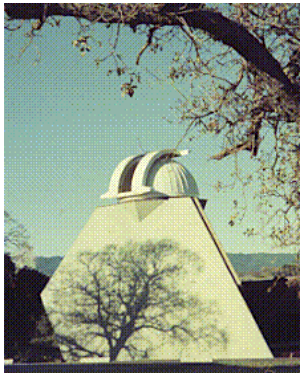


# *Inter-ocular* Comparisons of Group Number Reconstructions

Leif Svalgaard

Stanford University

Sept. 2019

For ISSI 417, Bern

"Il est, dans la carrière des Sciences comme ailleurs, certains fantômes, qui semblent d'abord vouloir arrêter nos pas, & dont il suffit de s'approcher pour reconnôitre & dissiper leur illusion". *J.D. De Cassini* (1791)

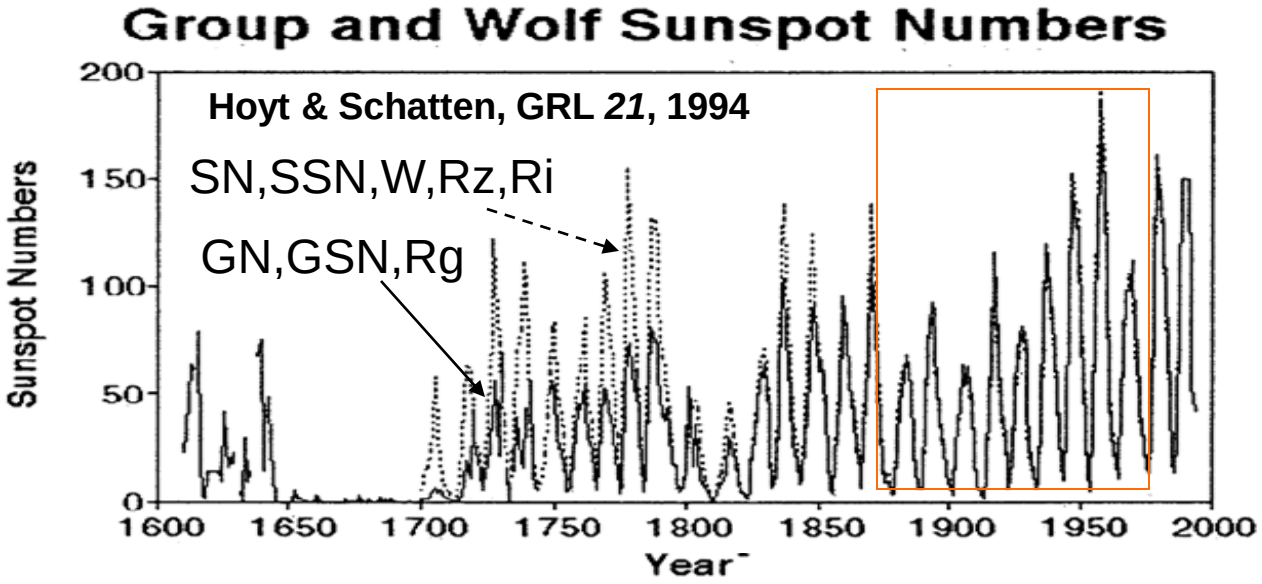
# The H&S Papers That Started it All

**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 Group Sunspot Number is designed to be more internally self-consistent (i.e., less dependent upon seeing the tiniest spots) and less noisy than the Wolf Sunspot Number. It uses the number of sunspot groups observed, rather than groups and individual sunspots. **Daily, monthly, and yearly means are derived from 1610 to the present**. […] The Group Sunspot Numbers also have estimates of their random and systematic errors tabulated. 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**.(2) There was a solar activity peak in 1801 and not 1805 so there is no long anomalous cycle of 17 years as reported in the Wolf Sunspot Numbers. The longest cycle now lasts no more than 15 years. (3) The Wolf Sunspot Numbers have many inhomogeneities in them arising from observer noise and this noise affects the daily, monthly, and yearly means. The Group Sunspot Numbers also have observer noise, but it is considerably less than the noise in the Wolf Sunspot Numbers. The Group Sunspot Number is designed to be similar to the Wolf Sunspot Number, but, even if both indices had perfect inputs, some differences are expected, primarily in the daily values.

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




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

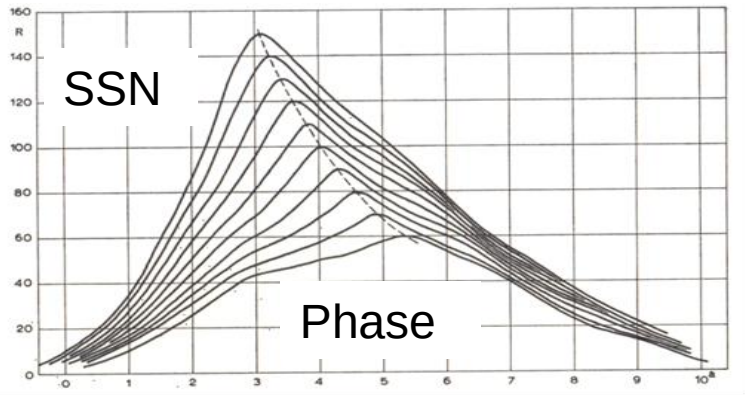
('1/10 Spots' was assumed to be a measure of the area of the group)

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

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

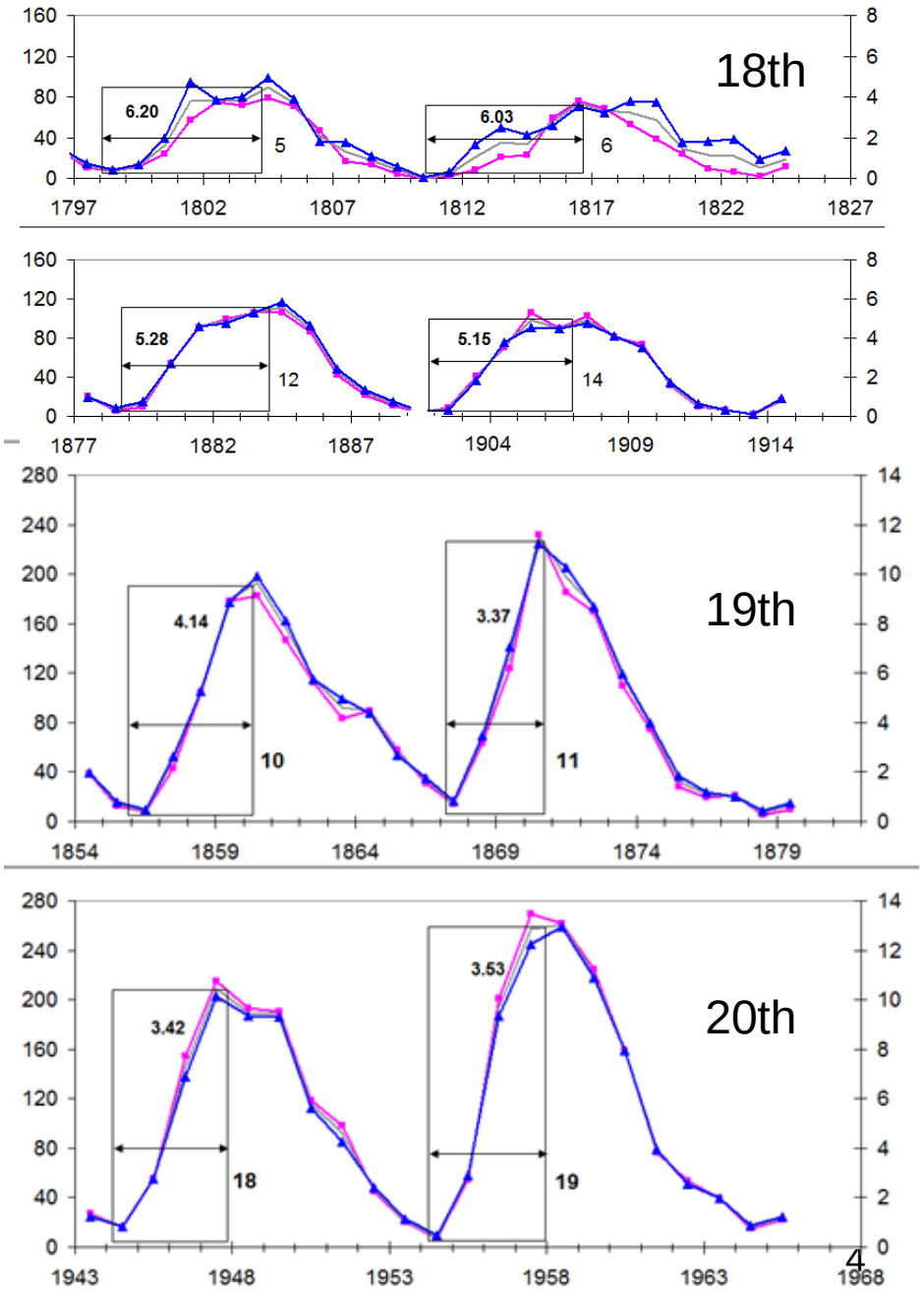
Hoyt & Schatten's [H&S] GSN = 12 * G where the '12' was chosen to make the GSN = W for the interval 1874-1976, so forcing an overall match with W for that.

