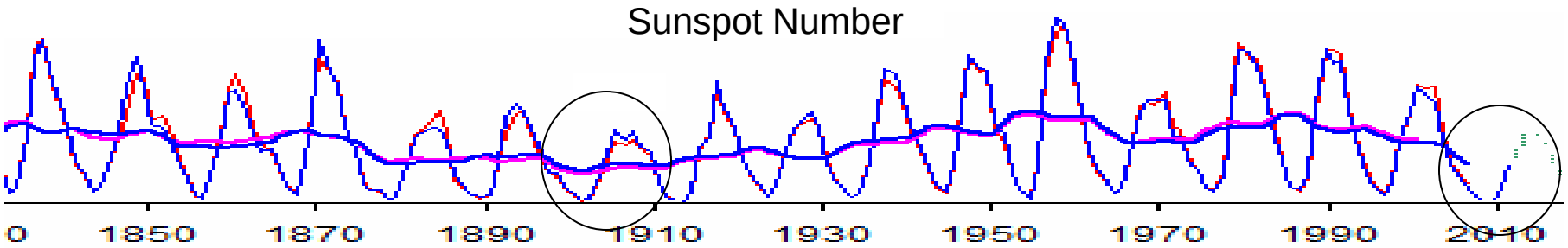
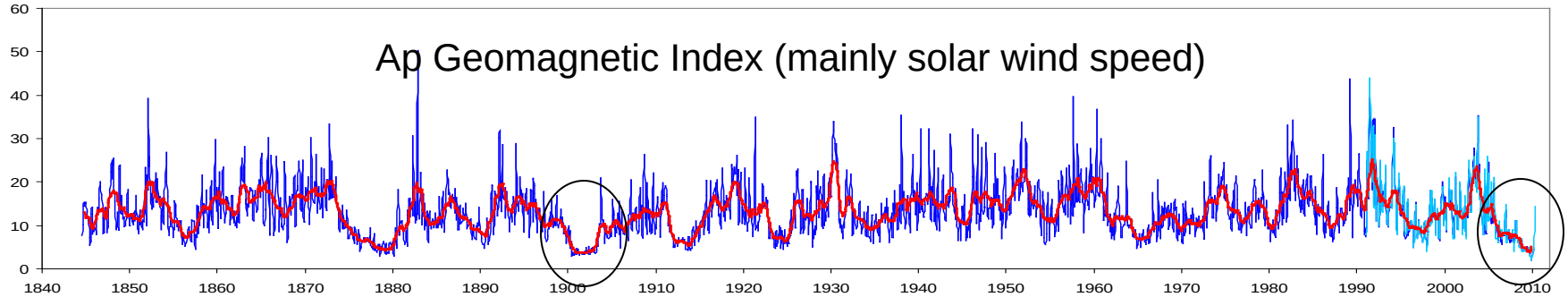
The Forgotten Sun

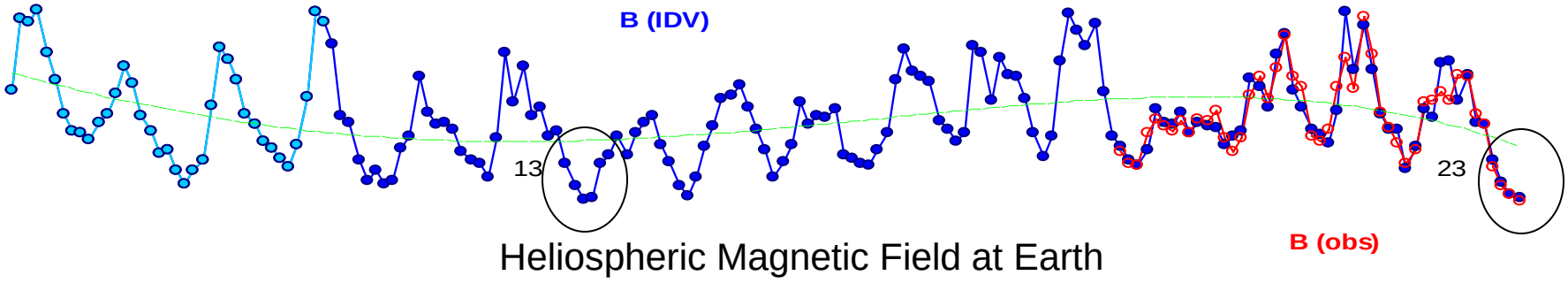
Leif Svalgaard
Stanford University
SHINE-2011, Snowmass, CO
13 July 2011

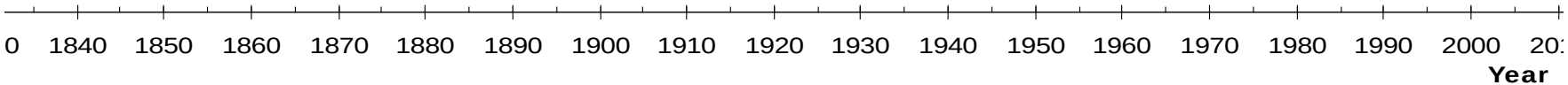
leif@leif.org

Solar Activity 1835-2011





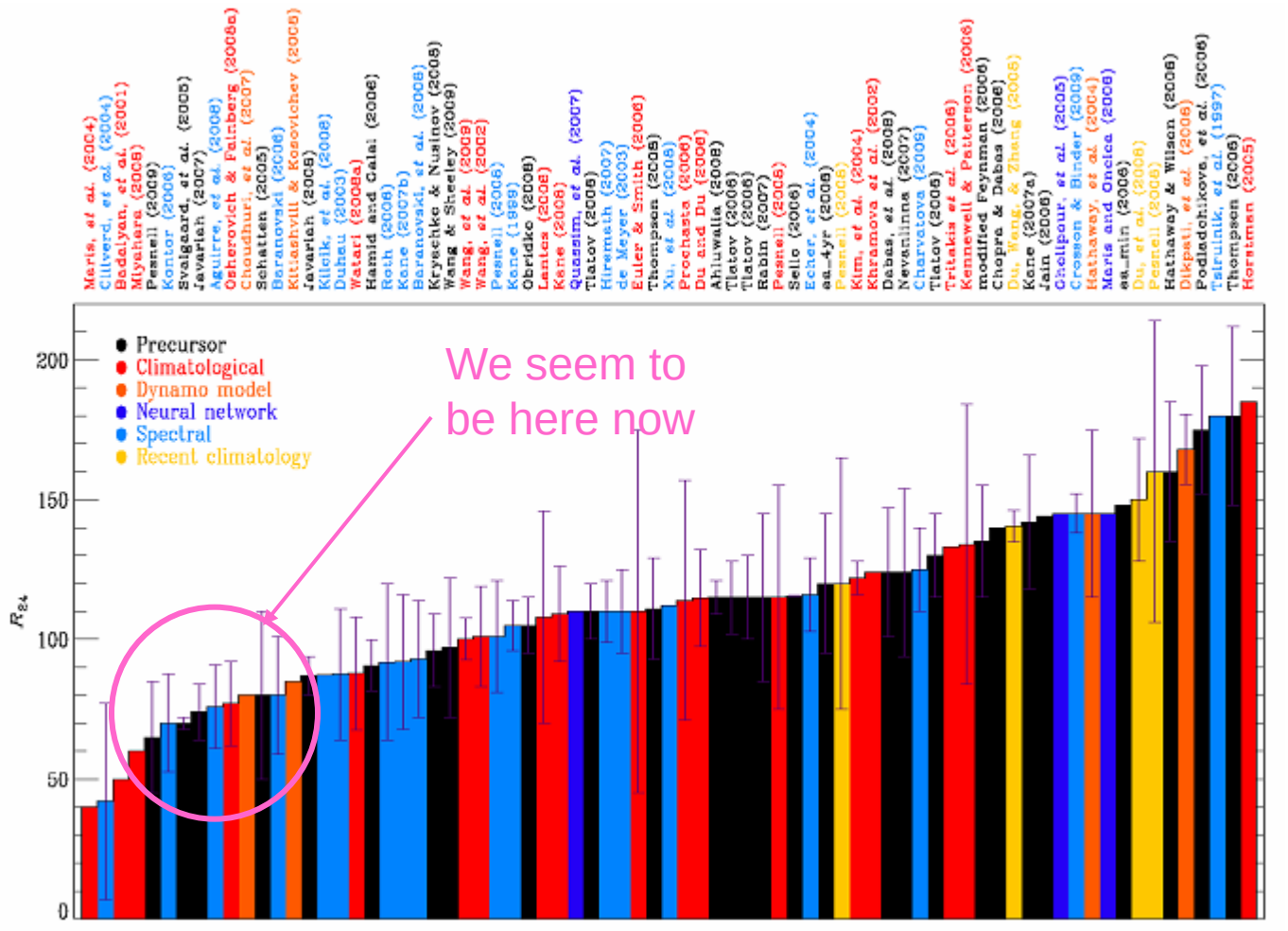


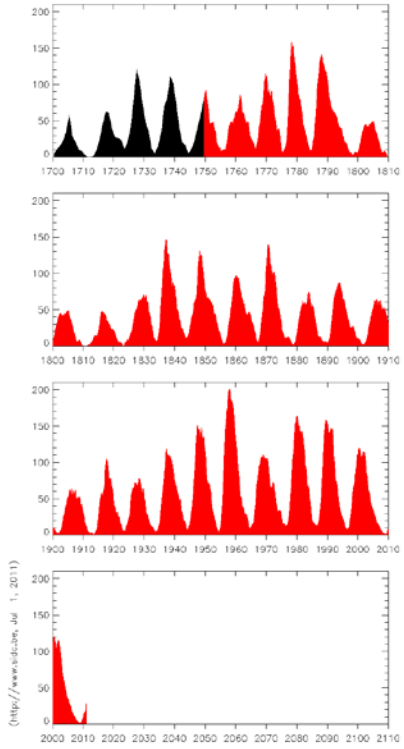


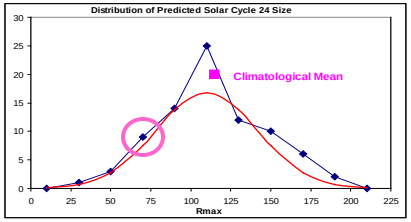
Summary of How the Sun is Similar Now to a Century ago

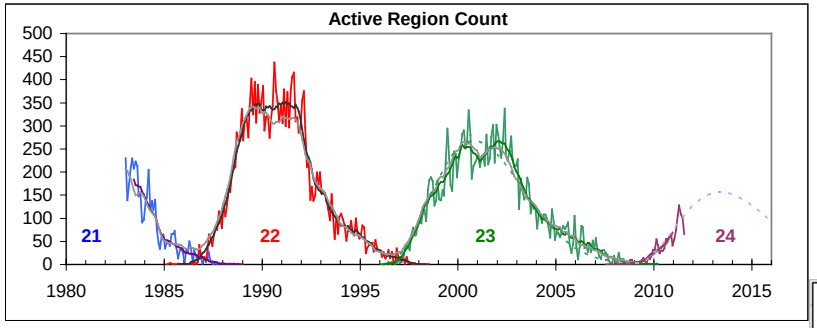
- Sunspot Number at Minimum was as low
- Minimum lasted as long
- Solar Wind Speed was Similarly Small
- Heliospheric Magnetic Field was as small
- Mid-century Solar Activity was Similarly High
- Ca II Network was Similar to Today's
- Cycle 24 is now Predicted to be Low ['lowest in a hundred years…]

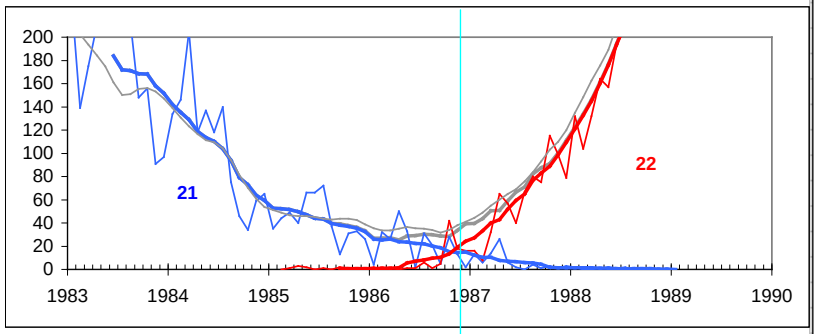
Reminder of the Near Zero Skill in Predicting the Solar Cycle (24)

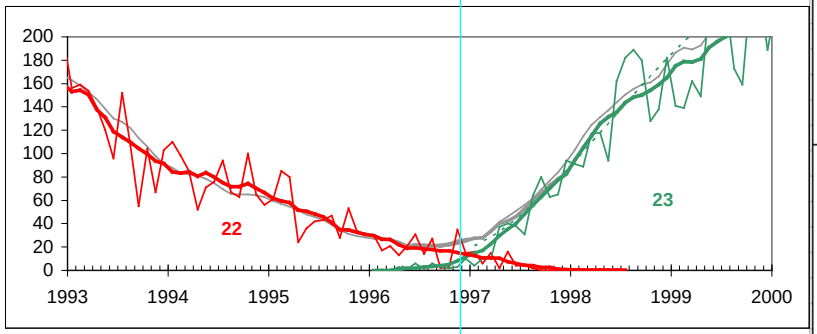


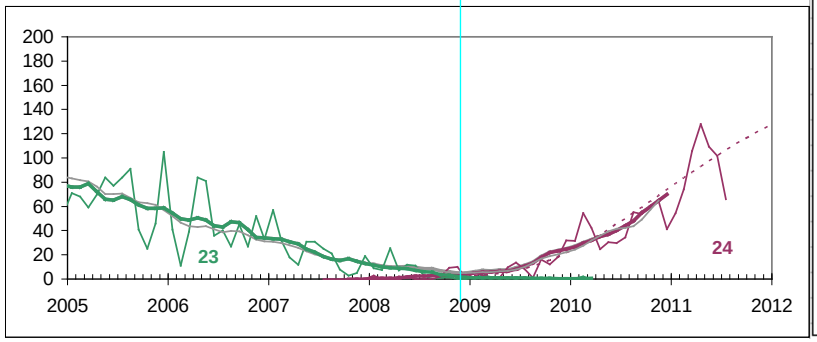




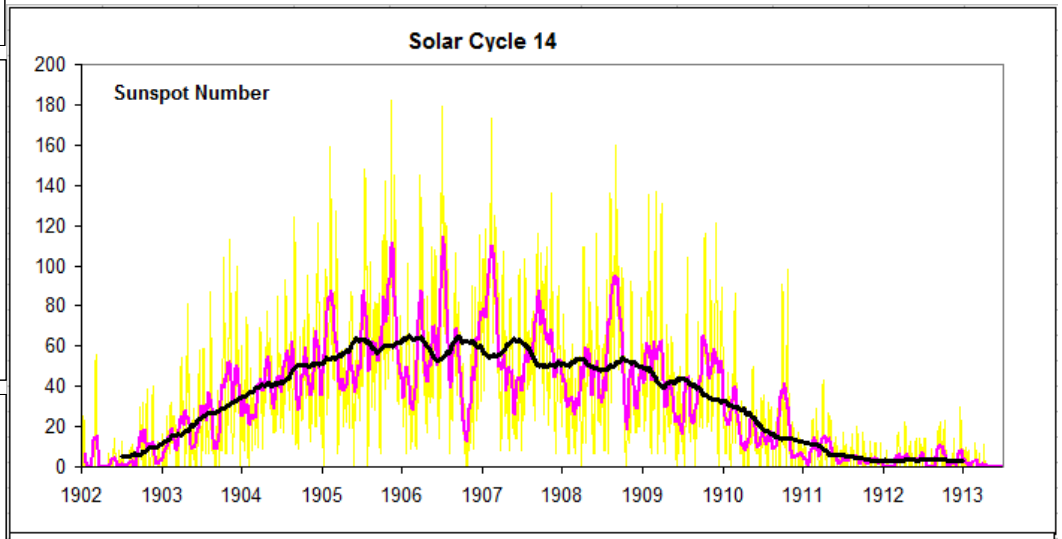


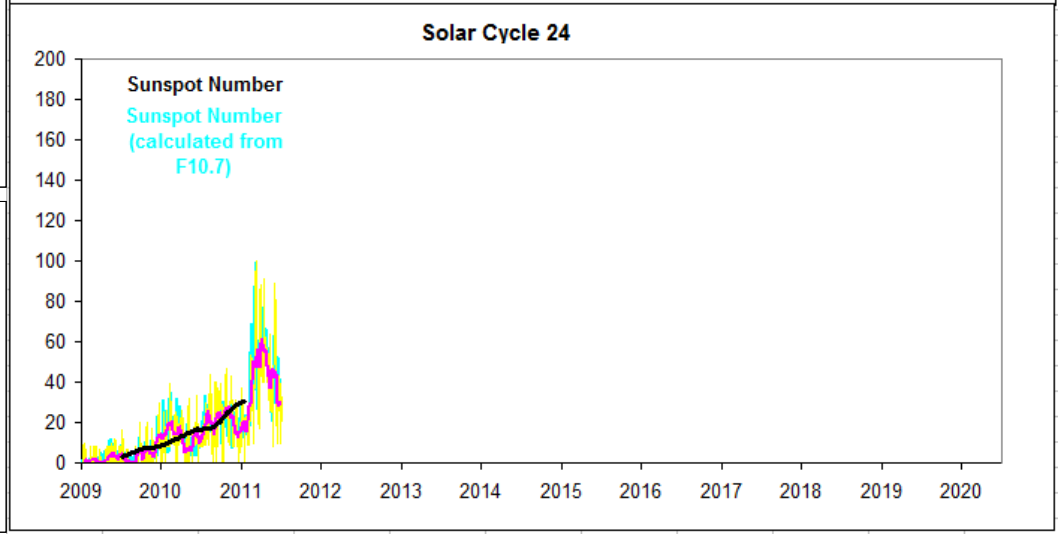


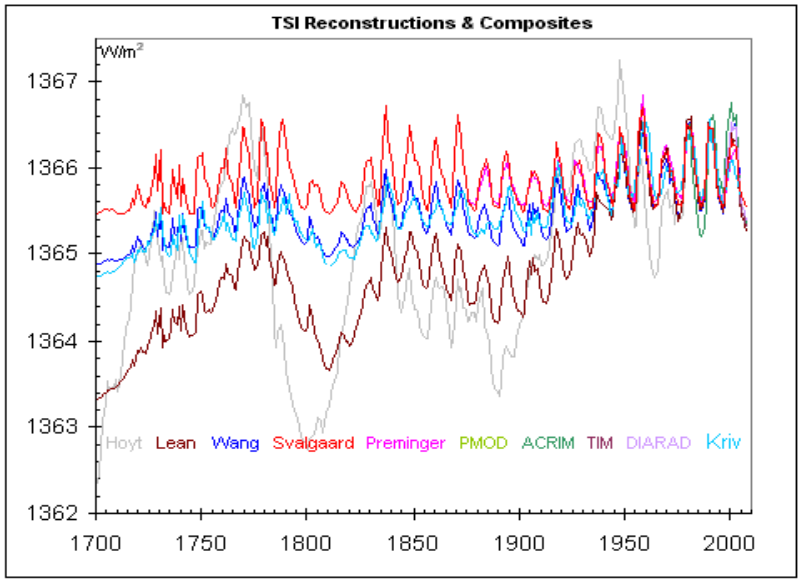




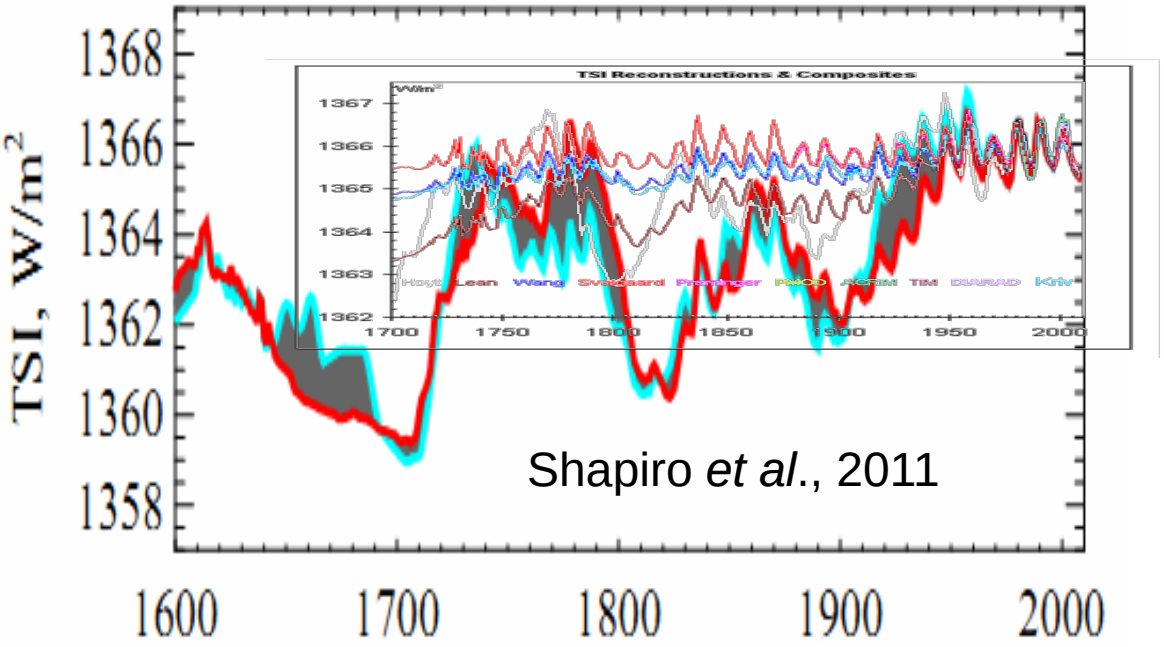
We have been there before, 108 years ago, but have largely forgotten how it was







Total Solar Irradiance has only been measured since 1978 and must be ‘reconstructed’ for times before that. Such reconstructions have a curious history as the ‘background’ variation on which the obvious solar cycle variation of only 0.1% seems to ride had become smaller and smaller.

