

## *Revisiting the Sunspot Number*

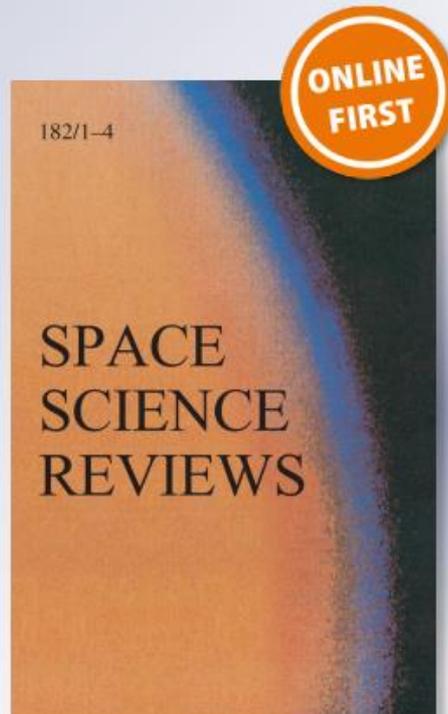
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Space Science Reviews

ISSN 0038-6308

Space Sci Rev

DOI 10.1007/s11214-014-0074-2



 Springer

# Revisiting the Sunspot Number

“Our knowledge of the long-term evolution of solar activity and of its primary modulation, the 11-year cycle, largely depends on a single direct observational record: the visual sunspot counts that retrace the last 4 centuries, since the invention of the astronomical telescope“

“We present the new concepts and methods used to self-consistently recalibrate the original sunspot series. This epochal revision of the Sunspot Number, the first since Wolf himself, and its reconciliation with the Group Number, is a long-awaited modernization that will feed solar cycle research into the 21st century”

# Why is the SSN series important?

The SSN is an index with considerable subjectivity, depending on manual determinations with small telescopes, so why do we need it?

Analogy with the cosmic distance scale: One needs a ladder of widely different techniques valid in a sequence of partially overlapping regimes.

Similarly to explore the history of solar variability we need a ladder of overlapping regimes that connect the present physical parameters (TSI, magnetograms, UV radiance, etc.) with the distant past. The time scale from the present back to Galileo can only be bridged by the SSN, which in turn allows the ladder to be continued by isotope methods, etc.

Stenflo [2014] <http://www.leif.org/research/SSN/Stenflo.pdf>



Sunspot 2011



Brussels 2012



Tucson 2013



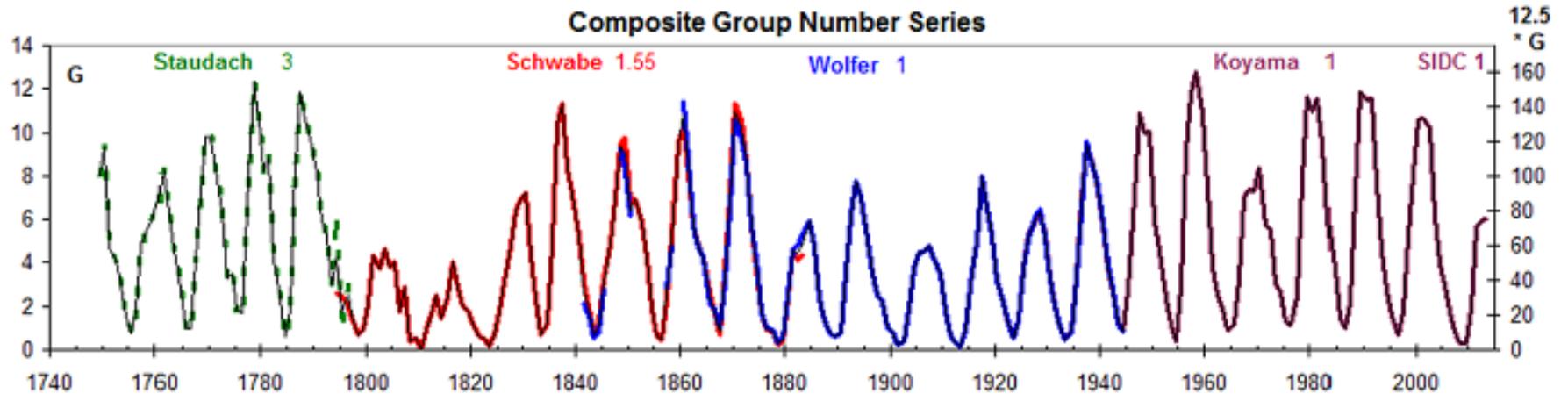
Locarno 2014

# The SSN Workshops

A series of workshops have led to a critical re-assessment of the Sunspot Number series