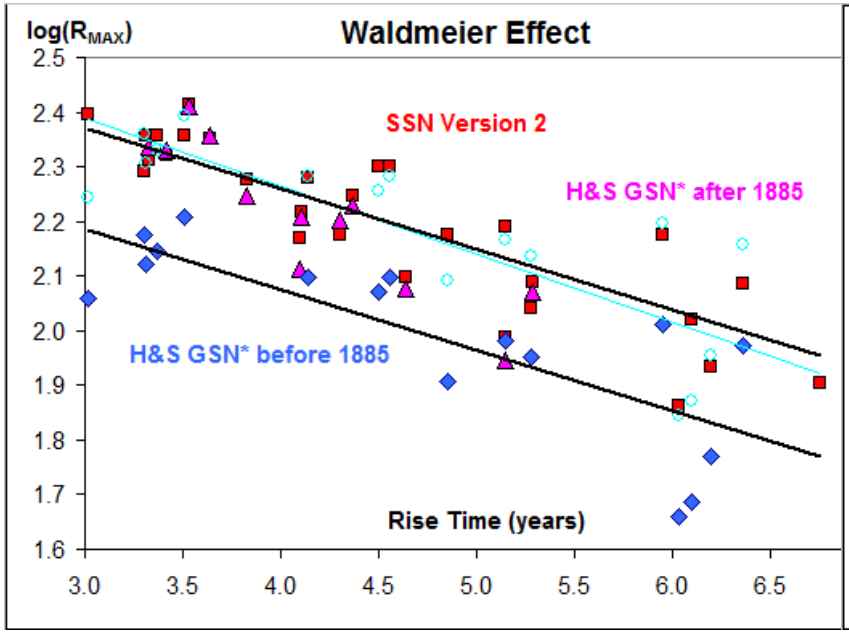
# The Waldmeier Effect

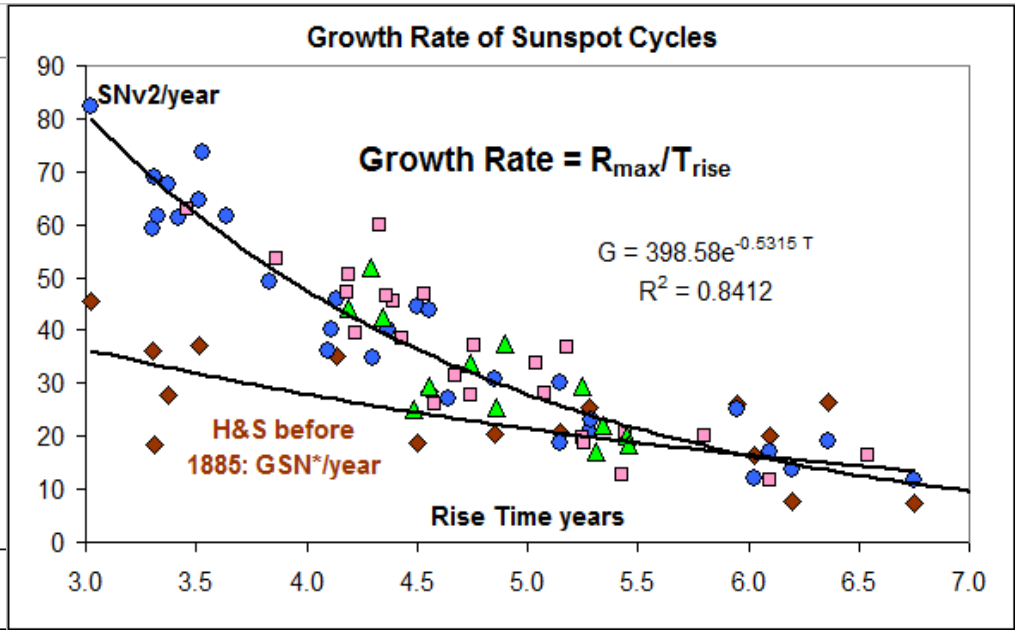


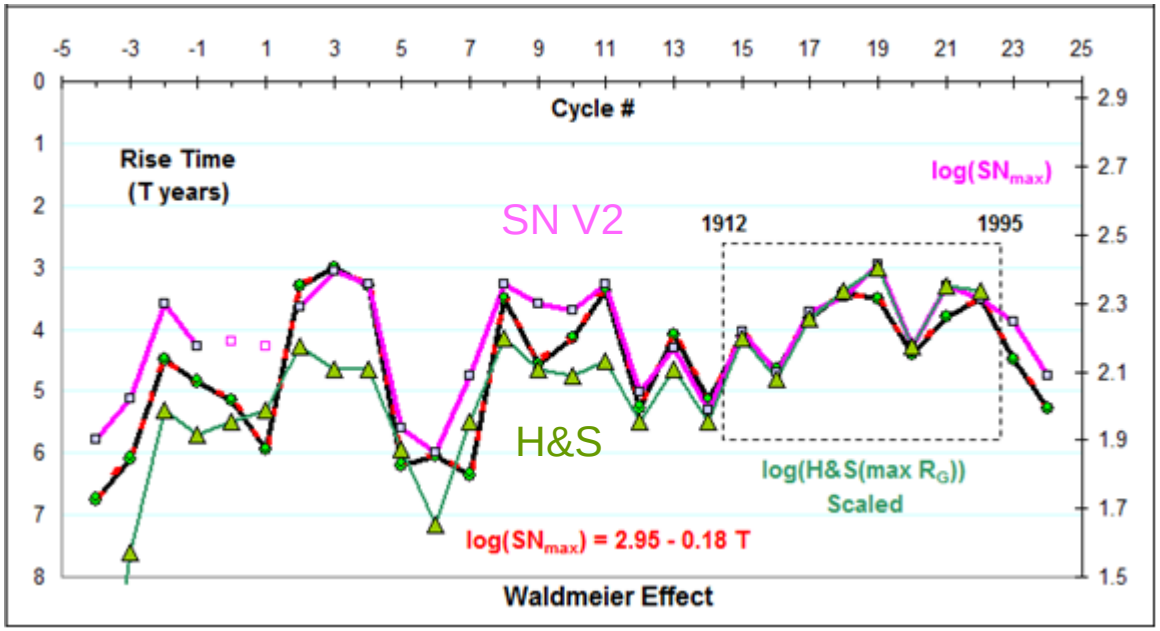

There is a relationship between the rise time T (in years) from minimum to maximum and the maximum smoothed monthly sunspot number. The times of the extrema can be determined without knowledge of the reduction (or scale) factors. **Since this relationship also holds for the years from 1750 to 1848 we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

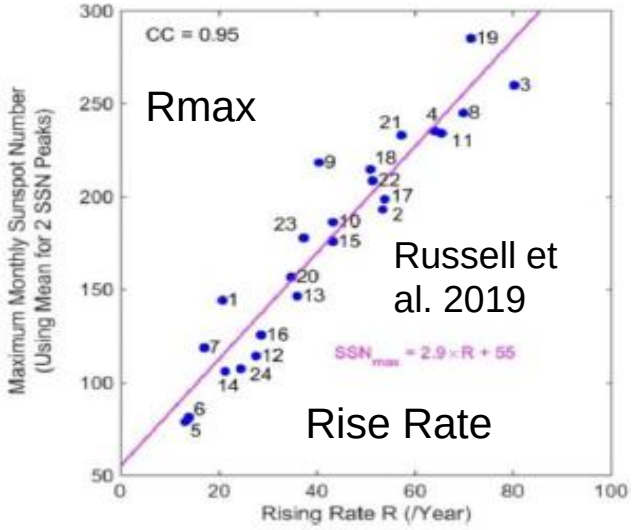





# More Waldmeier Effect




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

# A Proposed Solution for Reconciliation: The SSN Workshops (Utterly Failed its 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: Community-vetted and agreed-upon solar activity series;
we now have half 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** reference(s), 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 H&S reconstruction

2: A set of series that closely resemble the 'official' Sunspot series (both v1and v2)

