In Defense of the Sunspot Number Revisions and their Implications

Jack Harvey (2013): "It is ugly in there"

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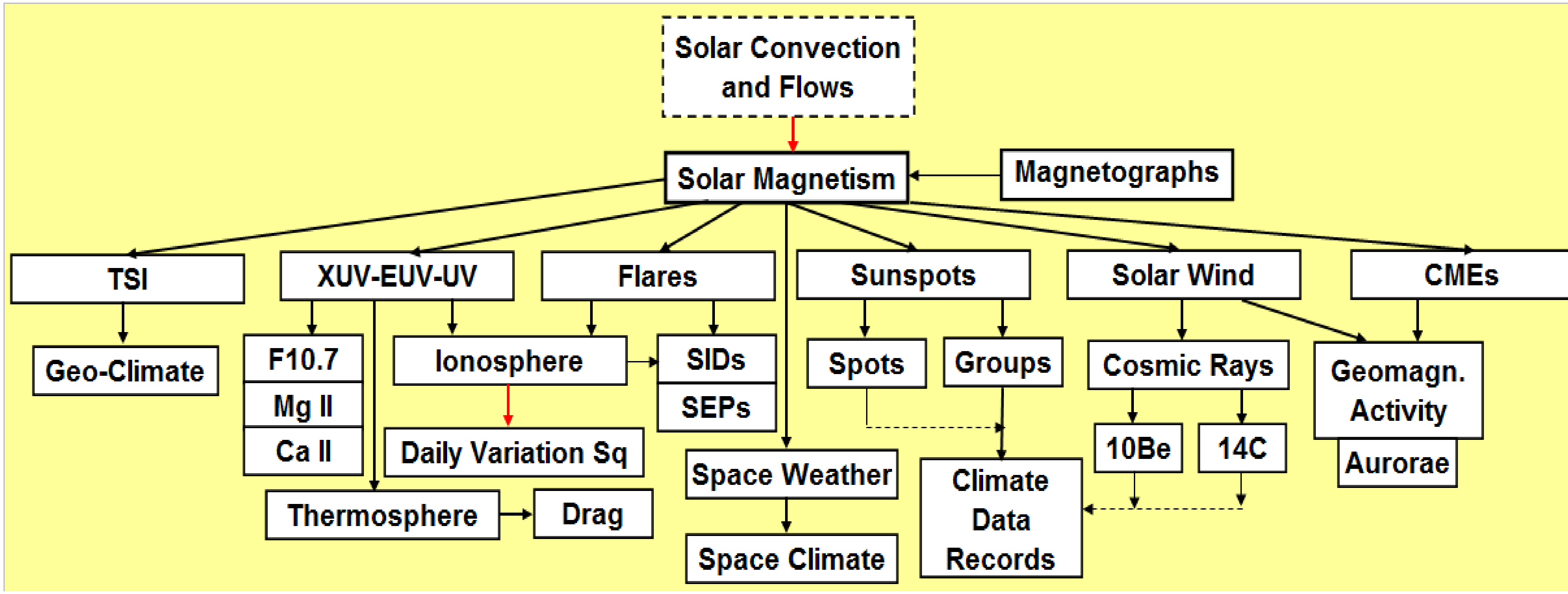
HAO, Boulder, CO

3 Aug. 2017

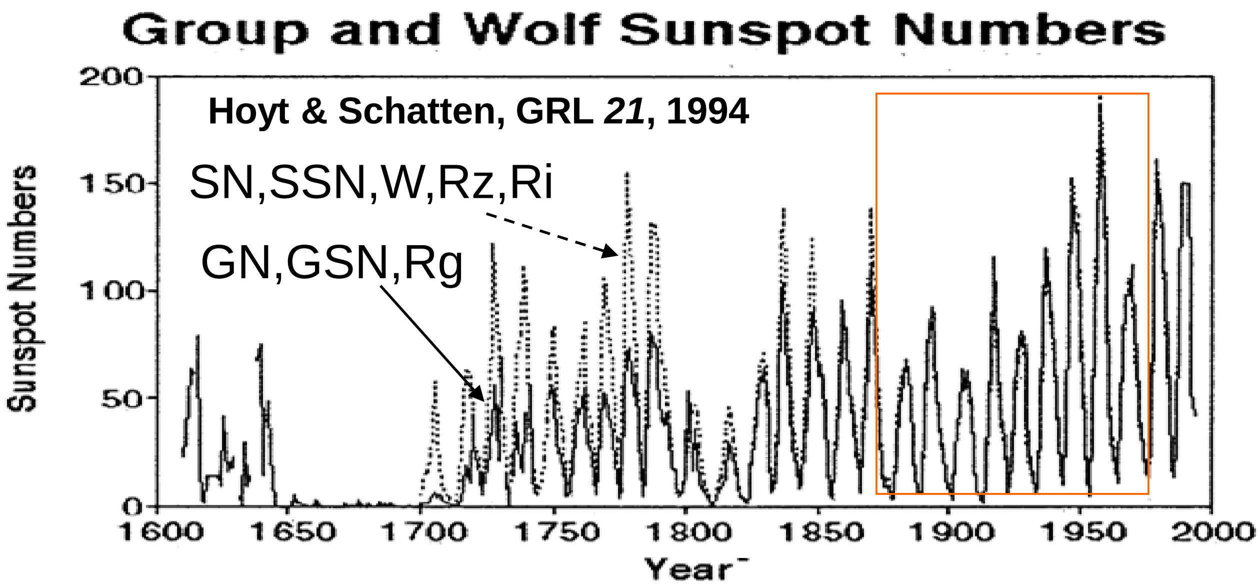
"Qui tacet consentire videtur."

A Systems Approach: Everything Must Fit



Faraday wrote to R. Wolf on 27th August, 1852: “I am greatly obliged and delighted by your kindness in speaking to me of your most remarkable enquiry, regarding the **relation existing between the condition of the Sun and the condition of the Earths magnetism**. The discovery of periods and the observation of their accordance in different parts of **the great system, of which we make a portion**, seem to be one of the most promising methods of touching the great subject of terrestrial magnetism...

The Problem: Two Very Different ‘Sunspot Series’. Which One to Use?



Original Wolf Number: W_o = Groups + 1/10 Spots

(‘1/10 Spots’ was assumed to be a measure of the area of the group)

Later streamlined to W = k (10 G + S)

The ‘k-factor’ was originally set to 1 for Wolf himself. Wolf did not count the smallest spots in order to be partly compatible with Heinrich Schwabe who used a smaller telescope. Wolf also counted a collection of spots within a common penumbra as just a single spot and thus did not take the structure and splitting of the umbra into account. His successor, Wolfer, argued that all spots should be counted, and found that [and adopted] a k-factor of 0.6 on his counts would put his Sunspot Numbers on Wolf’s scale, to maintain the homogeneity of the series. **This has been the cause of much confusion since**.

Hoyt & Schatten’s [H&S] GSN = 12 * G where the ‘12’ was chosen to make the GSN = W for the interval 1874-1976, so forcing an overall match with W for that.

A Proposed Solution for Reconciliation: The SSN Workshops (Failed its Goal)

Goal: Community-vetted and agreed-upon solar activity series

Example of the Failure of the SSN Workshops

M. Dasi-Espuig et al.: **Reconstruction of spectral solar irradiance since 1700 from simulated magnetograms,** Astronomy & Astrophysics, 2016:

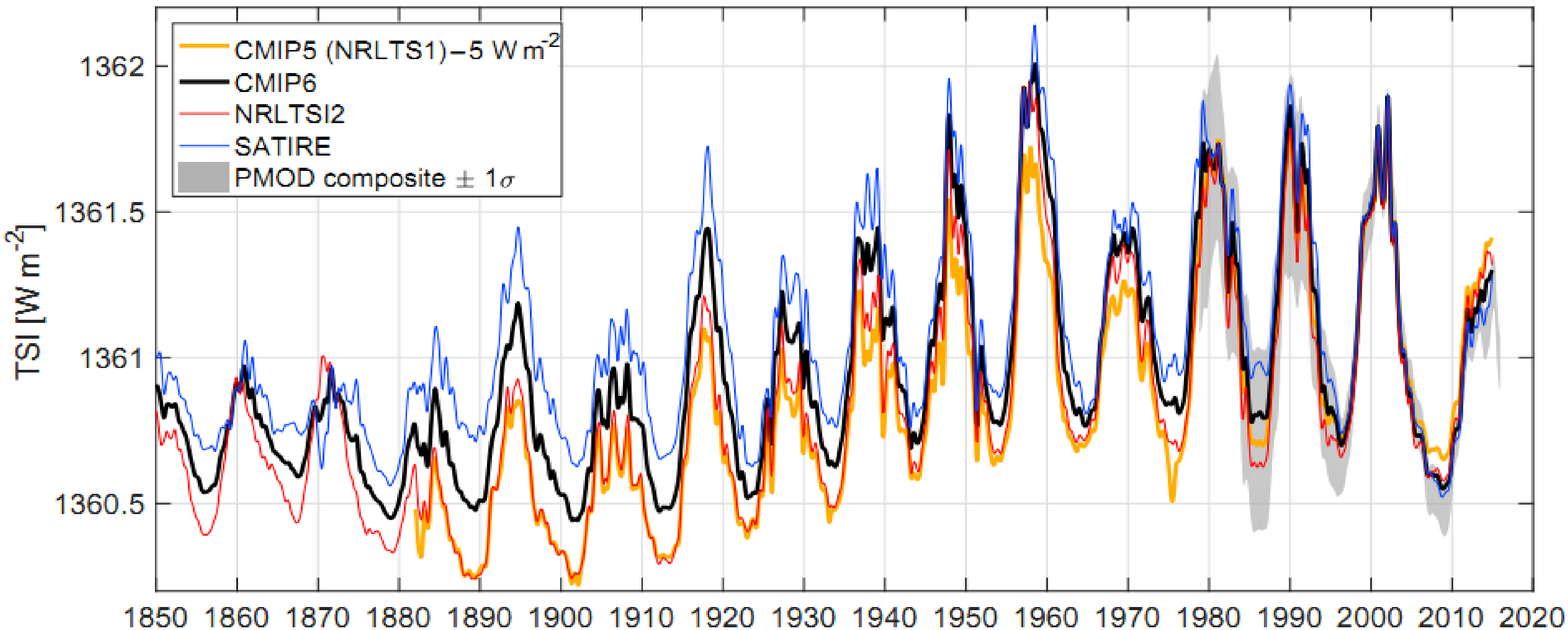
"The calibration of the sunspot numbers is currently in a state of flux. Clette et al. (2014) recently published a revised Rz and Rg record. Lockwood et al. (2014) compared the Rz to several other data sets to examine a possible calibration discontinuity around 1945, while additional independently corrected sunspot number series have been submitted (Usoskin et al. 2016; Svalgaard & Schatten 2015; Lockwood et al. 2016). For this reason **we decided to use in this paper the older and widely used data sets of Rz and Rg**"

And wrongly claims that "SATIRET2 uses one single **homogeneous** proxy for all magnetic features, the **sunspot group number**, Rg, to reconstruct the TSI over the past ~300 years…"

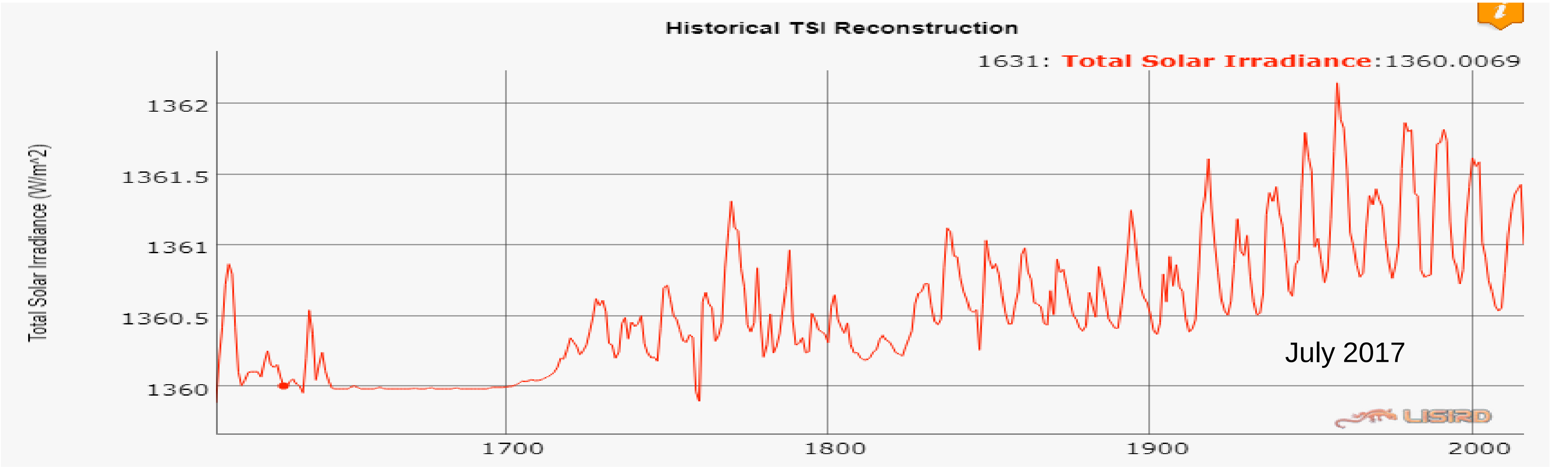
Solar Forcing in Climate Models

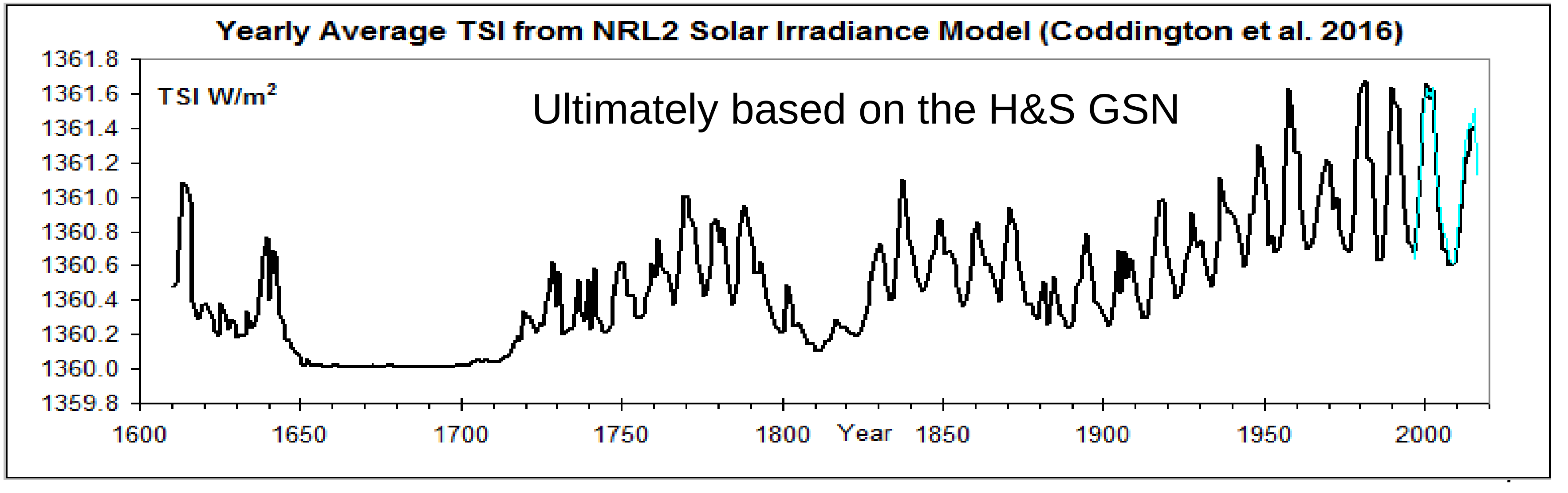
Katja Matthes et al.: Solar forcing for CMIP6, Geosci. Model Dev., **10**, 2017:

“Both NRLSSI2 and SATIRE rely on the sunspot number when no other solar proxies are available. For the CMIP6 composite, **we decided to rely on version 1.0** of the international sunspot number (from http://www.sidc.be/silso), even though a newer version 2.0 recently came out (Clette et al., 2014).”

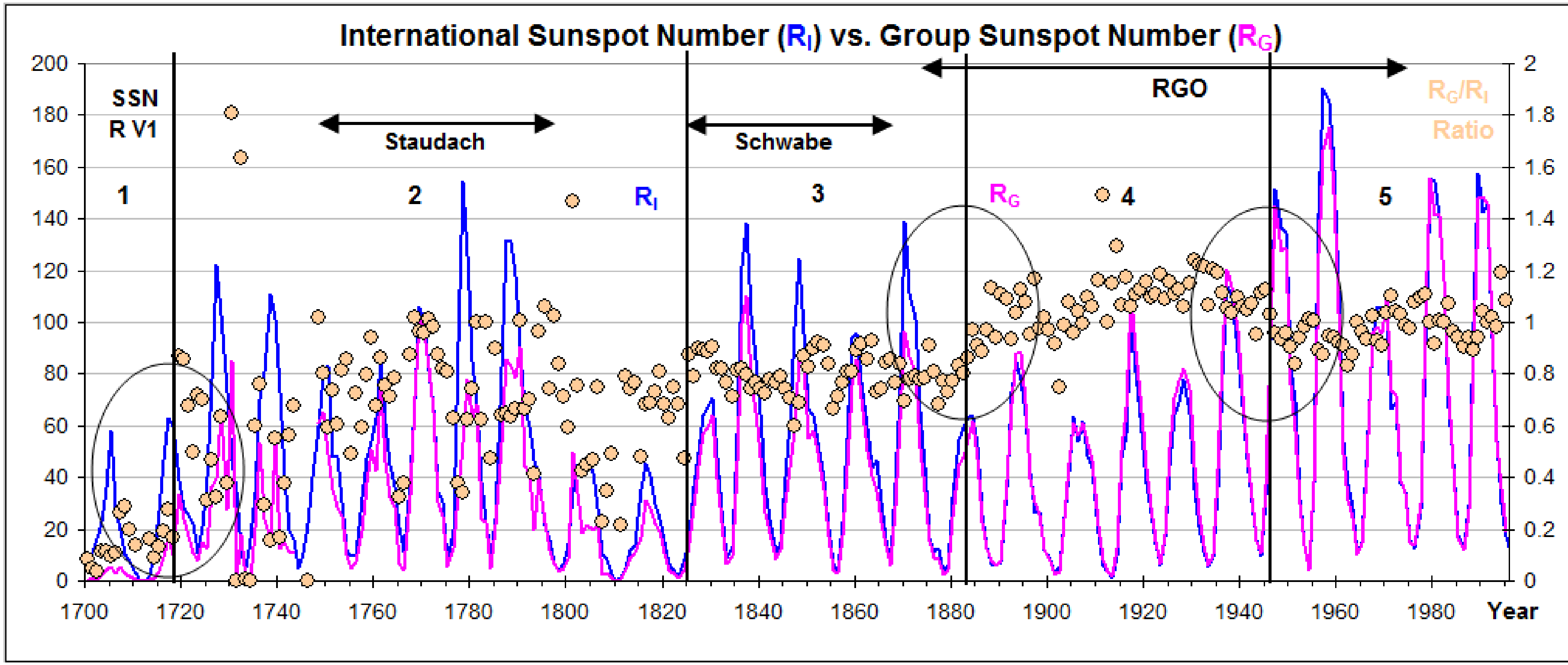


Yet Another SSN Workshop Failure





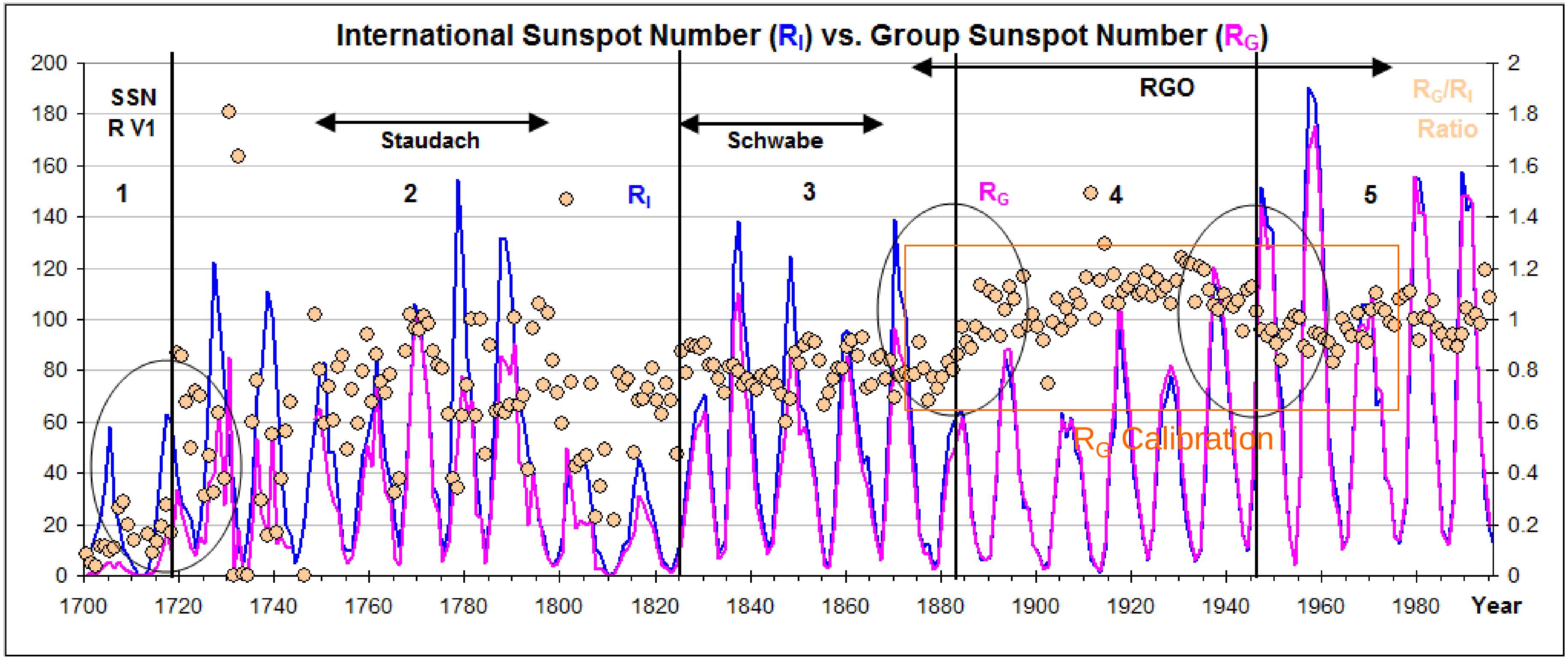
The Problem: Discordant Series



R_G: The Group Sunspot Number: the average number of sunspot groups per day multiplied by a scale factor (12.08) to match R_I for the interval of the RGO counts (Greenwich, 1874-1976)

R_I: The International Relative Sunspot Number introduced by Rudolf Wolf and now maintained by SILSO in Brussels (version 1)

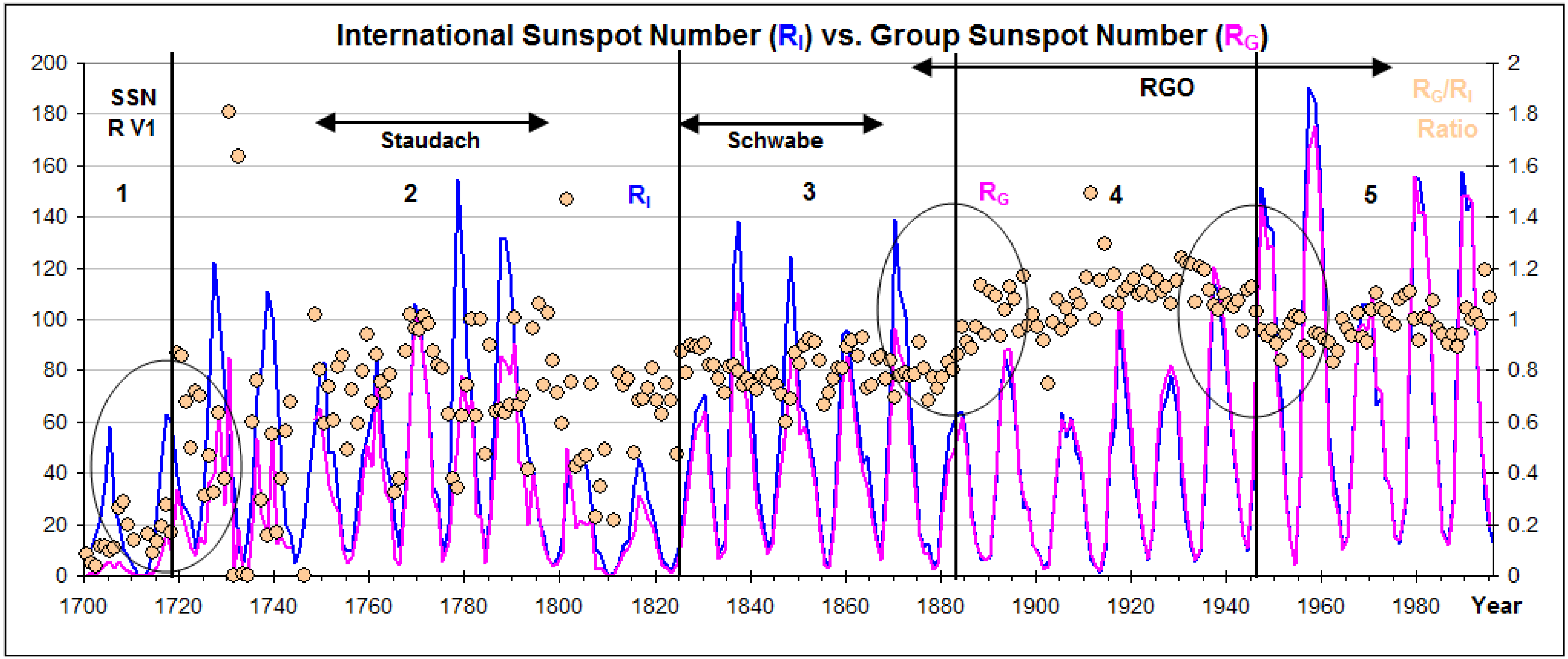
The Problem: Discordant Series



The disagreements are not random (i.e. not just noise) but are structured into about five distinct epochs as seen by taking the ratio per year between the two series

The series are ‘anchored’ by long-time, persistent observers (RGO [actually many observers over time], Schwabe, Staudach) who unfortunately do not overlap in time

The Problem: Discordant Series



Three [main] discontinuities were identified with some probable interpretations:

(1) R_G (GSN) too low during the Maunder Minimum before ~1715

(2) R_G (GSN) too low before ~1885

(3) R_I (SSN) too high after 1947

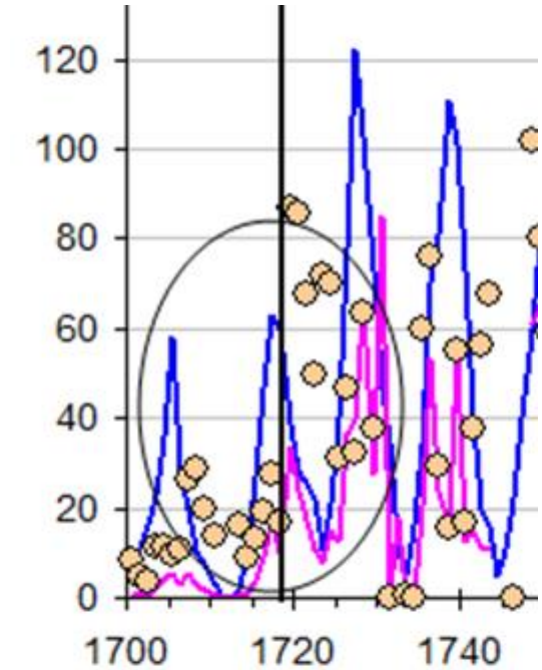
So only *three* problems to research and correct. We thought that would be easy. Little did we know how ugly it would be.

(1) Coming Out of the Maunder Minimum

NUMBER OF SUNSPOT GROUPS FOR THE YEAR: 1711
AS OBSERVED BY: DERHAM, W., UPMINSTER

H&S Data

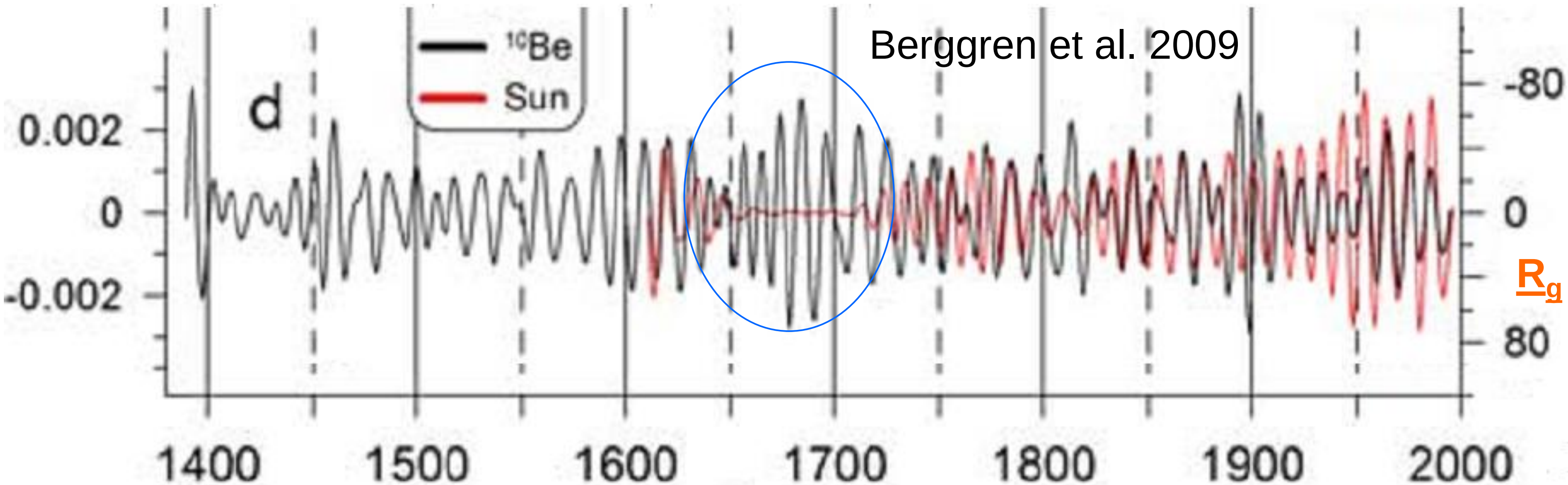
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	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	0	0	0	0	0	0	0	0	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 that year”

Should not be interpreted as 365 days of **observations** of zero spots

Cosmic Ray Modulation During the Maunder Minimum



Band pass (8-16 yrs) filtering of sunspot and 10Be data around the length of the Schwabe cycle. (d) NGRIP 10Be flux and H&S Group Sunspot Number. The large variation during the M.M. is helped by non-linear response of modulation.

The solar dynamo was apparently working producing magnetic fields and a solar wind (causing long and straight comet ion tails), but few visible sunspots (which are a threshold phenomenon).

Red Flash => 'Burning Prairie' => Network Magnetism

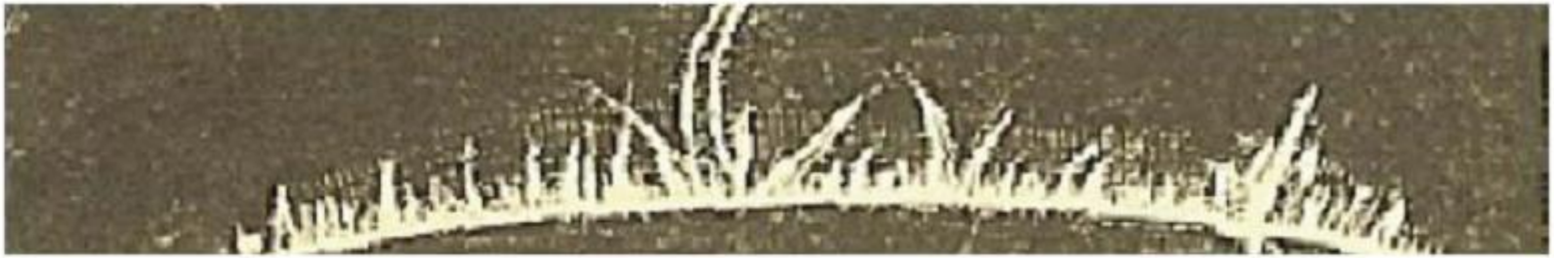


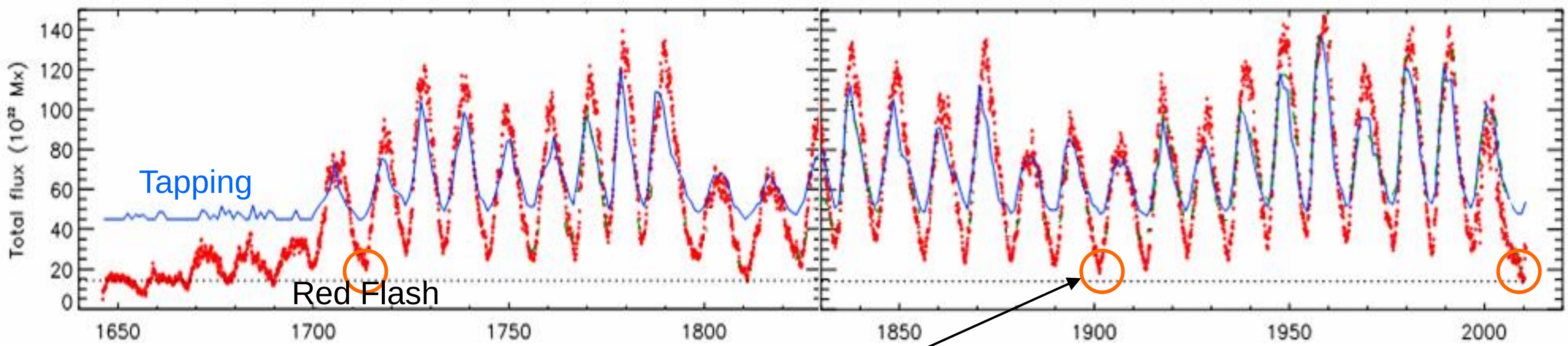
Figure 1 An early drawing of the "burning prairie" appearance of the Sun's limb made by C.A. Young, on 25 July 1872. All but the few longest individual radial structures are spicules.

