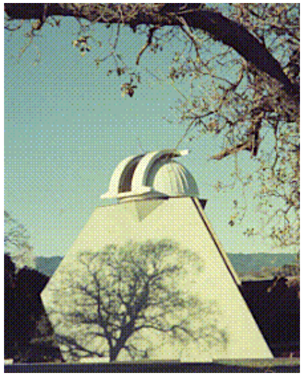
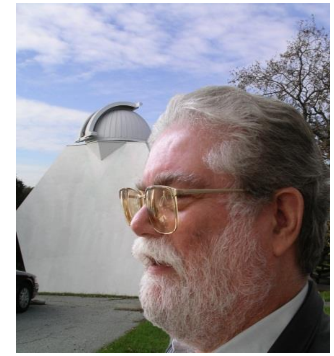




Three Centuries of Validated Monthly Sunspot Groups Numbers

Leif Svalgaard

Stanford University

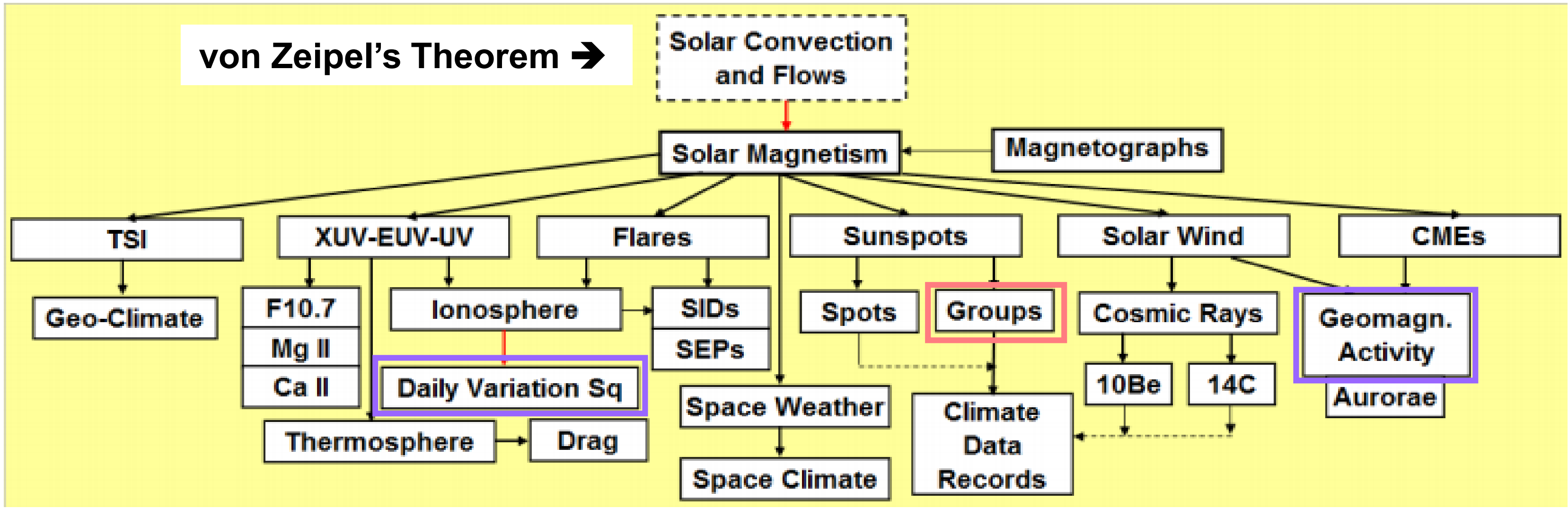
Jan. 2020

Sun-Climate Symposium 2020, Tucson, AZ

A Synthesis

We are Beginning to Understand the Complicated Physics of that 'Great System'

A Systems Approach: Everything Must Fit



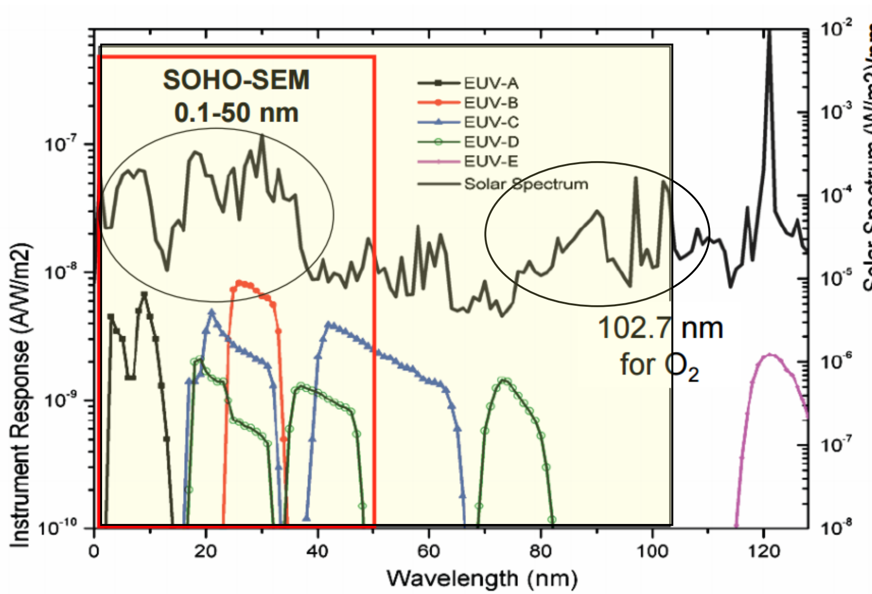
Faraday wrote to R. Wolf on 27th August, 1852: "I am greatly obliged and delighted by your kindness in speaking to me of your most remarkable enquiry, regarding the **relation existing between the condition of the Sun and the condition of the Earths magnetism**. The discovery of periods and the observation 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...

These are exciting times for Solar Physicists

Outline

- Observed EUV, Solar Microwave, and Magnetic flux records
- Deriving EUV [etc] from Geomagnetic Daily Variations
- Deriving Solar Wind Magnetic Field from Geomagnetism and Sunspots
- Comparing the Solar Flux(es) to the Sunspot (and Sunspot Group) Numbers

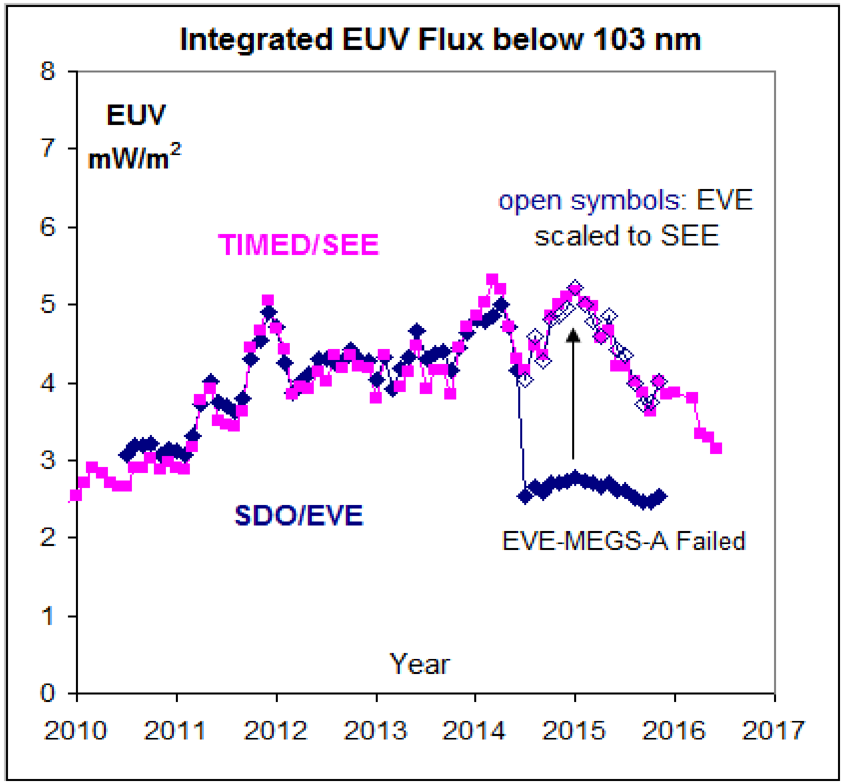
Sources of EUV Data: SEM, SEE, EVE



≤102.7 nm to ionize molecular Oxygen

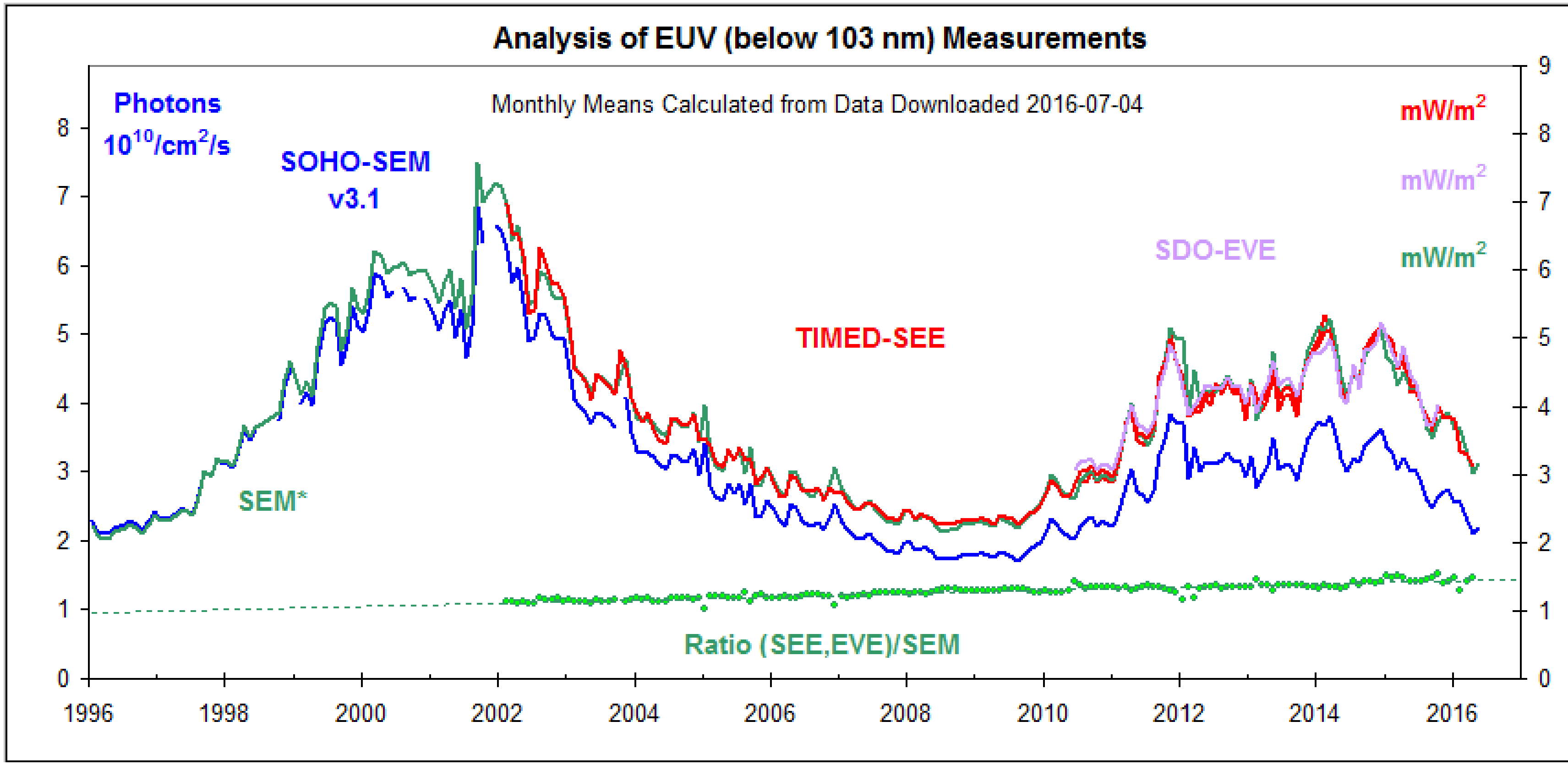
$$O_2 + h\nu \rightarrow O_2^+ + e^-$$

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



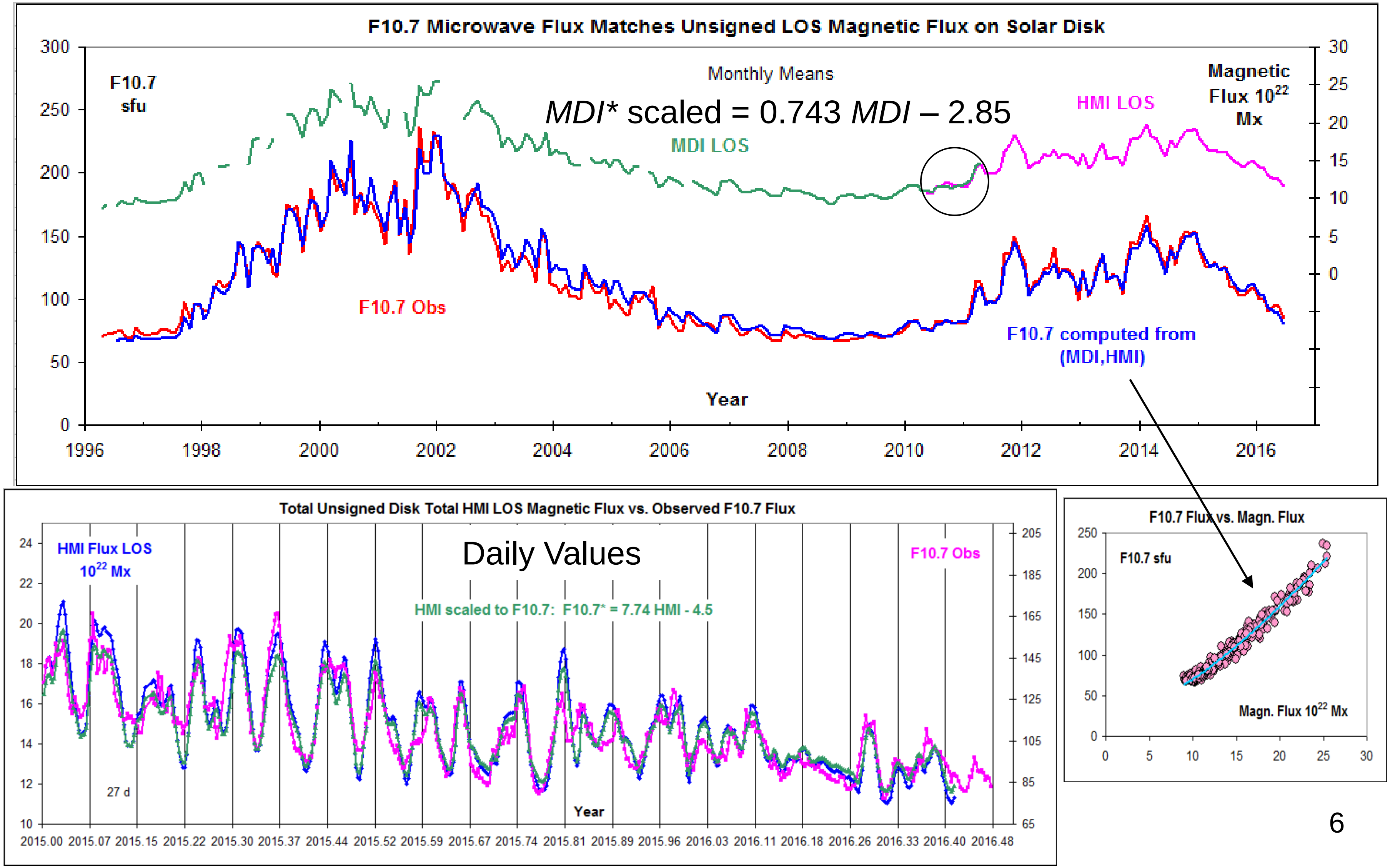
The detectors on the TIMED and SDO satellites agree well until the failure of the high-energy detector on EVE in 2014. We can still scale to earlier levels [open symbols]. 2016 not yet corrected.

Creating an EUV (<103 nm) Composite

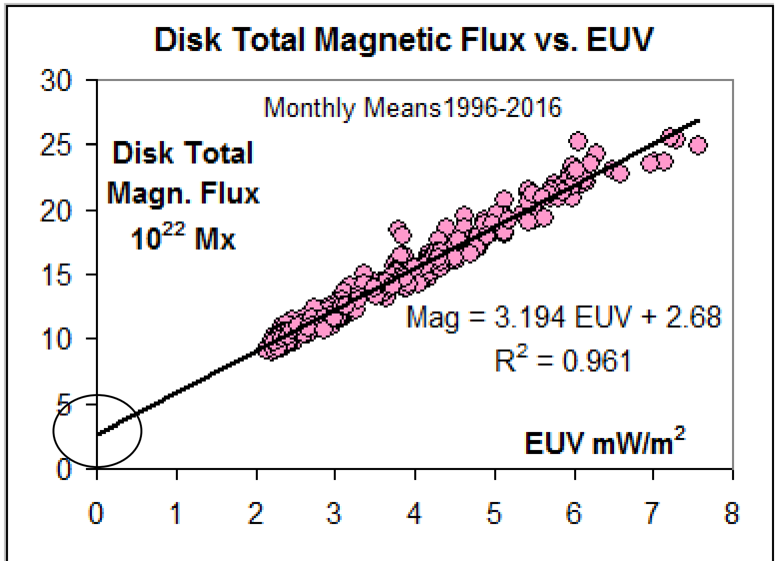


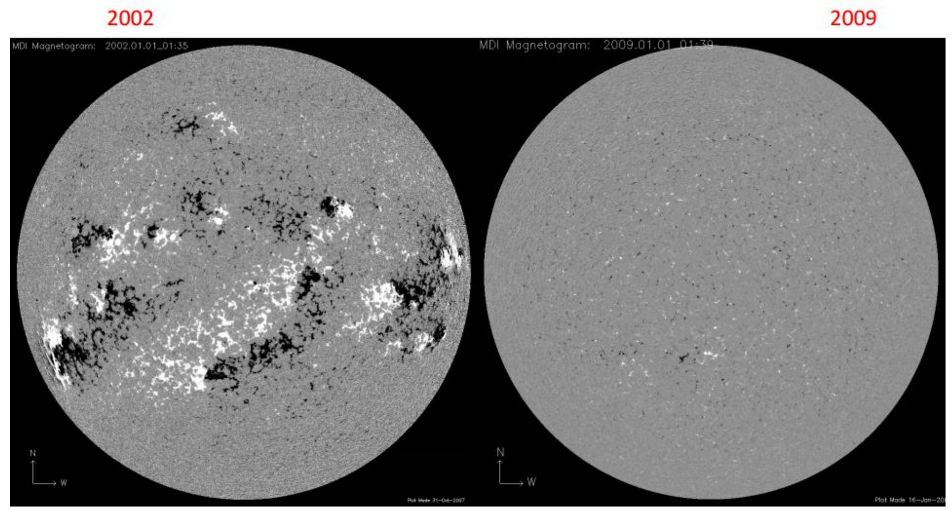
SEE and EVE agree nicely and we can form a composite (SEE,EVE) of them. SEM is on a different scale, but we can convert that scale to the scale of (SEE,EVE). The scale factor [green line] shows what to scale SEM with to match (SEE,EVE) [SEM*, upper green curve], to get a **composite** of all three (SEM*,SEE,EVE)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

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

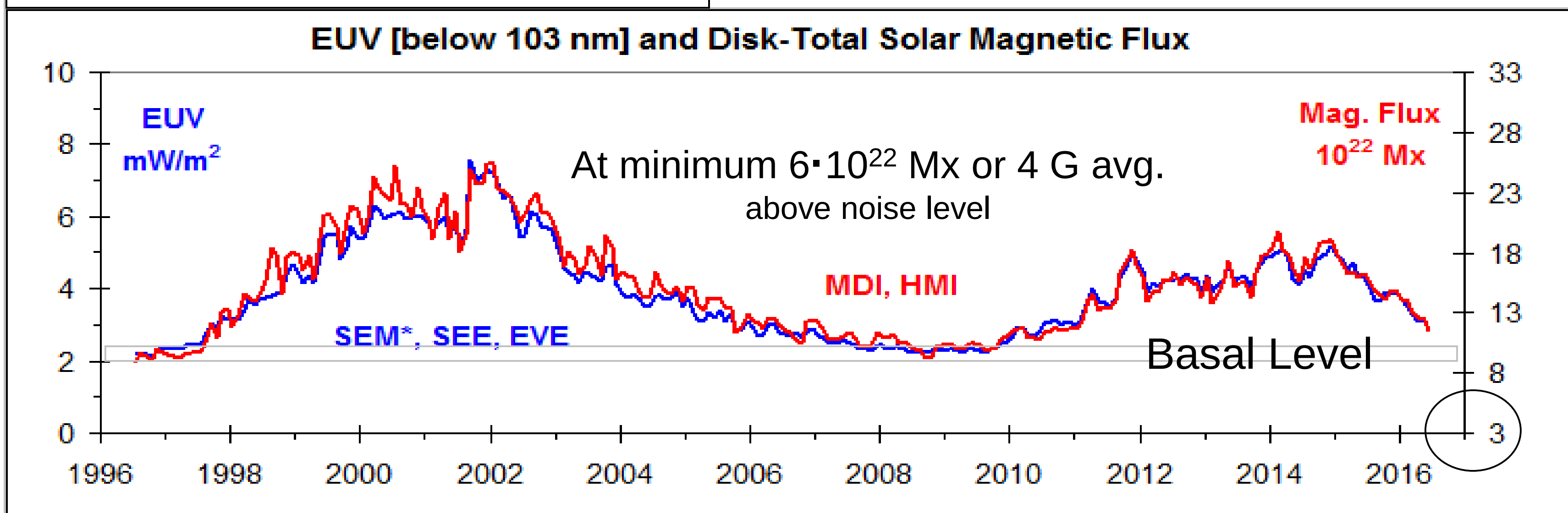


EUV Follows Total Unsigned Magnetic Flux



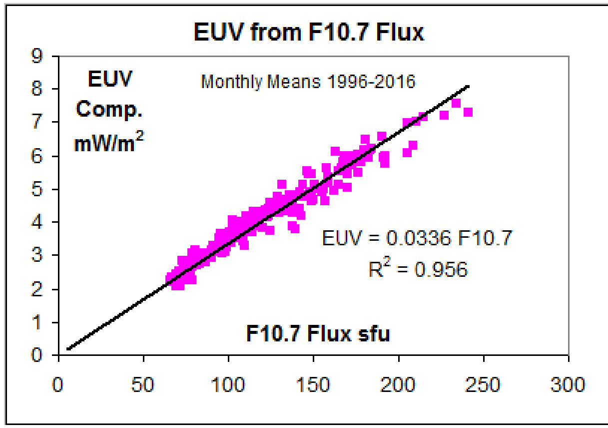


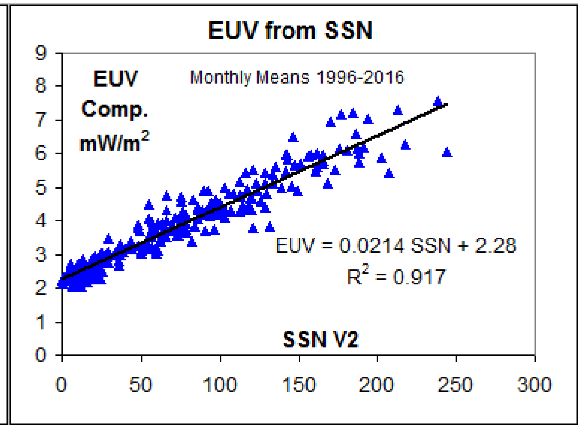
Offset interpreted as Noise Level ≈ 3·10^{22} Mx



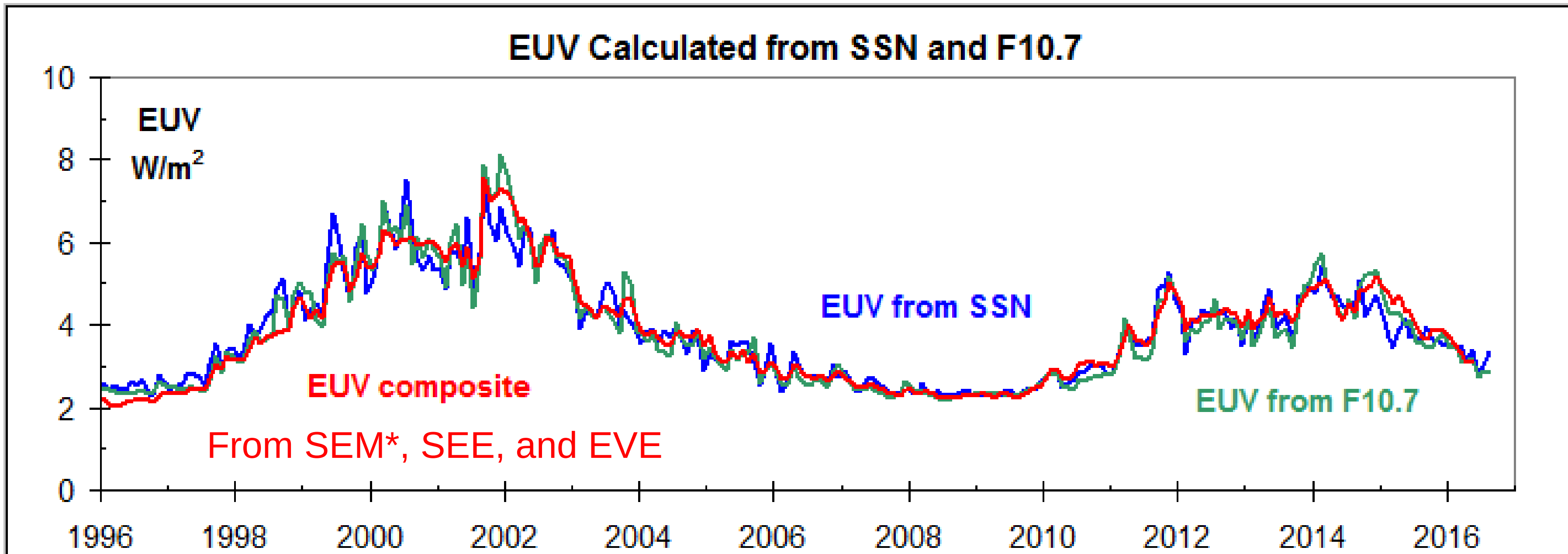
There is a ‘basal’ level at solar minima. Is this the case at every minimum?

EUV Composite Matches F10.7 and Sunspot Numbers

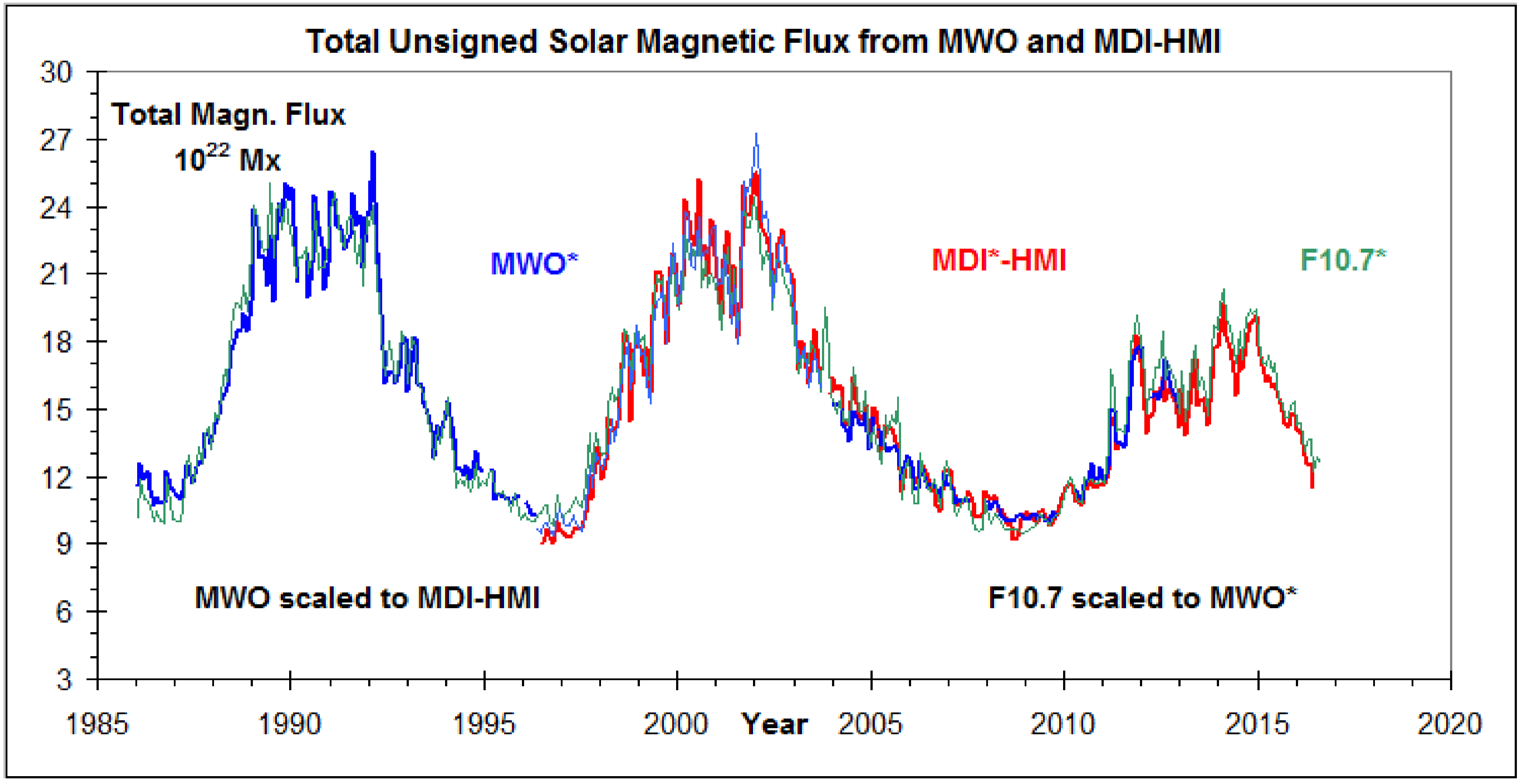




So, we can calculate the EUV flux both from the Sunspot Number and from the F10.7 flux which then is a good proxy for EUV [as is well-known].

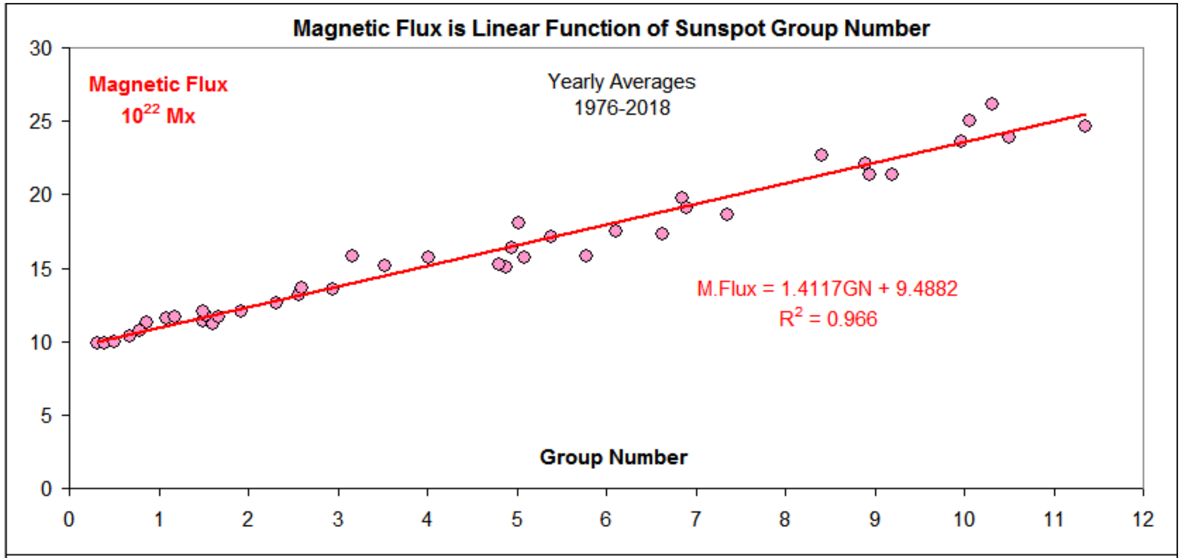


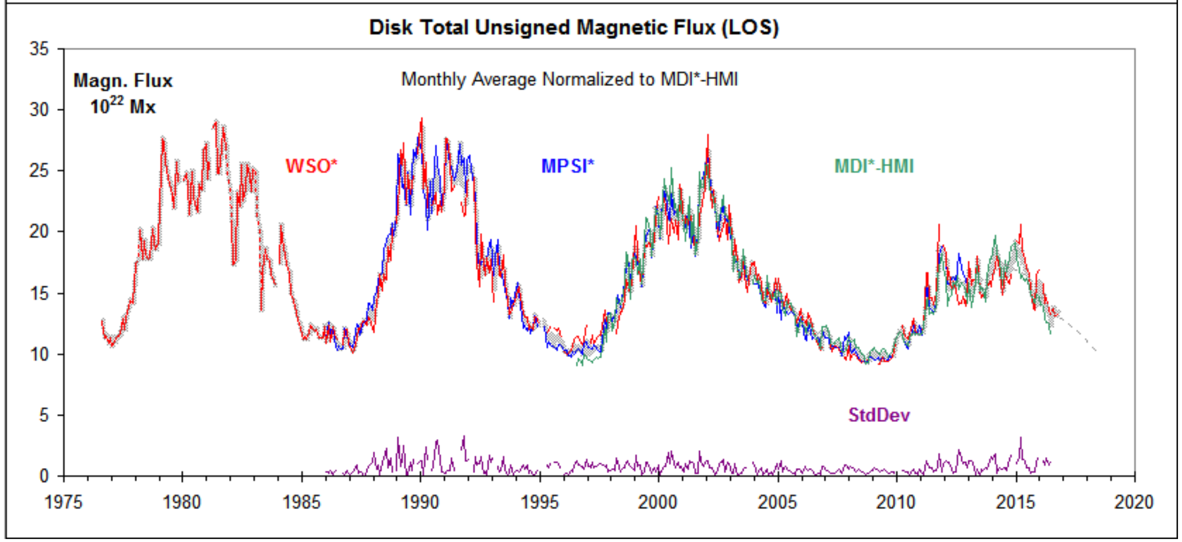
Magnetic Flux from MWO Tracks MDI-HMI and the F10.7 Flux



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.

Magnetic Flux back to 1976 and the Sunspot Group Number (SS16)





Scaling MWO to MDI-HMI and WSO to the result yields a good measure of the LOS unsigned full disk magnetic flux which turns out to be a linear function of the Sunspot Group Number (S&S 2016).

Even at the limit of zero Groups there is still a significant amount of solar magnetic flux as needed to explain the interplanetary flux.

