How Well Do We Know the Sunspot Number?

[And what we are doing to answer that question]

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Colloquium at HAO, Boulder, 19 Sept. 2012

Outline

- Effect of Weighting on Zürich SSN
- What is Wrong with the Group SSN
- Geomagnetic Calibration of SSN
- What to Do about All This
- Future Assessment of Solar Activity

The Effect of Weighting in Counting Sunspots

'The Waldmeier Discontinuity'

The directors of Zürich Observatory were:
1864-1893 Johann Rudolf Wolf (1816-1893)
1894-1926 Alfred Wolfer (1854-1931)
1926-1945 William Otto Brunner (1878-1958)
1945-1979 Max Waldmeier (1912-2000)

Waldmeier (1960) claimed that a counting with weighting began in 1882:

<u>CHANGES TO THE COUNTING METHOD</u>

Since Rudolph Wolf began the sunspot measurement, he set the standard. And although he counted each spot regardless of its size, he failed to include those smallest spots visible only under a stable atmosphere. Around 1882 Wolf's successors permanently changed the counting method in two ways to compensate for the large variation in spot size:

(1) by including the smallest spots visible under an atmosphere of constant transparency and

(2) by weighting spots with penumbrae according to their size and umbral structure.

This 'modified' counting method is still in use at the reference station Locarno used by SIDC in Brussels.

Relative Sunspot Number = K (10*Groups + Spots)

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, so did not count the smallest spots [to be compatible with Schwabe]
- His successor Wolfer disagreed, and pointed out that the above criterion was much too vague and instead 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 1.0]
- All subsequent observers have *adopted* that same 0.6 factor to stay on the original Wolf scale for 1849-~1865
- Waldmeier claimed that beginning in 1882, the Zürich observers began to count large spots with higher weight
- Wolfer states categorically in 1907 that every spot is counted only once regardless of its size

Waldmeier’s Description of his [?] Sunspot Counting Method

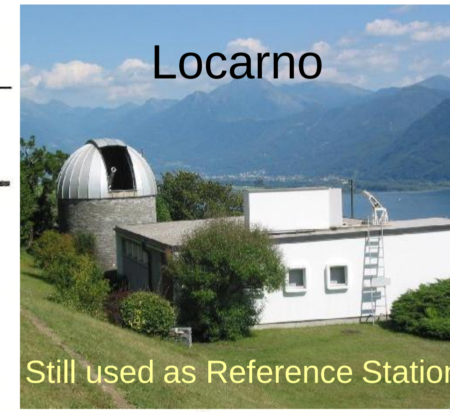
Astronomische Mitteilungen der Eidgenössischen Sternwarte Zürich
Nr. 285

1968

Die Beziehung zwischen der Sonnenflecken-relativzahl und der Gruppenzahl

Von

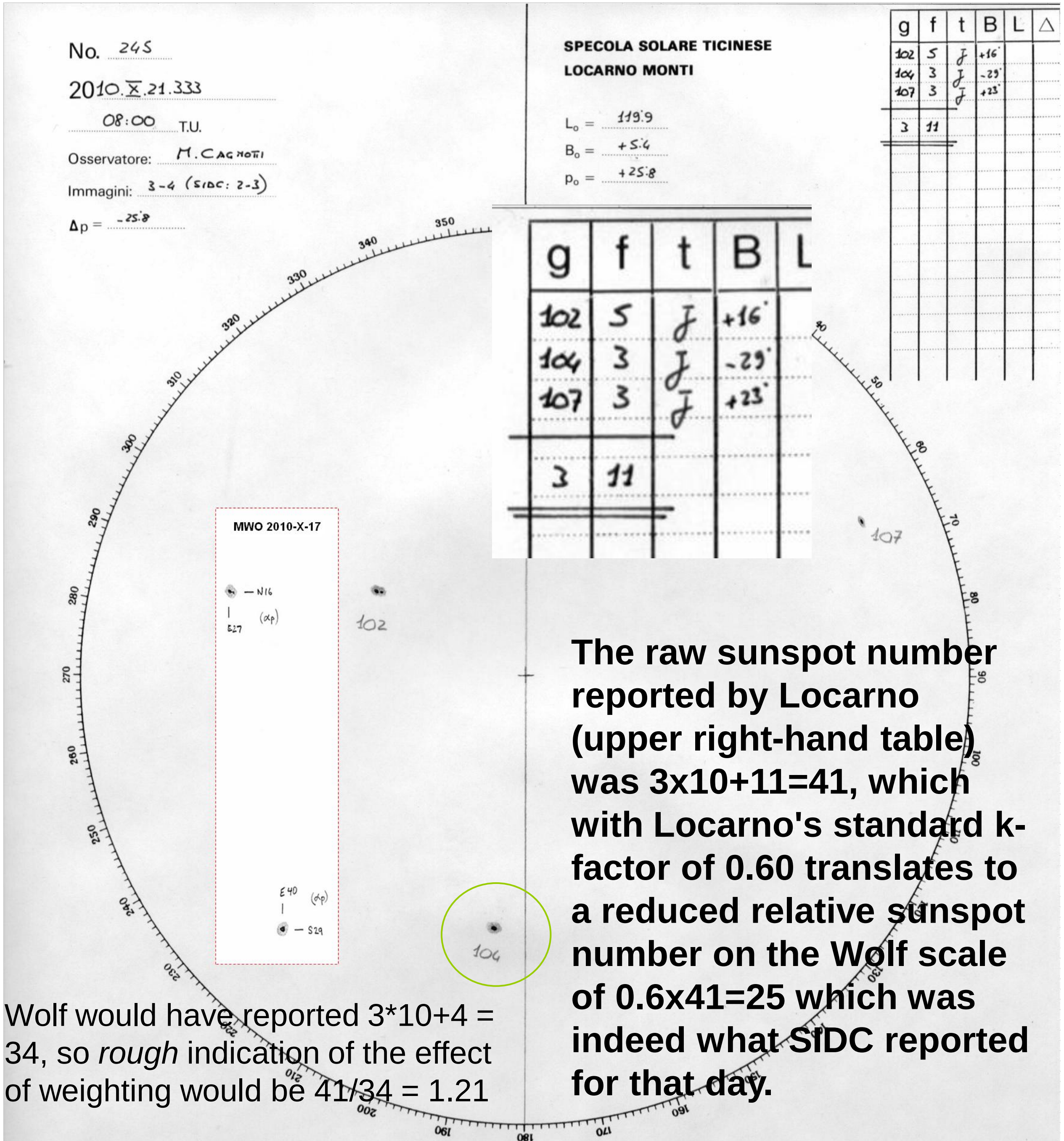
M. Waldmeier



Später wurden den Flecken entsprechend ihrer Größe Gewichte erteilt: Ein punktförmiger Fleck wird einfach gezählt, ein größerer, jedoch nicht mit Penumbra versehener Fleck erhält das statistische Gewicht 2, ein kleiner Hoffleck 3, ein größerer 5.

“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.

This very important piece of metadata was strongly downplayed and is not generally known



Wolf would have reported 3*10+4 = 34, so *rough* indication of the effect of weighting would be 41/34 = 1.21

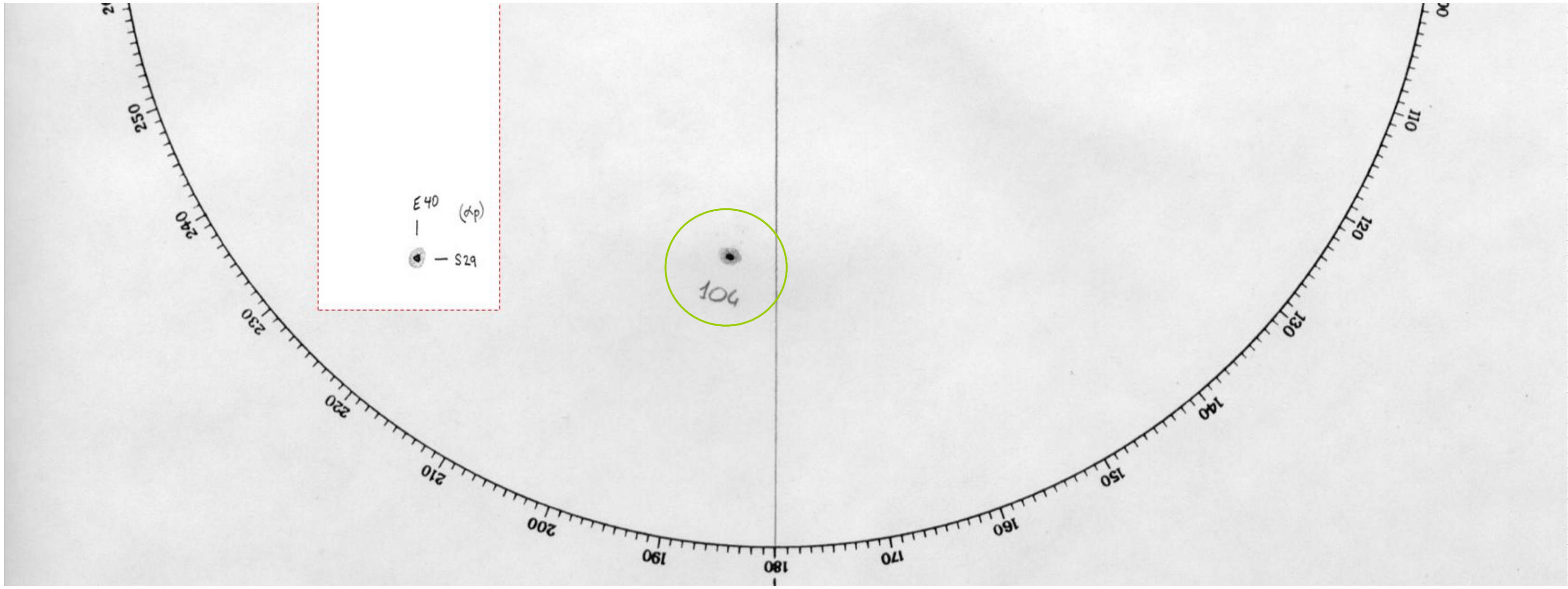
The raw sunspot number reported by Locarno (upper right-hand table) was 3x10+11=41, which with Locarno's standard k-factor of 0.60 translates to a reduced relative sunspot number on the Wolf scale of 0.6x41=25 which was indeed what SIDC reported for that day.

Drawing from Locarno 21 October, 2010 showing the three Locarno Regions 102, 104, and 107. The table gives the weight assigned to each group.

An insert (red border) shows the regions as observed at MWO on the 17th October (no observation the 21st).

From Hathaway's list we get the areas of those spots:

Year	M	D. UT	NOAA	Loc#	Area (obs.)
2010	10	21.50	11113	102	134 μH
2010	10	21.50	11115	104	223 μH
2010	10	21.50	11117	107	104 μH



-Note there is a spot of the same size back in 1920:
1920 11 21.55 *9263 MWO* 223 μH (it was the only spot)

Up until Waldmeier [who discontinued this!] the Zürich observers recorded their raw data for each day in this format

"Group Count . Total Spot Count"

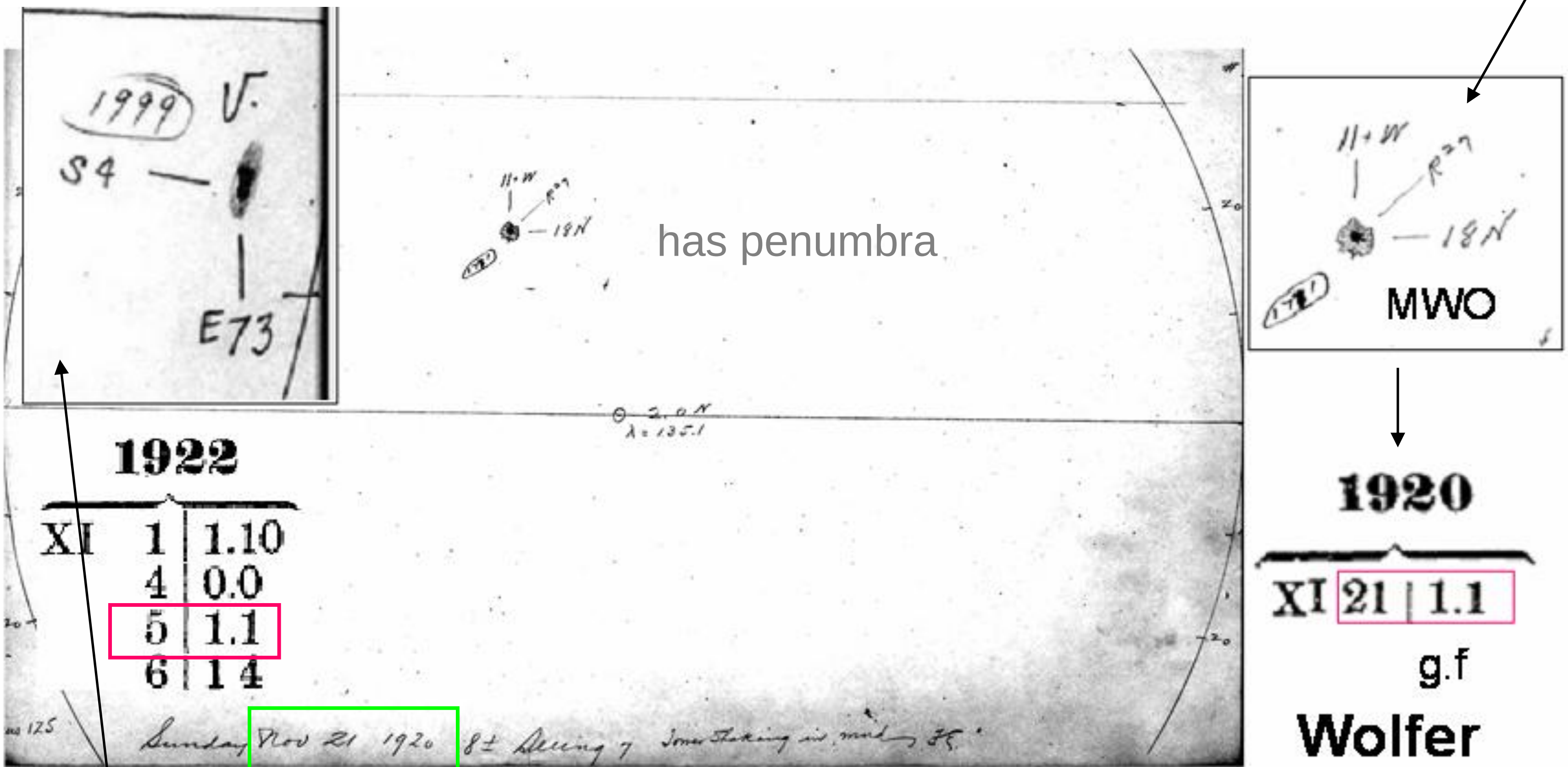
Sonnenfleckenbeobachtungen im Jahre 1849.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
1	9.31	3. 6	4. –	10.70	9.30	8.48	4.13	4 15	7.64	8.10	5.16	—
2	9.34	7.40	5. —	7. –	9.40	9.64	3. 3	6.18	5.35	7.10	7.41	8. 9
3	15. —	2. —	6.12	10.38	5.12	8.50	3. 6	6.15	4.27	3. 4	3.10	8.17
4	9.31	7.27	7.15	$\boxed{12.58}$	7.45	10.50	3 10	4.12	5.41	2. 3	4.31	—
5	9. –	9.22	2. —	8.20	8 50	8.45	7. —	5.20	1. 1	1. 2	—	9.47
6	8. —	10 34	7.24	10.60	7.38	7.45	4. 8	4.18	6.25	4. 6	—	2. 2
7	—	3. –	3. —	8.24	1. –	5. –	5.10	3.20	7.48	—	6.22	—
8	8.28	10.21	4. —	6.20	6.20	5.12	6.15	3.15	5.38	5.16	7.35	—
9	8.30	10.35	3. —	9.45	6.25	3. –	7.20	4.14	7.50	5.26	6.20	—

To calculate the relative sunspot number, e.g. on April 4th, one performs $R = k * (10*12 + 58) = 178$

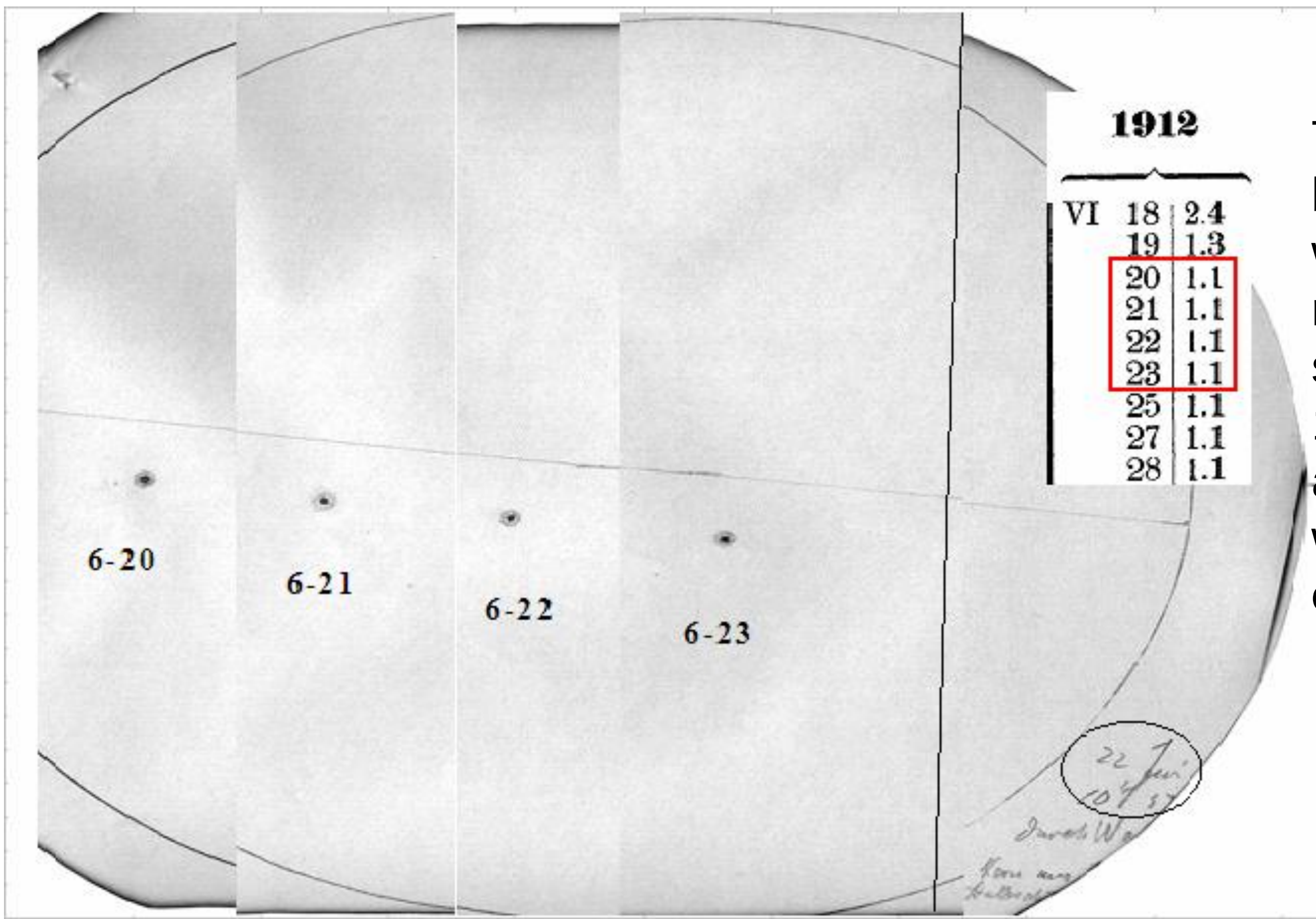
where the scale factor k is 1.00 for Wolf himself.