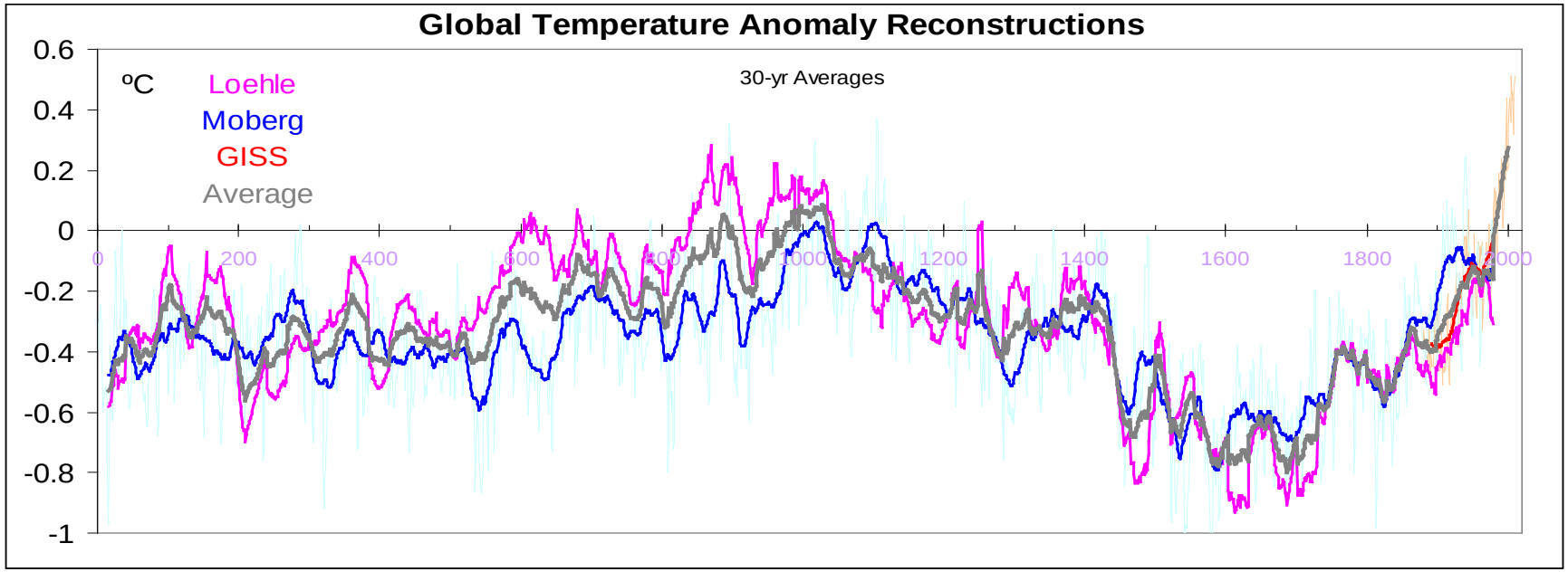


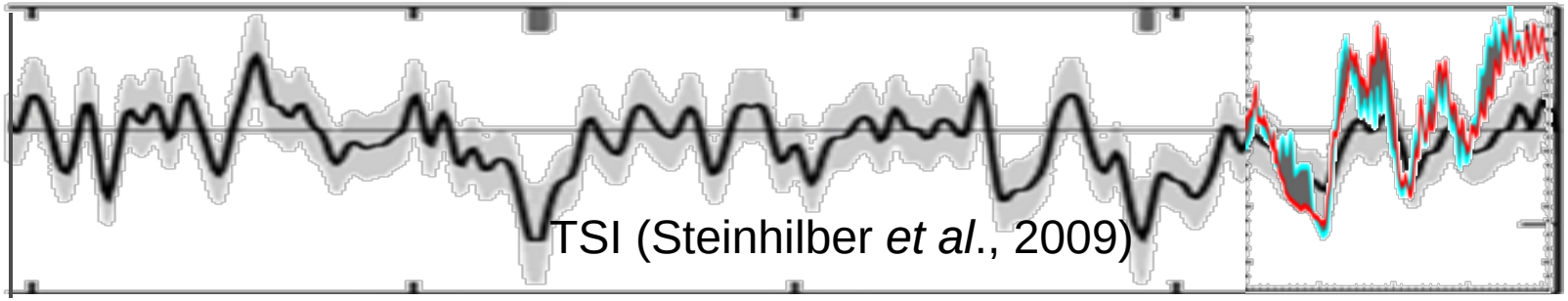
Shapiro *et al*., 2011

Recently, this issue has become ‘hot’ again with an inferred very large ‘secular’ trend since 1900.

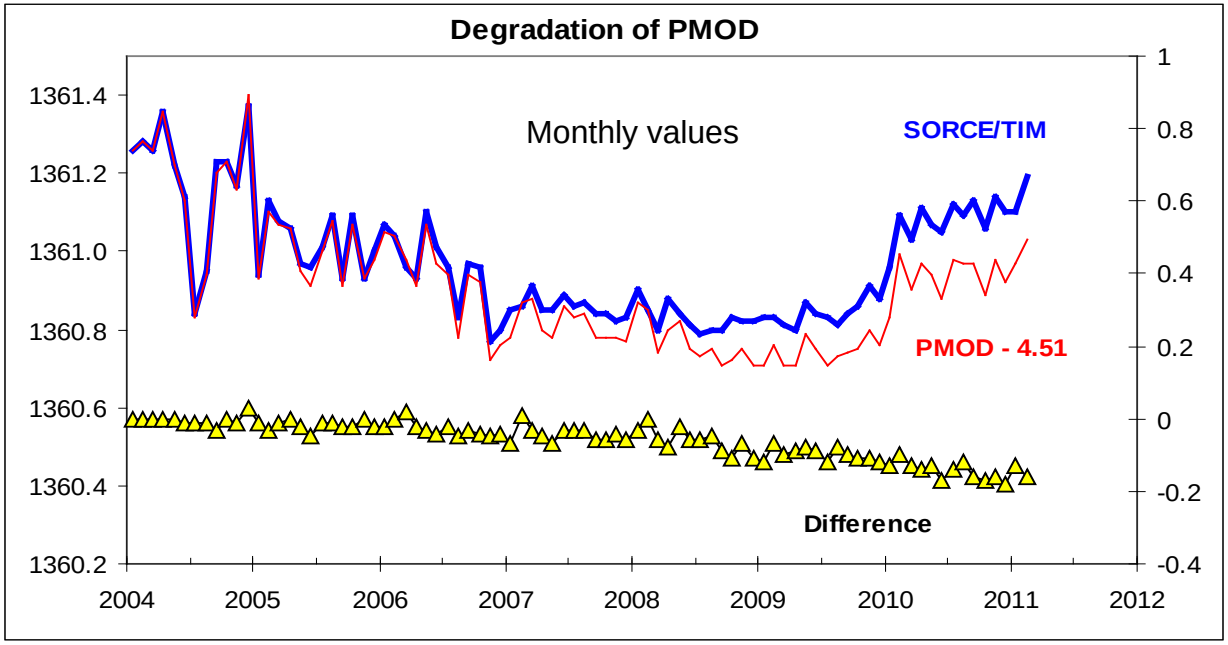
This in spite of the Sun being so similar back then to now. What have we forgotten?

How Much of Climate Variation is Due to Variation of Solar Activity?

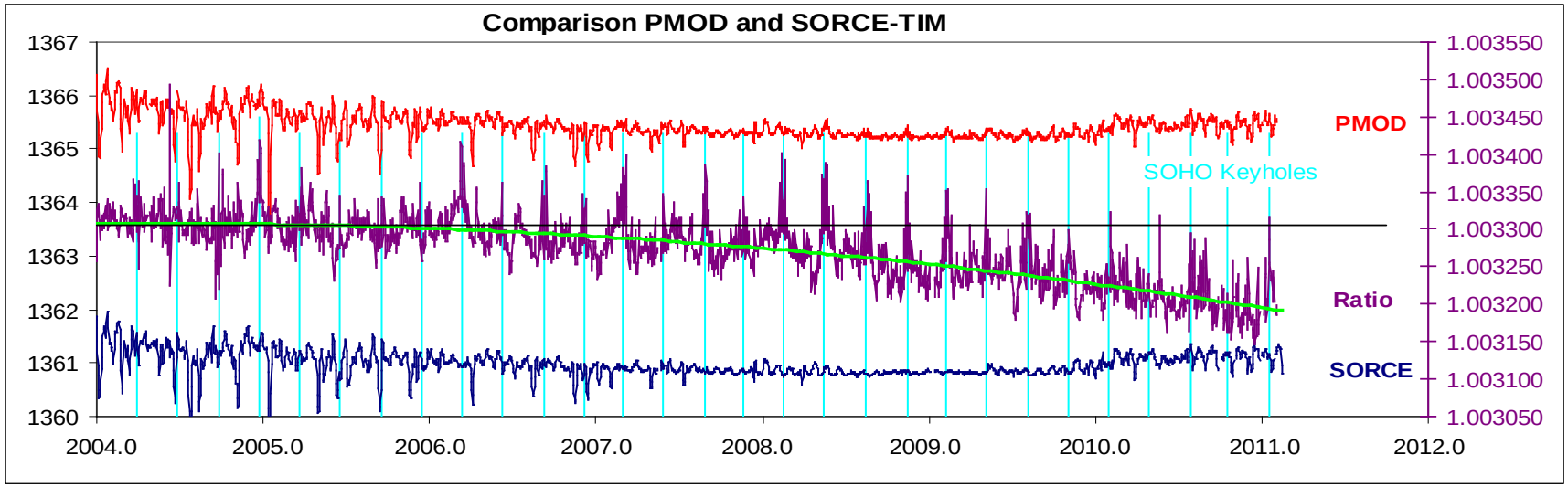




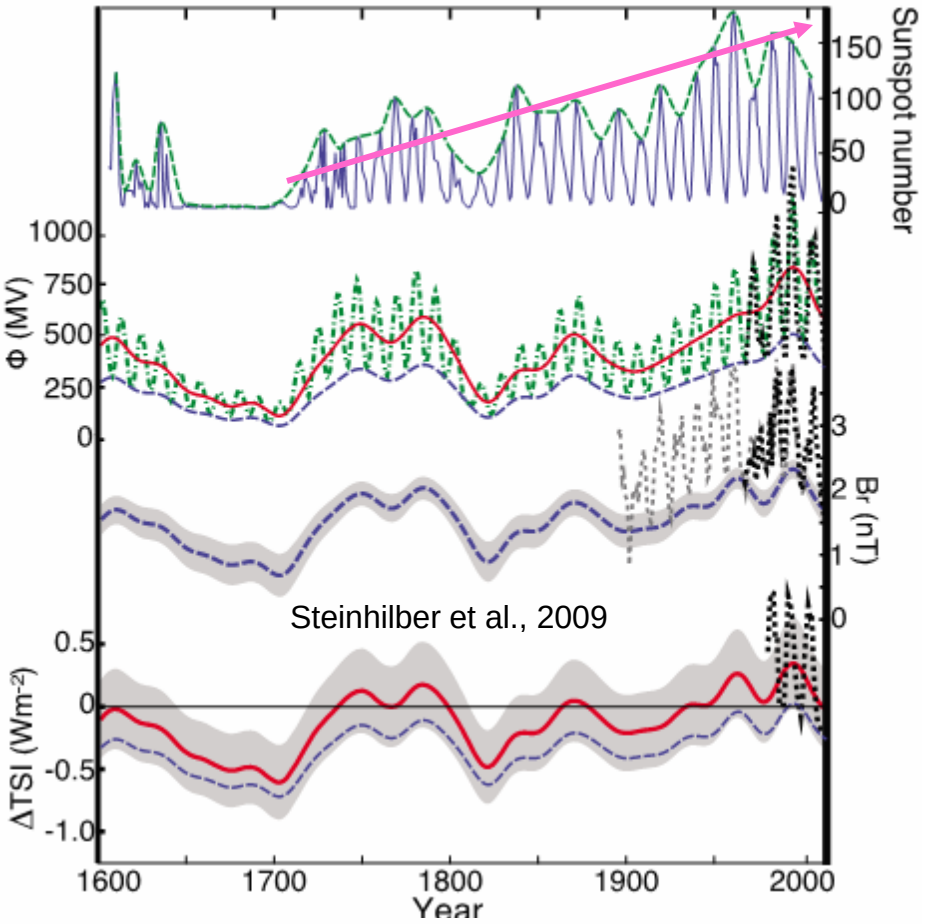
dTemp/Temp = ¼ * dTSI/TSI, so dTSI/TSI = 0.5% means dTemp = 0.4º

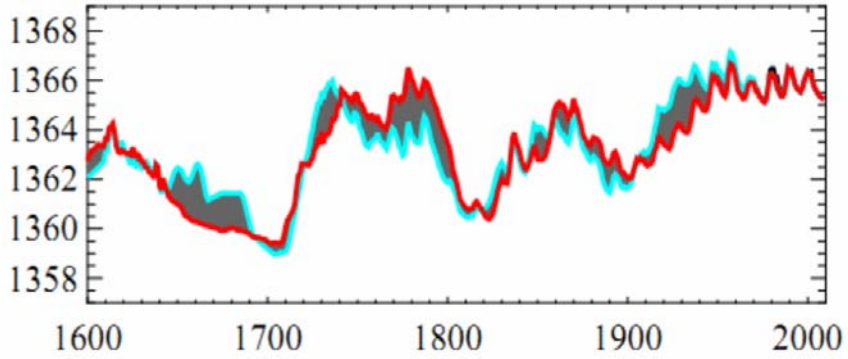


Is it that recent TSI is perhaps significantly smaller now? As claimed by Fröhlich [his PMOD composite] and that a 'fourth' [non-magnetic] parameter is needed: "It could be due to a global temperature change of Sun of 0.25K"



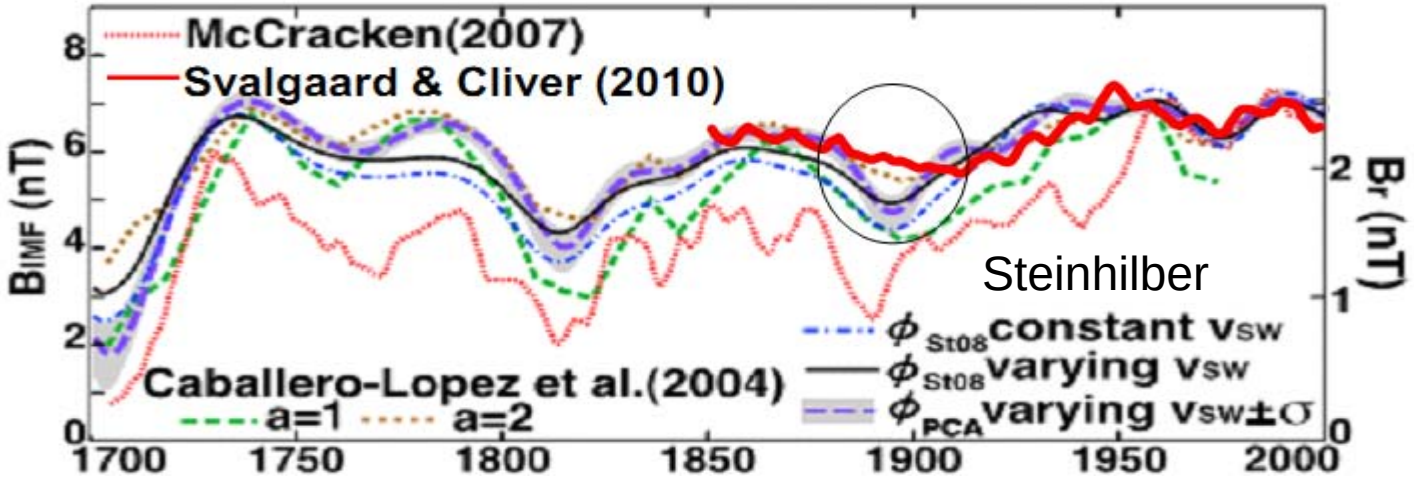
Comparison with SORCE/TIM suggests that PMOD has uncompensated degradation, and that there is no evidence for TSI this minimum being lower than at previous minima

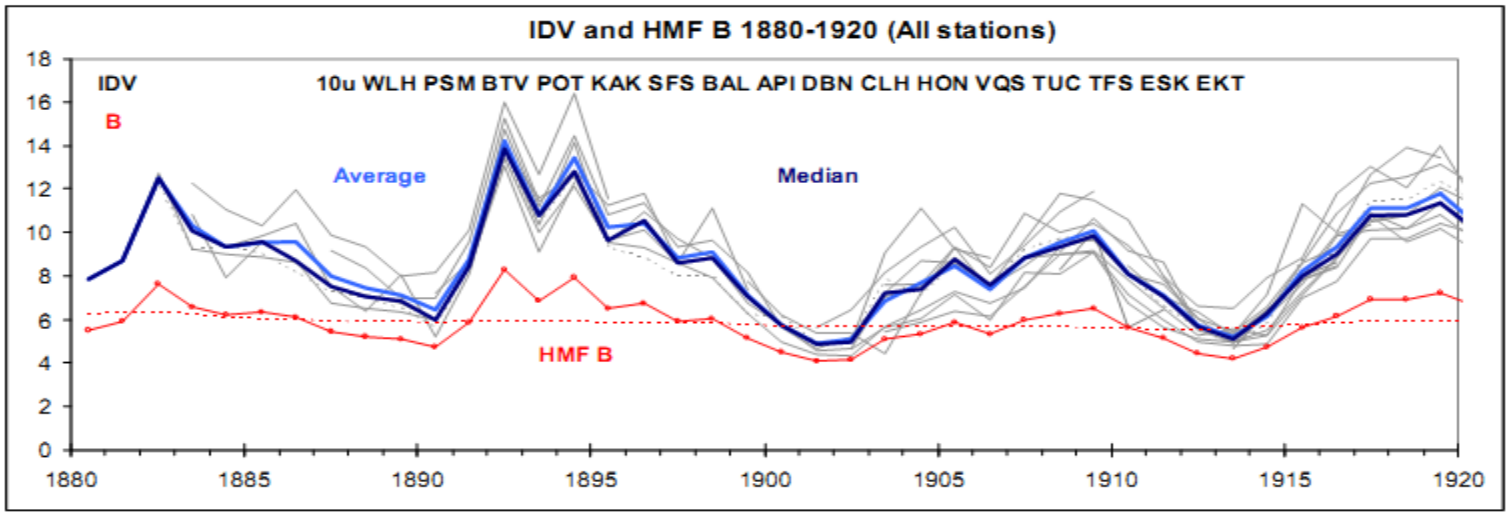




Recent TSI Reconstructions are partly calibrated using the PMOD smaller values the past minimum (and they were likely not smaller) and an assumed secular change in the (Group) Sunspot Number. And herein lies another problem: do we know the sunspot number well enough for this?

HMF From Ice Core 10Be



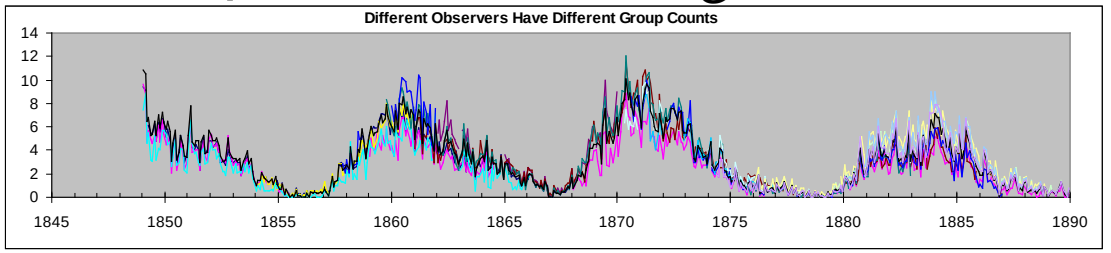


The Sunspot Number(s)

Rudolf Wolf (1816-1893)
Observed 1849-1893

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

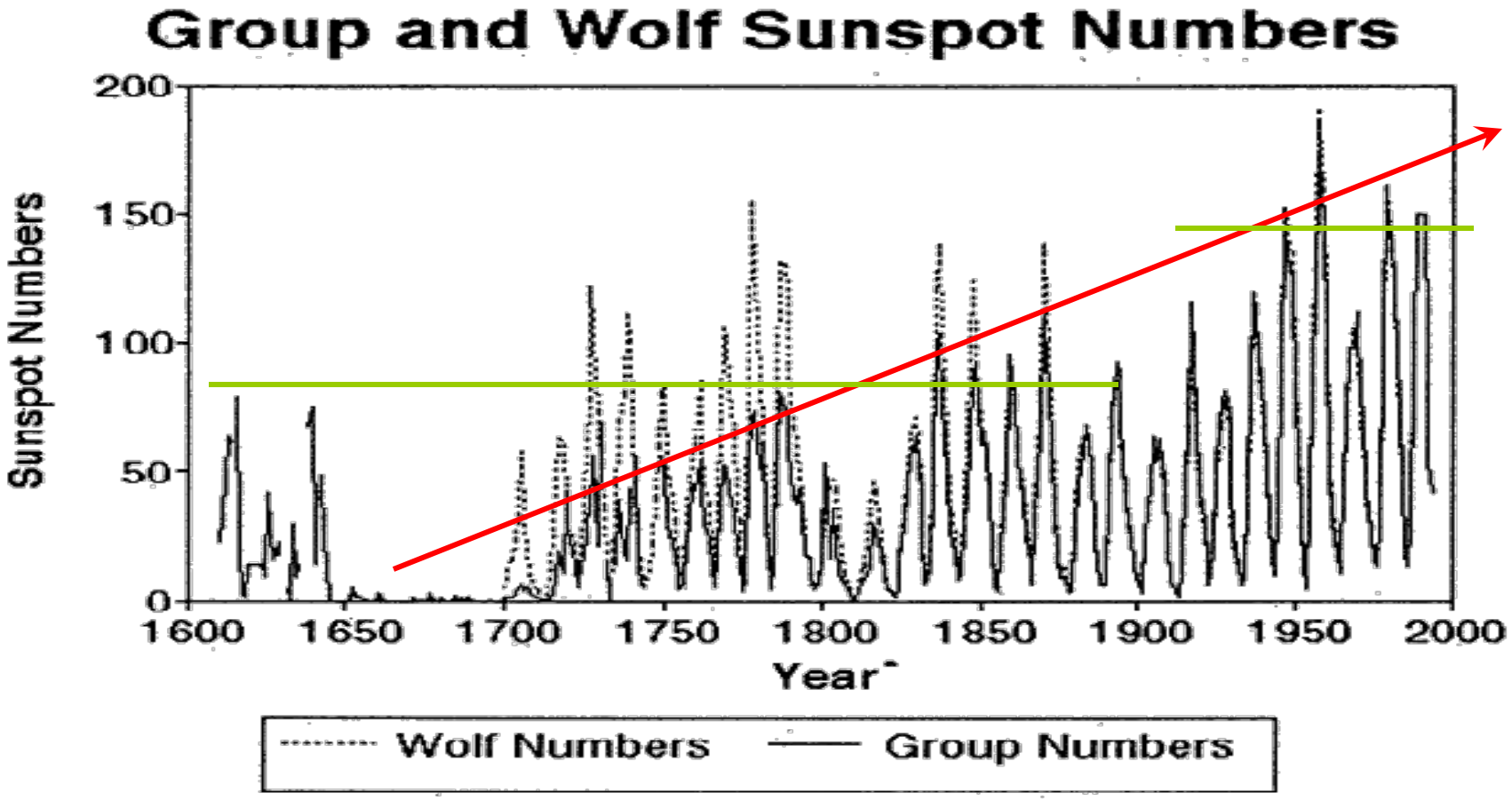
- Group Number = 12 k_G G



The '12' is to make the mean for the past ~100 years the same as the mean Wolf Number

