The History of the Sunspot Number

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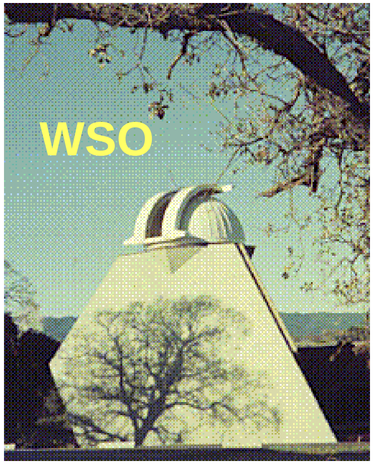
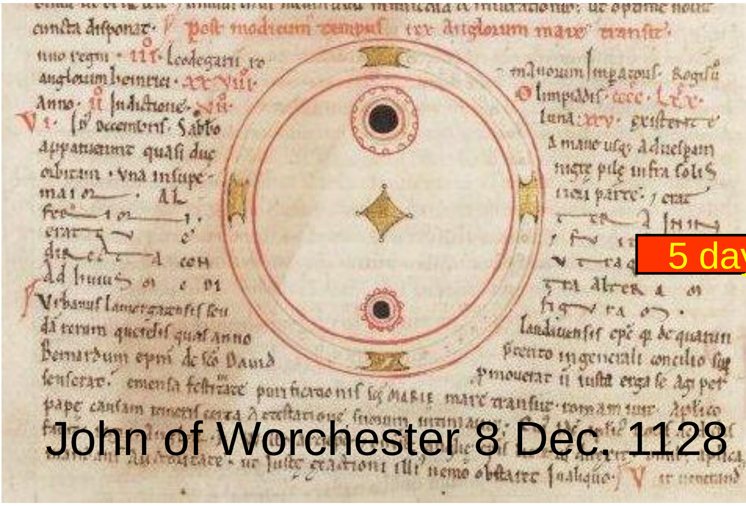
AOGS, Singapore, August 2015



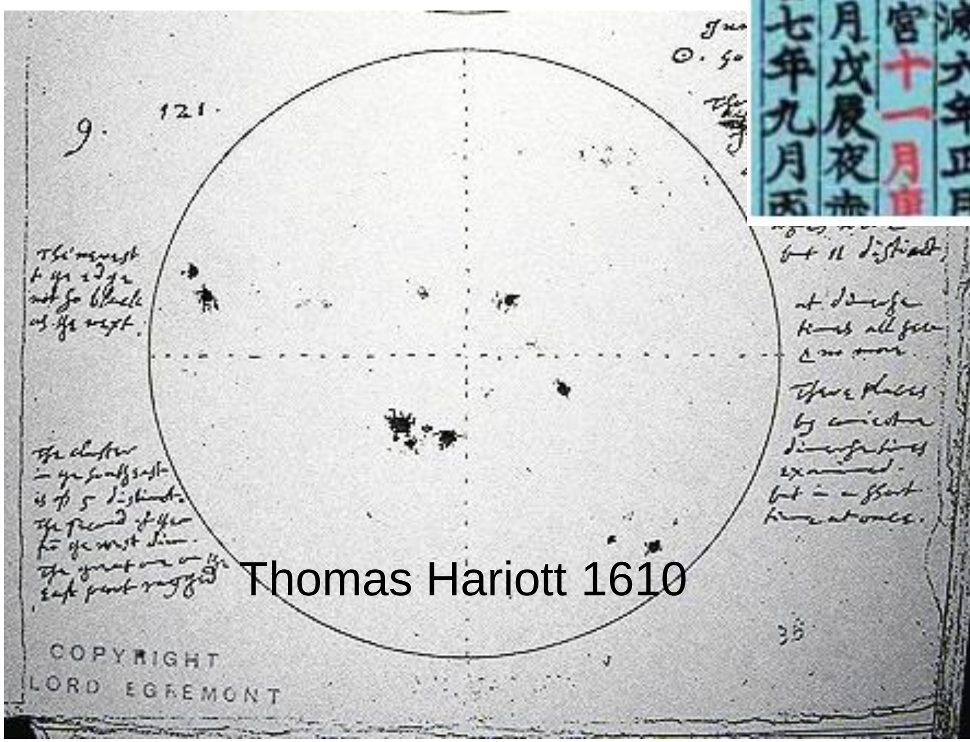
Early Observations

How to Quantify?
One needs a
Sunspot “Number”
or “Index”

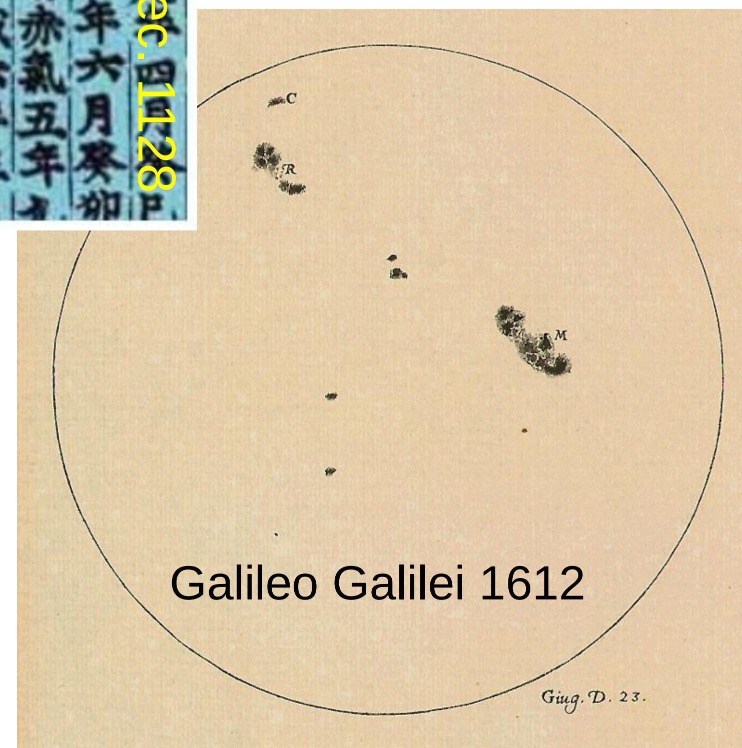

John of Worchester 8 Dec. 1128

5 days later


Korean Aurora 13 Dec. 1128



Thomas Hariott 1610



Galileo Galilei 1612

Six or Seven Groups

Six or Seven Groups

The Sunspot Number ~1856

Rudolf Wolf (1816-1893)

Observed 1849-1893

1849-1855 Bern

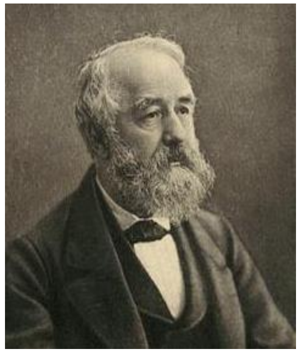
1856-1893 Zürich

- Wolf Number = $k_W\,(10{*}G + S)$
- G = number of groups
- S = number of spots
- k_W = telescope aperture + site seeing + personal factor + learning curve

Principal Actors and Observers

Samuel Heinrich Schwabe
1789–1875

(1825-1867)

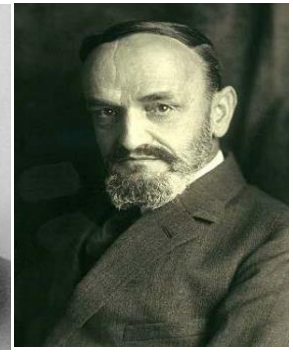


Johann Rudolf Wolf
1816-1893

(1849-1893)

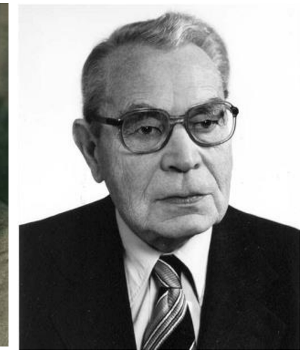
Alfred Wolfer
1854-1931

(1877-1928)



William Otto Brunner
1878-1958

(1926-1945)



Max Waldmeier
1912-2000

(1945-1980)

Sergio Cortesi
-

(1957-present)

Directors of Zurich Observatory

1825-1980 the Sunspot Number (SSN) was derived mostly from a single observer. Since then, the SSN is determined by SILSO in Brussels [Belgium] as an average of ~60 observers normalized to Cortesi in Locarno

Wolf initially used 4' Fraunhofer telescopes with aperture 80 mm [Magn. X64]

Still in use today [by T. Friedli] continuing the Swiss tradition [under the auspices of the Rudolf Wolf Gesellshaft]

This is the 'Norm' Telescope in Zürich

Wolf occasionally [and eventually – from 1860s on - exclusively] used much smaller handheld, portable telescopes [due to frequent travel], leaving the large 80mm telescope for his assistants

These telescopes also still exist and are still in use today to safeguard the stability of the series

Wolf estimated that to scale the count using the small telescopes to the 80mm Standard telescope, the count should be multiplied by 1.5 (The *k*-factor)