So, now back to the MWO spot on 21st Nov. 1920 that had the same size as Locarno 104 [which was counted as three spots or 1 spot with weight of 3.]



The insert shows a similar group observed at MWO on 5th Nov., 1922. For both groups, Wolfer should have recorded the observation as 1.3 if he had used the weighting scheme, but they were recorded as 1.1, clearly counting the large spots only once (*thus with no weighting*). The historical record Zürich sunspot number was 7 {=0.6x(10+1)} on both those days, consistent with ***no*** weighting.

Other Observatory Drawings Show Similar Results, e.g. Haynald (Kalocsa, Hungary):



This spot should have been counted with weight 3, so the recorded value should have been 1.3, if Wolfer had applied the weighting, which he obviously didn’t

There are many other such examples, (e.g. 16th September, 1922 and 3rd March, 1924 for which MWO drawings are readily available).

In addition, Wolfer himself in 1907 (Mitteilungen, Nr. 98) explicitly states: “If an observer with his instrument on a given day notes g spot groups with a total of f single spots, without regard to their size, then the therefrom deduced relative number for that day is $r = k(10g+f)$”. [Next slide]

We thus consider it established that Wolfer (and by extension [?] the other observers before Waldmeier) did not apply the weighting scheme contrary to Waldmeier's assertion

This is consistent with the fact that nowhere in Wolf's and Wolfer's otherwise meticulous yearly reports in the *Mittheilungen über Sonnenflecken* series is there any mention of a weighting scheme. Waldmeier himself was an assistant to Brunner in 1936 and performed routine daily observations with the rest of the team so should have known what the rules were. There is a mystery lurking here. Perhaps the Archives [in Zürich? Or the microfilm in Brussels] will provide a resolution of this conundrum. [Unfortunately the Archives are lost]

Wolfer in 1907: Ohne Rücksicht auf deren Grösse

Astronomische Mitteilungen,

gegründet von

Dr. Rudolf Wolf.

Nr. XCVIII,

herausgegeben von

A. Wolfer.

Die Häufigkeit und heliographische Verteilung der Sonnenflecken im Jahre 1906; Vergleichung mit den Variationen der magnetischen Deklination. Fortsetzung der Sonnenfleckenliteratur.

Der nachstehenden Übersicht über die Häufigkeit der Sonnenflecken während des Jahres 1906 liegen erstlich die Beobachtungen zu Grunde, die ich auf der Zürcher Sternwarte selbst an 278 Tagen mit dem von jeher dafür benutzten Fraunhoferschen „Normalfernrohr“ von 8 cm Öffnung, und während vorübergehender Abwesenheit an 7 weiteren Tagen mit einem kleineren von 4 cm Öffnung, dem „Handfernrohr I“, gemacht habe. Dazu kommen die korrespondierenden Beobachtungen des Herrn Assistent Broger mit demselben 8 cm-Fernrohr an 265 Tagen, und diese beiden Reihen zusammen lieferten allein schon die Flecken-Relativzahlen für 311 Tage des Jahres. Alle noch fehlenden Tage, an denen wir hier in Zürich wegen bedeckten Himmels keine Zählungen erlangt haben, konnten mit Hülfe von 20 weiteren Beobachtungsreihen gedeckt werden, die zum Teil bereits veröffentlicht vorlagen, teils mir von den betreffenden Herren Beobachtern mit sehr verdankenswerter Bereitwillig-

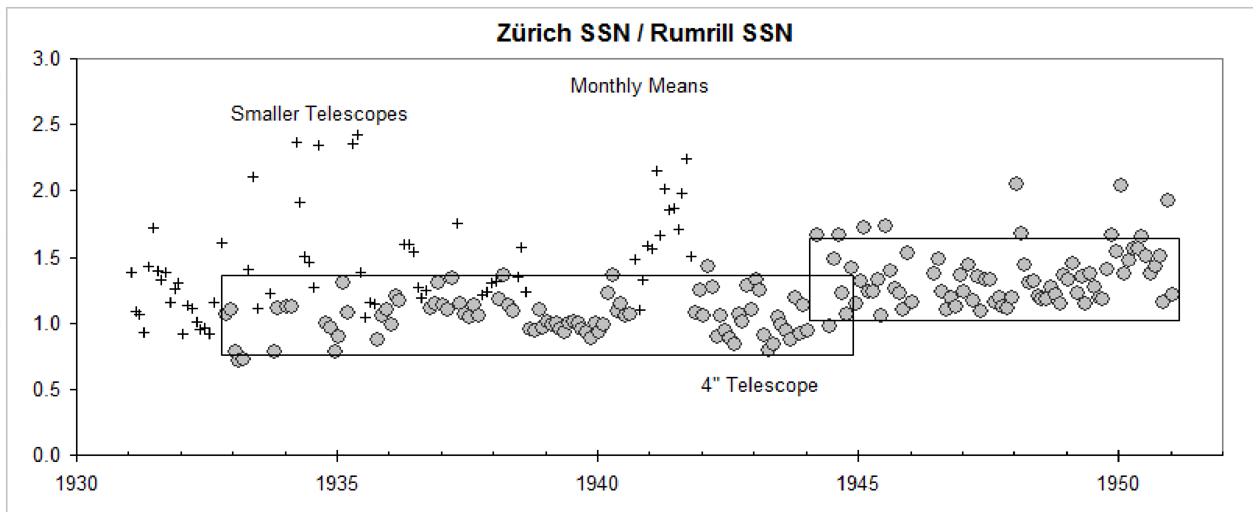
keit zur Verwendung mitgeteilt worden waren, und für welche auf die unten folgende „Sonnenfleckenliteratur“ zu verweisen ist. Die Relativzahlenreihe ist durch sie auch für dieses Jahr wieder eine lückenlose geworden.

Die in Tab. I gegebene Übersicht über die benutzten Beobachtungsreihen enthält die zu ihrer Verbindung mit unsern eigenen erforderlichen Reduktionsgrössen, über welche an folgendes zu erinnern ist. Notiert ein Beobachter mit seinem Instrumente an irgend einem Tage g Fleckengruppen mit insgesamt f Einzelflecken, ohne Rücksicht auf deren Grösse, so ist die daraus abgeleitete Relativzahl jenes Tages $r = k\,(10\,g + f)$, wo k einen für jeden Beobachter und sein Instrument besonders zu ermittelnden Faktor bezeichnet, durch welchen die Angaben des Beobachters auf die von Wolf gewählte Einheit der Relativzahlen — bestimmt durch ihn selbst als Beobachter und das oben erwähnte Normalfernrohr — reduziert werden. Er ist für meine Beobachtungen am 8 cm-Fernrohr konstant gleich 0.60 (vgl. Astr. Mitt. Nr. 86) angenommen worden und wird für jede andere Reihe semesterweise durch Vergleichung aller verfügbaren korrespondierenden Beobachtungen dieser und meiner eigenen bereits auf Wolf reduzierten Reihe berechnet. Diese Werte k findet man in Tab. I zusammengestellt, ebenso unter „Vgl.“ die Zahl der korrespondierenden Beobachtungen, aus denen k abgeleitet wurde; für die meisten Beobachtungsorte stimmen die beiden Halbjahrswerte von k soweit unter sich überein, als es bei gleichbleibender Beobachtungsweise erfahrungsmässig ungefähr erwartet werden kann. Die in Zürich gemachten Zählungen mit den Handfernröhren I, II und III bilden die Fortsetzung der Reihe vergleichender Beobachtungen, die ich 1894 begonnen habe, um eine allfällige Veränderlichkeit der Faktoren k mit der Grösse der Fleckenzahlen im Verlaufe der 11jährigen Periode festzustellen. Die drei letzten Kolonnen der Tab. I enthalten die Zahl der Beobachtungstage jeder Reihe, die Zahl der unter diesen zur Ausfüllung von Lücken benutzbaren „Ersatztage“ und die No. der Sonnenfleckenliteratur, unter der die betreffenden Reihen in extenso mitgeteilt sind.

H. B. Rumrill's Sunspot Observations

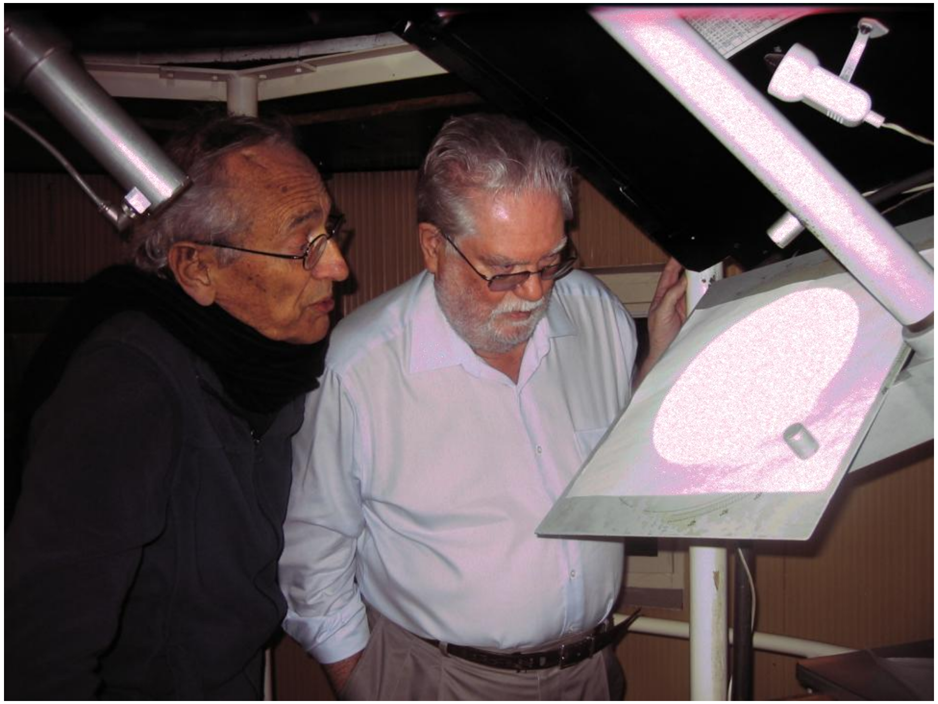
Harry Barlow Rumrill, president of the Rittenhouse Astronomical Society in 1932, with his 4-inch Brashear refractor. From *History of the Rittenhouse Astronomical Society*, courtesy Joy Crist.

H. B. Rumrill (1867-1951) was a friend of Rev. Quimby [see later] and continued (1922 to 1951) Quimby's observations of sunspots. His data and notebooks were considered lost until I with the help of 'The Antique Telescope Society' (Bart Fried, Jack Koester), located most of them in early 2012



The ratio between the Zürich SSN and the Rumrill SSN gives additional support for the 'Waldmeier Jump'

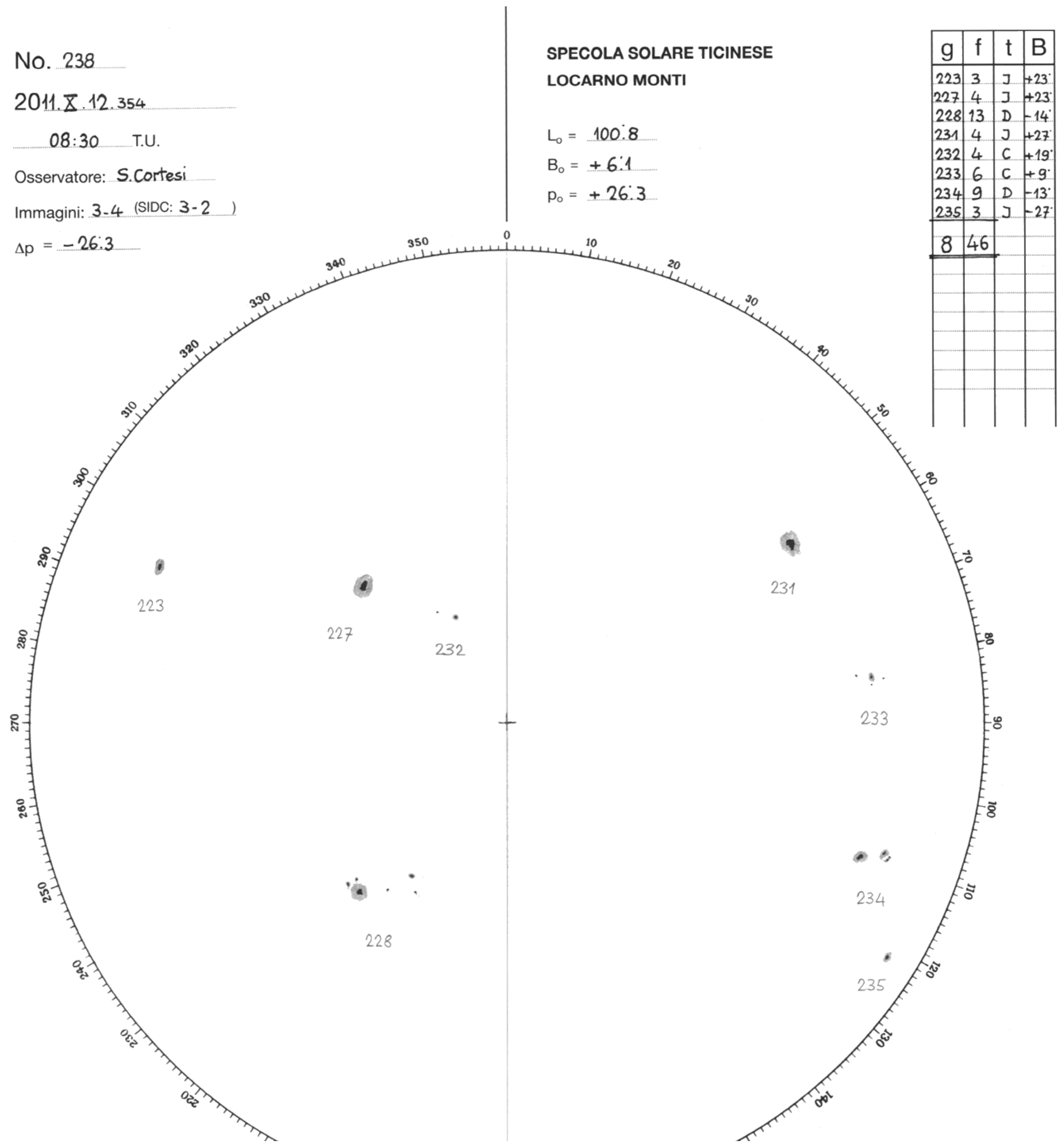
What Do the Observers at Locarno Say About the Weighting Scheme:



"For sure the main goal of the former directors of the observatory in Zürich was to maintain the coherence and stability of the Wolf number[…] Nevertheless the decision to maintain as "secret" the true way to count is for sure source of problems now!"