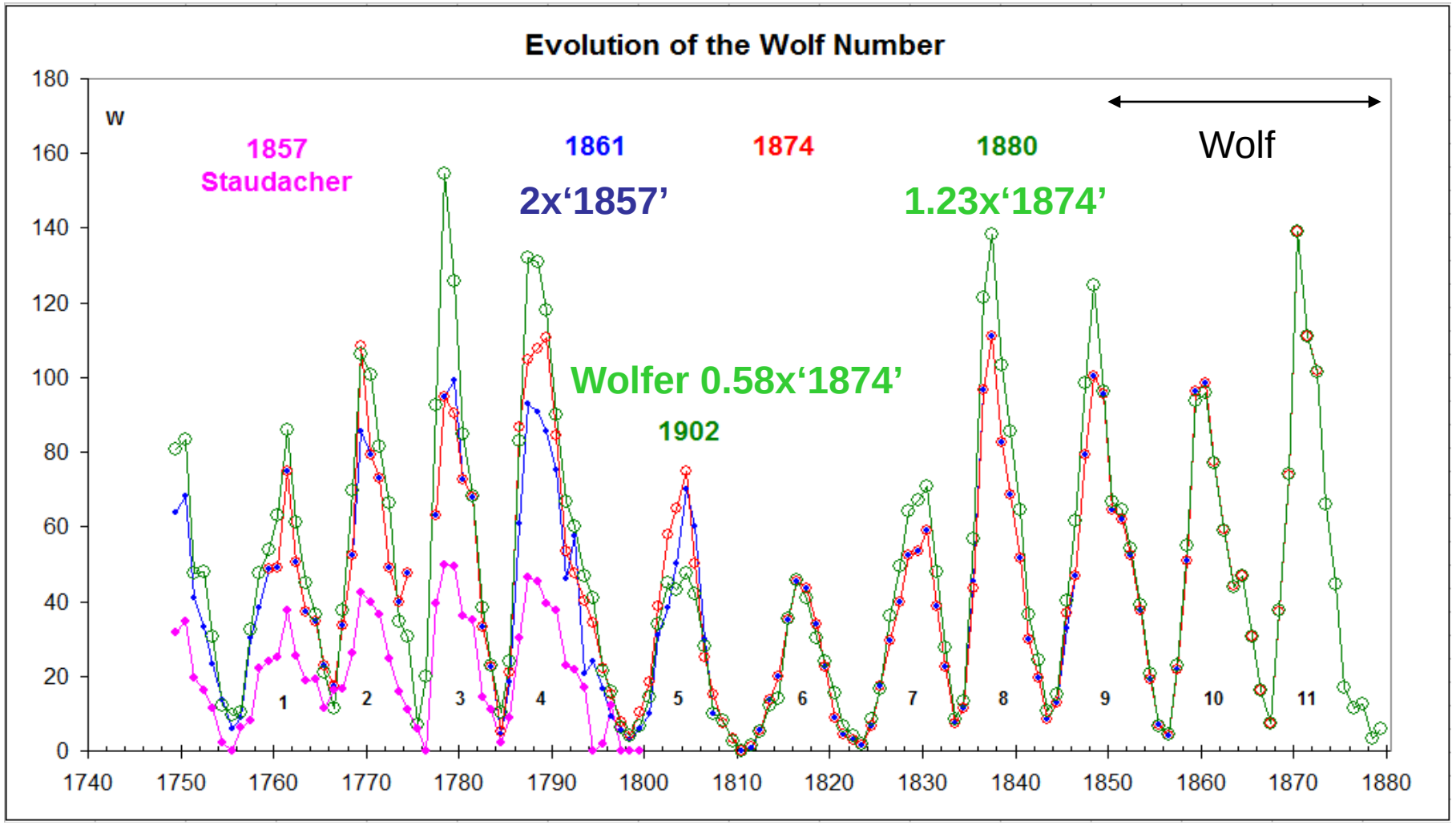
Ken Schatten

And Now, The Problem: Discordant Sunspot Numbers



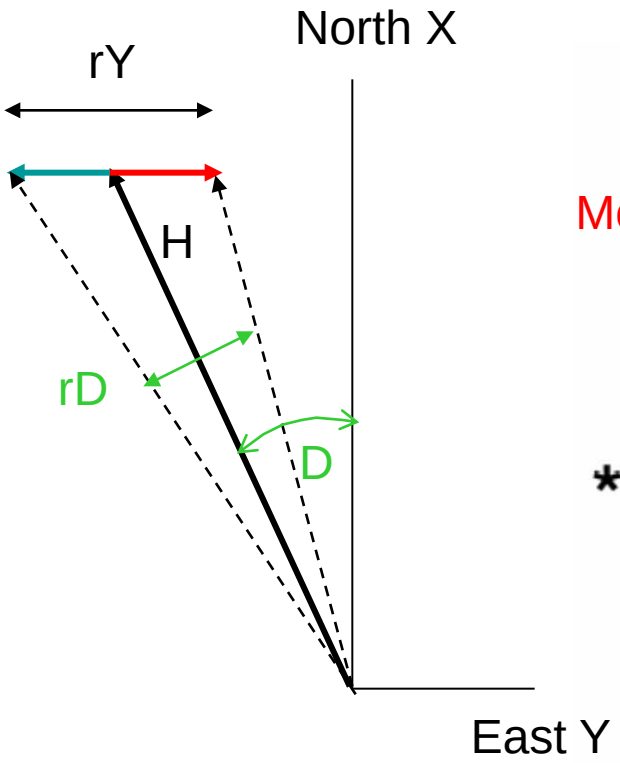
Hoyt & Schatten, GRL *21*, 1994

Major Adjustments to Wolf Number



Wolf published several versions of his series over time, but did not modify his own data

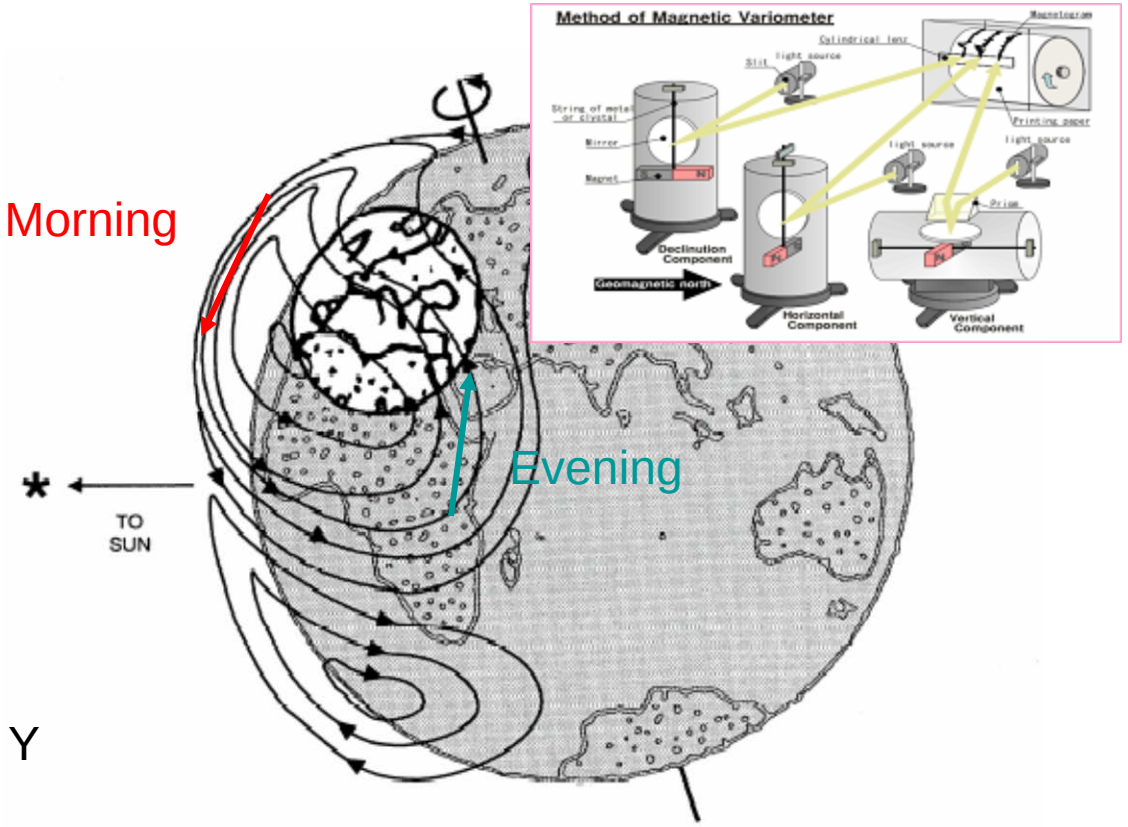
Justification of the Adjustments rests on Wolf's Discovery: $rD = a + b\,R_W$



$Y = H \sin(D)$

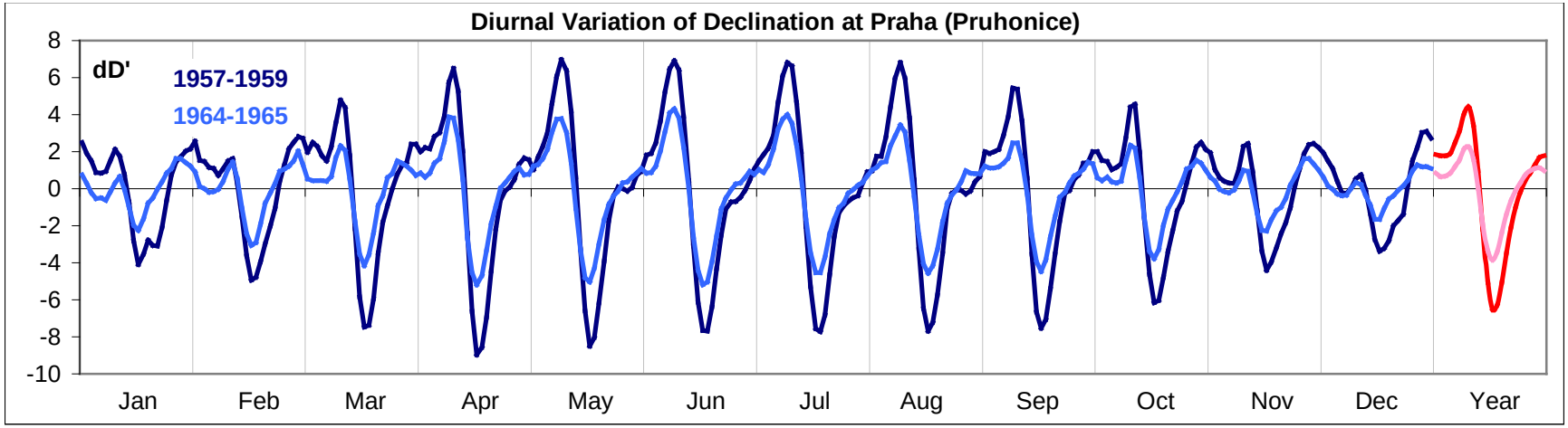
$dY = H \cos(D)\, dD$

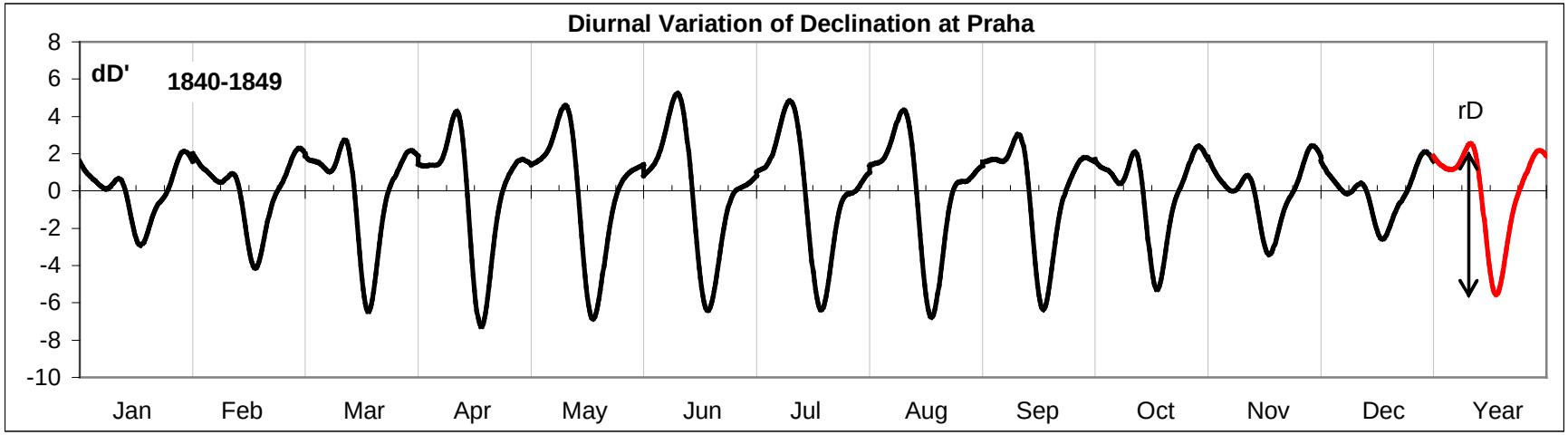
For small D, dD and dH



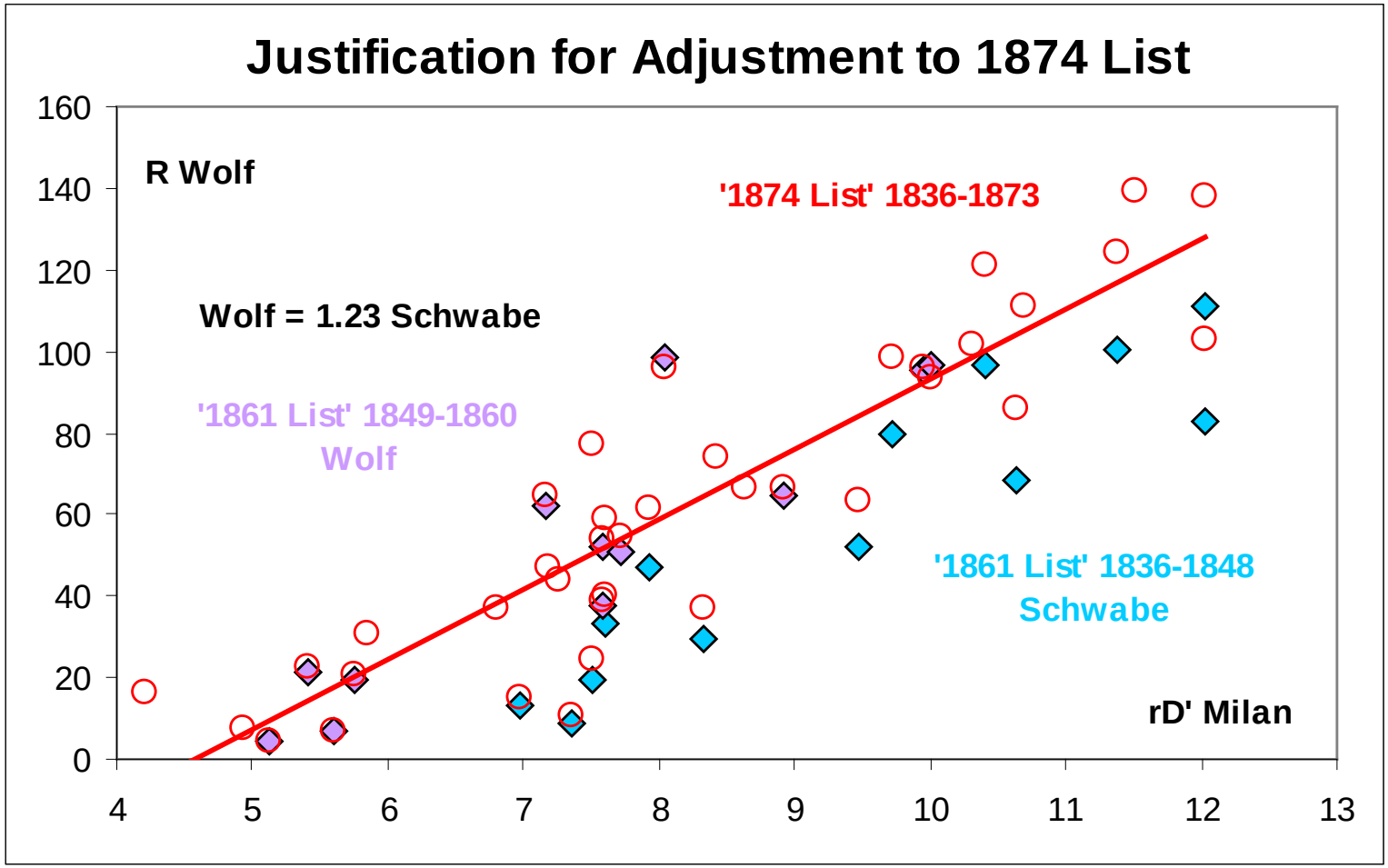
A current system in the ionosphere [E-layer] is created and maintained by solar FUV radiation. Its magnetic effect is measured on the ground.

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



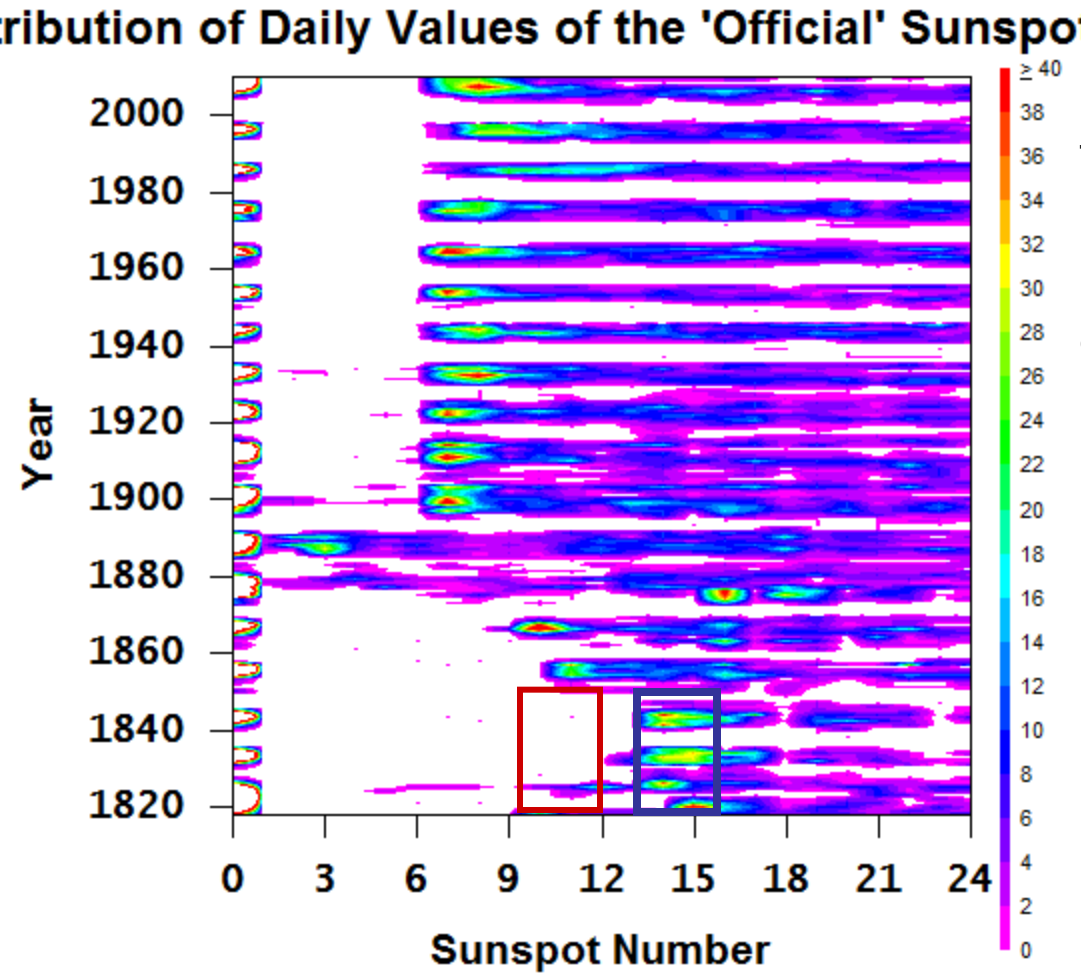


Wolf got Declination Ranges for Milan from Schiaparelli and it became clear that the pre-1849 SSNs were too low