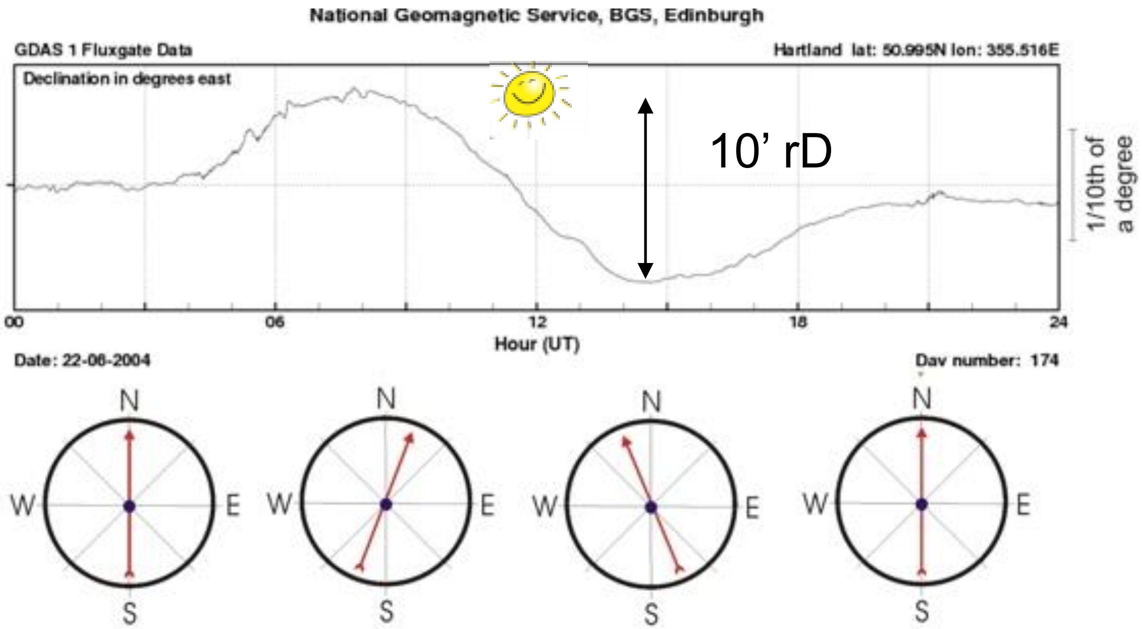
What do we have so far? #1

- We can construct an observed EUV composite back to 1996
- We can construct an observed Magnetic Flux composite back to 1976
- The EUV matches the Magnetic Flux
- The Microwave Flux [1-10 GHz] matches the EUV, Magnetic Flux, and Sunspot Number
- The magnetic flux matches the Sunspot Group Number linearly
- There is no good evidence of activity at solar minima being different between minima the past 70 years

Outline

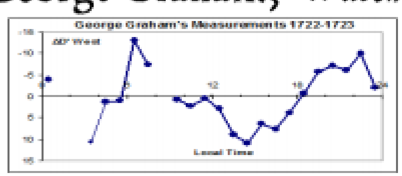
- Recent EUV, Solar Microwave, and Magnetic flux records
- Deriving EUV [etc] from Geomagnetic Daily Variations
- Deriving Solar Wind Magnetic Field from Geomagnetism and Sunspots
- Comparing the Solar Flux(es) to the Sunspot (and Sunspot Group) Numbers

The Diurnal Variation of the Direction of the Magnetic Needle



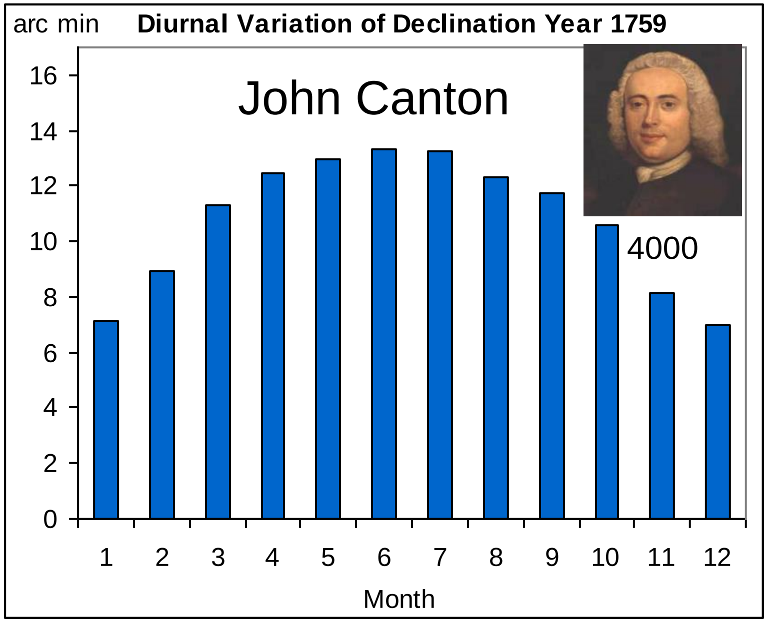
IV. *An Account of Obſervations made of the Variation of the Horizontal Needle at* London, *in the latter Part of the Year* 1722, *and beginning of* 1723. *By Mr.* George Graham, *Watch-maker, F. R. S.*

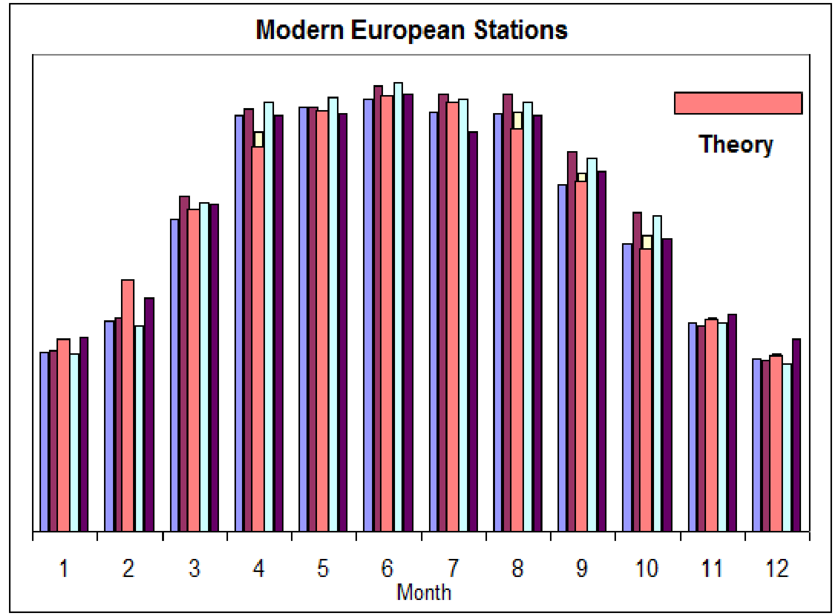
Made ~1000 observations

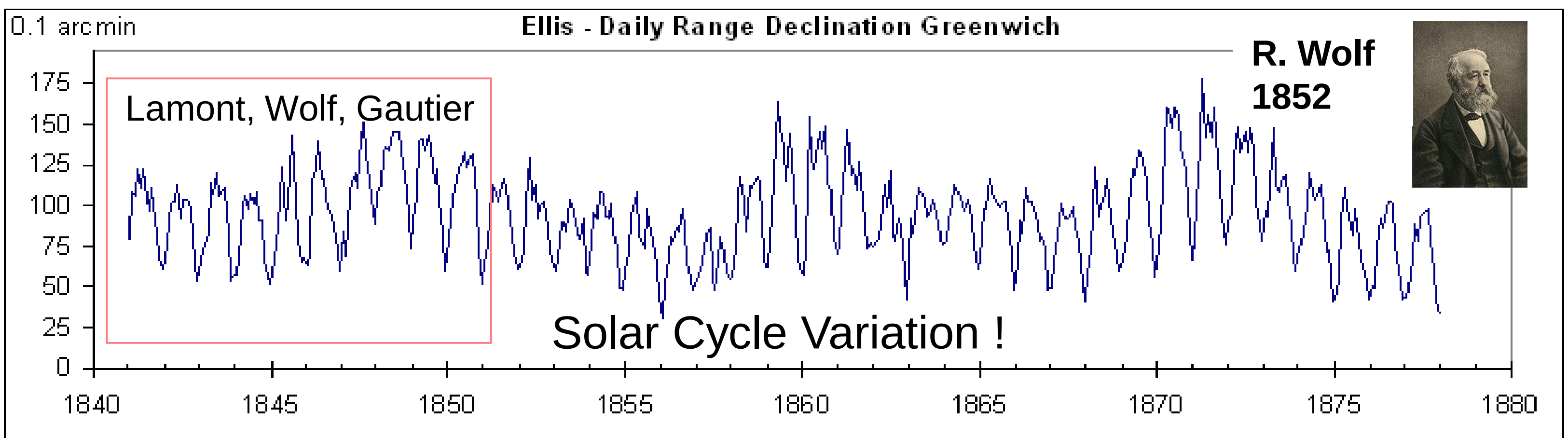


George Graham [London] discovered [1722] that the geomagnetic field varied during the day in a regular manner.

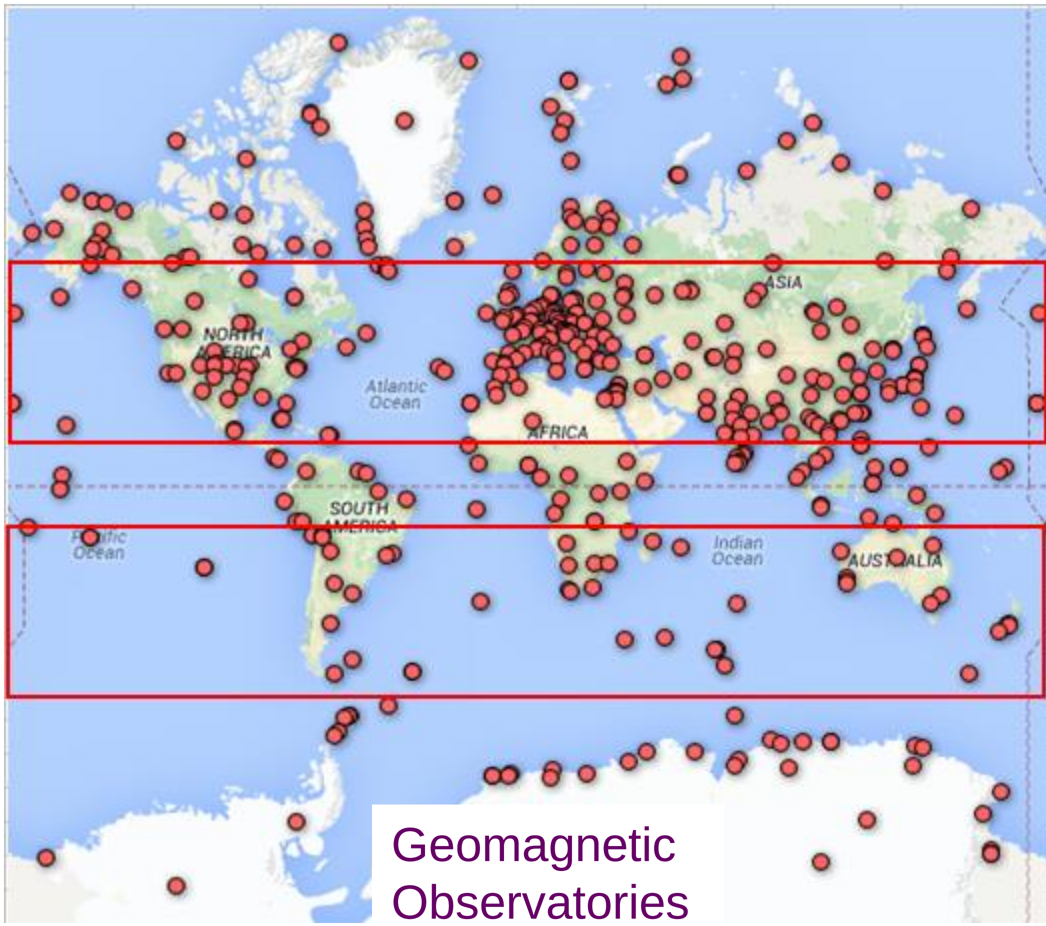
Zenith Angle Dependence Discovered

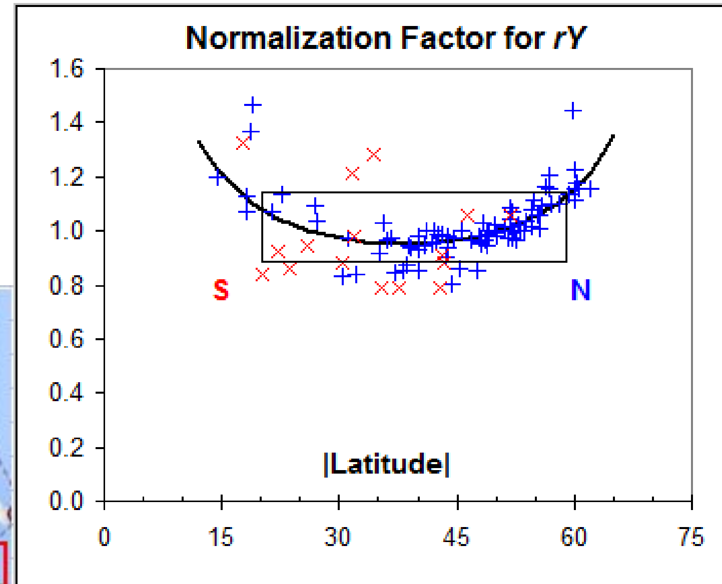


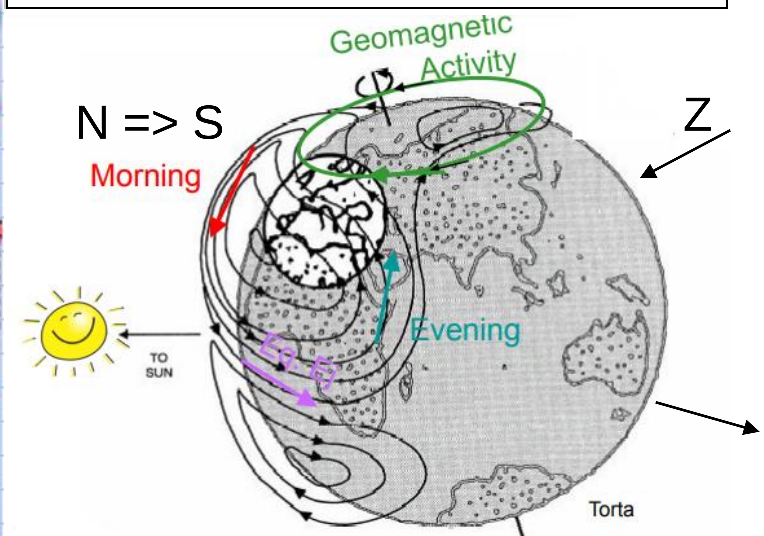




The Magnetic Signal at Midlatitudes



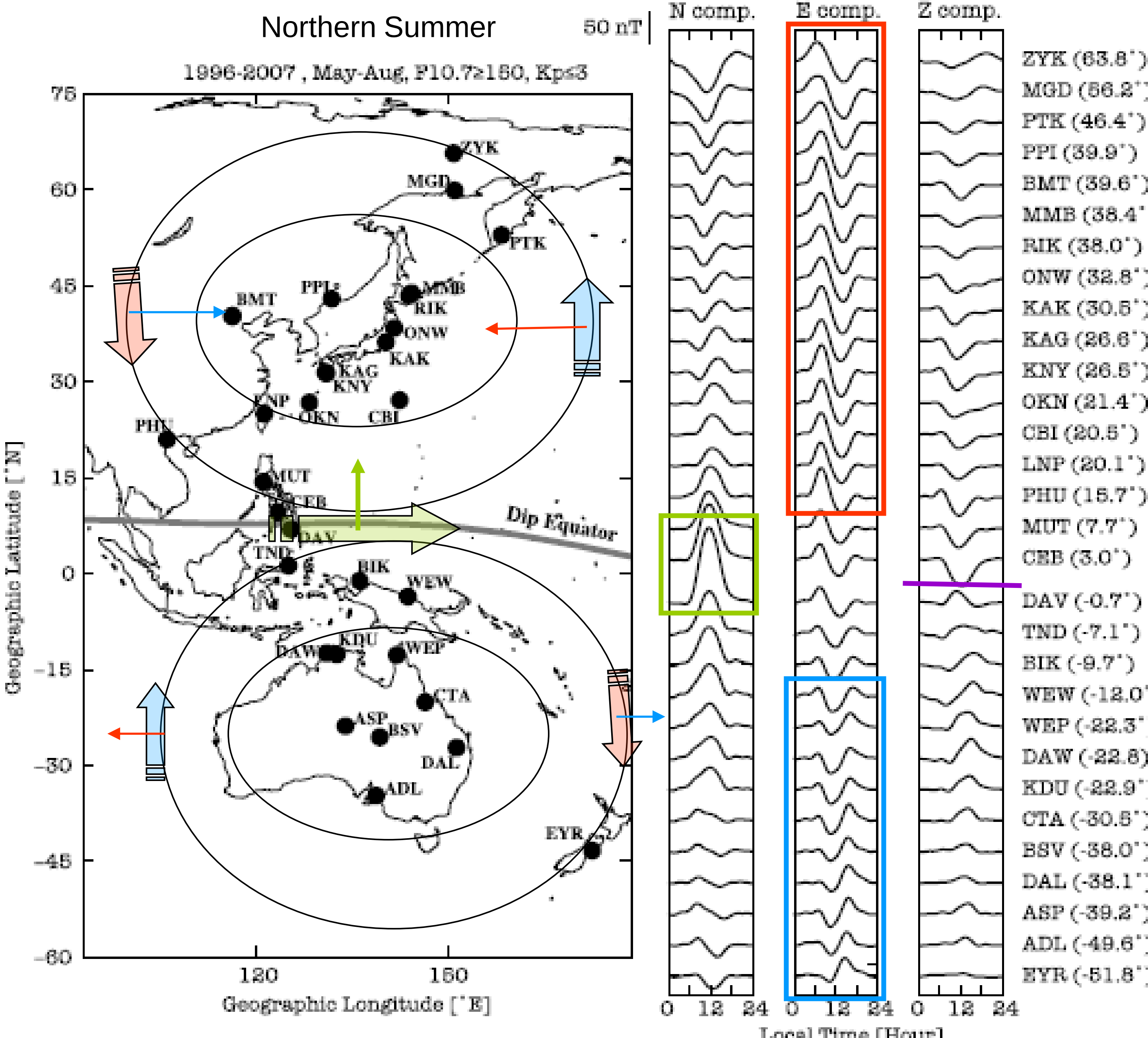




A current system in the ionosphere is created and maintained by solar EUV radiation

The effect in the Y-component is rather uniform for latitudes between 20º and 60

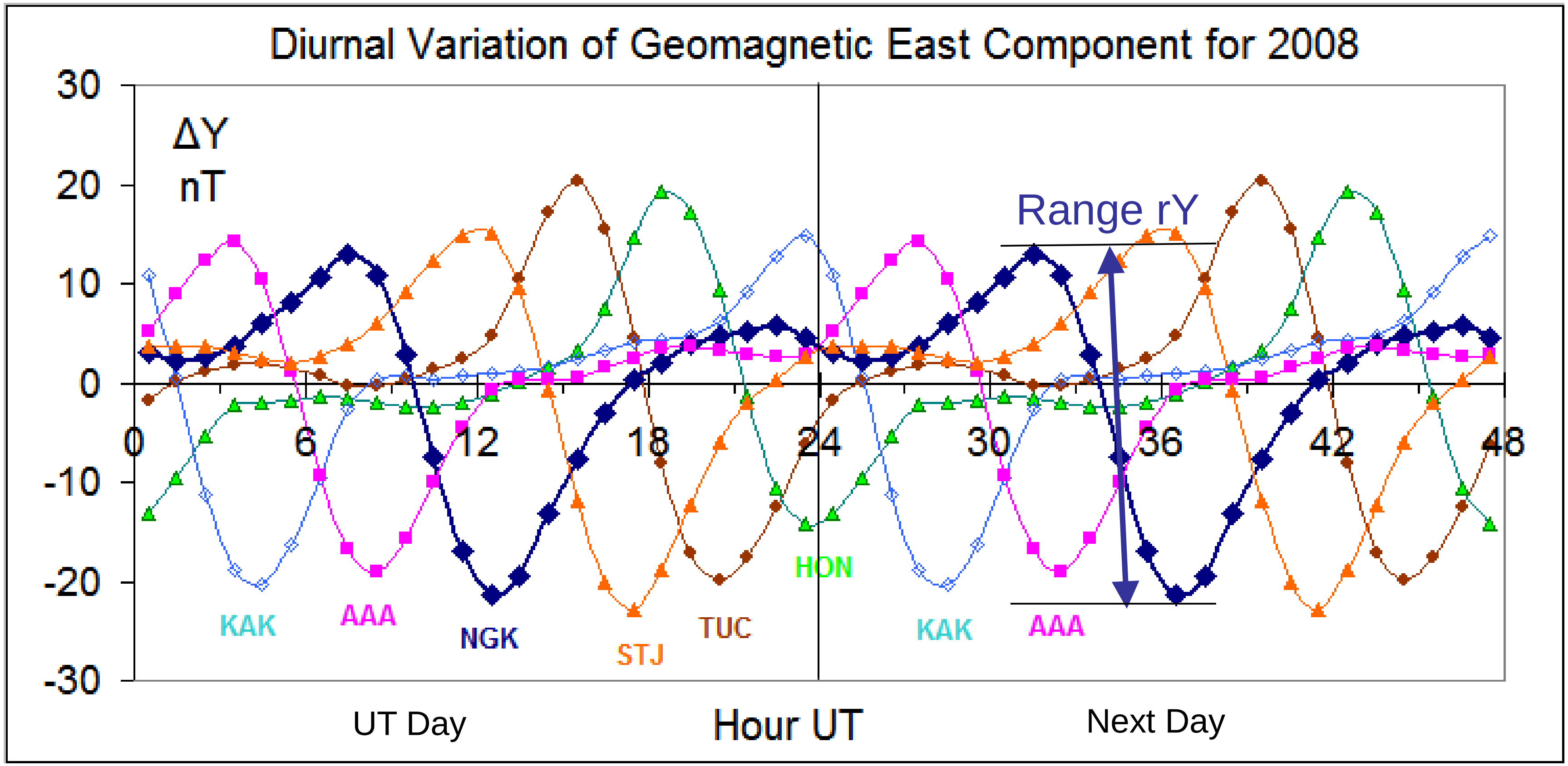
Diurnal Variation of Geomagnetic Field



Yamazaki & Maute, 2017

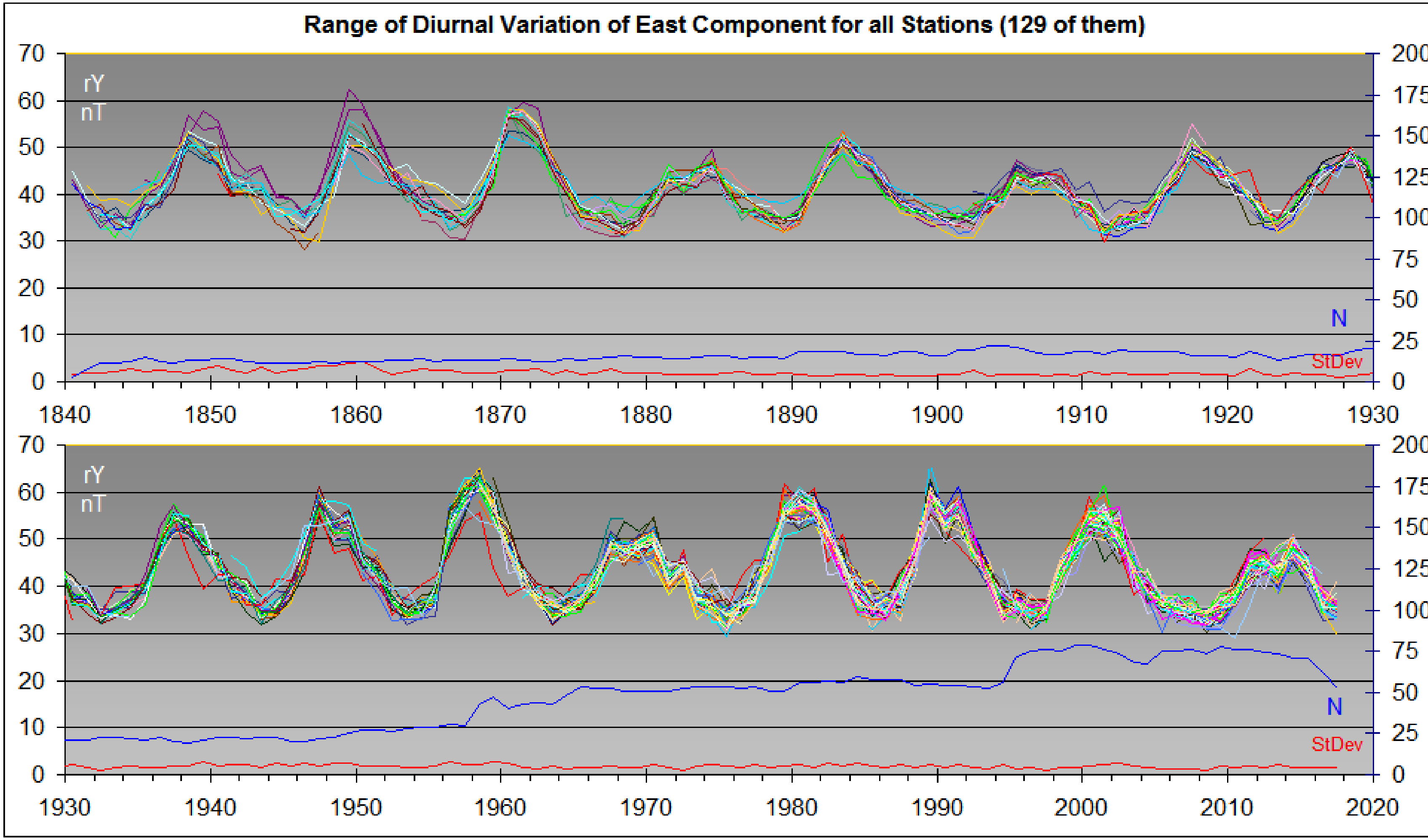
Already Julius Bartels (1946) emphasized the importance of the diurnal variation: “"The correlations between R and his W (wave-radiation)… are the **closest found so far** between solar and terrestrial phenomena"

The Shape of the Magnetic Signature is Remarkably Stable



Here we walk around the Globe to show that the variation [deviation from the mean] is the same from station to station, only differing slightly in amplitude, thus lending itself to straightforward normalization [e.g. to Niemegk, NGK].

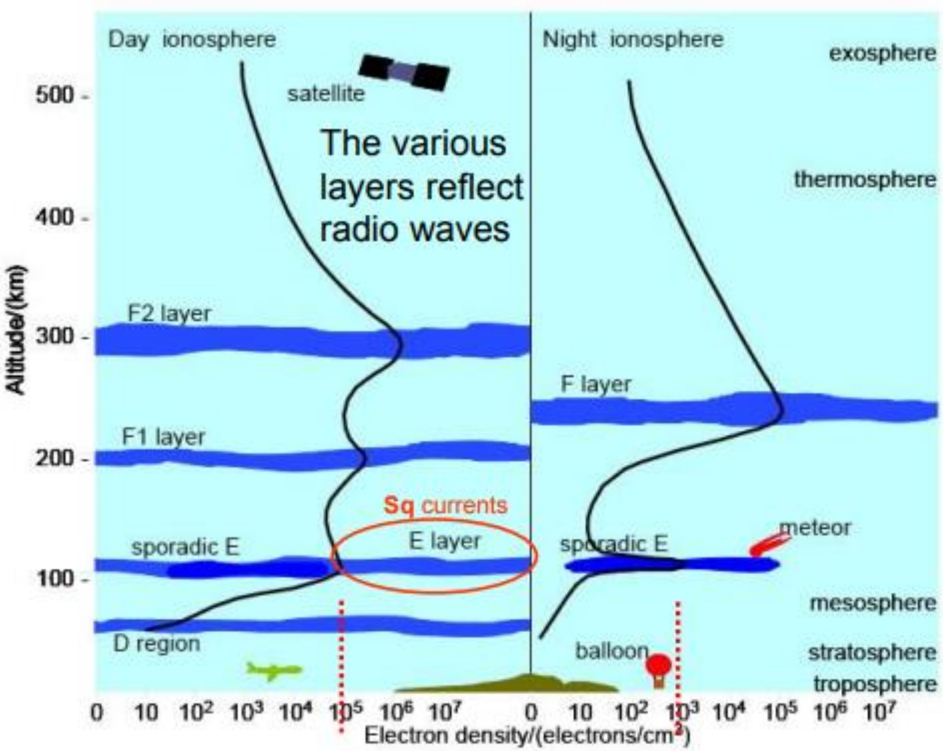
Normalized Observed Diurnal Ranges of the Geomagnetic East Component since 1840



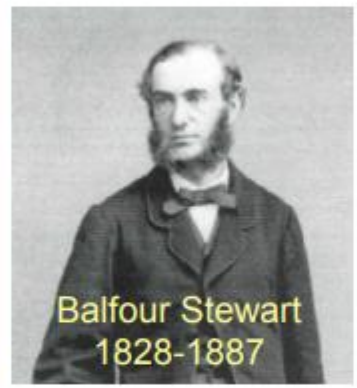
We plot the yearly average range to remove the effect of changing solar zenith angle through the seasons. A slight normalization for latitude and underground conductivity has been performed. Data used comprise 48 million hourly values.

The Physics of the Daily Variation

Ionospheric Conducting Layers



Winds moving the charges across the magnetic field creates a dynamo current, whose magnetic effect we can observe at the surface as Graham discovered



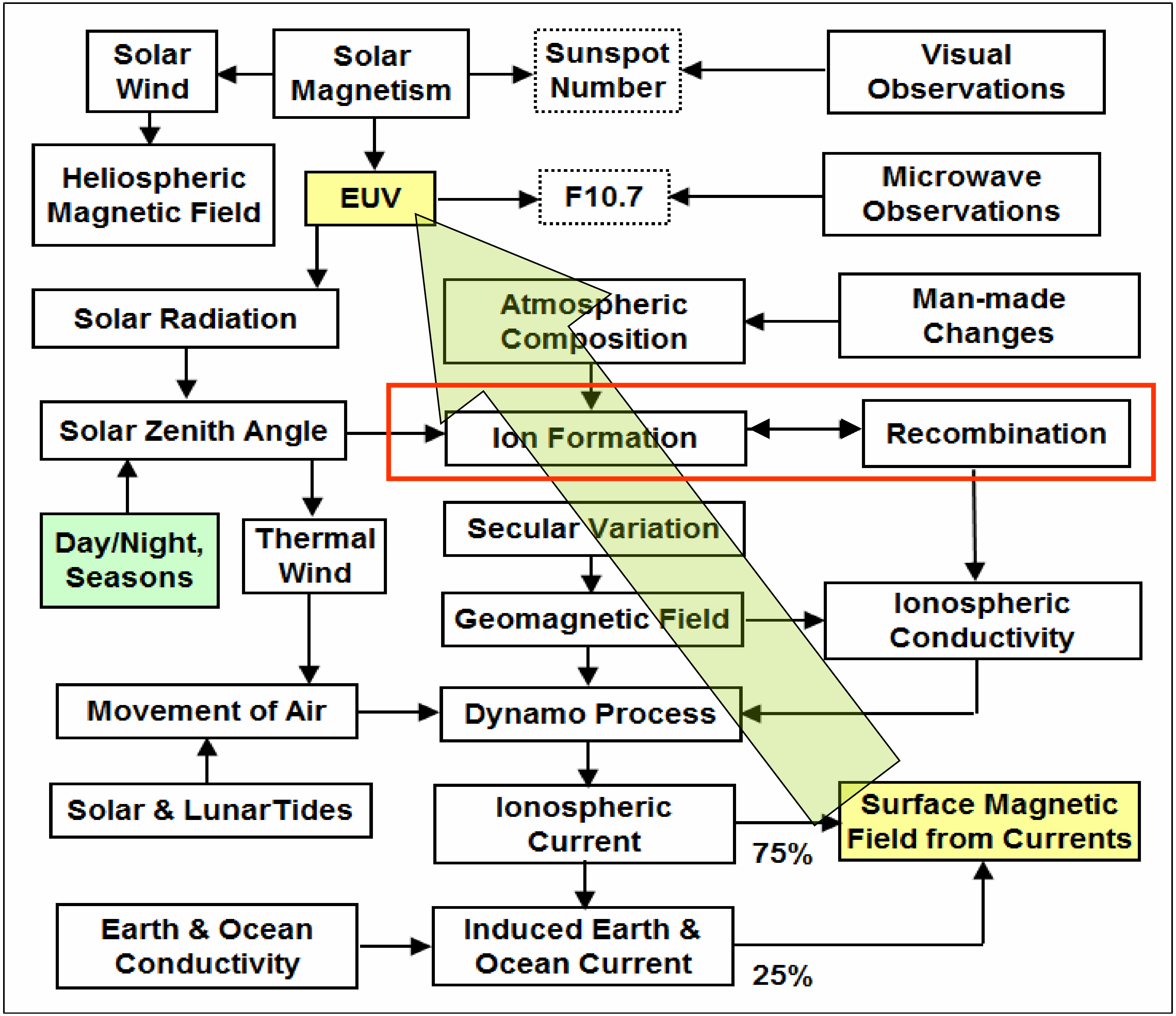
1882, Encyclopedia Britannica, 9th Ed.:

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

But why?

Dynamo

An effective dynamo process takes place in the dayside E-layer where the density, both of the neutral atmosphere and of the electrons are high enough.



