

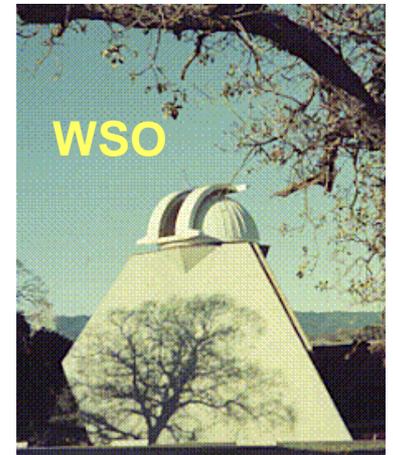
The New Sunspot Series: Methods, Results, Implications, Opposition

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Stanford University, California, USA

<http://www.leif.org/research>

Seminars at HEPL, LMSAL, LASP, HAO, and NOAA (SWPC)
July, 2015



Motivation for Revisiting the Sunspot Number Series

In the words of Jan Stenflo, <http://www.leif.org/research/SSN/Stenflo.pdf>, we can make an “analogy with the cosmic distance scale: One needs a ladder of widely different techniques valid in a sequence of partially overlapping regimes. Similarly, to explore the history of solar variability we need a ladder of overlapping regimes that connect the present physical parameters (TSI, magnetograms, F10.7 flux, UV radiance, etc.) with the distant past. The time scale from the present back to Galileo can only be bridged by the Sunspot Number, which in turn allows the ladder to be continued by isotope methods, etc”.

Jack Harvey (3rd SSN Workshop, Tucson 2013):

Needed as a pure solar activity index back 400 years to tie in with longer-lived, but less direct proxies.

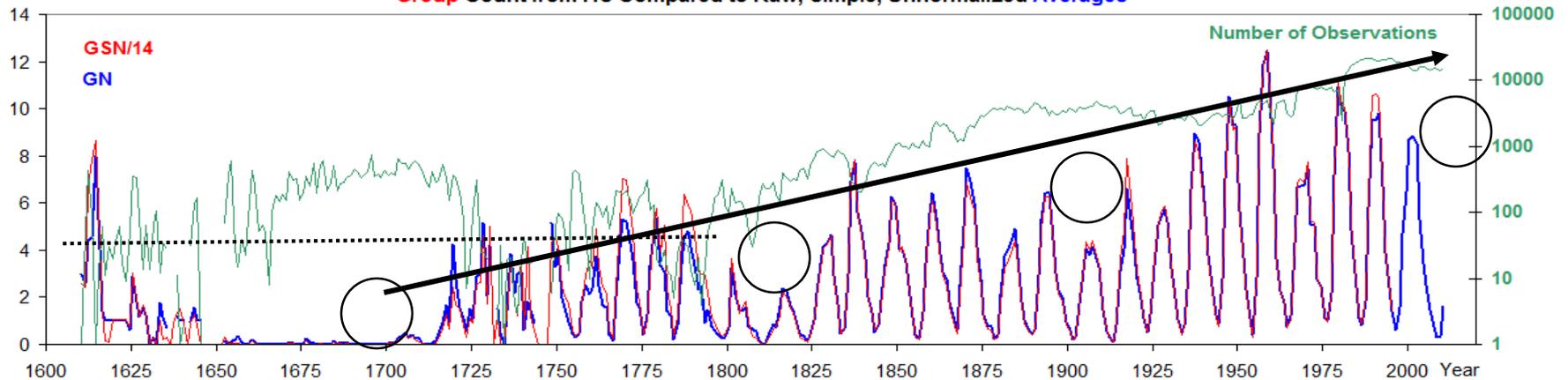
The SSN Workshops. The Work and Thoughts of Many People



Overview (Forensic Solar Physics)

- Reconstruction of the Sunspot Group Number 1610-2015: the Backbone Method (with Ken Schatten)
- Reconstruction of Solar Extreme Ultraviolet Flux 1740–2015 (with Olof Beckman)
- The Effect of Weighting of Sunspot Counts (with the Locarno Observers)
- The New SILSO Website (with Frédéric Clette)
- Solar Physics: Topical Issue (with Ed Cliver)
- What is Next? TSI? Cosmic Ray Proxies? Climate?

Group Count from HS Compared to Raw, Simple, Unnormalized Averages



NUMBER OF SUNSPOT GROUPS FOR THE YEAR: 1683
AS OBSERVED BY: SIVERUS, H., HAMBURG

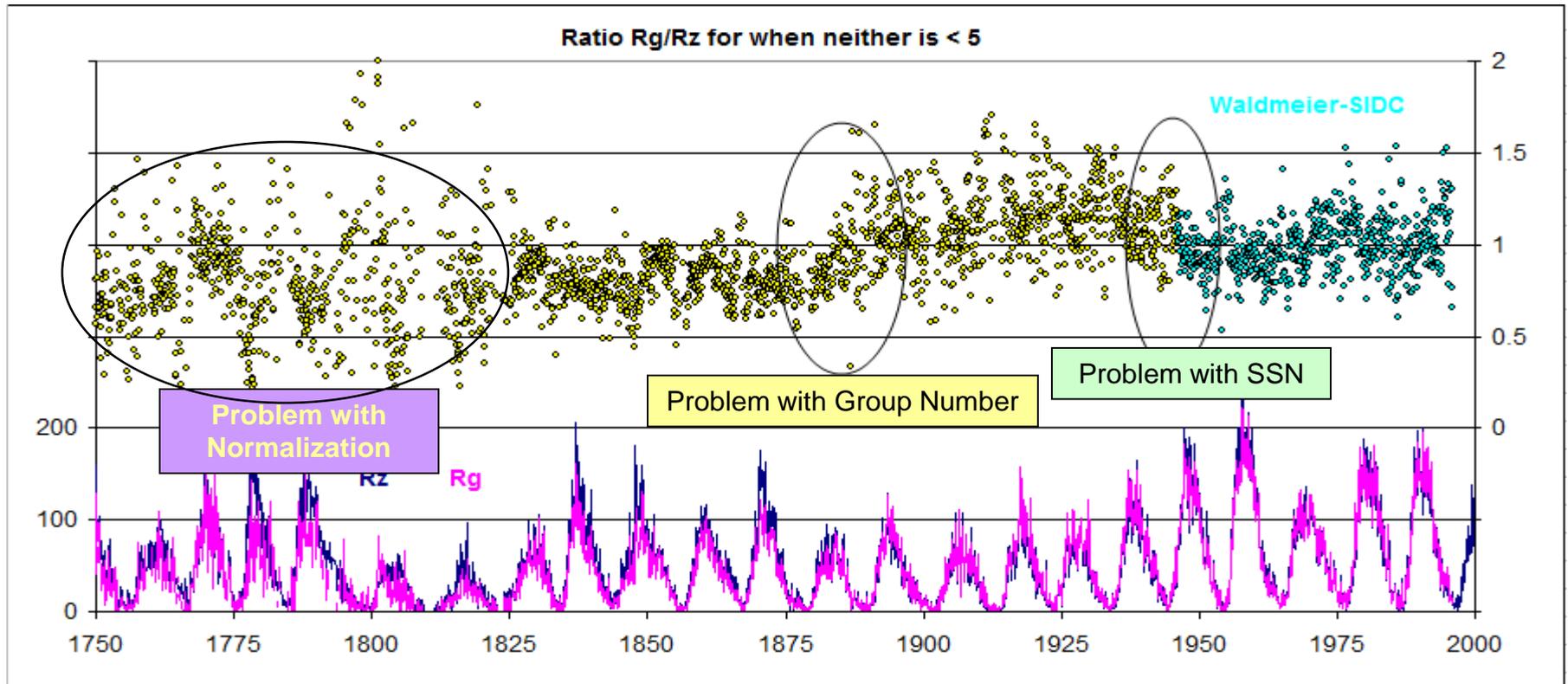
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0
29	0	-99	0	0	0	0	0	0	0	0	0	0
30	0	-99	0	-99	0	0	0	0	0	0	-99	0
31	0	-99	0	-99	0	-99	0	0	-99	0	-99	0
means :	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

"I didn't see any spots this year"

The Group Number

Douglas Hoyt and Ken Schatten proposed (1995) to replace the sunspot number with a count of **Sunspot Groups**. H&S collected almost 1/2 million observations (not all of them good) and labored hard to normalize them to modern observations

The Ratio Group/Zürich SSN has Two Significant Discontinuities



At ~1947 (After Max Waldmeier took over) and at 1876-1910 (Greenwich calibration drifting)

As we found problems with the H&S normalization, we decided to build a new Group Series 'from scratch'

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 'good' 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]

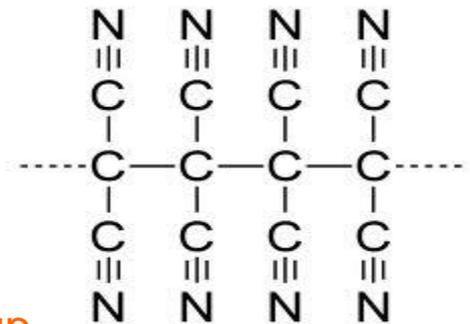


Chinese Whispers



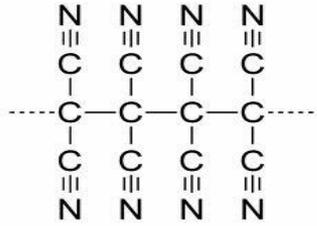
When several backbones have been constructed we can join [daisy-chain] the backbones. Each backbone can be improved individually without impacting other backbones

We have applied this methodology to reconstruct the Group Sunspot Number [using essentially the Hoyt&Schatten data]

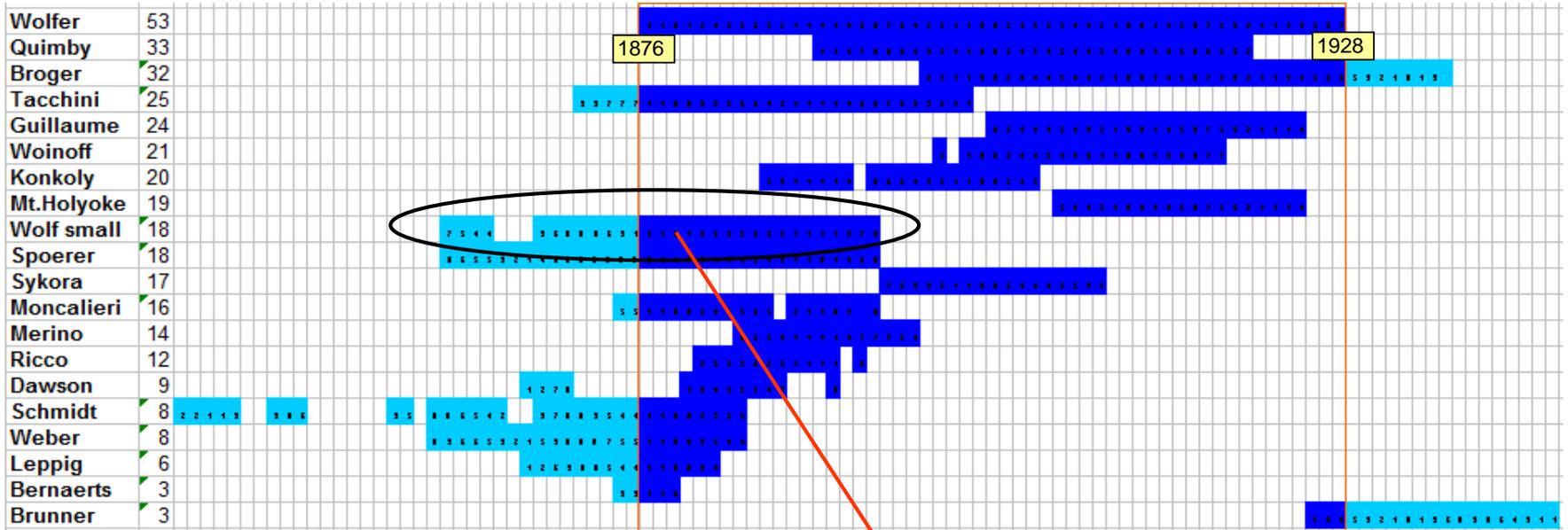


Carbon Backbone 7

The Wolfer Backbone



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



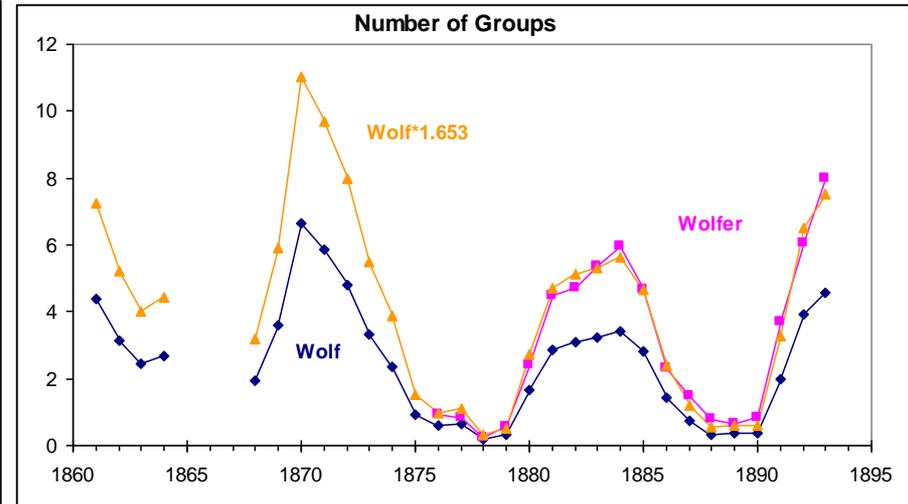
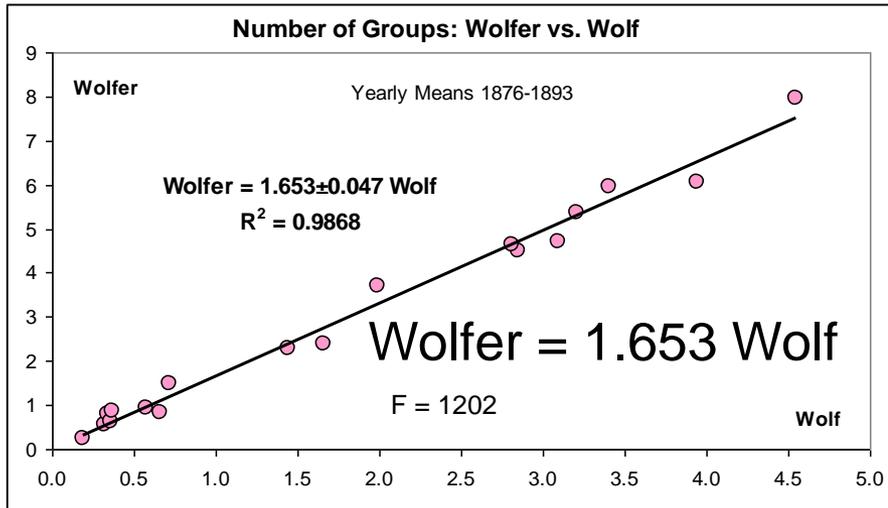
80 mm X64



37 mm X20

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

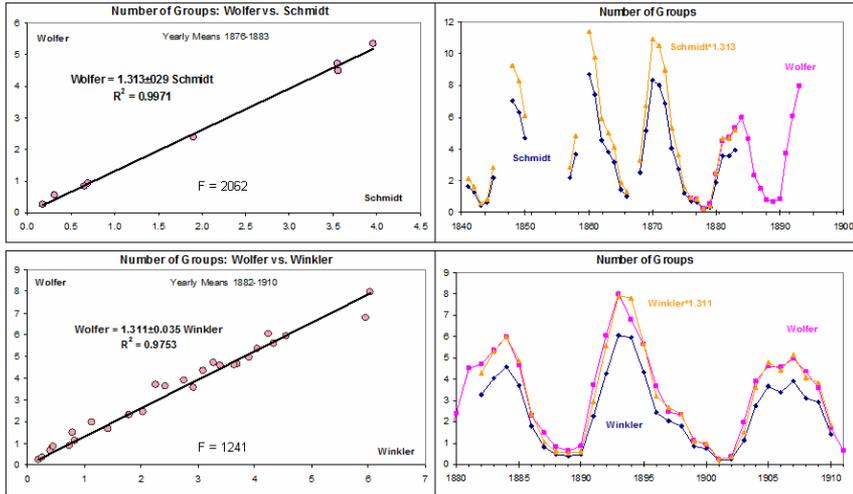
Normalization Procedure



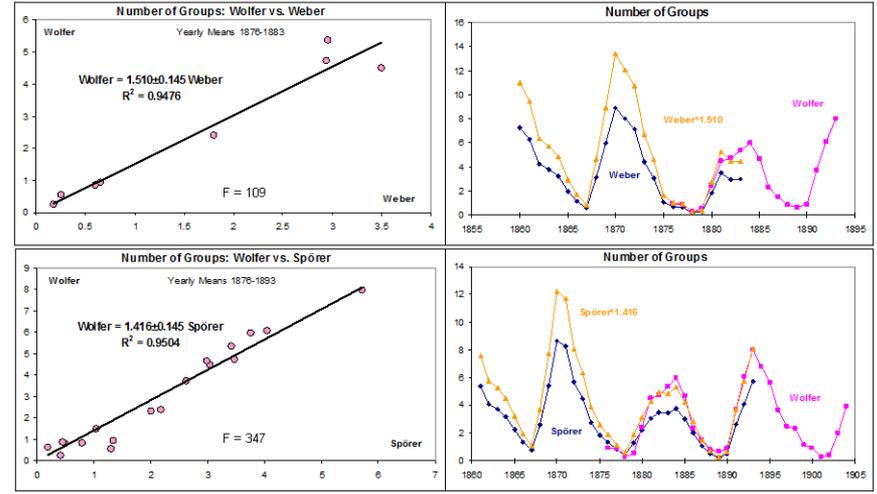
For each Backbone we regress each observers group counts for each year against those of the primary observer, and plot the result [left panel]. Experience shows that the regression line almost always very nearly goes through the origin, so we *force* it to do that and calculate the slope and various statistics, such as 1- σ uncertainty and the *F*-value. The slope gives us what factor to multiply the observer's count by to match the primary's. The right panel shows a result for the Wolfer Backbone: blue is Wolf's count [with his **small** telescope], pink is Wolfer's count [with the larger telescope], and the orange curve is the blue curve multiplied by the slope. It is clear that the harmonization works well.

Regress More Observers Against Wolfer...

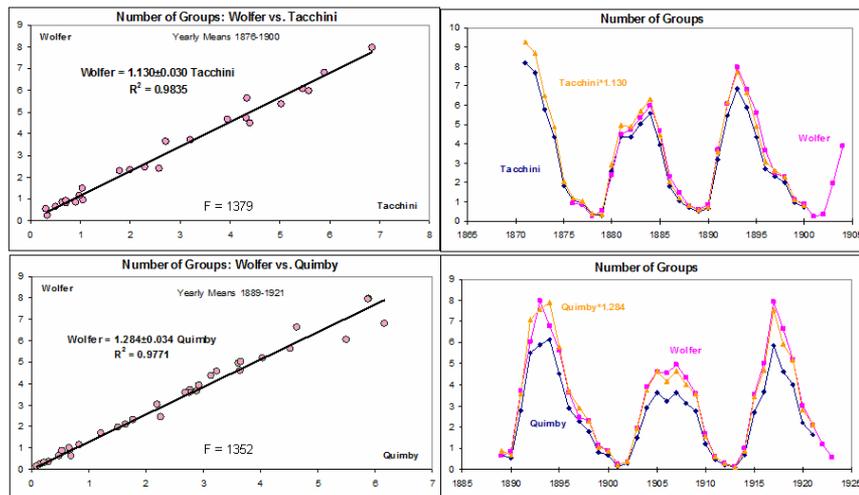
Schmidt, Winkler



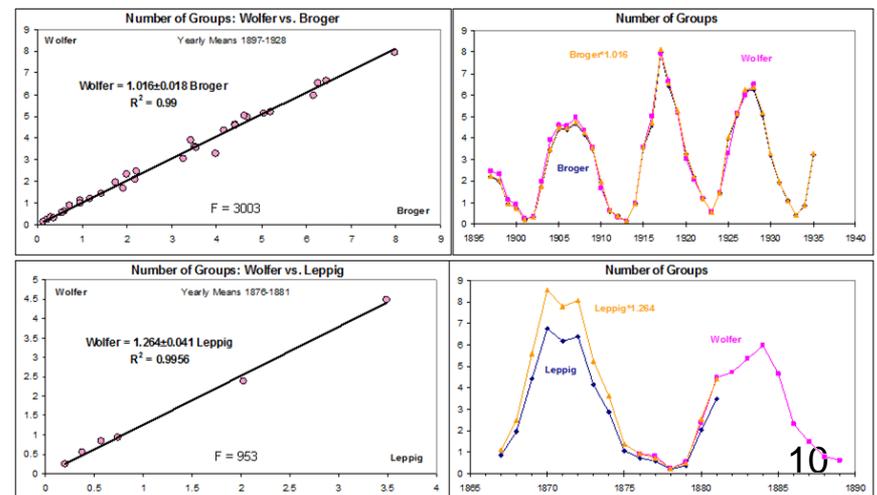
Weber, Spörer



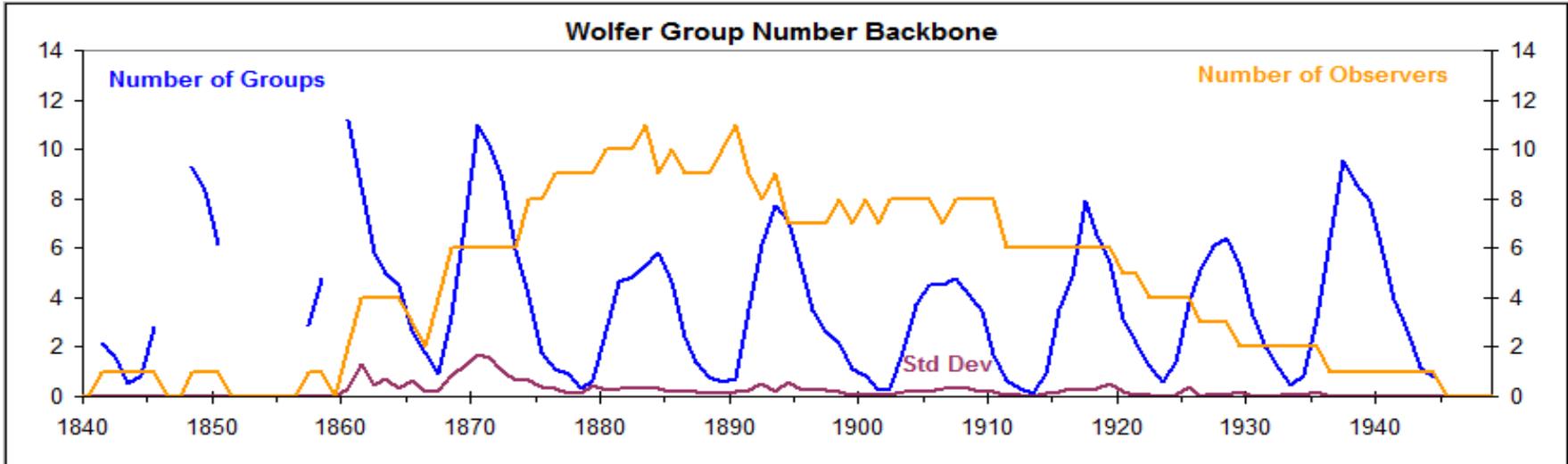
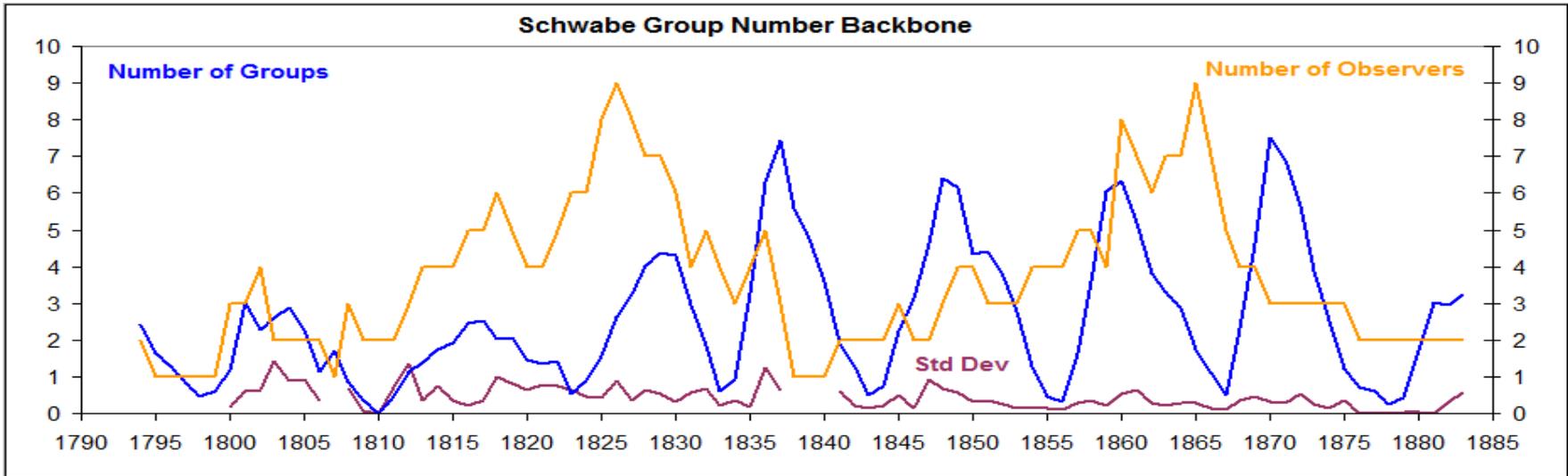
Tacchini, Quimby