k-factor Dependencies

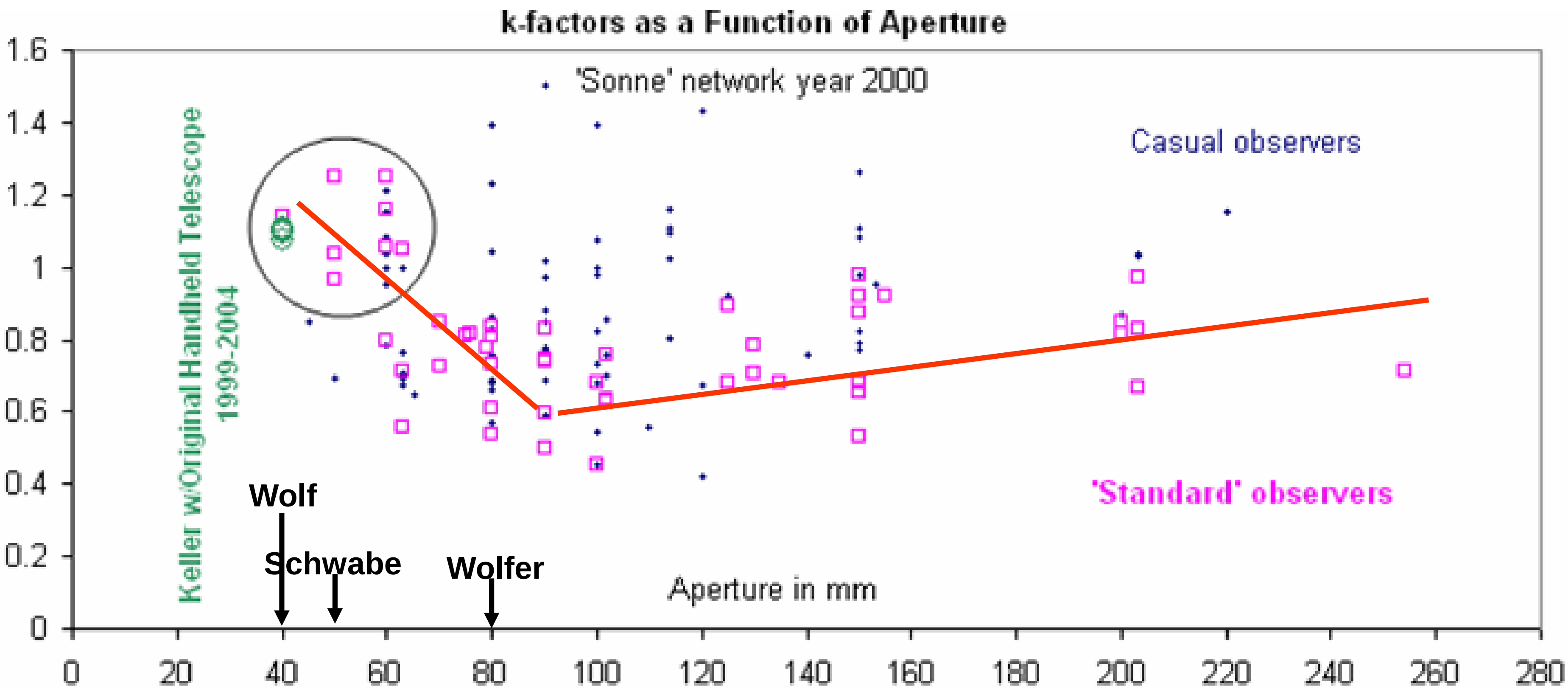


Table 2. *k*-factors as a function of seeing for Kandilli Observatory (Atlas *et al.*, 1998)

Seeing	1(worst)	2	3	4	5(best)
Days	244	473	812	682	126
k	0.96	0.95	0.90	0.83	0.74

Wolf increased all pre-1849 numbers by 25%

Abstract of his latest Results. By Prof. Wolf.

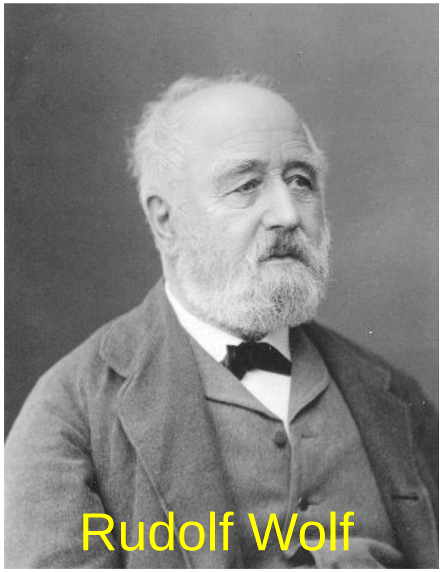
(*Translation communicated by Mr. Carrington.*)

Some fine series of observations of Flaugergues, Adams, Arago, and others, have enabled me to fill in previous breaks, and to express in the same unit my Relative numbers (for the abundance of Solar Spots in successive years) for the years from 1749 to 1860. They are as follows:—

1749	63·8	1777	63·0	1805	50·0?	1833	7·5 *m*
1750	68·2 M	78	94·8	06	30·0?	34	11·4
51	40·9	1779	99·2 M	07	10·0?	35	45·5
52	33·2	1780	72·6	08	2·2	36	96·7
53	23·1	81	67·7	1809	0·8	37	111·0 M
54	13·8	82	33·2	1810	0·0 *m*	38	82·6
55	6·0 *m*	83	22·5	11	0·9	1839	68·5
56	8·8	84	4·4 *m*	12	5·4	1840	51·8

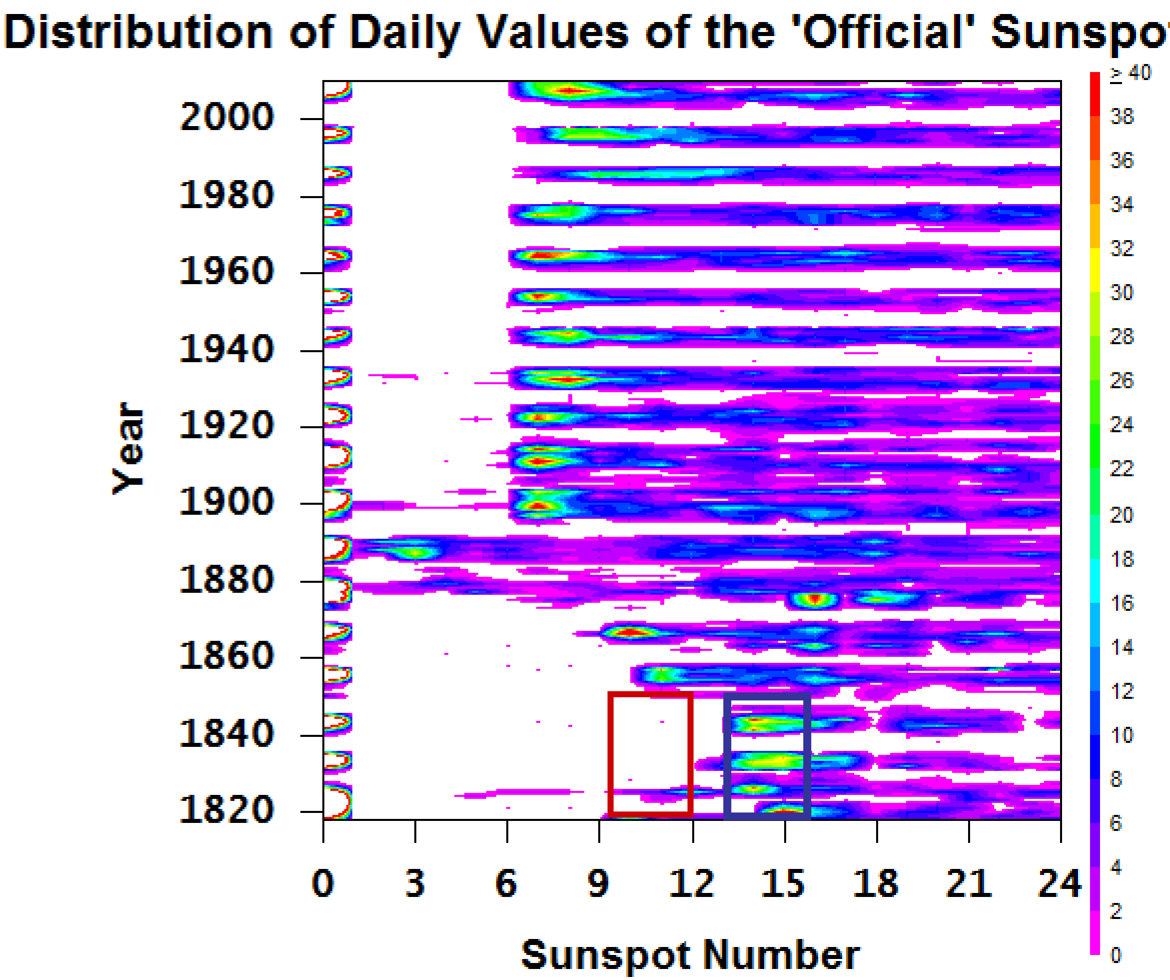
1749	80.9	1777	92.5	1805	42.2	1833	8.5 m
1750	83.4 M	78	154.4	06	28.1	34	13.2
51	47.7	1779	125.9 M	07	10.1	35	56.9
52	47.8	1780	84.8	08	8.1	36	121.5
53	30.7	81	68.1	1809	2.5	37	138.3 M
54	12.2	82	38.5	1810	0.0 m	38	103.2
55	9.6 m	83	22.8	11	1.4	1839	85.7
56	10.2	84	10.2 m	12	5.0	1840	64.6

From MNRAS, 1861 and from the current dataset at SIDC in Brussels



Schwabe's telescope was smaller than the standard 80mm and from comparison with other observers, Wolf (in 1865) decided to increase Schwabe's counts by 25%

The Wholesale Update of SSNs before 1849 is Clearly Seen in the Distribution of Daily SSNs



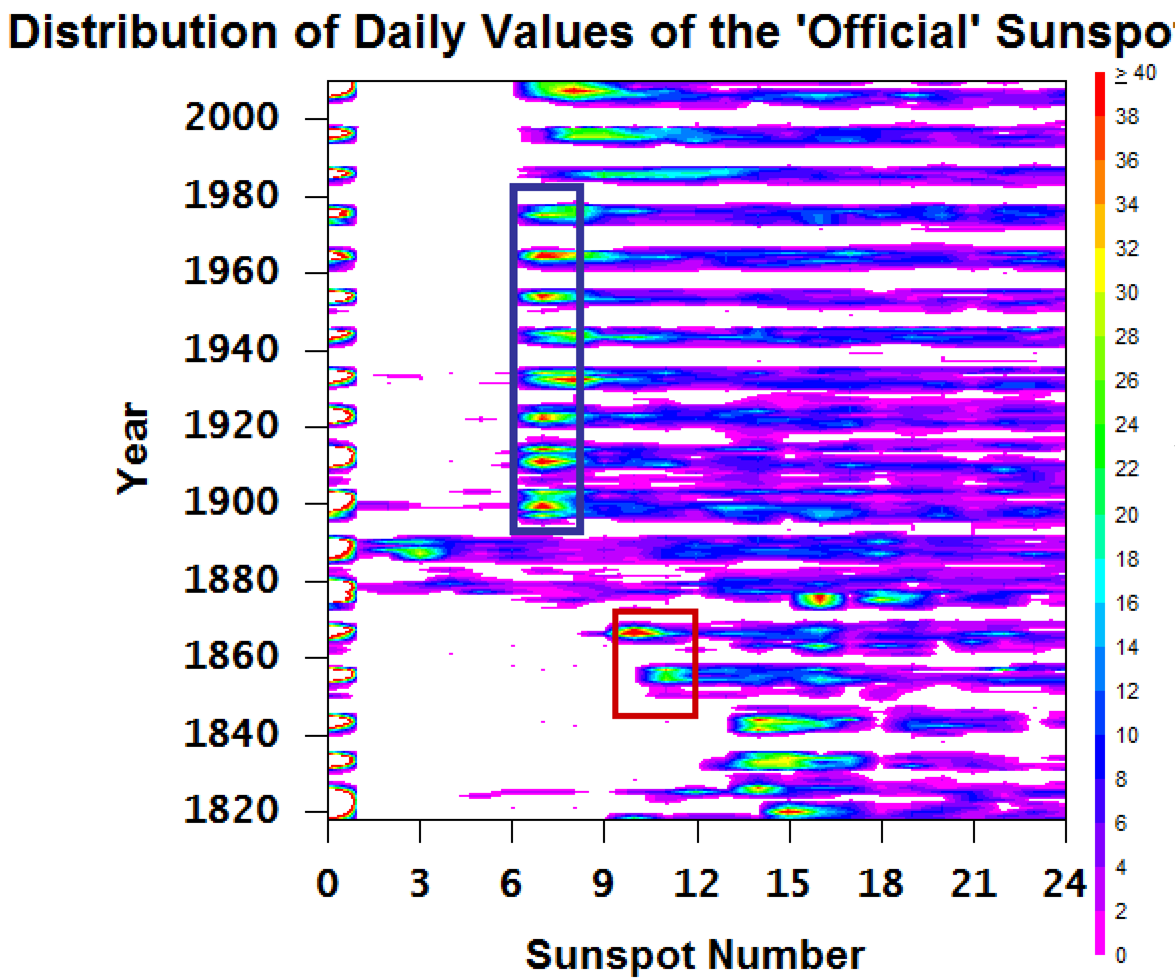
The smallest non-zero SSN is 11, but there are no 11s before 1849