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 can determine the EUV from the magnetic effects

Electron Density due to EUV

< 102.7 nm

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

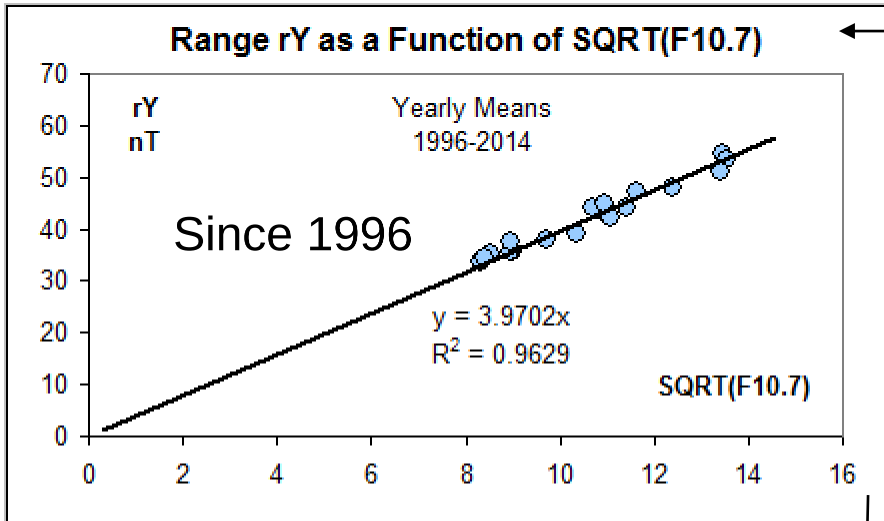
$$O_2^+ + e^- \xrightarrow{\alpha} O + O$$

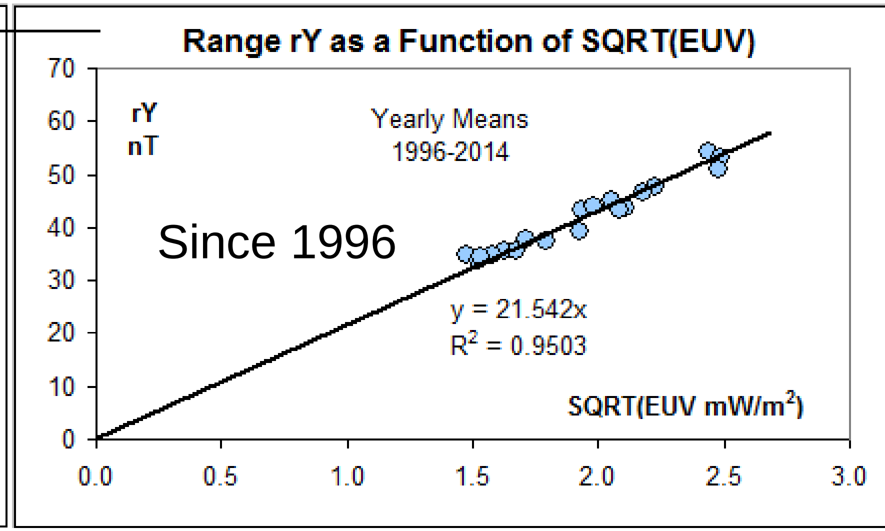
The conductivity at a given height is proportional to the electron number density N_e. In the dynamo region the ionospheric plasma is largely in photochemical equilibrium. The dominant plasma species is O^+_2, which is produced by photo ionization at a rate J (s^{-1}) and lost through recombination with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

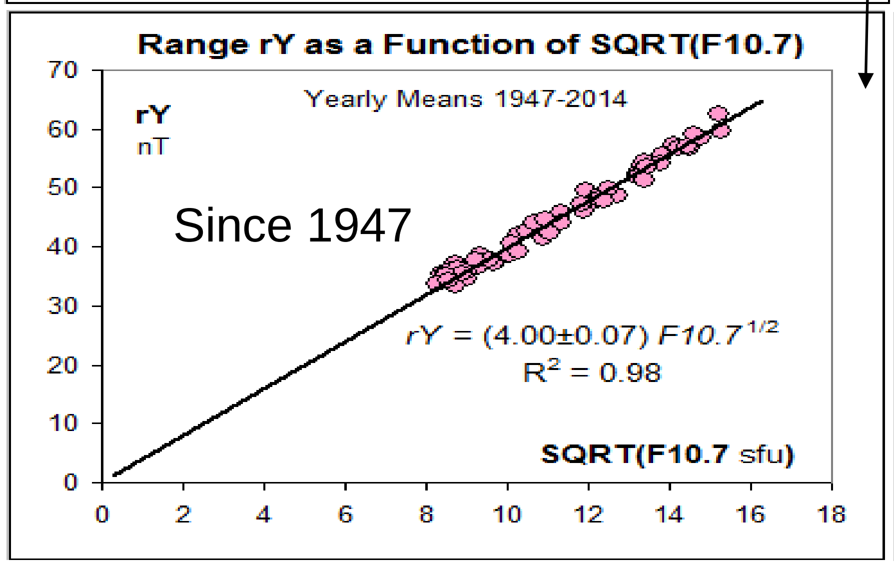
The rate of change of the number of ions N_i, dN_i/dt and in the number of electrons N_e, dN_e/dt are given by $dN_i/dt = J \cos(\chi) - \alpha N_i N_e$ and $dN_e/dt = J \cos(\chi) - \alpha N_e N_i$. Because the Zenith angle χ changes slowly we have a quasi steady-state, in which there is no net electric 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 $N = \sqrt{(J \alpha^{-1} \cos(\chi))}$

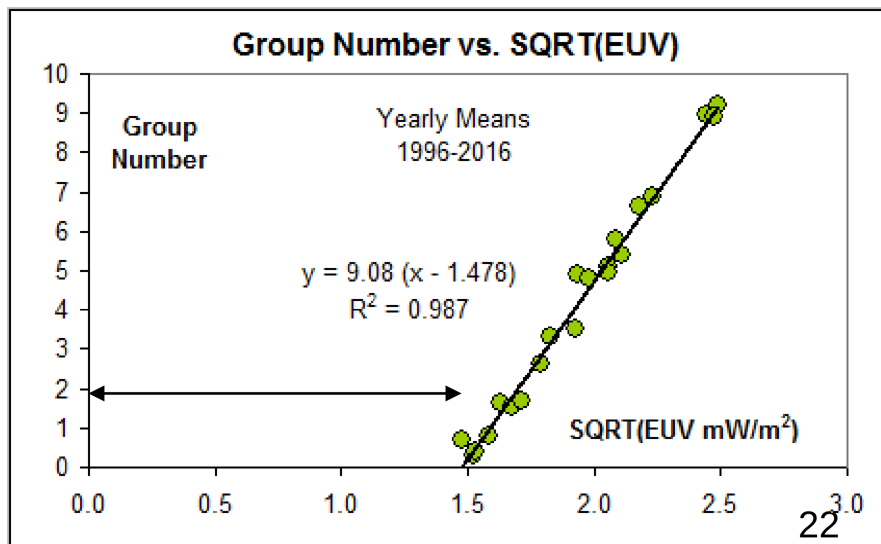
Since the conductivity, Σ, depends on the number of electrons N, we expect that Σ scales with the square root $\sqrt{(\boldsymbol{J})}$ of the overhead EUV flux with $\lambda < 102.7$ nm.

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:

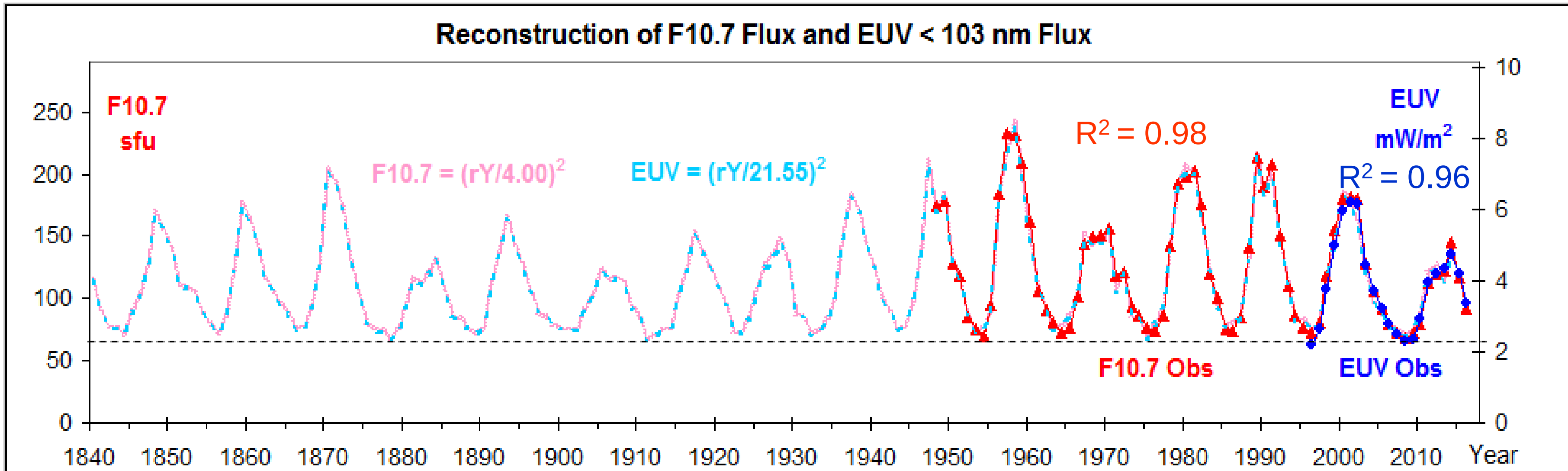


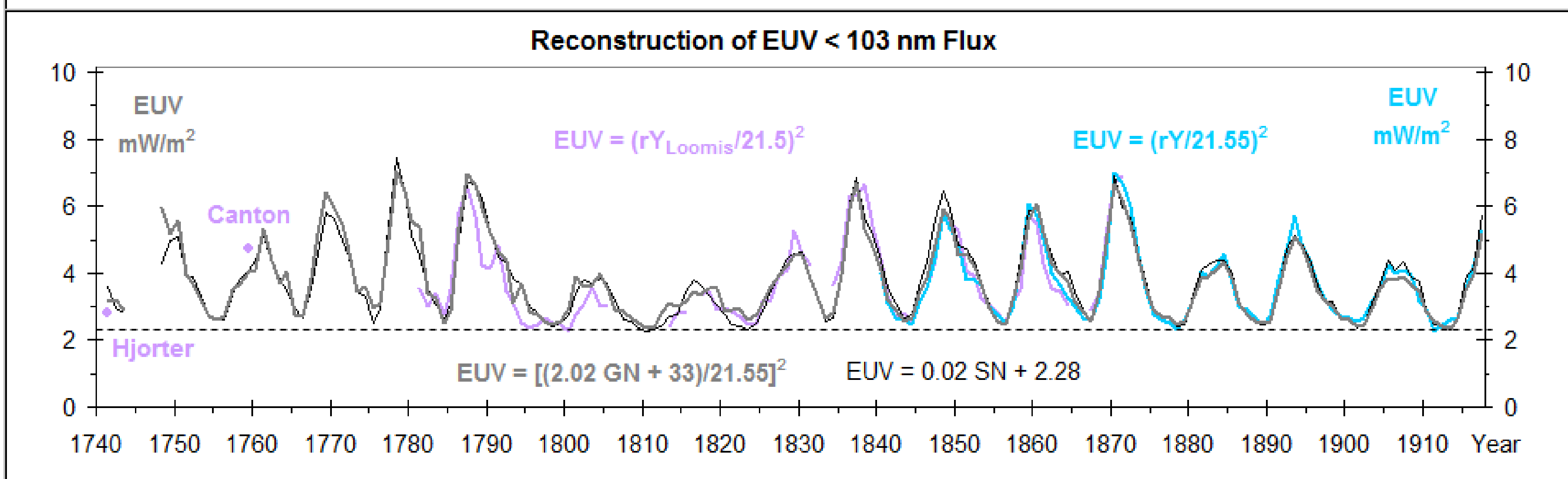






Reconstructions of EUV and F10.7





The Observational **Facts** are 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.

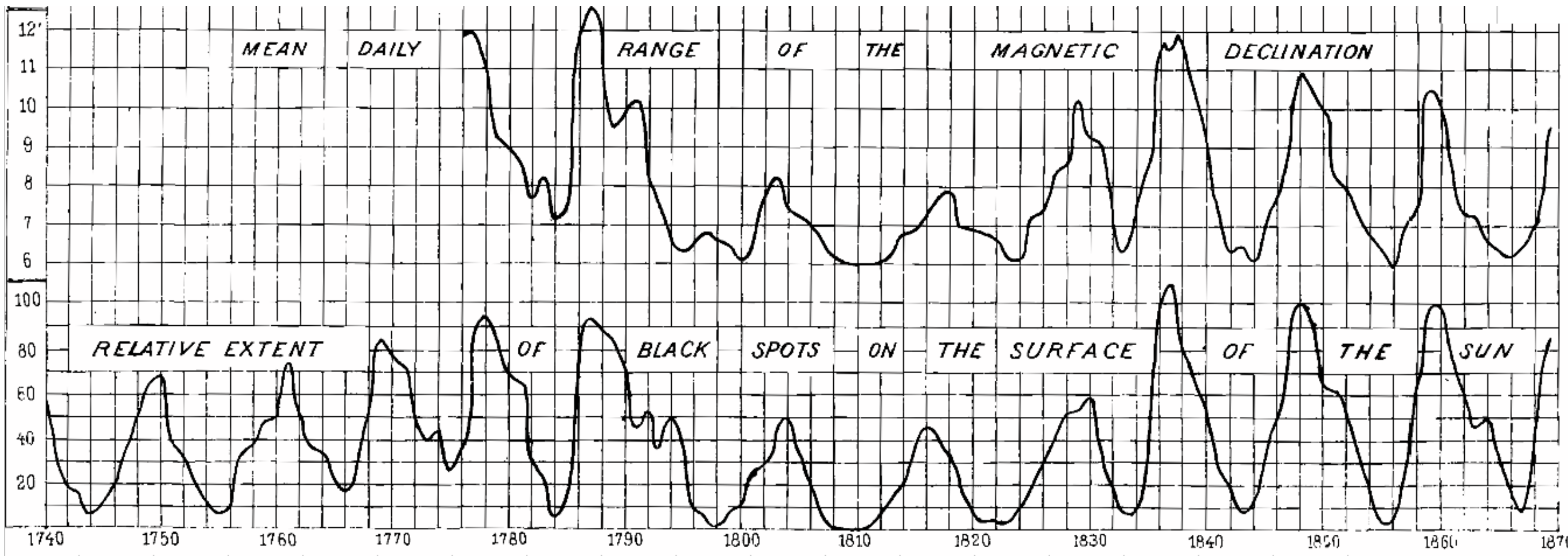
This comparison seems to warrant the following propositions:

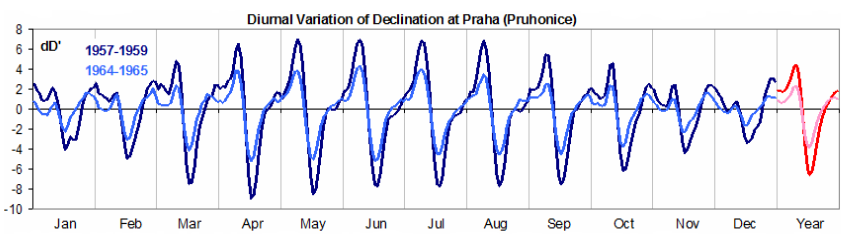
1. A diurnal inequality of the magnetic declination, amounting at Prague to about six minutes, is independent of the changes in the sun's surface from year to year.

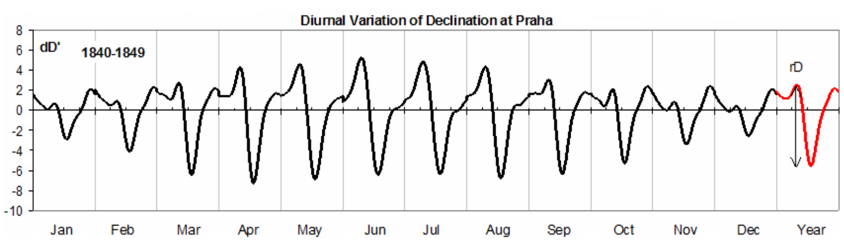
2. The excess of the diurnal inequality above six minutes as observed at Prague, is almost exactly proportional to the amount of spotted surface upon the sun, and may therefore be inferred to be produced by this disturbance of the sun's surface, or both disturbances may be ascribed to a common cause.

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

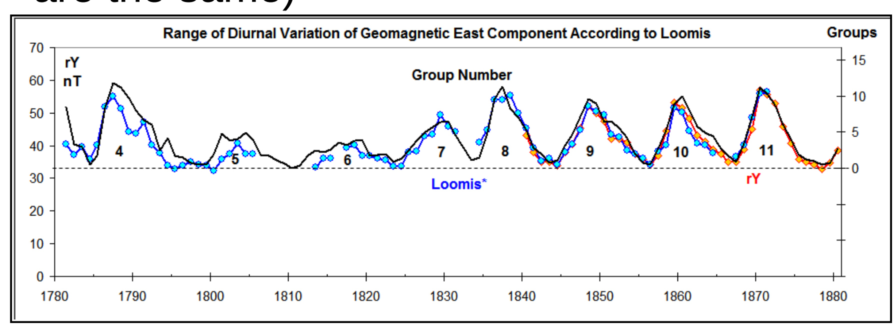
Loomis' Evidence for his Proposition







Comparison of the variation in the 1840s with modern data (1950-1960s) shows that the old data are good (even small 'wiggles' are the same)



What do we have so far? #2

- The Regular Diurnal Variation of the Geomagnetic Field depends on the Solar Zenith angle and Solar Activity, e.g. as given by the Sunspot Number (Wolf, Gautier, 1852) and has been widely observed at many geomagnetic observatories since its discovery in 1722
- The Amplitude of the Diurnal Variation is strictly proportional to the Square Root of the EUV [and F10.7] Flux
- We can reconstruct EUV and F10.7 [and similar indices like Mg II & Ca II] back to the 1740s, and thus also the Total Magnetic Flux http://www.leif.org/research/Reconstruction-of-Solar-EUV-Flux-1740-2015.pdf
- All our solar indices show that solar activity [magnetic field] is nearly constant at every solar minimum [apart from tiny residuals] for the past 275 years

Outline

- Observed EUV, Solar Microwave, and Magnetic flux records
- Deriving EUV [etc] from Geomagnetic Daily Variations
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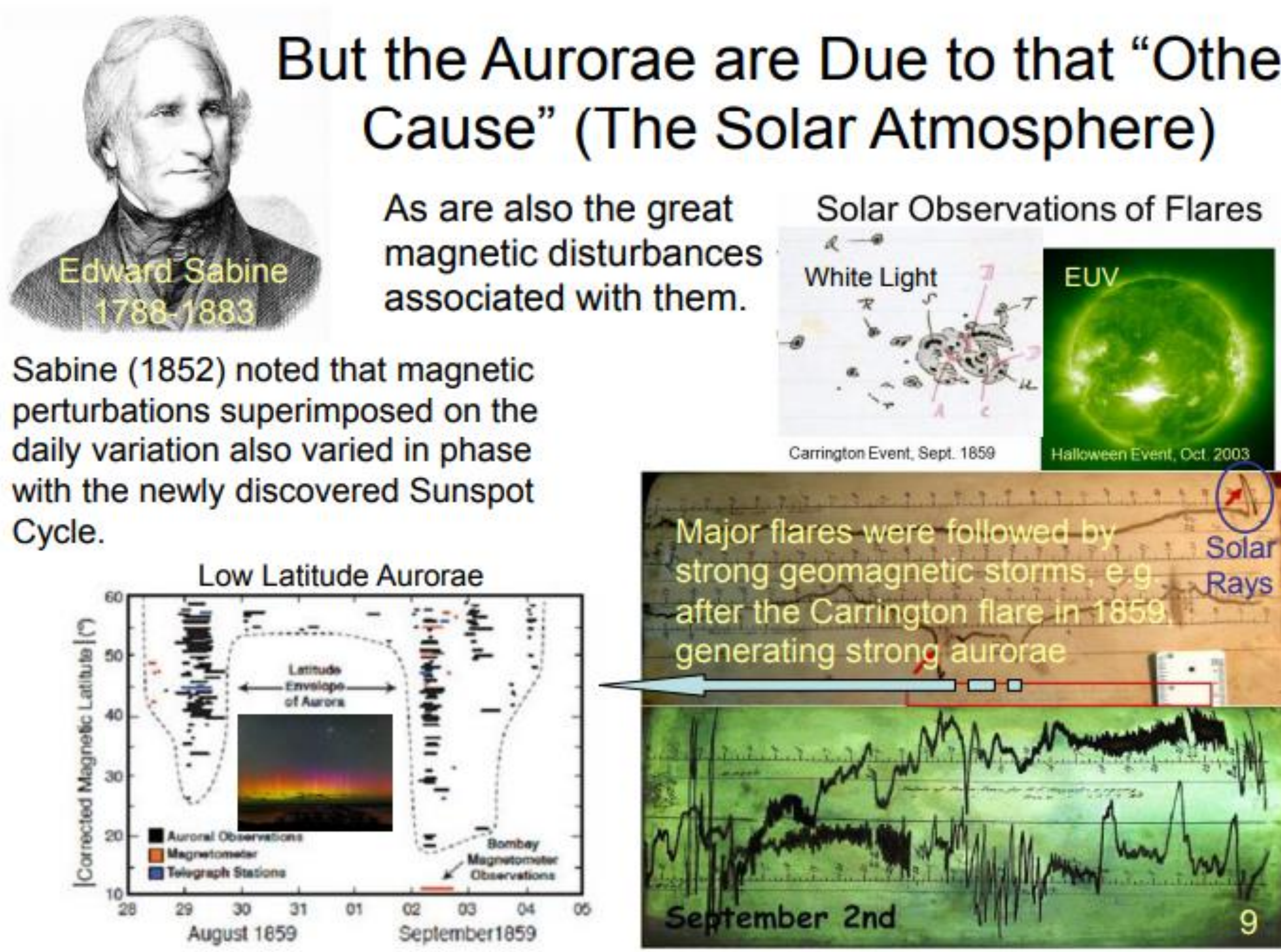
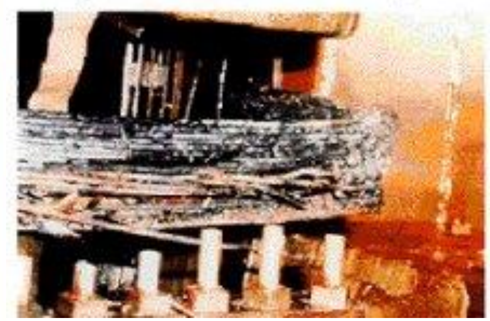
Geomagnetic Storms Caused by Sun



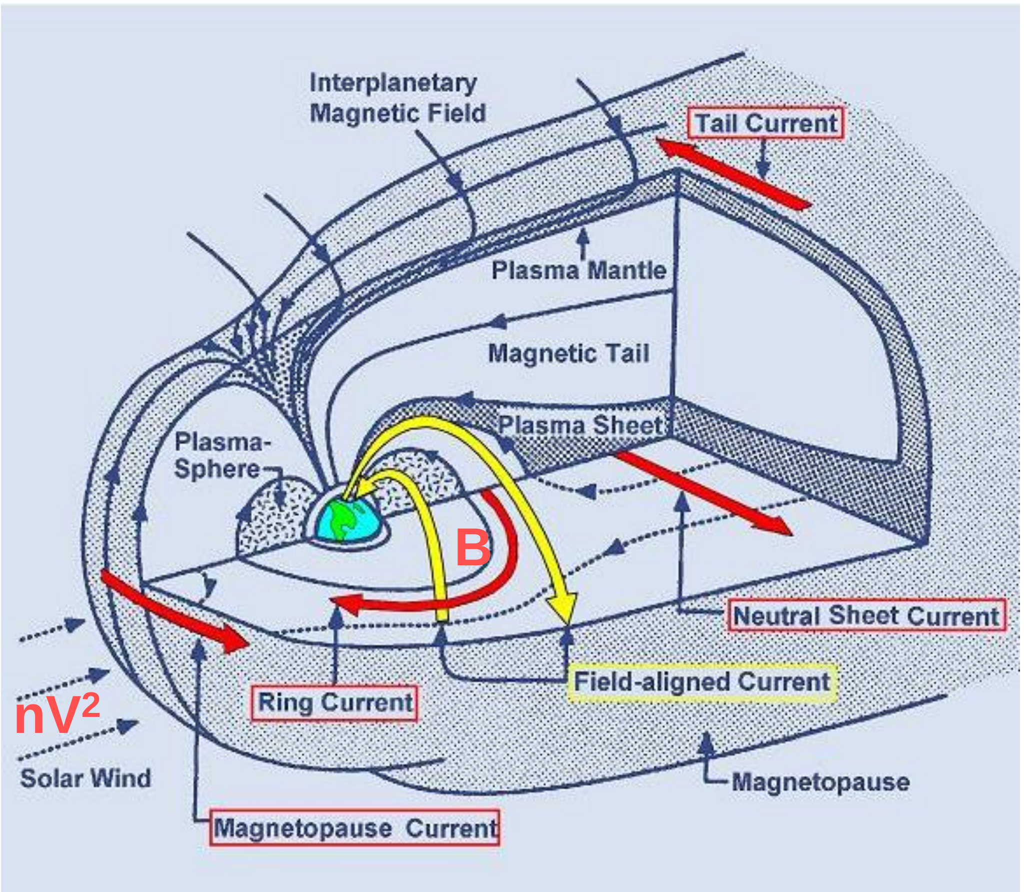
PJM Public Service Step Up Transformer

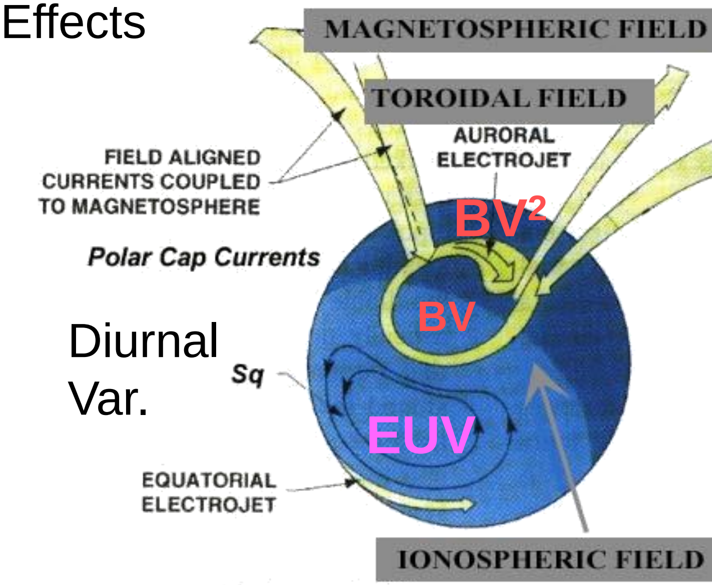
Severe internal damage caused by the space storm of 13 March, 1989

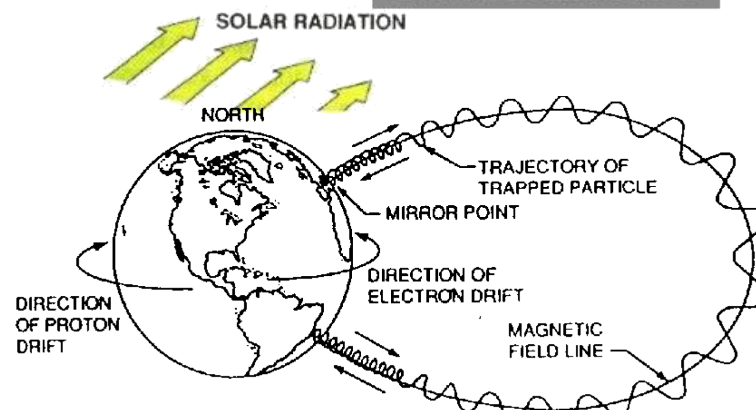


Electric Current Systems in Geospace

Different Current Systems ⇄ Different Magnetic Effects







We can now invert the Solar Wind – Magnetosphere relationships…

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

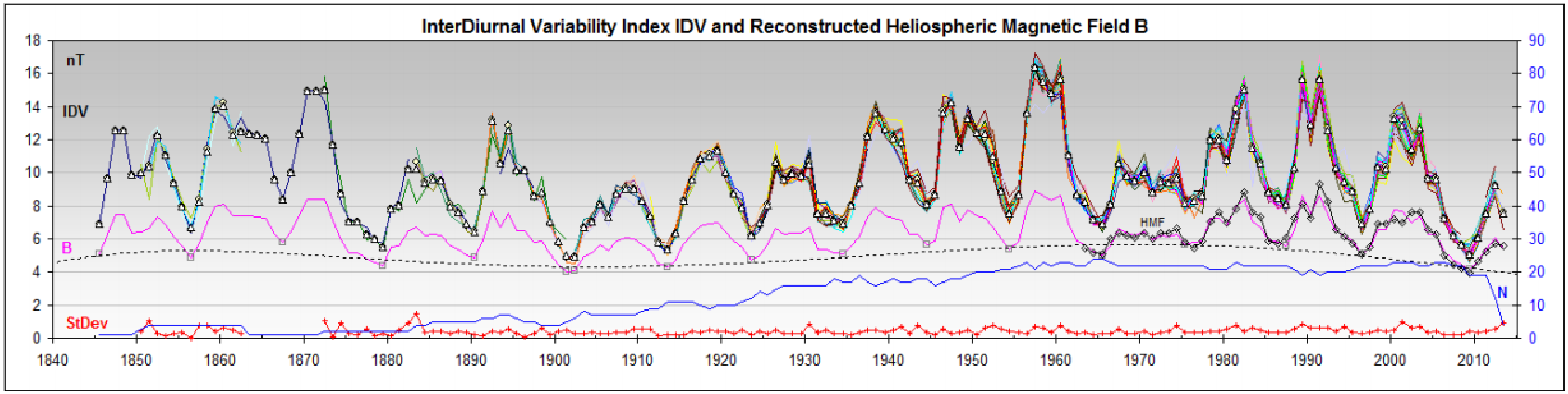
‘Different Strokes for Different Folks’

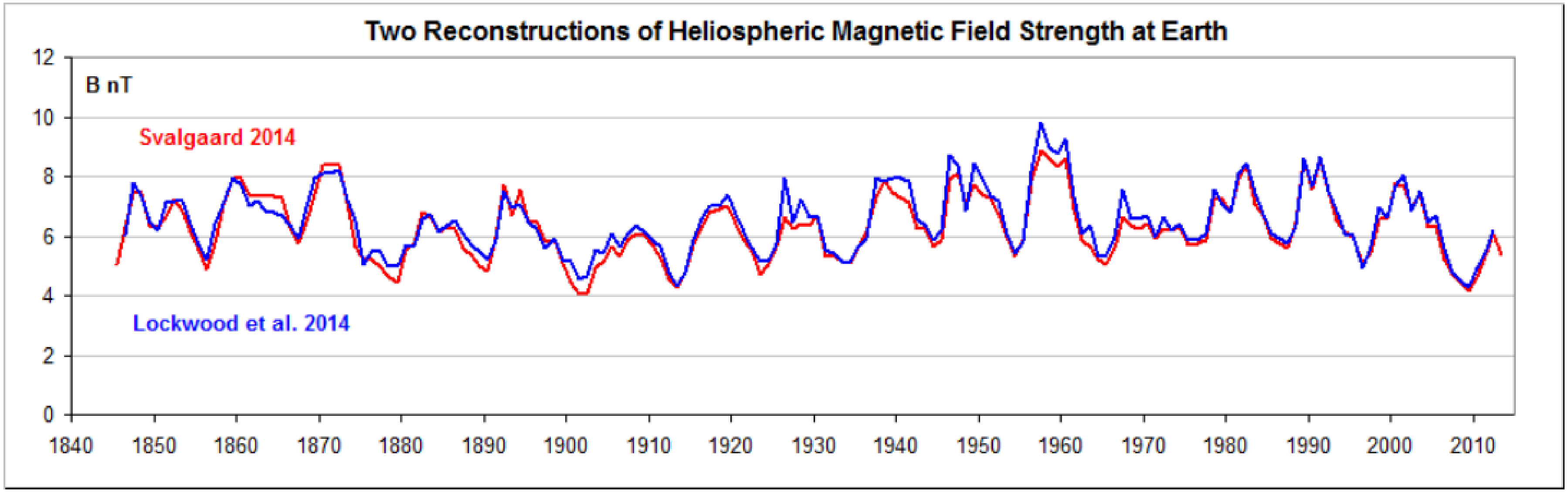
- The key to using geomagnetism to say something about the sun is the realization that geomagnetic ‘indices’ can be constructed that respond differently to different solar and solar wind parameters, so can be used to disentangle the various causes and effects
- In the last decade of research this insight (e.g. Svalgaard et al. 2003) has been put to extensive use and a consensus has emerged

The IDV Geomagnetic Index

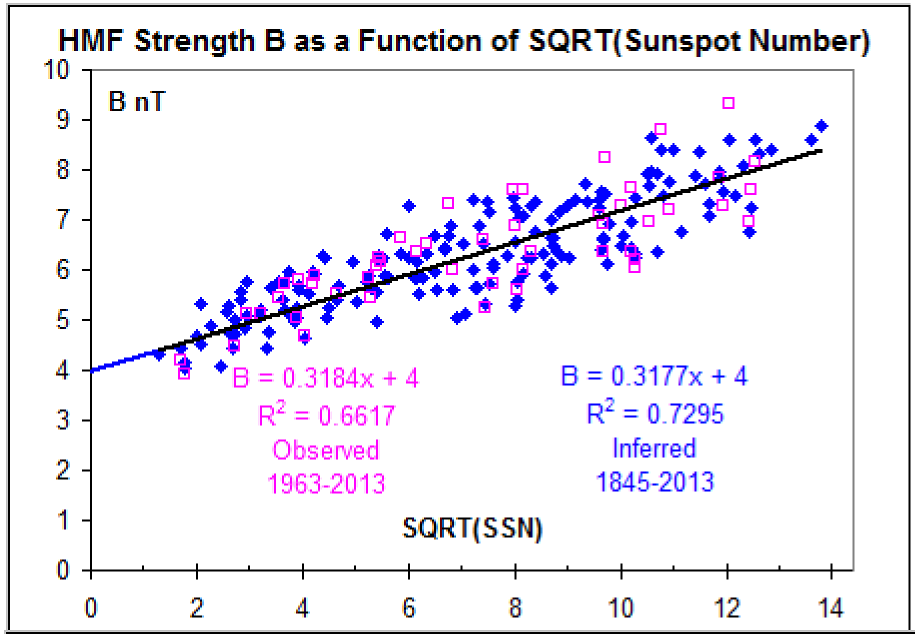
- Since the daily variation is fairly regular from day to day we can eliminate it by considering the difference between the fields on consecutive days
- Further suppression of the daily variation can be achieved by working only with the field during night hours or the average over a whole day
- That led to the definition of the Interdiurnal Variability Index [IDV] as the unsigned difference between a geomagnetic field component on consecutive local nights which has been found to be related to the heliospheric magnetic field impinging on the Earth
- IDV [from several stations] is a Global index
- IDV is a modern version of the *u*-measure (Bartels)

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

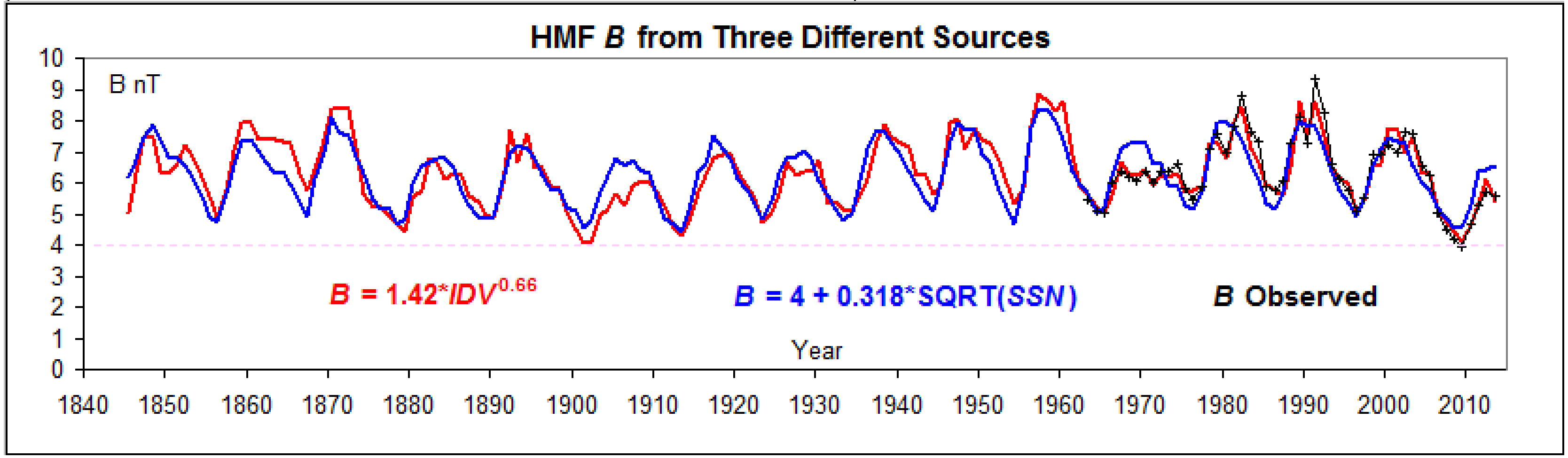




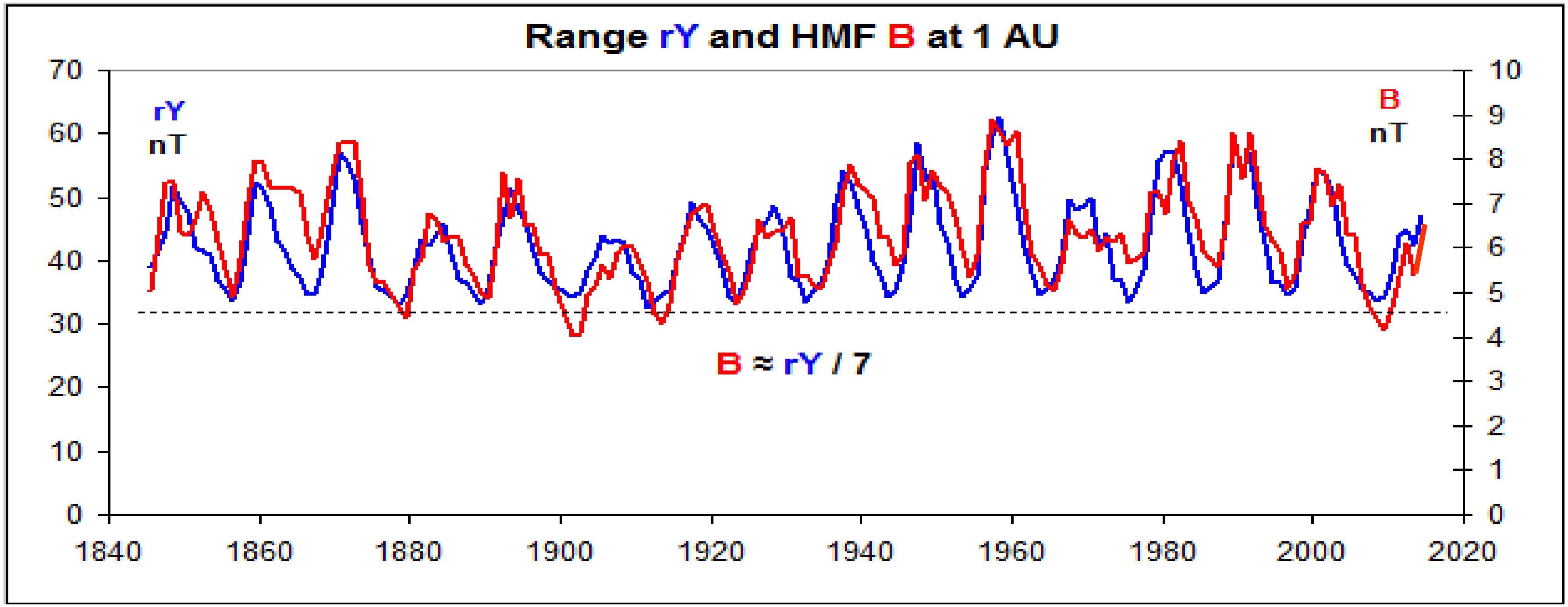
HMF *B* related to Sunspot Number



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]).



