Vistas in Solar Activity

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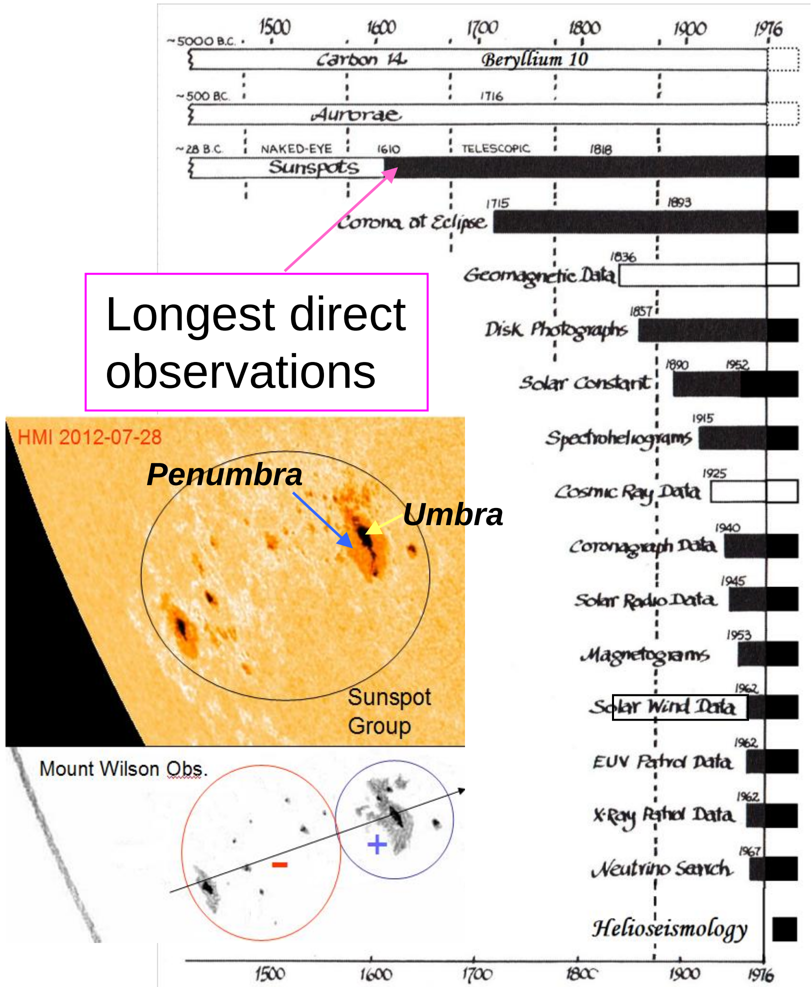
Brown Bag Lunch, Tucson, Jan. 2013

Indicators of Solar Activity

- Sunspot Number (and Area, Magnetic Flux)
- Solar Radiation (TSI, UV, …, F10.7)
- Cosmic Ray Modulation
- Solar Wind
- Geomagnetic Variations
- Aurorae
- Ionospheric Parameters
- Oscillations
- Climate?
- More…



After Eddy, 1976

Solar Activity is Magnetic Activity

The Sunspot Number(s)

Rudolf Wolf (1816-1893)
Observed 1849-1893

- Wolf Number = K_W (10*G + S)
- G = number of groups
- S = number of spots

- Group Number = 12 K_G G

Ken Schatten

Douglas Hoyt and Kenneth Schatten devised the *Group Sunspot Number* using just the group count (1993).

Unfortunately a *K*-factor was also necessary here, so the result really depends on how well the *K*-factor can be determined

Waldmeier's Description of the Weighting of Sunspots that began in the 1940s

Astronomische Mitteilungen der Eidgenössischen Sternwarte Zürich
Nr. 285

1968

Die Beziehung zwischen der Sonnenflecken-relativzahl und der Gruppenzahl

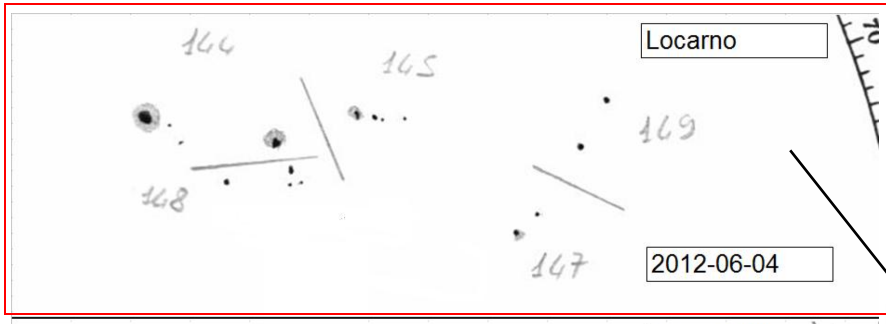
Von

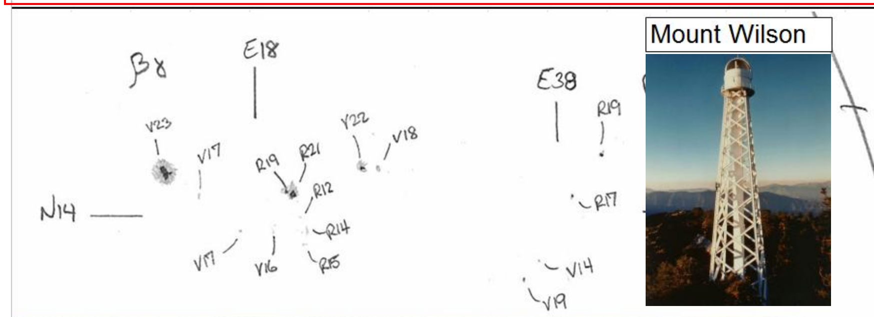
M. Waldmeier

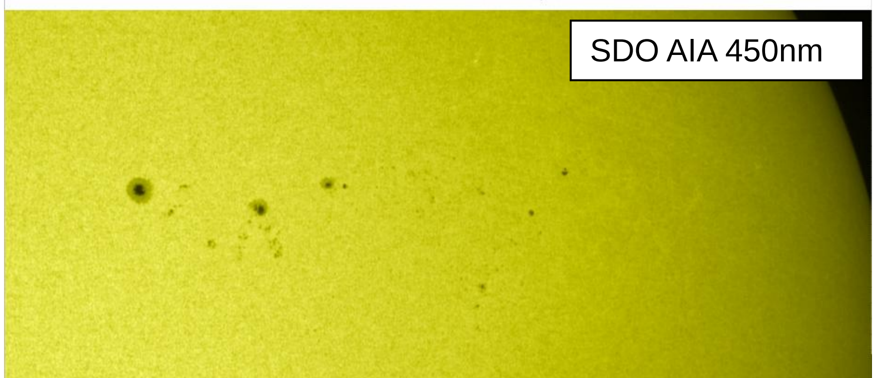
Später wurden den Flecken entsprechend ihrer Größe Gewichte erteilt: Ein punktförmiger Fleck wird einfach gezählt, ein größerer, jedoch nicht mit Penumbra versehener Fleck erhält das statistische Gewicht 2, ein kleiner Hoffleck 3, ein größerer 5.

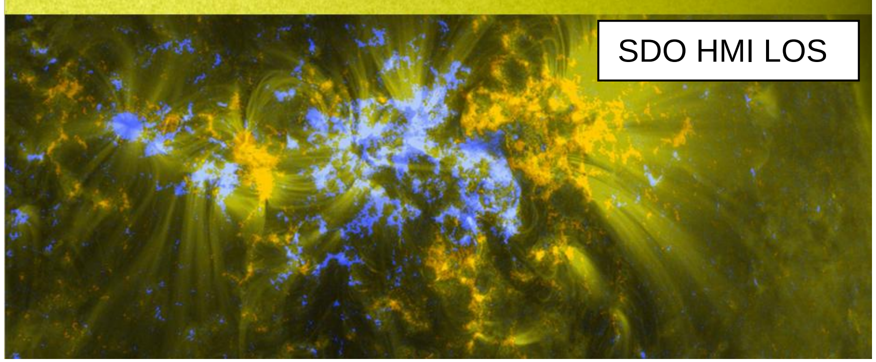
"A spot like a fine point is counted as one spot; a larger spot, but still without penumbra, gets the statistical weight 2, a smallish spot with penumbra gets 3, and a larger one gets 5." Presumably there would be spots with weight 4, too.

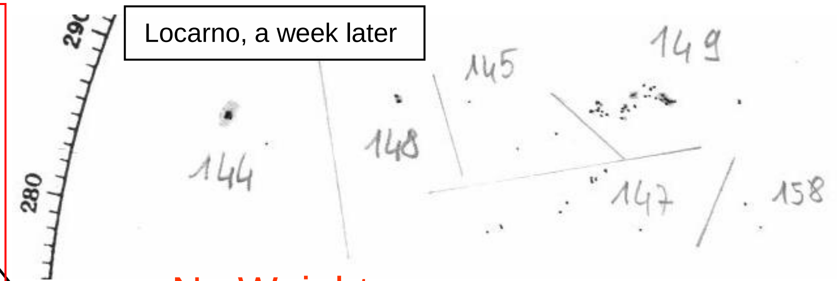
This very important piece of metadata was strongly downplayed and is not generally known











No Weight

g	f		B
143	4	2	-16°
144	7	4	+15°
145	5	4	+15°
146	12	6	-21°
147	4	2	+8°
148	5	4	+11°
149	4	2	+15°
150	6	2	+10°
151	1	1	+11°
152	2	2	+6°
153	2	1	-18°
11	52	30	

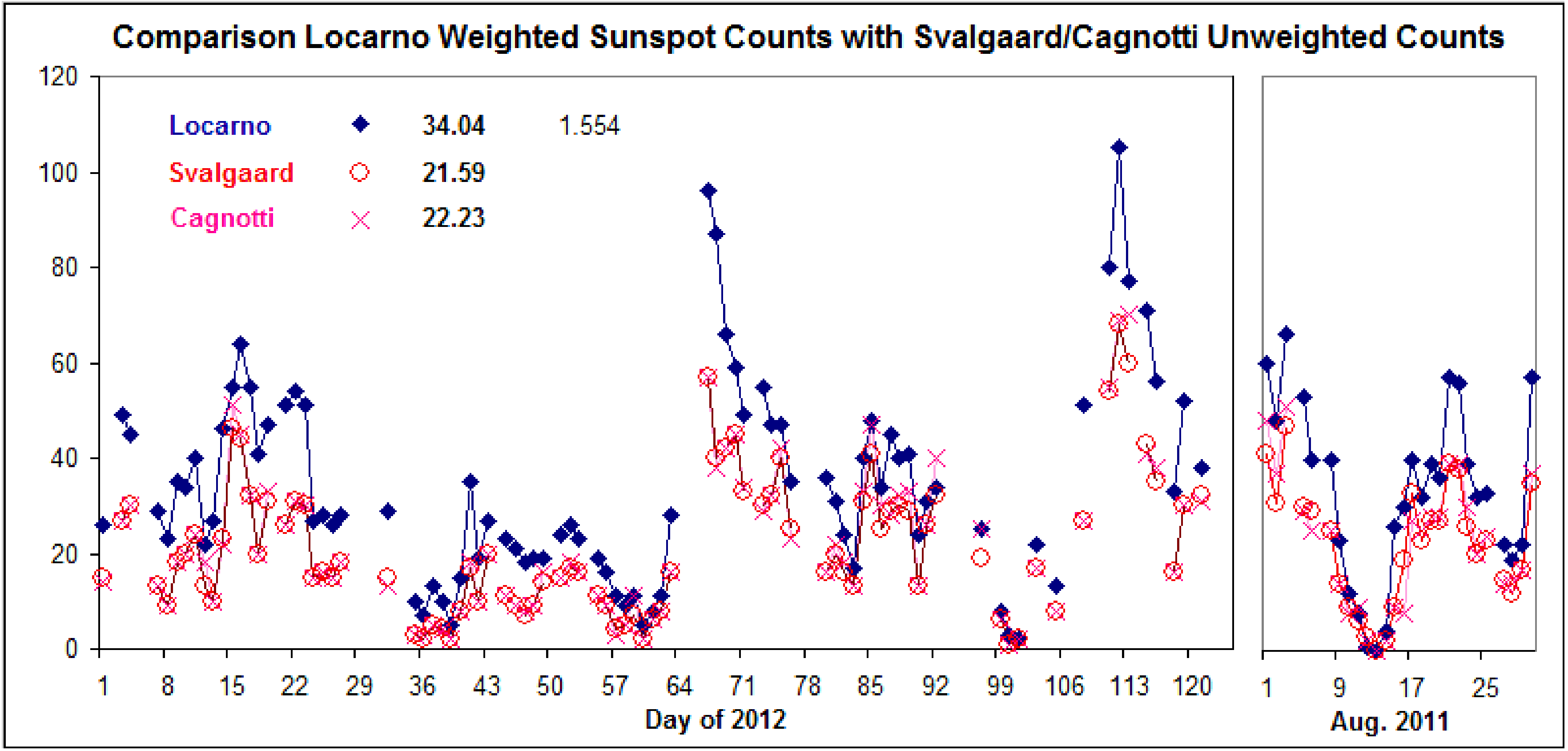
Groups ‘Spots’

10*11+52=162; 10*11+30=140; 162/140=1.16

Combined Effect of Weighting and More Groups is an Inflation of the Relative Sunspot Number by 20+%

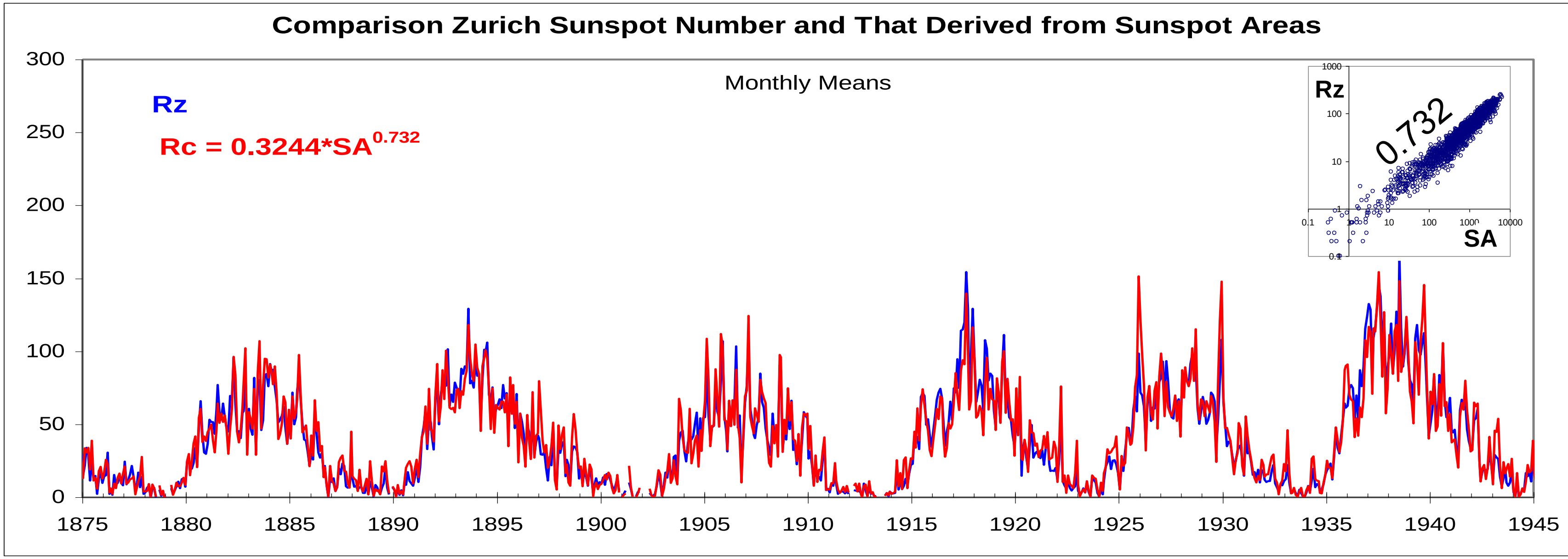
I have re-counted 43,000 spots without weighting for the last ten years of Locarno observations.

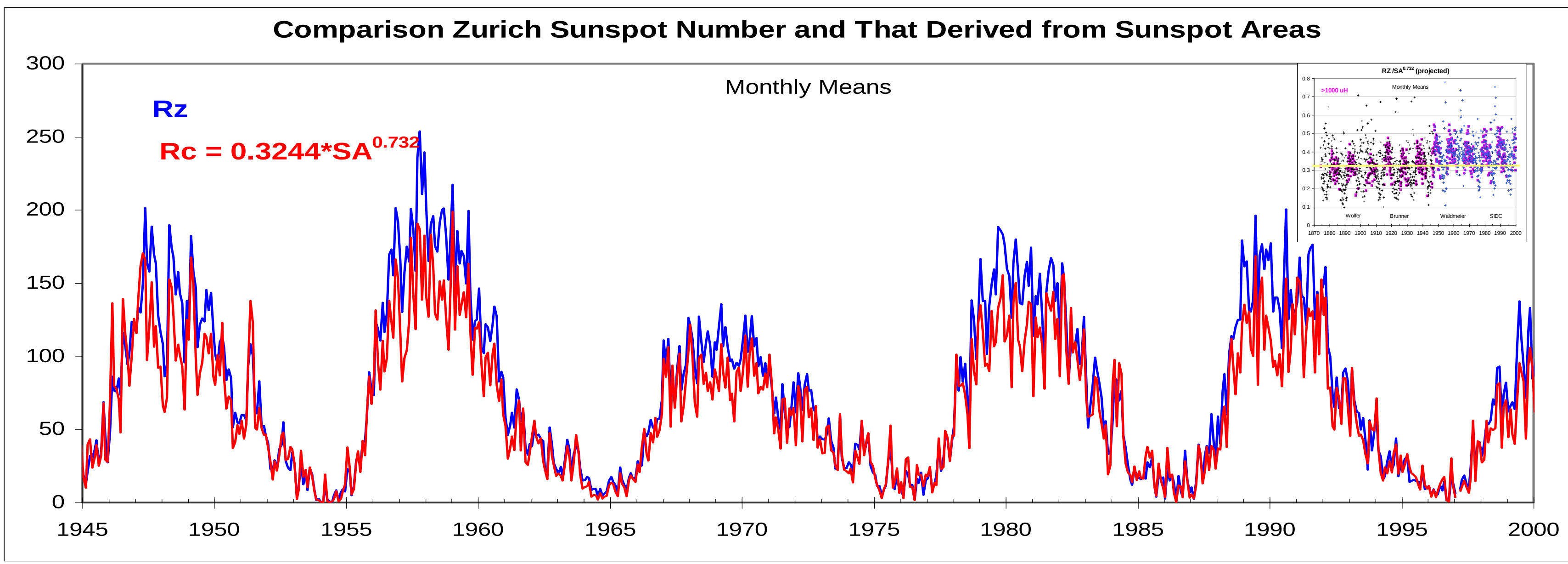
Double-Blind Test of My Re-Count



I proposed to the Locarno observers that they should also supply a raw count without weighting

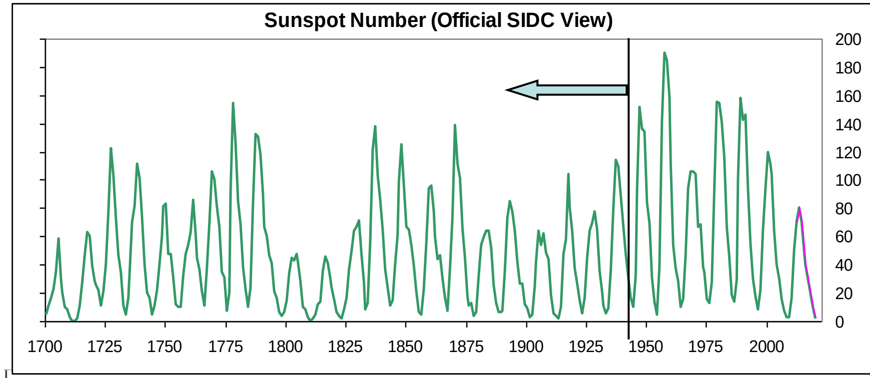
For typical number of spots the weighting increases the 'count' of the spots by 30-50% (44% on average)