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

An official revised series is scheduled for 2015

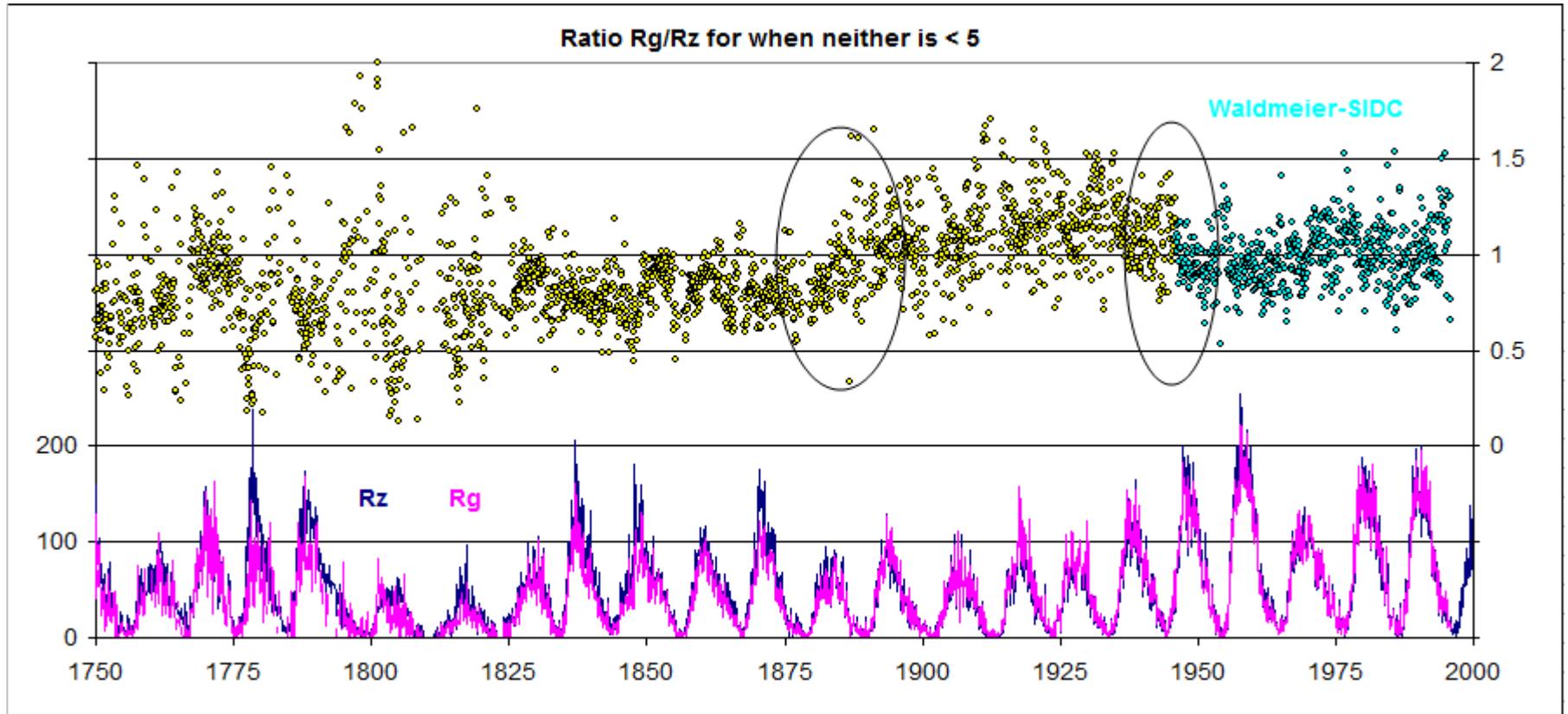


High solar activity in every century since 1700. None stand out as **Grand**

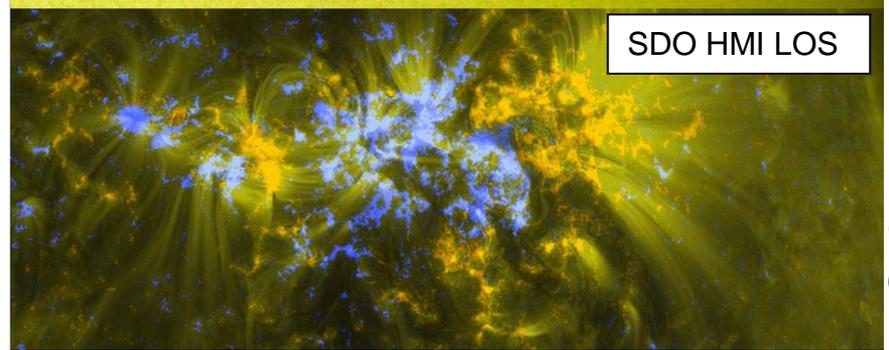
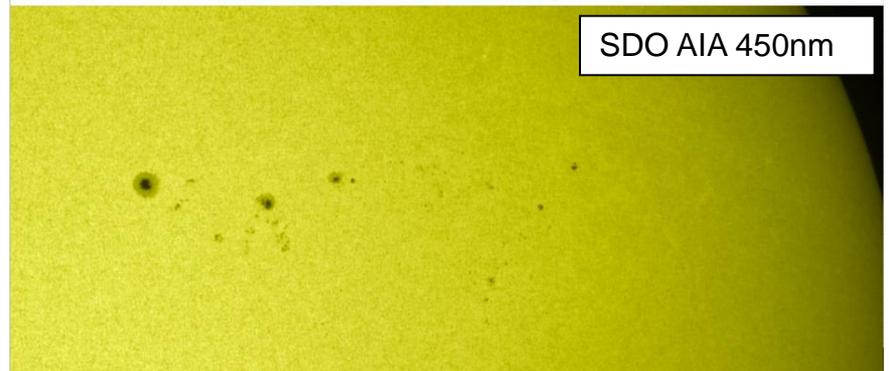
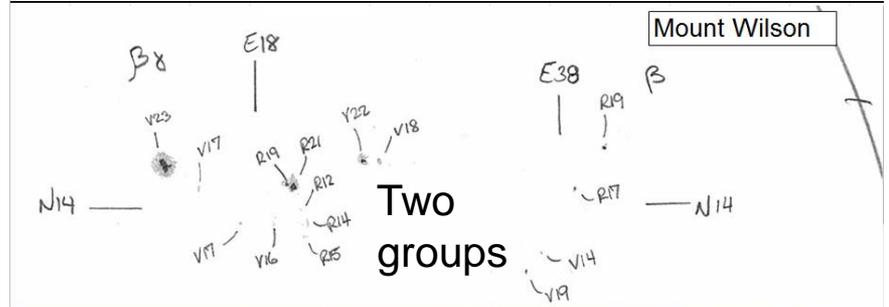
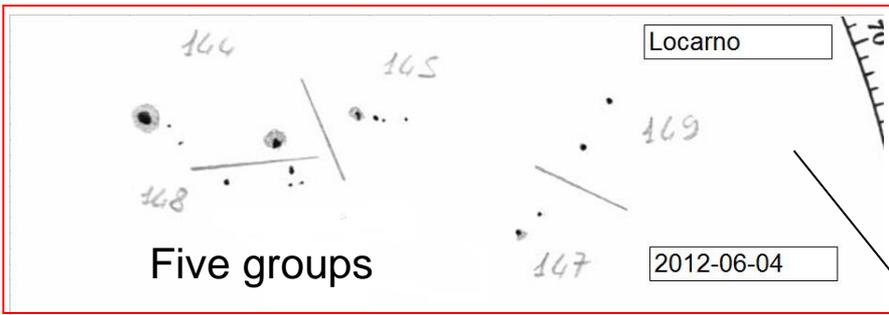
# Problems with the Sunspot Number(s)

- In the 1940s the observers in Zürich began to count larger spots more than once [weighting according to size], inflating the SSN by ~20% continuing until the present
- The Group Sunspot Number is about 50% too low prior to about 1885
- When the above problems are corrected there is no long-term trend over the past three hundred years, i.e. no Modern Grand Maximum

# The Ratio Group/Zürich SSN has Two Significant Discontinuities



At ~1946 (After Max Waldmeier took over) and at ~1885



Combined Effect of Weighting and More Groups is an **Inflation** of the Relative Sunspot Number by 20+%

No Weight

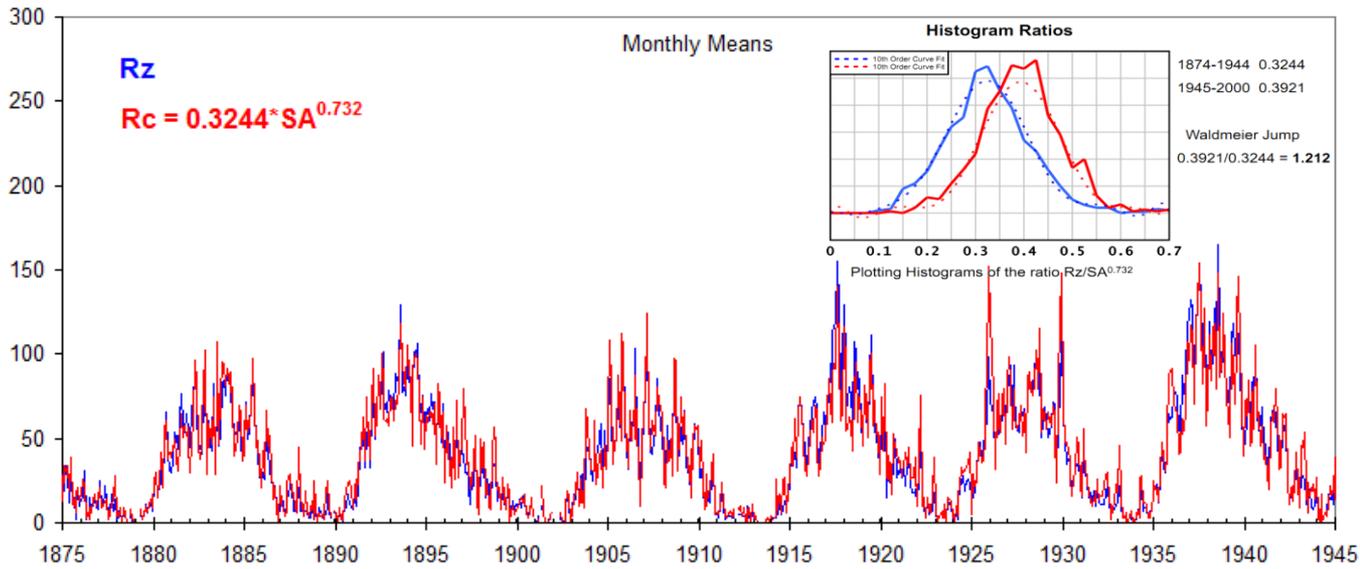
g	f		B
143	4	2	-16'
144	7	4	+15'
145	5	4	+15'
146	12	6	-21'
147	4	2	+8'
148	5	4	+11'
149	4	2	+15'
150	6	2	+10'
151	1	1	+11'
152	2	2	+6'
153	2	1	-18'
<hr/>			
11	52	30	