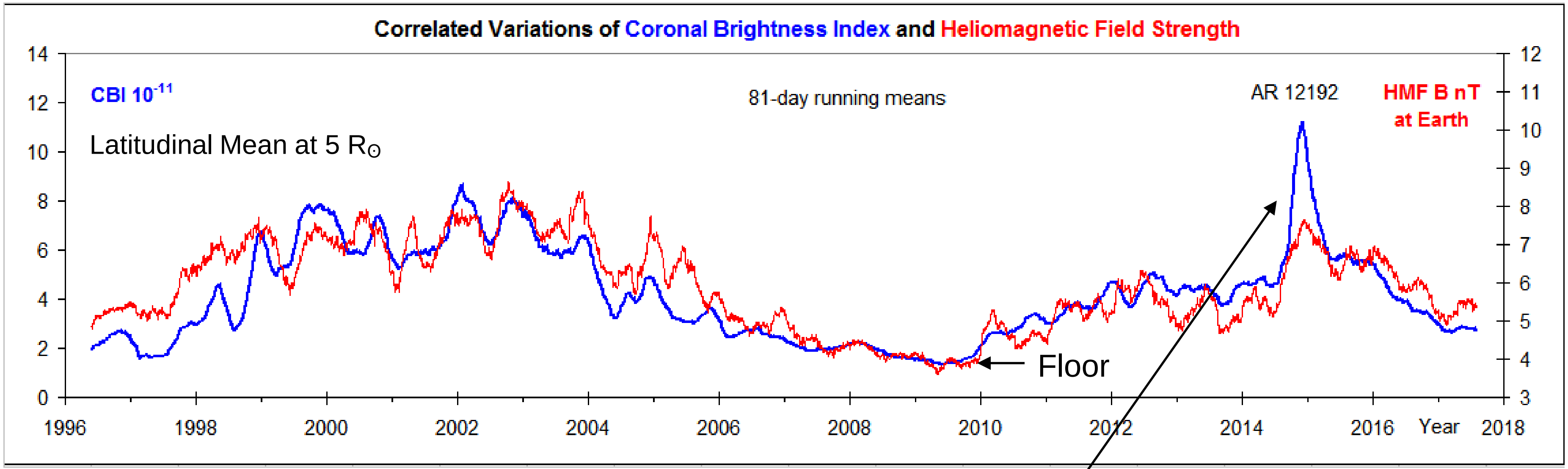
Network Field and Solar Wind Field

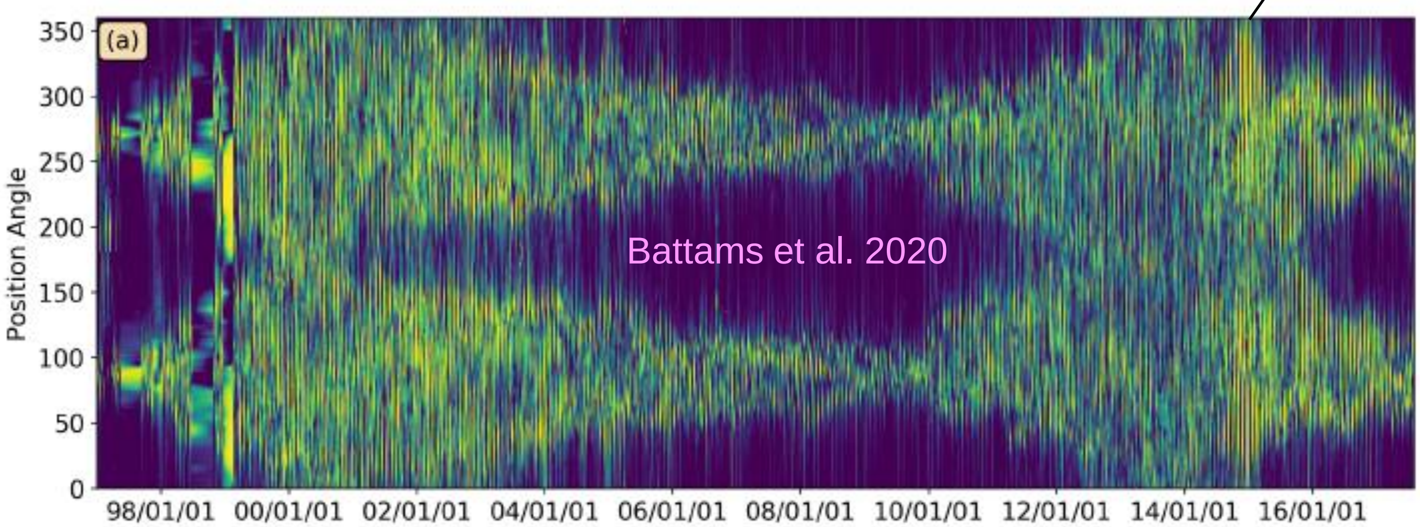


The magnetic field in the solar wind (the Heliosphere) ultimately arises from the magnetic field on the solar surface filtered through the corona, and one would expect an **approximate** relationship between the network field (EUV and rY) and the Heliospheric field, as observed.

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.

Coronal Brightness Correlates with Heliomagnetic Field at 1 AU



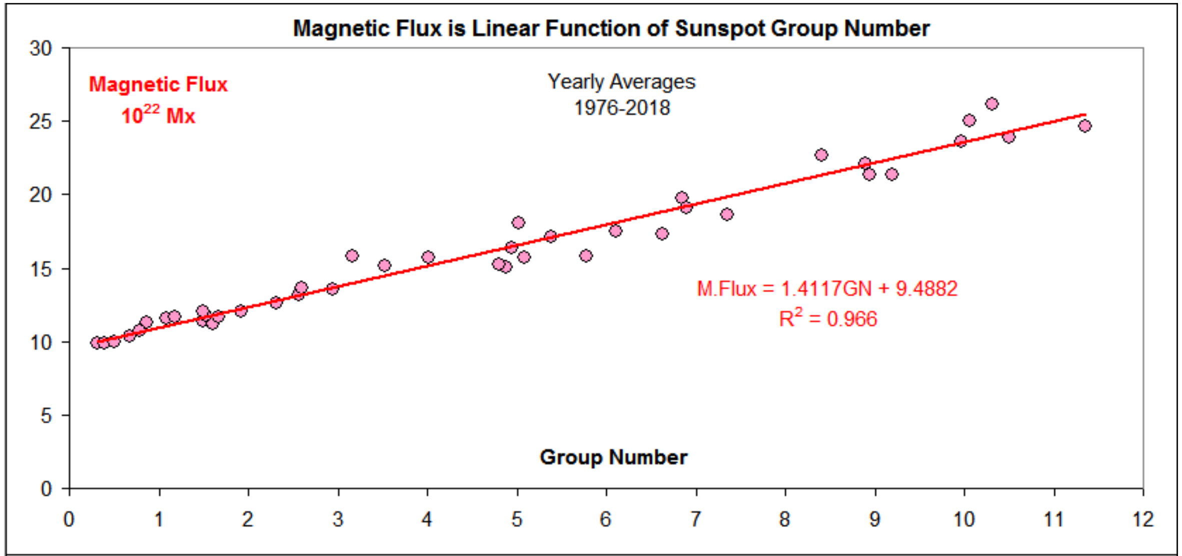


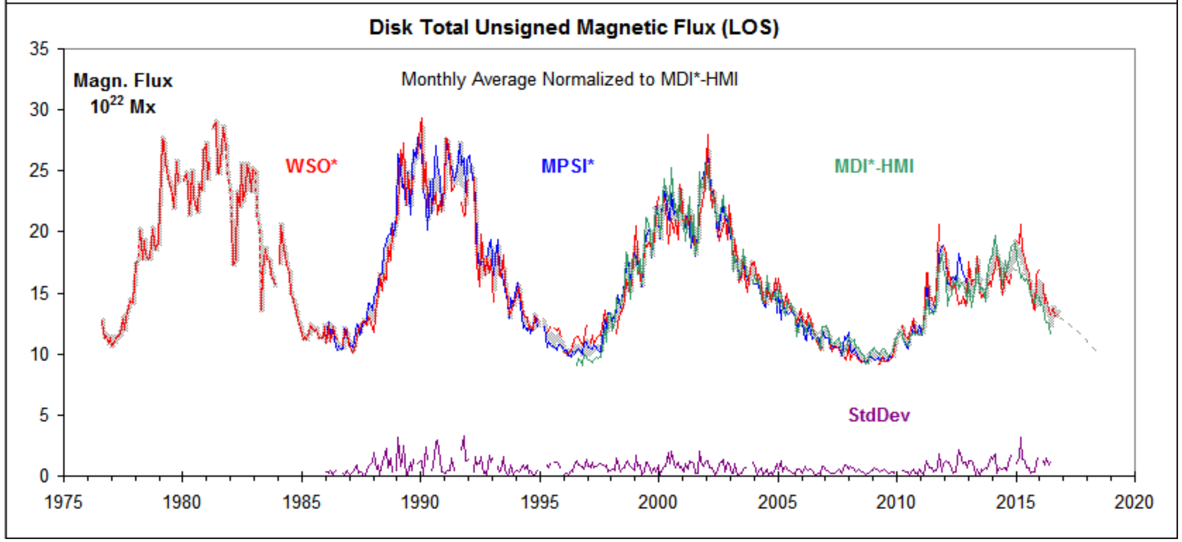
LASCO Coronal Brightness Index (at 5 R☉) likely a proxy for Solar Magnetic Flux

What do we have so far? #3

- Consensus reconstruction of Heliospheric magnetic field B for centuries past
- HMF B also has a ‘floor’ at every solar minimum, probably including the Maunder Minimum, and certainly the Dalton and modern Minima.
- The solar cycle variation of B above the floor is probably controlled by the CME rate [varying with Square Root of the sunspot number]
- There is a good relationship between HMF B and the Network Magnetic Field [EUV from diurnal geomagnetic variation, rY]
- In particular, there is no clear secular increase in solar activity the past 300 years

Magnetic Flux back to 1976 and the Sunspot Group Number (SS16)

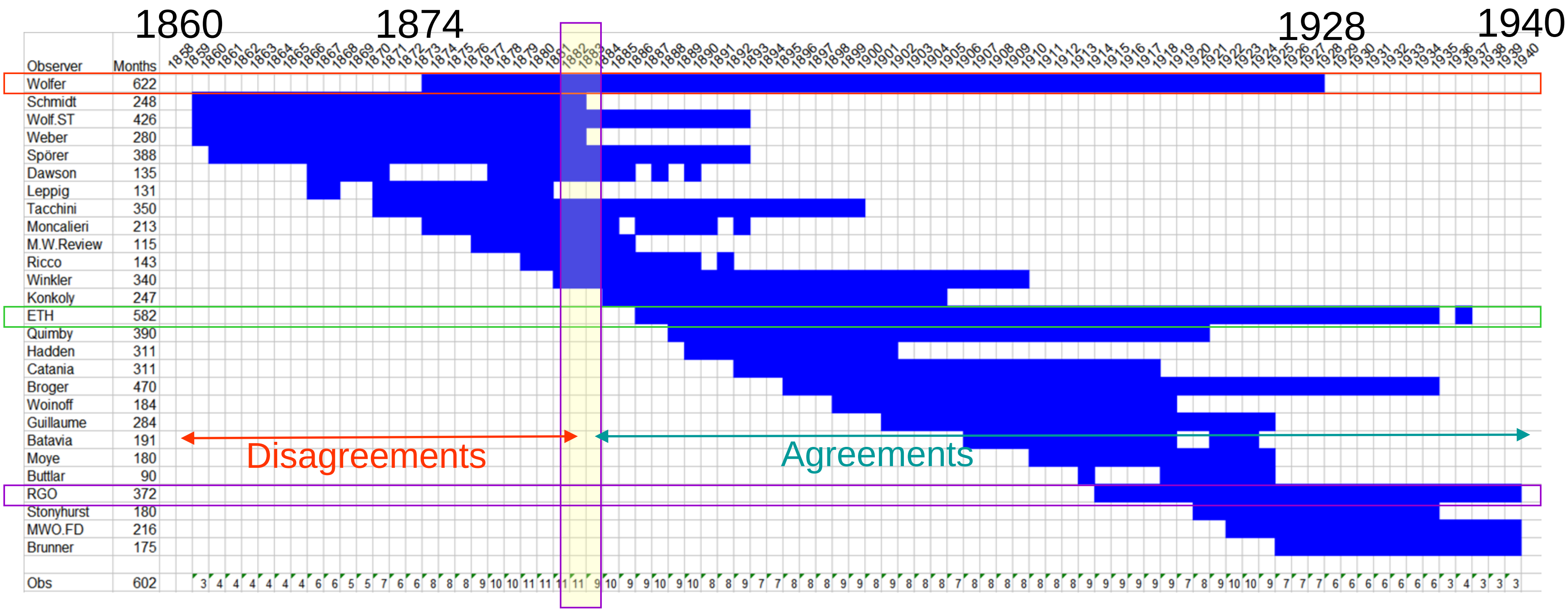




Scaling MWO to MDI-HMI and WSO to the result yields a good measure of the LOS unsigned full disk magnetic flux which turns out to be a linear function of the Sunspot Group Number (S&S 2016).

Even at the limit of zero Groups there is still a significant amount of solar magnetic flux as needed to explain the interplanetary flux.

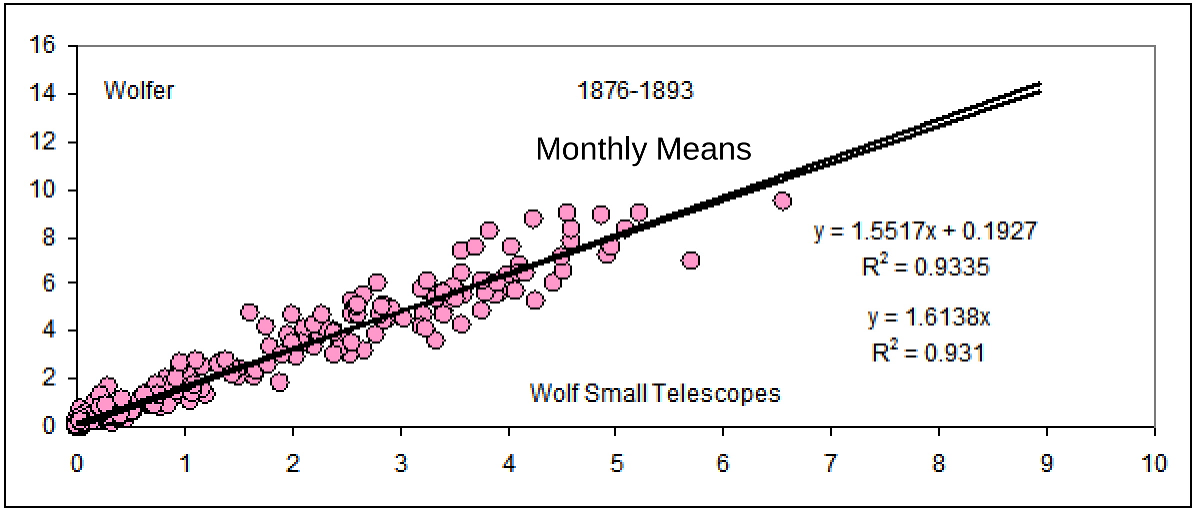
New Wolfer Backbone (Monthly)



Svalgaard & Schatten (2016) used a 'backbone' method to reconstruct the Sunspot Group Number since 1610. Five backbones where used, centered and anchored on the Wolfer Backbone, which then defines the scale of the series. Backbones are constructed by scaling observers directly to the primary observer (e.g. Wolfer) without daisy-chaining through intermediary observers thus avoiding accumulation of errors. Each observer is scaled to Wolfer and we check that the relation is linear with insignificant offset, defining a k-value. The data is taken from Svalgaard (2019) for the newly digitized Zürich drawings (ETH) and from Vaquero et al. (2016) for all other observers. To improve the time resolution (better determination of error bars) the new Wolfer Backbone has **monthly** resolution rather than the previous one's yearly values.

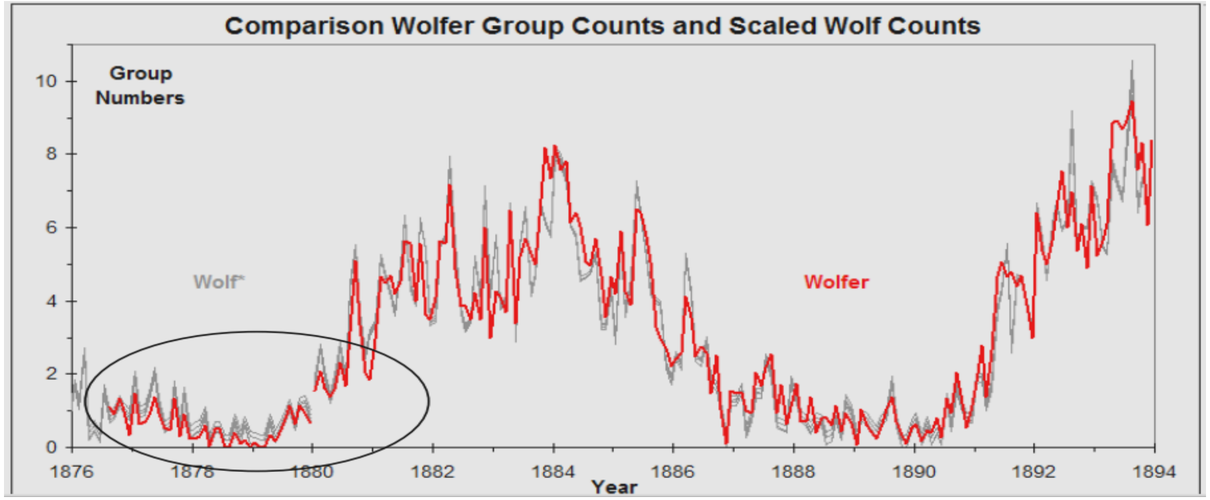
With a few exceptions (e.g. RGO) we use ALL the data from ALL observers

How Well Can We Reconstruct Wolfer's Count From Wolf's?



Wolfer = 1.6 Wolf ST

Aperture 37 mm X20

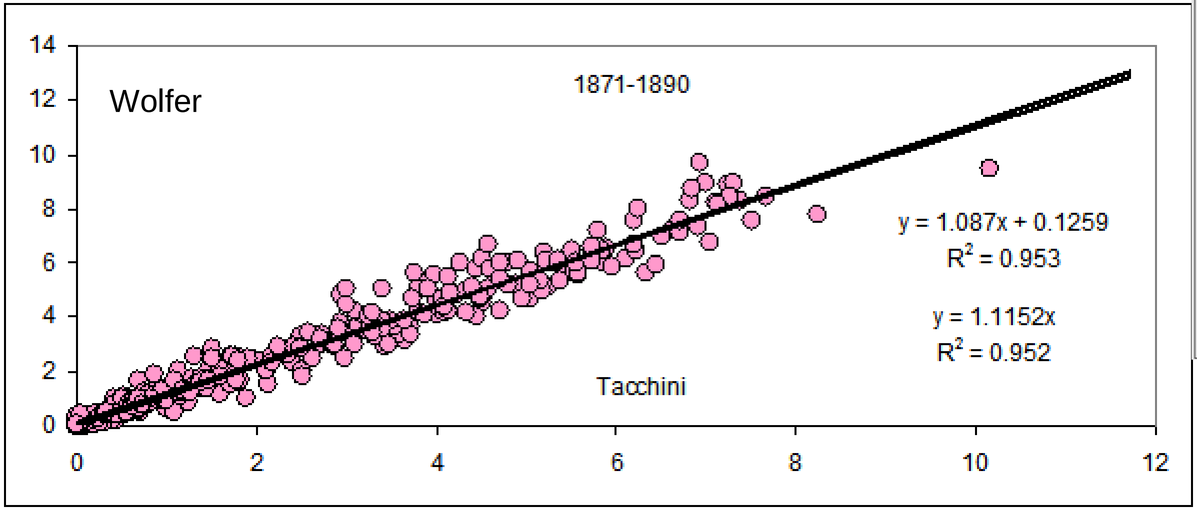


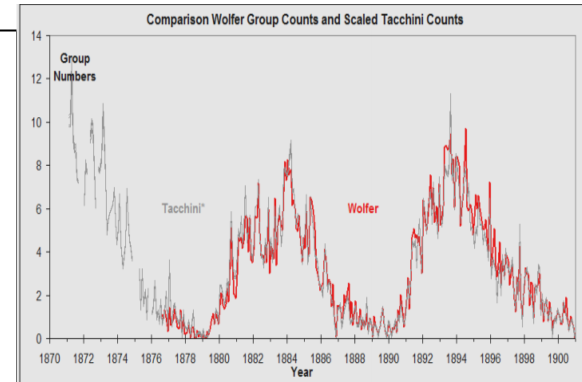
Learning curve…

We can reproduce the Wolfer count from Wolf (ST) with only 7% 'unexplained' variance

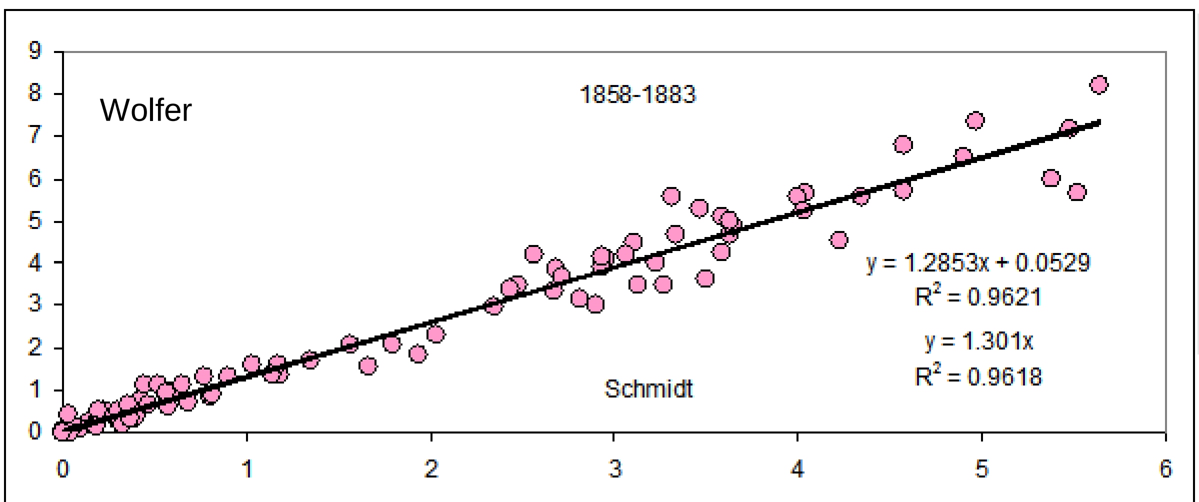
The relationship is linear and proportional

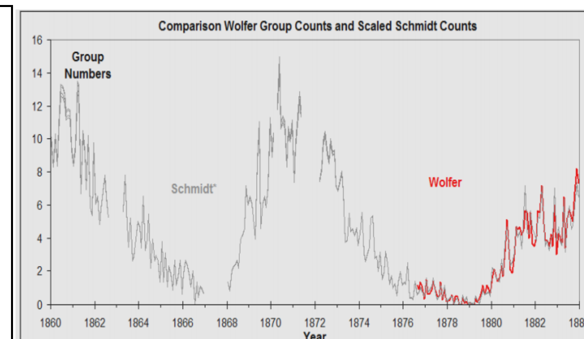
Early Regressions to Wolfer





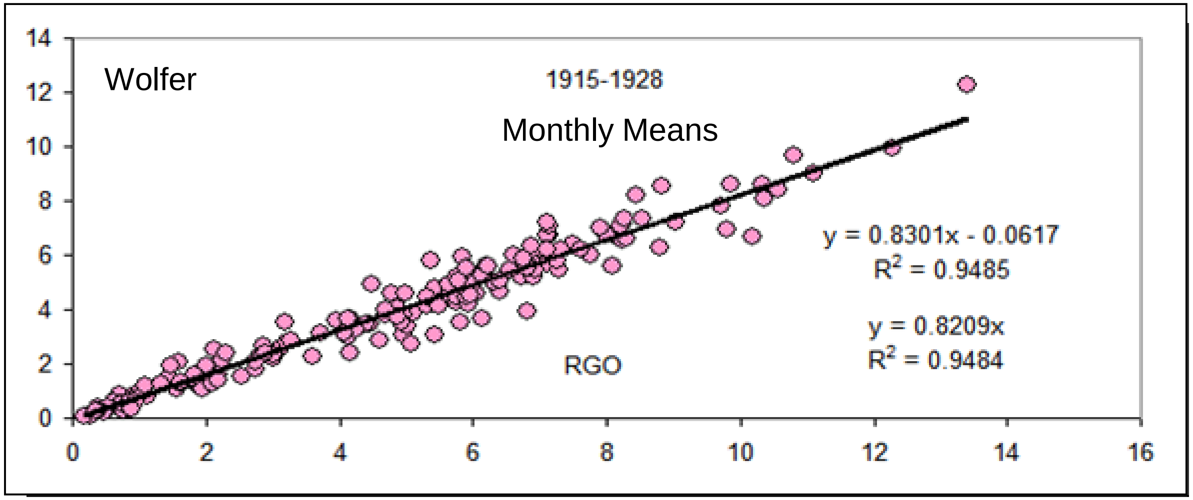
Just as for Wolf, the reproduction of Wolfer is very good (only 5% unexplained variance.

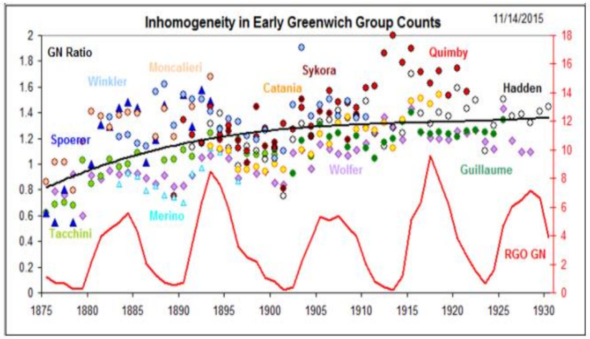




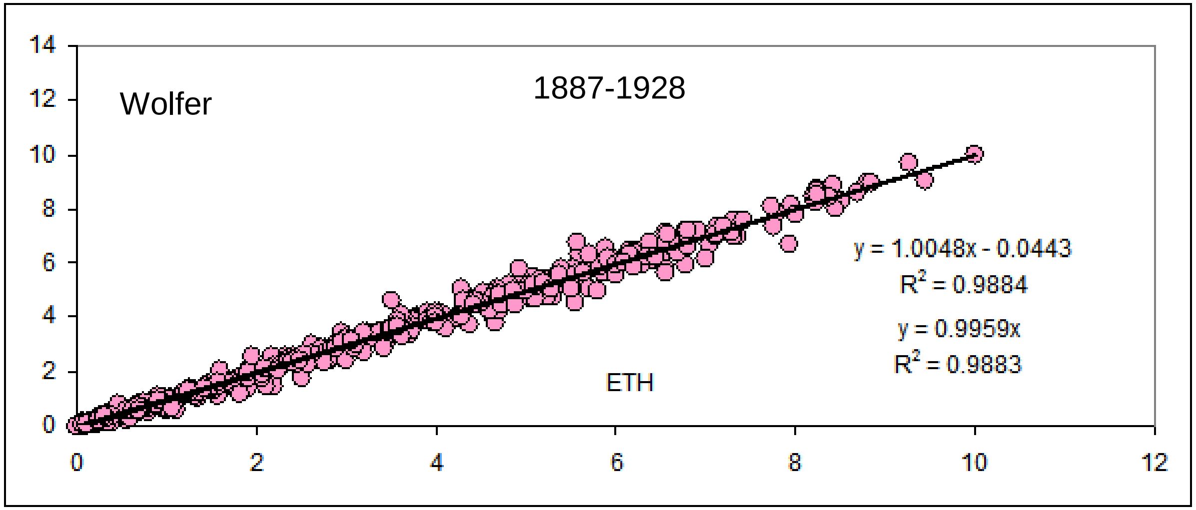
Same for Schmidt in Athens…

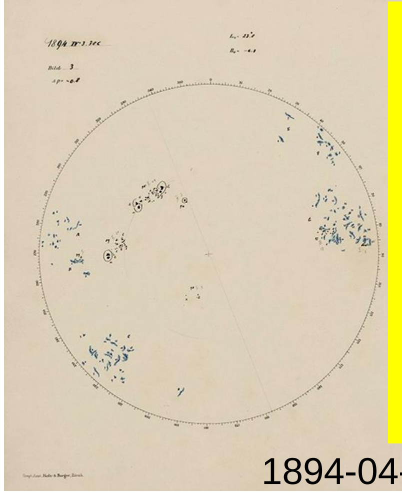
Later Regressions to Wolfer





RGO was drifting before ~1915 so we start in 1915





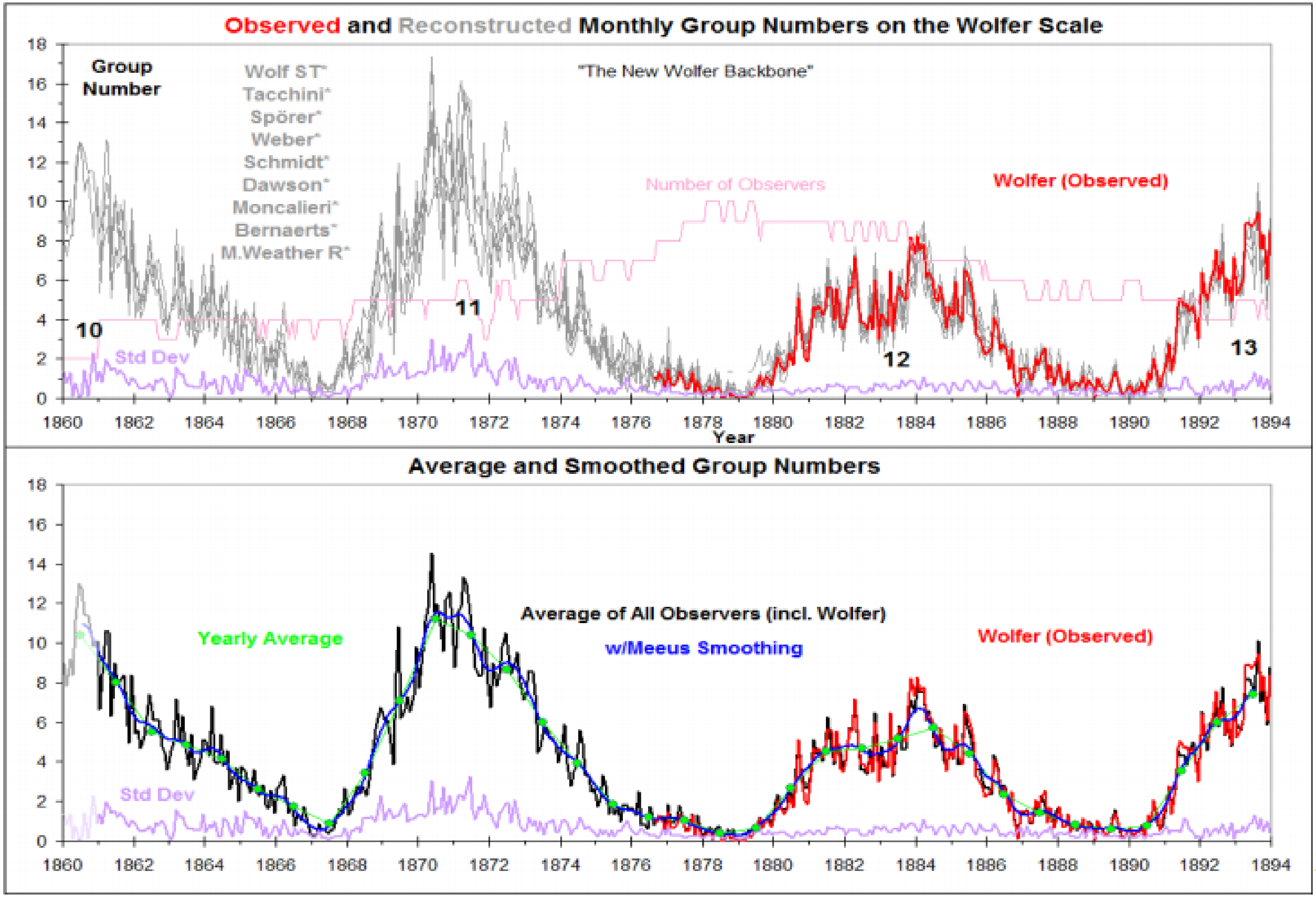
1887-1937: 13024 drawings, 42510 groups.

