Solar Activity – Past, Present, and Future

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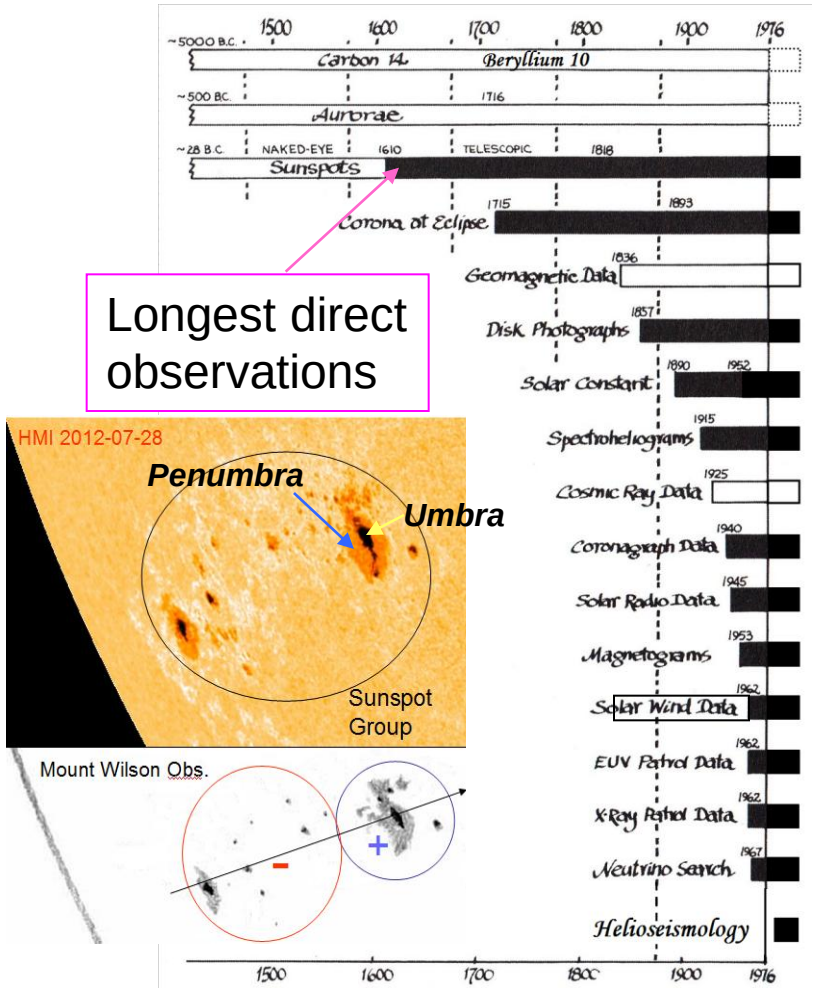
Indicators of Solar Activity

- 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

The Wolf Number, Zürich Sunspot Number, and International Sunspot Number are all synonyms for the same data, today maintained by the Solar Influences Data Center, SIDC, in Brussels, Belgium

Problem with The ‘Wolf’ Number

The effect of Weighting the sunspot count…

Zürich Observers

Wolf	1849-1893
Wolfer	1876-1928
Brunner	1929-1944
Waldmeier	1945-1995

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

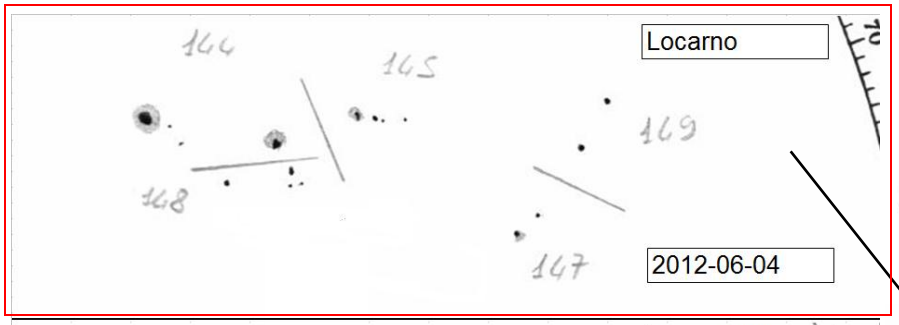
Von

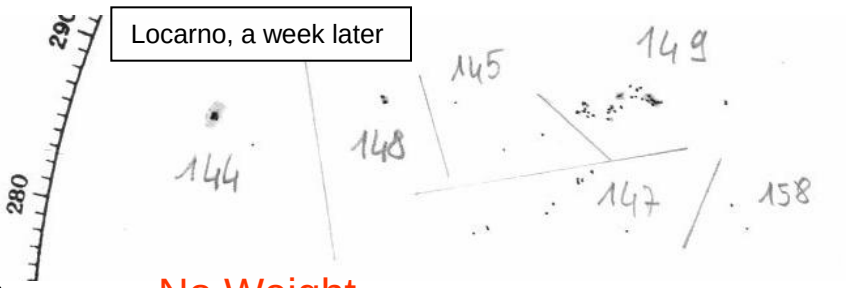
M. WALDMEIER

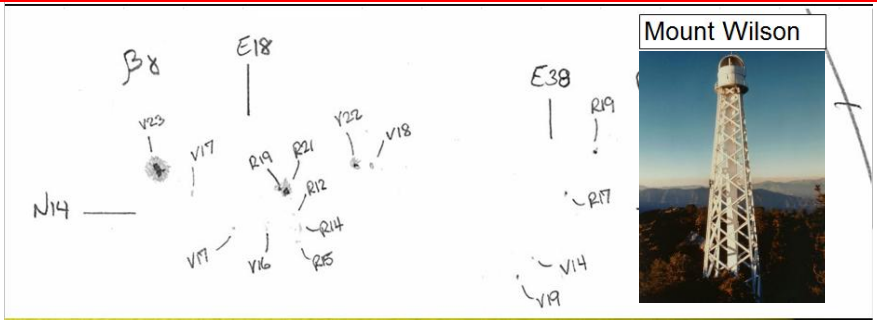
Später wurden den Flecken entsprechend ihrer Größe Gewichte erteilt: Ein punktförmiger Fleck wird einfach gezählt, ein größerer, jedoch nicht mit Penumbra versehener Fleck erhält das statistische Gewicht 2, ein kleiner Hoffleck 3, ein größerer 5.

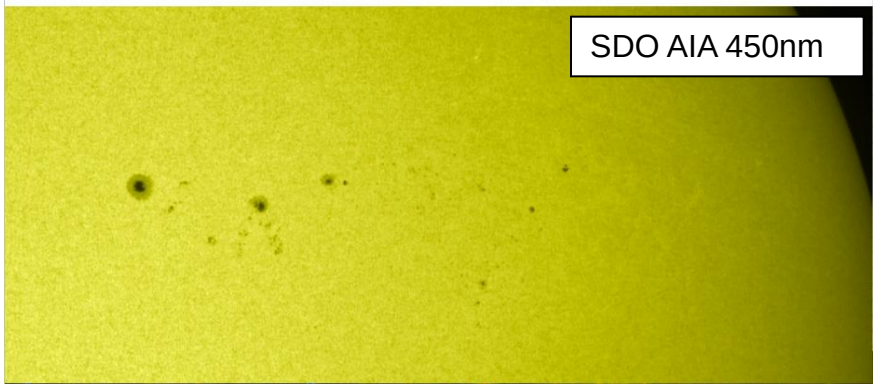
"A spot like a fine point is counted as one spot; a larger spot, but still without penumbra, gets the statistical weight 2, a smallish spot with penumbra gets 3, and a larger one gets 5." Presumably there would be spots with weight 4, too.

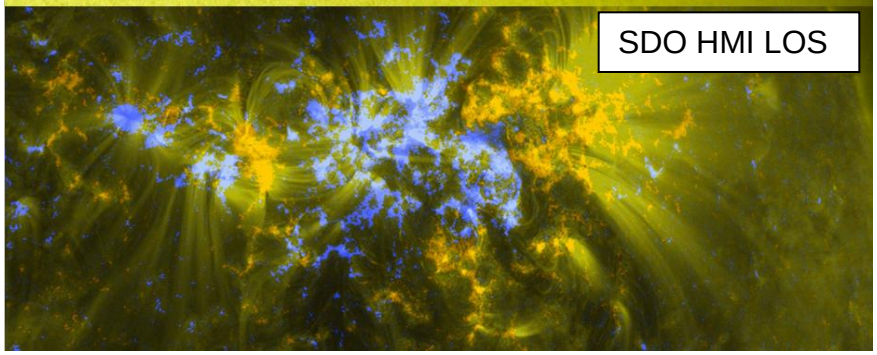
This very important piece of metadata was strongly downplayed and is not generally known











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	

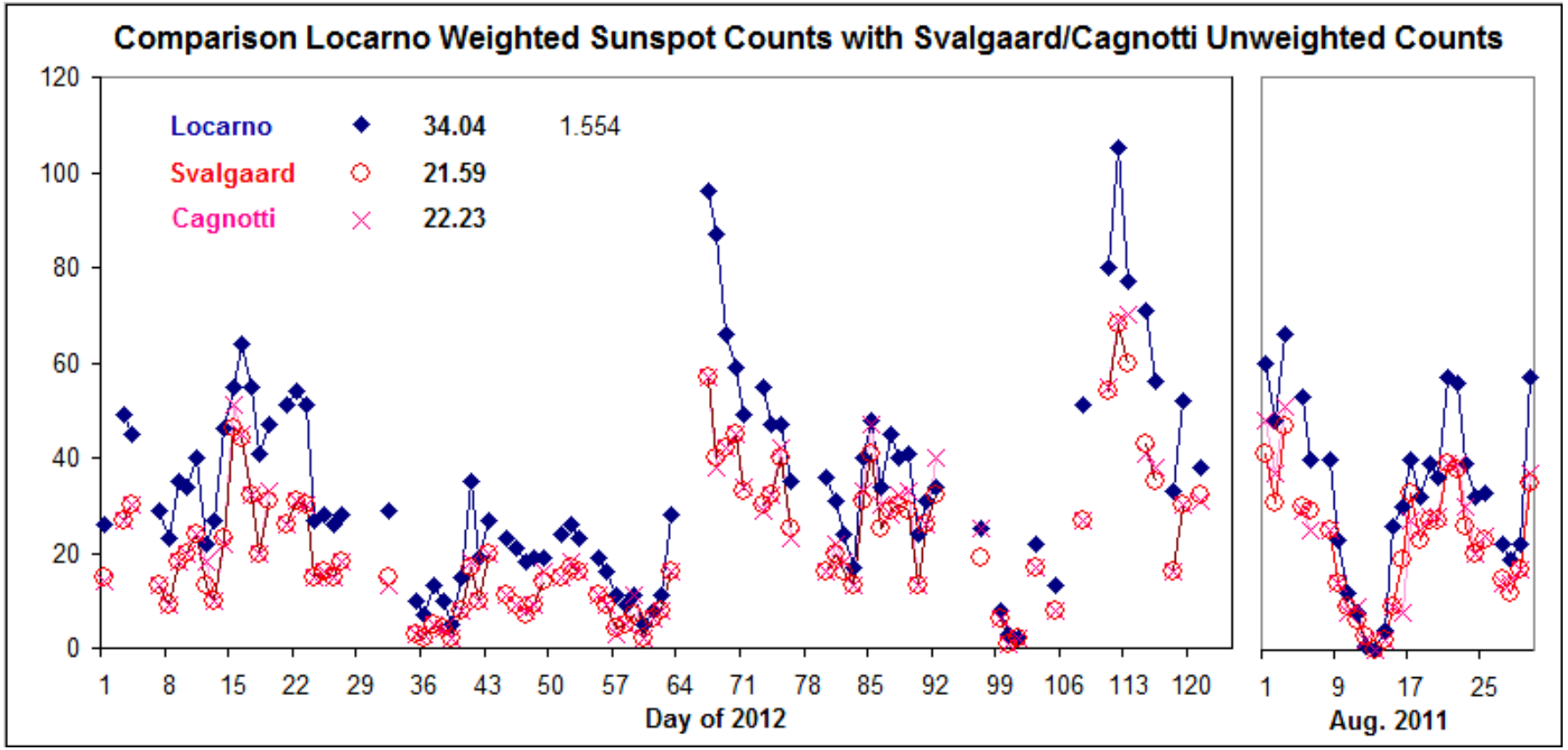
Groups ↑ ‘Spots’

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+%

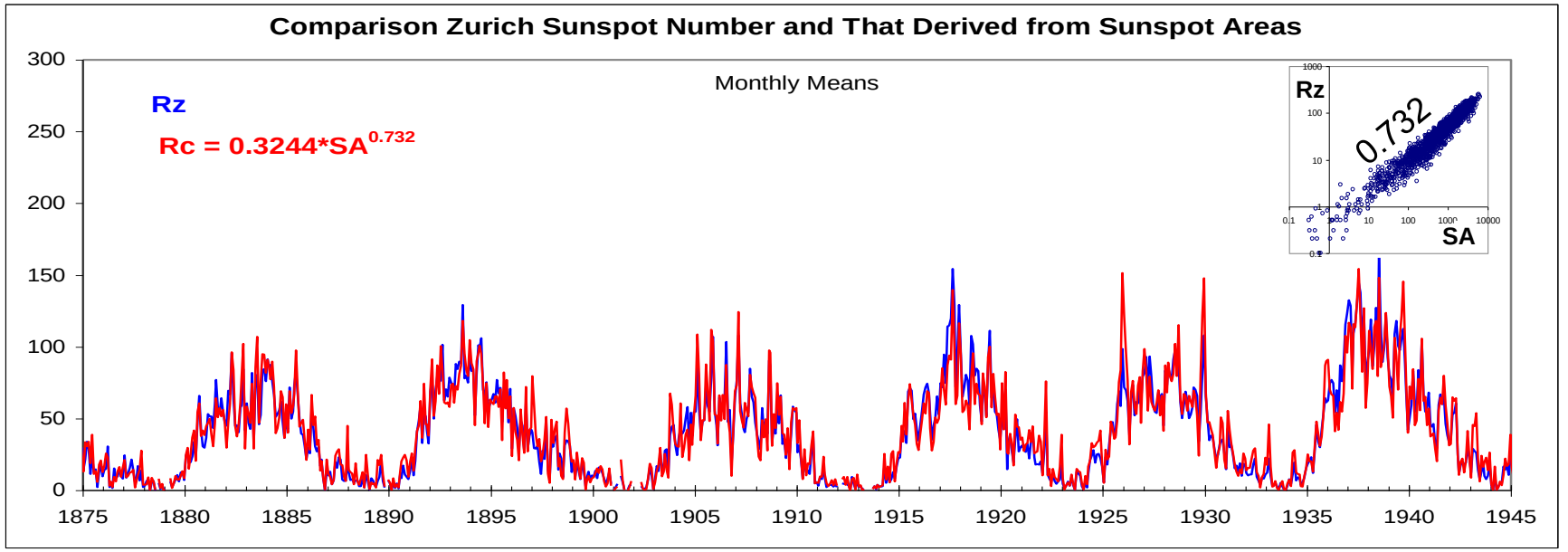
I have re-counted 43,000 spots without weighting for the last ten years of Locarno observations.