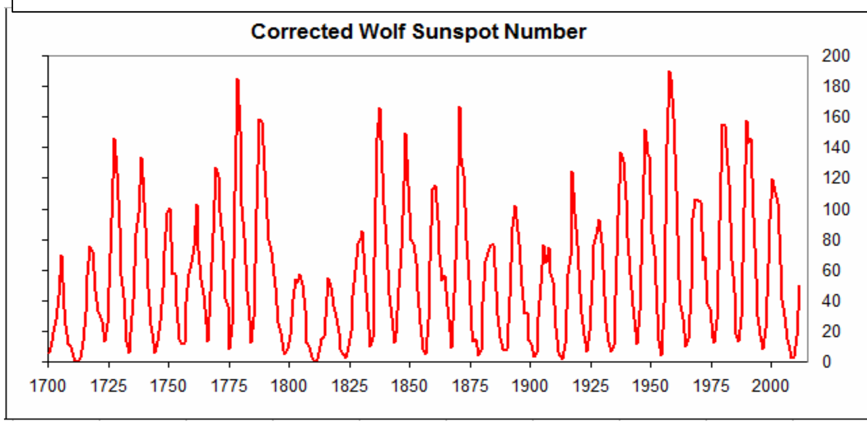


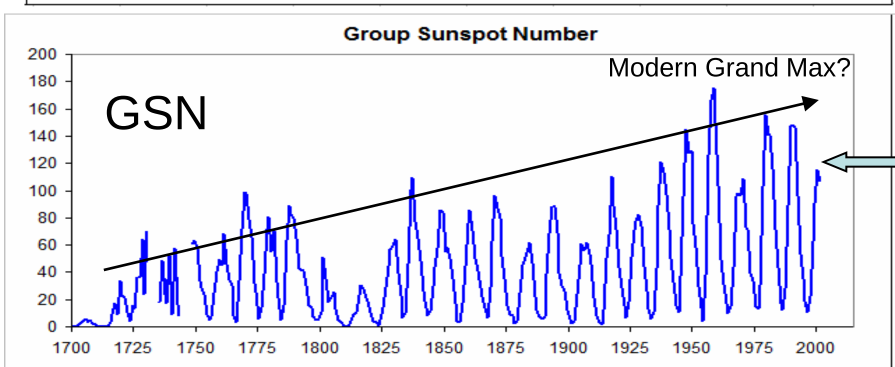


The 20% Inflation Caused by Weighting Spot Counts

Correcting for the 20% Inflation







R*corr* = R*official* * 1.2 before ~1947

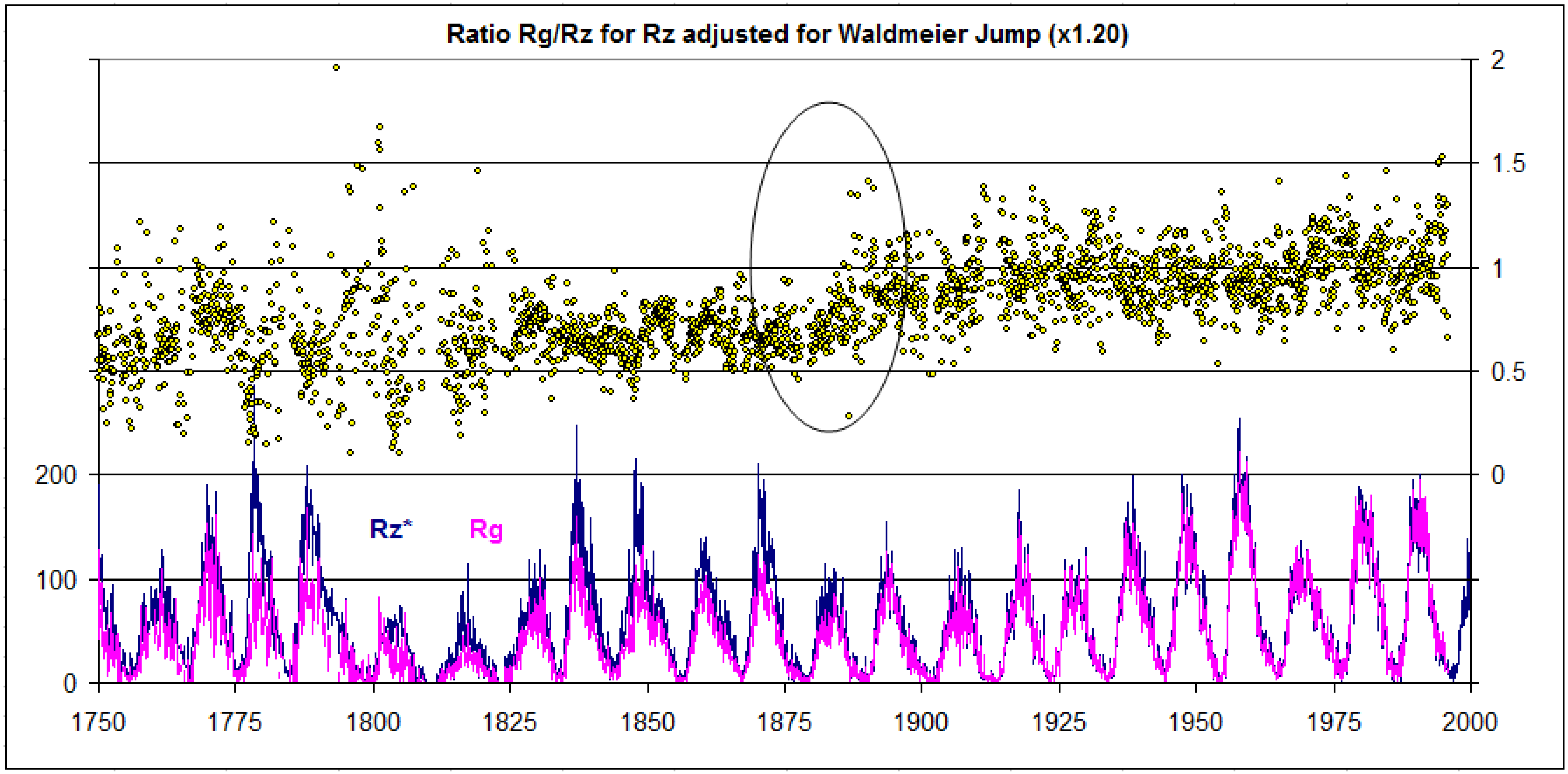
This issue is so important that the official agencies responsible for producing sunspot number series have instituted a series of now ongoing Workshops to, if at all possible, converge to an agreed upon, common, corrected series:

http://ssnworkshop.wikia.com/wiki/Home

The inflation due to weighting is now an established and accepted fact

That the corrected sunspot number is so very different from the Group Sunspot Number is a problem for assessing past solar activity and for predicting future activity. This problem must be resolved.

The Ratio between the Group Sunspot Number and the [corrected] Sunspot number

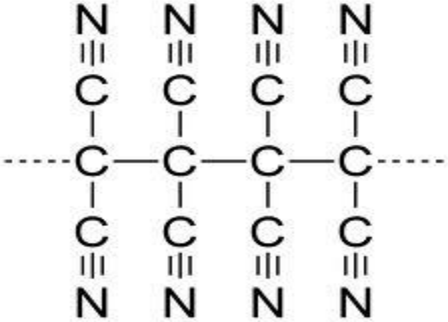


Shows that the significant discrepancy is largely due to data from the 1880s

Building Backbones

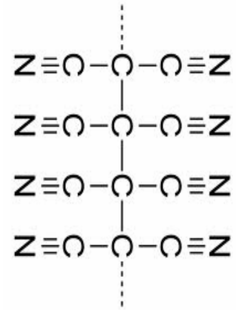
Building a long time series from observations made over time by several observers can be done in two ways:

- Daisy-chaining: successively joining observers to the 'end' of the series, based on overlap with the series as it extends so far [accumulates errors]
- Back-boning: find a primary observer for a certain [long] interval and normalize all other observers individually to the primary based on overlap with only the primary [no accumulation of errors]



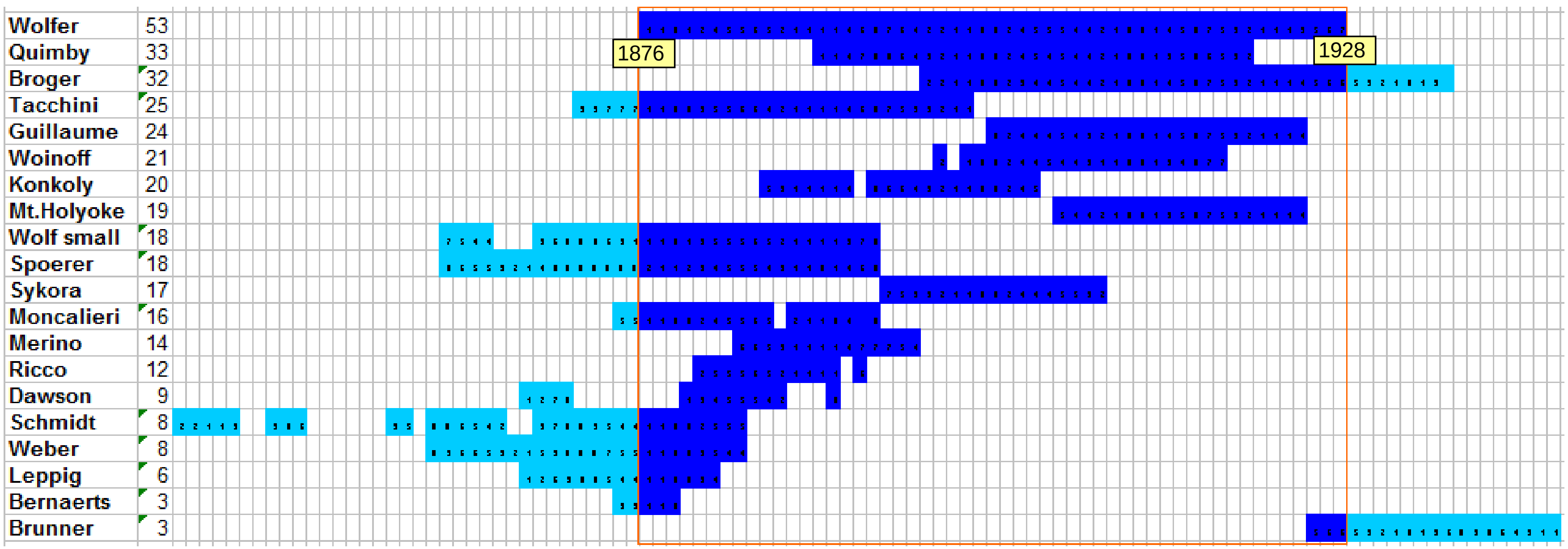
Carbon Backbone

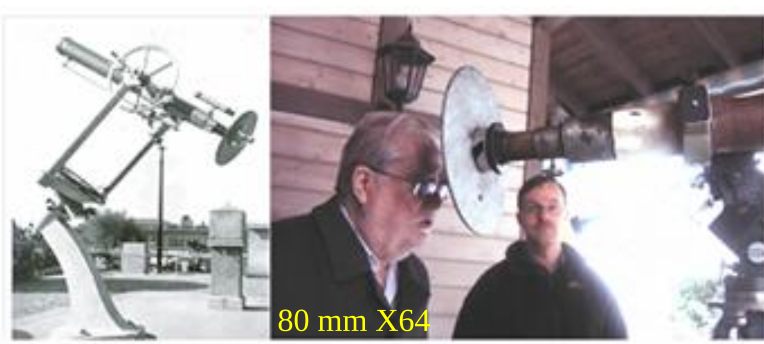
When several backbones have been constructed we can join [daisy-chain] the backbones. Each backbone can be improved individually without impacting other backbones



The Wolfer Backbone

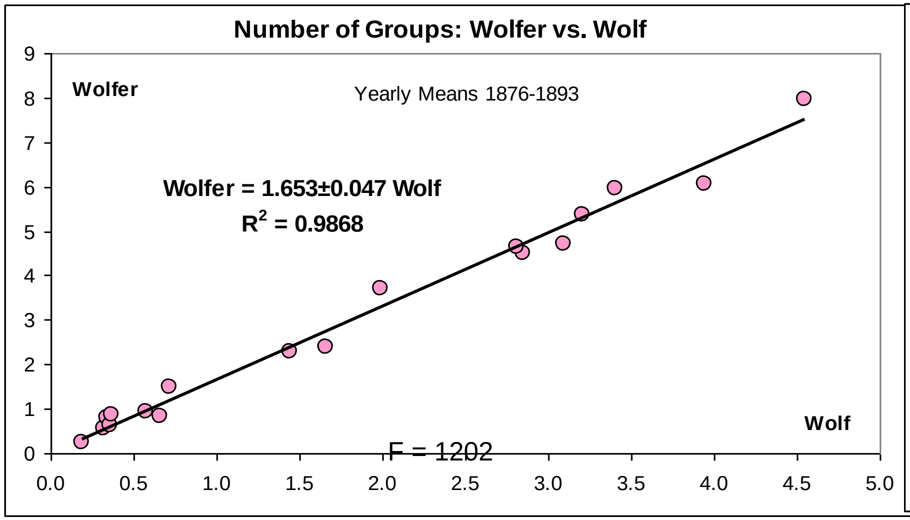
Alfred Wolfer observed 1876-1928 with the ‘standard’ 80 mm telescope

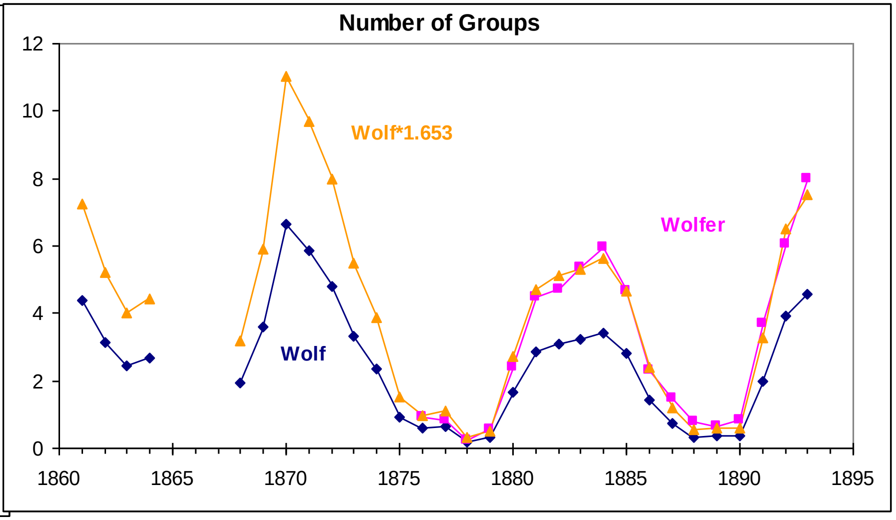


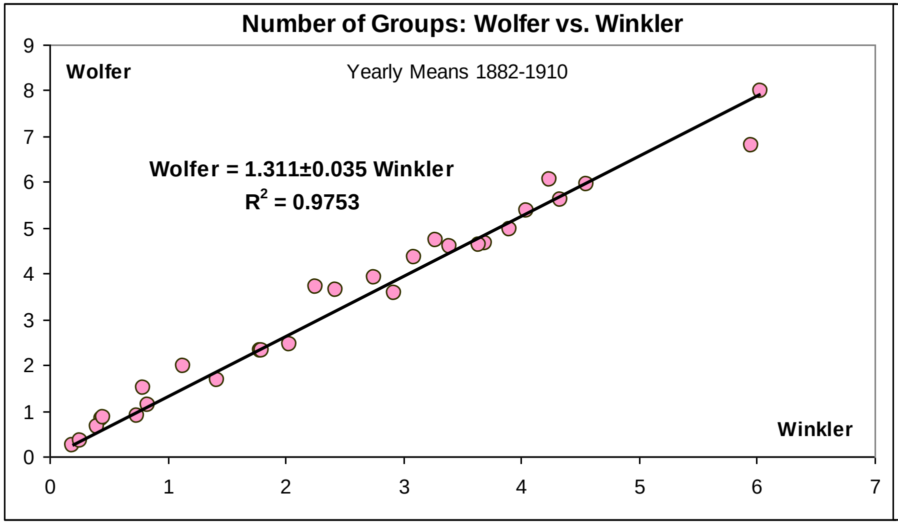


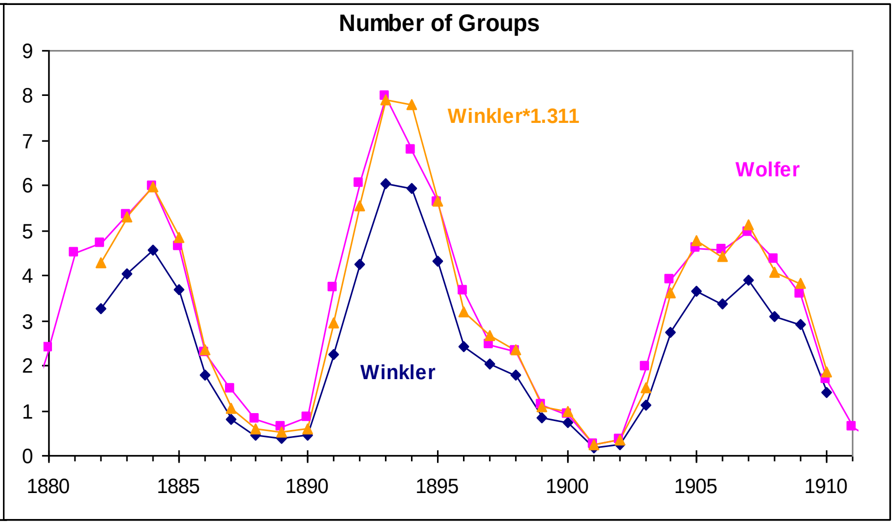
Rudolf Wolf from 1860 on mainly used smaller 37 mm telescope(s) so those observations are used for the Wolfer Backbone

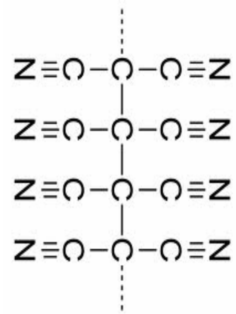
Normalization Procedure





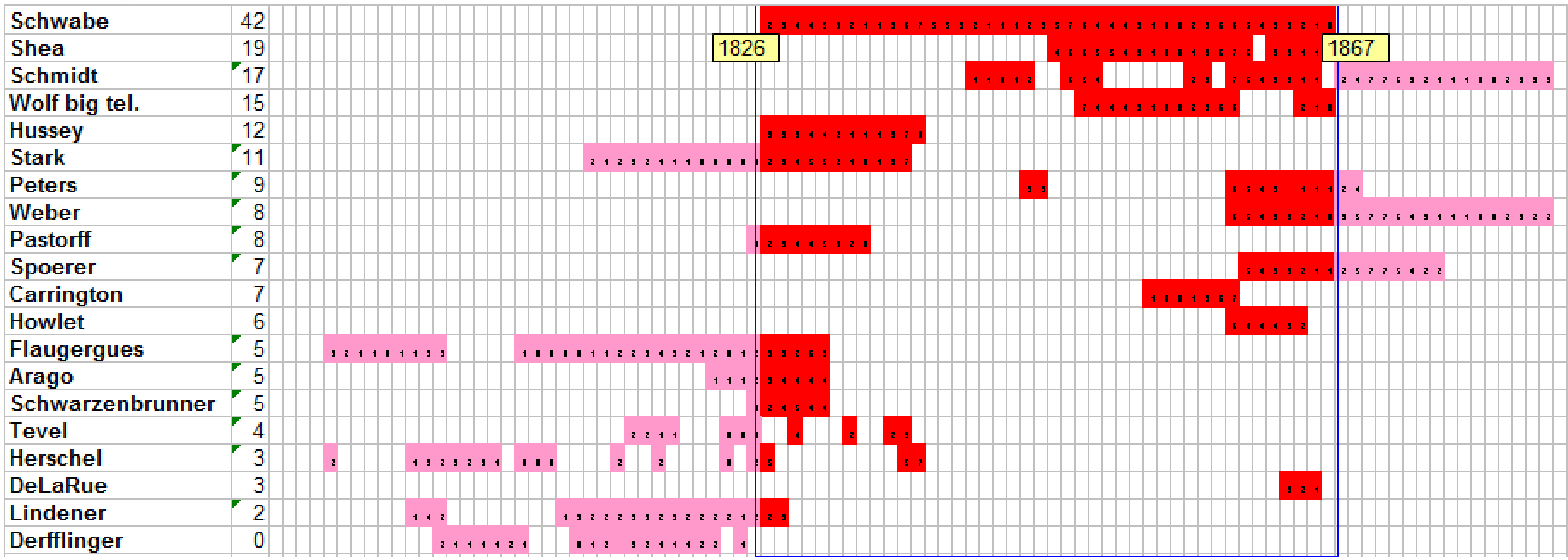


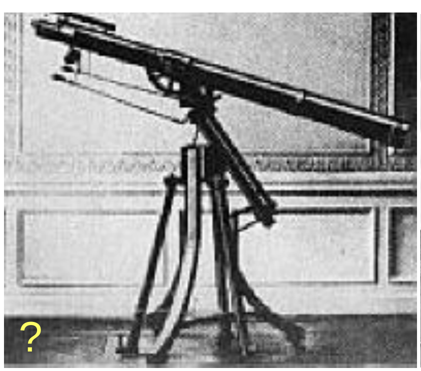




The Schwabe Backbone

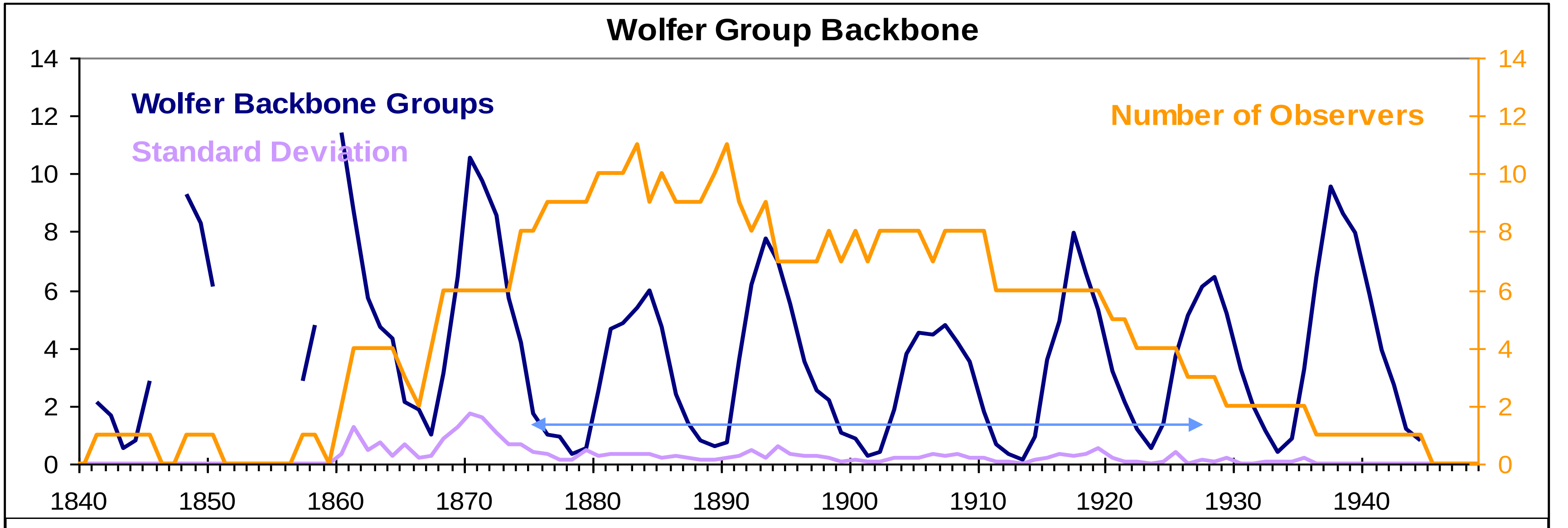
Schwabe received a 50 mm telescope from Fraunhofer in 1826 Jan 22. This telescope was used for the vast majority of full-disk drawings made 1826–1867.