11 * 5/4 = 14

Wolfer’s Change to Wolf’s Counting Method

- Wolf only counted spots that were ‘black’ and would have been clearly visible even with moderate seeing thus omitting the smallest spots
- Wolfer disagreed, and pointed out that the above criterion was much too vague and advocating counting every spot that could be seen
- This, of course, introduces a discontinuity in the sunspot number, which was corrected by using a much smaller k value [~0.6 instead of Wolf’s 1]

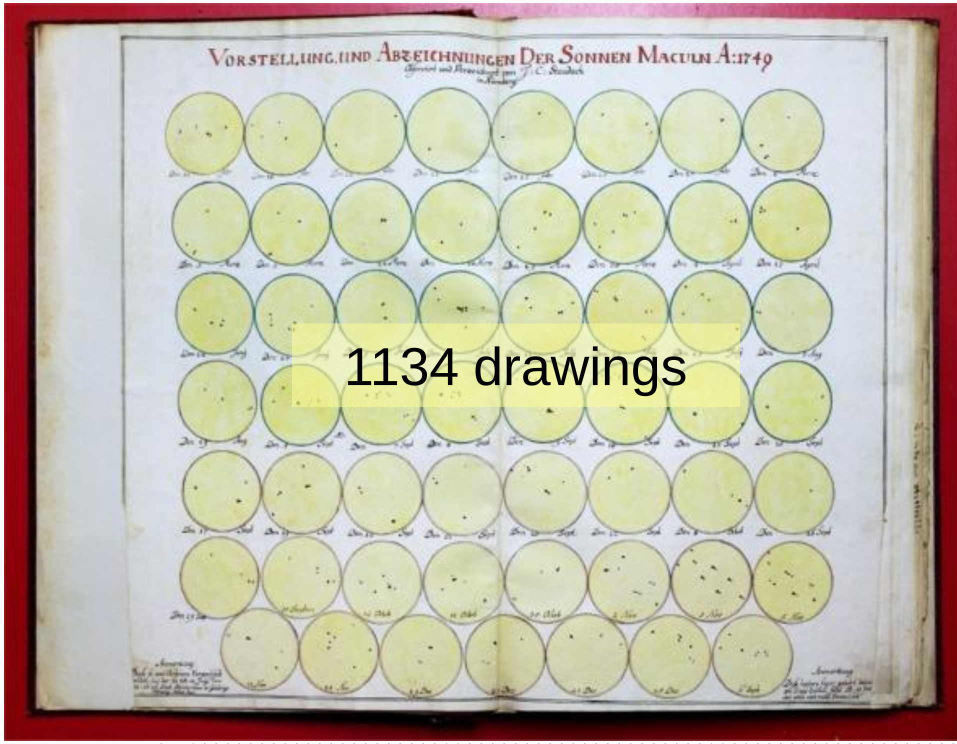
The effect of Wolfer's change to the counting method is also clearly seen in the daily SSN

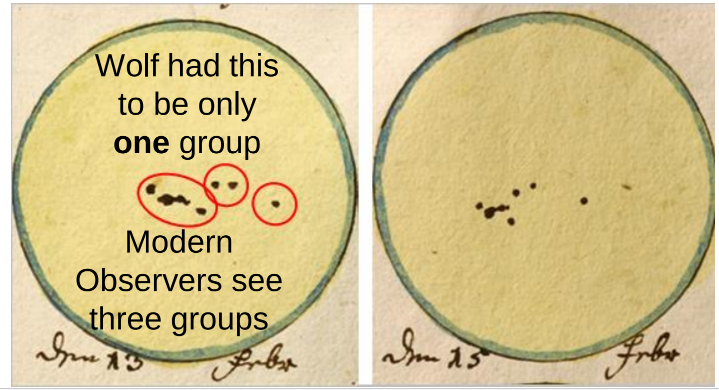


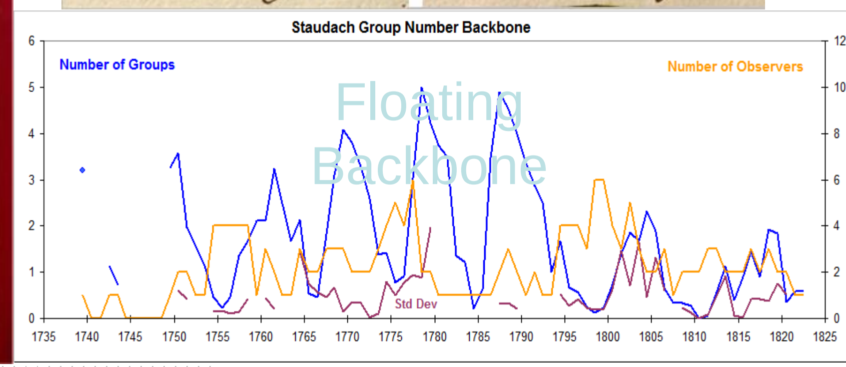
The smallest non-zero SSN is 11, but with the 0.6 k-factor the smallest reported values become 7

