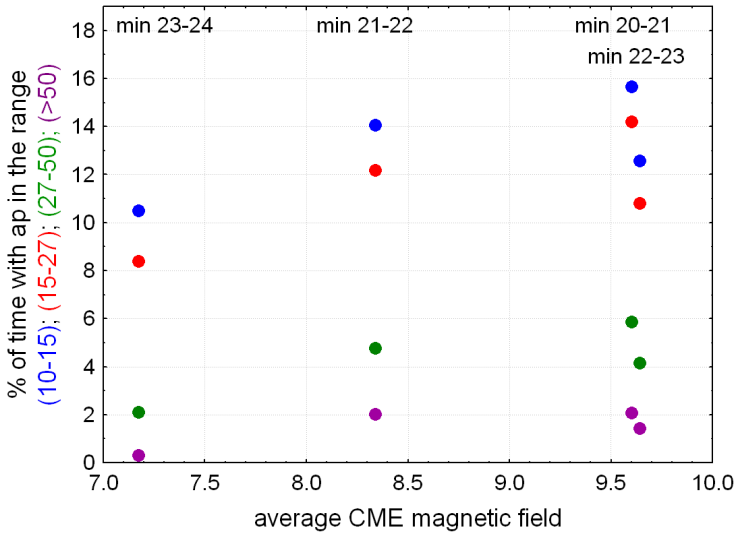
The number of CMEs follows the sunspot cycle and is very low during sunspot minimum