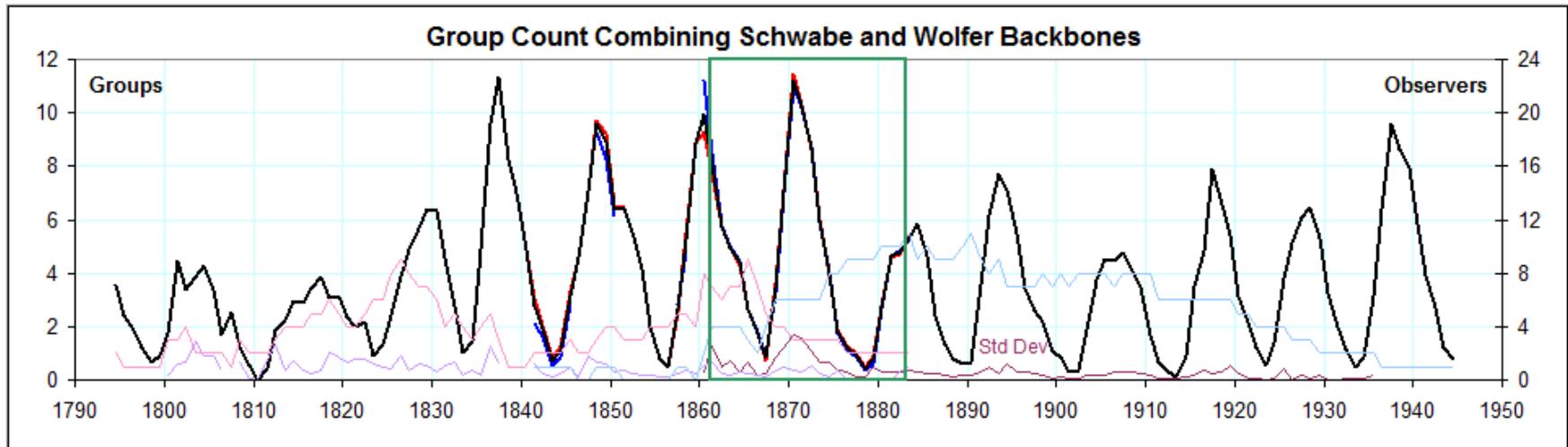
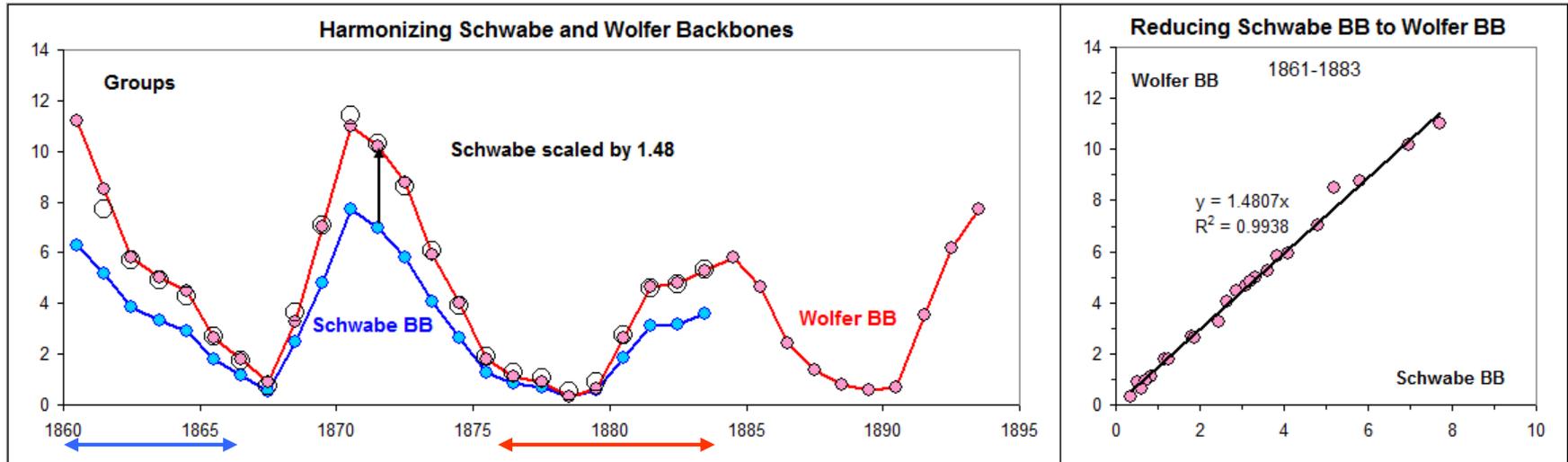
Broger, Leppig



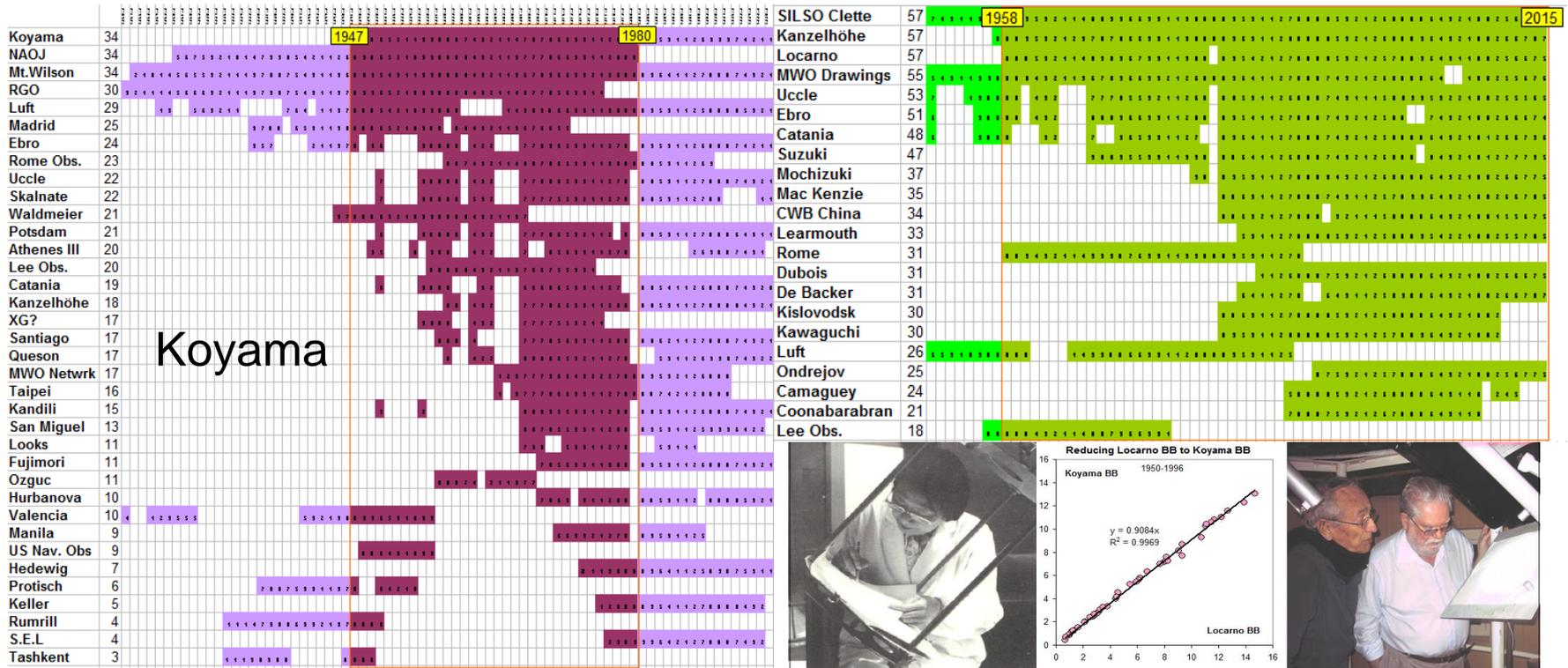
The Schwabe And Wolfer Group Backbones



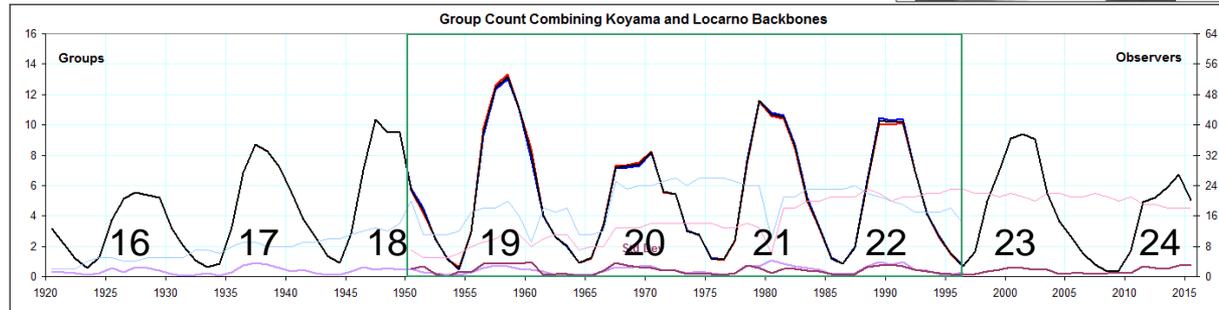
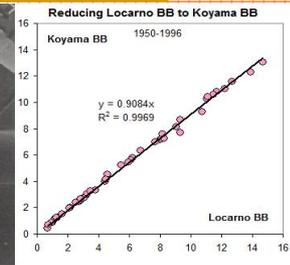
Harmonizing Schwabe and Wolfer Backbones



The Modern Backbones



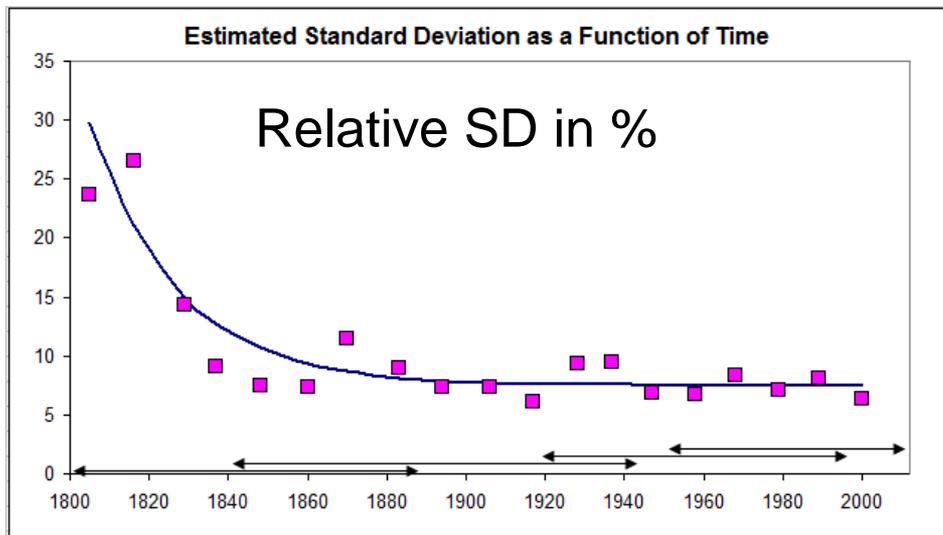
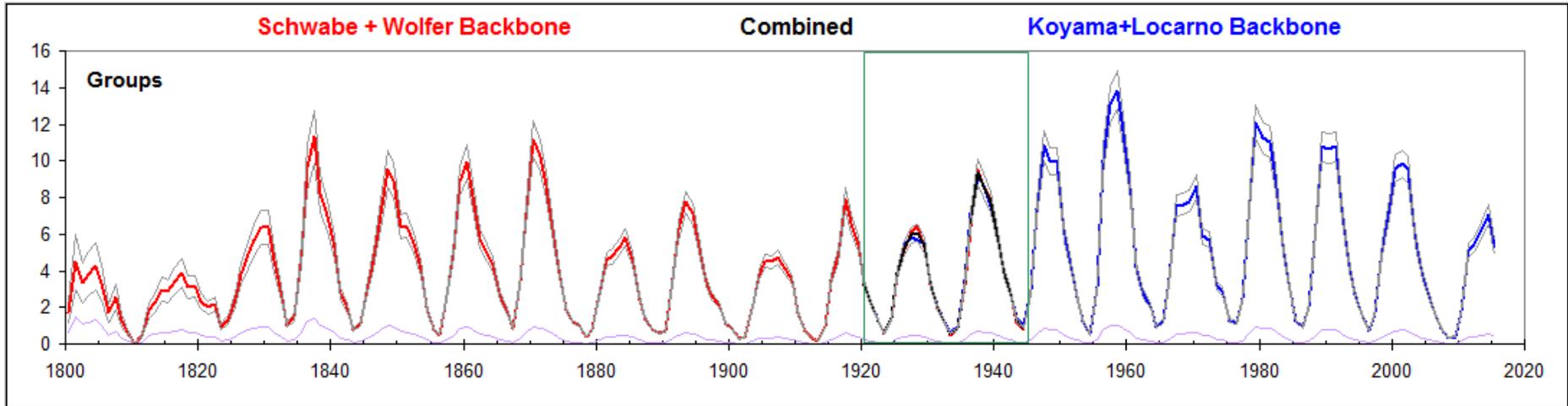
Koyama



Ms. Hisako Koyama,
小山ヒサ子 (1916-97).

Mr. Sergio Cortesi,
Locarno.

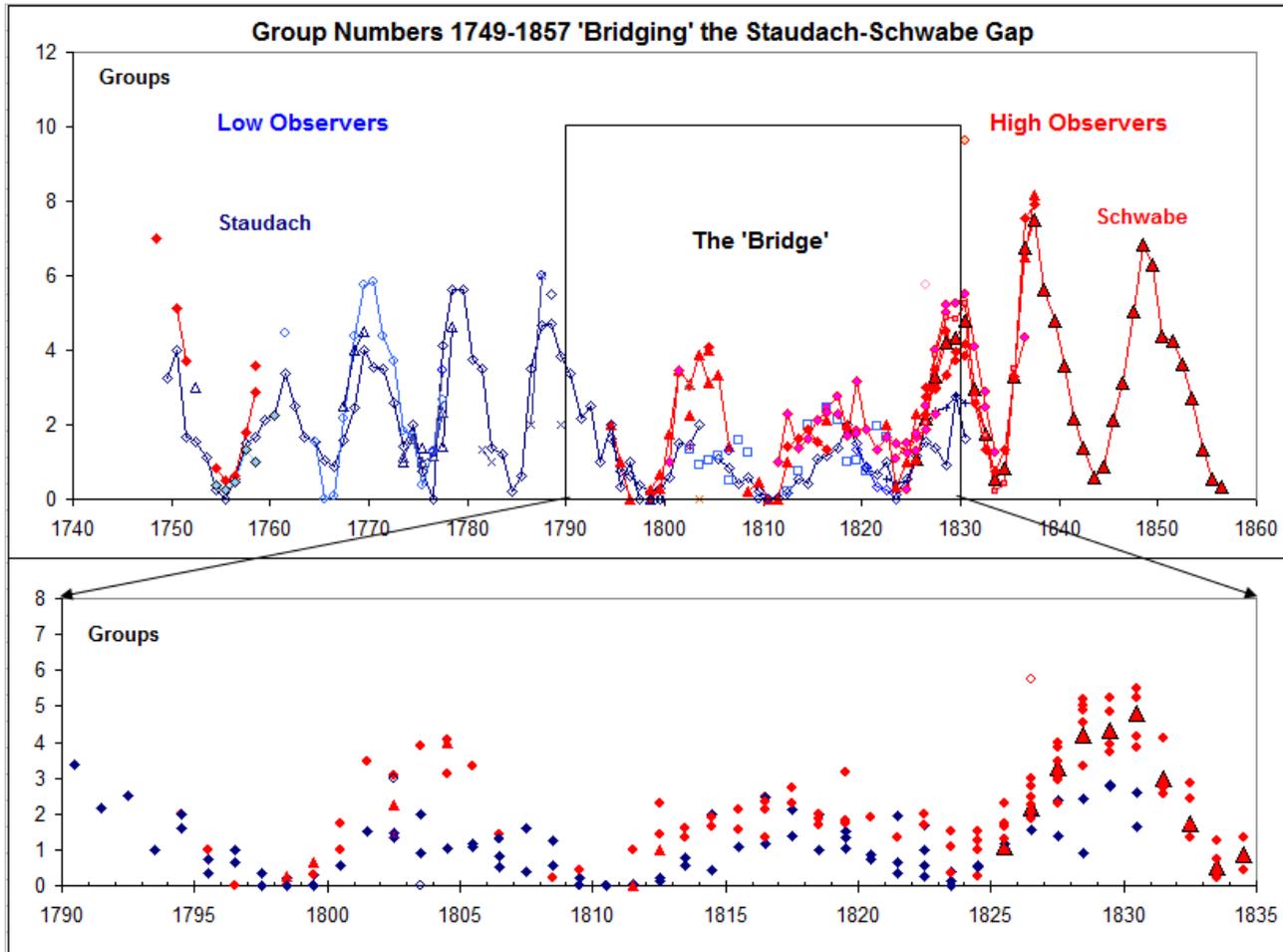
Combined Backbones back to 1800



The Standard Deviation falls from 30% in 1800 to a rather constant 8% from 1835 onwards

By choosing the middle Wolfer Backbone as the reference, we minimize 'daisy chaining' errors

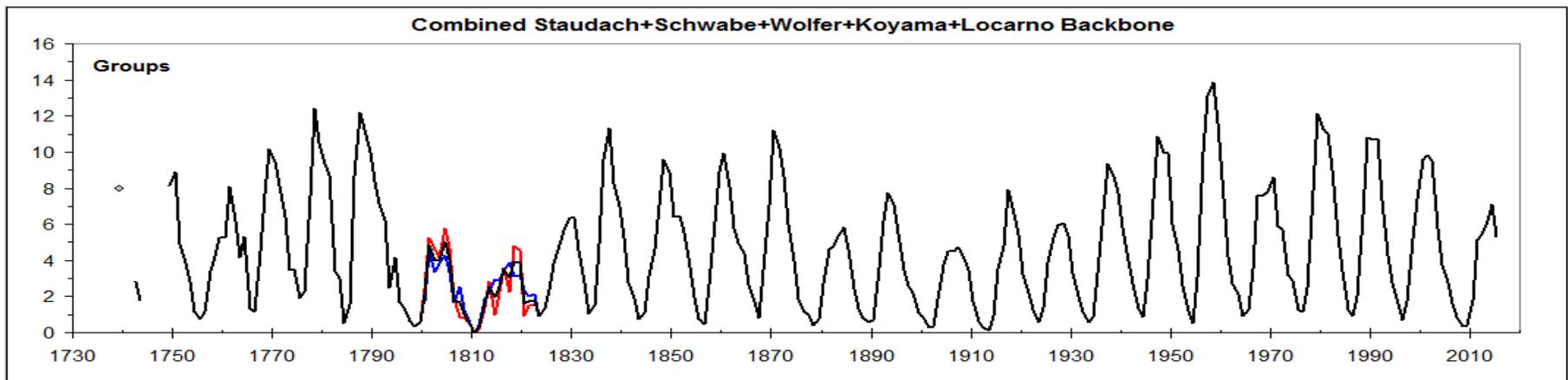
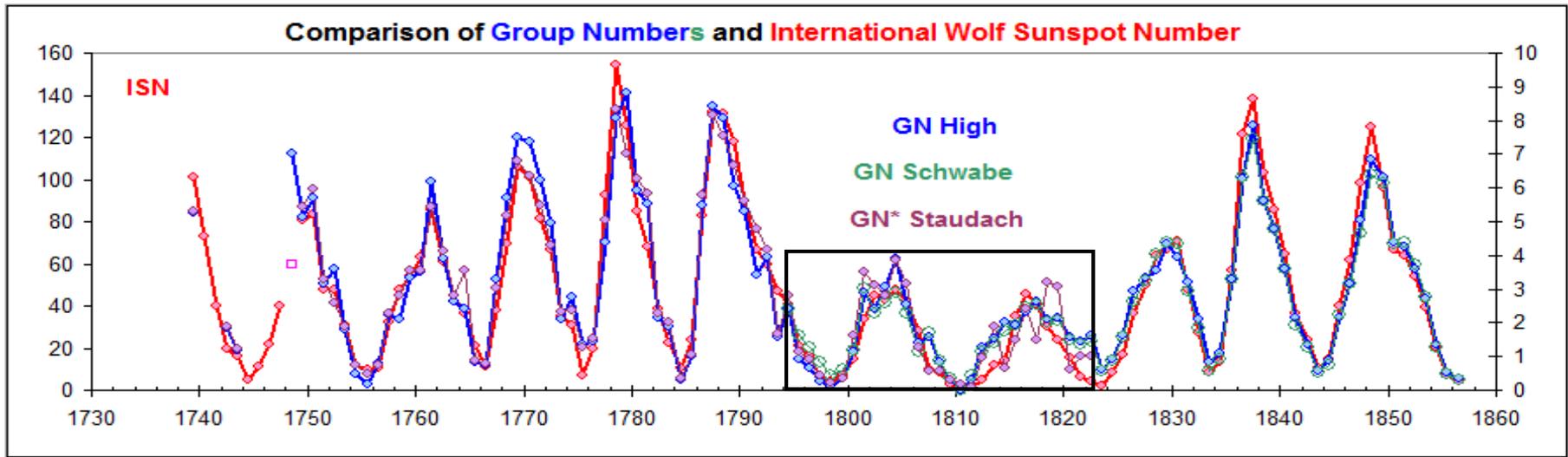
How do we combine the Staudach and Schwabe Backbones?



Examining the data for the decades surrounding the year 1800 it becomes evident that the group counts reported by the observers during that interval separate into two categories: 'low count' observers and 'high count' observers. It is tempting to lump together all observers in each category into two 'typical observers' for the now overlapping categories.