1938-1996 Still to do

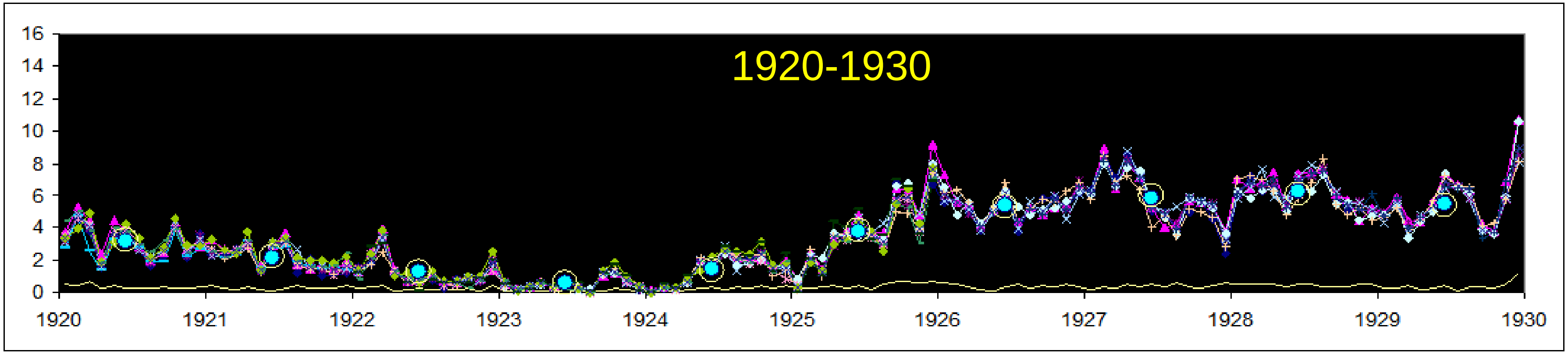
Total Sheets: 29296

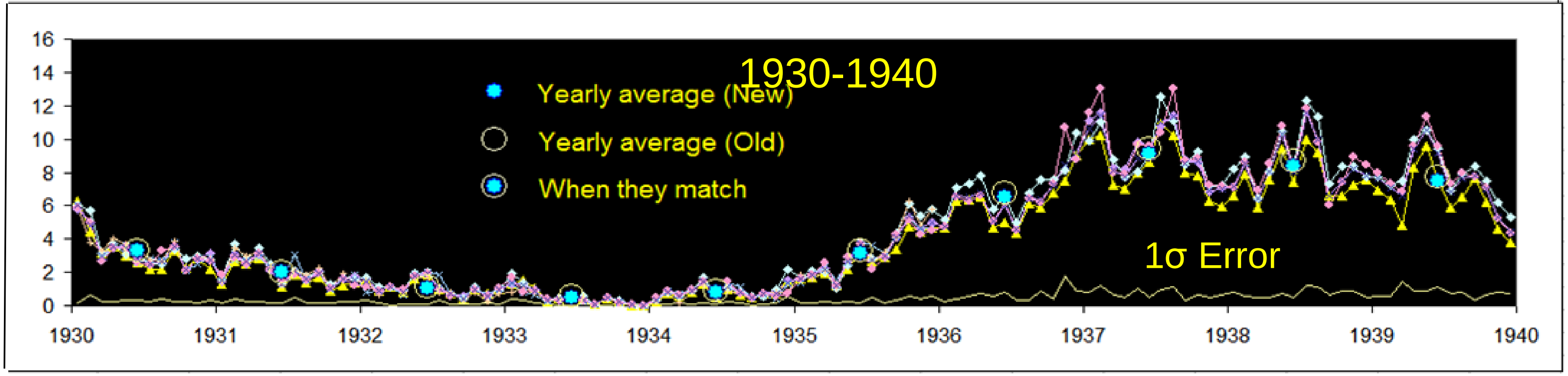
1894-04-03

Compilation of Early Observers



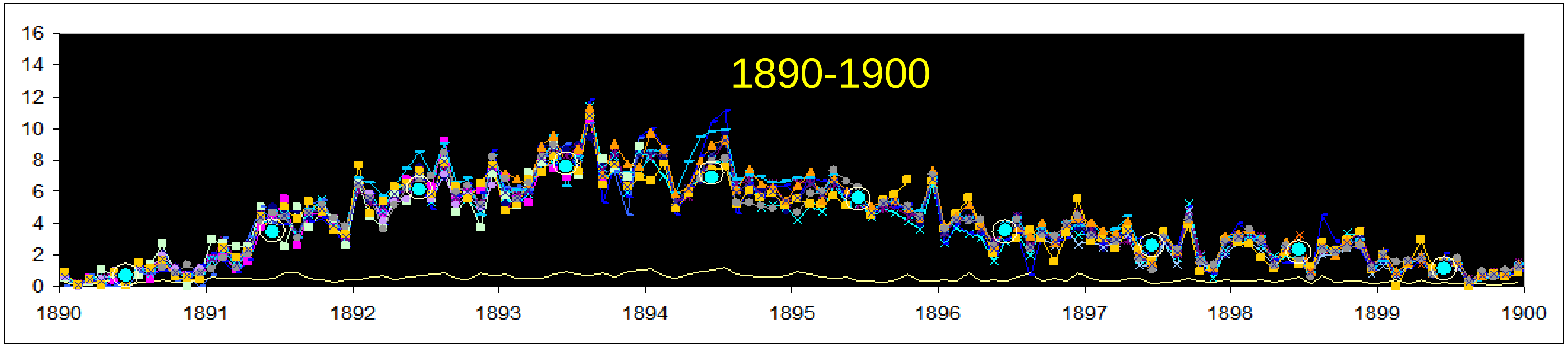
Composite of All Observers, III

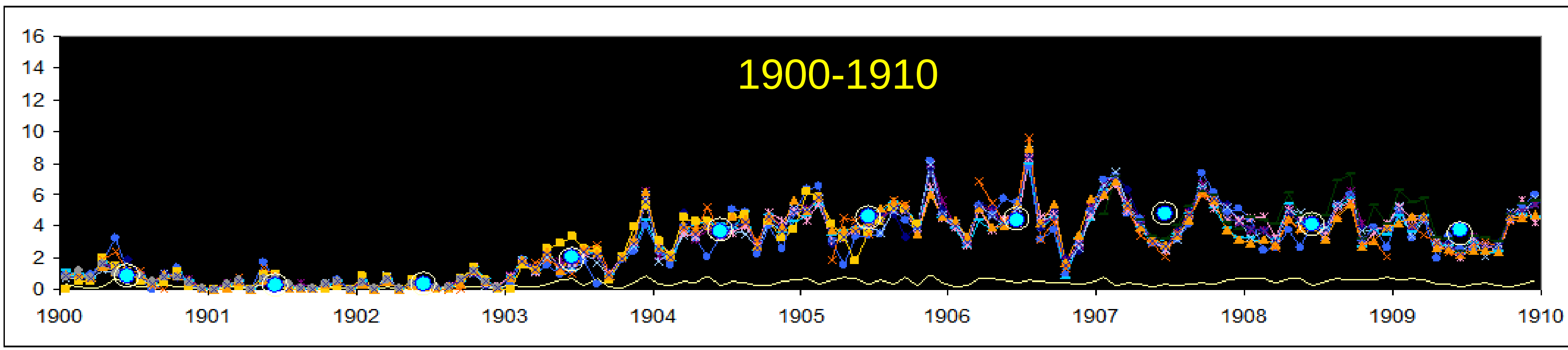


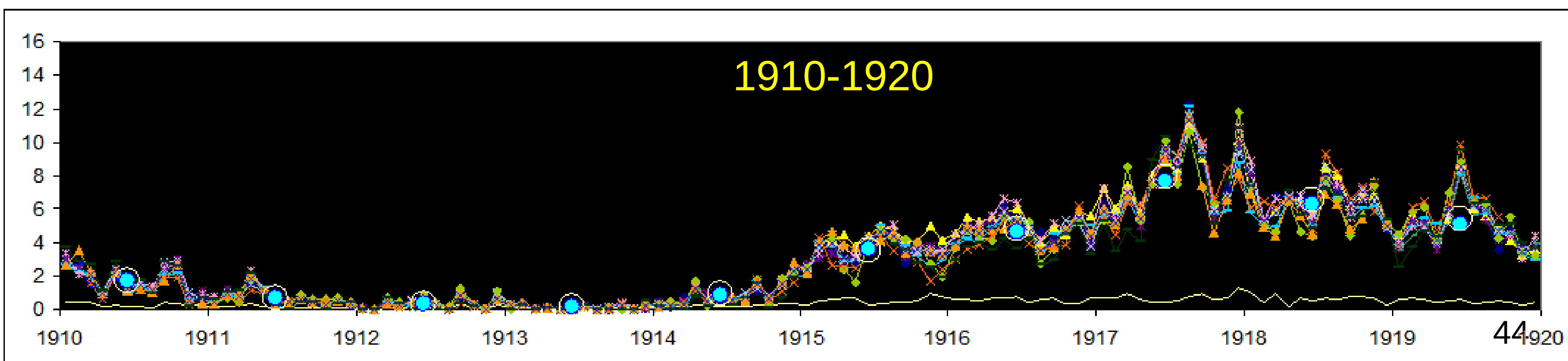


Using the scaling factors (k-values) for the best fit for each observer they are all put on the Wolfer Scale and plotted with different colors per observer for each decade. The 1-σ error (bottom yellow curve) is calculated as the standard deviation for the month divided by the square-root of the number of observers. Large blue dots show the yearly average group number (GN). Yellow circles show the old (S&S16) yearly GNs.

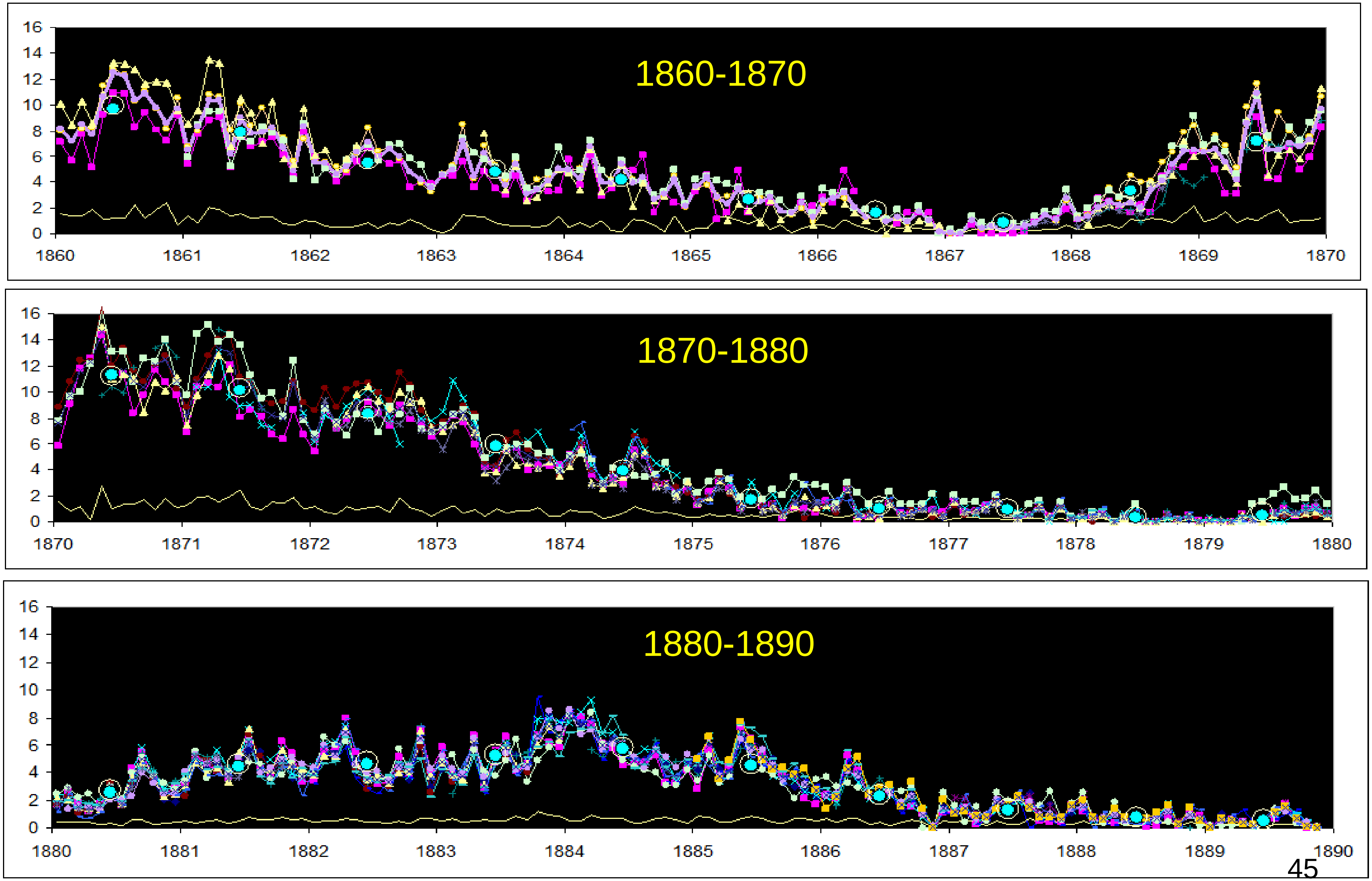
Composite of All Observers, II



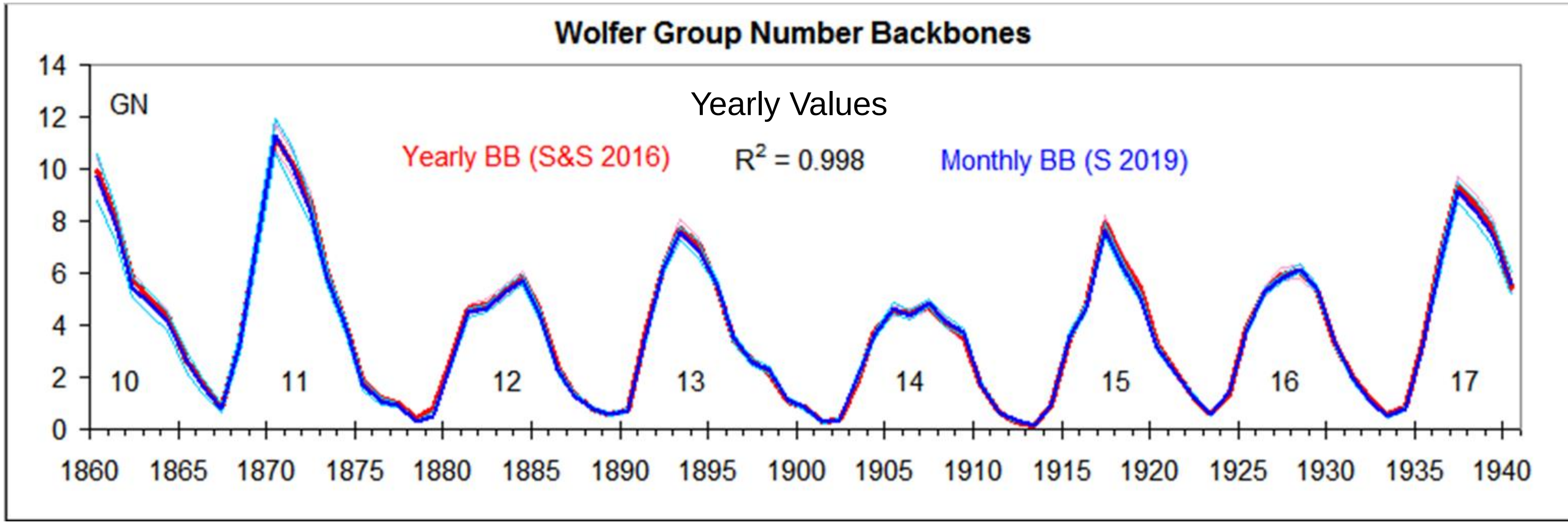




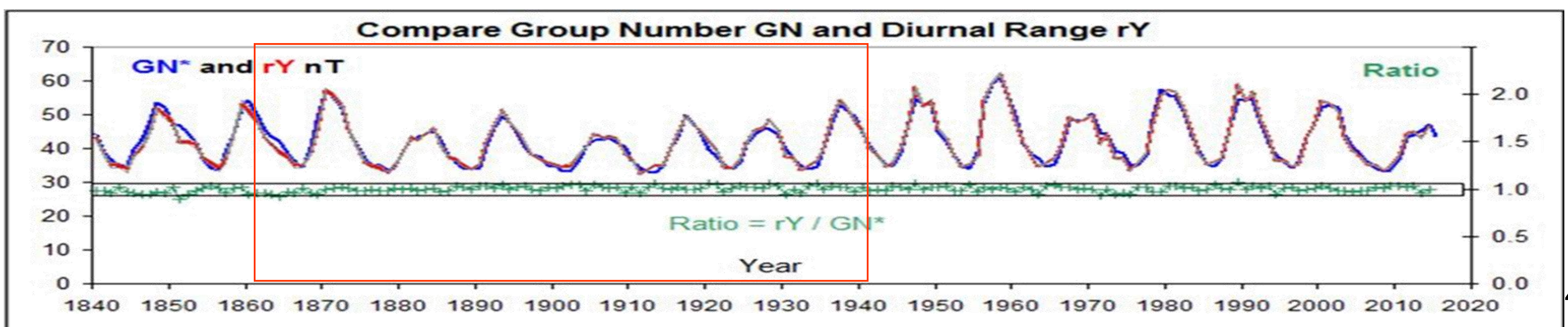
Composite of All Observers, I



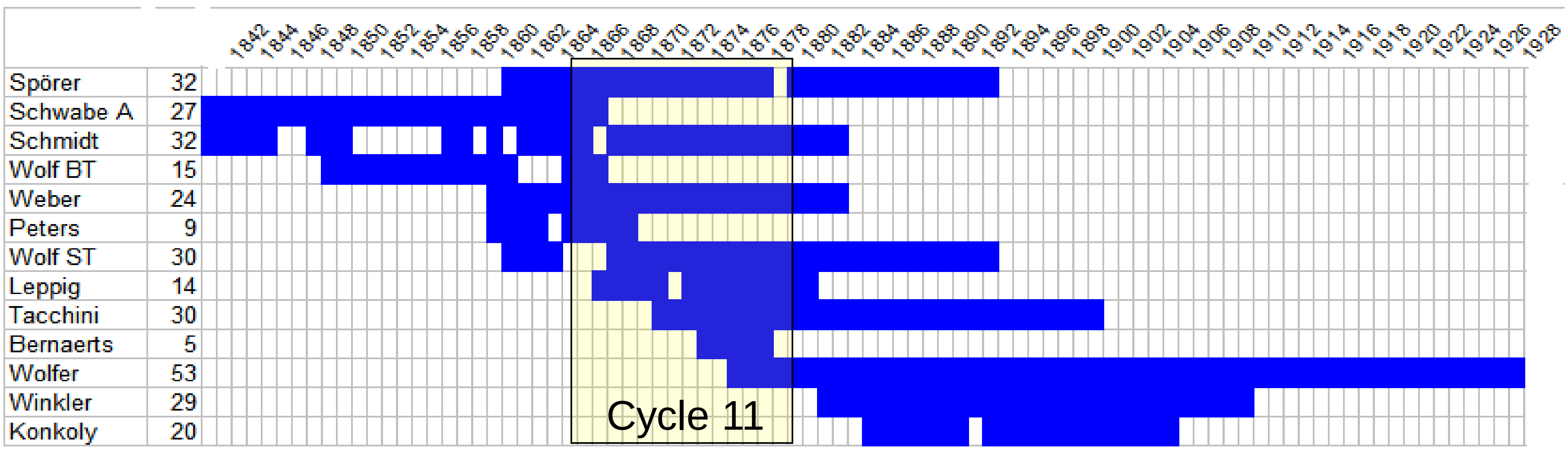
New Wolfer BB Agrees with Old

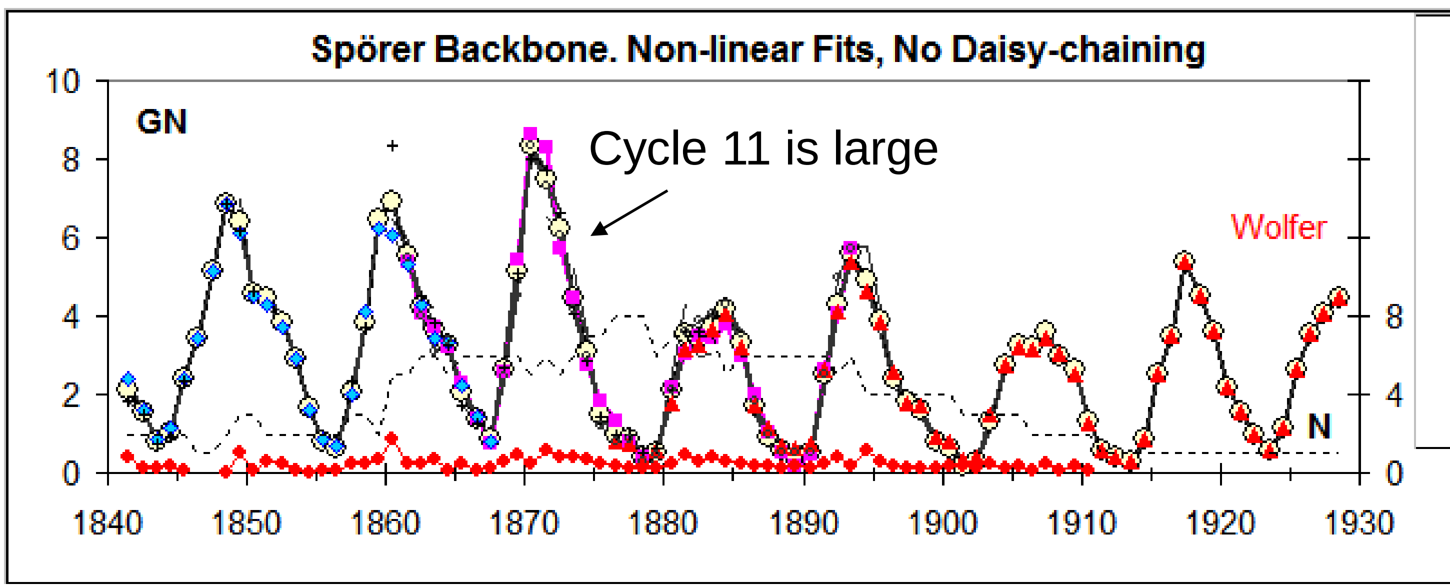


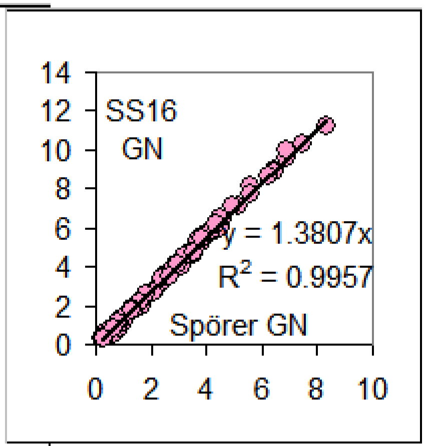
This Figure compares the yearly GNs for the old Wolfer Backbone (red curve) and the new Backbone presented here (blue curve). The two agree within their respective error bars.