The ‘1874’ list included the 25% [Wolf said 1/4] increase of the pre-1849 SSN

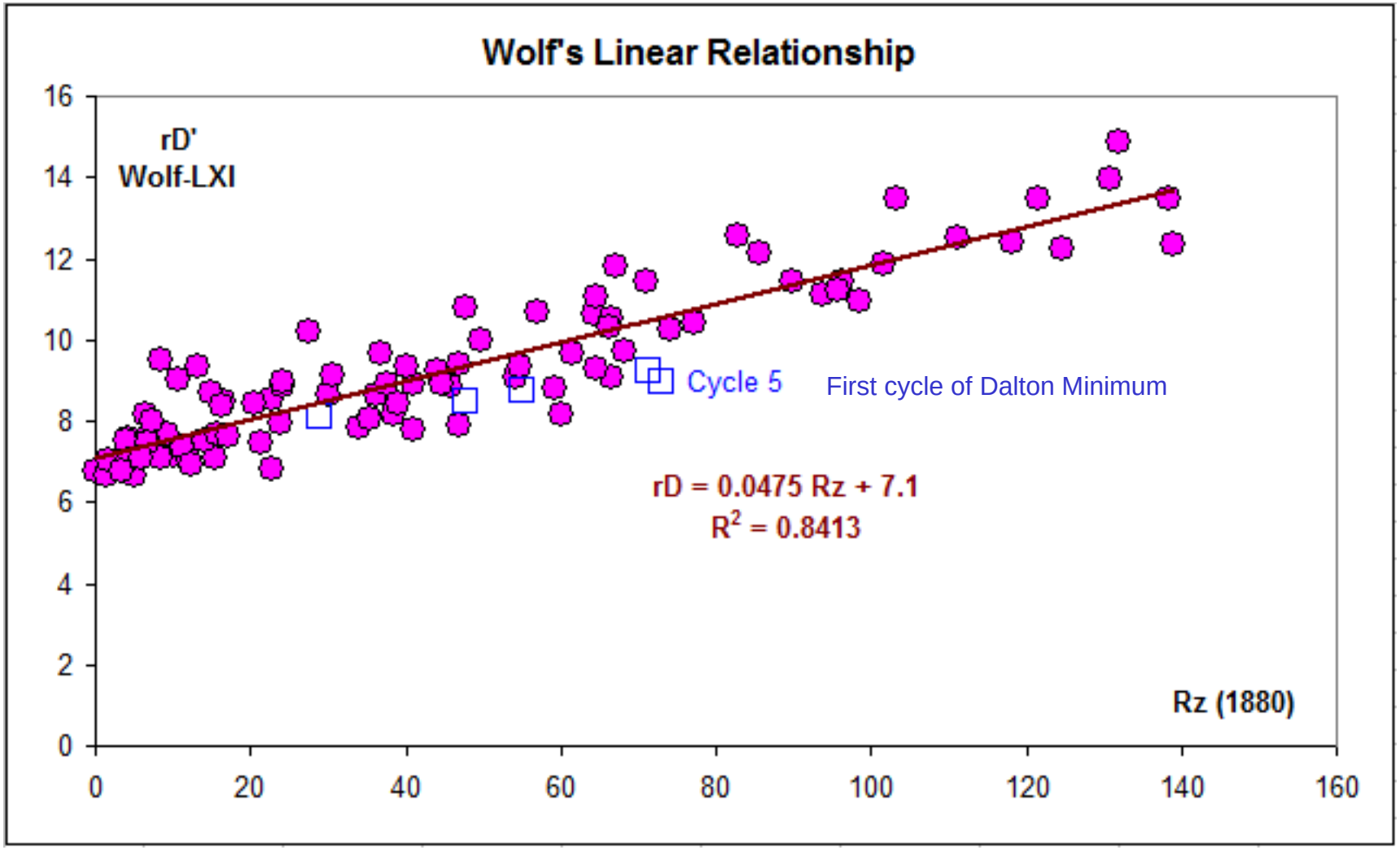
The Wholesale Update of SSNs before 1849 is Clearly Seen in the Distribution of Daily SSNs



The smallest non-zero SSN is 11, but there are no 11s before 1849

11 * 5/4 = 14

Wolf's SSN was consistent with his many-station compilation of the diurnal variation of Declination 1781-1880



It is important to note that the relationship is *linear* for calculating averages

Wolf used 4’ Fraunhofer telescopes with aperture 80 mm [Magn. X64]

Still in use today [by T. Friedli] continuing the Swiss tradition [under the auspices of the Rudolf Wolf Gesellshaft]

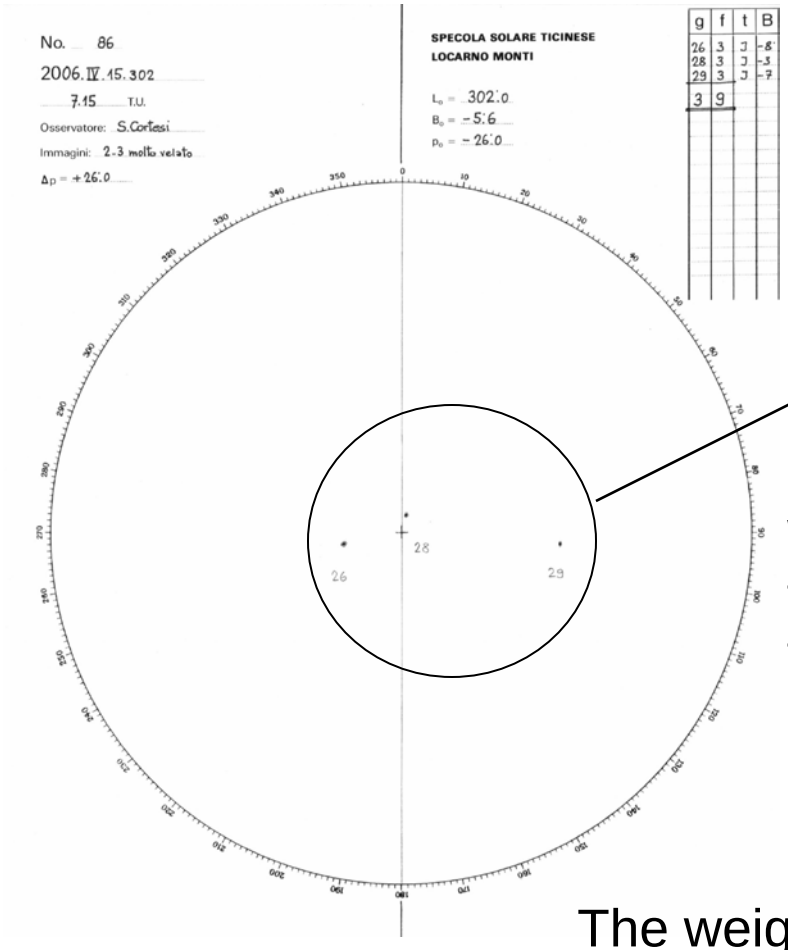
This is the ‘Norm’ Telescope

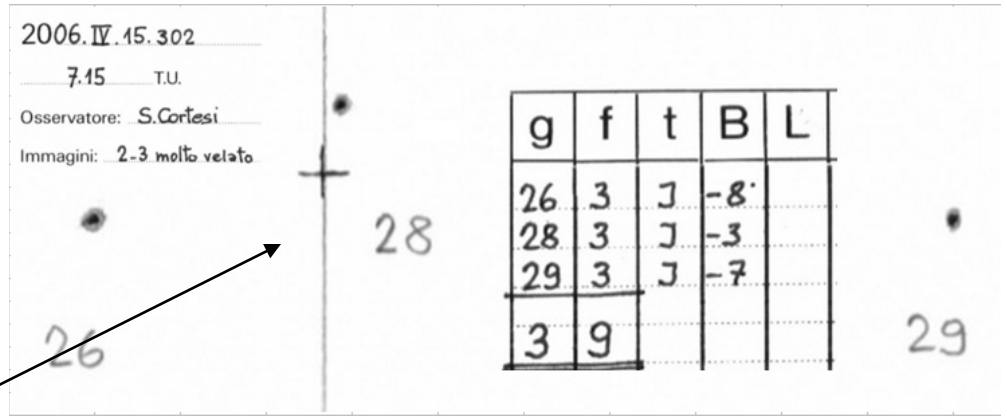
Wolf occasionally [and eventually – from 1870s on - exclusively] used much smaller handheld, portable telescopes [due to frequent travel], leaving the 80mm for his assistants or when he was home

These telescopes also still exist and are still in use today to safeguard the stability of the series

Wolf estimated that to scale the count using the small telescopes to the 80mm Standard telescope, the count should be multiplied by 1.5

At some point during the 1940s the Zürich observers began to weight sunspots in their count

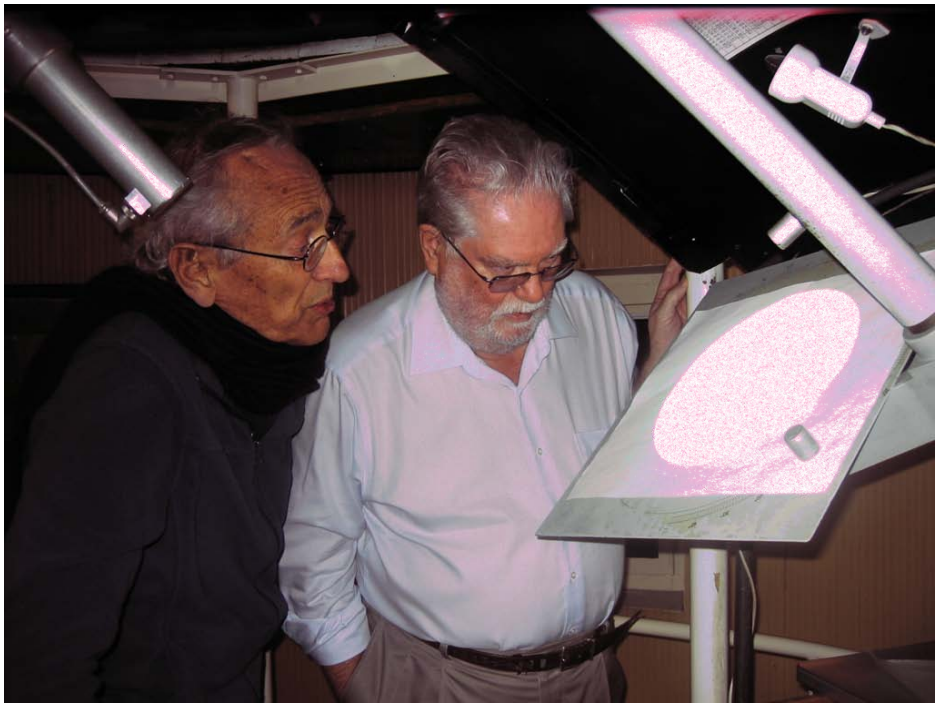




Weights [from 1 to 5] were assigned according to the size of a spot. Here is an example where the three spots present were counted as 9, inflating the sunspot number by 18% [(3*10+9)/(3*10+3)=1.18]

The weighting scheme is not generally known. One of those things that we have all forgotten.

What Do the Observers at Locarno Say About the Weighting Scheme:



Sergio Cortesi started in 1957, still at it, and in a sense is the *real* keeper of the SSN, as SIDC normalizes everybody's count to match Sergio's

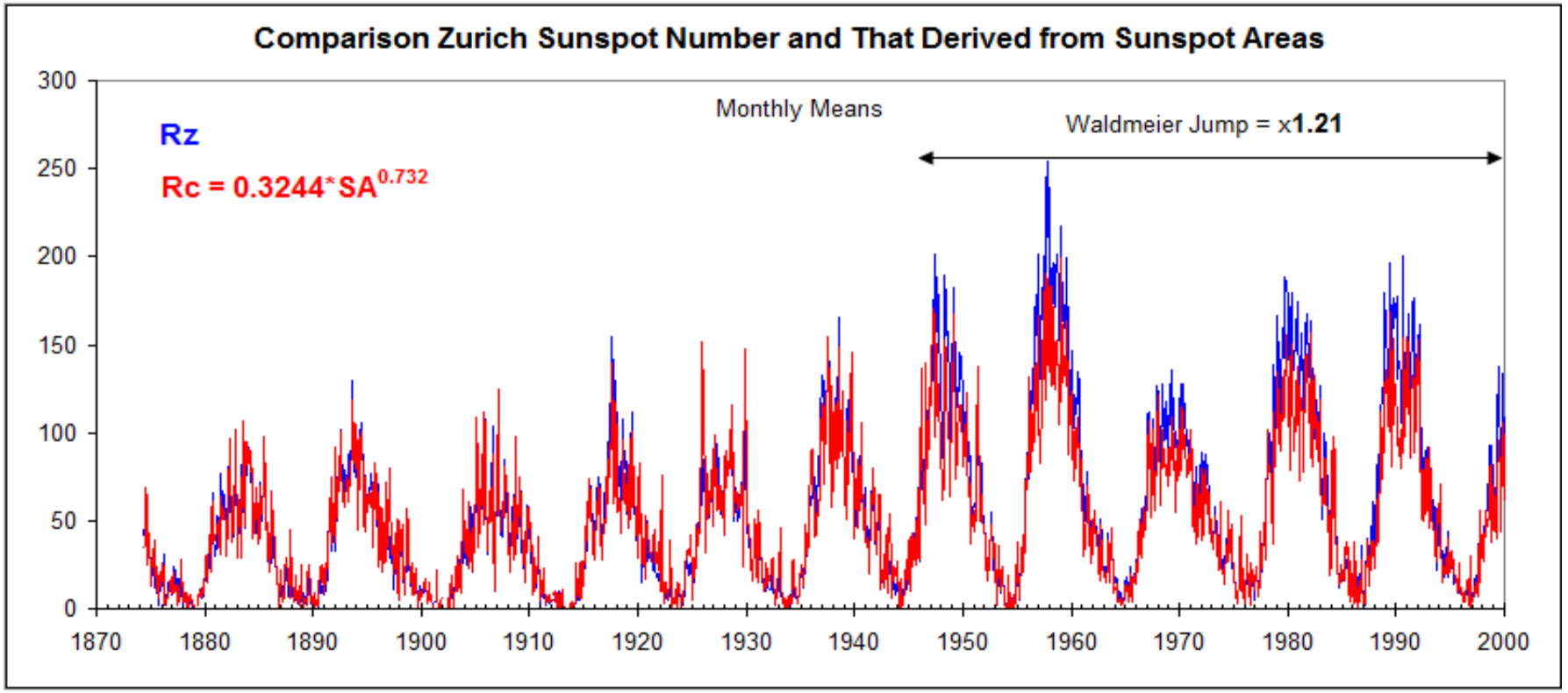
"For sure the main goal of the former directors of the observatory in Zurich was to maintain the coherence and stability of the Wolf number, and changes in the method were not done just as fun. I can figure out that they gave a lot of importance to verify their method of counting. Nevertheless the decision to maintain as "secret" the true way to count is for sure source of problems now!"

(email 6-22-2011 from Michele Bianda, IRSOL, Locarno)

Corroborating Indications of the ‘Waldmeier Discontinuity’ ~1946

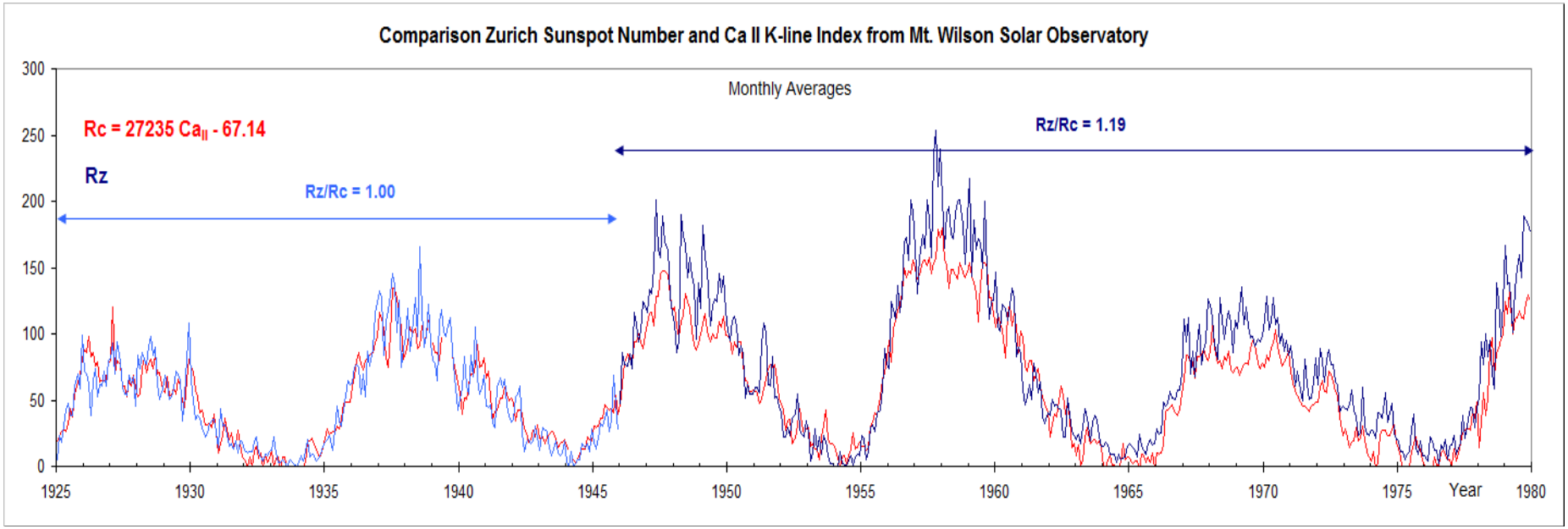
- SSN for Given Sunspot Area increased 21%
- SSN for Given Ca II K-line index up 19%
- SSN for Given Diurnal Variation of Day-side Geomagnetic Field increased by 20%
- Ionospheric Critical Frequency *foF2* depends strongly on solar activity. The slope of the correlation changed 20% between sunspot cycle 17 and 18

Illustrating that Observed Rz after 1945 is Higher than Deduced from Sunspot Areas



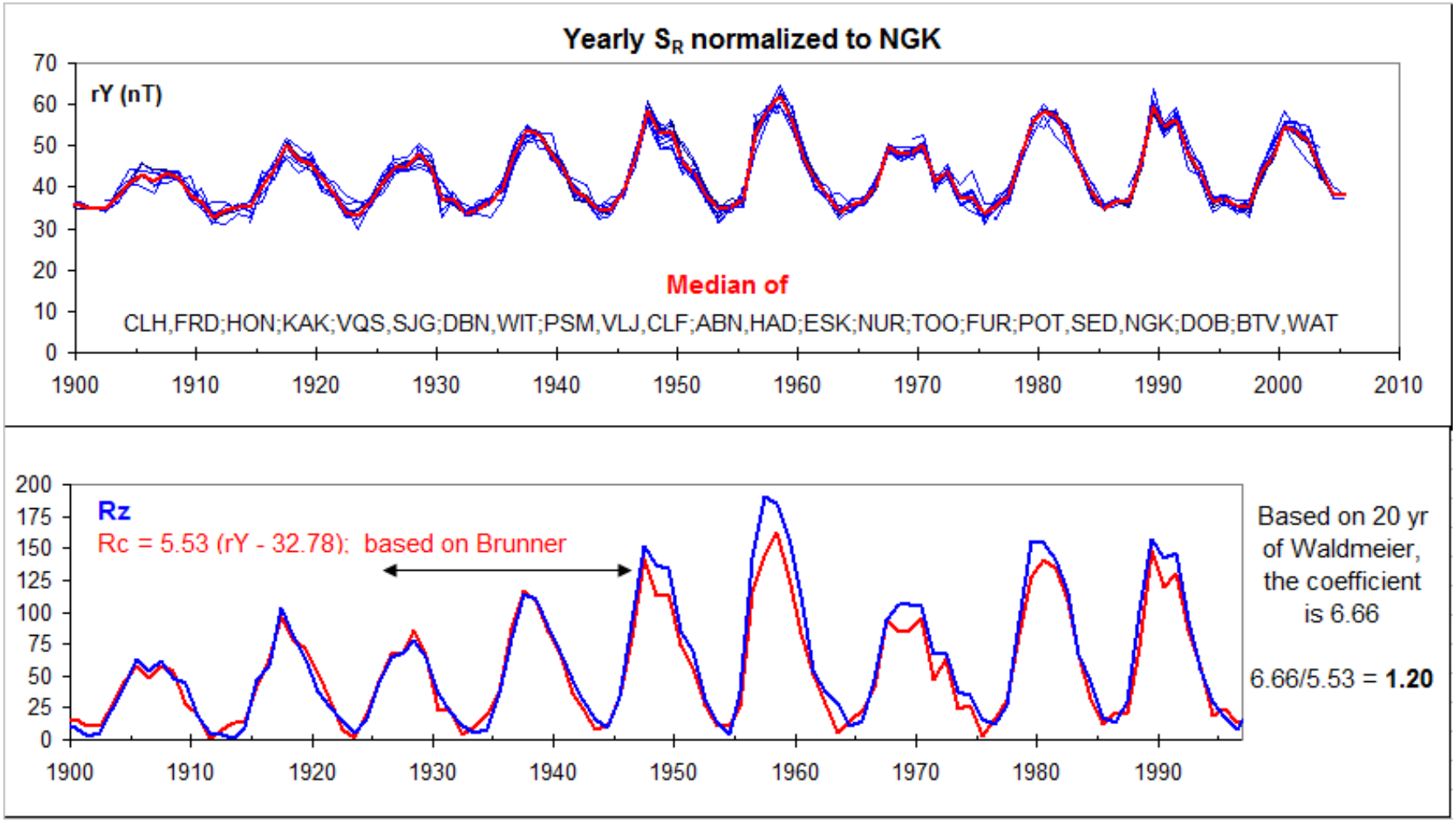
Ca II K-line Data Scaled to Rz shows similar Jump in Rz Sunspot Number after 1945

From ~40,000 CaK spectroheliograms from the 60-foot tower at Mount Wilson between 1915 and 1985, a daily index of the fractional area of the visible solar disk occupied by plages and active network has been constructed [Bertello et al., 2008]. Monthly averages of this index is strongly correlated with the sunspot number SSN = 27235 CaK – 67.14 [before 1946].

