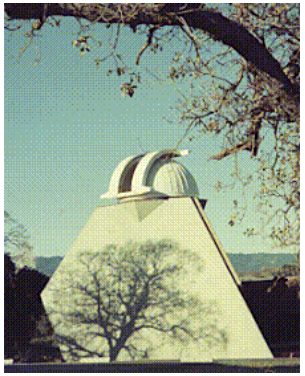
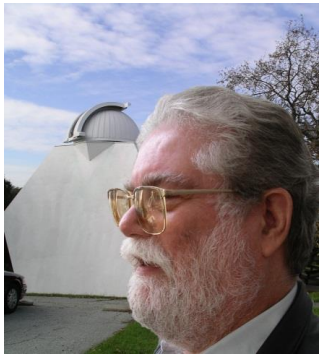




Three Centuries of Solar Activity

Leif Svalgaard

Stanford University

July 30th, 2020

A Major Controversy Resolved

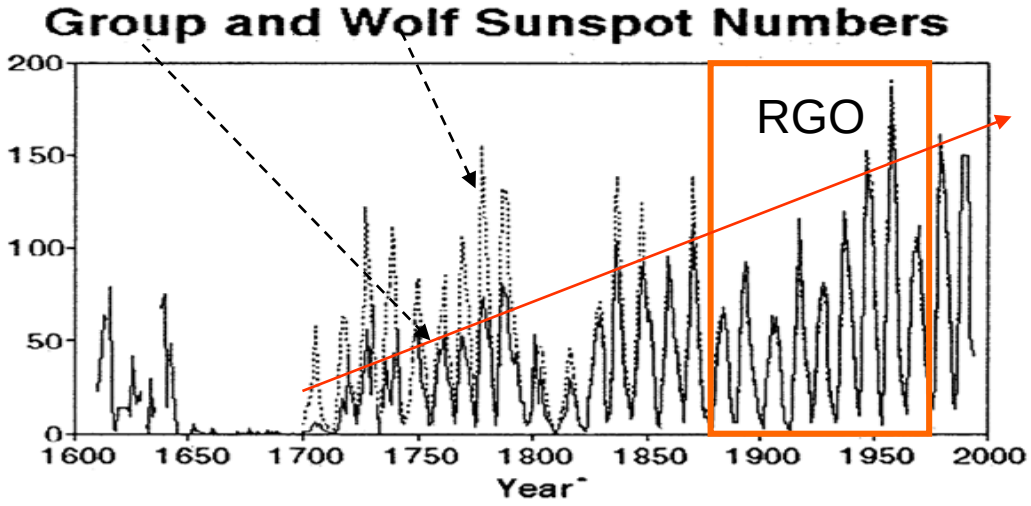
The H&S Papers That Started it All

Hoyt, Douglas V.; Schatten, Kenneth H.; Nesme-Ribes, Elizabeth: The one hundredth year of Rudolf Wolf's death: **Do we have the correct reconstruction of solar activity?** *Geophysical Research Letters, Volume 21, Issue 18, p. 2067-2070, 1994*

Hoyt, Douglas V.; Schatten, Kenneth H.: Group Sunspot Numbers: a new solar activity reconstruction. *Sol. Phys. 179, 189–219, 1998*. [HS98 in what follows]

"In this paper, we construct a time series known as the Group Sunspot Number. […] The generation and preliminary analysis of the Group Sunspot Numbers allow us to make several conclusions: (1) **Solar activity before 1882 is lower than generally assumed** and consequently **solar activity in the last few decades is higher than it has been for several centuries.**" [Other researchers have claimed for more than ≈10,000 years]

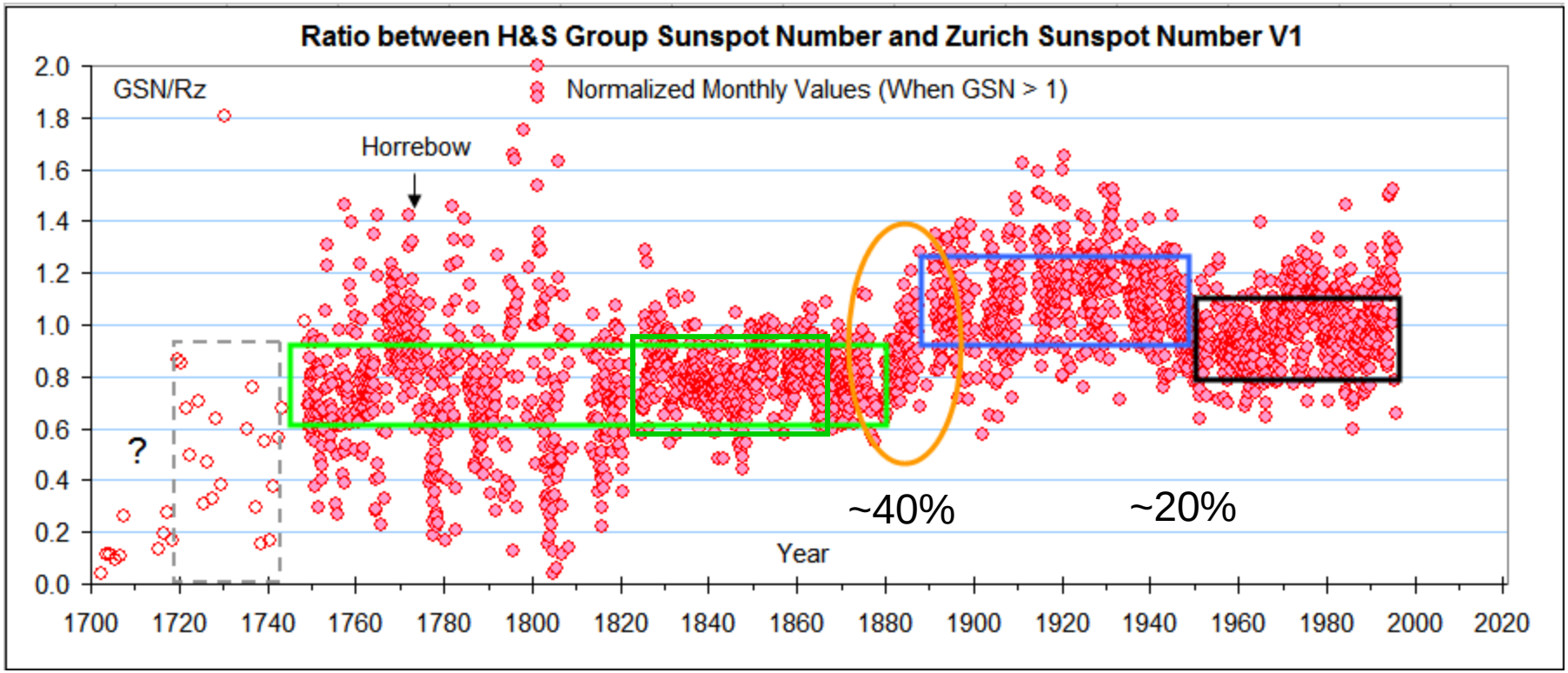
The Problem: Two Very Different 'Sunspot Series'. Which One to Use?



Original Wolf Number: W_o = Groups + 1/10 Spots. ('1/10 Spots' was assumed to be a measure of the area of the group). $W = k\ 10\ W_o$

H&S GSN = 12 G where the '12' was chosen to make the GSN = W for the interval 1874-1976

Discrepancies were Both Large and Systematic



The ratio of the H&S GSN and the Official [“Zürich”] Relative Sunspot Number [version 1] (when not too small) reveals some systematic variations, related to choice of observers…

I proposed a solution for reconciliation: The SSN Workshops (Utterly Failed the Goal)

http://ssnworkshop.wikia.com/wiki/Home


Sunspot, NM, 2011


Brussels, BE, 2012


Sunspot, NM, 2012


Tucson, AZ, 2013


Locarno, CH, 2014


Brussels, BE, 2015

Goal: a community-vetted and agreed-upon solar activity series;
Failure: we now have almost a dozen dissenting and different series…

The Principal Issue is Still Unresolved

A second attempt has recently been made to resolve the problem: **ISSI Team 417 (2017):** "This ISSI Team aims to resolve the uncertainties related to the sunspot series and to produce a consensus new-generation series, based on the modern methods and knowledge of physical processes leading to sunspot variability. The ultimate **goal is to provide a consensus "best" sunspot number** including accurate estimates of the uncertainties, for use by the whole scientific community (Meetings 2018 and 2019)

We now have basically two *classes* of reconstructions:

1: A set of series that closely resemble the original H&S reconstruction

2: A set of series that closely resemble the 'official' Sunspot series (both V1and V2; V2 is essentially just V1/0.6)

The main difference is (as pointed out by H&S) a discontinuity around 1880-1885 with up to 40% discrepancy between the two classes.

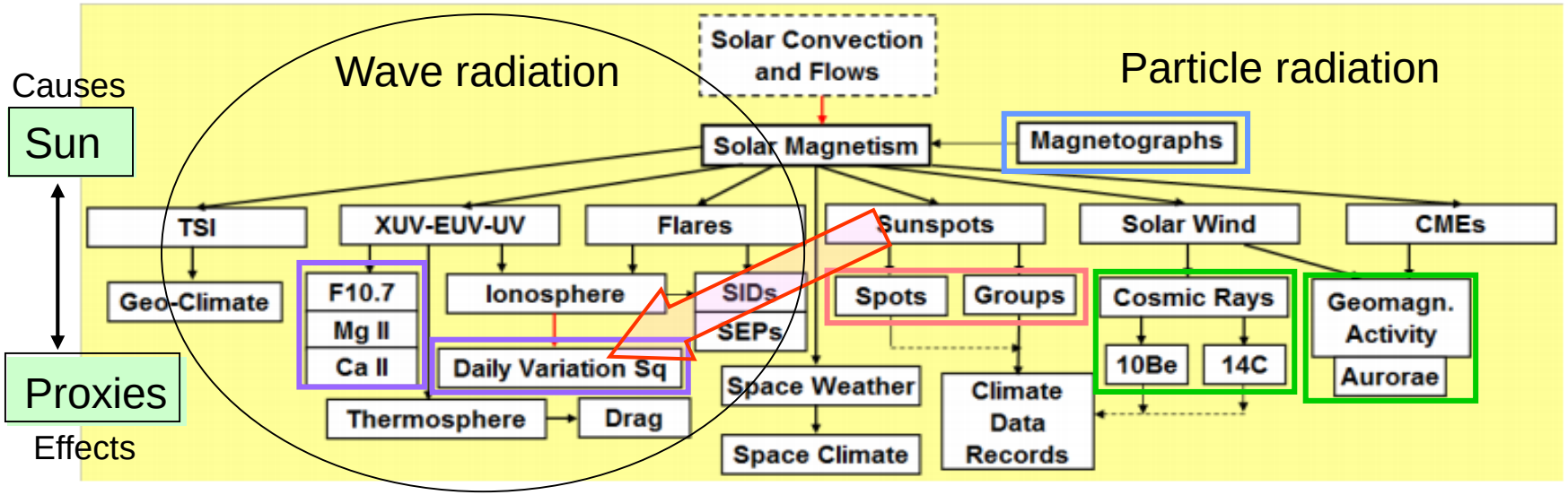
Instead of resolving the issue, opinions and claims have become more polarized and new reconstructions have marred the discourse with no end in sight

As the SSN workshops, this new effort also looks like a failure

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

A Systems Approach: Everything Must Fit

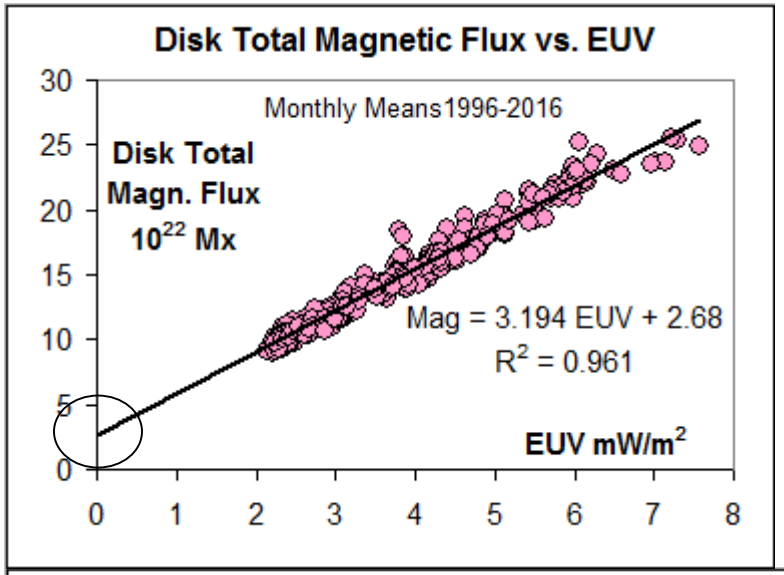
Hard, if we cannot agree on measures of 'Solar Activity'

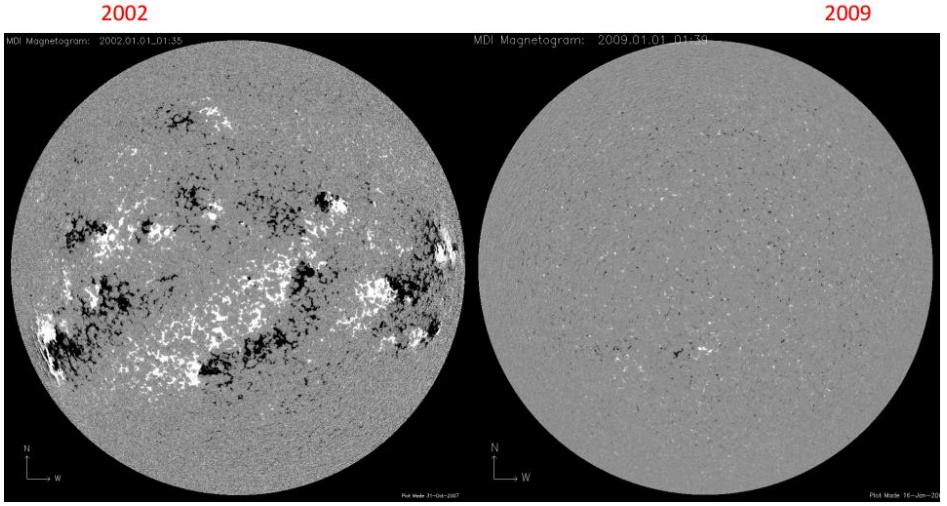


Faraday wrote to R. Wolf on 27th August, 1852: "I am greatly obliged and delighted by your kindness in speaking to me of your most remarkable enquiry, regarding the **relation existing between the condition of the Sun and the condition of the Earths magnetism**. The discovery of periods and the observation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

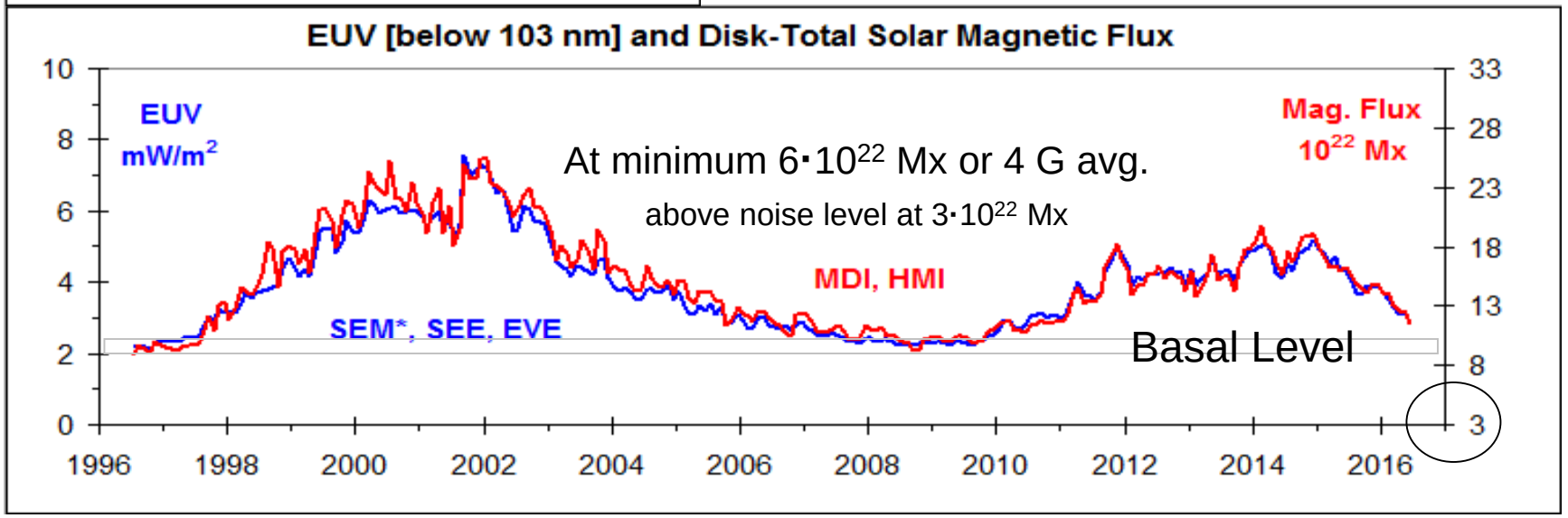
These are exciting times for Solar Physicists

EUV Follows Total Unsigned Magnetic Flux



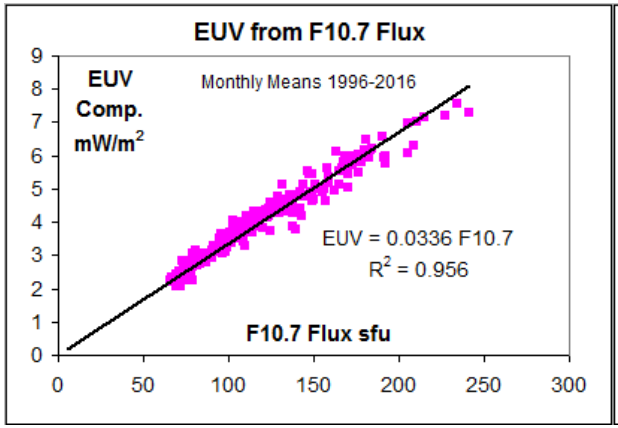


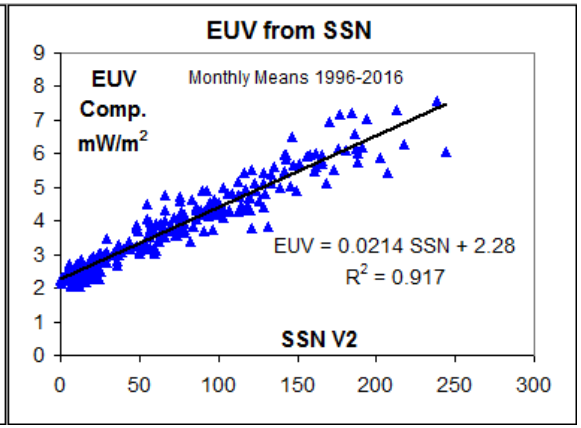
Offset interpreted as Noise Level ≈ 3·10^{22} Mx



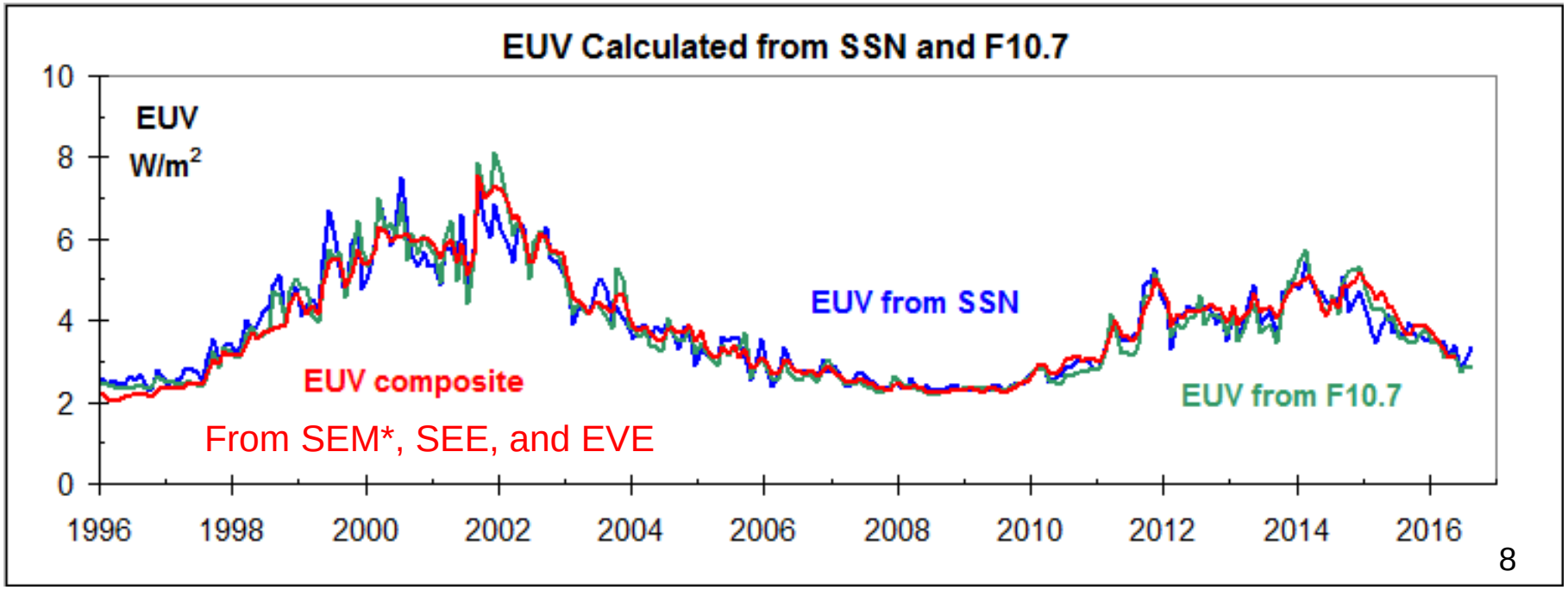
There is a 'basal' level at solar minima. This the case at every minimum

EUV Composite Matches F10.7 and Sunspot Numbers

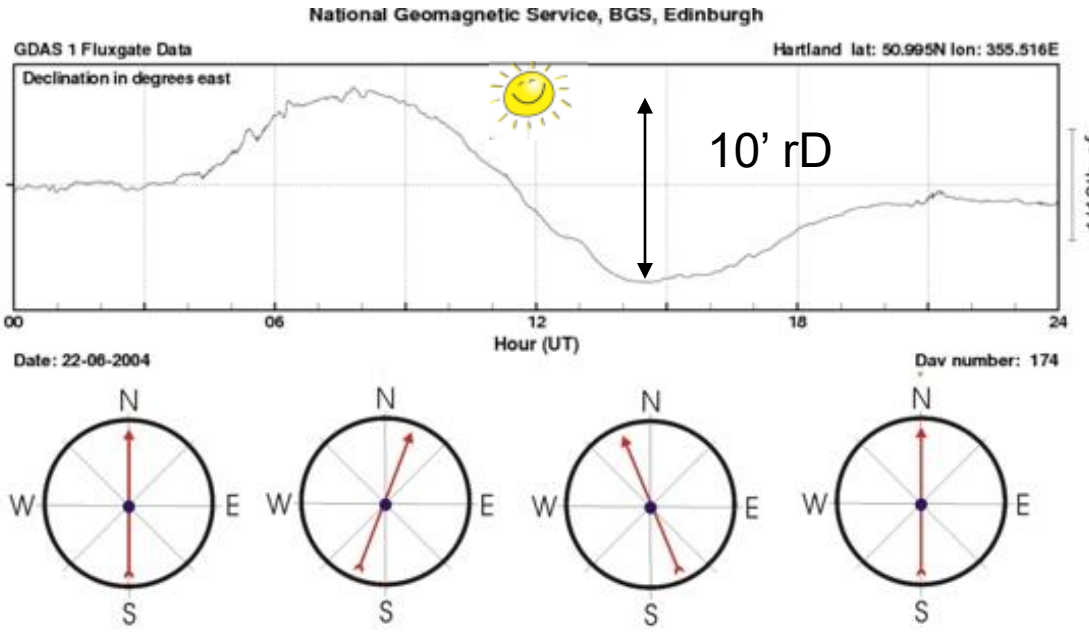




So, we can calculate the EUV flux both from the Sunspot Number and from the F10.7 flux which then is a good proxy for EUV [as is well-known].