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

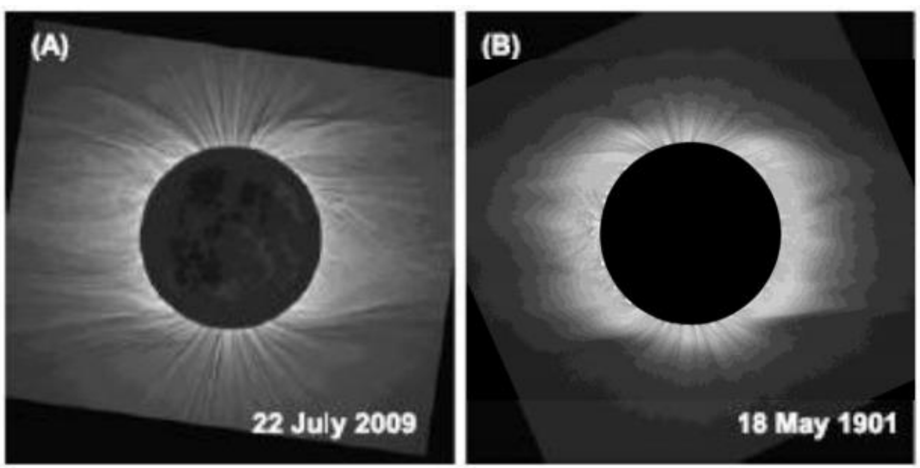
Foukal & Eddy, Solar Phys. 2007, *245*, 247-249

Perhaps There was a Base-level Solar Magnetic Field Even During the M. M.

Total Magnetic Flux on Sun (Schrijver, Livingston, Woods, Mewalt, GRL 2011)



Back to the Future

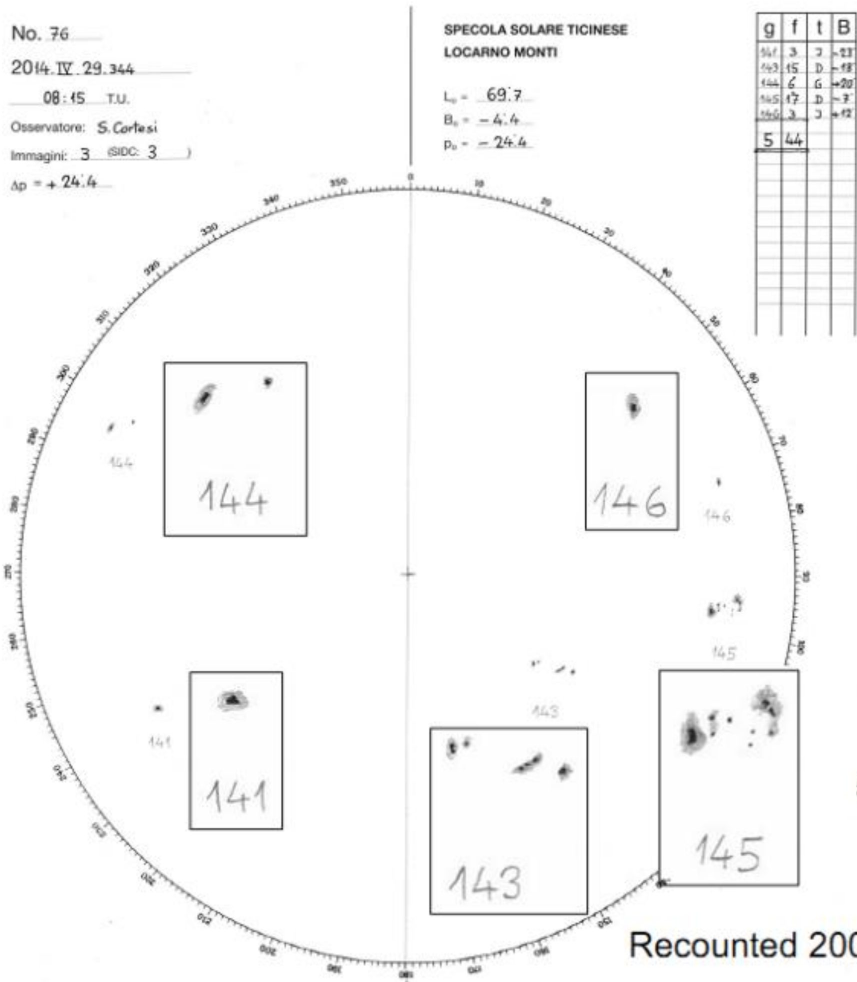


2008-2009 HMF B = 4.14 Sunspot Number, Ri = 3

1901-1902 HMF B = 4.10 nT Sunspot Number, Rz = 4

"Estimate of the unsigned surface magnetic flux based on a surface flux-transport model that uses the sunspot number records to determine flux emergence with 2D surface dispersal based on observed properties of the solar field. This model has no free parameters, assuming only that the frequency of active-region emergence changes over time in direct proportion to the yearly-averaged sunspot number."

(3) We are on Firmer Ground About the 'Waldmeier Discontinuity'

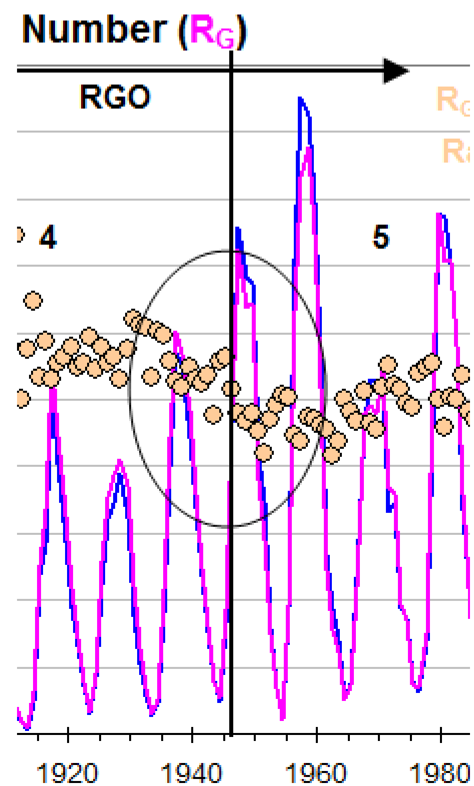


Counting with Weighting

g	f	No weighting
141	3	1
143	15	6
144	6	2
145	17	9
146	3	1
5	44	19

5x10+44=94 5x10+19=69

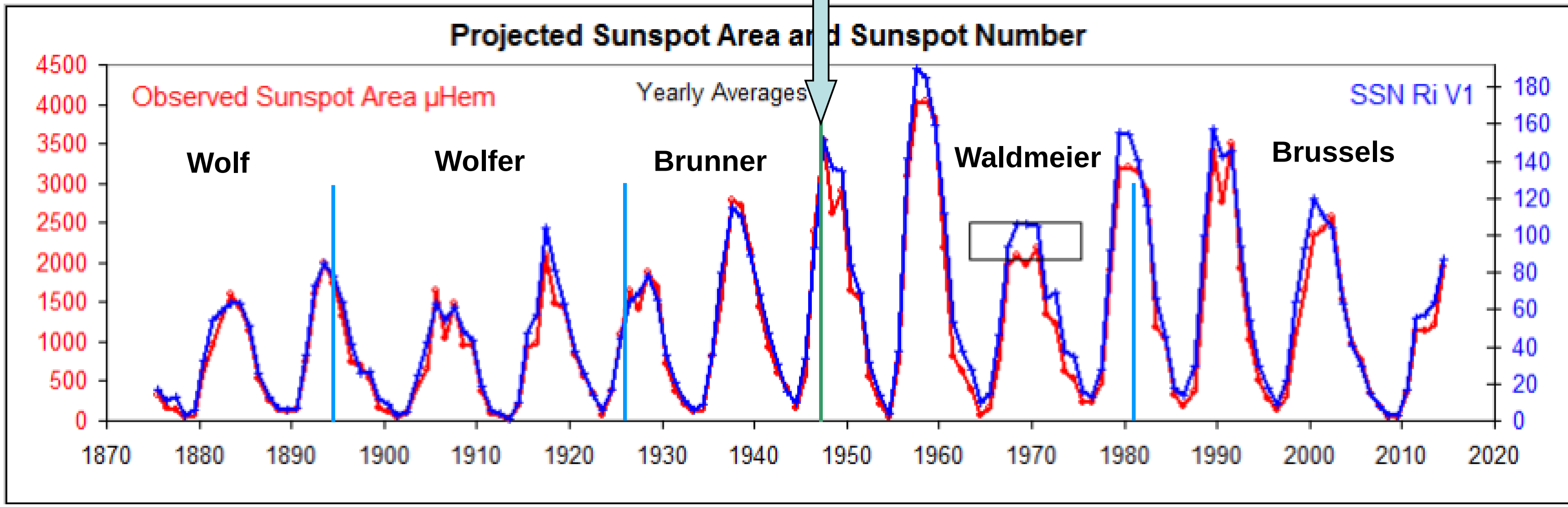
94/69 = 1.36



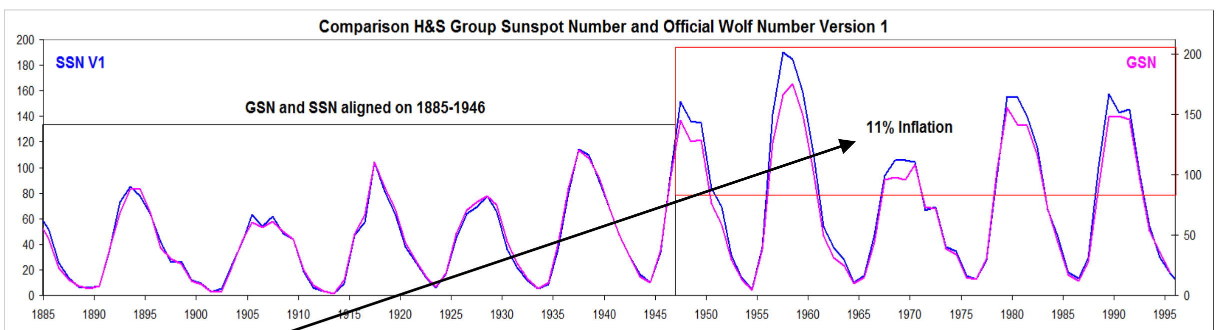
Recounted 2003-2014: ~55,000 spots

Max Waldmeier began to systematically 'weight' sunspots in 1947. Spots with penumbra were counted three times [or more] than spots without. This increases the 'number of spots' and decreases the ratio R_G/R_I. But Waldmeier claimed the weighting started back in 1882…

When Did the W.D. Happen? 1947



SSN V1

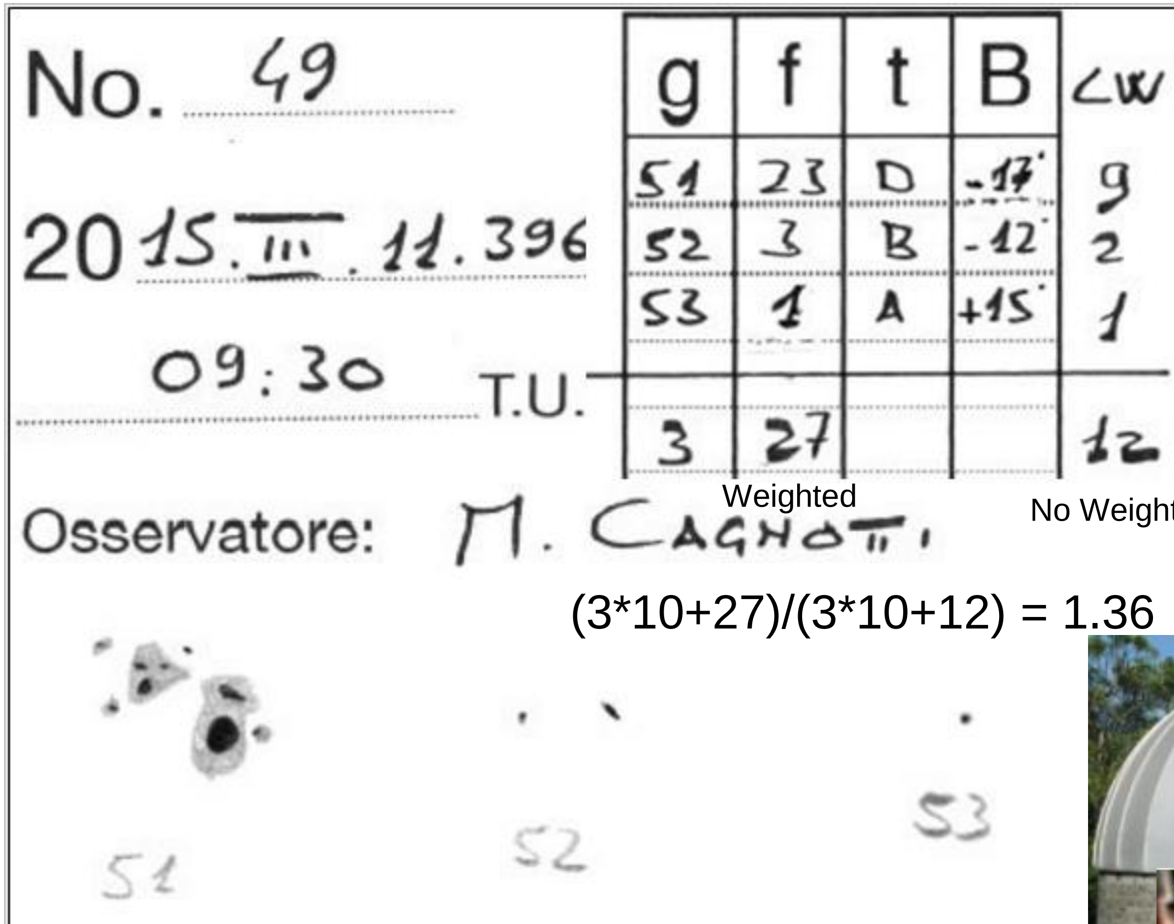


H&S GSN

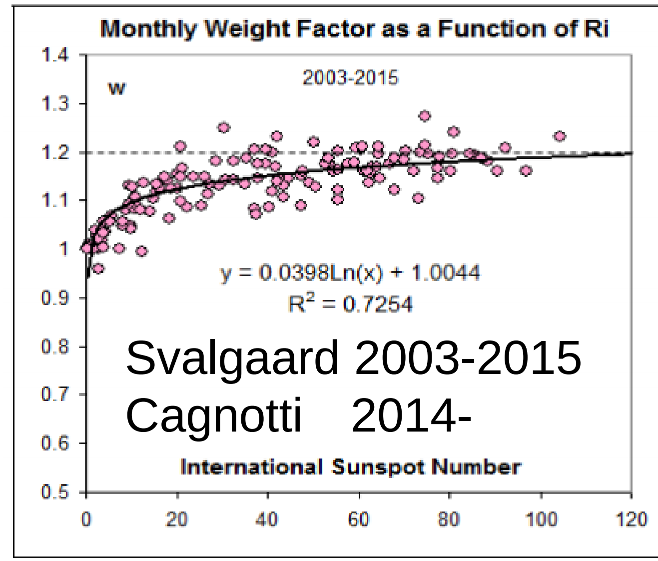
11% Inflation

But this (the 11%) is under several assumptions, e.g. that the data have correct calibration, are homogenous, that the relationships are strictly linear, and that "everything else is equal". The situation is a bit more complicated…

We Don't Need to Assume Anything. We Have Direct *Measurements* of the Inflation Due to Weighting



(3*10+27)/(3*10+12) = 1.36

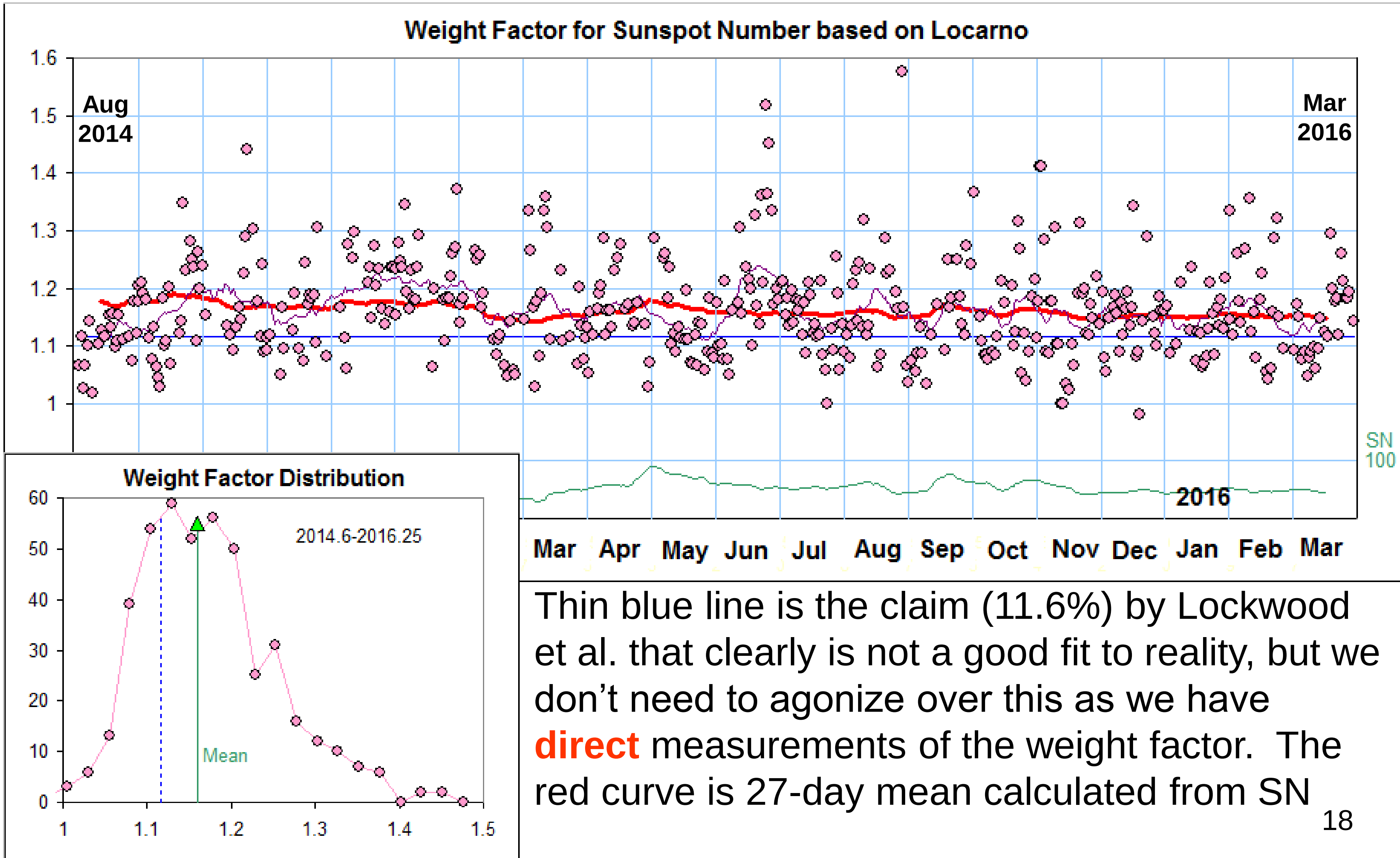


Locarno

Drawings and counts have been made since 1957 at Locarno, CH. Main observers: Cortesi, Cagnotti.

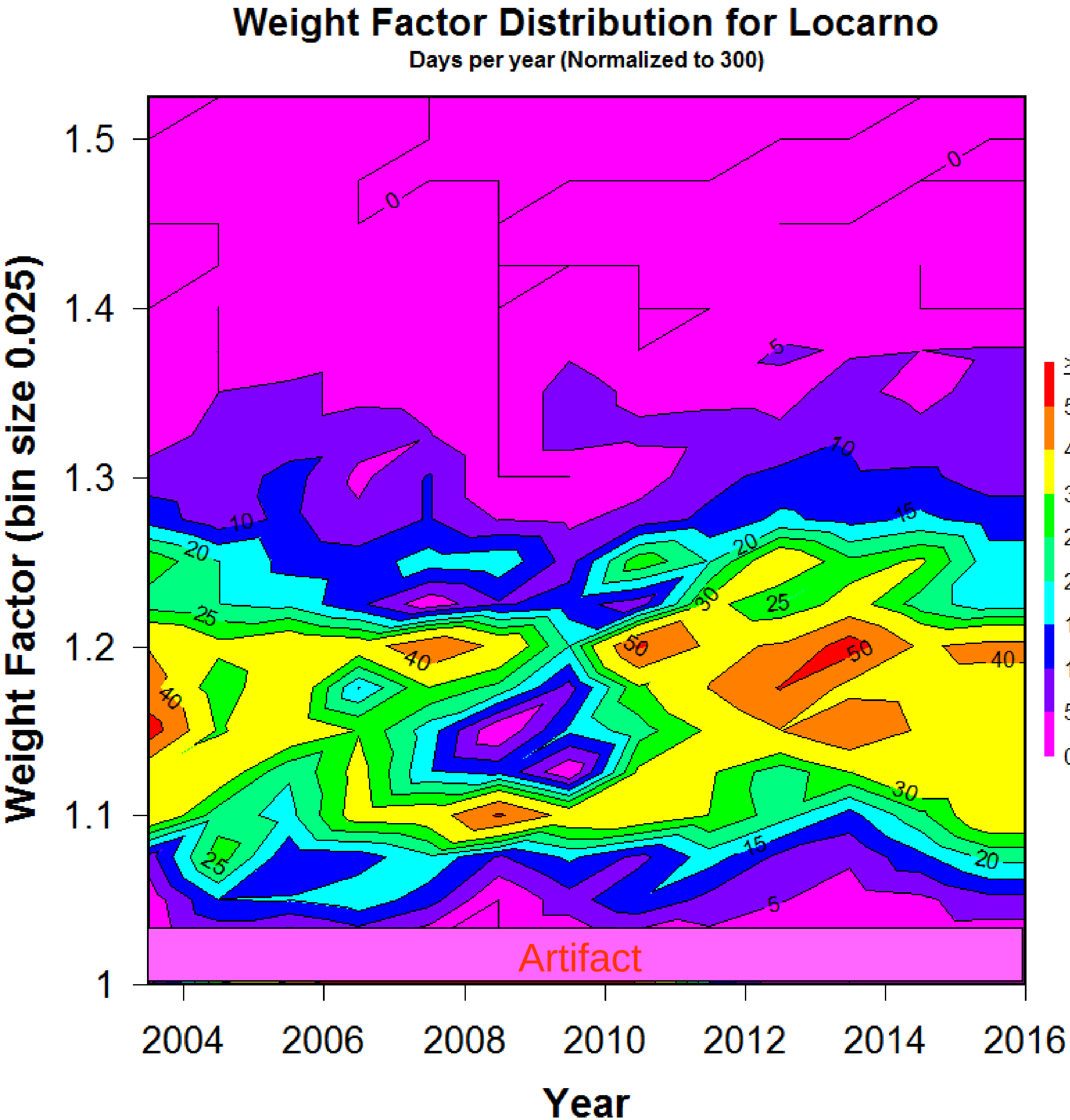
<= New Director

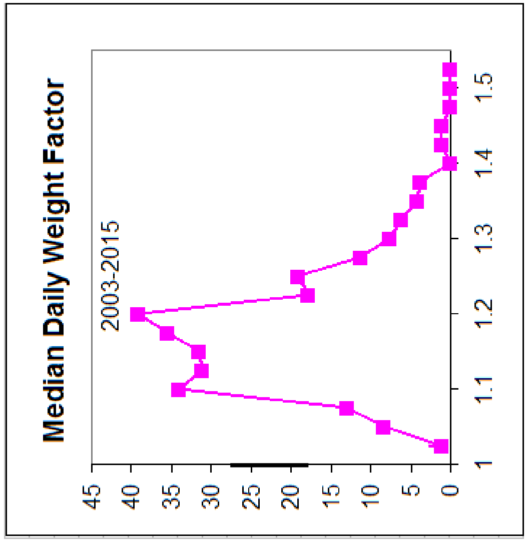
We Still Keep Track of the Locarno Weight Factor for Historical Reasons



Thin blue line is the claim (11.6%) by Lockwood et al. that clearly is not a good fit to reality, but we don’t need to agonize over this as we have **direct** measurements of the weight factor. The red curve is 27-day mean calculated from SN

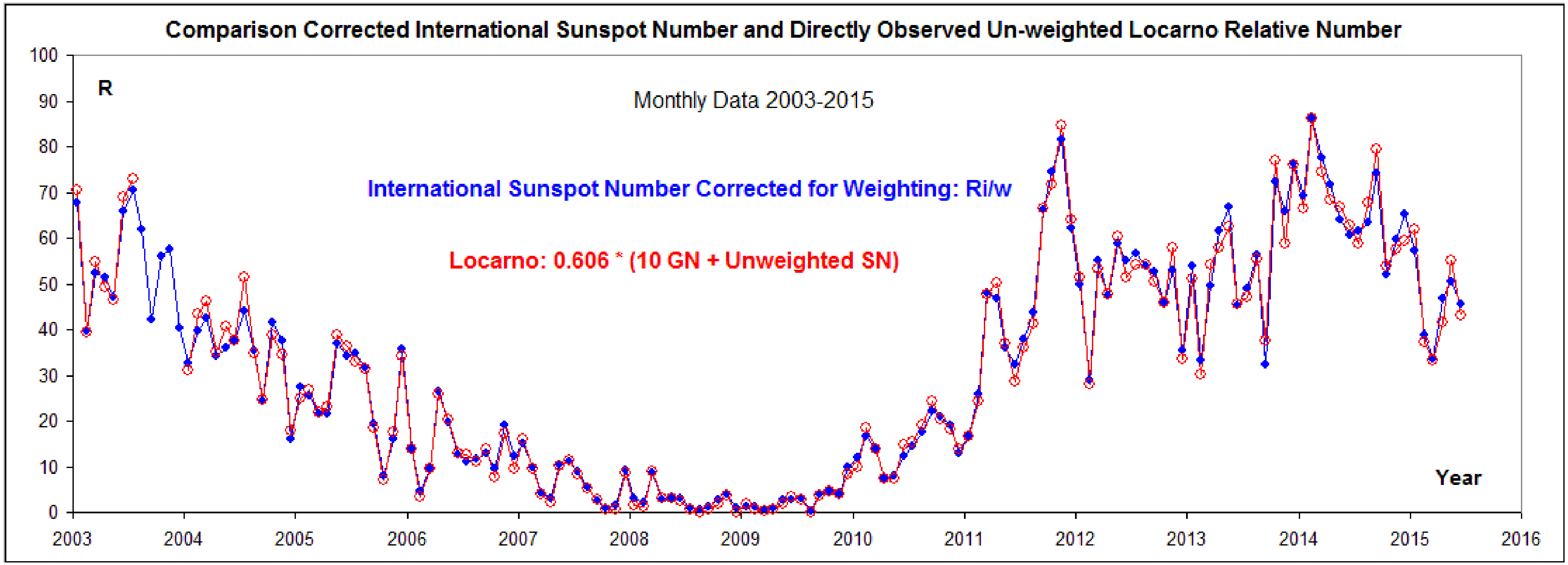
Distribution of Daily Weight Factors





At low activity there are few large spots so weighting is slight

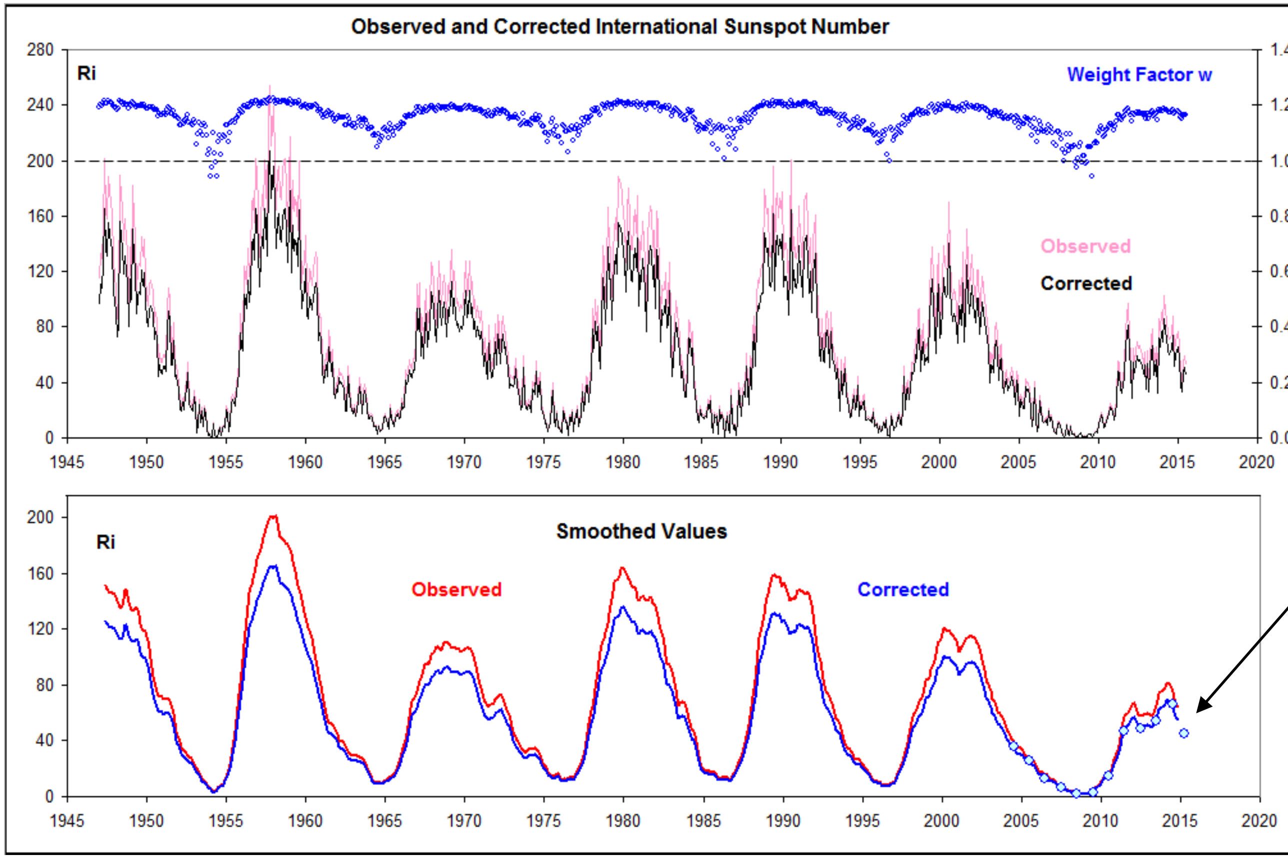
How well can we correct R_i? Very well, indeed



Conclusions on Weighting:

1) We have determined the weight factor by **direct** observation
2) We can correct for weighting with high precision (R^2 = 0.991)
3) Weighting is non-linear and simple-minded analysis will not do
4) Going forward, no more weighting in SSN Version 2

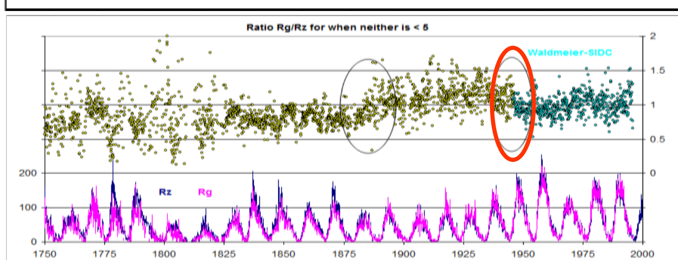
SSN with/without Weighting



The weight (inflation) factor

The observed (reported) SSN (pink) and the corrected SSN (black)

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

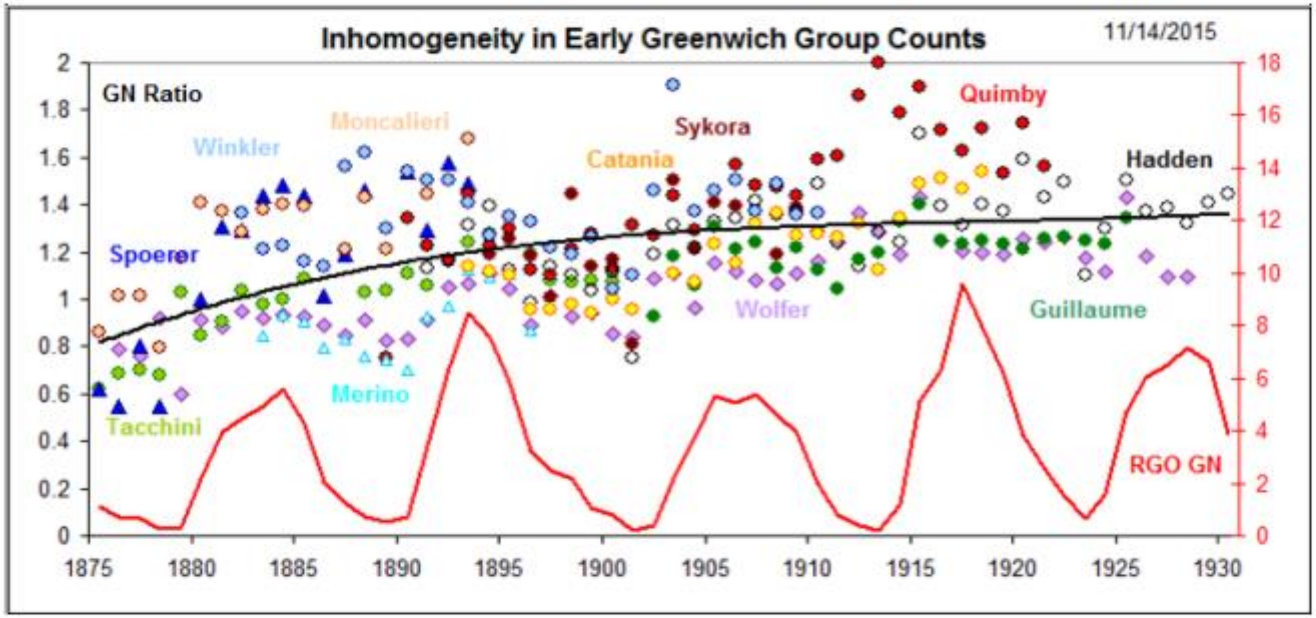


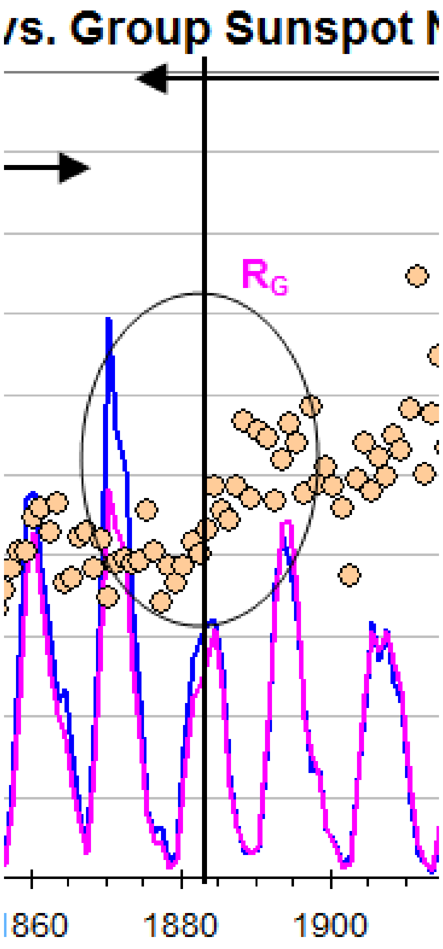
The inflation due to weighting largely explains the recent anomaly in the ratio between the GSN and the SSN

(2) The Elephant in the Room

The H&S GSN was constructed under the assumption that the RGO [Greenwich] group count was correct (the ‘perfect observer’). All other observers counts were directly normalized to RGO after 1883, but were ‘daisy-chained’ via intermediate observers for all times before that.