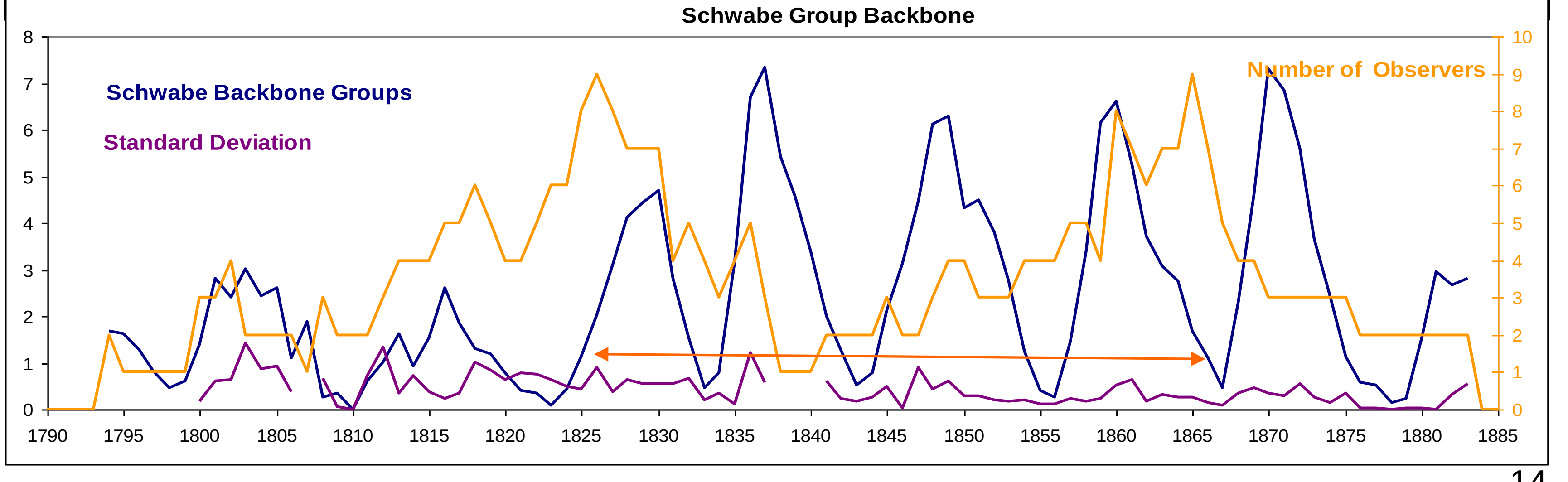




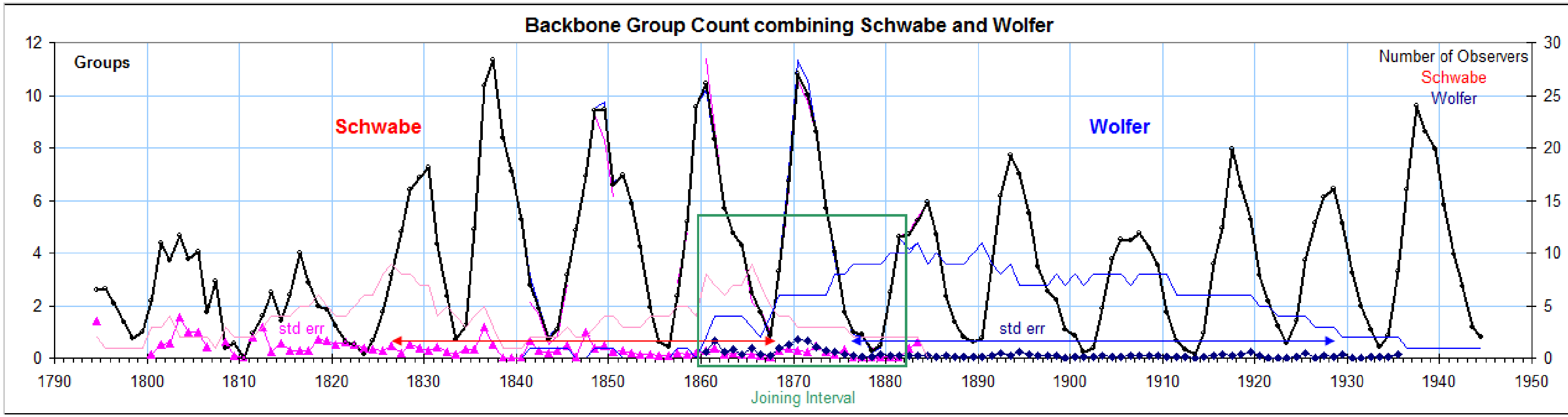
For this backbone we use Wolf's observations with the large 80mm standard telescope

The Wolfer & Schwabe Backbones

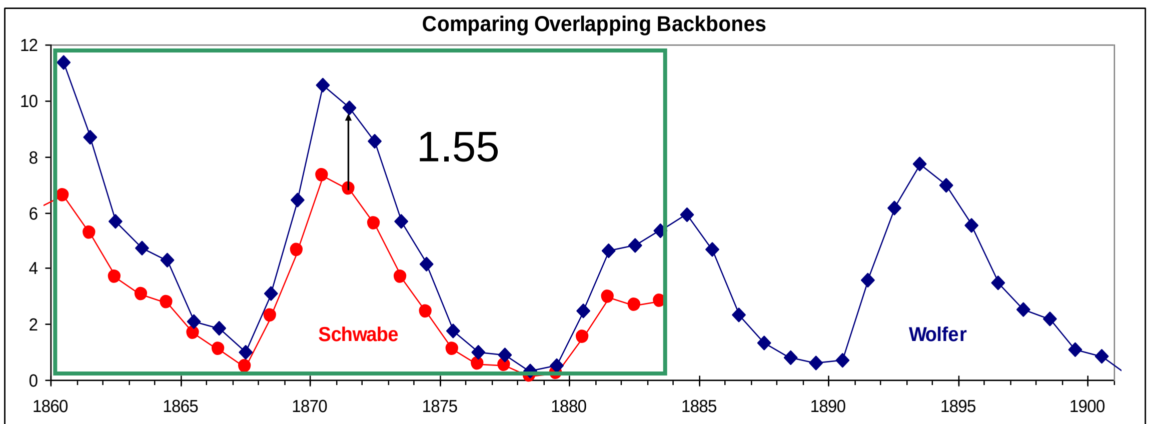


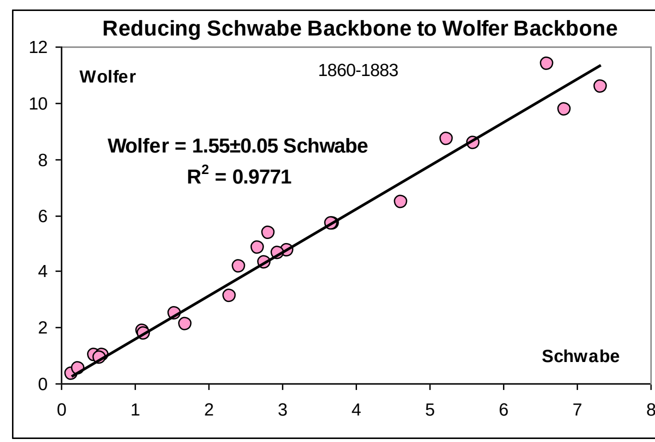


Joining two Backbones

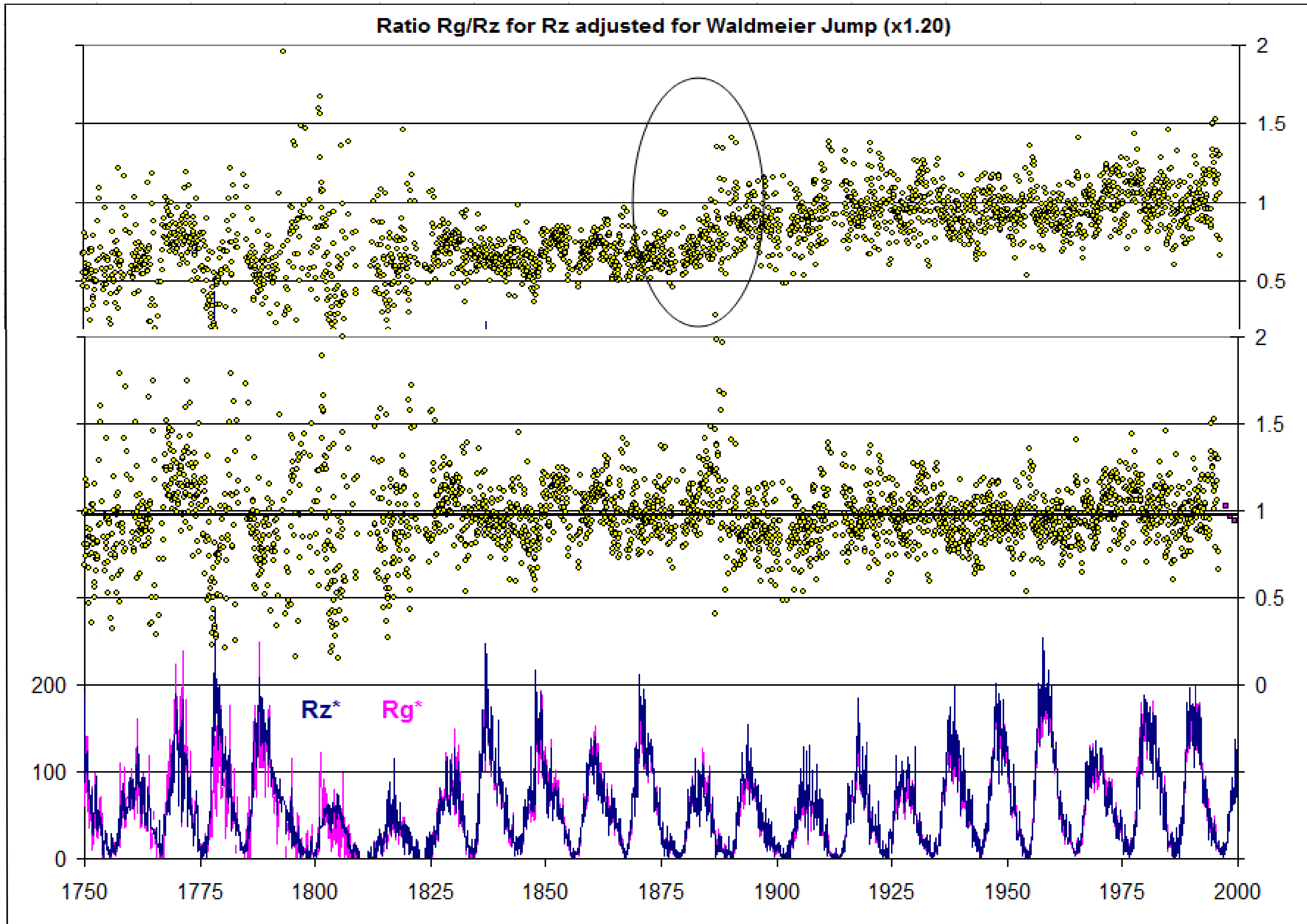


Comparing Schwabe with Wolfer backbones over 1860-1883 we find a normalizing factor of 1.55



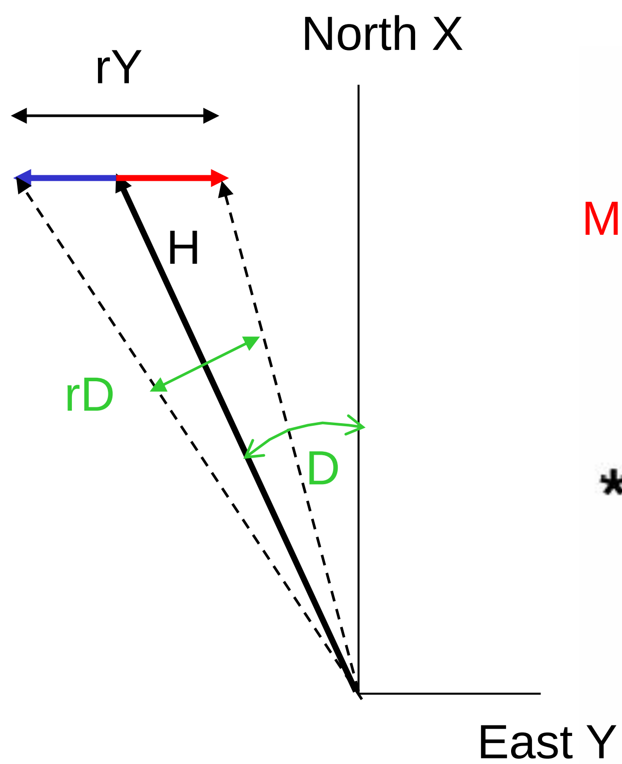


The Group Sunspot Number is now defined as 12 * Number of Groups



The corrected Sunspot Number Series [no Modern Grand Maximum]

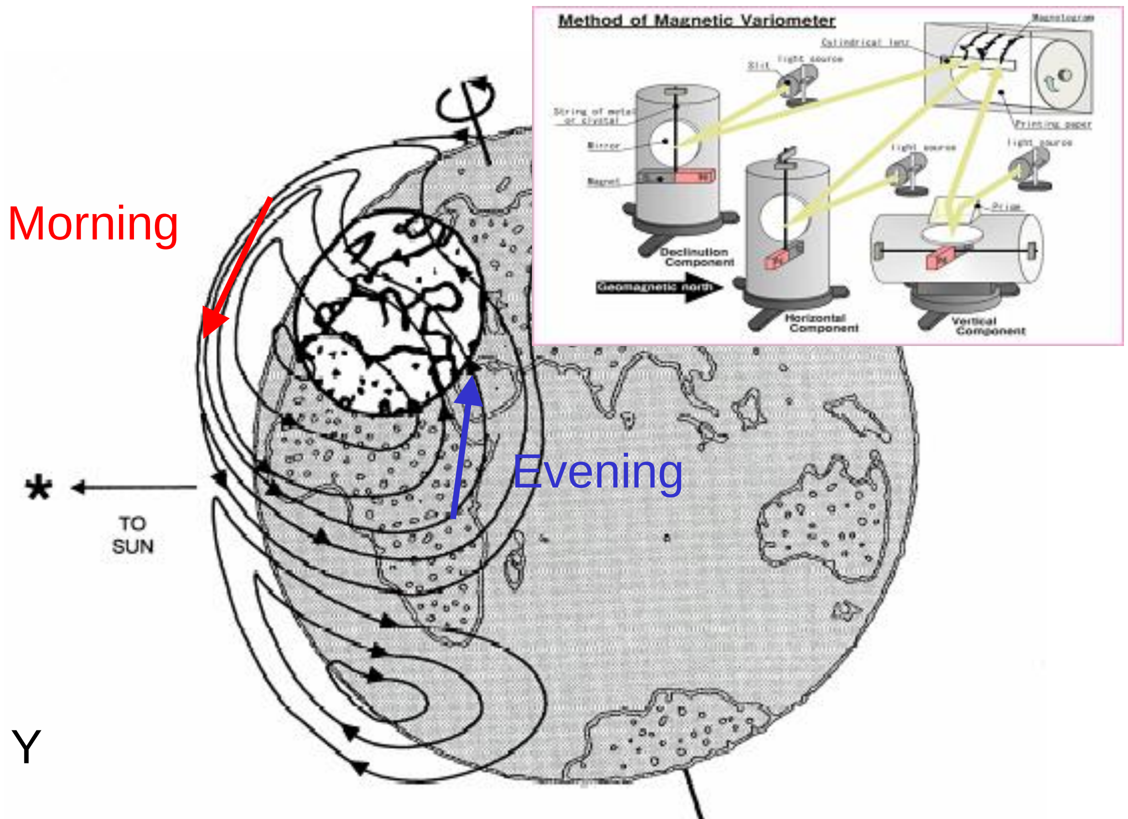
Wolf's Discovery: $rD = a + b\ R_W$



$Y = H \sin(D)$

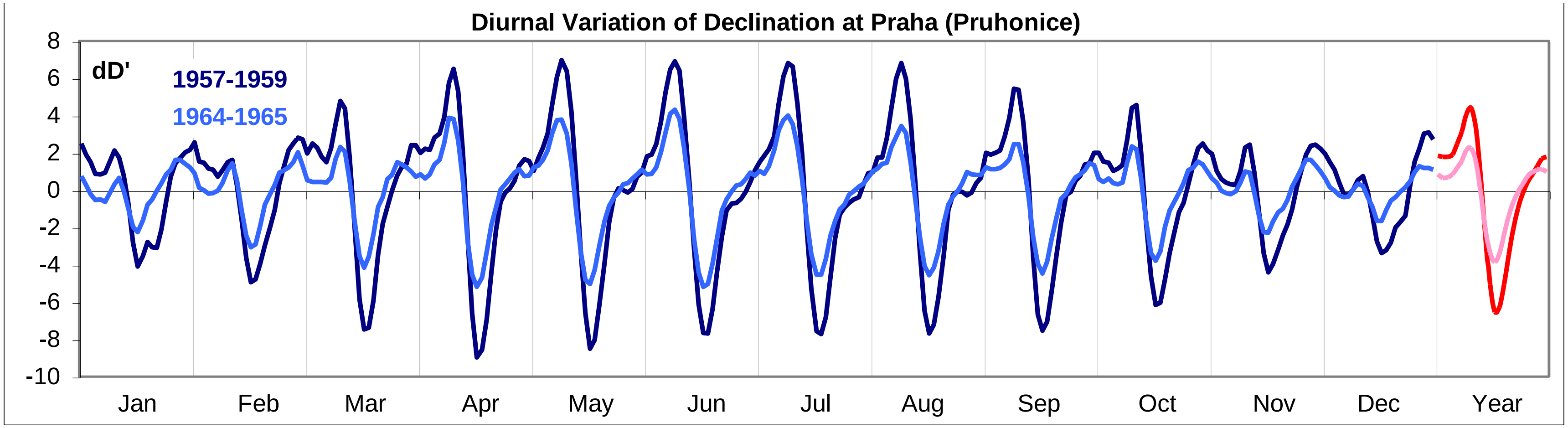
$dY = H \cos(D)\ dD$

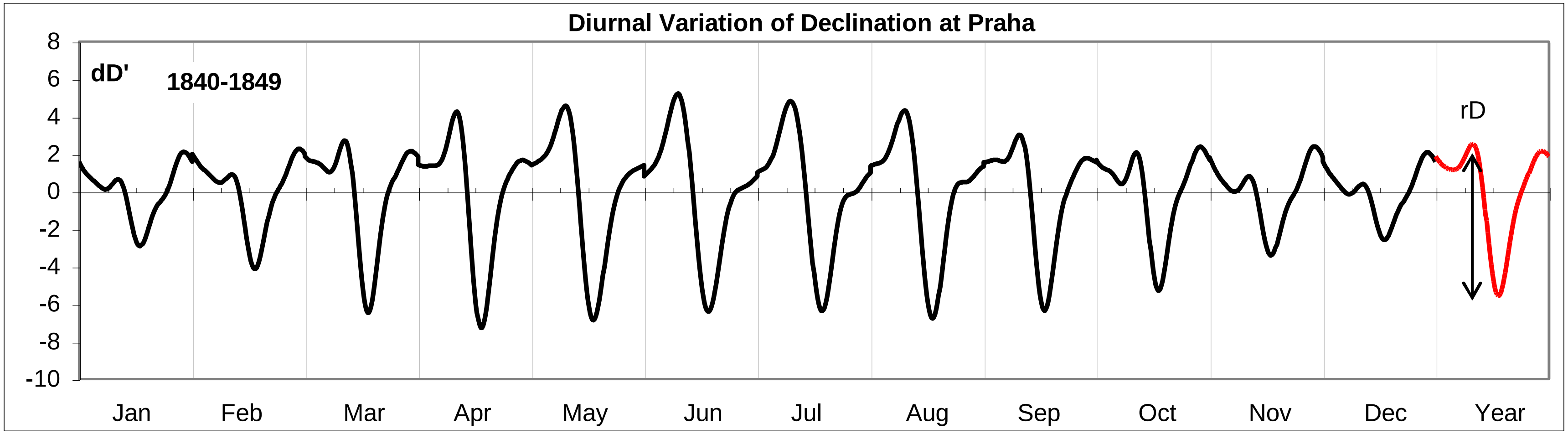
For small D, dD and dH



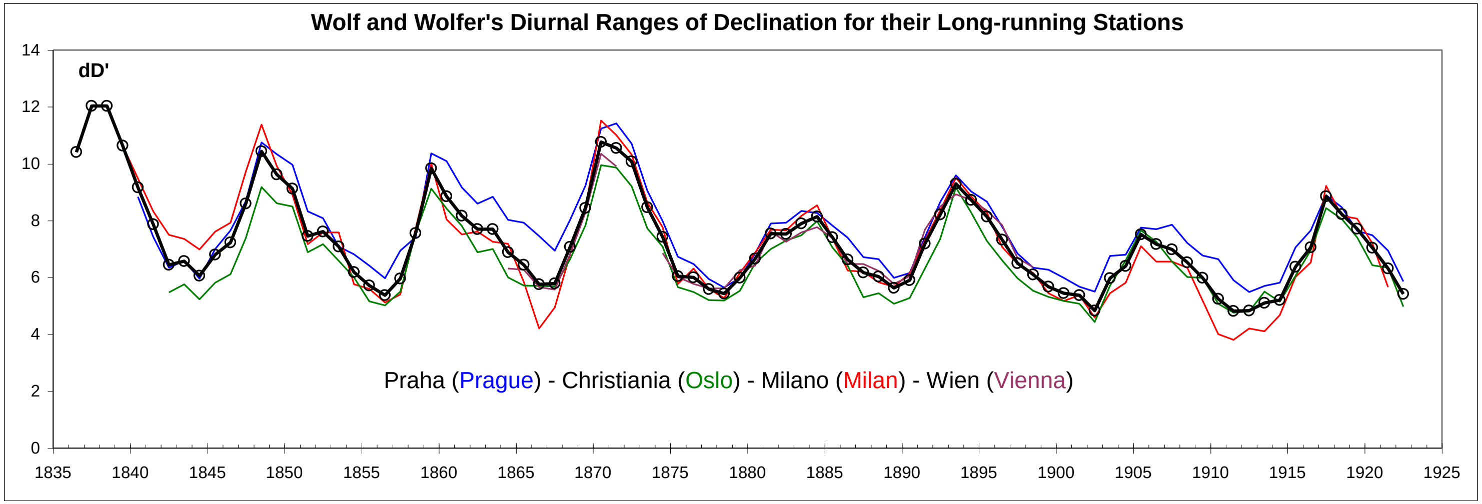
A current system in the ionosphere [E-layer] is created and maintained by solar FUV radiation. Its magnetic effect is measured on the ground. (George Graham, 1722)