Spörer Backbone Around Cycle 11

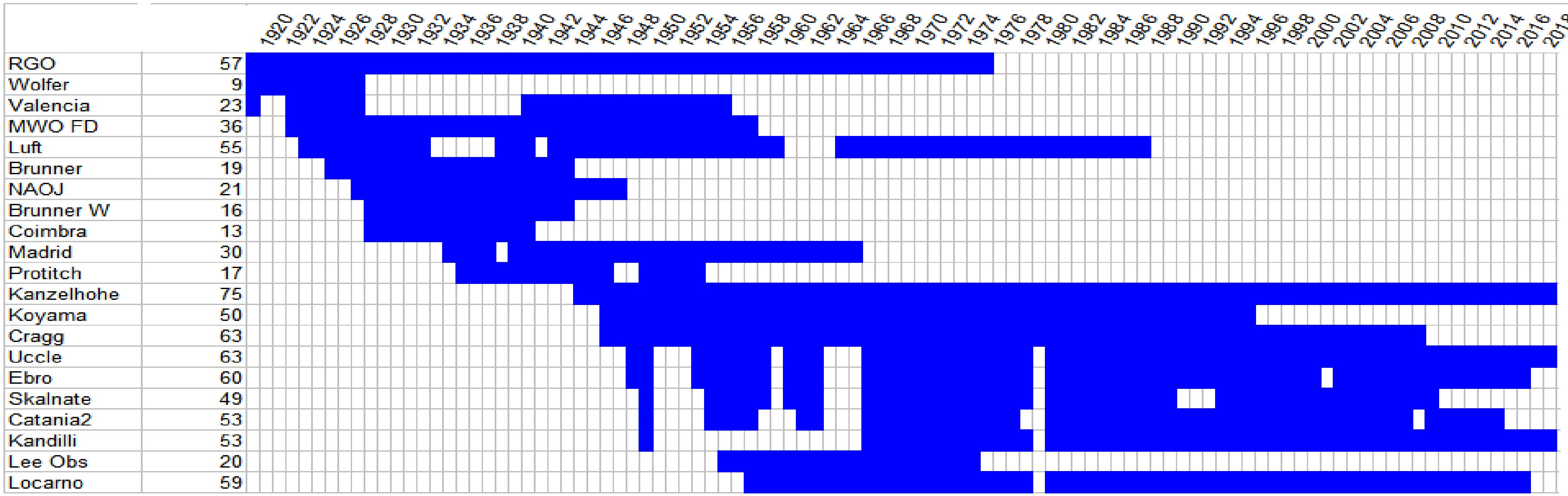


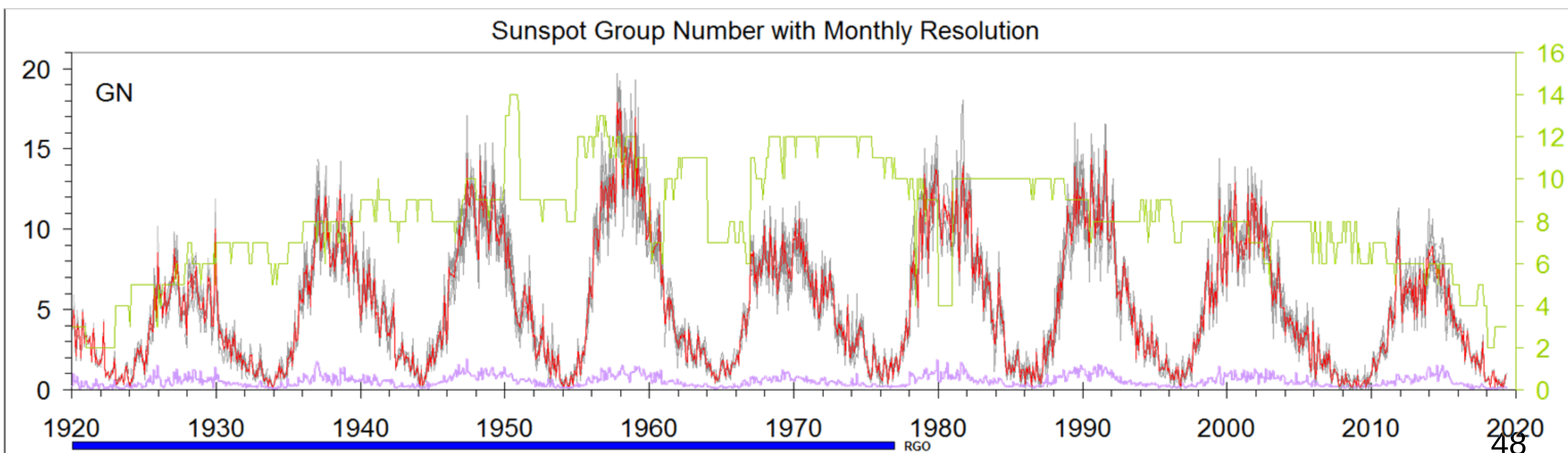




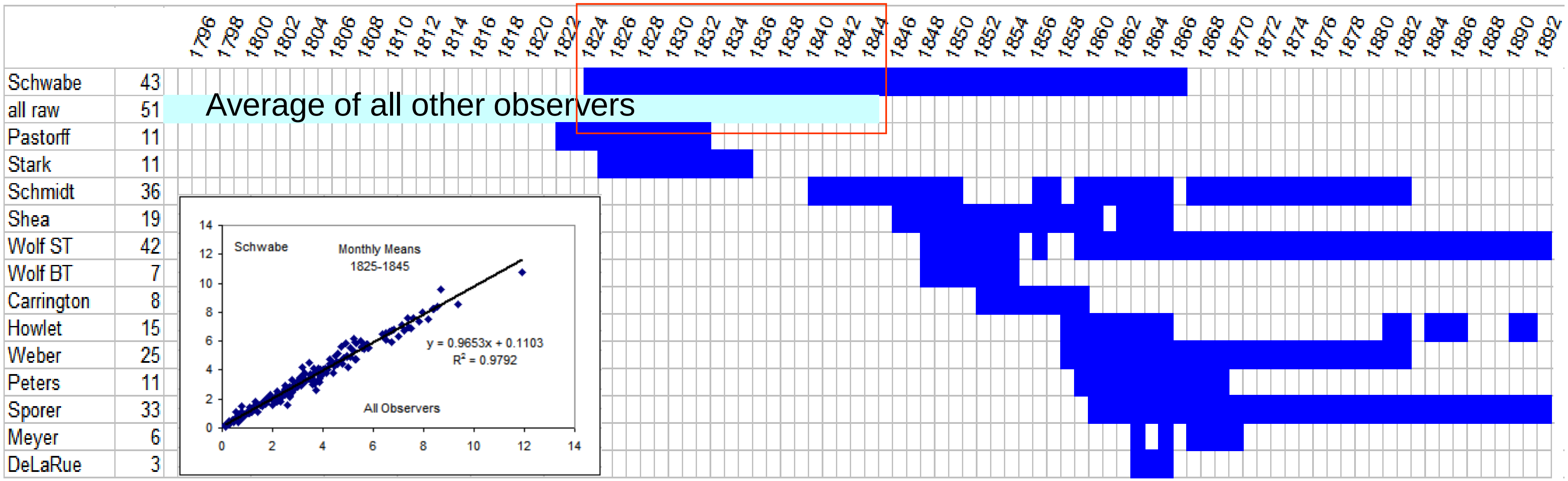
1.38*8.5 = 11.7

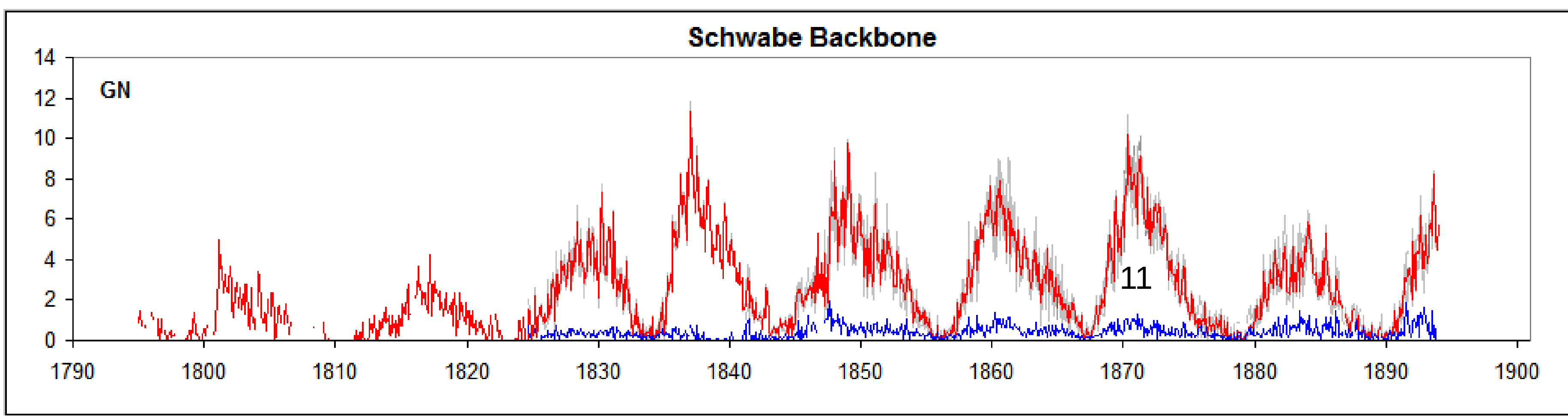
RGO Sunspot Group Number Backbone



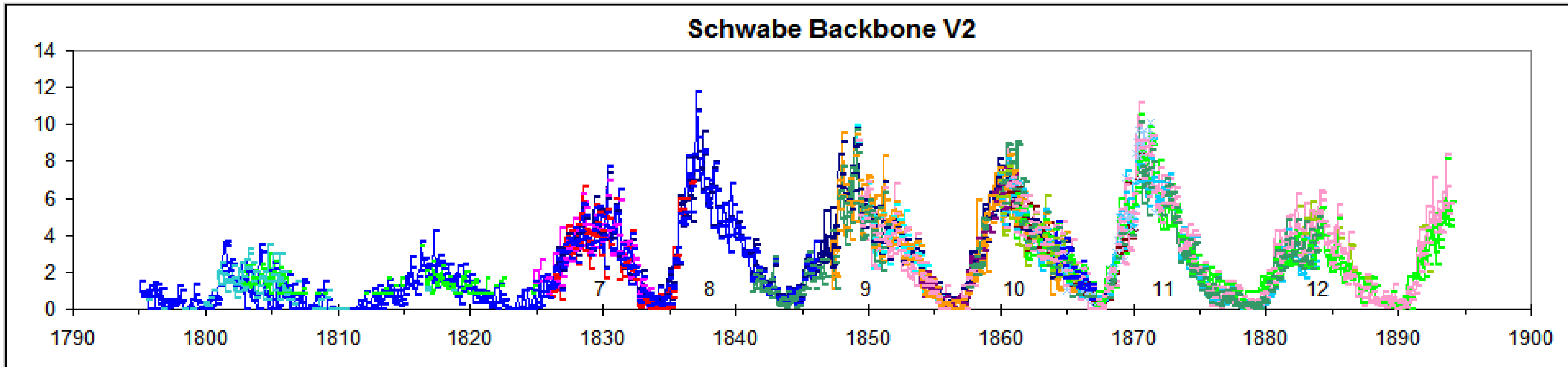


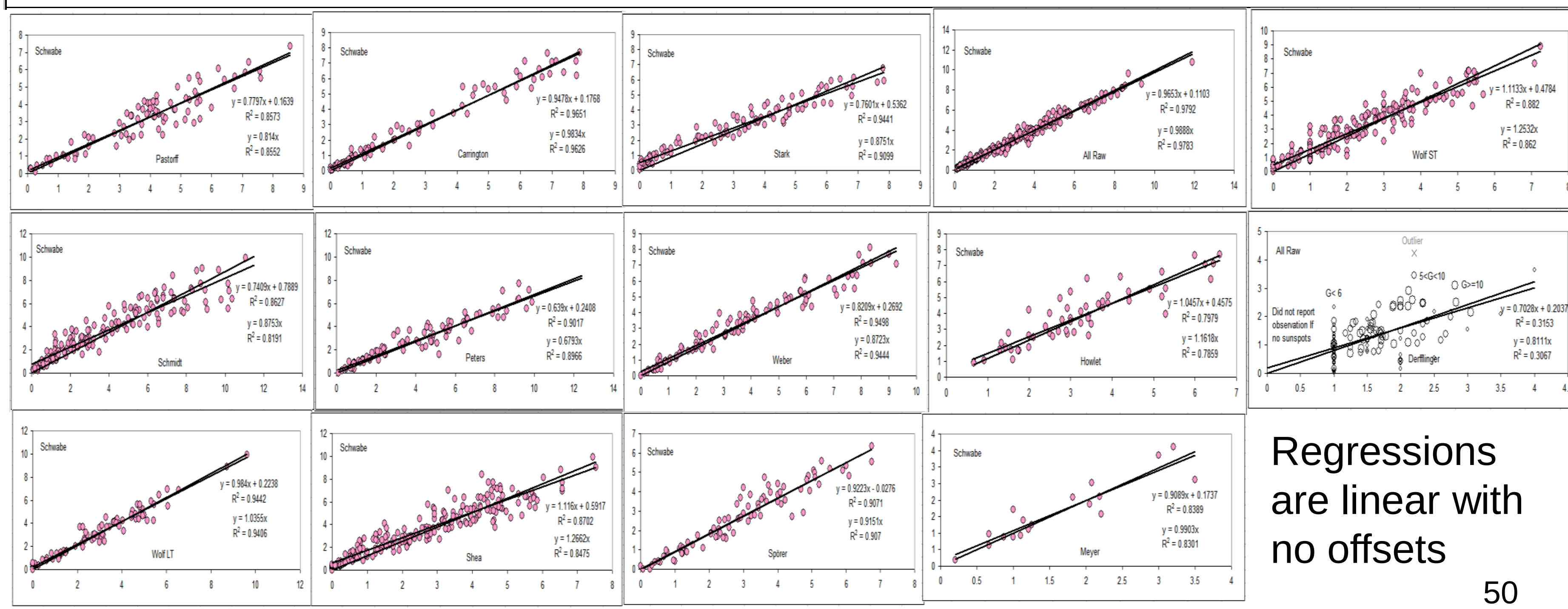
Schwabe Sunspot Group Number Backbone





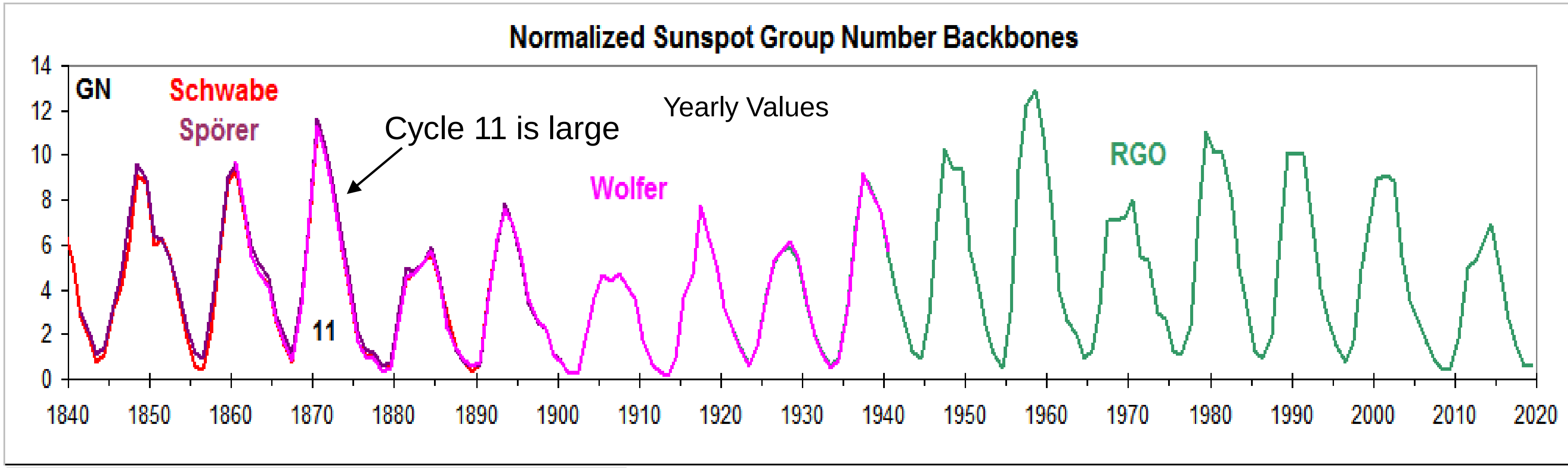
All Linear Relationships …

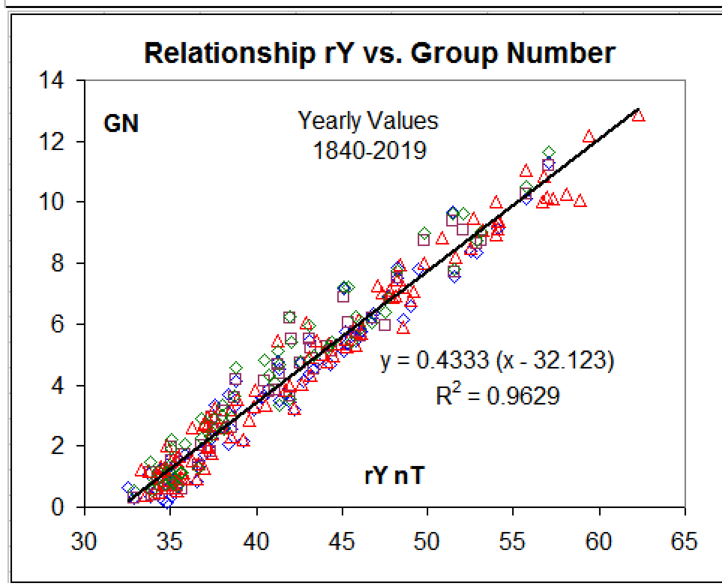




Regressions are linear with no offsets

Composite Sunspot Group Number Series

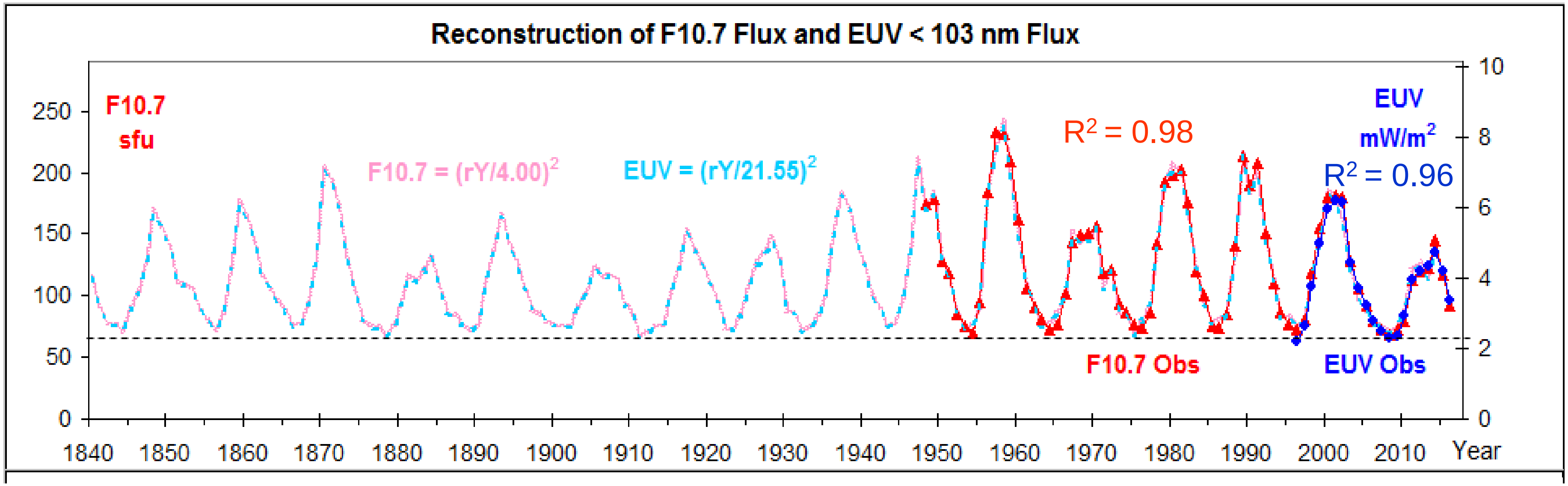


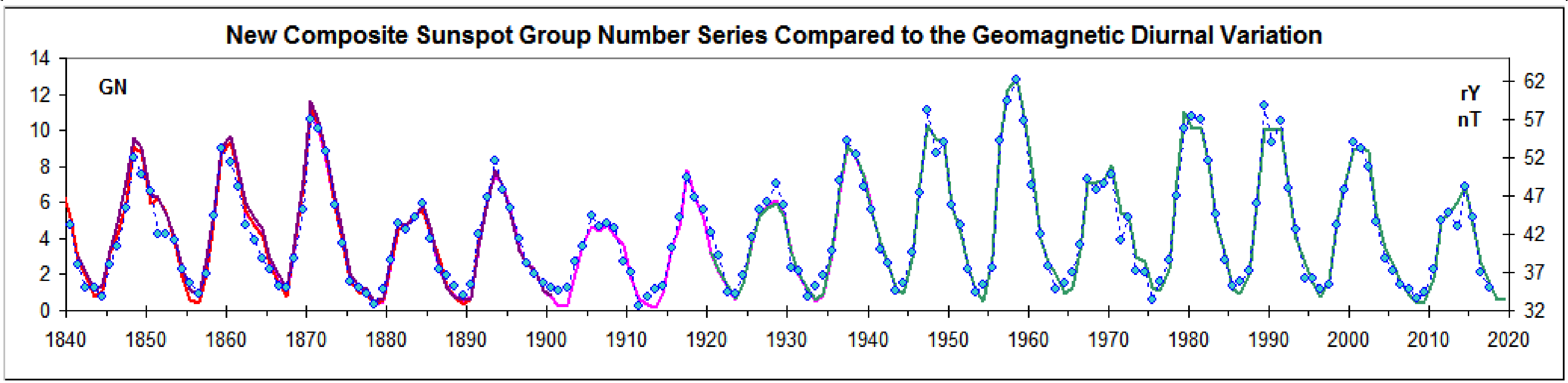


The Schwabe, Spörer, and RGO backbones overlap with the anchor Wolfer Backbone and can thus be scaled to the reference Wolfer Backbone. The scaling is found to be linear to high accuracy. The new composite is statistically indistinguible from the published S&S 2016 composite

The four individual new backbones each have the same relationship with the geomagnetic diurnal range variation [at left with different colors]

Reconstructions of EUV, F10.7, and GN



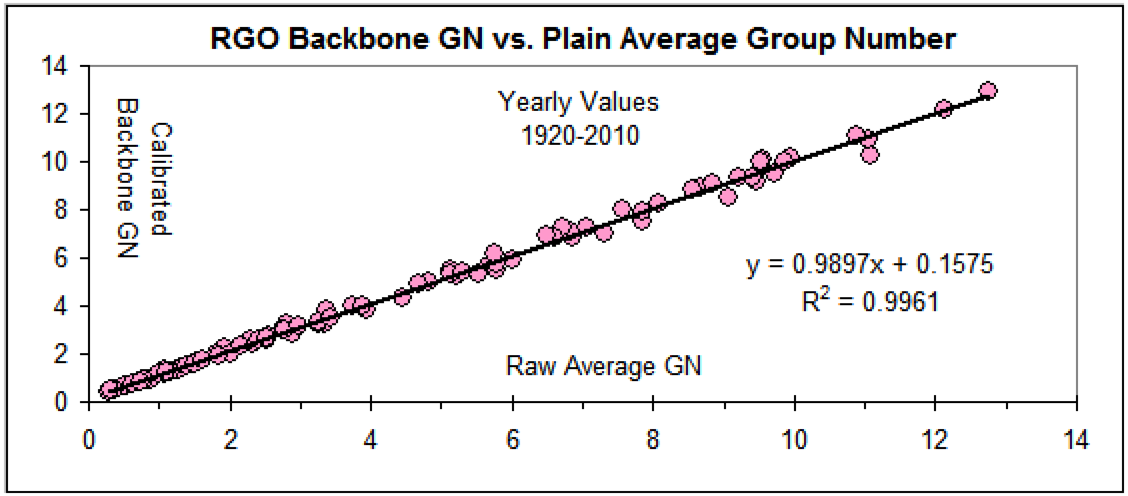


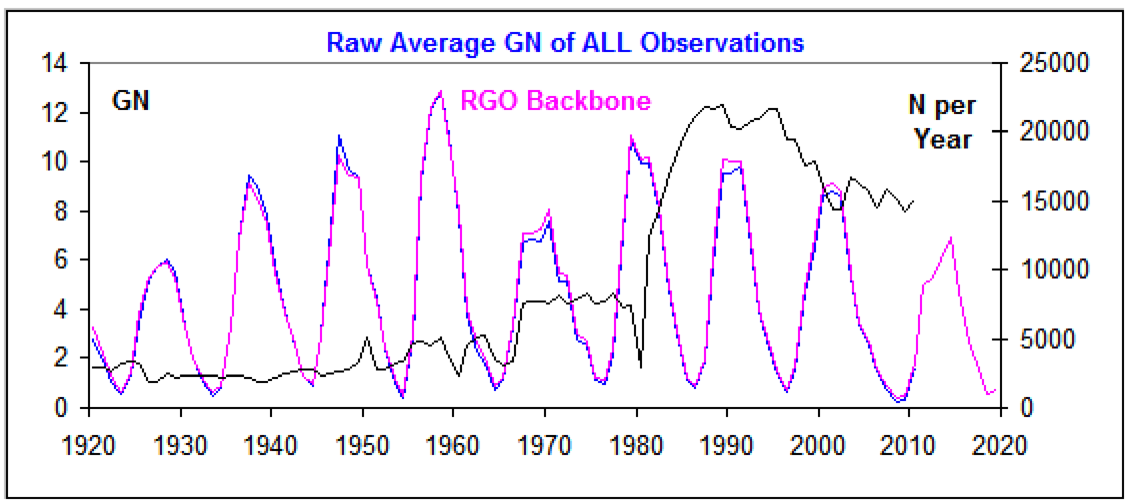
As the Group Number and the EUV both depend simply on the solar magnetic field it is no surprise that they agree. If they did not, you would have to explain why not.

The Backbone Method, pro et con

- Limited to observers with long-term [and good] records in order to get a good enough regression [selection effects?]
- How to deal with non-linear regressions [if any] and with missing data
- No accumulation of errors within the backbone [only one comparison with the primary observer, i.e. no daisy chaining]
- Possibility of undetected intra-backbone drifts
- Refusal of some people to grasp the basic idea
- Each backbone can be treated as an independent unit: changes to one do not impact the others
- Because several observers contribute to each average [e.g. yearly or monthly], error bars can be estimated
- A small (about 3) number of backbones limits the effect of daisy chaining from one to the next, especially if the ‘middle’ one is chosen as the reference scale, so don’t have many ‘mini’-backbones
- Each solar minimum [with almost no spots] provides a ‘reset’ of the errors preventing the oft claimed run-away ‘monotonic’ increase with time
- Constructing a backbone is a fair amount of work, e.g. with quality control
- There are probably more cons…

The Simple Average of ALL Observers is as Good as Our Carefully Constructed Backbones



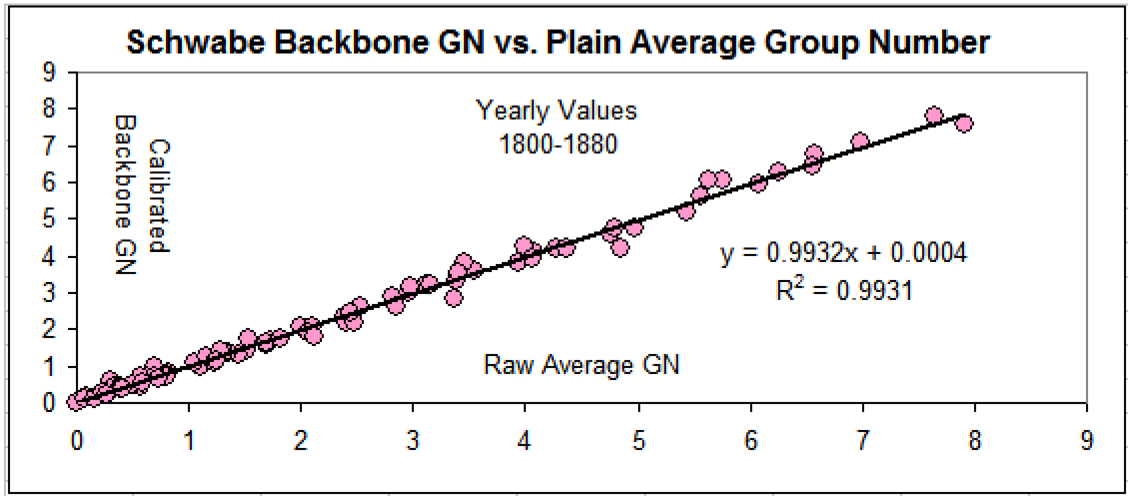


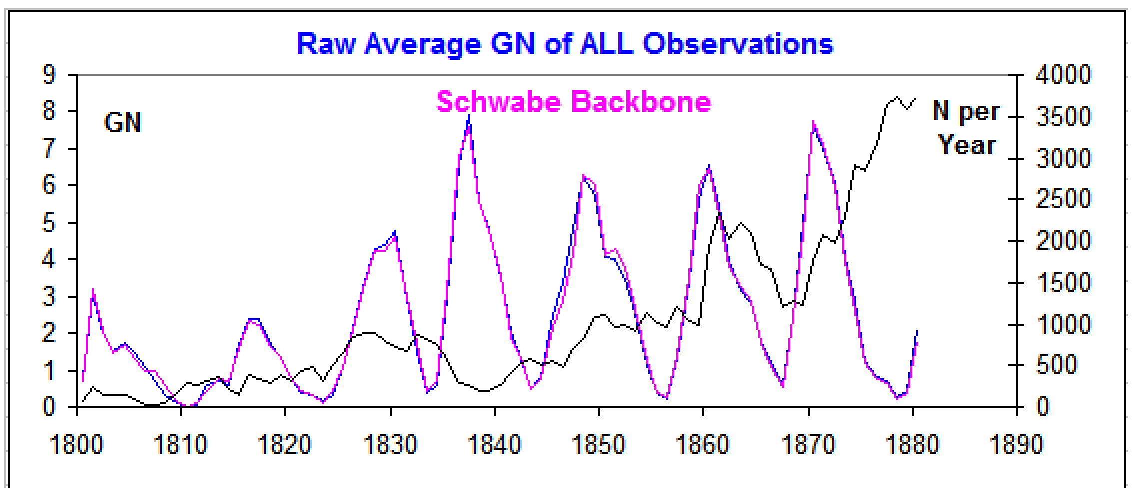
Observer #418 (MWO Central Disk) is, of course, omitted

As already remarked in S&S16 “It is remarkable that the average number of groups by all observers with no normalization at all closely matches the number of groups reported by H&S showing that their elaborate and obscure normalization procedures have almost no effect on the result.”

This is also true for our backbones, meaning that we could simply dispense with the normalization with its perceived potential problems.

The Simple Average of ALL Observers is as Good as Our Carefully Constructed Backbones

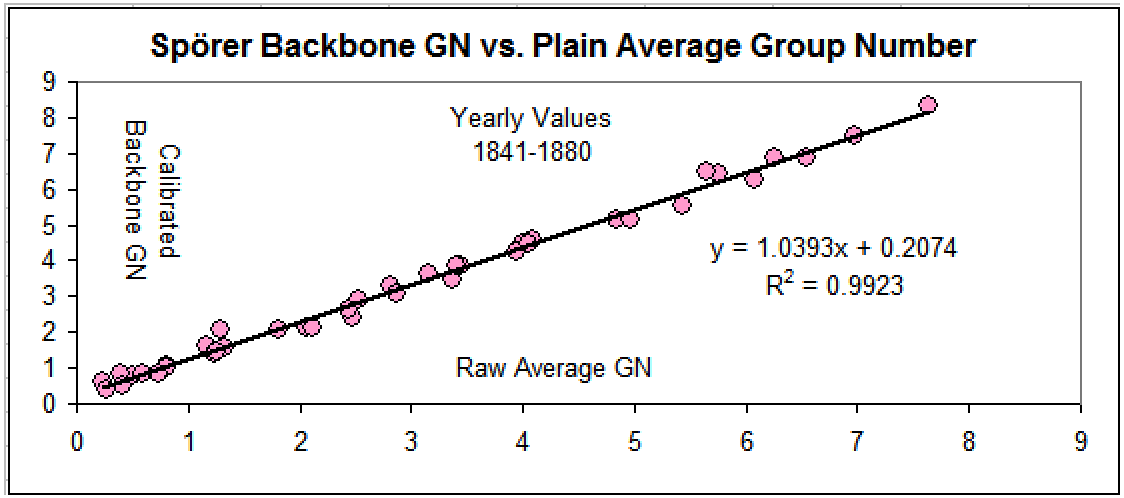




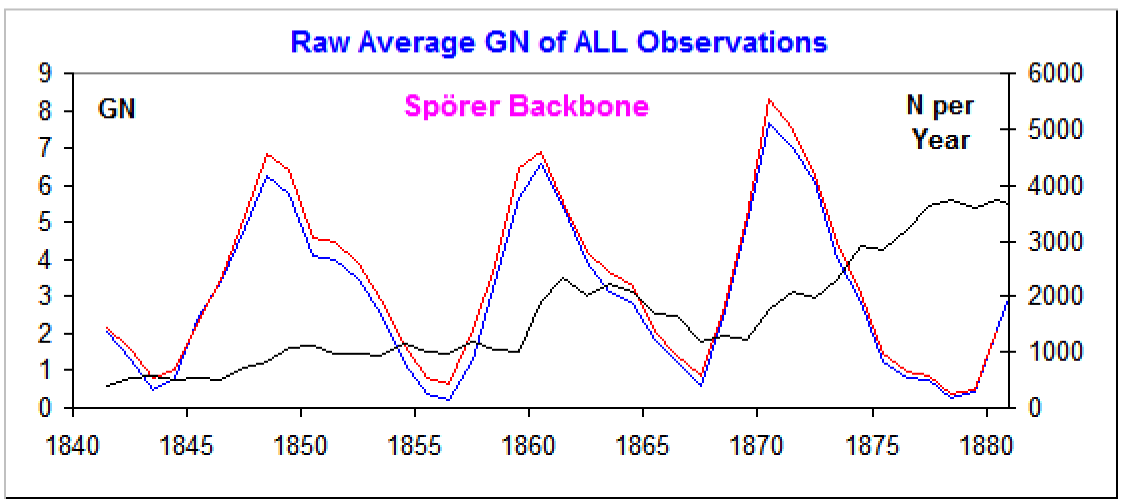
This holds also for the Schwabe Backbone. When the number of observations runs in the thousands, the statistical errors get very small.

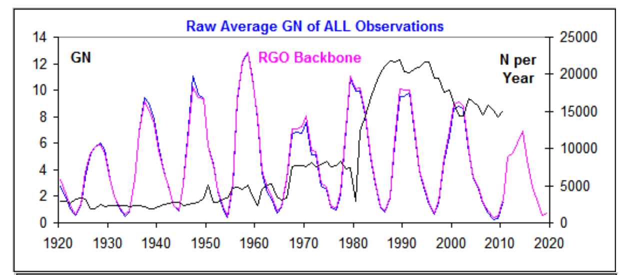
So, it seems that we have a nice non-parametric, non-overlapping, non-k-value regression, no selection effect, no ranking, no pair-wise comparison, no ADF- or PDF-based, non-*whatever* method for constructing a backbone including estimating its time-varying error bars [from the spread of the observations]

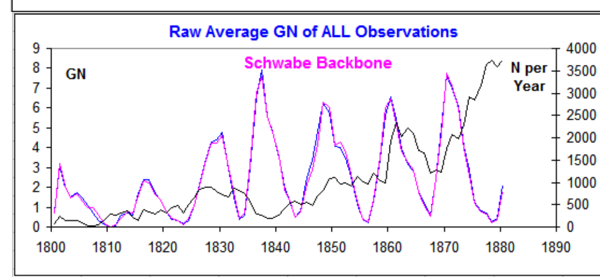
The Simple Average of ALL Observers is as Good as Our Carefully Constructed Backbones



For the RGO and Schwabe Raw [ALL] averages we were lucky that the two ‘observers’ [RGO and Schw.] evidently were [seeing and] reporting group numbers close to the typical [and hence average] observers of their time:

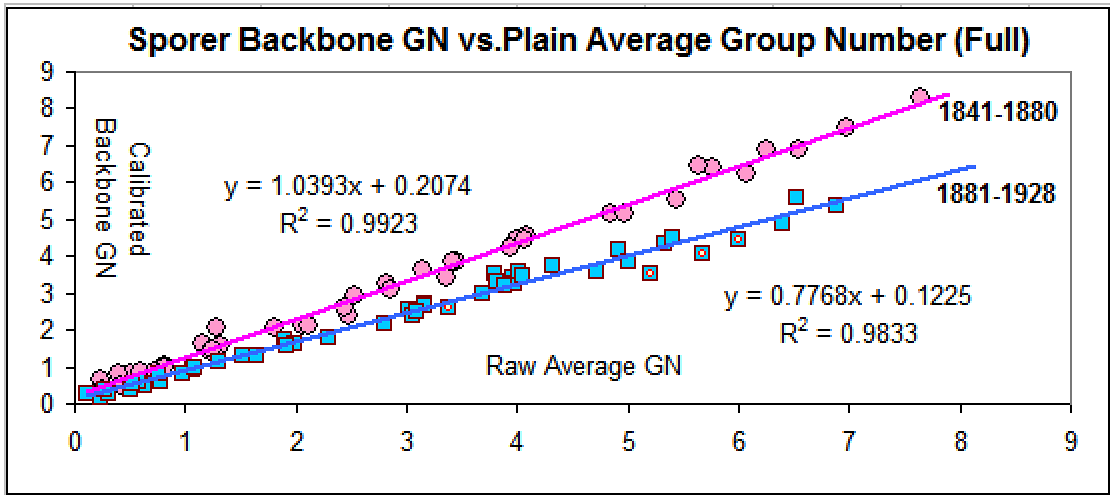


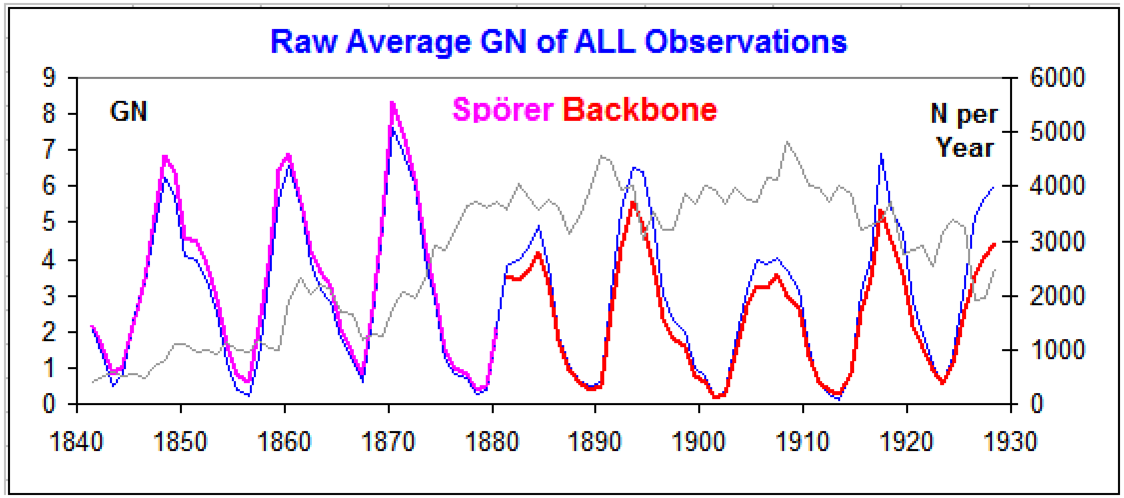




But it doesn’t have to be so for all our backbone observers. Spörer is an example, seeing slightly more [reddish curve] than the average observer

Full Spörer Backbone 1841-1928



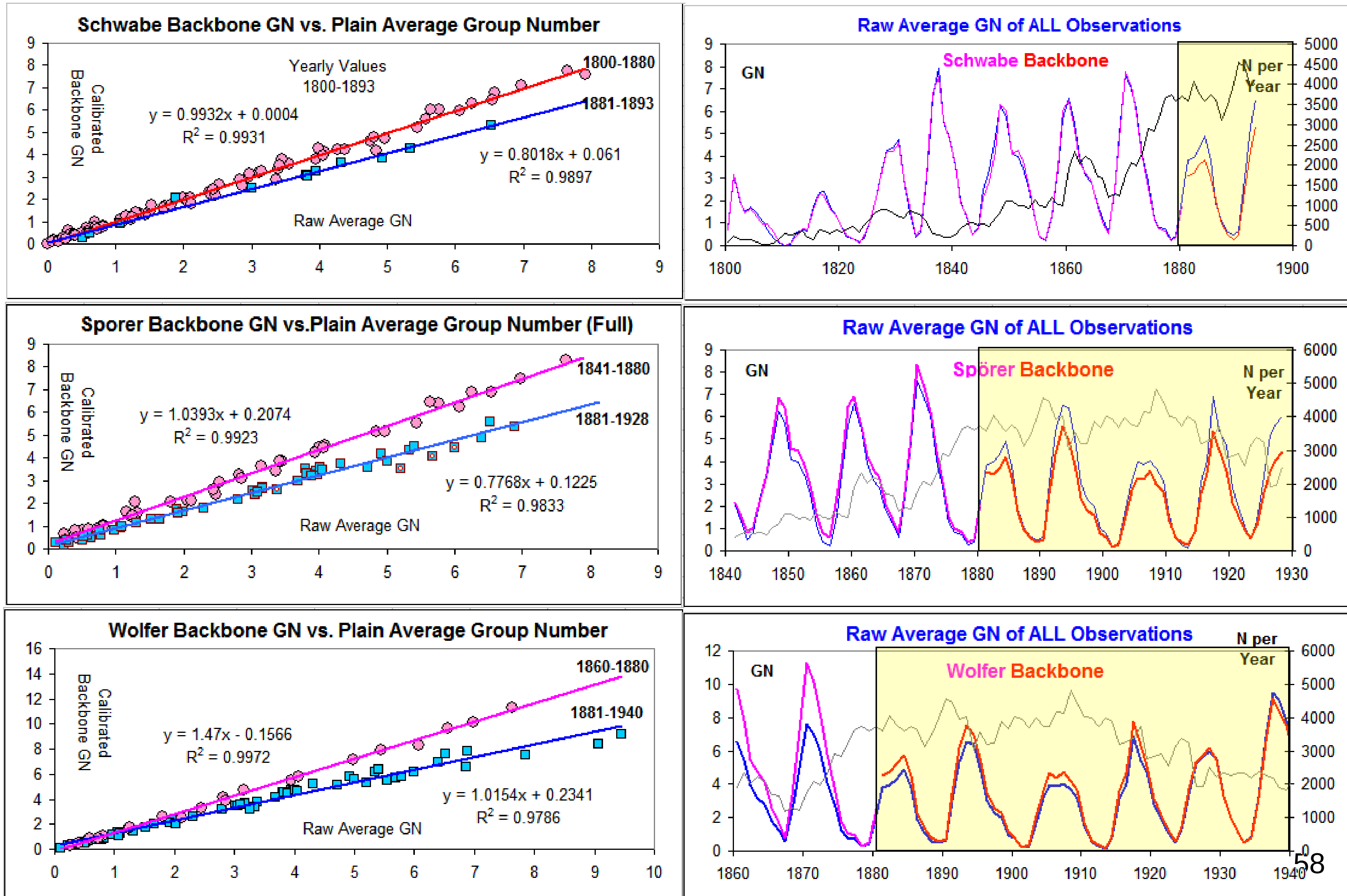


The difference between Spörer and the overall average seems to increase with time after 1880.

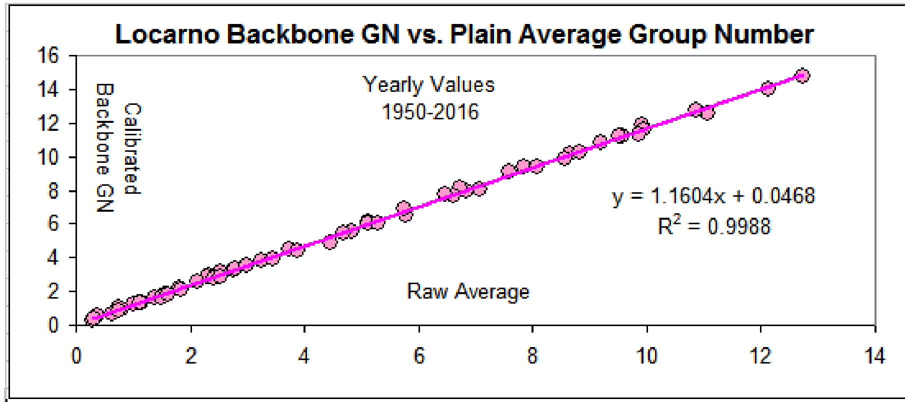
Before 1881, Spörer's group count was 4% larger than average, but abruptly that changed by 1881 so that Spörer's count became increasingly smaller than average as time went on.

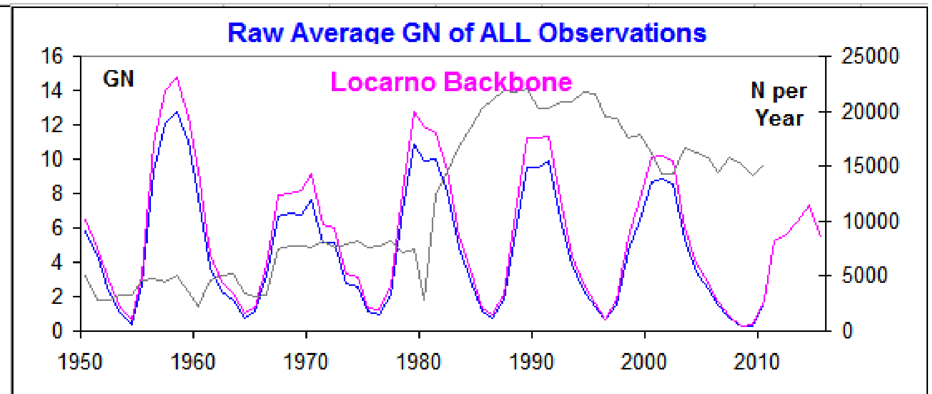
The simplest explanation would be that Spörer changed his telescope and/or his way of counting groups. On the other hand, other backbones show the same discontinuity around 1881, suggestive of the (at first sight unlikely) possibility that observers at large after 1880 were using better telescopes and/or had developed a better understanding of what is a group.