↑ Groups      ↑ 'Weighted Spots'

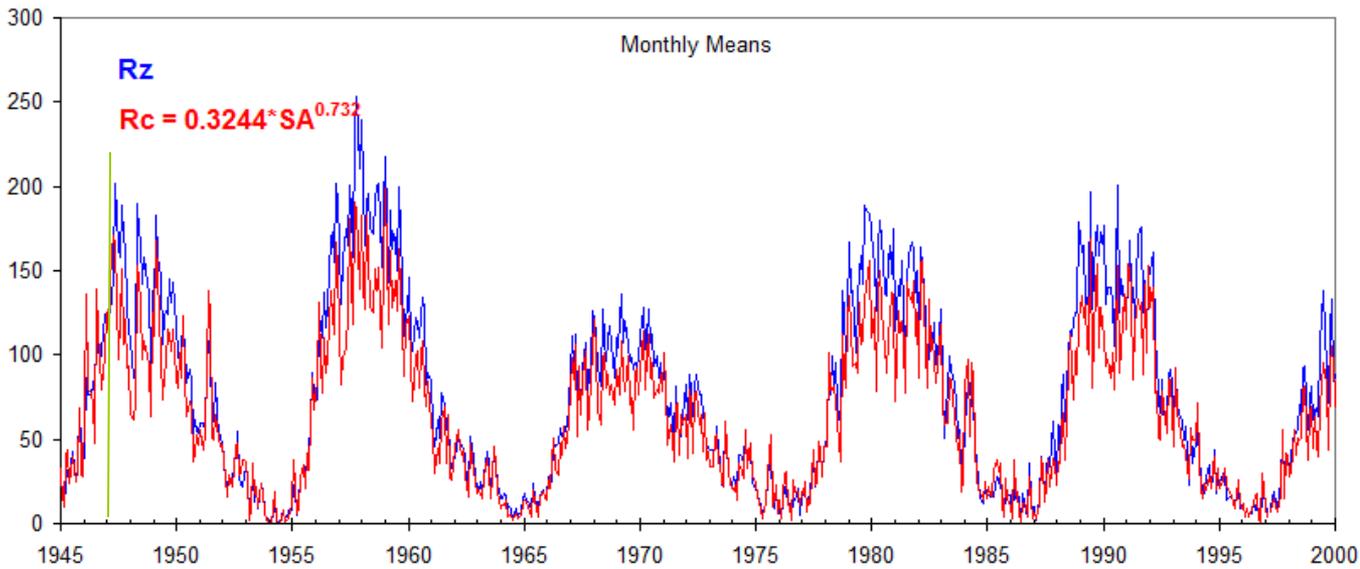
I have re-counted 50,000 spots without weighting for the last 12 years of Locarno observations.

<http://www.leif.org/EOS/Kopecky-1980.pdf> specifically notes that "according to [observer] Zelenka (1979a), the introduction of the Zürich group classification with regard to their morphological evolution by Waldmeier and Brunner, has led to increased estimates of number of groups in comparison with Wolfer's estimates". Wolfer was assistant to Wolf and later his successor.

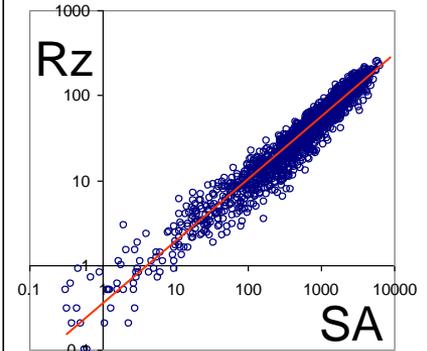
Comparison Zurich Sunspot Number and That Derived from Sunspot Areas



Comparison Zurich Sunspot Number and That Derived from Sunspot Areas



Compared with Sunspot Area (obs)



Not linear relation, but a nice power law with slope 0.732. Use relation for pre-1945 to compute  $R_z$  from Area, and note that the reported  $R_z$  after 1945 is too high [by 21%]

# Building Backbones

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

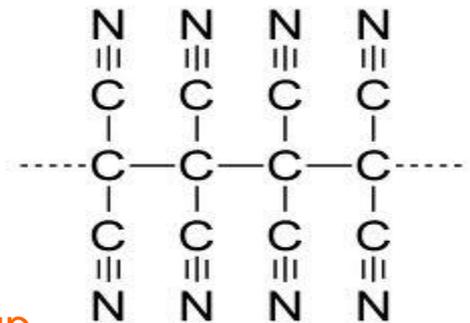
- Daisy-chaining: successively joining observers to the 'end' of the series, based on overlap with the series as it extends so far [accumulates errors]
- Back-boning: find a primary observer for a certain [long] interval and normalize all other observers individually to the primary based on overlap with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