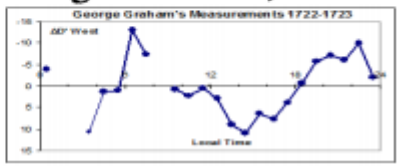


The Diurnal Variation of the Direction of the Magnetic Needle



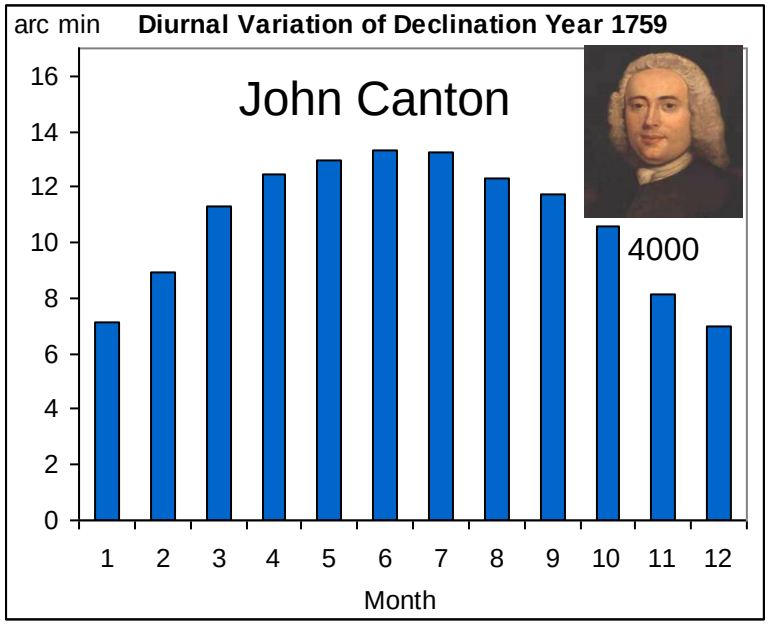
IV. *An Account of Observations made of the Variation of the Horizontal Needle at* London, *in the latter Part of the Year* 1722, *and beginning of* 1723. *By Mr.* George Graham, *Watch-maker, F. R. S.*

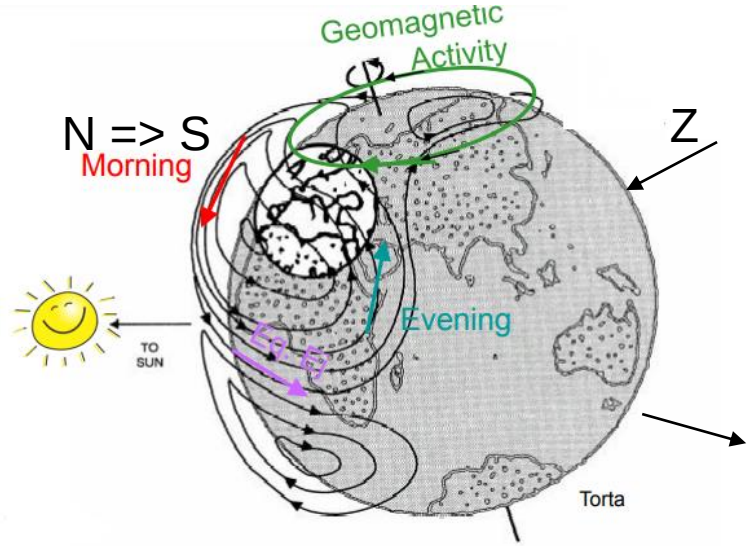
Made ~1000 observations



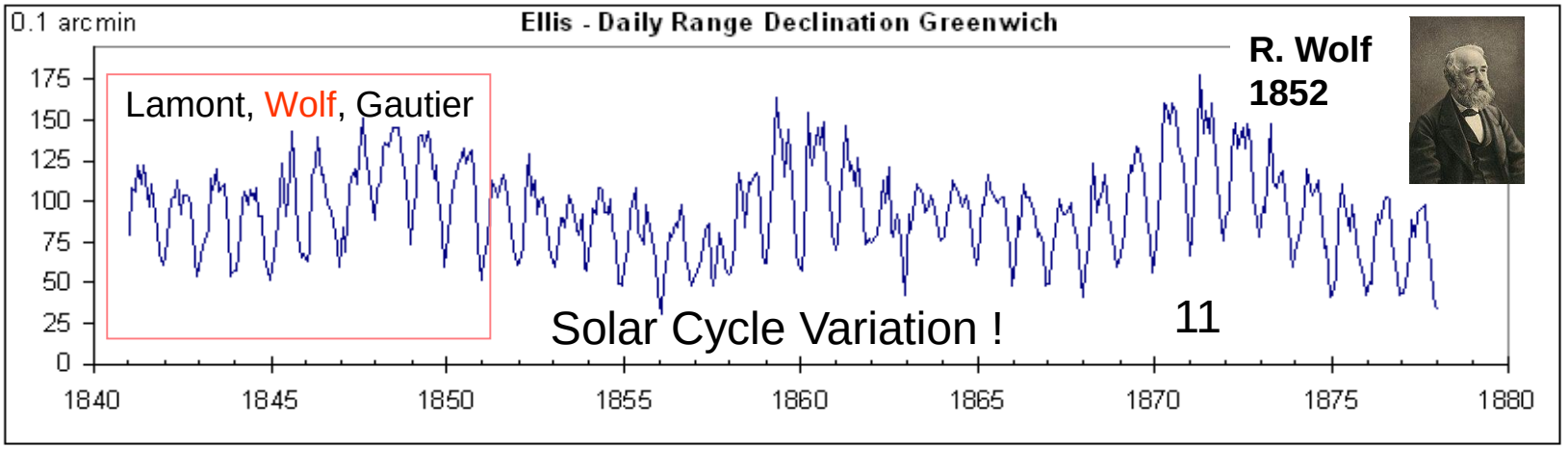
George Graham [London] discovered [1722] that the geomagnetic field varied during the day in a regular manner.

Zenith Angle Dependence Discovered

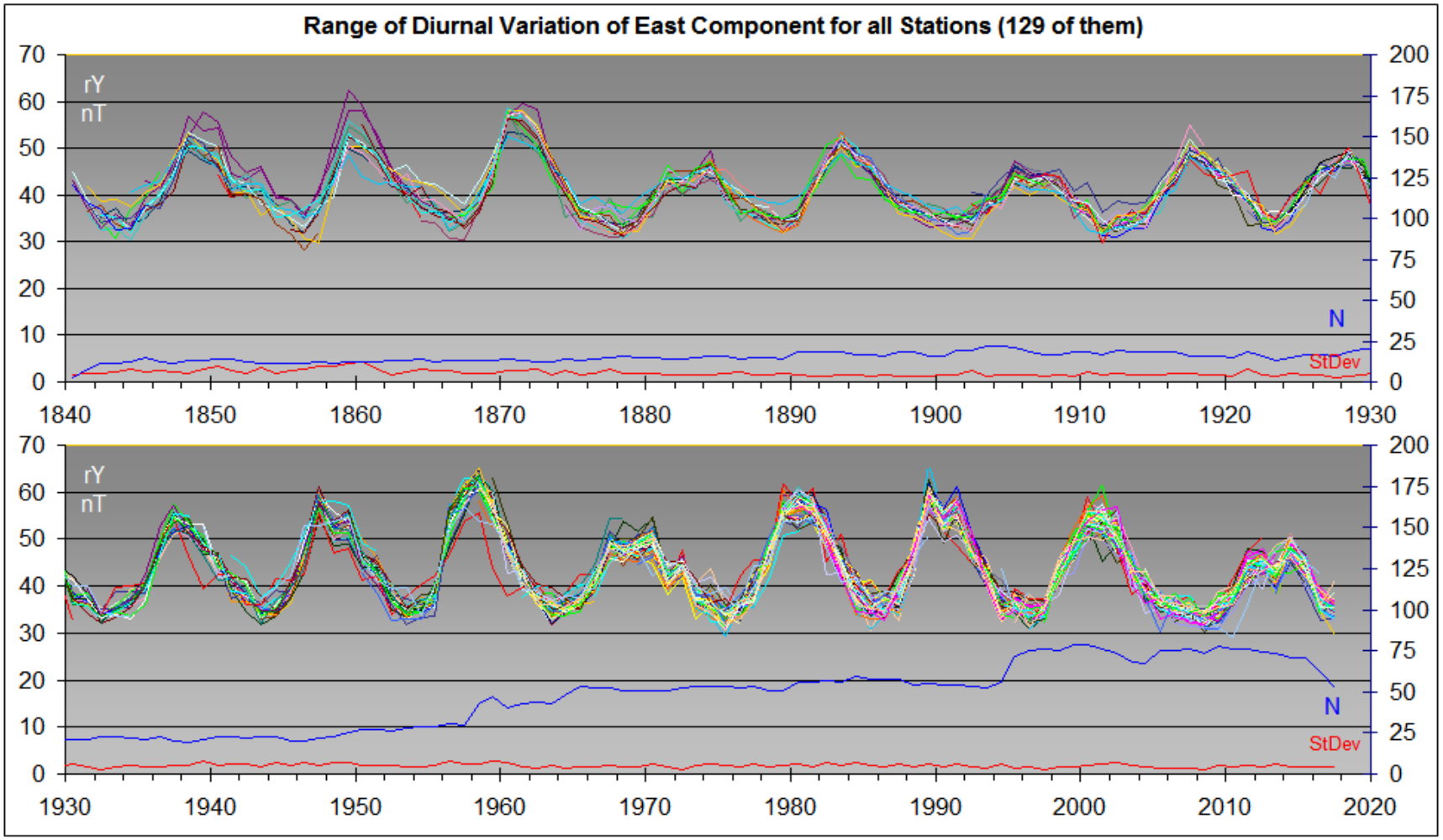




A current system in the ionosphere is created and maintained by solar EUV radiation

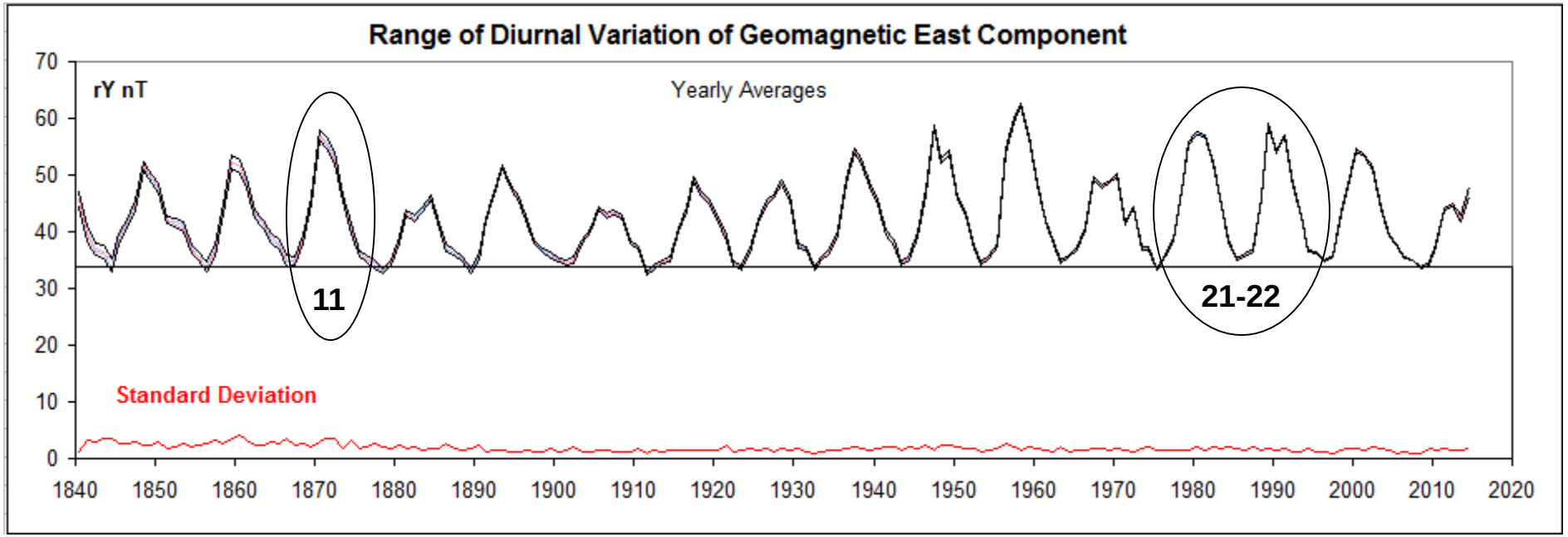


Normalized Observed Diurnal Ranges of the Geomagnetic East Component since 1840



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.

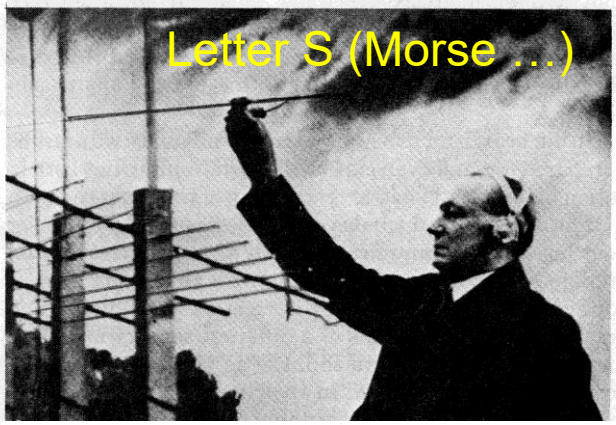
Composite *rY* Series 1840-2014



From the Standard Deviation and the Number of Station in each Year we can compute the Standard Error of the Mean and plot the ±1-sigma envelope.

Of note is the constancy of the range at every sunspot minimum and that Cycle 11 is on par with Cycles 21-22

We all Know about Marconi's Long-Distance Radio Transmissions



Guglielmo Marconi sends message from England to Newfoundland

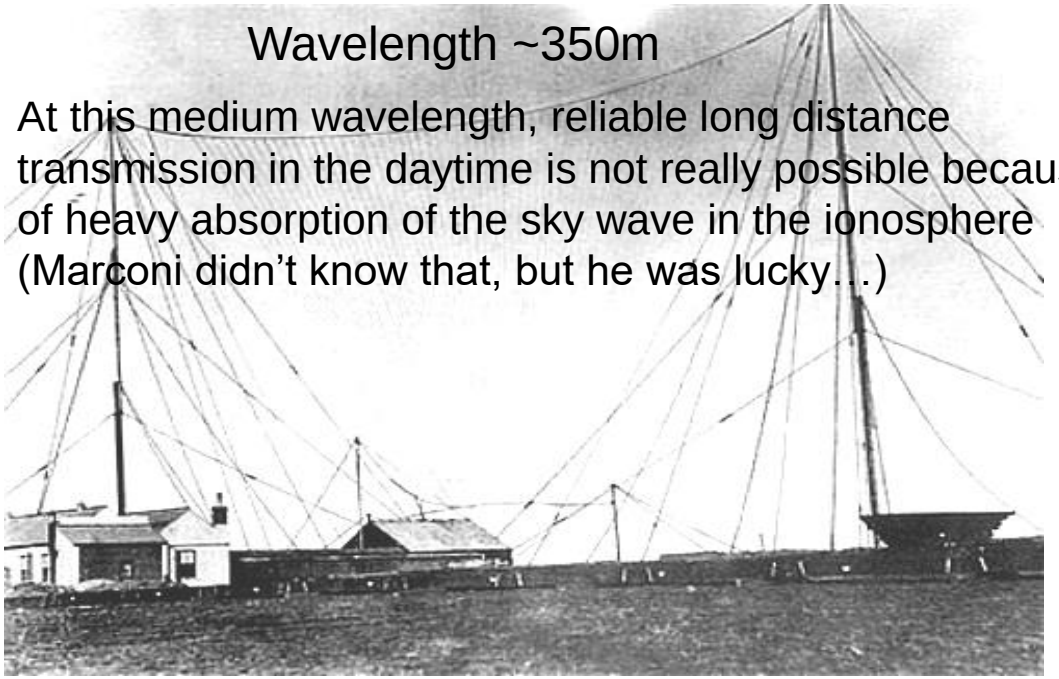
Dec 12. The Italian physicist Guglielmo Marconi, who sent wireless telegraphic messages across the English Channel from Dover, England, to Boulogne, France, on March 29, 1899, repeated his experiment today over the Atlantic Ocean, a distance of 2,232 miles.

In order to carry out this experiment, Marconi set up a 164-foot-high antenna in Poldhu, Cornwall, England. Then, he erected a receiver in St. John's, Newfoundland, Canada. In spite of the earth's curvature, he received a Morse signal corresponding to the letter "S" from the Poldhu station across the ocean.

When Marconi realized the importance of his first discoveries in 1895, he asked the Italian Minister of Telecommunication to help him. But the minister found that Marconi's experiments were too extravagant. That's why Marconi went to England, where he won the support of Sir William Peace, the Postmaster General, who immediately understood the significance of the young Marconi's work. Thanks to Peace's perspicacity and the help of Professor Adolf Slaby, Marconi could hit his target today (→ 2/22/03).

Guglielmo Marconi and his first wireless.

Dec. 12, 1901



Wavelength ~350m

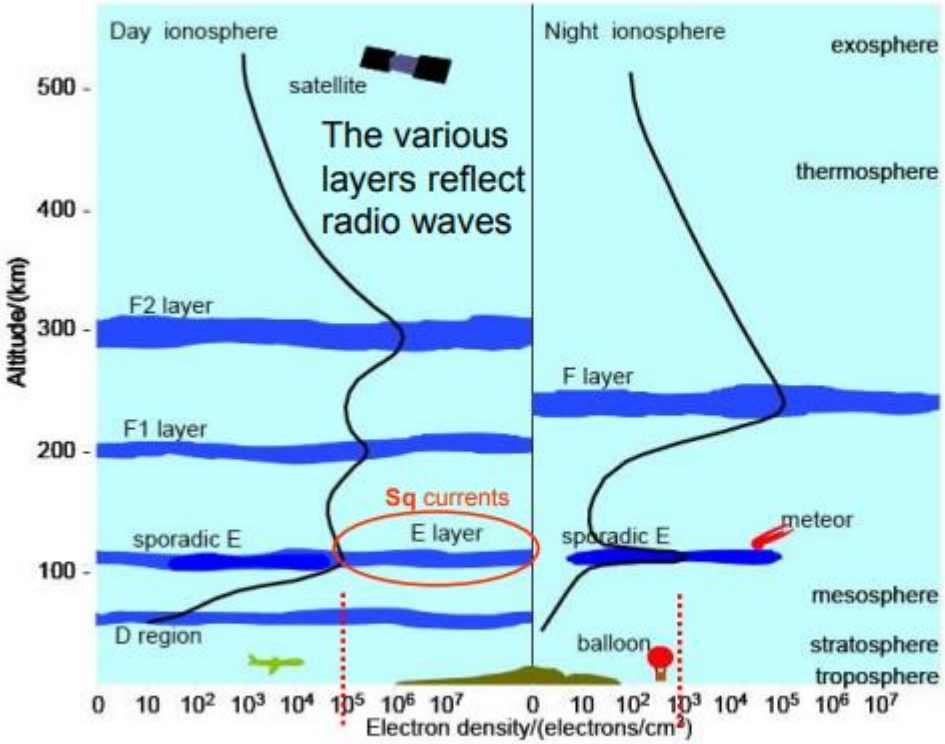
At this medium wavelength, reliable long distance transmission in the daytime is not really possible because of heavy absorption of the sky wave in the ionosphere (Marconi didn't know that, but he was lucky…)

Later he managed to send a message from US president Theodore Roosevelt to the King of the UK via his Glace Bay station in Nova Scotia, Canada, across the Atlantic on 18 January 1903.

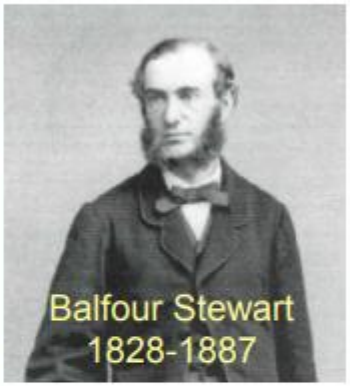
Kennely and Heaviside independently suggested [in 1902] the existence of a conducting layer to 'guide the radio waves around the Earth'.

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

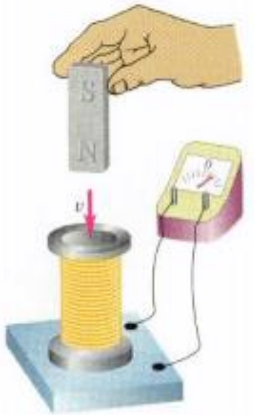


1882, Encyclopedia Britannica, 9th Ed.:

"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.

Electron Density due to EUV

$\lambda < 102.7$ nm

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

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

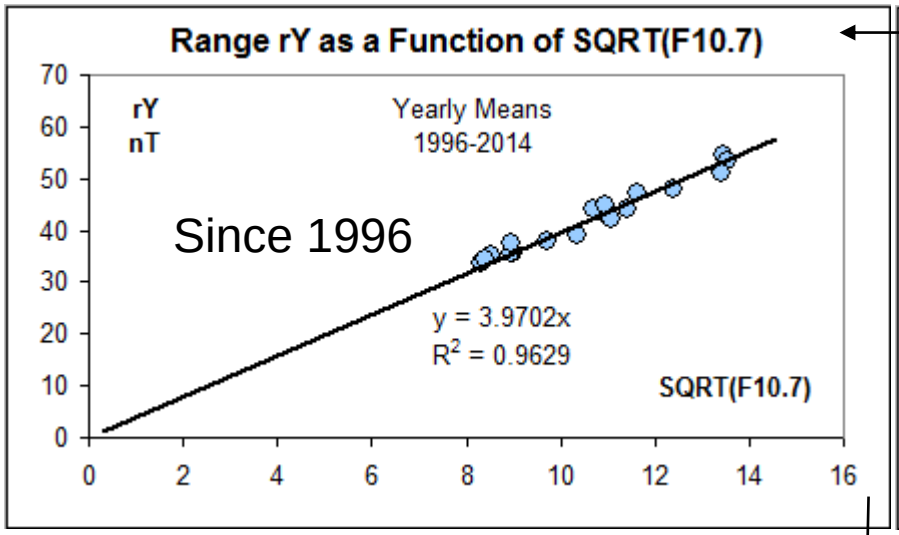
The conductivity at a given height is proportional to the electron number density N_e. In the dynamo region the ionospheric plasma is largely in photochemical equilibrium. The dominant plasma species is O^+_2, which is produced by photo ionization at a rate J (s^{-1}) and lost through recombination with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

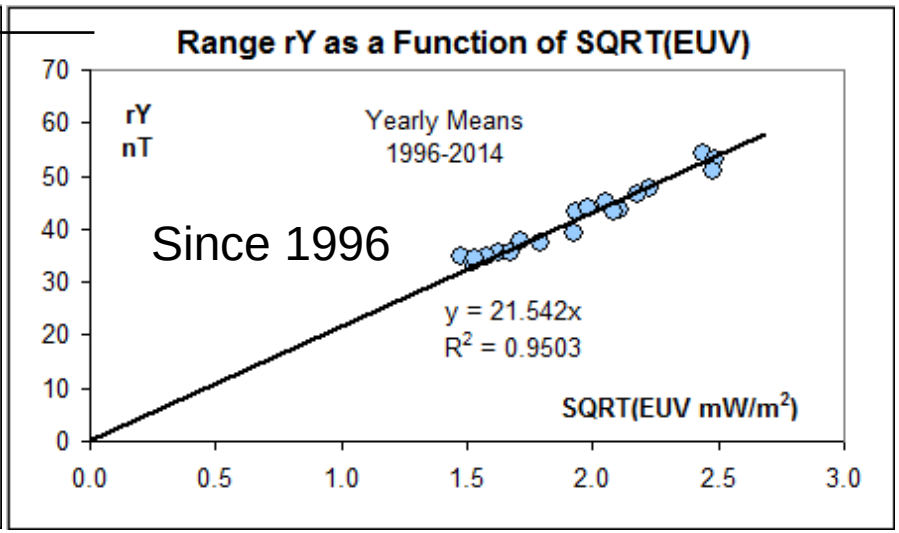
The rate of change of the number of ions N_i, dN_i/dt and in the number of electrons N_e, dN_e/dt are given by $dN_i/dt = J\cos(\chi) - \alpha N_i N_e$ and $dN_e/dt = J\cos(\chi) - \alpha N_e N_i$. Because the Zenith angle χ changes slowly we have a quasi steady-state, in which there is no net electric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

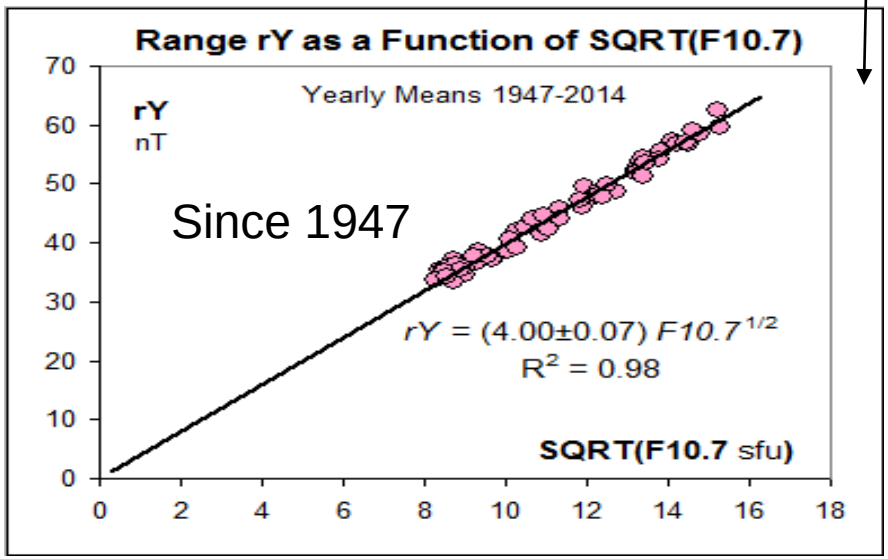
$$N = \sqrt{(J\,\alpha^{-1}\cos(\chi))}$$

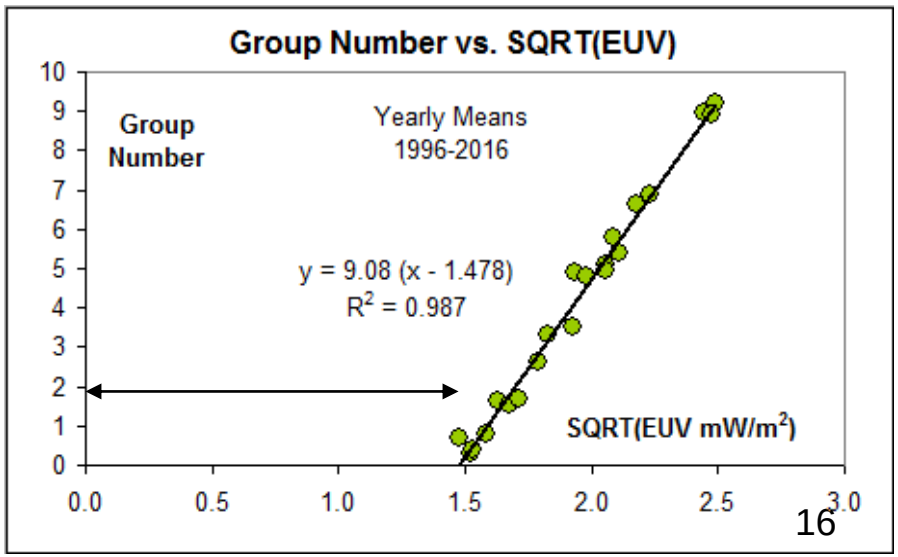
Since the conductivity, Σ, depends on the number of electrons N, we expect that Σ scales with the square root $\sqrt{(J)}$ of the overhead EUV flux with $\lambda < 102.7$ nm.