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 was also an abject failure

# The ADF-Method: Extrapolating from Low Activity to High Activity

**T. Willamo, I.G. Usoskin, and G. A. Kovaltsov, 2017,** [WEA in what follows] *Updated sunspot group number reconstruction for 1749–1996 using the active day fraction method, Astronomy & Astrophysics manuscript no. 29839JN˙C*:
Sunspot number series are composed from observations of hundreds of different observers that require careful normalization to standard conditions. Here we present a new normalized series of the number of sunspot groups for the period 1749–1996. **The reconstruction is based on the active day fraction (ADF) method**, which is slightly updated with respect to previous works, and a revised database of sunspot group observations. Stability of some key solar observers has been evaluated against the composite series. The Royal Greenwich Observatory dataset appears relatively stable since the 1890s but is approximately 10% too low before that. A declining trend of 10–15% in the quality of Wolfer's observations is found between the 1880s and 1920s, suggesting that using him as the reference observer may lead to additional uncertainties. Wolf (small telescope) appears relatively stable between the 1860s and 1890s, without any obvious trend. The new reconstruction reflects the centennial variability of solar activity as evaluated using the singular spectrum analysis method. **It depicts a highly significant feature of the modern grand maximum of solar activity in the second half of the 20th century, being a factor 1.33–1.77 higher than during the 18 and 19$^{th}$ centuries.** The new series of the sunspot group numbers with monthly and annual resolution […] is provided forming a basis for new studies of the solar variability and solar dynamo for the last 250 years.

# A ‘Modern’ Method: PDF Matrix Calibration with Daisy-Chaining

**Theodosios Chatzistergos, Ilya G. Usoskin, Gennady A. Kovaltsov, Natalie A. Krivova, and Sami K. Solanki**, New reconstruction of the sunspot group numbers since 1739 using direct calibration and “backbone” methods, *A&A 602, A69 (2017):* [CEA in what follows]

The group sunspot number (GSN) series constitute the longest instrumental astronomical database providing information on solar activity. This database is a compilation of observations by many individual observers, and their intercalibration has usually been performed using linear rescaling. There are multiple published series that show different long-term trends for solar activity. We aim at producing a GSN series, with a non-linear non-parametric calibration. The only underlying assumptions are that the differences between the various series are due to different acuity thresholds of the observers, and that the threshold of each observer remains constant throughout the observing period. We used a daisy chain process with backbone (BB) observers and calibrated all overlapping observers to them. We performed the **calibration of each individual observer with a probability distribution function (PDF) matrix constructed considering all daily values** for the overlapping period with the BB. […] The final series was constructed by merging different BB series. We modeled the propagation of errors straightforwardly with Monte Carlo simulations. […] The final series extends back to 1739 and includes data from 314 observers. This series suggests moderate activity during the 18th and 19th century, **which is significantly lower than the high level of solar activity predicted by other recent reconstructions applying linear regressions**. The new series provides a robust reconstruction, based on **modern and non-parametric** methods, of sunspot group numbers since 1739, and it confirms the existence of the modern grand maximum of solar activity in the second half of the 20th century.

# Breakthrough or Hype?

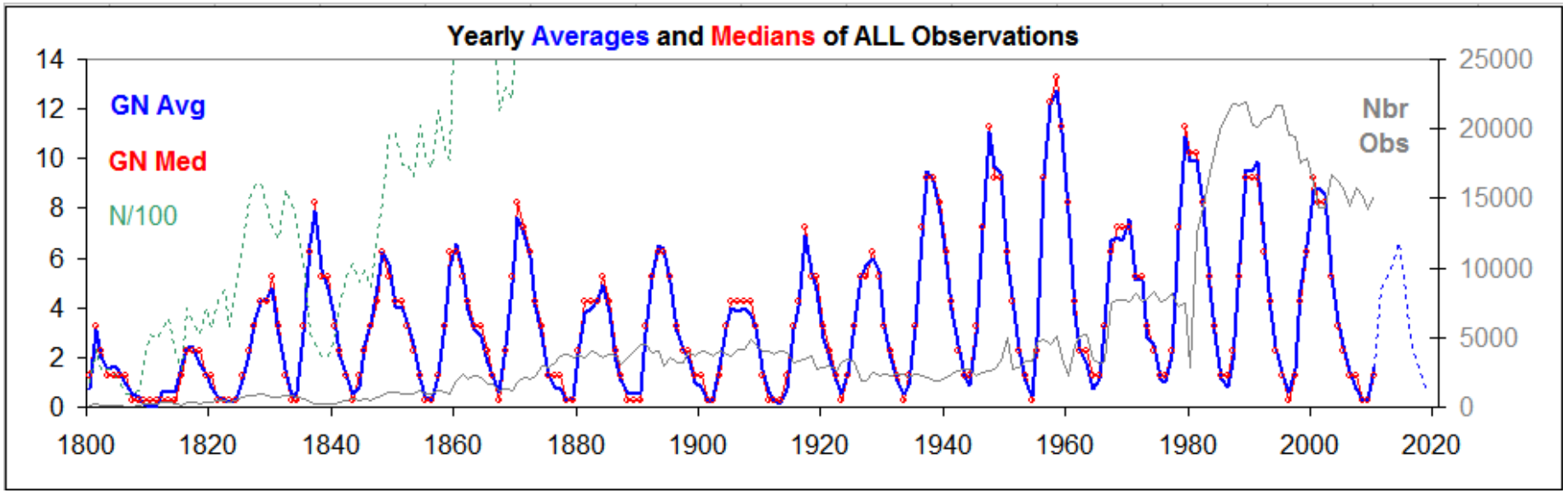
**Thierry Dudok de Wit & Ed W. Cliver,** *Space Climate 7, 2019* (Abstract):

The group sunspot number, which is a unique record of past solar activity, is based on a vast ensemble of different and often quite heterogeneous data sets. The recent reevaluation of the group sunspot number record has revealed the need for intercalibrating the different observers before combining their observations. In addition, a suitable method is required for stitching together data sets that only partly overlap in time. Here we present a new approach that bypasses the need for intercalibration and in addition avoids the artificial introduction of backbone observers for stitching records together. The first novelty is the combination of partly overlapping records in a natural way by means of a statistical method named expectation maximization. Thanks to this method no specification of backbones or daily-chaining is required. The second novelty is the use of order statistics to avoid intercalibration. More precisely, we combine ranked group sunspot numbers and not the original numbers. Tests with synthetic data simulating observers that have different nonlinear responses confirm the robustness of the method. We illustrate the method with real data and propose a new reconstruction of the group sunspot number whose exact spot-to-observer scaling can now be freely determined.

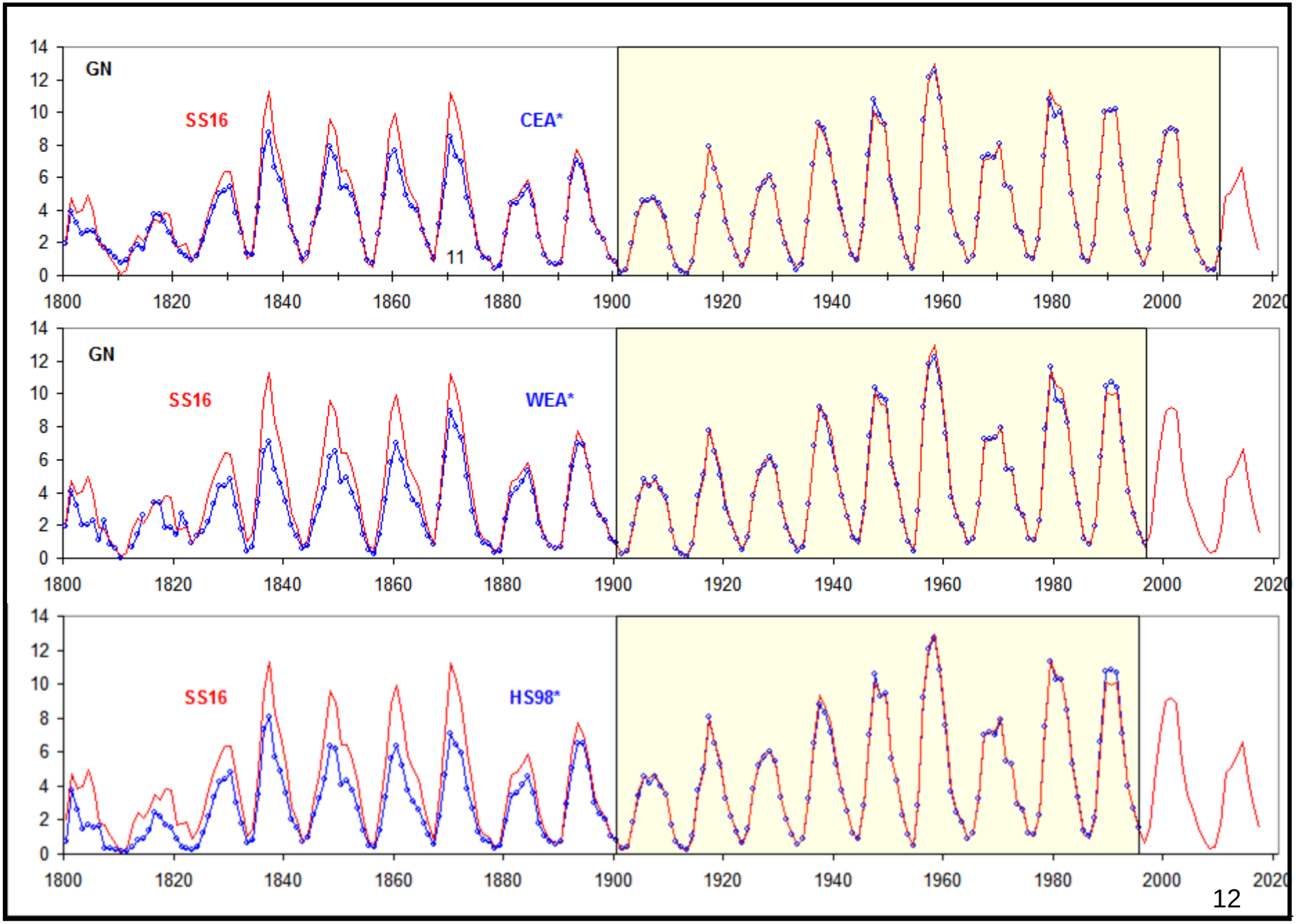
The authors caution that their poorly [*sic*] validated series is not yet ready for 'public distribution'