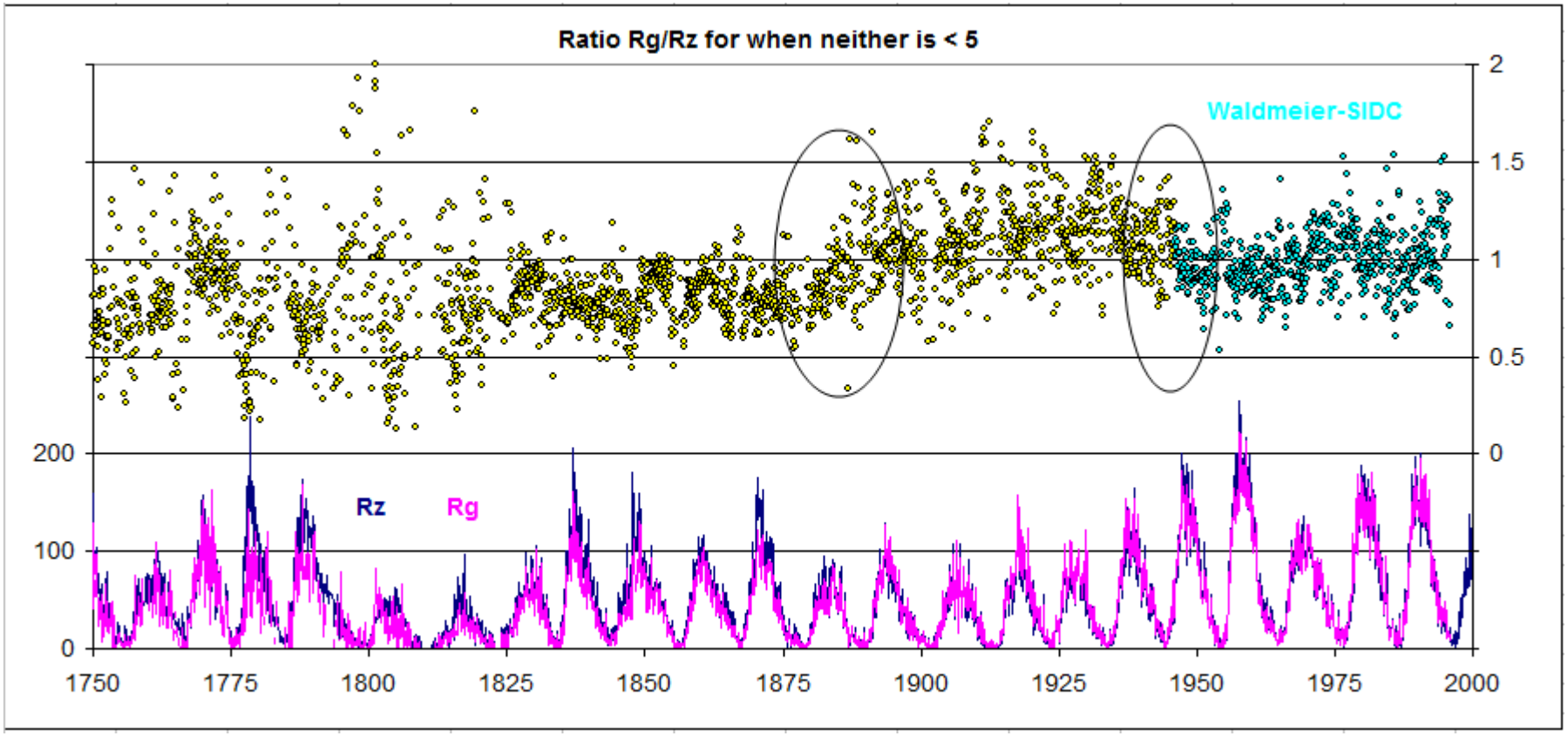


Waldmeier's Sunspot Number 19% higher than Brunner's from Ca II K-line

The Amplitude of the Diurnal Variation, *rY*, [from many stations] shows the same Change in Rz ~1945

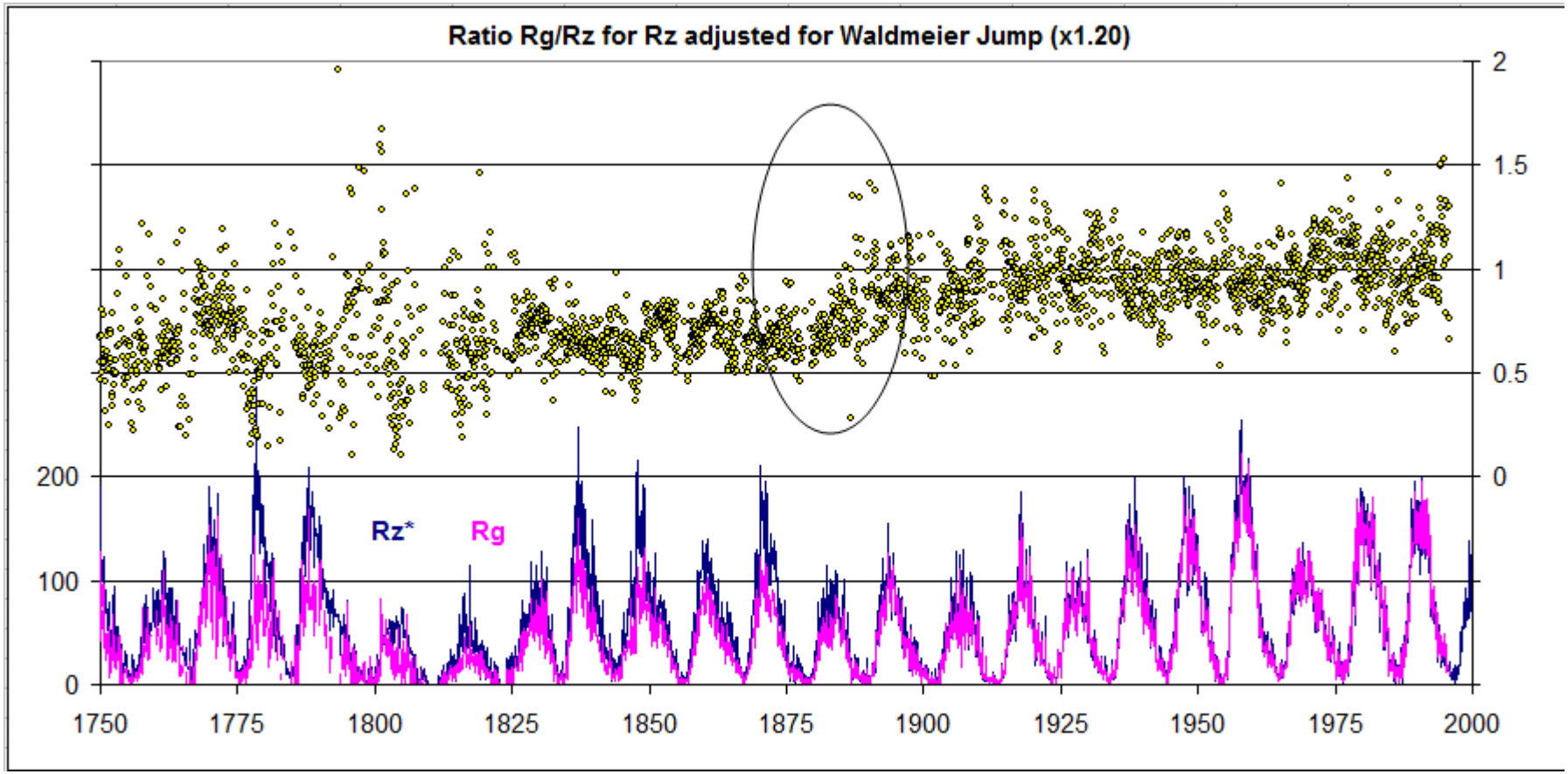


The Ratio Group/Zurich SSN has Two Significant Discontinuities



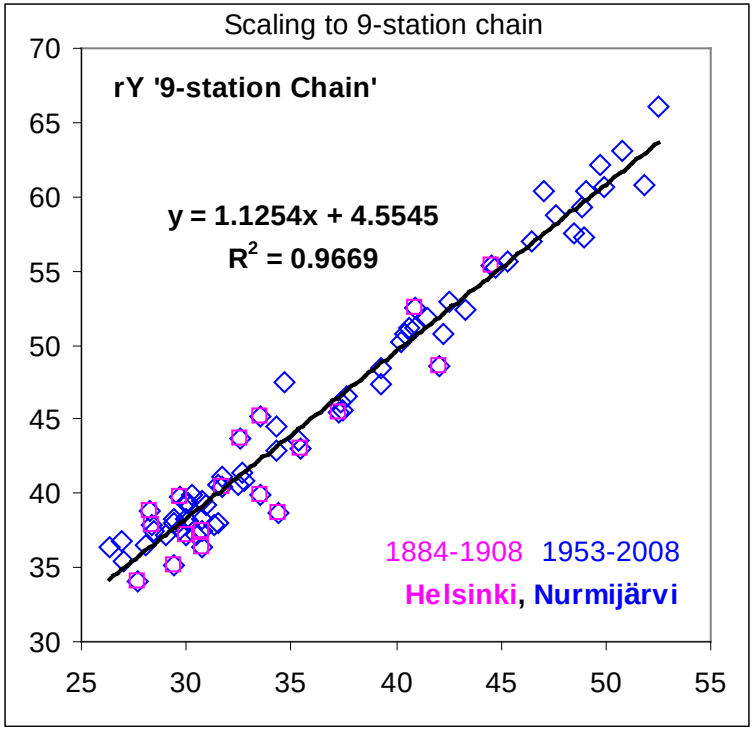
At ~1946 (After Max Waldmeier took over) and at ~1885

Removing the Recent one [+20%] by Multiplying Rz before 1946 by 1.20, Yields

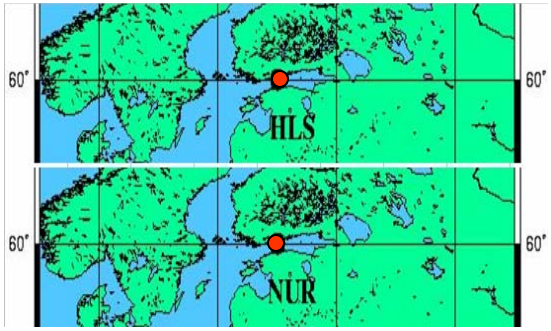


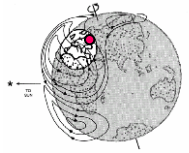
Leaving one significant discrepancy ~1885

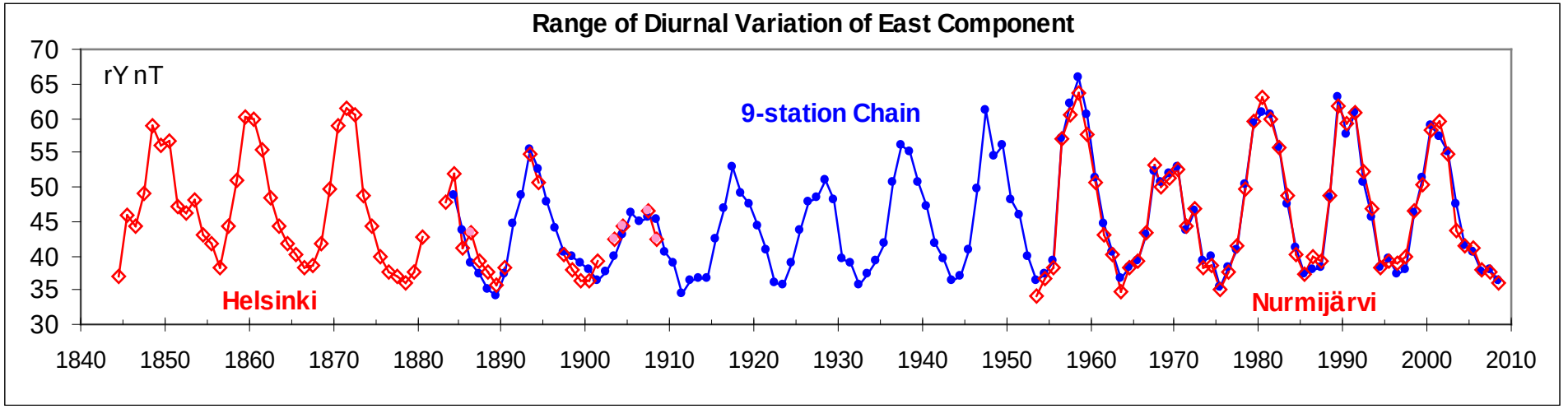
Helsinki-Nurmijärvi Diurnal Variation



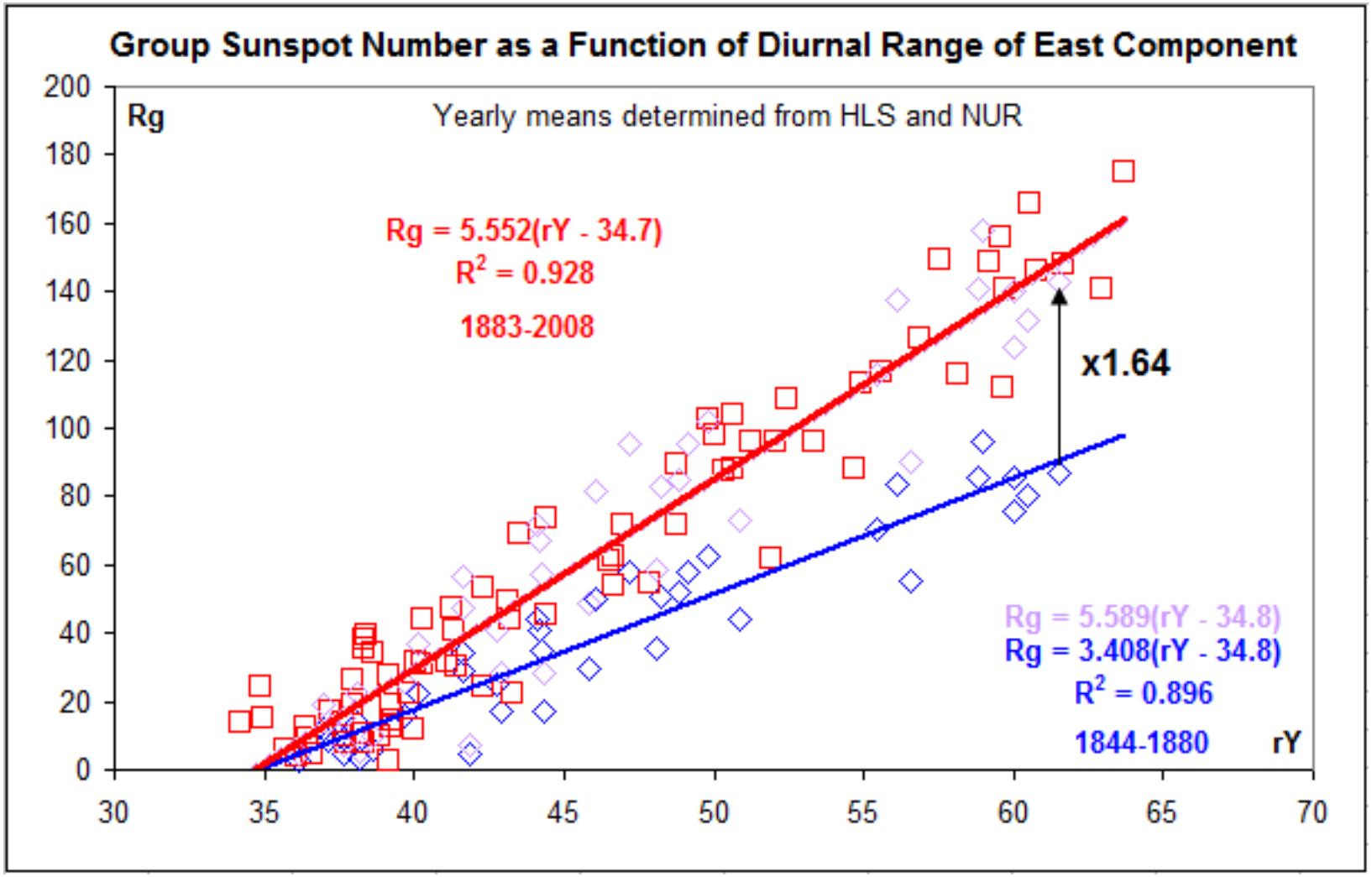
Helsinki and its replacement station Numijärvi scales the same way towards our composite of nine long-running observatories and can therefore be used to check the calibration of the sunspot number (or more correctly to reconstruct the F10.7 radio flux – see next slide)





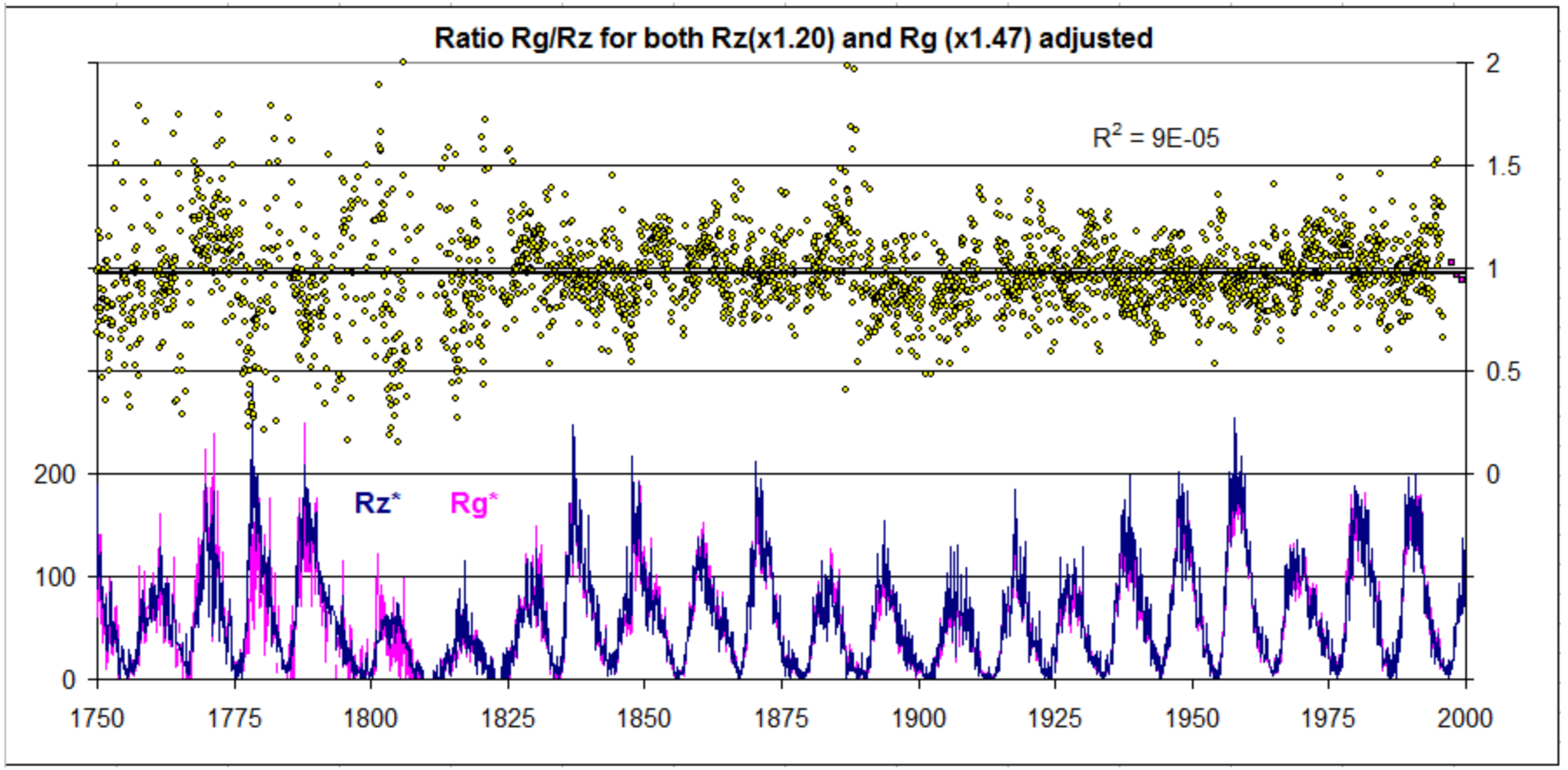


The HLS-NUR data show that the Group Sunspot Number before 1880 must be Increased by a factor 1.64±0.15 to match *rY* (F10.7)



This conclusion is independent of the calibration of the Zürich SSN, Rz

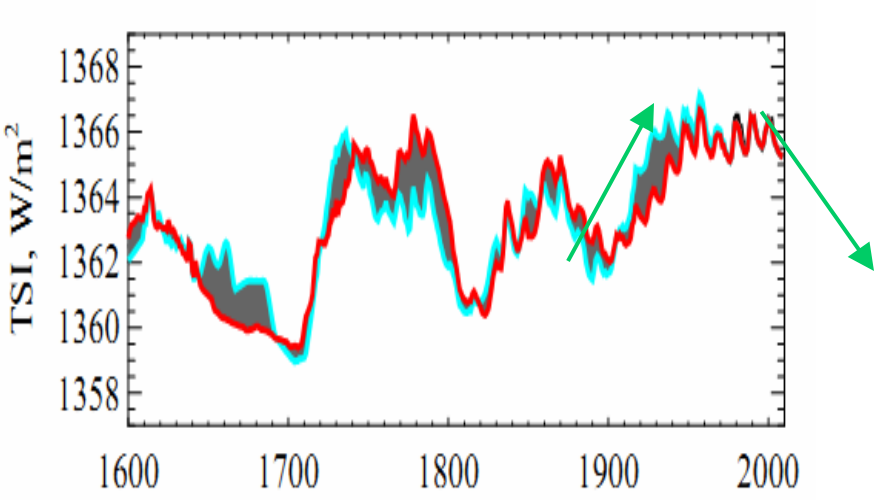
Removing the Early one by multiplying Rg by 1.47, Yields

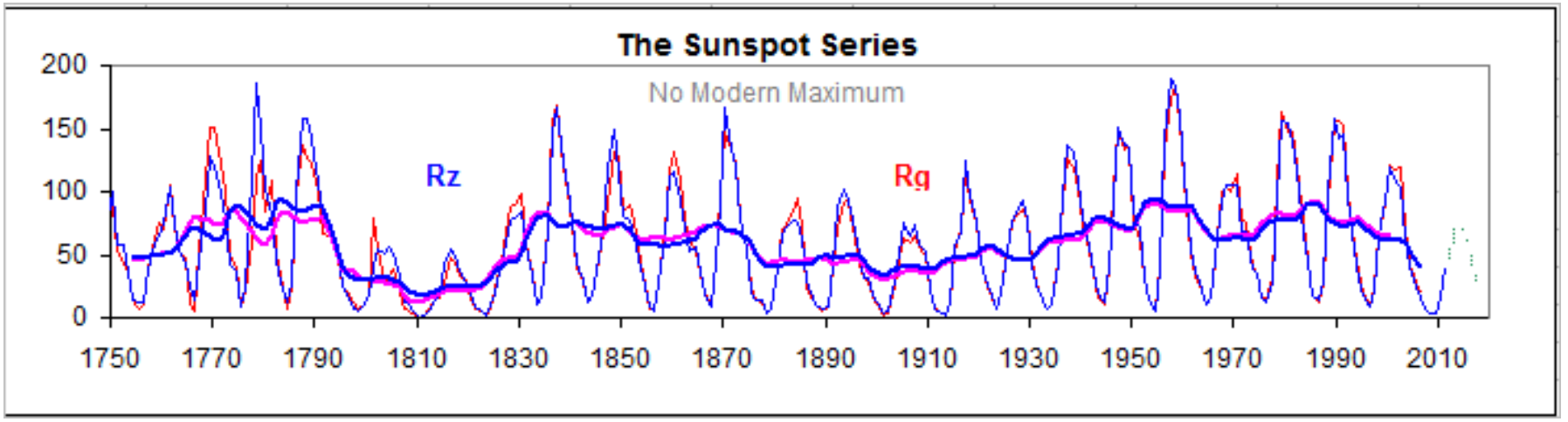


There is still some ‘fine structure’, but only TWO adjustments remove most of the disagreement

The Sunspot Number Series

- The Zürich Sunspot Number, Rz, and the Group Sunspot Number, Rg, can be reconciled by making only TWO adjustments:
- The first adjustment [20%] is to Rz ~1945
- The second adjustment [~50%] is to Rg ~1885
- No justification for secular trend

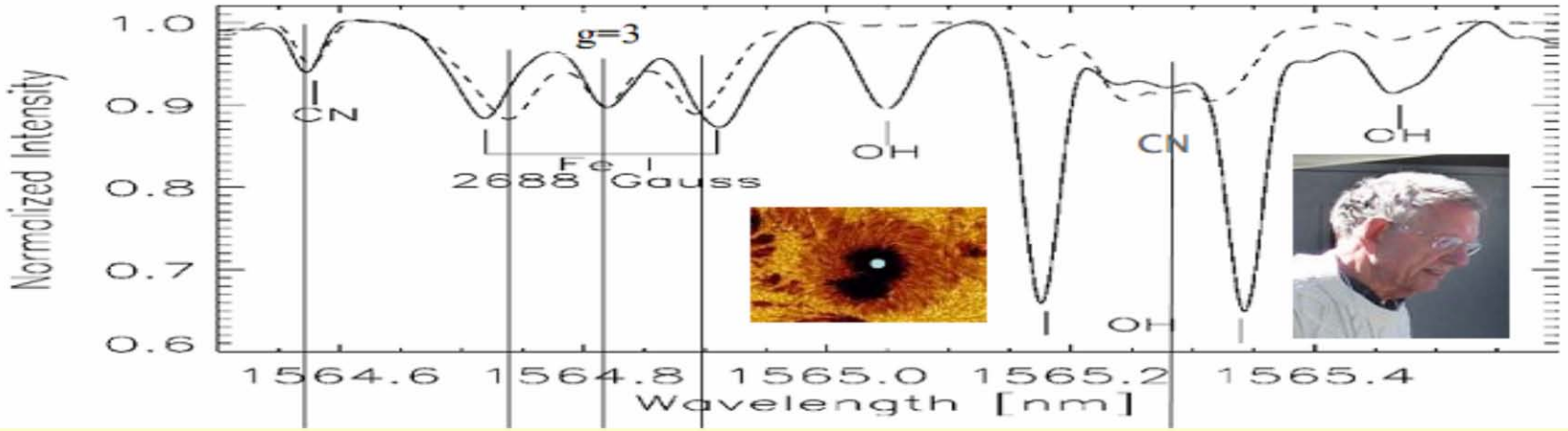




Of note is that there is no Modern Grand Maximum

That was the Past. How about the Future?