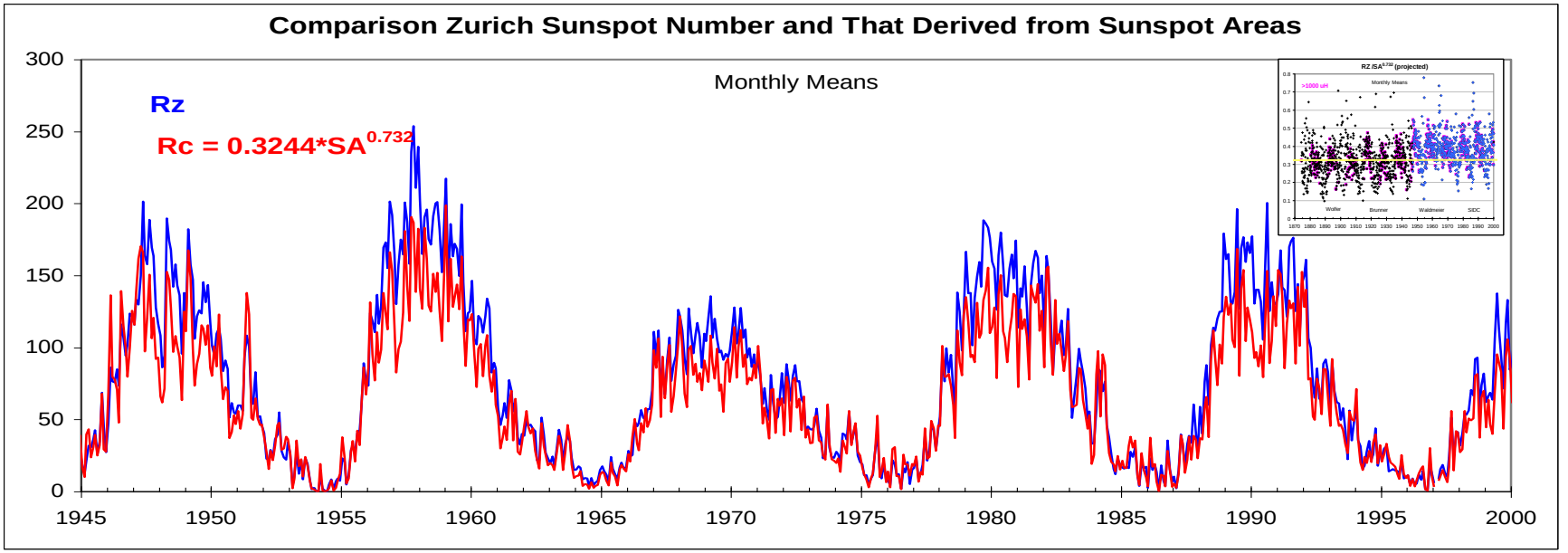
Double-Blind Test of My Re-Count



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

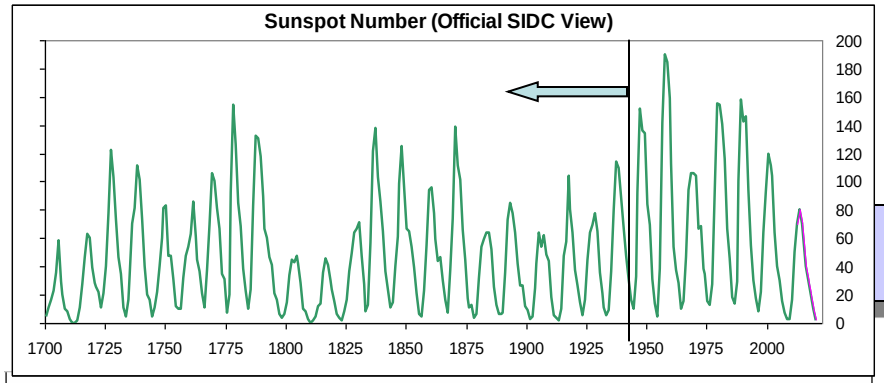
For typical number of spots the weighting increases the 'count' of the spots by 30-50% (44% on average)

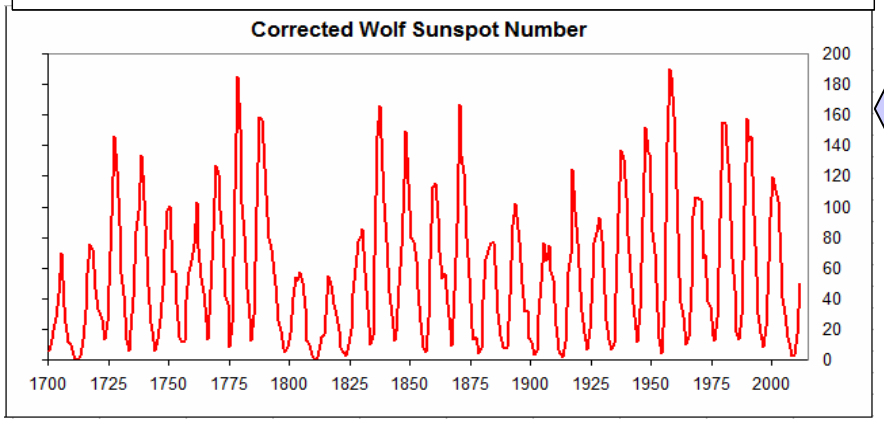


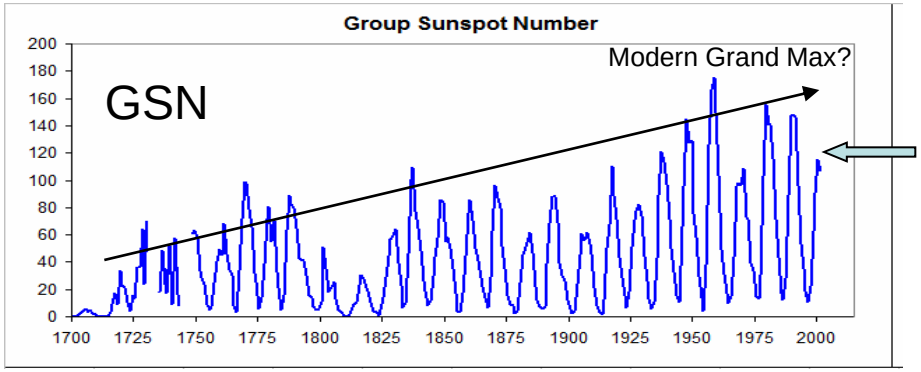


The 20% Inflation Caused by Weighting Spot Counts

Correcting for the 20% Inflation







R*corr* = R*official* * 1.2 before ~1946

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

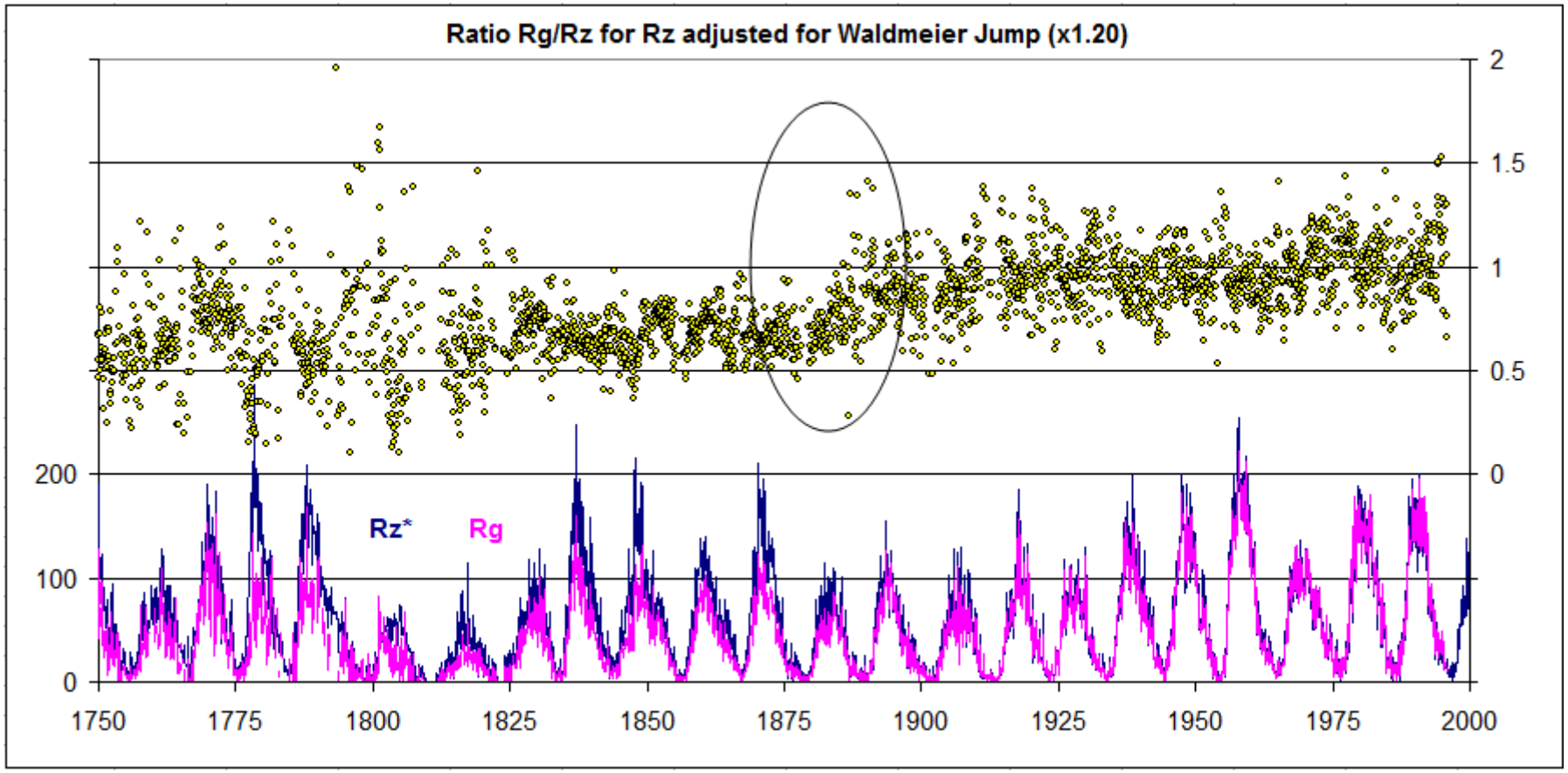
The inflation due to weighting is now an established and accepted fact

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.

Problem with the Group Sunspot Number

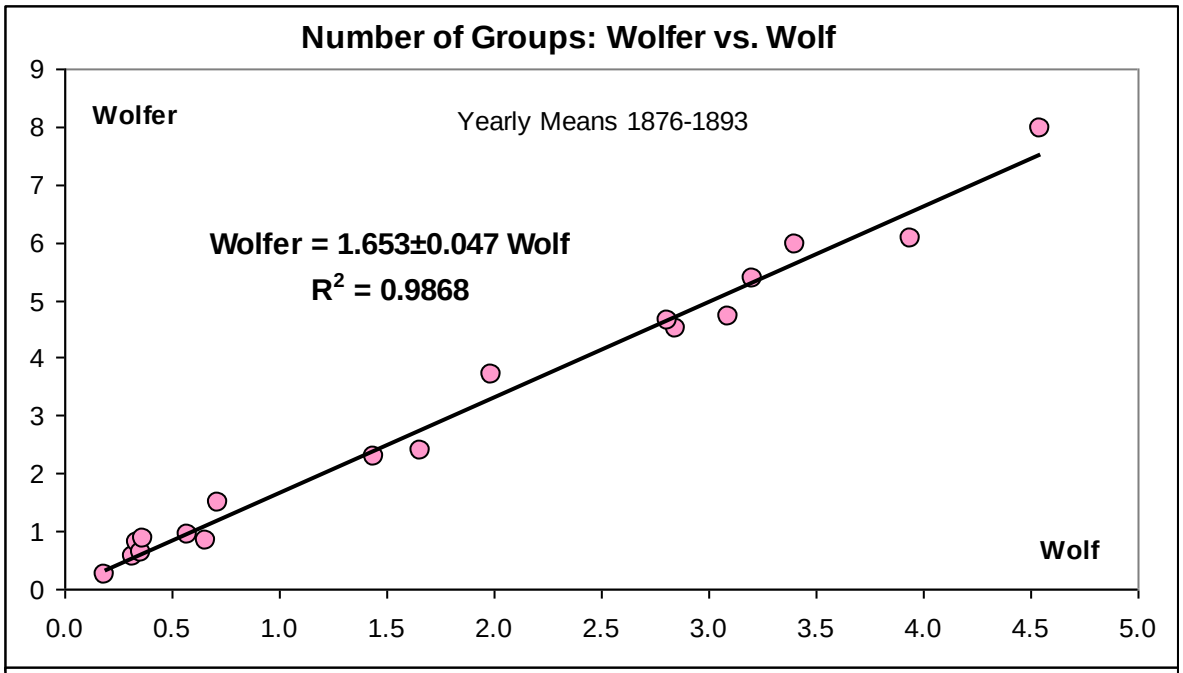
Determining correct K-factors…

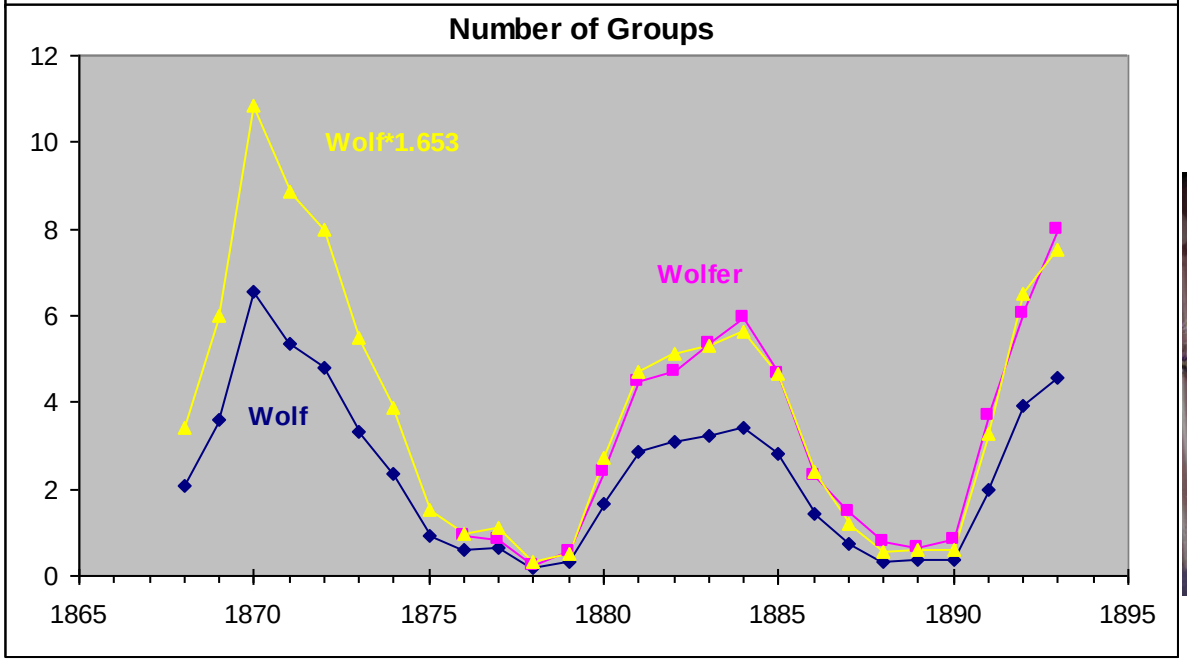
The Ratio between the Group Sunspot Number and the [corrected] Sunspot number

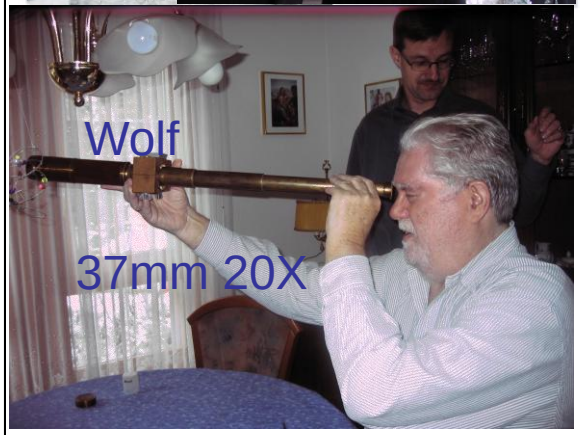


Shows that the significant discrepancy is largely due to data from the 1880s

Wolf-Wolfer Groups







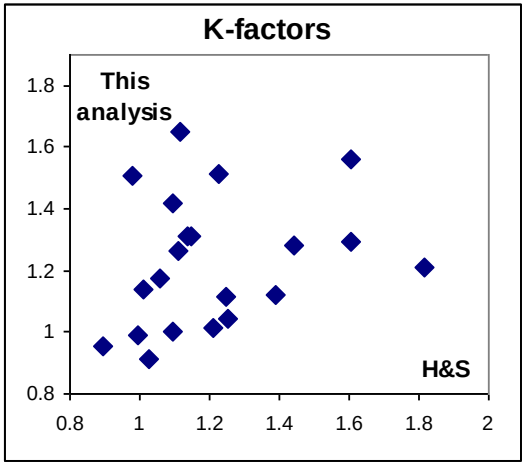
Why are these so different?