(email 6-22-2011 from Michele Bianda, IRSOL, Locarno)

Sergio Cortesi started in 1957, still at it, and in a sense is the *real* keeper of the SSN, as SIDC normalizes everybody's count to match Sergio's [multiplied by the adopted 0.6 *k*-factor]



Estimating Unweighted Sunspot Count From Locarno Drawings

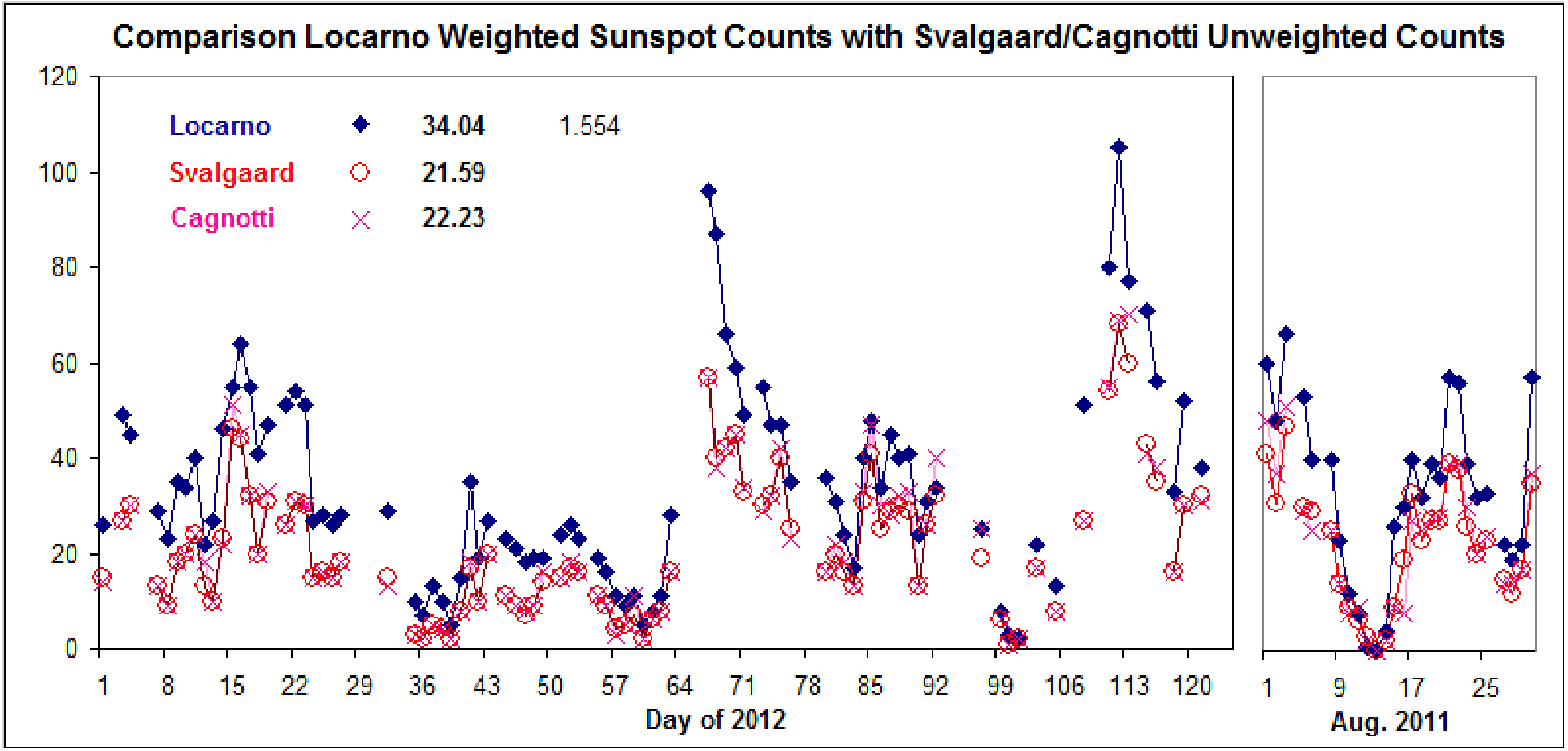
223	3	**1**
227	4	**1**
228	13	**6**
231	4	**1**
232	4	**2**
233	6	**4**
234	9	**4**
235	3	**1**
8	46	**20**
10*8+…	126	**100**

26% inflated

Unweighted count red

I have recounted the last 41500+ spots. How good is my count?

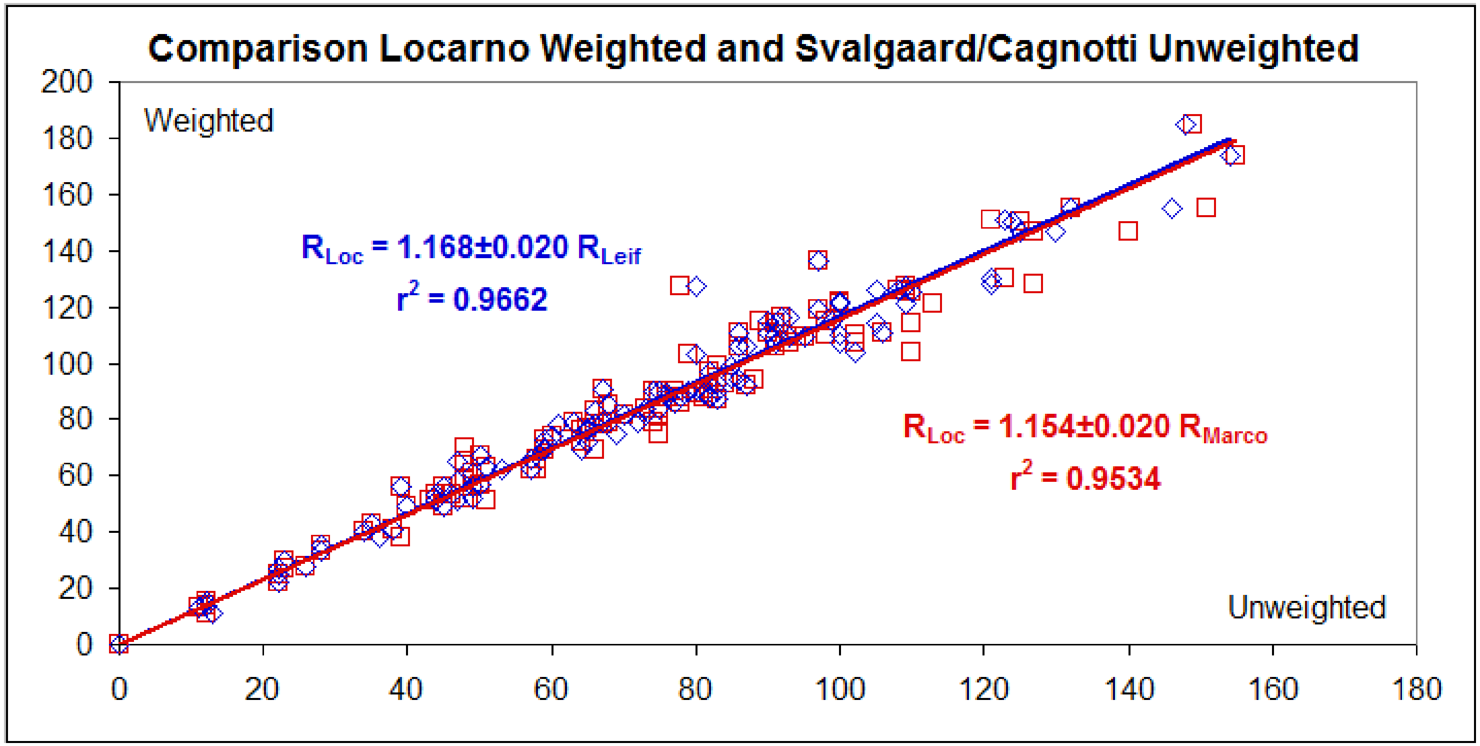
Double-Blind Test of My Re-Count



I proposed to the Locarno observers that they should also supply a raw count without weighting

For typical number of spots the weighting increases the 'count' of the spots by 30-50% (44% on average)

Comparison of ‘Relative Numbers’



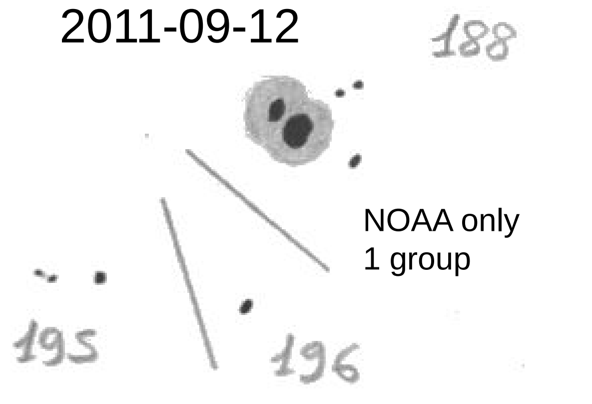
But we are interested in the effect on the Relative SSN where the group count will dilute the effect by about a factor of two. The result is that there is no difference between Svalgaard and Cagnotti. We take this a [preliminary] justification for my determination of the influence of weighting [+16%] on the Locarno [and by extension on the Zürich and International] sunspot numbers

How Many Groups?

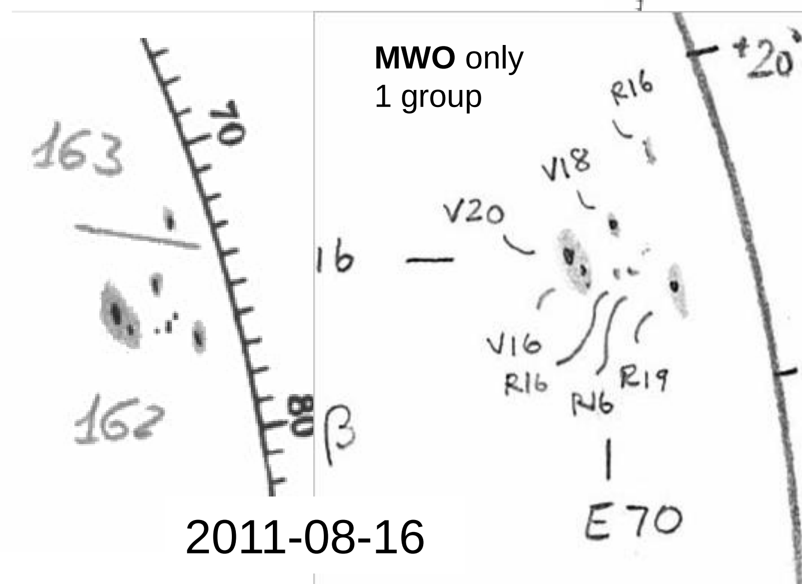
The Waldmeier Classification May lead to Better [larger] Determination of Groups

Locarno

2011-09-12

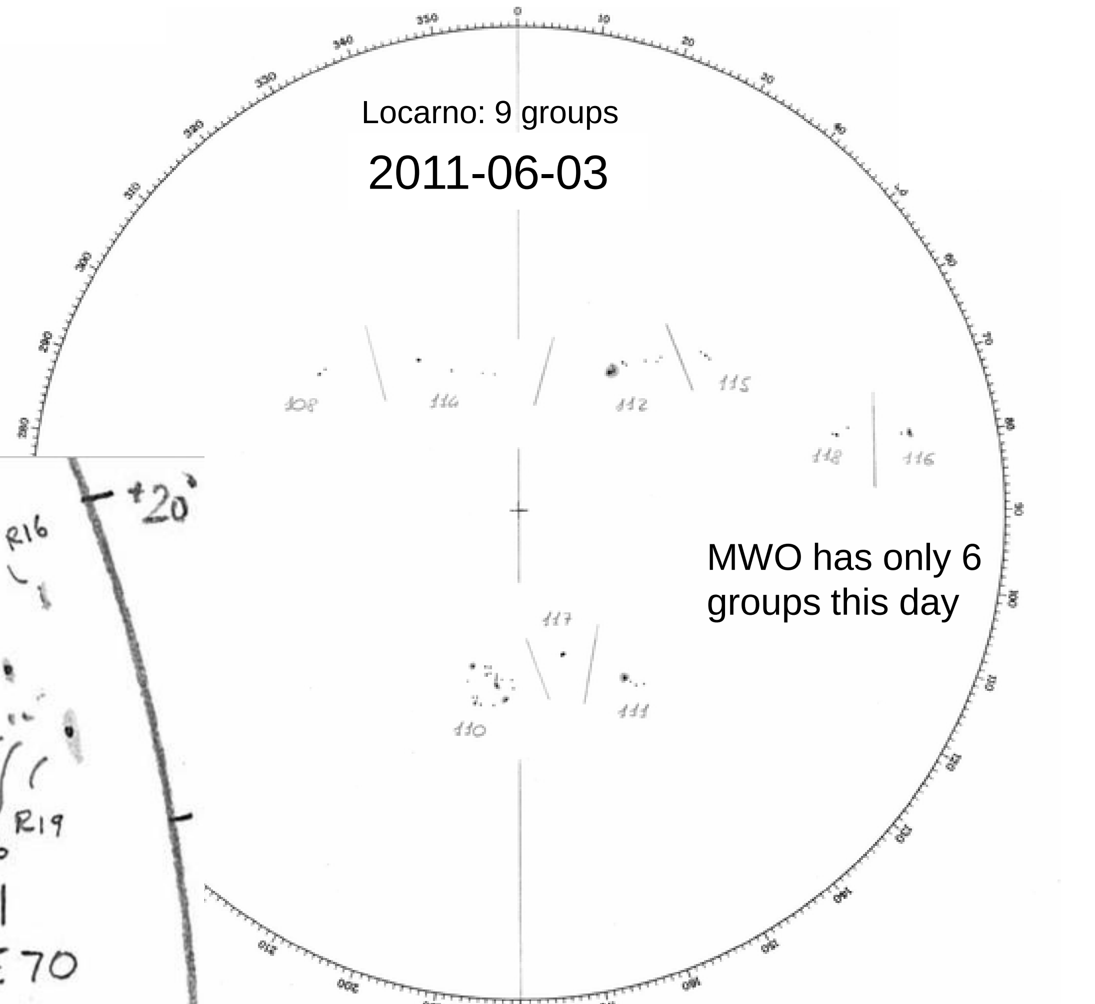


NOAA only
1 group



MWO only
1 group

2011-08-16



Locarno: 9 groups

2011-06-03

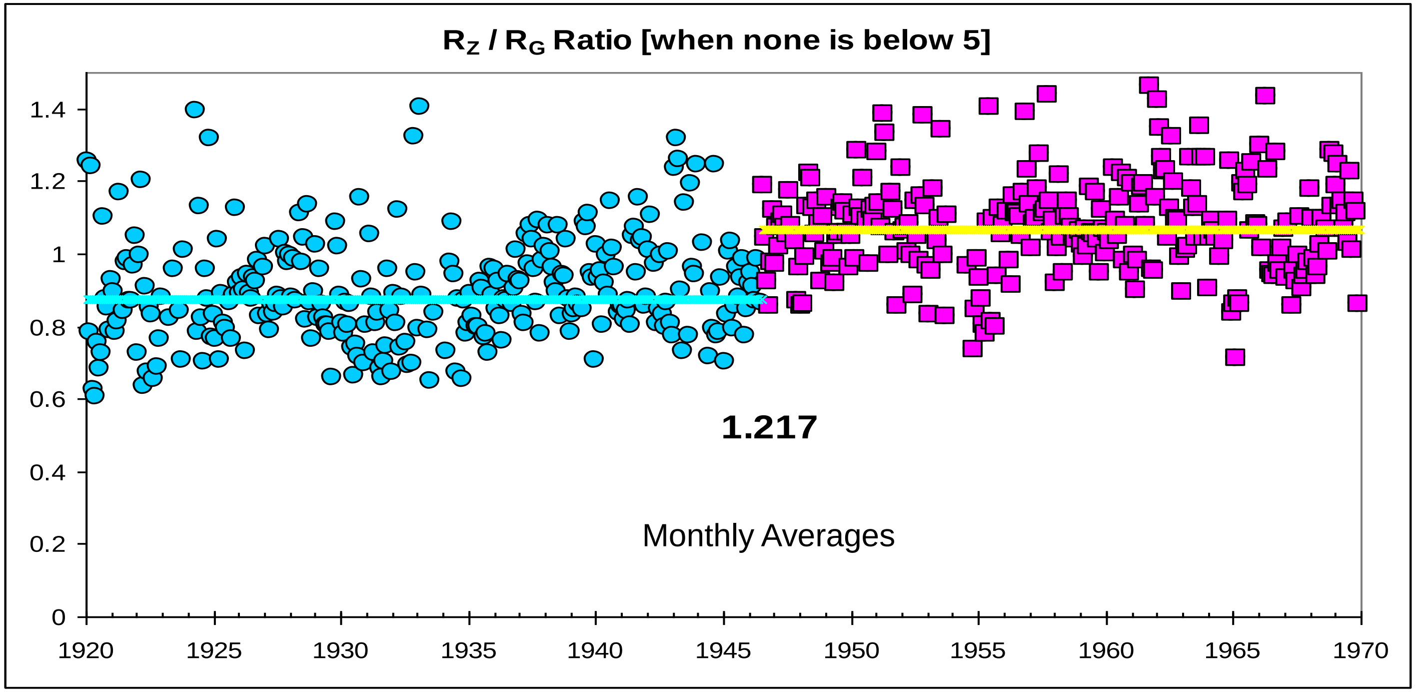
MWO has only 6 groups this day

Counting Groups

- This deserves a full study. I have only done some preliminary work on this, but estimate that the effect amounts to a few percent only, perhaps 5% [?] One day in five has an ‘extra’ group. This work in ongoing.
- This would increase the ‘Waldmeier Jump” to about 21%
- My suggested solution is to increase all pre-Waldmeier SSNs by ~20%, rather than decrease the modern counts which may be used in operational programs