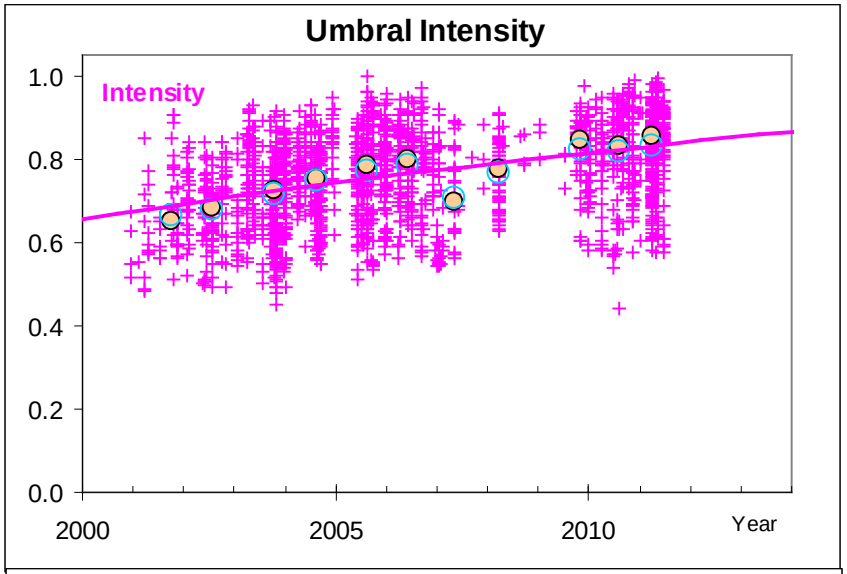
The Fe I line at 1564.8 nm has a very large and easily measured Zeeman splitting. The Hydroxyl radical OH is very temperature sensitive and the lines weaken severely at higher temperatures.

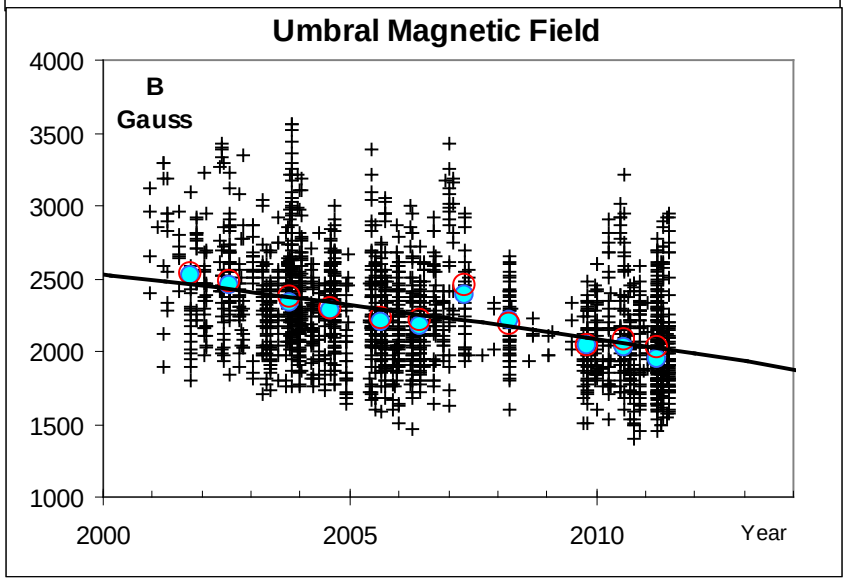


Courtesy Bill Livingston

From 2001 to 2011 Livingston and Penn have measured field strength and brightness at the darkest position in umbrae of 1843 spots using the Zeeman splitting of the Fe 1564.8 nm line. Most observations are made in the morning [7h MST] when seeing is best. Livingston measures the absolute [true?] field strength averaged over his [small: 2.5 ″x2.5″] spectrograph aperture, and not the Line-of-Sight [LOS] field.

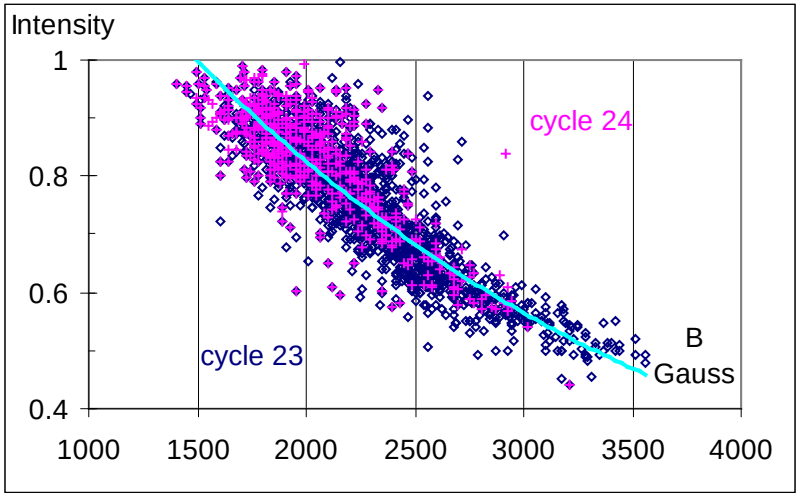
In spite of large scatter the magnetic field has decreased 500 G since 2000



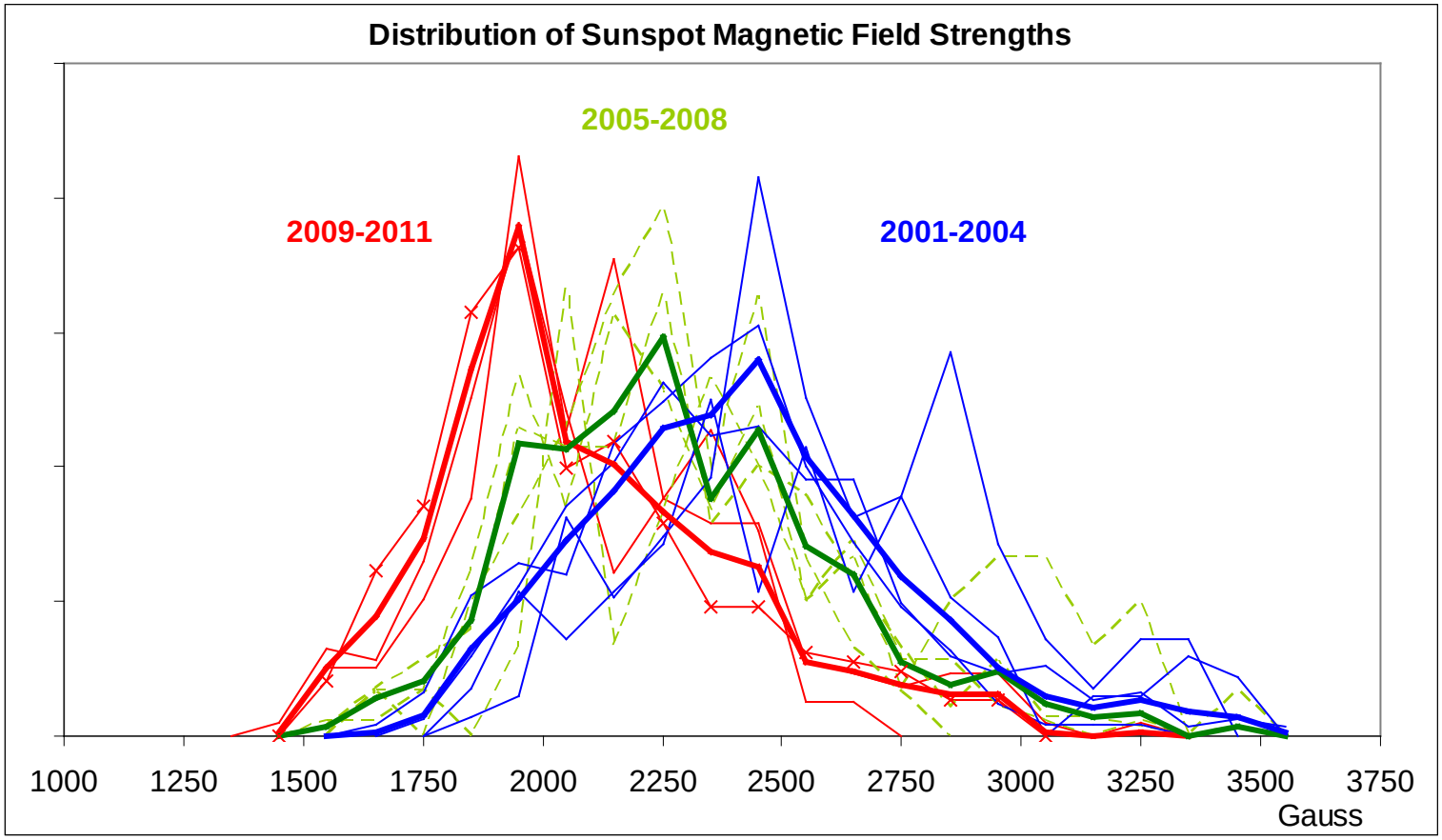


Livingston also measures the intensity of the umbra compared to the continuum and finds that [in the infrared] that for all spots he can see [i.e. intensity < 1] the field is greater than ~1450 G. Another 500 G to go...

Hence his statement that if [when?] the decline of the field continues, spots will effectively 'disappear' or at least be much less visible.

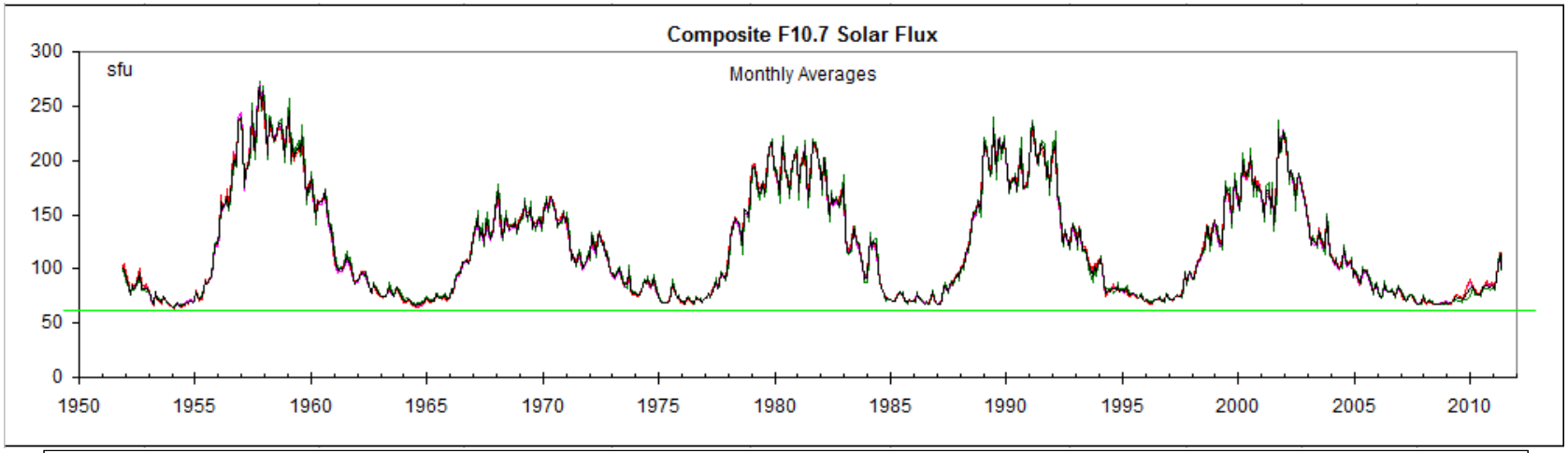


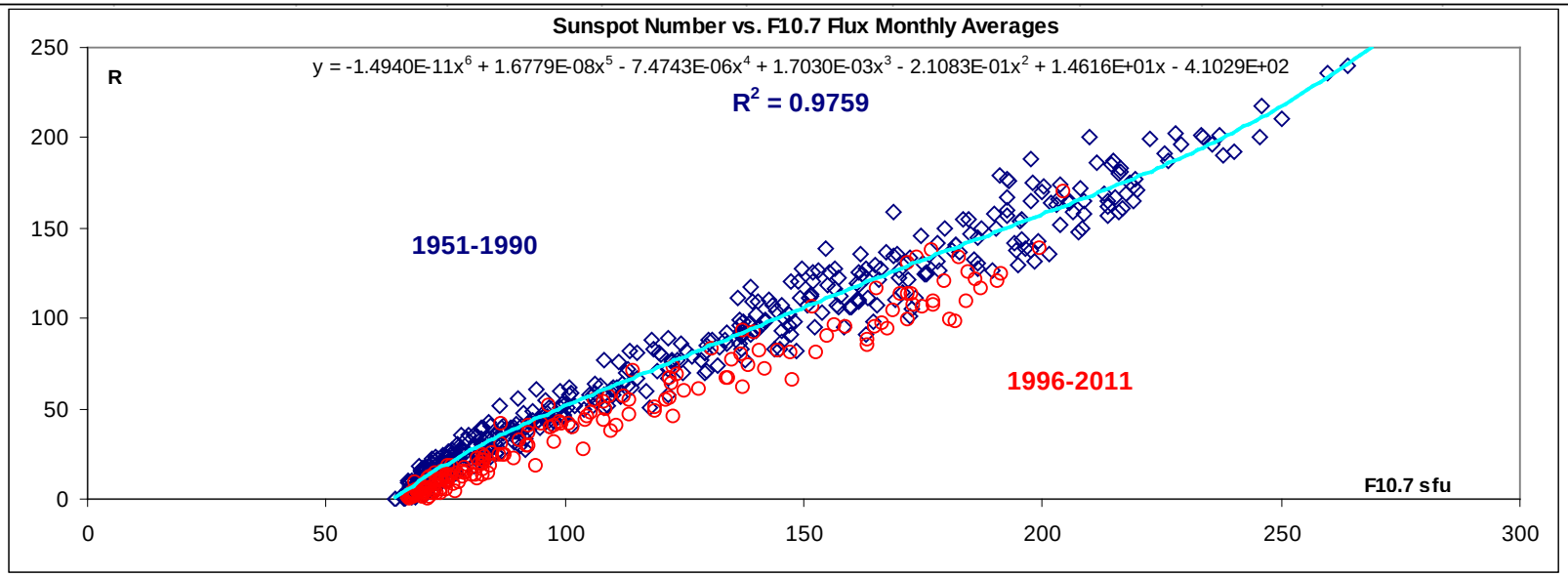
The Distribution of Field Strengths has Shifted with Time



Is this just a sunspot cycle dependence?

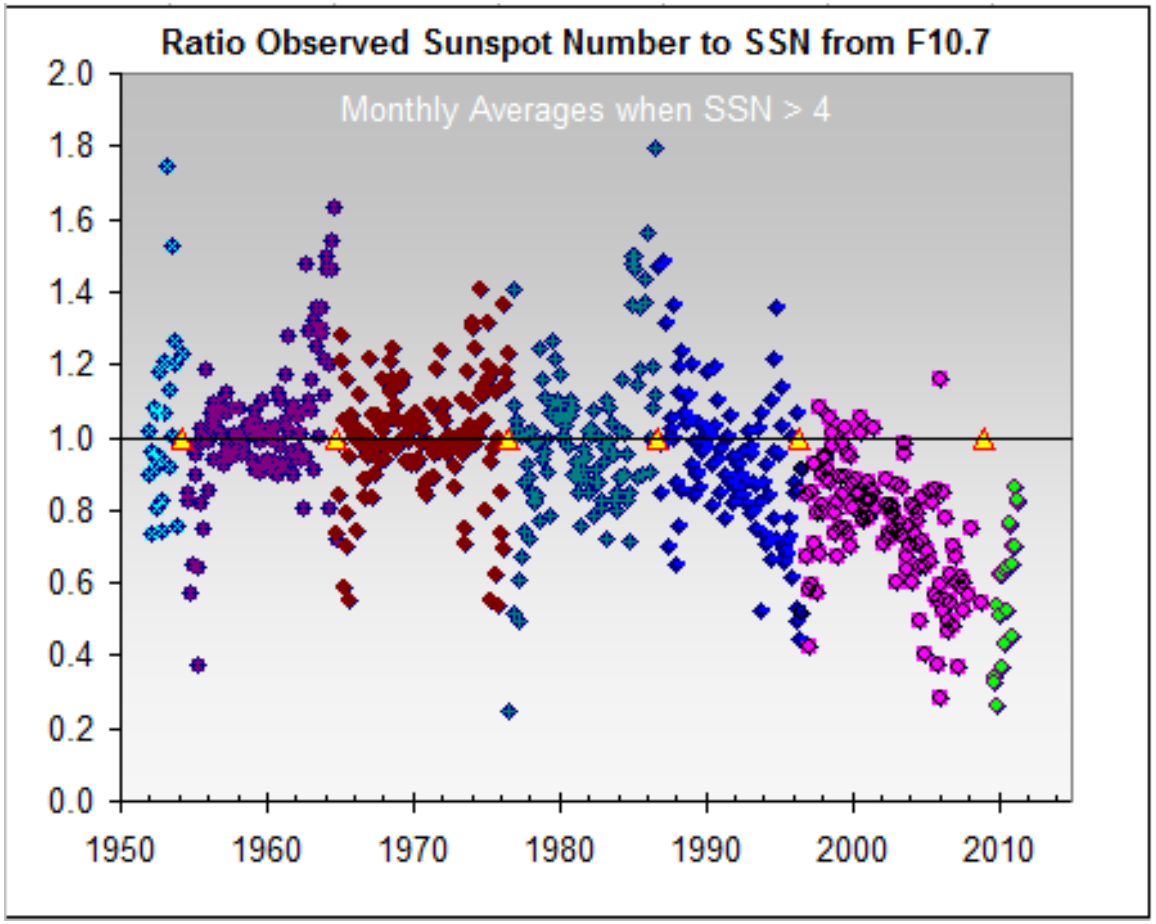
Other indications of fewer spots?





Since ~1996 there have been fewer visible sunspots for a given F10.7 flux

The Observed Sunspot Number vs. that Calculated from the ‘old’ Relationship is too low Recently

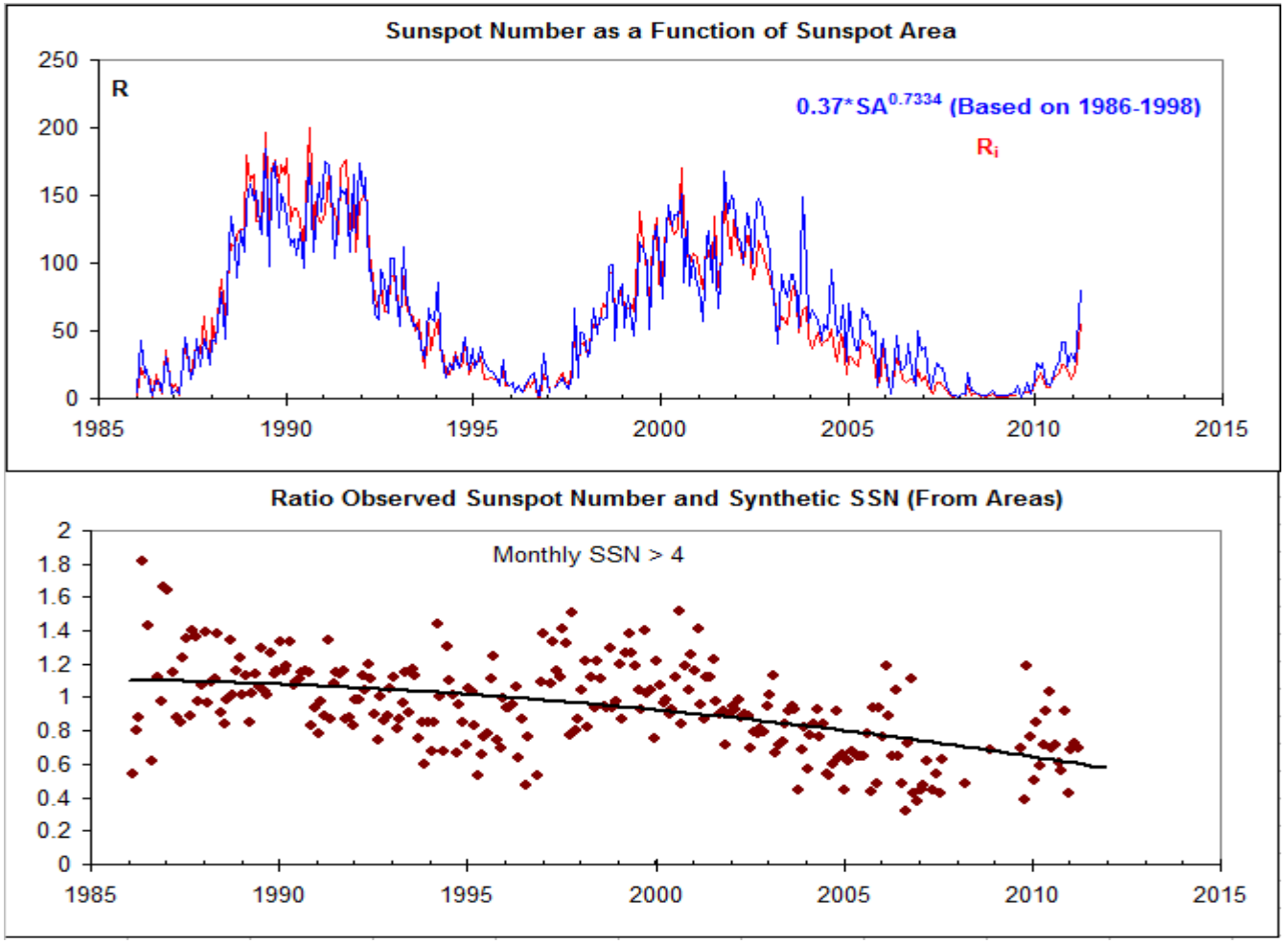


Since the Sunspot Number is dominated by the number of small spots, the loss of visibility of small spots might be a natural explanation.