No relation of average and CME-related geomagnetic activity

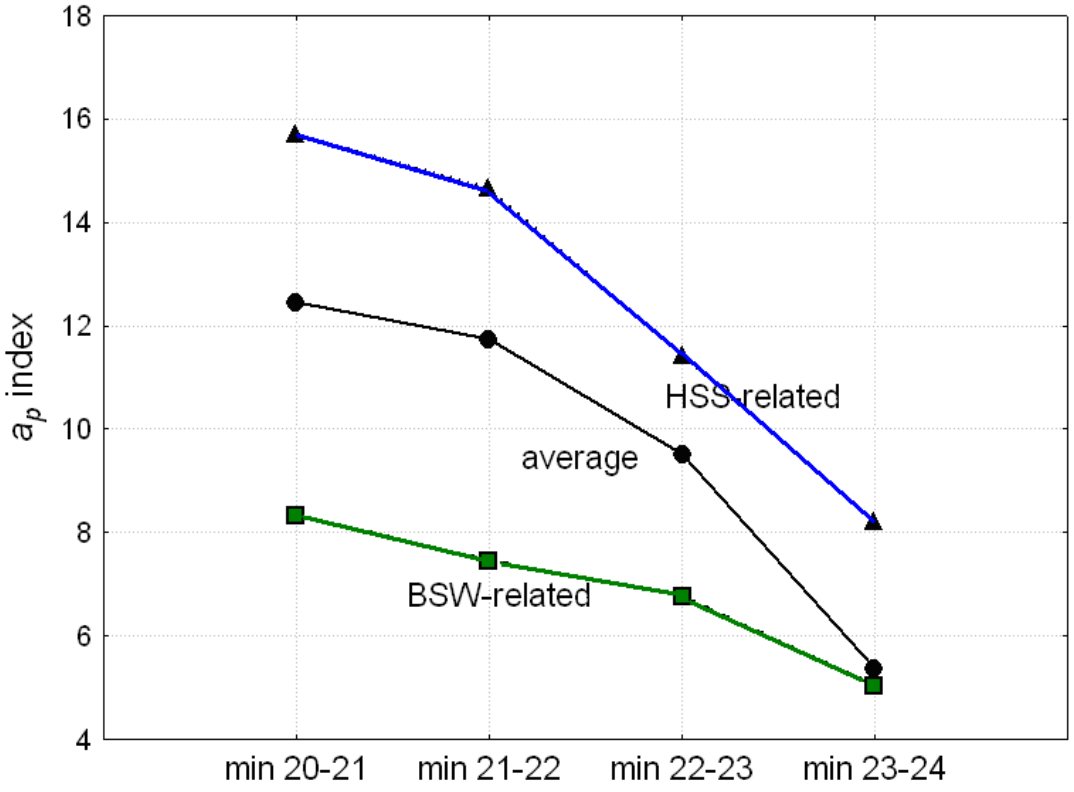


No dependence on the time spent with CMEs or on CME's magnetic field



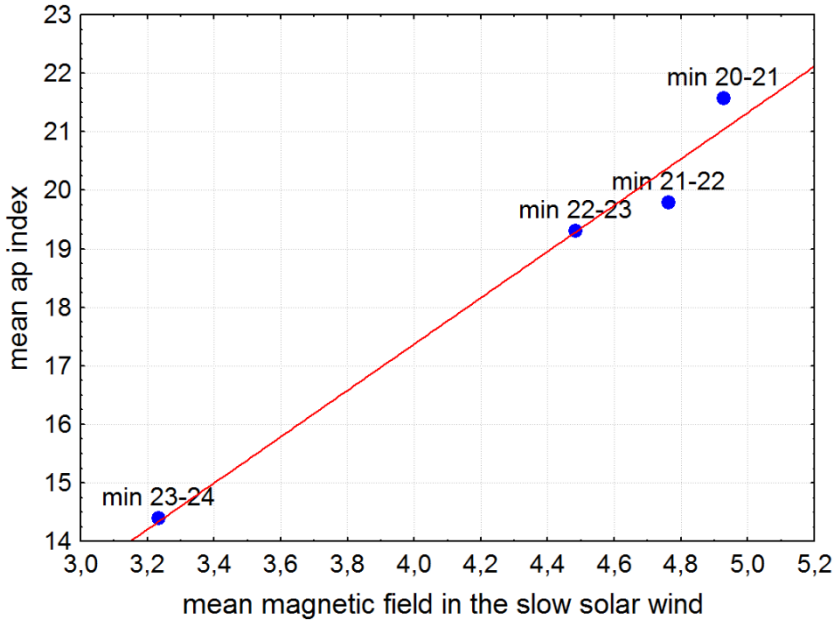


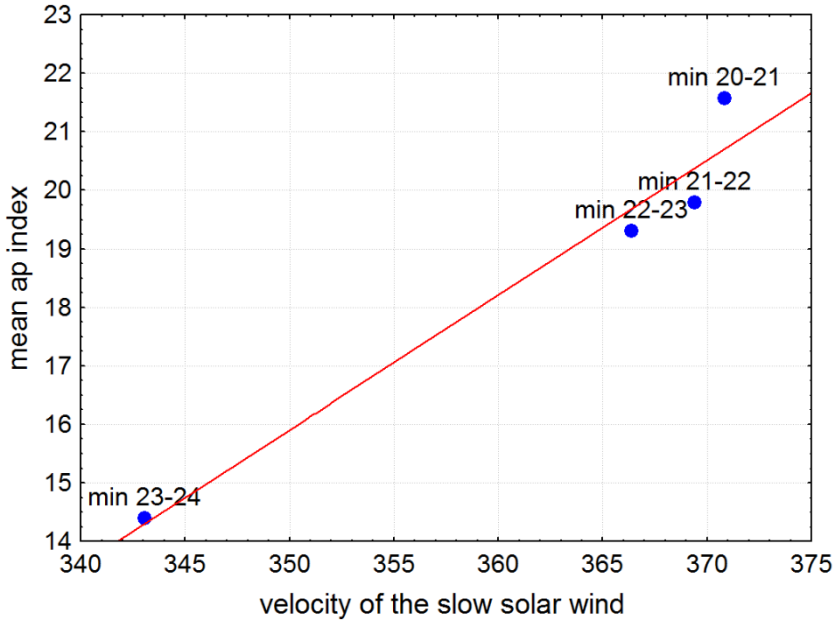
Possible effects of the parameters of HSS and slow solar wind