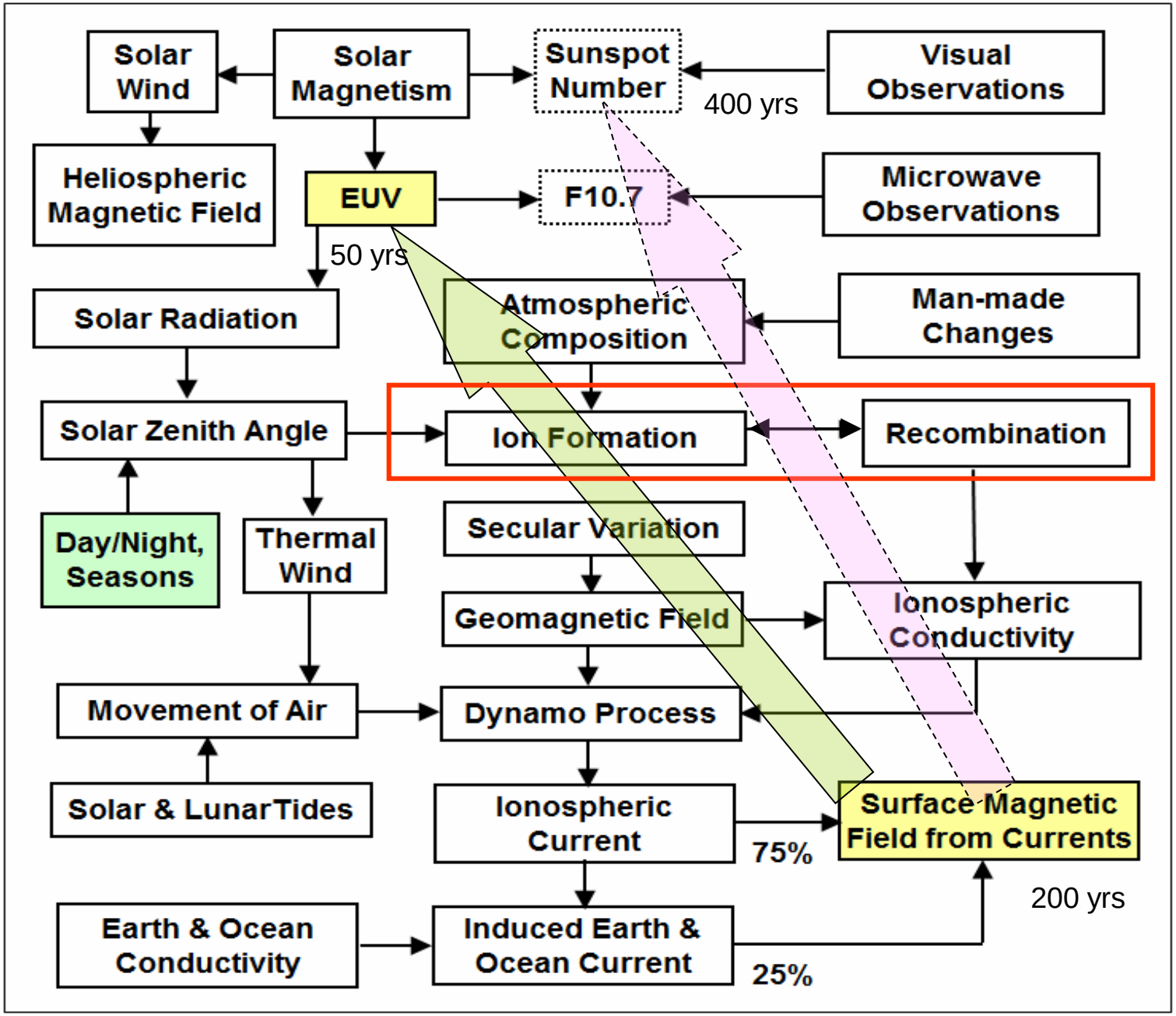
We saw that the conductivity [and thus rY] should vary as the square root of the EUV [and F10.7] flux, and so it does:









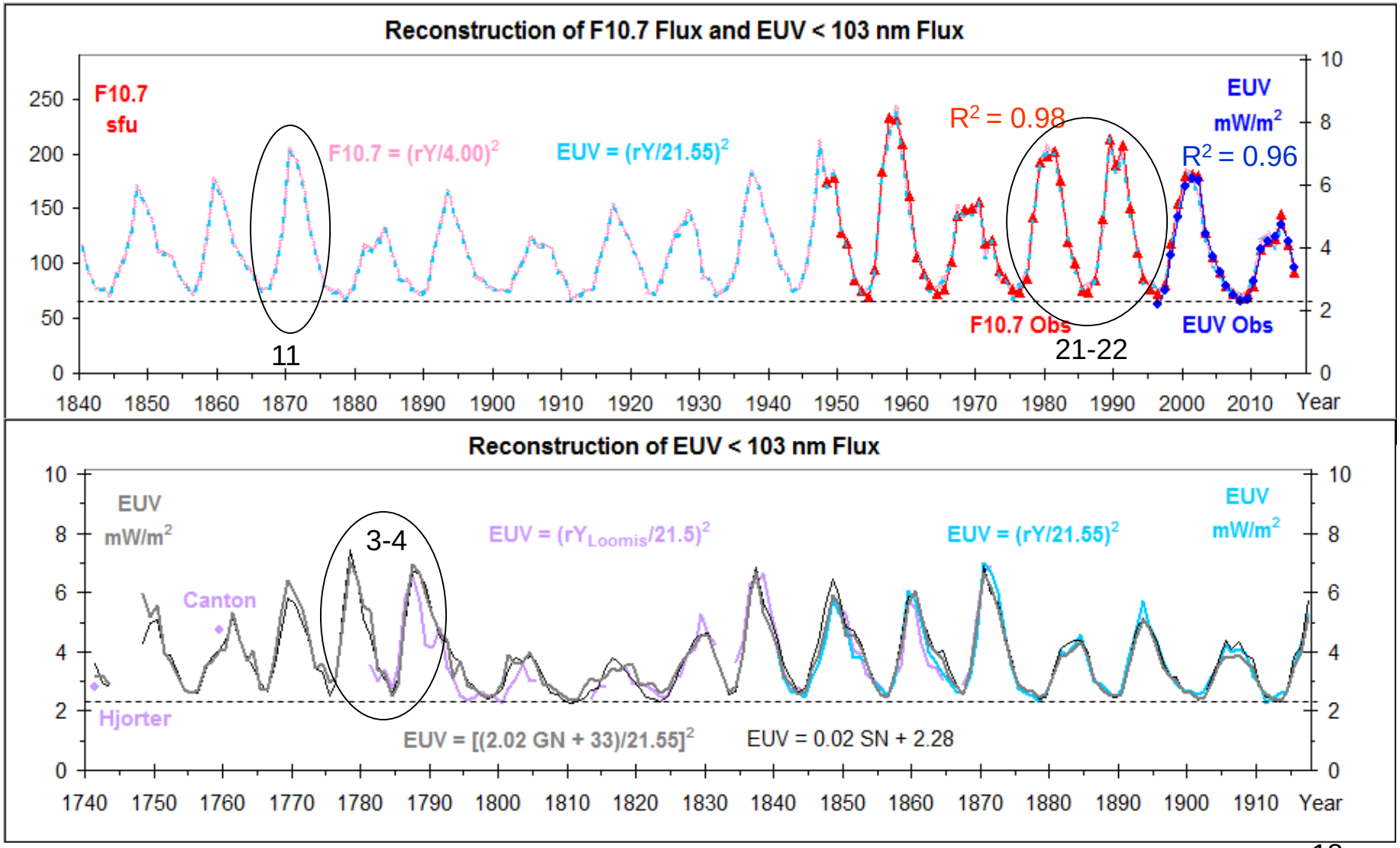


Determining EUV Flux from the magnetic effect of dynamo currents in the E-region of the ionosphere

The physics of the boxes is generally well-known

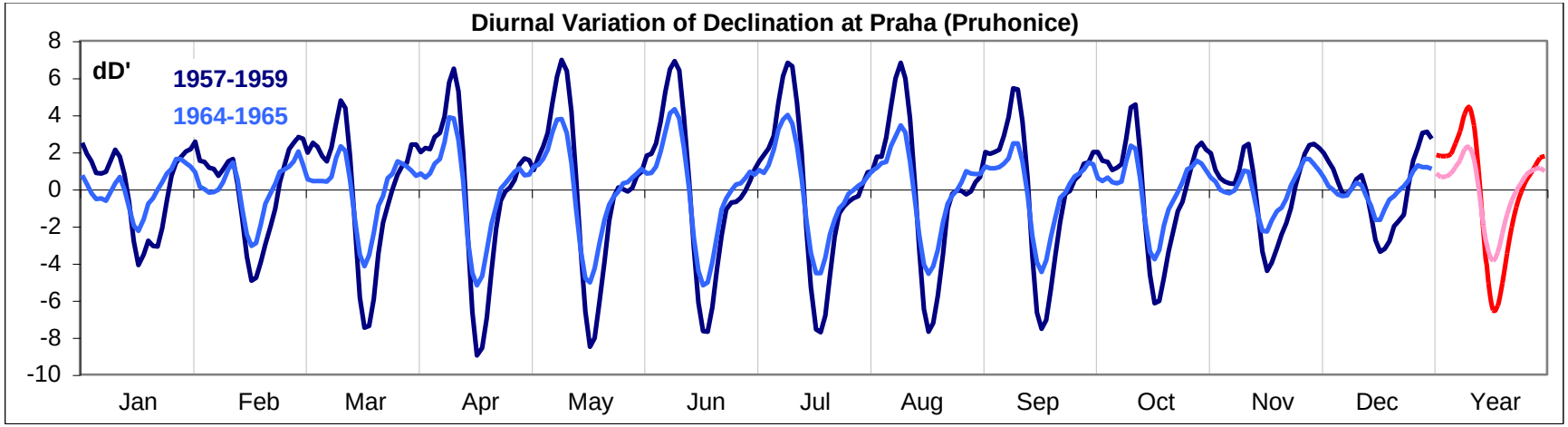
We can determine the EUV from the magnetic effects

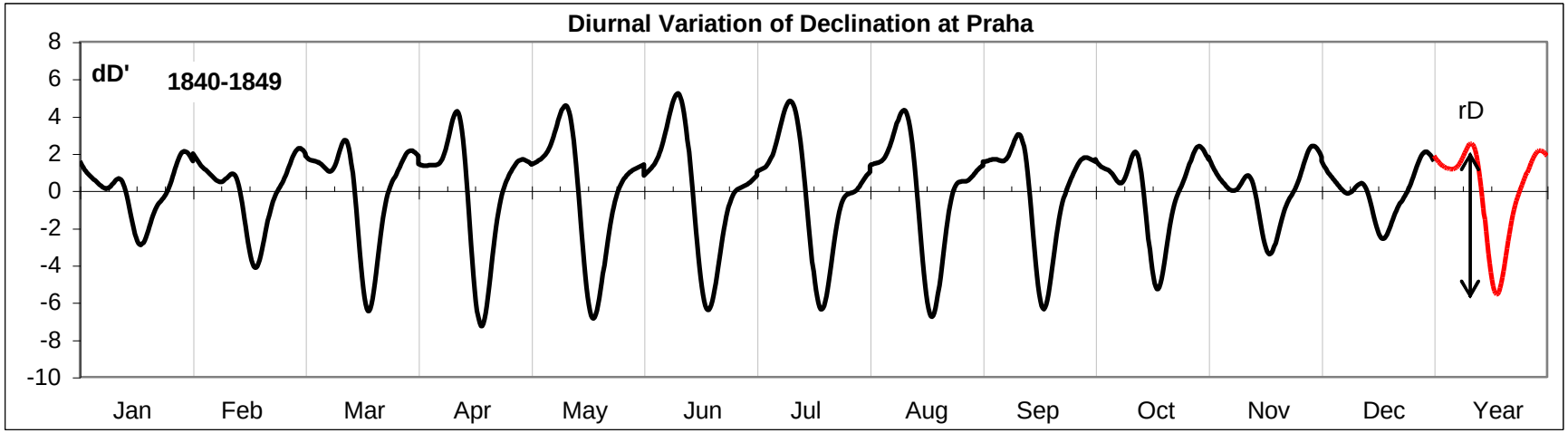
Reconstructions of EUV and F10.7



Note that Cycles 3-4 and 11 are on par with modern Cycles 21-22

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





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.

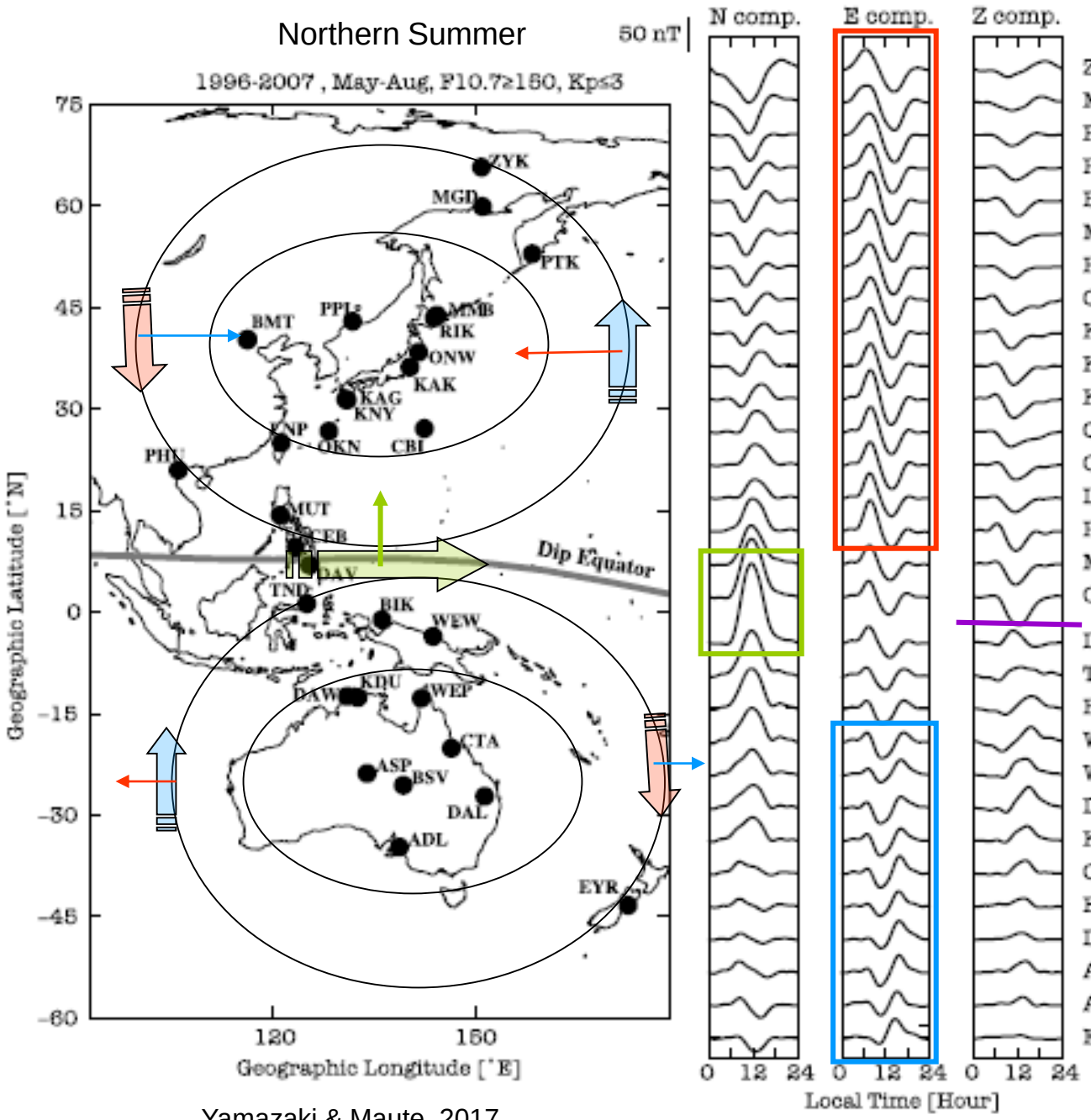
This comparison seems to warrant the following propositions:

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

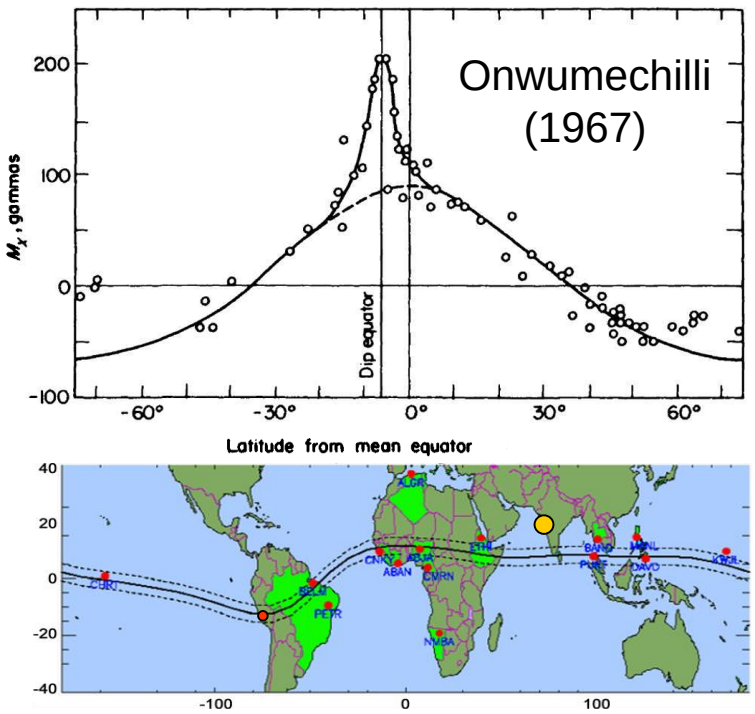
Diurnal Variation of Geomagnetic Field



Yamazaki & Maute, 2017

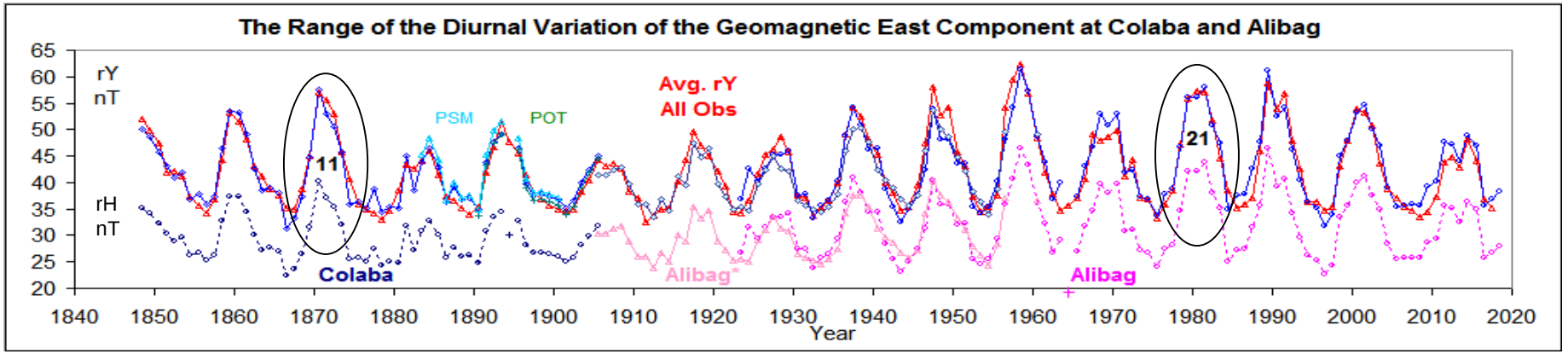
Already Julius Bartels (1946) emphasized the importance of the diurnal variation: “"The correlations between R and his W (wave-radiation)… are the **closest found so far** between solar and terrestrial phenomena"

The Equatorial Electrojet

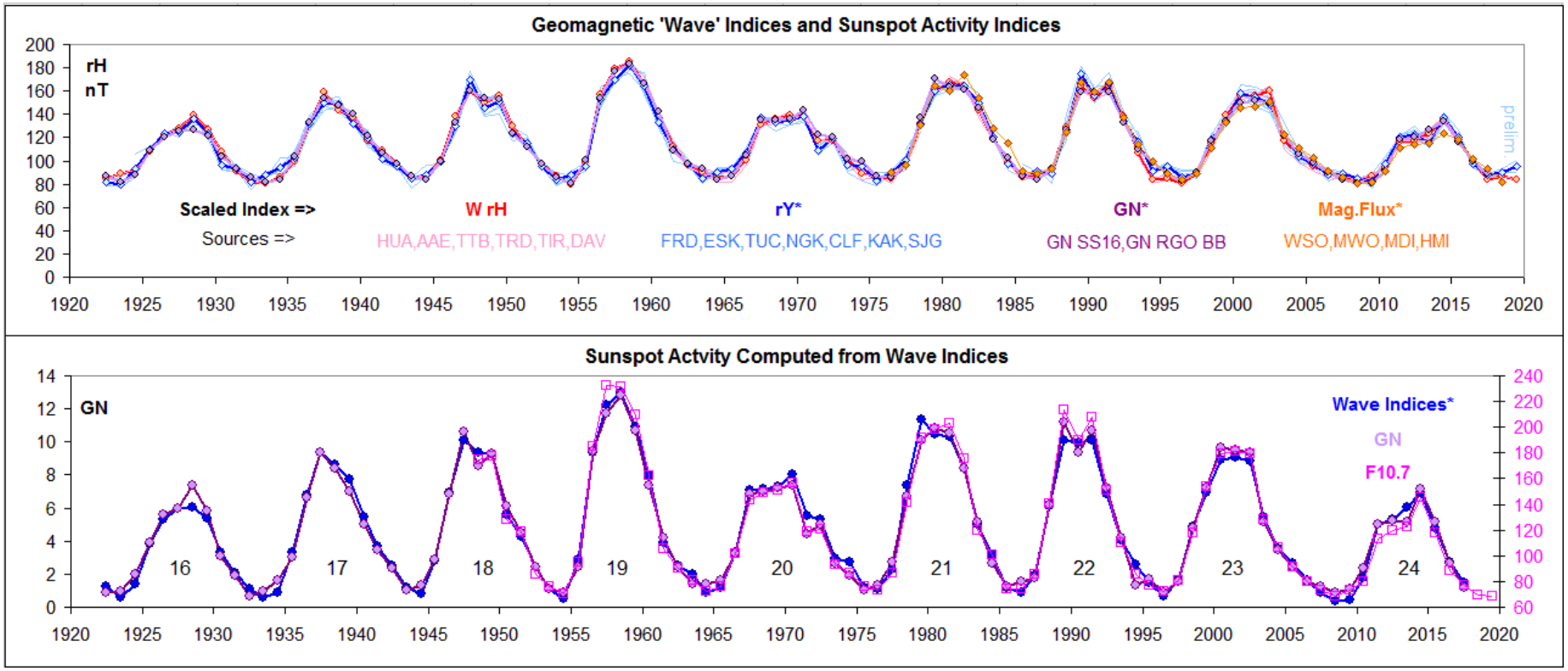


Variation of the daily range of horizontal component of magnetic field with latitude on international quiet days during September and October, 1958. The EEJ field is caused by the ionospheric current flowing along the narrow channel (±3° in latitudinal range) of the enhanced ionospheric (Cowling) conductivity which is formed along the dayside dip equator.

"The most suitable for measuring W, [are] the daily amplitudes of the north component or of the horizontal force, near the equator, and of the east component rY […], in middle latitudes. As a provisional result of […] data from Bombay [Colaba and Alibag] and Greenwich, it was found that the high sunspot-maximum of 1870.6 [Cycle 11] actually brought high values of W, expressed in large amplitudes of Sq. *This agreement, in turn, corroborates the estimate of the sunspot number*." [Bartels, 1946].



The Wave-Radiation is an Almost Perfect Solar Activity Indicator

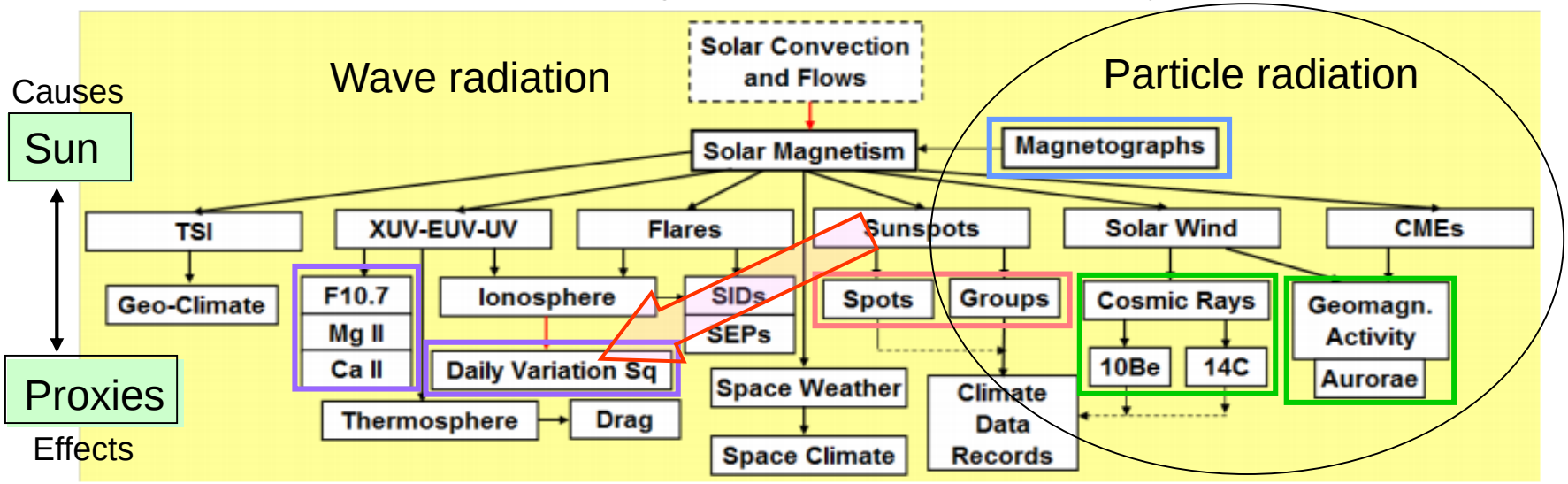


If this is not true at all times, we must postulate a new and unexpected solar-terrestrial effect. Occam's razor tells us that *pluralitas non est ponenda sine necessitate*: plurality should not be posited without necessity. So we should conclude and accept that Cycles 3-4 and 11 were on par with Cycle 21.