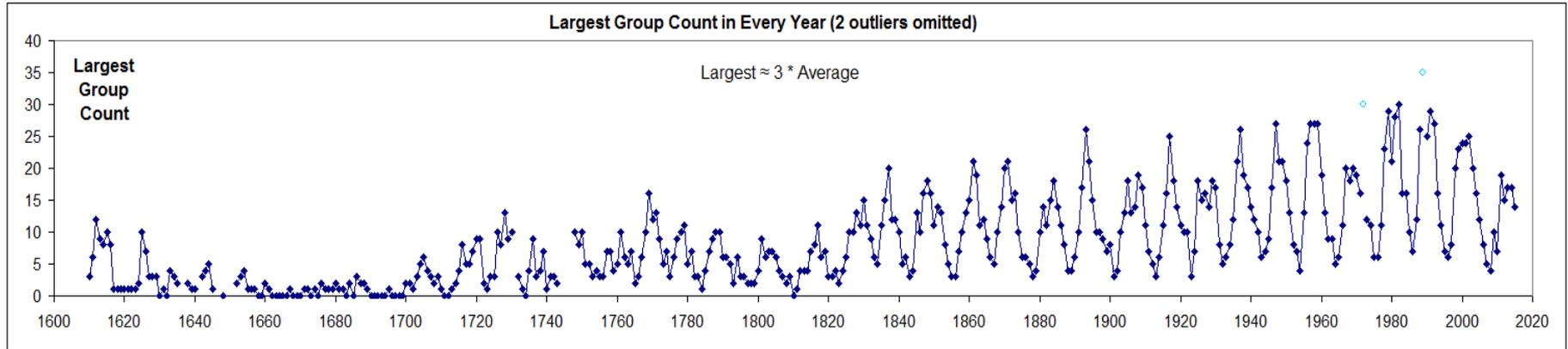
And *now* we can regress one category against the other and scale the low category to the high category, which now overlaps sufficiently with the Schwabe Backbone

We can now scale the Staudach (High) Backbone to Schwabe's



And construct a composite back to ~1750

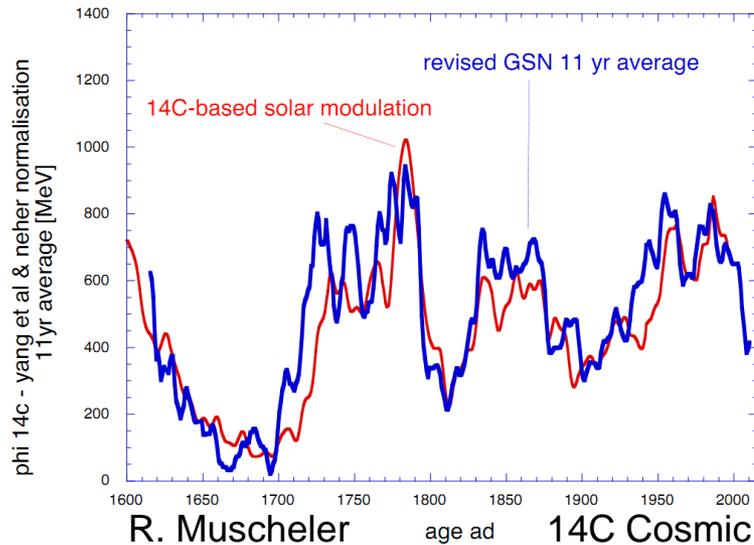
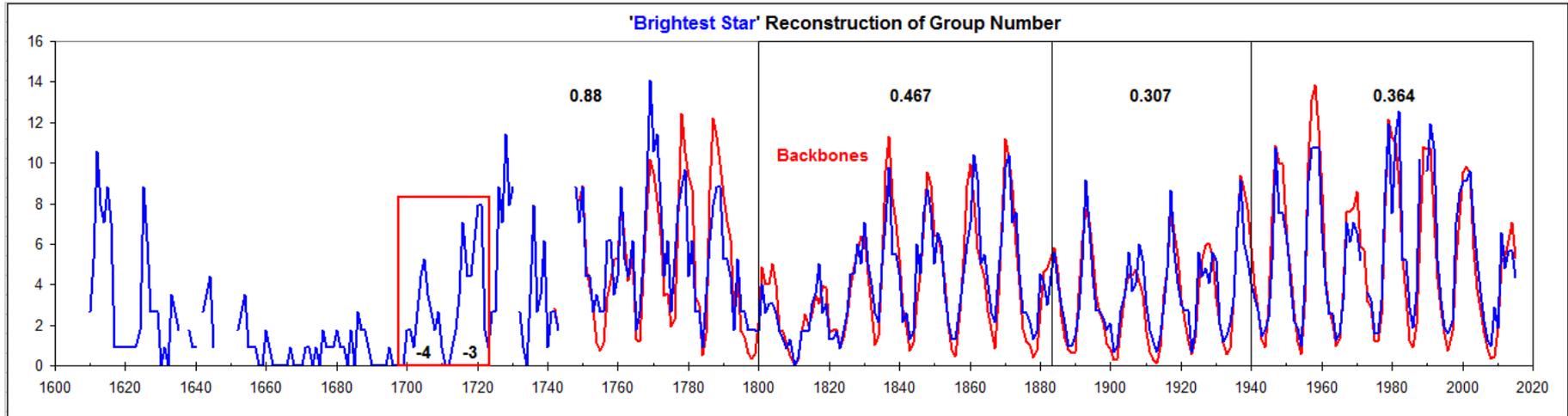
'Brightest Star Method'



In Edwin Hubble's (1929) landmark paper showing the galaxy velocity-distance relation he used, of necessity, the brightest star in nebulae and the brightest galaxy in clusters as distance indicators, calibrated against the few nebulae whose distance could be ascertained by more reliable methods. We could apply the same procedure here and use the **highest group count** in each year by *any* observer as a rough indicator of solar activity (which still needs to be suitably calibrated)

This may be our only way of assessing the data before ~1730

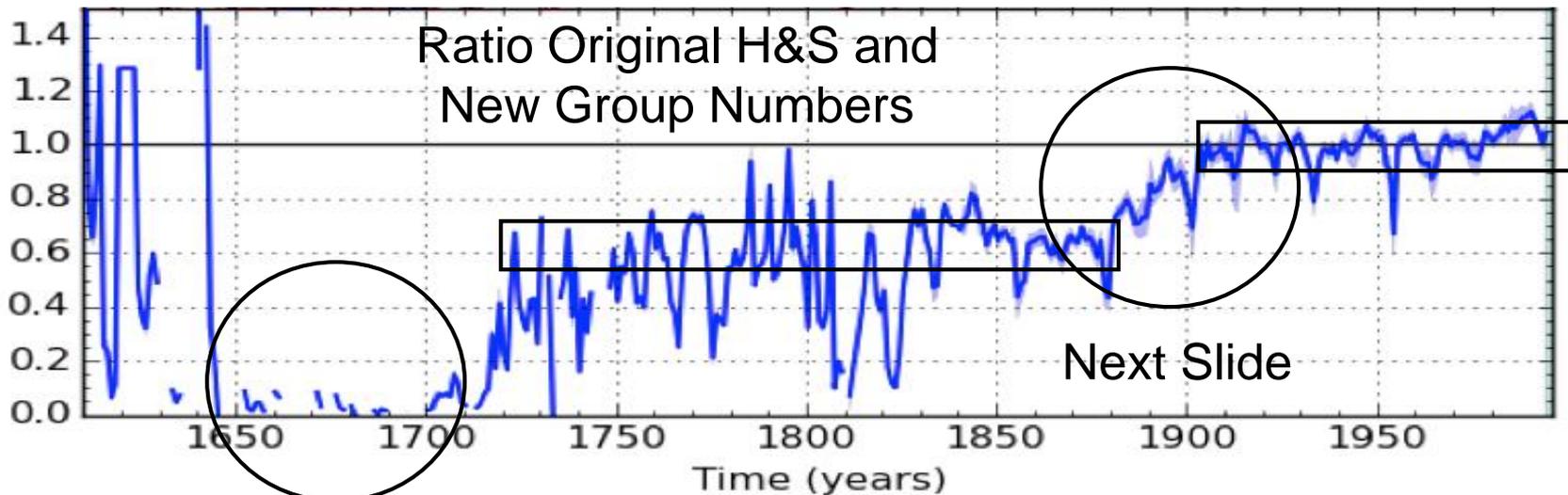
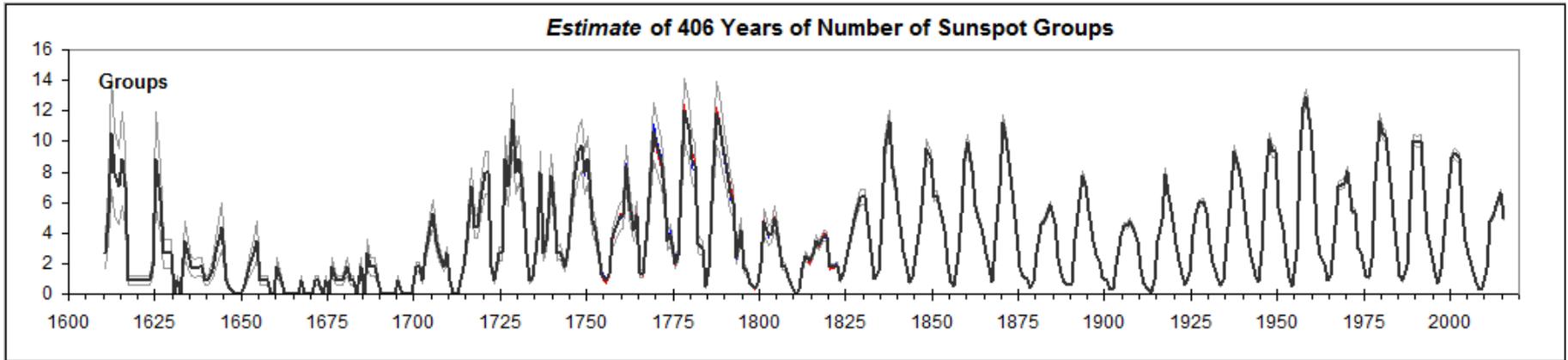
Calibrating “Brightest Star” Data



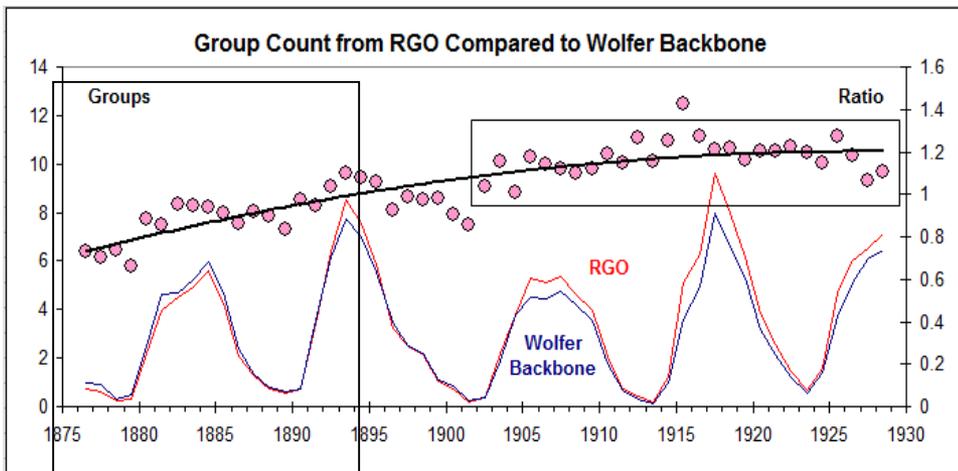
revisedGroupSunspotNumber 11yr average

We now find the reduction factor that will best match the backbones (red curves) that we have established. For the time before 1800 that factor is 0.88 and we apply it all the way back to 1610 having no other purely solar data.

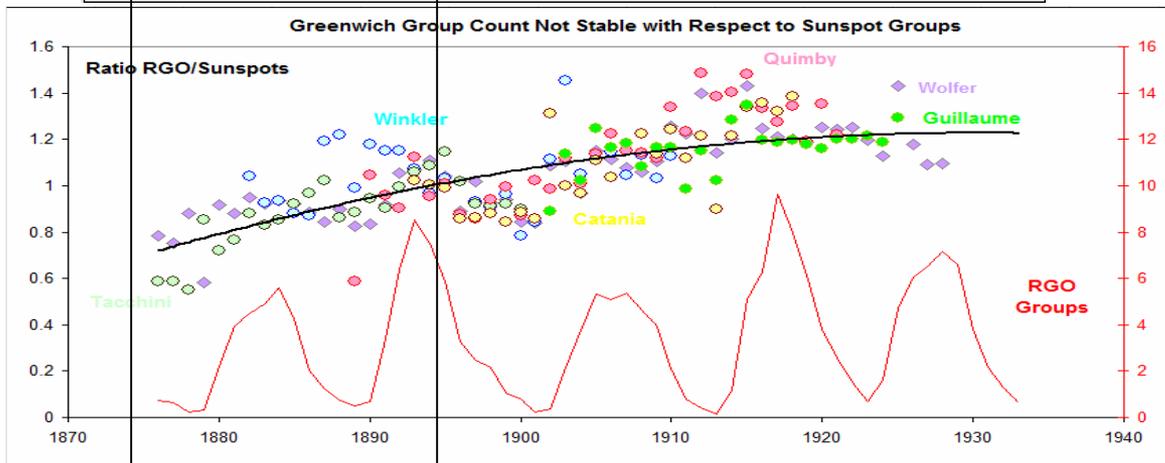
Putting it All Together (Pure Solar)



Excessive Zeroes + Mystery



Hoyt & Schatten used the Group Count from RGO [Royal Greenwich Observatory] as their Normalization Backbone. Why don't we?



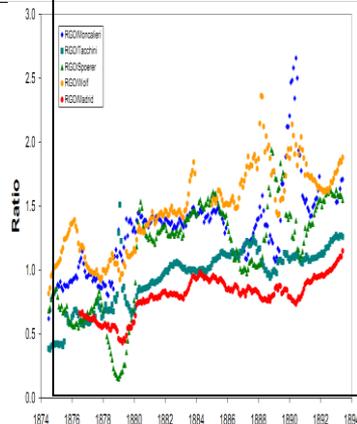
Because there are strong indications that the RGO data is drifting before ~1900

And that is a major reason for the ~1885 change in the level of the H&S Group Sunspot Number

José Vaquero found a similar result which he reported at the 2nd Workshop in Brussels.

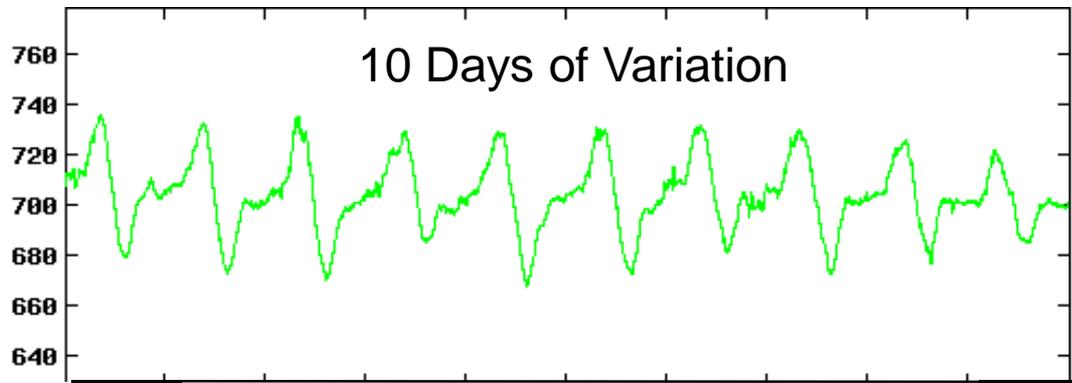
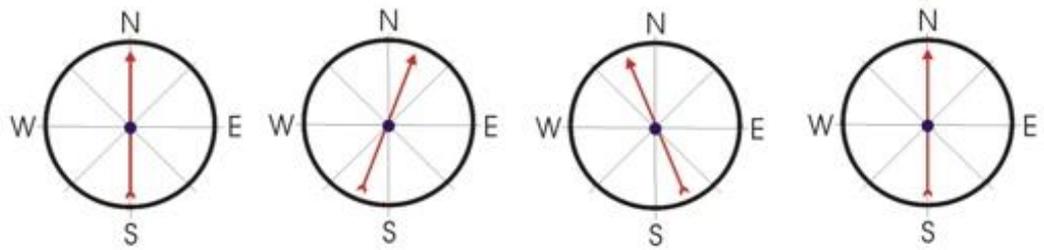
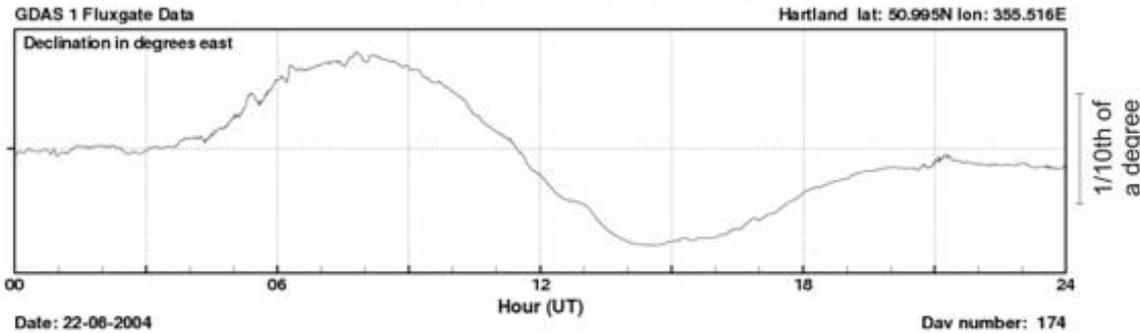
Sarychev & Roshchina report in Solar Sys. Res. 2009, 43: "There is evidence that the Greenwich values obtained before 1880 and the Hoyt–Schatten series of Rg before 1908 are incorrect".

And now for something superficially different → 22



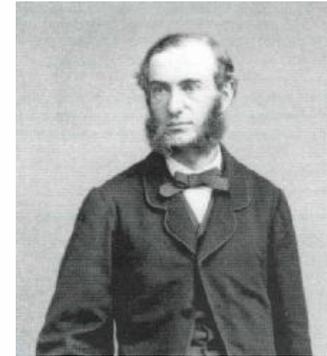
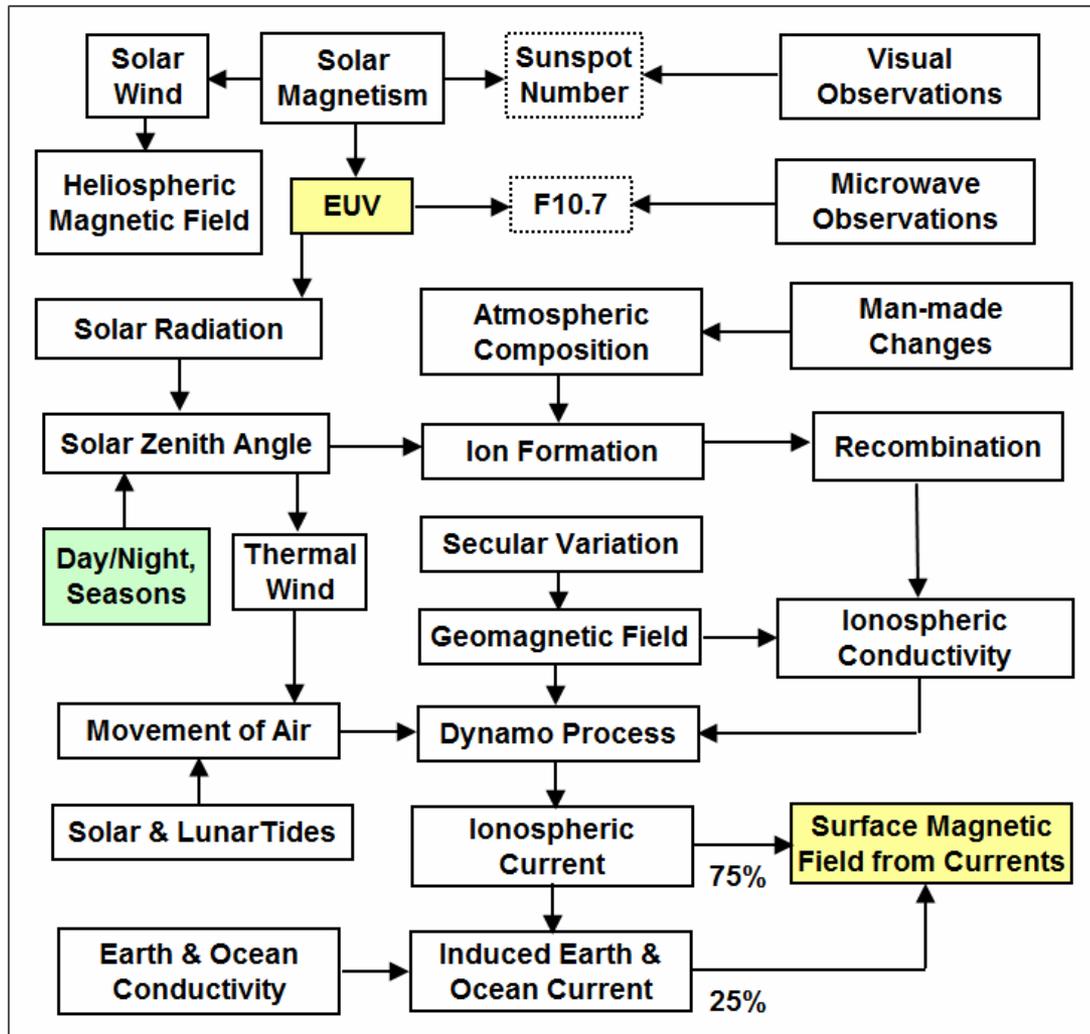
The Diurnal Variation of the Direction of the Magnetic Needle

National Geomagnetic Service, BGS, Edinburgh



George Graham [London] discovered [1722] that the geomagnetic field varied during the day in a regular manner

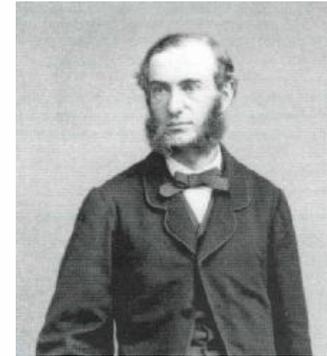
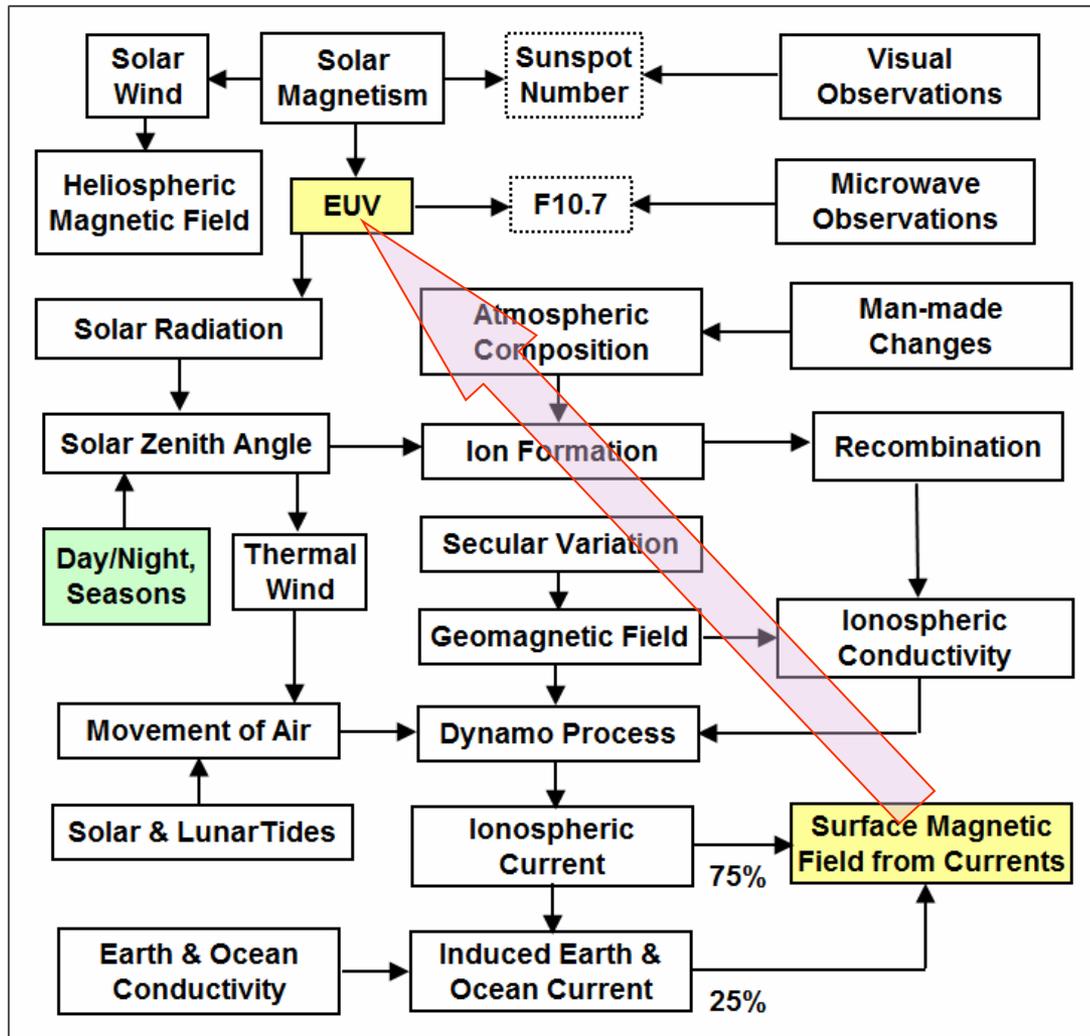
The Cause of the Daily Variation



Balfour Stewart,
1882,
Encyclopedia
Britannica,
9th Ed.