The geoeffectiveness of both the high speed wind outside the heliosheet and the slow solar wind inside the heliosheet decreases

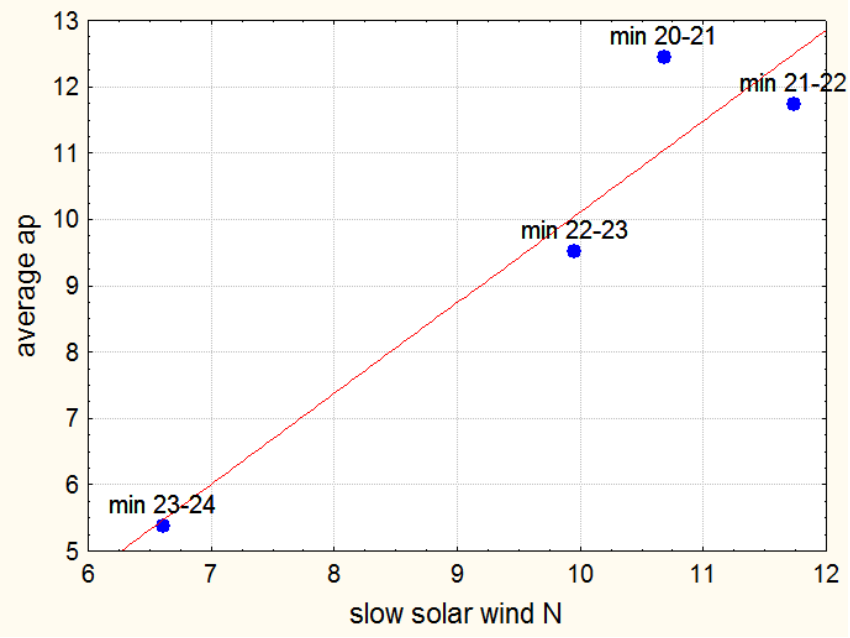
B and V of the slow solar wind are decreasing in the last 4 sunspot minima