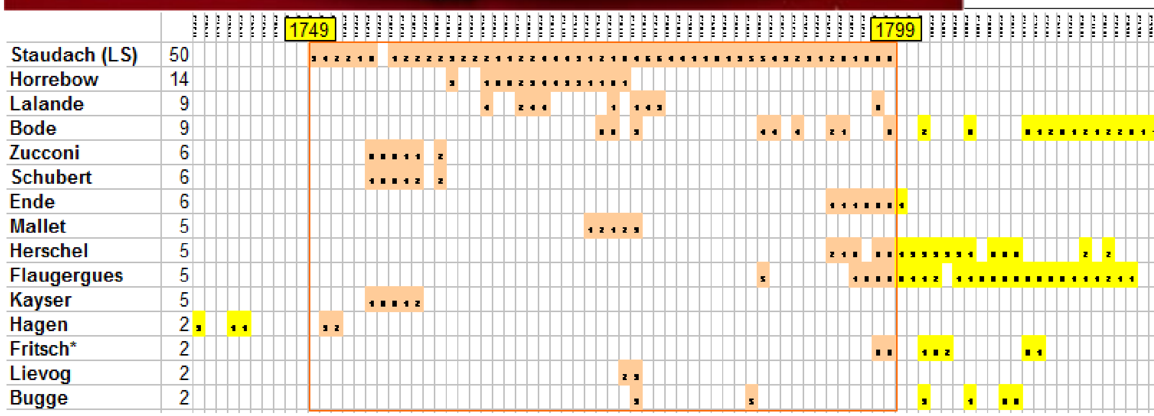
11 * 0.6 = 6.6 ~7

J.C. Staudach's Drawings 1749-1799



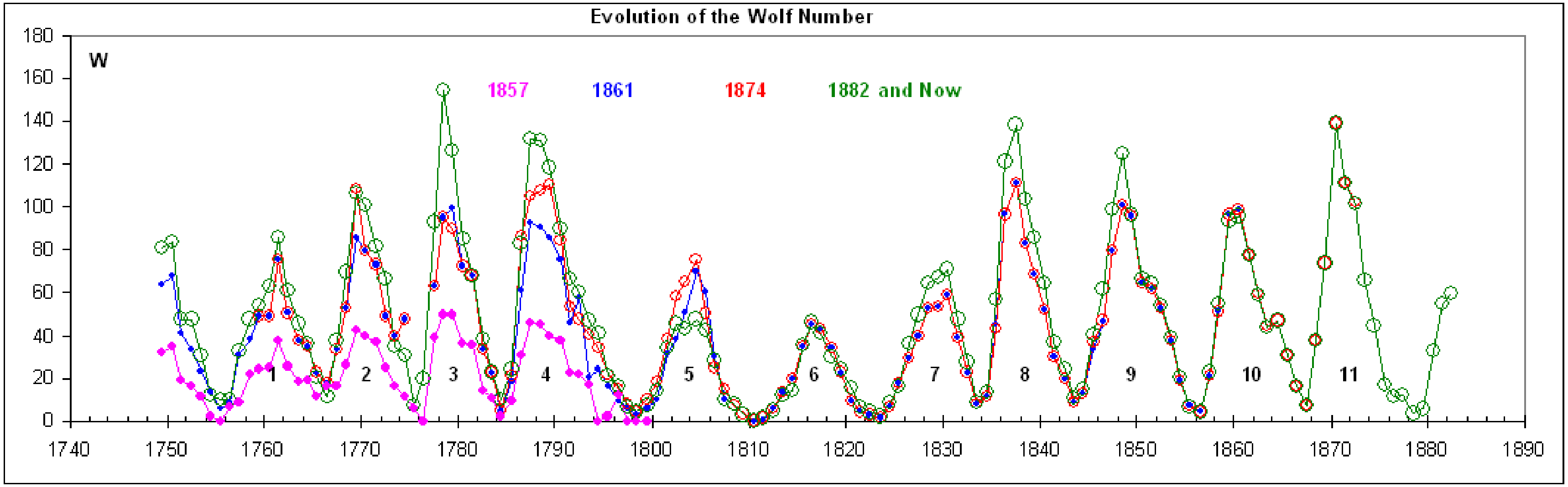


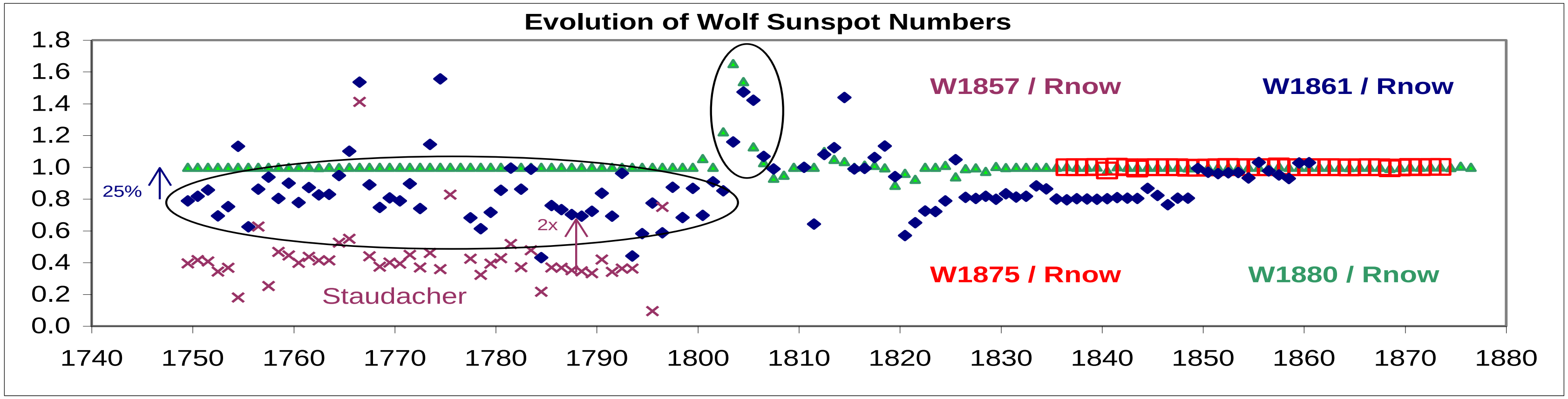


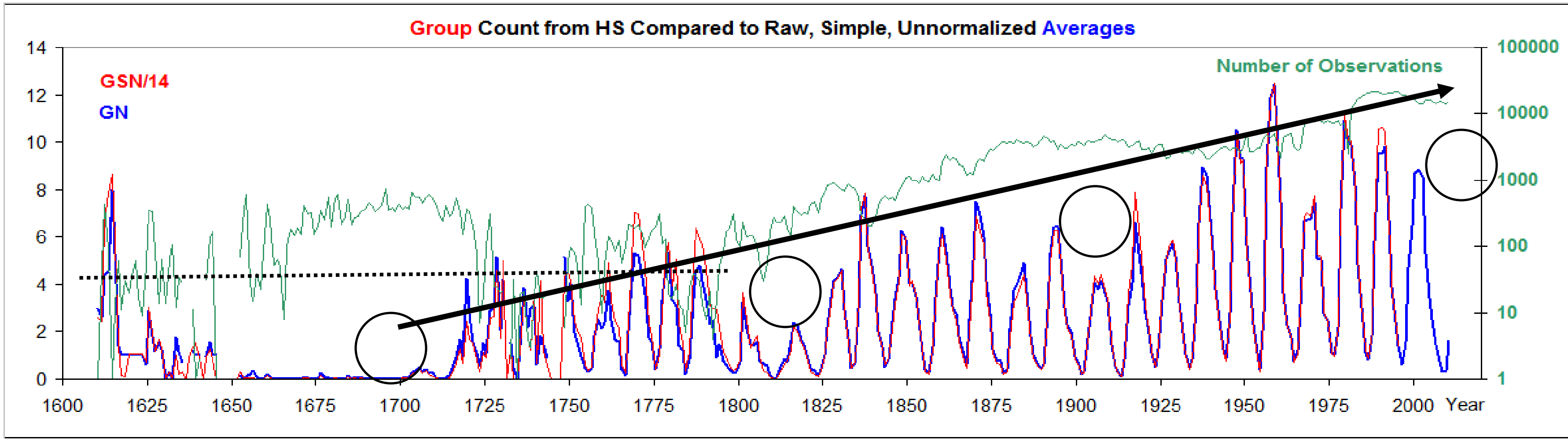


Wolf undercounted the number of groups on the Staudach drawings by 25%. We use my re-count in building the backbone

The Sunspot Number was repeatedly subject to revisions and upgrades and not 'carved in stone'







NUMBER OF SUNSPOT GROUPS FOR THE YEAR: 1683
AS OBSERVED BY: SIVERUS, H., HAMBURG

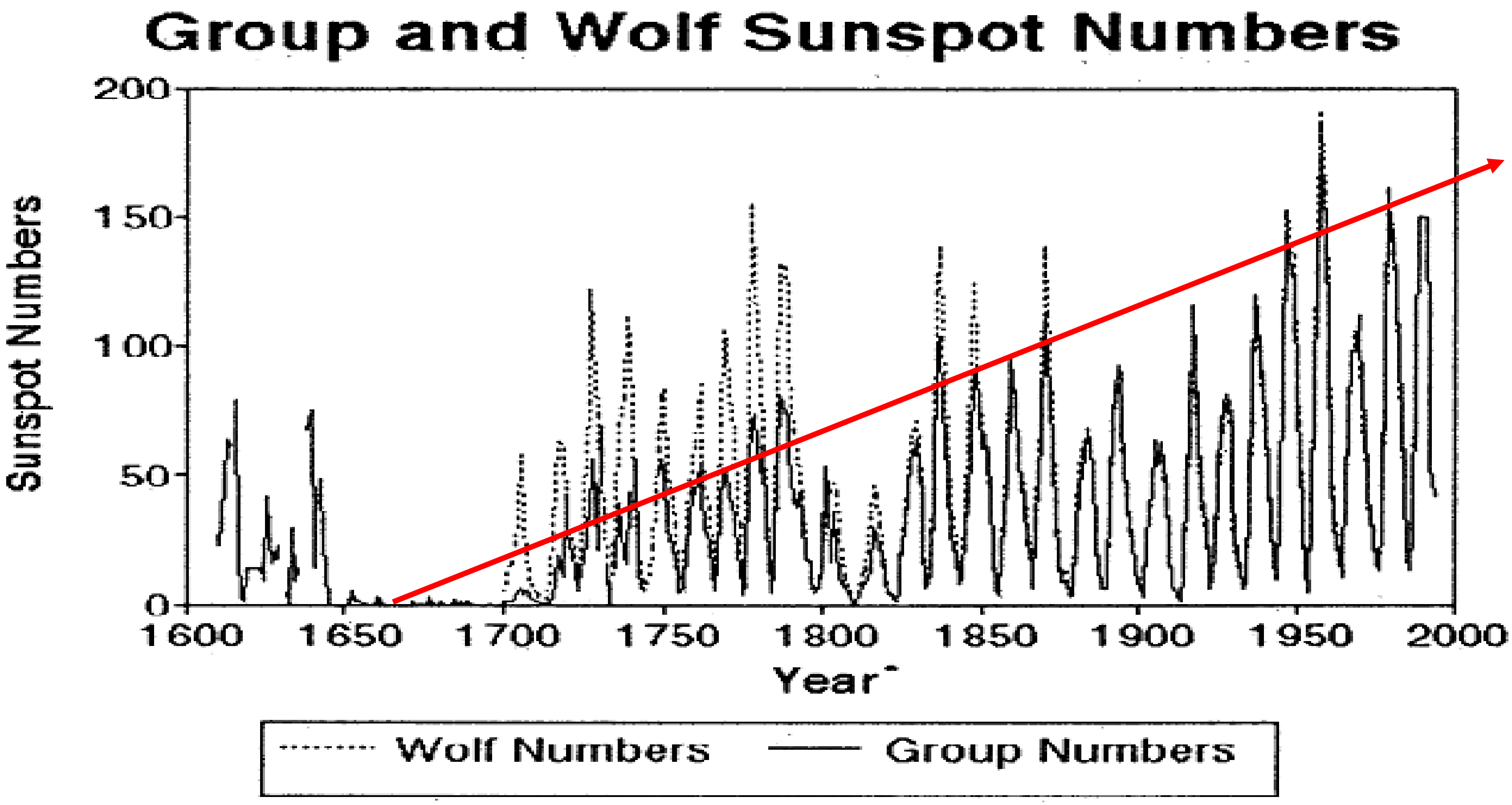
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0
29	0	-99	0	0	0	0	0	0	0	0	0	0
30	0	-99	0	0	0	0	0	0	0	0	0	0
31	0	-99	0	-99	0	-99	0	0	-99	0	-99	0
means:	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

"I didn't see any spots this year"

The Group Number

Douglas Hoyt and Ken Schatten proposed (1995) to replace the sunspot number with a count of Sunspot Groups. H&S collected 350,000 observations (not all of them good) and labored hard to normalize them to modern observations