# *Vox Populi* (The Wisdom of Crowds), F. Galton, *Nature* 1907

If the Group Number data collected by Wolf, by H&S, and since 1981 by SILSO are indeed accurate and represent [raw] counts of what the observers and the rapporteurs believed to be Sunspot Groups, then Modern Reconstructions of solar activity given by the Group Numbers must closely resemble the historical record shown below. If not, it must be explained *why* not.




Luckily, they generally do, conforming to Galton's insight


GN
SS16
CEA*
11
GN
SS16
WEA*
SS16
HS98*
0
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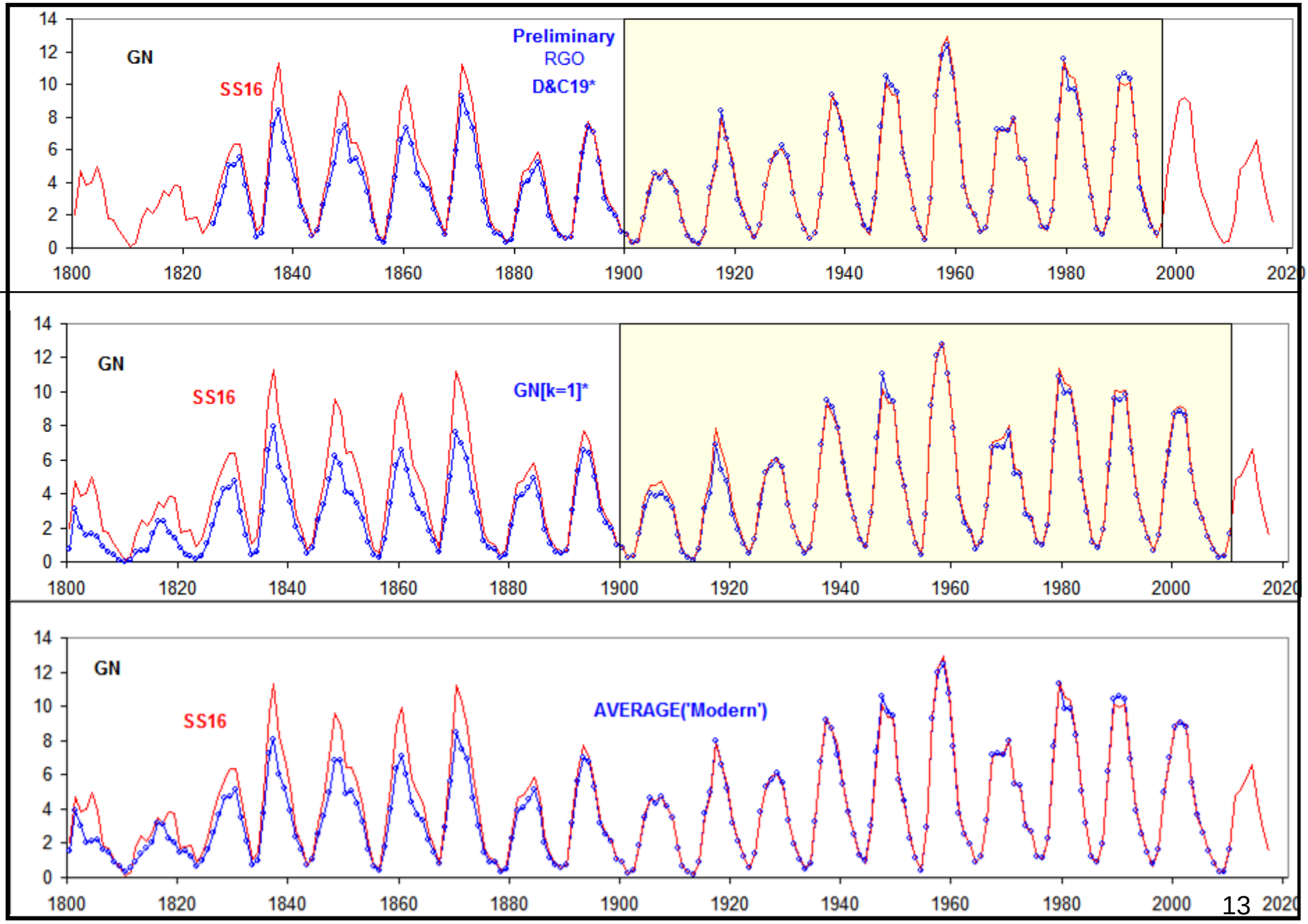
GN
SS16
Preliminary
RGO
D&C19*
GN
SS16
GN[k=1]*
GN
SS16
AVERAGE('Modern')
0
2
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6
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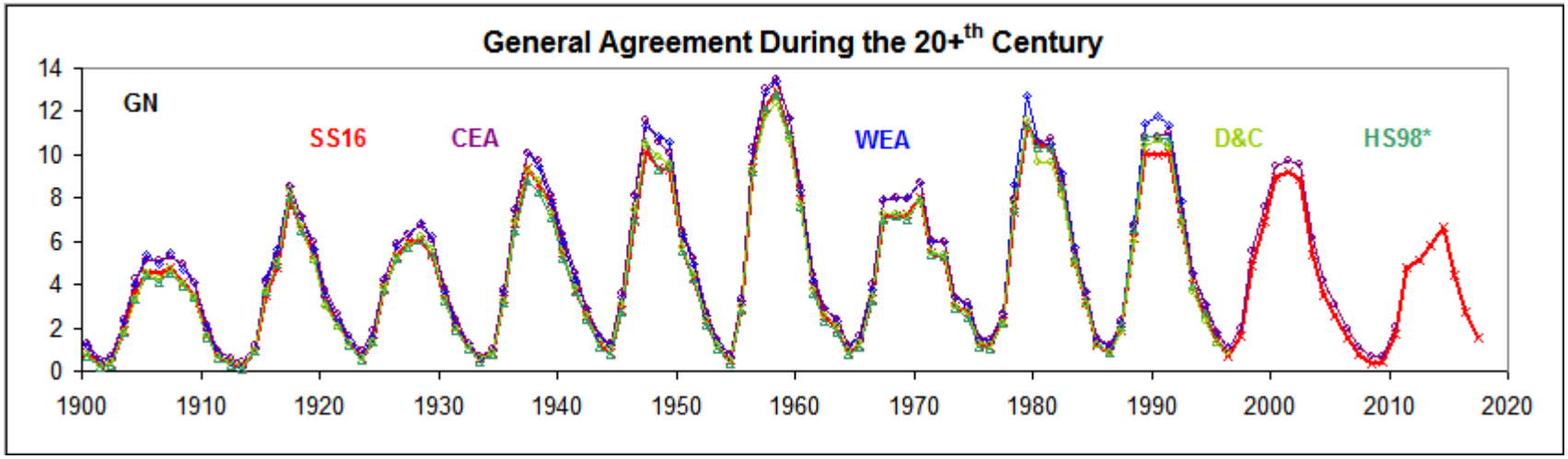
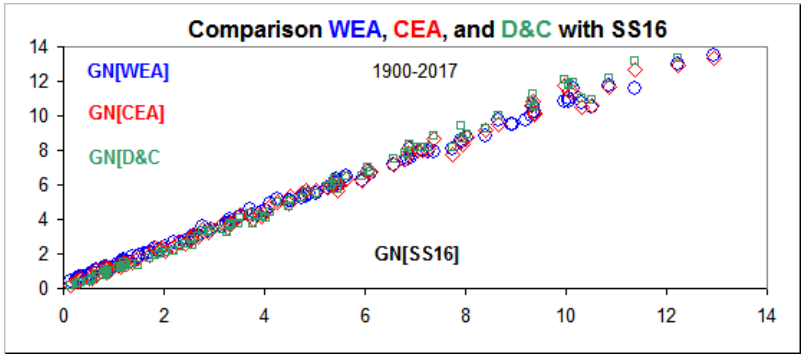
2020