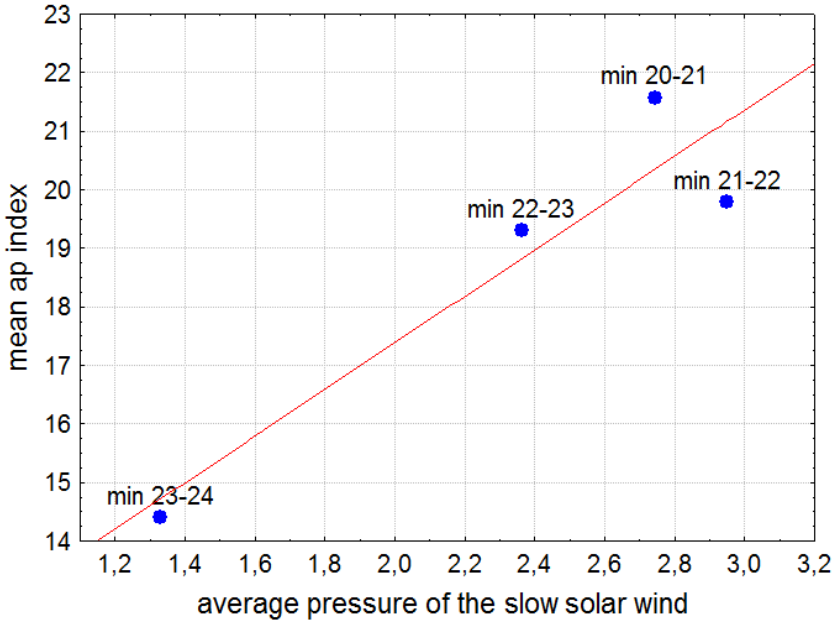




And so is geomagnetic activity

Density and pressure of the slow solar wind are decreasing

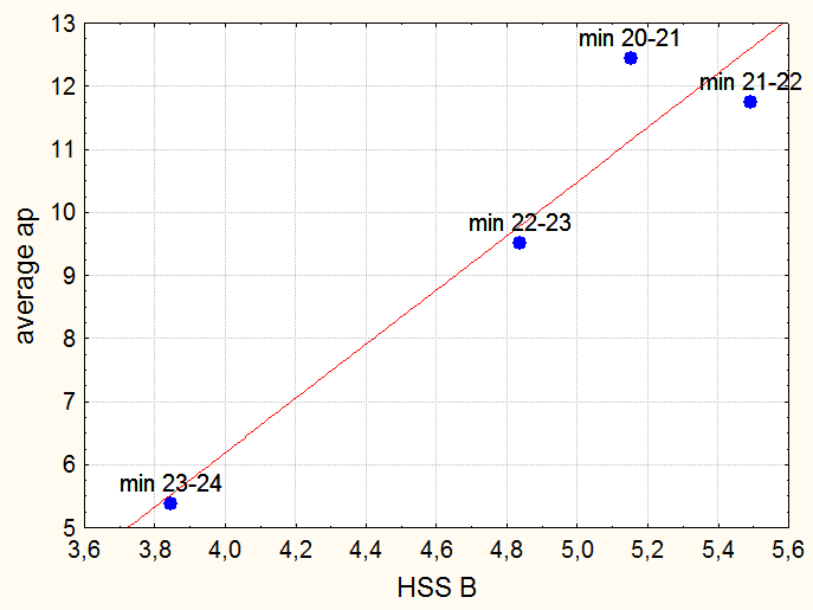




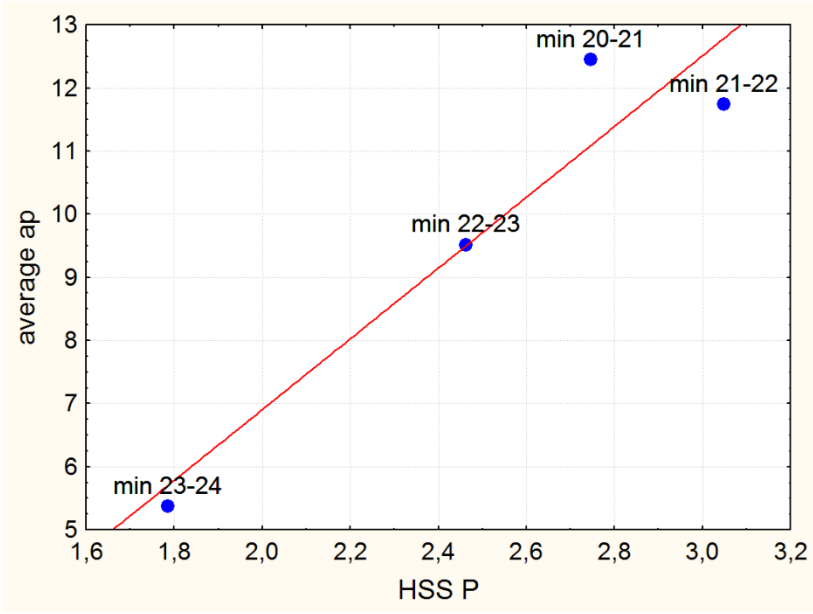
And so is geomagnetic activity (exception min 20-21)