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

A Systems Approach: Everything Must Fit

Hard, if we cannot agree on measures of 'Solar Activity'

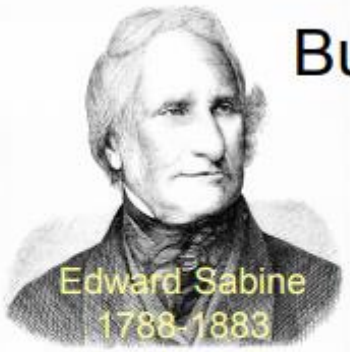


Faraday wrote to R. Wolf on 27th August, 1852: "I am greatly obliged and delighted by your kindness in speaking to me of your most remarkable enquiry, regarding the **relation existing between the condition of the Sun and the condition of the Earths magnetism**. The discovery of periods and the observation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

Geomagnetic Storms Caused by Sun

Canton found [1759] that on days with 'irregular' daily variation, aurorae were invariably seen



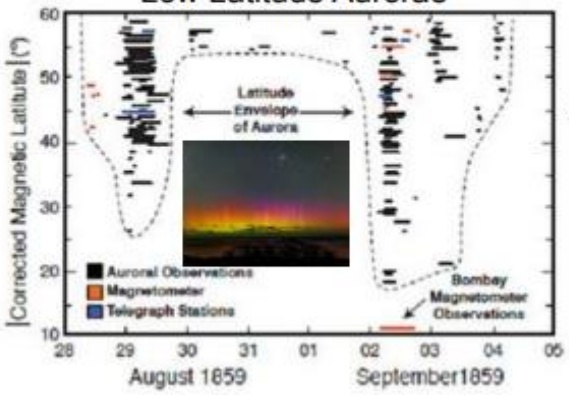
But the Aurorae are Due to that "Other Cause" (The Solar Atmosphere)

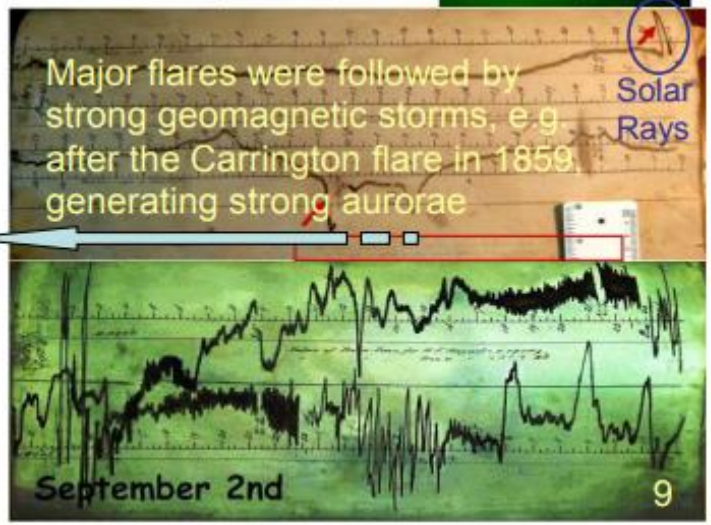
As are also the great magnetic disturbances associated with them.

Solar Observations of Flares

Sabine (1852) noted that magnetic perturbations superimposed on the daily variation also varied in phase with the newly discovered Sunspot Cycle.

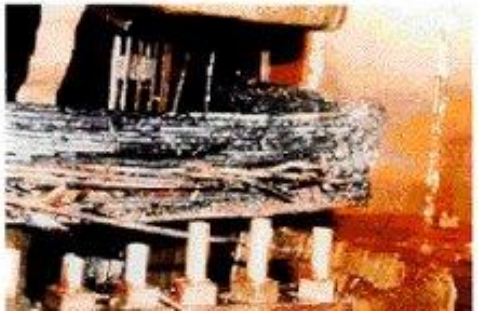
Low Latitude Aurorae



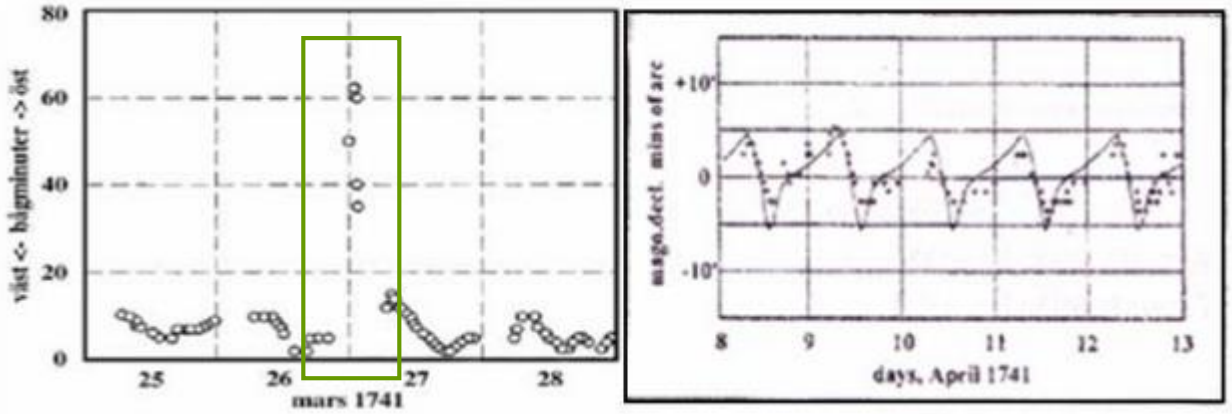


PJM Public Service
Step Up Transformer

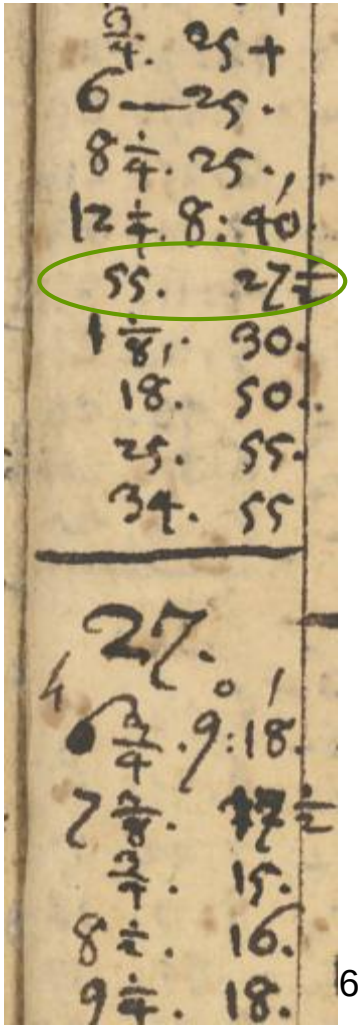
Severe internal damage caused by the space storm of 13 March, 1989



Observations in the 1740s



Olof Petrus Hjorter was married to Anders Celsius' sister and made more than 10,000 observations of the magnetic declination in the 1740s.



Right: Hjorter's measurements of the magnetic declination at Uppsala during April 8-12, 1741 (old style). The curve shows the average variation of the magnetic declination during April 1997 at nearby Lovö (Sweden).

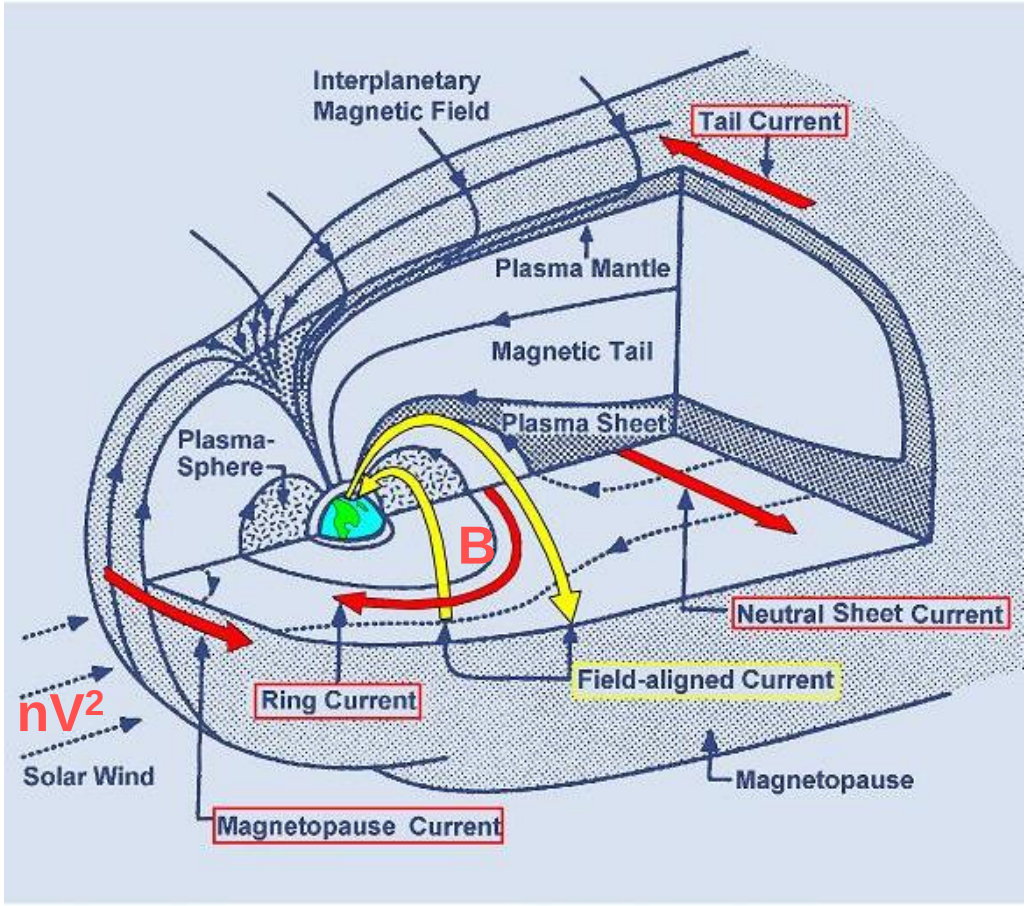
Left: Variation during strong Northern Light on March 27th. Also observed by Graham in London, showing that the aurorae and magnetic field are connected on a large scale and not just local meteorological phenomena.

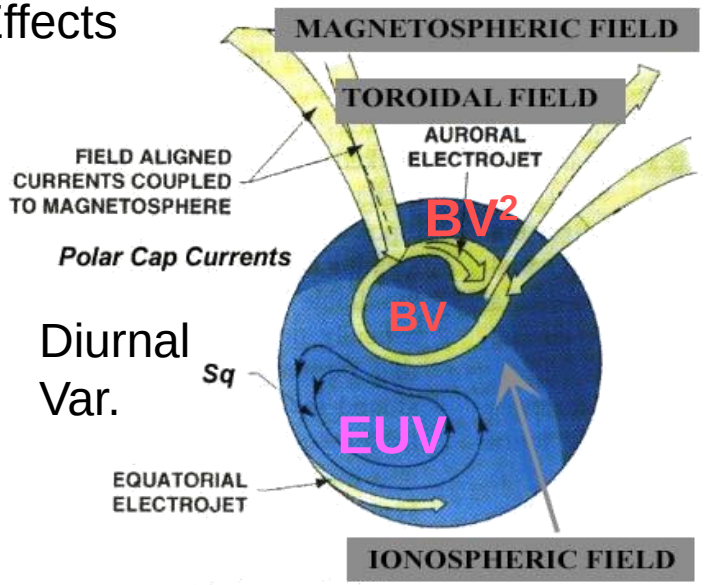
Note there are really two phenomena going on, regular daily variation and sporadic, large aurora-related excursions…

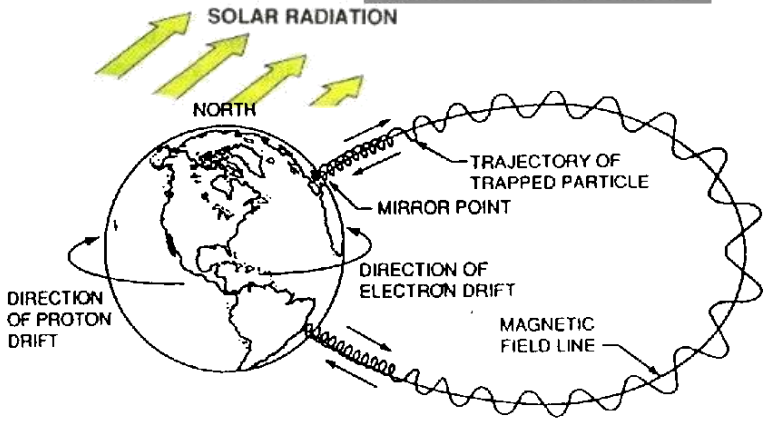
This is from Hjorter's original notebook for that day. Observations were made with an instrument constructed by Graham.

Electric Current Systems in Geospace

Different Current Systems ⇄ Different Magnetic Effects







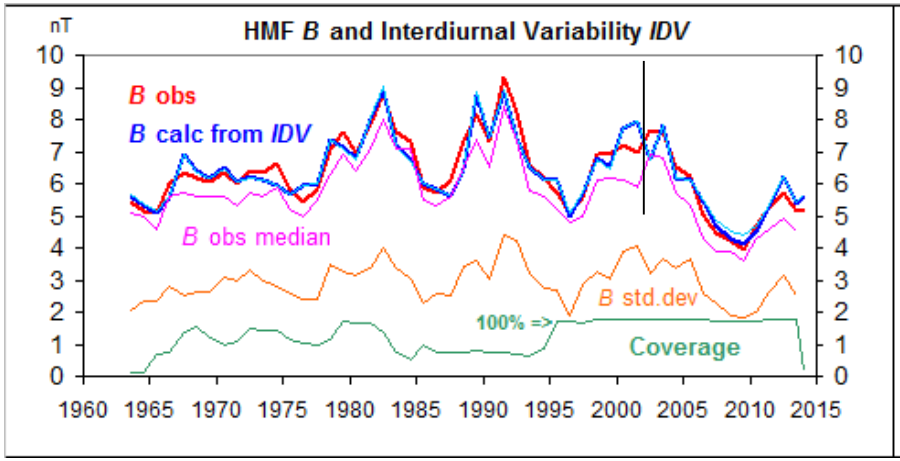
We can now invert the Solar Wind – Magnetosphere relationships…

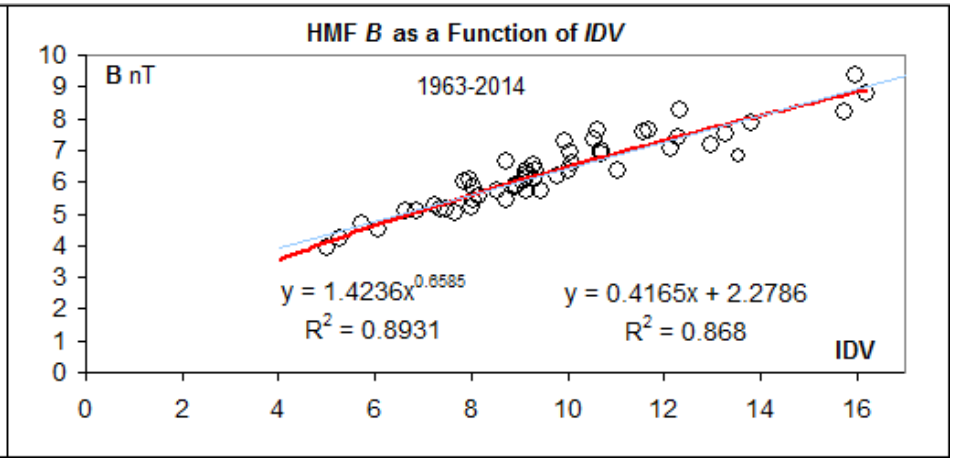
Oppositely charged particles trapped in the Van Allen Belts drift in opposite directions giving rise to a net westward 'Ring Current'.

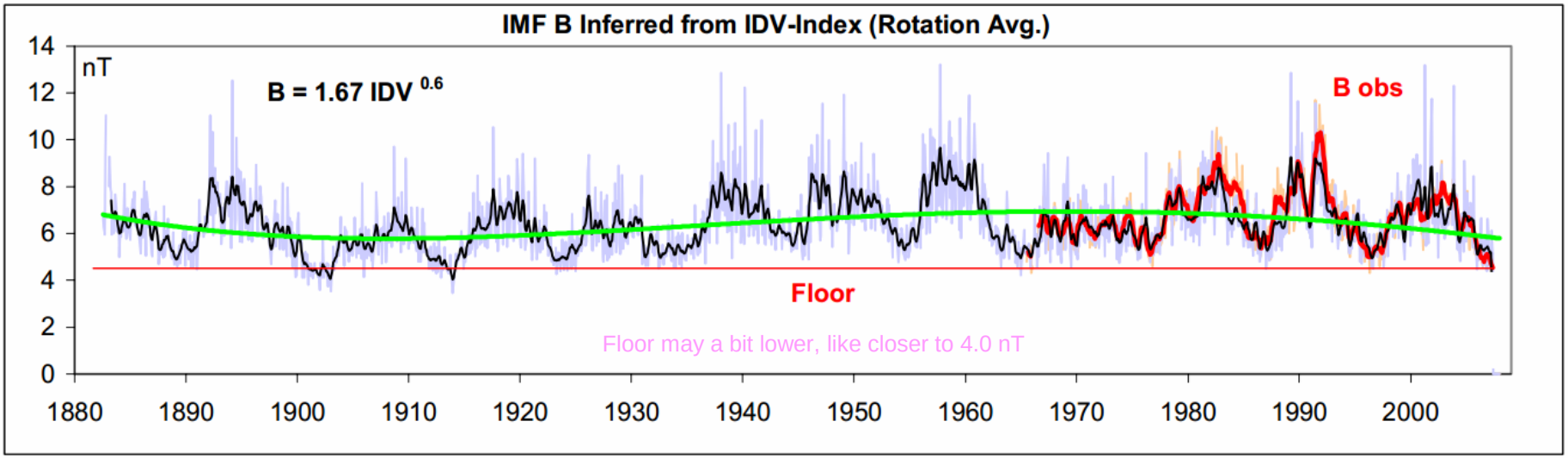
‘Different Strokes for Different Folks’

- The key to using geomagnetism to say something about the sun is the realization that geomagnetic ‘indices’ [e.g. our IDV-index] 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

Relationship between HMF *B* and *IDV*

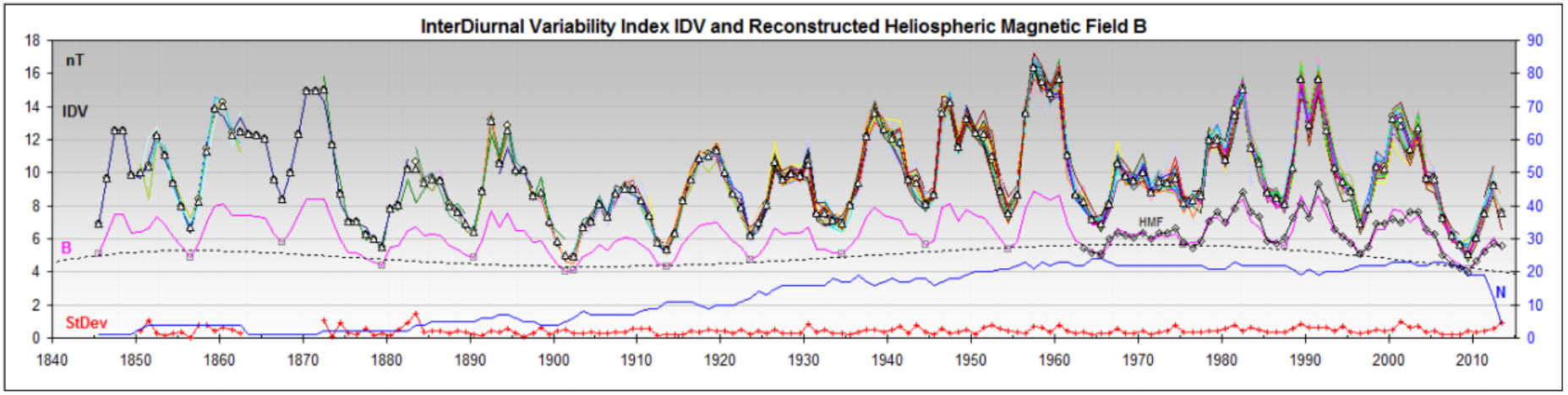


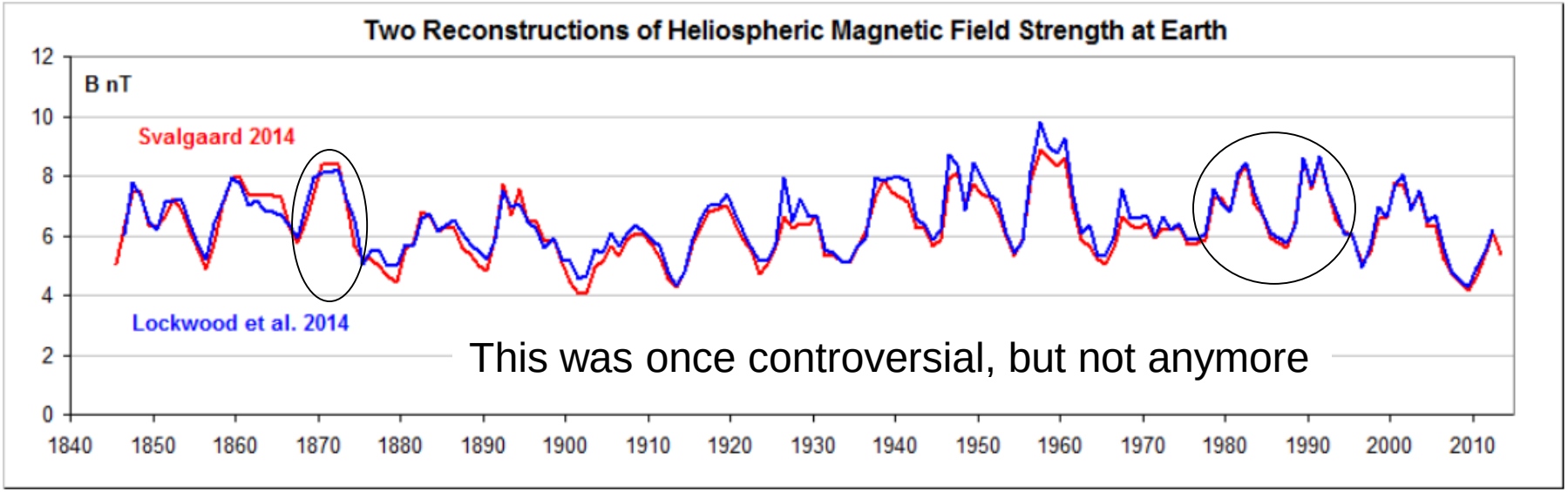




Also holds on timescales shorter than one year

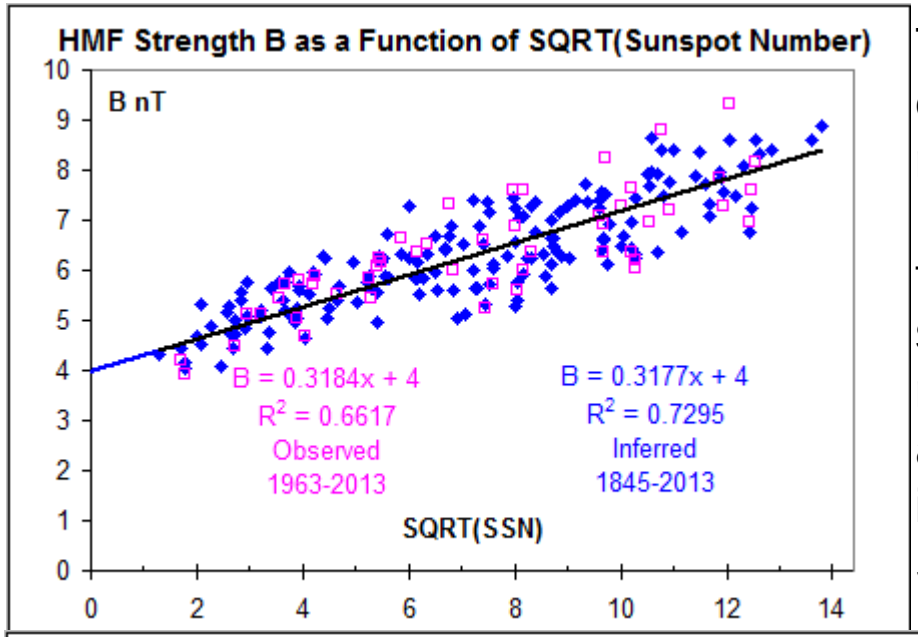
From the IDV relationship we can reconstruct HMF magnetic field B with Confidence:



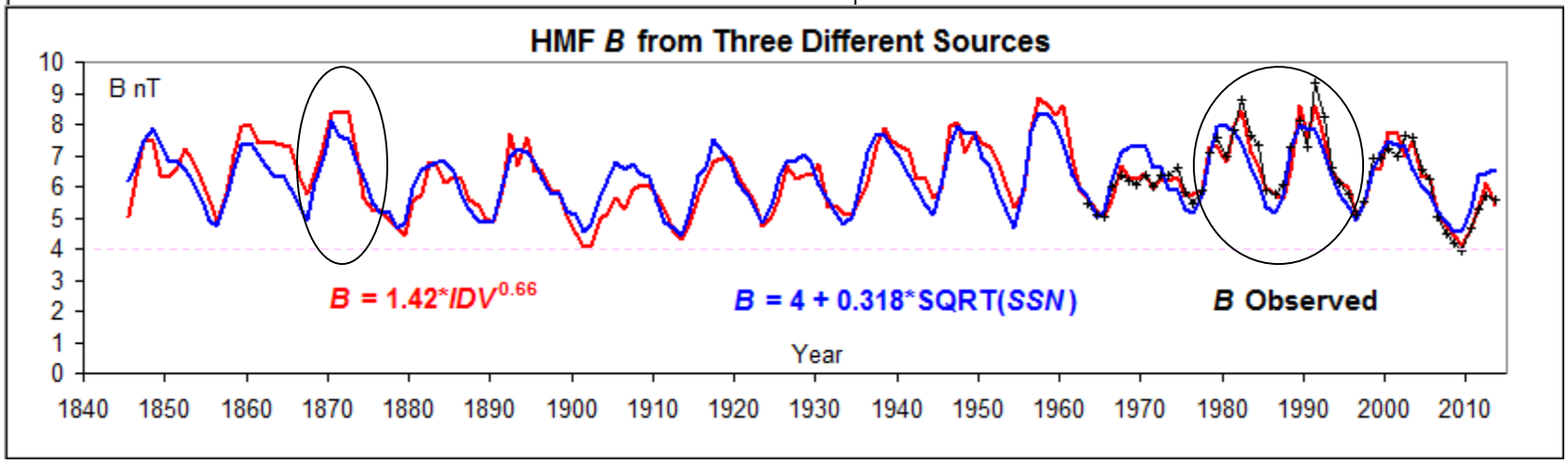


Note our ‘friends’ Cycle 11 and 21-22…

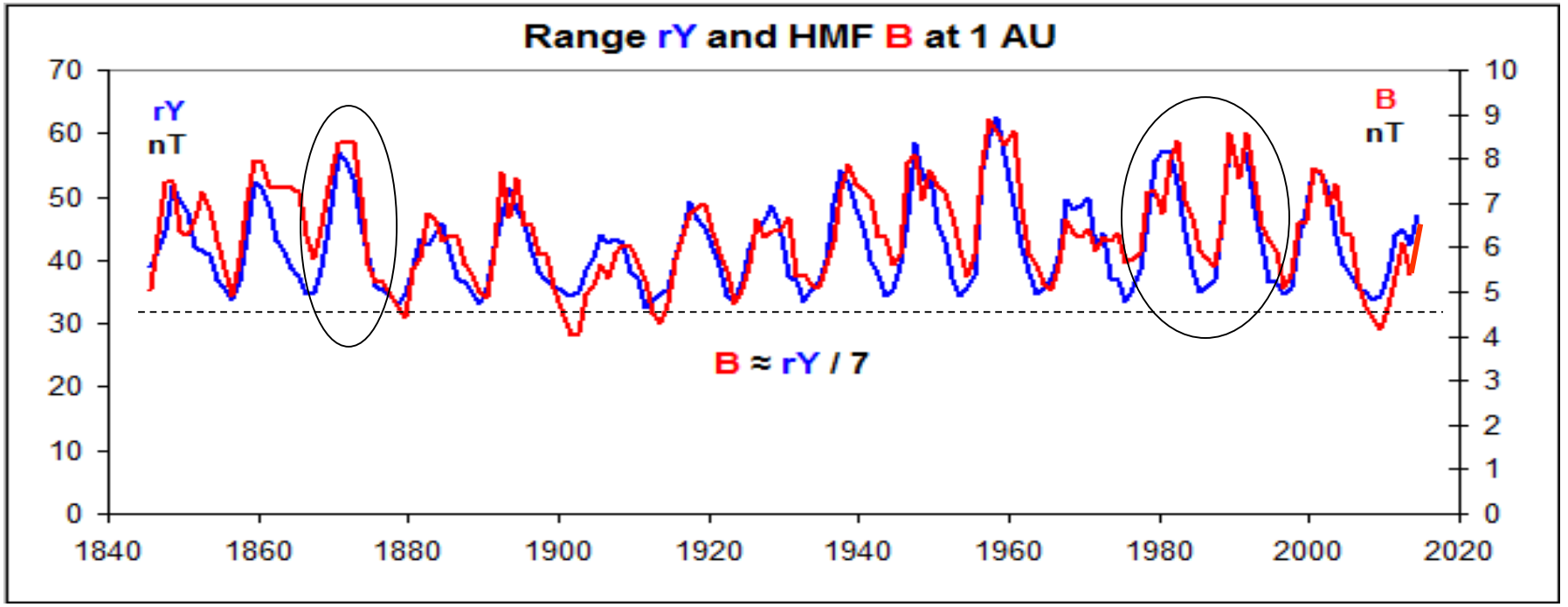
HMF *B* related to Sunspot Number



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.

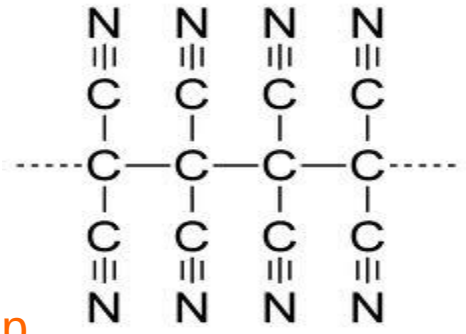
Building Backbones

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

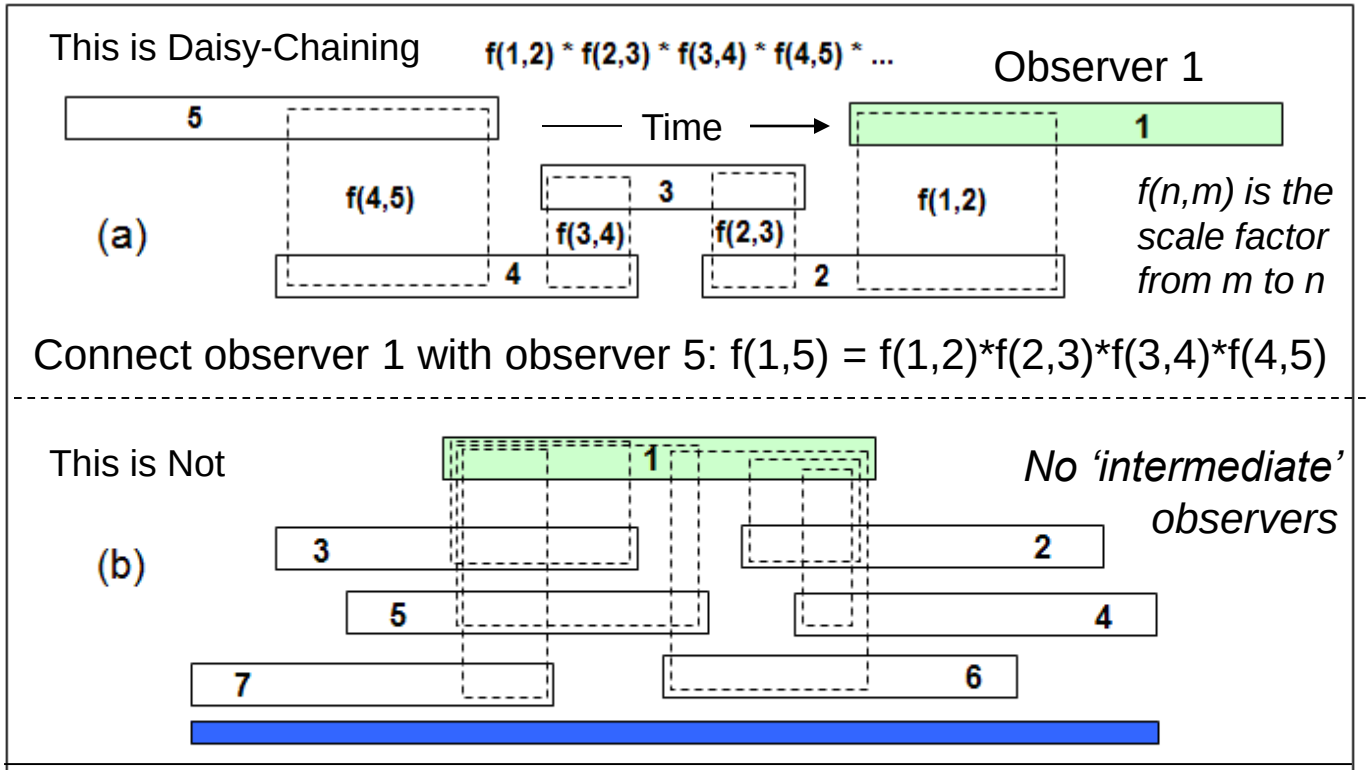
- Daisy-chaining: successively joining observers to the ‘end’ of the series, based on overlap with the series as it extends so far [accumulates errors]
- Back-boning: find a ‘good’ primary observer for a certain [long] interval and normalize all other observers individually to the primary based on overlap with only the primary [no accumulation of errors]

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

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


Carbon Backbone

Daisy-Chaining: When is it and When is it Not (Backbones)



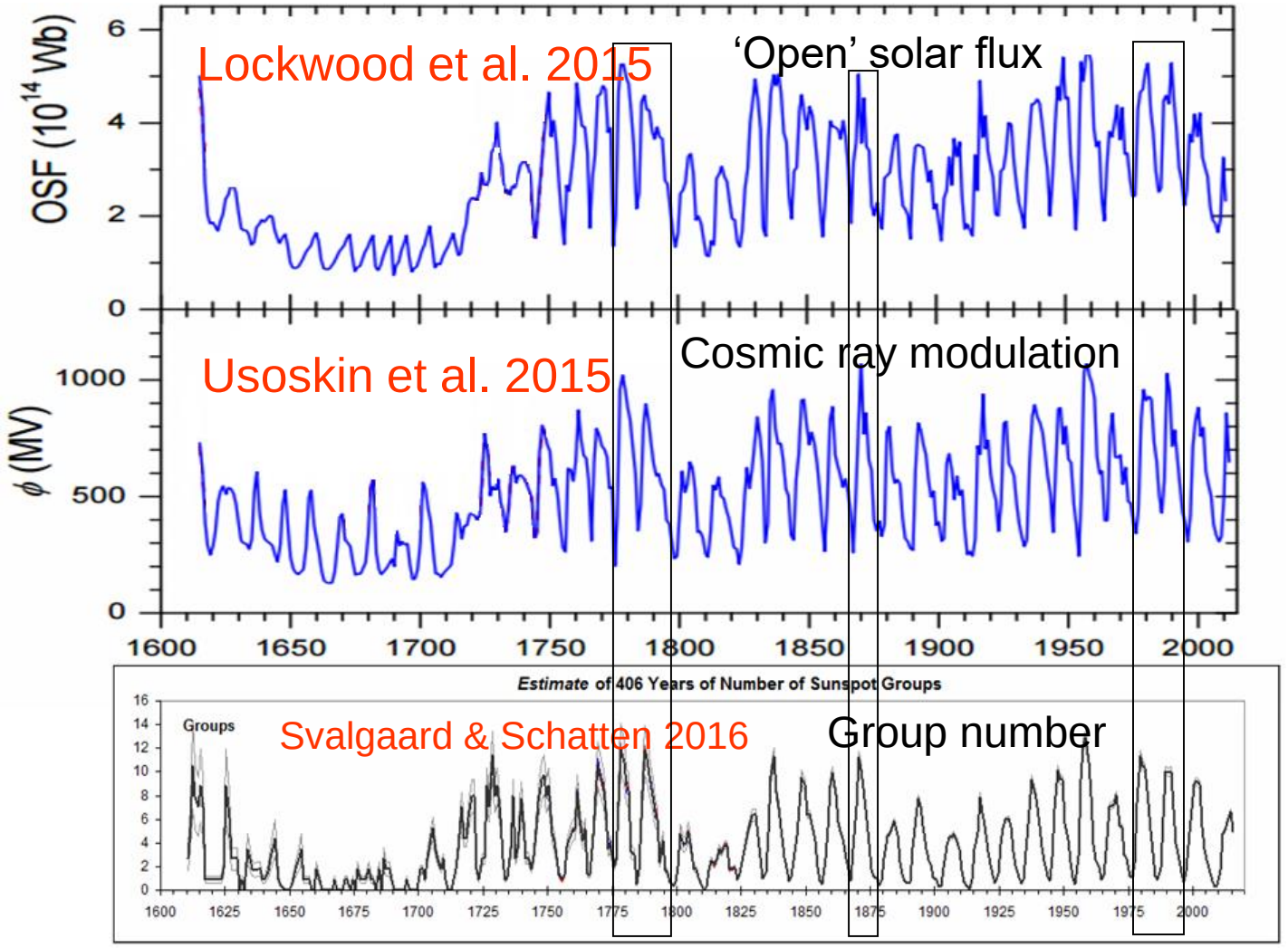
Error Accumulation: $E15=SQRT(E12^2+E23^2+E34^2+E45^2)$ i.e. *increases* with the number of observers

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

The error of the average *decreases* with the number of observers

Ken Schatten (the 'S' of H&S) and myself (realizing that the H&S reconstruction of the Group Sunspot Number was flawed) decided [in 2014-2016] to try again but using the 'Backbone' methodology on yearly averages of the observations instead of the daisy-chaining employed by H&S [for data before 1882]

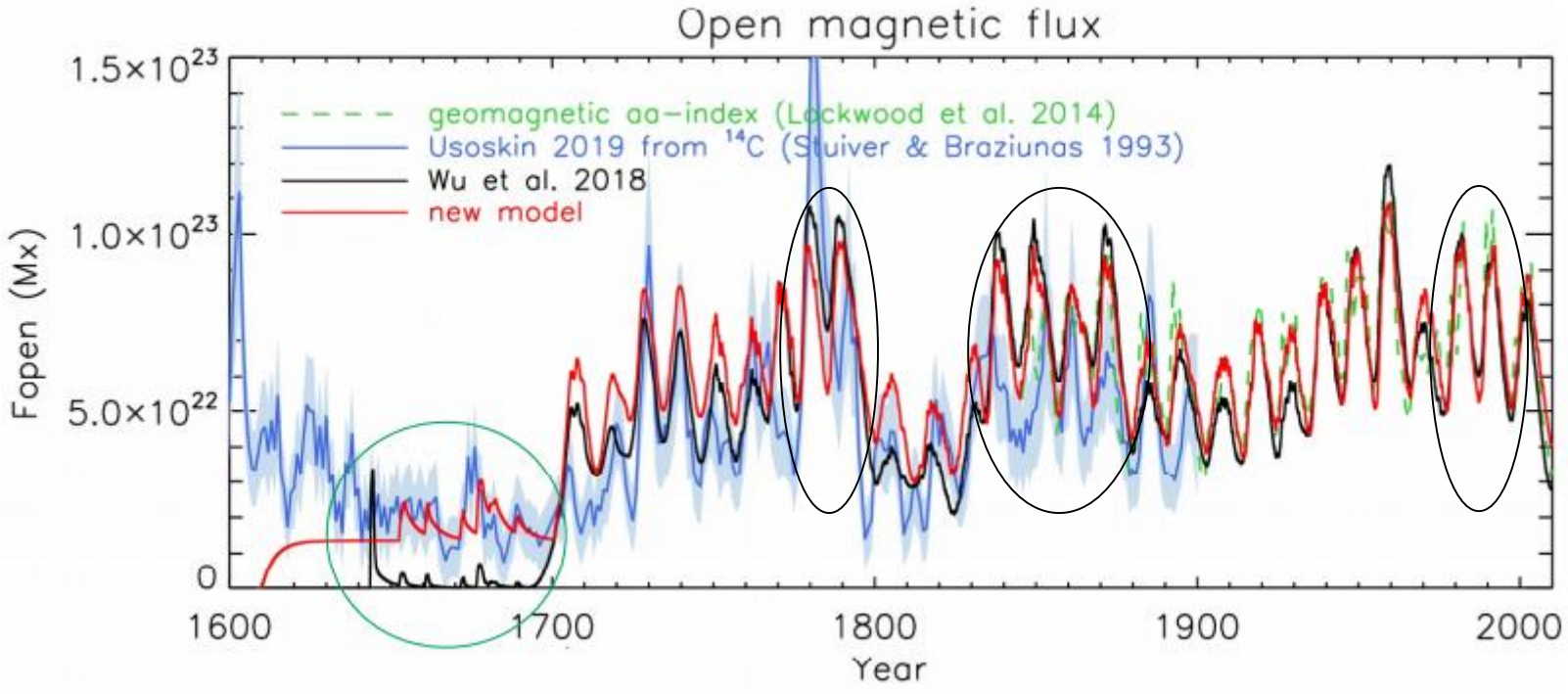
Beginning Reconciliation (Real Progress!)



Very good agreement between different reconstructions.

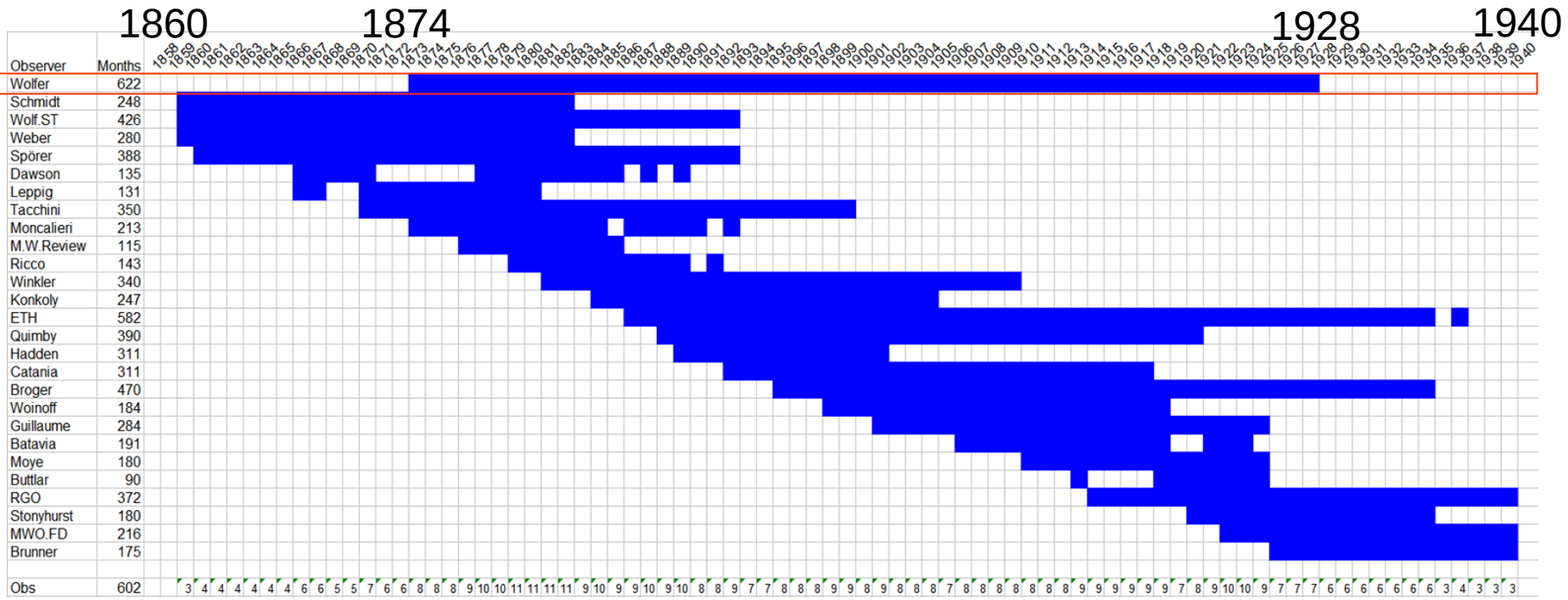
Full Disclosure: There is still a rear-guard debate about the early record

Recent Progress: Open Flux



Hofer, B., Krivova, N. A., Wu, C.-J., Usoskin, I. A., and Cameron, R.: Towards a more reliable reconstruction of the historical solar variability: EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-17086, https://doi.org/10.5194/egusphere-egu2020-17086, 2020

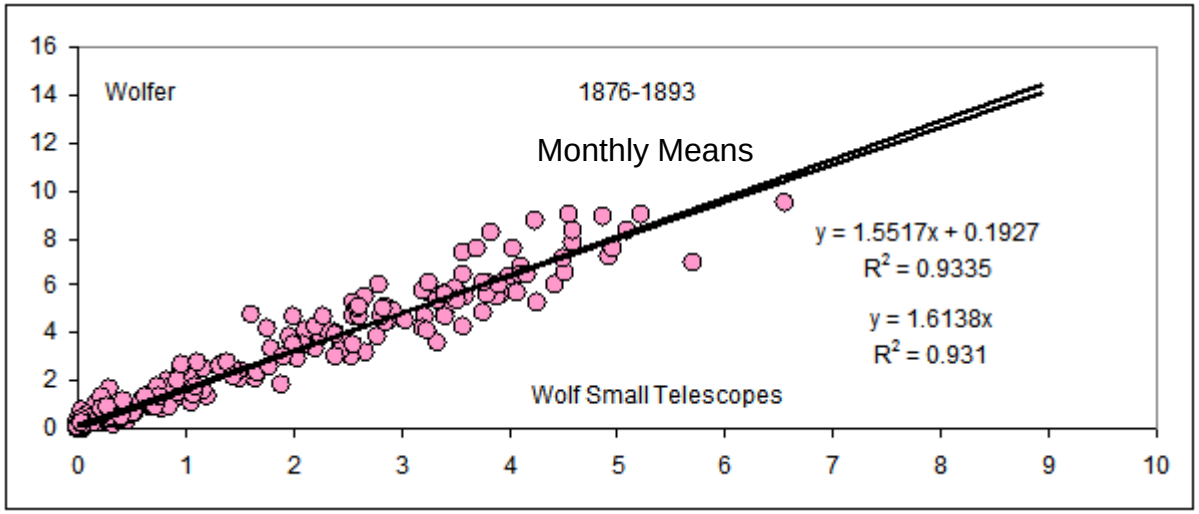
New Wolfer Backbone (Monthly)



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.