# 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 belong to the same population.



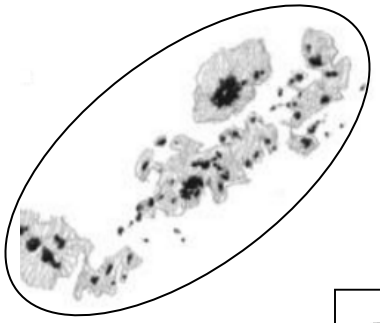

When analyzing yearly values, the regression lines are remarkably linear (even proportional), belying claims that they are not.

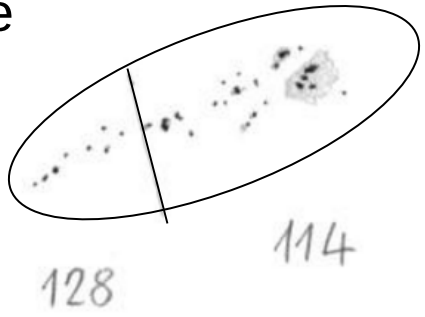
# A New Paradigm (Different Populations)

- 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

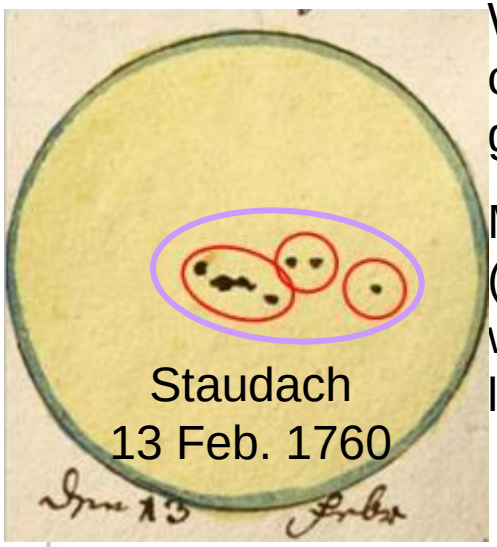
# Fundamental Issue: What Is a Group?

Definition has changed over time



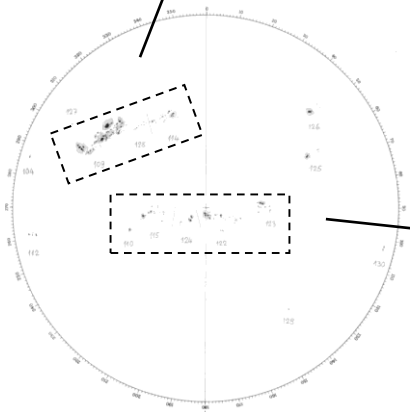




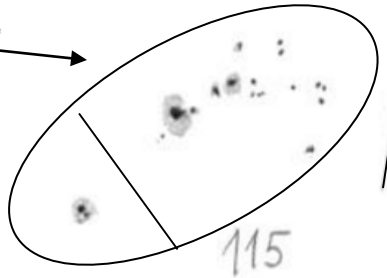

Wolf (1857) counted only one group on that day.

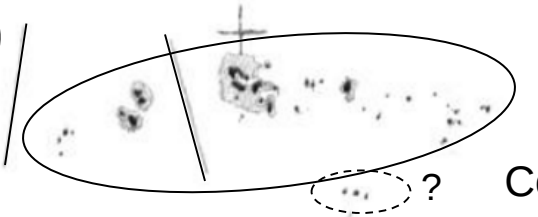
Modern observers (Cortesi, even me) would count at least three groups.

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



Locarno





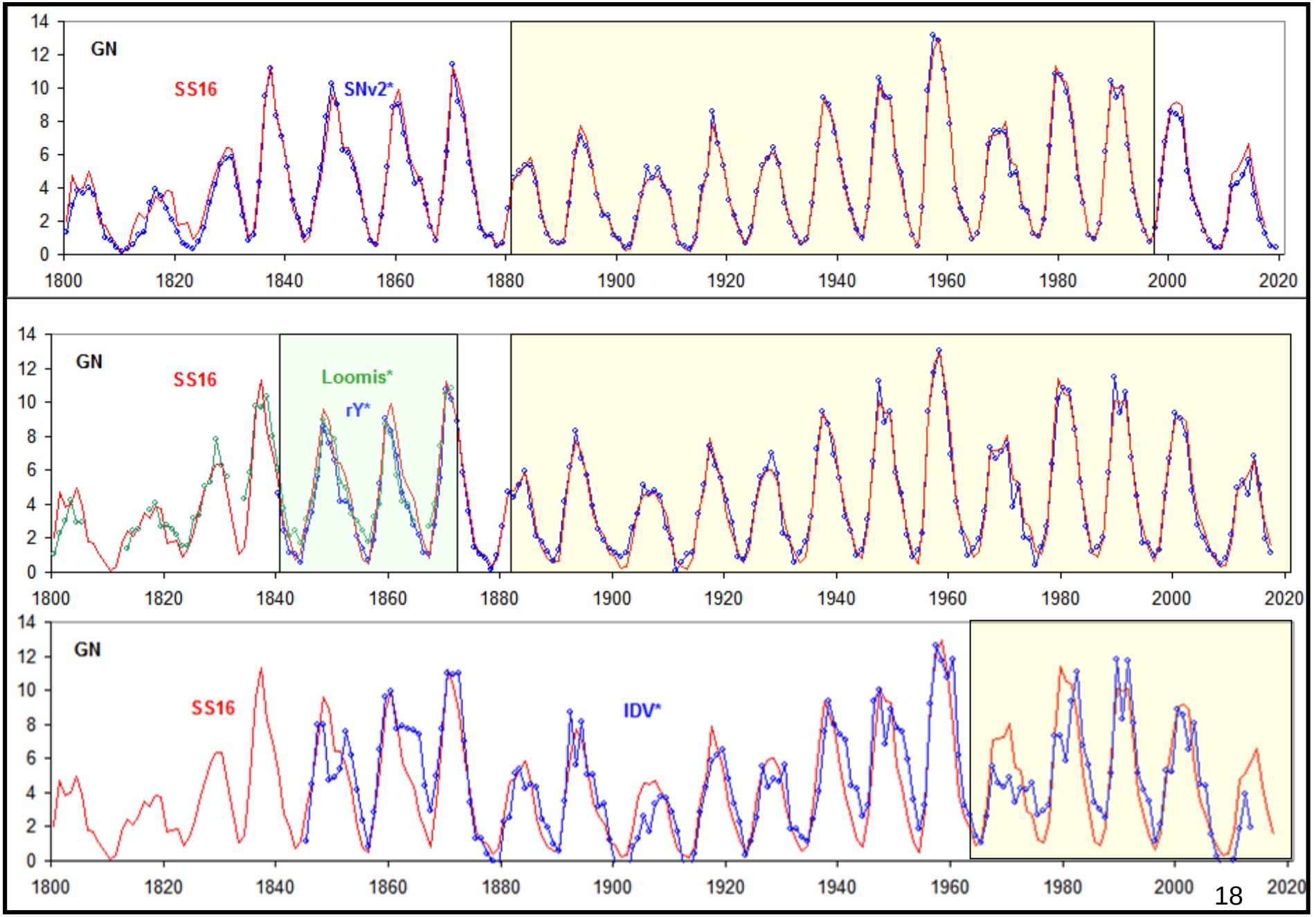
Cortesi counted 8 groups. Early observers would likely have counted only 5 groups

# Some Major Proxies for Solar Activity

Wolfer (1893) introduced an improved method of counting sunspots and insisted on counting all spots [and groups] that could be seen, not omitting small and fleeting spots and corrected for the previous undercounts [the infamous correction factor of 0.6]. **So the classical Relative Sunspot Number already incorporates the effect of the New Paradigm**. The recent revision (Version 2) made needed corrections [e.g. for the Waldmeier jump in 1947]. There is a strong correlation between the Relative Sunspot Number SN and the Group Number GN, so SN is a good proxy for GN.