“The various speculations on the cause of these phenomena [daily variation of the geomagnetic field] have ranged over the whole field of likely explanations. (1) [...], (2) It has been imagined that convection currents established by the sun’s heating influence in the **upper regions of the atmosphere are to be regarded as conductors moving across lines of magnetic force, and are thus the vehicle of electric currents which act upon the magnet,** (3) [...], (4) [...].

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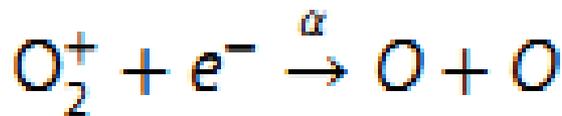
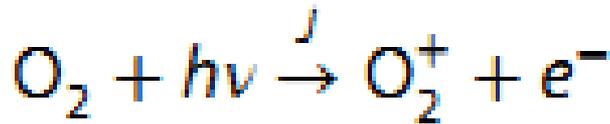
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We'll use this process in reverse to determine the EUV flux

A Dynamo

Electron Density due to EUV

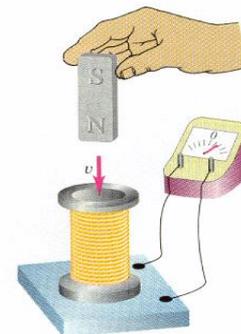
< 102.7 nm



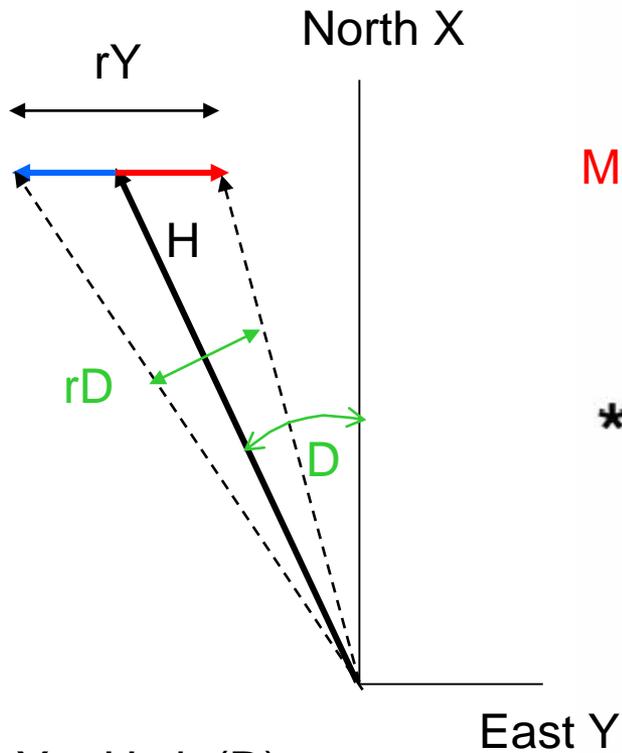
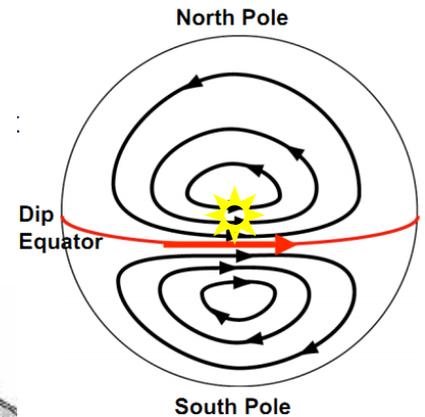
The conductivity at a given height is proportional to the electron number density N_e . In the dynamo region the ionospheric plasma is largely in photochemical equilibrium. The dominant plasma species is O^+_{2} , which is produced by photoionization at a rate J (s^{-1}) and lost through recombination with electrons at a rate α (s^{-1}), producing the Airglow.

Because the process is slow (the Zenith angle χ changes slowly) we have a quasi steady-state, in which there is no net electric charge, so $N_i = N_e = N$. In a steady-state $dN/dt = J \cos(\chi) - \alpha N^2 = 0$ and so $N = \sqrt{J \alpha^{-1} \cos(\chi)}$

Since the effective conductivity, Σ , depends on the number of electrons N , we expect that Σ scales with the square root \sqrt{J} of the overhead EUV flux with $\lambda < 102.7$ nm.

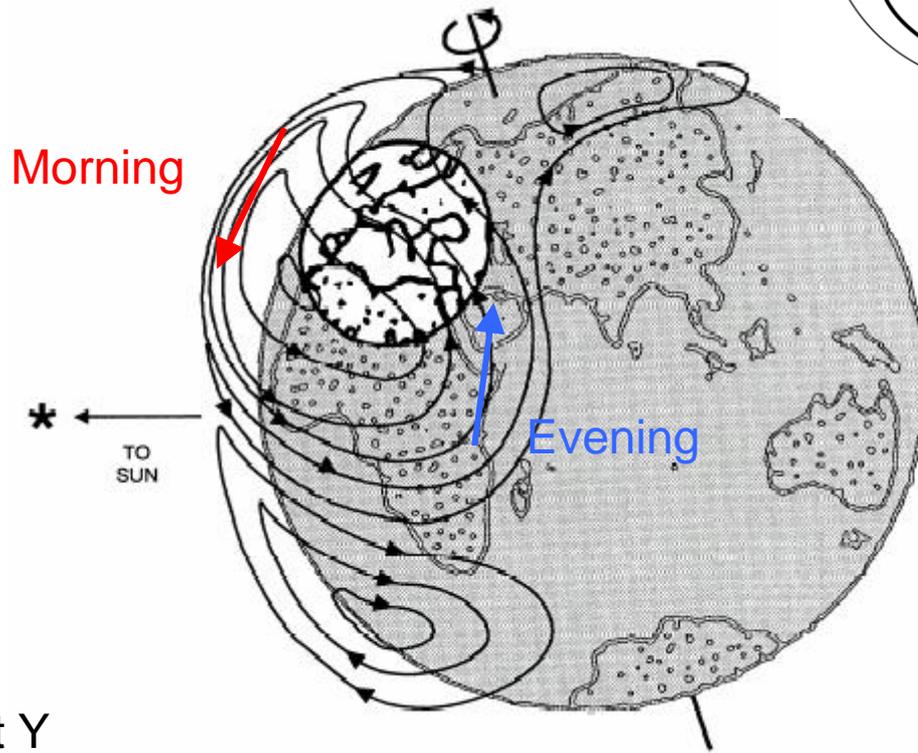


The E-layer Current System



$$Y = H \sin(D)$$

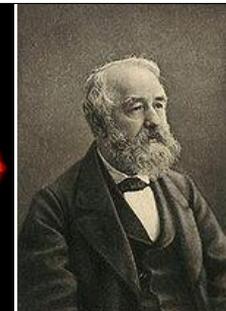
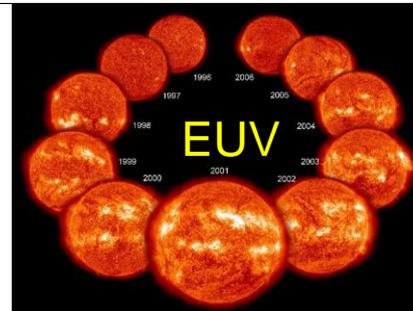
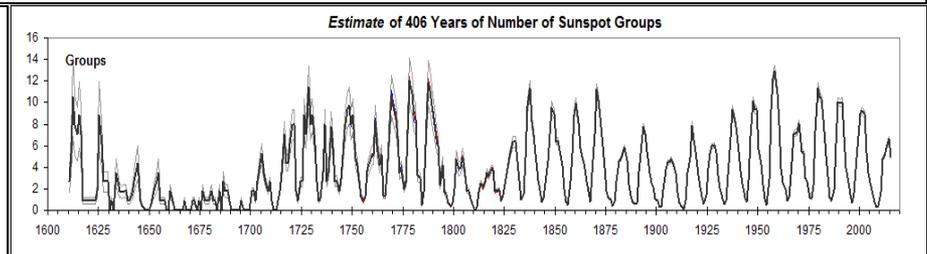
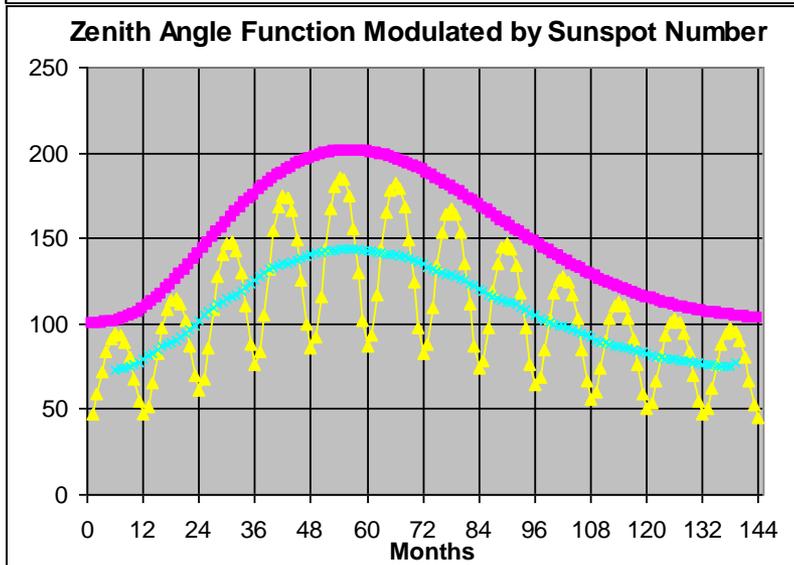
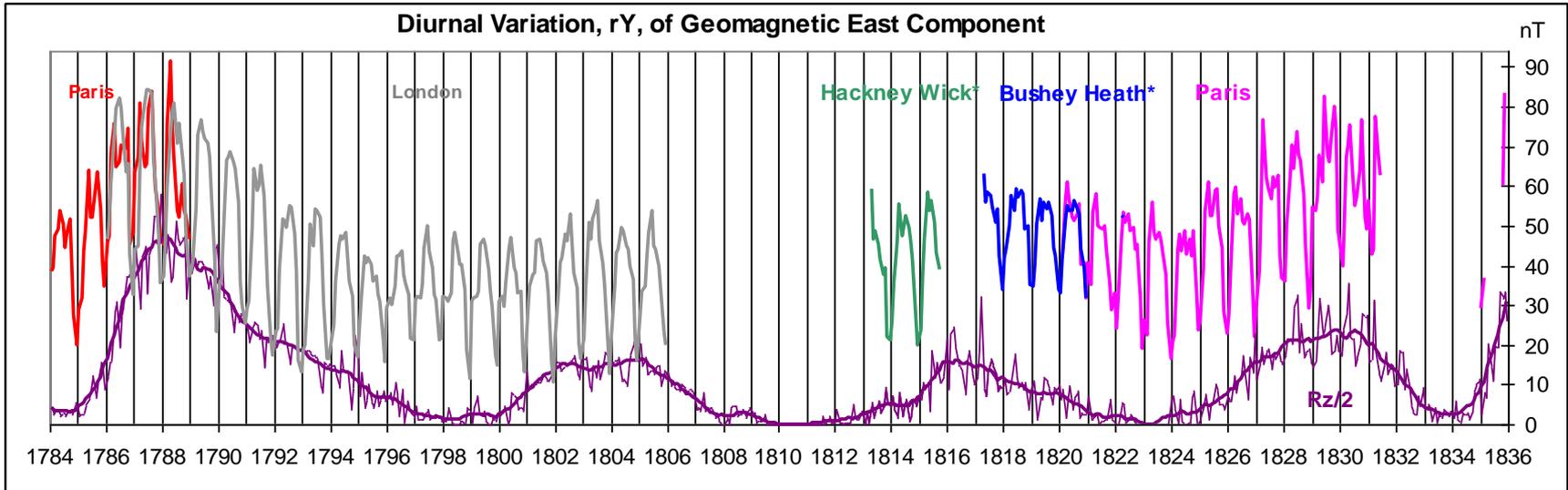
$$dY = H \cos(D) dD \text{ For small } dD$$



A current system in the ionosphere is created and maintained by solar EUV radiation

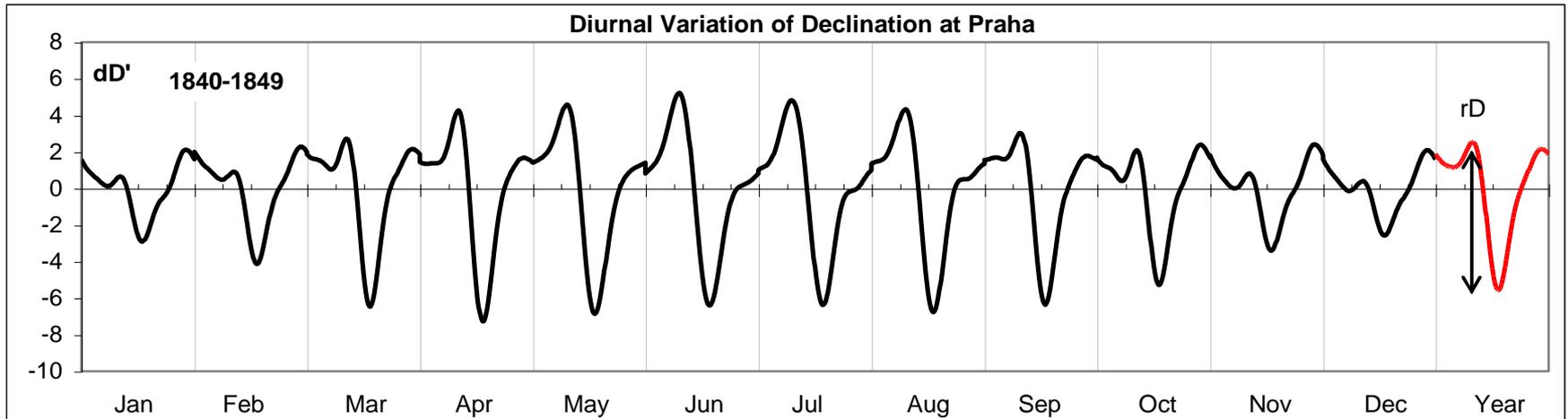
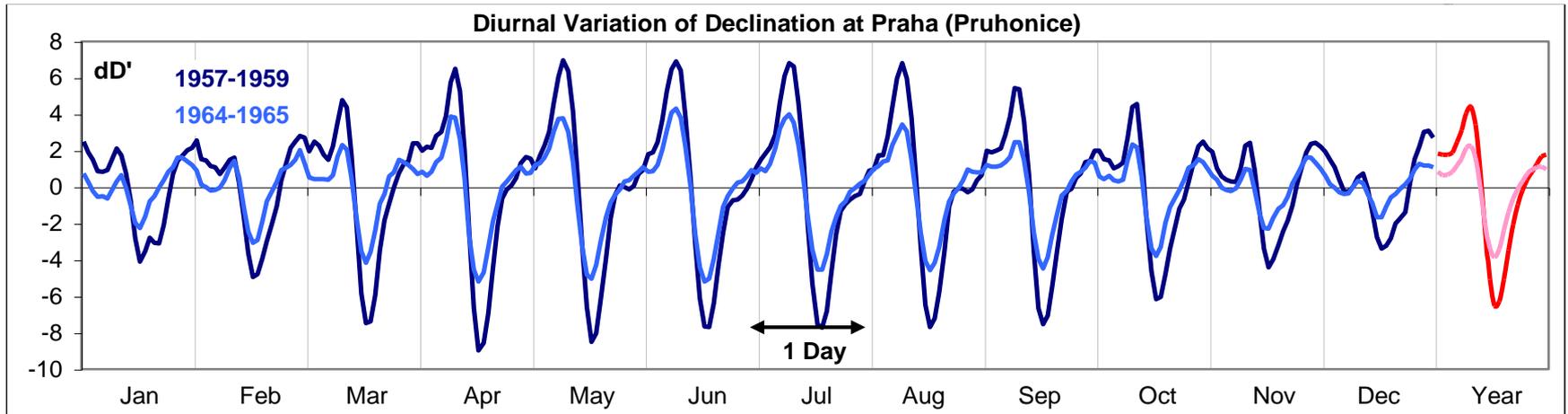
The magnetic effect of this system was what George Graham discovered

Solar Cycle and Zenith Angle Control

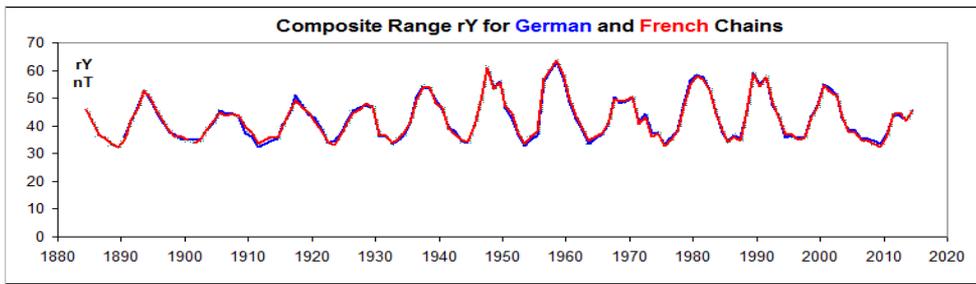


Rudolf Wolf,
J-A Gautier
1852

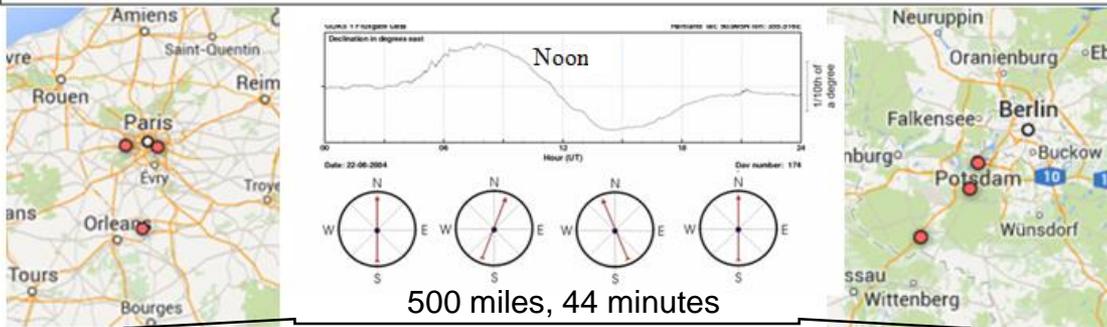
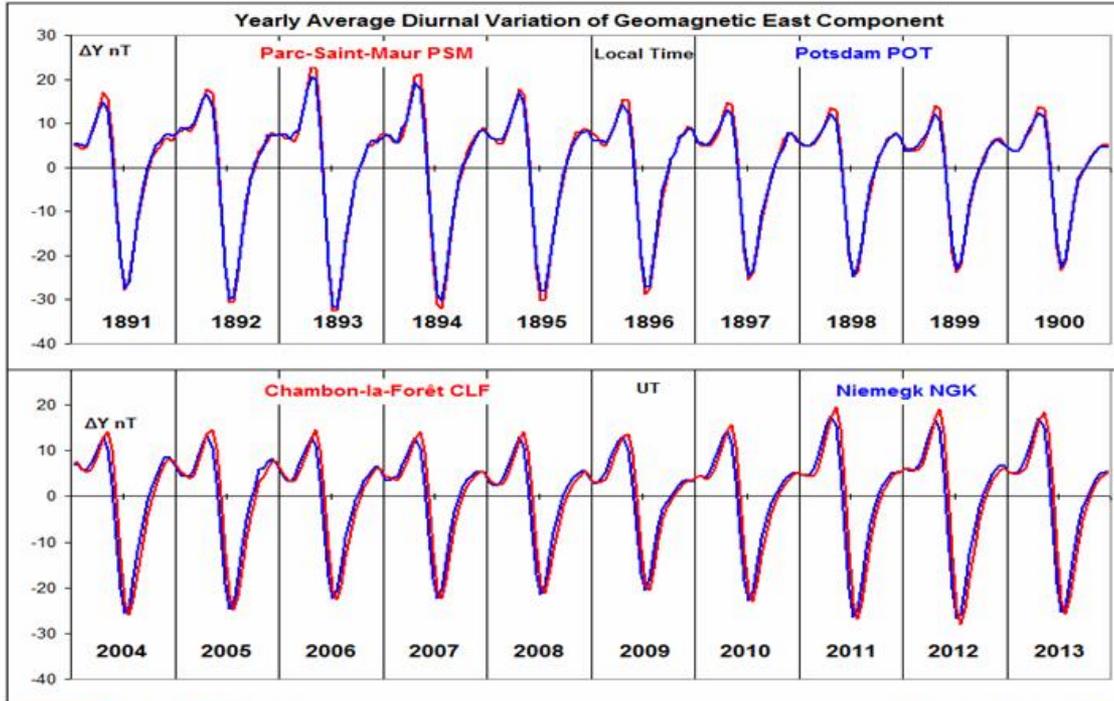
The Diurnal Variation of the Declination for Low, Medium, and High Solar Activity



We can eliminate the Zenith Angle dependence by using the annual mean amplitude 29



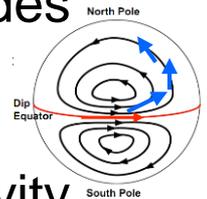
PSM-POT-VLJ-SED-CLF-NGK Chains



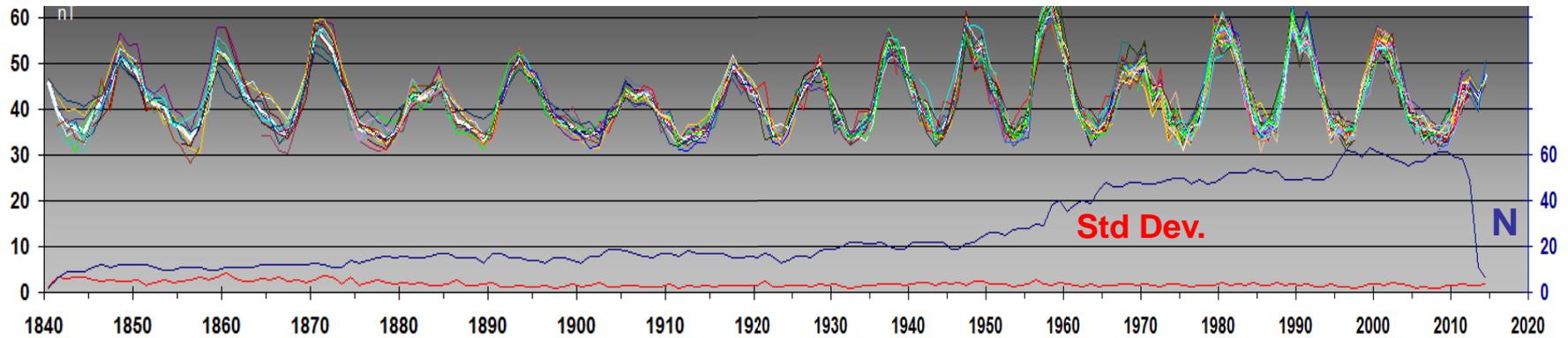
A 'Master' record can now be built by averaging the yearly range for the German and French chains.