The Problem: Discordant Sunspot Numbers

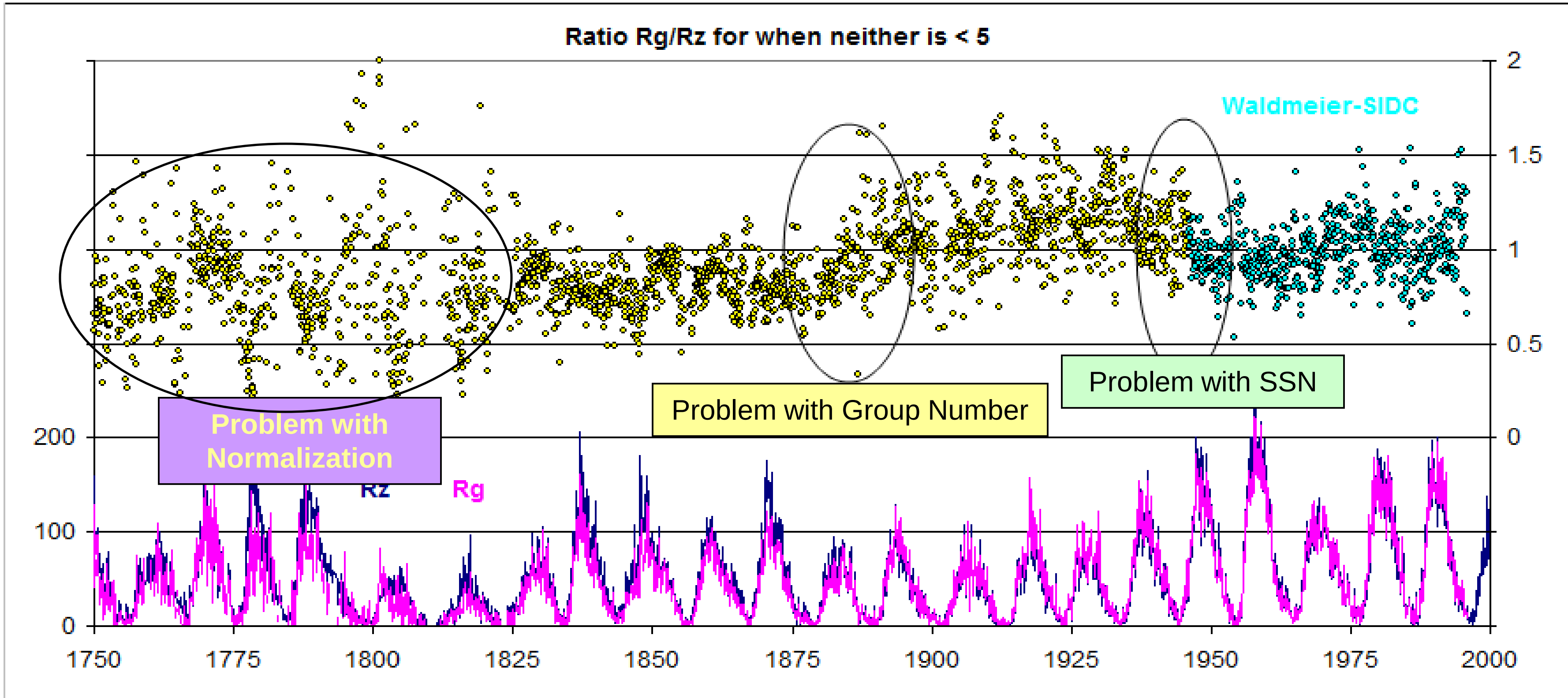


Hoyt & Schatten, GRL *21*, 1994

The SSN Workshops. The Work and Thoughts of Many People

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

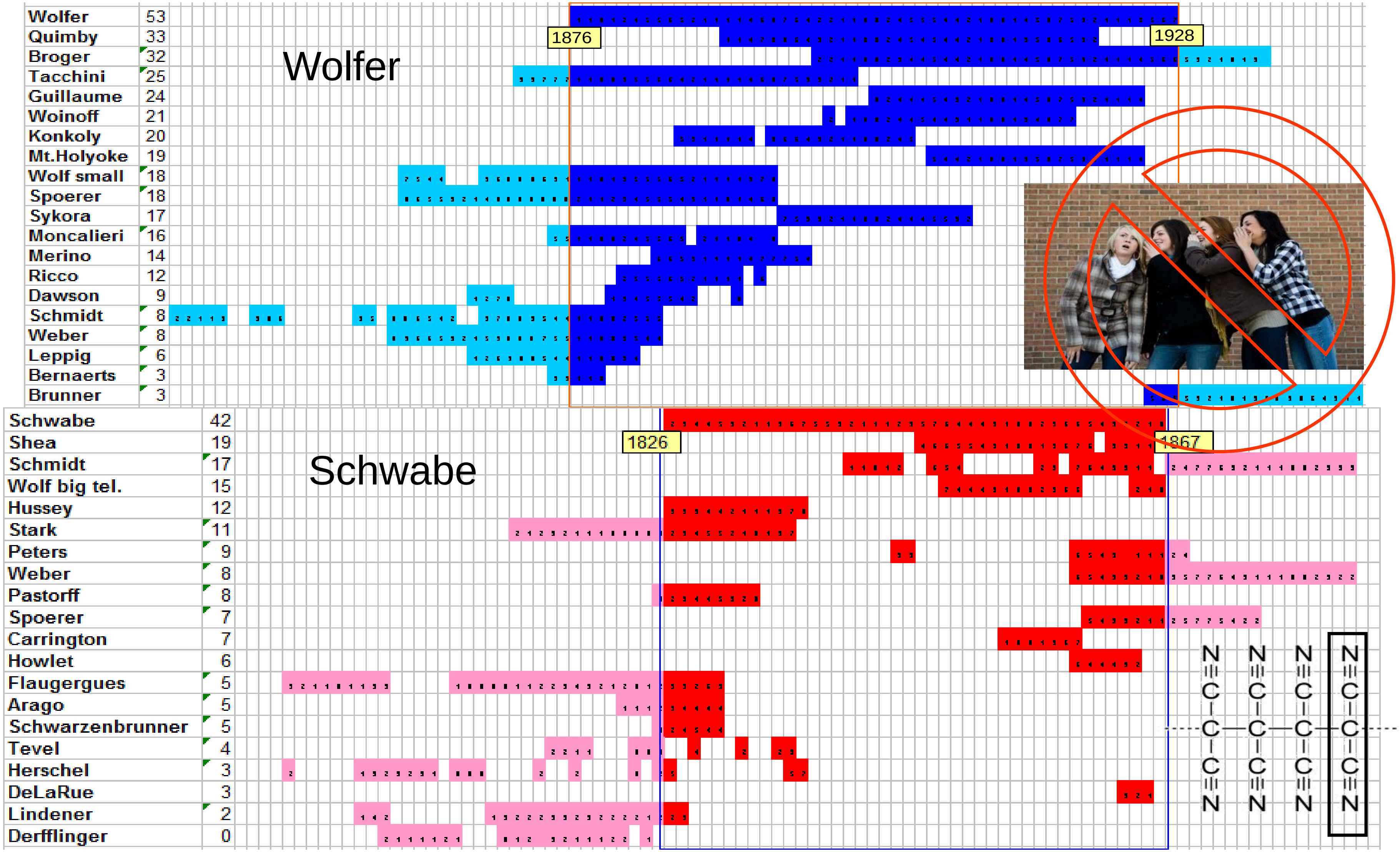
The Ratio Group/Zürich SSN has Two Significant Discontinuities



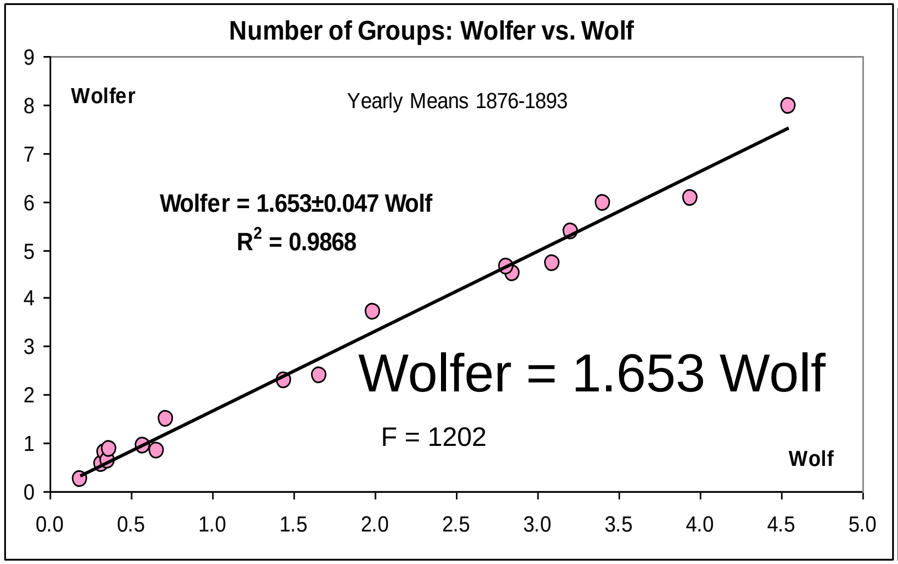
At ~1947 (After Max Waldmeier took over) and at 1876-1910 (Greenwich calibration drifting)

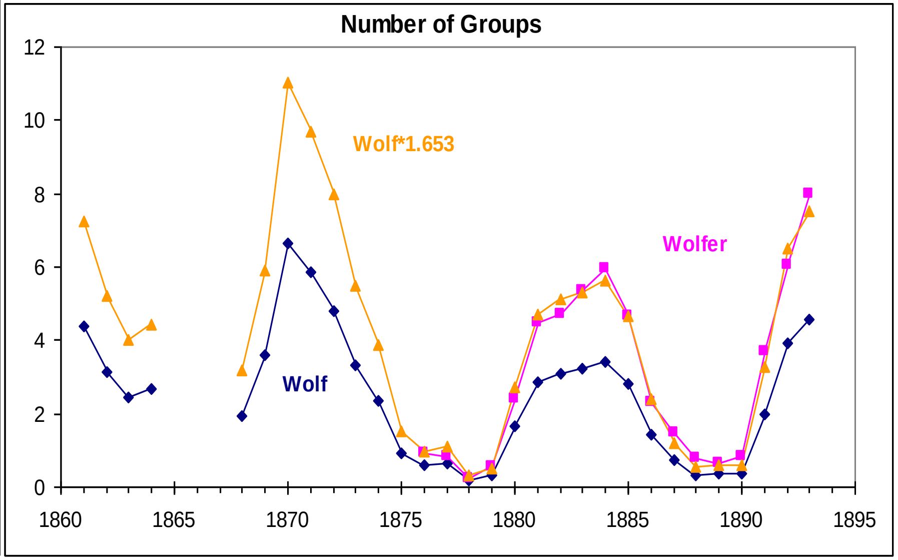
As we found problems with the H&S normalization, we (Svalgaard & Schatten) decided to build a new Group Series 'from scratch'

A New Approach: The Backbones



Normalization Procedure



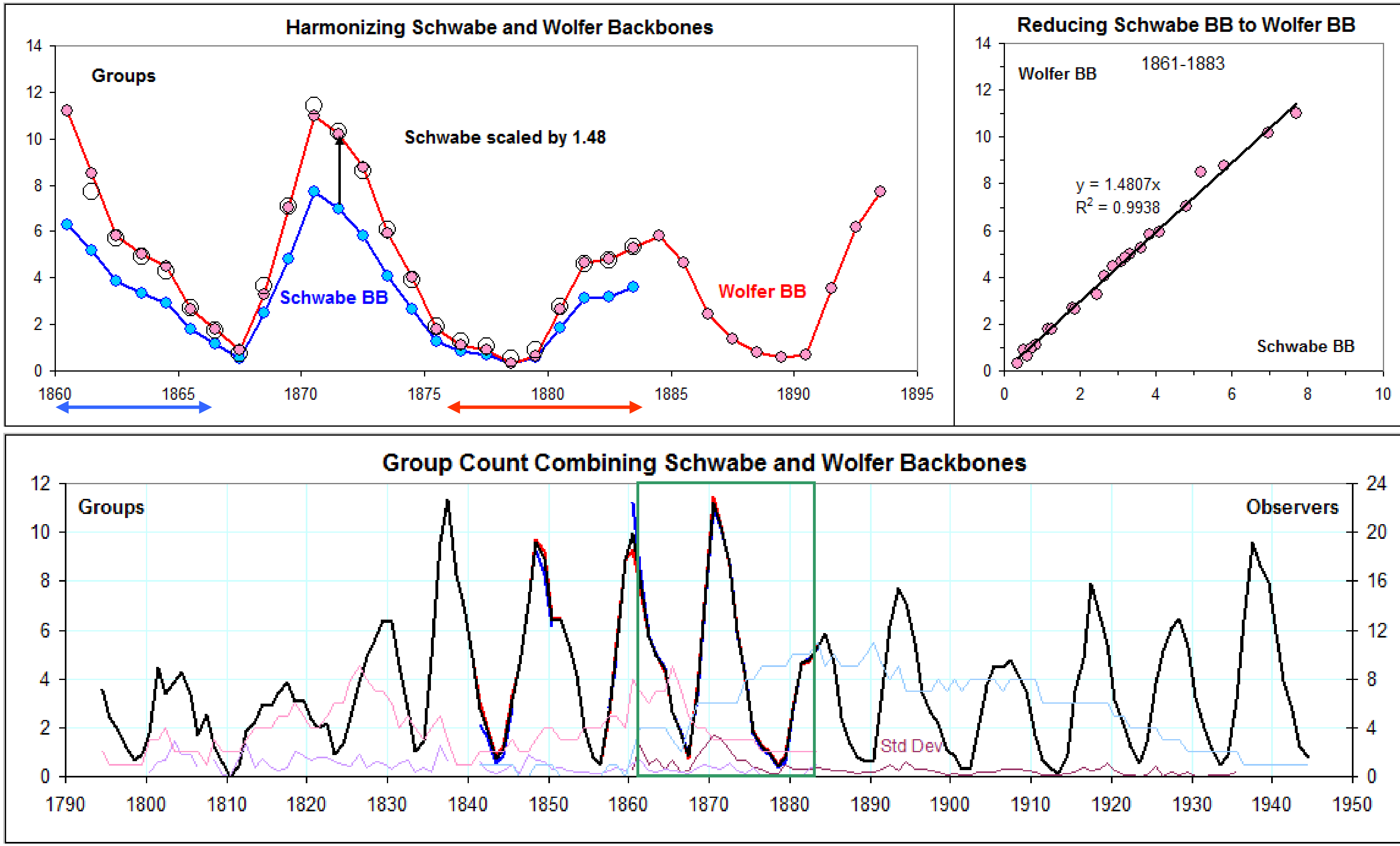


For each Backbone we regress each observers group counts for each year against those of the primary observer, and plot the result [left panel]. The slope gives us what factor to multiply the observer's count by to match the primary's.