HSS and geomagnetic activity in min

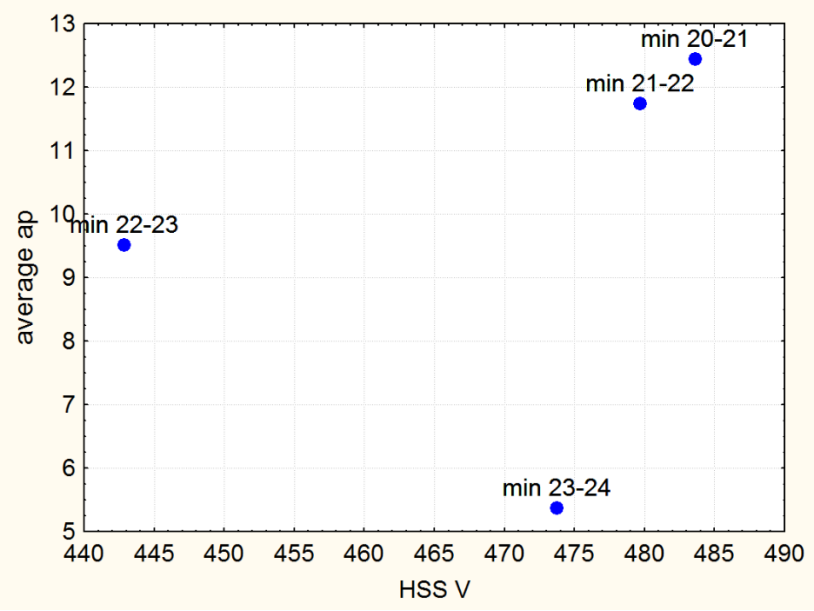
Decreasing HSS magnetic field and ap



Decreasing HSS pressure and ap

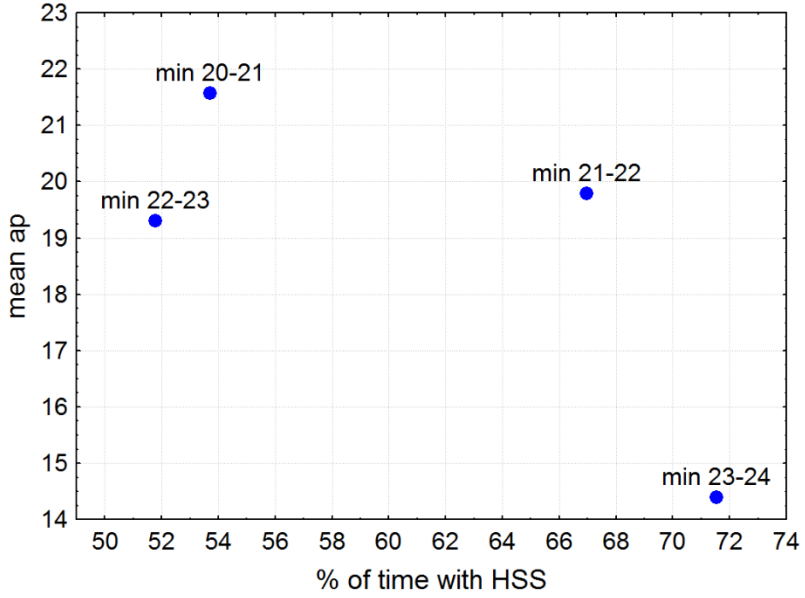


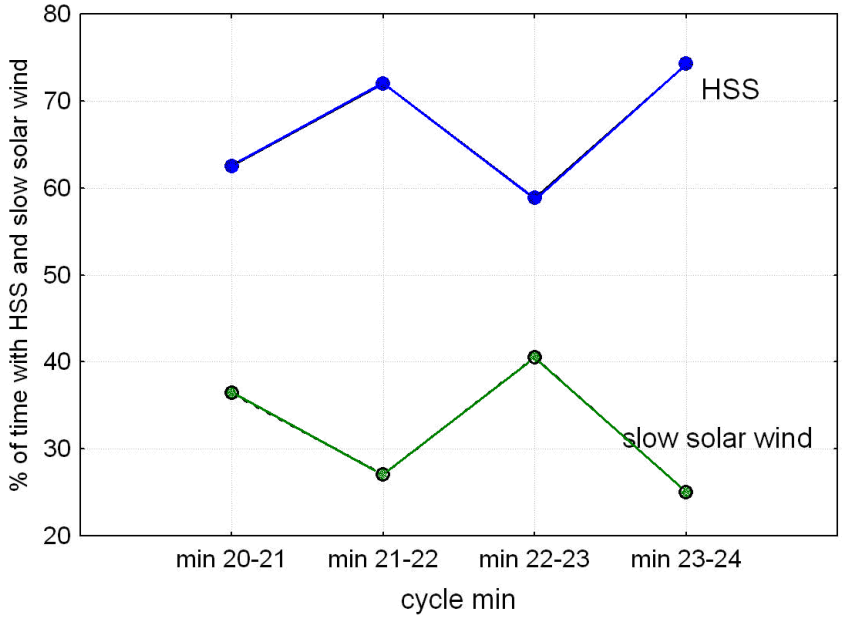