Chinese Whispers



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

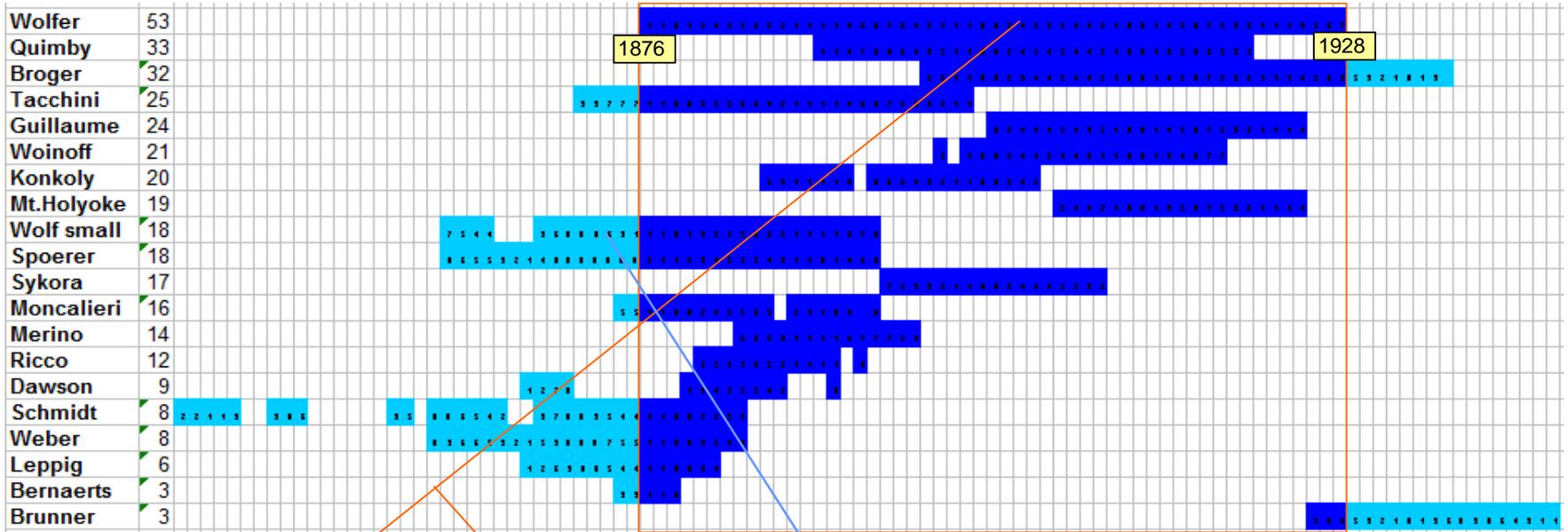


We have applied this methodology to reconstruct the Group Sunspot Number [using essentially the Hoyt&Schatten data]

Z≡O-O-O≡Z  
 Z≡O-O-O≡Z  
 Z≡O-O-O≡Z  
 Z≡O-O-O≡Z

# The Wolfer Backbone

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



80 mm X64

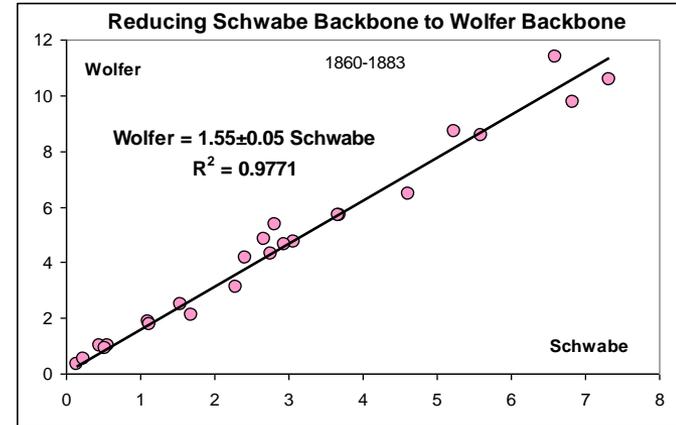
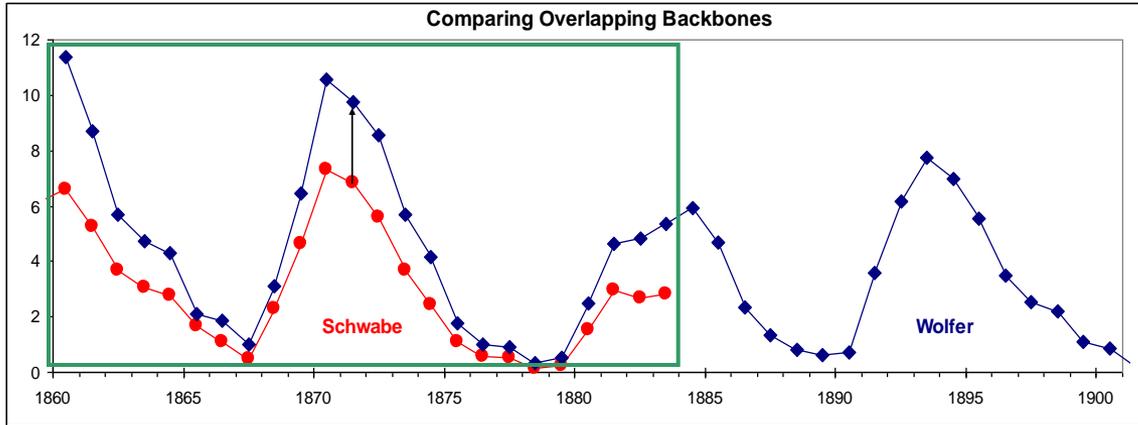


37 mm X20

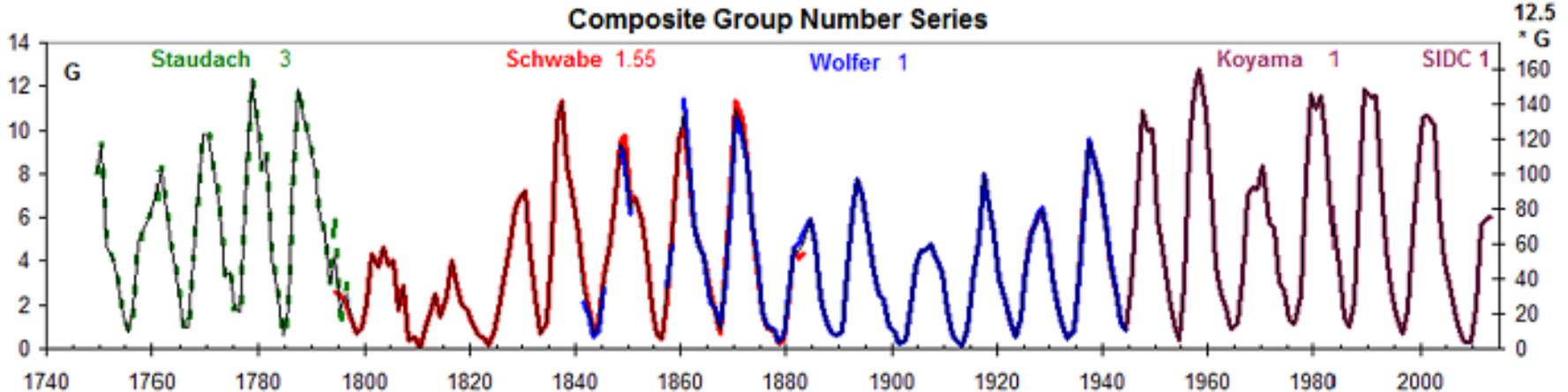
Rudolf Wolf from 1860 on mainly used smaller 37 mm telescope(s) so those observations are used for the Wolfer Backbone