Solar EUV creates the ionospheric E-region. Dynamo induced electric currents have a magnetic effect observed as diurnal variations (e.g. rY) at geomagnetic observatories for centuries. Already Julius Bartels (1941, 1946) emphasized the importance of the diurnal variation: The correlations between the Sunspot Number and the diurnal variations… "are the **closest found so far between solar and terrestrial phenomena**", so rY is also an excellent proxy for GN.

The geomagnetic IDV-index is a measure of the energy in the Magnetospheric Ring Current [Van Allen Belts] and has been found to be a **strong proxy for the Hemispheric Magnetic field** [B at Earth] which in turn is related to the Solar Wind 'Open' Magnetic flux, and thus also a proxy for the Solar Magnetic Field and GN.


GN
SS16
SNv2*
GN
SS16
Loomis*
rY*
GN
SS16
IDV*
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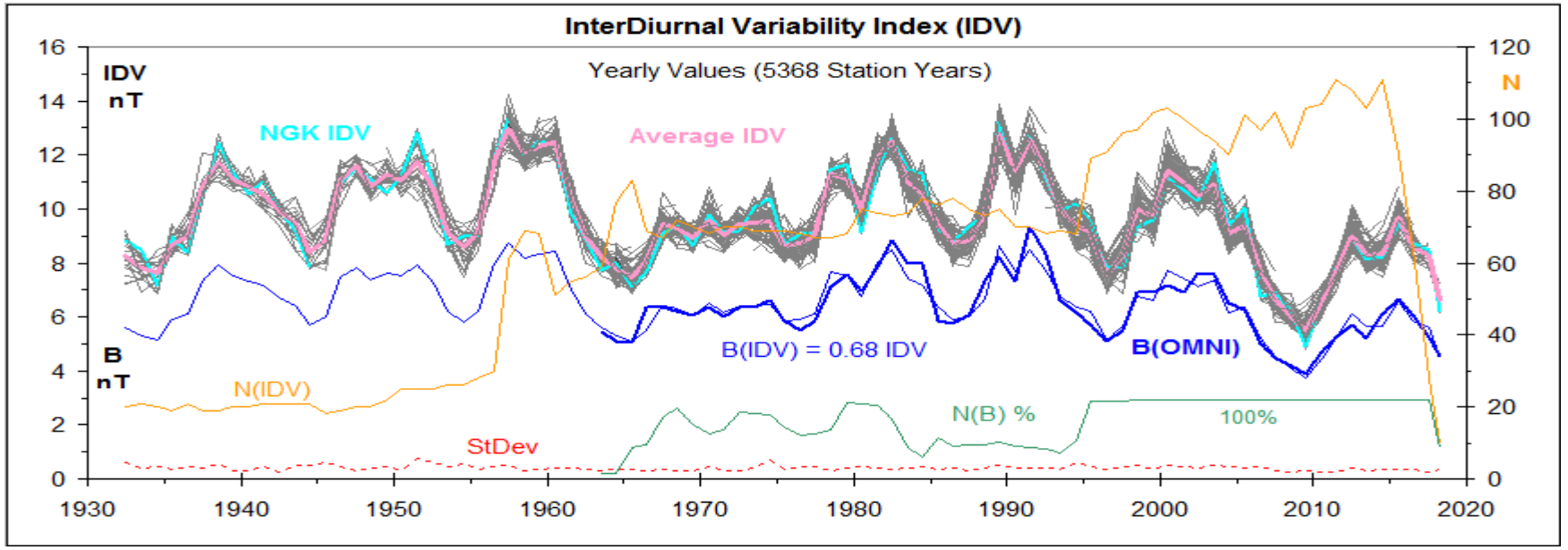
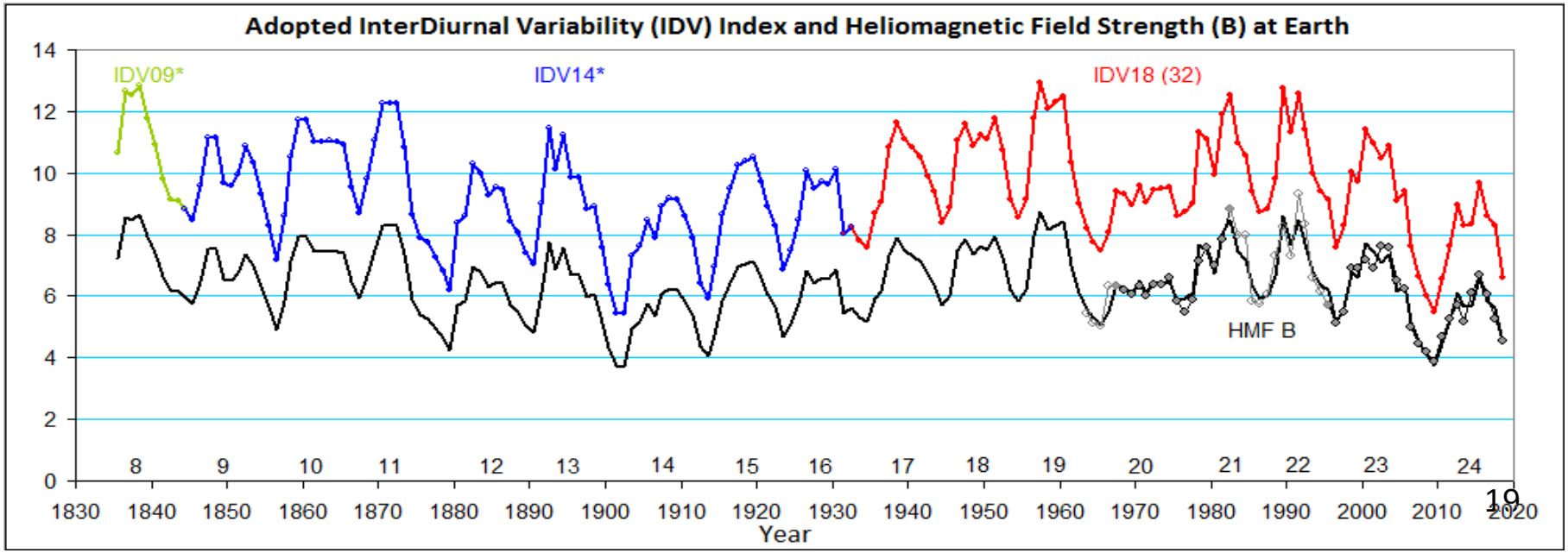
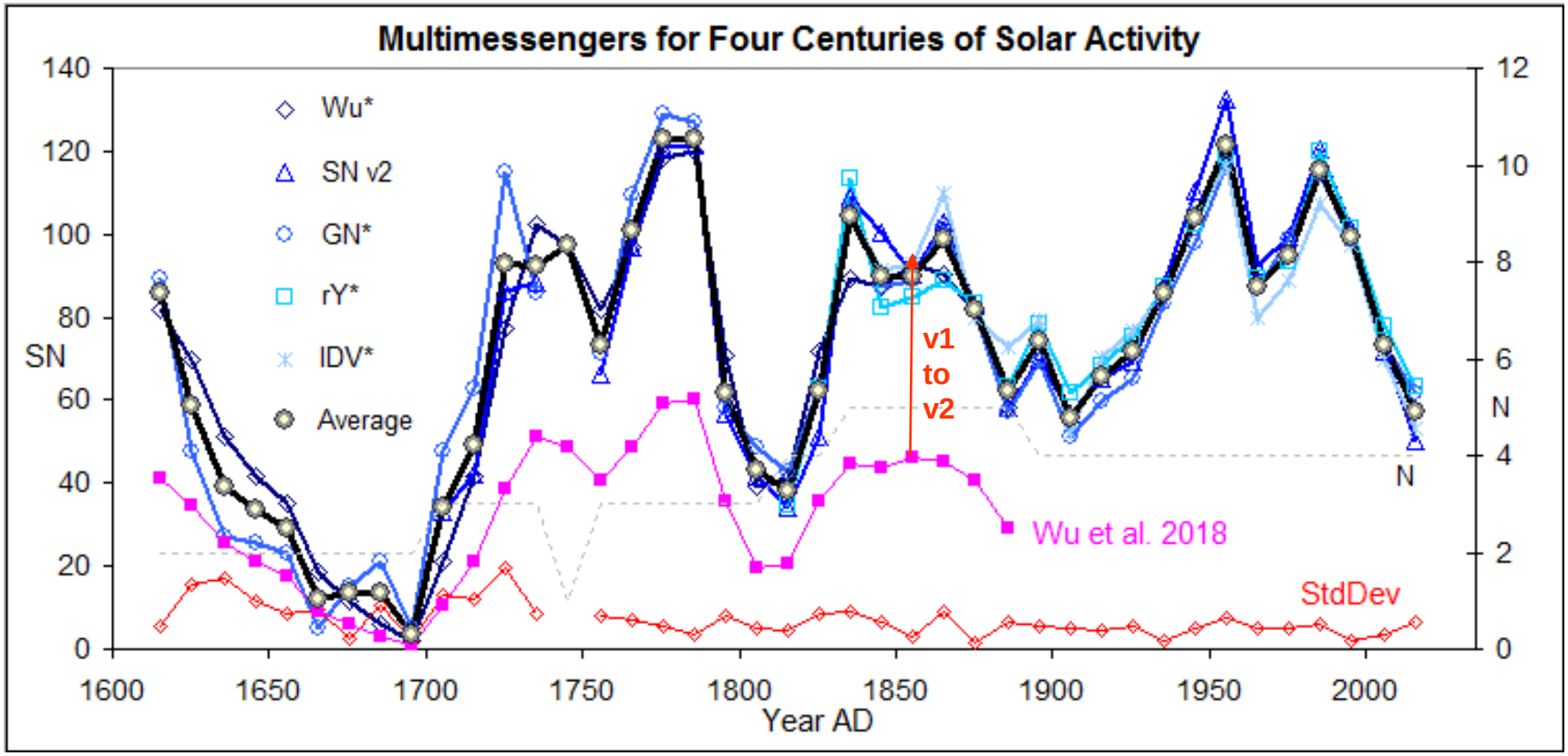
# IDV is a Good Proxy for the Heliospheric Magnetic Field