No clear trend and dependence on HSS velocity



What about the time spent in HSS and slow solar wind?

A surprising result





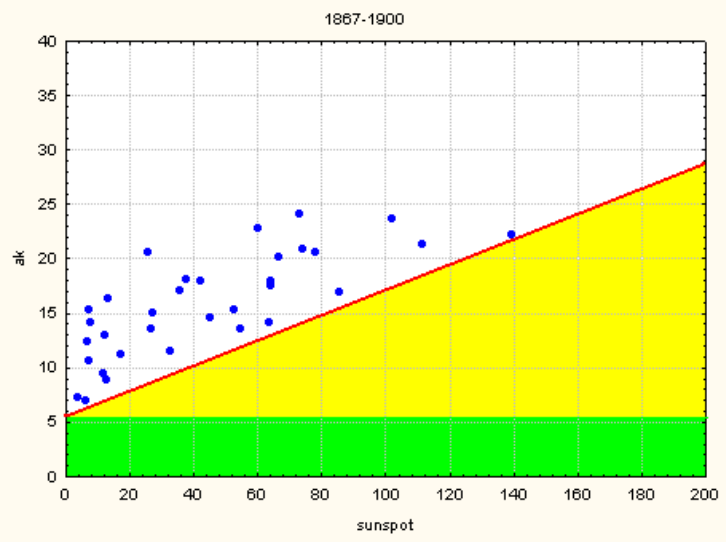
No trend in time spent by the Earth in HSS