# Joining two Backbones

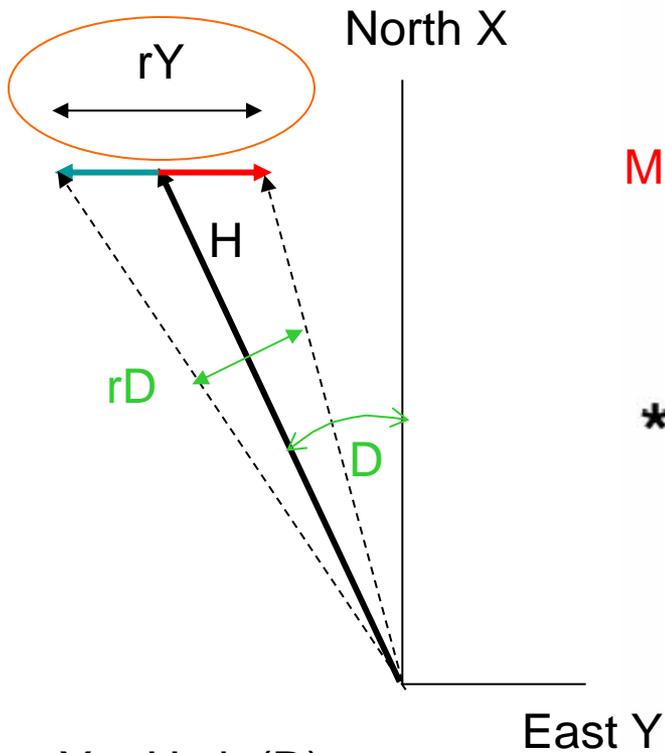
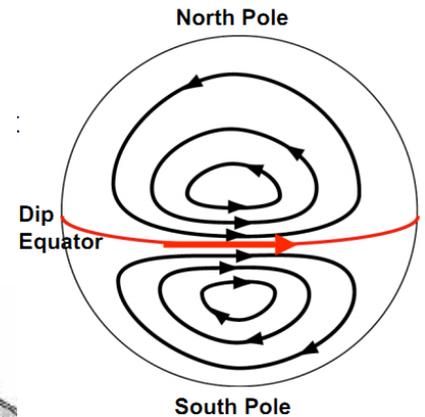


Comparing Schwabe with Wolfer backbones over 1860-1883 we find a normalizing factor of 1.55



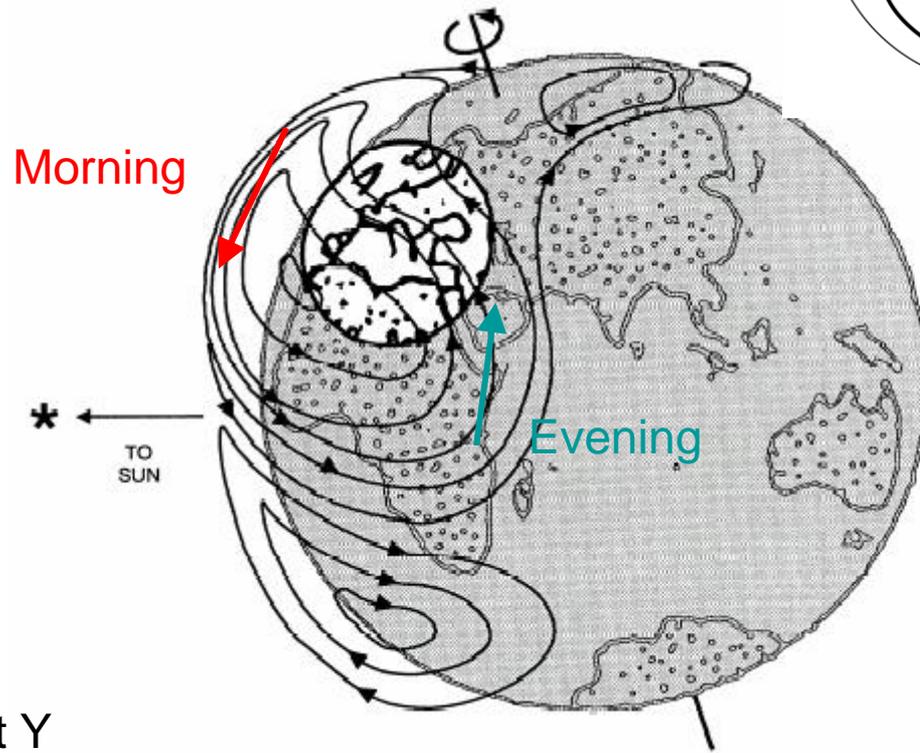
The Group Sunspot Number is now defined as  $12 * \text{Number of Groups}$

# The E-layer Current System



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

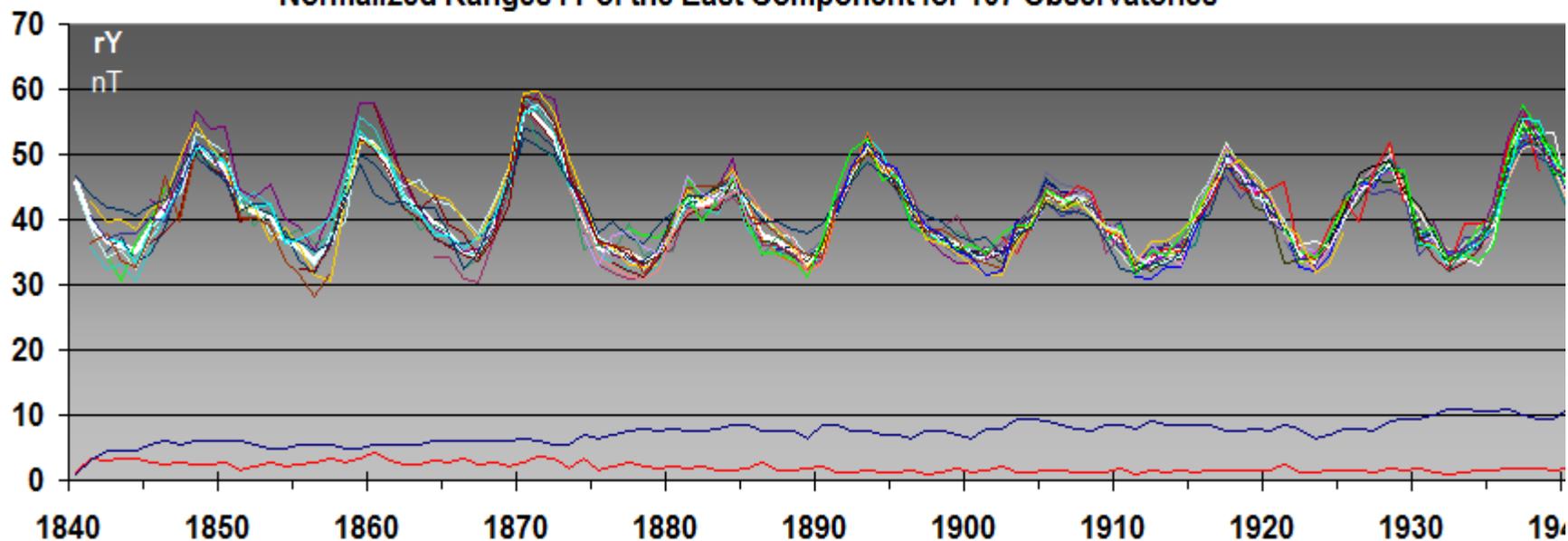
$$dY = H \cos(D) dD \text{ For small } dD$$