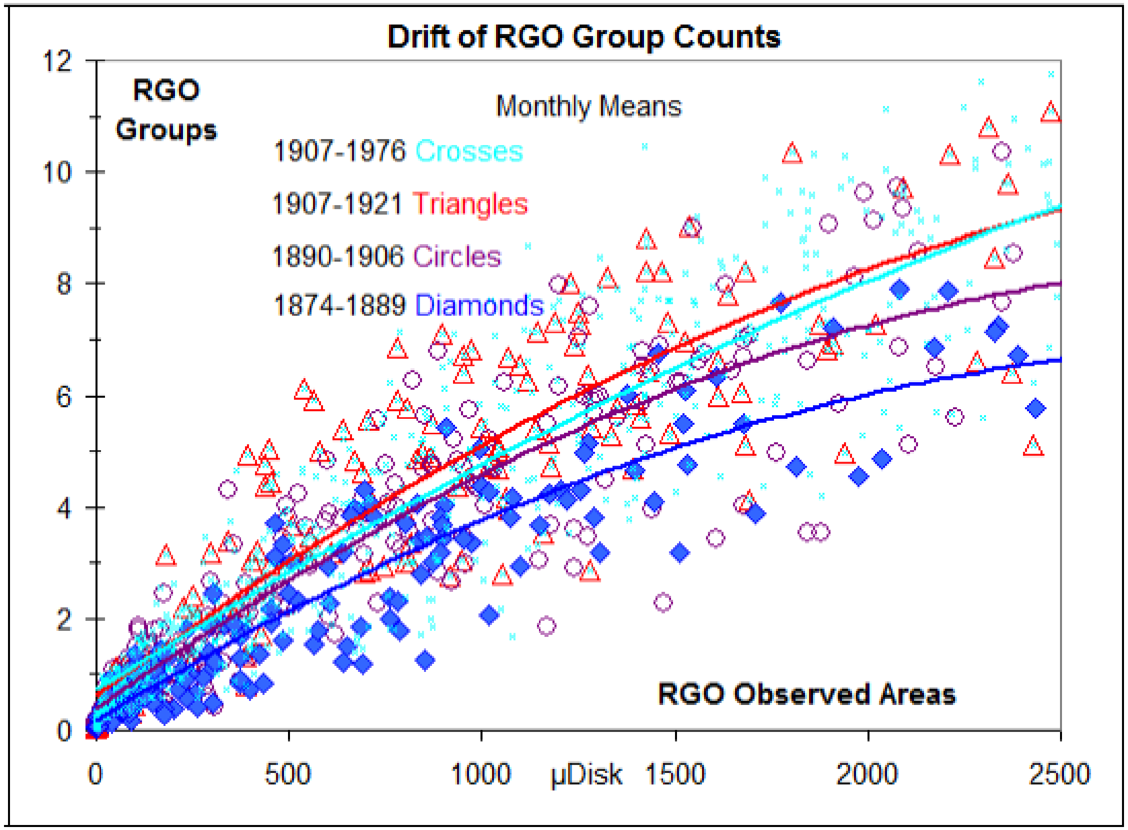
However, comparison with other, long-term, high-quality observers shows a strong drift of the early RGO counts:





Did all these observers get it wrong, while the ‘counter of the day’ at RGO got it right?

The RGO Drift is Real



The number of groups reported by RGO for the three intervals 1874-1889, 1890-1906, and 1907-1921. Second order polynomial fits show the progressive increases of the count for equal disk-averaged sunspot areas [observed, foreshortened; Balmaceda et al., 2009]. For the whole interval from 1907 until the end of the RGO data in 1976 the number of groups is shown as small cyan crosses.

Determining the Area of the Groups is Easy: just count black pixels, so there is nothing wrong with the RGO areas.

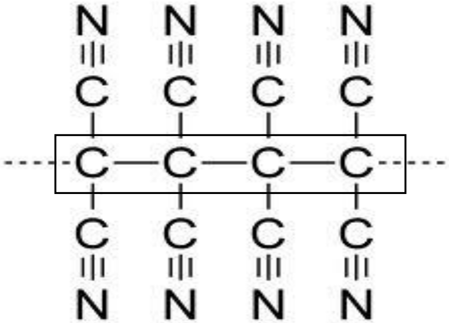
The apportioning of spots to groups is Hard. It takes several years to learn to do this right. At RGO, several observers were engaged in the data reduction and there very likely was a learning curve for each.

The ‘Drift’ or the Undercount in the first ~10 years of RGO was daisy-chaining by H&S back in time to all earlier data and is the main reason for the problem around 1885

Building Backbones

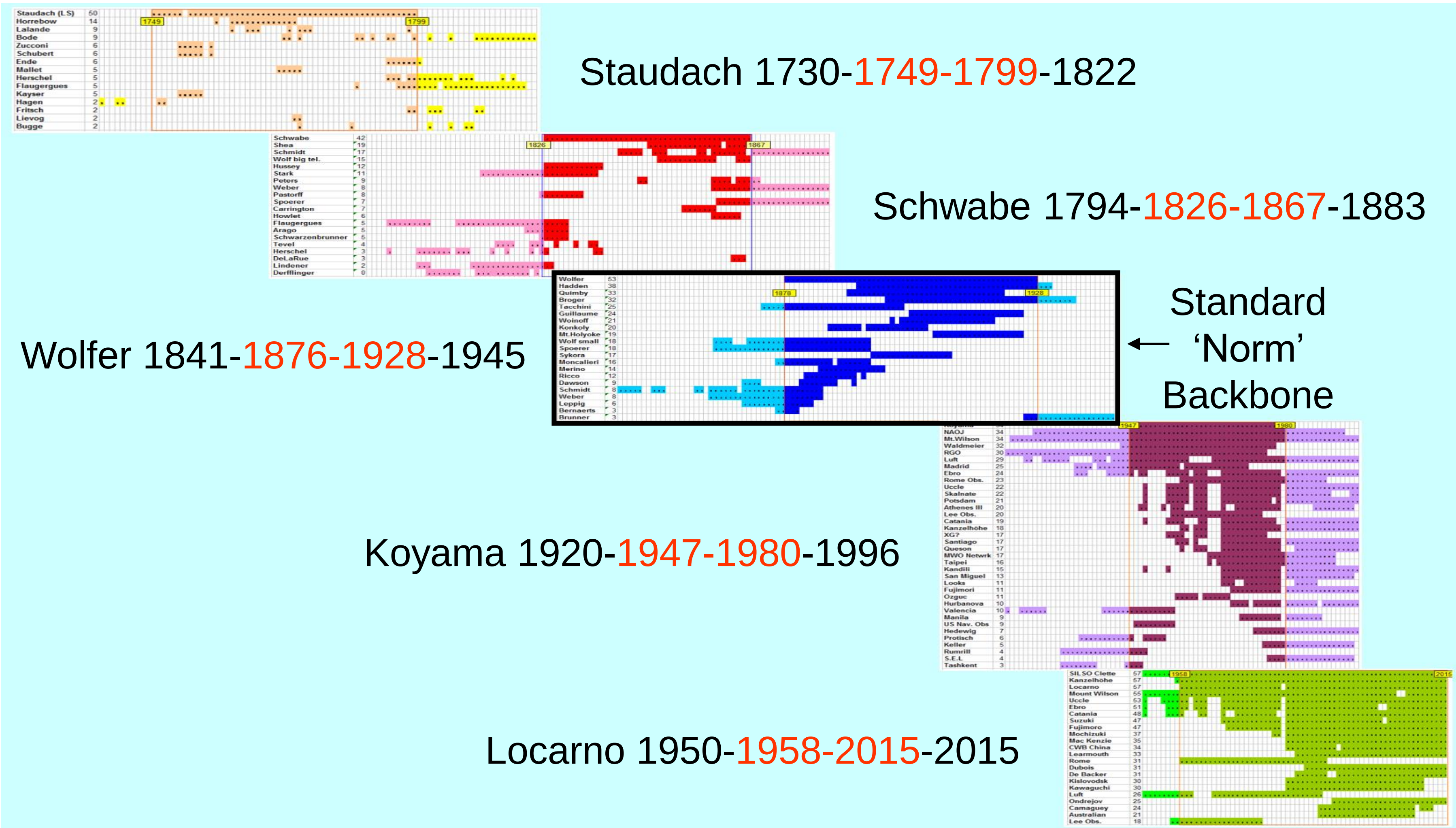
Building a time series from observations made over a long time by several observers can be done in basically two ways:

- Daisy-chaining: successively joining several intermediate observers to the ‘end’ of the series, based on overlap with the series as it extends so far [accumulates and **propagates** 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]. Several, but few, independent backbones can then be daisy-chained together for the long series.


Carbon Backbone

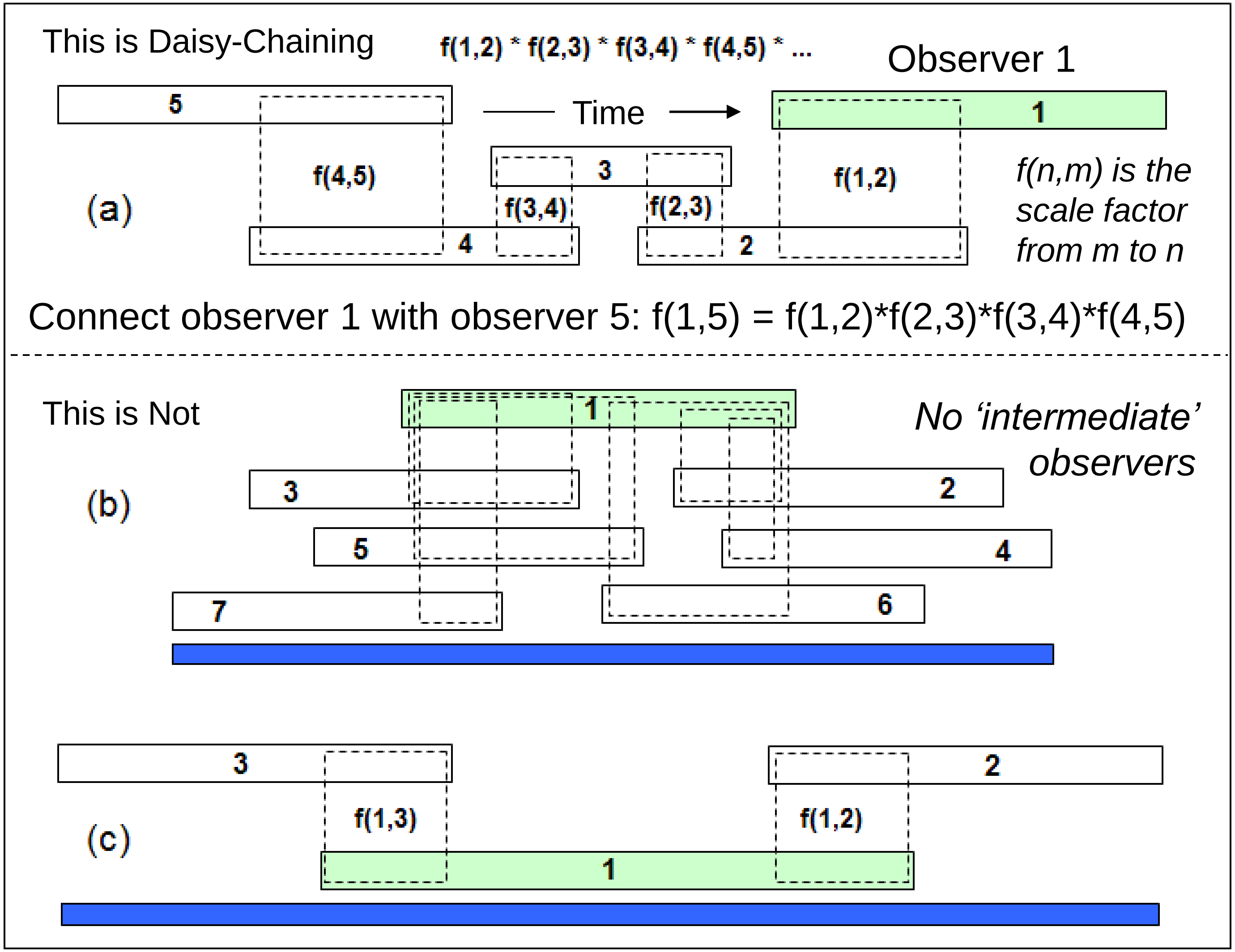
We [Ken Schatten (of H&S) and I] have applied the Backbone method to reconstruct the Group Sunspot Number [using essentially the Hoyt & Schatten data supplemented with newer data.] with the goal of avoiding the pitfalls of H&S, and not even use RGO as primary.

The Backbones



106 unique ‘observers’ [some are assemblies of many individual observers, e.g. RGO]

Daisy-Chaining: When is it and When is it Not



Error Accumulation: E15=SQRT(E12^2+E23^2+E34^2+E45^2) i.e. *increases* with the number of observers

The 'effective' scale factor is an average of all the individual factors <f(n,1)>.

The error of an average *decreases* as the SQRT of the number of observers

Proportionality? Yes!

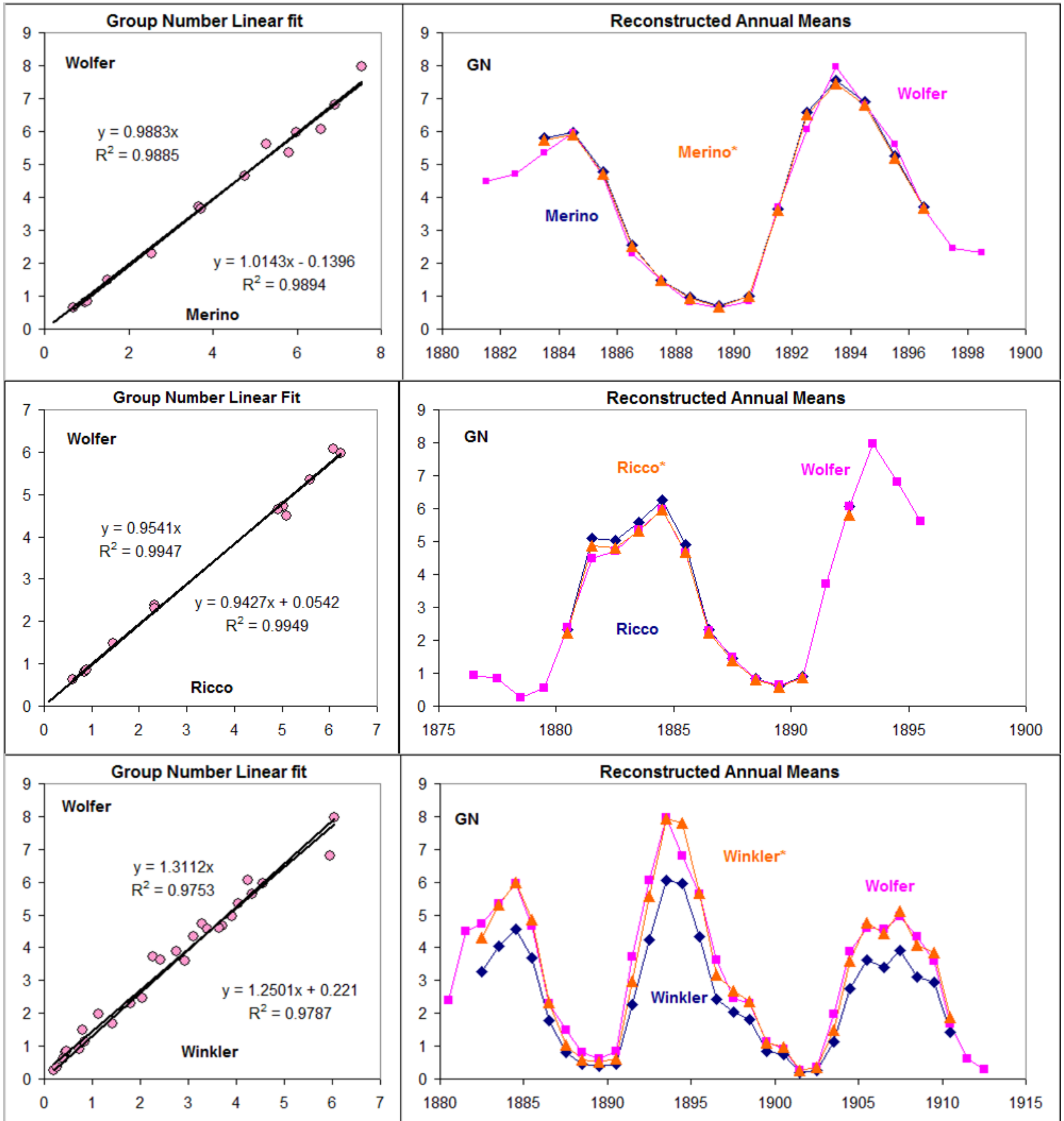
The notion of scale factors requires proportionality between the values from different observers averaged over some [long enough] time interval.

In their (Lockwood et al. [2016], Usoskin et al. [2016]) critical 'assessment' (that many people cling to) of the sunspot number revisions they state "We find that proportionality of annual means of the results of different sunspot observers is generally invalid and that assuming it causes considerable errors in the long-term." They mention these "errors" 63 times.

If this were true, reconstructions (both of the Wolf Number relying on 'k-factors' and the Group Number relying on linear scaling of observers) would indeed be suspect and this would be the case for both the revised series (Version 2) and even more so for the earlier, and much used and liked, series (Version 1).

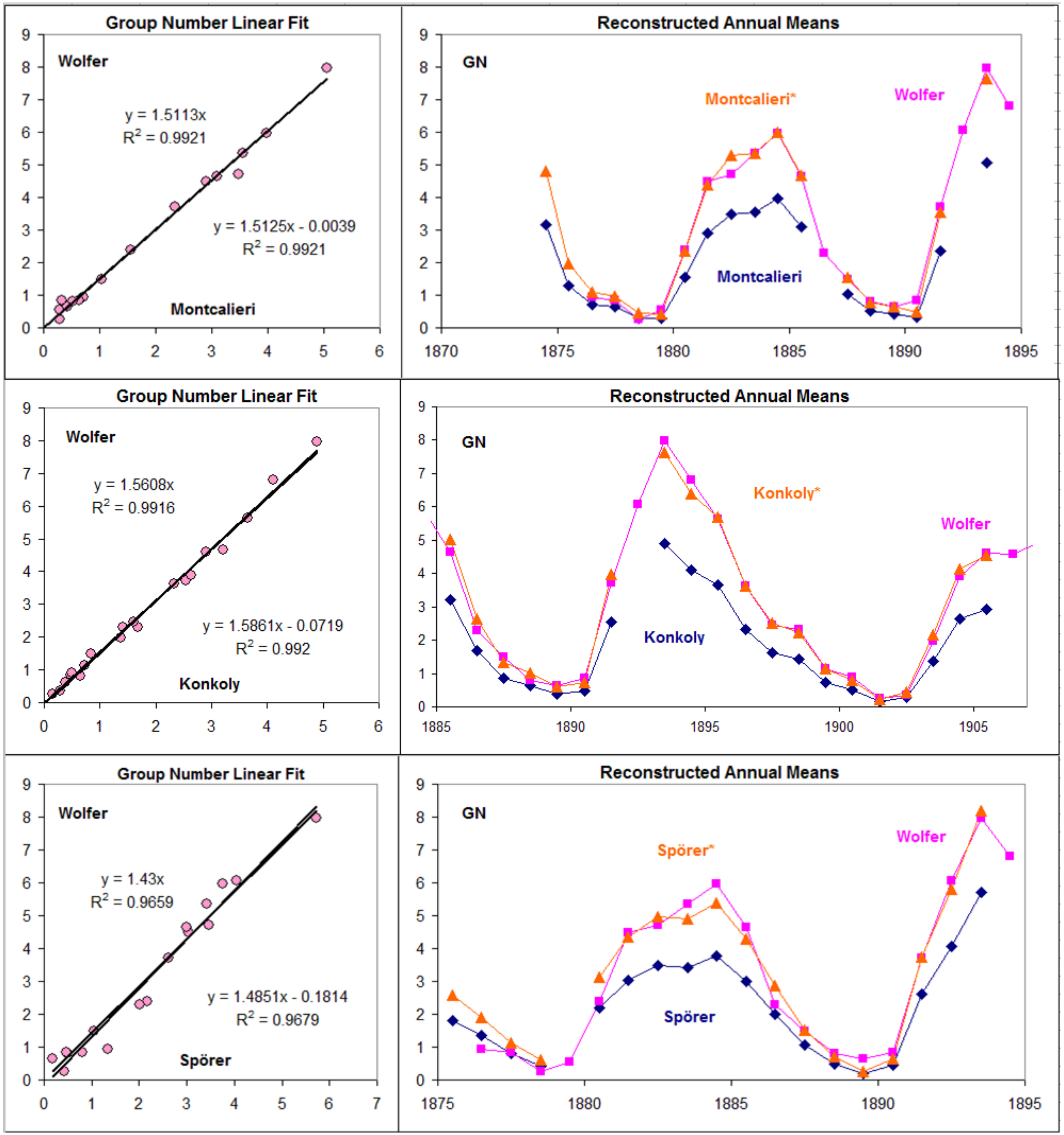
However, their statement is not true as we shall show on the following slides. **Proportionality of annual means is an observational fact and not an assumption**, hence does not "cause considerable errors in the long- term", nor errors in the short-term.

Showing Proportionality for the Wolfer Backbone (I)



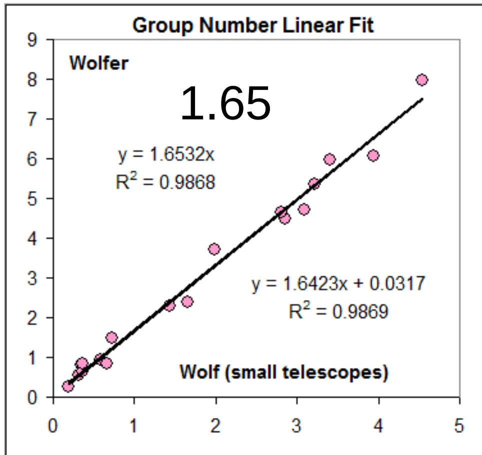
Left: Two linear fits, one going through the origin and one with an offset. They are not statistically different.

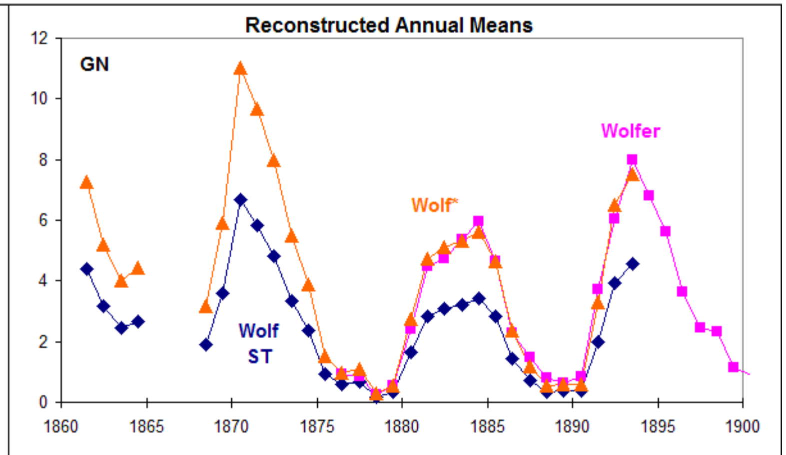
Right: Observed Group Number (blue diamonds). Scaled Group Number (orange triangles) and for the primary observer (pink squares; Wolfer)

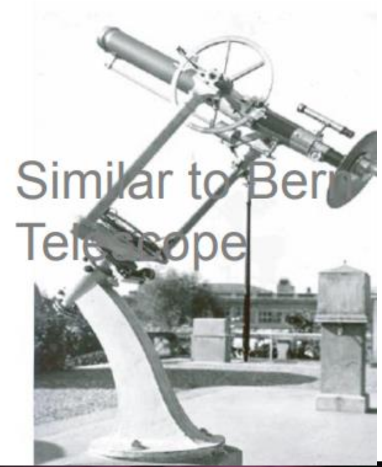


Showing Proportionality for the Wolfer Backbone (II)

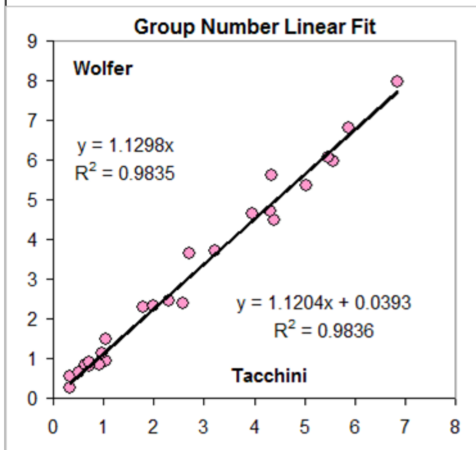
It is important to get the Wolfer Backbone correct as it straddles the critical transition in the 1880s.

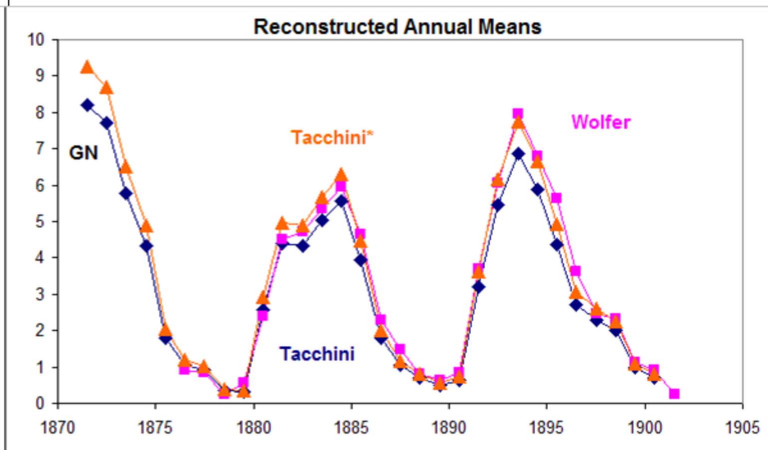


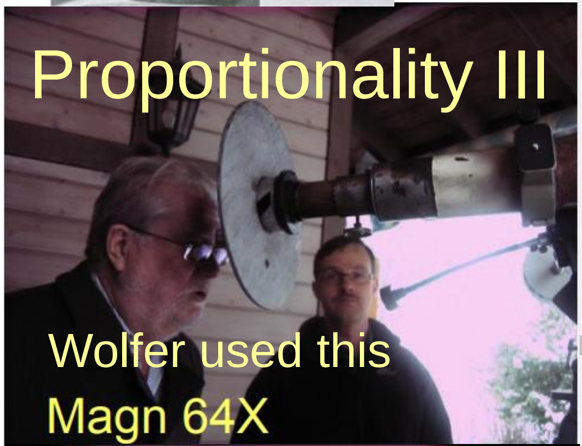


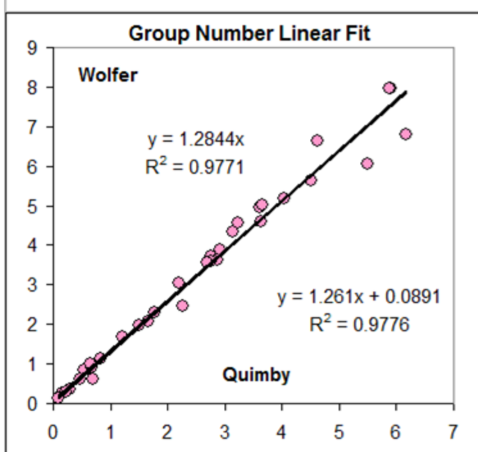


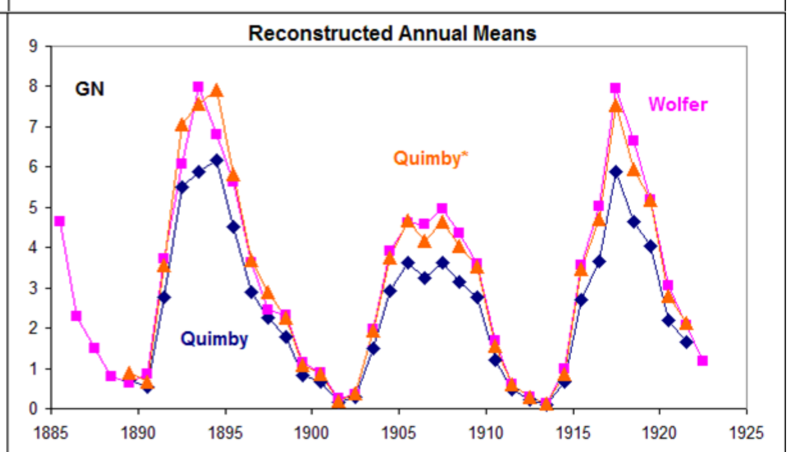
Why Wolfer saw 65% more groups than Wolf





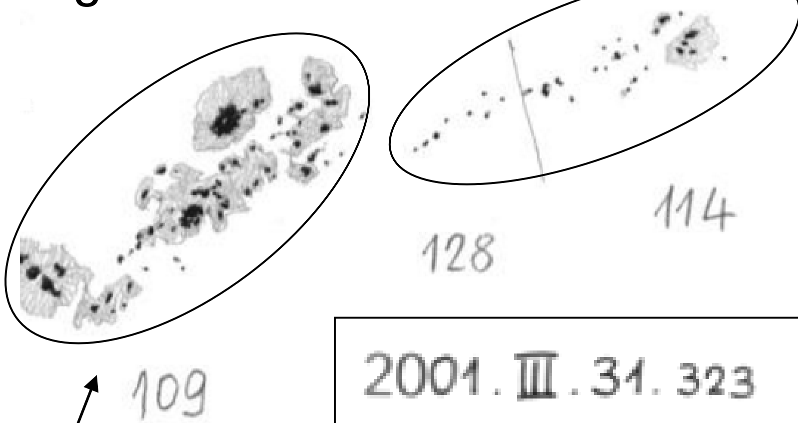


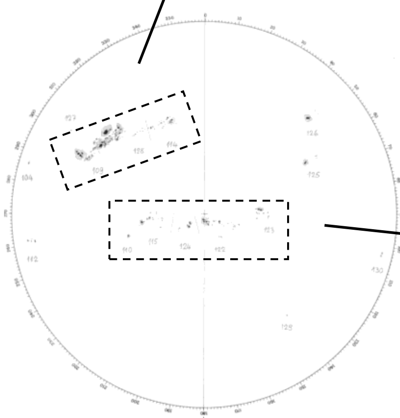




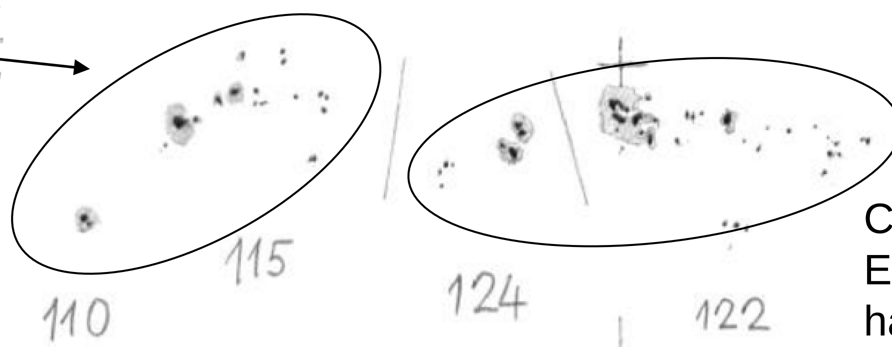
Fundamental Issue: What Is a Group?