K-Factors

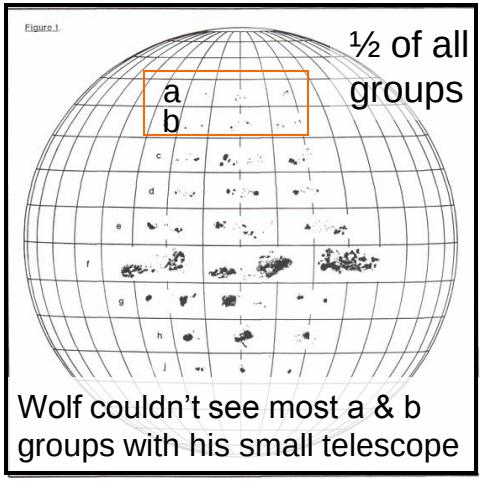
This is the main reason for the discrepancy

Observer	H&S RGO	to Wolfer	Begin	End
Wolfer, A., Zurich	1.094	1	1876	1928
Wolf, R., Zurich	1.117	1.6532	1876	1893
Schmidt, Athens	1.135	1.3129	1876	1883
Weber, Peckeloh	0.978	1.5103	1876	1883
Spoerer, G., Anclam	1.094	1.4163	1876	1893
Tacchini, Rome	1.059	1.1756	1876	1900
Moncalieri	1.227	1.5113	1876	1893
Leppig, Leibzig	1.111	1.2644	1876	1881
Bernaerts, G. L., England	1.027	0.9115	1876	1878
Dawson, W. M., Spiceland, Ind.	1.01	1.1405	1879	1890
Ricco, Palermo	0.896	0.9541	1880	1892
Winkler, Jena	1.148	1.3112	1882	1910
Merino, Madrid	0.997	0.9883	1883	1896
Konkoly, Ogylla	1.604	1.5608	1885	1905
Quimby, Philadelphia	1.44	1.2844	1889	1921
Catania	1.248	1.1132	1893	1918
Broger, M, Zurich	1.21	1.0163	1897	1928
Woinoff, Moscow	1.39	1.123	1898	1919
Guillaume, Lyon	1.251	1.042	1902	1925
Mt Holyoke College	1.603	1.2952	1907	1925

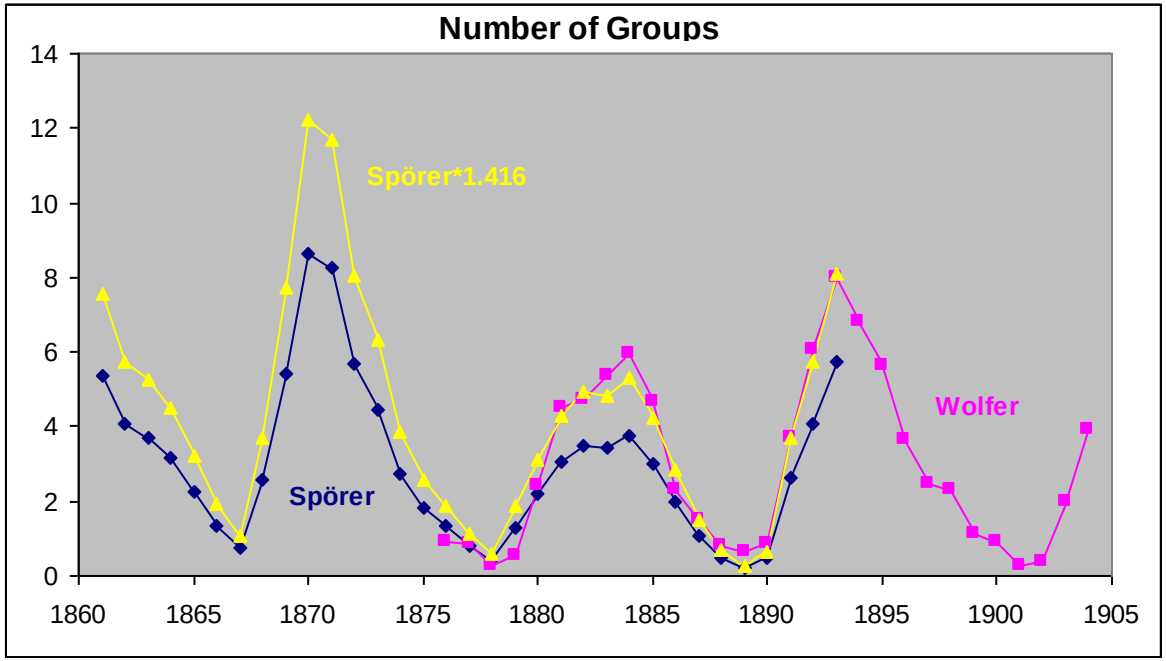
2% diff.

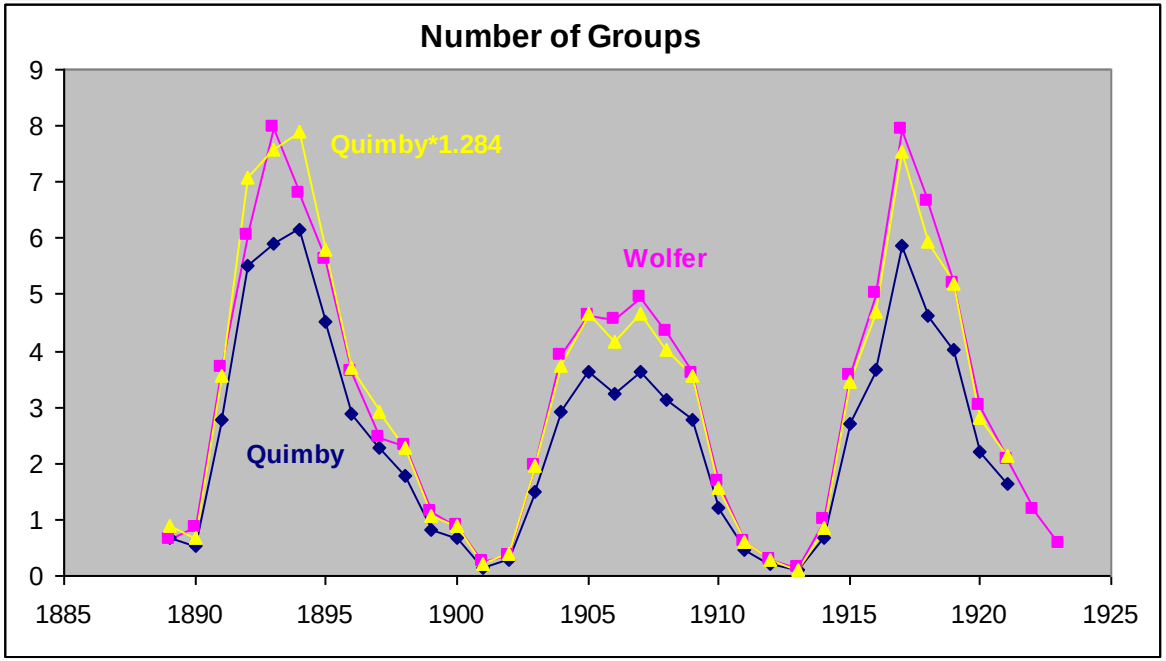


Zürich Classification:



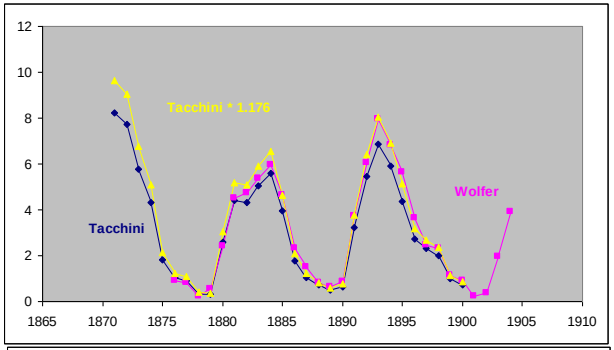
A still unresolved question is how Hoyt & Schatten got the *K*-factors so wrong

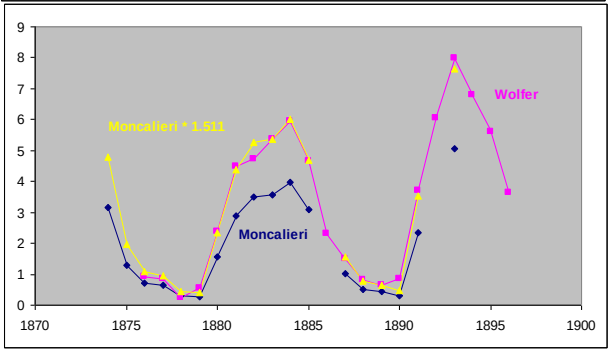




Comparing G. Spörer & Rev. A. Quimby [Philadelphia] to Wolfer

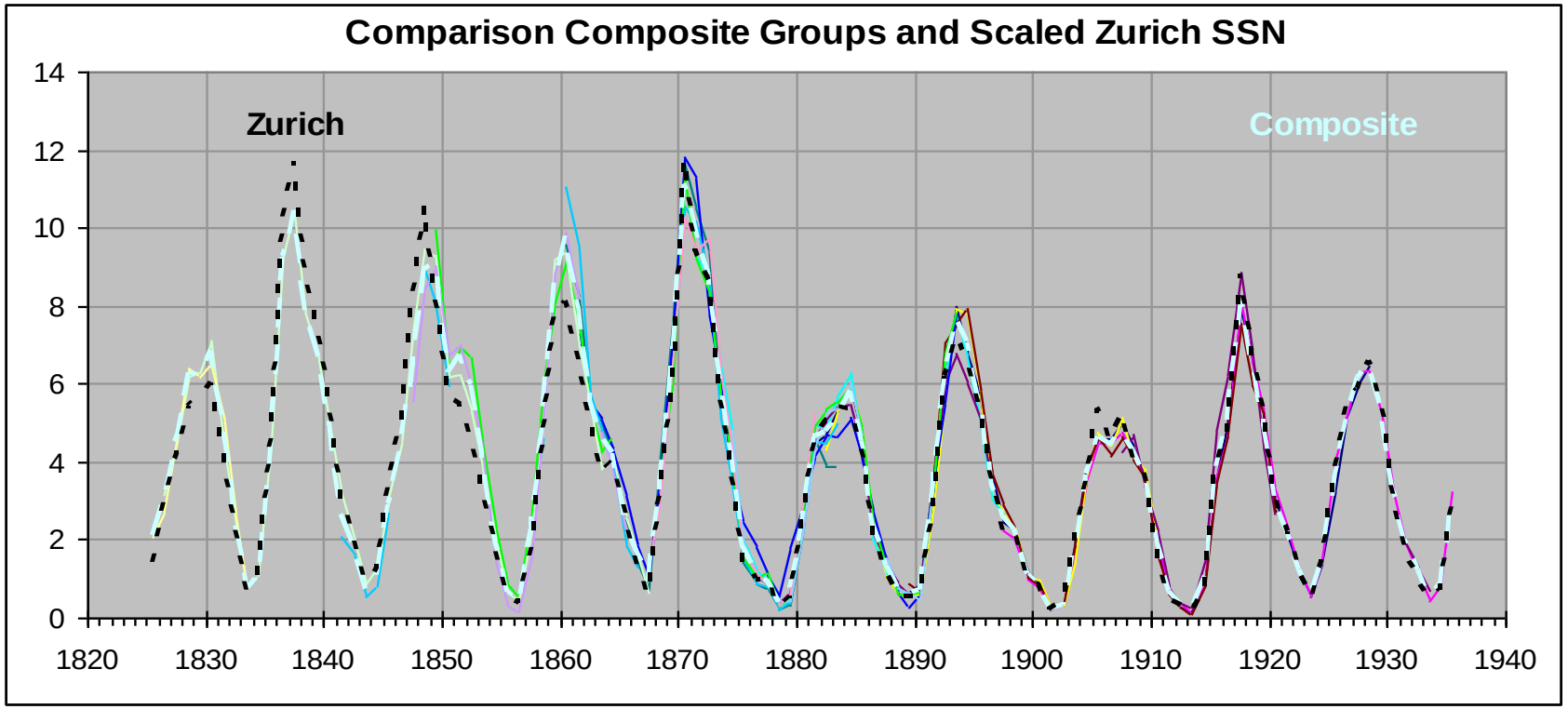
Same good and stable fit, showing that Wolfer's count had not drifted with time





Constructing a Composite

Comparing 22 observers that overlap with each other one can construct a composite group number successively back to Schwabe and up to Brunner:

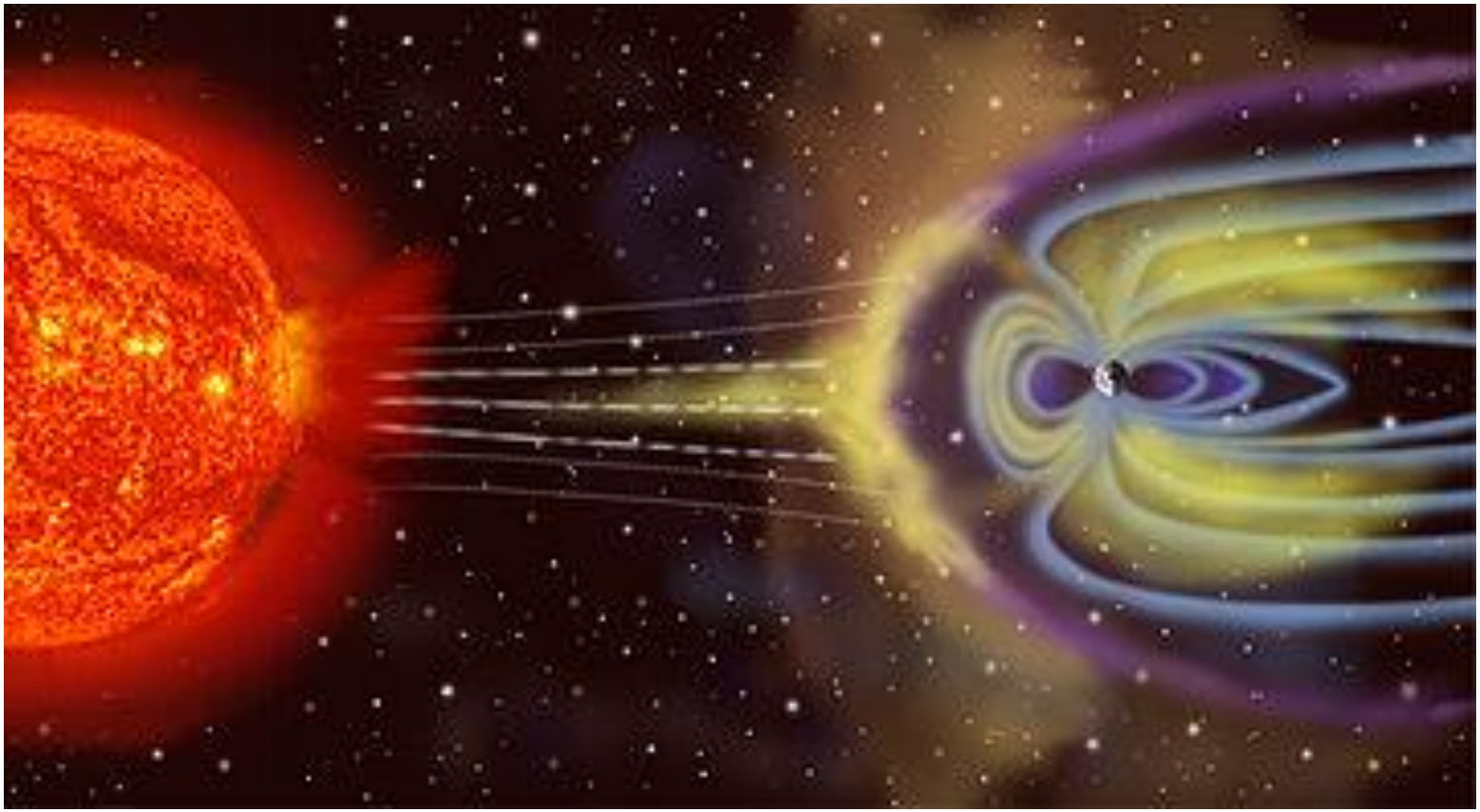


There is now no systematic difference between the Zürich SSN and a Group SSN reconstructed here by using correct *K*-factors relative to Wolfer.