No trend in the portion of time spent inside and outside the heliosheet

conclusion

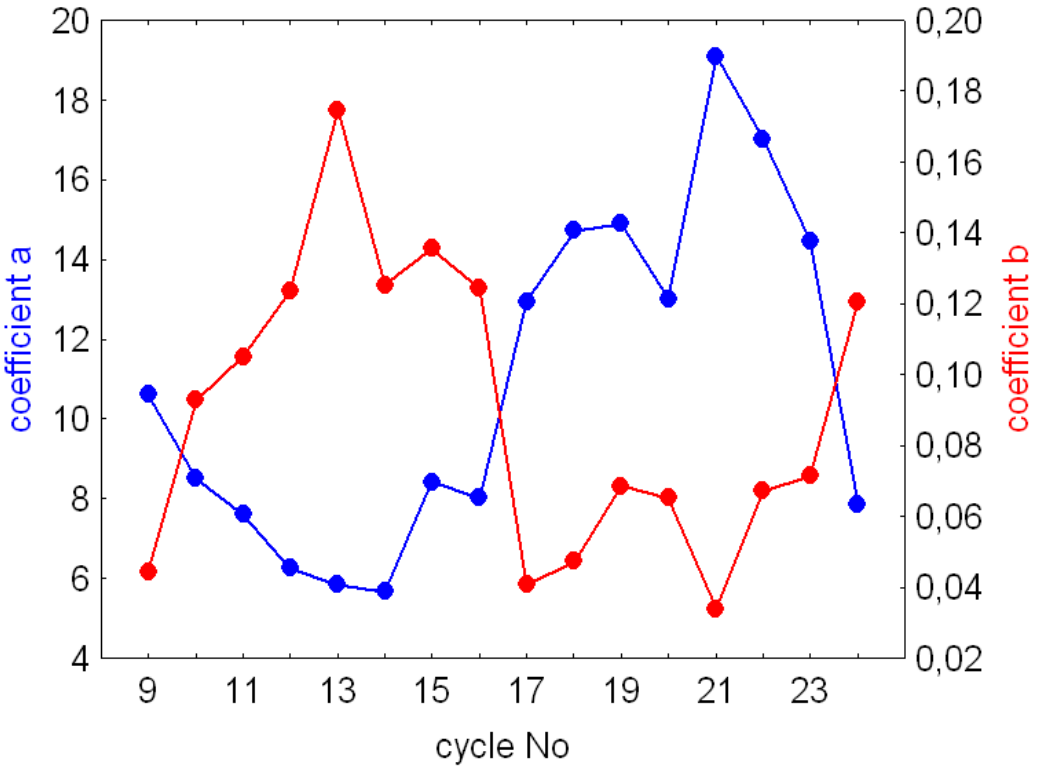
- The geomagnetic activity in sunspot cycle minimum is mostly determined not by the time spent by the Earth in the slow solar wind and HSS but by the magnetic field and plasma pressure of the solar wind both inside the heliosheet and from superradially expanding high latitude coronal holes

Geomagnetic activity components



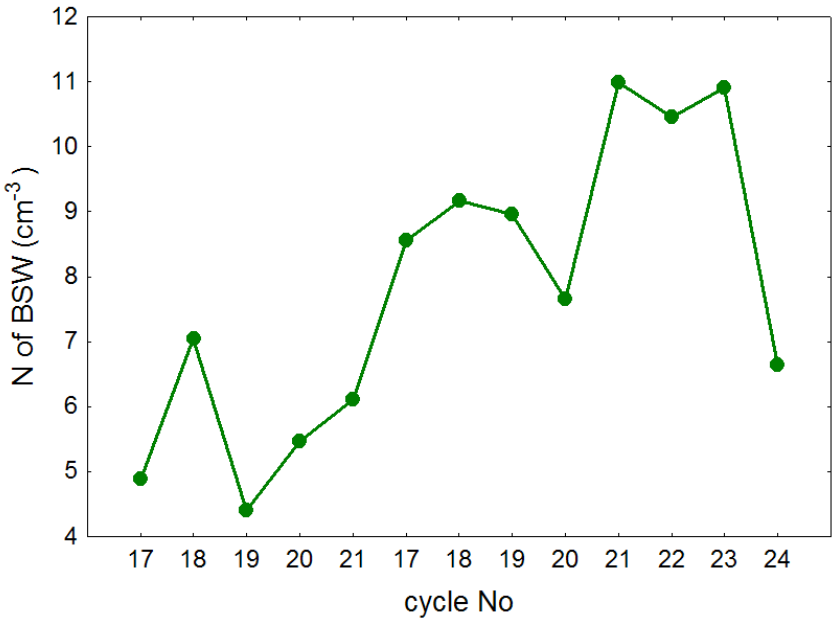
- The geomagnetic activity “floor” is determined by the parameters of the slow solar wind in the heliosheet
- The slope of the straight line is determined by the number and parameters of CMEs
- The non-sunspot related geomagnetic activity (above the line) is determined by the number and parameters of HSS

Linear dependence of the geomagnetic activity floor on the slow solar wind parameters



Therefore, from the level of the geomagnetic activity floor we can estimate the parameters of the slow solar wind

Example: long-term variations of the density of the slow solar wind



- N of the heliosheet varies by a factor of more than 2
- B almost 2 times
- V by 10%
- P – 3 times