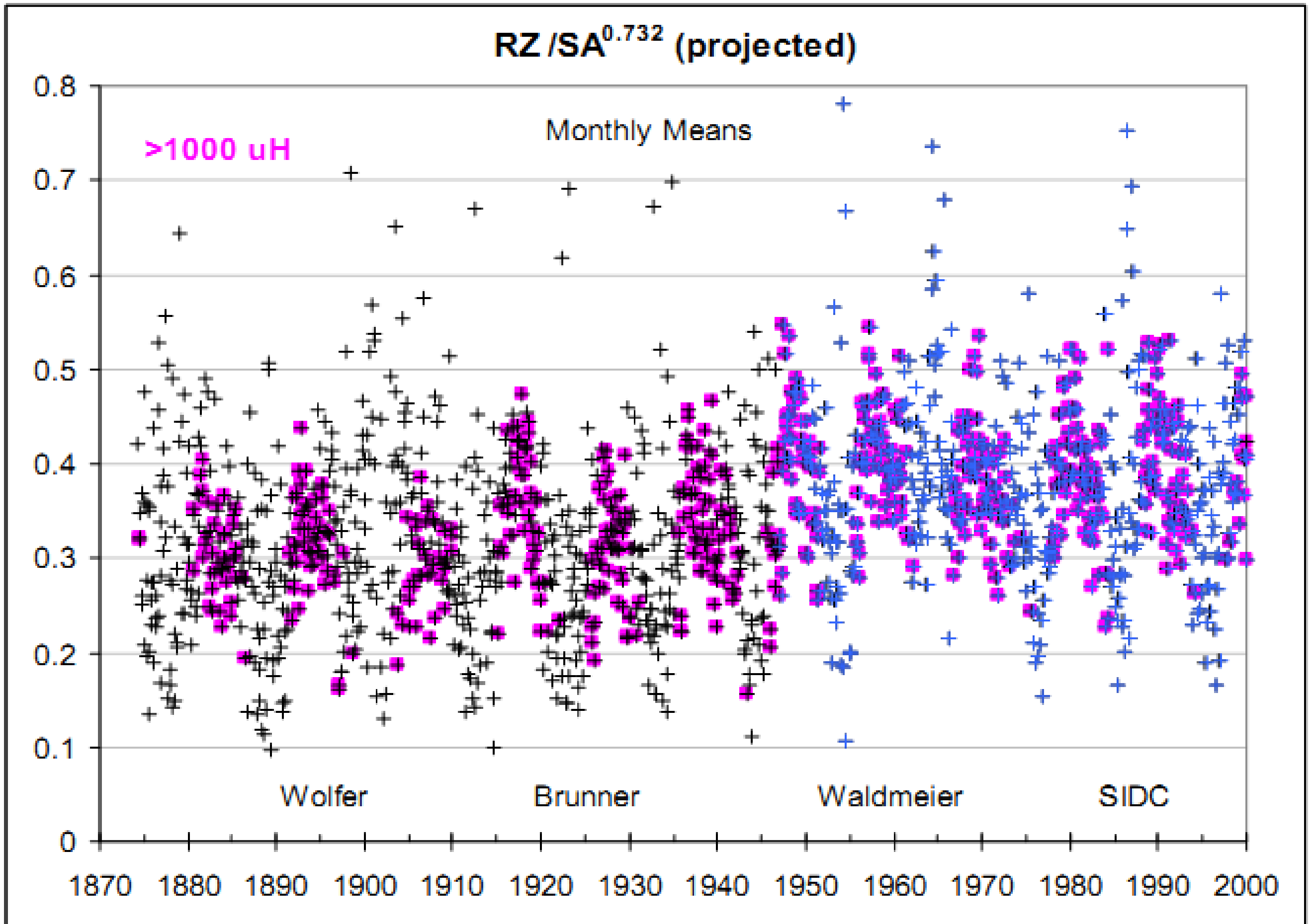
- http://www.leif.org/EOS/Kopecky-1980.pdf specifically notes that “according to [observer] Zelenka (1979a), the introduction of group classification with regard to their morphological evolution by Waldmeier and Brunner, has led to increased estimates of number of groups in comparison with Wolfer’s estimates”
- Exactly when this began is under investigation, but ‘some time in the 1940s’ is a good guesstimate for now

Can we validate this Inflation using other data? Comparing with the Group Sunspot Number:



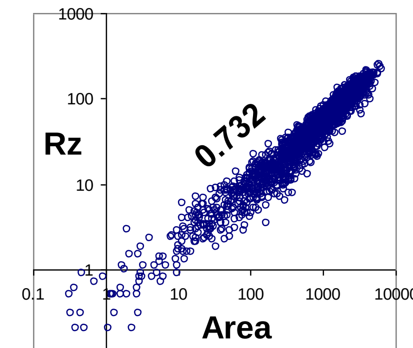
We can compute the ratio WSN (Rz)/GSN (Rg) [staying away from small values] for some decades on either side of the start of Waldmeier's tenure, assuming that GSN mainly derived from the RGO [Greenwich] photographic data has constant calibration over that interval. There is a clear discontinuity corresponding to a jump of a factor of 1.22 around 1946. This compares favorably with the estimated size of the increase due to the weighting [and more groups]

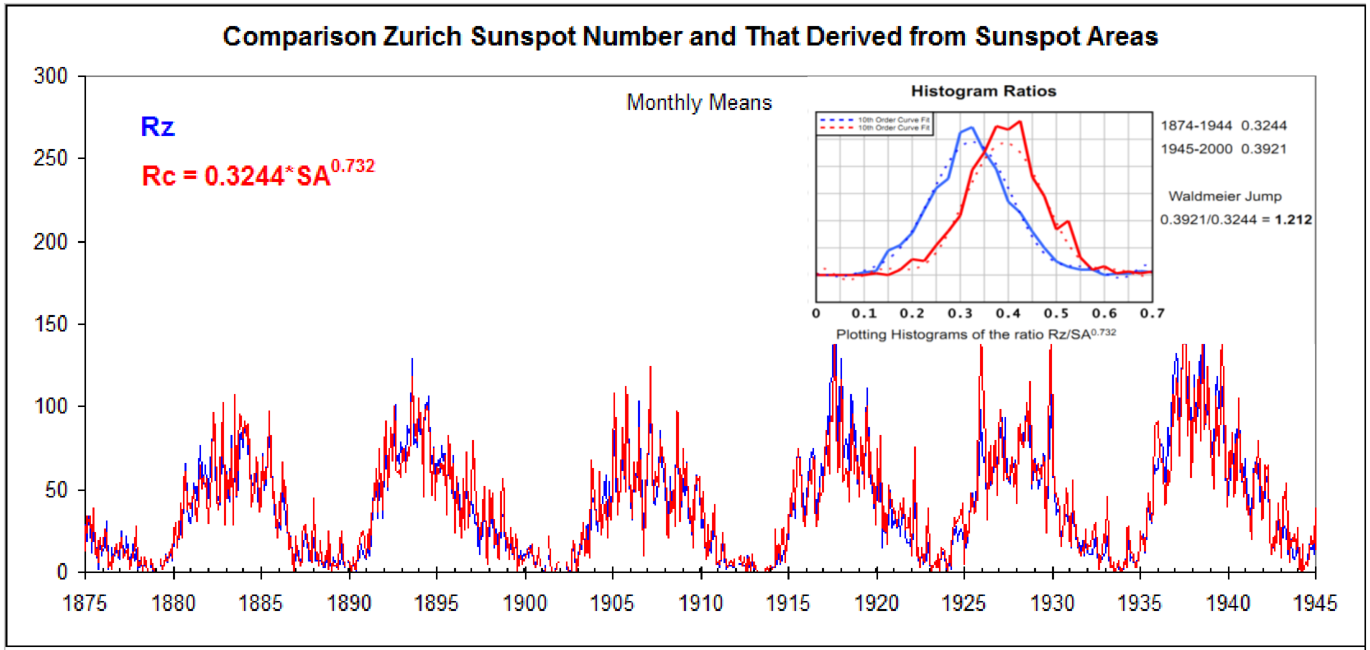
Sunspot Areas vs. Rz

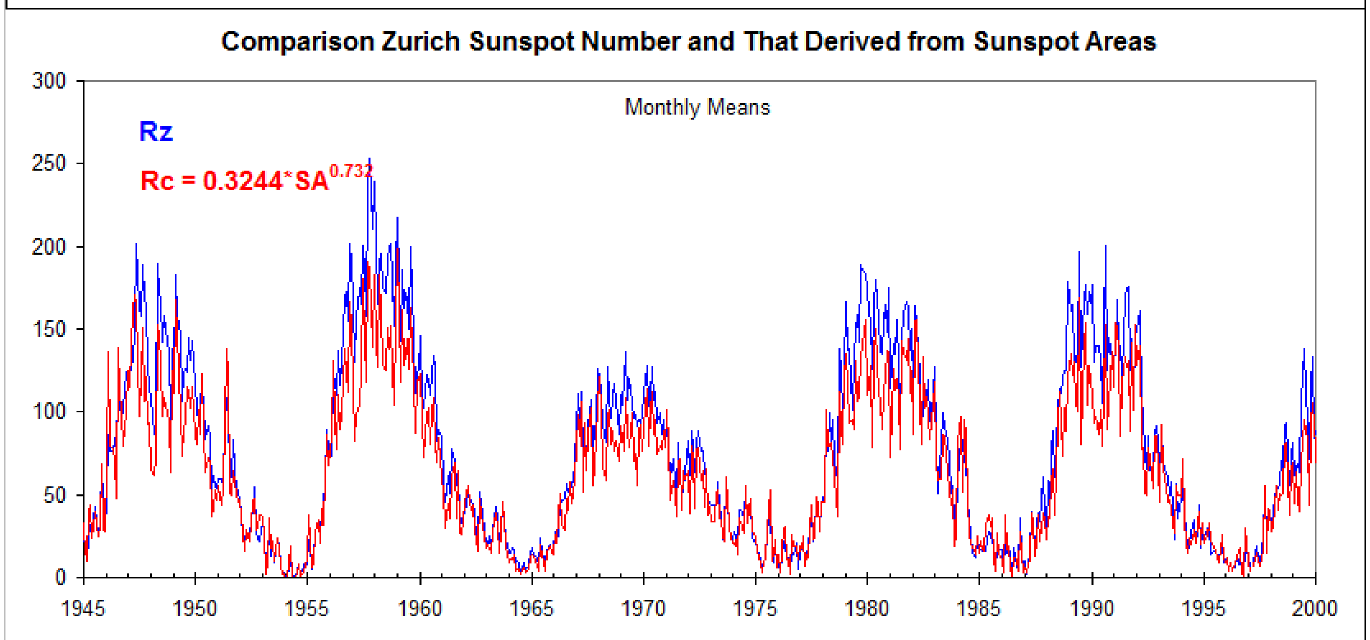


Clear change in the relationship around 1945

The relationship between sunspot number and sunspot area [SA, Balmaceda] is not linear, but can be made linear raising SA to the power of 0.732. Then taking the ratio makes sense.





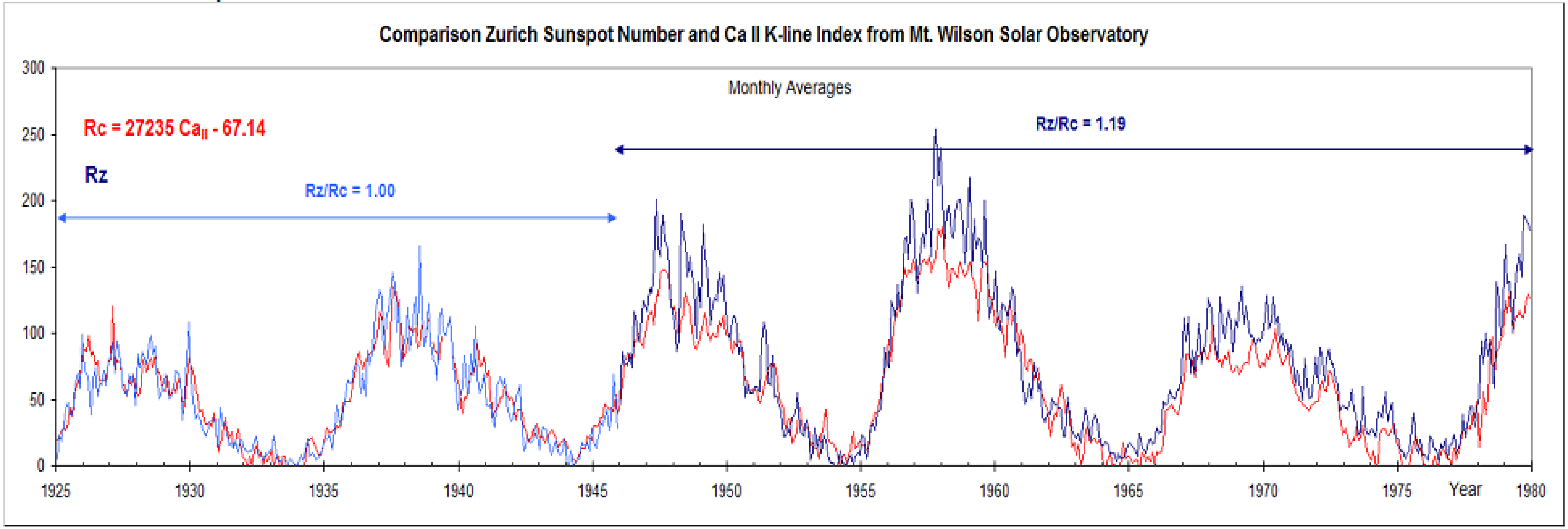


Comparison Observed Rz and Rz Calculated from projected [observed] Sunspot Areas

The post-1945 Zürich Sunspot Numbers are observed to be 21% higher than for the same sunspot area before 1945

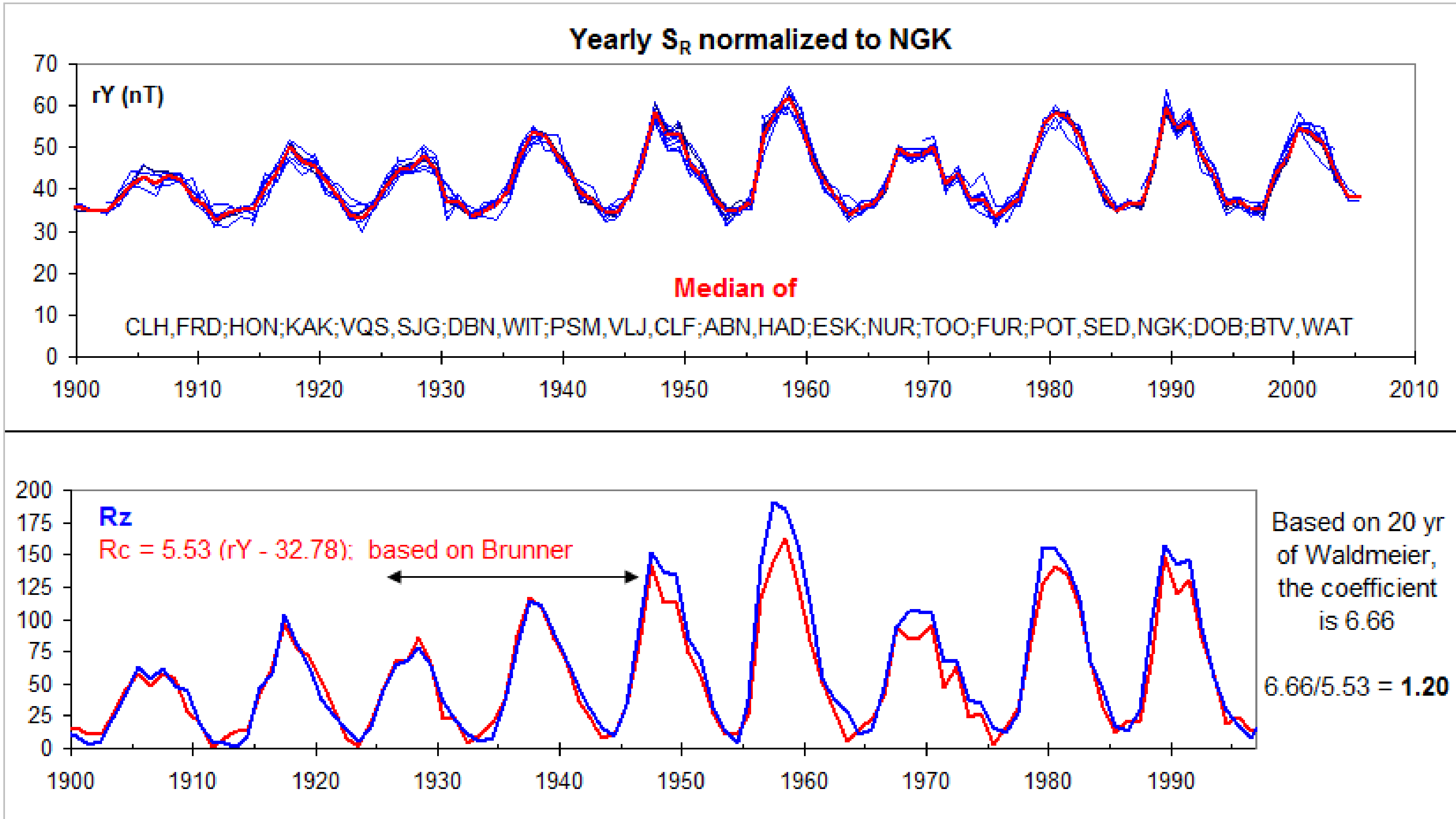
Ca II K-line Data Scaled to Rz shows similar Jump in Rz Sunspot Number after 1945

From ~40,000 CaK spectroheliograms from the 60-foot tower at Mount Wilson between 1915 and 1985, a daily index of the fractional area of the visible solar disk occupied by plages and active network has been constructed [Bertello et al., 2008]. Monthly averages of this index is strongly correlated with the sunspot number SSN = 27235 CaK – 67.14 [before 1945].