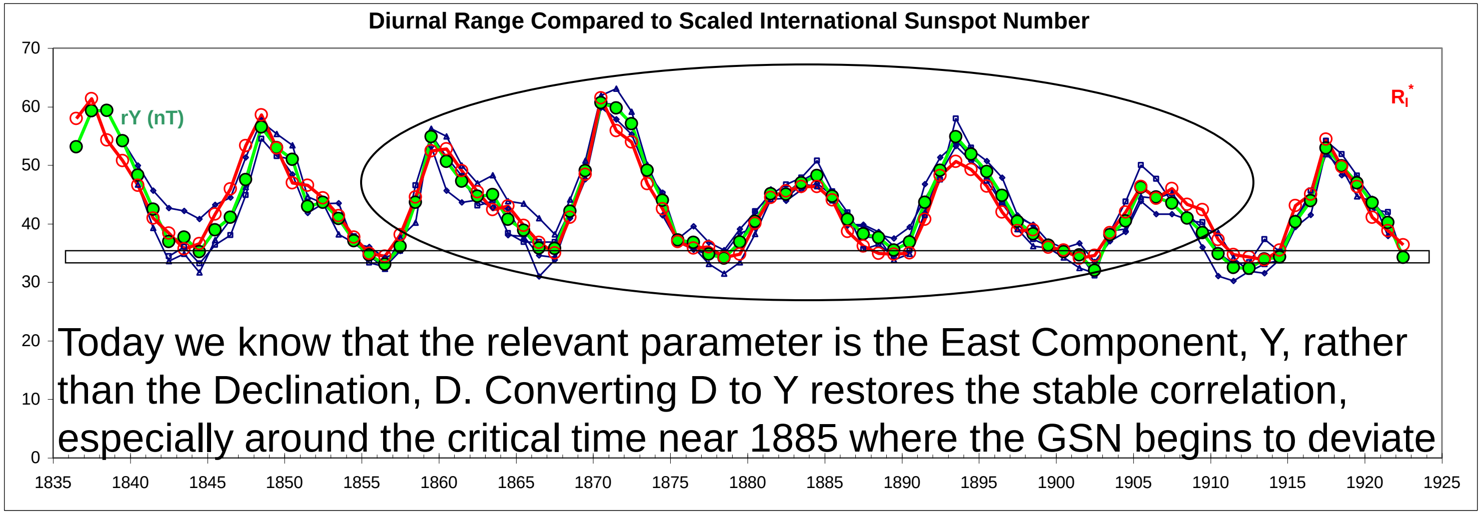
The Diurnal Variation of the Declination for Low, Medium, and High Solar Activity





Wolf’s Original Geomagnetic Data

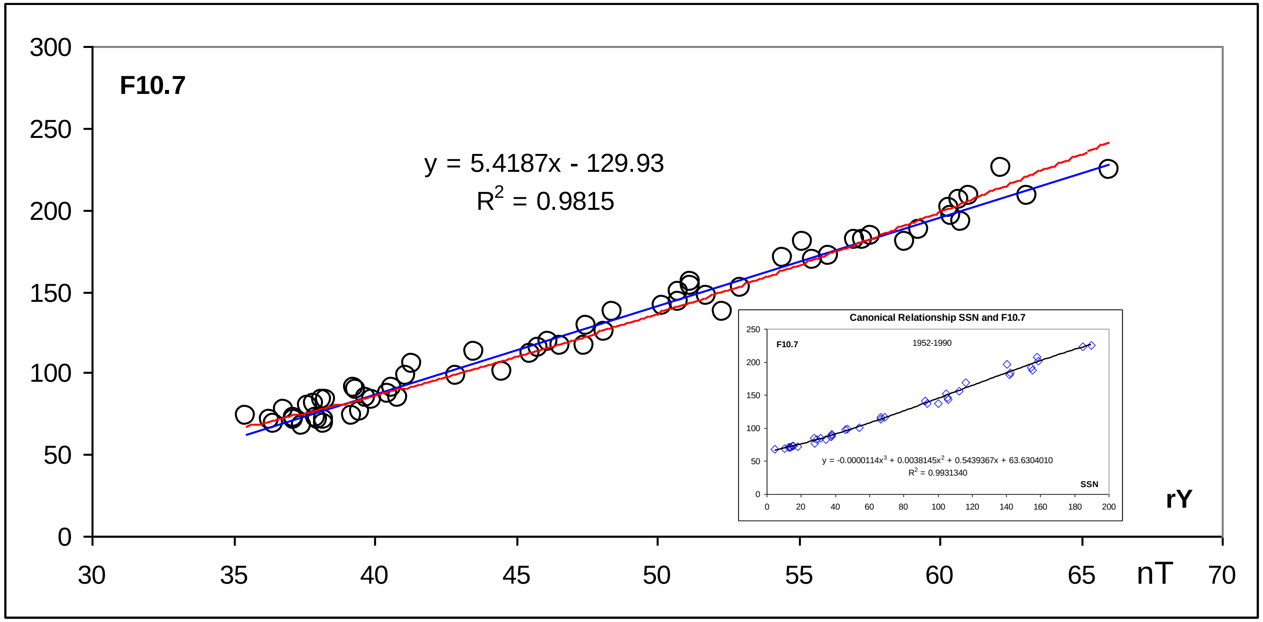




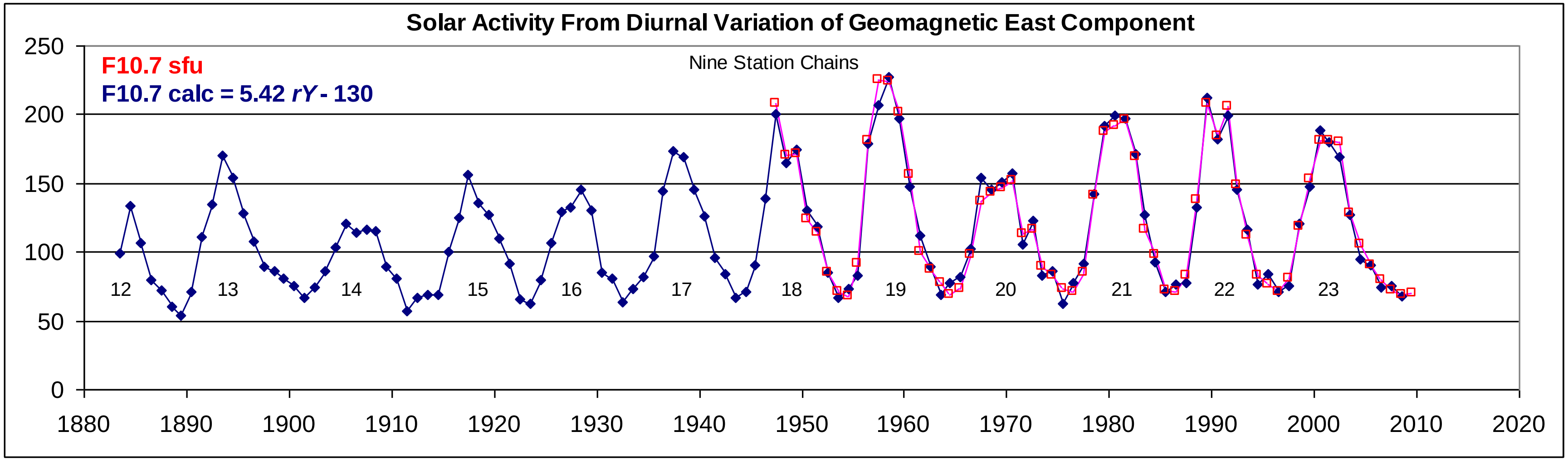
Wolf found a very strong correlation between his Wolf number and the daily range of the Declination.

Wolfer found the original correlation was not stable, but was drifting with time and gave up on it in 1923.

The geomagnetic response is just what we would expect from the Sunspot Number

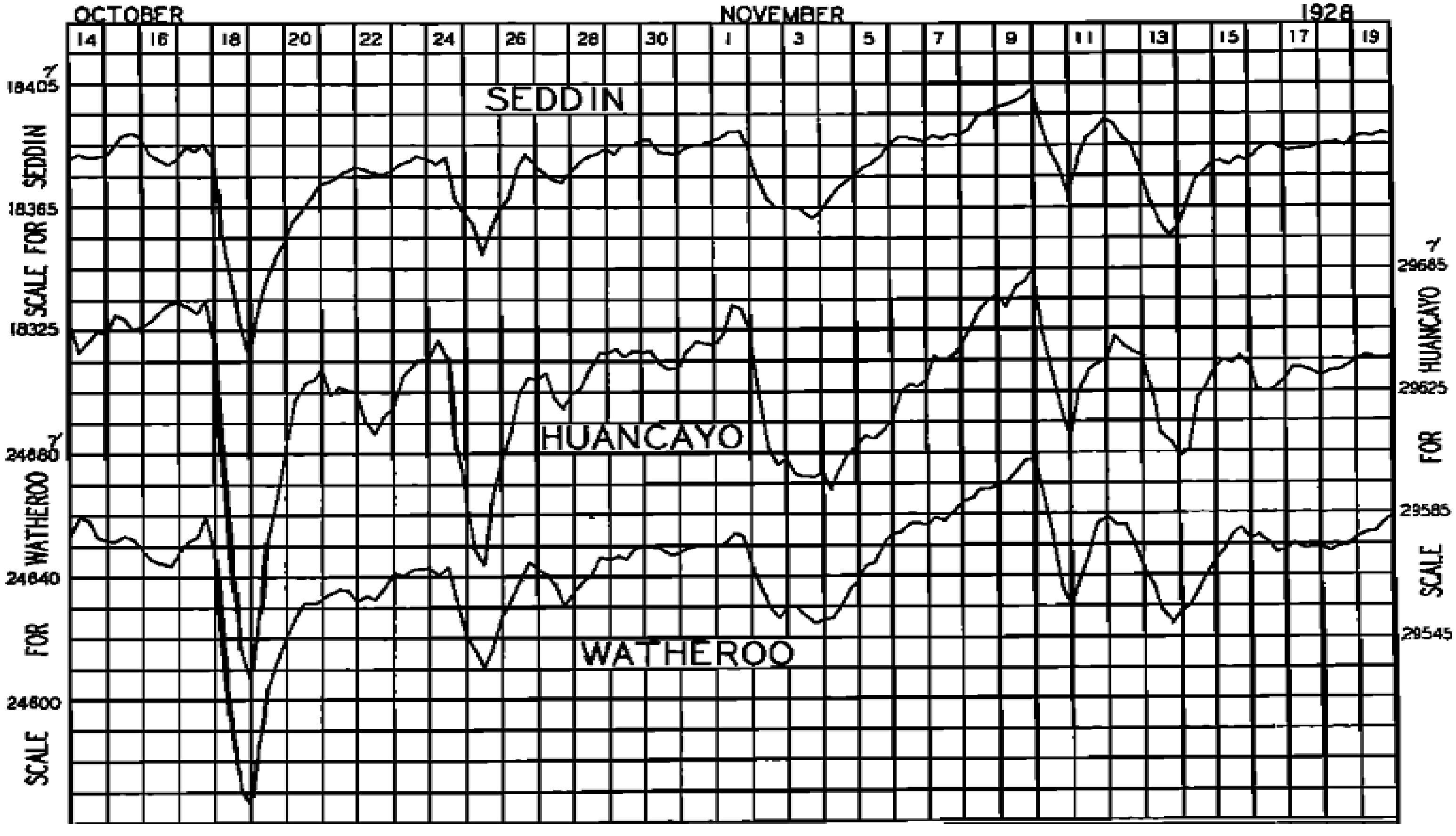


Using *rY* from nine station ‘chains’ we find that the correlation between *F10.7* and *rY* is extremely good (more than 98% of the variation is accounted for)



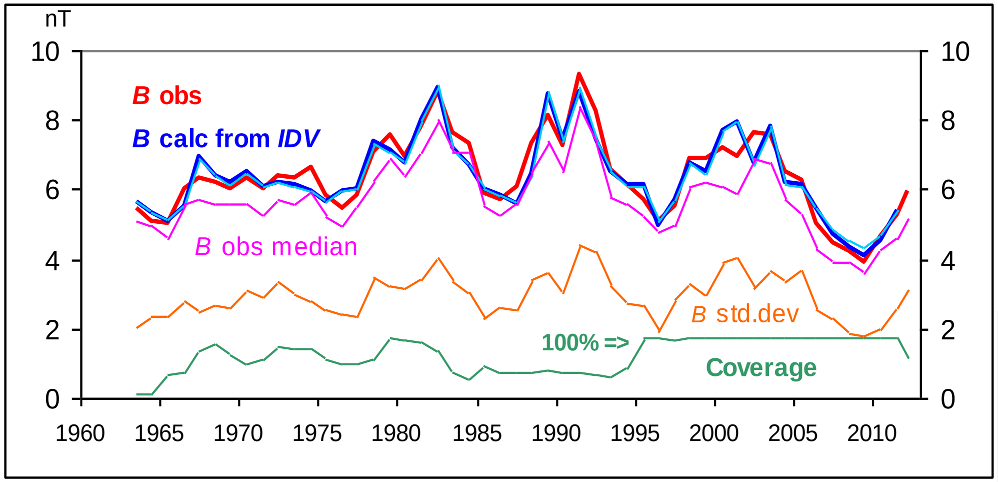
So, the geomagnetic diurnal variation is a good proxy for the F10.7 microwave flux

24-hour running means of the Horizontal Component of the low- & mid-latitude geomagnetic field remove most of local time effects and leaves a Global imprint of the Ring Current [Van Allen Belts]:

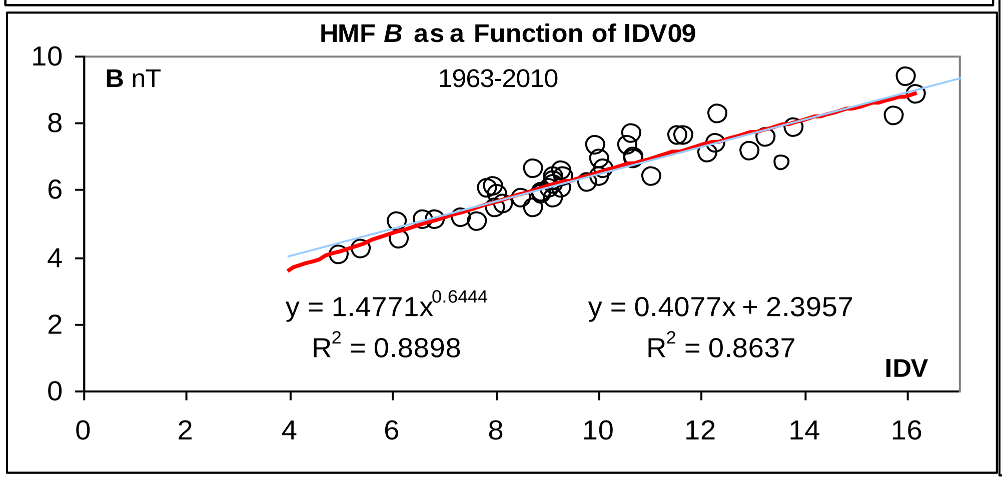


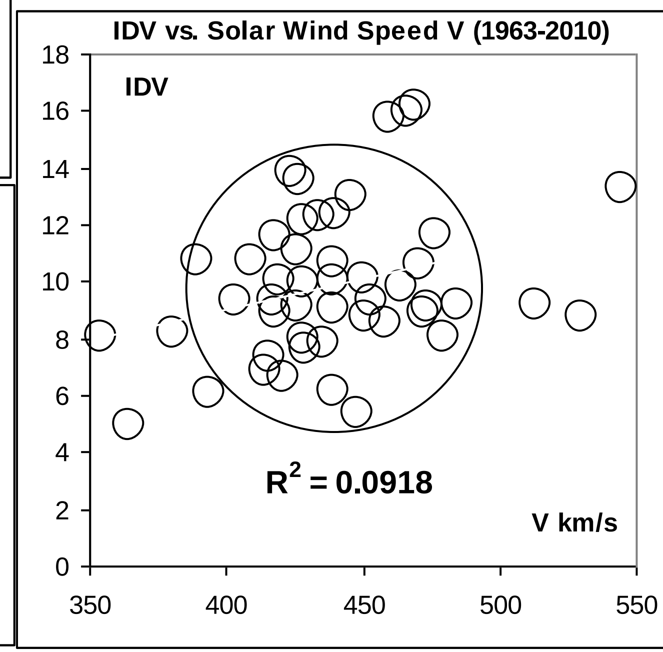
A quantitative measure of the effect can be formed as a series of the unsigned differences between consecutive days: The InterDiurnal Variability, IDV-index. Similar to Bartels' *u*-index and the 'Nachstörung' popular a century ago.

IDV is strongly correlated with solar wind magnetic field *B*, but is blind to solar wind speed *V*

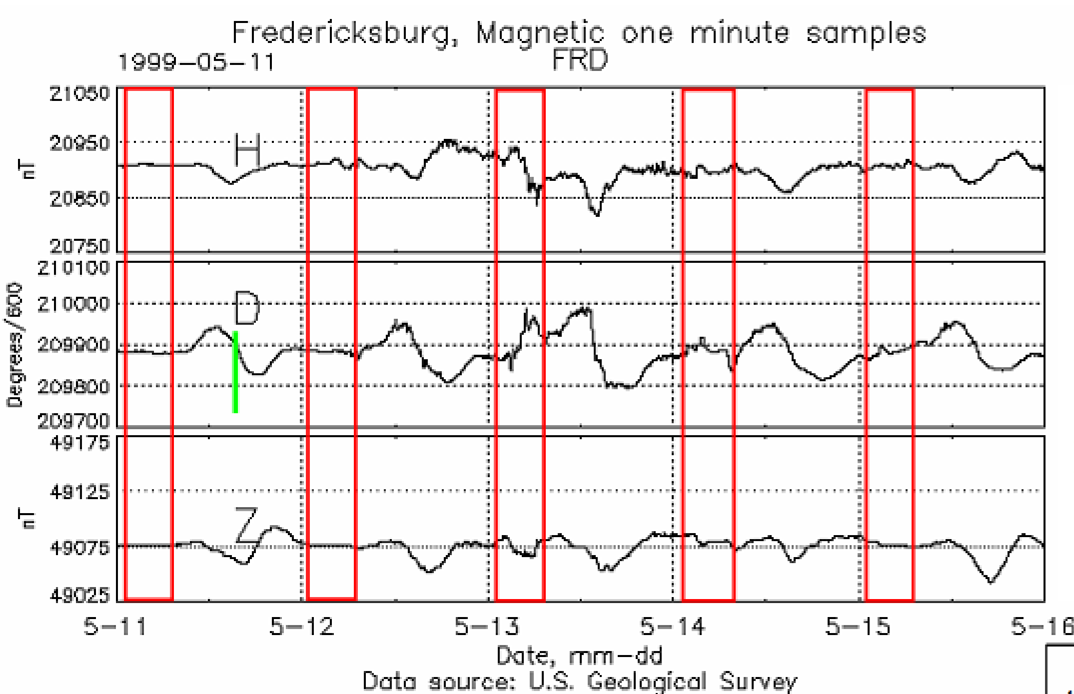


So, from IDV we can get HMF B

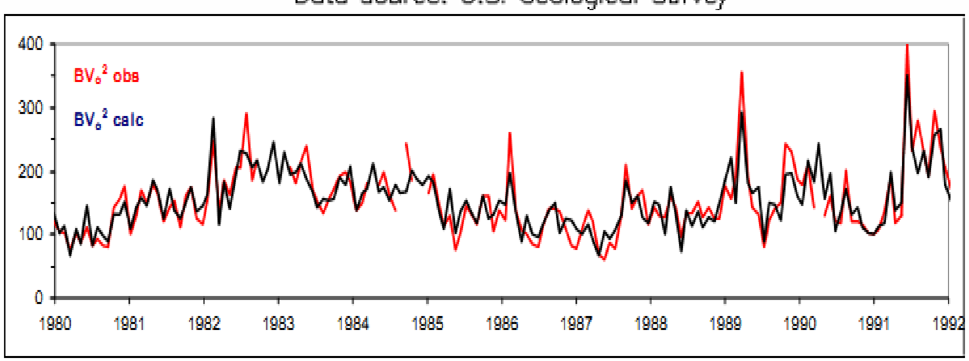


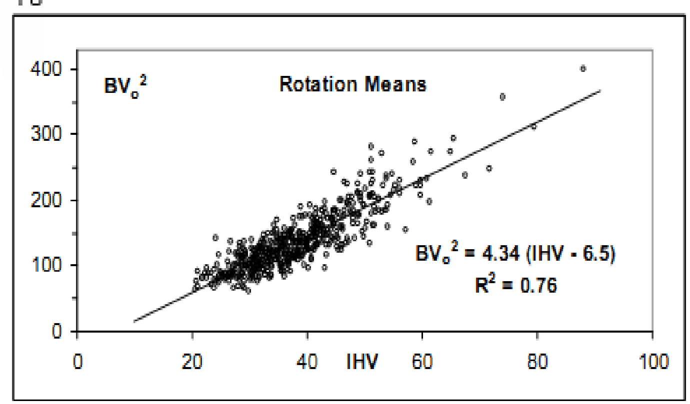


The *IHV* Index gives us BV^2

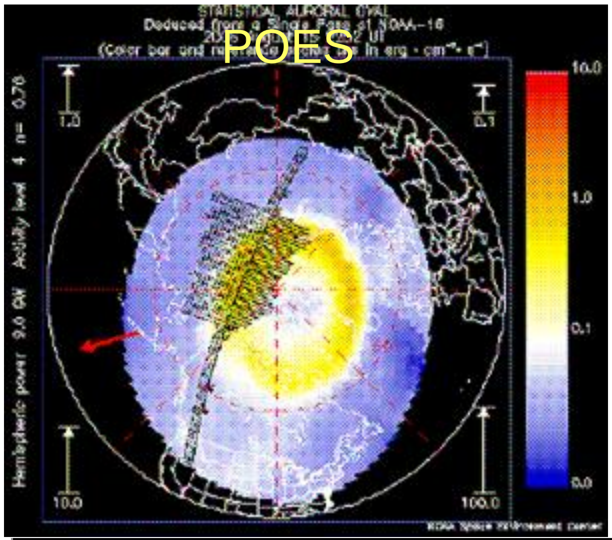


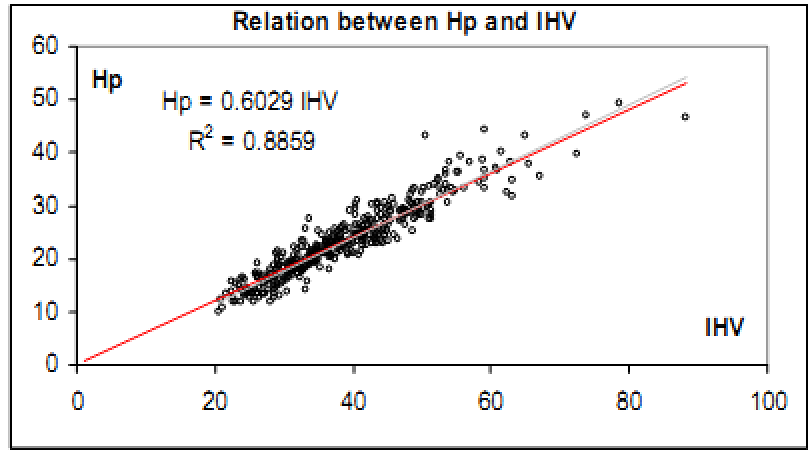
Calculating the variation (sum of unsigned differences from one hour to the next) of the field during the night hours [red boxes] from simple hourly means (the Interhourly Variation) gives us a quantity that correlates with BV^2 in the solar wind