We shall normalize all other stations to this Master record.

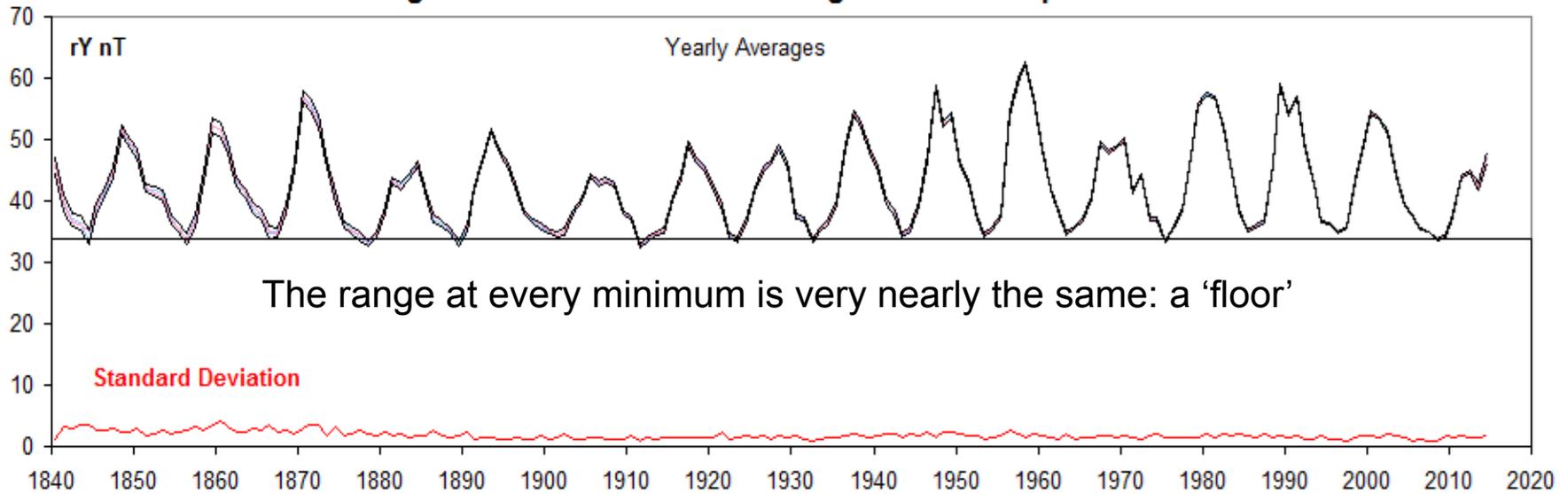
Normalization is necessary because of different latitudes and different underground electric conductivity



Normalized Ranges rY of the East Component for 107 Observatories



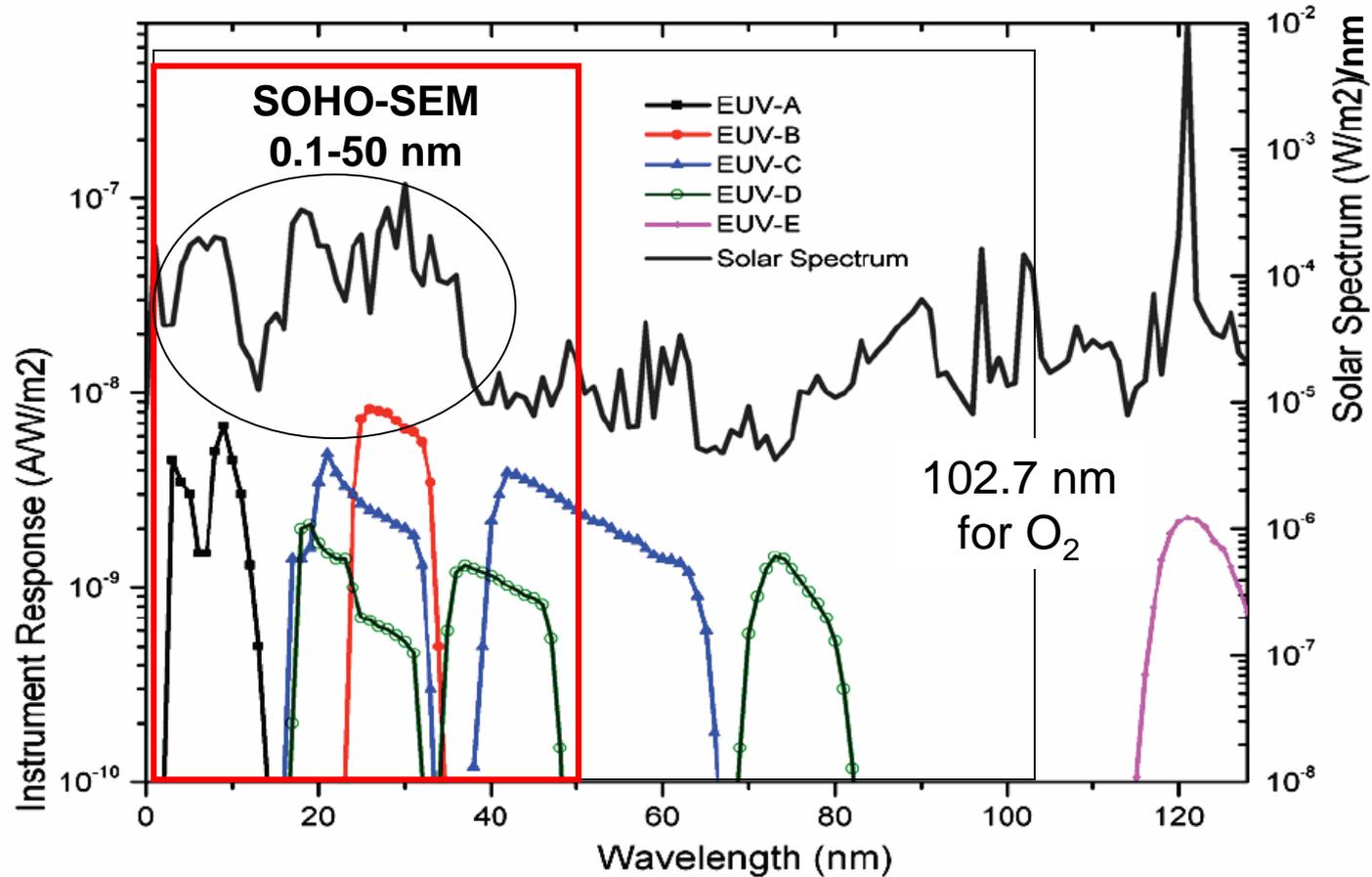
Range of Diurnal Variation of Geomagnetic East Component



Because the standard deviation and the number of stations for each year are known we can compute the 1- σ standard error of the mean

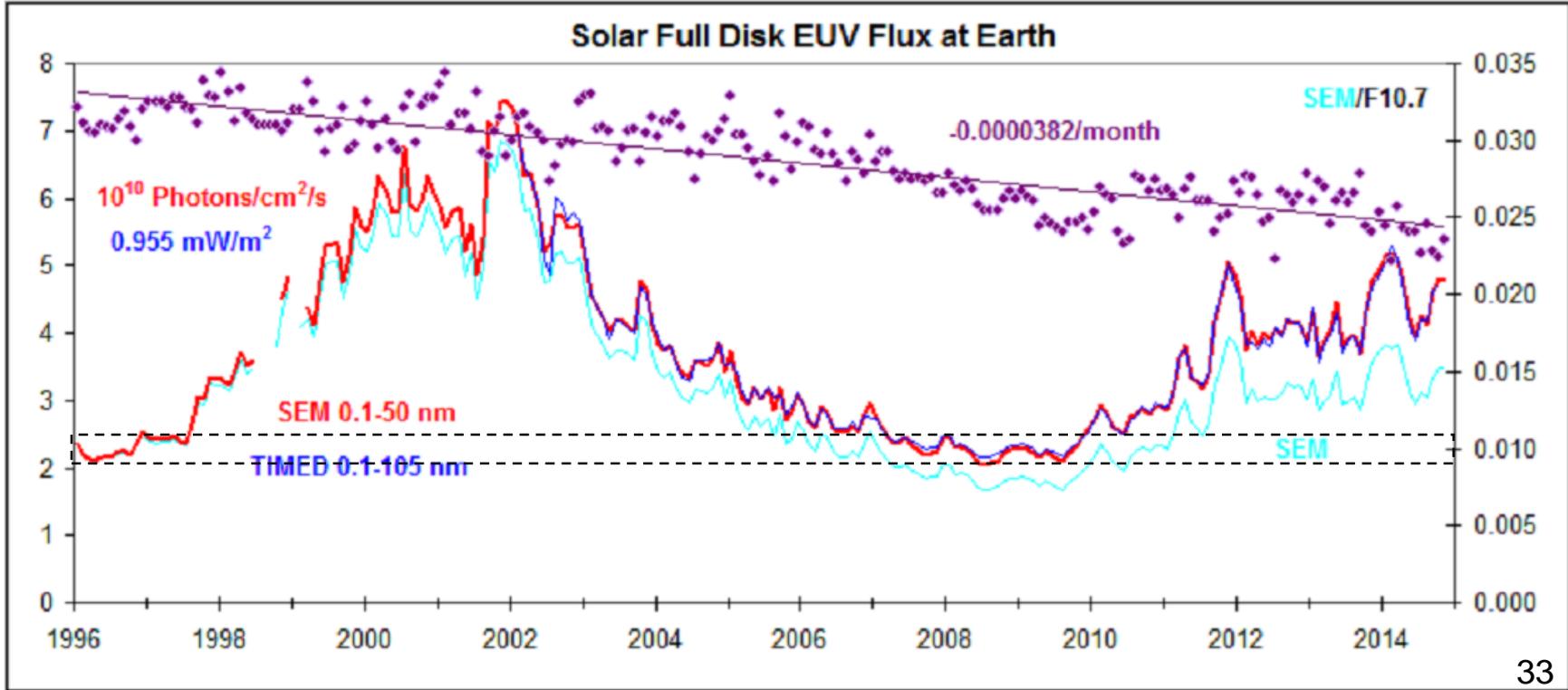
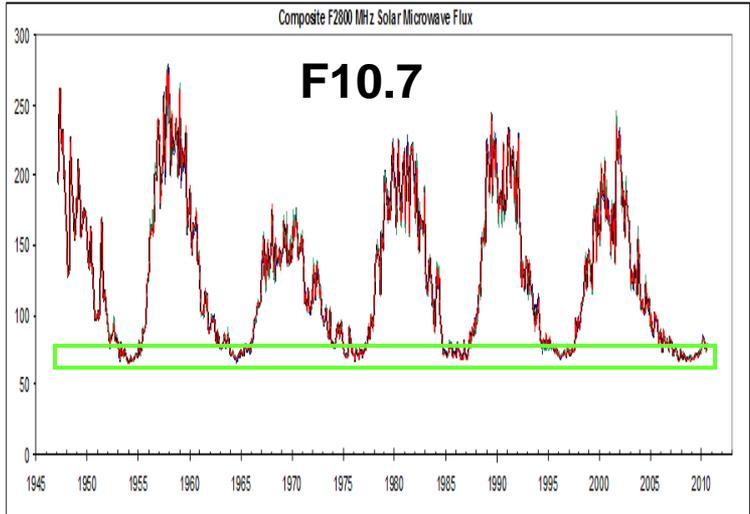
EUV Bands and Solar Spectrum

Most of the Energetic Photons are in the 0.1-50 nm Band

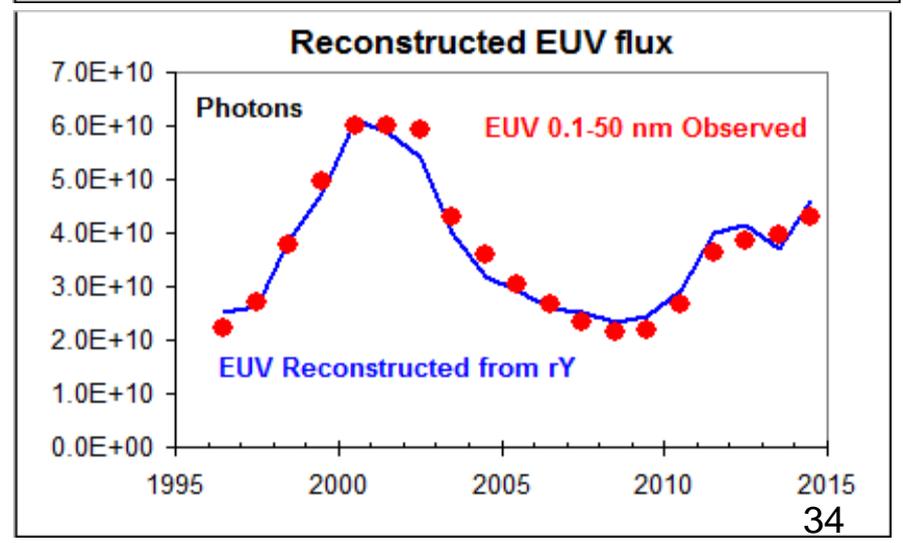
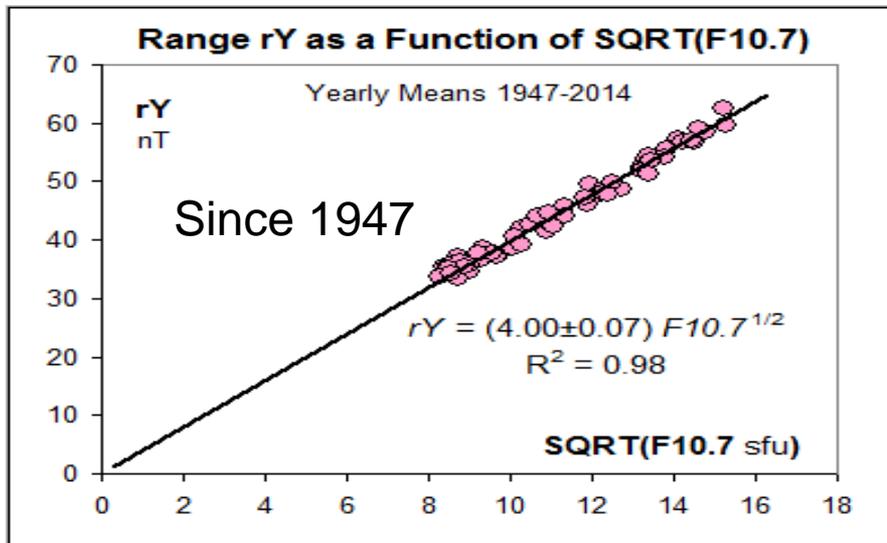
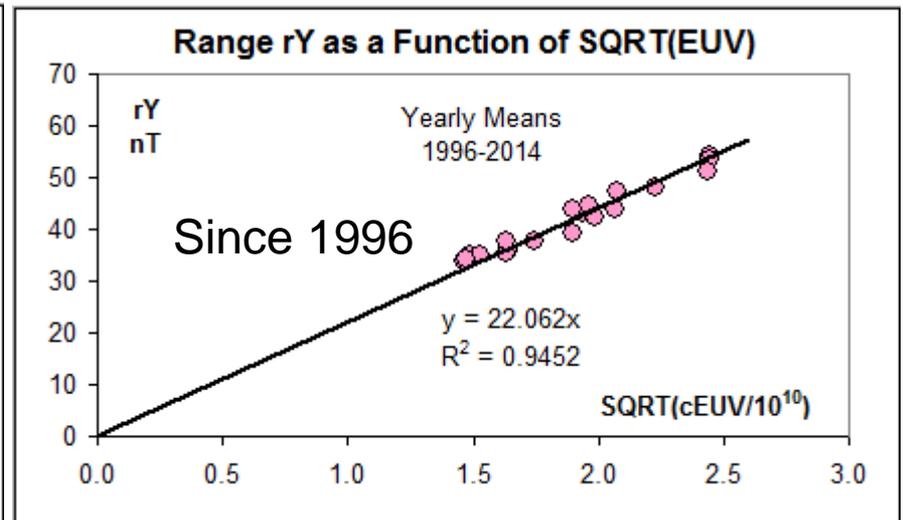
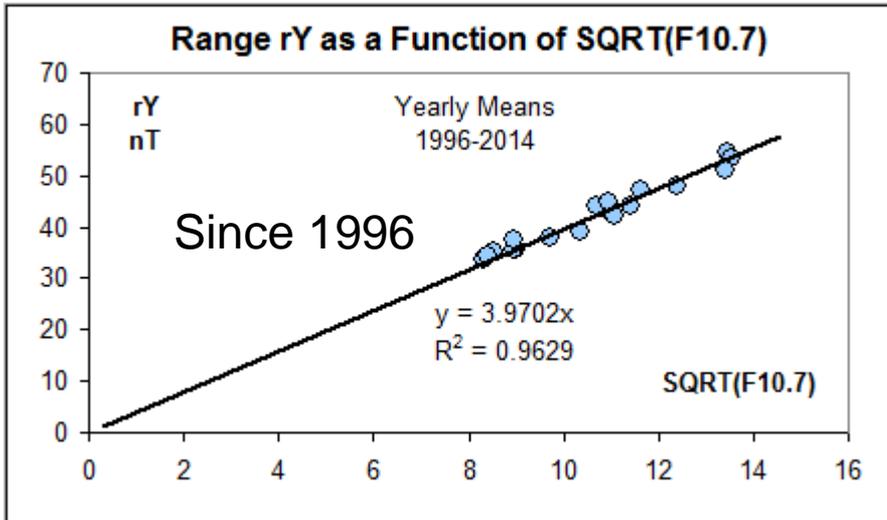


EUV and its proxy: F10.7 Microwave Flux (with 'floors')

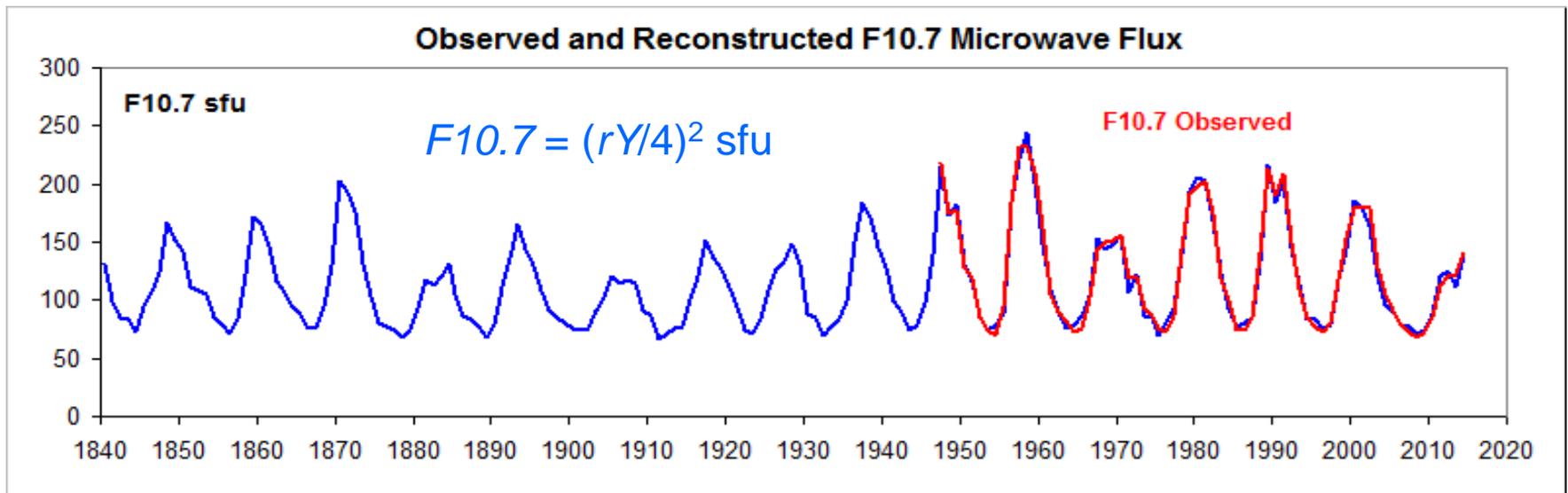
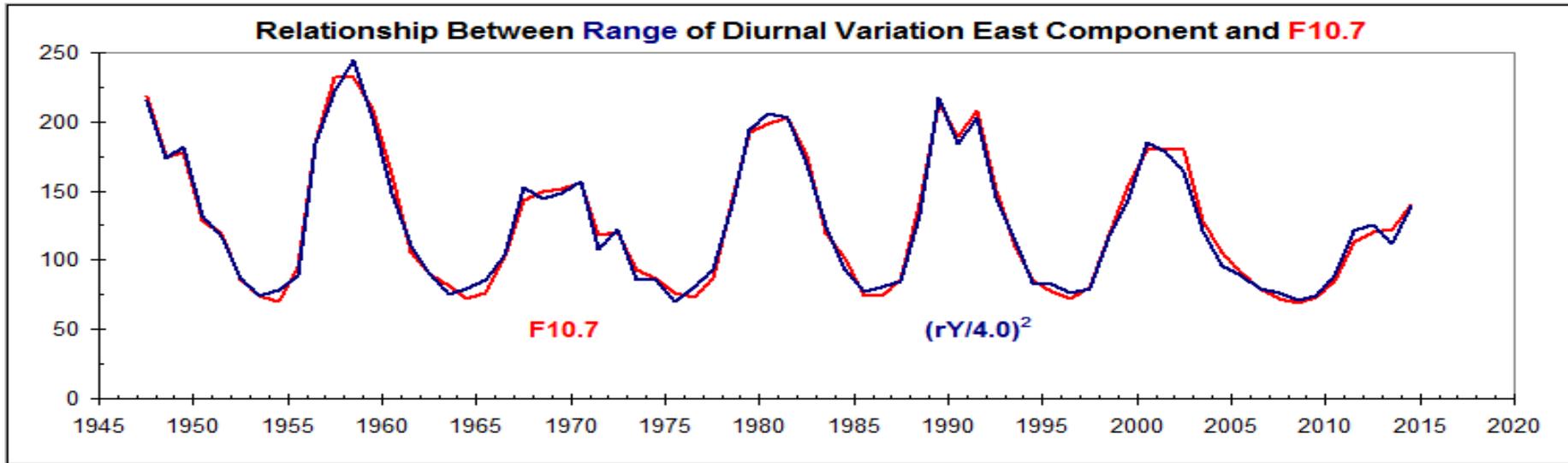
Space is a harsh environment:
Sensor Degradation