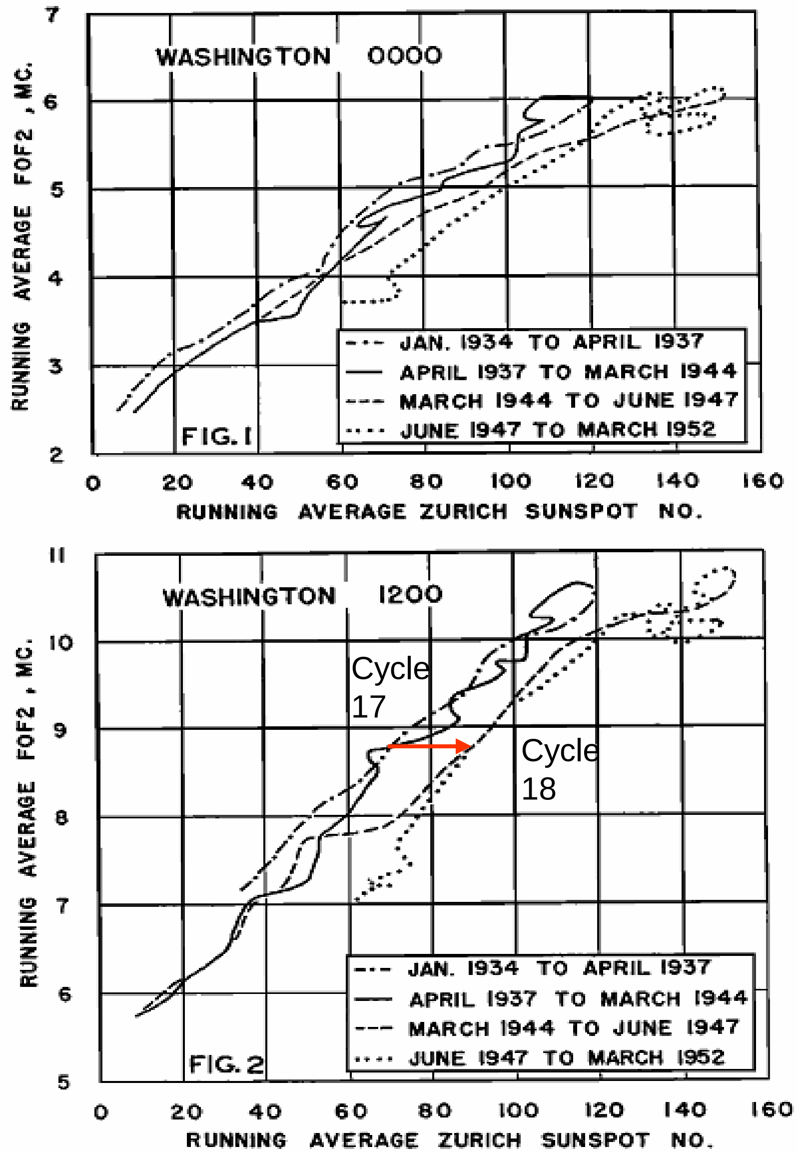


Waldmeier's Sunspot Number 19% higher than Brunner's from Ca II K-line

The Amplitude of the Diurnal Variation, *rY*, [from many stations] shows the same Change in Rz ~1945



We'll return to this relationship later in the talk



FIGS. 1 AND 2—PLOT OF 12-MONTH RUNNING AVERAGE OF MONTHLY MEDIAN f^oF2 AGAINST 12-MONTH RUNNING AVERAGE OF MONTHLY ZURICH SUNSPOT NUMBER, LOCAL TIME

f^oF2

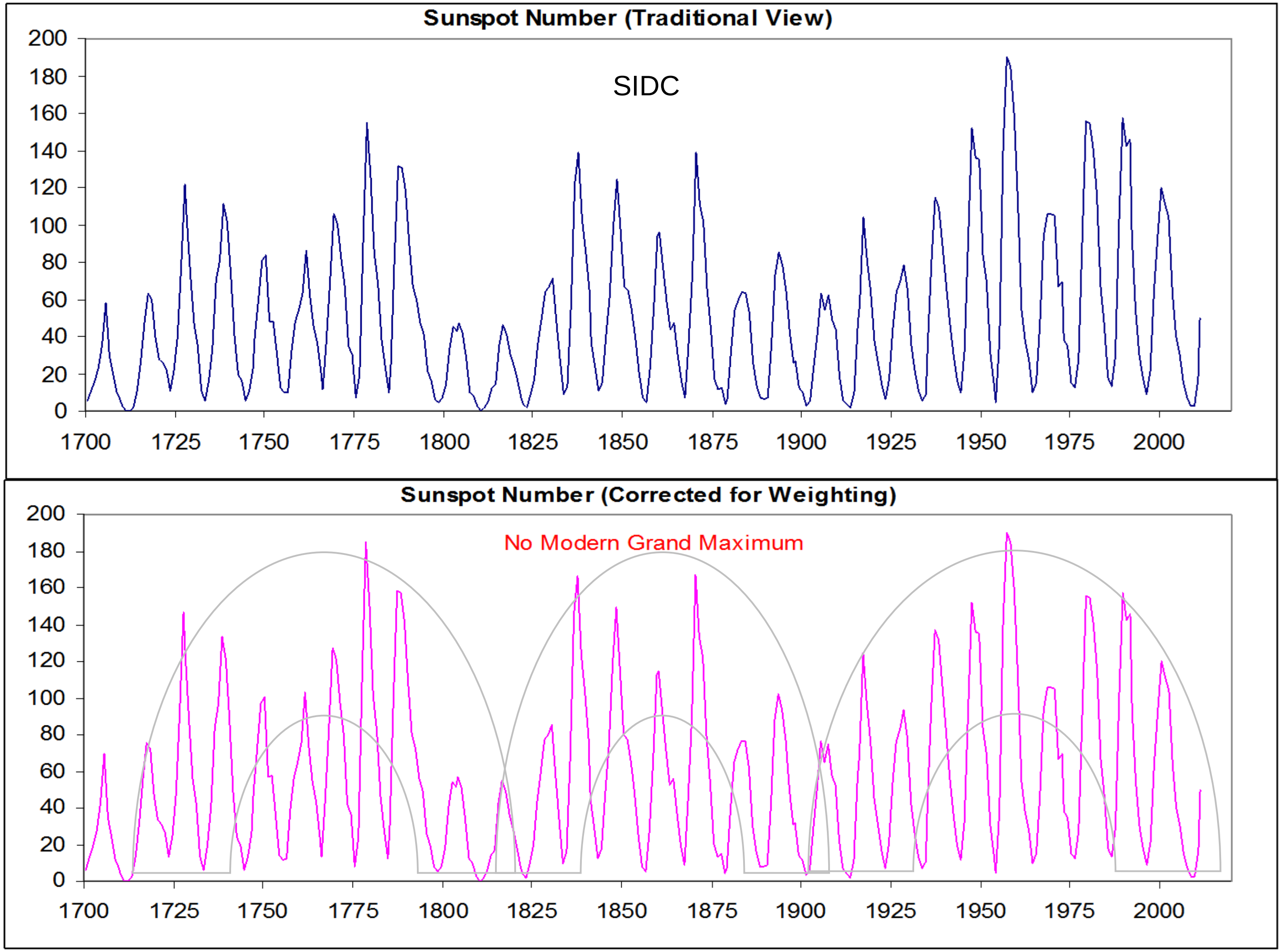
F2-layer critical frequency. This is the maximum radio frequency that can be reflected by the F2-region of the ionosphere at vertical incidence (that is, when the signal is transmitted straight up into the ionosphere). And has been found to have a profound solar cycle dependence.

The shift in SSN to bring the curves for cycles 17 and 18 to overlap is 21%

So, many lines of evidence point to an about 20% Waldmeier Weighting Effect

We can compensate for the effect by increasing all pre-1945 values by 20%

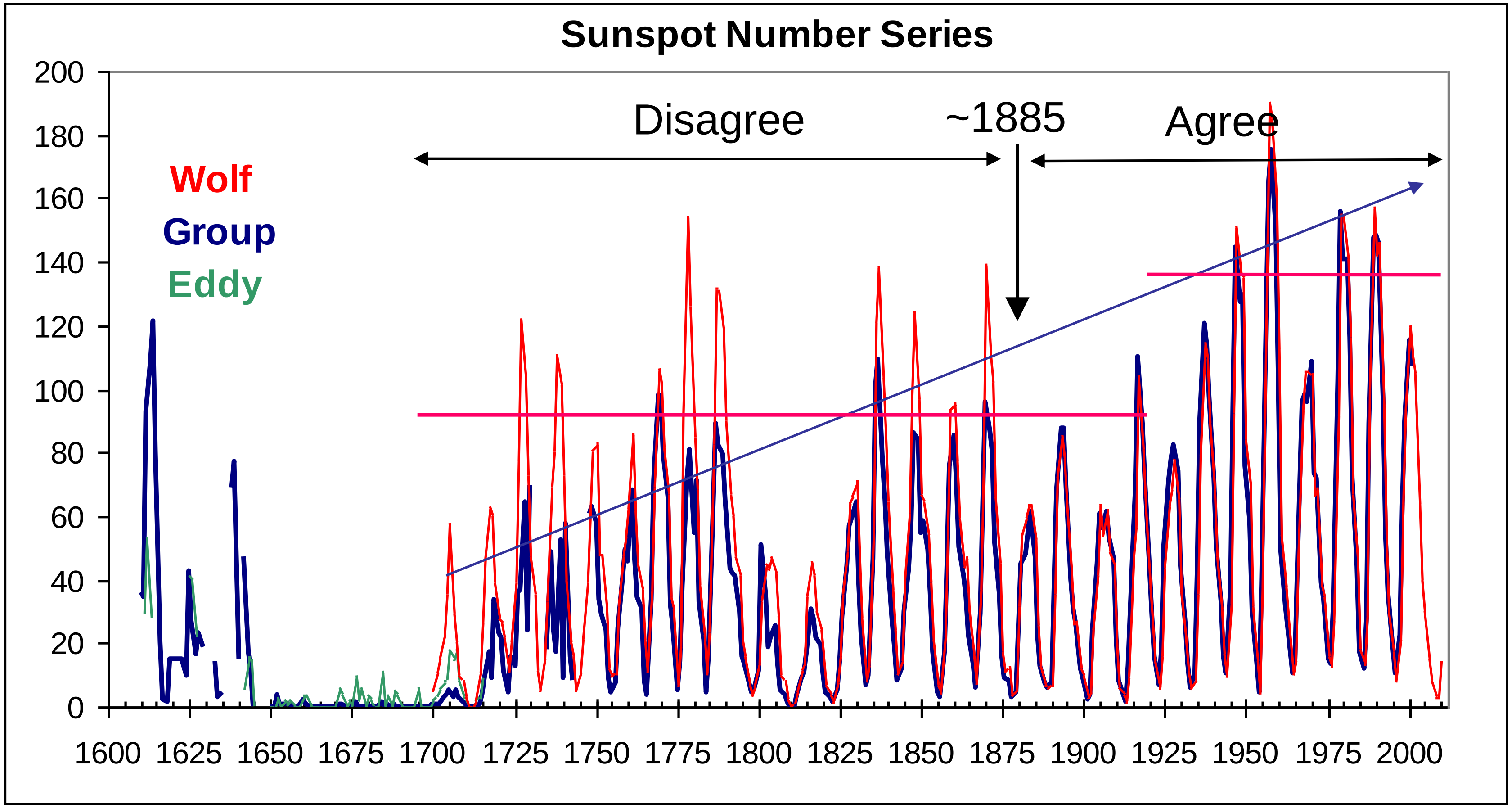
The Effect on the Sunspot Curve



No long-term trend the last 300 years

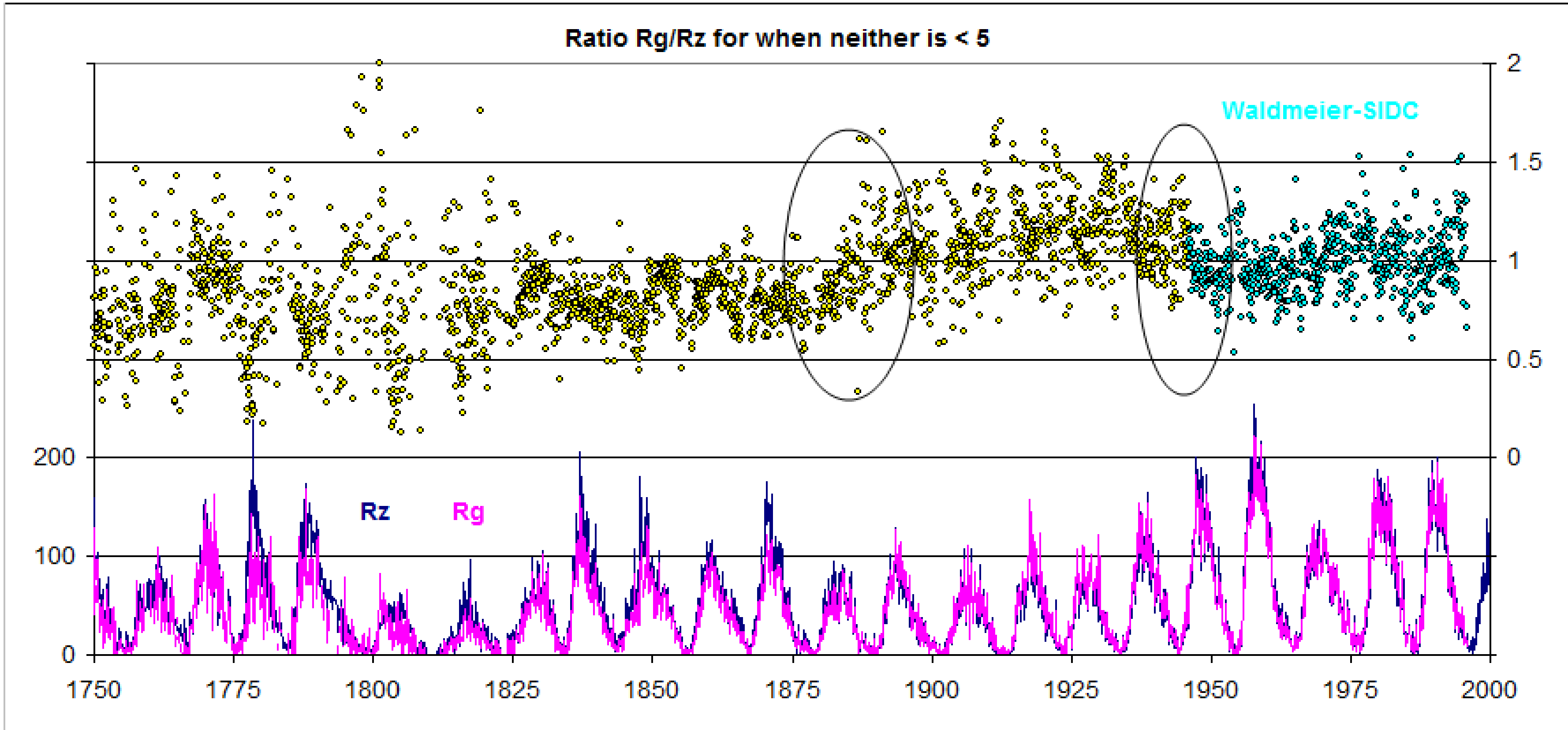
What is Wrong with the Group Sunspot Number and How to Fix it

The Problem: Two Sunspot Series



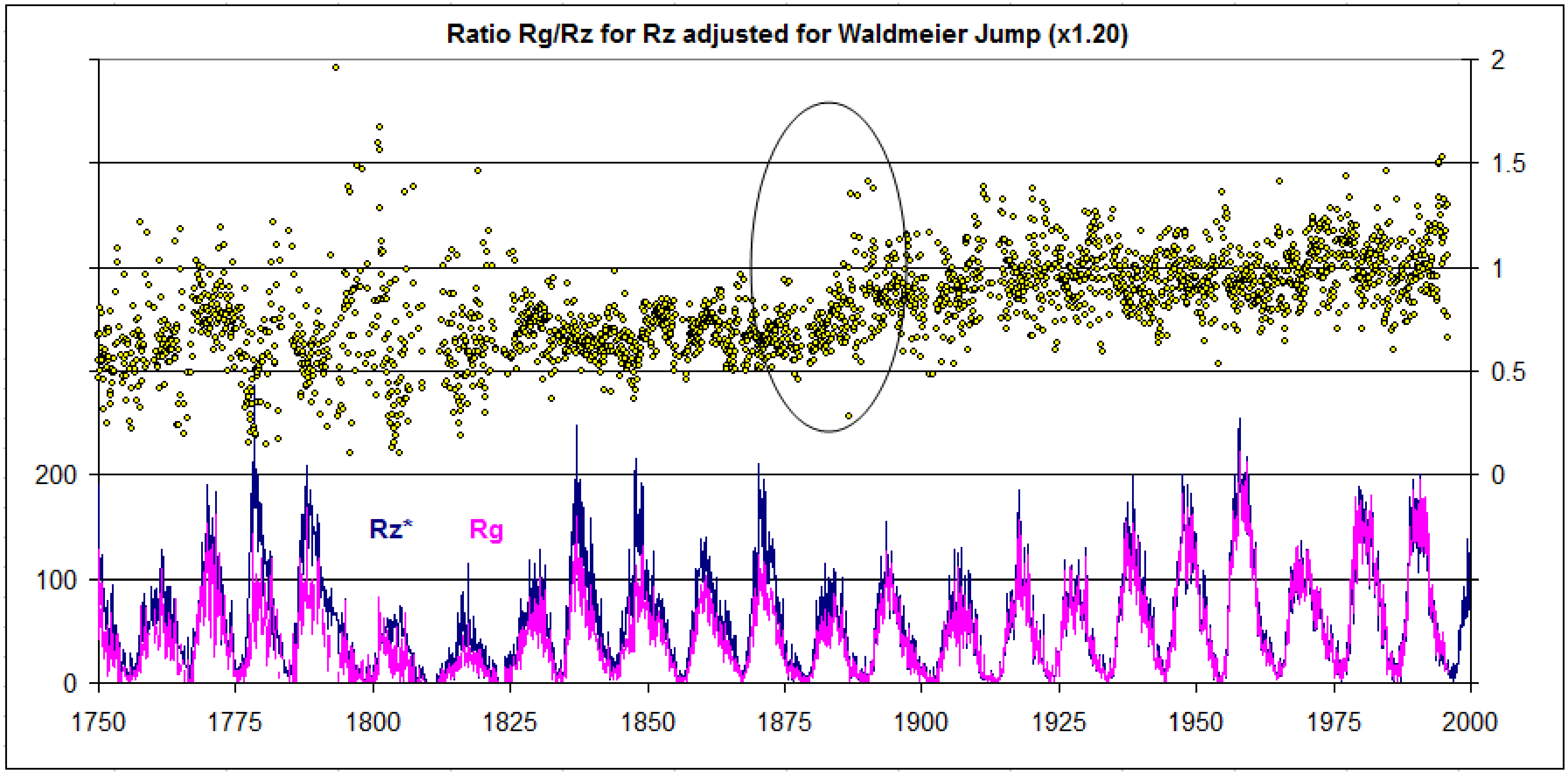
Researchers tend to cherry-pick the one that supports their pet theory the best – this is not a sensible situation. We should do better.

The Ratio Group/Zurich SSN has Two Significant Discontinuities



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

Removing the Recent one [+20%] by Multiplying Rz before 1946 by 1.20, Yields



Leaving one significant discrepancy ~1885

The Sunspot Number(s)

Rudolf Wolf (1816-1893)
Observed 1849-1893

- Wolf Number = K_W (10*G + S)
- G = number of groups
- S = number of spots

Ken Schatten

Group Number = 12 G

Douglas Hoyt and Kenneth Schatten devised the *Group Sunspot Number* using just the group count (1993).