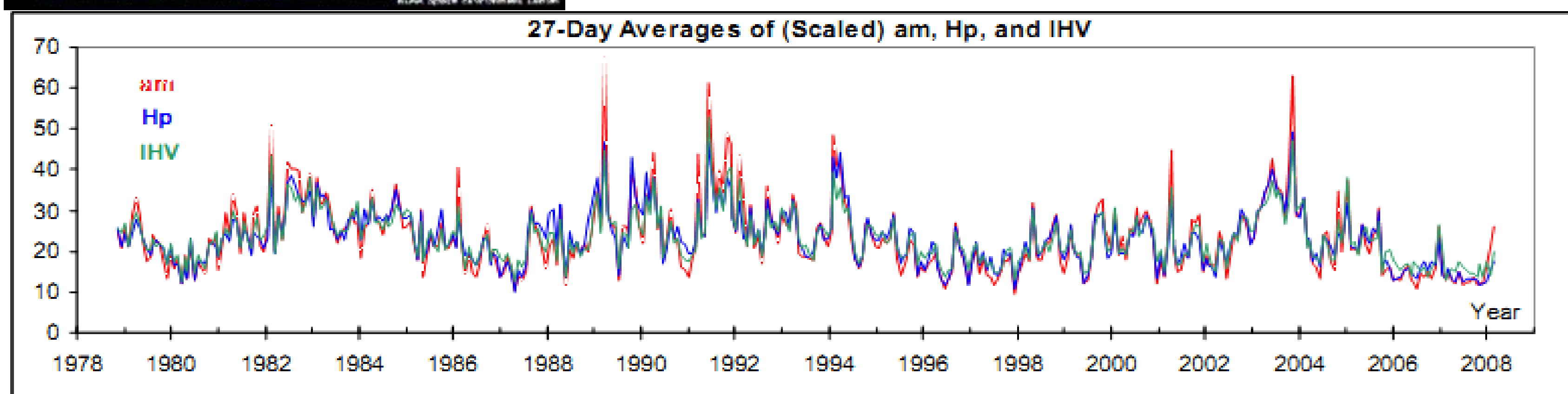




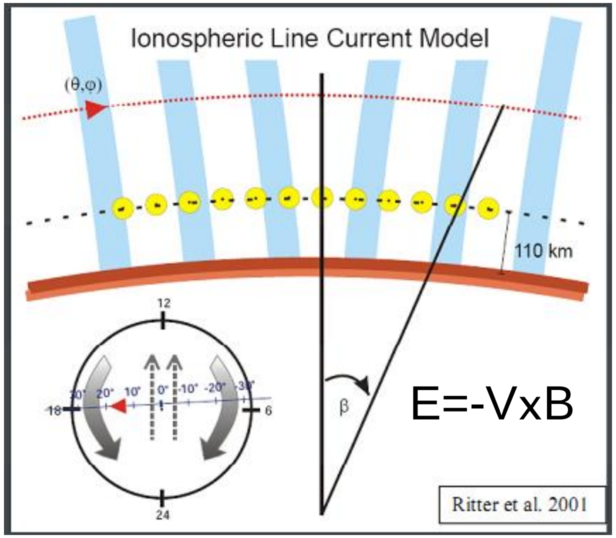
Physical meaning of IHV: the index is directly proportional to the auroral power input, HP, to the polar regions

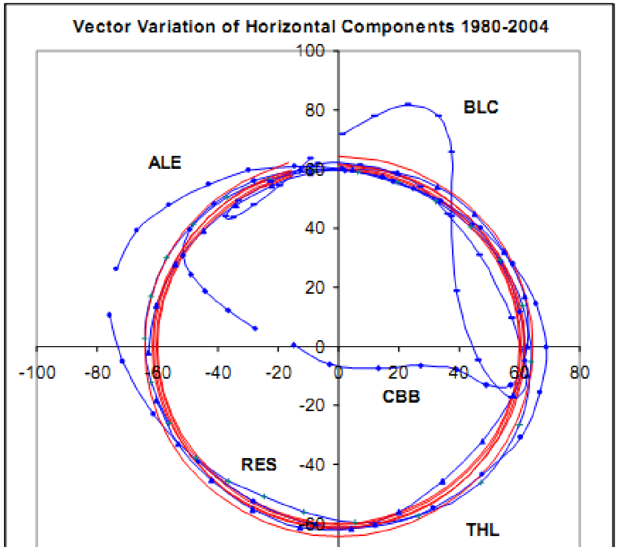


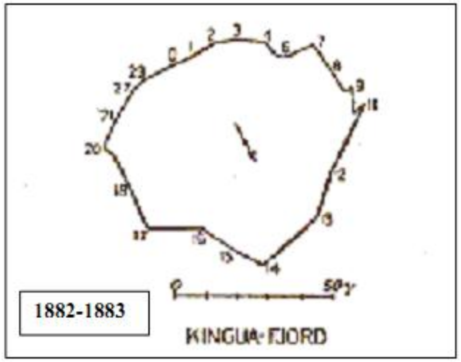




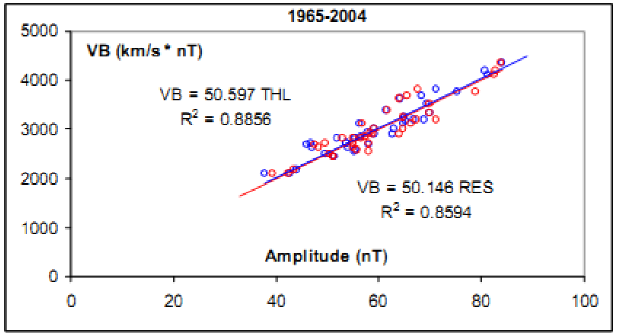
Polar Cap Diurnal Variation gives us V times B

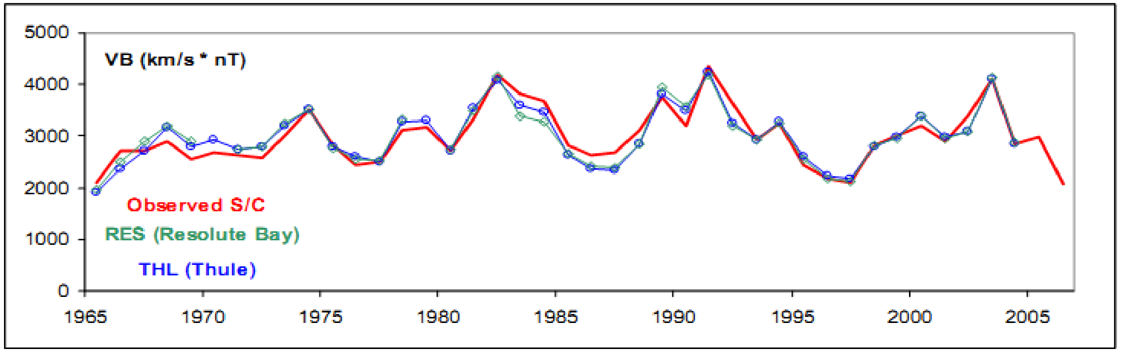




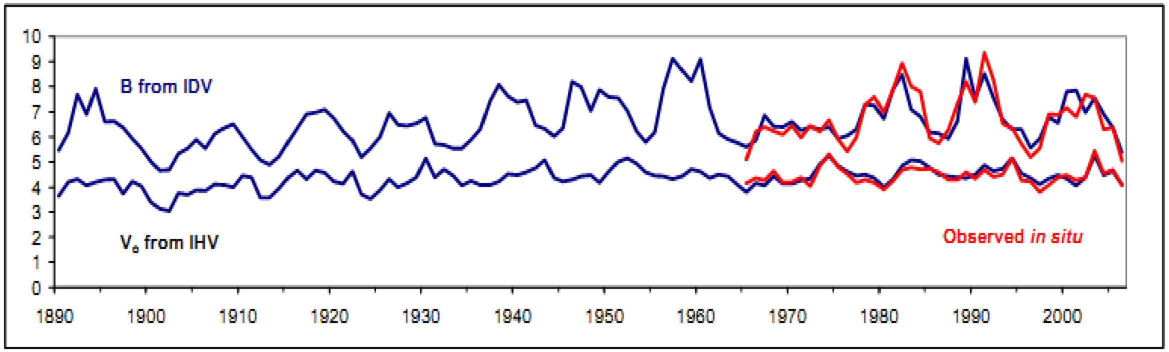


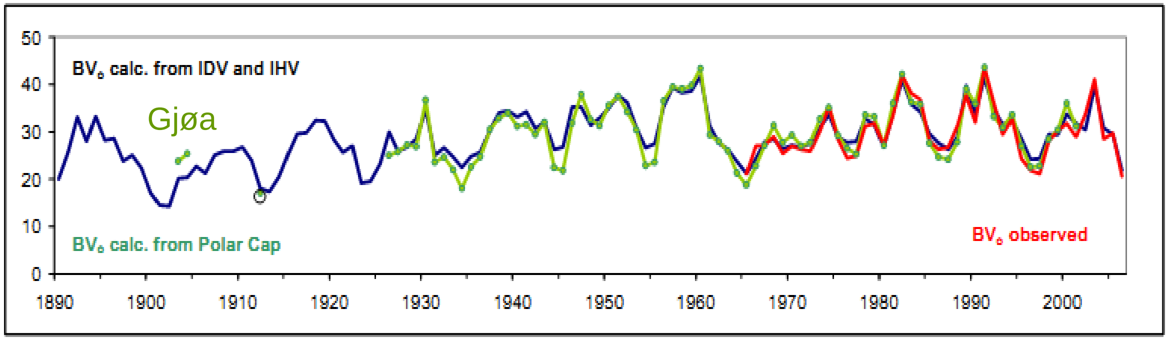
This variation has been known for more than 125 years





Overdetermined System: 3 Eqs, 2 Unknowns



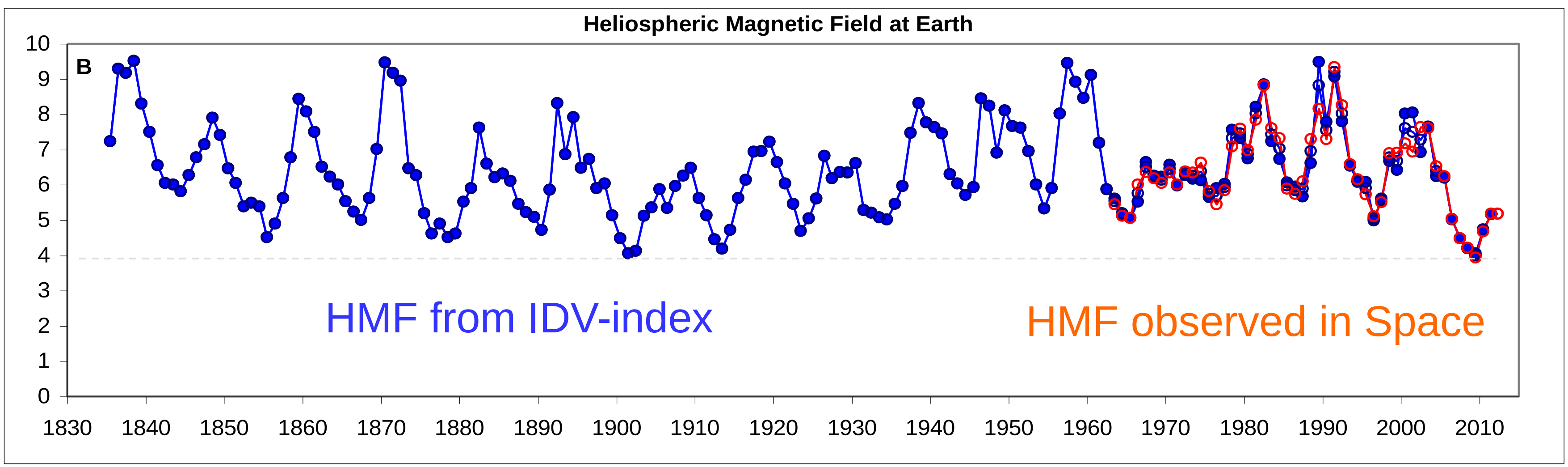


$B \quad = p\ (IDV)$

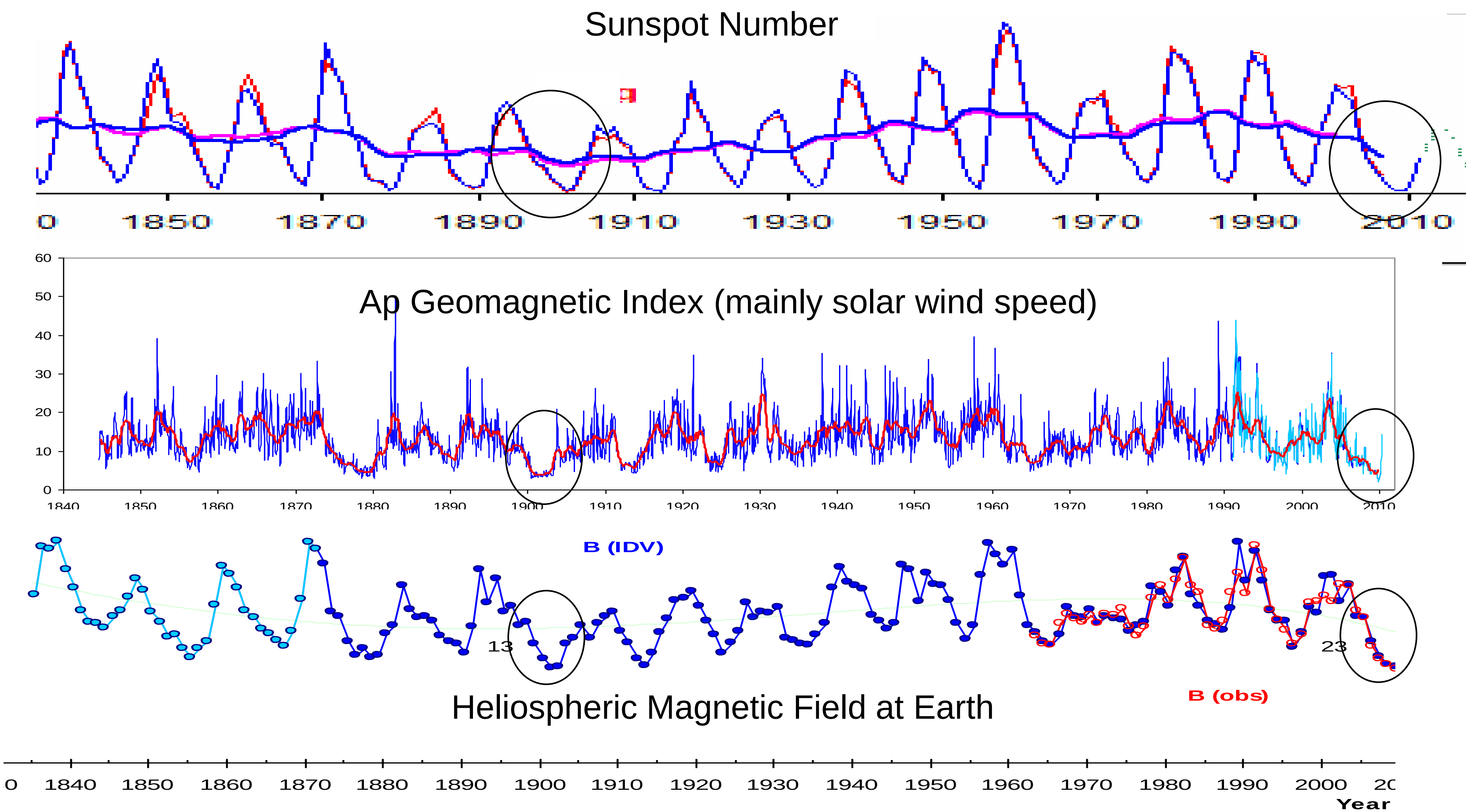
$BV^2 = q\ (IHV)$

$VB \quad = r\ (PCap)$

Here is B back to the 1830s:

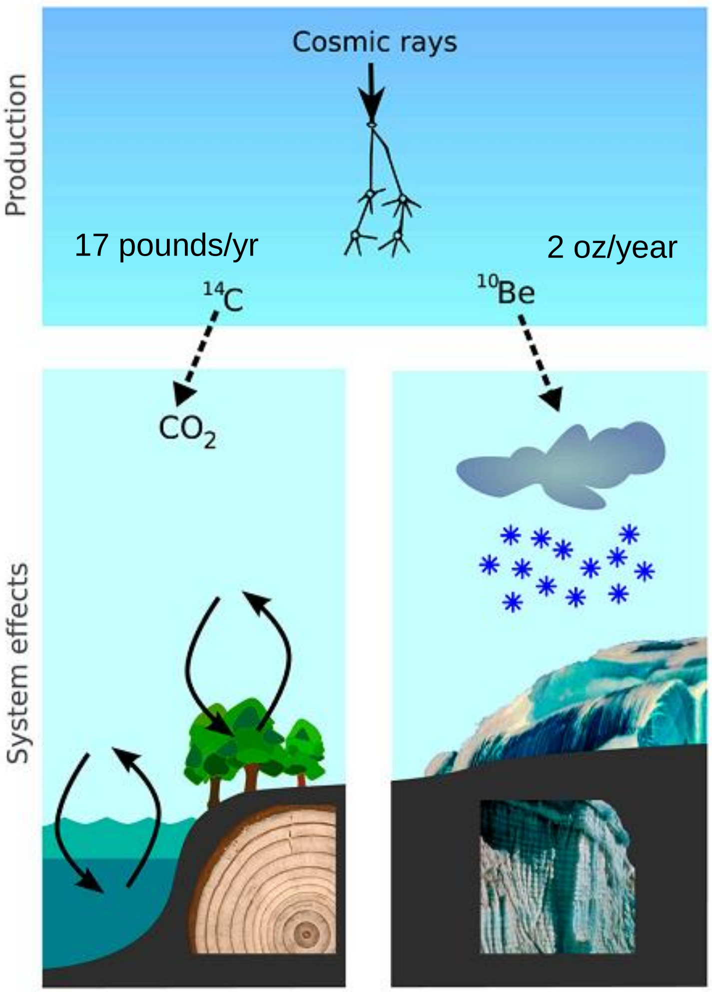


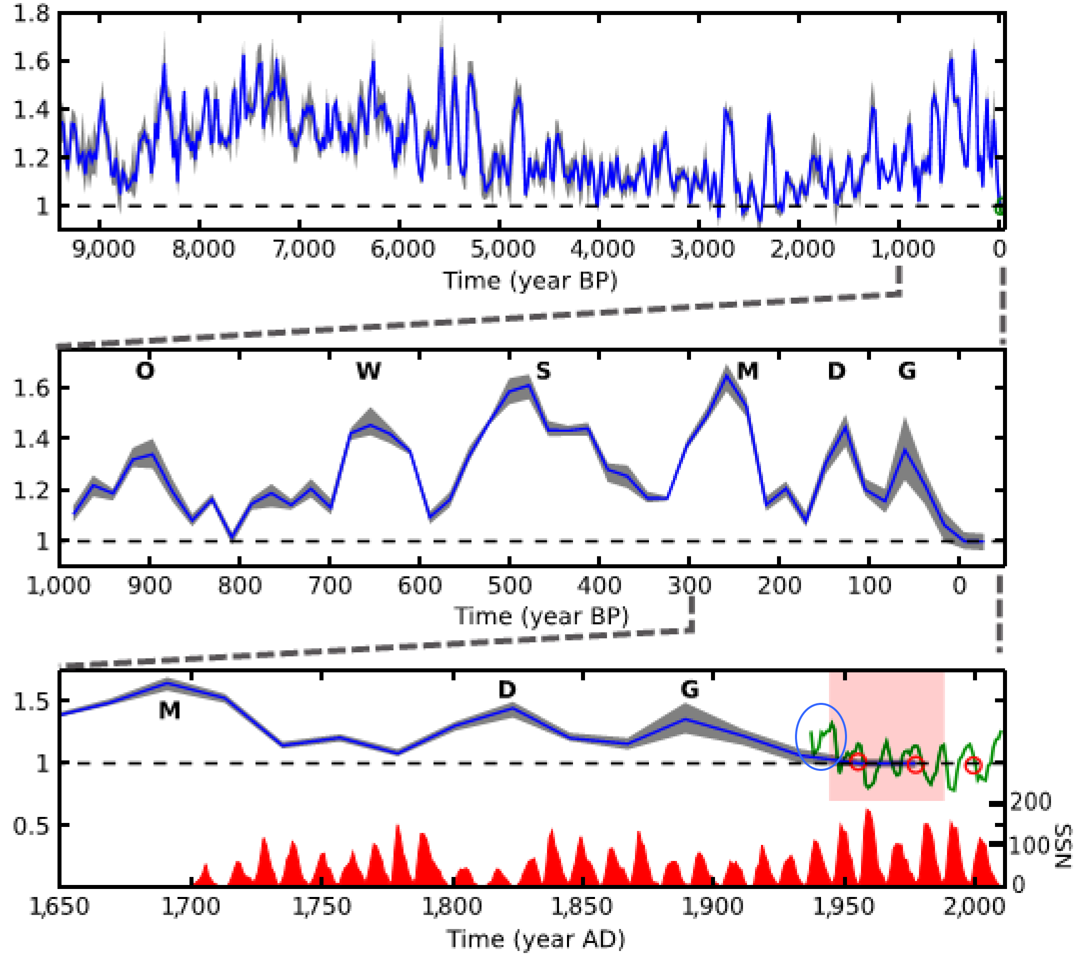
Solar Activity 1835-2012



Activity now is similar to what it was a century ago

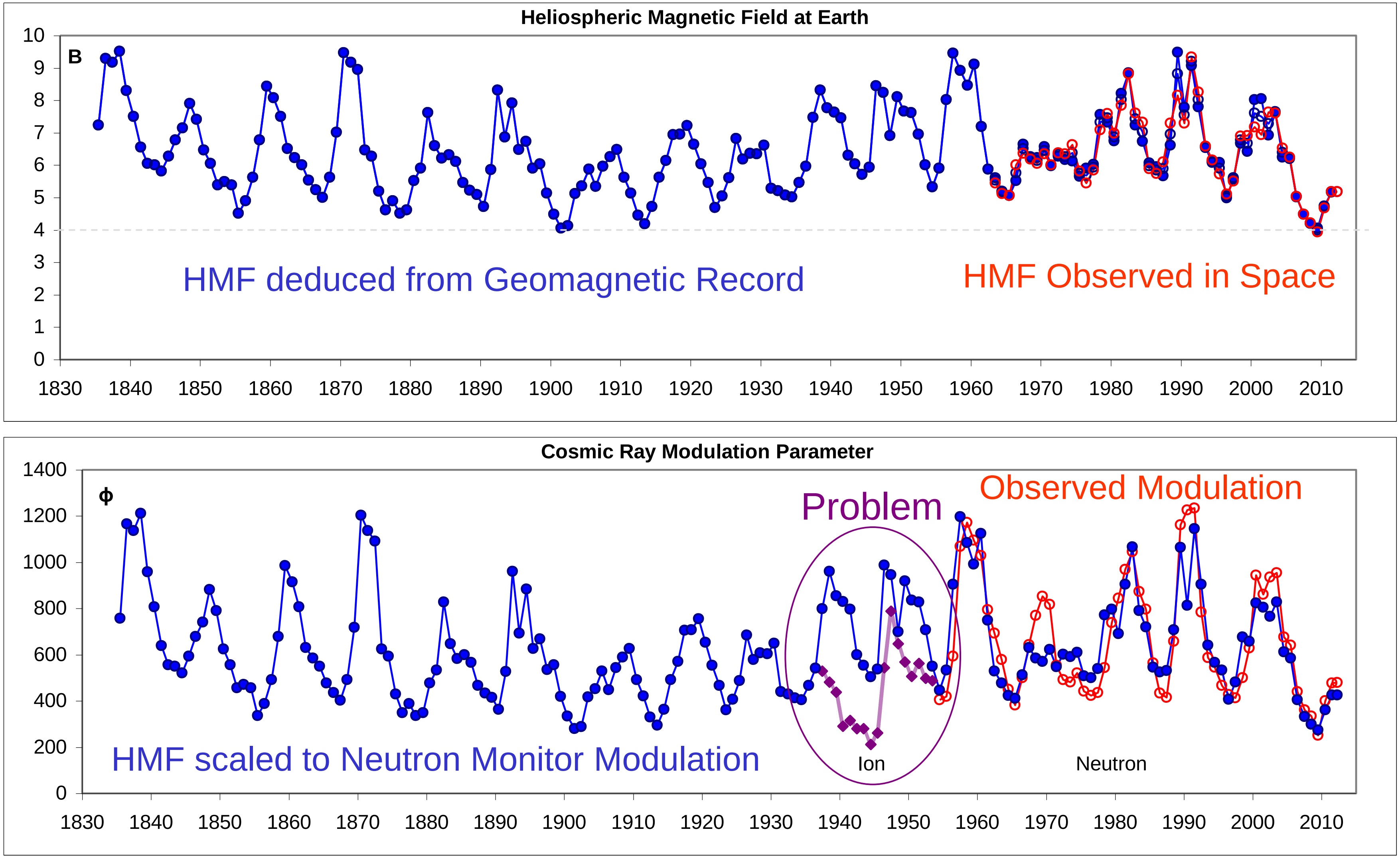
The Cosmic Ray Record is also a Proxy for Solar Activity, but there are Problems

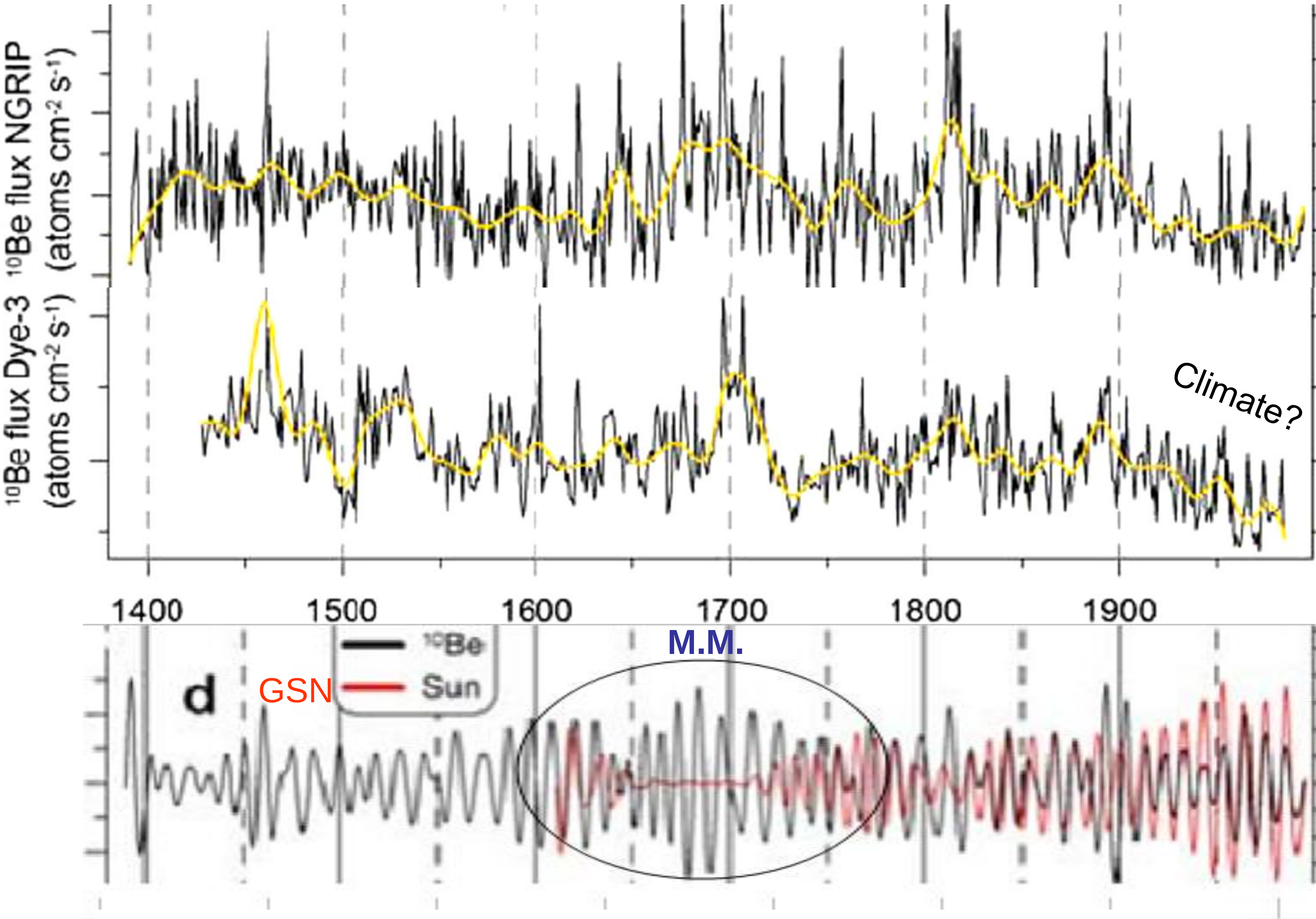




Steinhilber et al. 2012

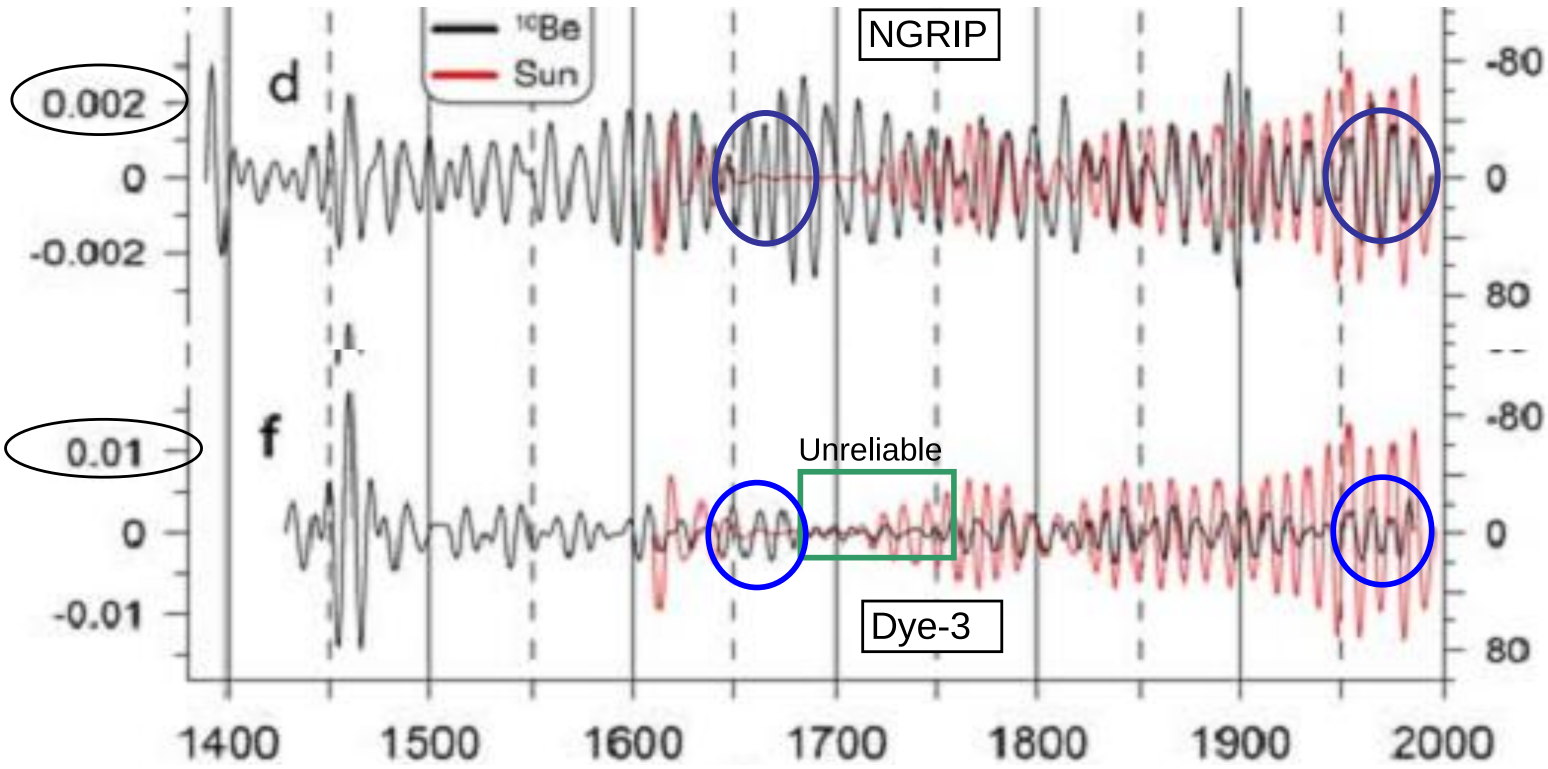
Cosmic Ray Modulation as Governed by Strength of Magnetic Field in Heliosphere





Cosmic Ray Proxy [Berggren et al.]

NGRIP is better than Dye-3



Note scale difference by factor of 5. Dye-3 has problems between 1680-1770.

The Figures show the Flux of the 10Be atoms, not the Concentration.

‘Burning Prairie’ => Magnetism

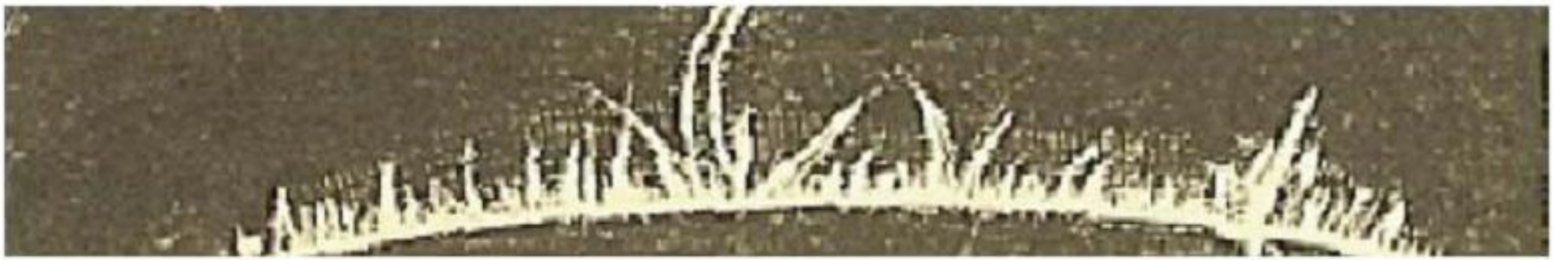


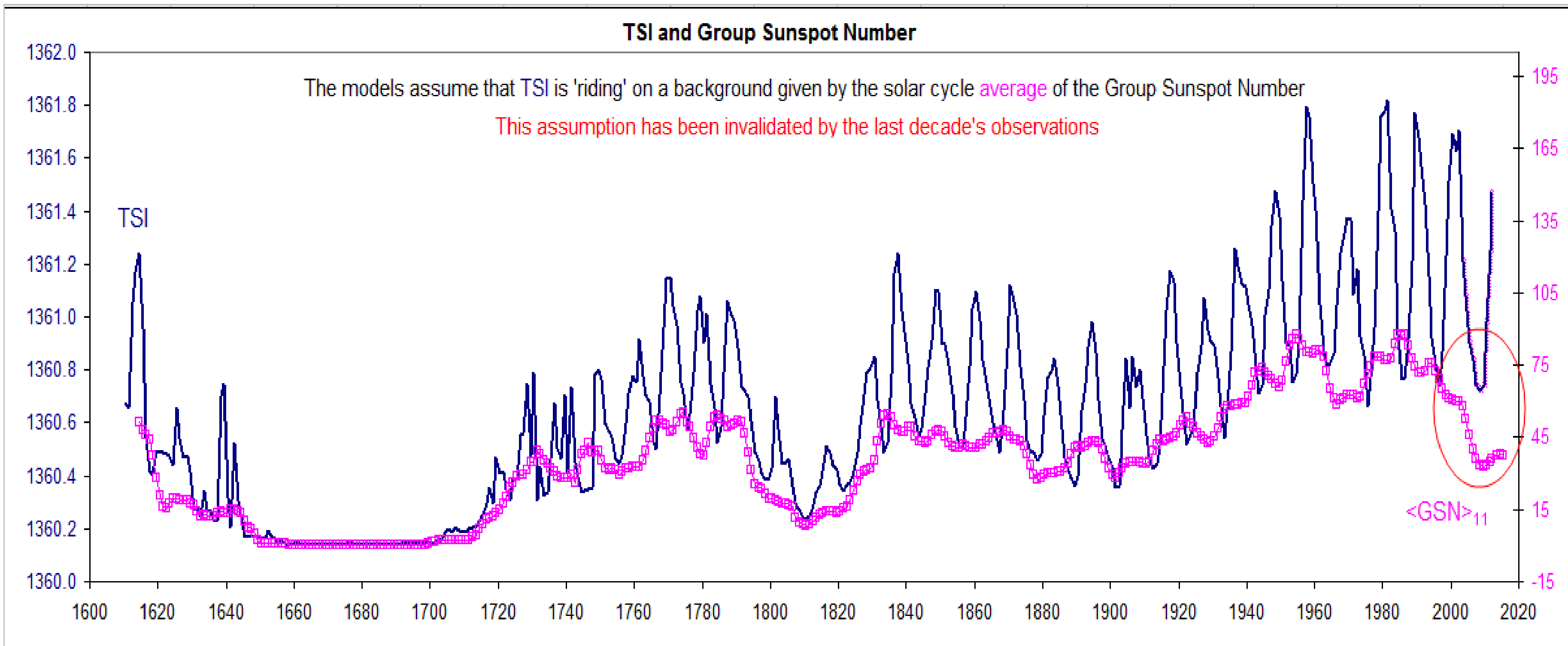
Figure 1 An early drawing of the “burning prairie” appearance of the Sun’s limb made by C.A. Young, on 25 July 1872. All but the few longest individual radial structures are spicules.

It is now well known (see, *e.g.*, the overview in Foukal, 2004) that the spicule jets move upward along magnetic field lines rooted in the photosphere outside of sunspots. Thus the observation of the red flash produced by the spicules requires the presence of widespread solar magnetic fields. Historical records of solar eclipse observations provide the first known report of the red flash, observed by Stannyan at Bern, Switzerland, during the eclipse of 1706 (Young, 1883). The second observation, at the 1715 eclipse in England, was made by, among others, Edmund Halley – the Astronomer Royal. These first observations of the red flash imply that a significant level of solar magnetism must have existed even when very few spots were observed, during the latter part of the Maunder Minimum.

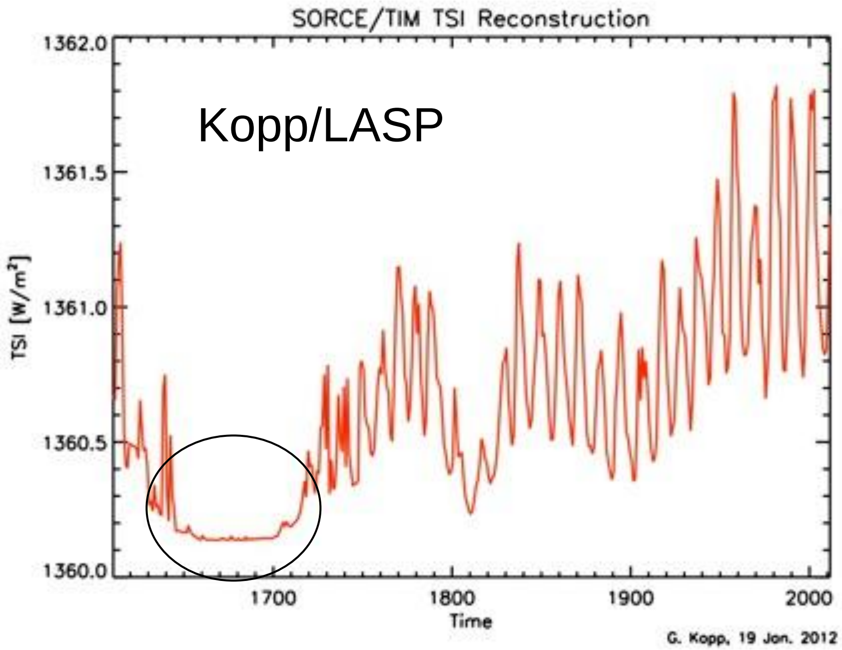
Foukal & Eddy, Solar Phys. 2007, *245*, 247-249

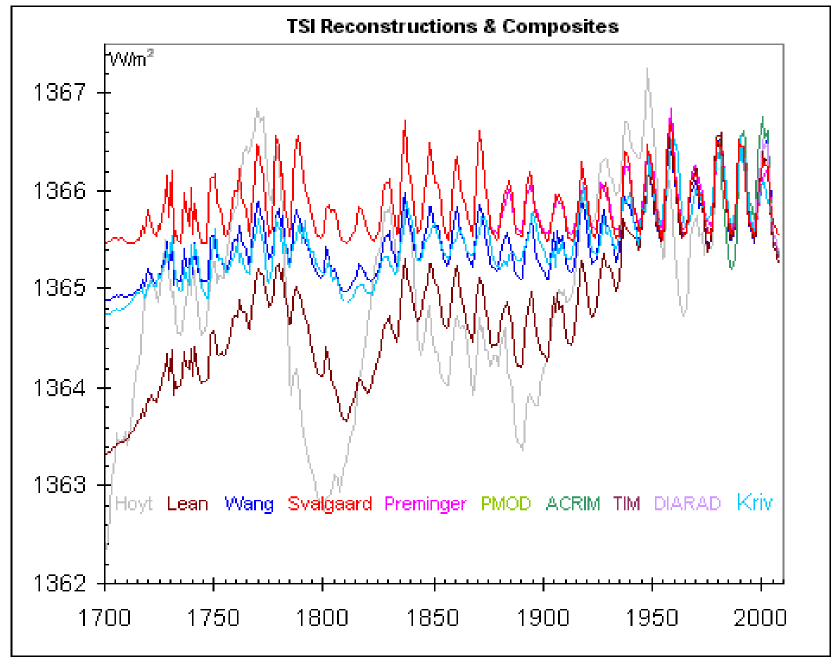
Removing the discrepancy between the Group Number and the Wolf Number removes the ‘background’ rise in reconstructed TSI