Geomagnetic Calibration of Sunspot Numbers

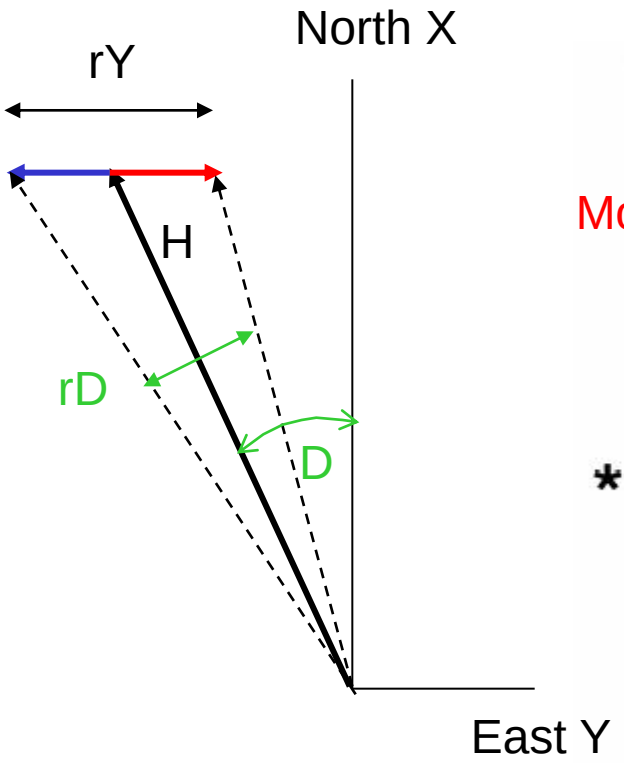
Wolf did it…

Geomagnetic Regimes



1) Solar UV maintains the ionosphere and influences the daytime field.
2) Solar Wind creates the magnetospheric tail and influences mainly the nighttime field

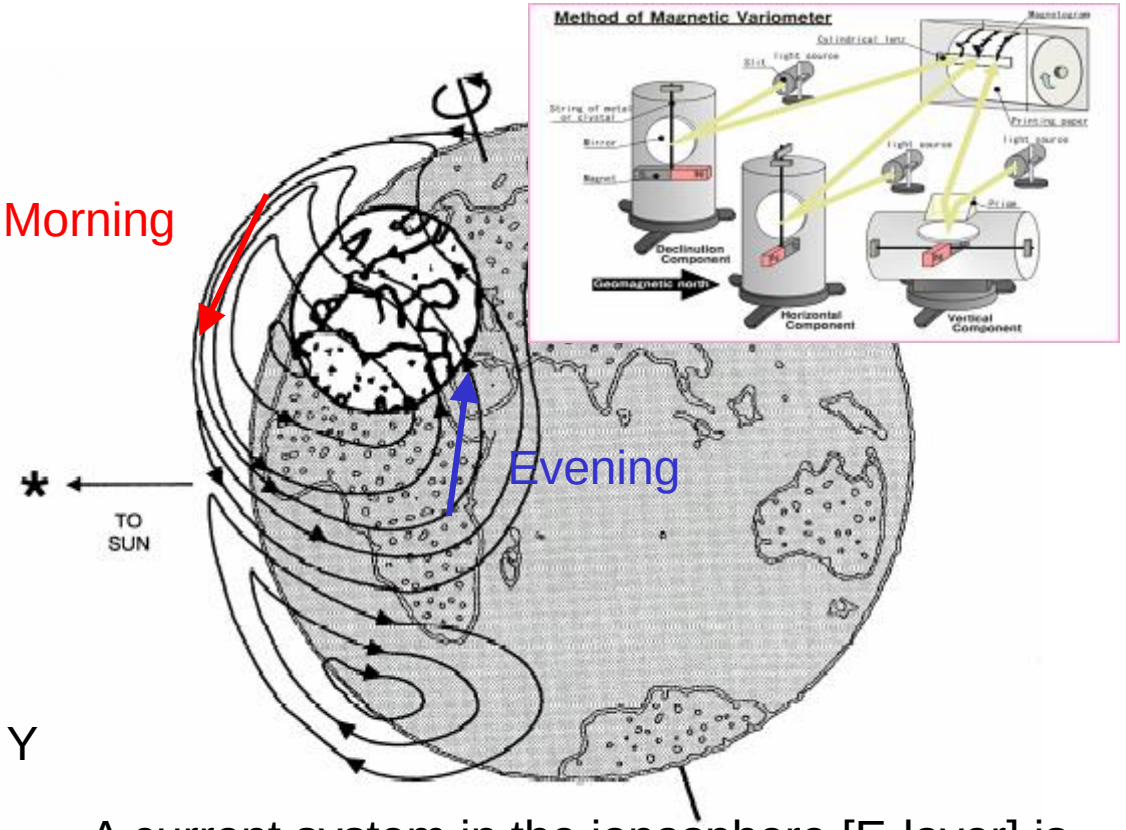
Wolf's Discovery: $rD = a + b\,R_W$



$Y = H \sin(D)$

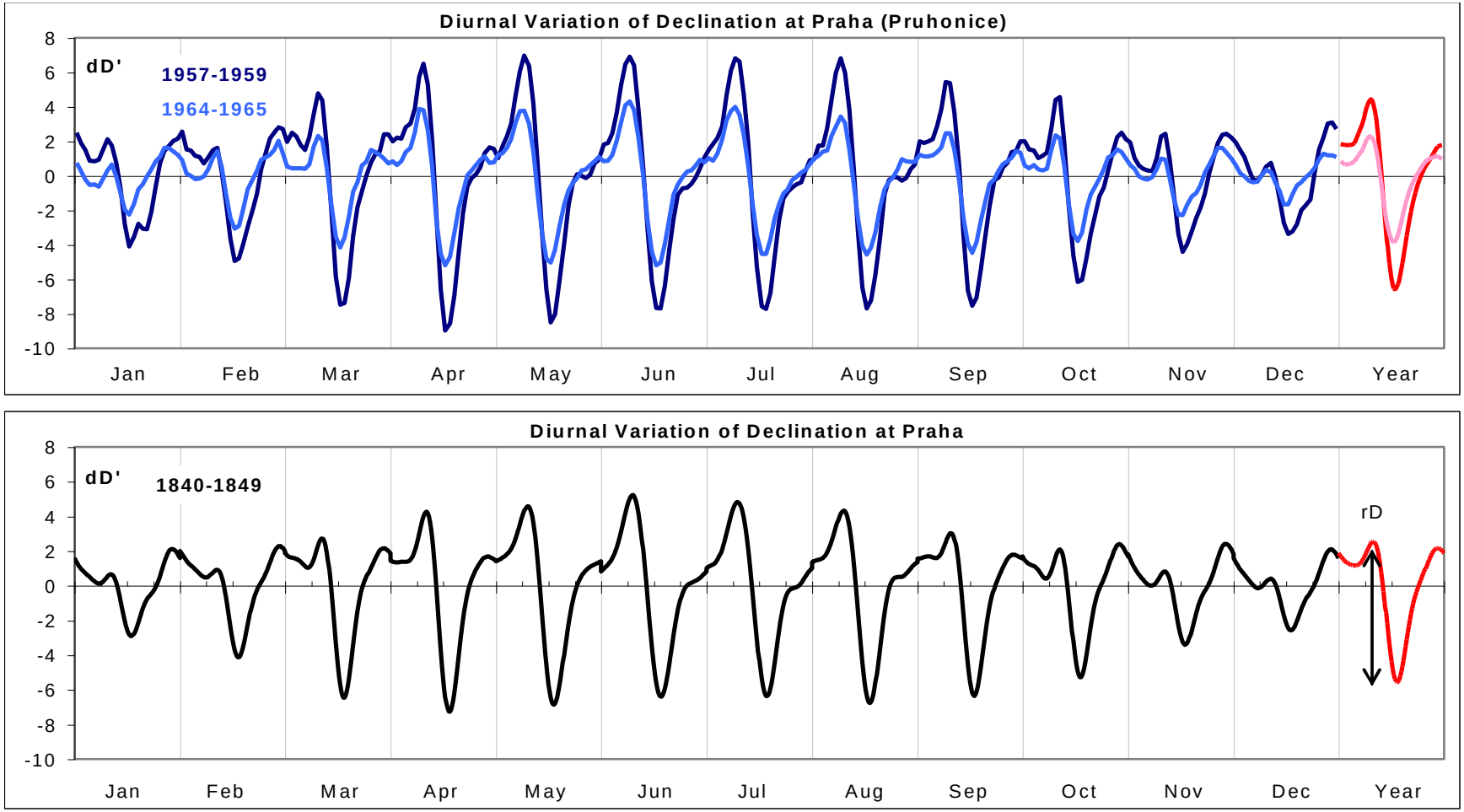
$dY = H \cos(D)\, dD$

For small D, dD and dH

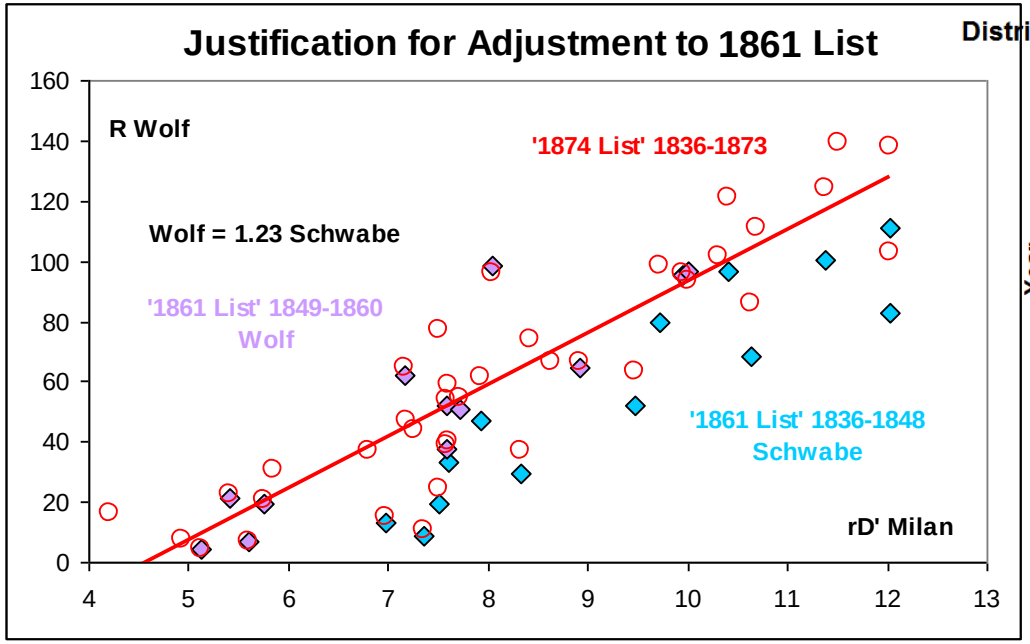


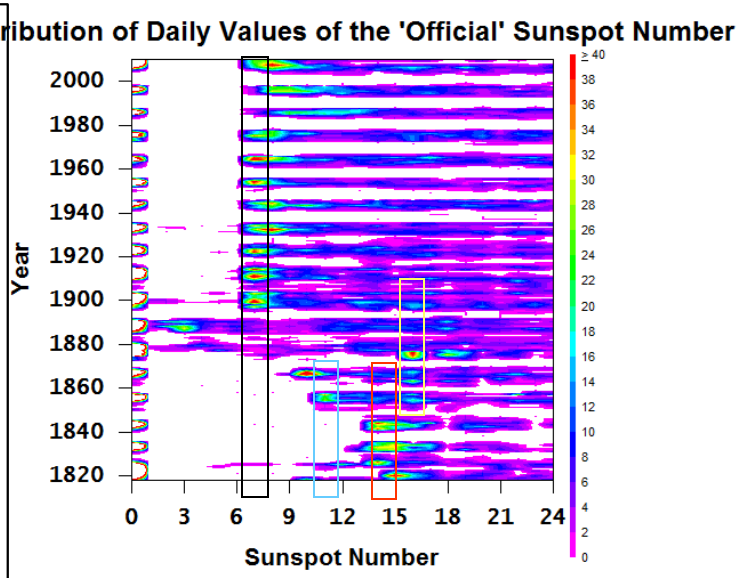
A current system in the ionosphere [E-layer] is created and maintained by solar FUV radiation. Its magnetic effect is measured on the ground. (George Graham, 1722)

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



Wolf got Declination Ranges for Milan from Schiaparelli and it became clear that the pre-1849 SSNs were too low



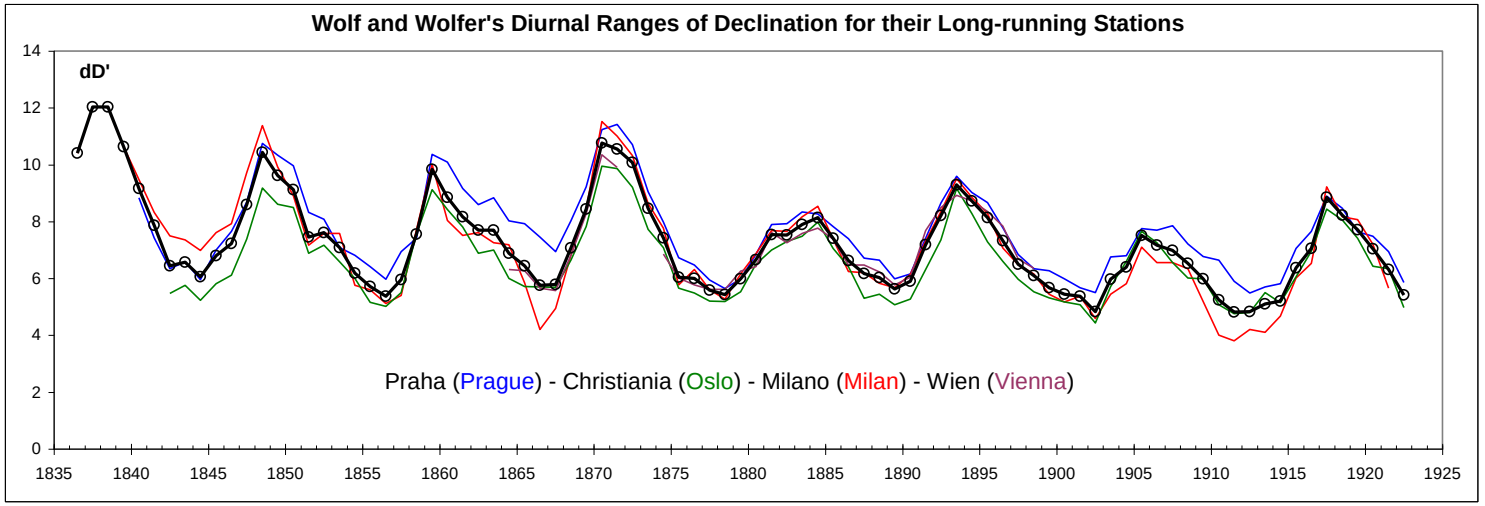


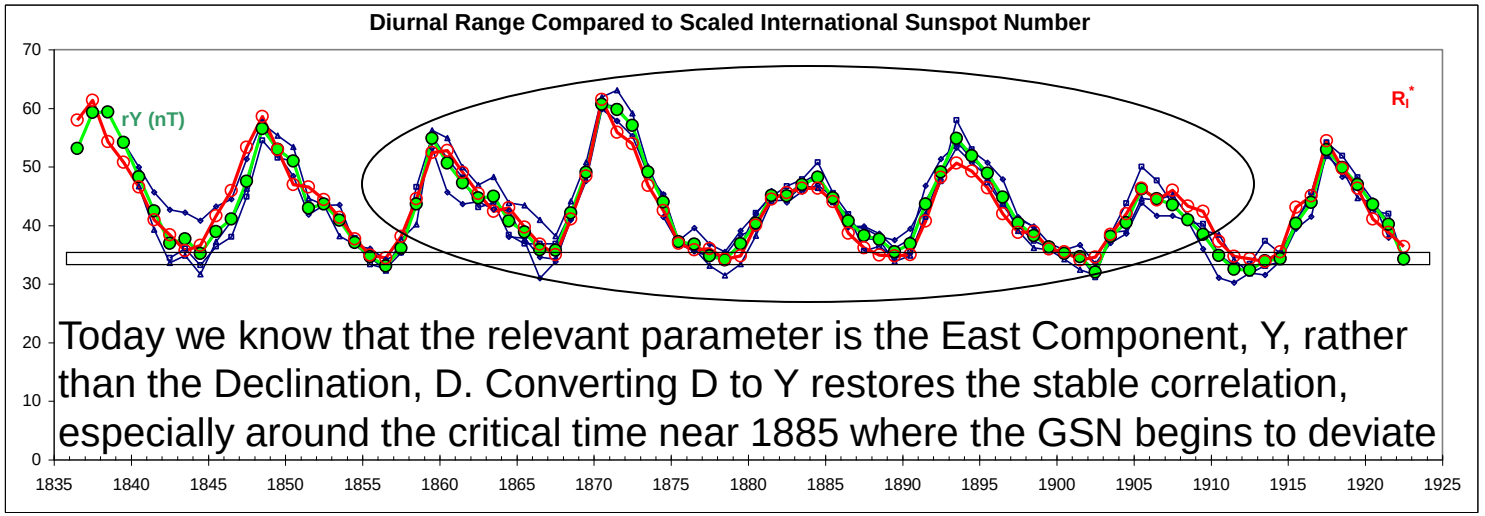
The values for 1836-1848 came from Schwabe. Wolf decided to increase them by 25% to match his own relationship with Milan's Declination

The smallest non-zero SSN should be 11. When it is not, it indicates adjustments were made

The '1874' list included the 25% [Wolf said 1/4] increase of the pre-1849 SSN. Was this a sensible thing to do?