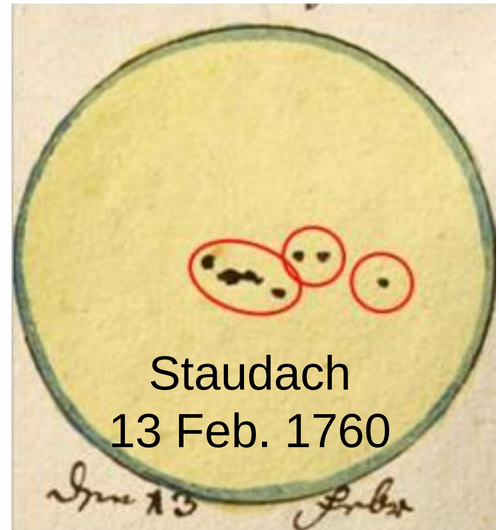
Definition has changed over time





Locarno





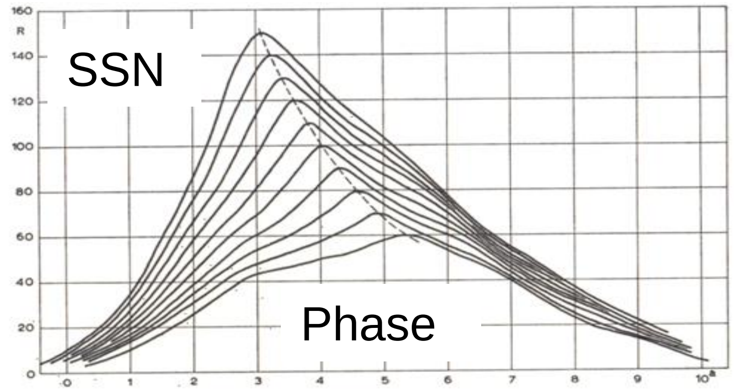
Wolf (1857) counted only one group on that day.

A modern observer (Cortesi, me) would count three groups.

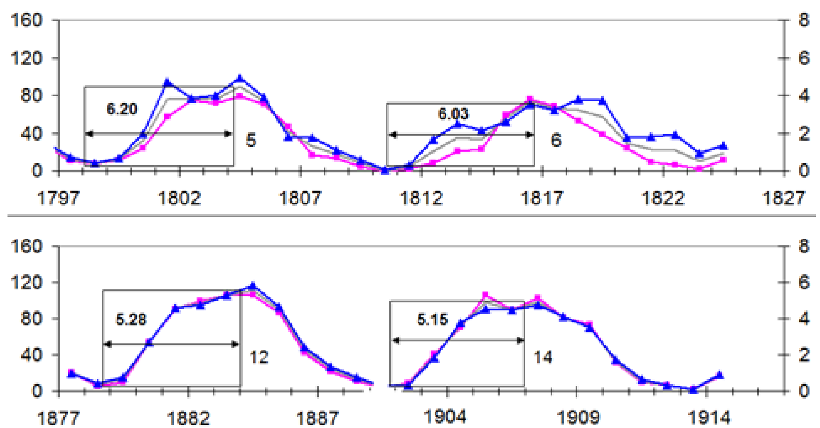
Contrary to common belief, counting spots is easy, counting groups is **hard**

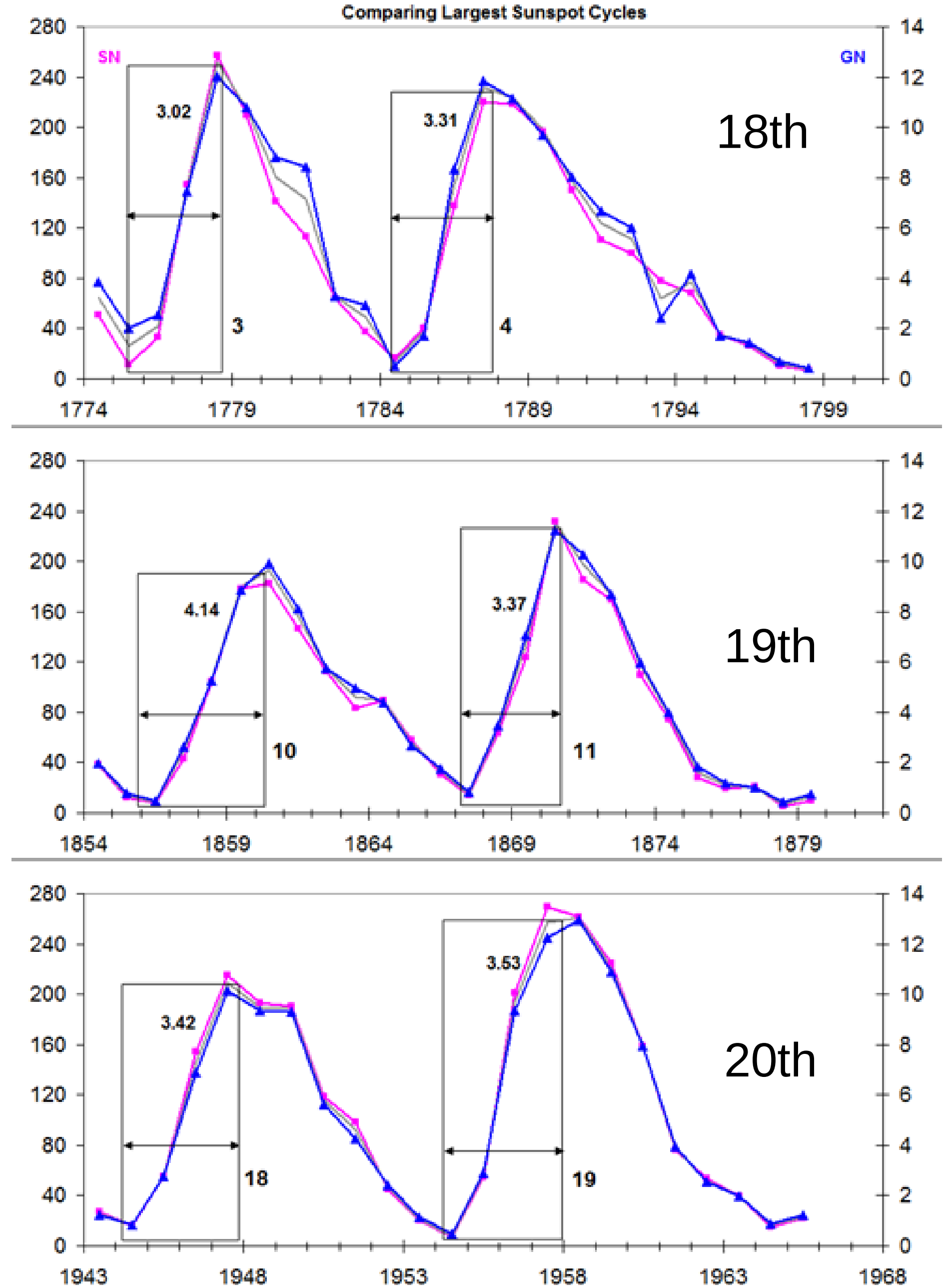
Cortesi counted 8 groups. Early observers would likely have counted only 5 groups

The Waldmeier Effect

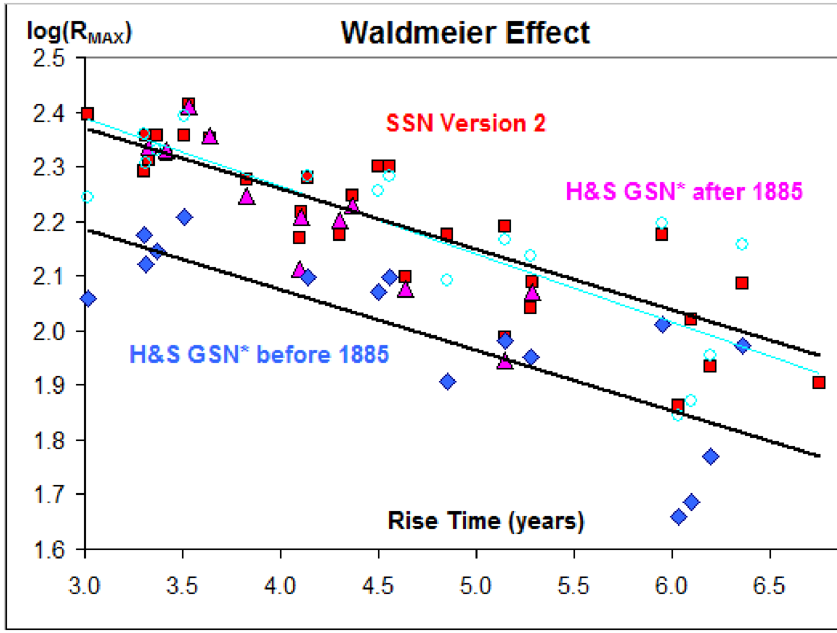


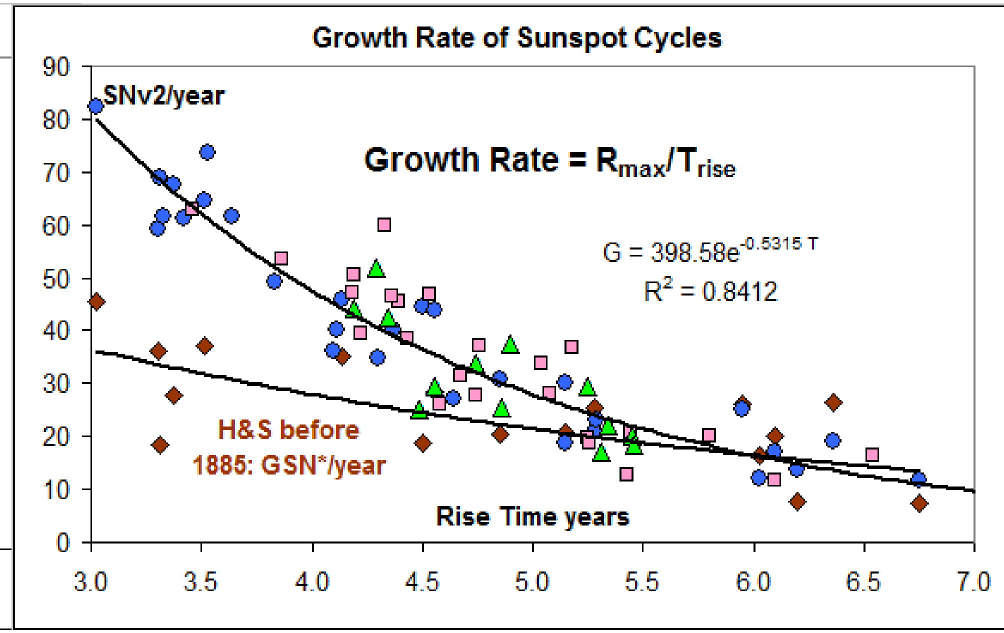
There is a relationship between the rise time T (in years) from minimum to maximum and the maximum smoothed monthly sunspot number. The times of the extrema can be determined without knowledge of the reduction (or scale) factors. **Since this relationship also holds for the years from 1750 to 1848 we can be assured that the scale value of the relative sunspot number over the last more than 200 years has stayed constant** or has only been subject to insignificant variations. Waldmeier (1978).

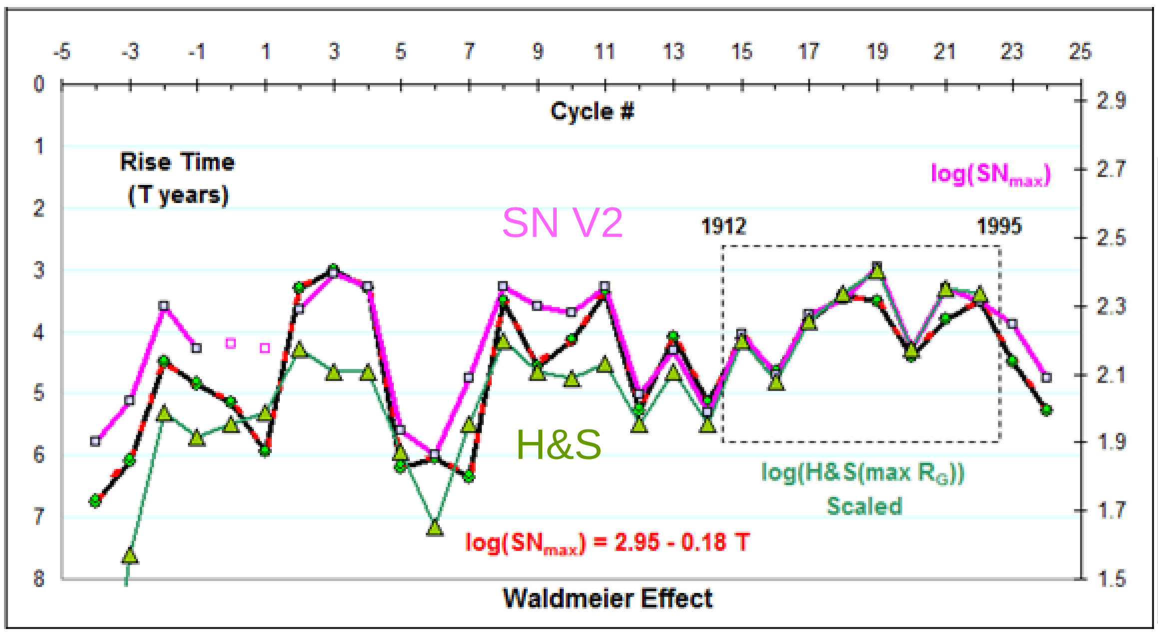


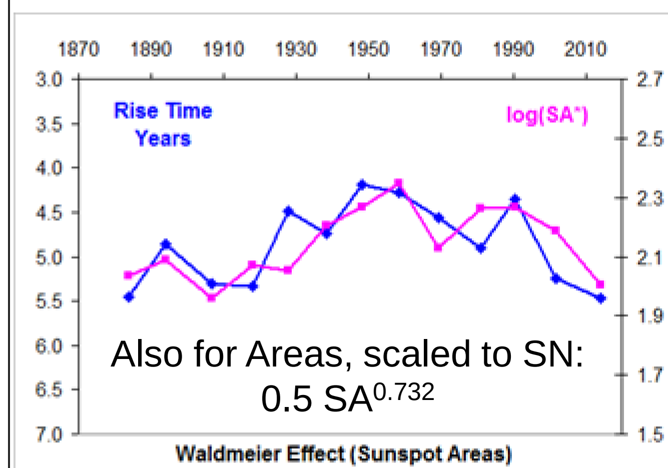


More Waldmeier Effect



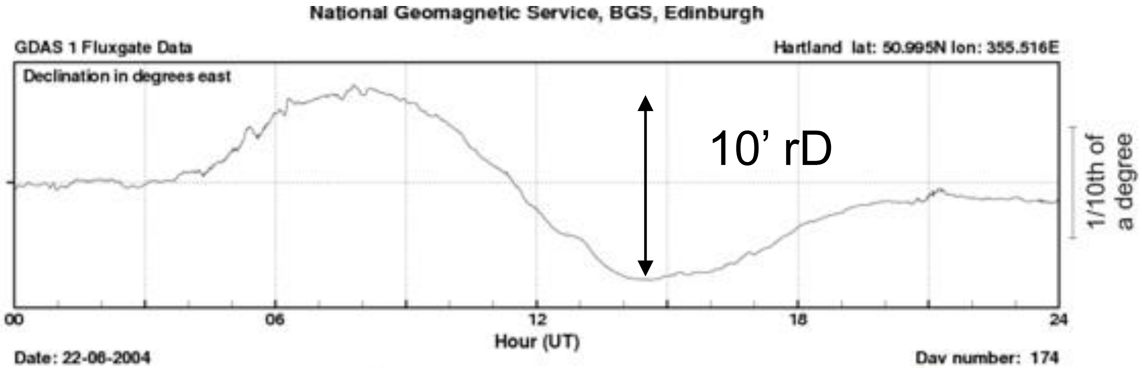


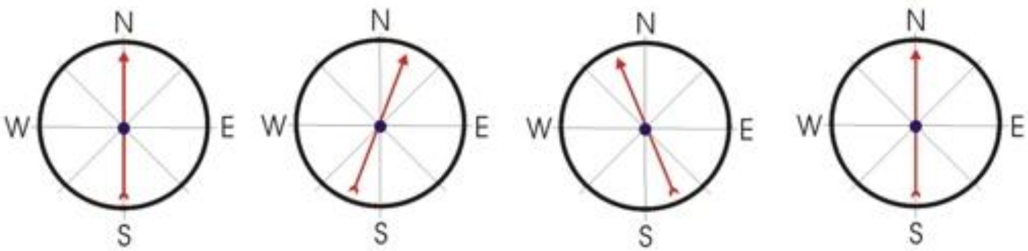


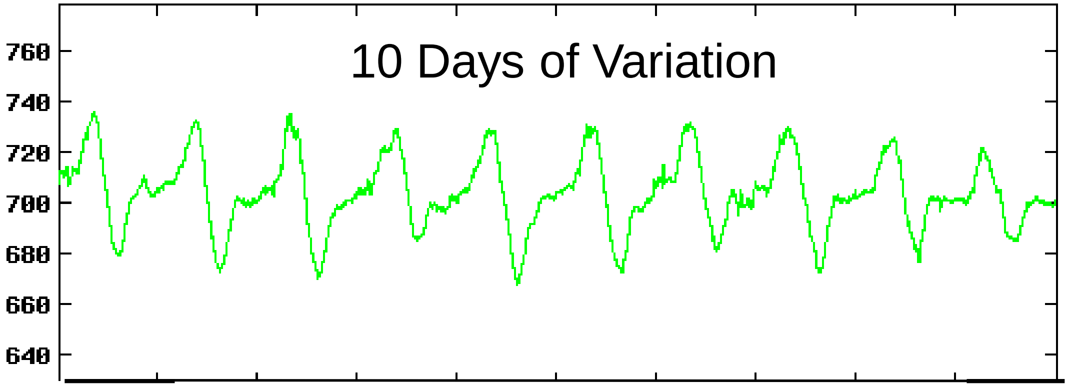


The H&S GSN fits the Waldmeier Effect after 1885, but not before (is too low).

The Diurnal Variation of the Direction of the Magnetic Needle





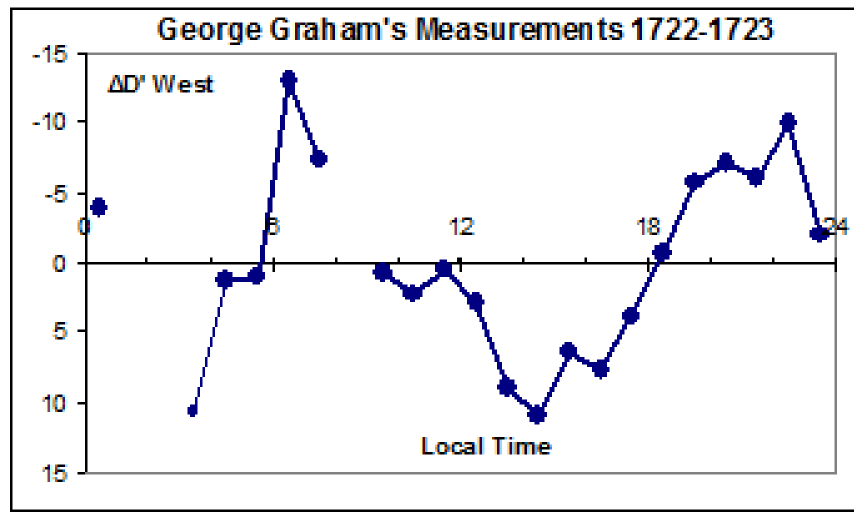


George Graham [London] discovered [1722-1724] that the geomagnetic field varied during the day in a regular manner.

George Graham's Paper

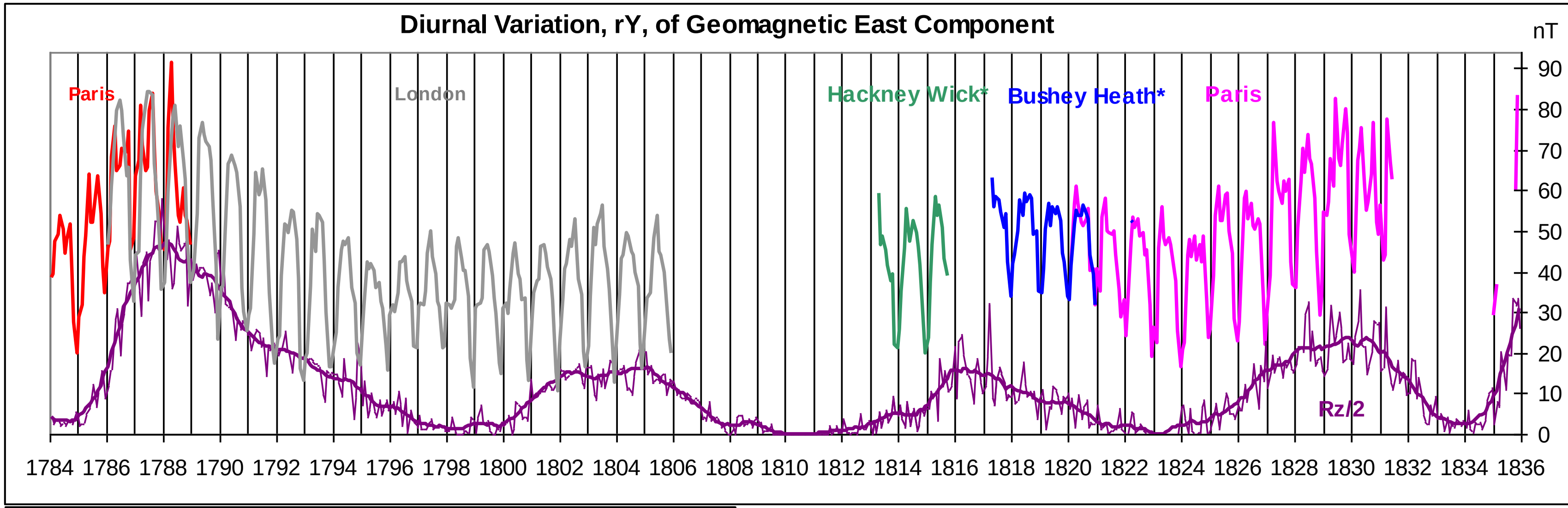
IV. *An Account of Observations made of the Variation of the Horizontal Needle at* London, *in the latter Part of the Year* 1722, *and beginning of* 1723. *By Mr.* George Graham, *Watch-maker, F. R. S.*

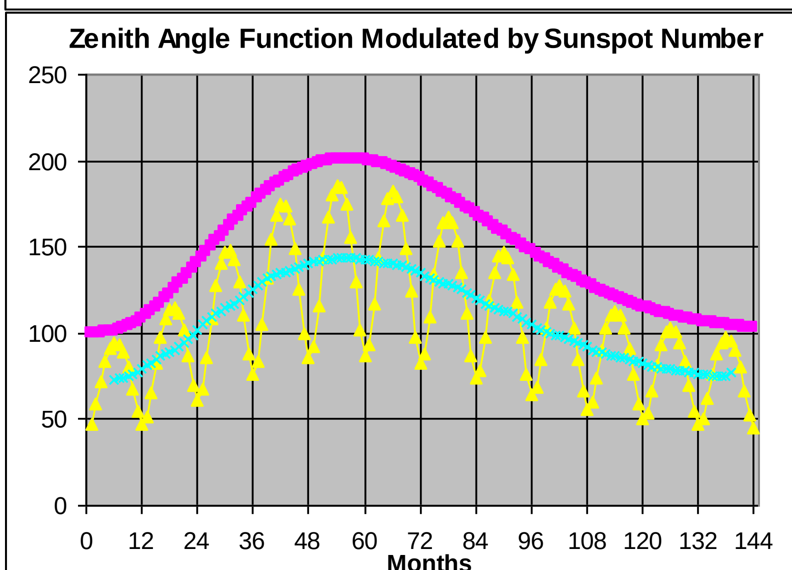
"From February 6, 1722 to the 10th of May following, I made above [*sic*] a thousand Observations in the same place; and the greatest Variation Westward, was 14 degrees 45 minutes, and the least 13 degrees 50 minutes. It was seldom less than 14 degrees, or greater than 14 degrees 35 minutes"



Phil. Trans., **33**, 1724-1725, doi:10.1098/rstl.1724.0020, Jan.1, 1724

Solar Cycle and Zenith Angle Control

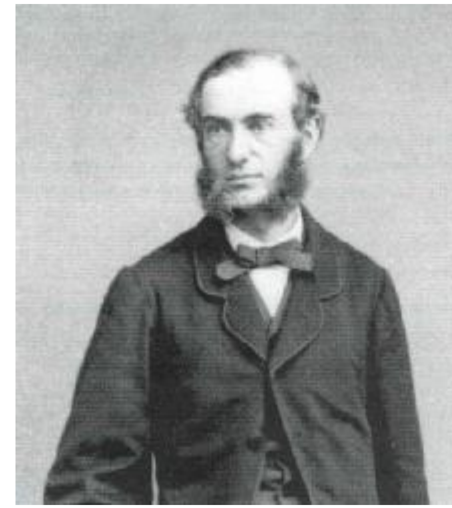




Rudolf Wolf and J-A Gautier, 1852

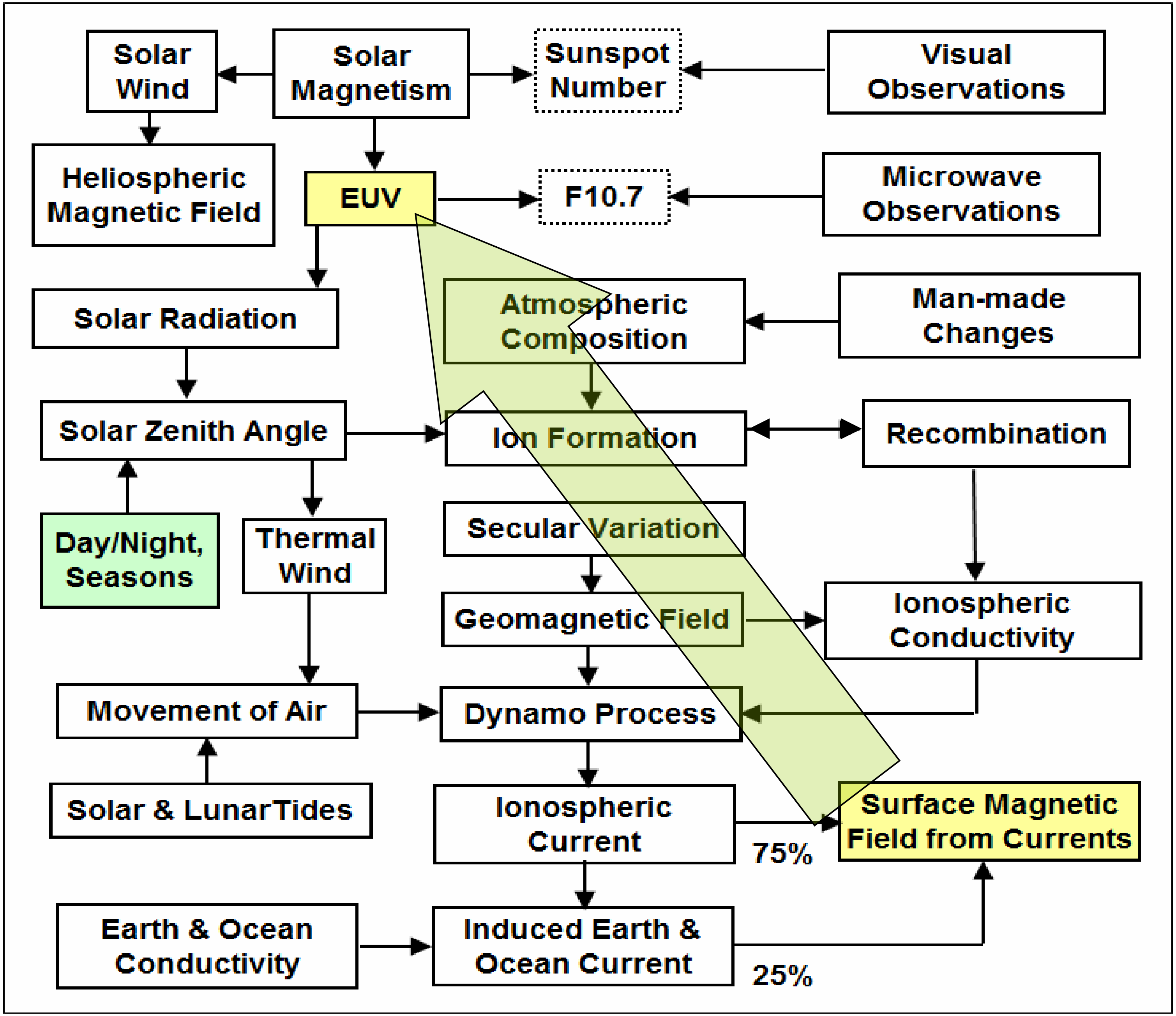
Balfour Stewart, 1882, Encyclopedia Britannica, 9th Ed.

"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) […].



Balfour Stewart
1828-1887

"there seems to be grounds for imagining that their **conductivity may be much greater than has hitherto been supposed**."