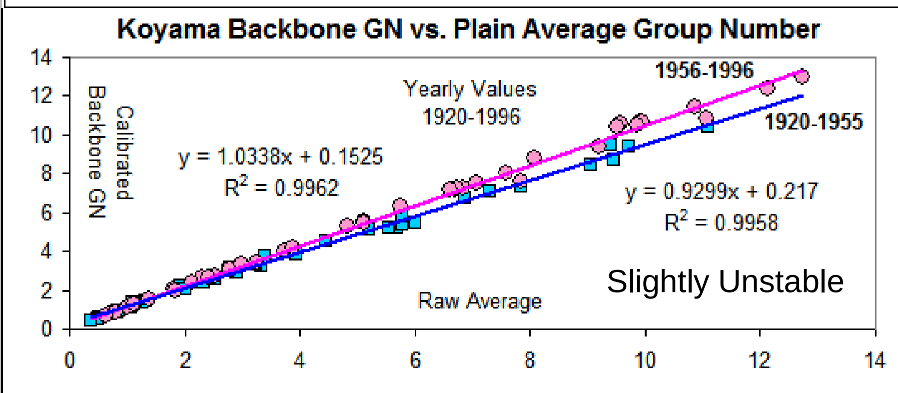
The 1881 Discontinuity

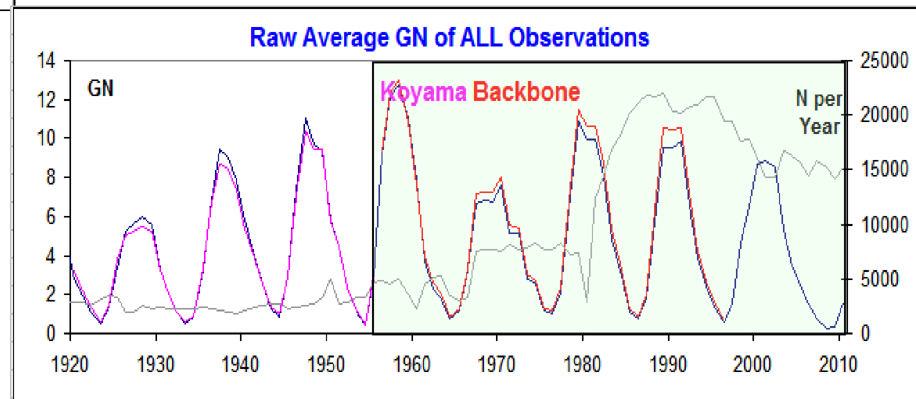


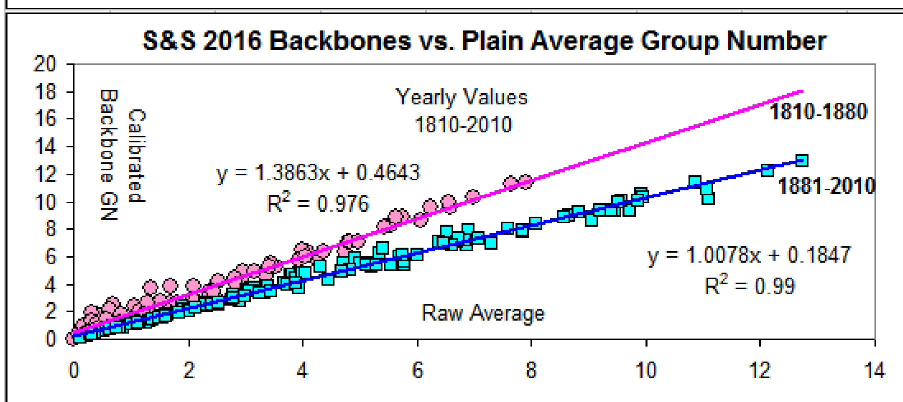
More Backbones vs. Raw Averages

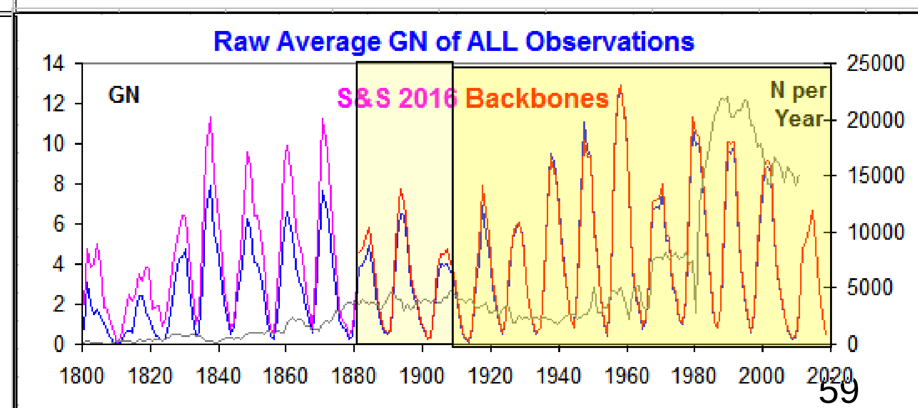




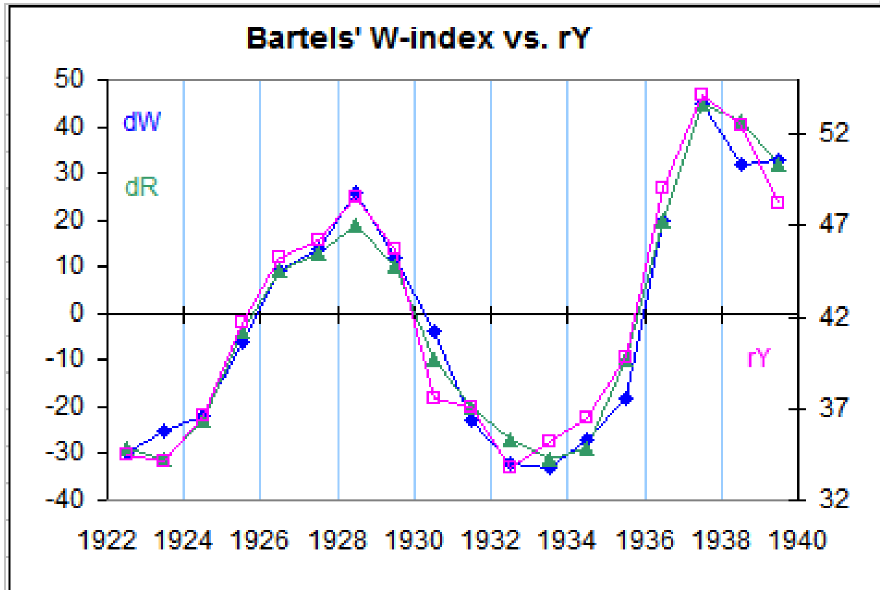


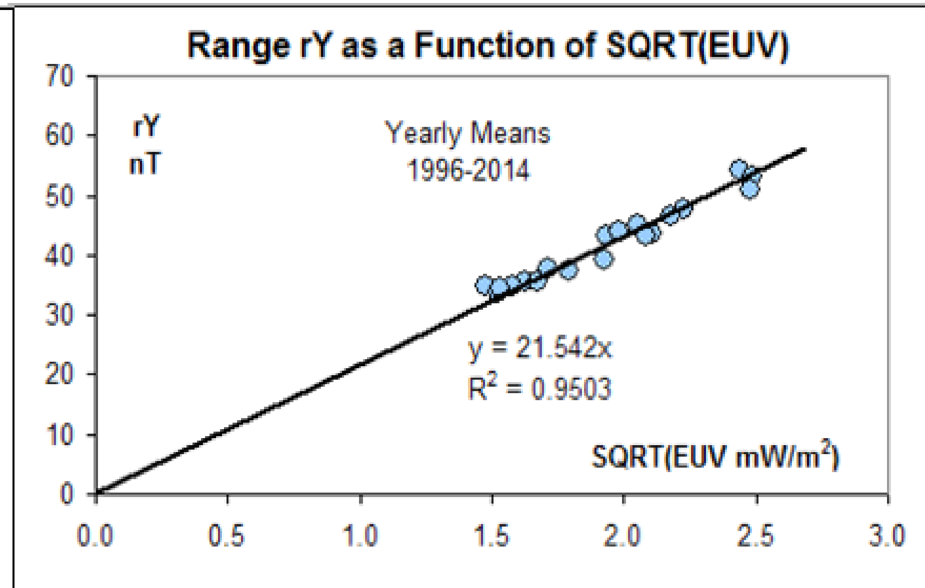


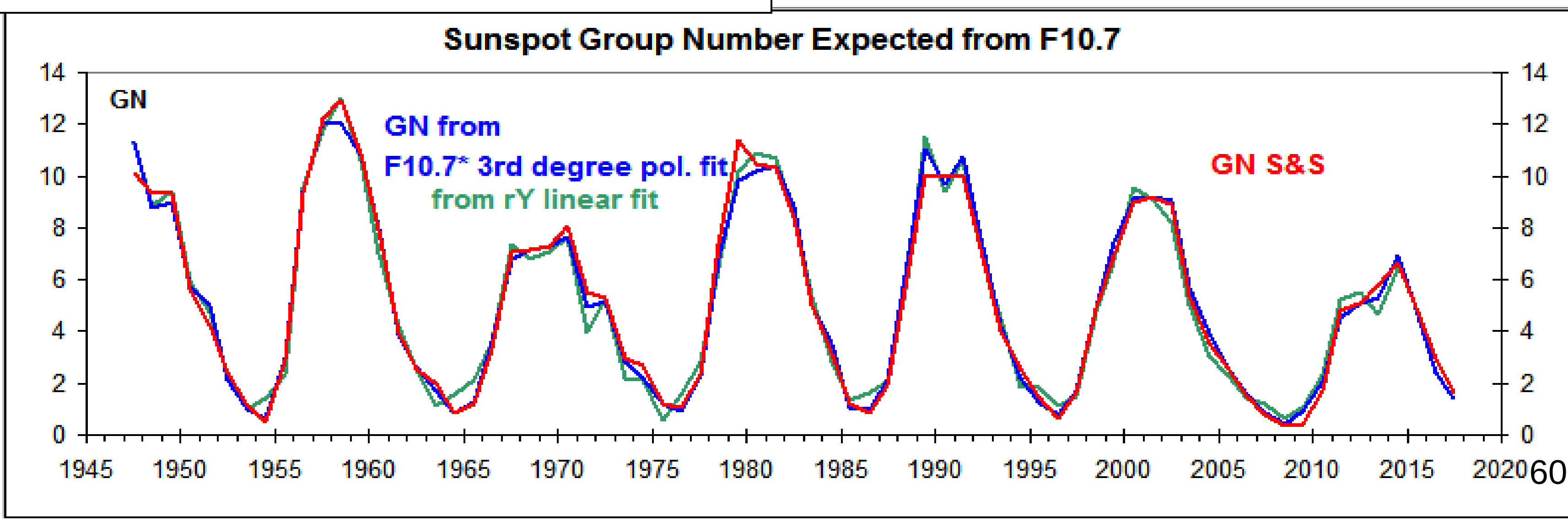




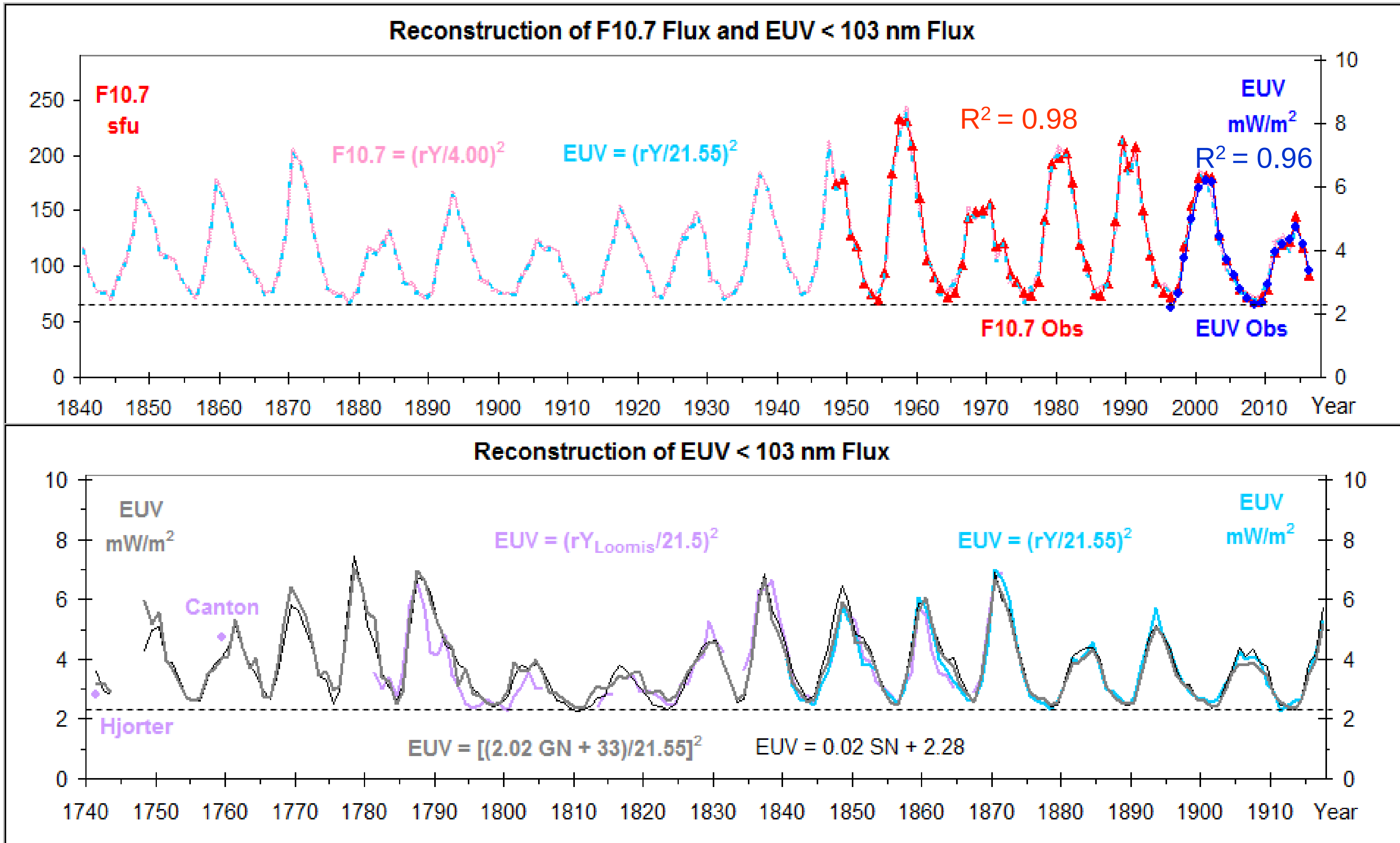
W-index, Rz, rY and GN Correlations







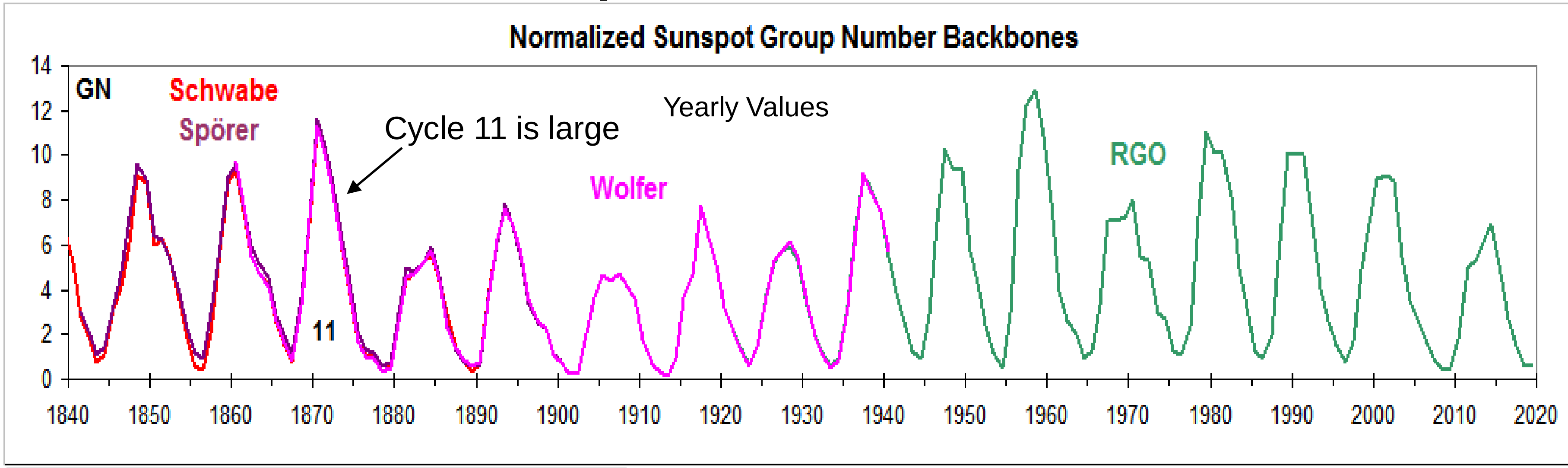
Reconstructions of EUV and F10.7

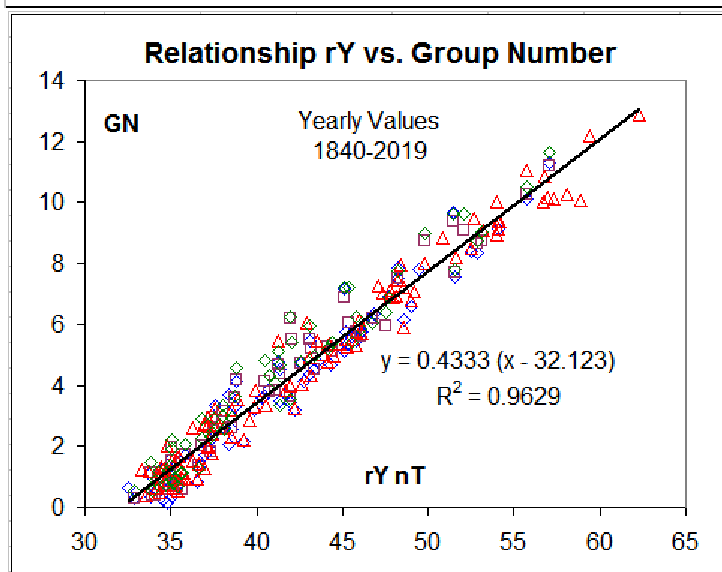


Outline

- Observed EUV, Solar Microwave, and Magnetic flux records
- Deriving EUV [etc] from Geomagnetic Daily Variations
- Deriving Solar Wind Magnetic Field from Geomagnetism and Sunspots
- Comparing the Solar Flux(es) to the Sunspot (and Sunspot Group) Numbers.

Composite Normalized Sunspot Group Number Series





The Schwabe, Spörer, and RGO backbones overlap with the anchor Wolfer Backbone and can thus be scaled to that reference Backbone. The scaling is found to be linear to high accuracy. The new composite is statistically indistinguishable from the published S&S 2016 composite

The four individual new backbones each have the same relationship with the geomagnetic diurnal range variation [at left with different colors]

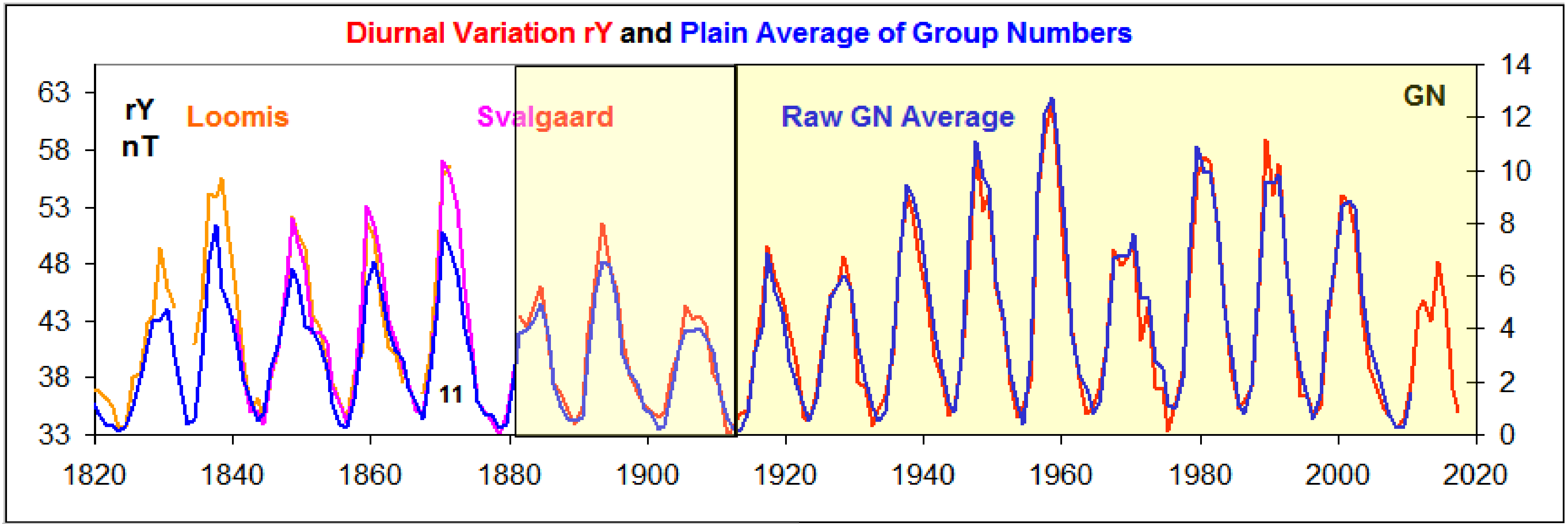
Choose the Lesser Miracle

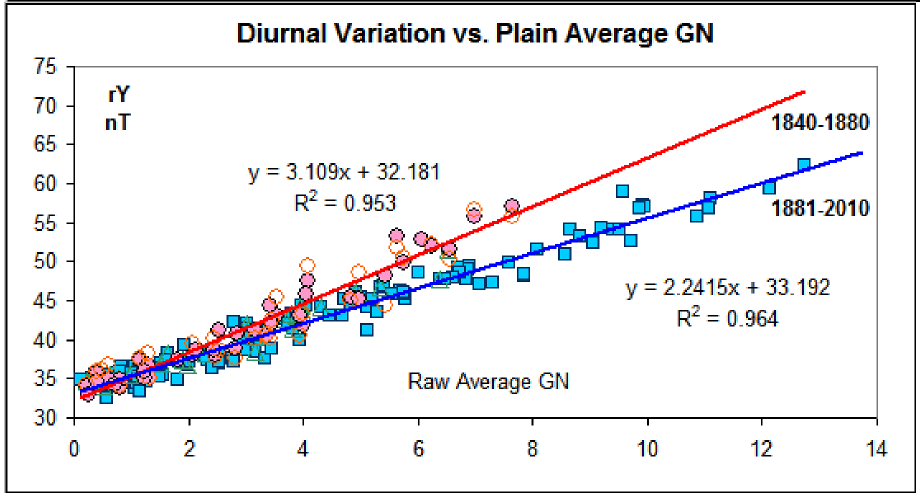
Any researcher [*nn*] who claims he has a method to dowse or divinate solar activity can express his result as a time series of Group Numbers (GN[*nn*]), or equivalently of Sunspot numbers (SN[*nn*]), with yearly resolution. GN derived from the diurnal variation (GN[*rY*]) are the values we would expect, assuming that the terrestrial response has not undergone a dramatic [~40%] change in 1881. So we must expect GN[*nn*] ≈ GN[*rY*] within their respective error bars. If it is not, we have two possibilities:

A: Researcher *nn* is mistaken and his method does not work as claimed, or
B: The response of the terrestrial upper atmosphere to solar activity changed dramatically in 1881 (this would be an unexpected, new solar-terrestrial effect)

David Hume (in Section X of *Enquiry Concerning Human Understanding* [1748]) argued that a rational person should never believe that a miracle (he is using the word 'miracle' in the everyday sense, meaning something that is merely out of the ordinary) had actually taken place unless it would be a greater miracle that the person reporting the miracle (i.e. that GN[*nn*] is not ≈ GN[*rY*]) is simply mistaken. We should always believe whatever would be the *lesser miracle*, which in our case would be choice A.

The Diurnal Variation Shows the 1881 Discontinuity Very Clearly

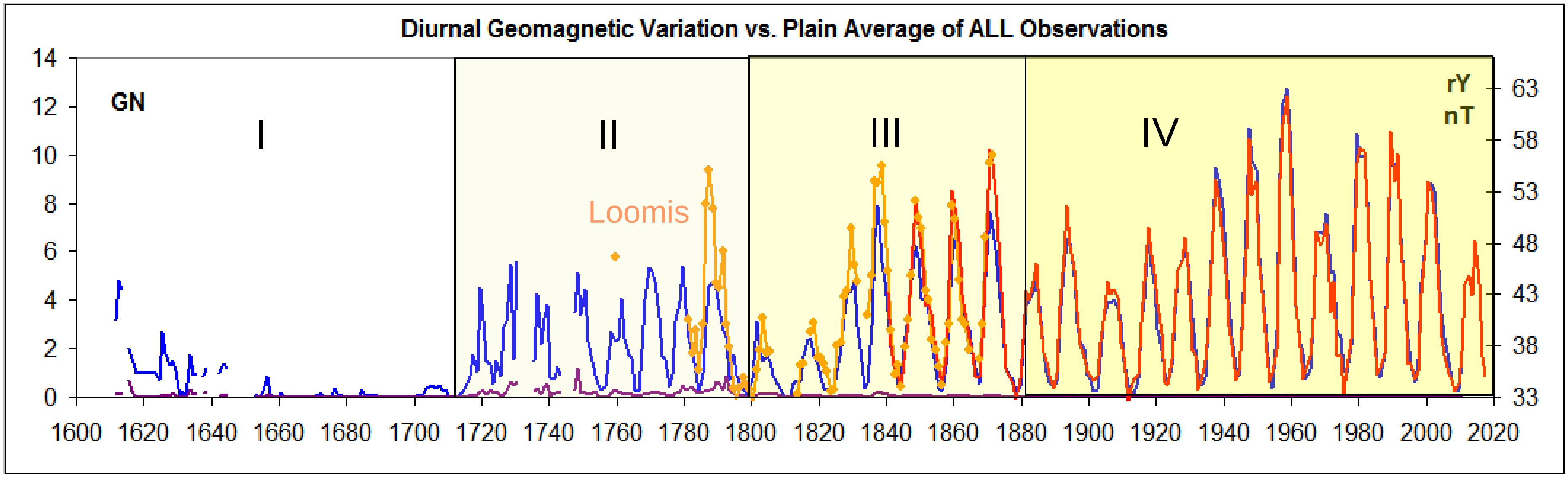




We see the same two populations: one before 1881 and one after ~1910 with a transitional period 1881-1910. This means that one cannot assume the statistical properties of the latter population to hold about the former.

The ratio between slopes is 1.39

Four Speculative Populations of GNs

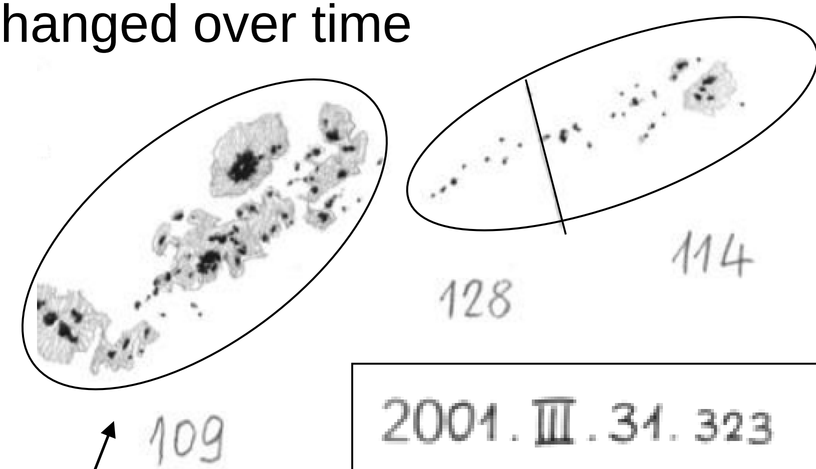


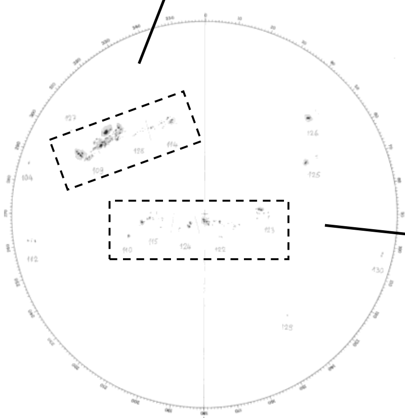
The different populations are the result both of evolving technology, e.g achromatic lenses, and of improved understanding of the definition of a group (blue curve). The diurnal variation (reddish curves) of the East component of the geomagnetic field relies primarily on measurements of an angle [the Declination] and as such does not require calibration and thus does not evolve with time. We speculatively identify four populations as shown above.

Because of the evolving populations, the backbones themselves [no matter how constructed] must be normalized to a common standard [Wolfer's].

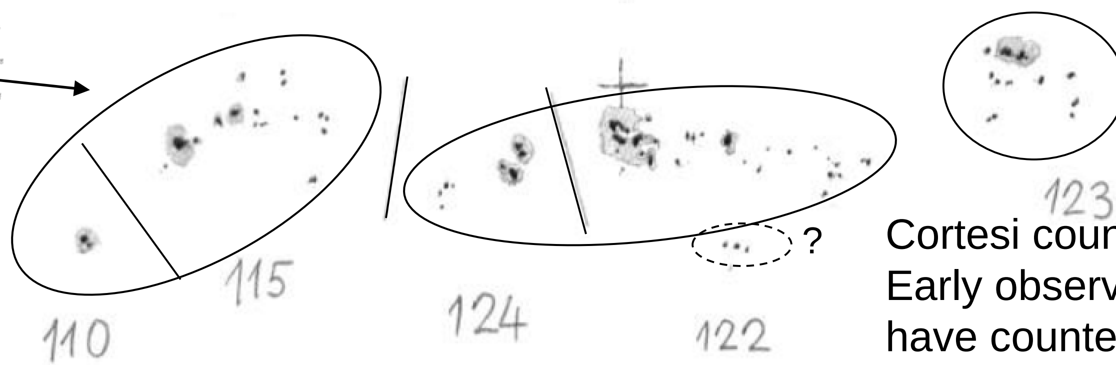
Fundamental Issue: What Is a Group?

Definition has changed over time





Locarno



Staudach
13 Feb. 1760

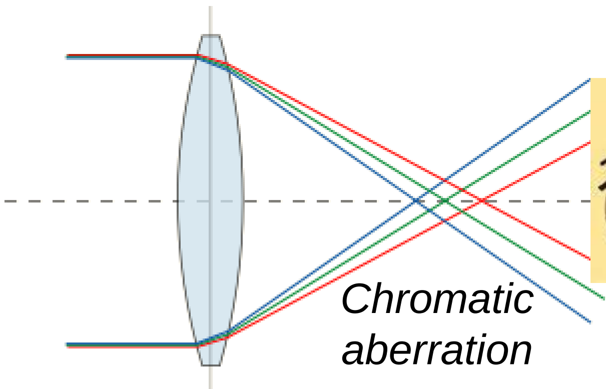
Wolf (1857) counted only one group on that day.

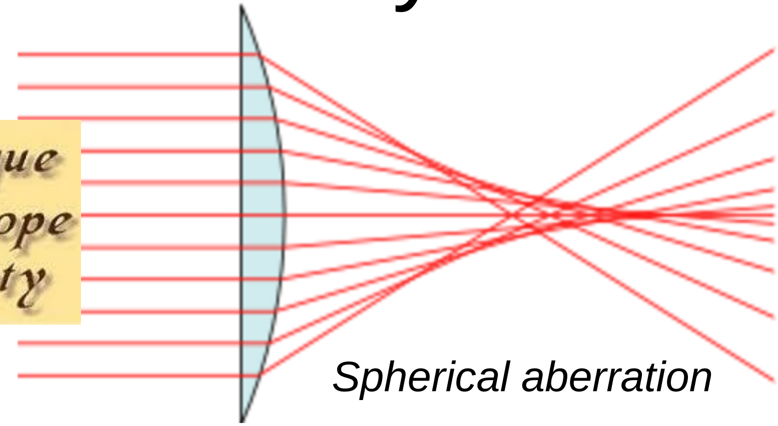
Modern observers (Cortesi, even me) would count at least three groups.