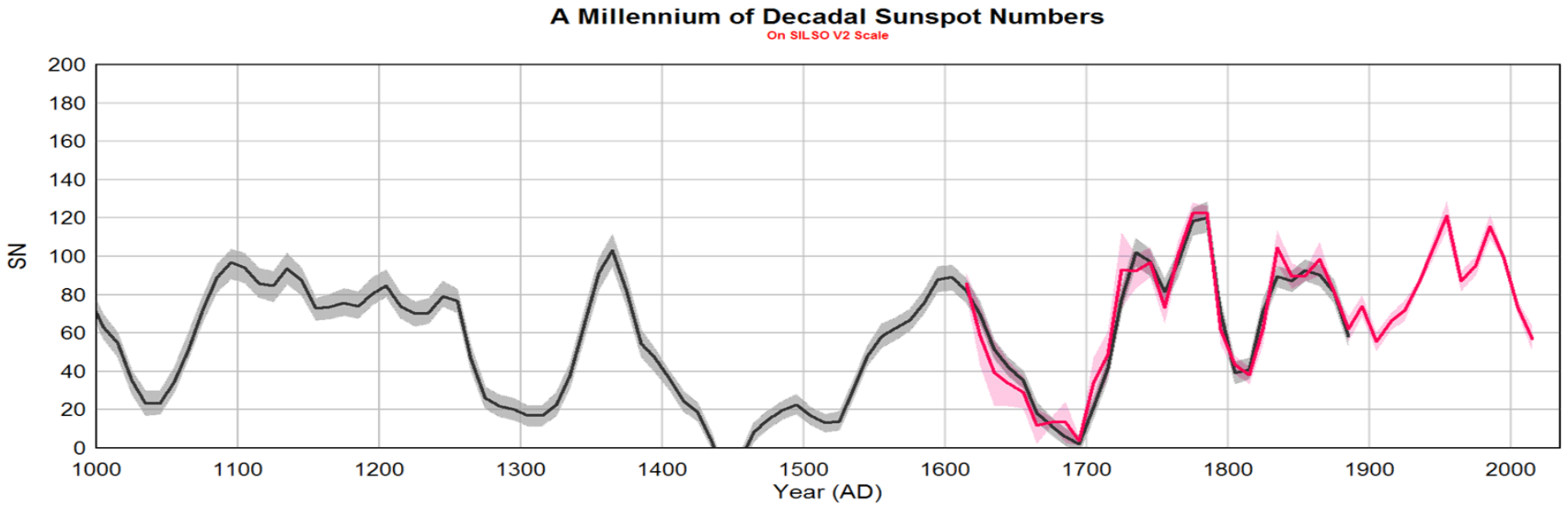



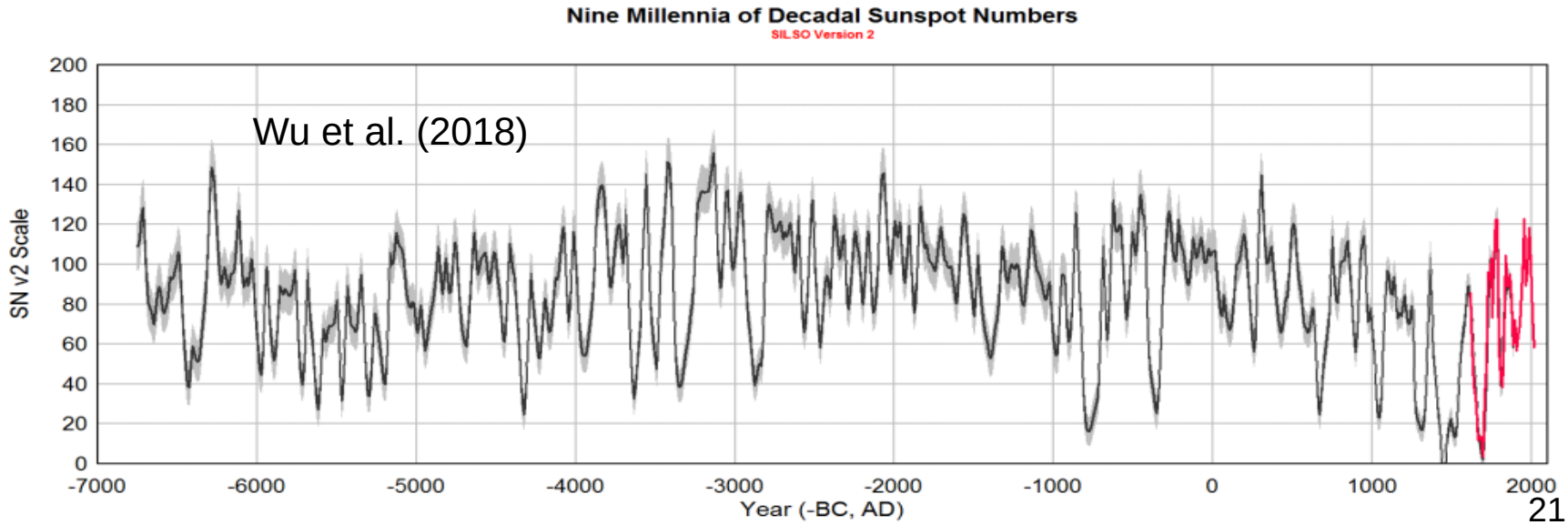
# SN, GN, rY, GCR, IDV



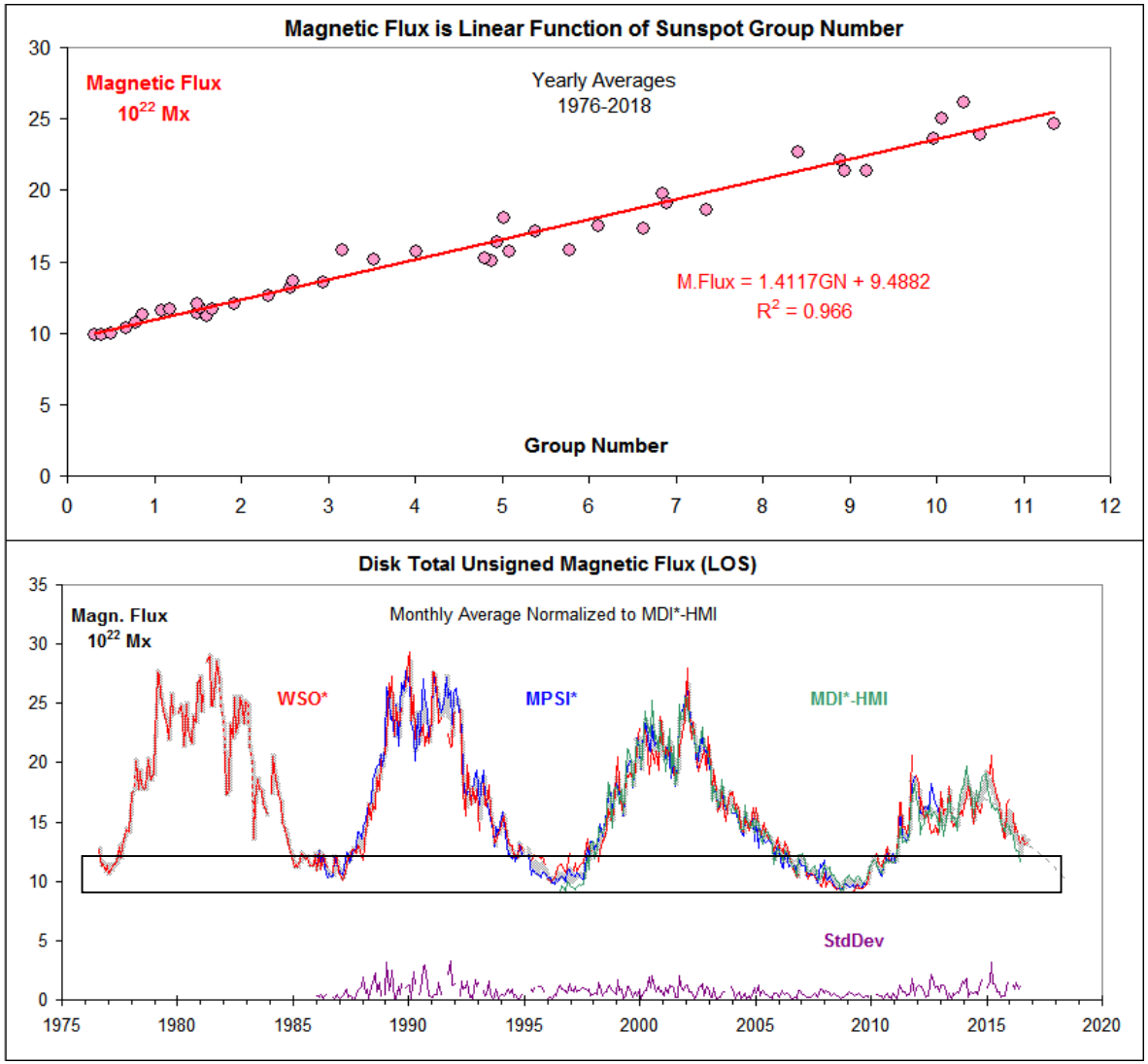

To convert the Cosmic Ray (GCR)-based reconstruction by Wu et al. (2018) from SNv1 to SNv2, one has to multiply by a factor of 2.

# The longer view: Nine millennia



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

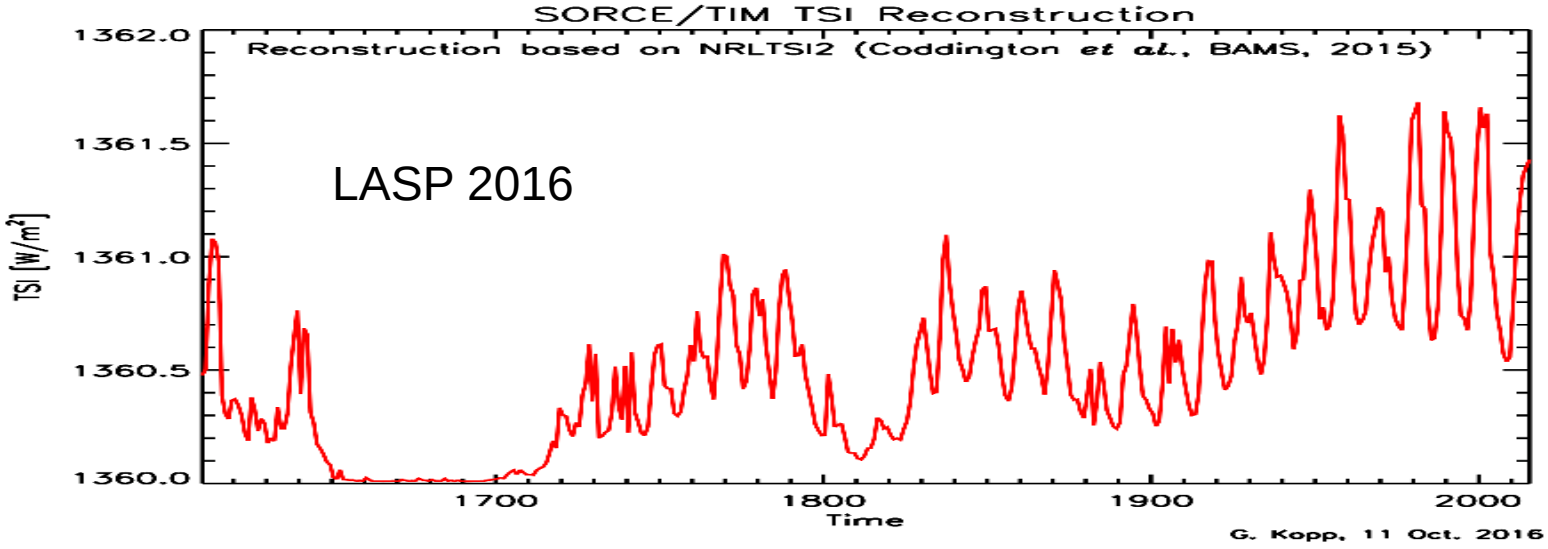


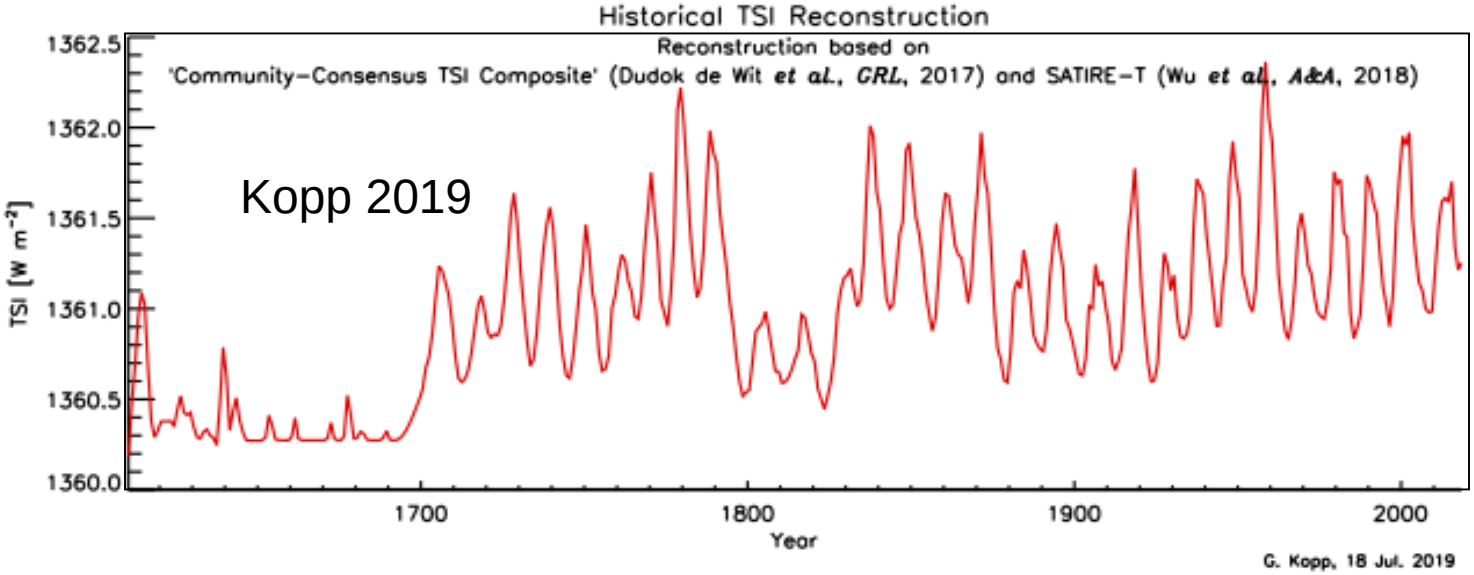

Scaling MWO to MDI-HMI and WSO to the result yields a good measure of the LOS unsigned full disk magnetic flux which turns out to be a linear function of the Sunspot Group Number (S&S 2016).

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 a Difference a Corrected Solar Activity Record Makes

**The Total Solar Irradiance [TSI] record is important for the terrestrial climate variation**




Still some issues around sunspot minima: what is TSI for the 'quiet' sun?

But we'll take whatever progress we can get…

# 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 as several solar-activity proxies for at least the last 200 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 for most of the 19th century.
- This conclusion ‘hits you right between your eyes’