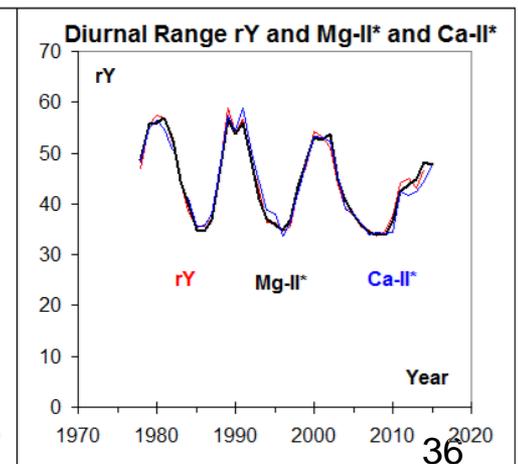
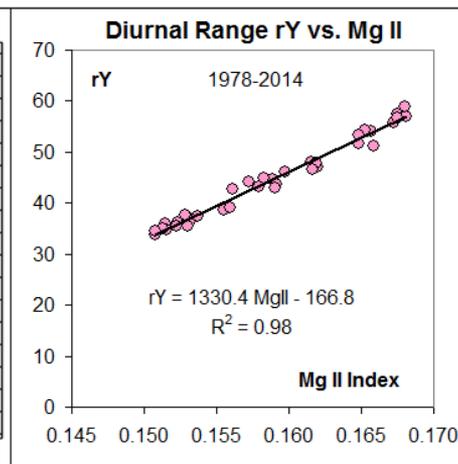
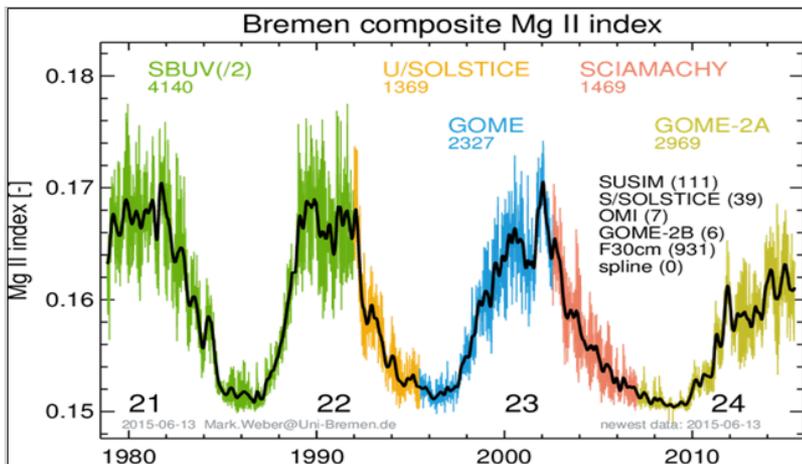
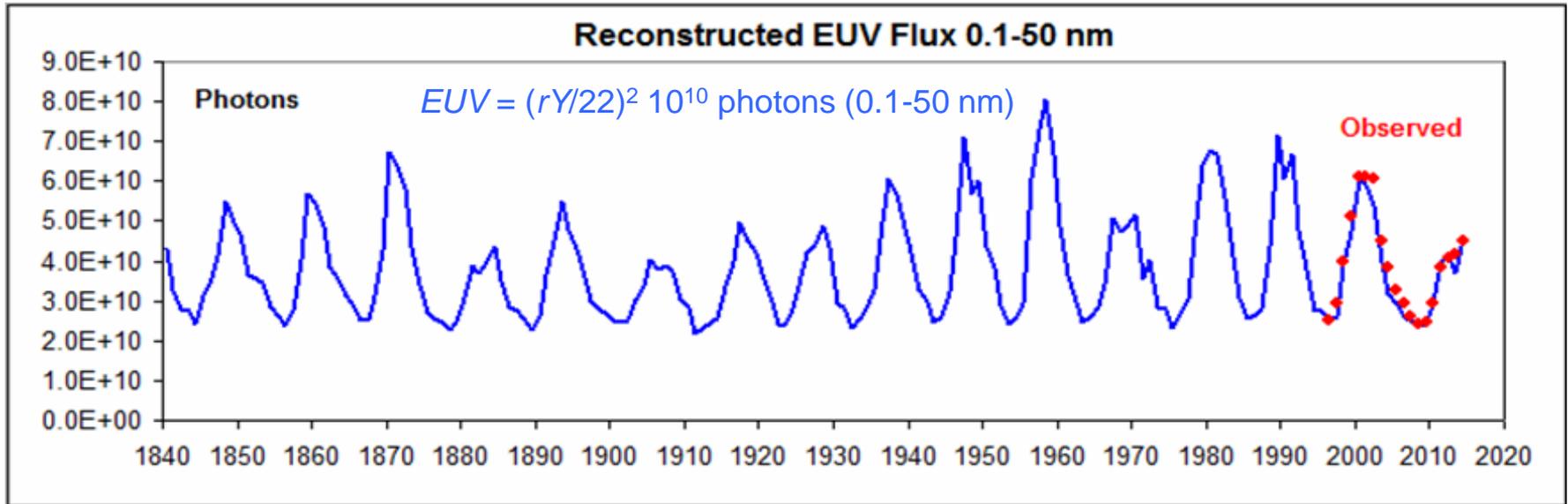
rY and $F10.7^{1/2}$ and $EUV^{1/2}$



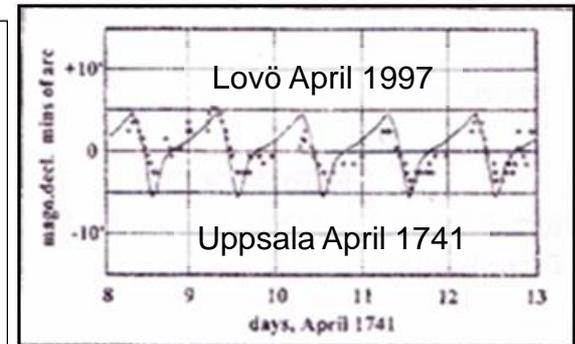
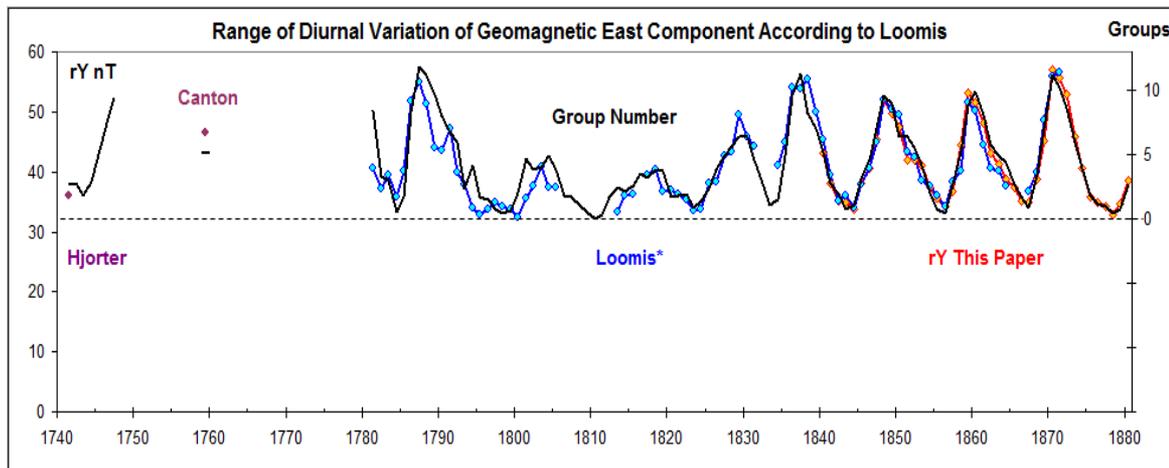
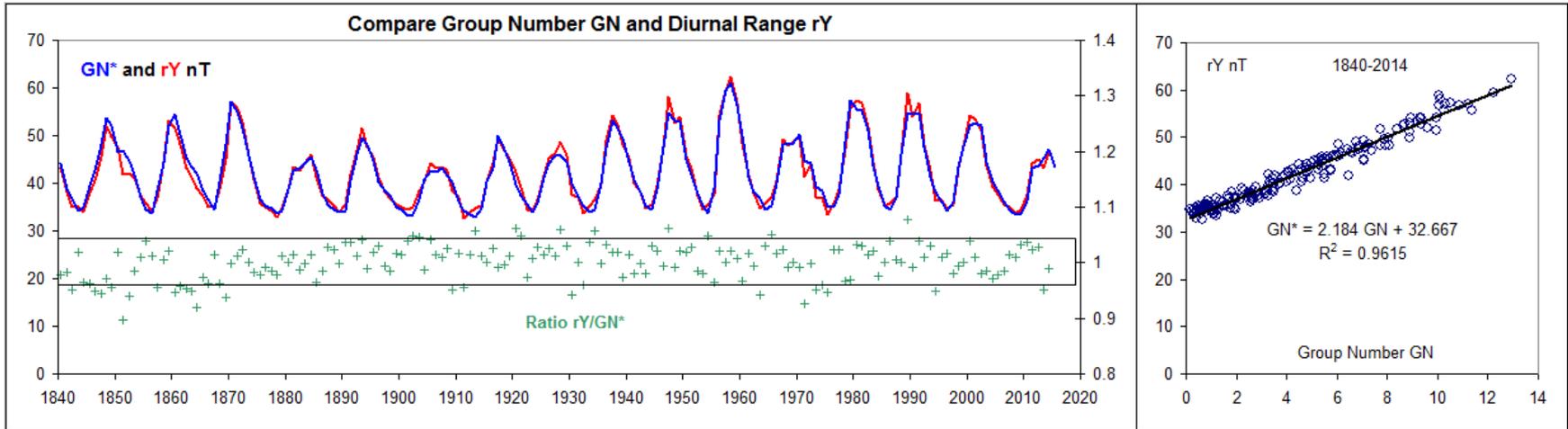
Reconstructed F10.7 (an EUV proxy)



Reconstructed EUV-UV



Range rY matches Group Number well and can be taken back to 1741

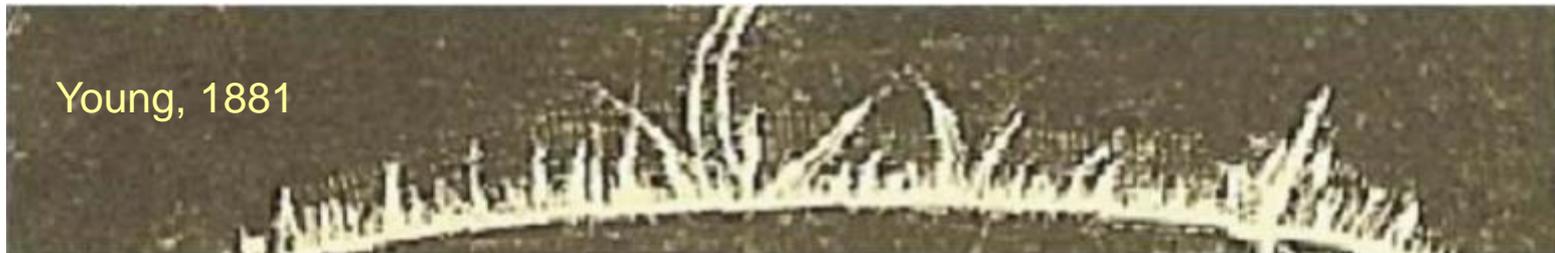


**Olof Hjorter
1741-1747**

Diurnal Ranges from Loomis (1870, 1873)

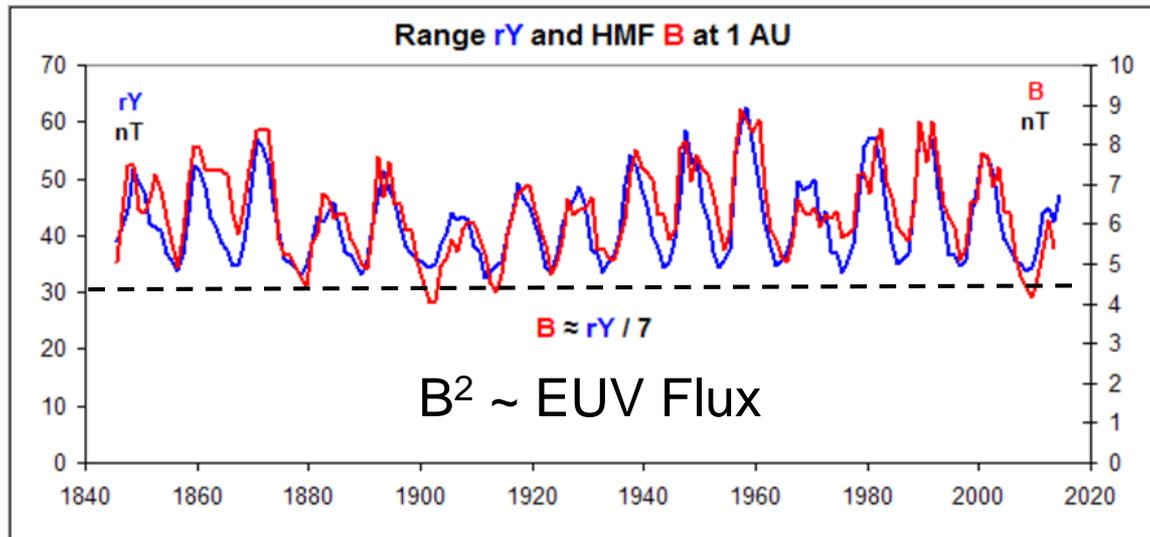
Ever-Present Basal Network?

- The constant $2.5 \cdot 10^{10}$ photons/cm²/sec EUV flux in the 0.1-50 nm wavelength range inferred for every sunspot minimum the past 235 years appears to be a 'basal' flux, present even when visible solar activity has died away
- The lack of any variation of this basal flux suggests that the flux (and the network causing it) is always there, presumably also during Grand Minima
- If the magnetic network is always present, this means that a chromosphere is also a permanent feature, consistent with the observations of the 'red flash' observed during the 1706 and 1715 solar eclipses (Young, 1881). This is, however, a highly contentious issue (e.g. Riley *et al.*, 2015), but one of fundamental importance



Connection with the Heliospheric Field

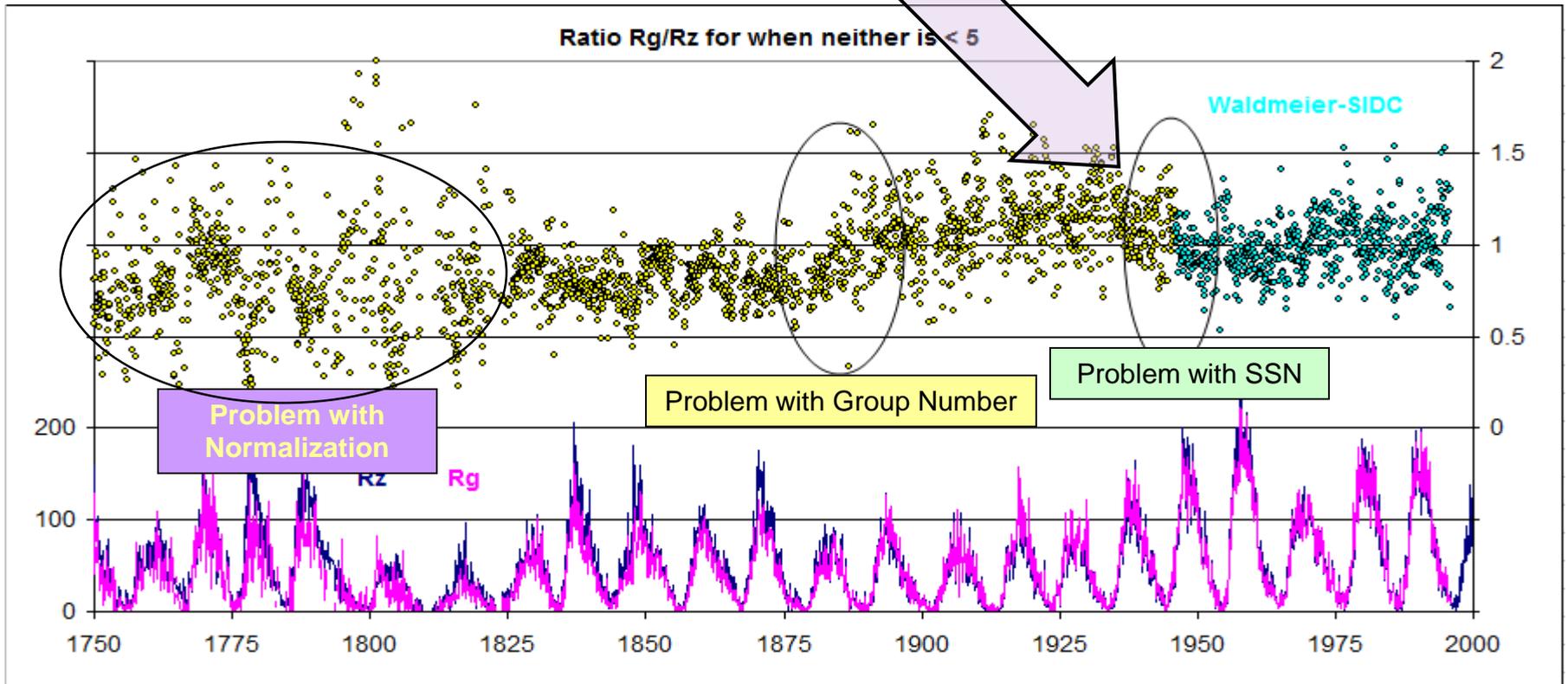
As the magnetic field in the solar wind (the Heliosphere) ultimately arises from the magnetic field on the solar surface filtered through the corona, one would expect an approximate relationship between the network field and the Heliospheric magnetic field, the latter now firmly constrained (Svalgaard, 2003, 2015). Here is a comparison of the rY proxy for the EUV flux from the surface network magnetic field structures, connected in the higher solar atmosphere to the coronal magnetic field, and then carried out into the Heliosphere to be observed near the Earth:



Assuming that the EUV flux results from release of stored magnetic energy and therefore scales with the energy of the network magnetic field (B^2), we can perhaps understand the correspondence between the Heliospheric field and the network field.

Again we are faced with the puzzle that there seems to be a 'floor' in both and with the question what happens to this floor during a Grand Minimum

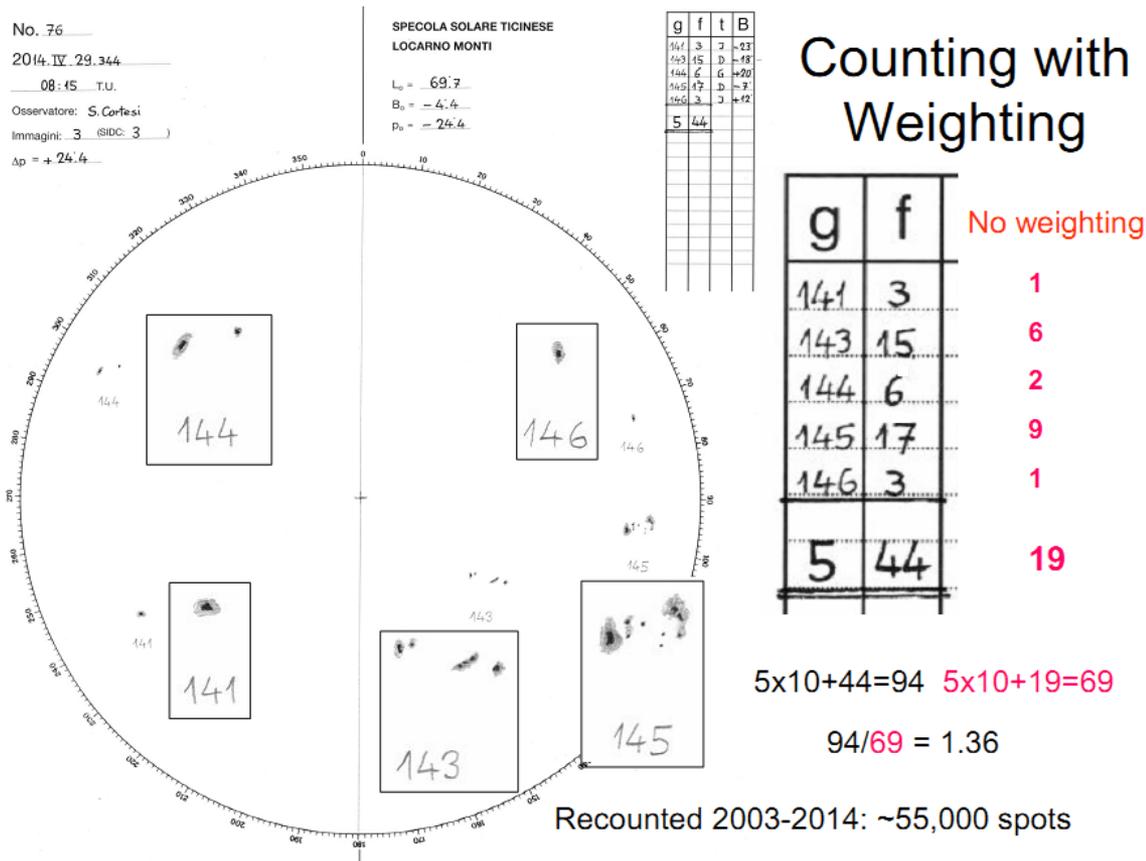
Remember This Slide?



At ~1947 (After Max Waldmeier took over) and at 1876-1910 (Greenwich calibration drifting)

We now seek to find out what caused the discontinuity in 1947

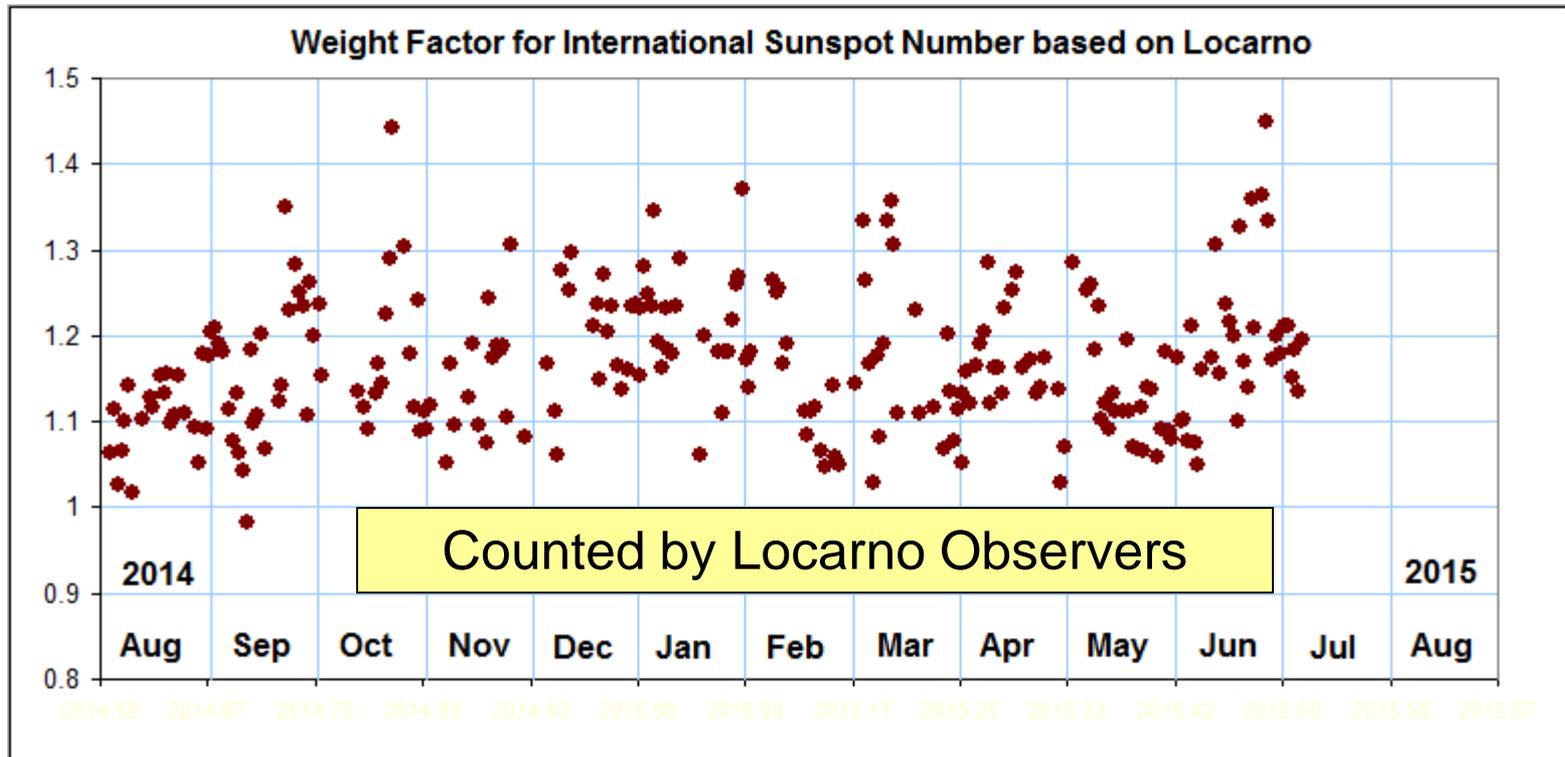
In 1940s Waldmeier in Zürich began to 'weight' larger spots and count them more than once



Weighting Rules: “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.