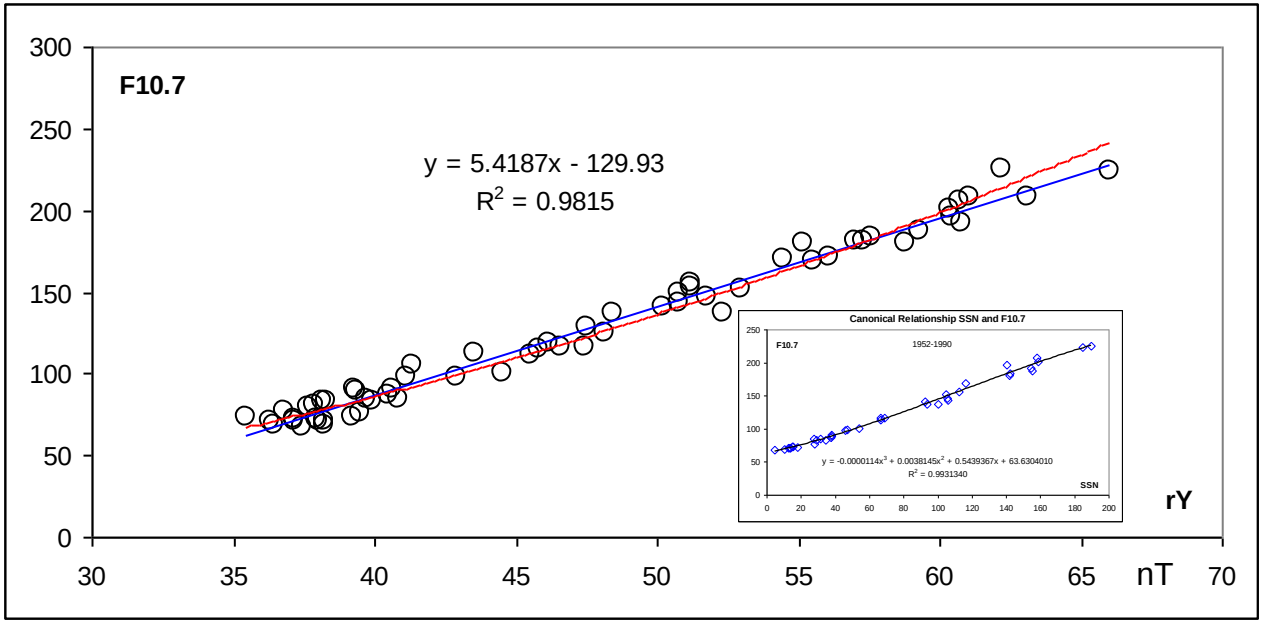
Wolf's Original Geomagnetic Data



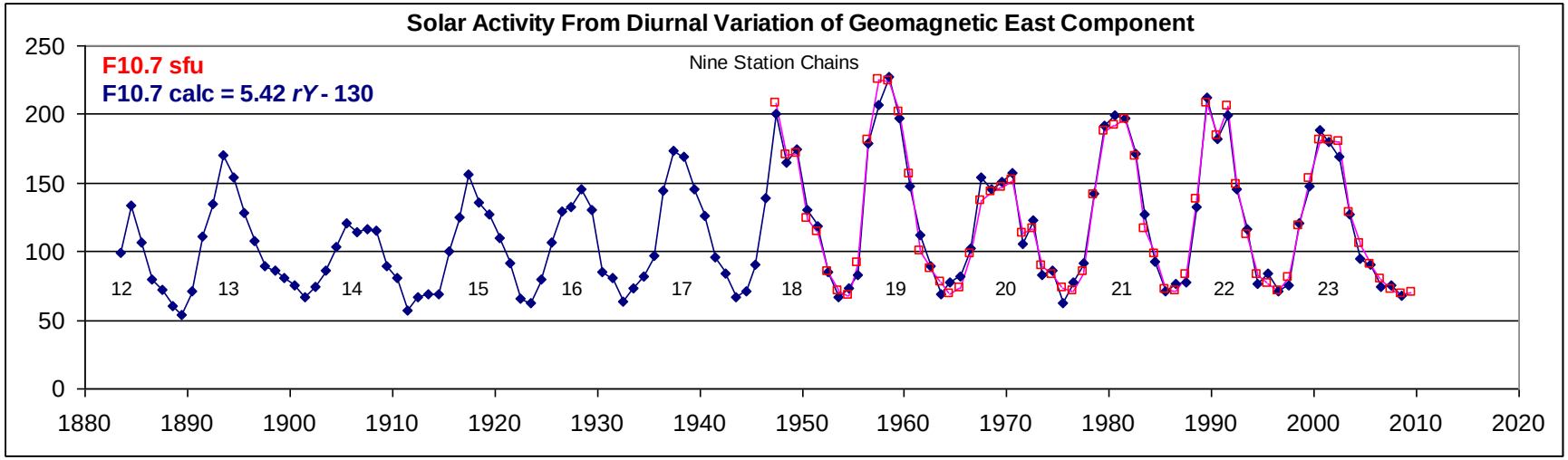


Wolf found a very strong correlation between his Wolf number and the daily range of the Declination.

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



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)

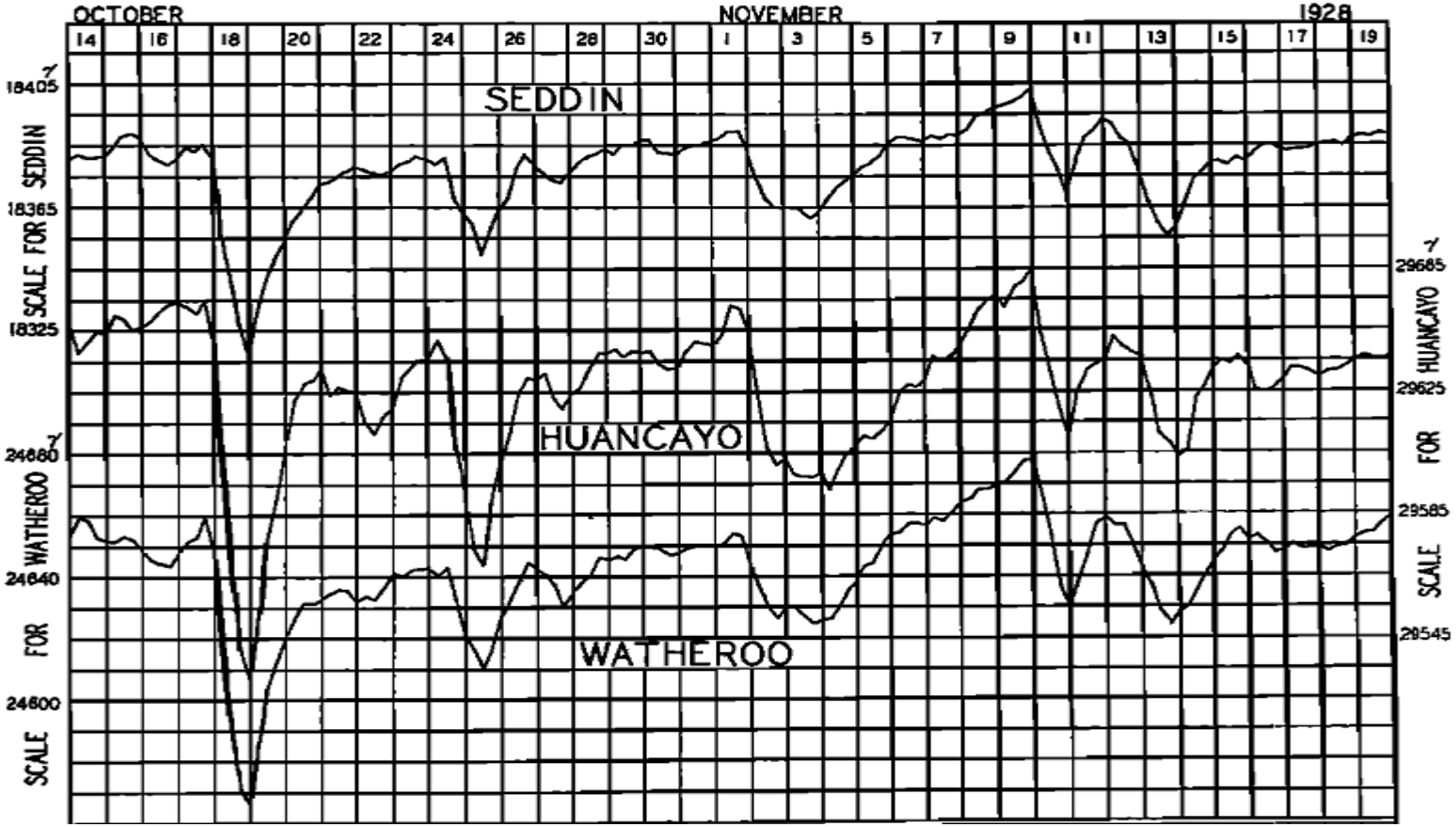


This establishes that Wolf's procedure and calibration are physically sound, and that the diurnal variation gives us a method for calibration of the SSN

Solar Wind in the Past

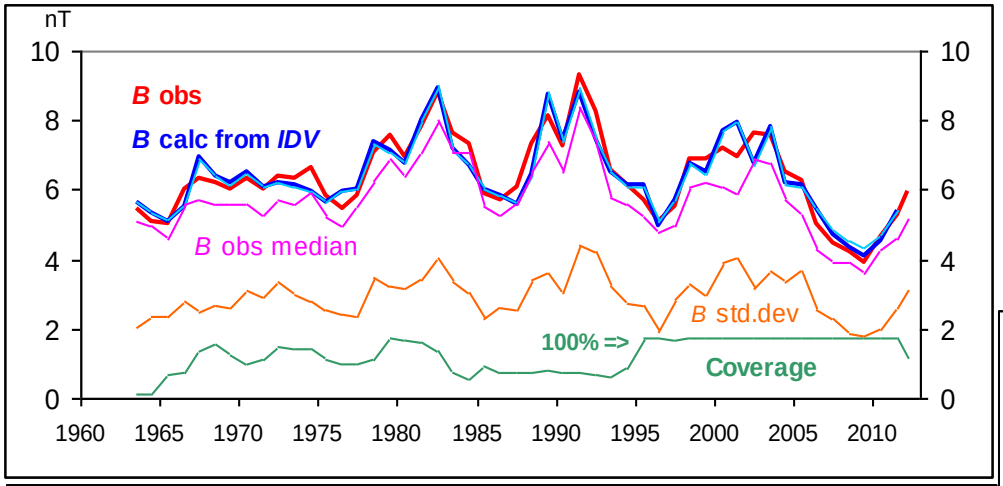
The Geomagnetic Record Allows us to Reconstruct the Solar Wind Properties for the Past 180 years

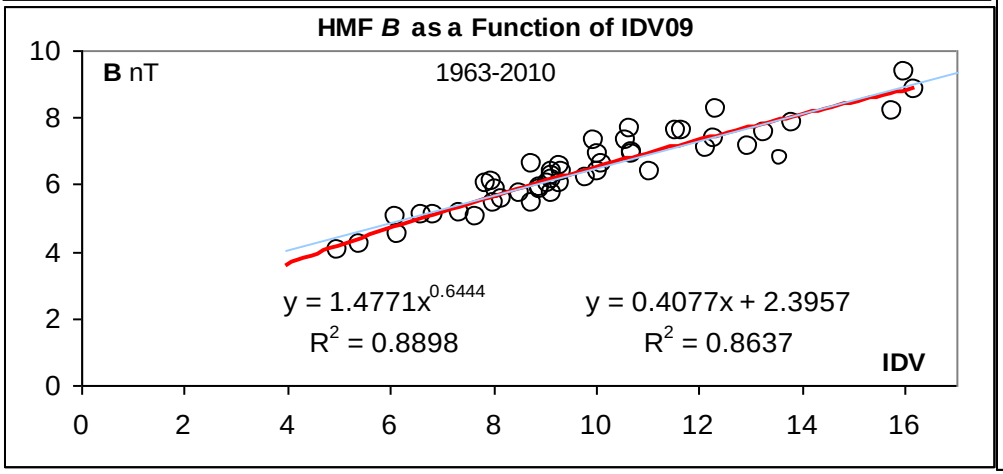
24-hour running means of the Horizontal Component of the low- & mid-latitude geomagnetic field remove most of local time effects and leaves a Global imprint of the Ring Current [Van Allen Belts]:



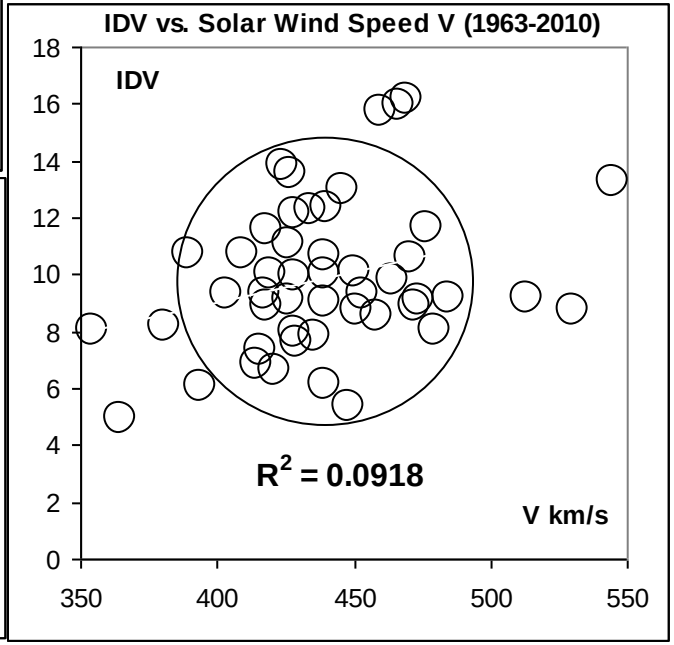
A quantitative measure of the effect can be formed as a series of the unsigned differences between consecutive days: The InterDiurnal Variability, IDV-index. Similar to Bartels' *u*-index and the 'Nachstörung' popular a century ago.