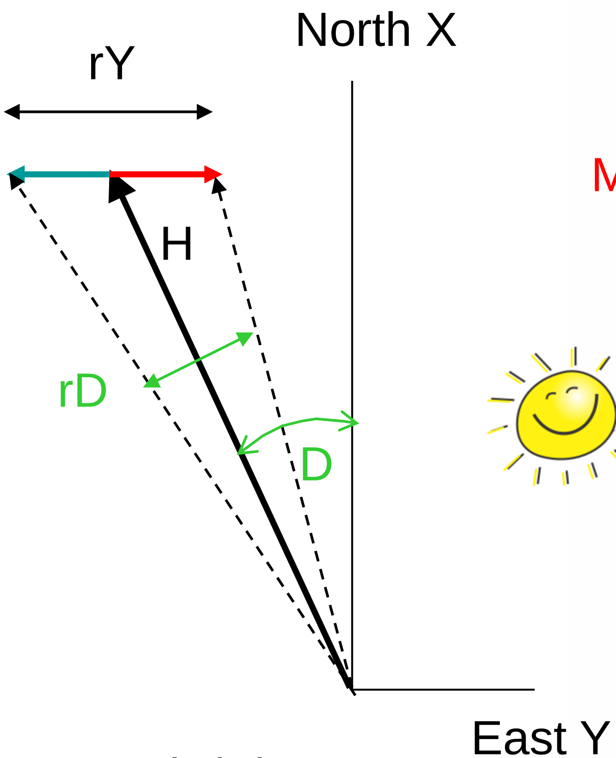


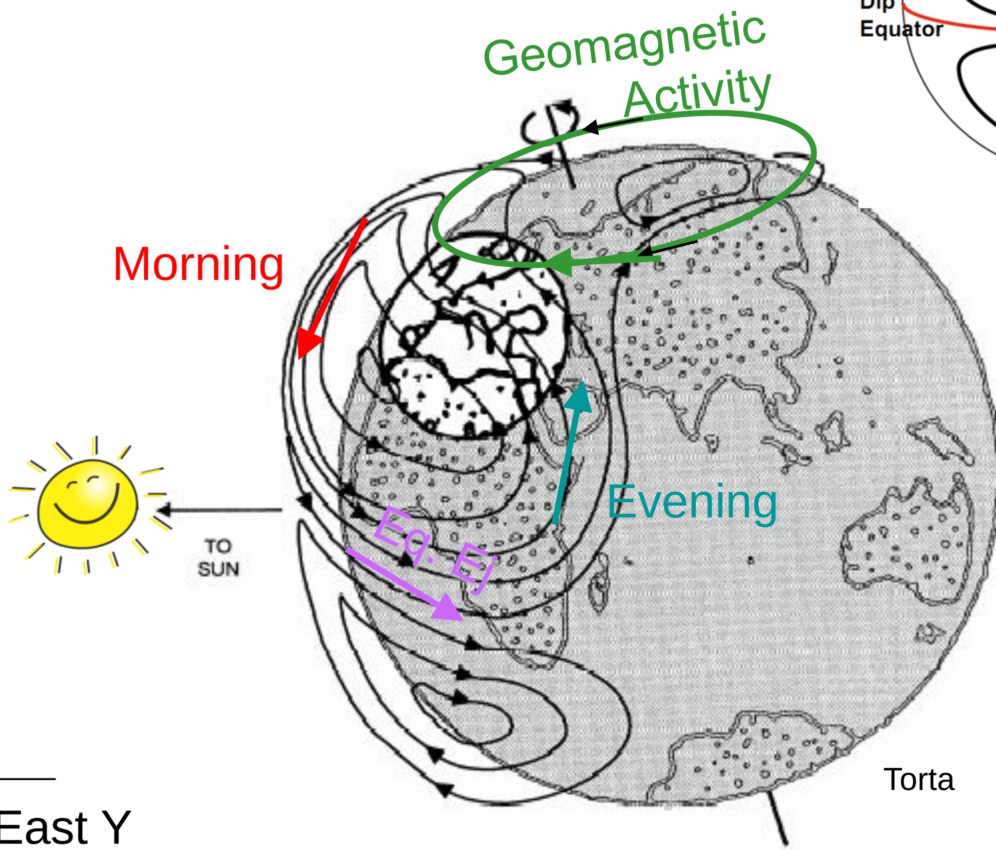
Determining EUV Flux from the magnetic effect of dynamo currents in the E-region of the ionosphere

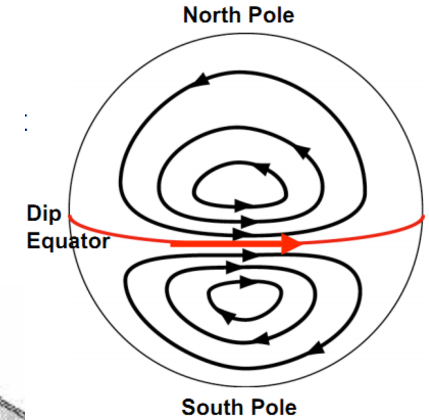
The physics of the boxes is generally well-known

We shall determine the EUV from the magnetic effects

The E-layer Current System







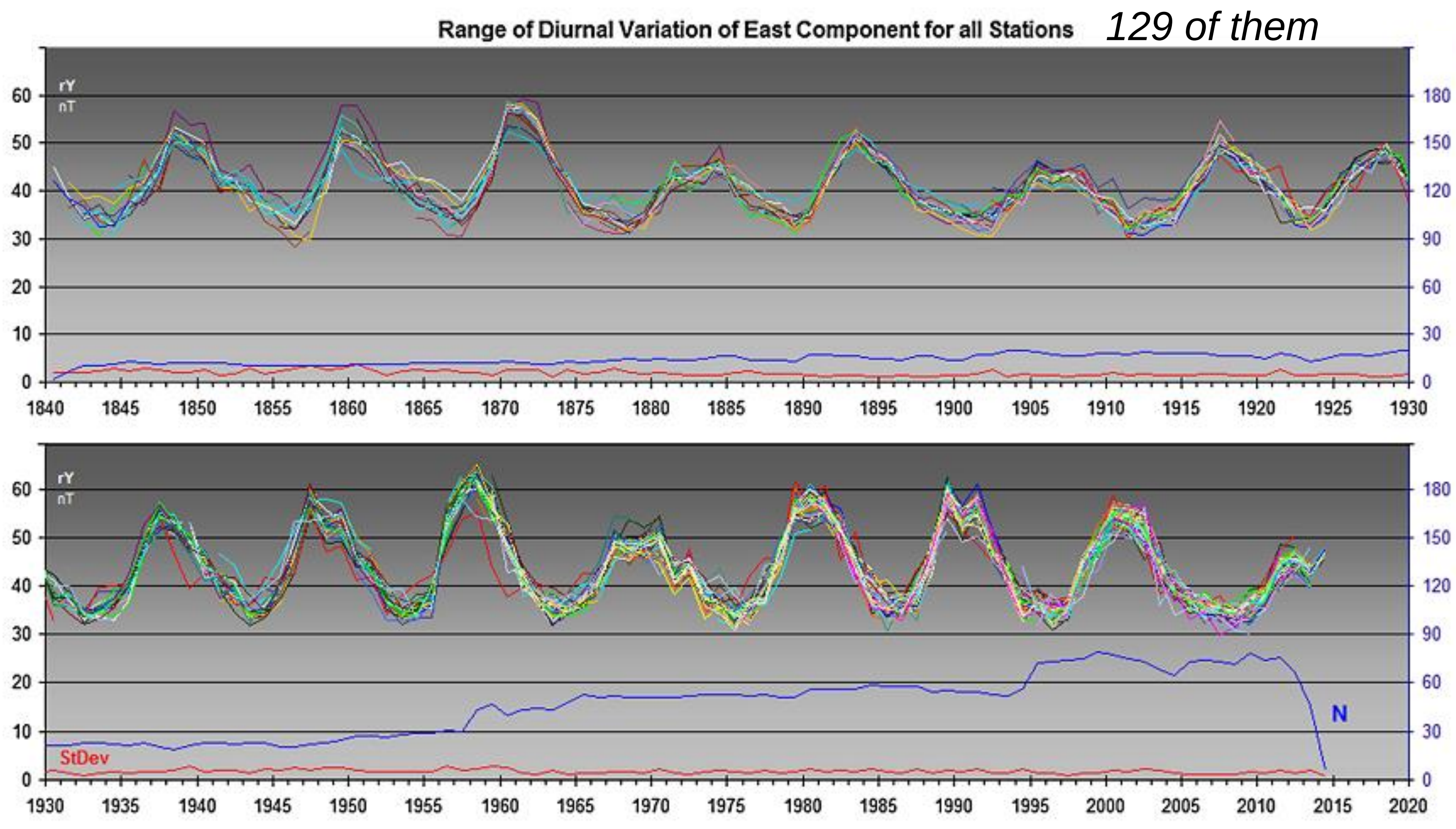
$Y = H \sin(D)$

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

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

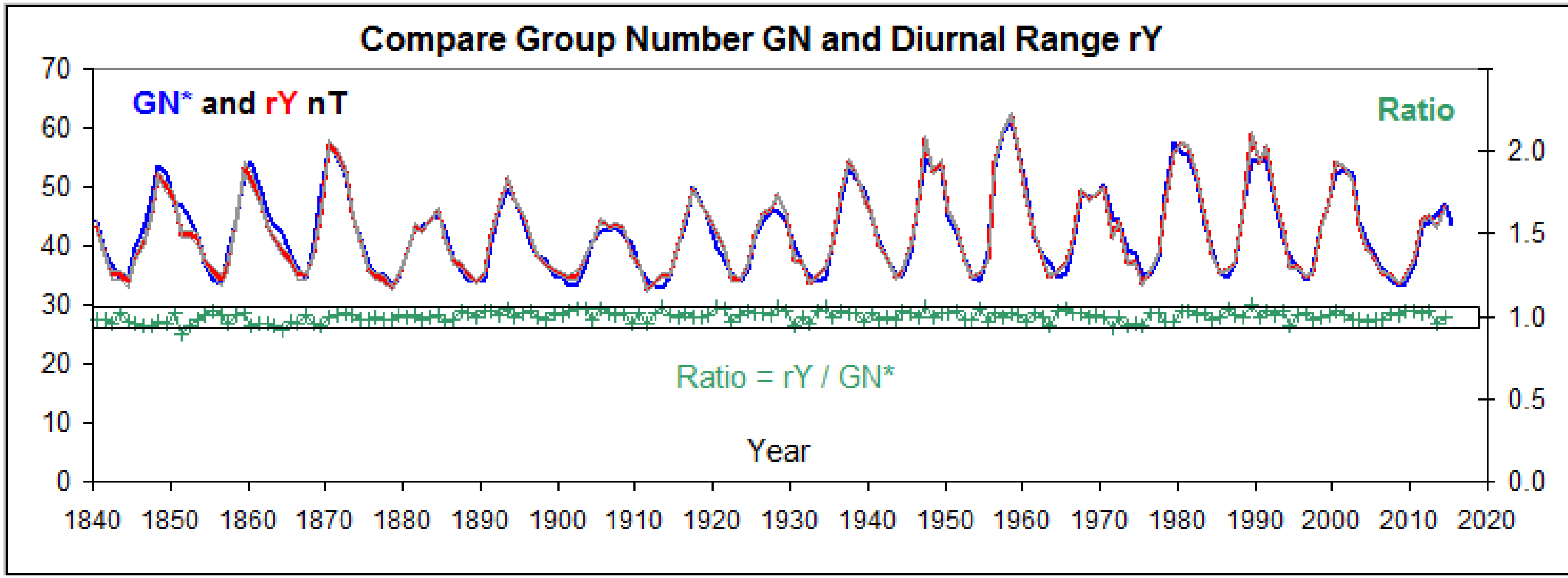
The magnetic effect of this system was what George Graham discovered

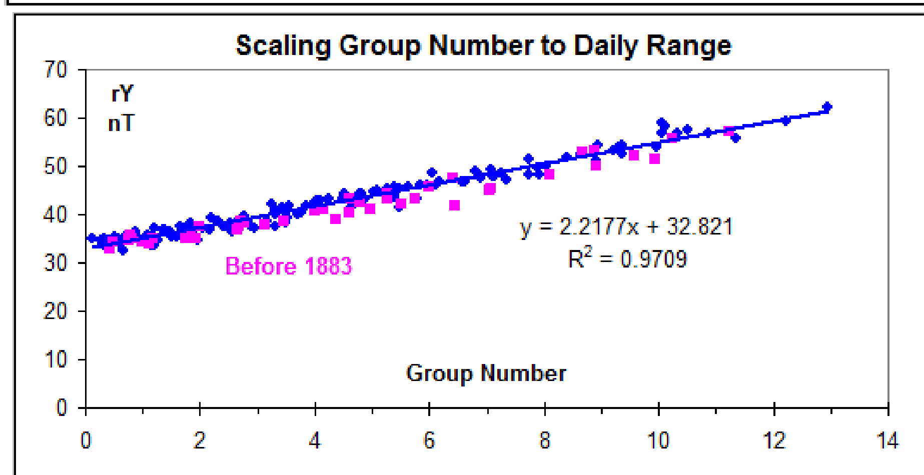
Observed Diurnal Ranges of the Geomagnetic East Component since 1840



We plot the yearly average range to remove the effect of changing solar zenith angle through the seasons. A slight normalization for latitude and underground conductivity has been performed. The blue curve shows the number of stations

The Range (Amplitude) of the Daily Variation Matches that of the Revised Group Numbers





There is a good **linear** relationship between the Daily Range, rY, and the Group Number, GN, allowing us the scale GN to rY. The relationship is not different before [pink squares] and after 1883 [blue dots]. The ratio rY/GN* [green] is unity throughout.

Electron Density due to EVU

< 102.7 nm

$$O_2 + h\nu \xrightarrow{J} O_2^+ + e^-$$

$$O_2^+ + e^- \xrightarrow{\alpha} O + O$$

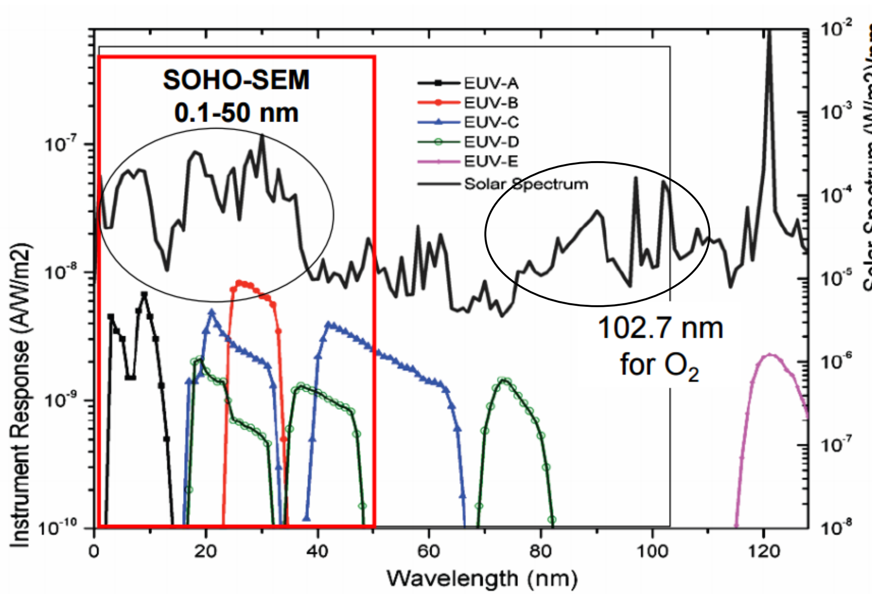
The conductivity at a given height is proportional to the electron number density N_e. In the dynamo region the ionospheric plasma is largely in photochemical equilibrium. The dominant plasma species is $O^+{}_2$, which is produced by photo ionization at a rate J (s^{-1}) and lost through recombination with electrons at a rate α (s^{-1}), producing the Airglow.

The rate of change of the number of ions N_i, dN_i/dt and in the number of electrons N_e, dN_e/dt are given by $dN_i/dt = J \cos(\chi) - \alpha N_i N_e$ and $dN_e/dt = J \cos(\chi) - \alpha N_e N_i$. Because 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 $dN/dt = 0$, so the equations can be written $0 = J \cos(\chi) - \alpha N^2$, and so finally

$$N = \sqrt{(J \alpha^{-1} \cos(\chi))}$$

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

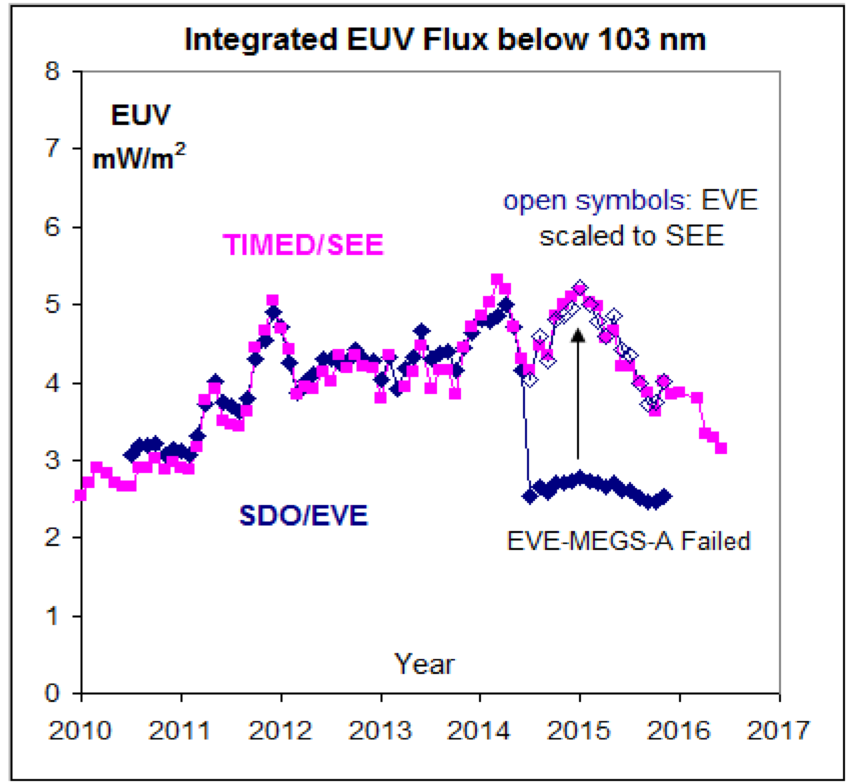
Sources of EUV Data: SEM, SEE, EVE



≤102.7 nm to ionize molecular Oxygen

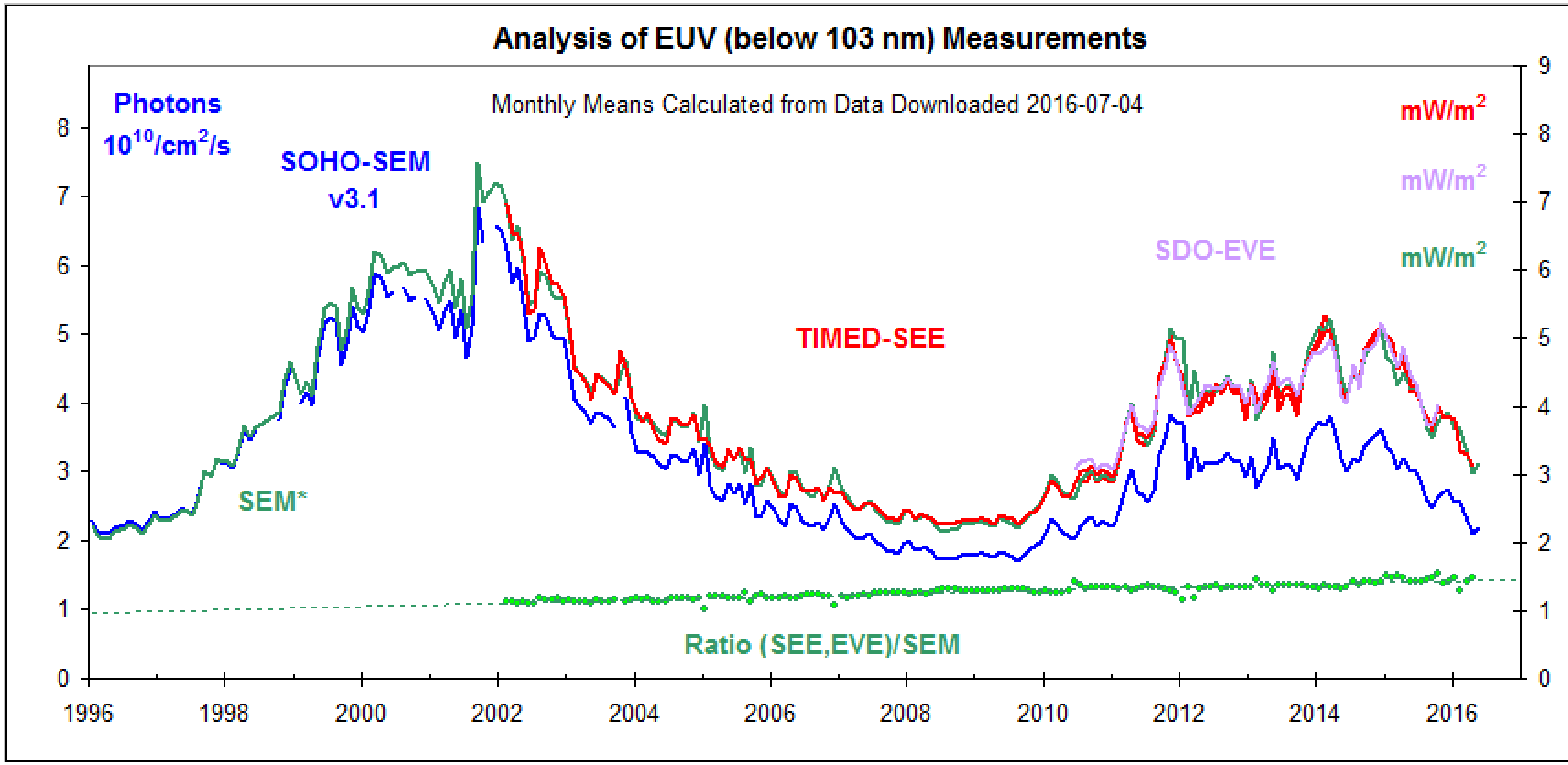
$$O_2 + h\nu \xrightarrow{J} O_2^+ + e^-$$

This reaction creates and maintains the conducting E-region of the Ionosphere (at ~105 km altitude)



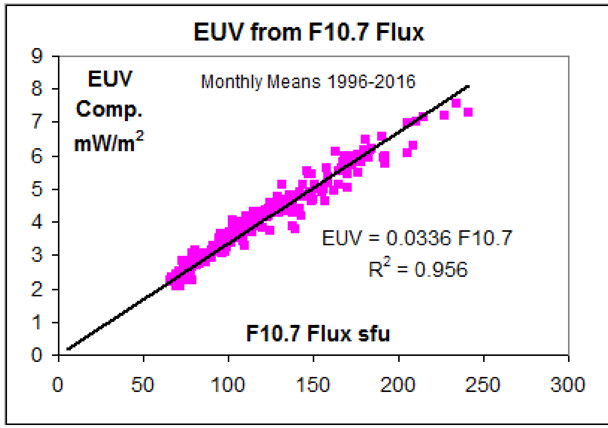
The detectors on the TIMED and SDO satellites agree well until the failure of the high-energy detector on EVE in 2014. We can still scale to earlier levels [open symbols]. 2016 not yet corrected.

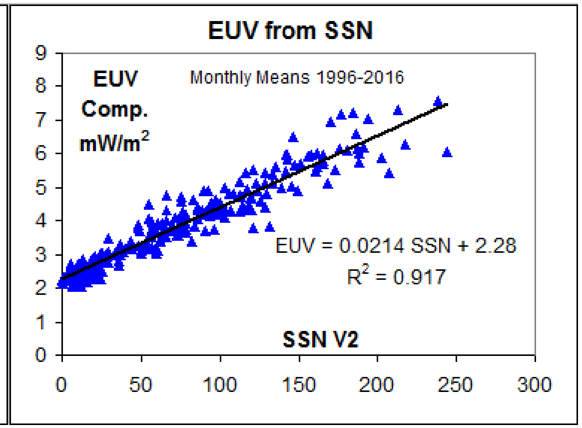
Creating an EUV (<103 nm) Composite



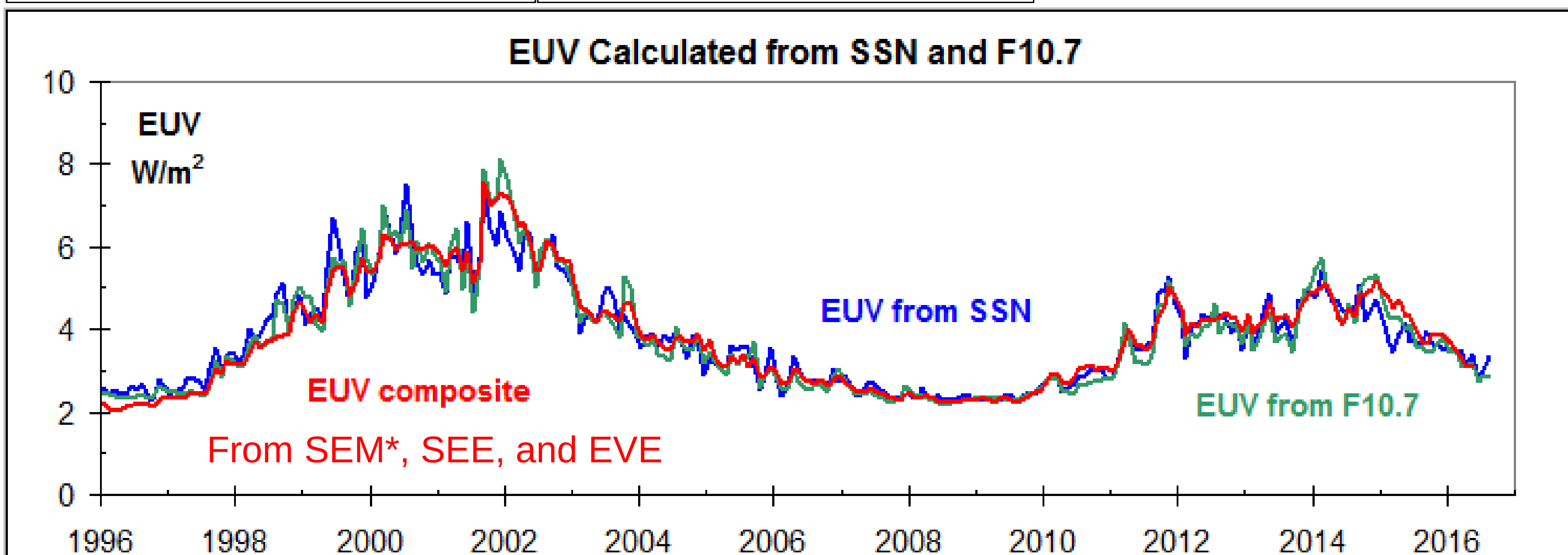
SEE and EVE agree nicely and we can form a composite (SEE,EVE) of them. SEM is on a different scale, but we can convert that scale to the scale of (SEE,EVE). The scale factor [green line] shows what to scale SEM with to match (SEE,EVE) [SEM*, upper green curve], to get a **composite** of all three (SEM*,SEE,EVE) covering 1996-2016, in particular the two minima in 1996 and 2008.

EUV Composite Matches F10.7 and Sunspot Numbers

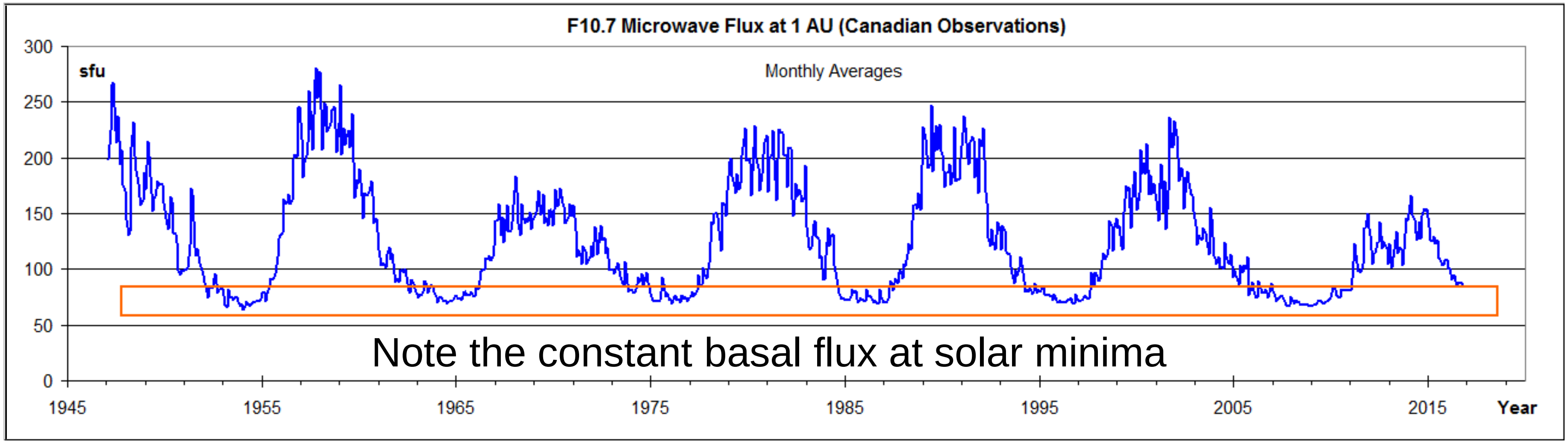


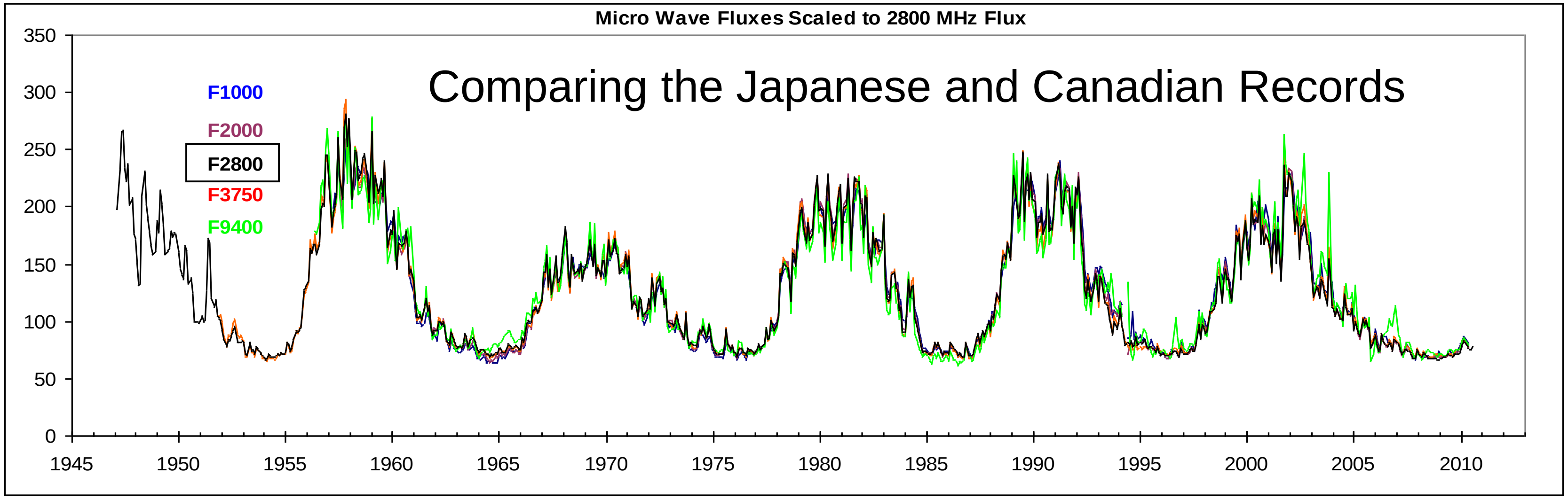


So, we can calculate the EUV flux both from the Sunspot Number and from the F10.7 flux which then is a good proxy for EUV [as is well-known].

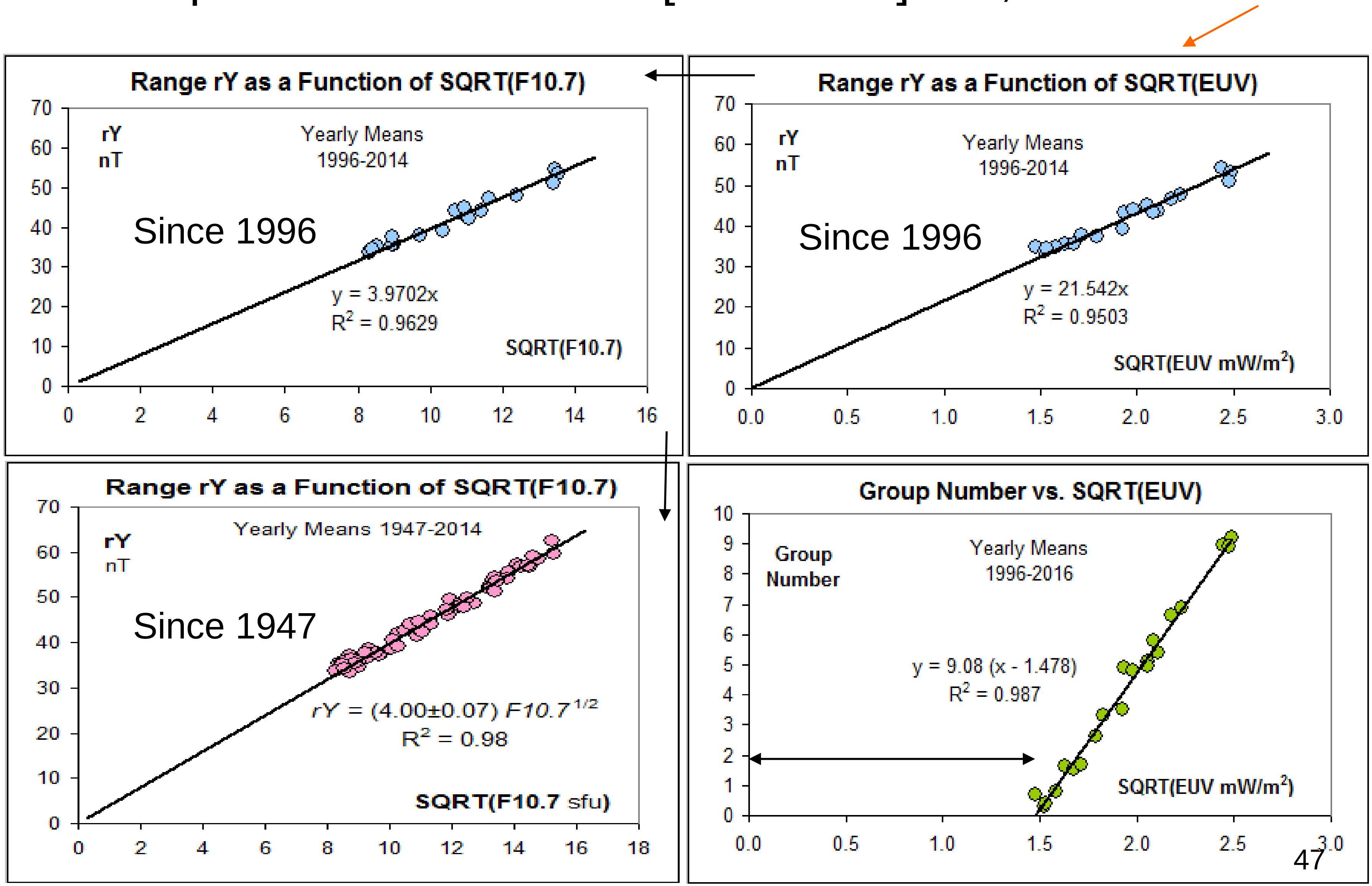


The Japanese and Canadian F10.7 Microwave Records agree

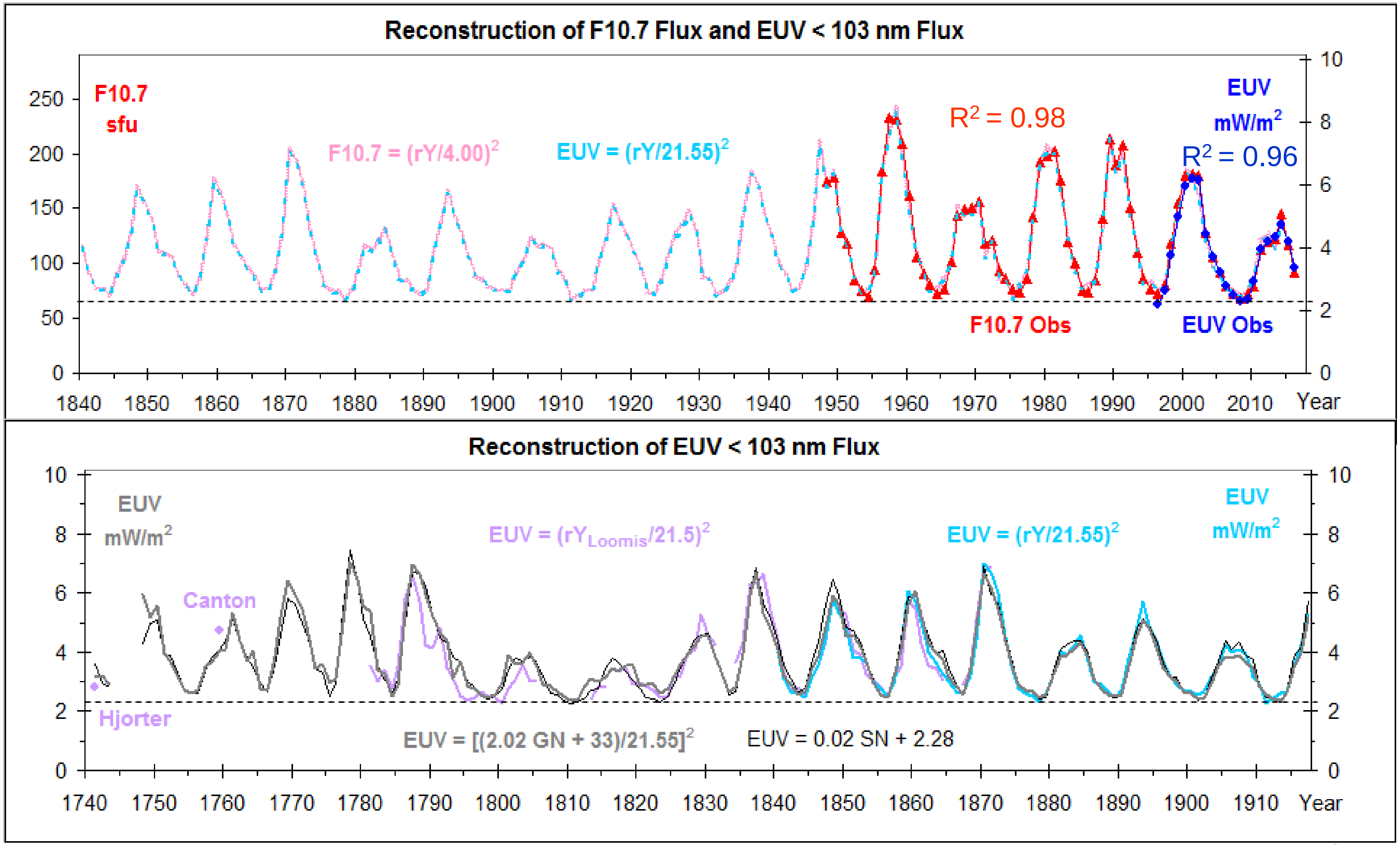




Theory tells us that the conductivity [and thus rY] should vary as the square root of the EUV [and F10.7] flux, and so it does:

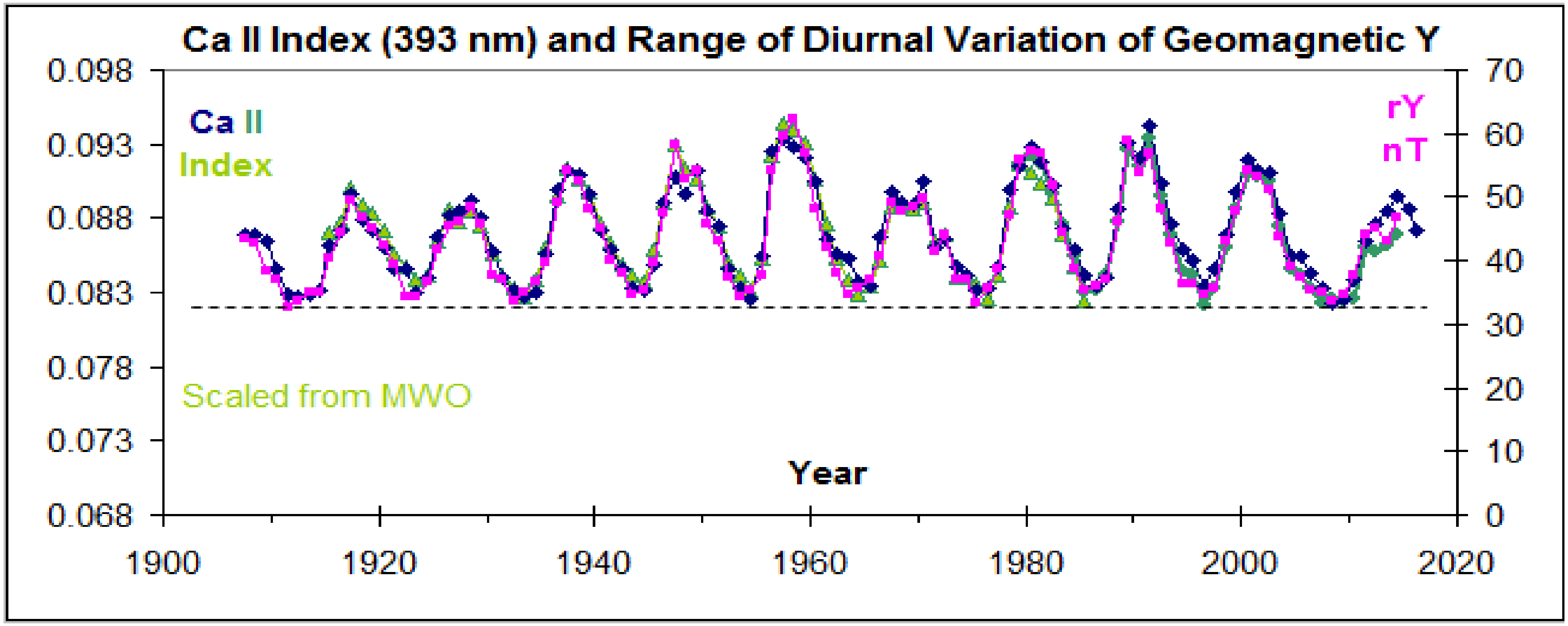


Reconstructions of EUV and F10.7



Note the constant basal level at *every* solar minimum

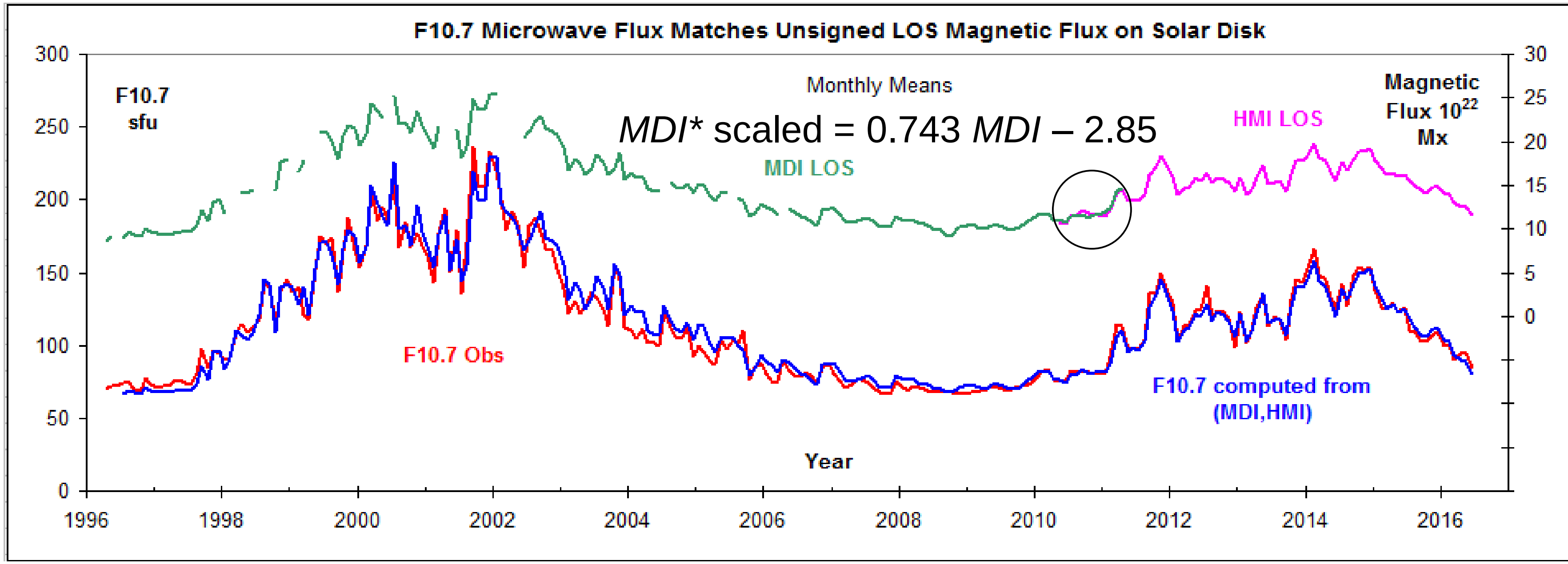
The Ca II Index Shows the Same Basal Floor at Minima as rY and EUV

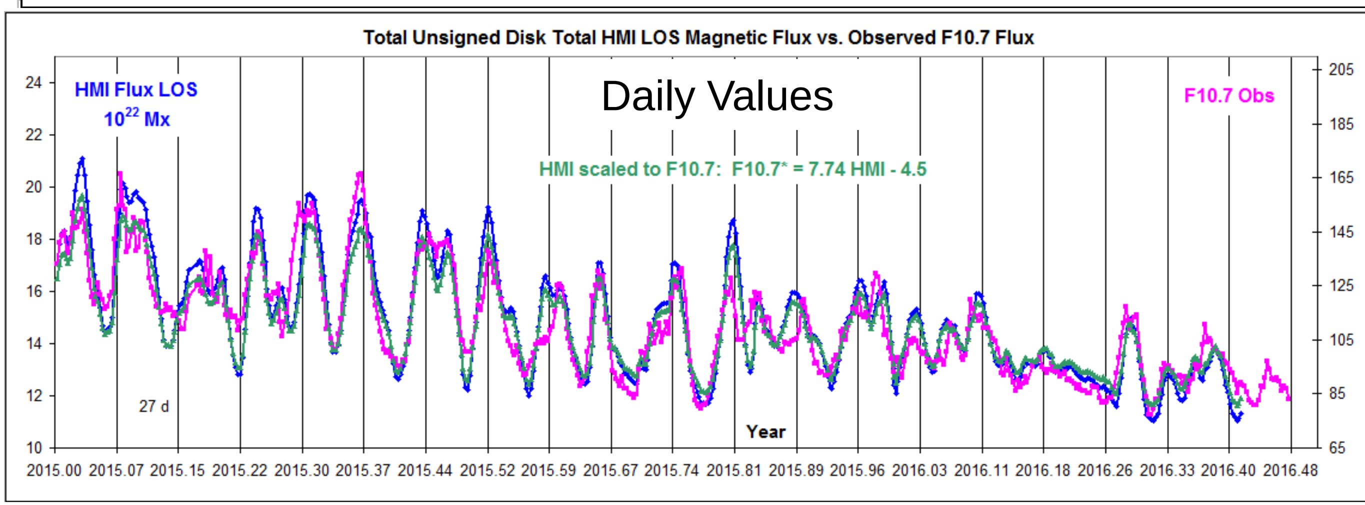


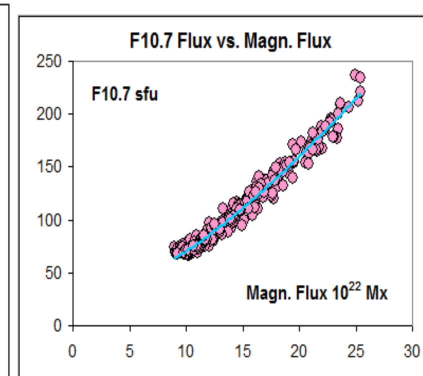
The long-term **Ca** II Index is constructed from Kodaikanal, Sacramento Peak, and SOLIS/ISS data [Luca Bertello, NSO]. Data from Mount Wilson [**Green**] has been scaled to the Kodaikanal series. Calibration of the old spectroheliograms is a difficult and on-going task.

Bottom Line: All our solar indices show that solar activity [magnetic field] is constant at every solar minimum. [except for *tiny* SSN residual variation]

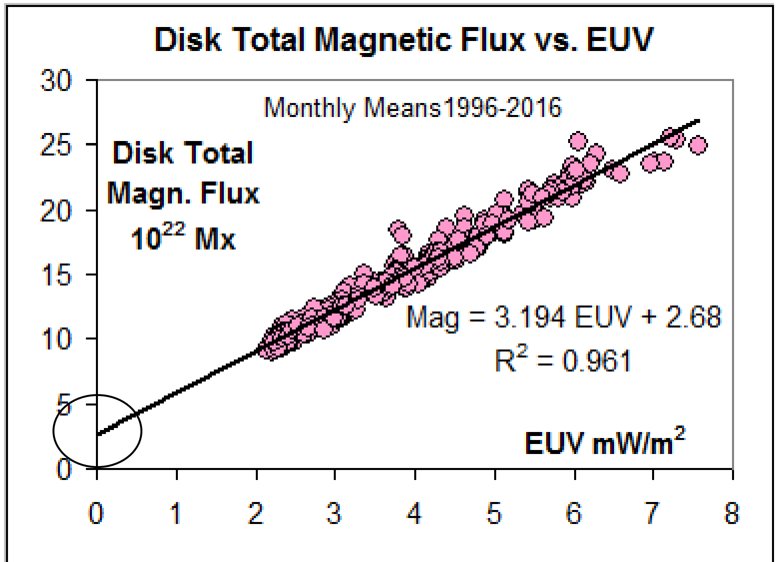
Magnetic Flux from MDI and HMI Match F10.7 Microwave Flux

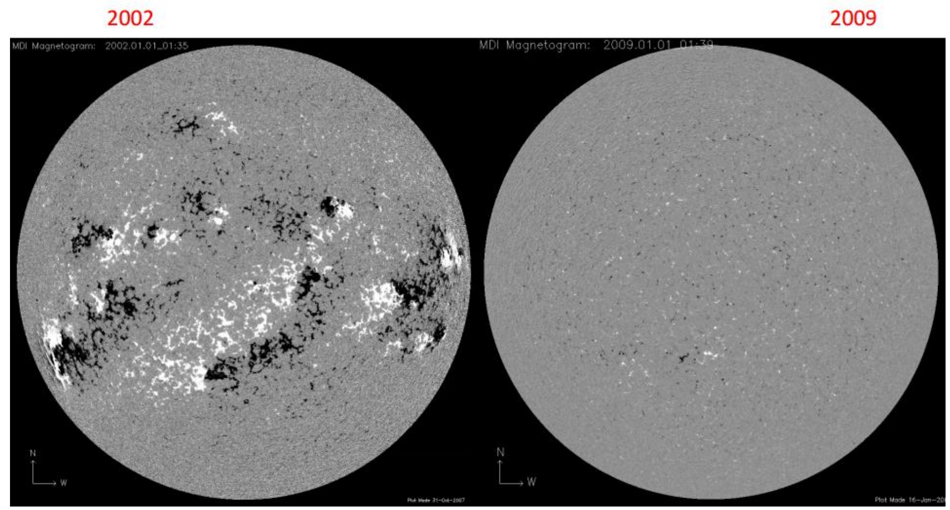




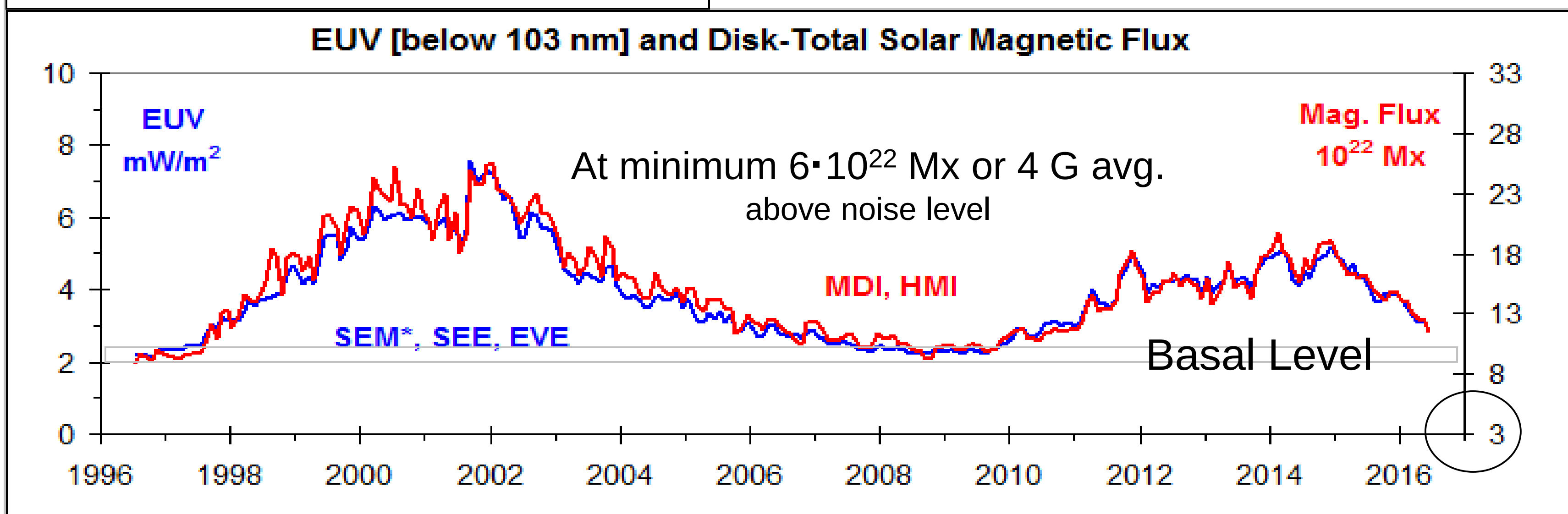


EUV Follows Total Unsigned Magnetic Flux



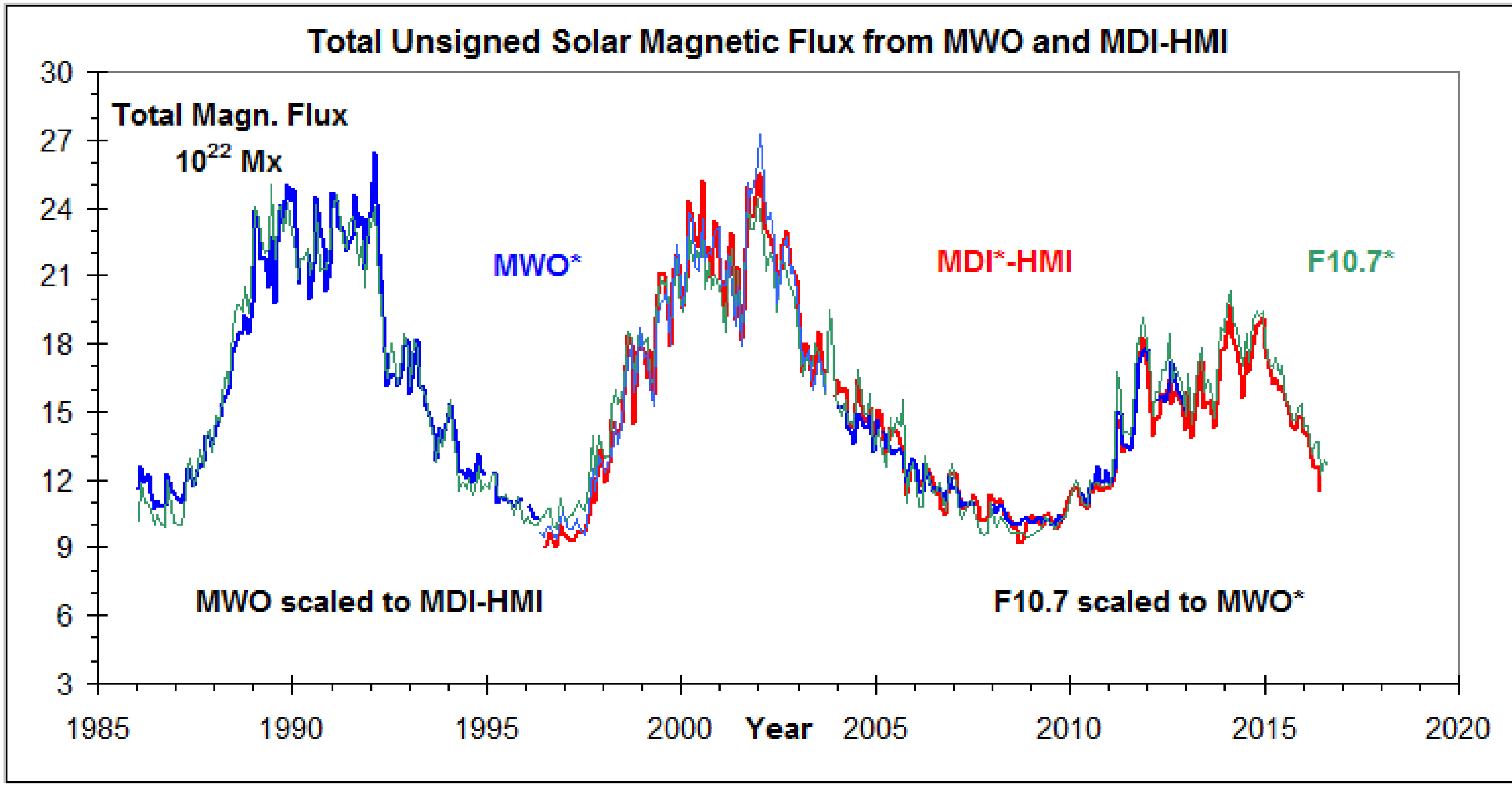


Offset interpreted as Noise Level ≈ 3·10^{22} Mx



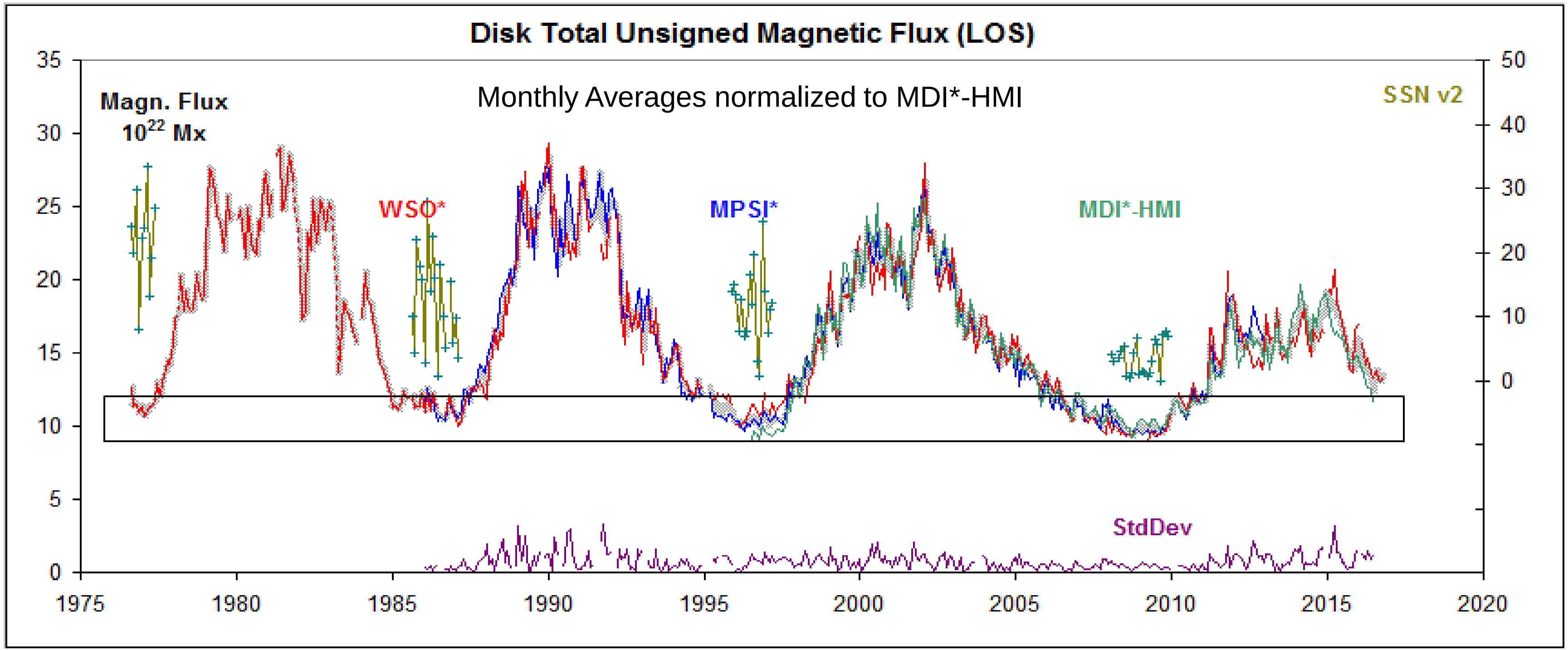
There is a ‘basal’ level at solar minima. Is this the case at every minimum?

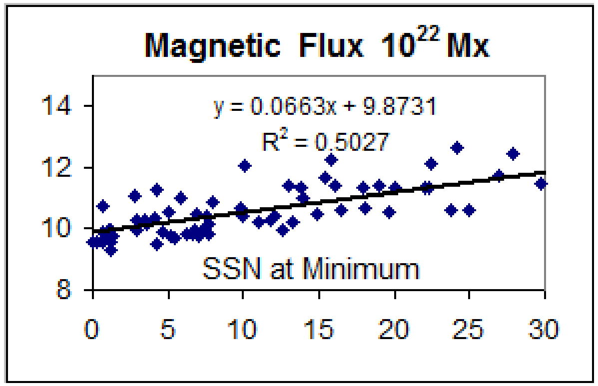
Magnetic Flux from MWO Tracks MDI-HMI and the F10.7 Flux



MWO magnetic flux from digital magnetograms can be put on the MDI-HMI scale and, just as MDI-HMI, tracks the F10.7 flux very well.

WSO: Magnetic Flux back to 1976





The Wilcox Solar Observatory and the Mount Wilson Observatory give us a longer baseline. A very slight decrease with time of the flux at solar minimum is probably due to the effect of decreasing residual sunspot number [if not instrumental]. Note the ‘floor’ at solar minimum.

The Floor: This Observational **Fact** is Not New

THE AMERICAN JOURNAL OF SCIENCE AND ARTS. Second Series

ART. XVI.-Comparison of the mean daily range of the Magnetic Declination, with the number of Auroras observed each year, and the extent of the black Spots on the surface of the Sun, by ELIAS LOOMIS, Professor of Natural Philosophy in Yale College. Vol. L, No.149. Sept.1870, pg 160.

This comparison seems to warrant the following propositions:

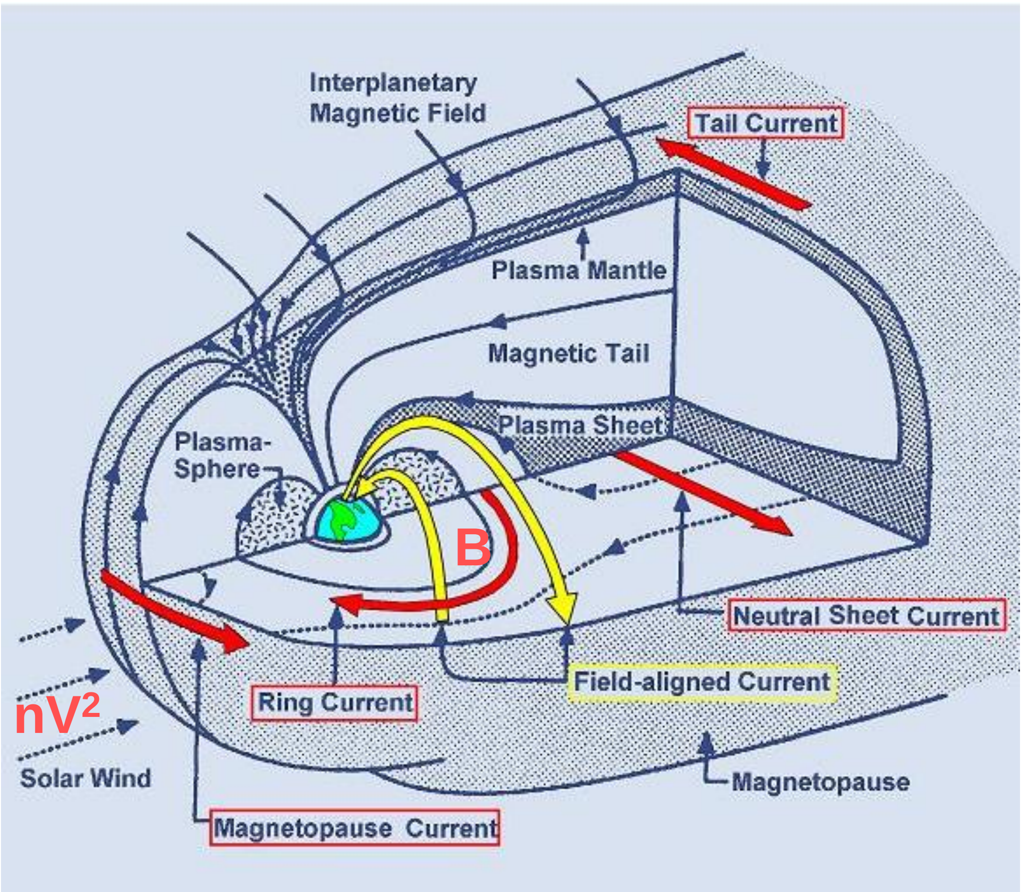
1. A diurnal inequality of the magnetic declination, amounting at Prague to about six minutes, is independent of the changes in the sun's surface from year to year.

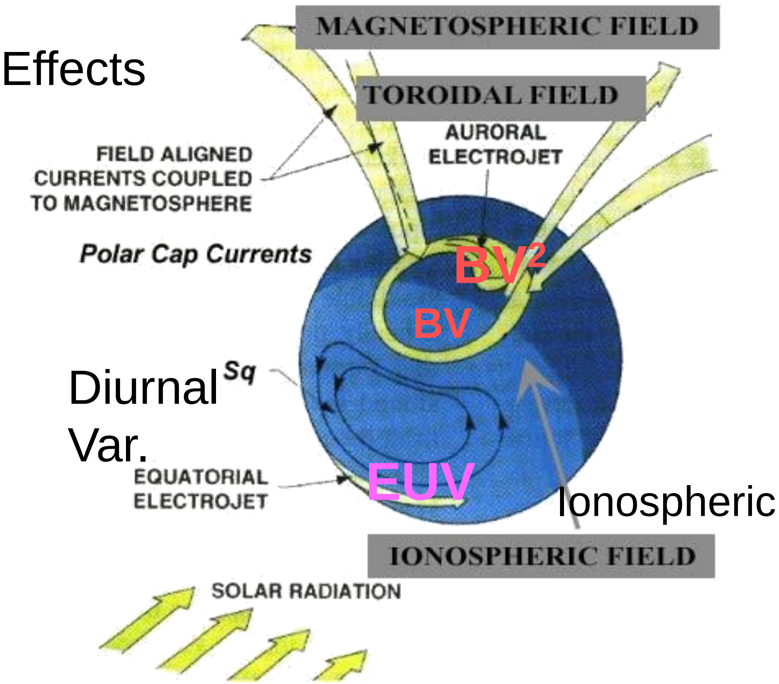
2. The excess of the diurnal inequality above six minutes as observed at Prague, is almost exactly proportional to the amount of spotted surface upon the sun, and may therefore be inferred to be produced by this disturbance of the sun's surface, or both disturbances may be ascribed to a common cause.

19th century 'Inequality' = deviation from [i.e. 'not equal to'] the mean

Electric Current Systems in Geospace

Different Current Systems ⇄ Different Magnetic Effects





Oppositely charged particles trapped in the Van Allen Belts drift in opposite directions giving rise to a net westward ‘Ring Current’.