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

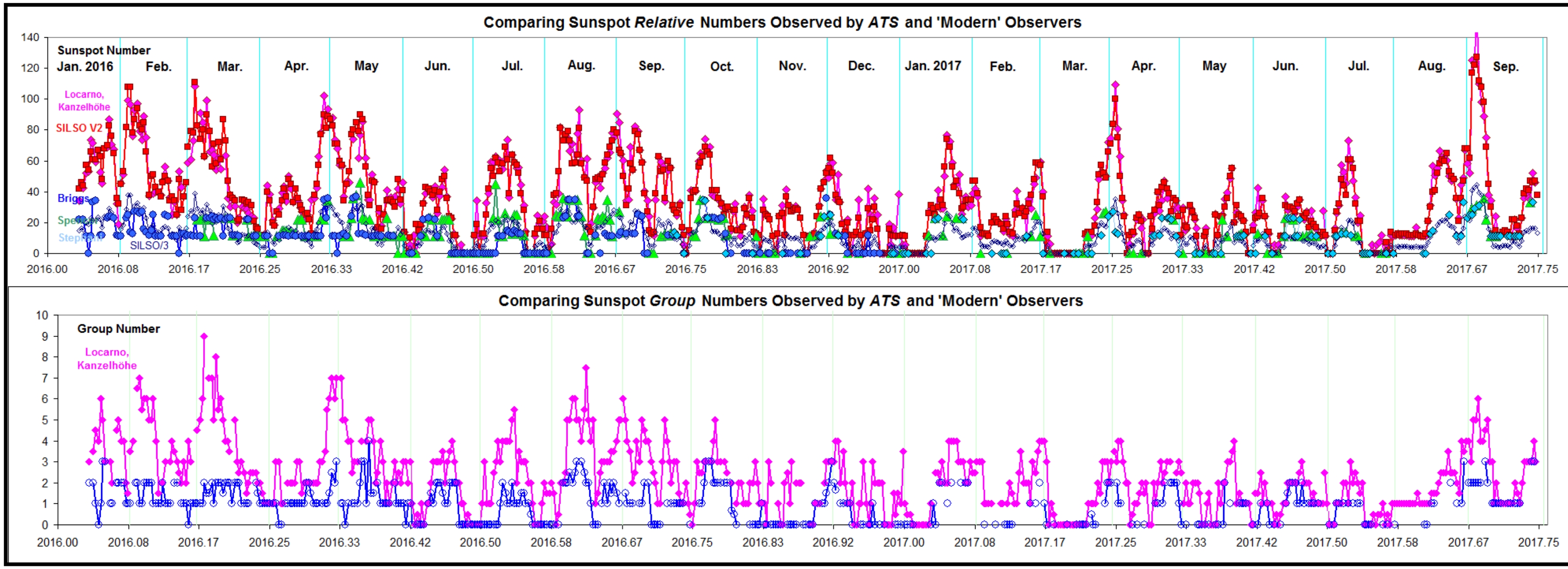
Cortesi counted 8 groups.
Early observers would likely have counted only 5 groups

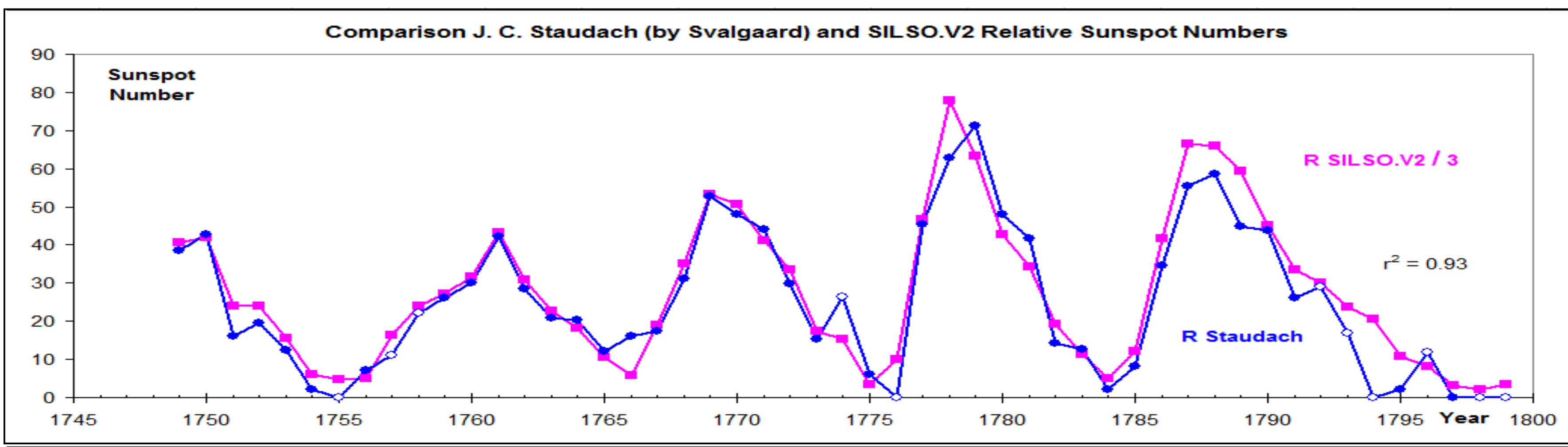
Construct Telescopes with the Same Flaws as Typical 18th Century Ones



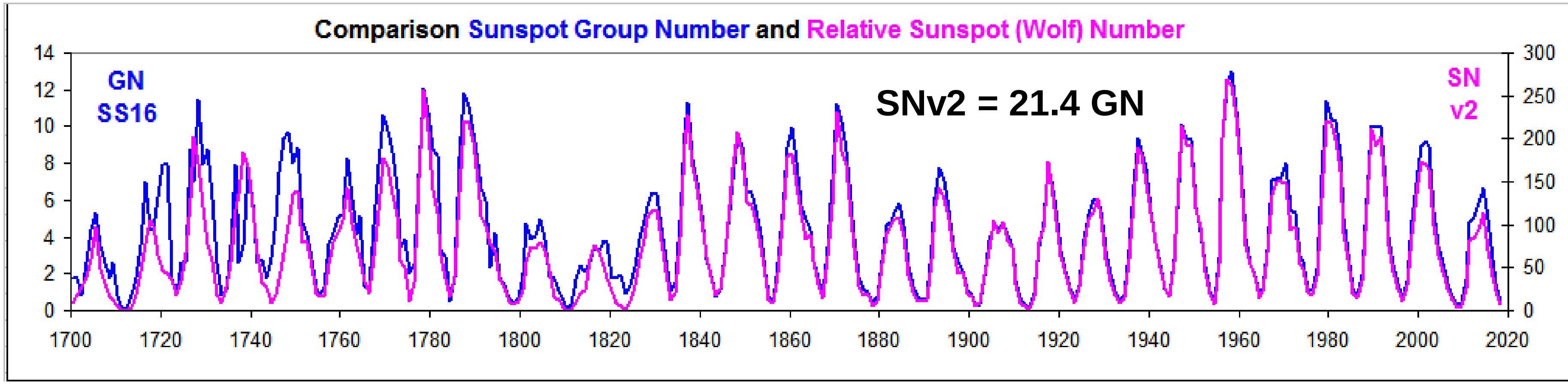


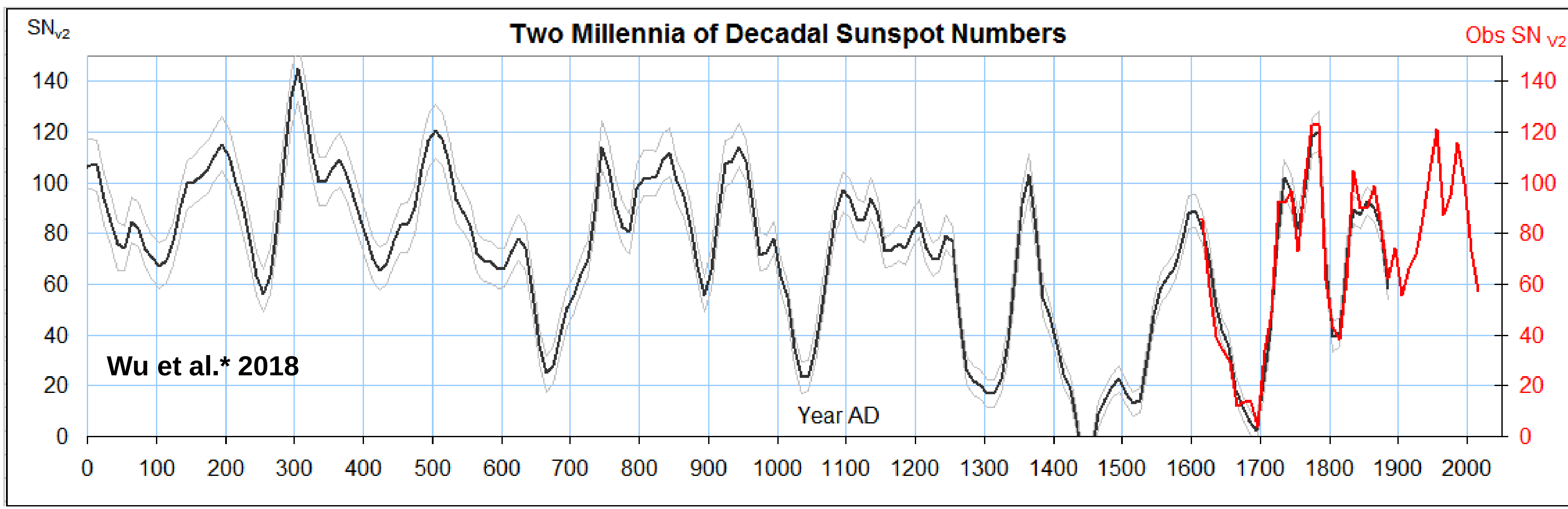
Modern Observers See Three Times as Many Spots as The Old Telescopes Show





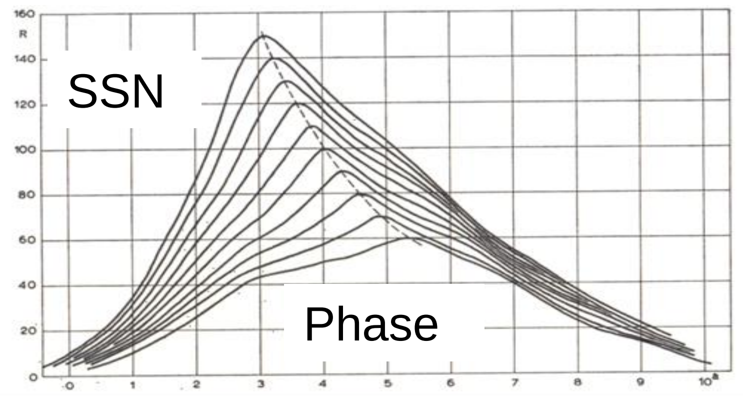
Brewing Consensus: GN vs. SNv2





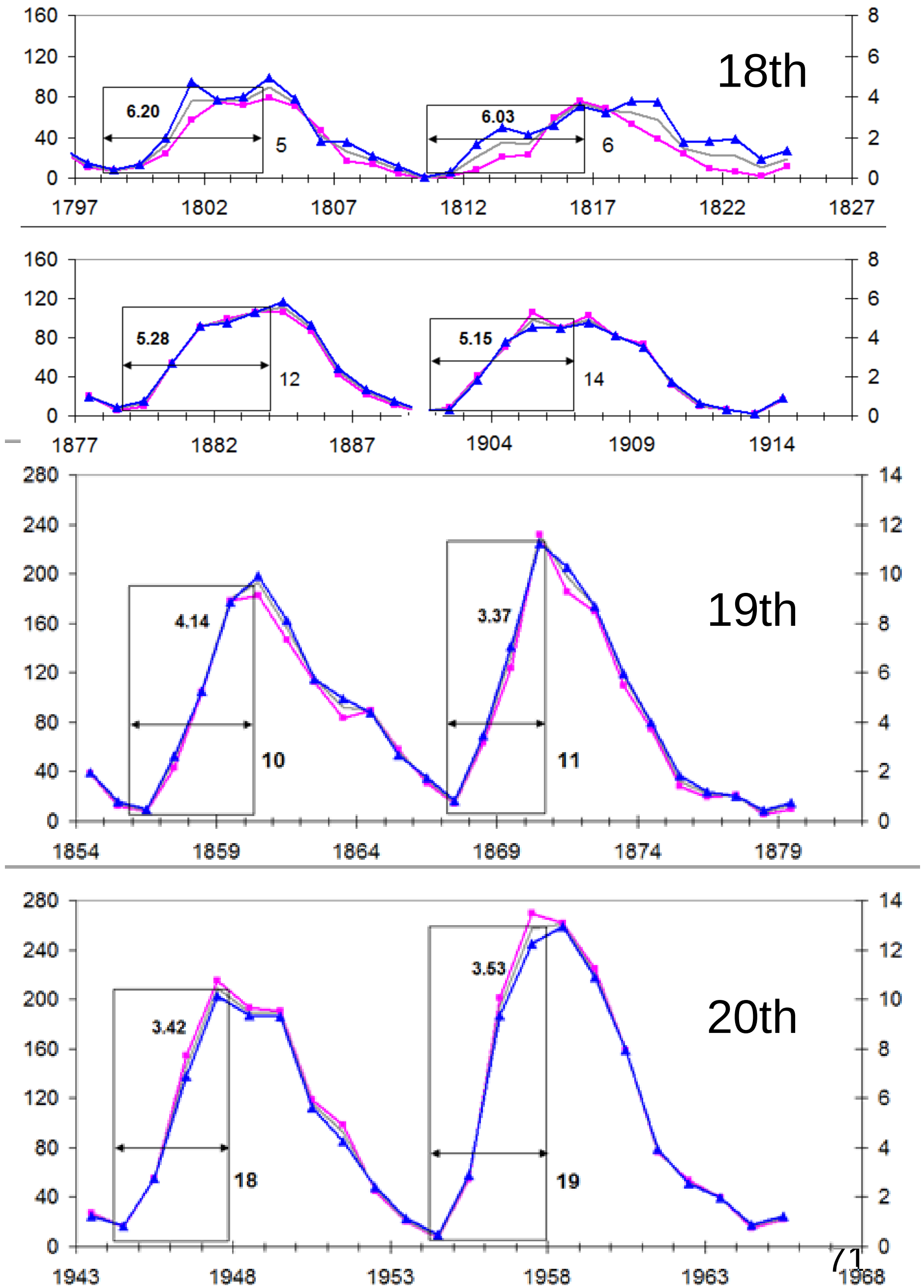
It is clear that the series before, say, 1750 needs more work

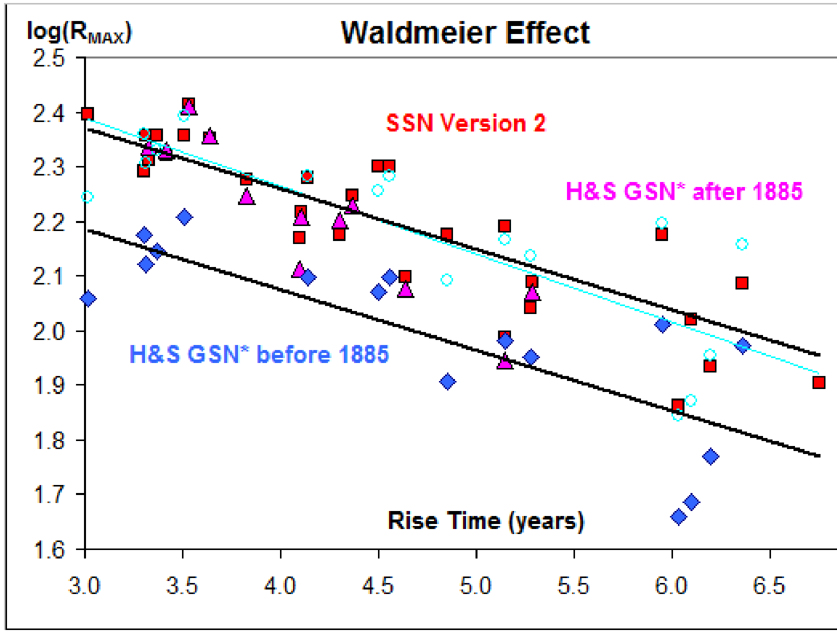
The Waldmeier Effect

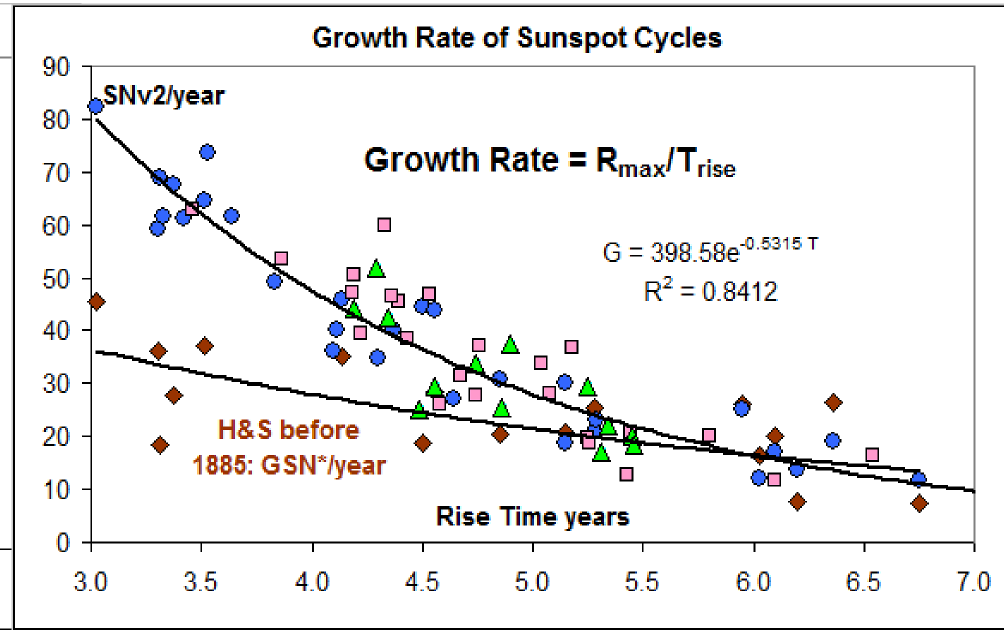


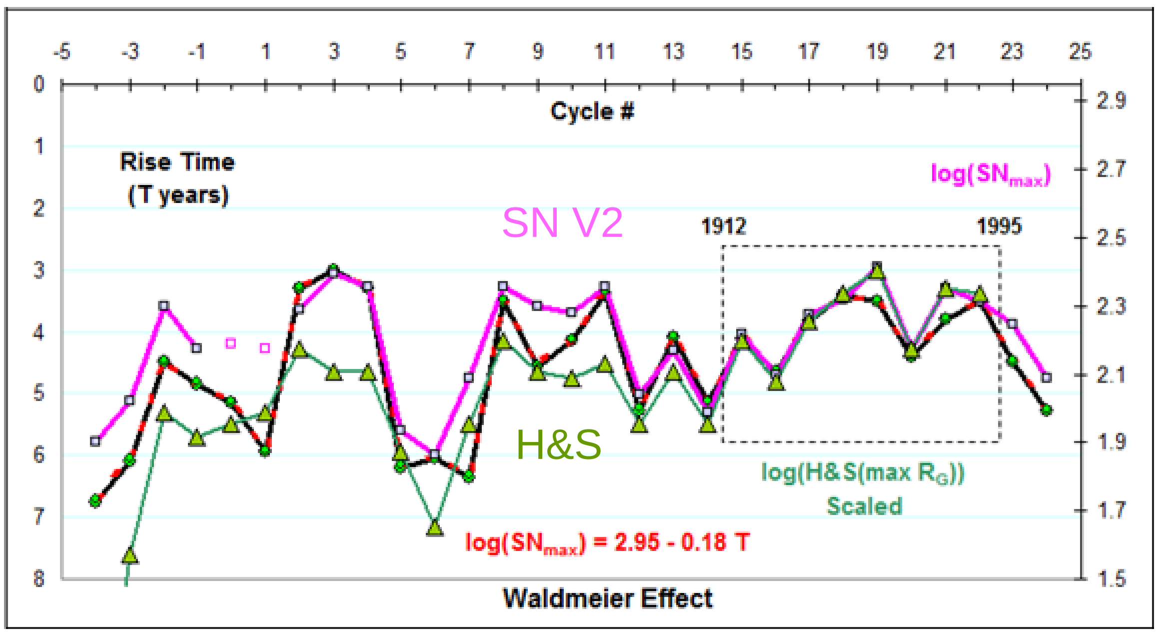
There is a relationship between the rise time T (in years) from minimum to maximum and the maximum smoothed monthly sunspot number. The times of the extrema can be determined without knowledge of the reduction (or scale) factors. **Since this relationship also holds for the years from 1750 to 1848 we 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).

Later cycles have confirmed that the scale has stayed constant more than 250 years

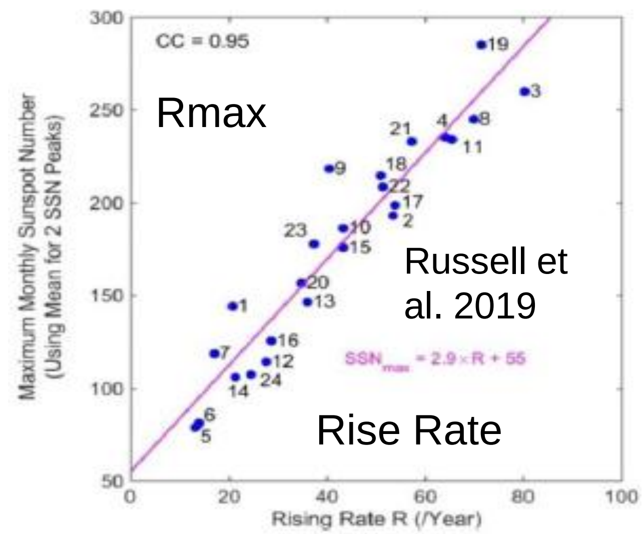






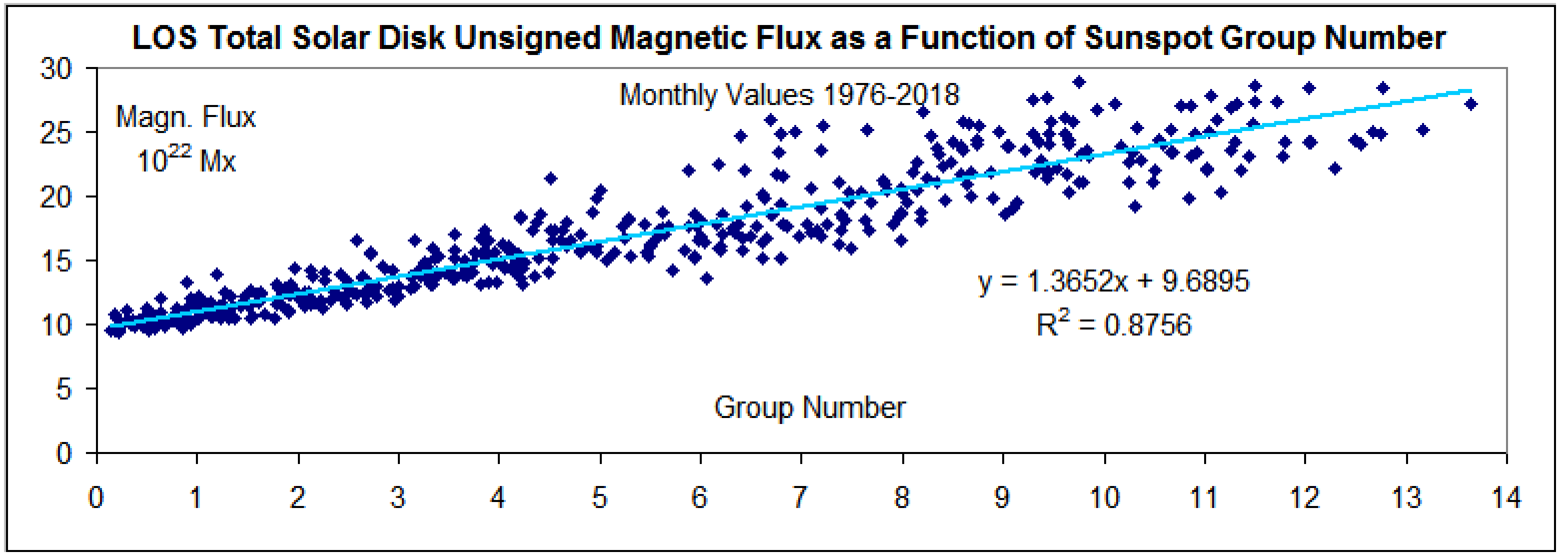


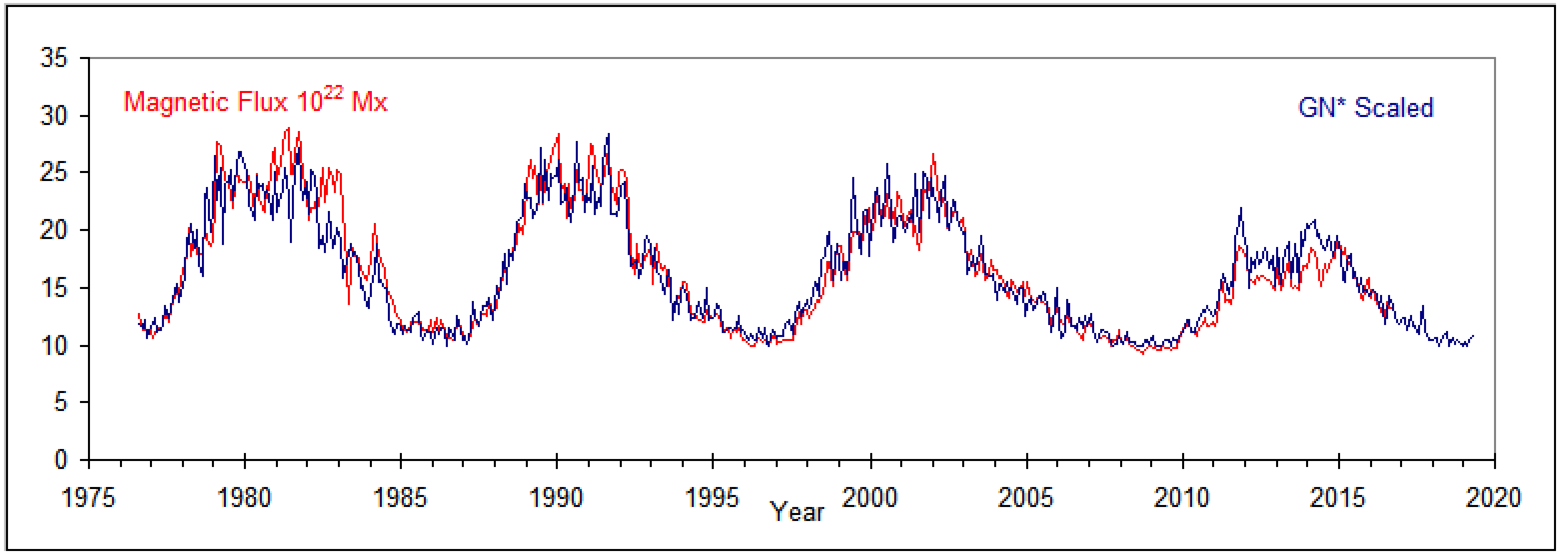
More Waldmeier Effect



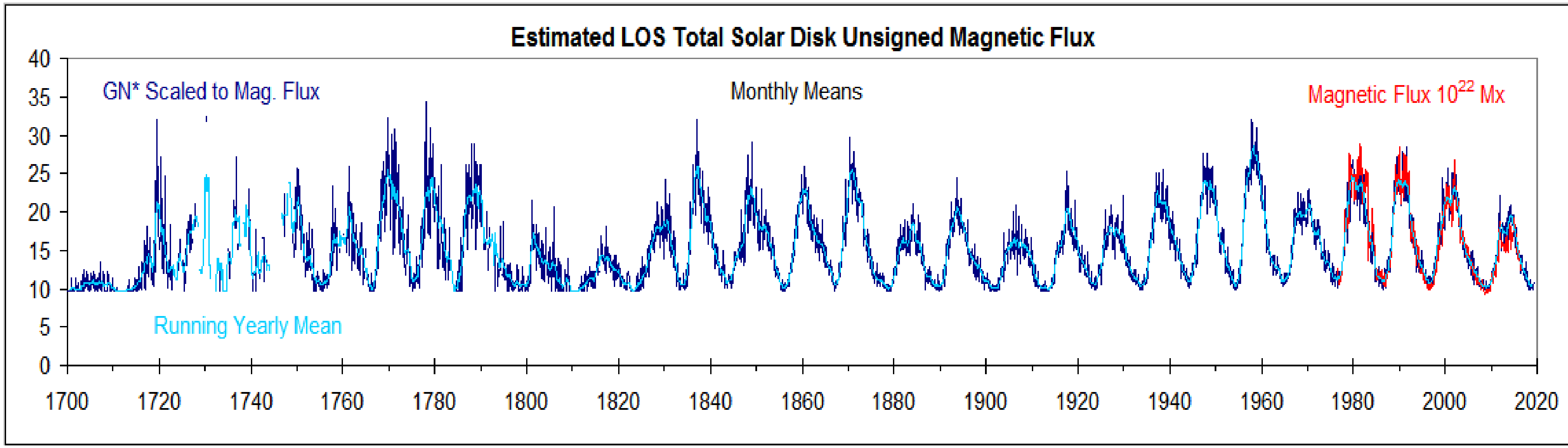
The H&S GSN fits the Waldmeier Effect after ≈1885, but not before (is too low).

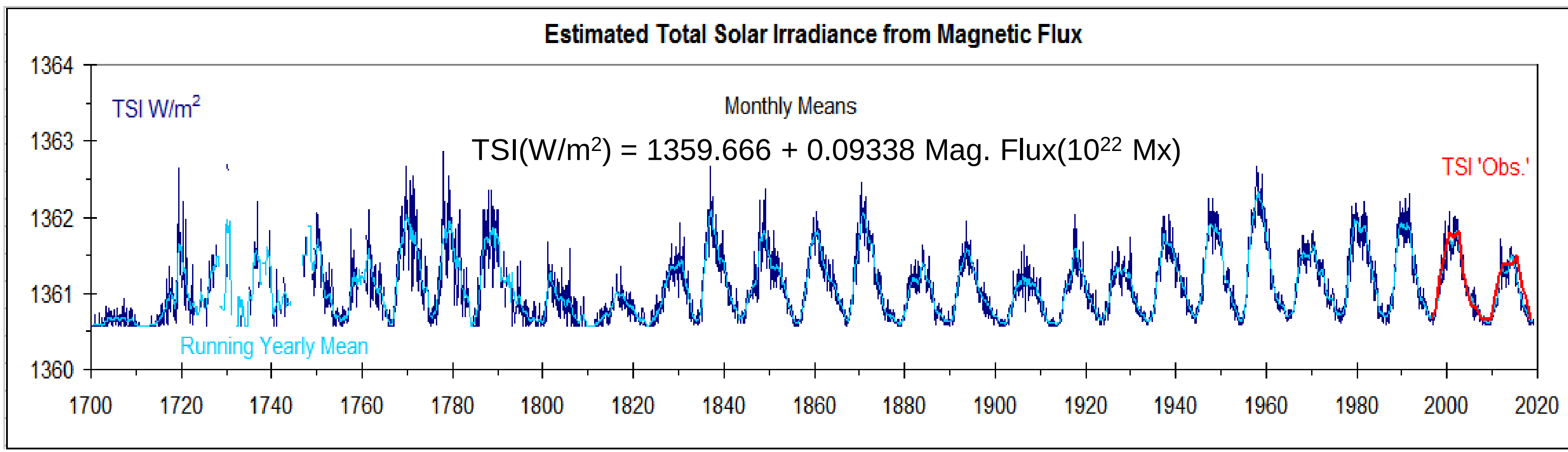
Group Number to Magnetic Flux



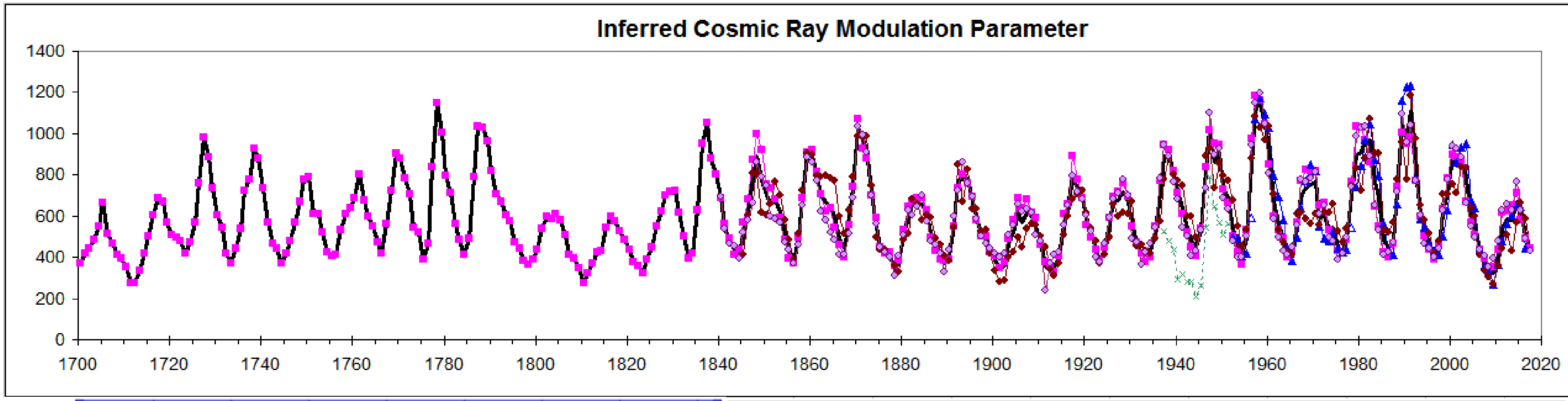


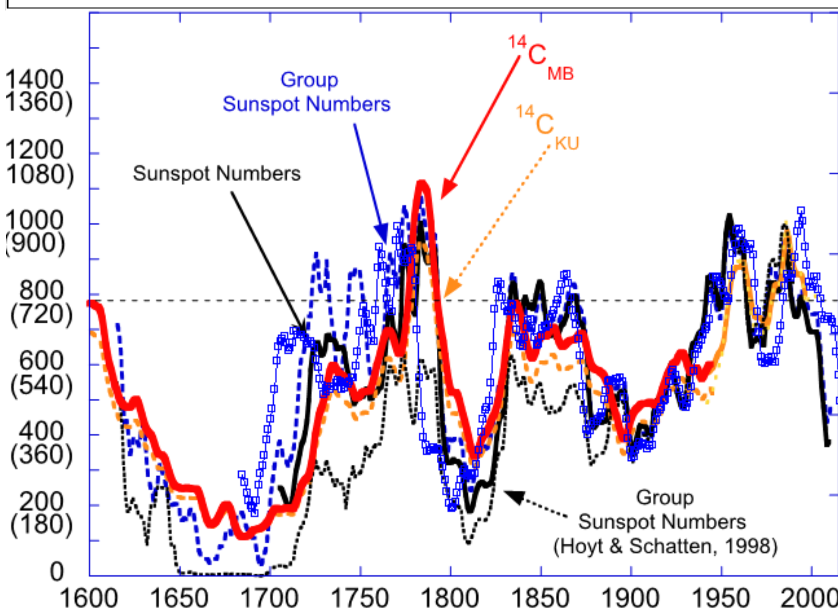
Three Centuries Magnetic Flux and TSI

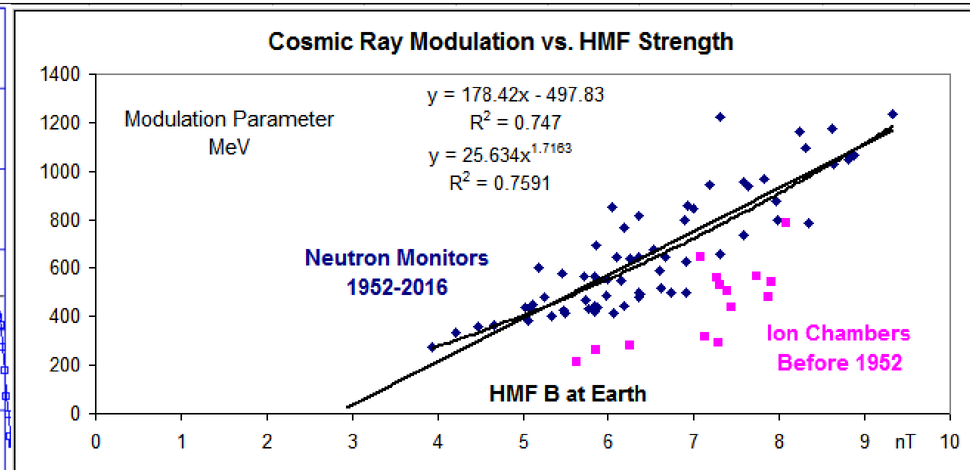




Cosmic Ray Modulation by HMF







Cosmic Rays carry a signature of HMF B

A New Paradigm (Different Populations)

- We shall therefore argue that the set of new Group Number series resembling the H&S series actually accurately represents the archived raw observational data (assembled first by Wolf and later by H&S and today curated by Vaquero)
- And that the secular increase (from one population to the next) in archived Group Numbers is due to evolving technology and understanding of what makes a group, rather than to errors and mistakes committed by the researchers
- And that the true evolution of solar activity can only be validated by agreement with other manifestations of said activity (often derisively called ‘proxies’) of which there are many

Conclusions

- From the fact that all reconstructions agree for the 20^{th} century one must conclude that the different methods basically work and that therefore it is not productive to argue which is 'better' or which has severe errors or uses 'unsound procedures'.
- The Revised Sunspot Number (v2) and the Svalgaard & Schatten (2016) Group Numbers vary as several solar-activity proxies for at least the last 300 years,
- supporting the New Paradigm that there are at least two different 'populations' of observed Group Numbers [with a dividing year in the 1880s]. Not taking this into account produces ≈40% artificially lower numbers [that should not be used] for most of the 19^{th} century and further back.

Abstract

Svalgaard & Schatten (2016) used a 'backbone' method to reconstruct the Sunspot Group Number since 1610. Five backbones were used, centered and anchored on the Wolfer Backbone, which then defines the scale of the series. Backbones are constructed by scaling observers directly to the primary observer (e.g. Wolfer) without daisy-chaining through intermediary observers thus avoiding accumulation of errors. To improve the time resolution (with better determination of error bars) the new Backbones have monthly resolution rather than the previous one's yearly values. There seems to be several different 'populations' of sunspot group counts by observers over time. One cannot blindly assume the statistical properties of one population to hold about the other. Speculatively we identify four populations the last 400 years. One major population belongs to years before 1881 followed by another major one after ~1915, separated by a transitional period between 1881 and ~1915. Those major populations differ by ~40%. The difference is poorly understood, but may be due to evolving telescope technology and/or increasing understanding of what constitutes a group. The average number of groups over a year by all observers with no normalization at all closely matches (i.e. are proportional to) the yearly numbers of groups in backbones constructed within each population showing that elaborate normalization procedures have almost no effect on the result. This means that we can dispense with the normalization altogether; although adjacent, overlapping backbone segments still have to be stitched together by par-wise comparison. So, it seems that we have a nice non-parametric, non-overlapping, non-k-value-regression, non-selection-effect, non-ranking, no pair-wise comparison, no ADF- or PDF-based, non-whatever method for constructing a backbone segment including estimating its time-varying error bars (from the spread of the observations).