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

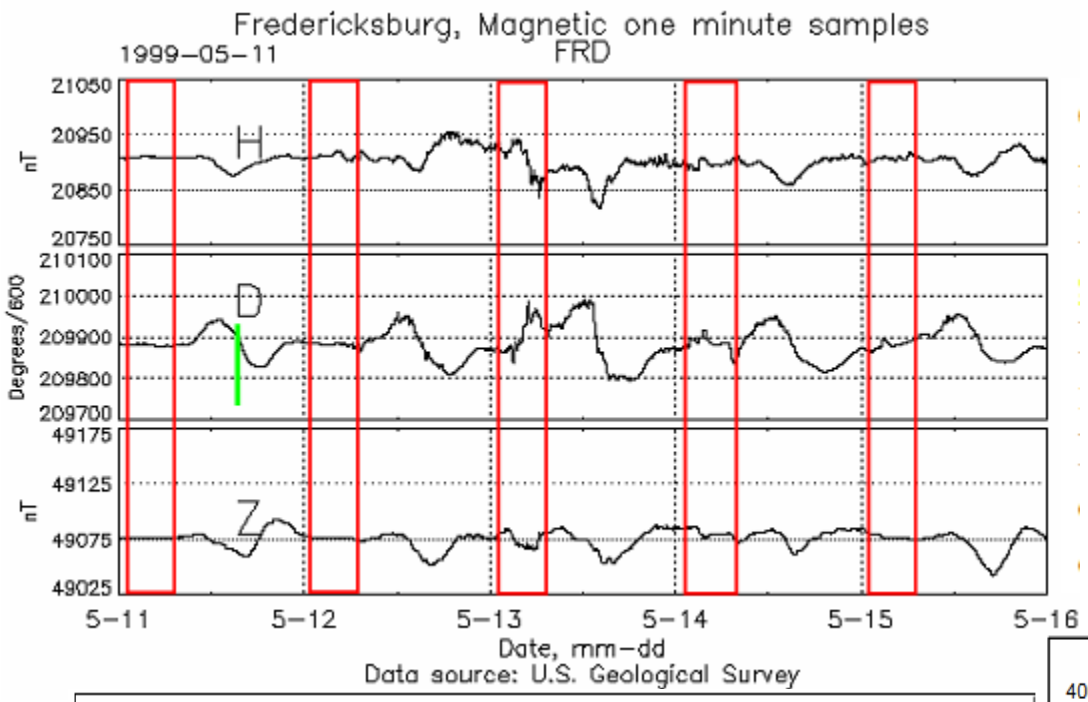




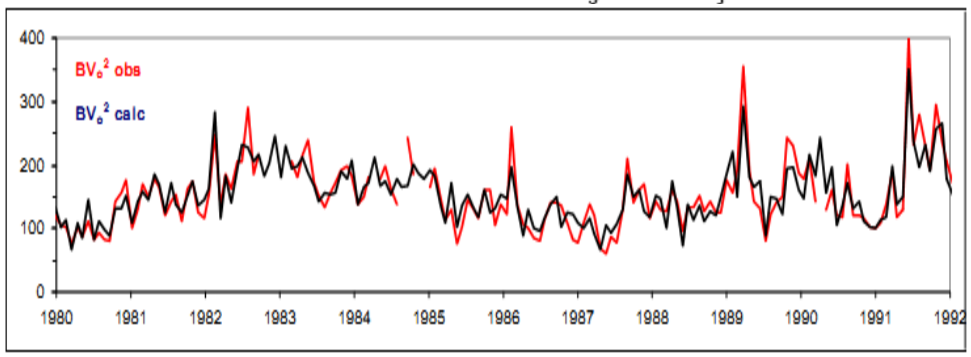
So, from IDV we can get HMF B

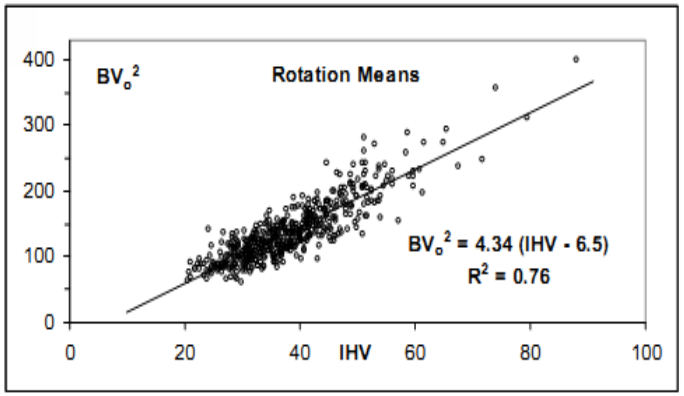


The *IHV* Index gives us BV^2

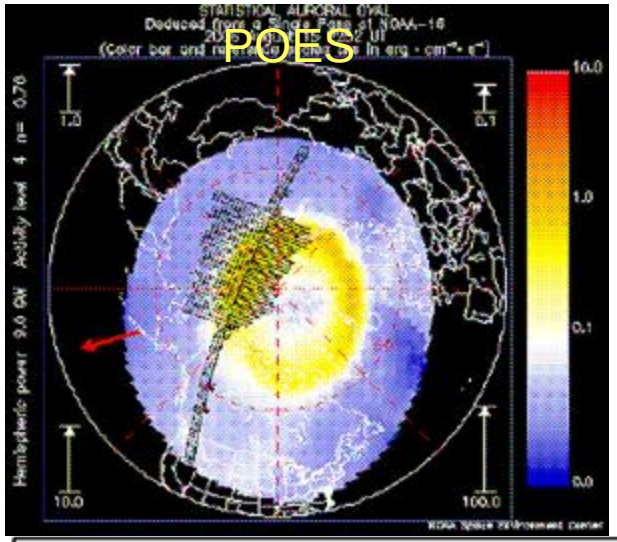


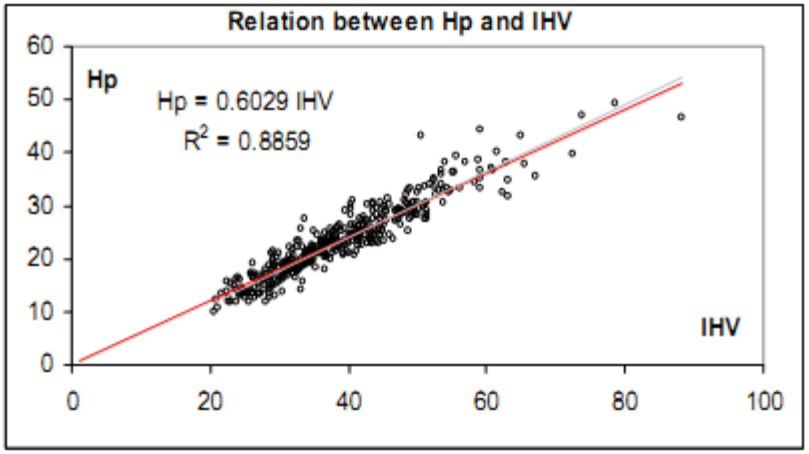
Calculating the variation (sum of unsigned differences from one hour to the next) of the field during the night hours [red boxes] from simple hourly means (the Interhourly Variation) gives us a quantity that correlates with BV^2 in the solar wind

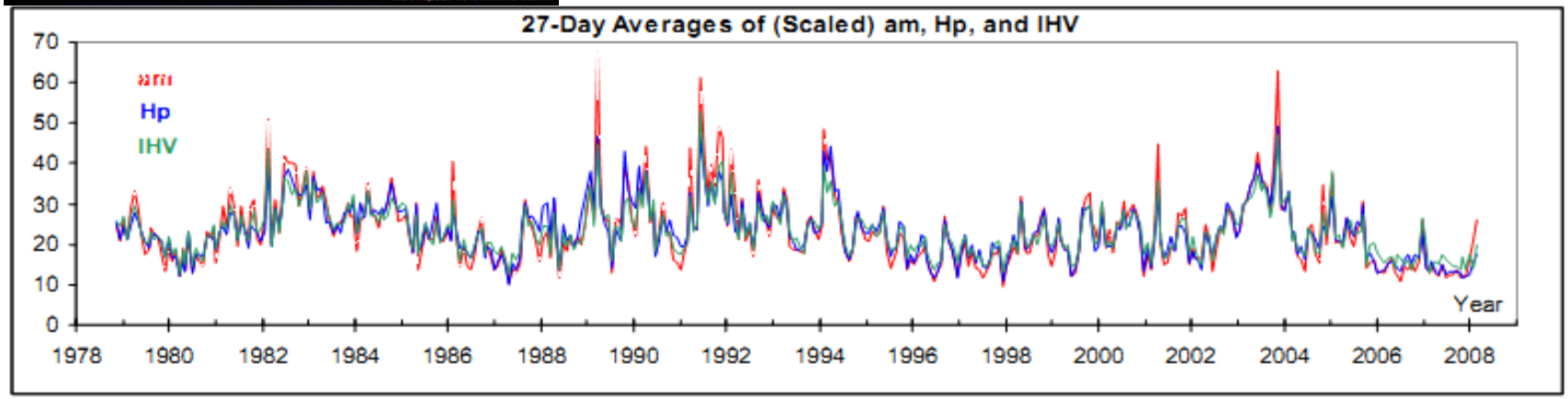




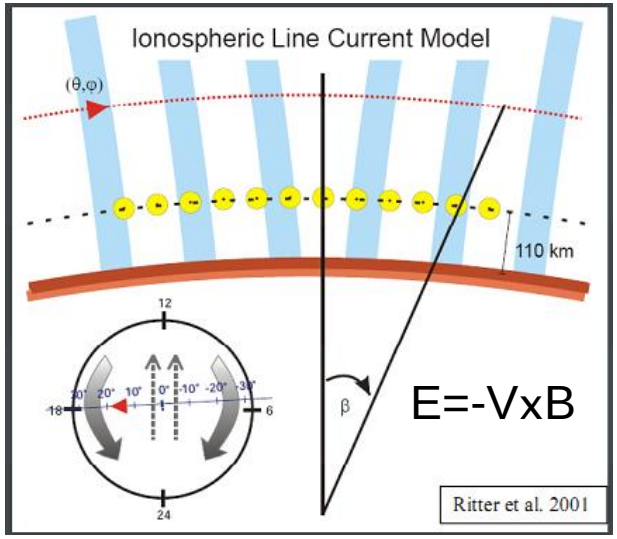
Physical meaning of IHV: the index is directly proportional to the auroral power input, HP, to the polar regions

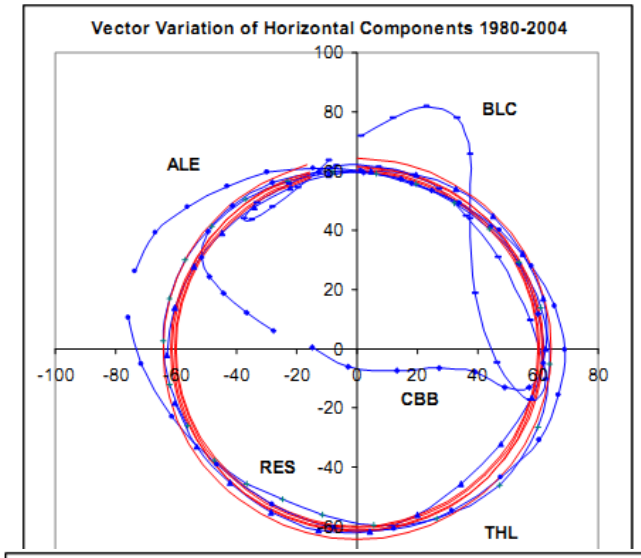


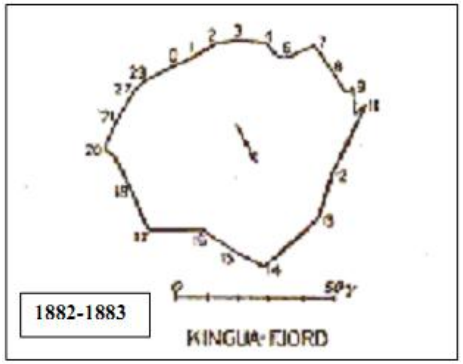




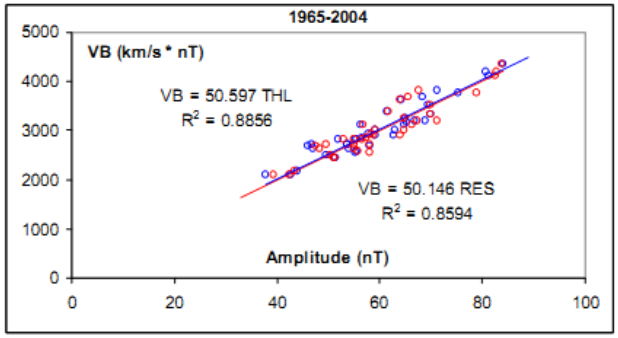
Polar Cap Diurnal Variation gives us V times B

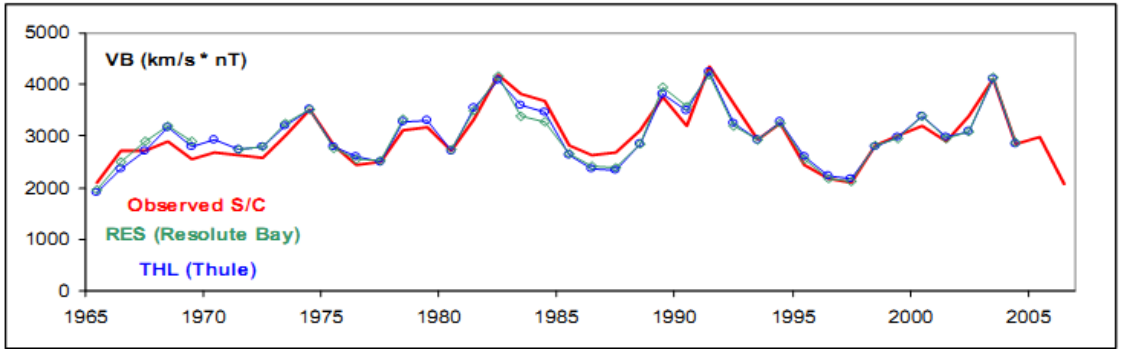


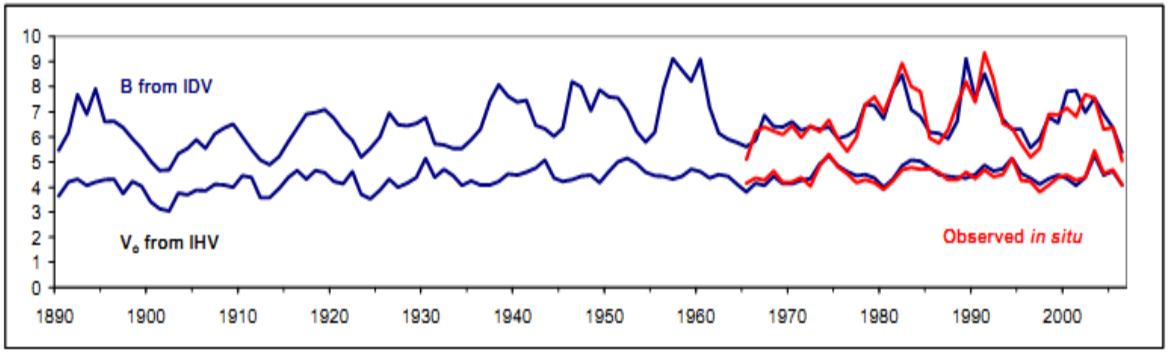


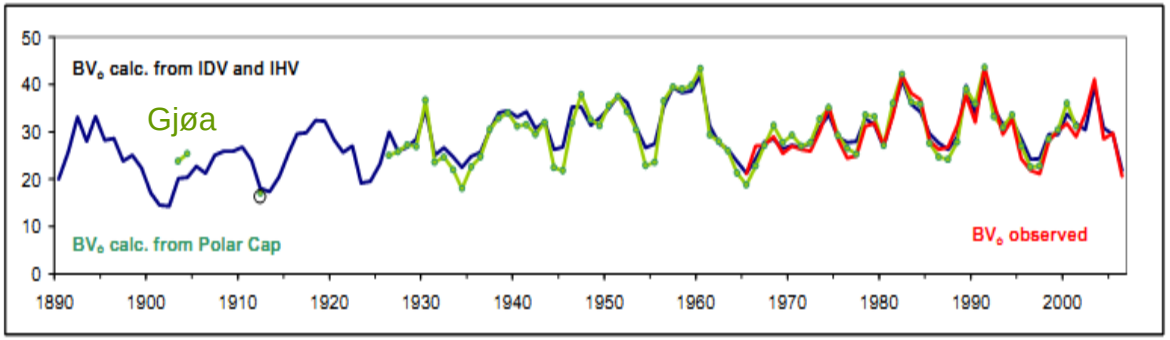


This variation has been known for more than 125 years









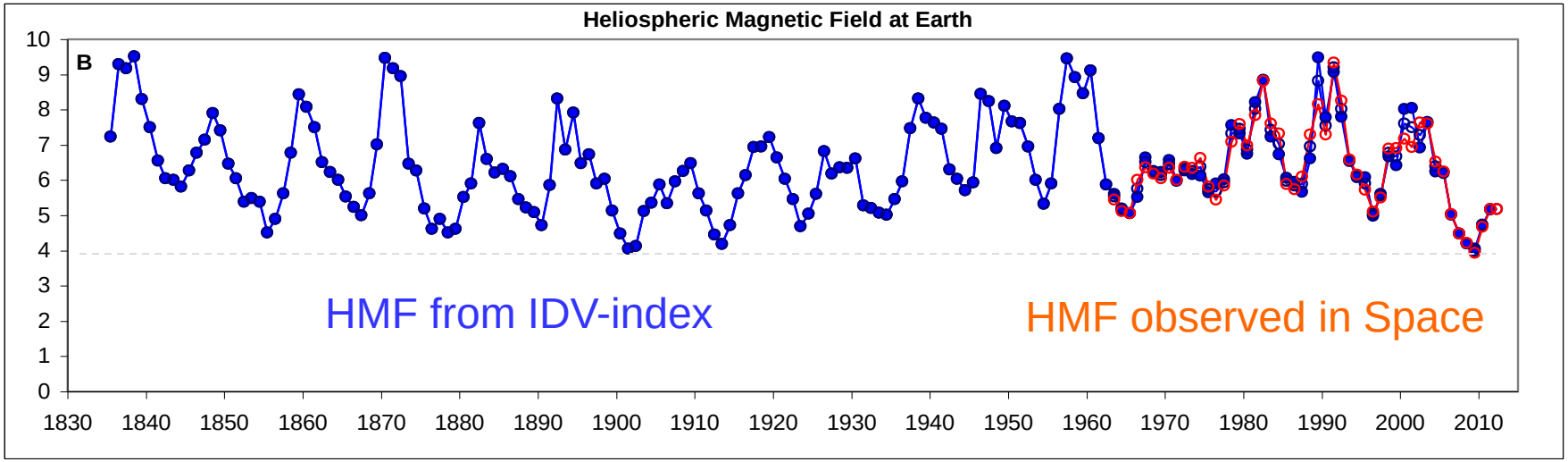
Overdetermined System: 3 Eqs, 2 Unknowns