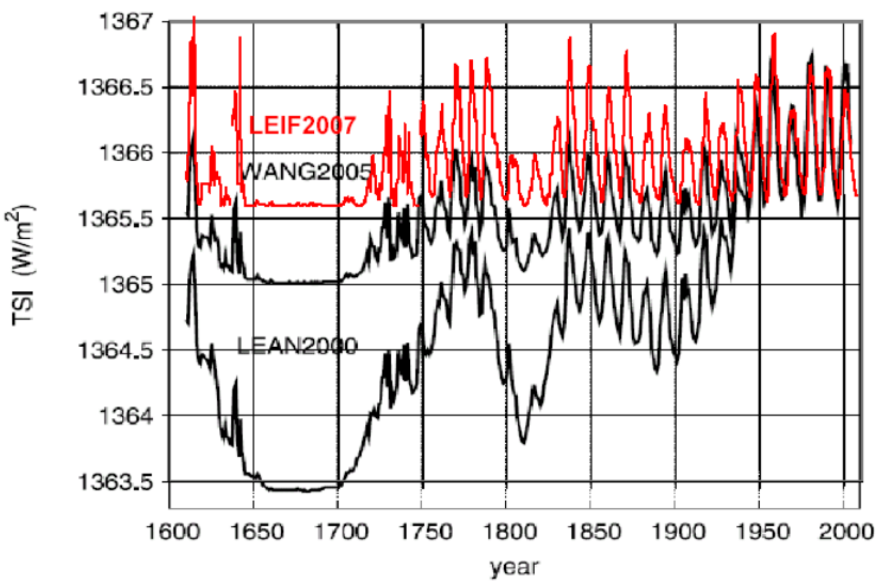
I expect a strong reaction against ‘fixing’ the GSN from people that ‘explain’ climate change as a secular rise of TSI and other related solar variables



Some More TSI Reconstructions

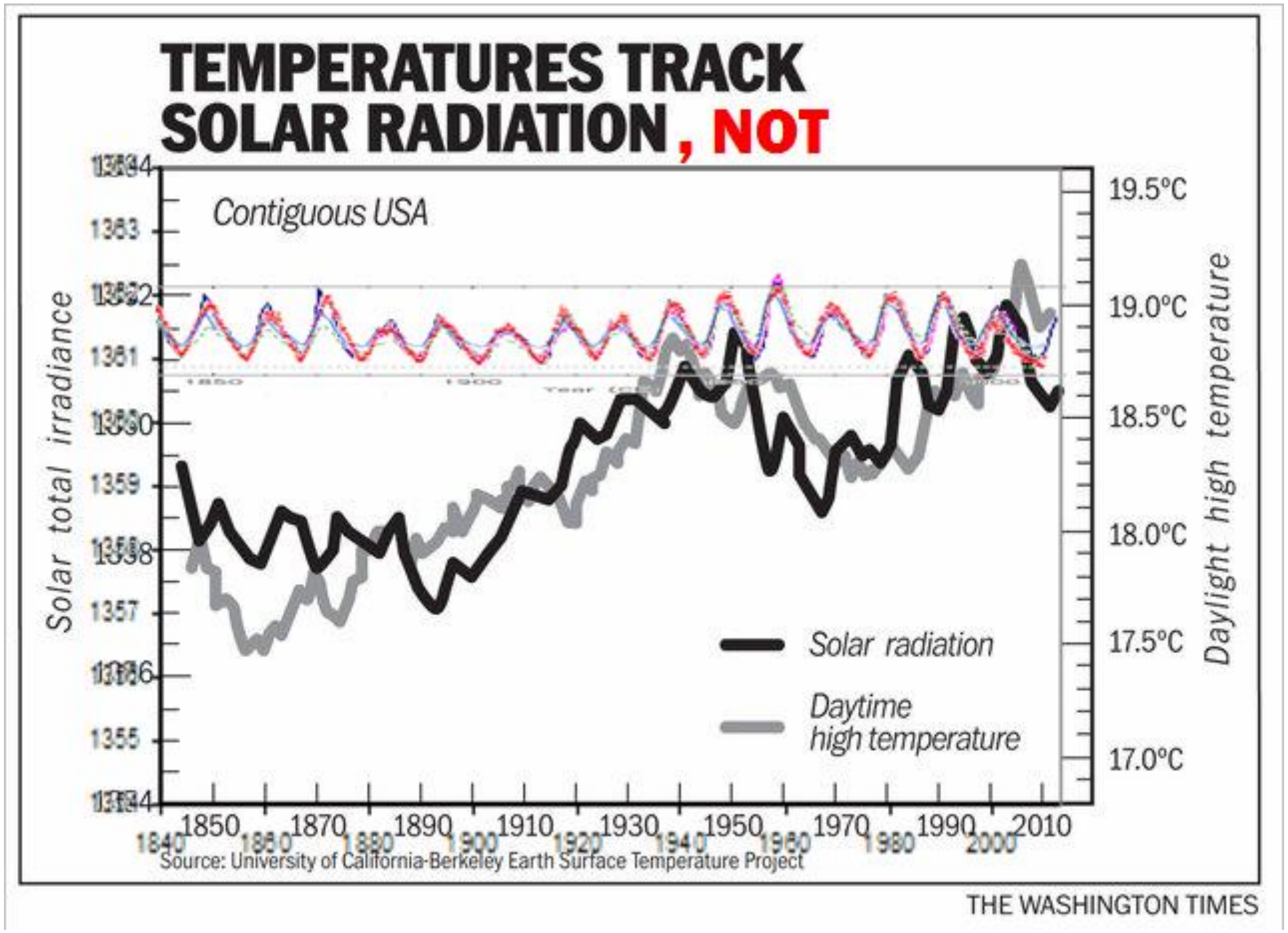






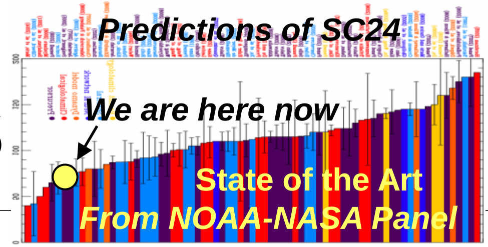
Crucial question: is there a slowly varying background? I think not.

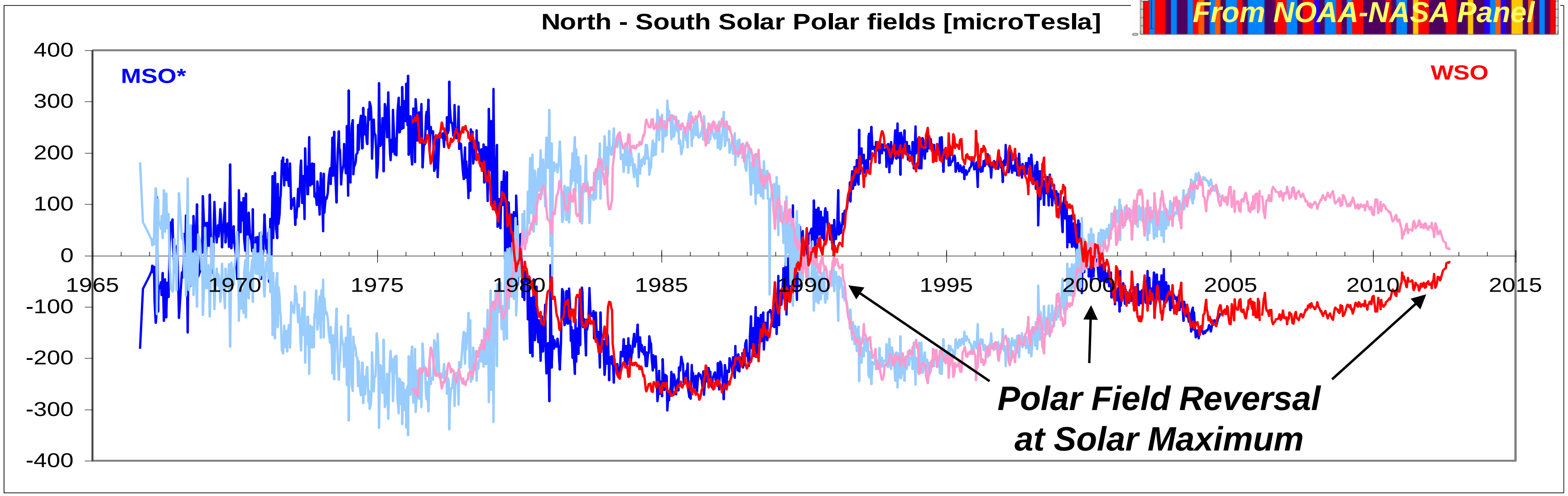
Who Cares?

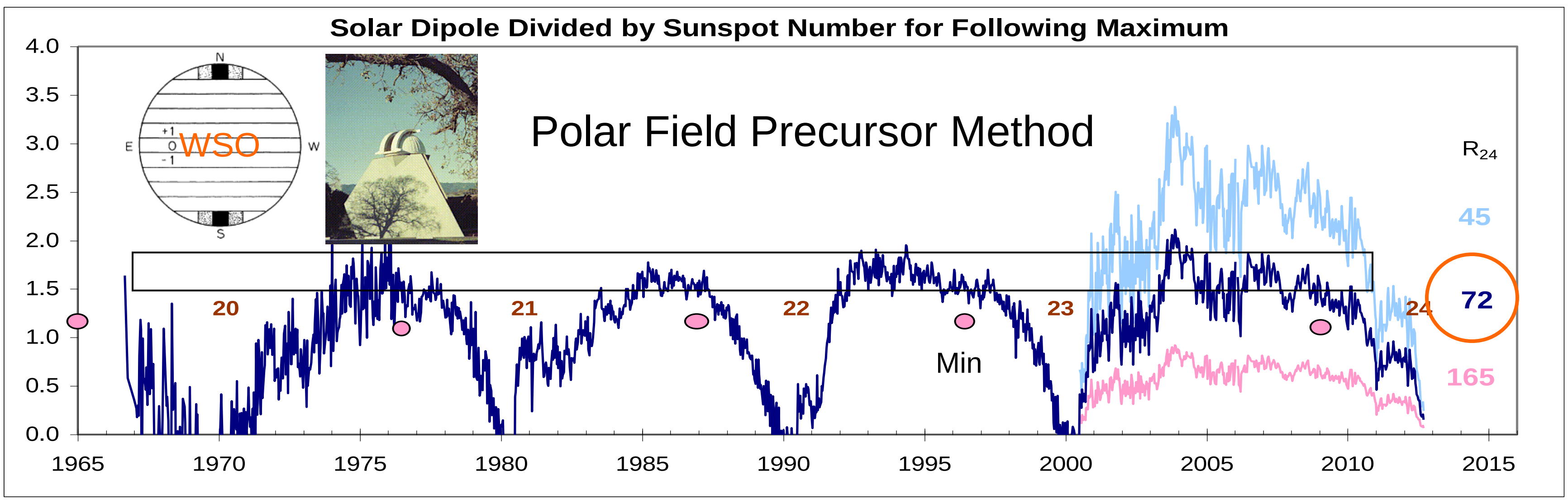


The Public cares!

Prediction of Solar Cycles

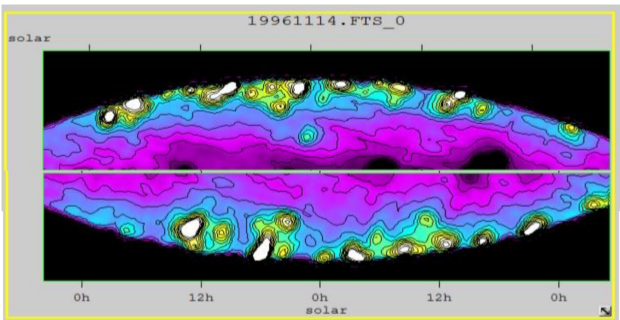


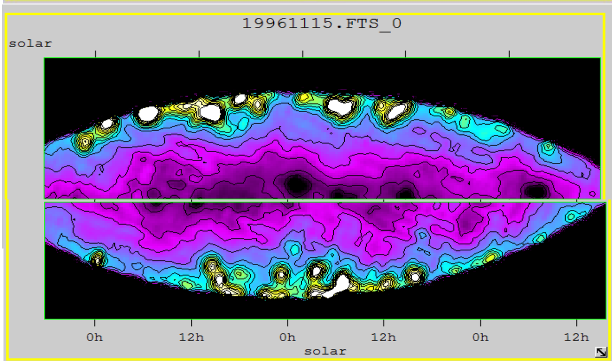


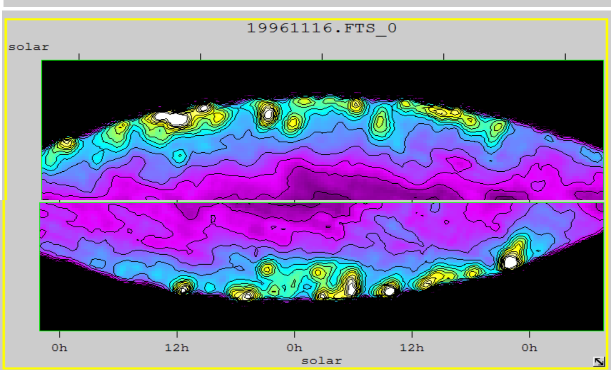


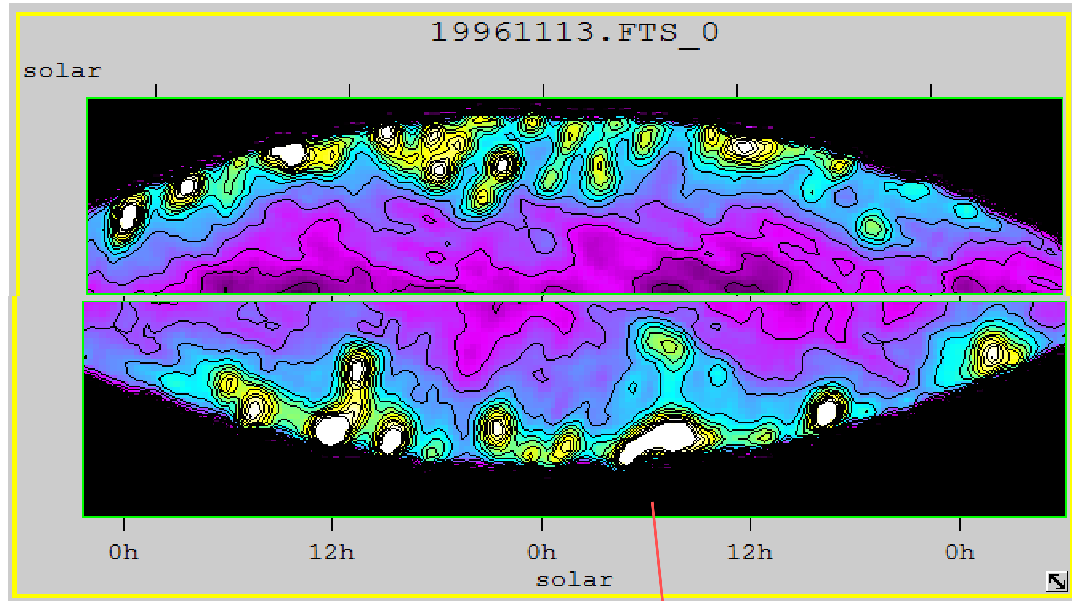
Polar Concentrations in 17 GHz Radioflux from Nobeyama