When the auxiliary station ‘Locarno’ became operational in 1957 they adopted the same counting rules as Zürich and continue to this day 41

Weighting increases the Sunspot Number by a 'Weight Factor'

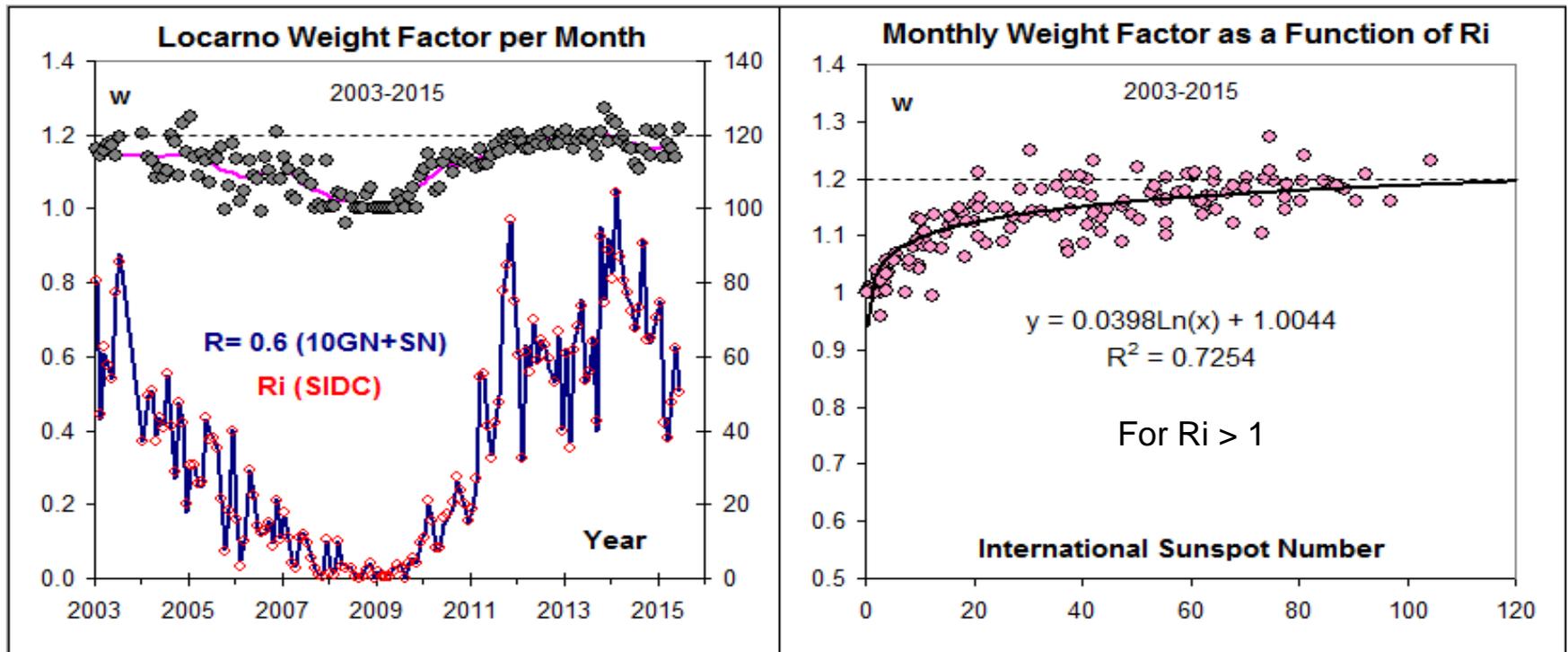


Weighted SSN = $10 * GN + \text{weighted SN}$

Unweighted SSN = $10 * GN + \text{actual real SN}$

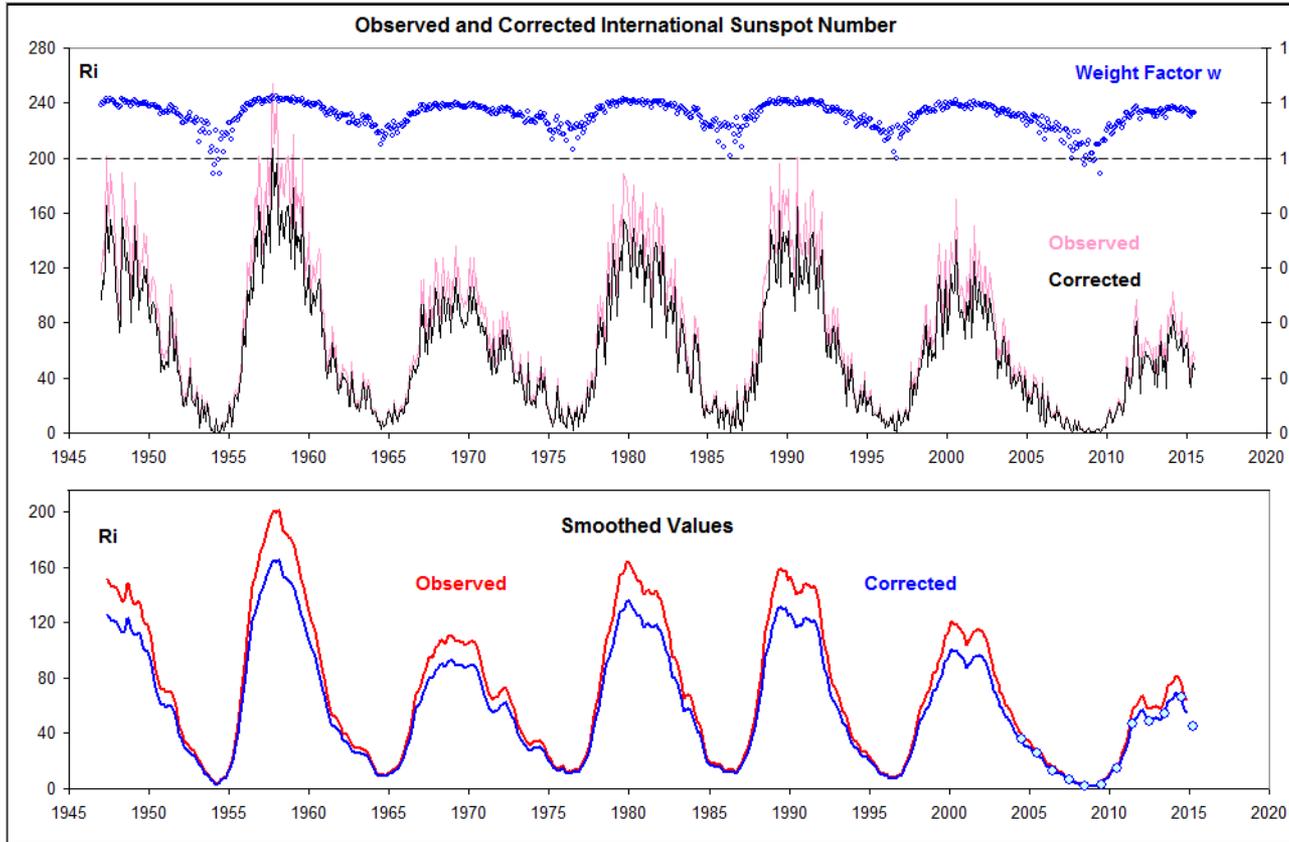
Weight Factor = $\text{Weighted SSN} / \text{Unweighted SSN}$

The Weight Factor Varies a bit with Activity Level (not surprisingly)

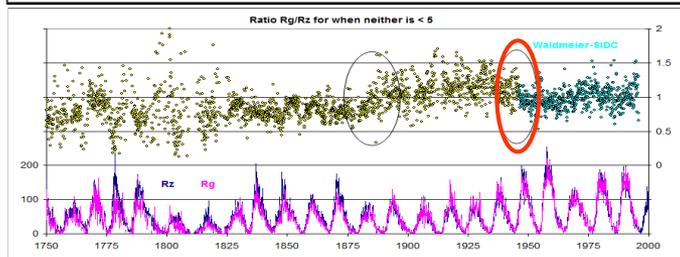


We can use the empirical relationship to remove the effect of weighting, at least statistically, on a monthly basis

SSN with/without Weighting

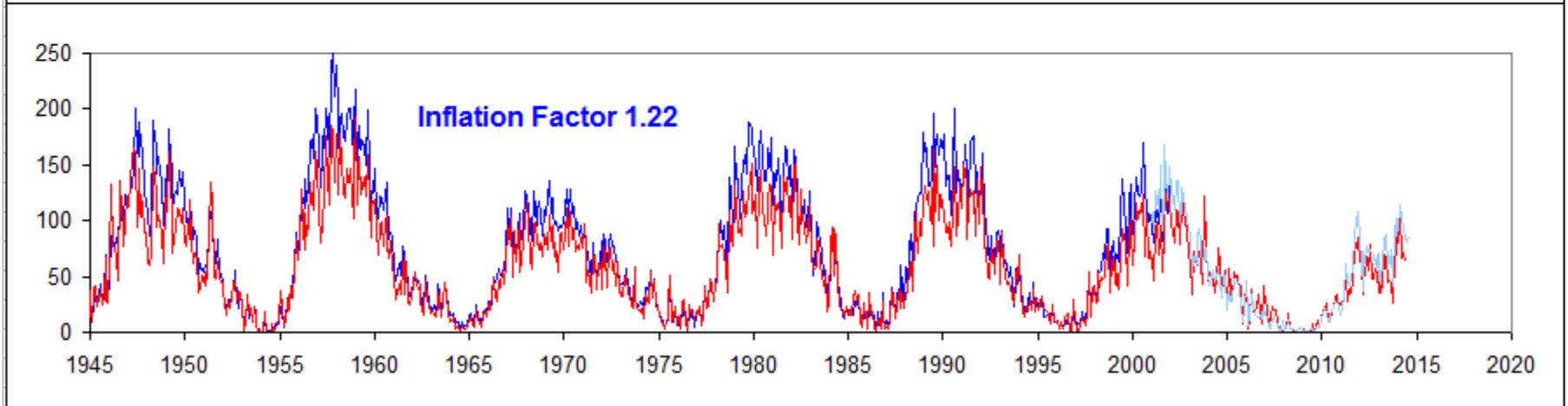
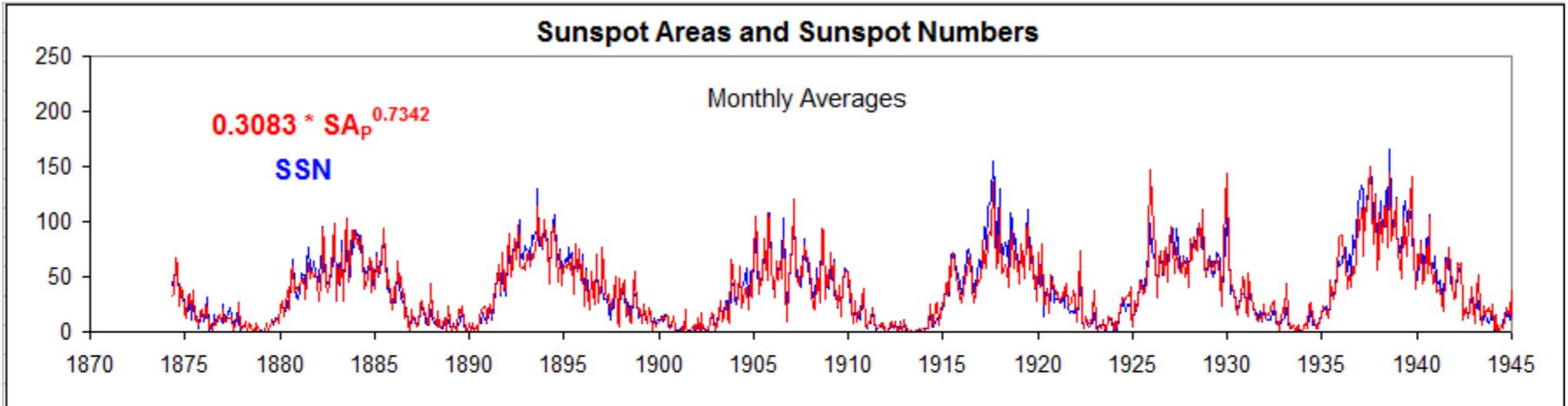
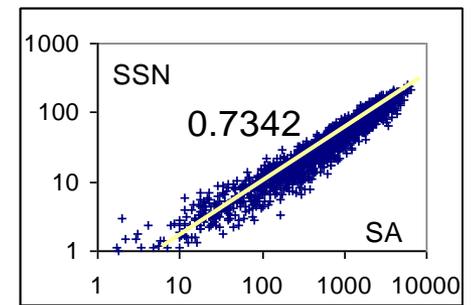


Light blue dots show yearly values of un-weighted counts from Locarno, *i.e.* not relying on the weight factor formula. The agreement is excellent



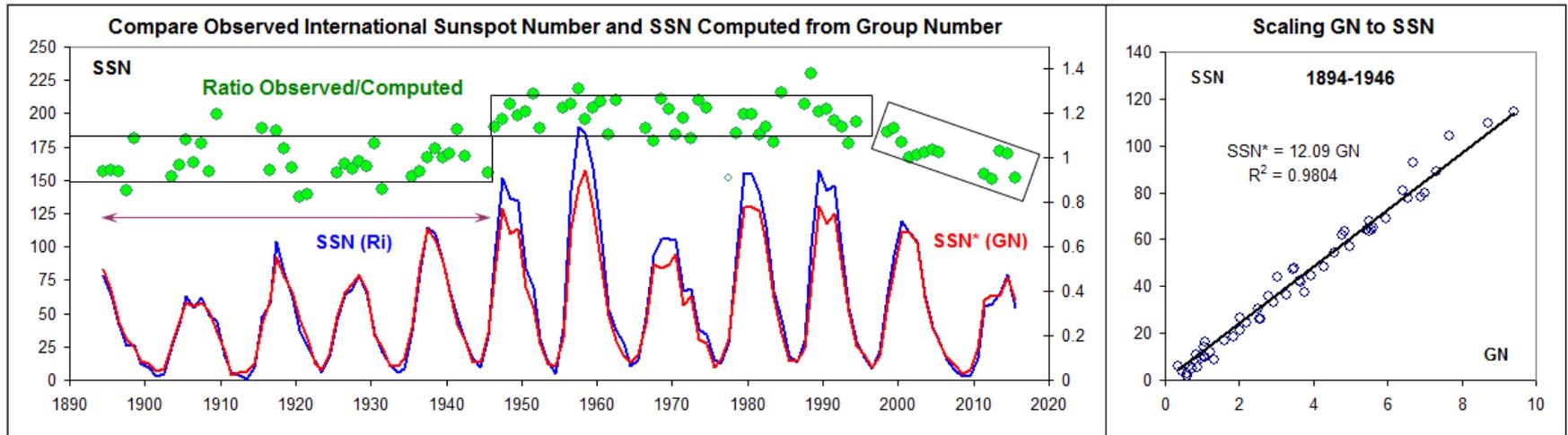
The inflation due to weighting explains the second anomaly

Sunspot Area and SSN



Computing the SSN from the Sunspot Area [SA] requires a larger scale factor from 1947 on

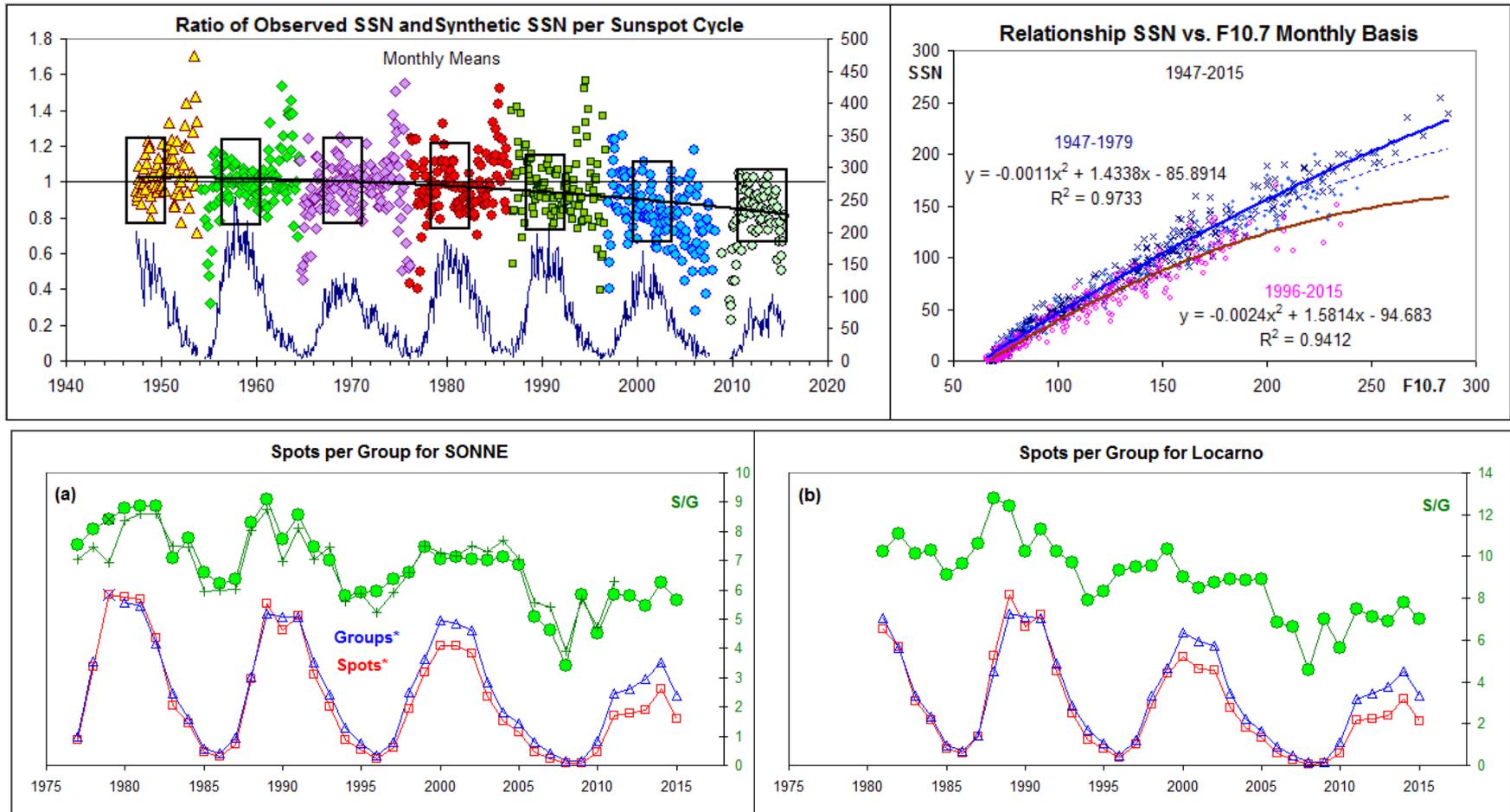
Comparing Groups and Sunspot Numbers



We can also see the effect of Weighting as the difference between the blue and red curves, indicated by the 'boxes' around values (green dots) of the ratio between the 'observed' International Sunspot Number and that scaled from the Group number.

Then what is happening in the slanted box since ~1995?

The Number of Spots per Group is Decreasing and that Skews the SSN

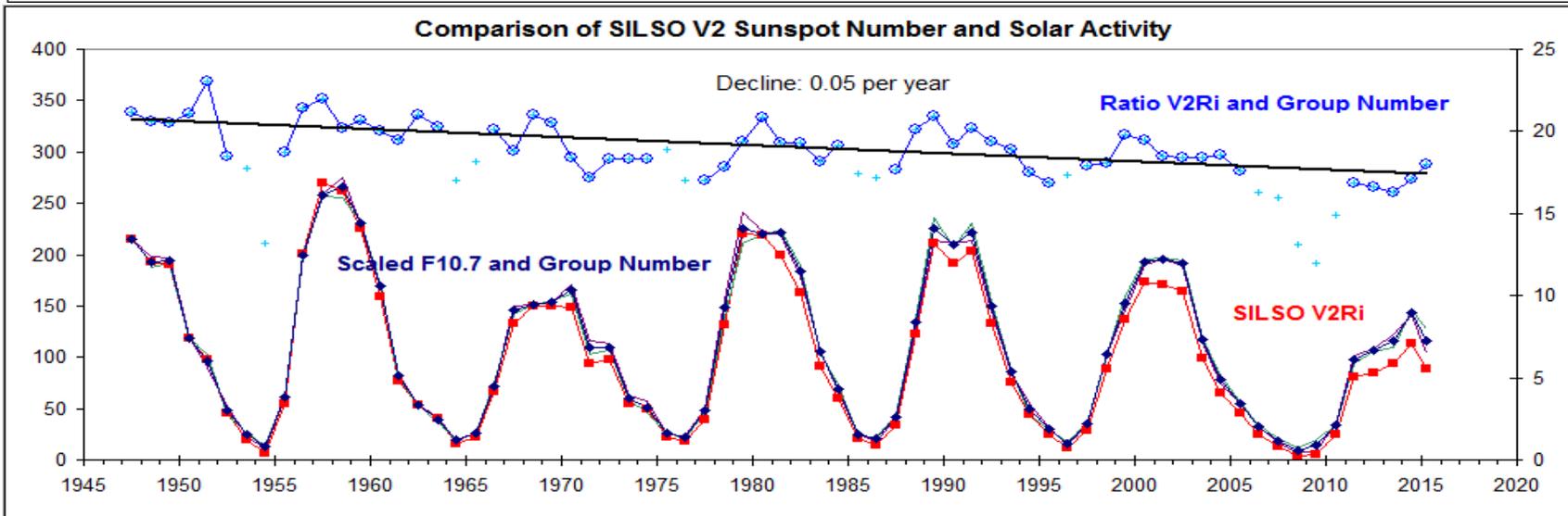
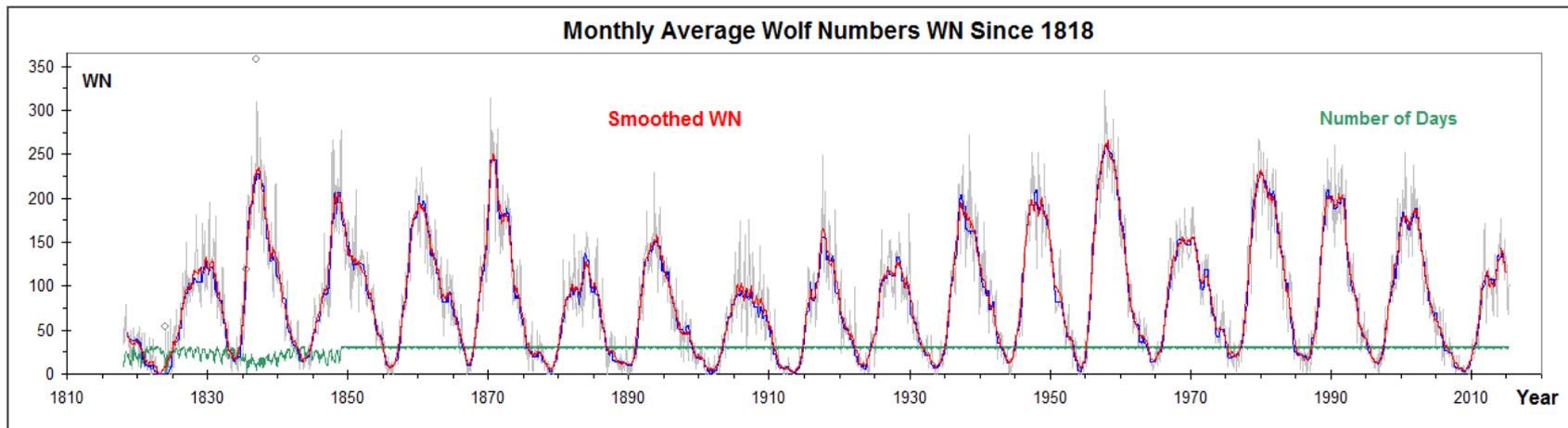


If the smallest spots are disappearing, the SSN will be affected but F10.7, EUV, Sunspot Areas, TSI(?) and such other indices will not be as much

Does Building a Relative Sunspot Number Make Sense? A Qualified 'Yes' (A personal view)

- Our Users want a single series. What to give them?
- The Group Number? That correlates very well with other solar indices (F10.7, EUV, TSI, Areas)
- The SSN afflicted with a decreasing spot/group ratio? That no longer correlates or where the correlation is changing over time making long-term comparisons difficult
- I propose a compromise (the Wolf Number), namely to adjust the daily SSN such that it maintains a constant ratio with the Group Number (e.g. on a yearly basis)
- In any event the 'raw' [and also published] data will be GN = the number of groups and SN = the number of [unweighted] spots.
- Needless to say there will be opposition to this, but there is always opposition to *anything* new.