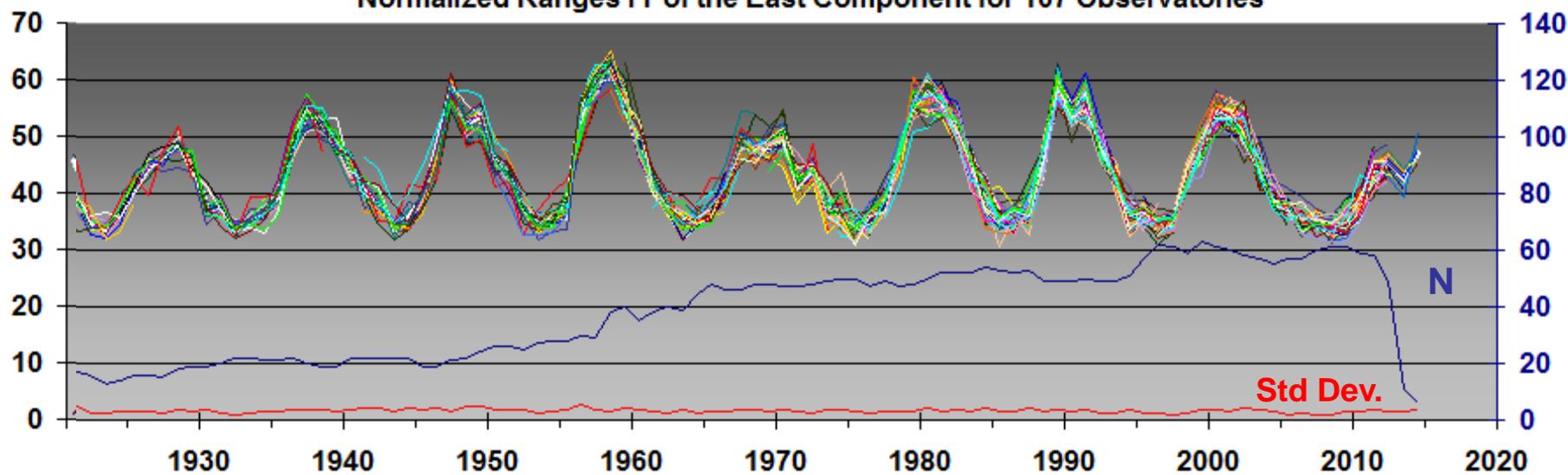
A current system in the ionosphere is created and maintained by solar EUV radiation

The magnetic effect of this system was discovered by George Graham in 1722

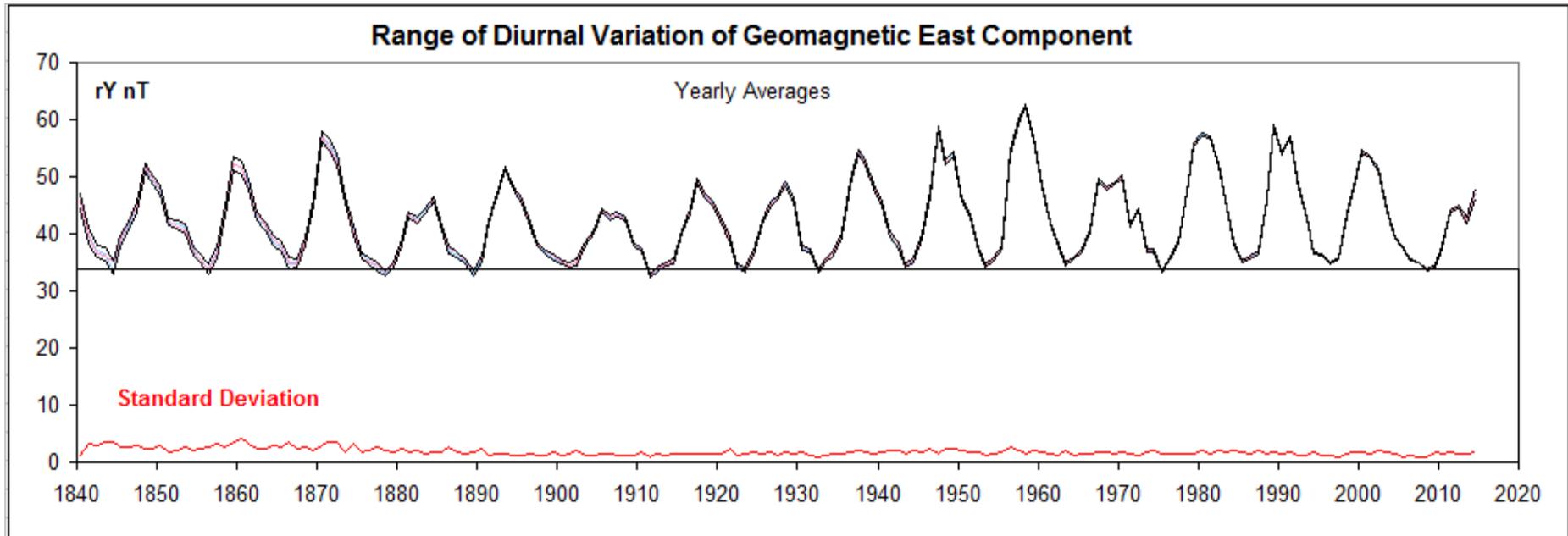
Normalized Ranges  $rY$  of the East Component for 107 Observatories



Normalized Ranges  $rY$  of the East Component for 107 Observatories



# Composite $rY$ Series 1840-2014

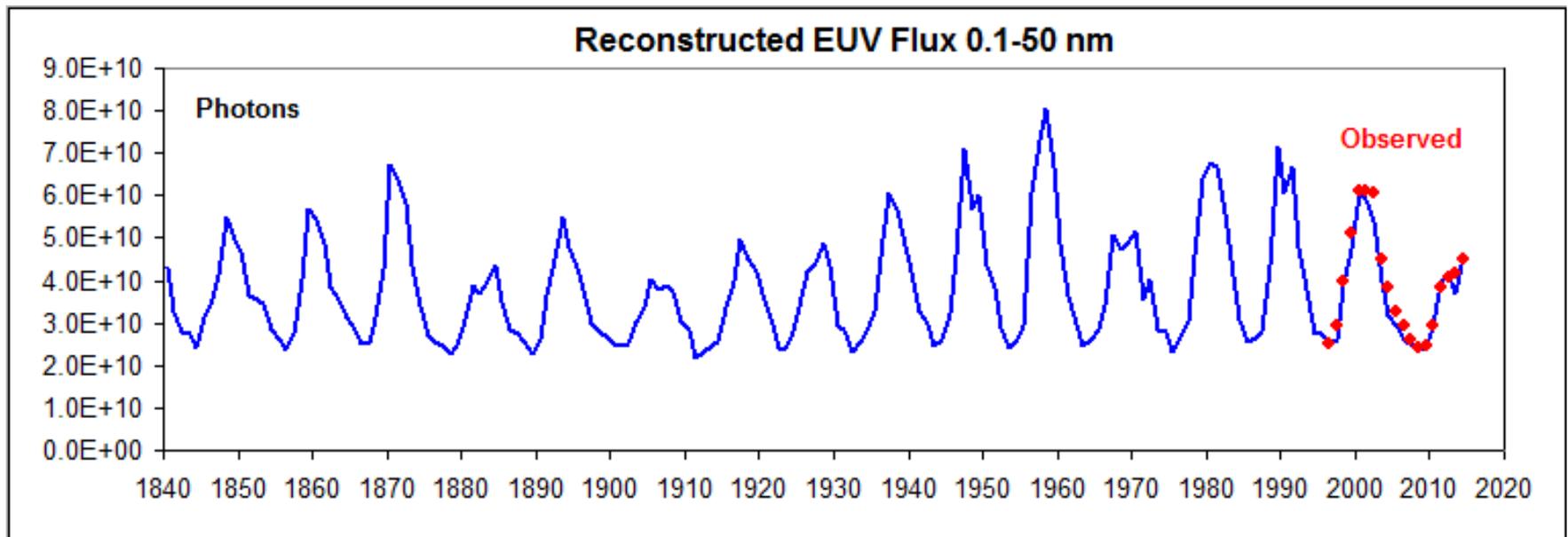


From the Standard Deviation and the Number of Station in each Year we can compute the Standard Error of the Mean and plot the  $\pm 1$ -sigma envelope