Groups have *K*-factors too

Schaefer (ApJ, **411**, 909, 1993) noted that with

R_{Group} = *Norm-factor G* , there is no *K* factor. In essence, this is because all telescopic observers see the same groups (at least statistically), so a spot count based on *G* alone will be free of biases.

Alas, as H&S quickly realized, different observers do ***not*** see the same groups, so a correction factor, K_G, had to be introduced into the Group Sunspot Number as well: $R_{Group} = 12\ K_G\ G$ [averaged over all observers]

And therein lies the rub: it comes down to determination of a *K*-value for each observer [and with respect to what?]

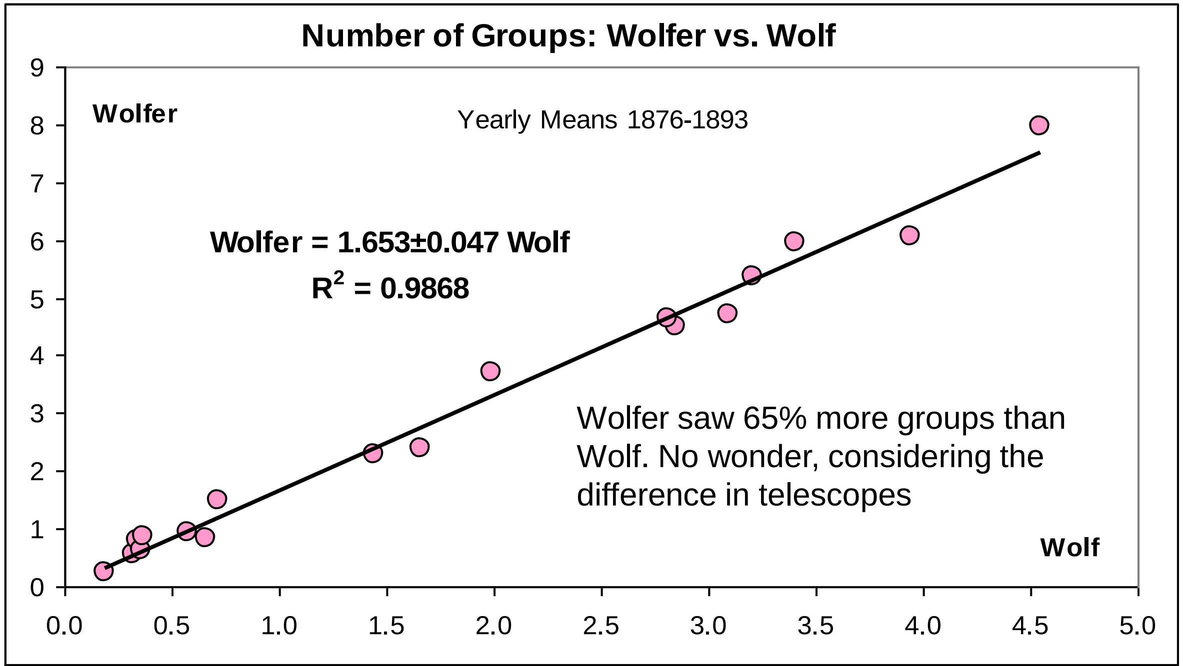
With respect to what?

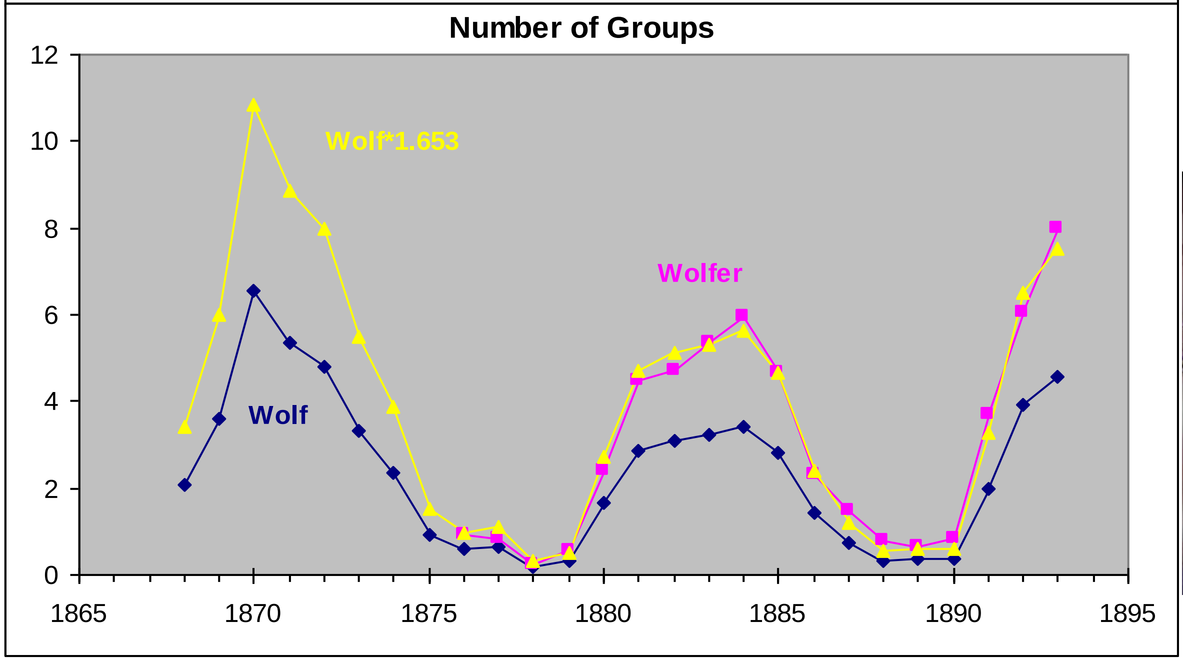
H&S compared with the number of groups per day reported by RGO in the 'Greenwich Helio-Photographic Results'. The plates, from different instruments on varying emulsions, were measured by several [many] observers over the 100-year span of the data.

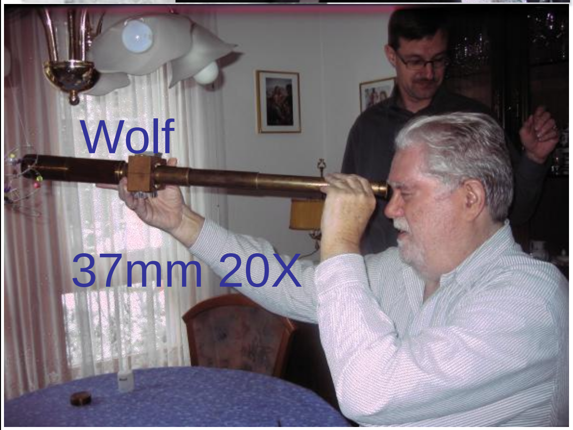
H&S – having little direct evidence to the contrary - assumed that the data was homogenous [having the same calibration] over the whole time interval.

We'll not make any such assumption. But shall compare sunspot groups between different overlapping observers, assuming only that each observer is homogenous within his own data (this assumption can be tested as we shall see)

K_G-factor for Wolf to Wolfer Groups

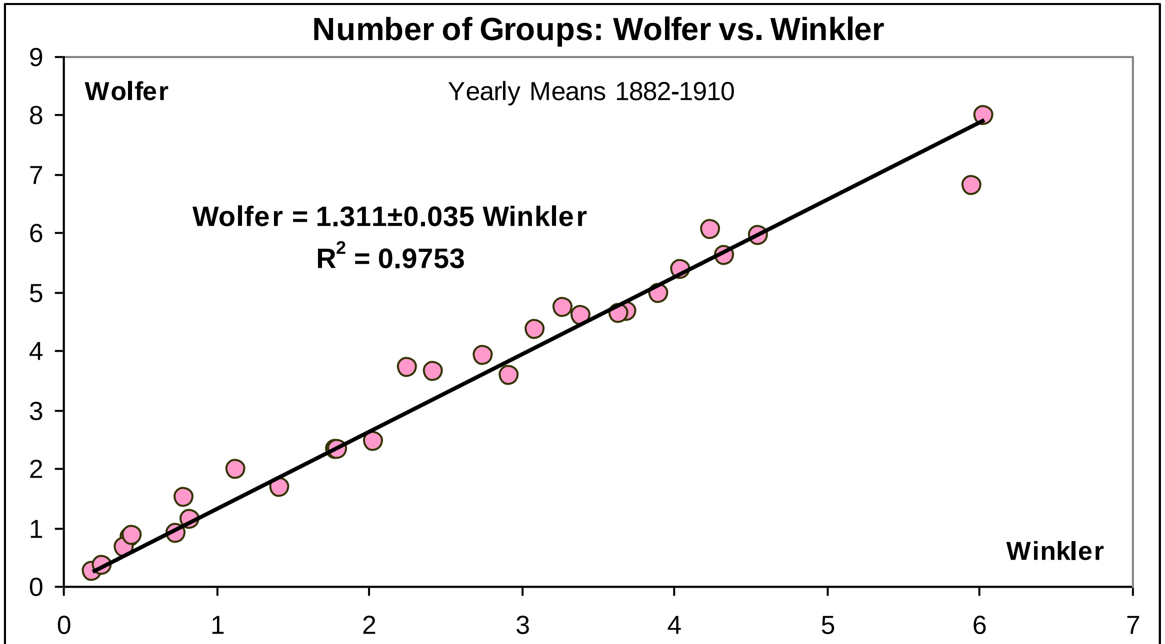


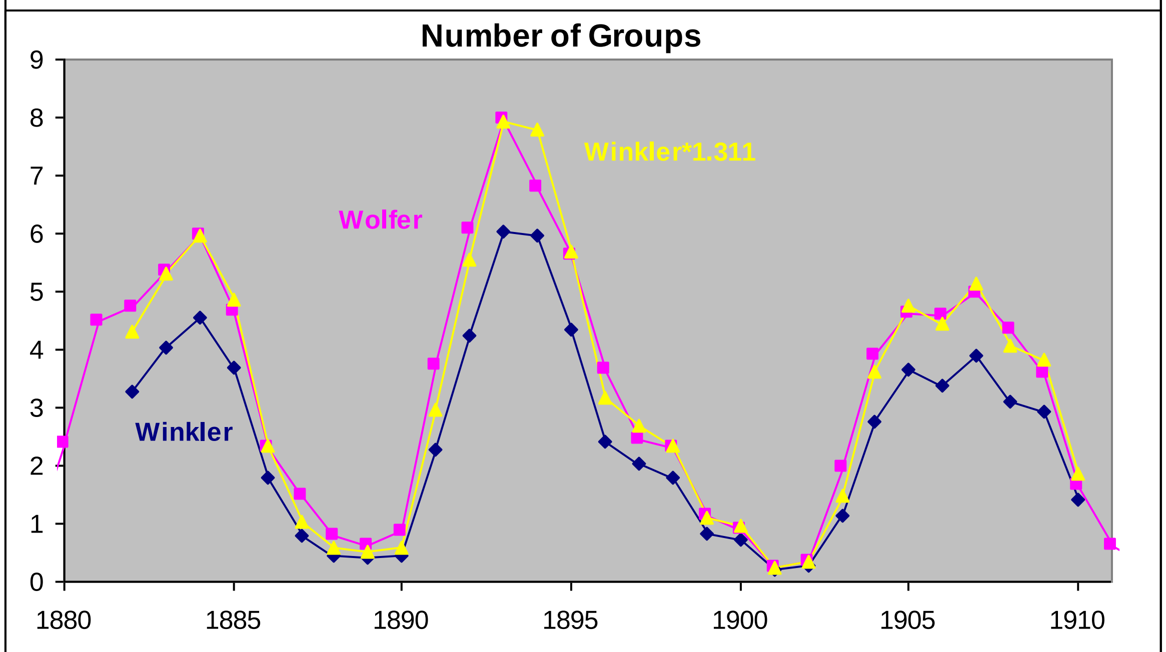




The K-factor shows in daily values too

1883 Month	Day	Wolf G	Wolf S	Wolf R	Wolfer G	Wolfer S	Wolfer R
8	16	3	4	34	7	29	99
8	17	3	6	36	11	29	139
8	18	3	6	36	7	31	101
8	19	3	5	35	8	30	110
8	20	2	3	23	7	18	88
8	21	2	3	23	7	40	110
8	22	2	4	24	7	41	111
8	23	2	4	24	5	37	87
8	24	2	4	24	6	35	95
8	25	2	4	24	5	32	82
8	26	4	8	48	4	55	95
8	27	3	9	39	4	60	100
8	28	4	12	52	5	91	141
8	29	4	10	50	5	62	112
8	30	6	12	72	7	82	152
8	31	6	16	76	6	88	148
9	1	5	15	65	8	81	161
Average		3.29	7.35	40.29	6.41	49.47	113.59
				x1.5	G Ratio	S Ratio	x0.6
To place on Wolf's scale with the 80mm				60	1.95	6.73	68