So, here is the Wolf Number (replacing Caution with Courage)

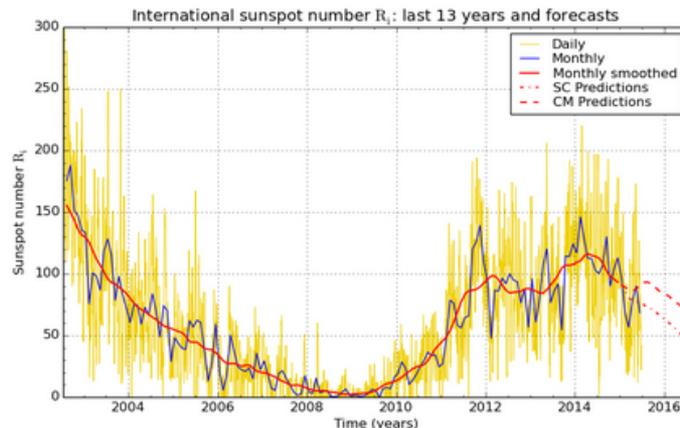


V2Ri is the New Series on the WDC/SILSO website

World Data Center for the production, preservation and dissemination of the international sunspot number

Major change of data set on July 1st, 2015: key information

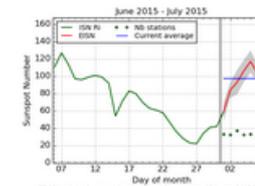
Sunspot number series: latest update



SILSO graphics (<http://sidc.be/silso>) Royal Observatory of Belgium 2015 July 1

Latest Sunspot Bulletin

Daily estimated sunspot number



EISN DATA FILES

- 03 July : 93
- 04 July : 106
- 05 July : 117
- 06 July : 104
- 07 July : 117

Latest USET observations (ROB, Brussels) 07/07/2015



This is a major (and long-needed) advance.

The result of hard work by many people.

A Topical Issue of 'Solar Physics' is devoted to documenting, discussing, opposing, and criticizing the new series.

We have a SOI of ~55 papers as of today.

Transition to the new Sunspot Number successfully completed

Today marked a triple transition for us:

- Uploading the new Sunspot Number archive files containing the daily, monthly and yearly re-calibrated sunspot numbers and the new Group Number series
- In our Web site, switching to the new "Data" pages giving access to the new files, to updated graphics and also to the past version of the Sunspot Number
- Adapting and running the entire monthly procedure to produce the provisional Sunspot Numbers for June 2015 and the associated 12-months forecast and EISN.

Thus a lot of work in a single day for our small team.



Sunspot Index and Long-term Solar Observations

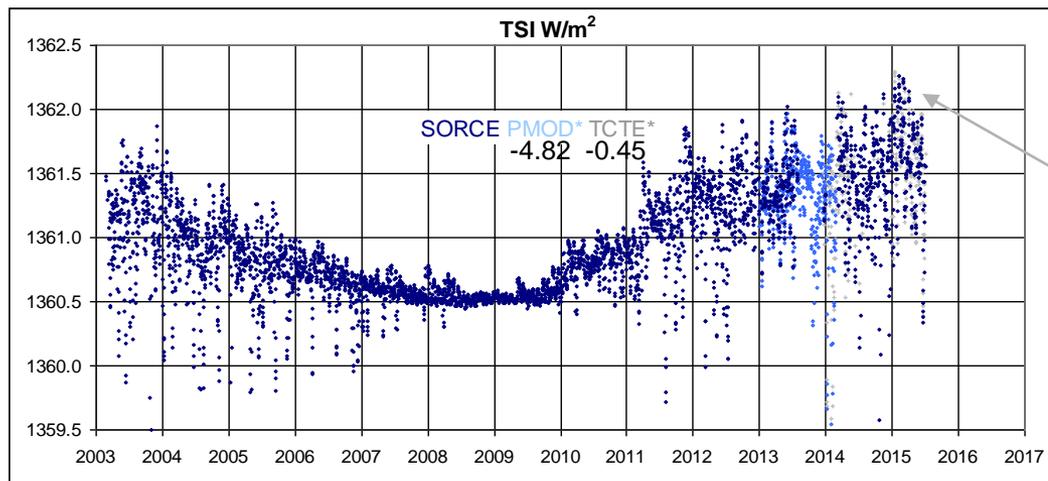
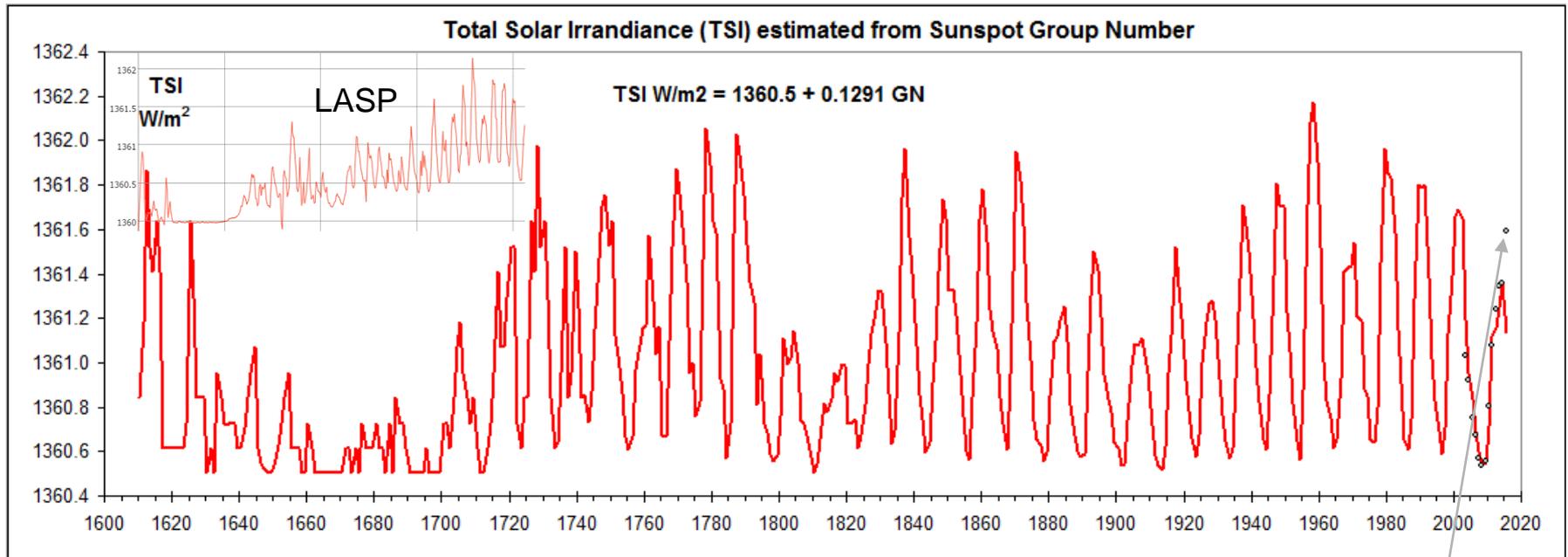
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New SSN = Old SSN / 0.6

What is Next? TSI? Cosmic Ray Proxies? Climate???



Scaling Group Number to
SORCE+PMOD+TCTE TSI
without variable Background.
Most prominent feature is that
**there is no Modern Grand
Maximum**

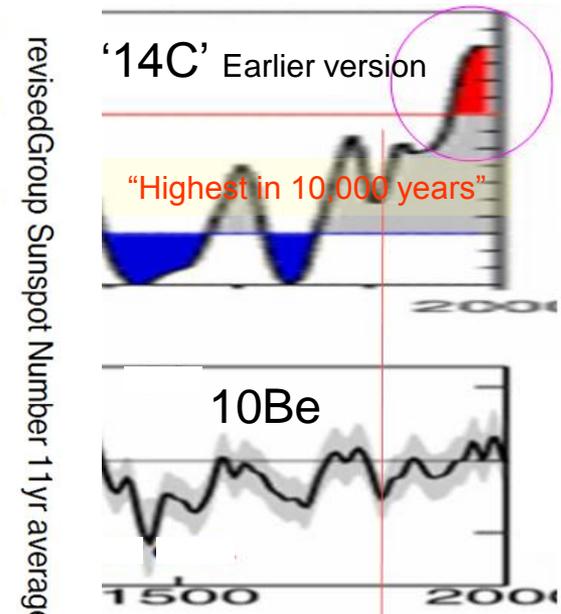
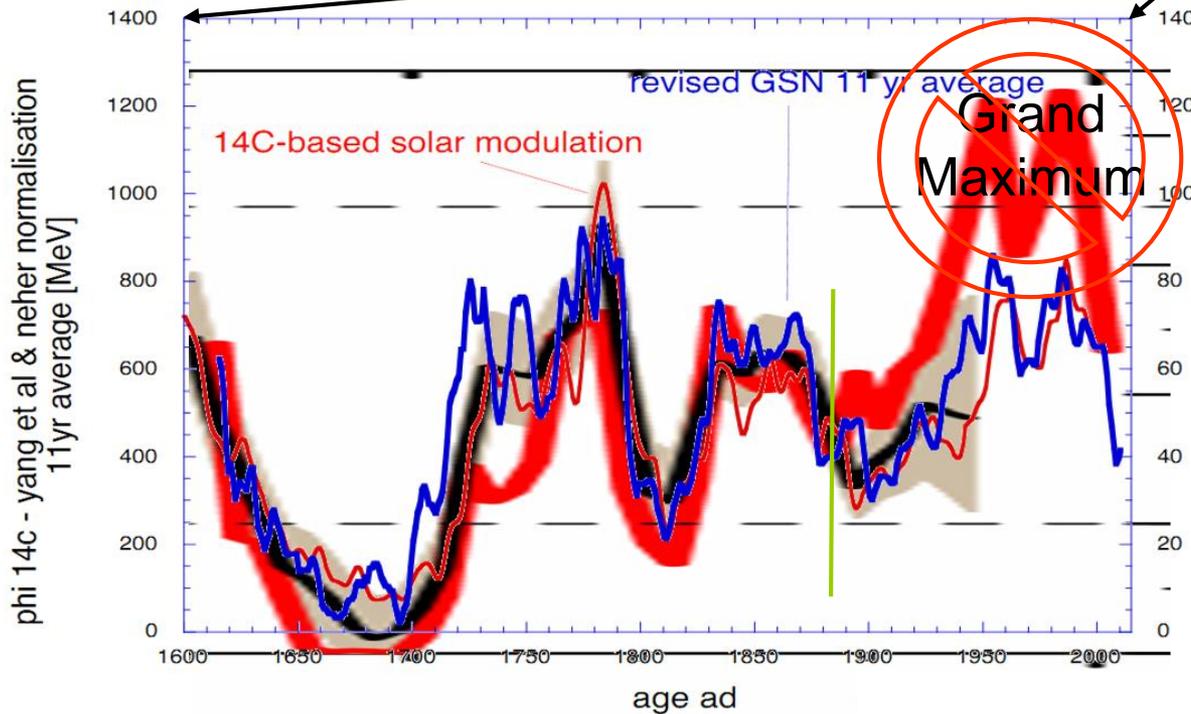
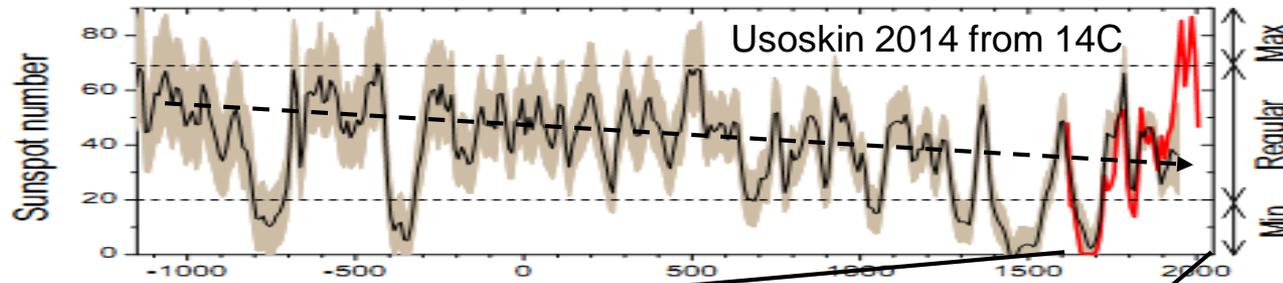
Why is 2015 TSI so high?

Opposition and Rearguard Action

As Jack Harvey (3rd SSN Workshop, Tucson 2013) pointed out:

It's ugly in there!

Solar activity has generally been decreasing the last ~3000 years



Muscheler (thin red line) and Usoskin's (black line) 14C values are aligned

The non-existing Grand Modern Maximum is not based on 14C, but on the flawed H & S Group Number reconstruction and is not seen in 10Be data 52

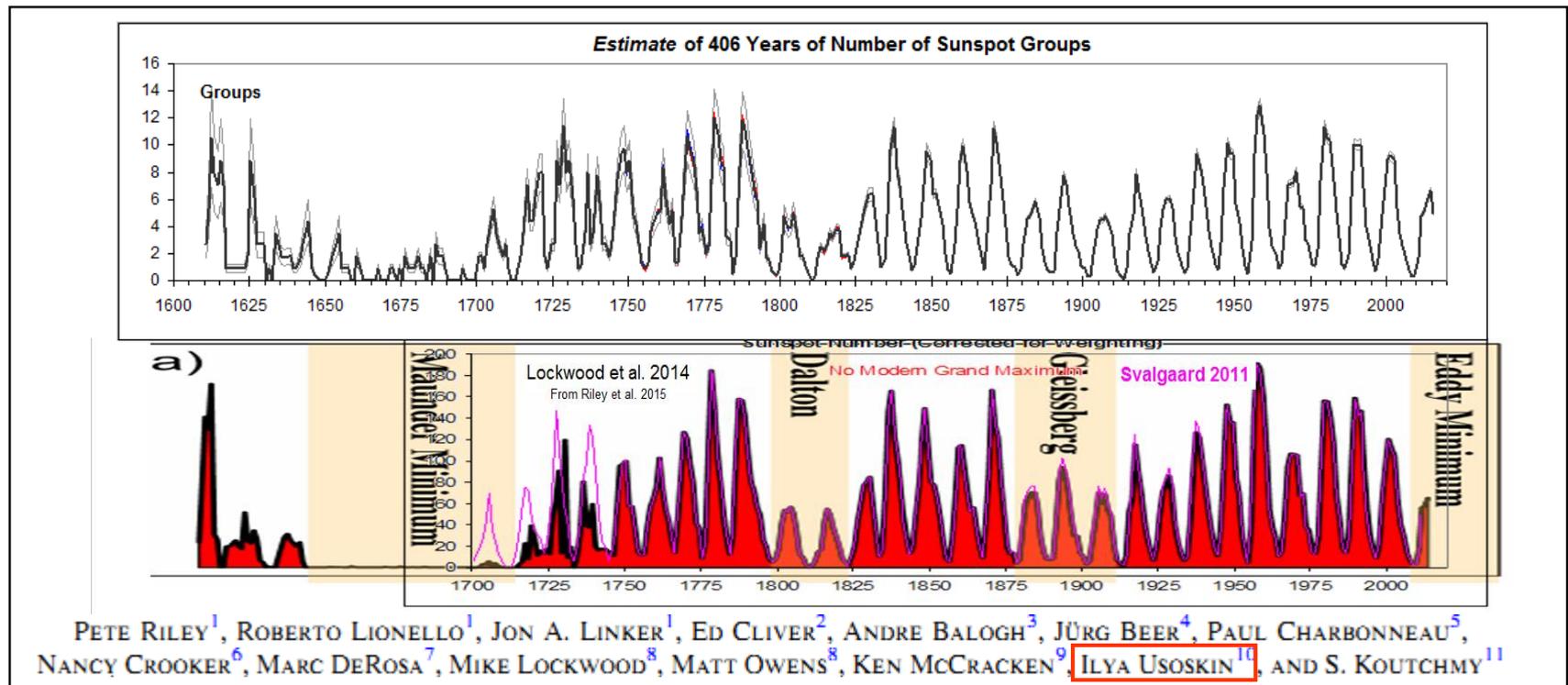
Opposition and Rearguard Action

As Jack Harvey (3rd SSN Workshop, Tucson 2013) pointed out:

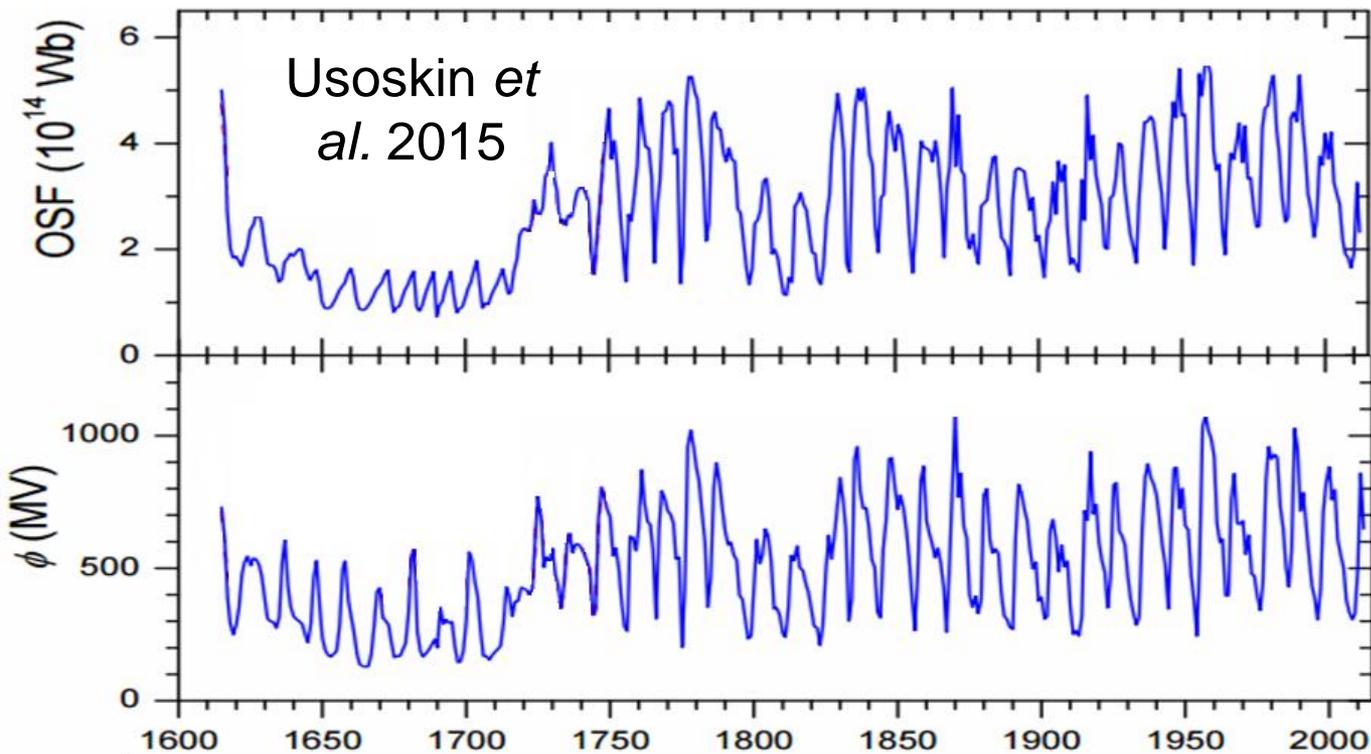
It's ugly in there!



There was a Seminar at HAO a week ago (7/14 by Usoskin):
presenting the Modern Grand Maximum as an 'Observational Fact'



These illustrious authors seem to advocate a series very close to ours

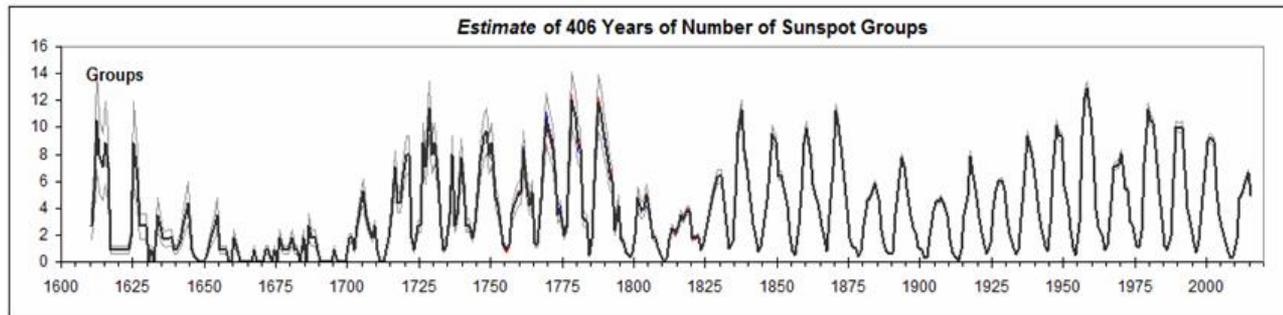


Usoskin *et al.* 2015

The open solar magnetic flux (OSF) is the main heliospheric parameter driving the modulation of cosmic rays.

The OSF has been modeled by quantifying the occurrence rate and magnetic flux content of coronal mass ejections fitted to geomagnetic data.

The OSF and the cycle-variable geometry of the heliospheric current sheet allows reconstruction of the cosmic ray modulation potential, ϕ .



Reconciliation !
'This just in'

Ilya G. Usoskin, Rainer Arlt, Eleanna Asvestari, Ed Hawkins, Maarit Käpylä, Gennady A. Kovaltsov, Natalie Krivova, Michael Lockwood, Kalevi Mursula, Jezebel O'Reilly, Matthew Owens, Chris J. Scott, Dmitry D. Sokoloff, Sami K. Solanki, Willie Soon, and José M. Vaquero, *Astronomy & Astrophysics*, July 21, 2015

Conclusions

- Both the International Sunspot Number and the Group Sunspot Number had serious errors
- Correcting the errors reconciles the two series
- The new *pure* solar series are confirmed by the geomagnetic records and by the cosmic ray records
- There is no **Grand** Modern Maximum, rather several similar maxima about 120 years apart
- There is much more work to be done:
“Hoc opus, hic labor”

Abstract

The New Sunspot Series, Methods, Results, Implications, Opposition

We have reconstructed the sunspot group count, not by comparisons with other reconstructions and correcting those where they were deemed to be deficient, but by a re-assessment of original sources. The resulting series is a pure solar index and does not rely on input from other proxies, e.g. radionuclides, auroral sightings, or geomagnetic records. ‘Backboning’ the data sets, our chosen method, provides substance and rigidity by using long-time observers as a stiffness character. Solar activity, as defined by the Group Number, appears to reach and sustain for extended intervals of time the same level in each of the last three centuries since 1700 and the past several decades do not seem to have been exceptionally active, contrary to what is often claimed.

Solar Extreme Ultraviolet (EUV) radiation creates the conducting E-layer of the ionosphere, mainly by photo ionization of molecular Oxygen. Solar heating of the ionosphere creates thermal winds which by dynamo action induce an electric field driving an electric current having a magnetic effect observable on the ground, as was discovered by G. Graham in 1722. The current rises and sets with the Sun and thus causes a readily observable diurnal variation of the geomagnetic field, allowing us to deduce the conductivity and thus the EUV flux as far back as reliable magnetic data reach. High-quality data go back to the ‘Magnetic Crusade’ of the 1830s and less reliable, but still usable, data are available for portions of the hundred years before that. J.R. Wolf and, independently, J.-A. Gautier discovered the dependence of the diurnal variation on solar activity, and today we understand and can invert that relationship to construct a reliable record of the EUV flux from the geomagnetic record. We compare that to the F10.7 flux and the sunspot number, and find that the reconstructed EUV flux reproduces the F10.7 flux with great accuracy. On the other hand, it appears that the Relative Sunspot Number as currently defined is beginning to no longer be a faithful representation of solar magnetic activity, at least as measured by the EUV and related indices. The reconstruction suggests that the EUV flux reaches the same low (but non-zero) value at every sunspot minimum (possibly including Grand Minima), representing an invariant ‘solar magnetic ground state’.