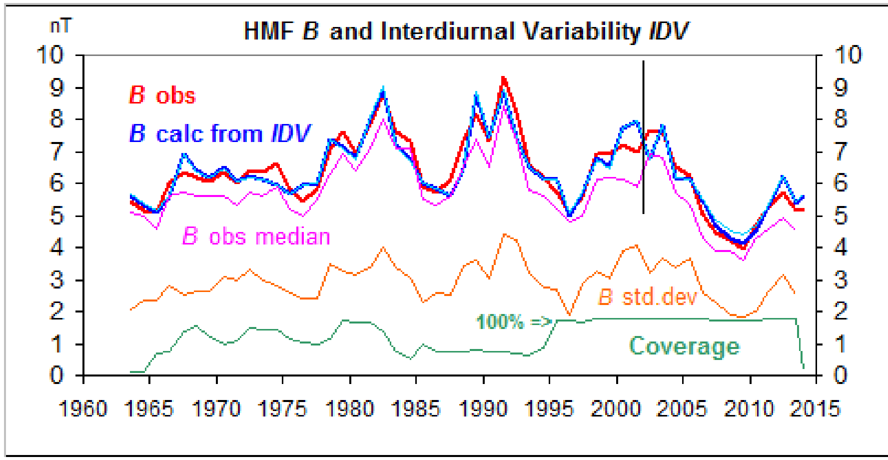
The IDV and Dst magnetic indices are good proxies for that current and thus for the magnetic field **B** in space

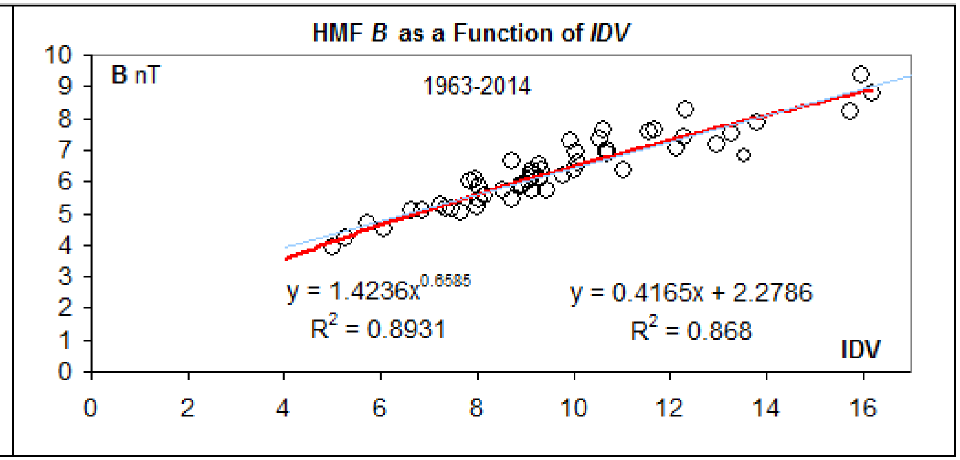
We can now invert the Solar Wind – Magnetosphere relationships…

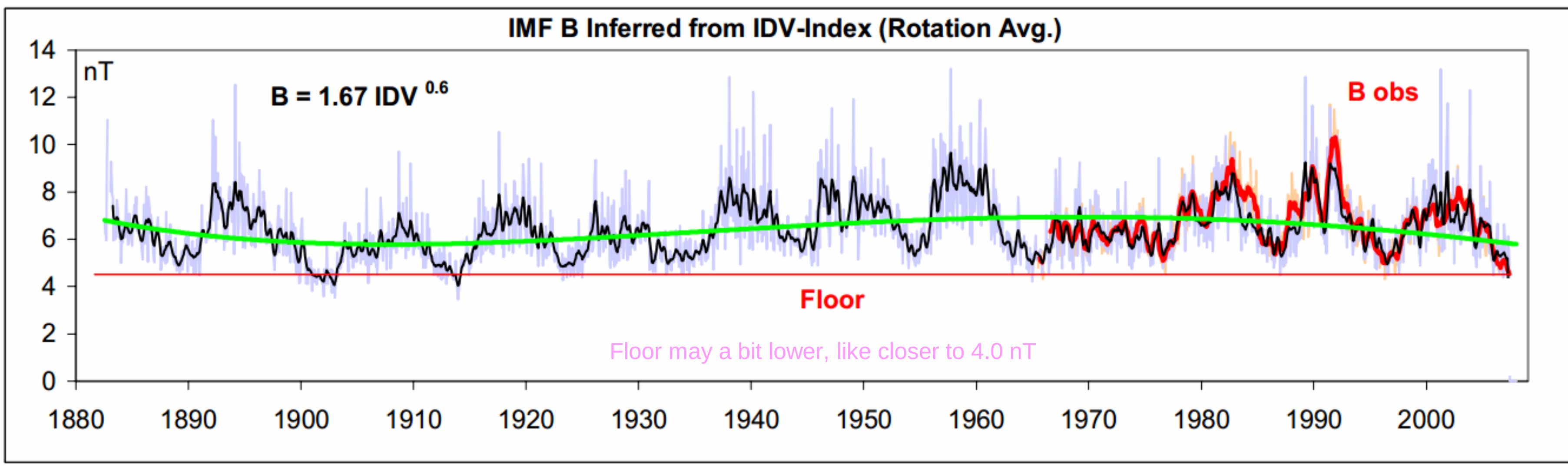
Examples of High Solar Wind B and Geomagnetic Activity A

$$A = k\, q(a,f)\,(B\,V)\,(n\,V^2)^{1/3} \;\sim B\,V^2$$

Relationship between HMF *B* and *IDV*

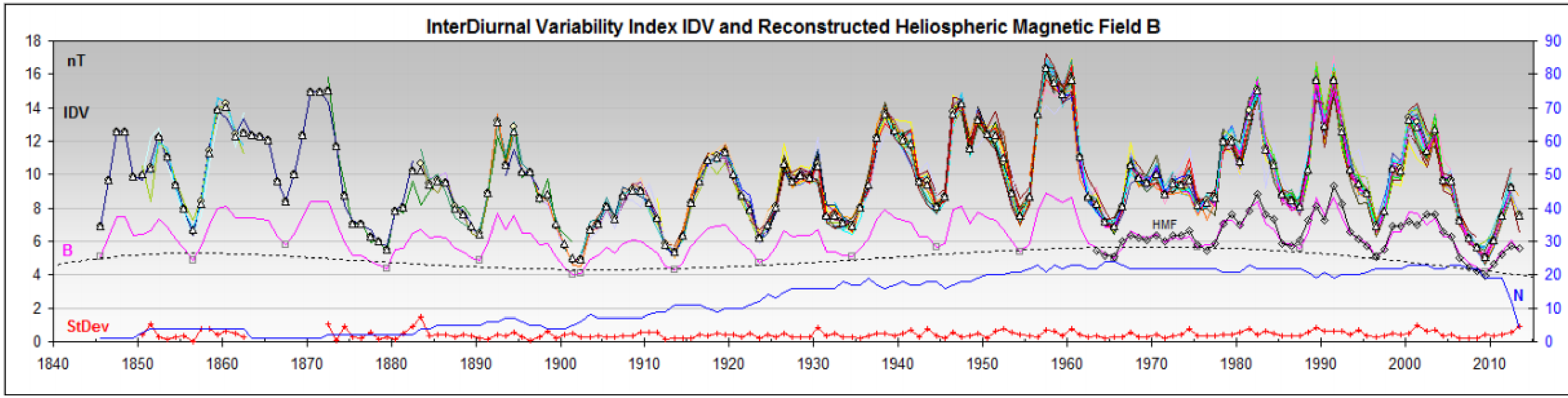


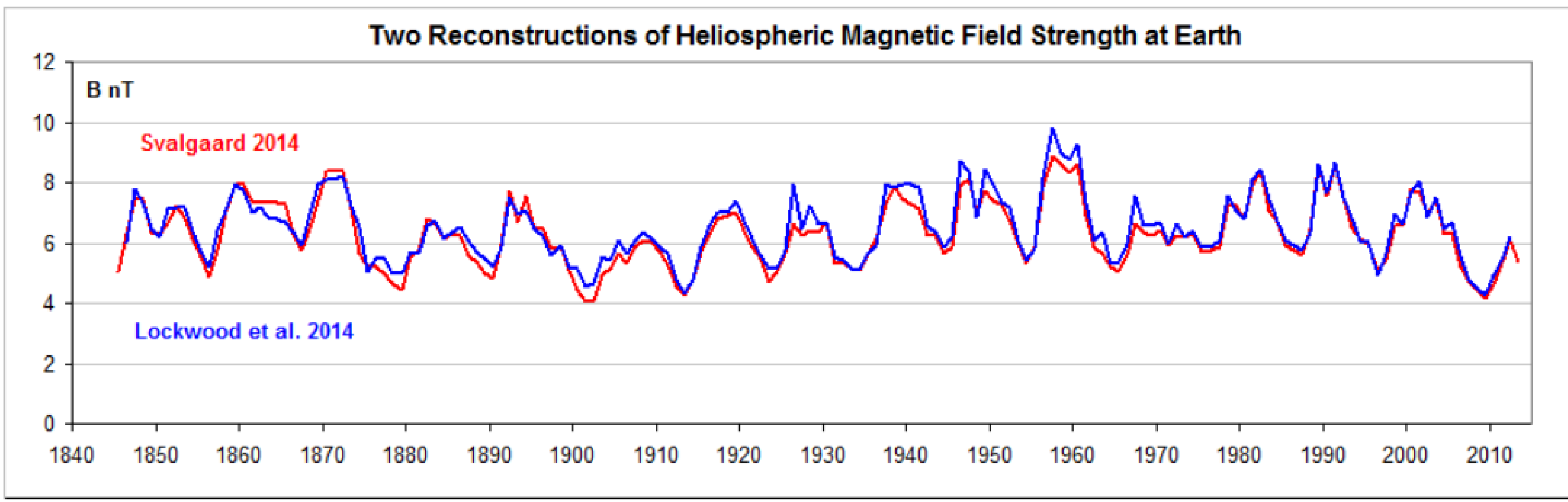




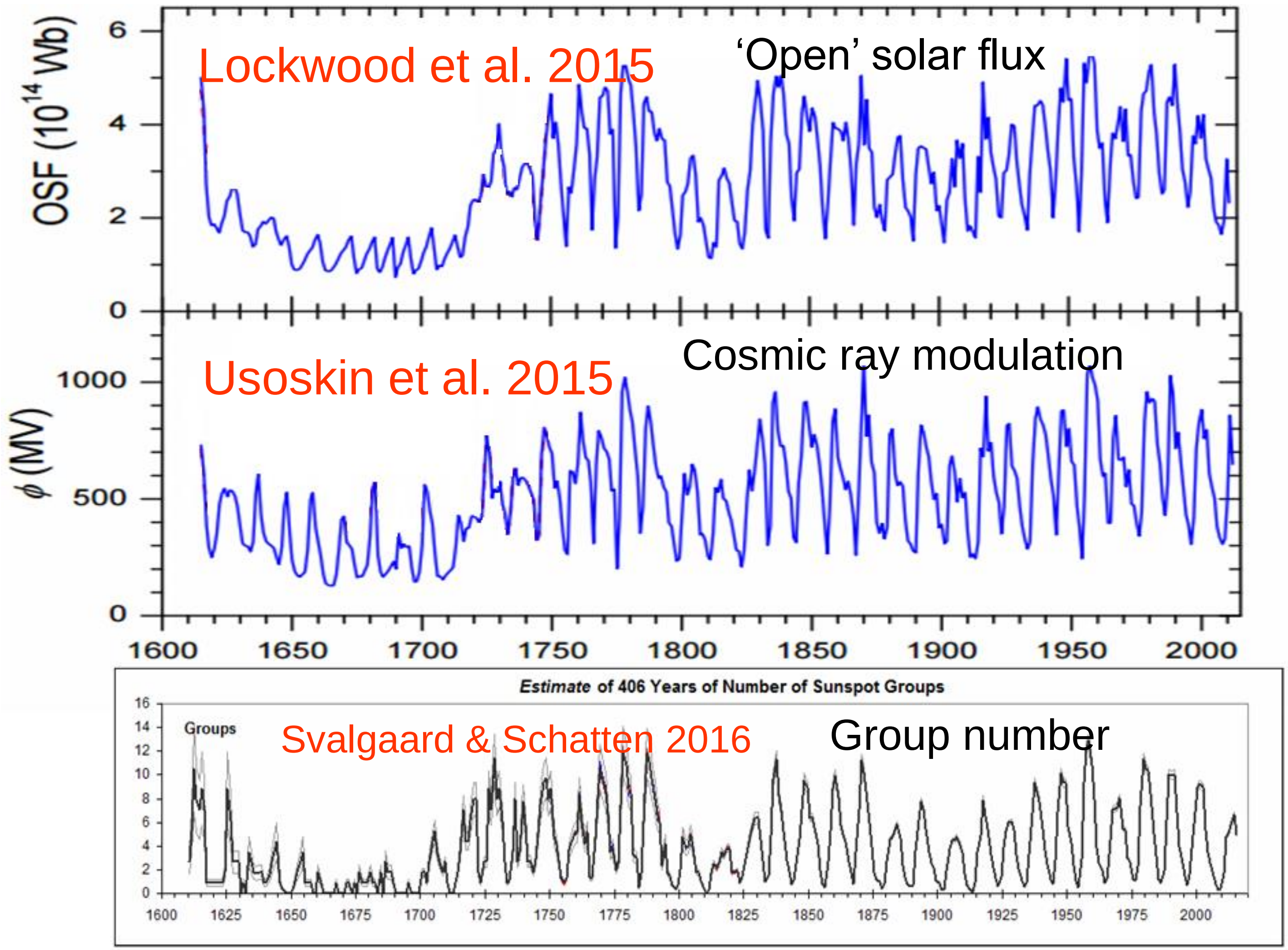
Also holds on timescales shorter than one year

Applying the relationship we can reconstruct HMF magnetic field B with Confidence:





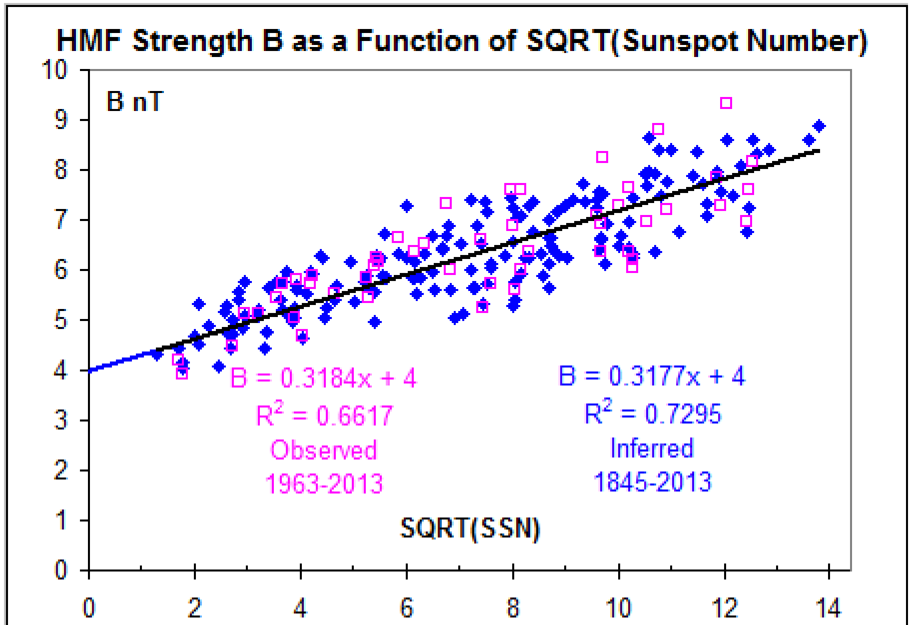
Putting it All Together (Real Progress!)



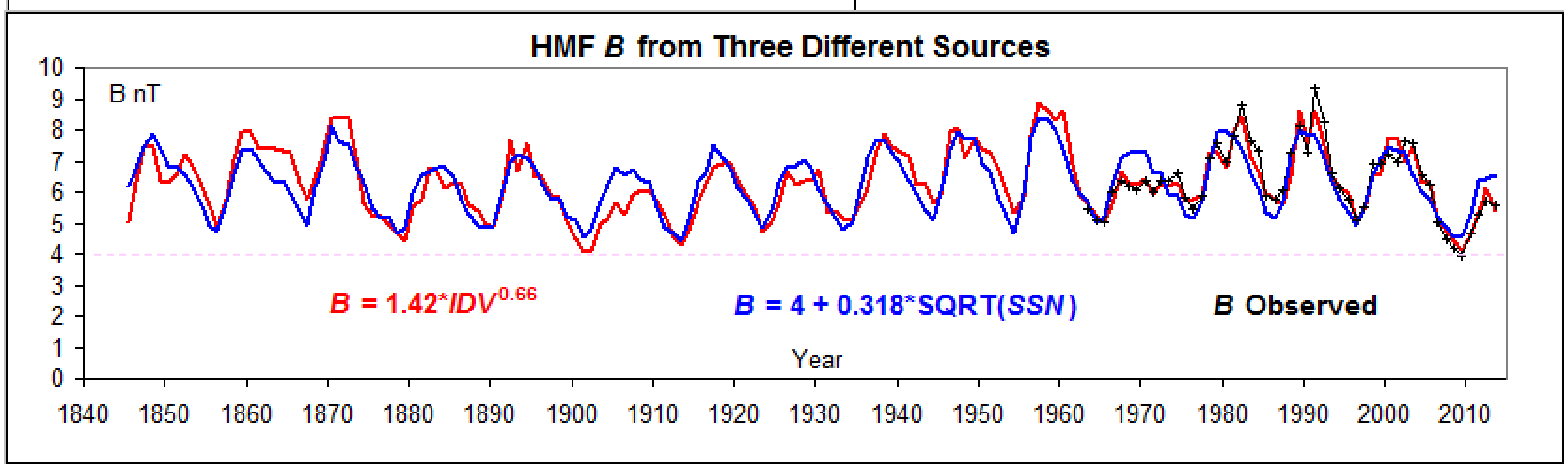
Very good agreement between different reconstructions.

Full Disclosure: There is still a rear-guard debate about the early record

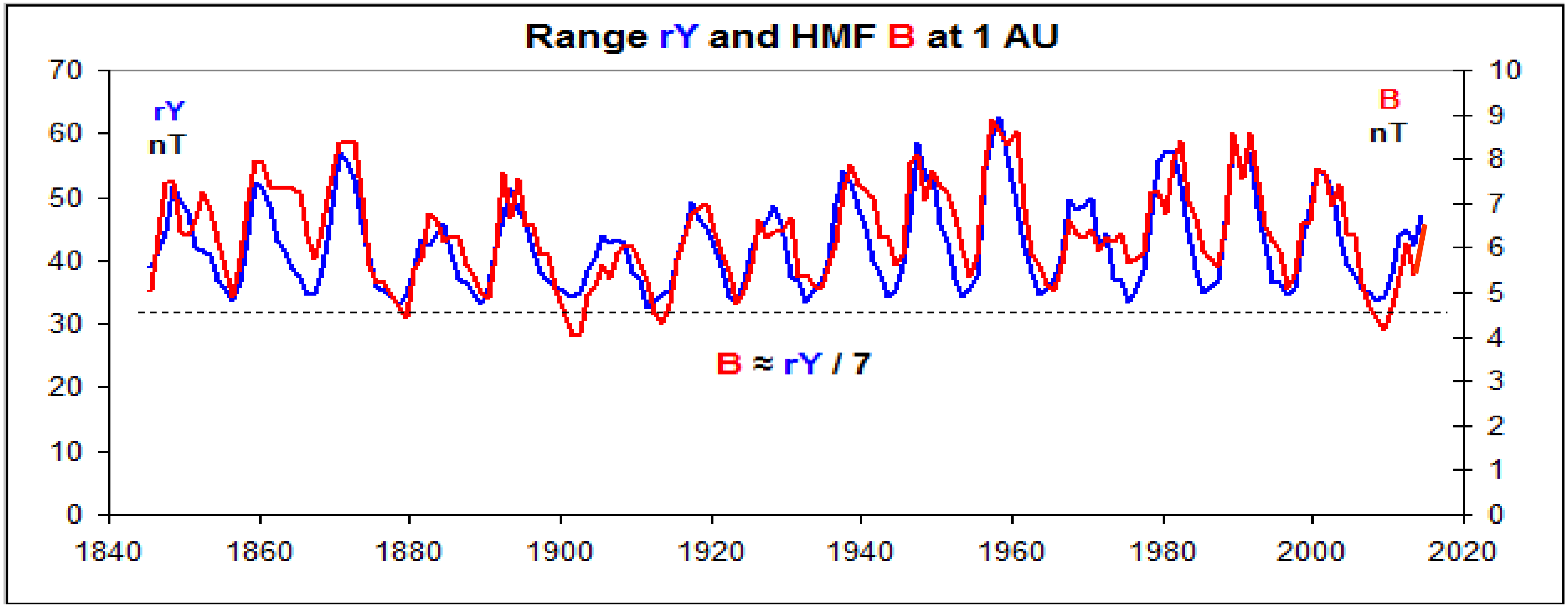
HMF *B* related to Sunspot Number



The main sources of the equatorial components of the Sun's large-scale magnetic field are large active regions. If these emerge at random longitudes, their net equatorial dipole moment will scale as the square root of their number. Thus their contribution to the average HMF strength will tend to increase as $SSN^{1/2}$ (see: Wang and Sheeley [2003]; Wang et al. [2005]).



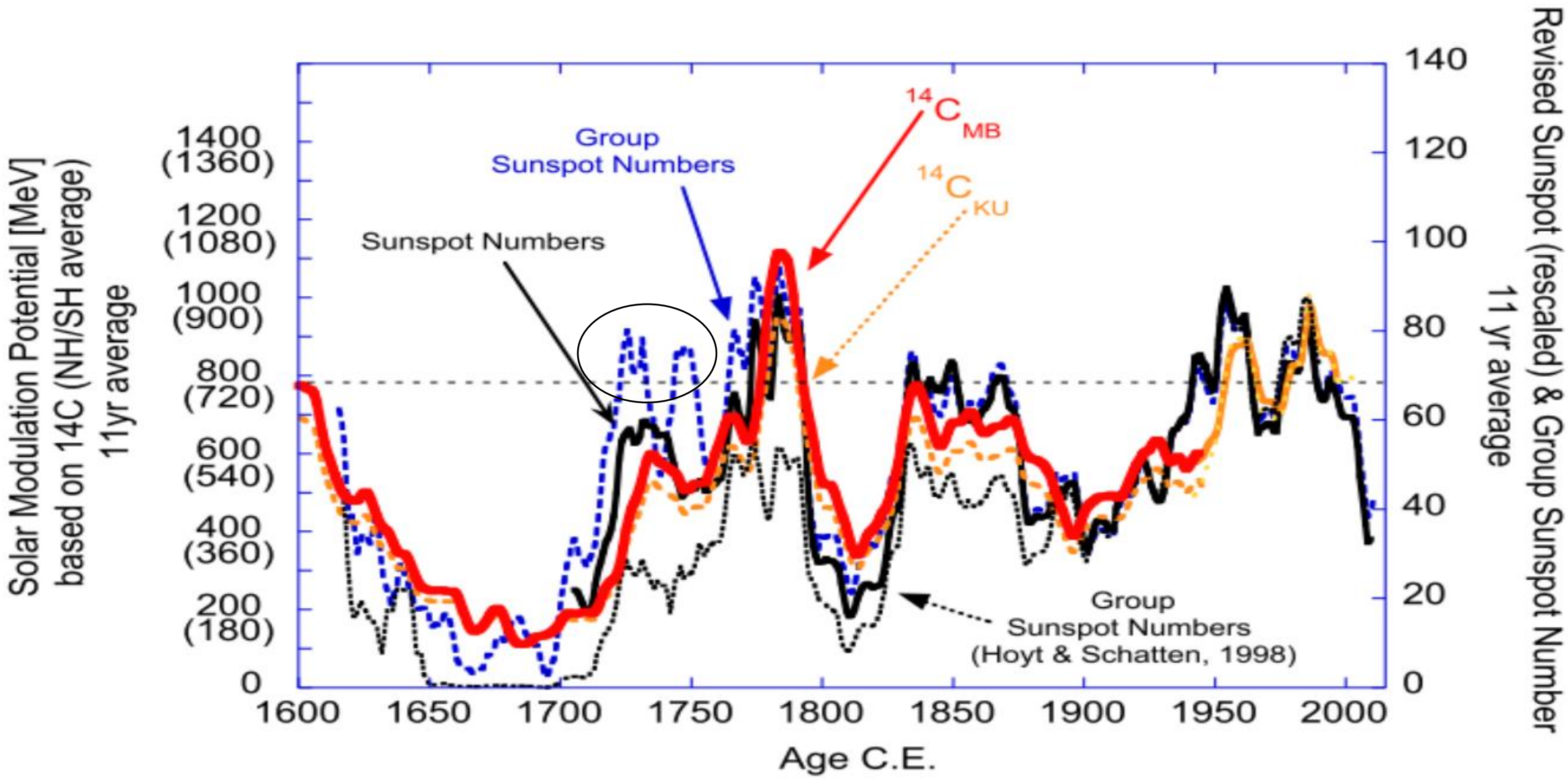
Network Field and Solar Wind Field



The magnetic field in the solar wind (the Heliosphere) ultimately arises from the magnetic field on the solar surface filtered through the corona, and one would expect an **approximate** relationship between the network field (EUV and rY) and the Heliospheric field, as observed.

For both proxies we see that there is a constant ‘floor’ upon which the magnetic flux ‘rides’. I see no good reason that the same floor should not be present at all times, even during a Grand Minimum.

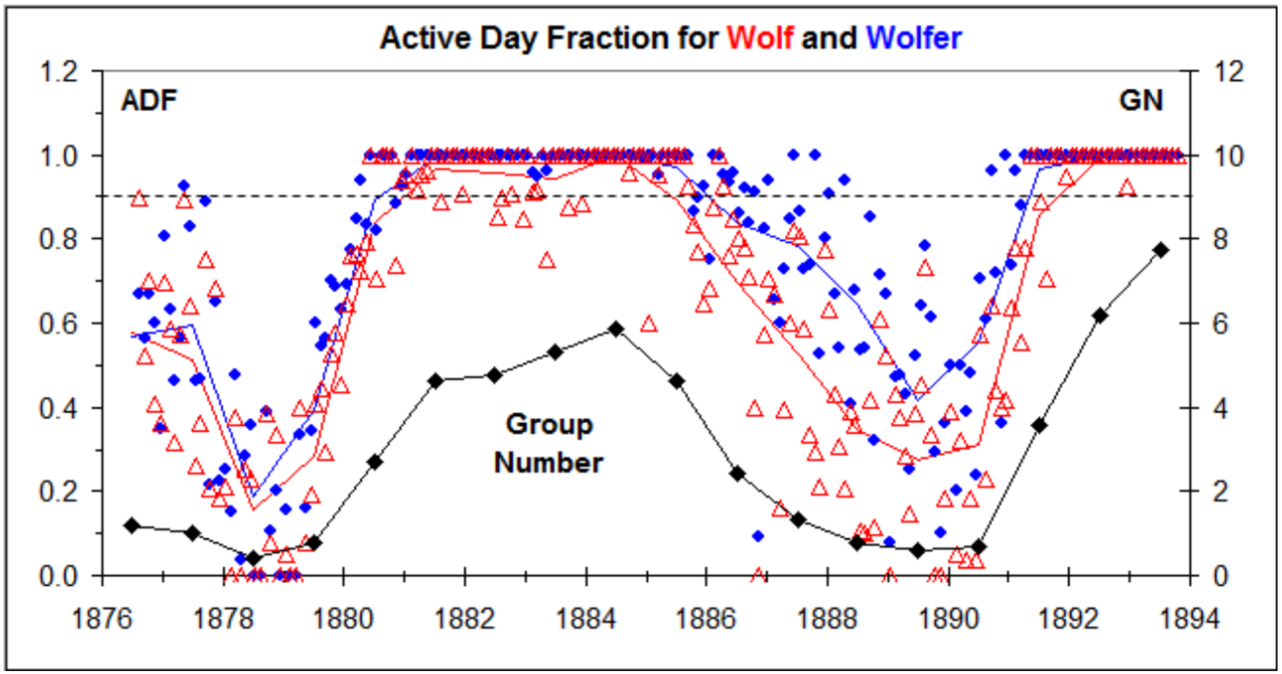
Cosmic Rays Proxies Agree with the New Sunspot Group Series



Muscheler et al. [2016]

The Active-Days-Fraction Method

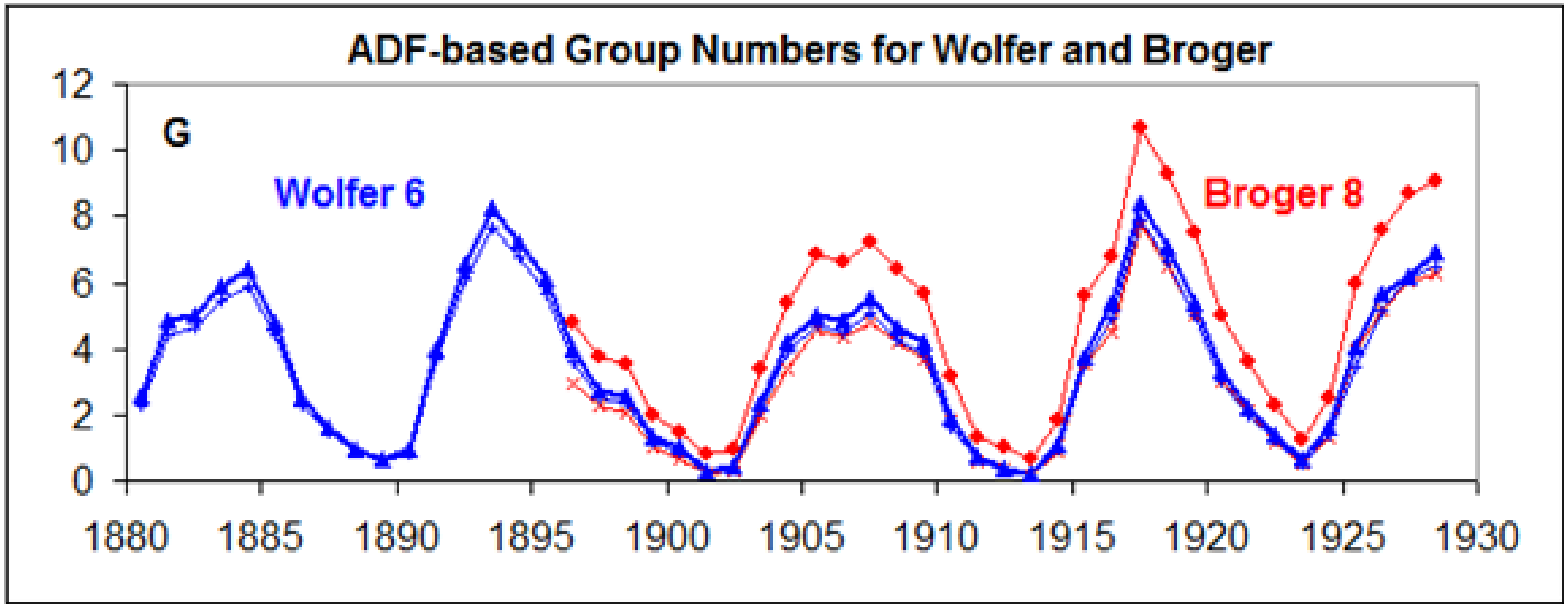
Usoskin et al. [2016] suggest using the ratio between the number of days per month when at least one group was observed and the total number of days with observations. This Active Days Fraction, ADF, is assumed to be a measure of the 'quality' of each observer given by an observational threshold area, *S*, on the solar disk of all the spots in a group (s)he can see.



Information gleaned from low-activity times must be extrapolated to cover solar maxima under the hard-to-verify assumption that the extrapolation is valid regardless of activity, instrument, and counting rules.

The problem is that at solar maximum every day is an 'Active Day' so ADF cannot be used. This 'information shadow' obscures activity when it is most needed

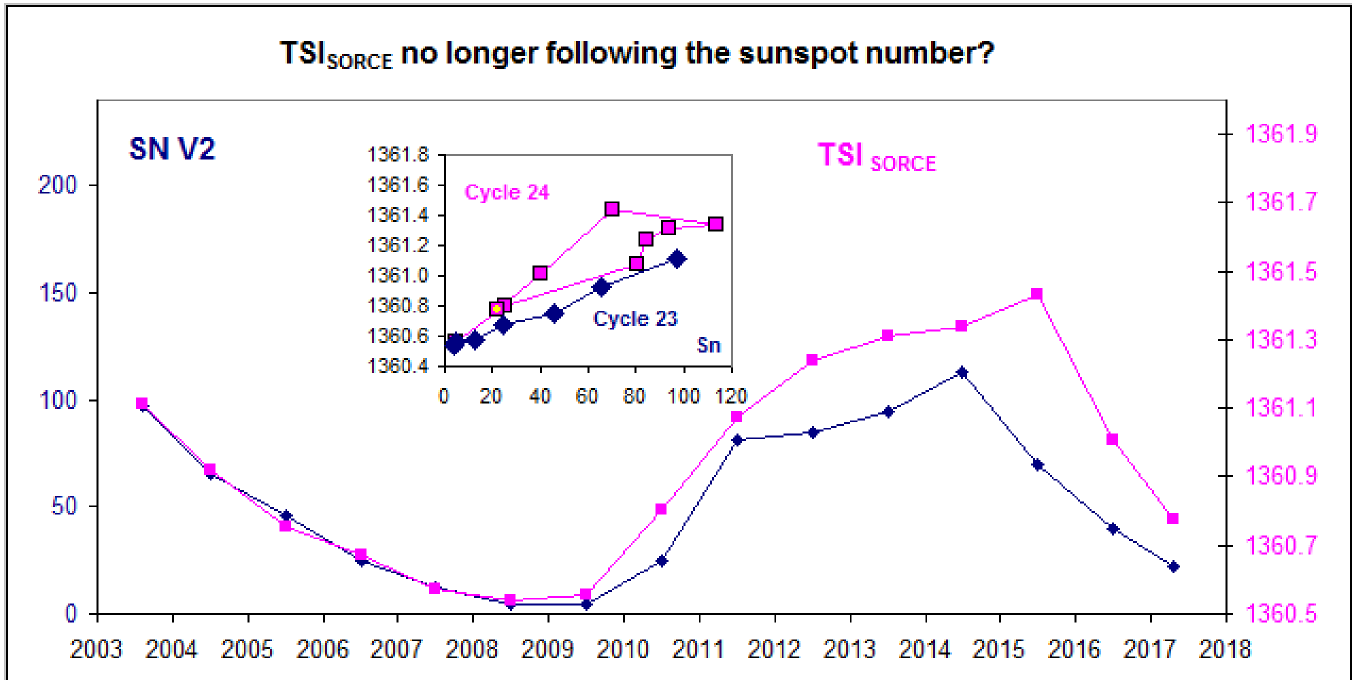
ADF Fails for Equivalent Observers

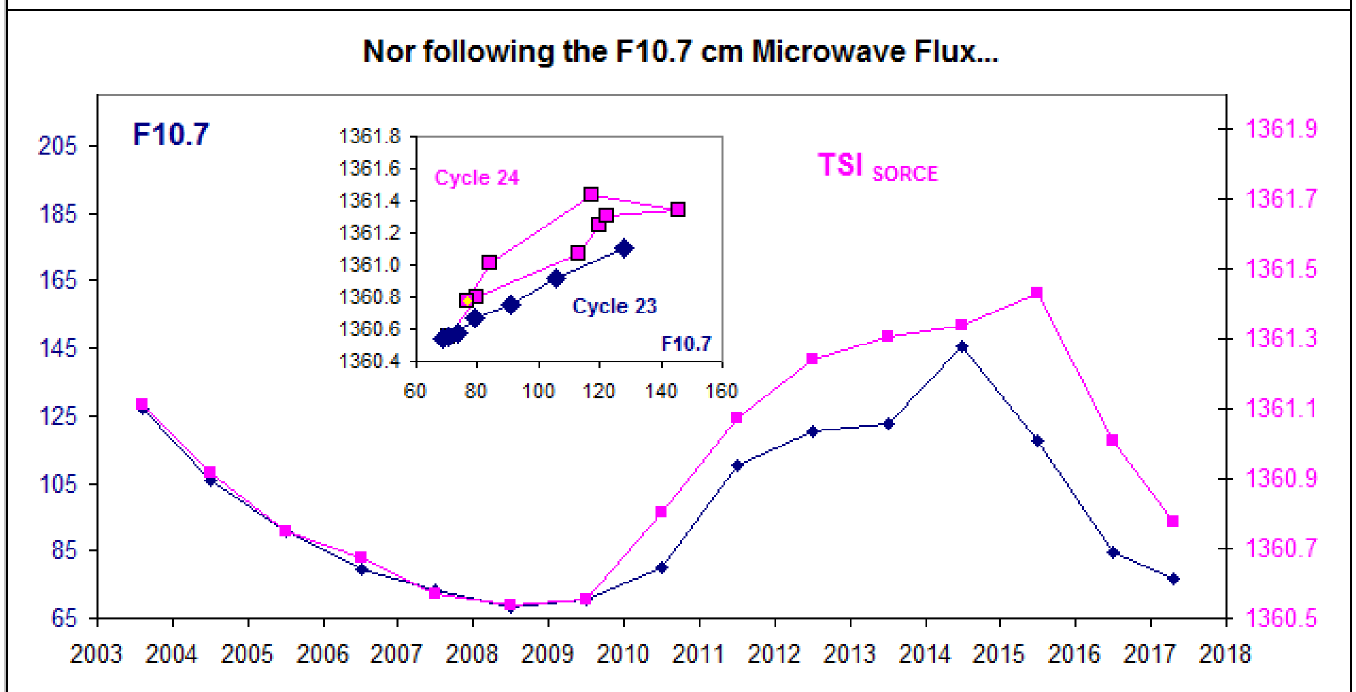


If two observers have the same [or nearly so] area threshold, S, they should be reporting the same number of groups. According to Willamo [2016] Wolfer (S=6) should be almost equivalent to Broger (S=8), actually slightly better, yet the ADF method gives the result that Broger saw more groups (red diamonds) than Wolfer (blue triangles). In actual fact they saw very nearly the same number of groups (red and blue crosses). The same failure occurs for all other pairs of equivalent observers.