Was the Maunder Minimum just an example of an extreme L&P effect?

Is this happening again?

Similar effect seen in SSN compared to sunspot areas



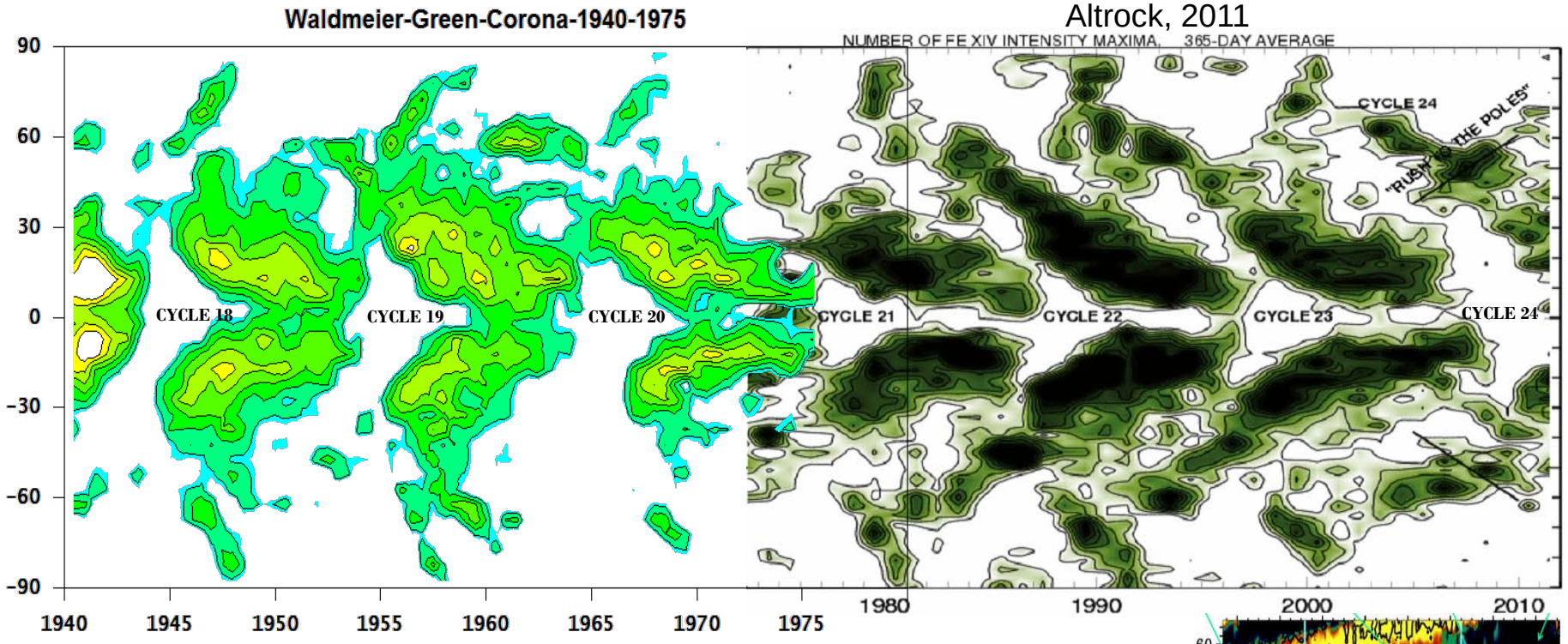
Livingston, Penn, and Svalgaard:

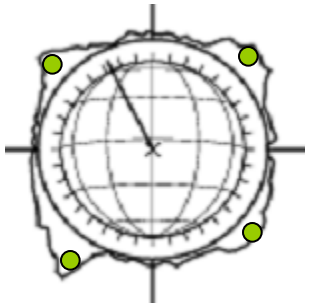
Extrapolating the behavior from the past 13 years into the next 13 years suggests the Sun may enter a new Grand Minimum.

If true, we shall learn a lot about ‘The Forgotten Sun’ that nobody alive today has ever seen, with obvious implications for the climate debate and environmental issues generally.

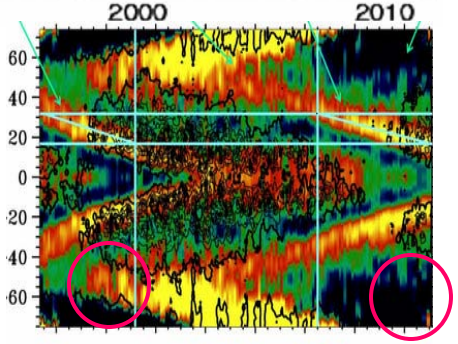
Are there other indications that this might happen?

Where is the Extended Cycle?

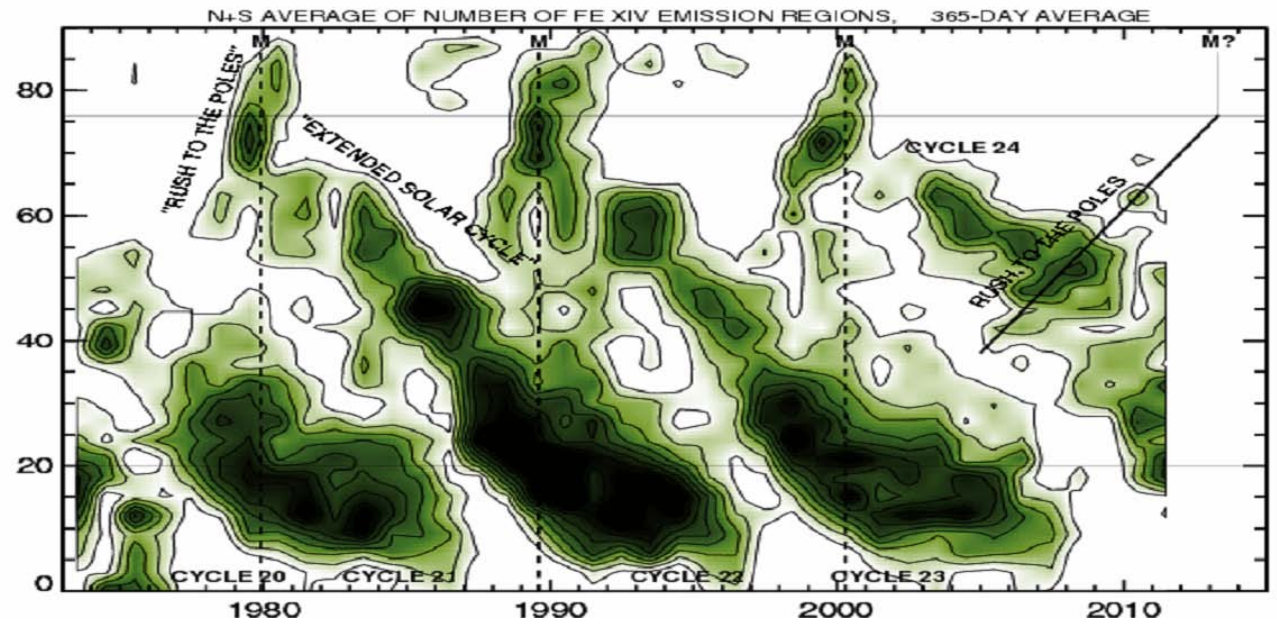




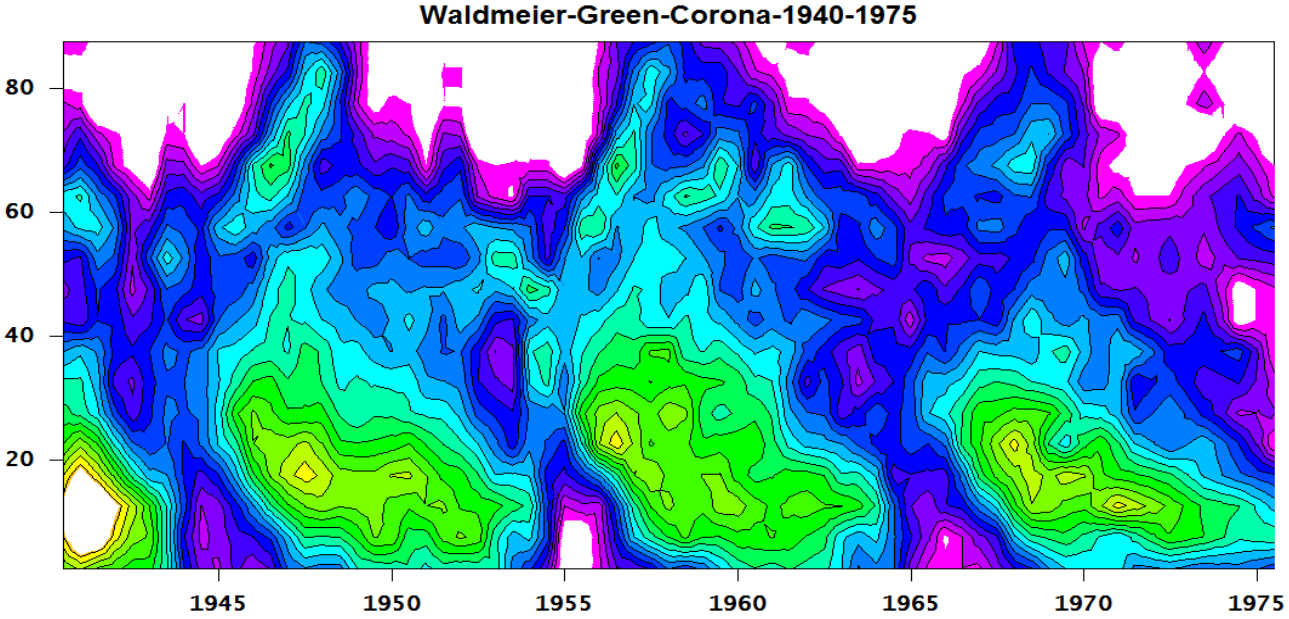
Measurements of the location of ‘peaks’ of Fe XIV coronal emission at 503 nm (the ‘Green Line Corona’) over 7 solar cycles. The plots show the probability of observing a ‘peak’ at a given latitude as a function of time.



TO: Hill, 2011



Fold South unto North



The Extended Cycle [if any] is not very clear

Our ‘Understanding’ of the Extended Cycle

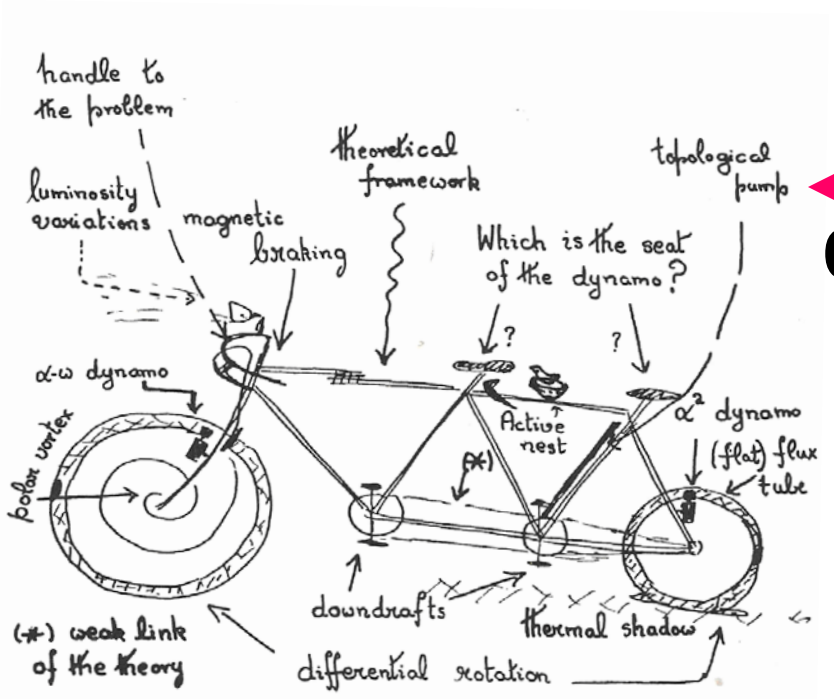
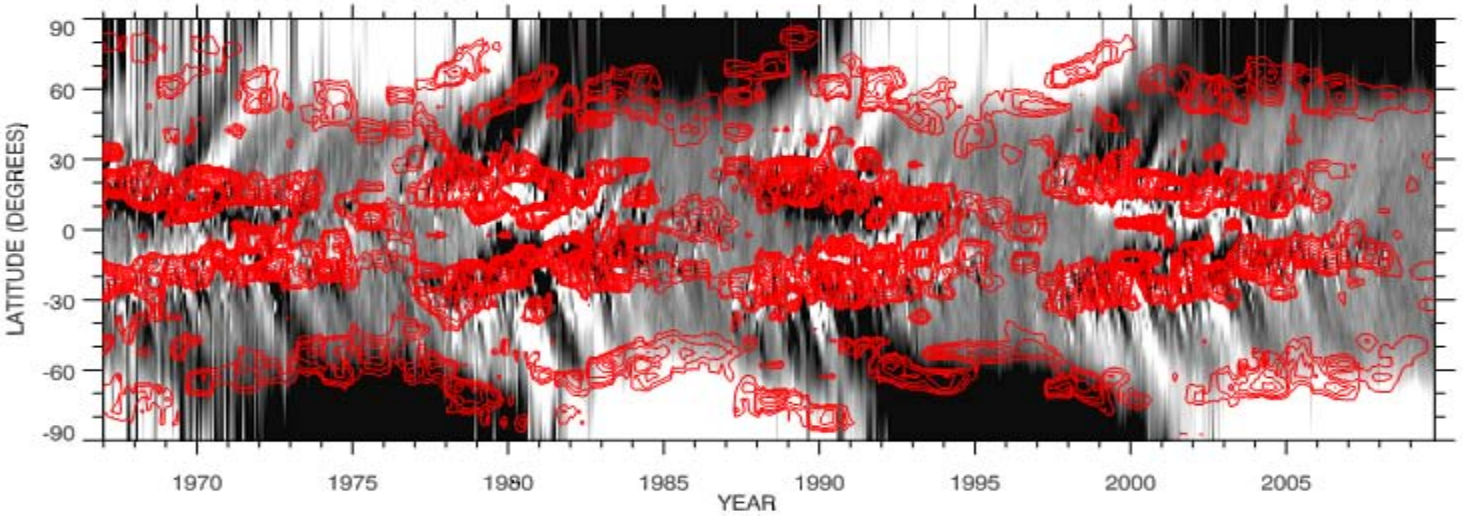


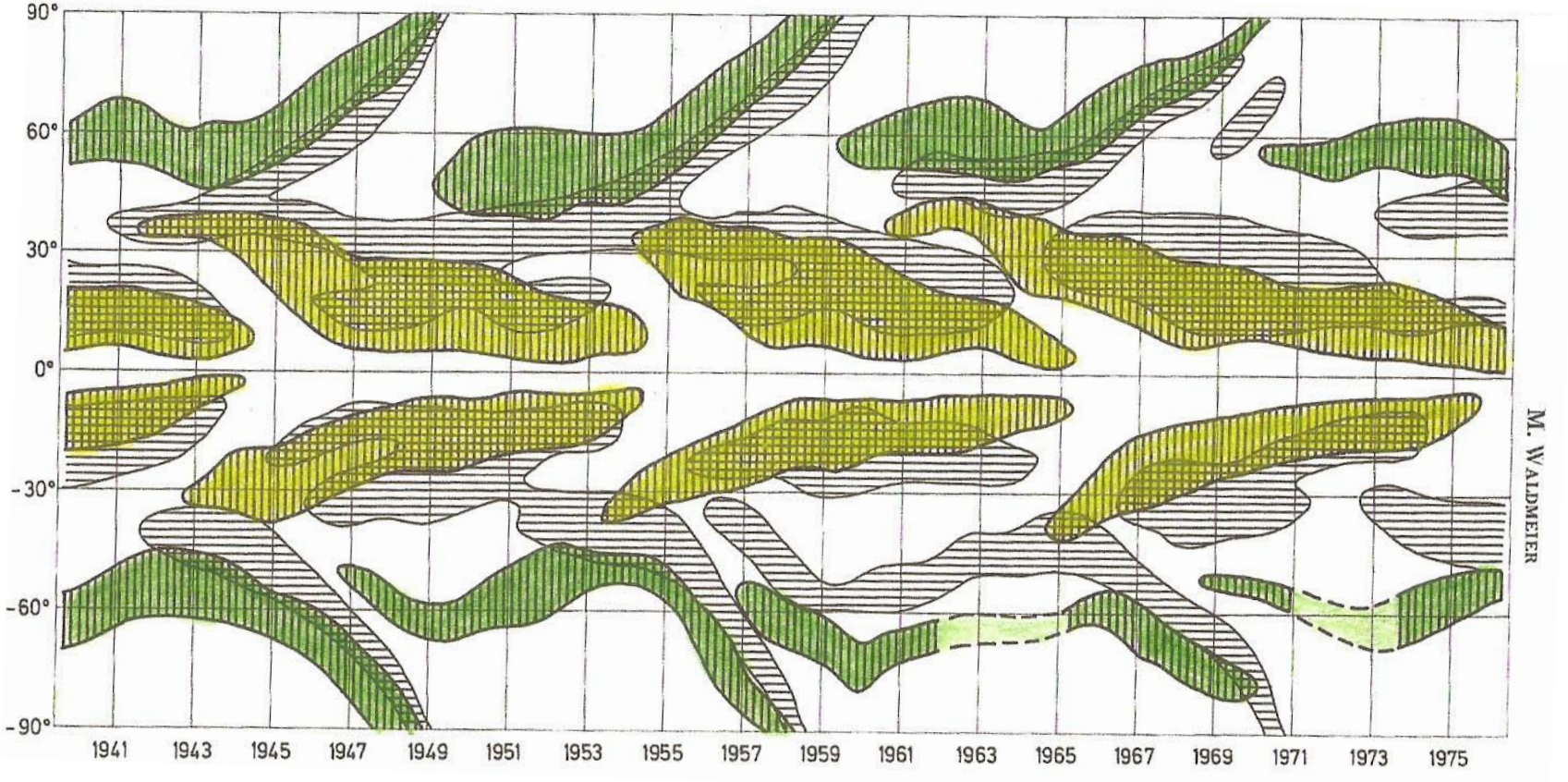
Fig. 8.8 A diagram of the *Xtended Cycle* constructed at a party held during the Sunspot meeting of the Solar Cycle Workshop in 1991. The author disclaims any responsibility but understands that Jean-Paul Zahn is liable for the drawing,

Robbrecht et al. ApJ, 2010:
“We conclude that the so-called extended cycle in coronal emission is a manifestation not of early new-cycle activity, but of poleward concentration of old-cycle trailing-polarity flux by meridional flow”

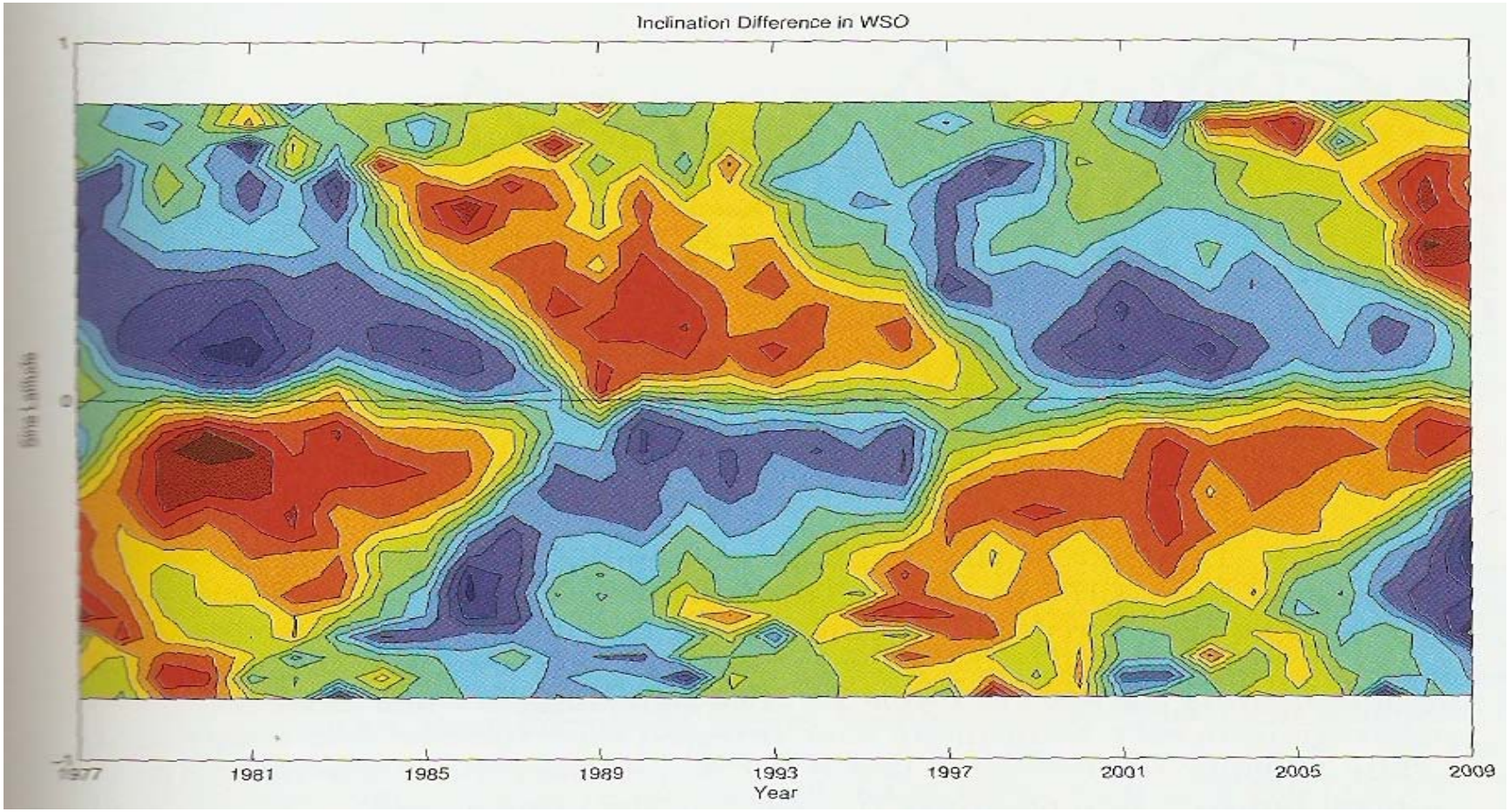


The red contours computed from PFSS coronal field (MWO)