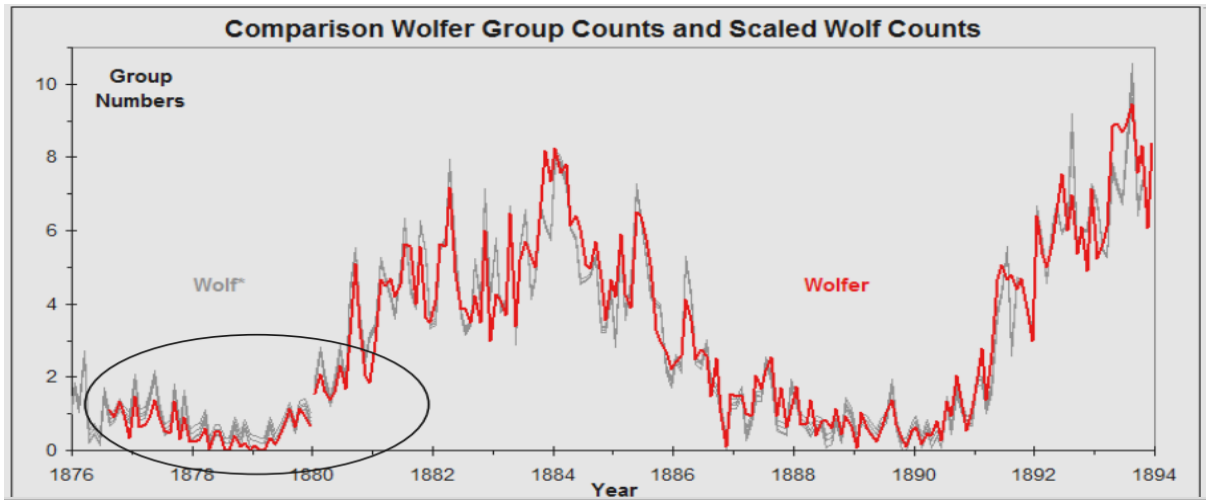
With a few exceptions we use ALL the data from ALL observers

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



Wolfer = 1.6 Wolf ST

Aperture 37 mm X20

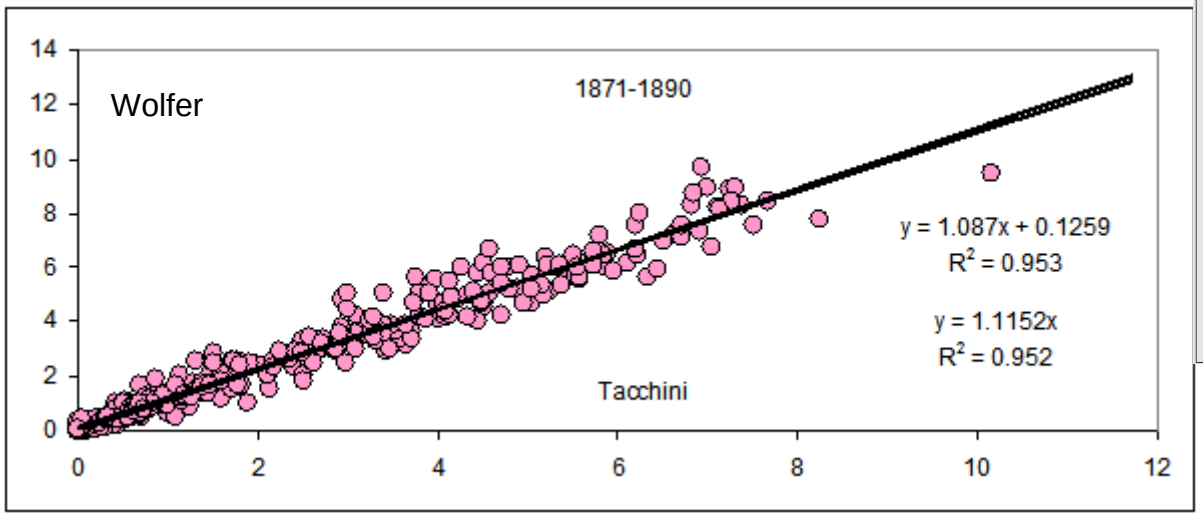


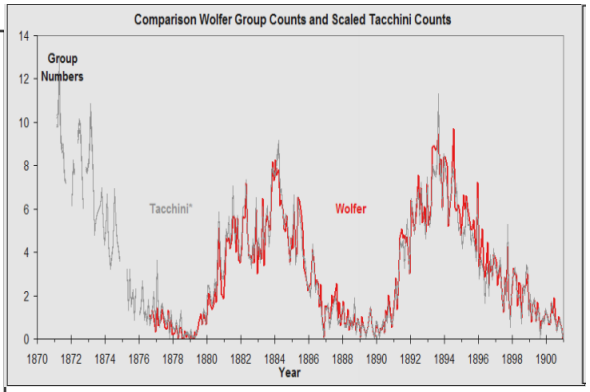
We can reproduce the Wolfer count from Wolf (ST) with only 7% 'unexplained' variance

The relationship is linear and proportional

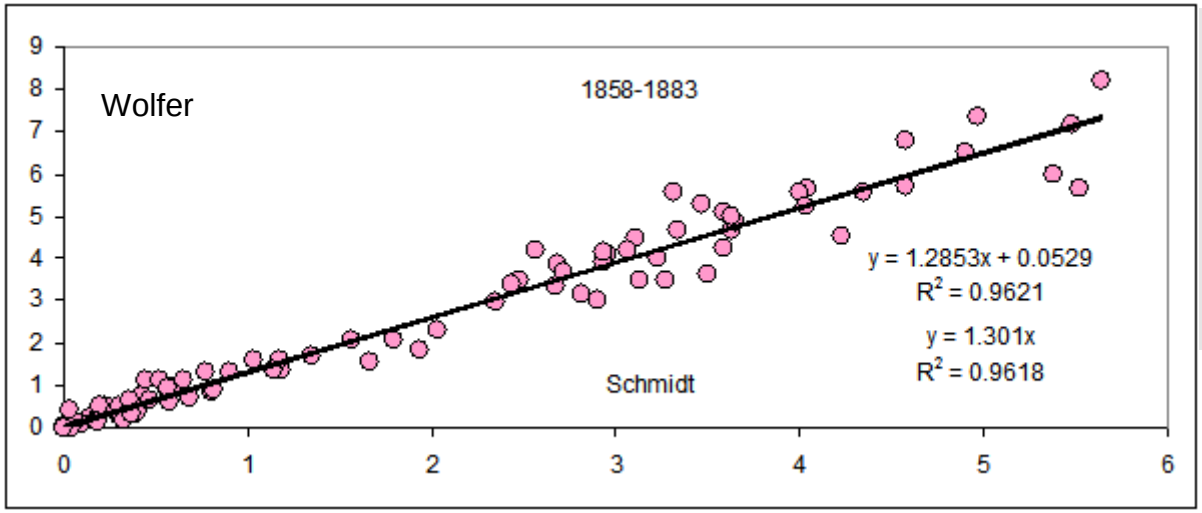
Learning curve…

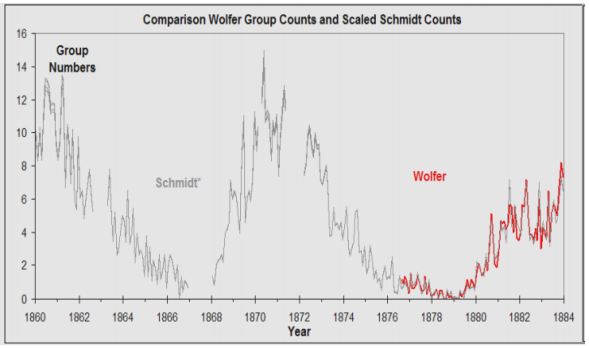
Early Regressions to Wolfer





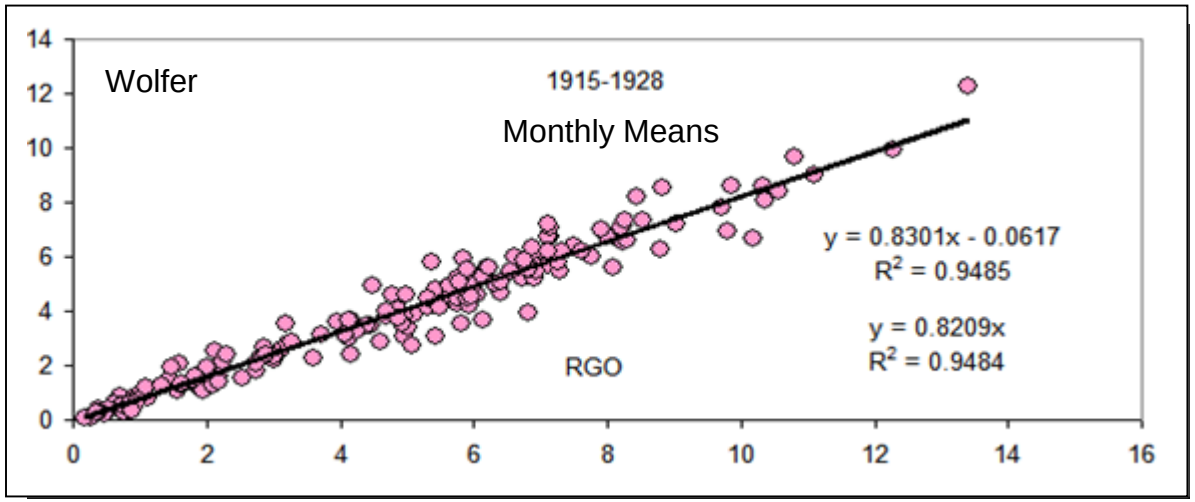
Just as for Wolf, the reproduction of Wolfer is very good (only 5% unexplained variance.

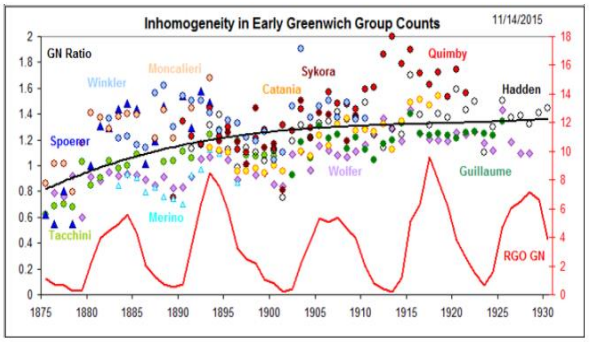




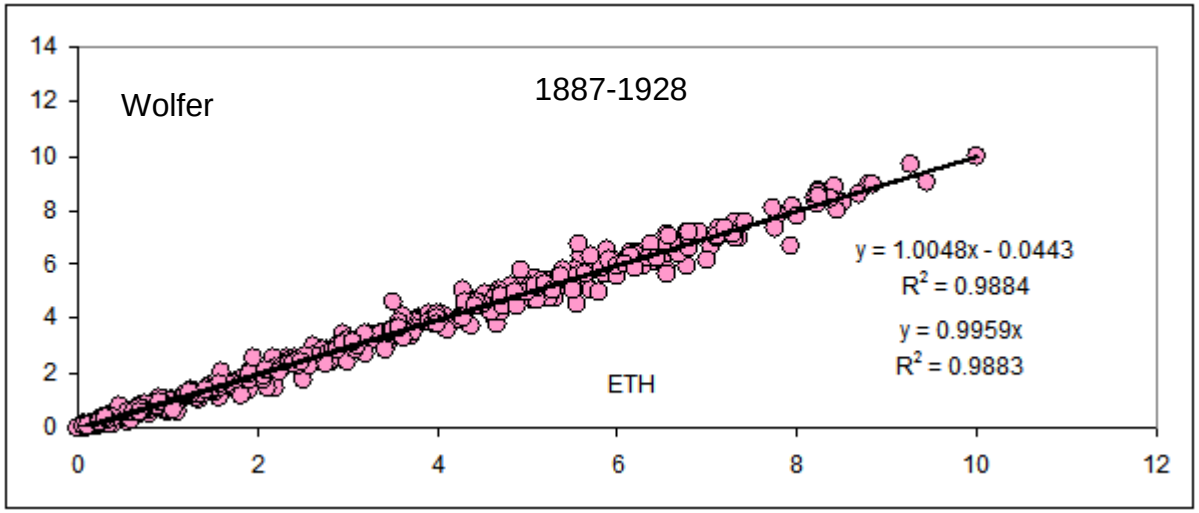
Same for Schmidt in Athens…

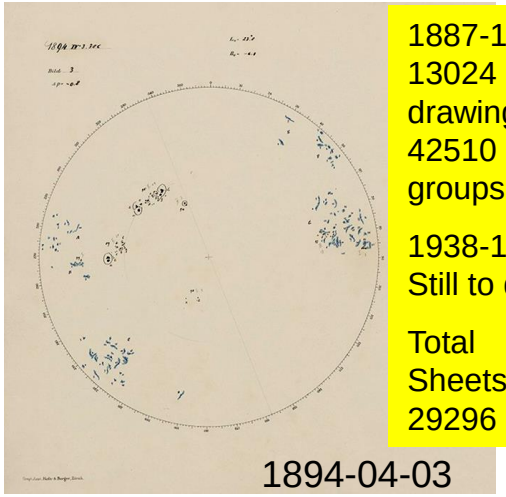
Later Regressions to Wolfer





RGO was drifting before ~1915 so we start in 1915





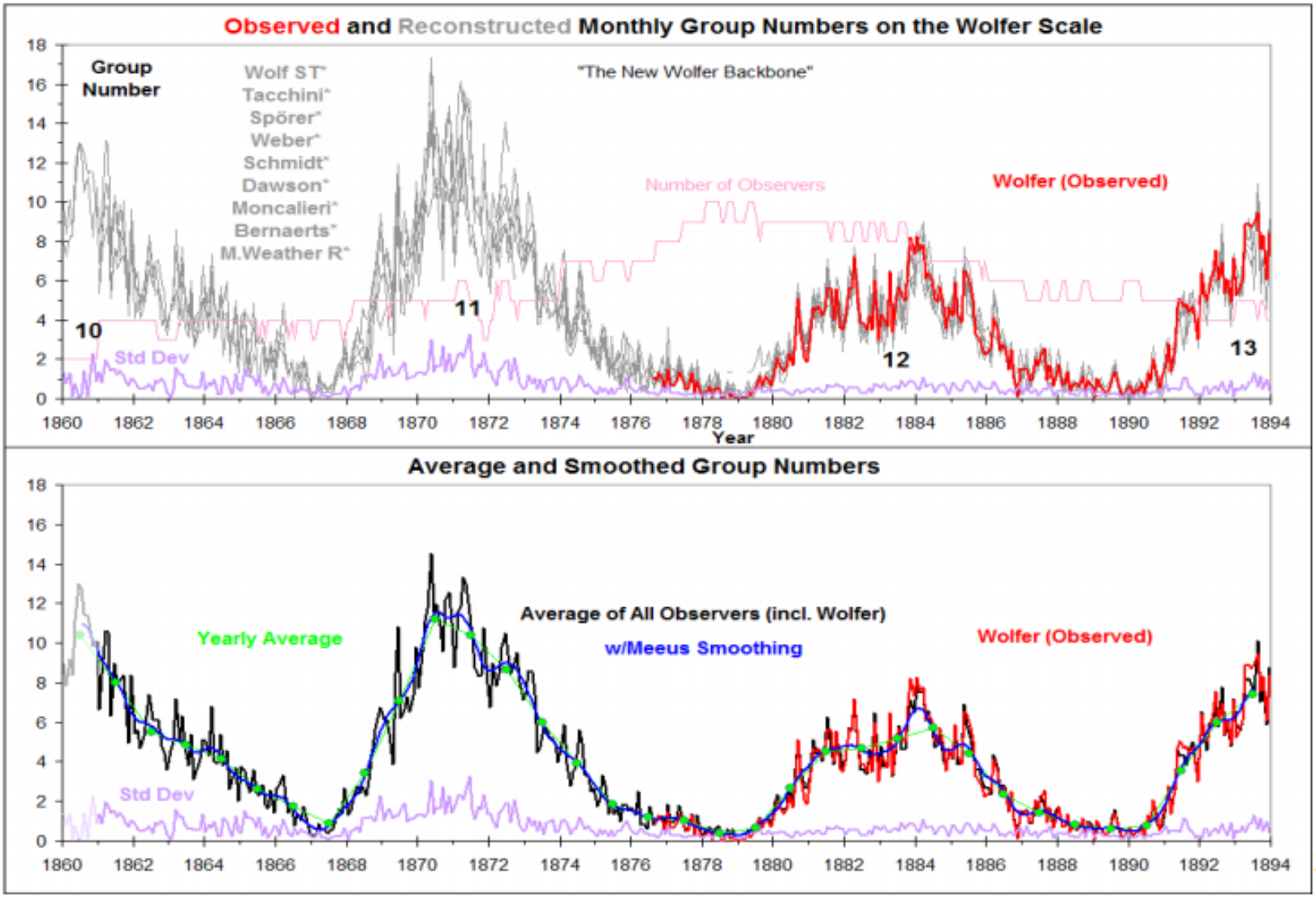
1887-1937: 13024 drawings, 42510 groups.

1938-1996 Still to do

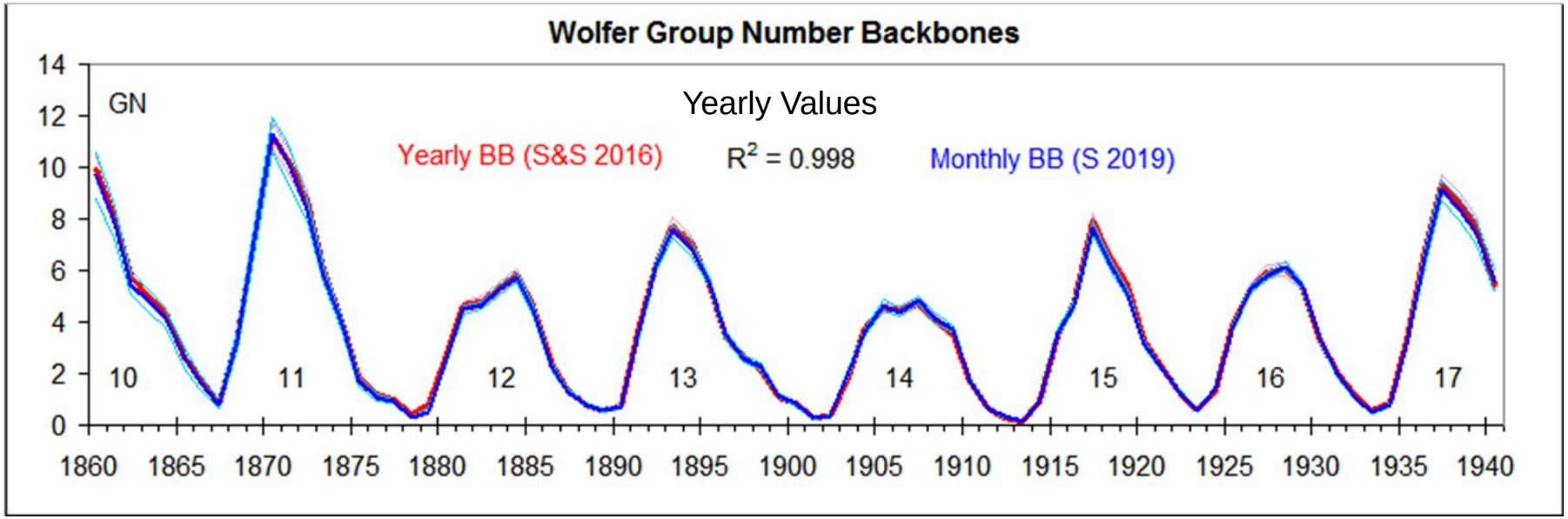
Total Sheets: 29296

1894-04-03

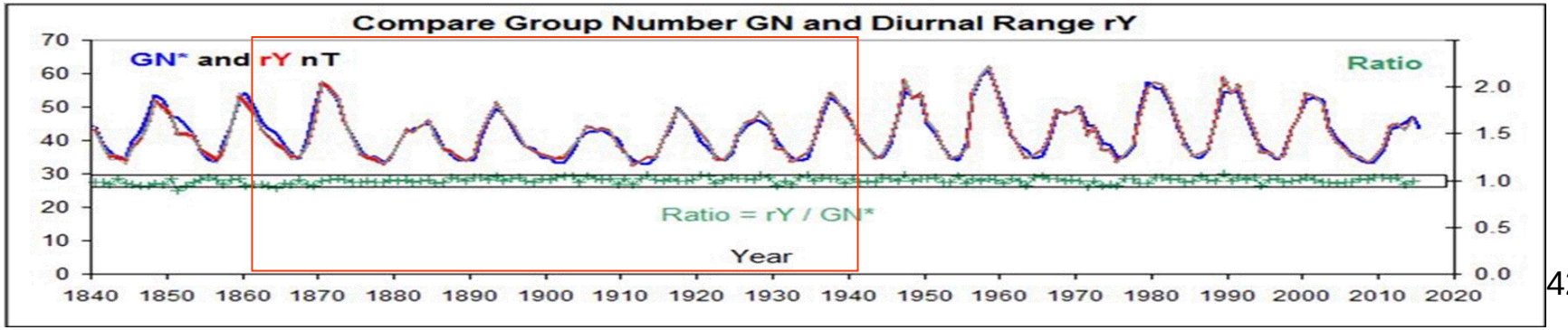
Compilation of Early Observers



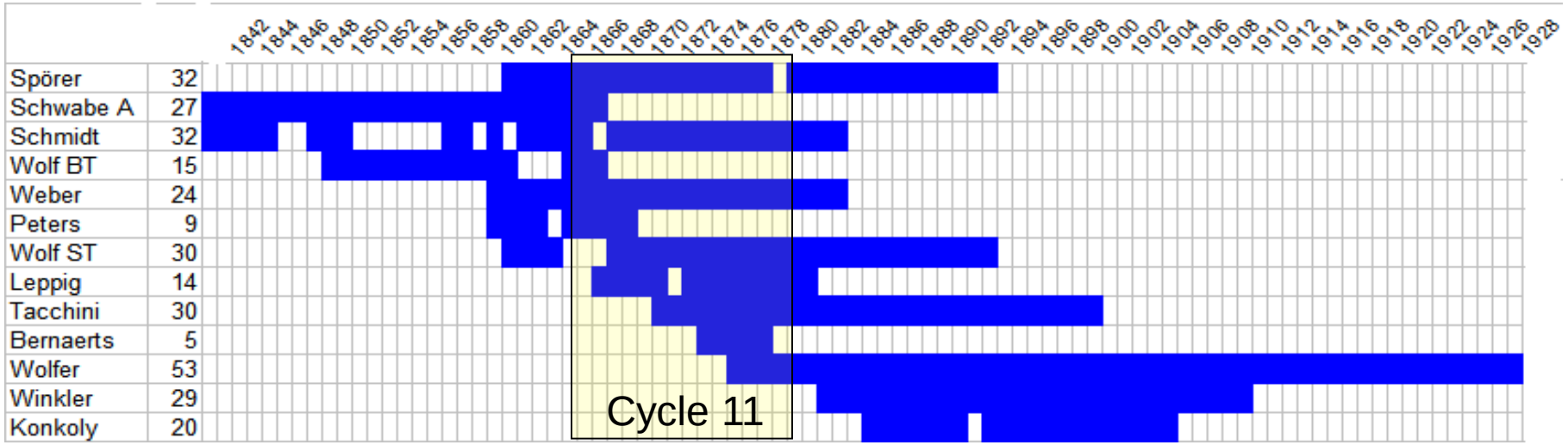
New Wolfer BB Agrees with Old

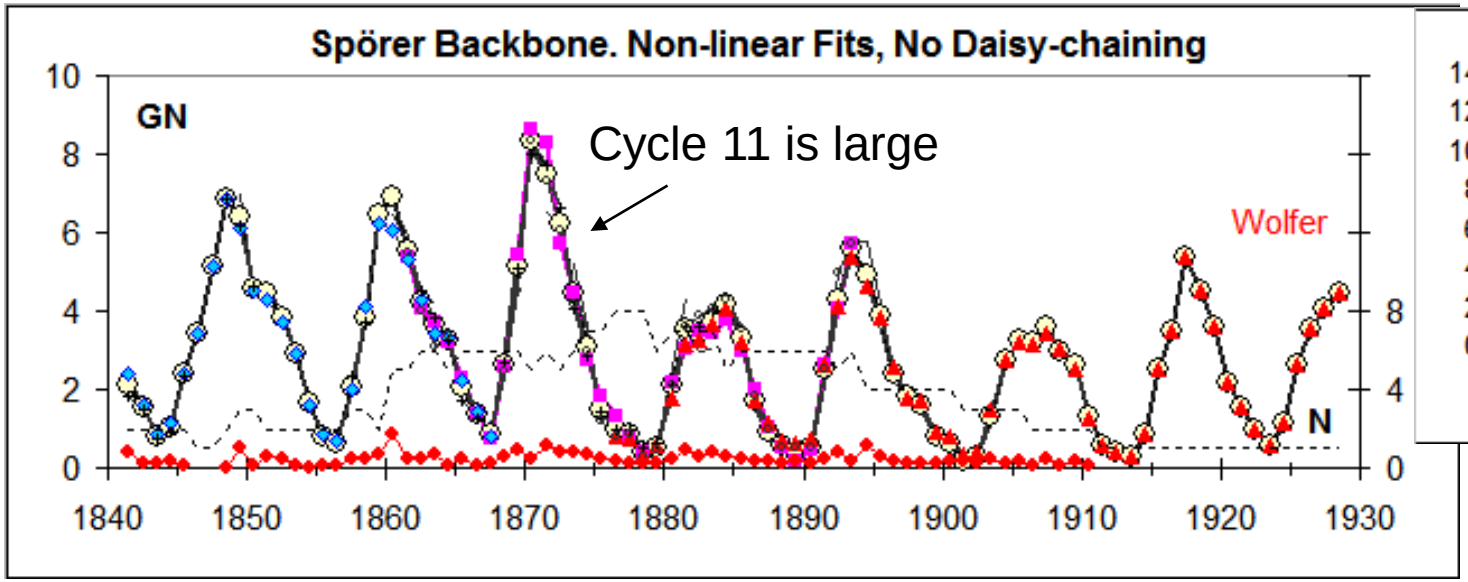


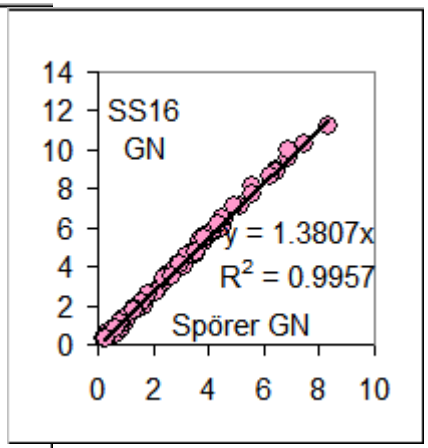
This Figure compares the yearly GNs for the old Wolfer Backbone (red curve) and the new Backbone presented here (blue curve). The two agree within their respective error bars.