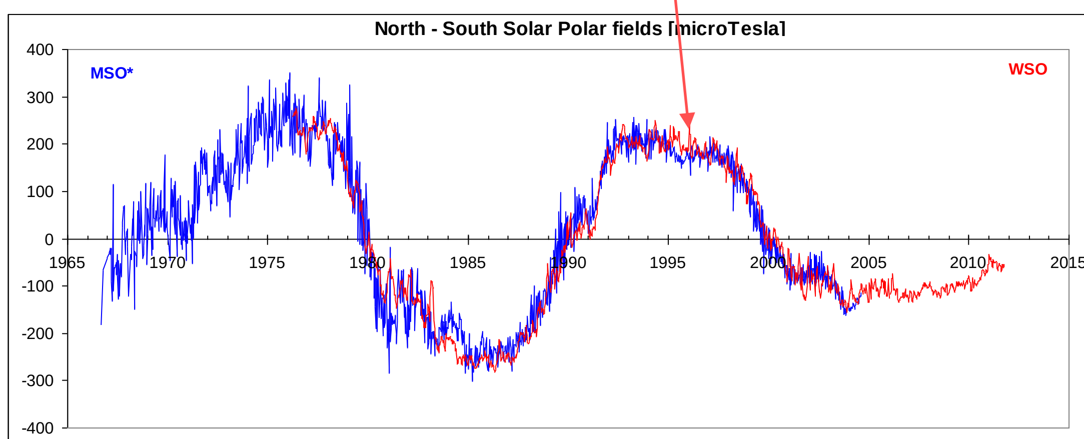
Rotate and long-lived



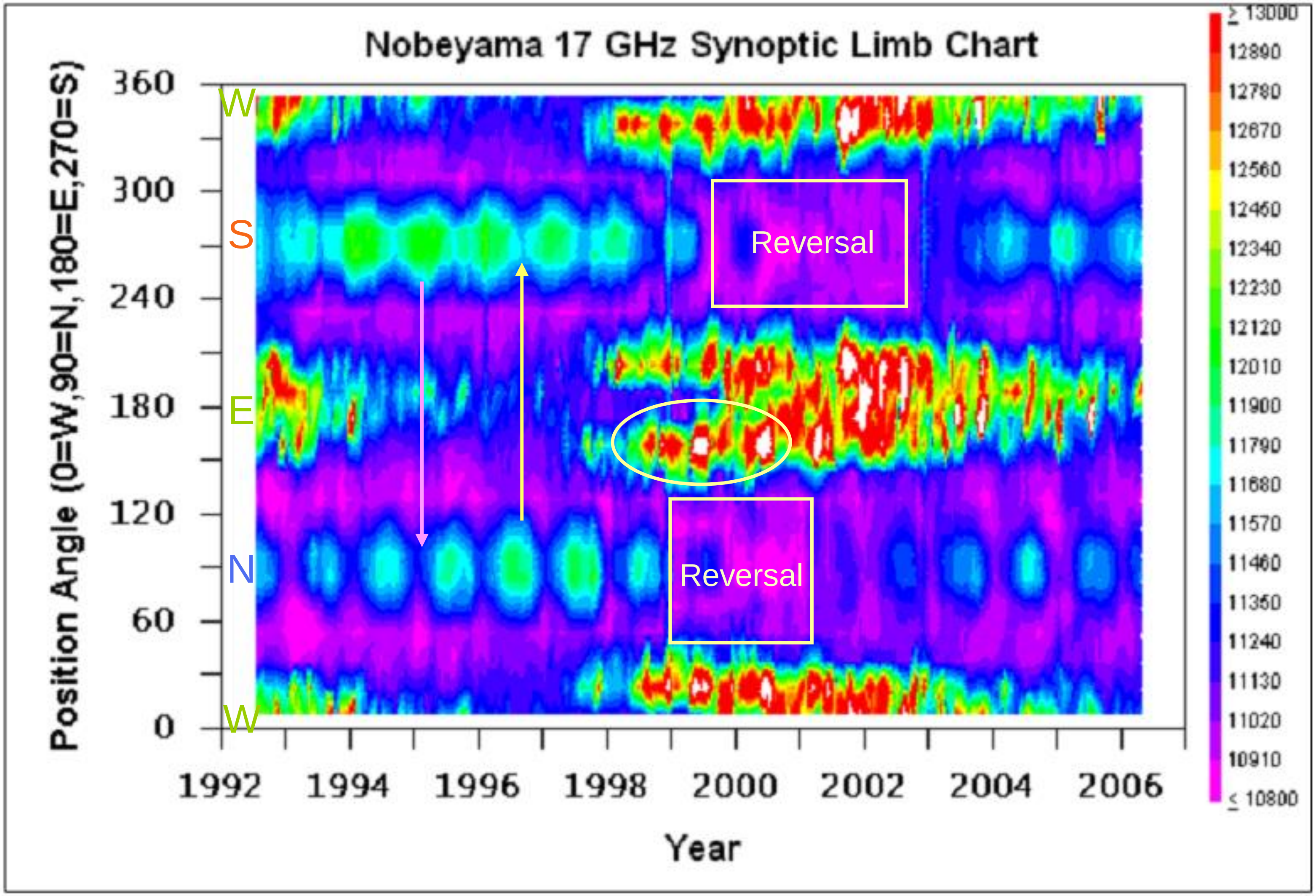




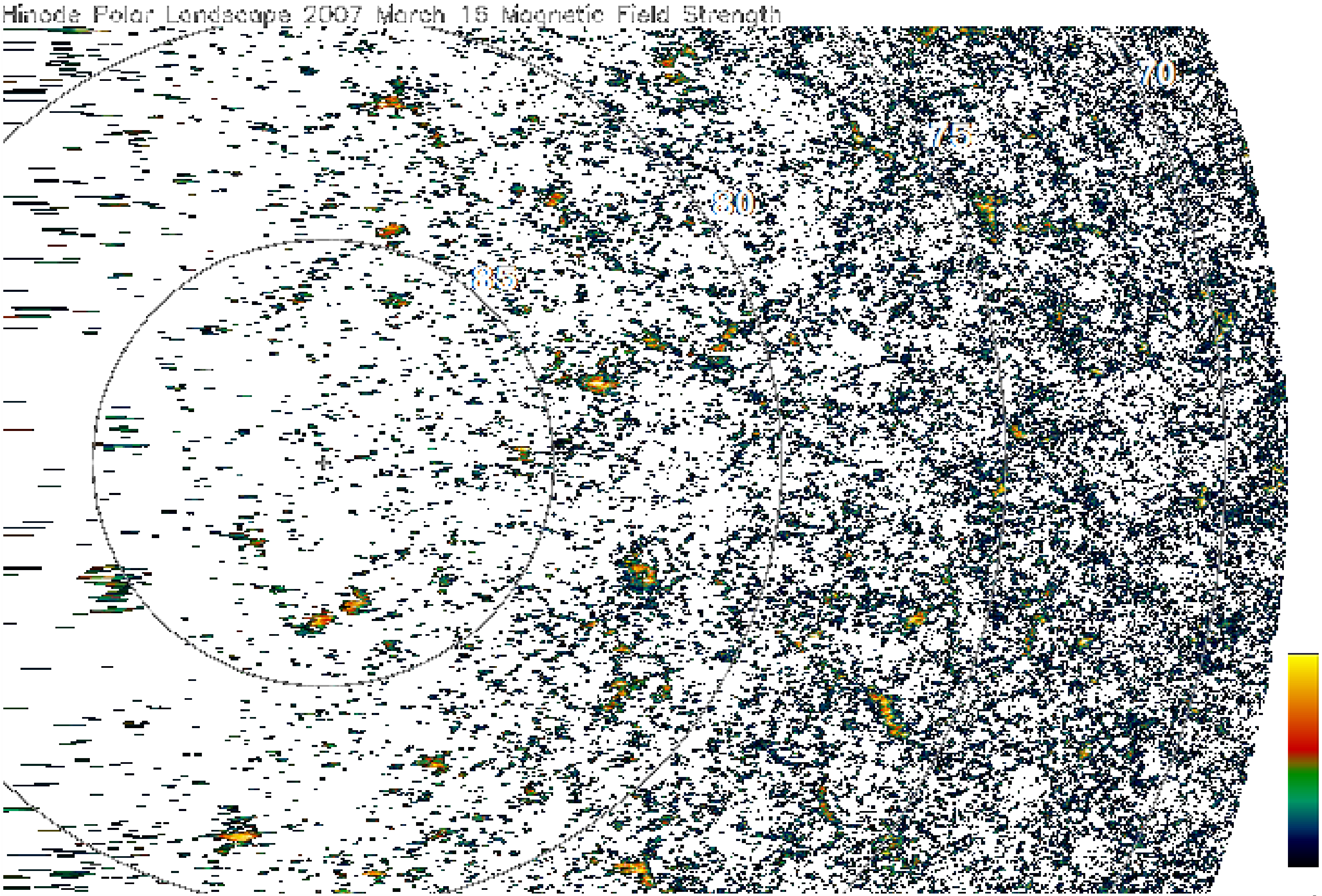




Evolution of Patches over the Cycle

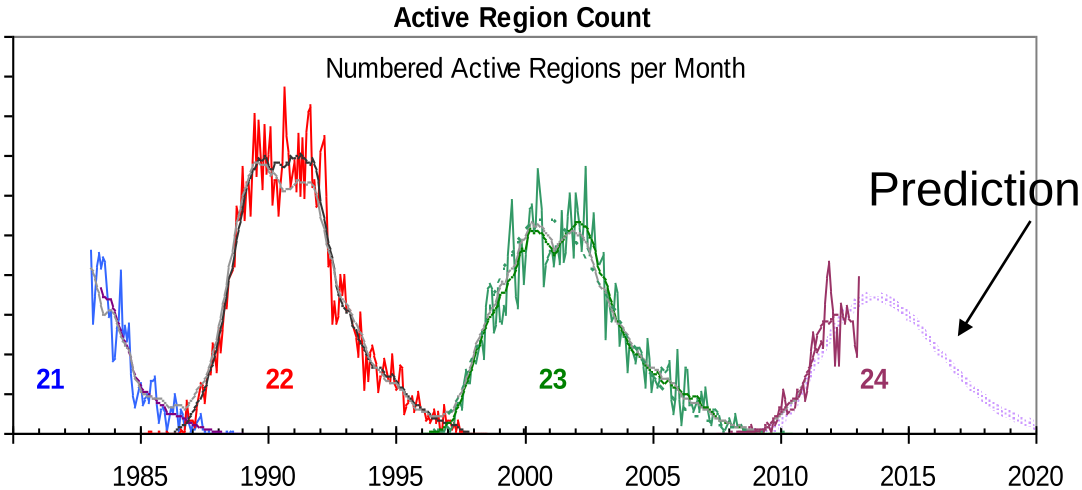


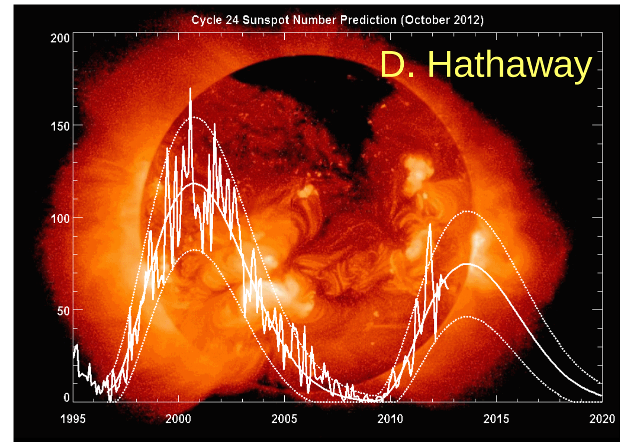
Polar Magnetic Landscape

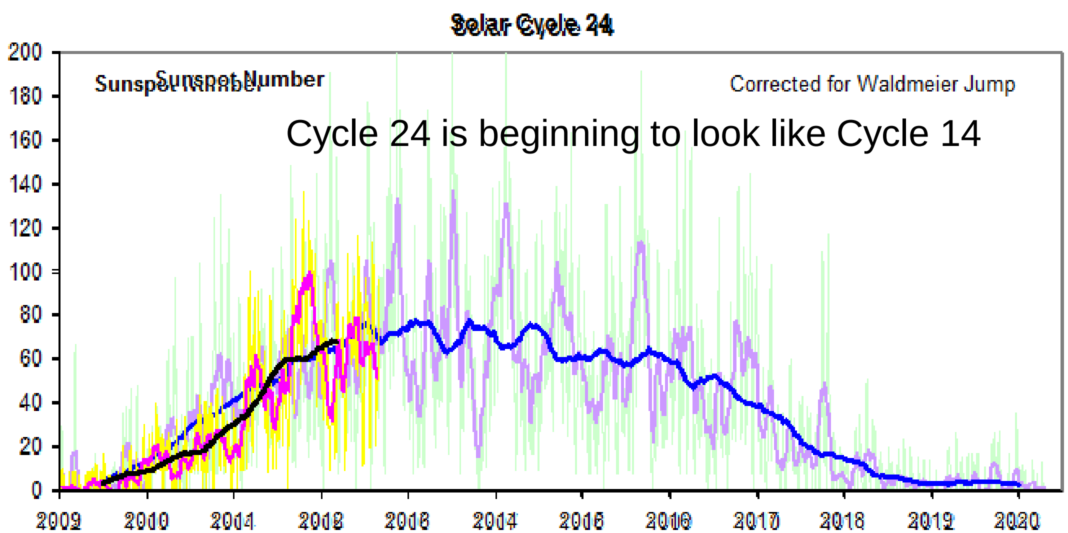


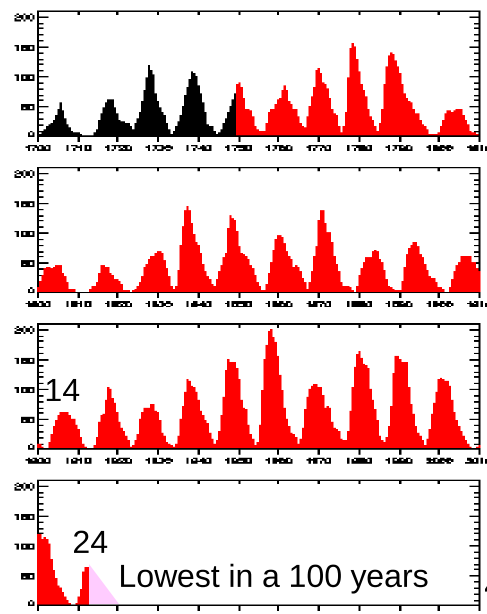
Tsuneta et al. ApJ, 2008

How is Cycle 24 Evolving? As Predicted!
So, the polar field precursor method seems to work

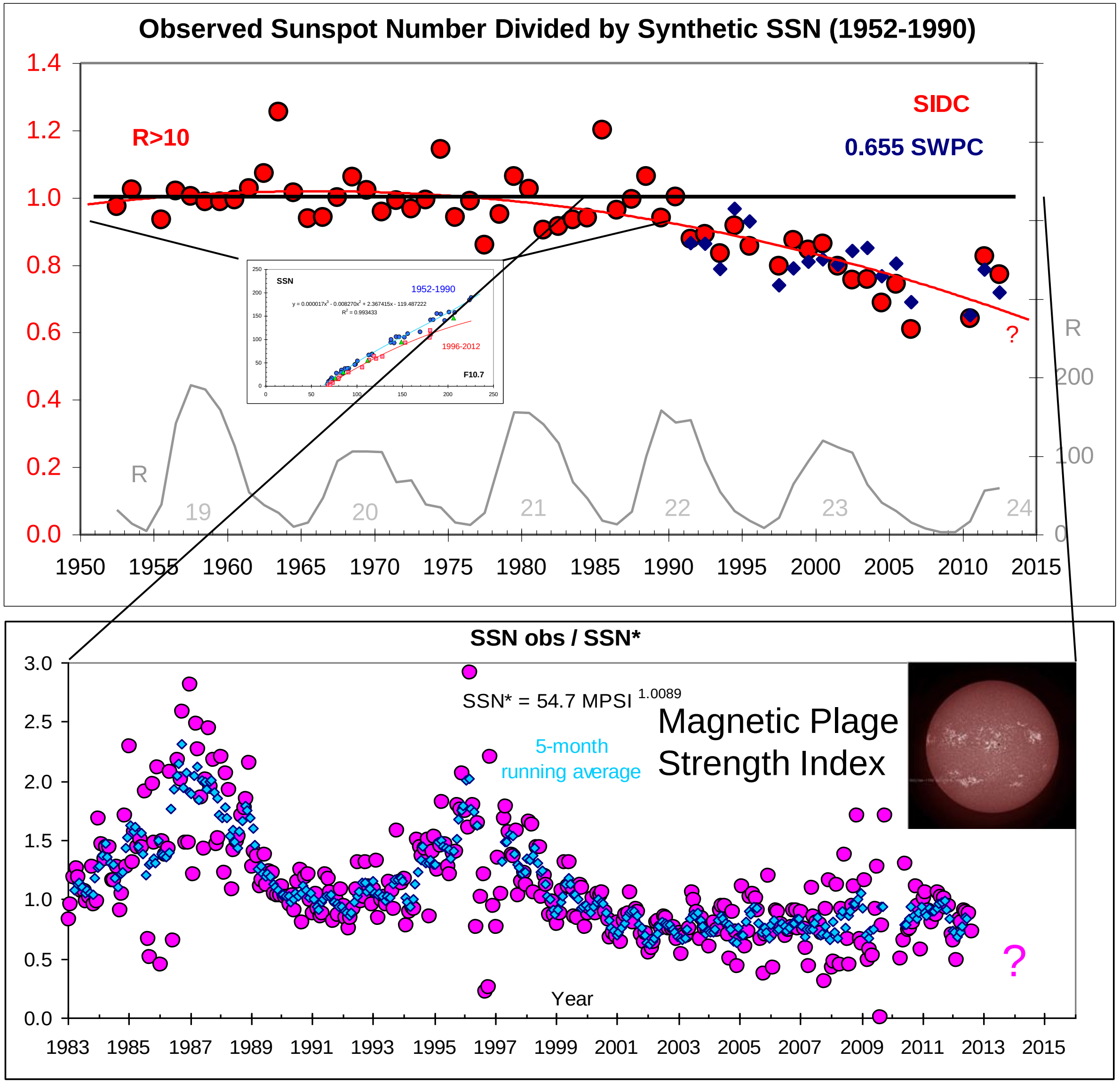


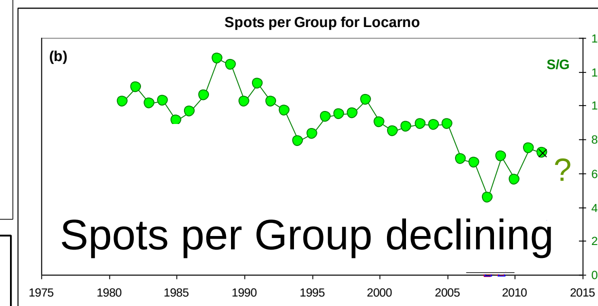


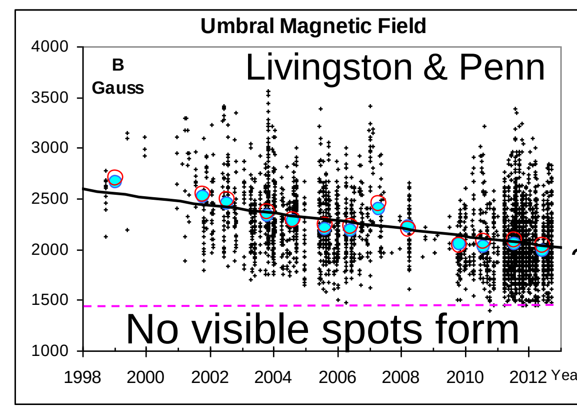




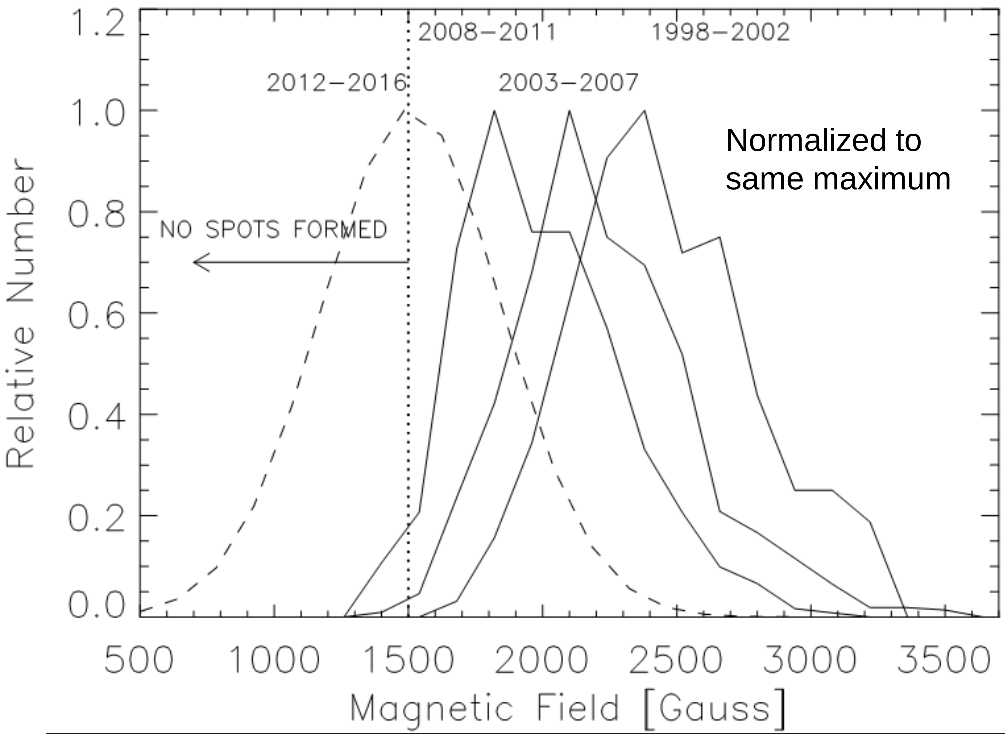
Something *is* happening with the Sun



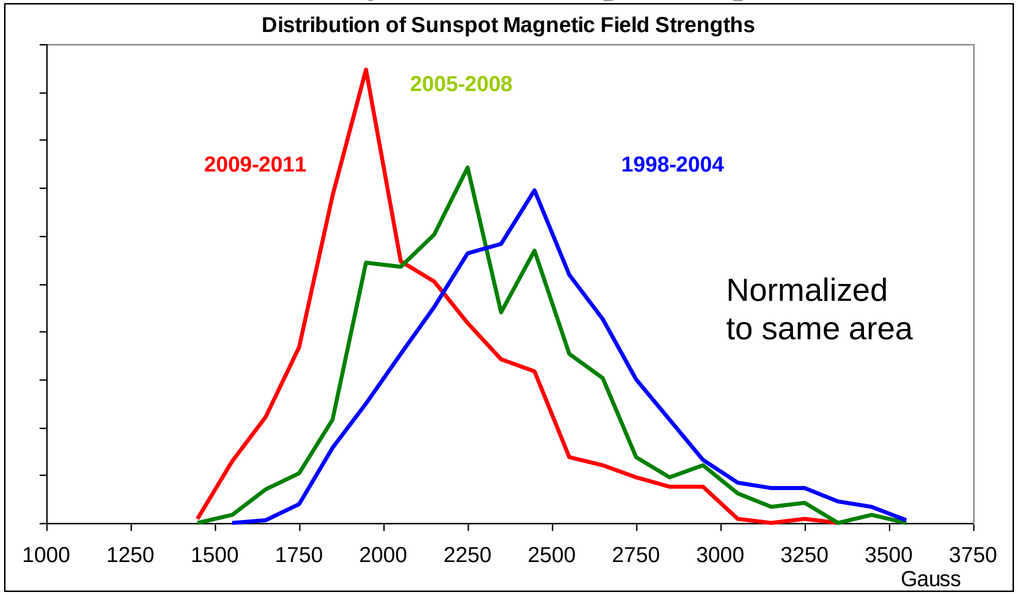




We don't know what causes this, but sunspots are becoming more difficult to see or not forming as they used to. There is speculation that this may be what a Maunder-type minimum looks like: magnetic fields still present [cosmic rays still modulated], but just not forming spots. If so, exciting times are ahead.

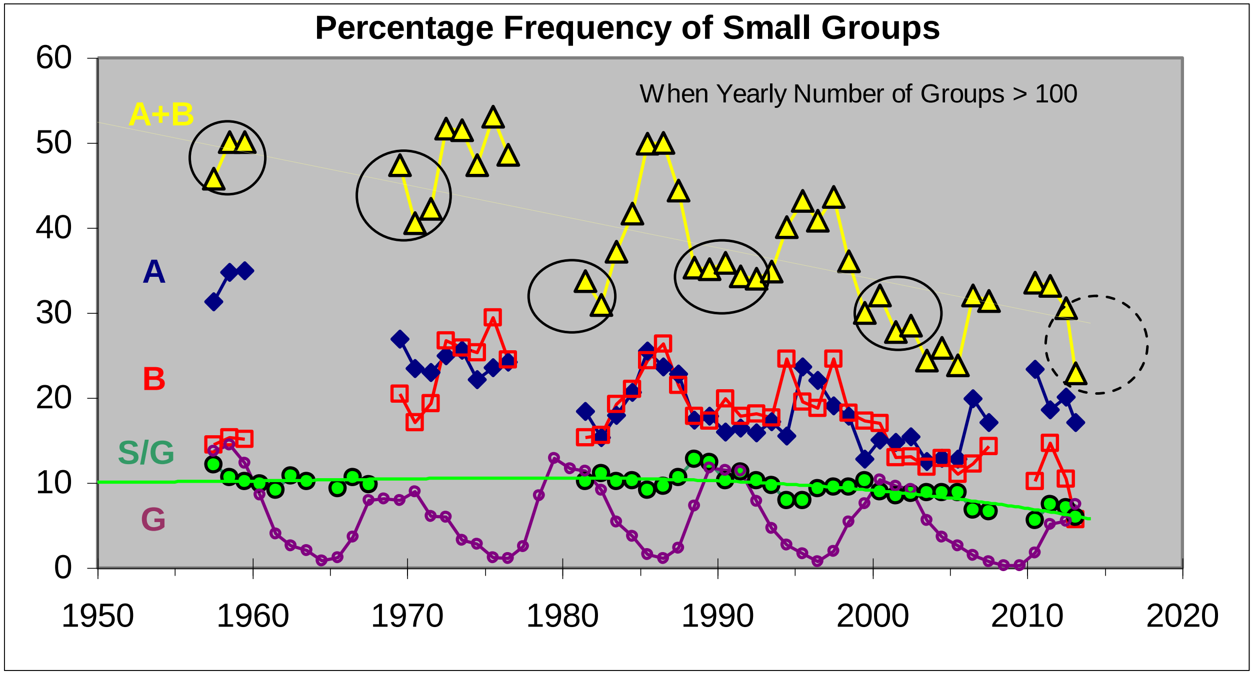


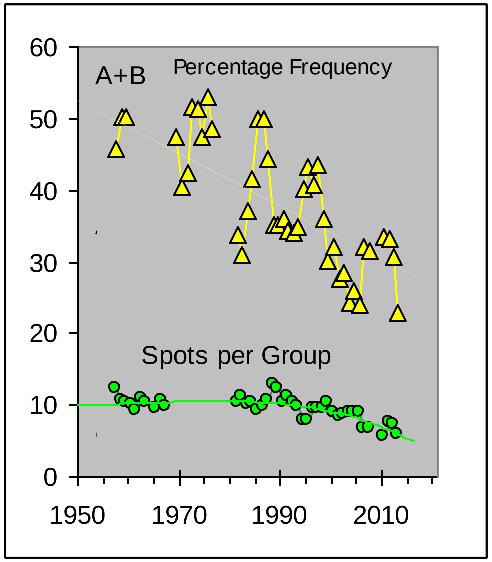
Evolution of Distribution of Magnetic Field Strengths



Sunspots form by assembly of smaller patches of magnetic flux. As more and more magnetic patches fall below 1500 G because of the shift of the distribution, fewer and fewer visible spots will form, as observed

Small Spots are Disappearing





Zurich and Locarno

The occurrence of groups of class A and B is decreasing as is the number of spots per group

Working Hypothesis

- The Maunder Minimum was not a serious deficit of magnetic flux, but
- A lessening of the efficiency of the process that compacts magnetic fields into visible spots
- This may now be happening again
- If so, there is new solar physics to be learned