B = p (IDV)

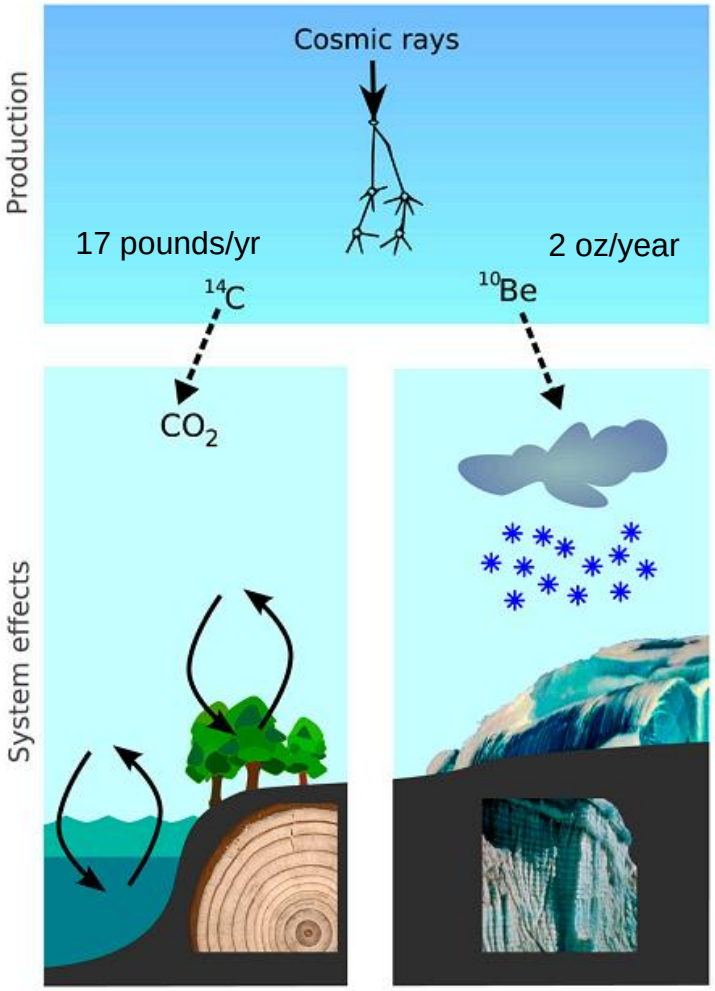
BV^2 = q (IHV)

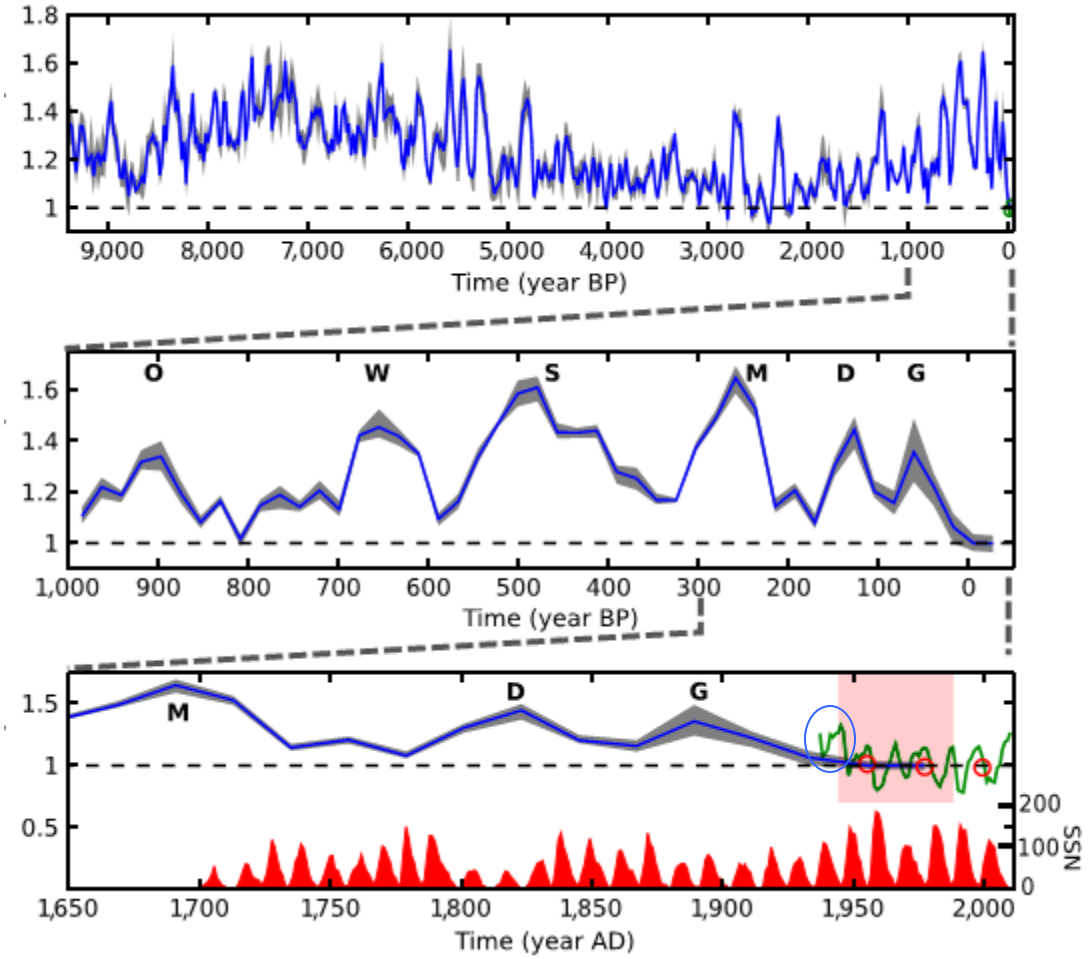
VB = r (PCap)

Here is B back to the 1830s:



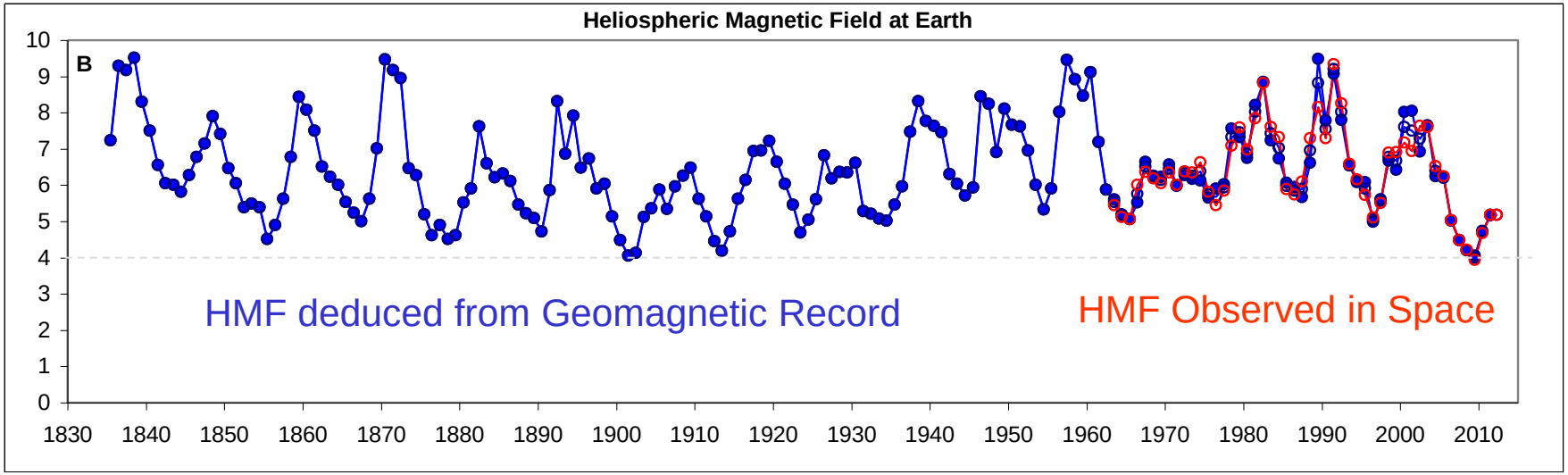
The Cosmic Ray Record has Promise, but is not without Problems

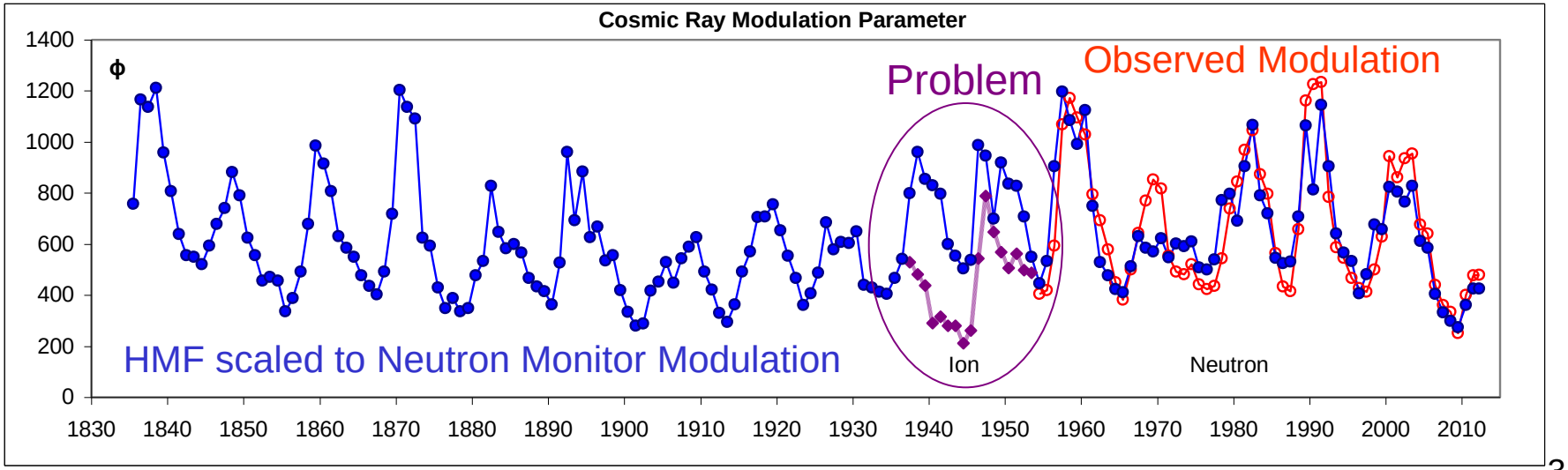




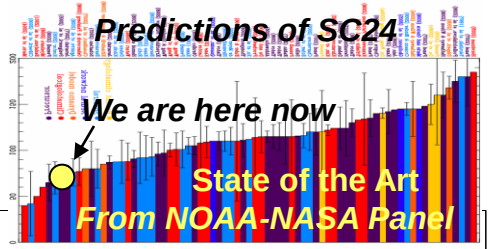
Steinhilber et al. 2012

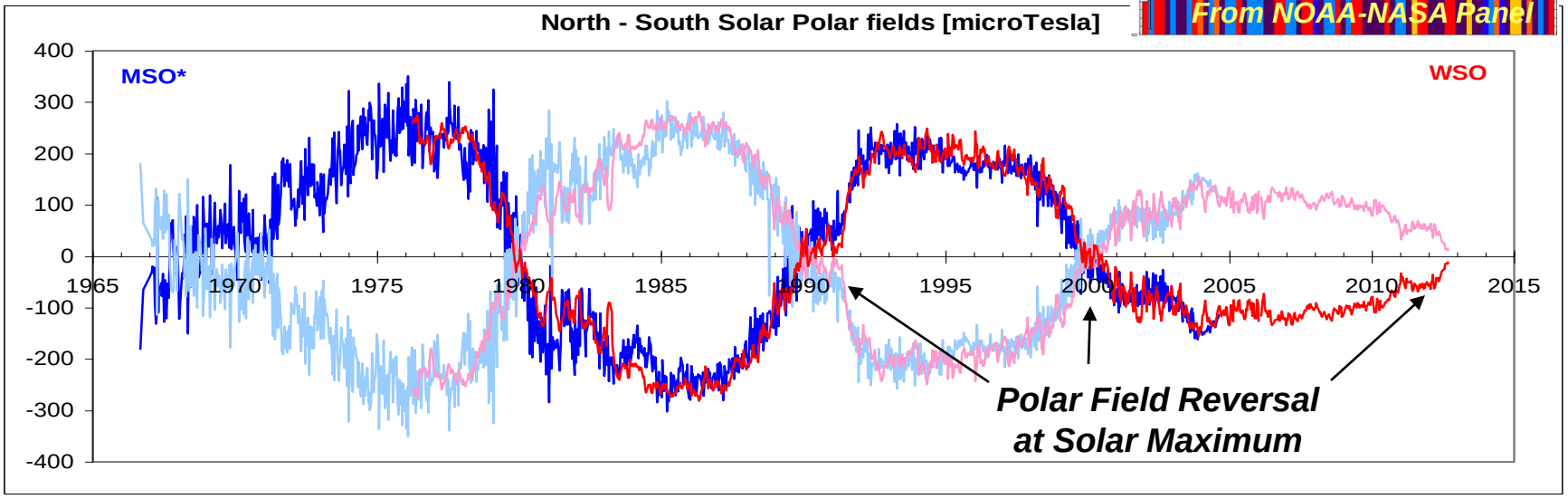
Cosmic Ray Modulation as Governed by Strength of Magnetic Field in Heliosphere