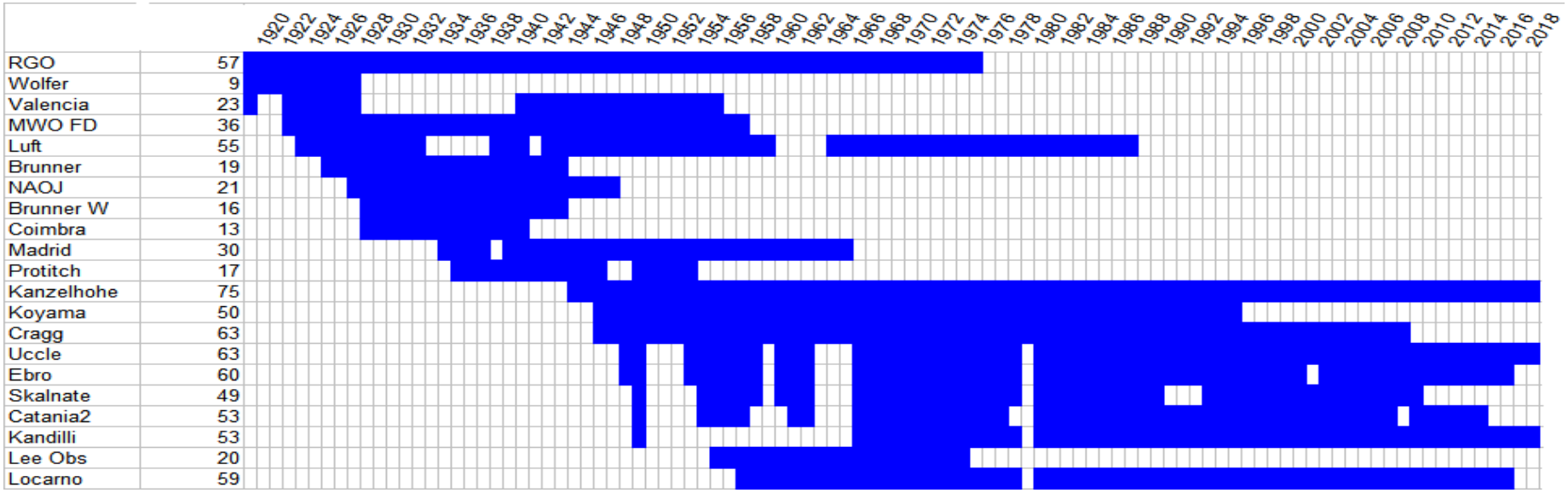
Spörer Backbone Around Cycle 11

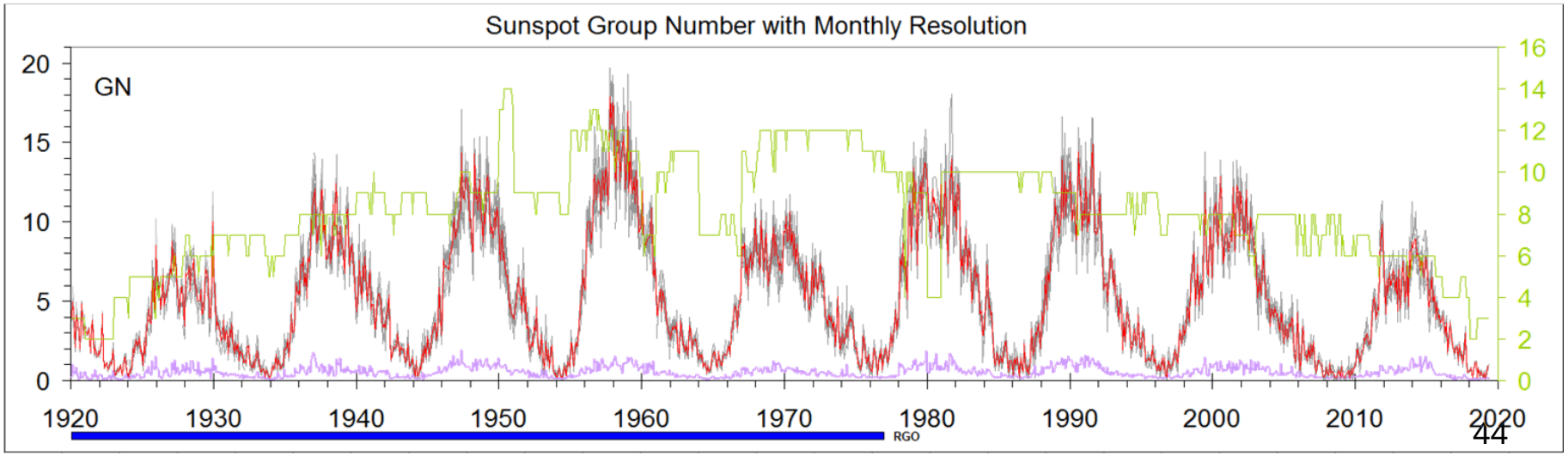




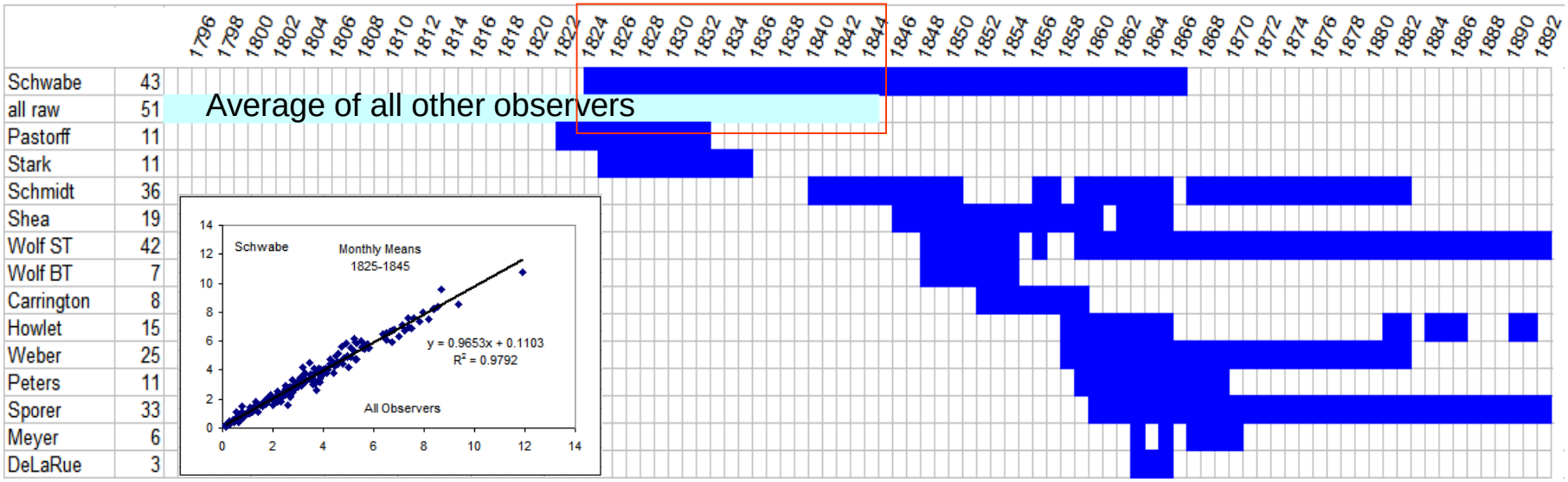


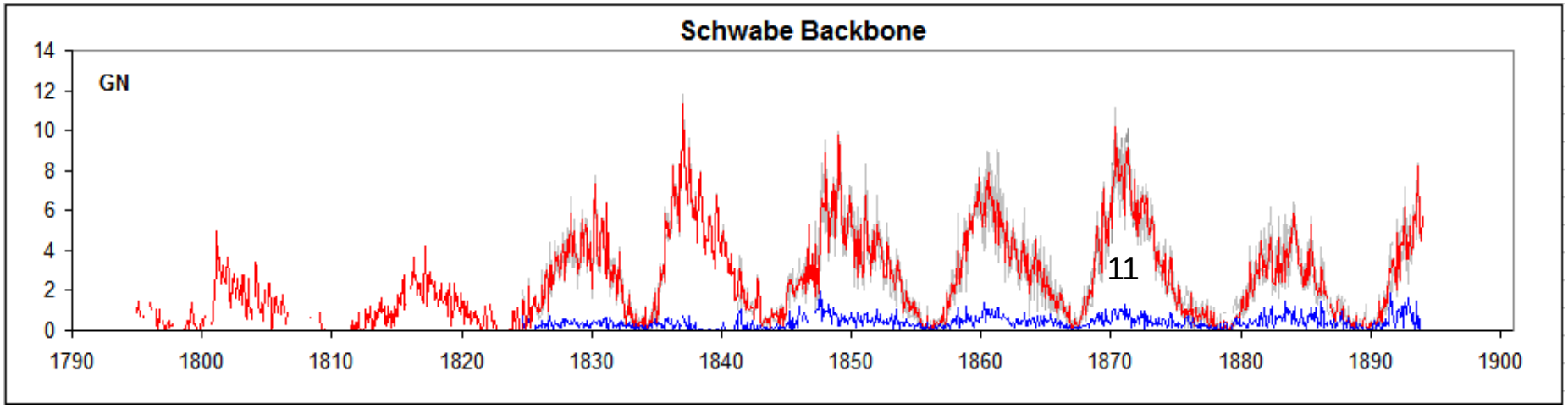
RGO Sunspot Group Number Backbone



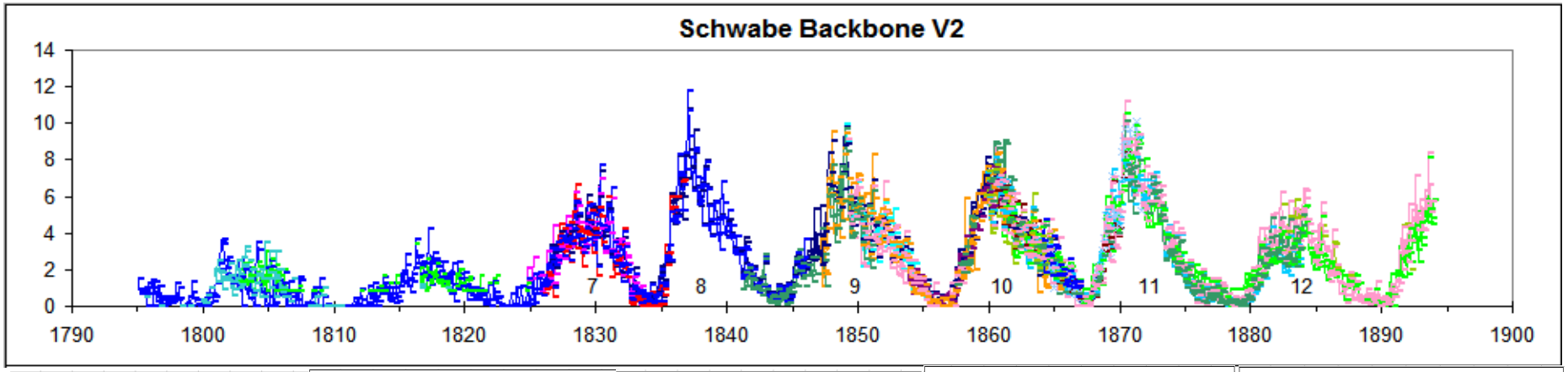


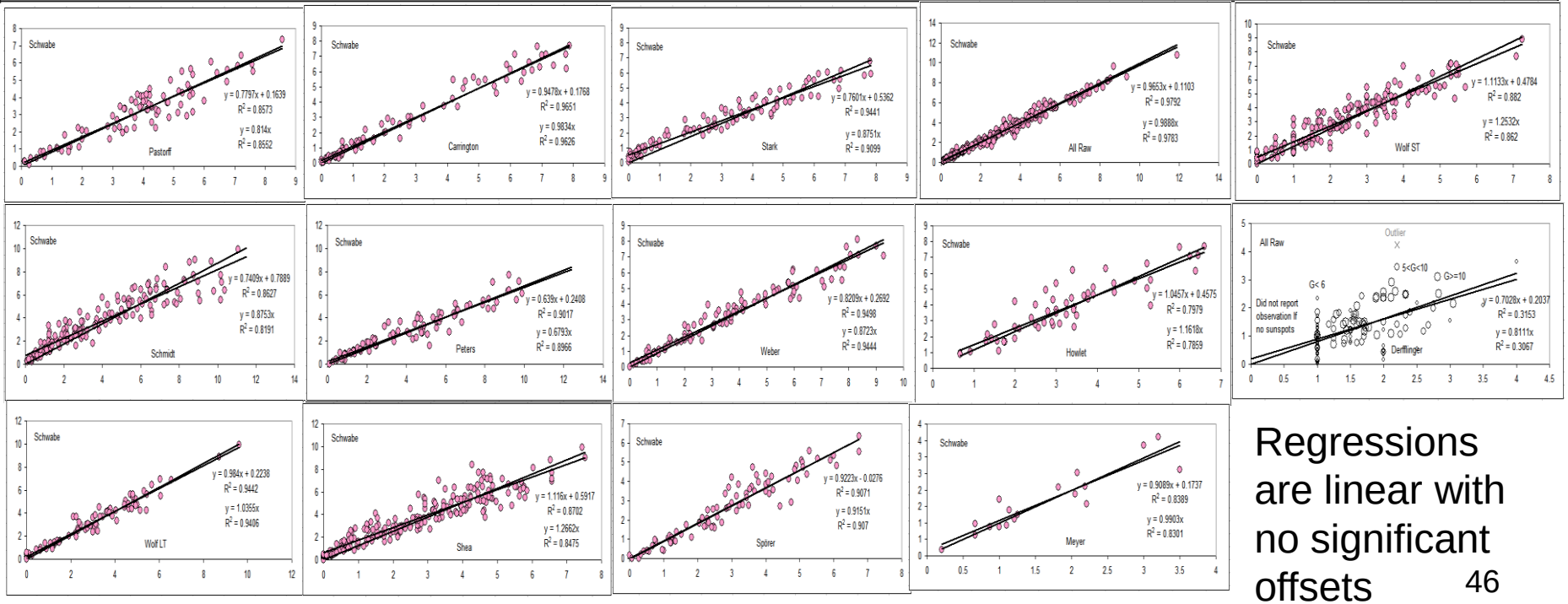
Schwabe Sunspot Group Number Backbone





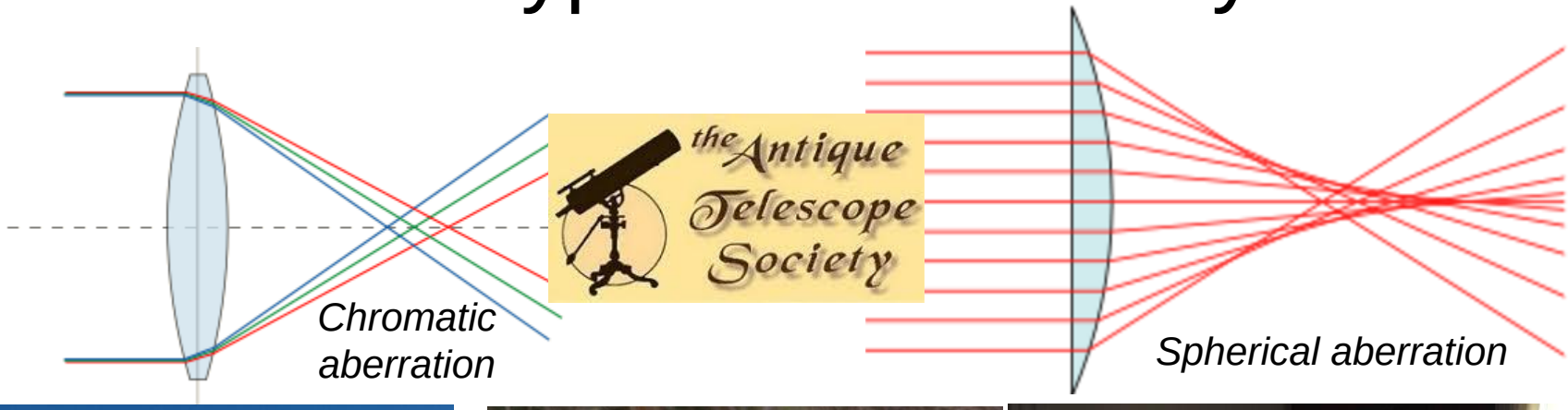
All Linear Relationships …





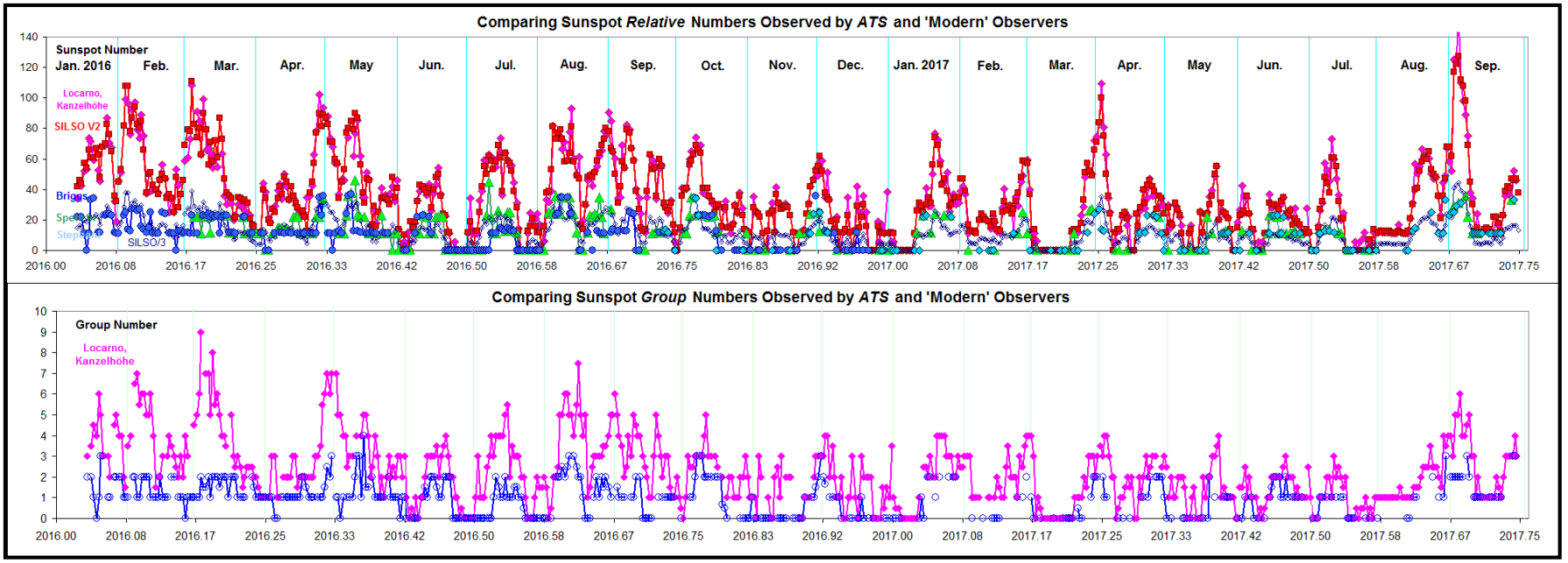
Regressions are linear with no significant offsets

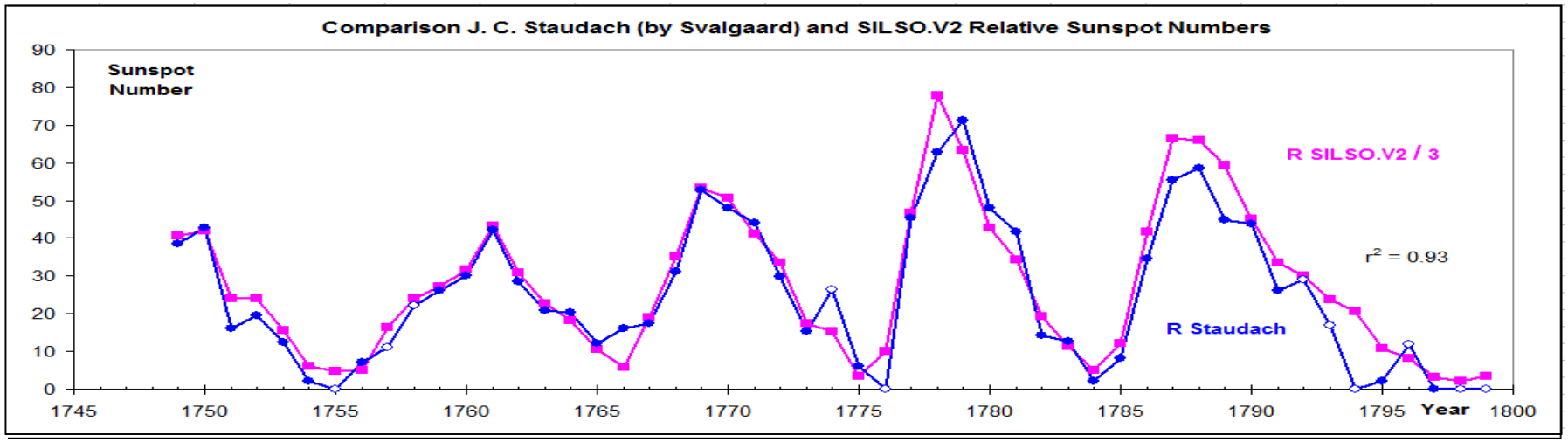
Construct Telescopes with the Same Flaws as Typical 18th Century Ones



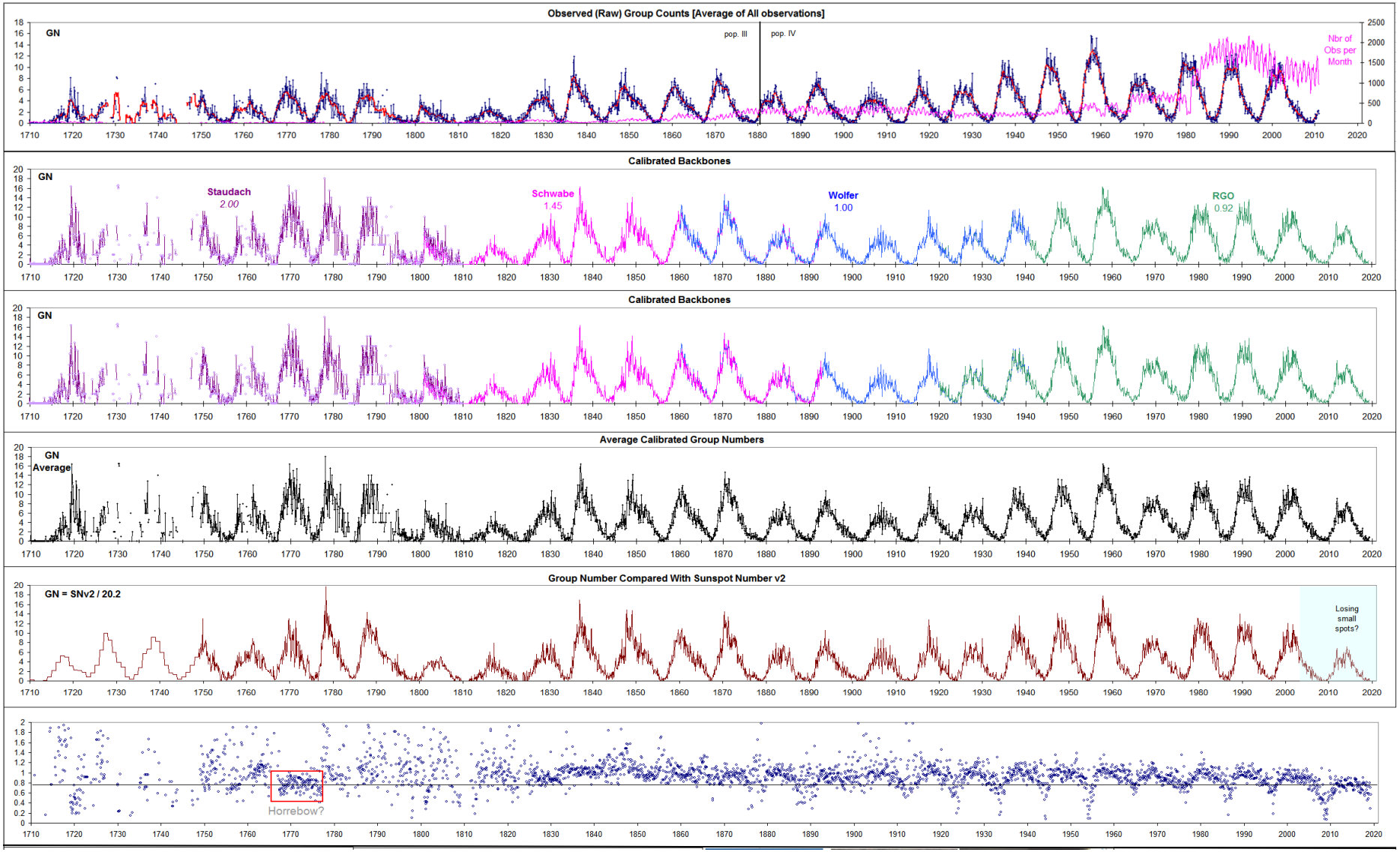
the Antique Telescope Society

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

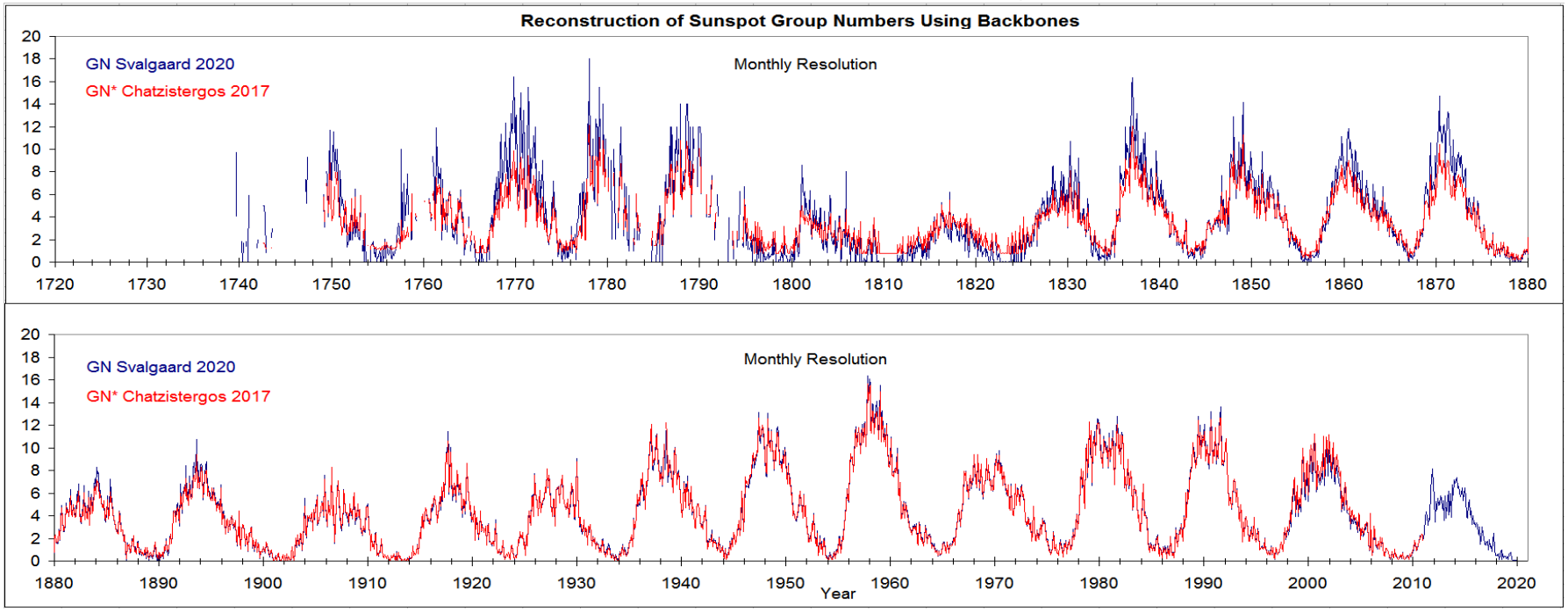




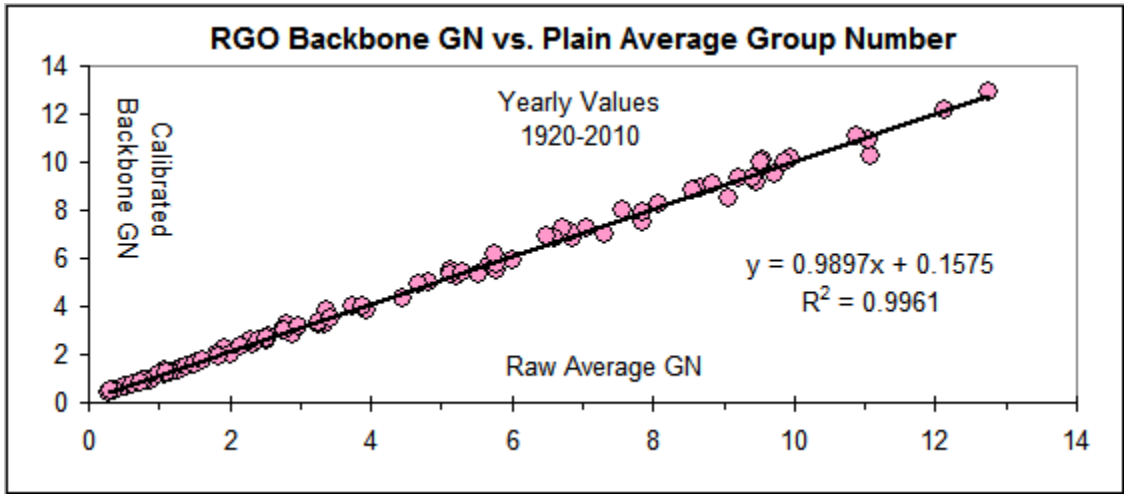
Three Centuries of Solar Activity

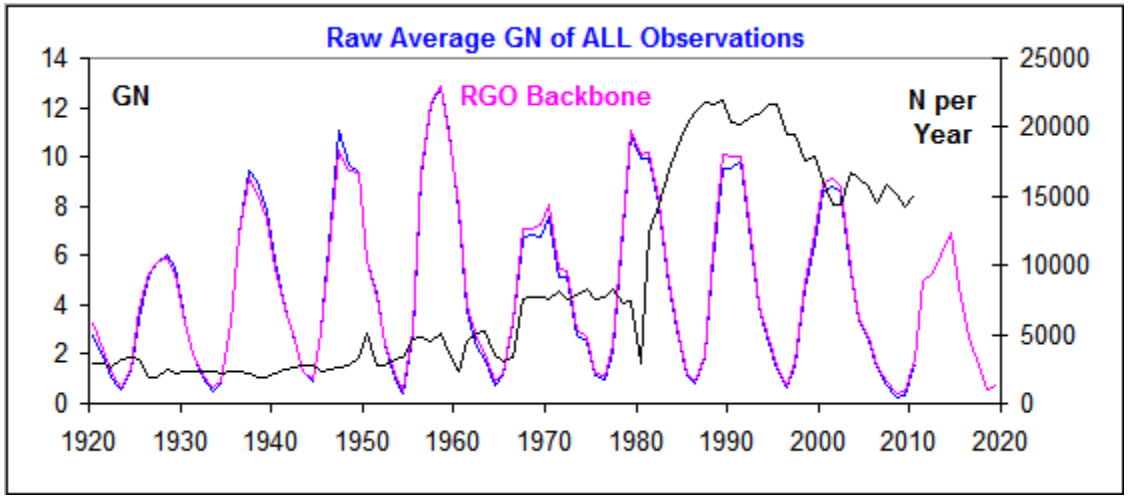


Typical Discrepancy with Popular Series often Promoted by ISSI Team



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





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.