Rebutting the Invalid Principal Objections to the Backbone Reconstruction of the Group Number

- "*it uses unsound procedures and assumptions in its construction*". This is primarily about whether it is correct to use a constant proportionality factor when calibrating observers to the primary observer. We showed that proportionality is an observational fact within the error of the regression
- "*it fails to match other solar data series or terrestrial indicators of solar activity*". We showed that our group numbers match the variation of the diurnal amplitude of the geomagnetic field and the HMF derived from the geomagnetic IDV index and that they match the (modeled) cosmogenic radionuclide record
- "*it requires unlikely drifts in the average of the calibration k-factors for historic observers* " We showed in Section 6 that the RGO group counts were drifting during the first twenty years of observation and that other observers agree during that period that the RGO group count drift is real
- "*it does not agree with the statistics of observers' active-day fractions*". We showed that the ADF-method fails for 'equivalent observers' and thus is not generally applicable

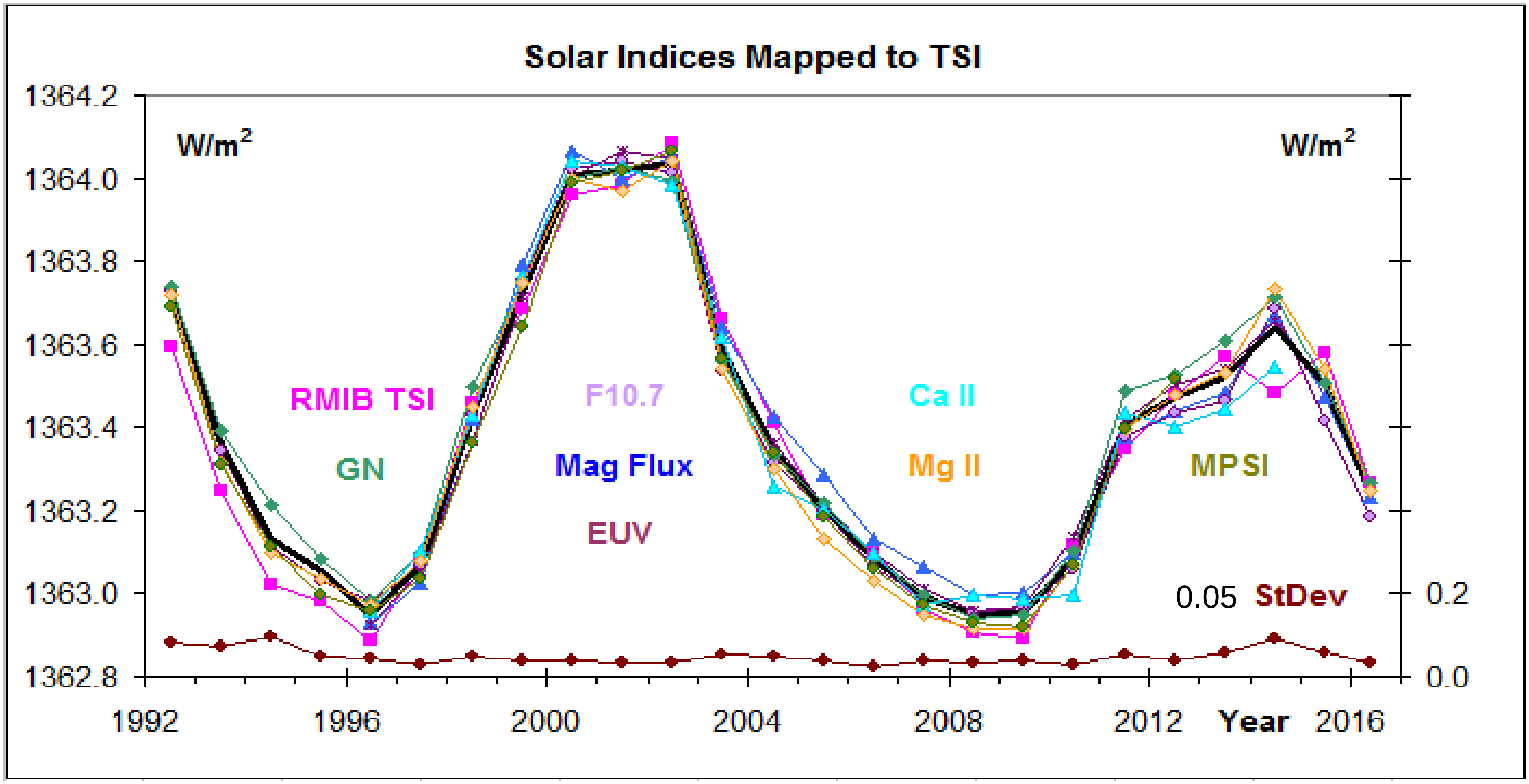




TSI (SORCE/ TIM) no longer following Sunspot Numbers nor F10.7 Flux

I have been following this for some time and was puzzled by this behavior of my 'Gold Standard'

Solar Indices Mapped Linearly to TSI



The TSI record is that by the Belgian Meteorological Institute [RMIB]

DeWitte and Nevens Suggest that SORCE/TIM TSI is Drifting

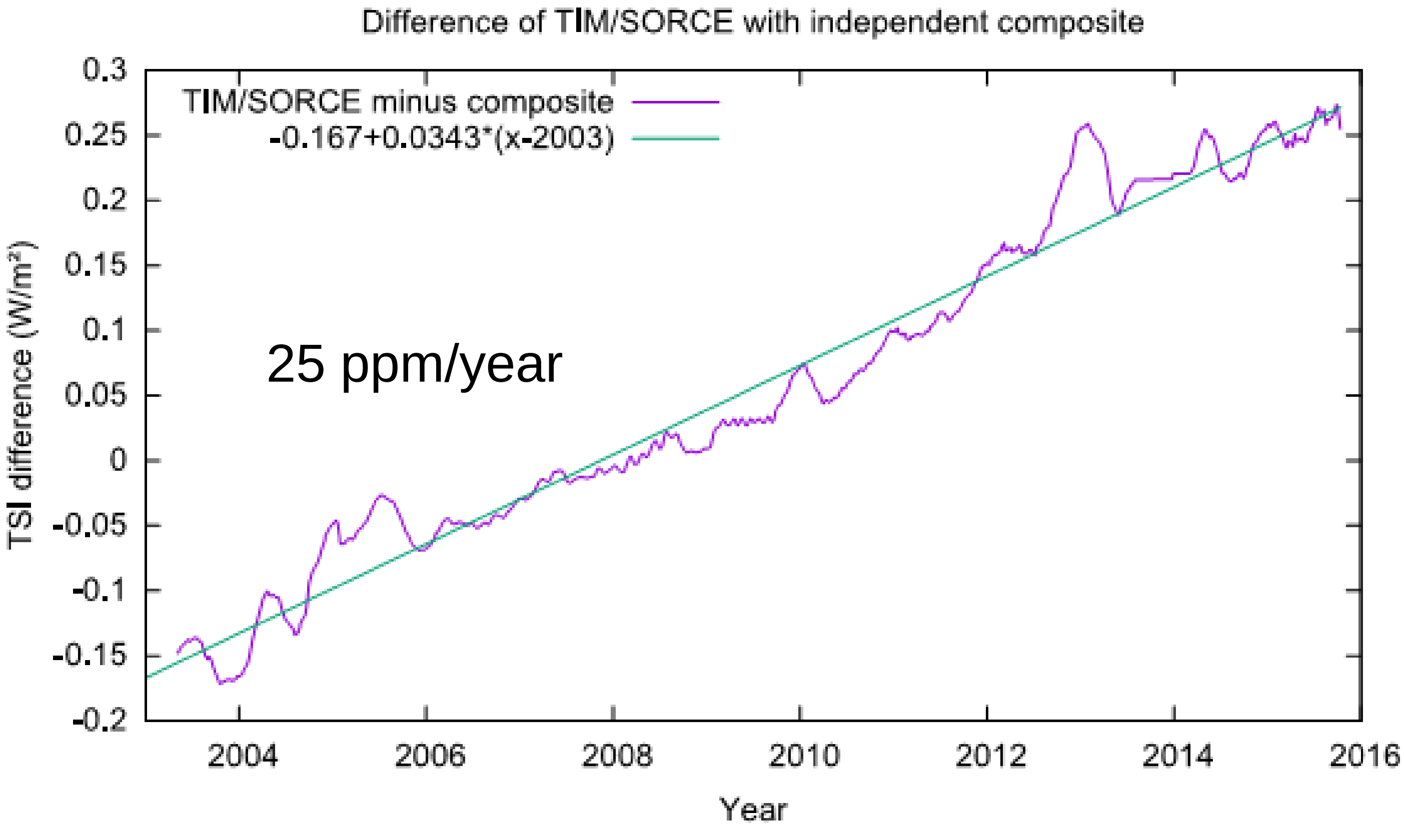
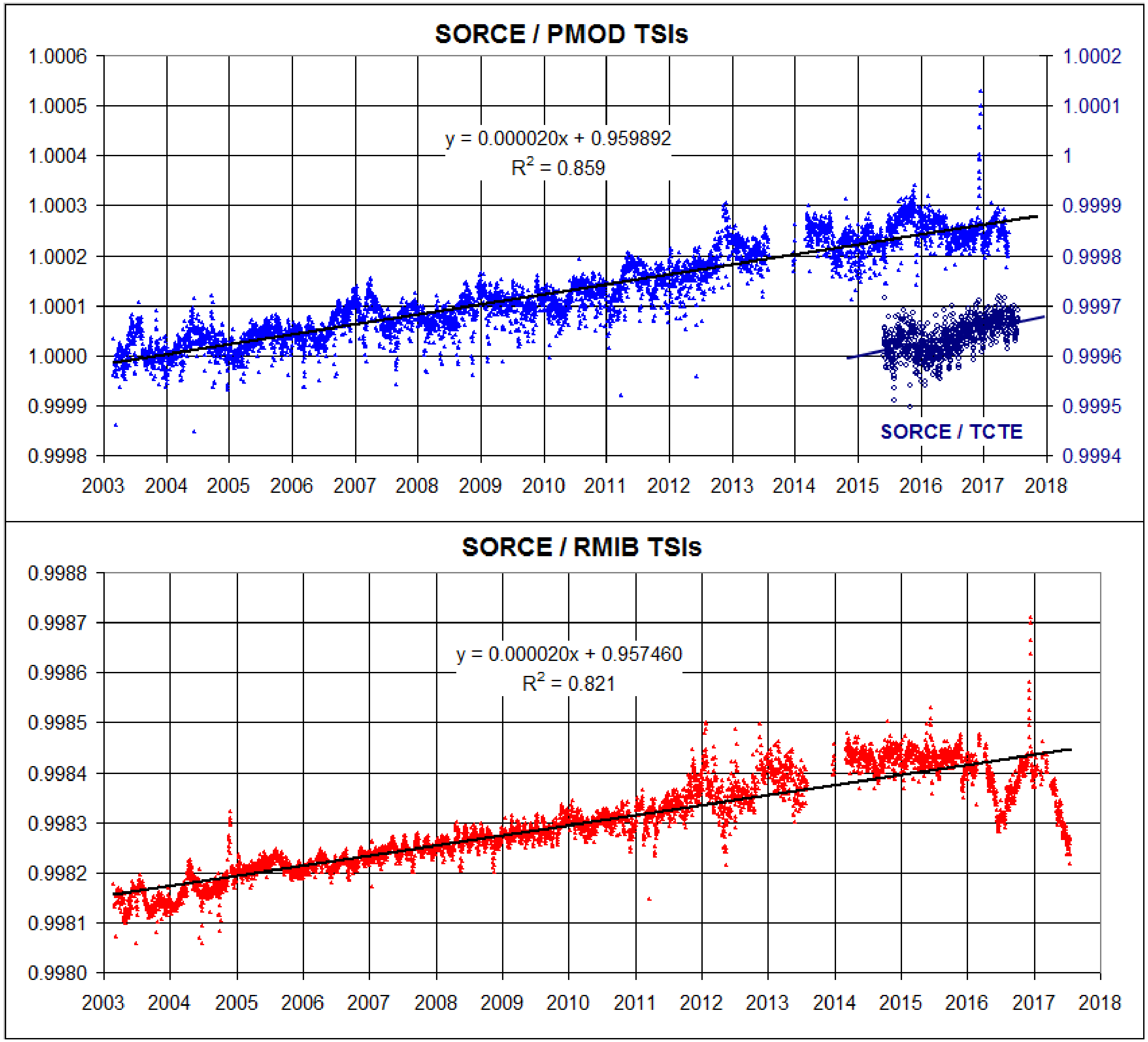


Figure 3. Difference of TIM/SORCE to independent composite (average) of DIARAD/VIRGO, PMO6B/VIRGO, and ACRIM3, and linear fit to this difference.

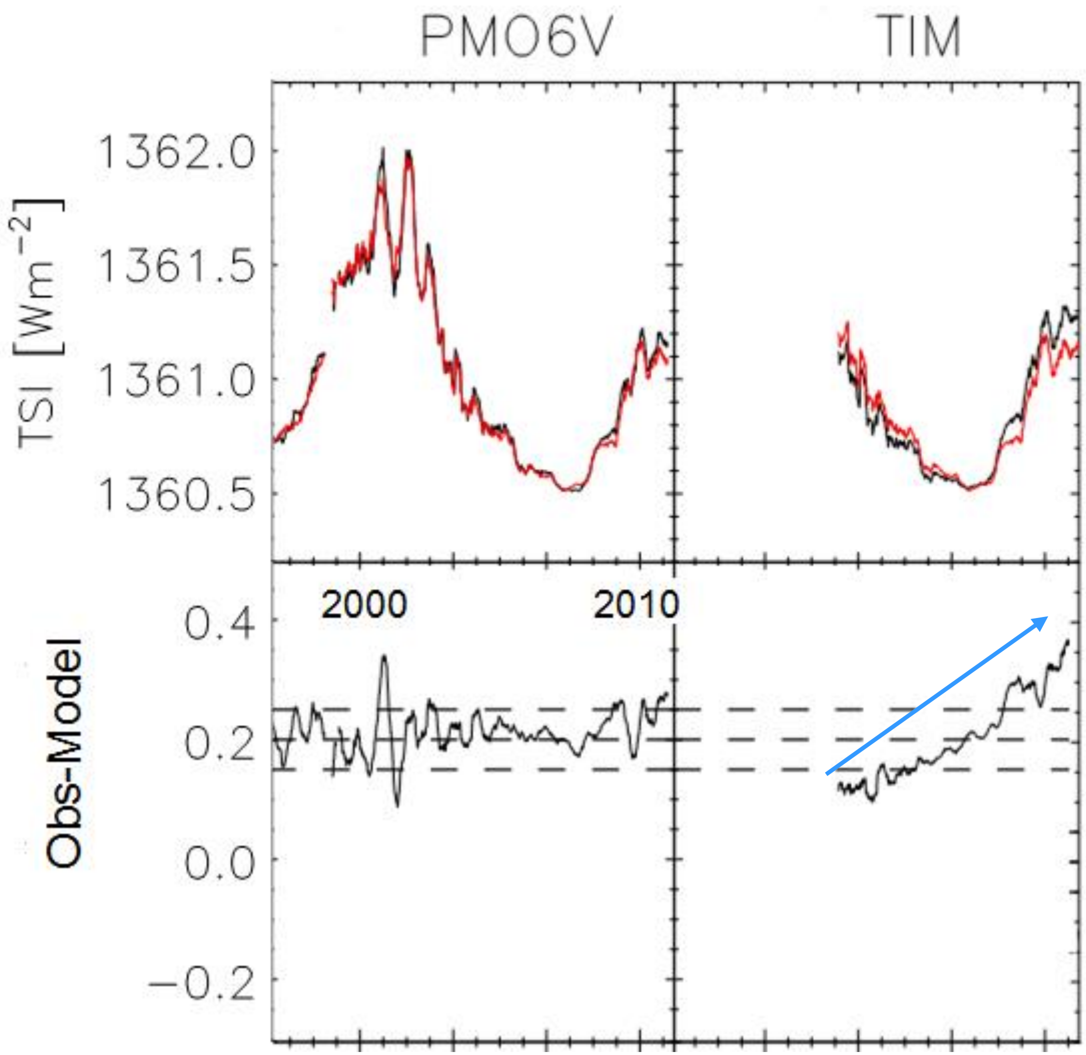
DeWitte, S. & Nevens, S.: ApJ, **830**, 25 (2016)

Comparison with RMIB



PMOD is not independent from RMIB, but it would be strange that they both should have the same drift

The Yeo Model et al. (2014) Compared to Observations

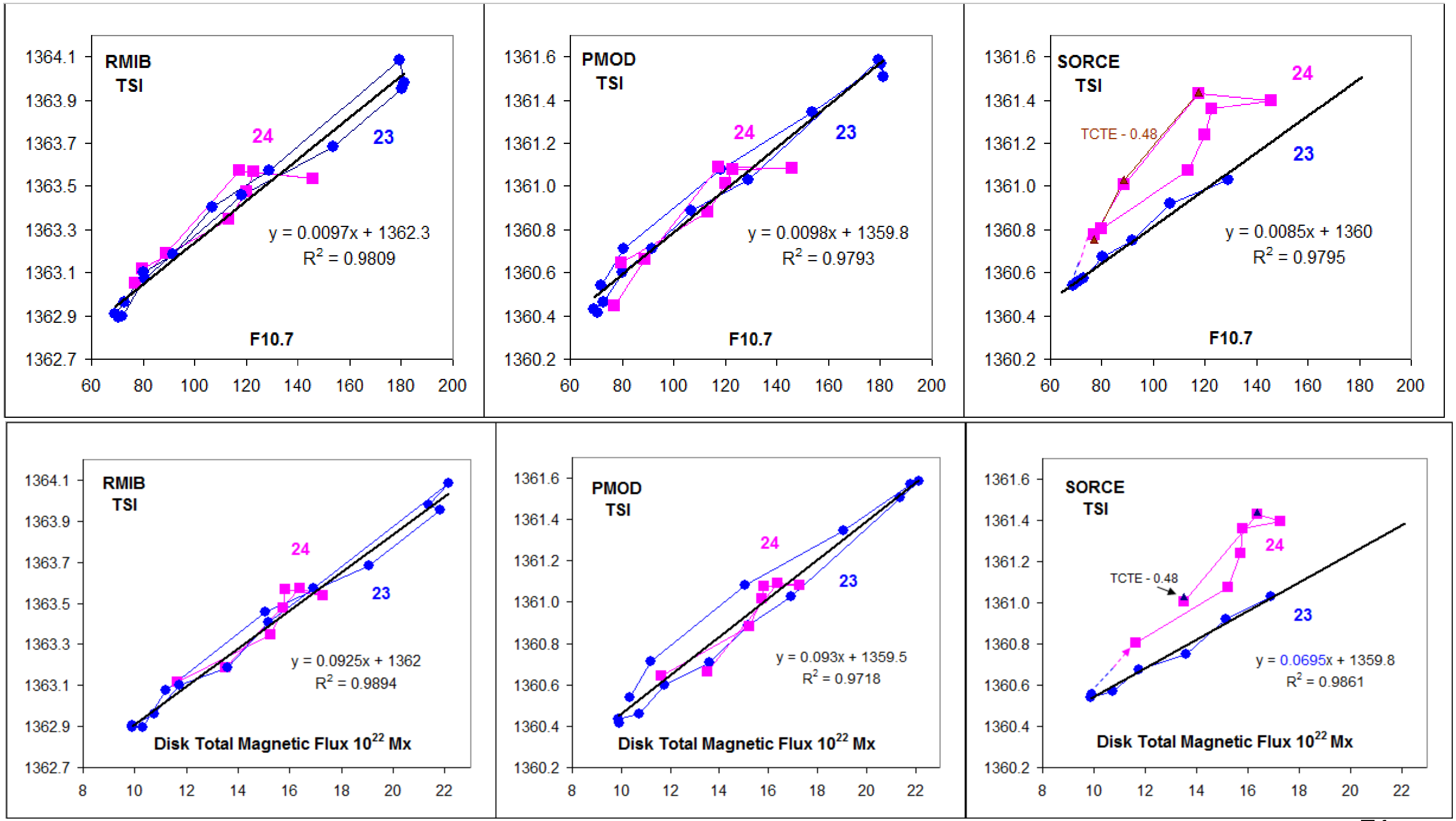


The Yeo et al. model reconstructs TSI (red curves) from MDI and HMI magnetograms. TIM has the least noise but seems to be drifting (upwards)

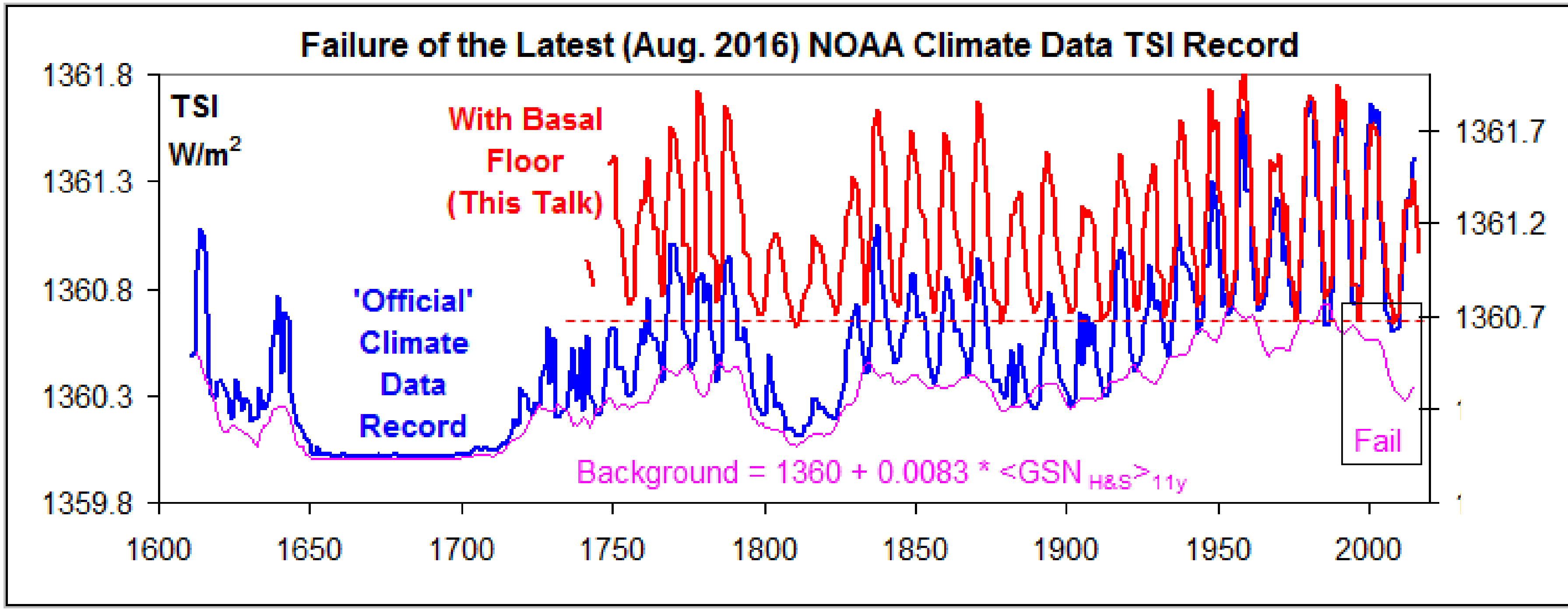
Yeo et al., A&A **570**, A85 (2014)

PMO6V is independent from DIARAD.

TSI Dependence on F10.7 and Total Magnetic Flux

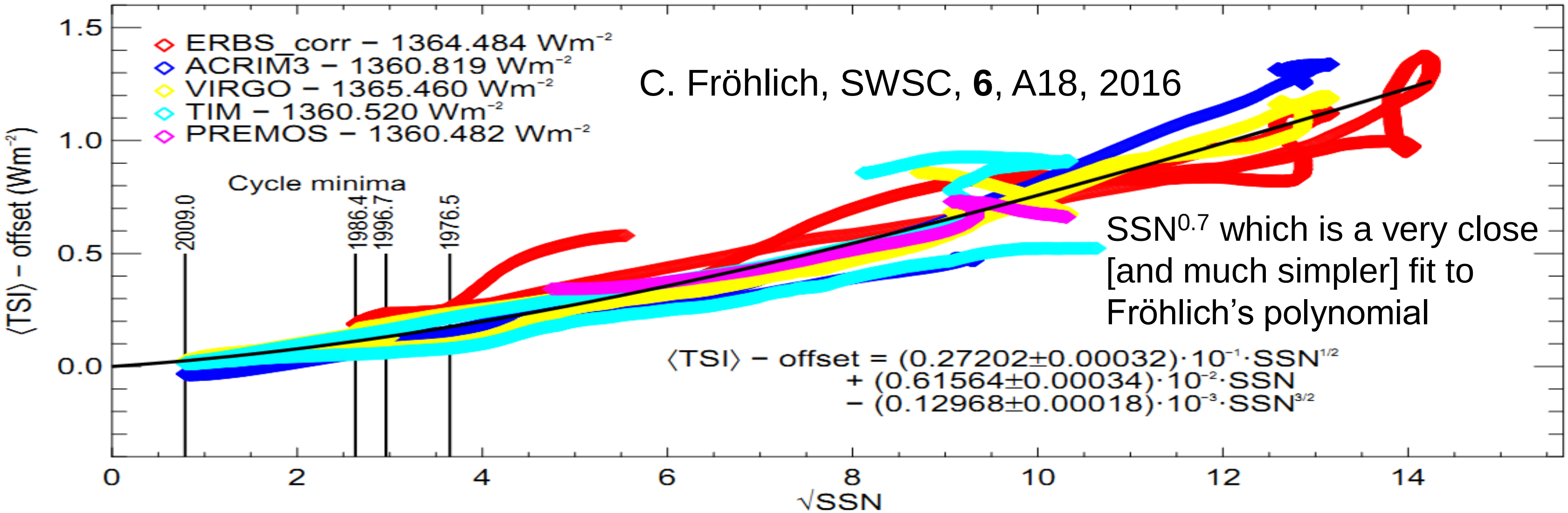


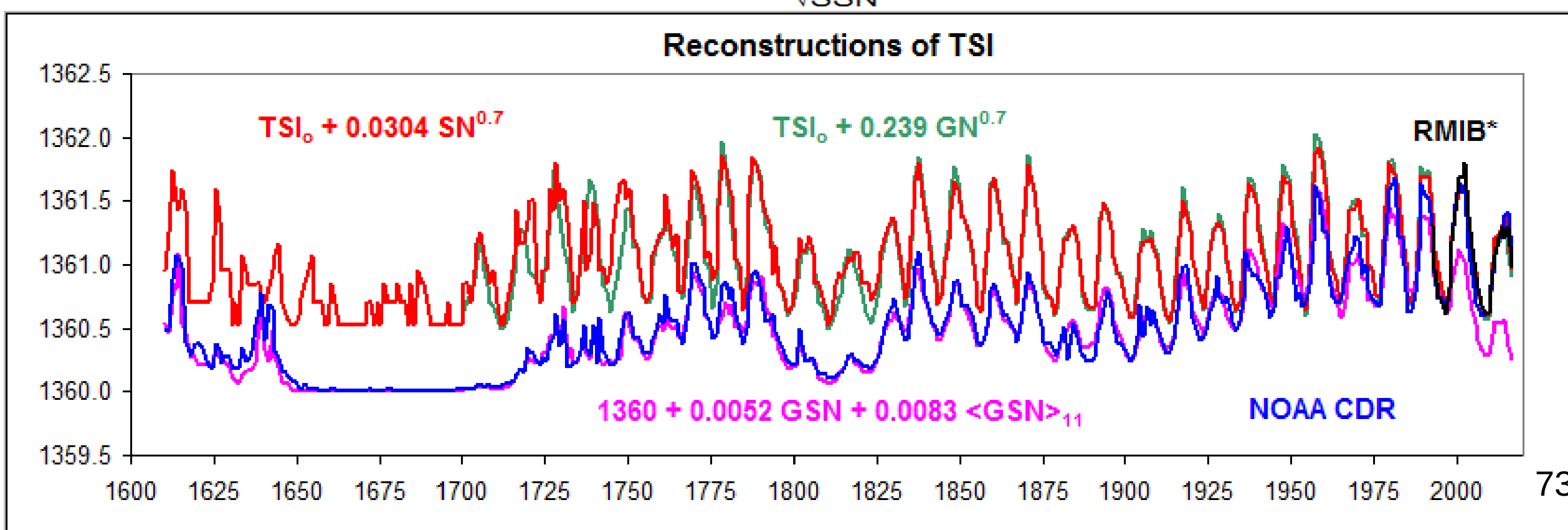
The Basal EUV and Magnetic Flux Records Do Not Support the NOAA Climate Data Record, CDR



1: **One can fit EUV to the instrumental part of NOAA's Climate Data Record**
2: There is no support for a variable 'Background' (pink curve) and surely not
3: if constructed from the obsolete Hoyt & Schatten Group Sunspot Number
4: which the CDR didn't even use during the 'instrumental era'

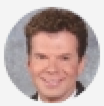
Claus Fröhlich Lined up TSIs as a Function of the Square Root of the Sunspot Number





Who Cares? The Public May.

Will the sun put the brakes on global warming?



By **Michael Guillen Ph.D.** • Published July 16, 2017 • Fox News

“The last grand maximum peaked circa 1958, after which the sun has been steadily quieting down. Today, the drop in activity is at its steepest in 9,300 years[1].”

1. Lockwood, M. Reconstruction and prediction of variations in the open solar magnetic flux and interplanetary conditions . *Living Rev. Solar Phys.* **10**, 4 (2013).

“Using computer simulations, scientists at the National Center for Atmospheric Research in Boulder, Colorado, estimate that “a grand solar minimum in the middle of the 21st century would slow down human-caused global warming and reduce the relative increase of surface temperatures by several tenths of a degree [Celsius, equal to 0.5 degrees Fahrenheit].” But at the end of the grand minimum, they say, the warming would simply pick up where it left off.”

The End

Abstract

The long-term record of solar activity is of fundamental importance for solar physics, solar-terrestrial relations, and even the climate debate. A decade ago, the discrepancies between the International Sunspot Number and the newer Group Sunspot Number were clearly identified and quantified. I urged the solar community to resolve the problems and reconcile the two series. The resulting Sunspot Number Workshops [2011-2015] brought many details and new data to light, but have turned out to be complete failures: instead of arriving at the hoped-for, agreed-upon, and unified solar activity record, the field has splintered into ~seven 'new and improved' but incompatible records hindering current and future research into solar activity influence on our environment and into the sun itself, in addition to polluting our science by ugly and acrimonious activism not becoming serious scientific discourse. I show that it is possible to 'rescue' the revision efforts and to recover from the failures. The resulting record has implications for NOAA's Solar Irradiance Climate Data Record and for calibrations and reconstructions of the Total Solar Irradiance record.