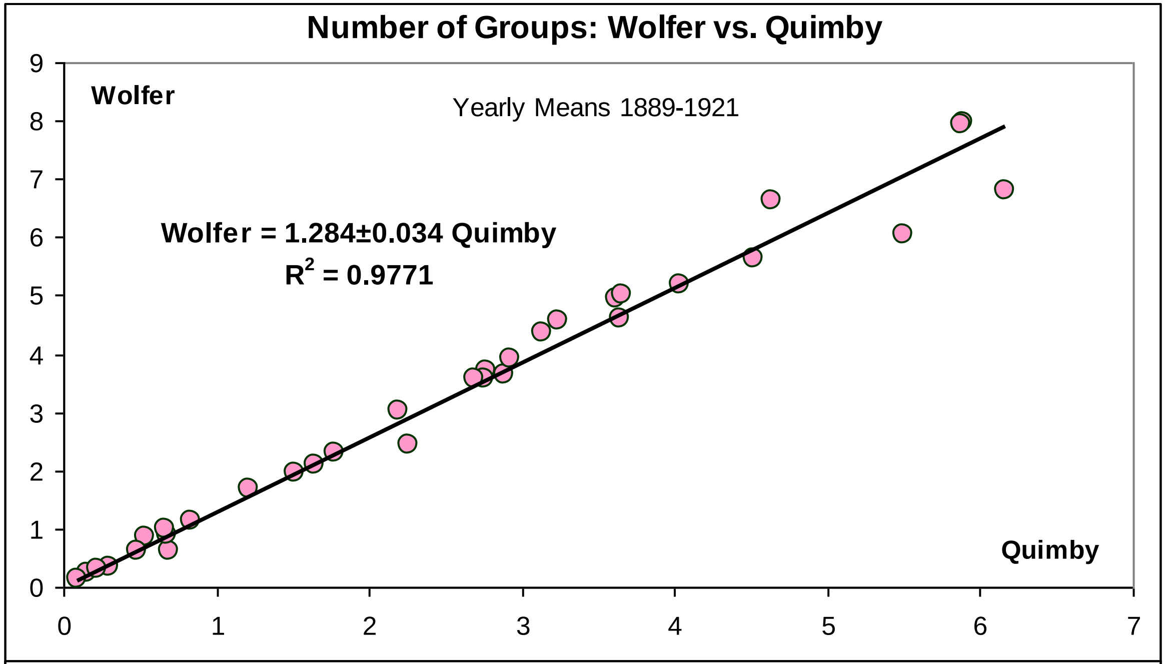


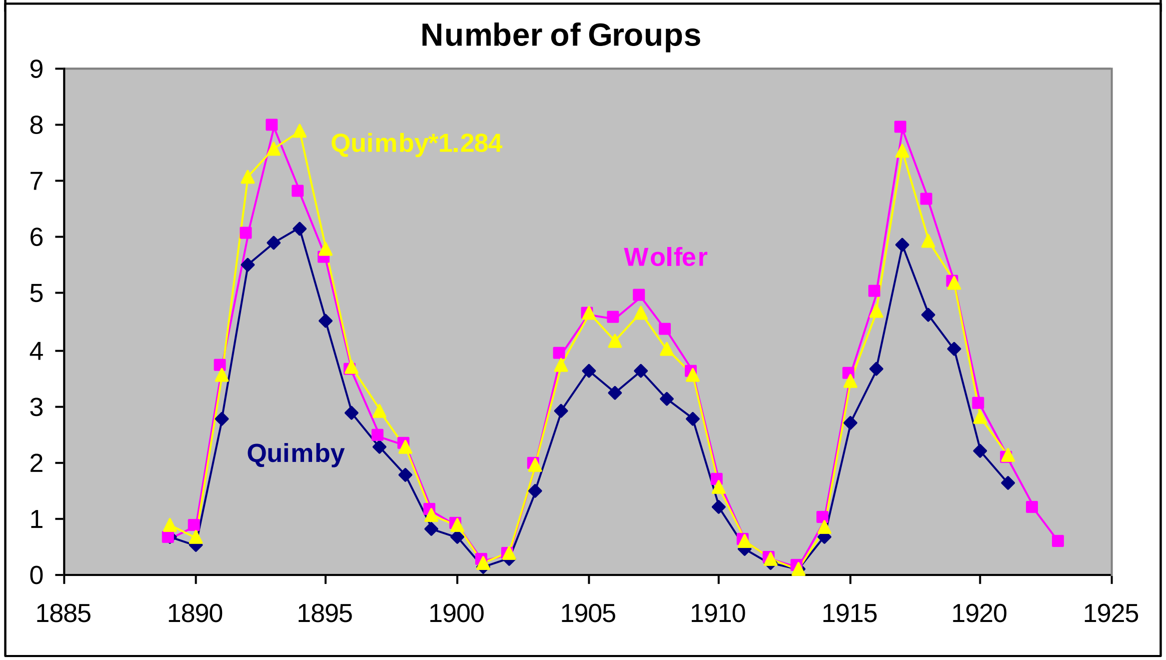


We can make the same type of comparison between observers Winkler and Wolfer

Again, we see a strong correlation indicating homogenous data

Again, scaling by the slope yields a good fit



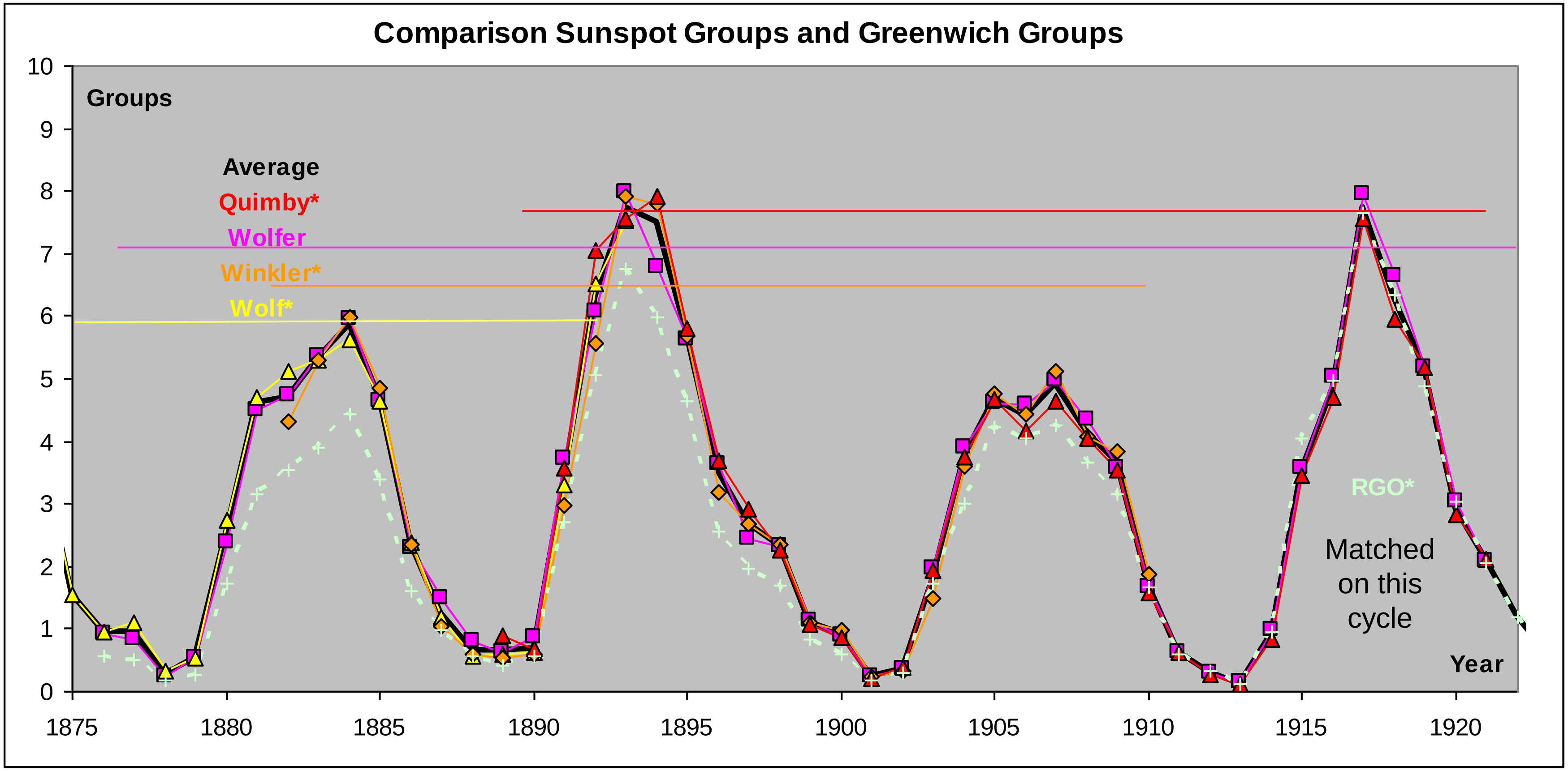


And between Rev. A. Quimby [Philadelphia] and Wolfer

Same good and stable fit

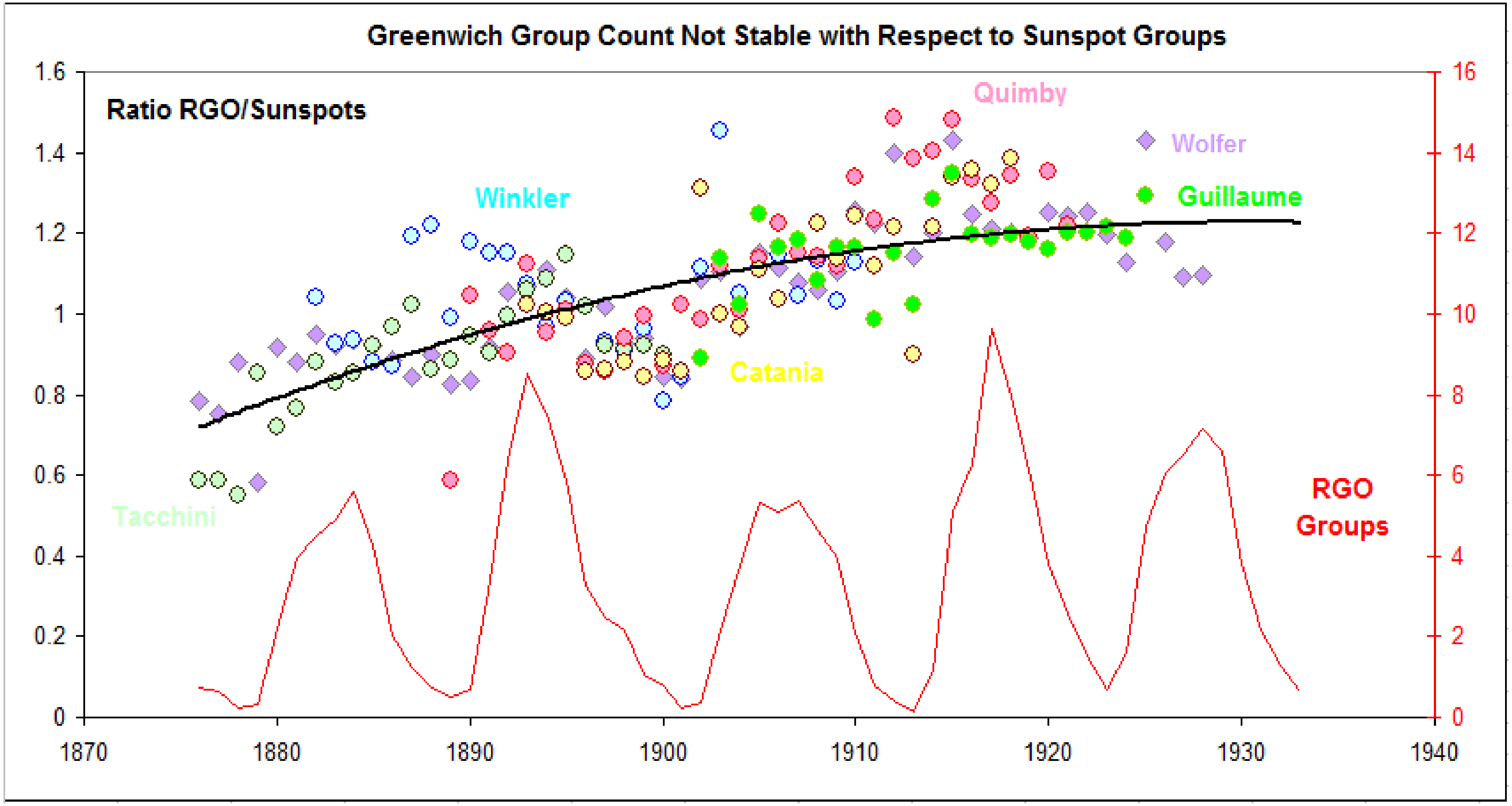
Quimby's friend H. B. Rumrill continued the series of observations until 1951, for a total length of 63 years.

Making a Composite



Compare with group count from RGO [dashed line] and note its drift

RGO Groups/Composite Sunspot Groups



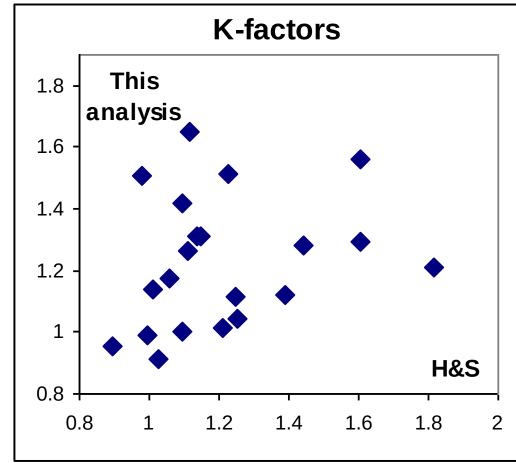
Early on, RGO count fewer groups than the Sunspot Observers. There was a significant fraction of days with no observations. H&S count these days as having a group count of zero, worsening the trend

Why are these so different?

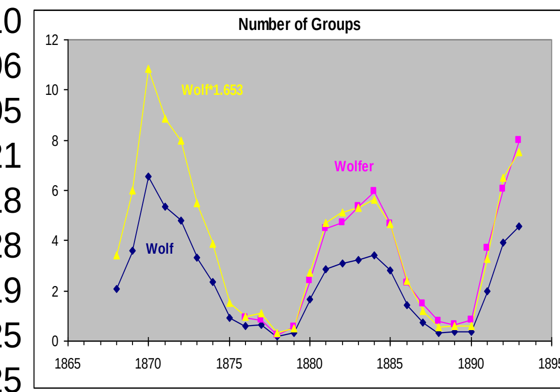
Our K-Factors vs. H&S's

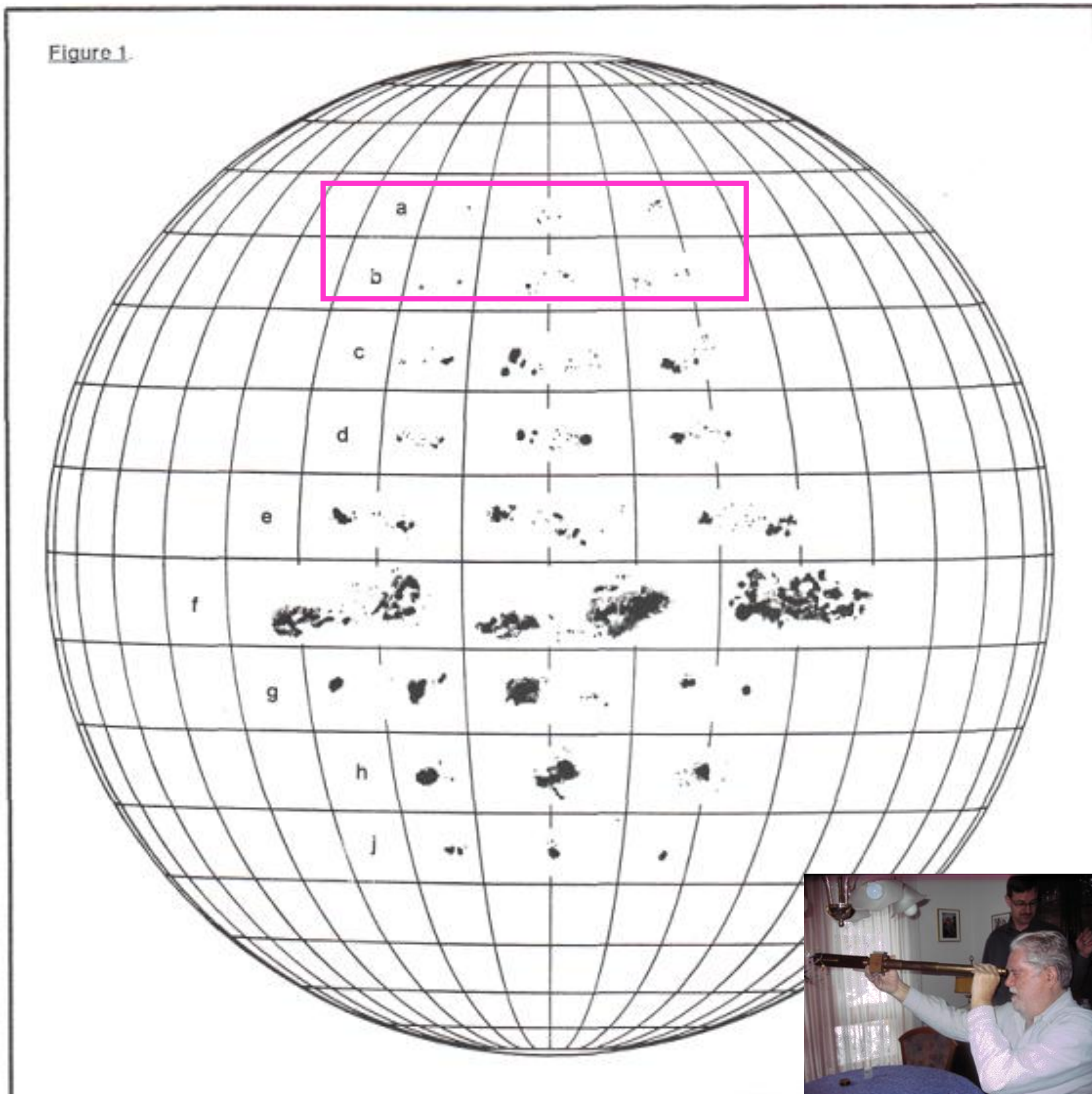
2% diff.

Observer	H&S RGO	to Wolfer	Begin	End
Wolfer, A., Zurich	1.094	1	1876	1928
Wolf, R., Zurich	1.117	1.6532	1876	1893
Schmidt, Athens	1.135	1.3129	1876	1883
Weber, Peckeloh	0.978	1.5103	1876	1883
Spoerer, G., Anclam	1.094	1.4163	1876	1893
Tacchini, Rome	1.059	1.1756	1876	1900
Moncalieri	1.227	1.5113	1876	1893
Leppig, Leibzig	1.111	1.2644	1876	1881
Bernaerts, G. L., England	1.027	0.9115	1876	1878
Dawson, W. M., Spiceland, Ind.	1.01	1.1405	1879	1890
Ricco, Palermo	0.896	0.9541	1880	1892
Winkler, Jena	1.148	1.3112	1882	1910
Merino, Madrid	0.997	0.9883	1883	1896
Konkoly, Ogylla	1.604	1.5608	1885	1905
Quimby, Philadelphia	1.44	1.2844	1889	1921
Catania	1.248	1.1132	1893	1918
Broger, M, Zurich	1.21	1.0163	1897	1928
Woinoff, Moscow	1.39	1.123	1898	1919
Guillaume, Lyon	1.251	1.042	1902	1925
Mt Holyoke College	1.603	1.2952	1907	1925



No correlation



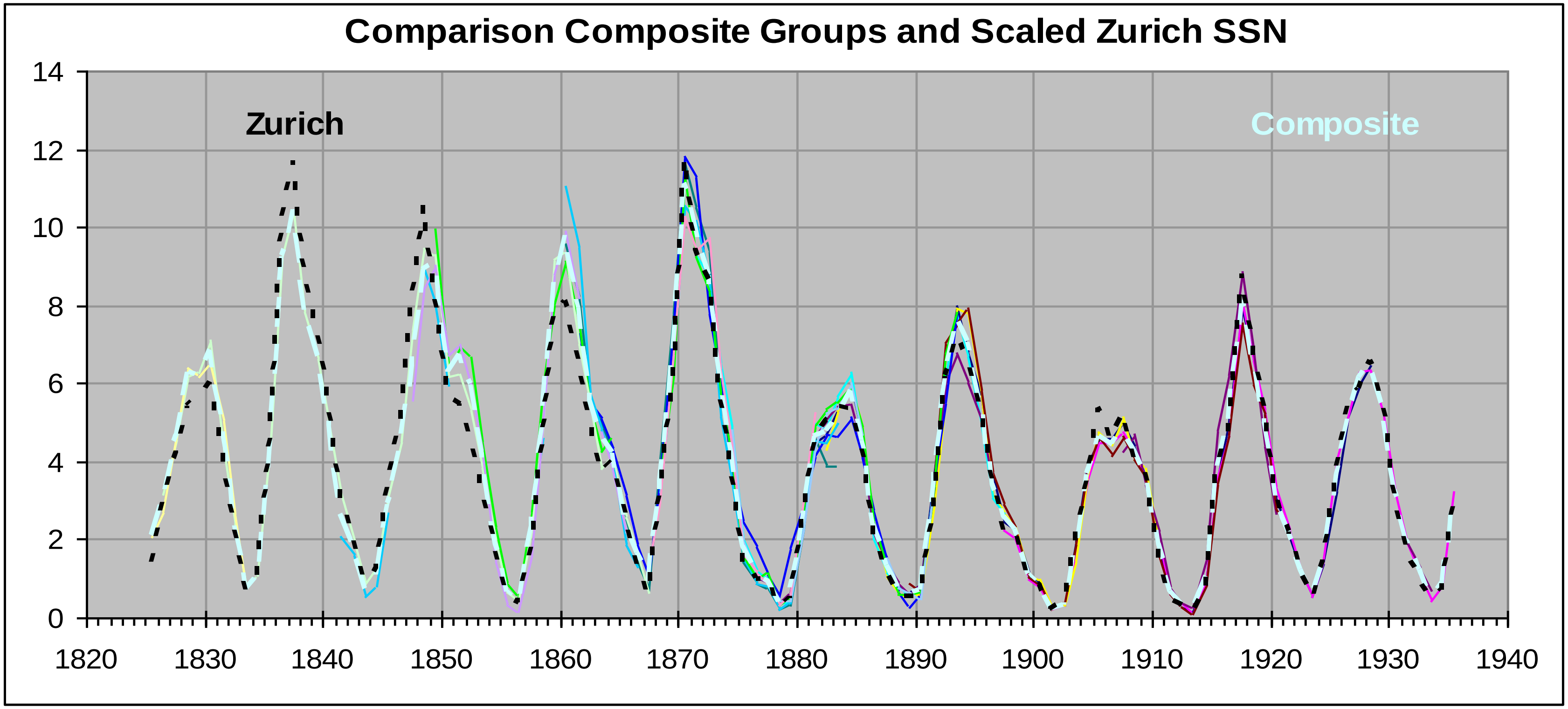


Why the large difference between Wolf and Wolfer?