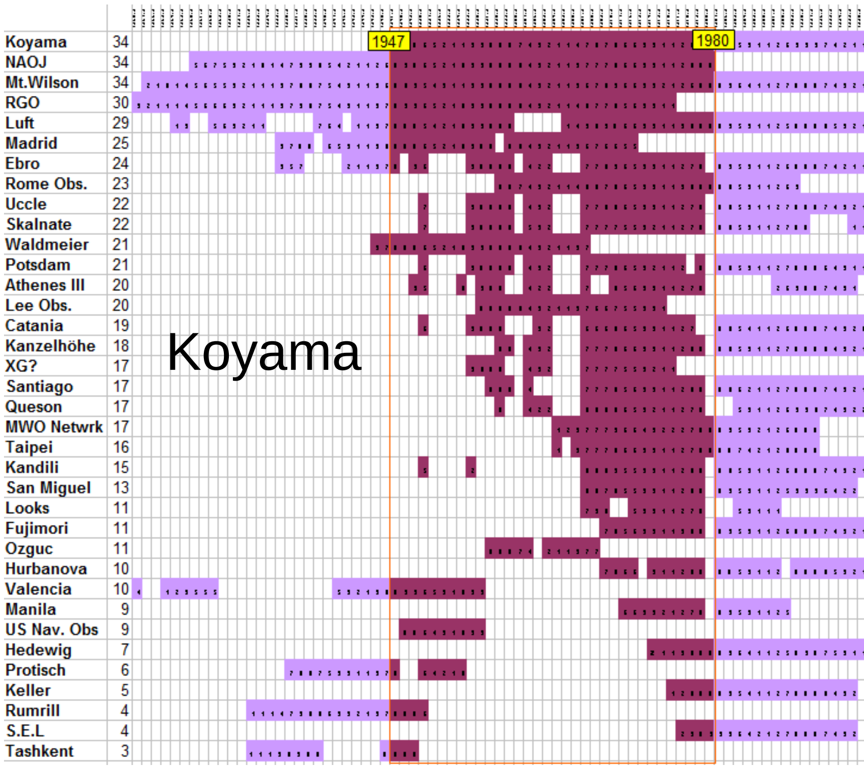
The right panel shows a result for the Wolfer Backbone: blue is Wolf's count [with his small telescope], pink is Wolfer's count [with the larger telescope], and the orange curve is the blue curve multiplied by the slope.

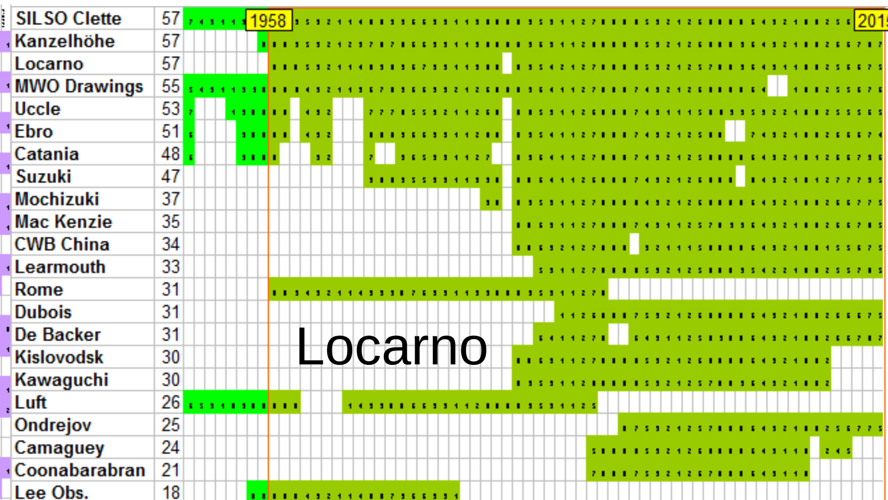
The Backbone is then constructed as the average normalized counts of all observers that are part of the backbone

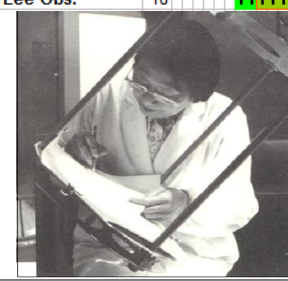
Harmonizing Schwabe and Wolfer Backbones

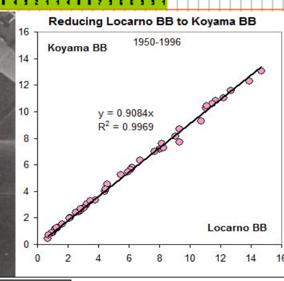


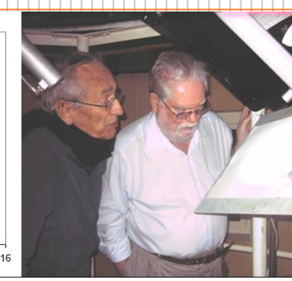
The Modern Backbones

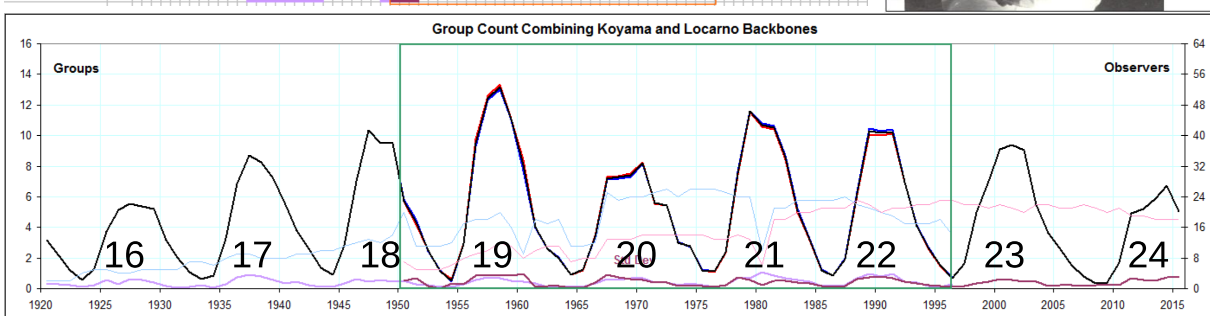








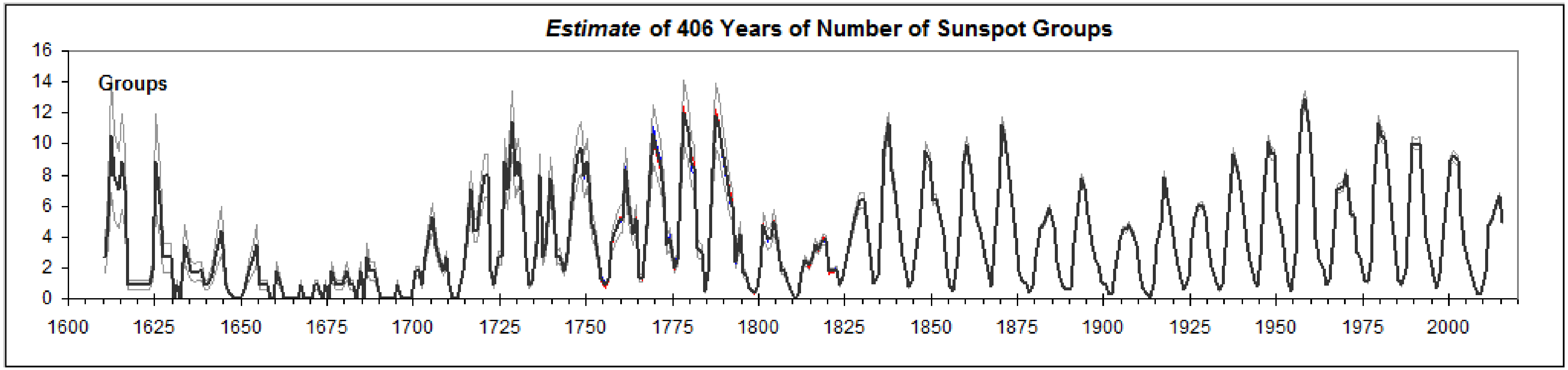


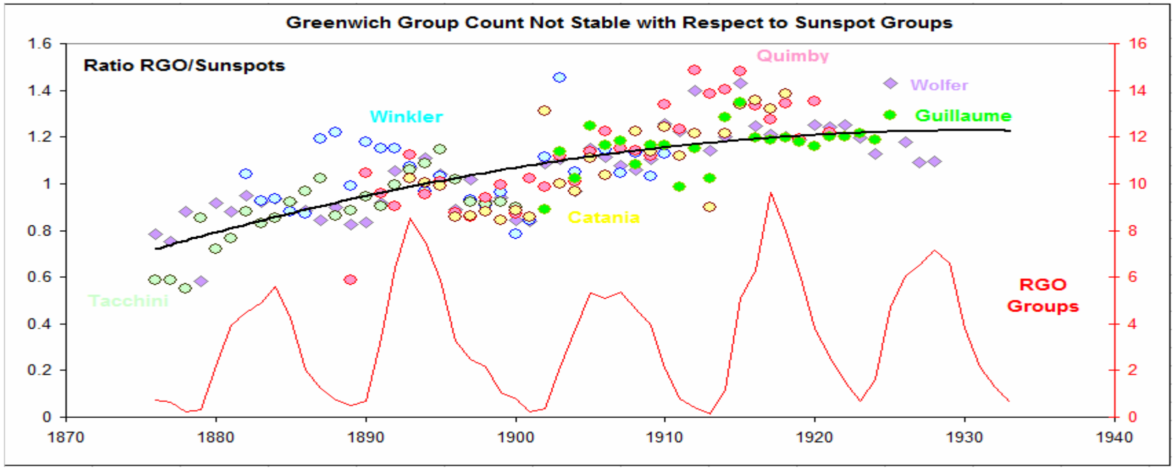


Ms. Hisako Koyama,
小山 ヒサ子 (1916-1997)

Mr. Sergio Cortesi,
Locarno.