Since the ionospheric conductivity,  $\Sigma$ , depends on the number of electrons  $N$ , we expect that  $\Sigma$  scales with the square root of the overhead EUV flux (the Chapman function:  $N = \sqrt{(J/\alpha \cos(\chi))}$ ,  $J$  = ionization rate,  $\alpha$  = recombination rate,  $\chi$  = Zenith angle for the dominant plasma species  $O^+_2$  for  $\lambda < 102.7$  nm)

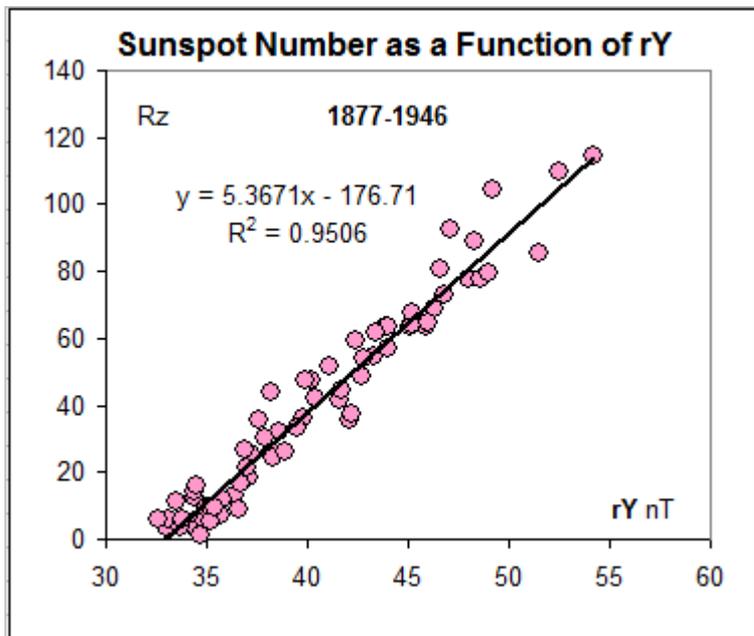
# From this Effect we can Reconstruct the EUV Flux 1840-2014

$$\text{EUV [photons]} = 3.3 \cdot 10^9 [\text{rY nT}]^2$$



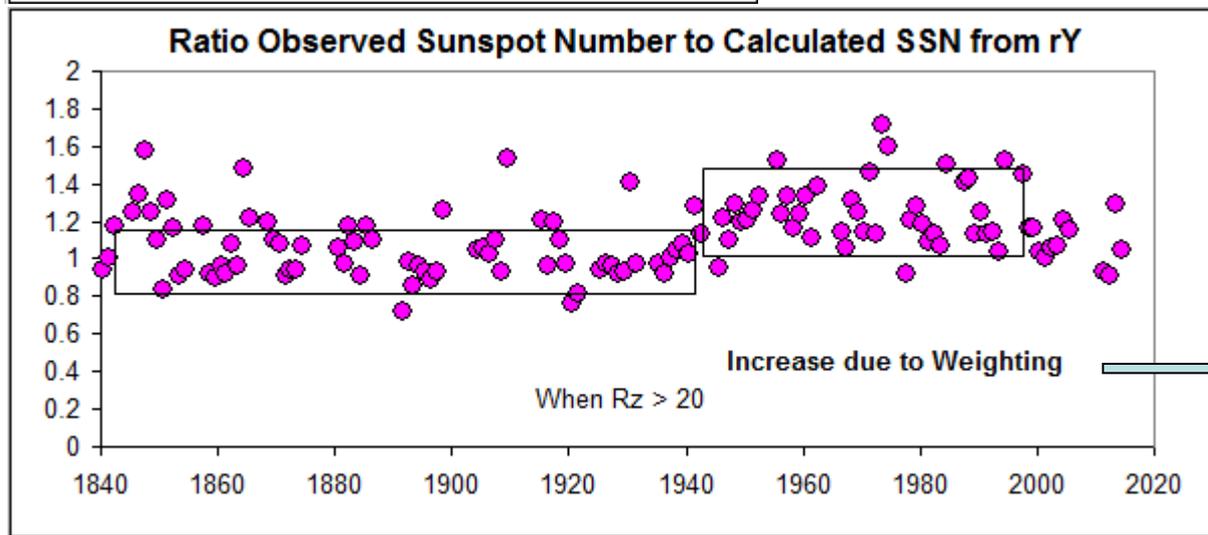
This is, I believe, an accurate depiction of solar activity since 1840 at least as measured by the magnetic field driving the EUV [and F10.7]