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

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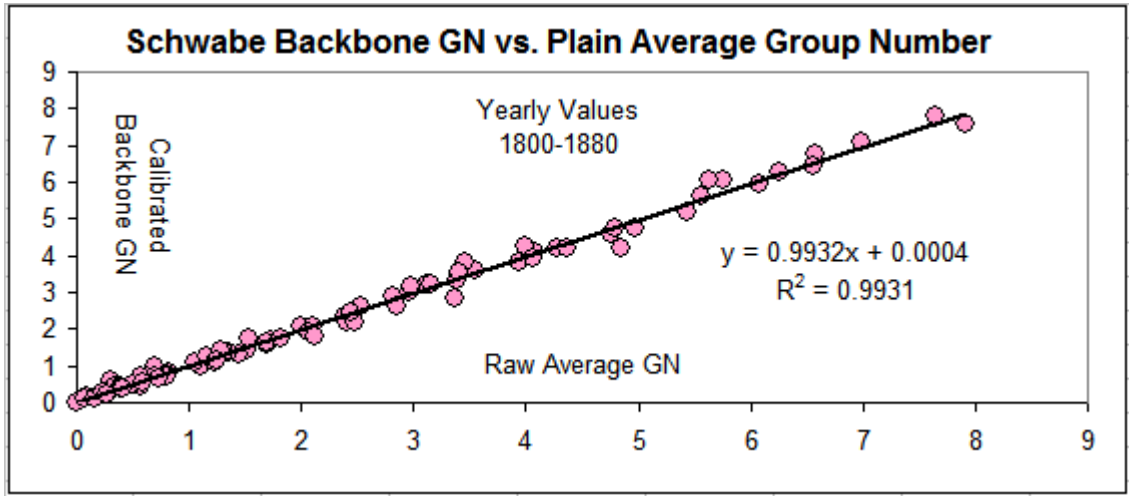
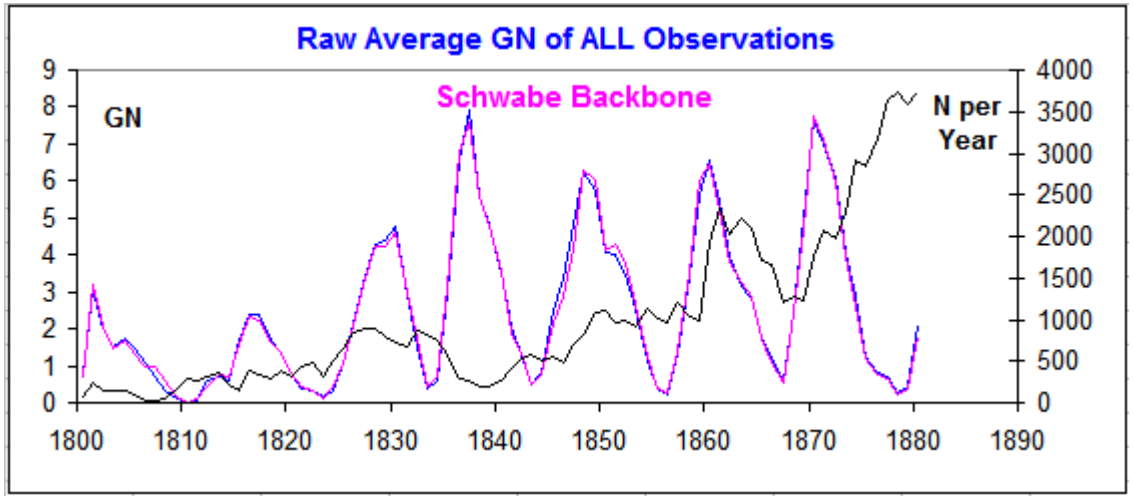
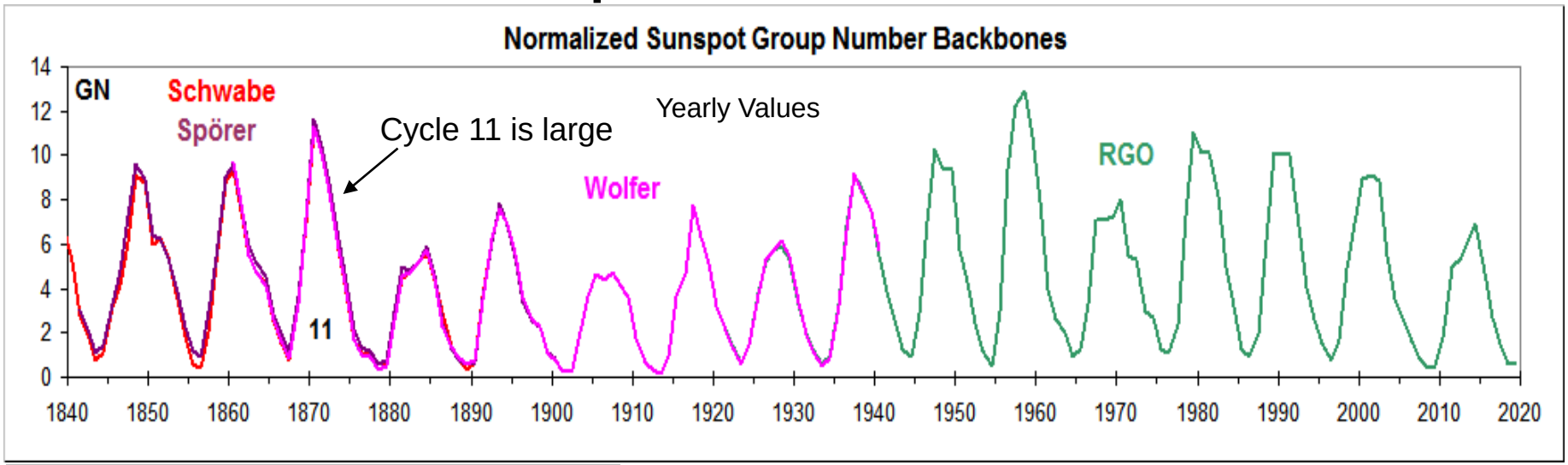


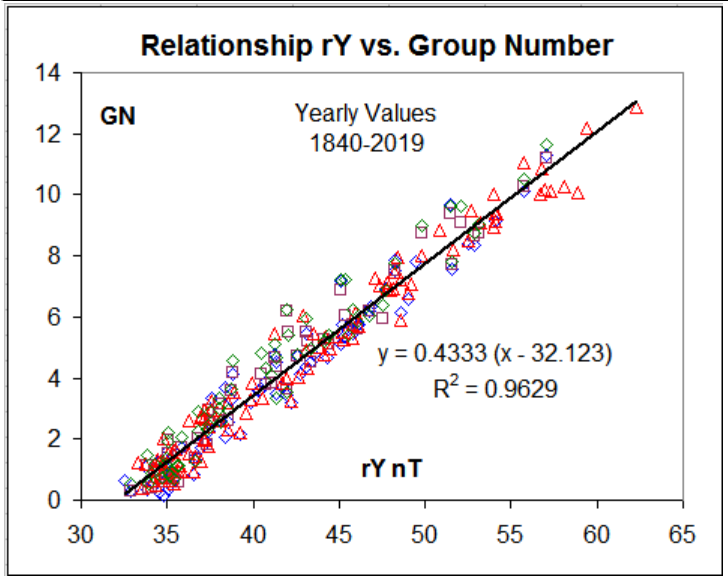


This holds also for the Schwabe Backbone. When the number of observations runs in the thousands, the statistical errors get very small.

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]

Composite Normalized Sunspot Group Number Series

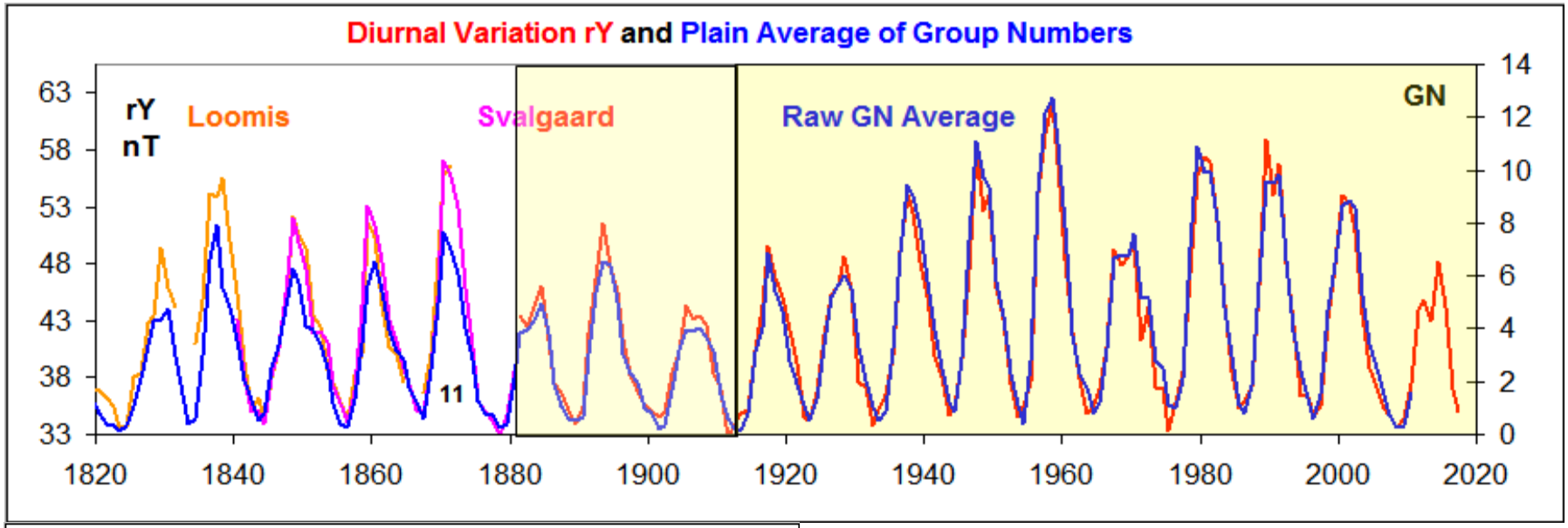


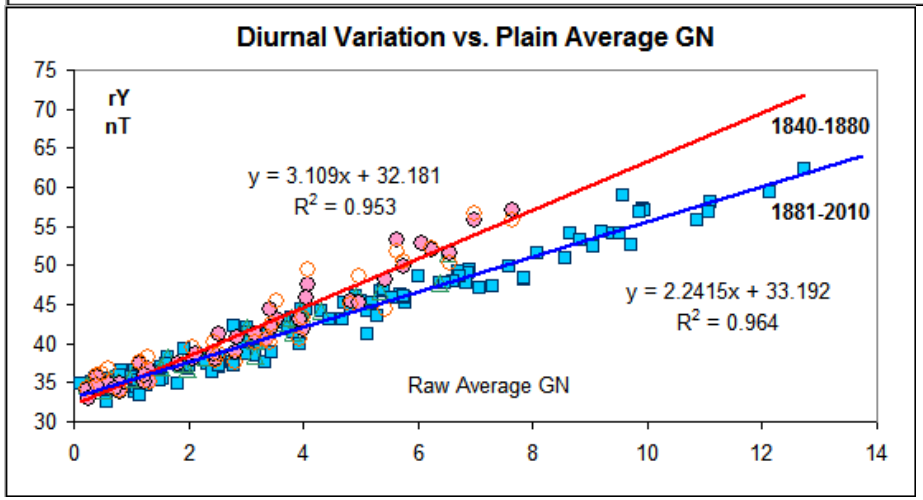


The Schwabe, Spörer, and RGO backbones overlap with the anchor Wolfer Backbone and can thus be scaled to that reference Backbone. The scaling is found to be linear to high accuracy. The new composite is statistically indistinguishable from the published S&S 2016 composite

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

The Diurnal Variation Shows the 1881 Discontinuity Very Clearly

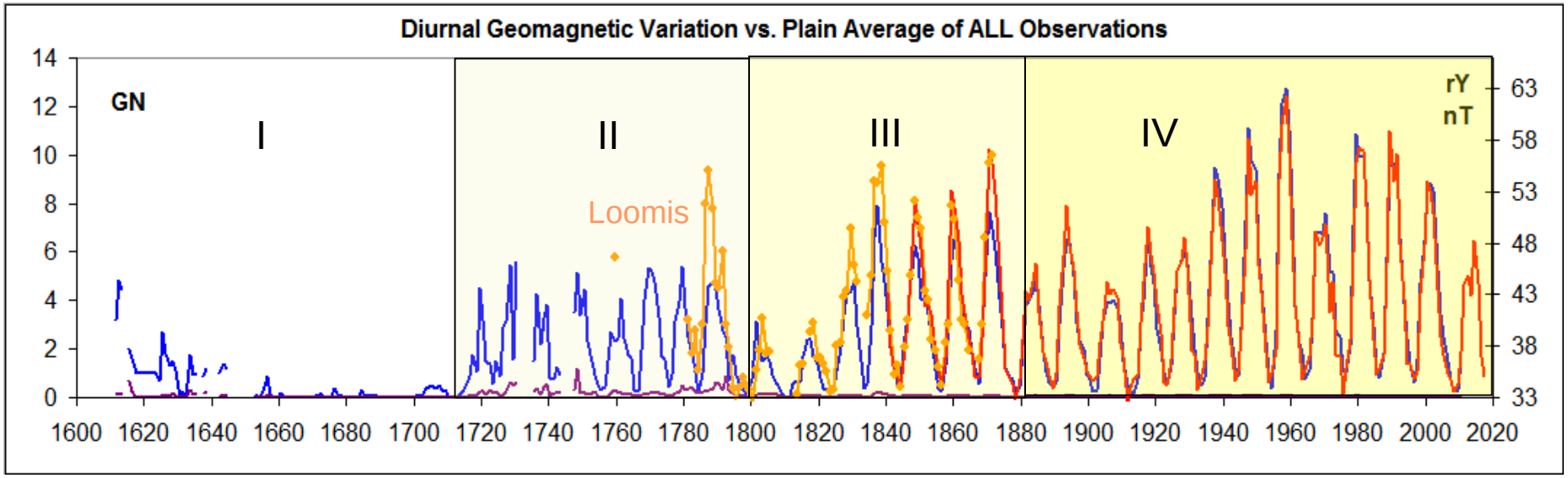




We see the same two populations: one before 1881 and one after ~1910 with a transitional period 1881-1910. This means that one cannot assume the statistical properties of the latter population to hold about the former.

The ratio between slopes is 1.39

Four Speculative Populations of GNs

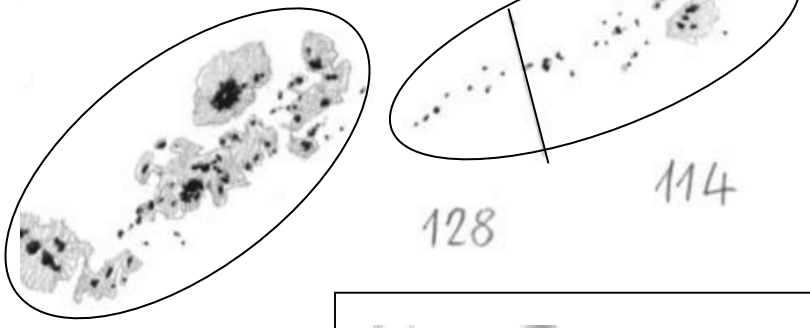


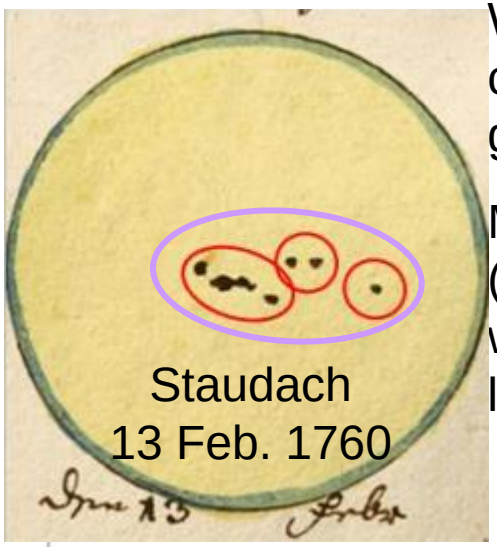
The different populations are the result both of evolving technology, e.g achromatic lenses, and of improved understanding of the definition of a group (blue curve). The diurnal variation (reddish curves) of the East component of the geomagnetic field relies primarily on measurements of an angle [the 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

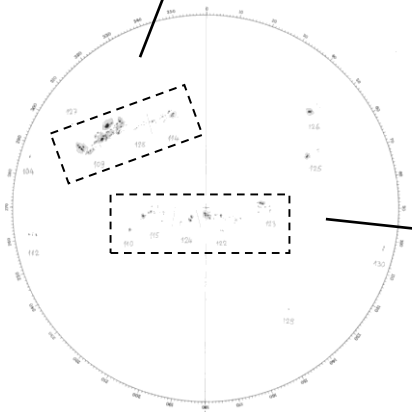




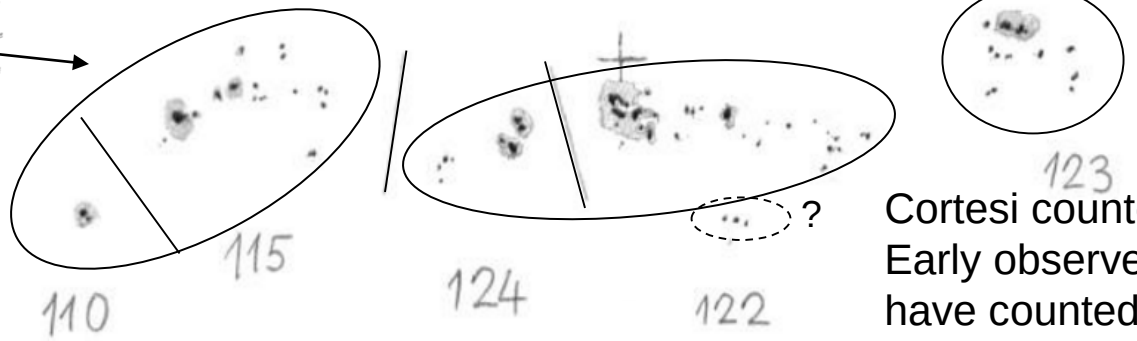
Wolf (1857) counted only one group on that day.

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

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

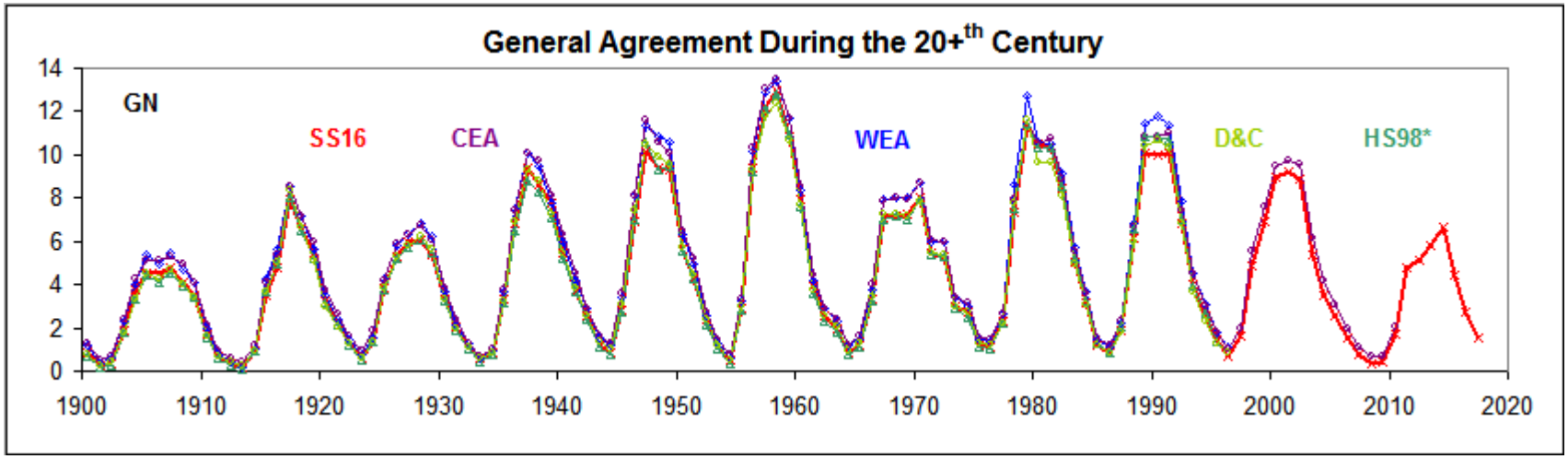


Locarno

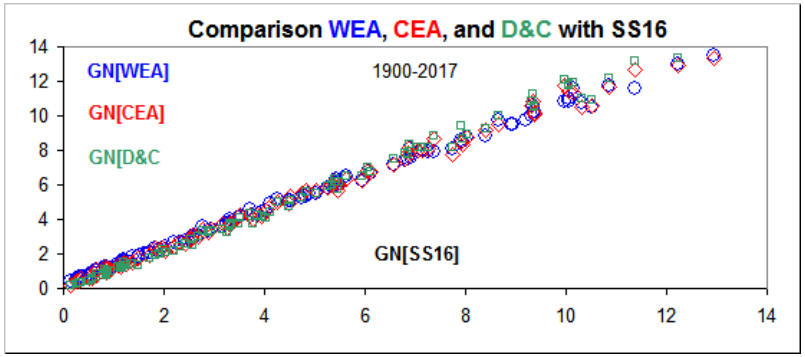


Cortesi counted 8 groups. Early observers would likely have counted only 5 groups

Everybody Agrees About 20th Century



This suggests that the [very] different methods [apart from minor details and scaling matching] ***basically*** **work** and that therefore it is **not productive to argue which is 'better'** or which has severe errors or uses 'unsound procedures'. So, in spite of all the objections, hand wringing, gnashing of teeth, and general acrimony, all methods give the same results within ±3% when the underlying data are good and belong to the same population.



When analyzing yearly values, the regression lines are remarkably linear (even proportional), belying claims that they are not.

Conclusions

- From the fact that all reconstructions agree for the 20th 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 just as several solar-activity proxies for at least the last 300 years [showing no secular increase], therefore
- supporting the New Paradigm that there are at **least** two (probably more) 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 19th century and further back.

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

The Big Picture