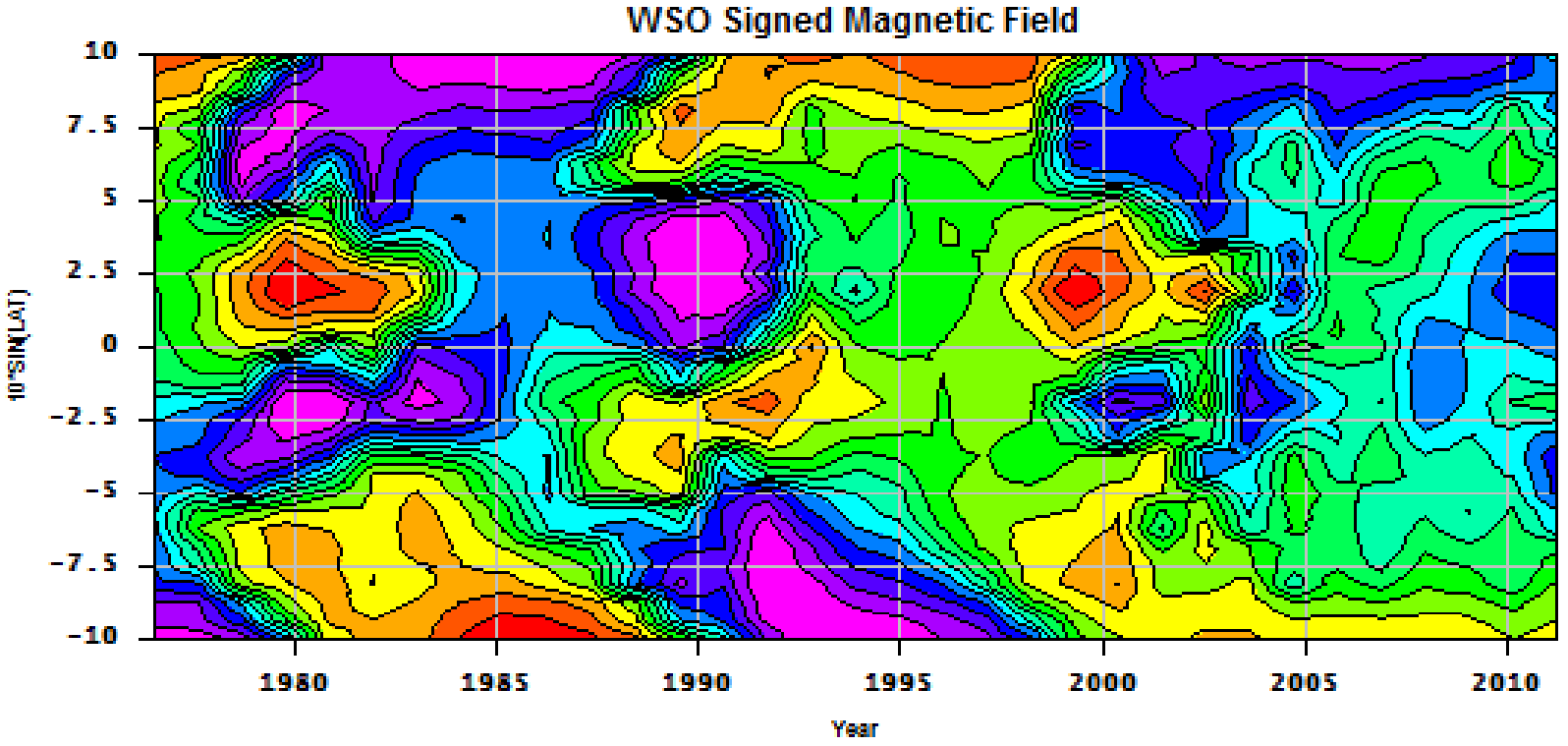
Waldmeier also Interpreted The Green Line Emission as Marking the Boundary of the Polar Cap, ‘Rushing to the Pole’ when the New Cycle Started



The angle between B and Br seems to show an ‘extended cycle’

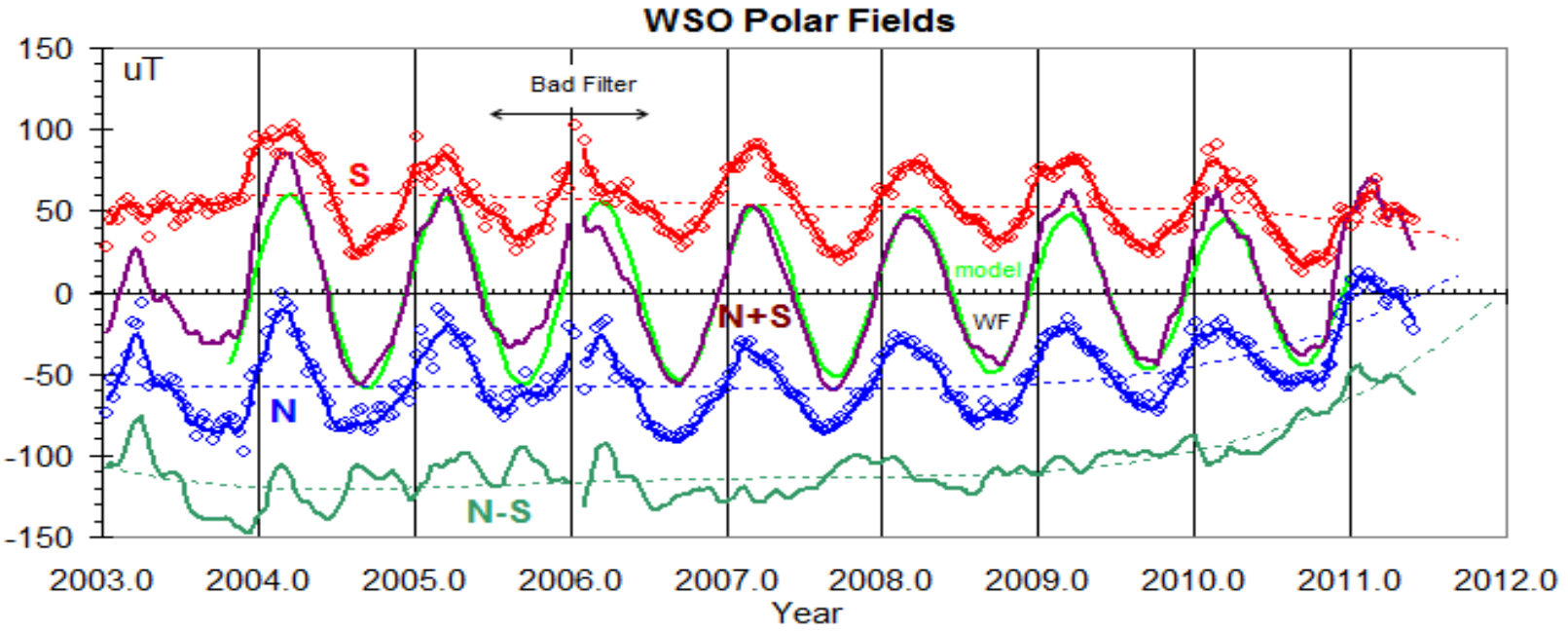


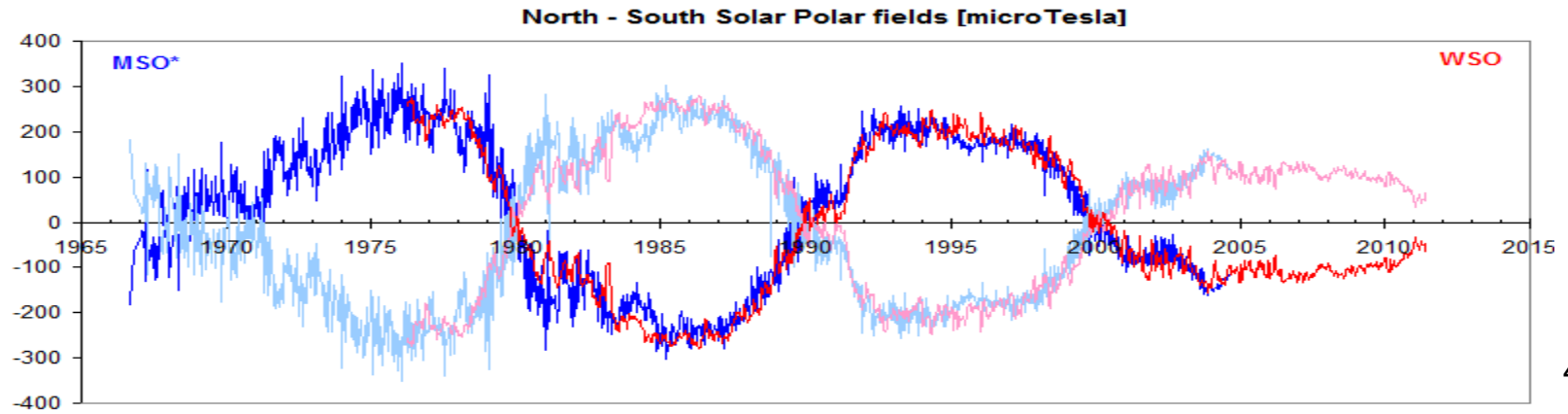
The average signed magnetic field shows a large-scale structure without any hint of extended cycles

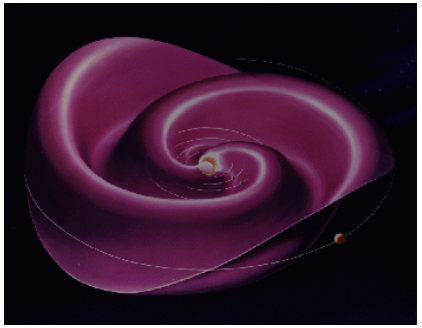


Solving the Enigma of the ‘Extended Cycle’ is a worthy Goal of SC24 Research

The Polar Fields are as Mysterious as Ever, perhaps Reversing Early

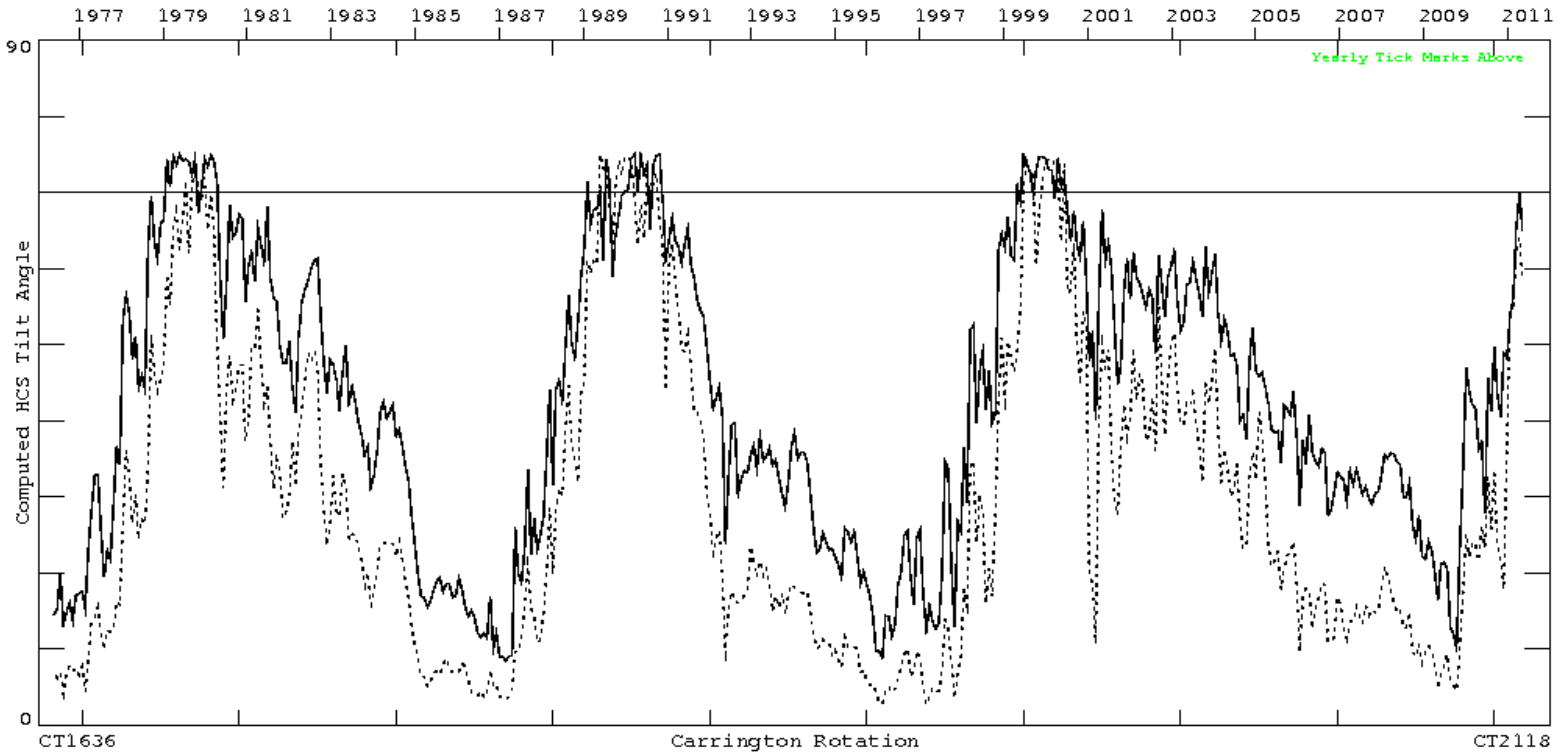






The HCS is Approaching Typical Solar ‘Maximum’ Inclinations

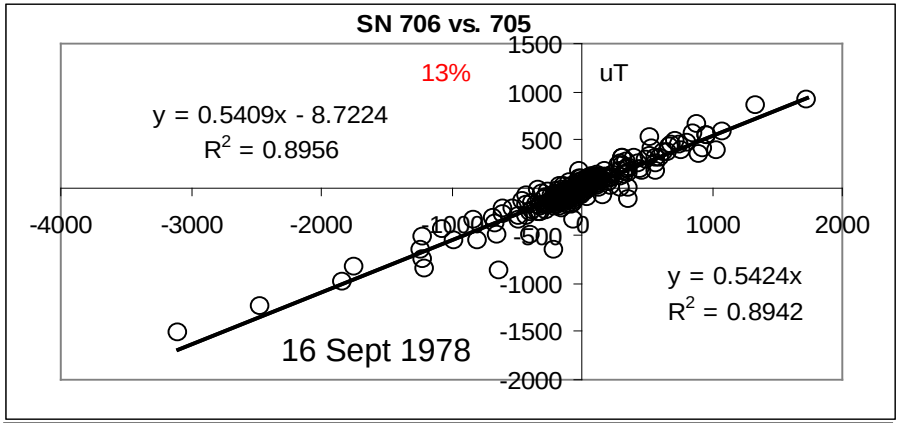
Maximum Inclination of the Current Sheet (N-S Mean): 1976-2011

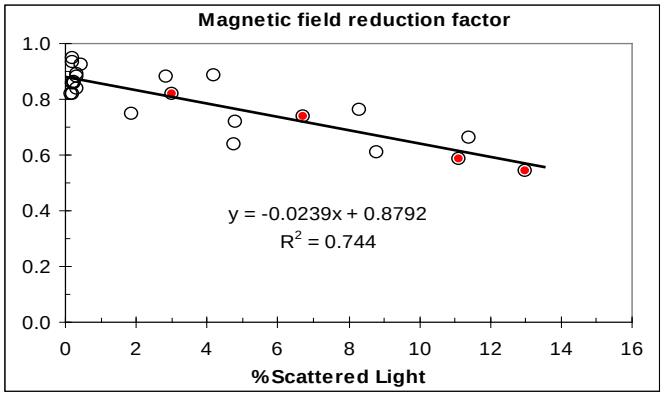


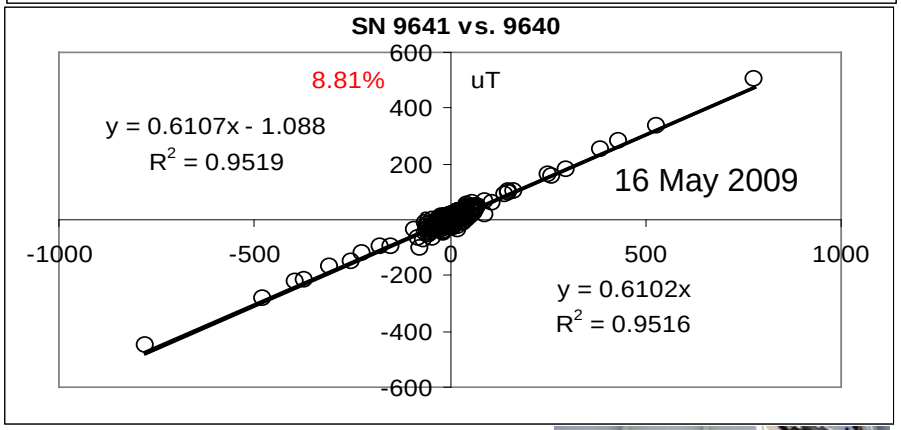
Solid=Classic PFSS Model (preferred) Dashed=Radial Rs=3.25

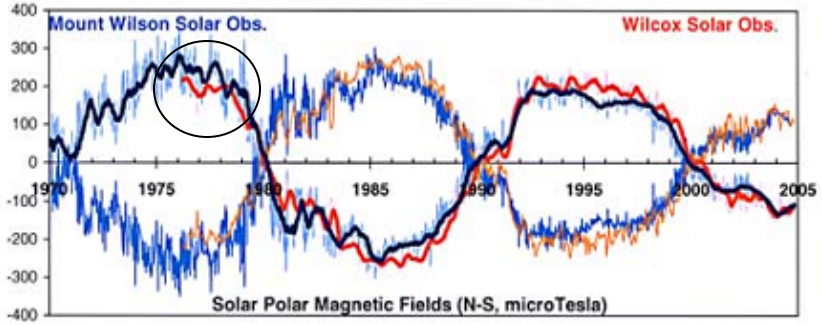
Unexpected early for a small solar cycle

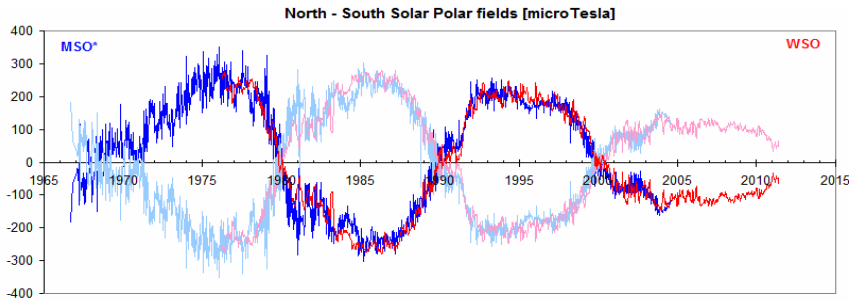
Scattered Light Decreases Measured Magnetic Fields











Compare magnetograms taken with clean and dirty coelostat mirror

What a Mess!

Our time series of solar activity indicators are inconsistent and poorly calibrated.

People pick the ones they like in support of their pet theories.

We cannot provide other disciplines with properly vetted solar data

What to do about this?

Sunspot Workshop in 2011

We view the September workshop as the first step in an effort to provide the solar community with a vetted long-term sunspot number and the tools to keep it on track.

Ed Cliver (Co-Organizer), Leif Svalgaard (Co-organizer), Rainer Arlt, K.S. Balasubramaniam, Luca Bertello, Tom Bogdan or Doug Biesecker, Frederic Clette, Ingrid Cnossen, Thierry Dudok de Wit, Peter Foukal, Thomas Friedli, David Hathaway, Carl Henney, Phil Judge, Ali Kilcik, Laure Lefevre, Bill Livingston, Jeff Morrill, Kalevi Mursula, Alexei Pevtsov, Art Richmond, Aaron Ridley, Alexis Rouillard, Ken Schatten, Ken Tapping, Jose Vaquero, Stephen White

An ISSI Workshop in 2012

The Team proposal that you have submitted in response to the 2011 Call was evaluated by the Science Committee and the ISSI Directorate and considered to be of high scientific value and relevance . The proposal is thus approved for implementation.

International Teams in Space Science Proposal 2011

Title: Long-term reconstruction of Solar and Solar Wind Parameters

Co-Organizers: Leif Svalgaard (USA), Mike Lockwood (UK), Jürg Beer (Switzerland)

Team members: Andre Balogh (UK), Paul Charbonneau (Canada), Ed Cliver (USA), Nancy Crooker (USA), Marc DeRosa (USA), Ken McCracken (Australia), Matt Owens (UK), Pete Riley (USA), George Siscoe (USA), Sami Solanki (Germany), Friedhelm Steinhilber (Switzerland), Ilya Usoskin (Finland), Yi-Ming Wang (USA)