# We can compare that with the Zurich Sunspot Number



	ratio
1840-1876	1.052
1877-1946	1.000
1947-1999	1.210
2000-Now	1.022

Wolfer & Brunner

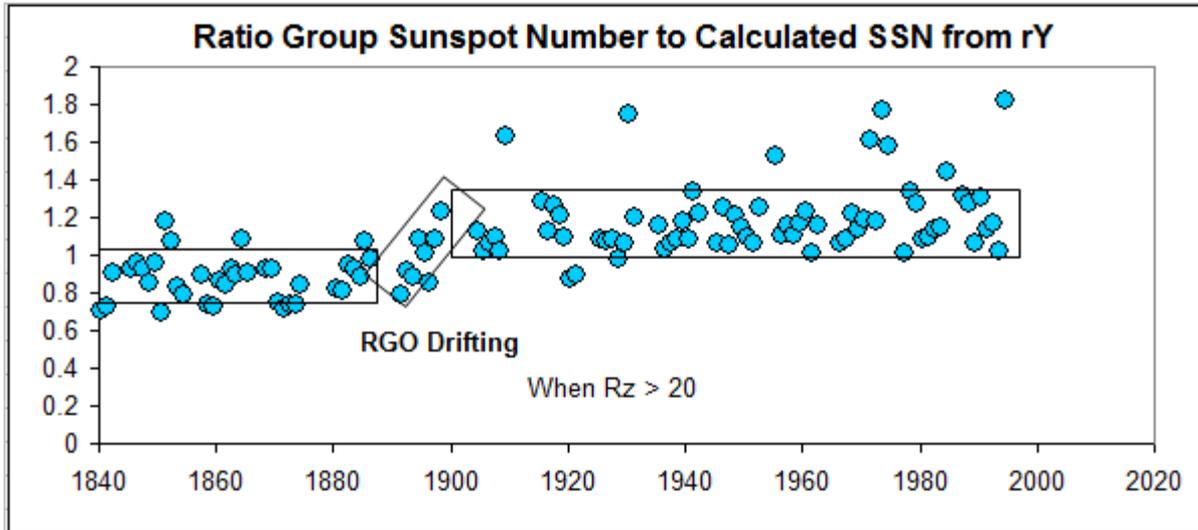


313 1 spot  
 Locarno 2014-9-22

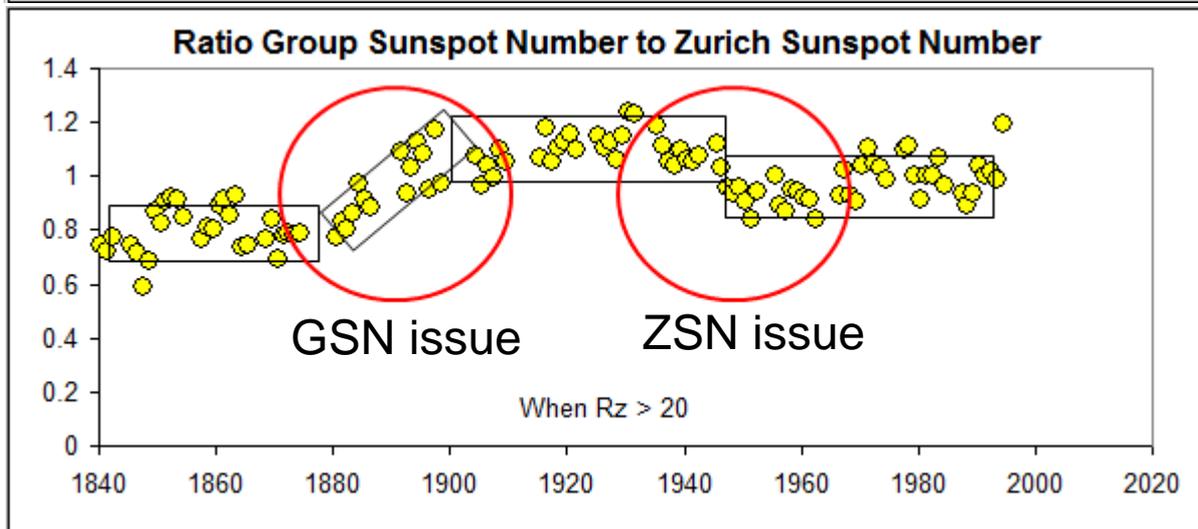
316 2 spots

g	f	t	B
313	3	J	+11'
316	4	C	+5'

# How About the Group Sunspot Number?

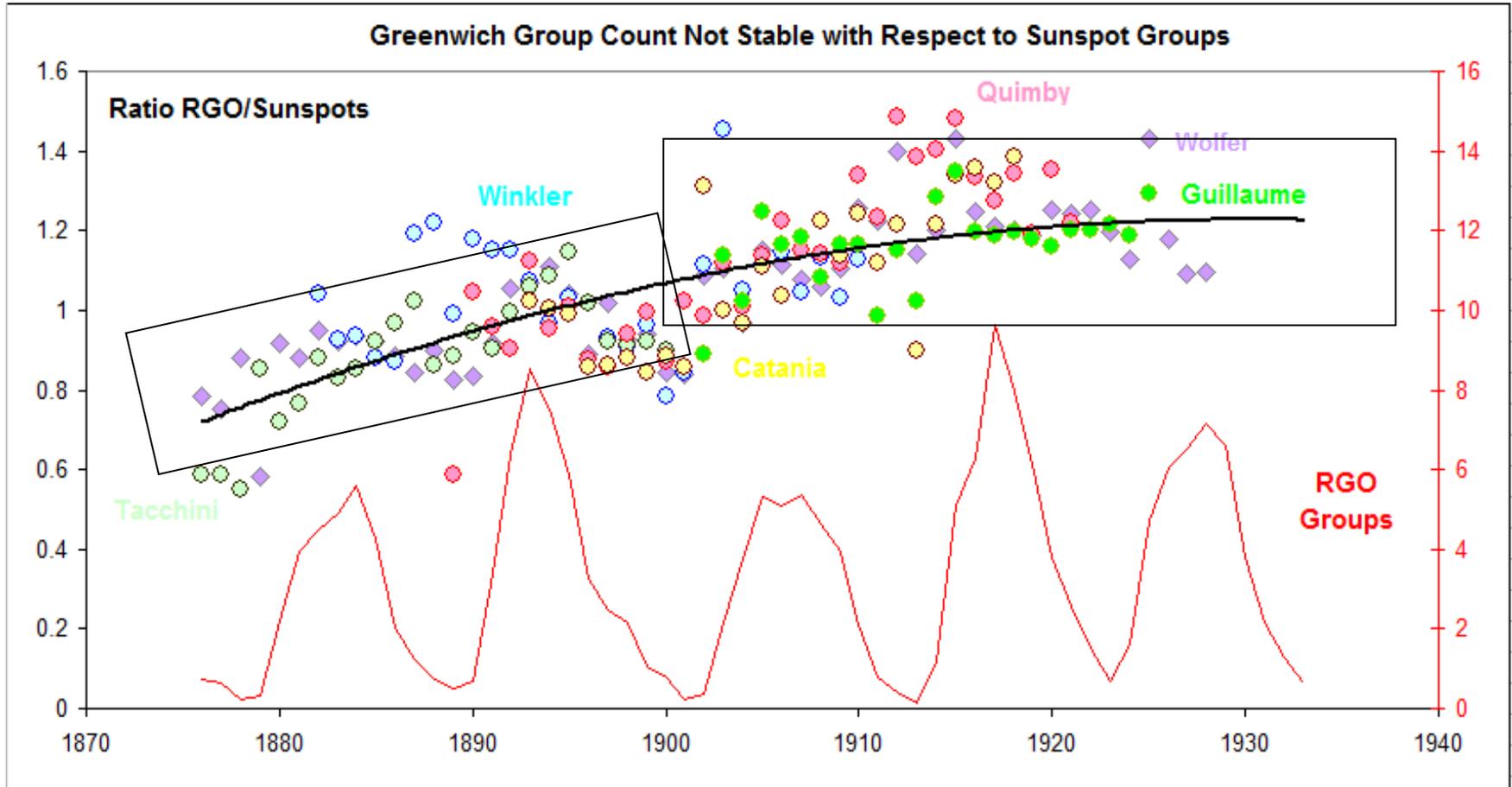


The main issue with the GSN is a change relative to the ZSN during 1880-1900. This is mainly caused by a drift in the reference count of the standard (Royal Greenwich Observatory)



The ratio between the Group Sunspot Number and the Zürich Sunspot Number reveals two major problem areas. We can now identify the cause of each

# RGO Groups/Sunspot Groups



Early on RGO counts fewer groups than Sunspot Observers

# Conclusions

“In order to move forward and assemble a fully revised and extended SN series, three main steps are required:

- Combining all corrections obtained independently and verifying the global consistency of the resulting series.
- Determining more accurately the magnitude and time domain of each correction, and deriving estimates of the uncertainties.
- Extending the original SN series, so far limited to 1750, back to the first telescopic observations. The scarcity of data will most probably impose the use of the group number for this early part. It is thus essential that the GN and SN series are brought first in full agreement for the whole interval following 1750.

Several issues remain open and require deeper analyses that may still span many years. The revised series will thus be open to future improvements as new results are published and new historical documents are progressively recovered. Therefore, in order to properly document future occasional modifications the WDC-SILSO will implement a versioning system, with an incremental description of changes added to each version.”

# Sneak Peek

- Transform the current SSN time series, from Galileo to the present time, to a scale that is homogeneous in terms of counting criteria (those of Wolf and Wolfer) and has no k factor (i.e.,  $k = 1$ , no artificial factor 0.6).
- The transformed time series will not be called the “International Sunspot Number” anymore, but simply the “Wolf number”:

$$W = 10 G + S .$$

- While  $W$  should be used by the international community as the reference solar activity index, other counting methods (e.g. spot weighting) and proxies will be explored in parallel, and their correlations with the  $W$  number will be studied.