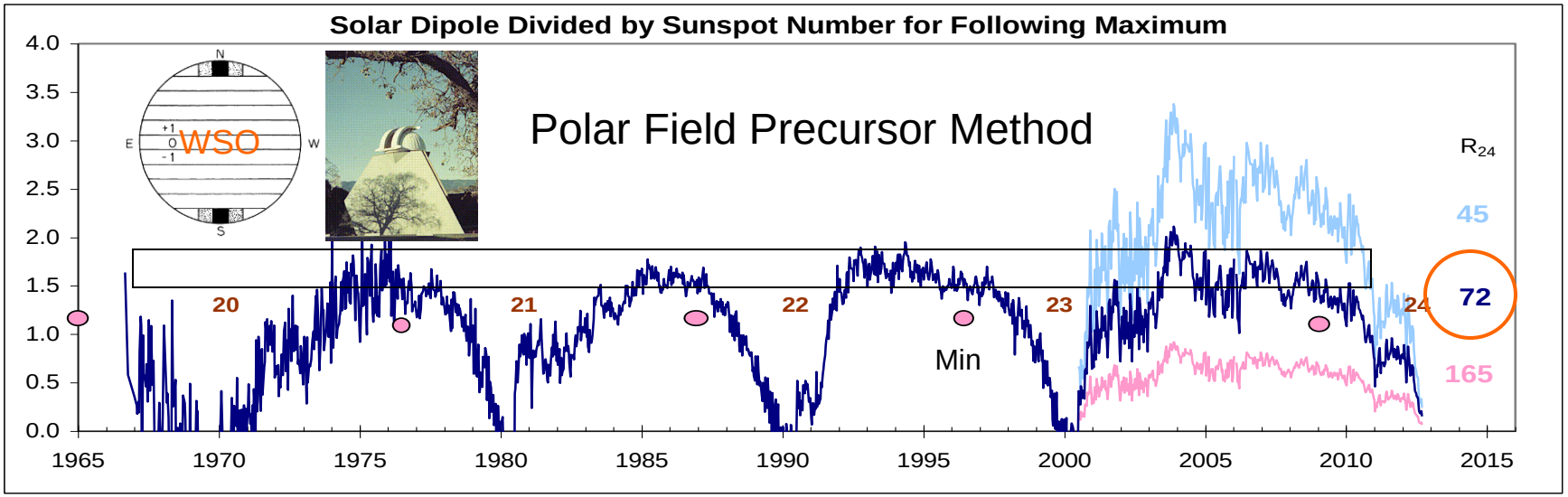




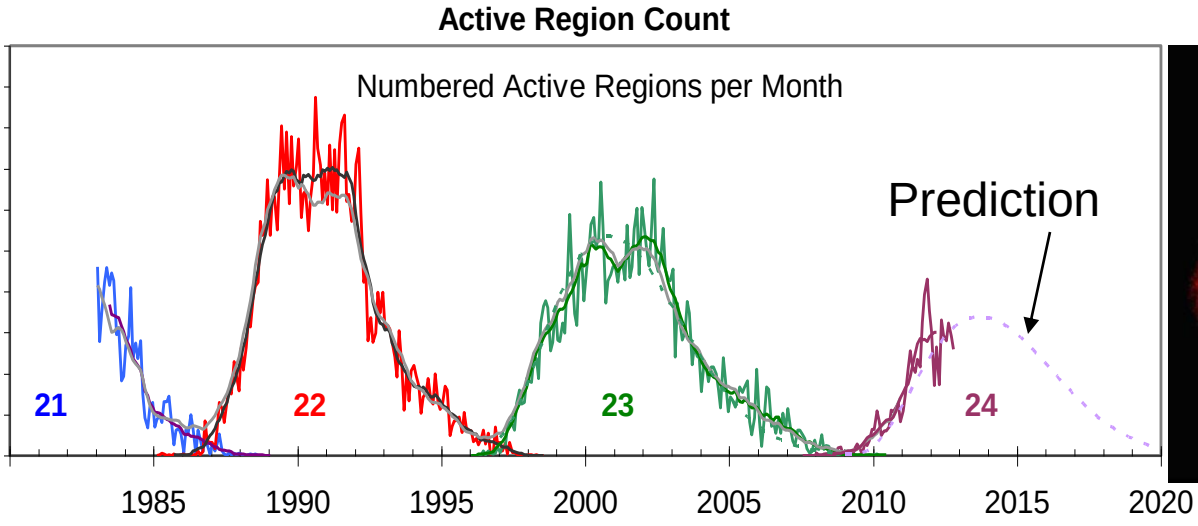
Prediction of Solar Cycles

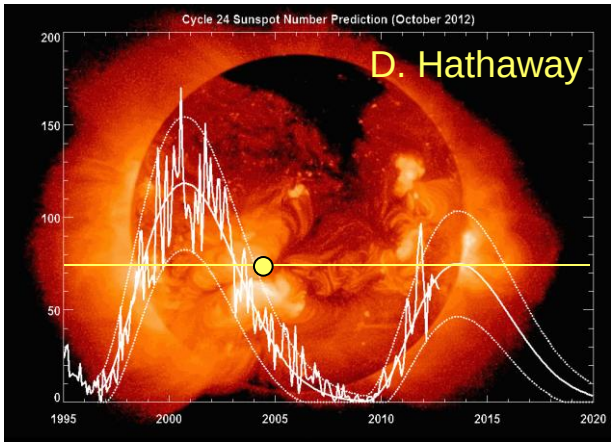


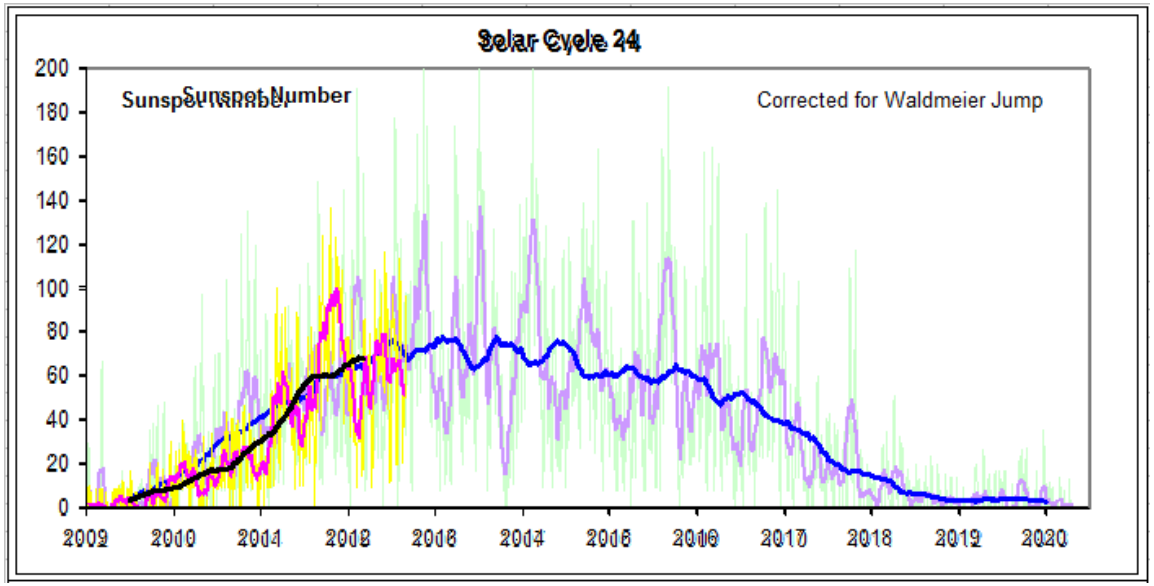


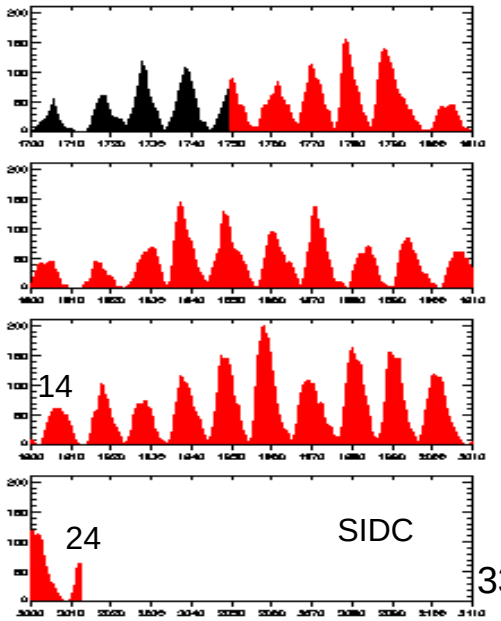


How is Cycle 24 Evolving? As Predicted!

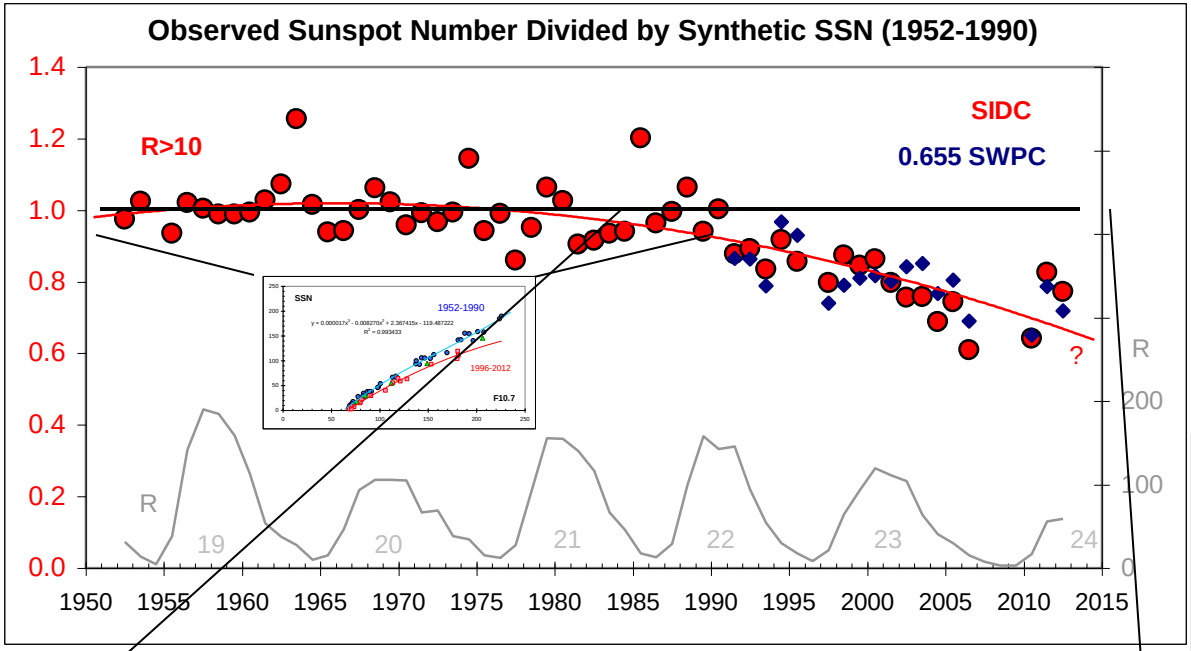


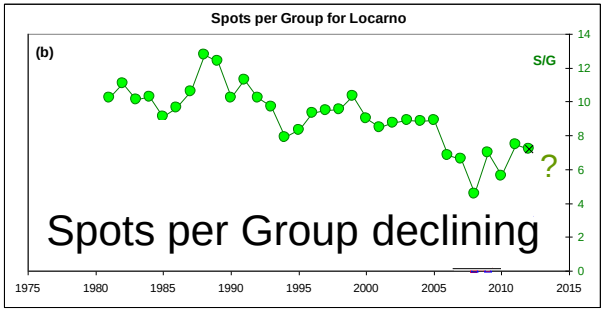


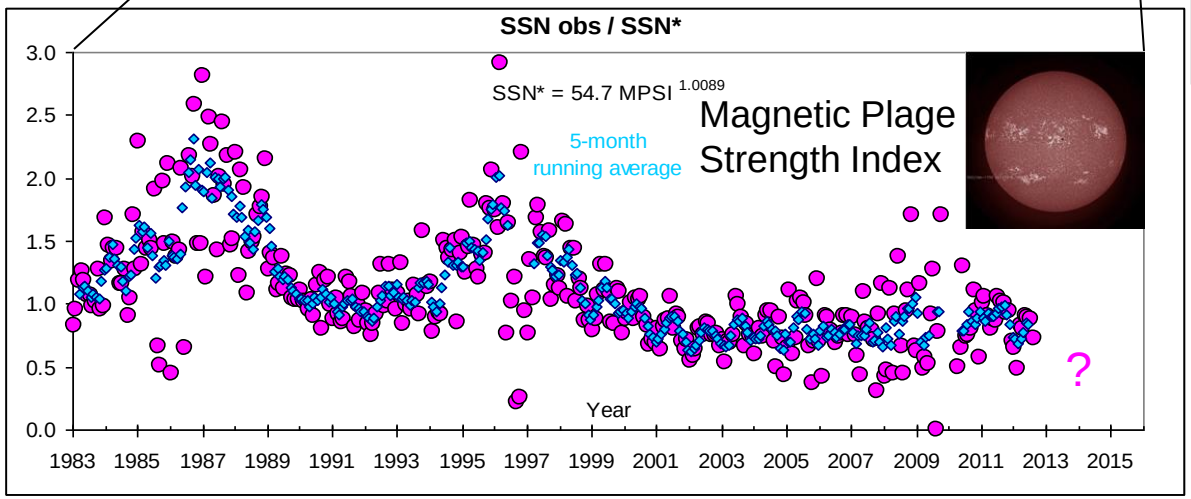


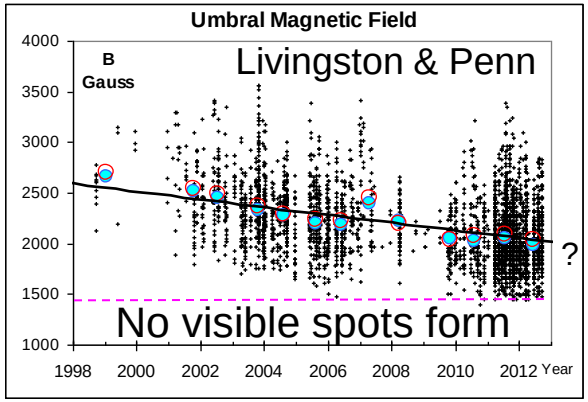


Something *is* happening with the Sun



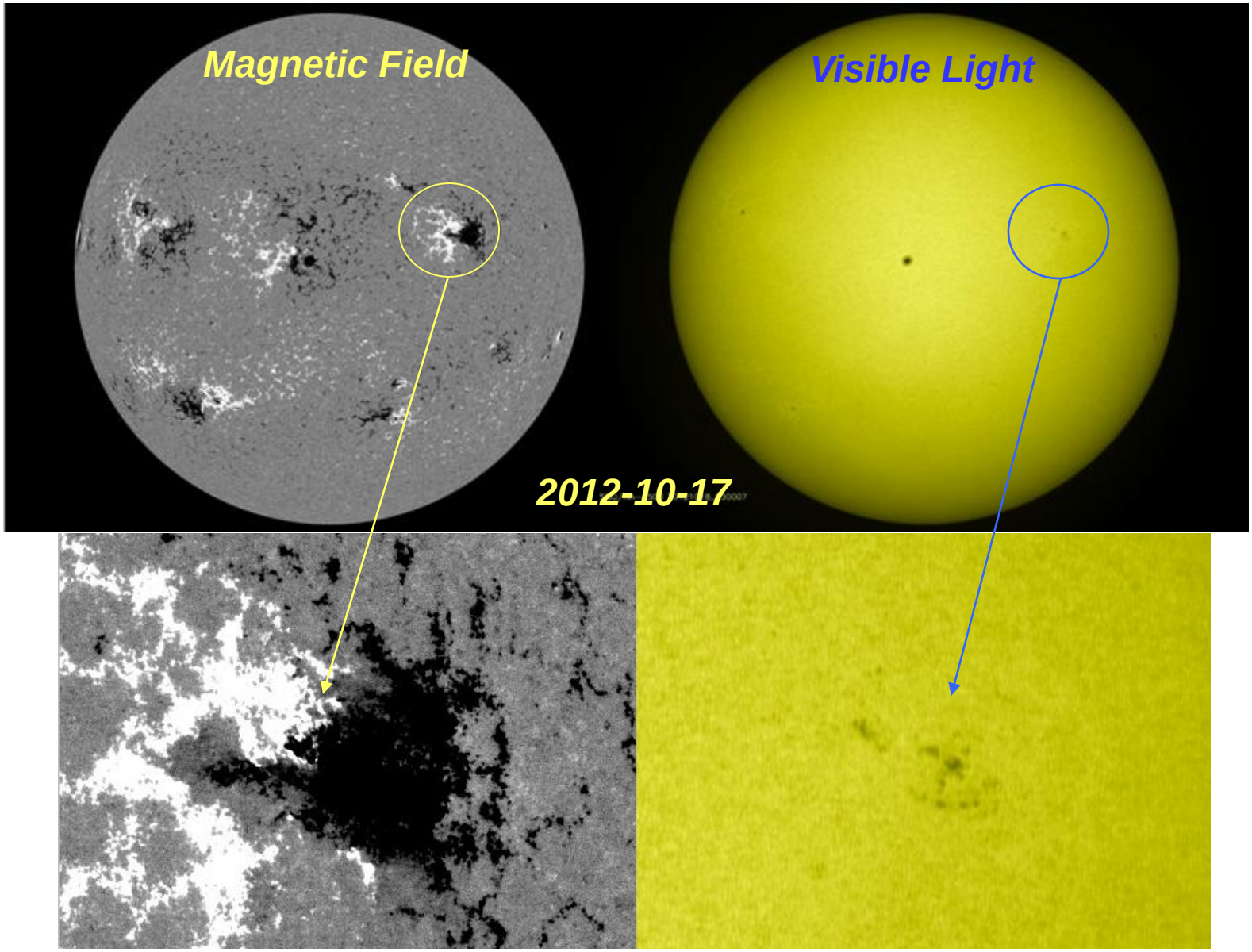






We don't know what causes this, but sunspots are becoming more difficult to see or not forming as they used to. There is speculation that this may be what a Maunder-type minimum looks like: magnetic fields still present [cosmic rays still modulated], but just not forming spots. If so, exciting times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

Perhaps like this:



Conclusions

- The historical (official) ‘Wolf’ sunspot record has been re-assessed and need revision
- The Group Sunspot Number is flawed and should not be used anymore
- There likely was no Modern Grand Maximum
- The Cosmic Ray record calibration is uncertain
- The polar field precursor method for prediction of a low solar cycle 24 has worked well
- The Sun may be entering a new regime of very low activity