Putting it All Together (Pure Solar)

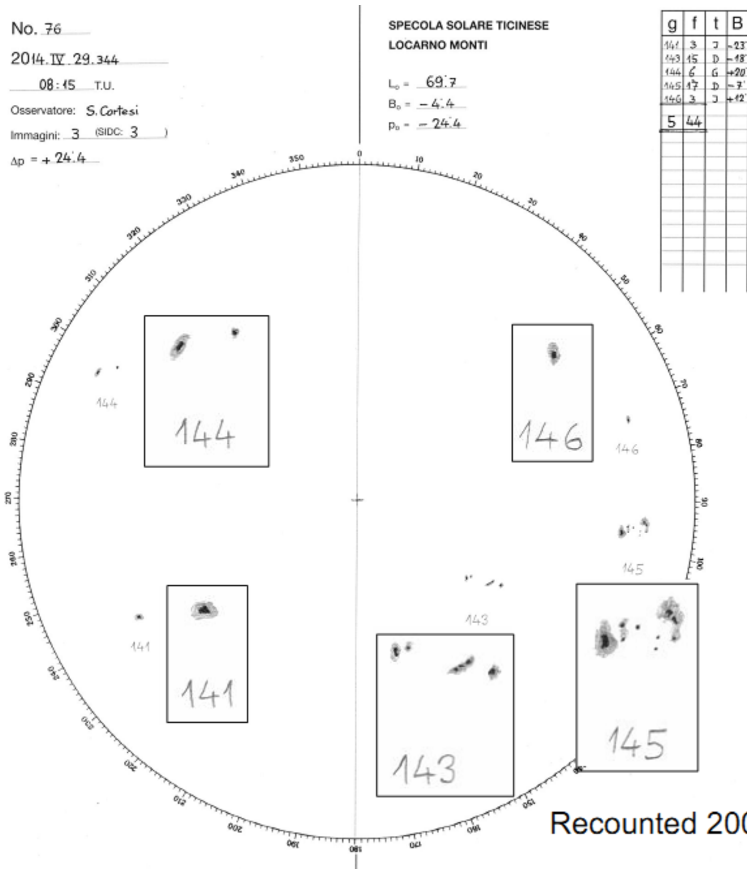




Hoyt & Schatten used the Group Count from RGO [Royal Greenwich Observatory] as their Normalization Backbone. Why don't we?

Because there are strong indications that the RGO data is drifting before ~1900. And that is a major reason for the ~1885 change in the level of the H&S Group Sunspot Number

In 1940s Waldmeier in Zürich began to ‘weight’ larger spots and count them more than once



Recounted 2003-2014: ~55,000 spots

Counting with Weighting

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

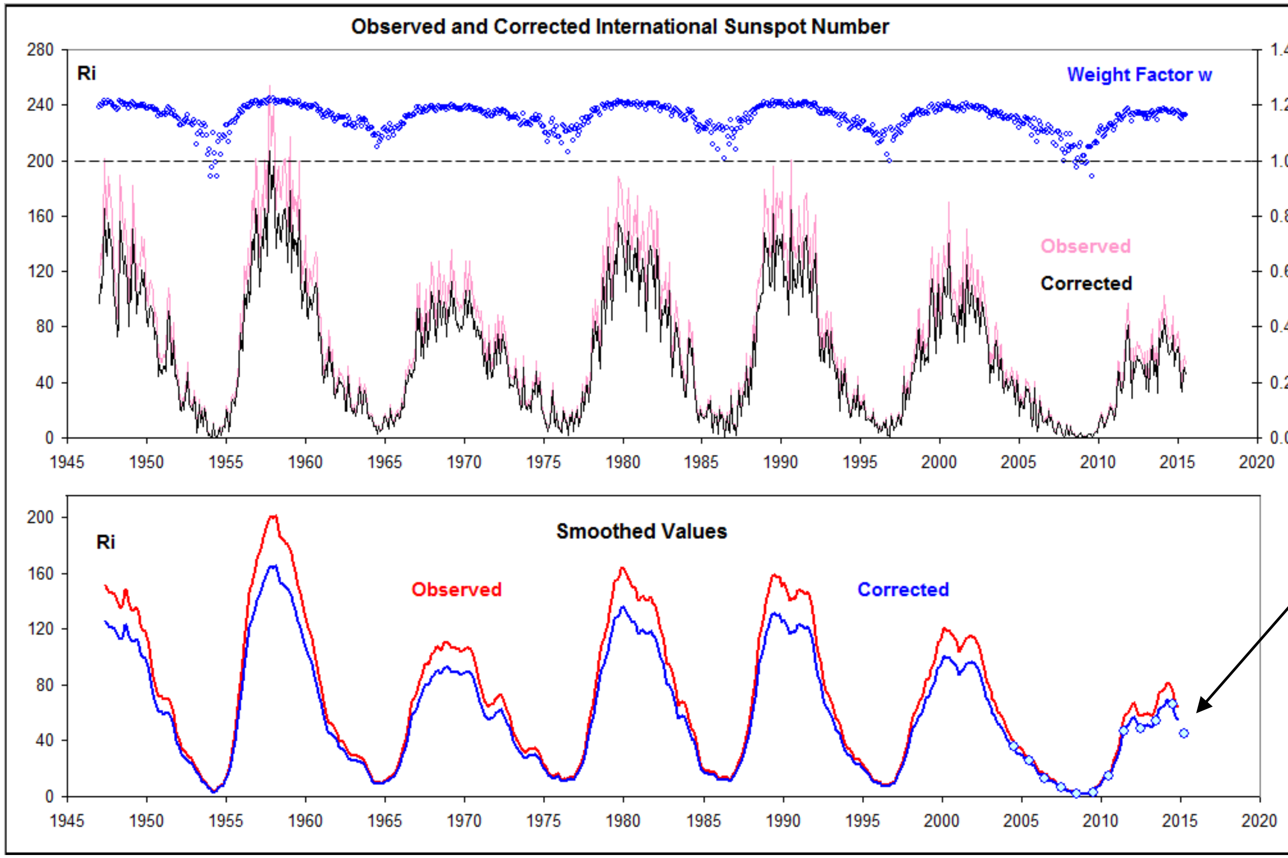
5x10+44=94 5x10+19=69

94/69 = 1.36

Weighting Rules: “A spot like a fine point is counted as one spot; a larger spot, but still without penumbra, gets the statistical weight 2, a smallish spot with penumbra gets 3, and a larger one gets 5.” Presumably there would be spots with weight 4, too.

When the auxiliary station ‘Locarno’ became operational in 1957 they adopted the same counting rules as Zürich and continue to this day

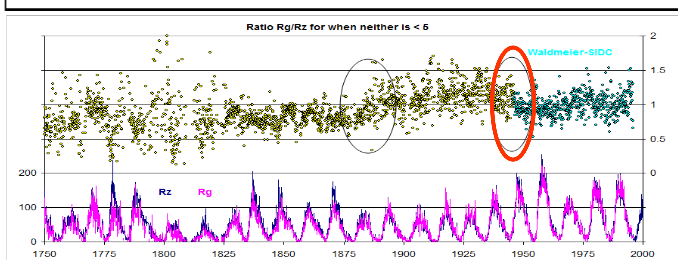
SSN with/without Weighting



The weight (inflation) factor

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

Light blue dots show yearly values of un-weighted counts from Locarno, *i.e.* not relying on the weight factor formula. The agreement is excellent



The inflation due to weighting explains the second anomaly

New series: http://www.sidc.be/silso/home

SILSO

Sunspot Index and Long-term Solar Observations

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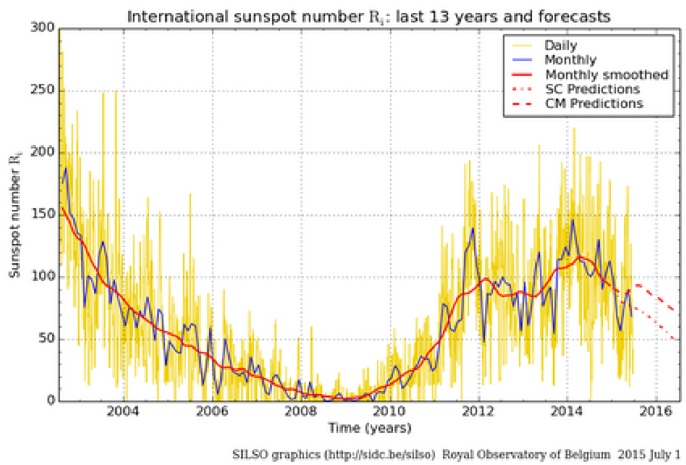
World Data Center for the production, preservation and dissemination of the international sunspot number

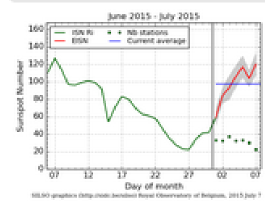
Major change of data set on July 1st, 2015: key information

Sunspot number series: latest update



Latest Sunspot Bulletin

Daily estimated sunspot number



EISN DATA FILES

03 July : 93
04 July : 106
05 July : 117
06 July : 104
07 July : 117

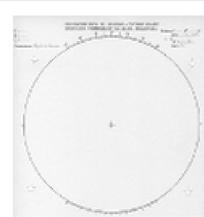
Transition to the new Sunspot Number successfully completed

Today marked a triple transition for us:

- Uploading the new Sunspot Number archive files containing the daily, monthly and yearly re-calibrated sunspot numbers and the new Group Number series
- In our Web site, switching to the new "Data" pages giving access to the new files, to updated graphics and also to the past version of the Sunspot Number
- Adapting and running the entire monthly procedure to produce the provisional Sunspot Numbers for June 2015 and the associated 12-months forecast and EISN.

Thus a lot of work in a single day for our small team.

Latest USET observations (ROB, Brussels) 07/07/2015



New SSN = Old SSN / 0.6

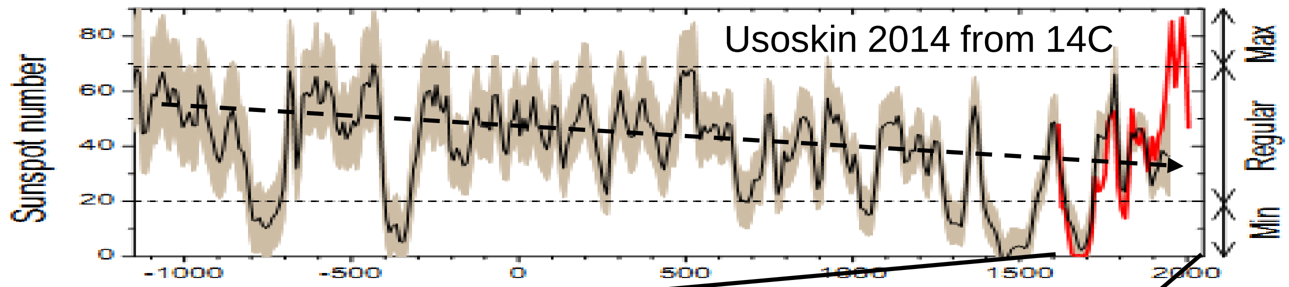
This is a major (and long-needed) advance.

The result of hard work by many people.

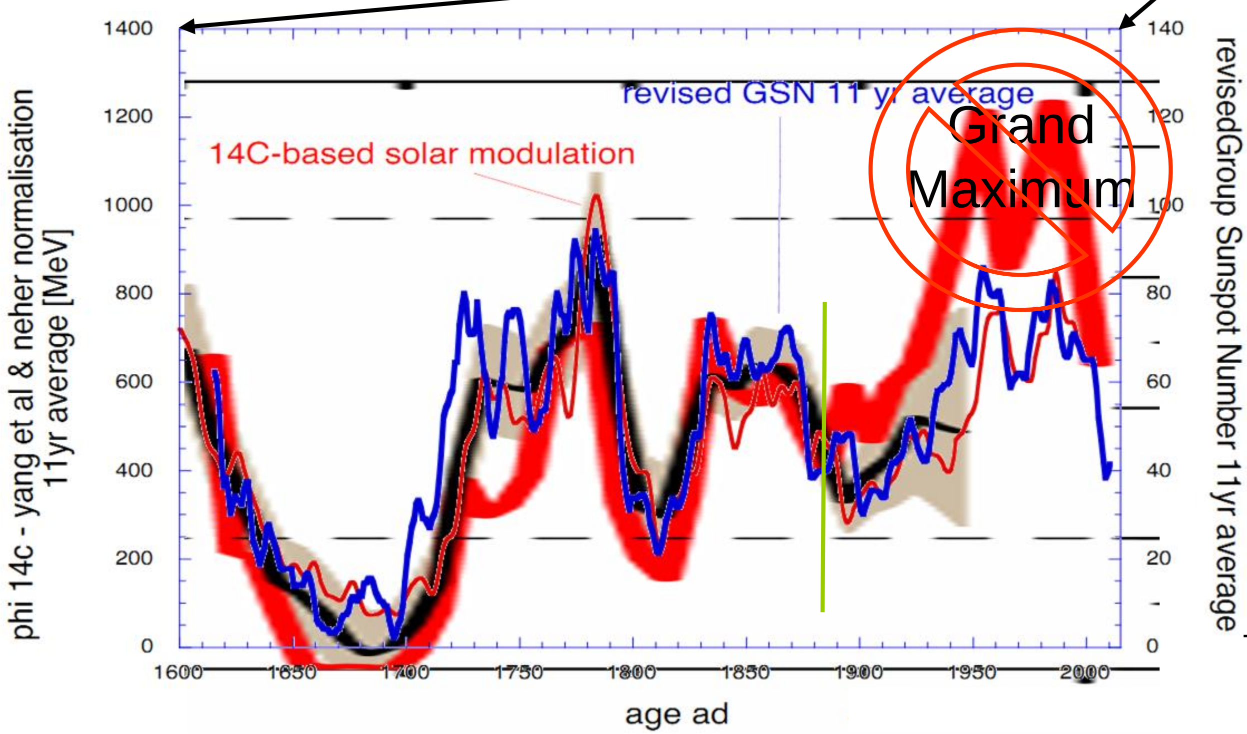
A Topical Issue of ‘Solar Physics’ is devoted to documenting, discussing, opposing, and criticizing the new series.

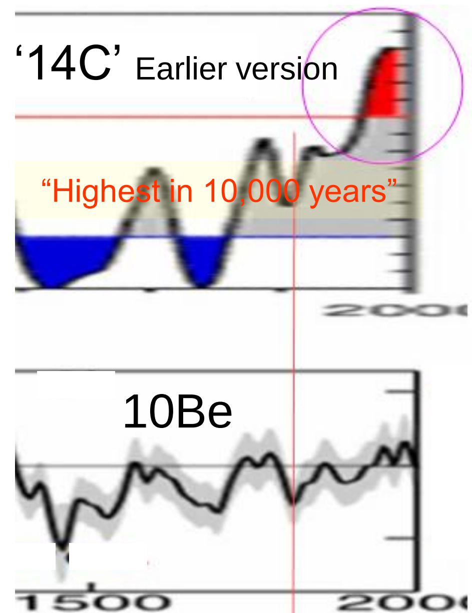
We have a SOI of 54 papers as of today.

Opposition and Rearguard Action



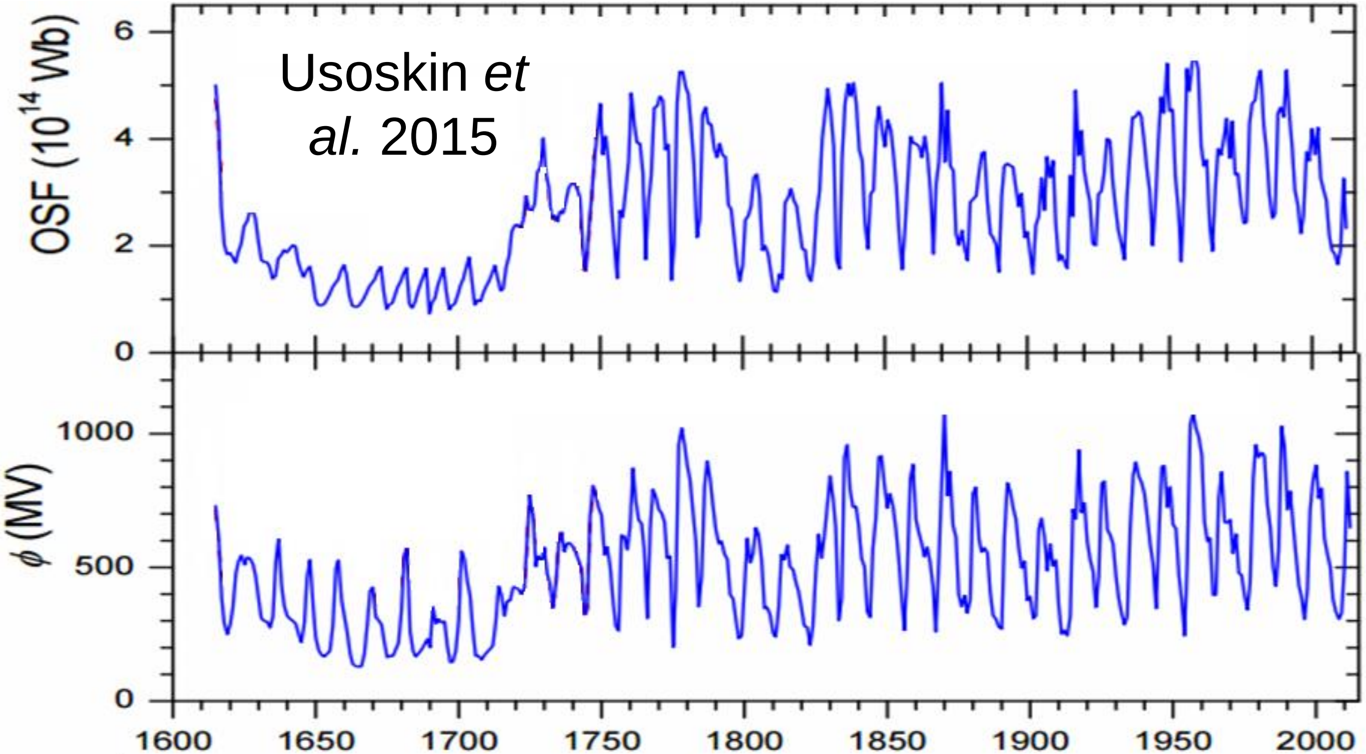
Solar activity has generally been decreasing the last ~3000 years

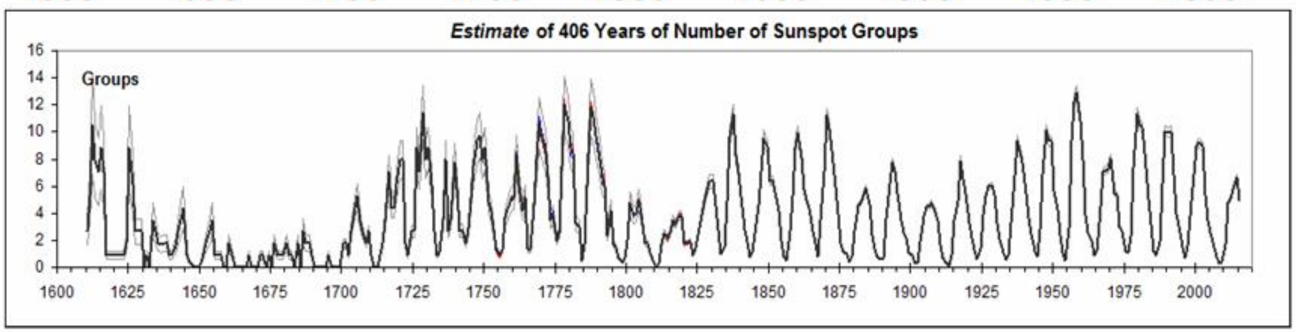




The non-existing Grand Modern Maximum is not based on 14C, but on the flawed H & S Group Number reconstruction and is not seen in 10Be data

Muscheler (thin red line) and Usokin's (black line) 14C values are aligned





The open solar magnetic flux (OSF) is the main heliospheric parameter driving the modulation of cosmic rays.

The OSF has been modeled by quantifying the occurrence rate and magnetic flux content of coronal mass ejections fitted to geomagnetic data.

The OSF and the cycle-variable geometry of the heliospheric current sheet allows reconstruction of the cosmic ray modulation potential, φ.

Reconciliation !
‘This just in’

Ilya G. Usoskin, Rainer Arlt, Eleanna Asvestari, Ed Hawkins, Maarit Käpylä, Gennady A. Kovaltsov, Natalie Krivova, Michael Lockwood, Kalevi Mursula, Jezebel O’Reilly, Matthew Owens, Chris J. Scott, Dmitry D. Sokoloff, Sami K. Solanki, Willie Soon, and José M. Vaquero, *Astronomy & Astrophysics,* July 21, 2015

Conclusions

- Both the International Sunspot Number and the Group Sunspot Number had serious errors
- Correcting the errors reconciles the two series and new sunspot series have been constructed
- The new *pure* solar series are confirmed by the geomagnetic records and by the cosmic ray records
- There is no **Grand** Modern Maximum, rather several *similar* maxima about 120 years apart
- There is still much more work to be done, and a mechanism has been put in place for updating the sunspot record as needed

The end