Because Wolf either could not see groups of Zurich classes A and B [with his small telescope] or deliberately omitted them early on when he used the standard 80mm telescope. The A and B groups make up almost half of all groups

Extending the Composite

Comparing observers back in time [that overlap first our composite and then each other] one can extend the composite successively back to Schwabe:



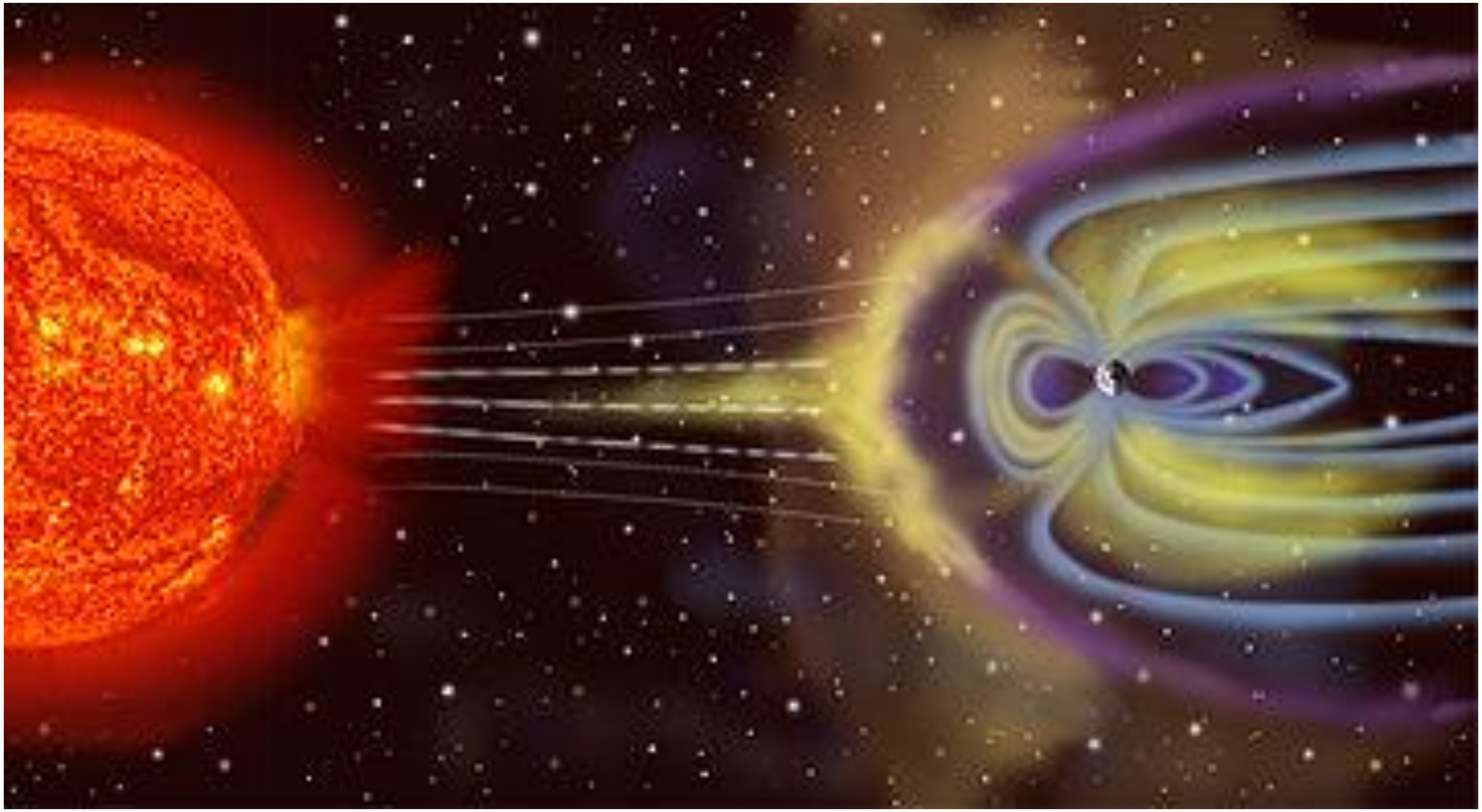
There is now no systematic difference between the Zurich SSN and a Group SSN constructed by not involving RGO.

Geomagnetic Calibration of Sunspot Numbers

Wolf's Several Lists of SSNs

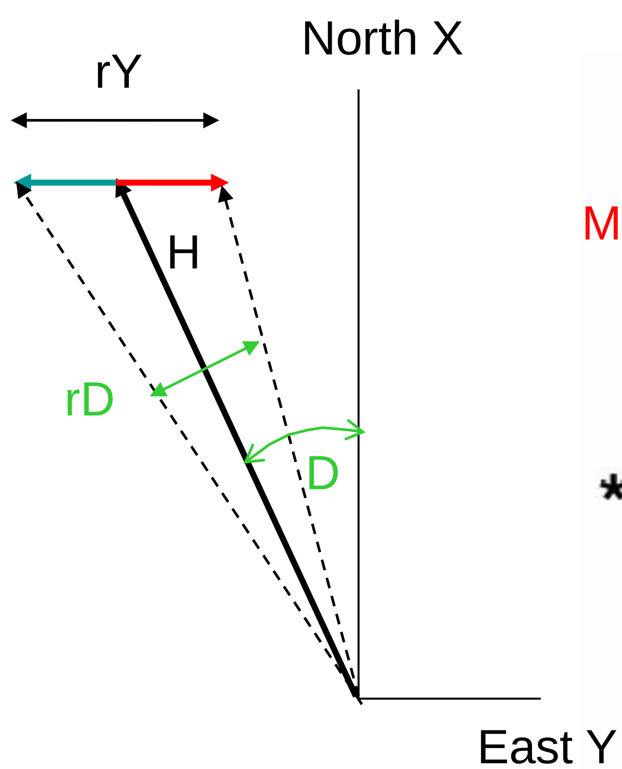
- During his life Wolf published several lists of his 'Relative Sunspot Number':
- 1857 Using Sunspot Drawings By Staudacher 1749-1799 as early SSNs
- 1861 Doubling Staudacher's Numbers to align with the large variation of the 'Magnetic Needle' in the 1780s
- 1874 Adding newer data and published new list
- 1880 Increasing all values before his own series [beginning 1849] by ~25% based on Milan Declination
- 1902 [Wolfer] reassessment of cycle 5 reducing it significantly, obtaining the 'Definitive' List in use today

Geomagnetic Regimes



1) Solar FUV maintains the ionosphere and influences the daytime field.
2) Solar Wind creates the magnetospheric tail and influences mainly the nighttime field

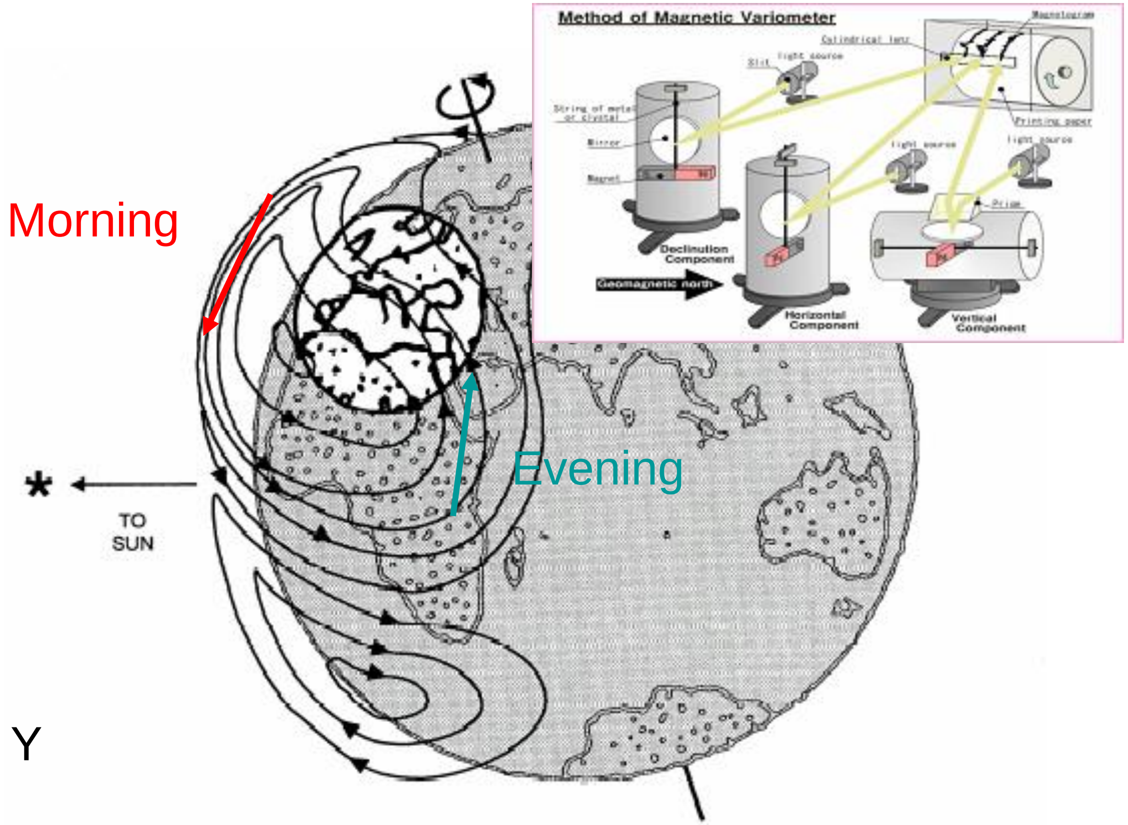
Justification of the Adjustments rests on Wolf's Discovery: $rD = a + b\ R_W$



$Y = H \sin(D)$

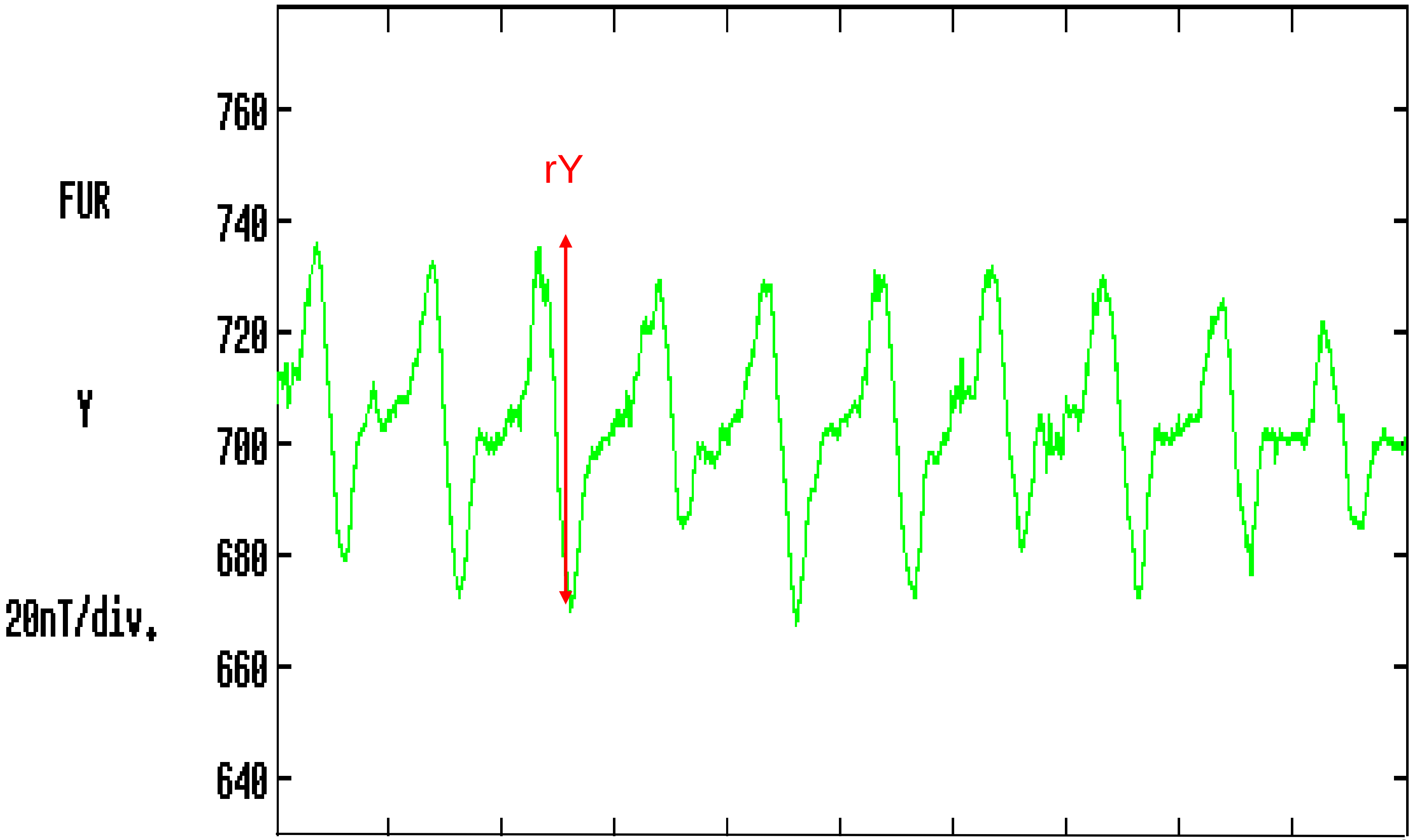
$dY = H \cos(D)\ dD$

For small D, dD and dH

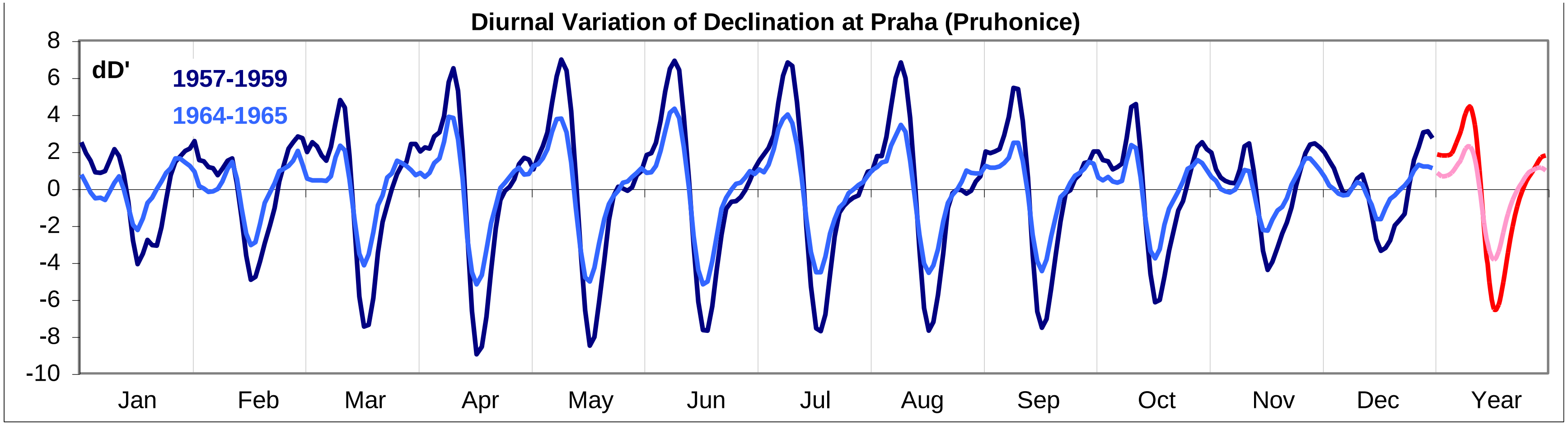


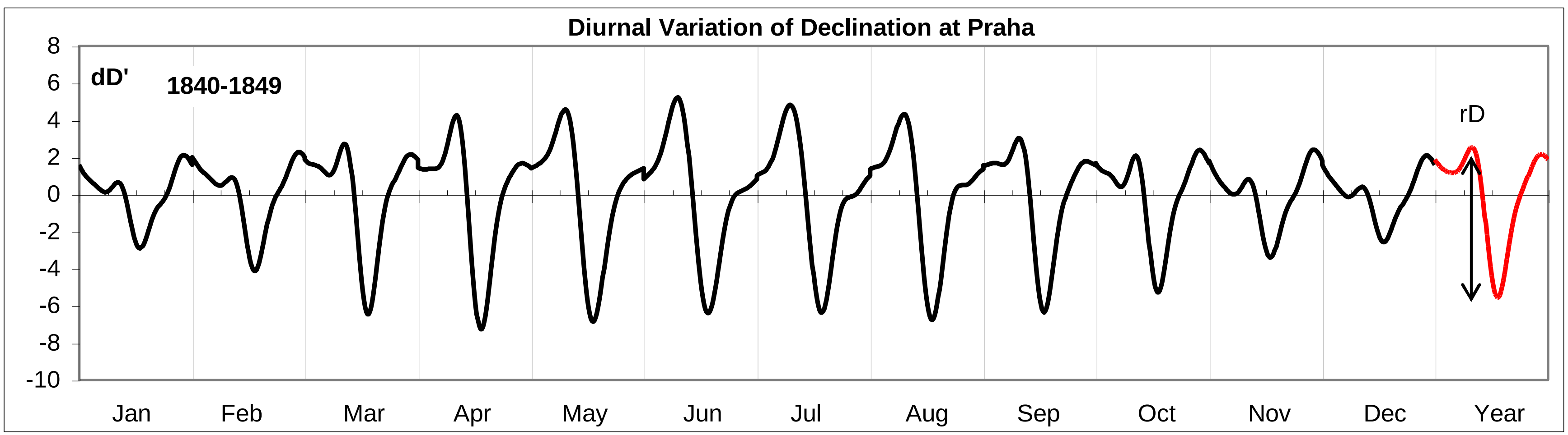
A current system in the ionosphere [E-layer] is created and maintained by solar FUV radiation. Its magnetic effect is measured on the ground.

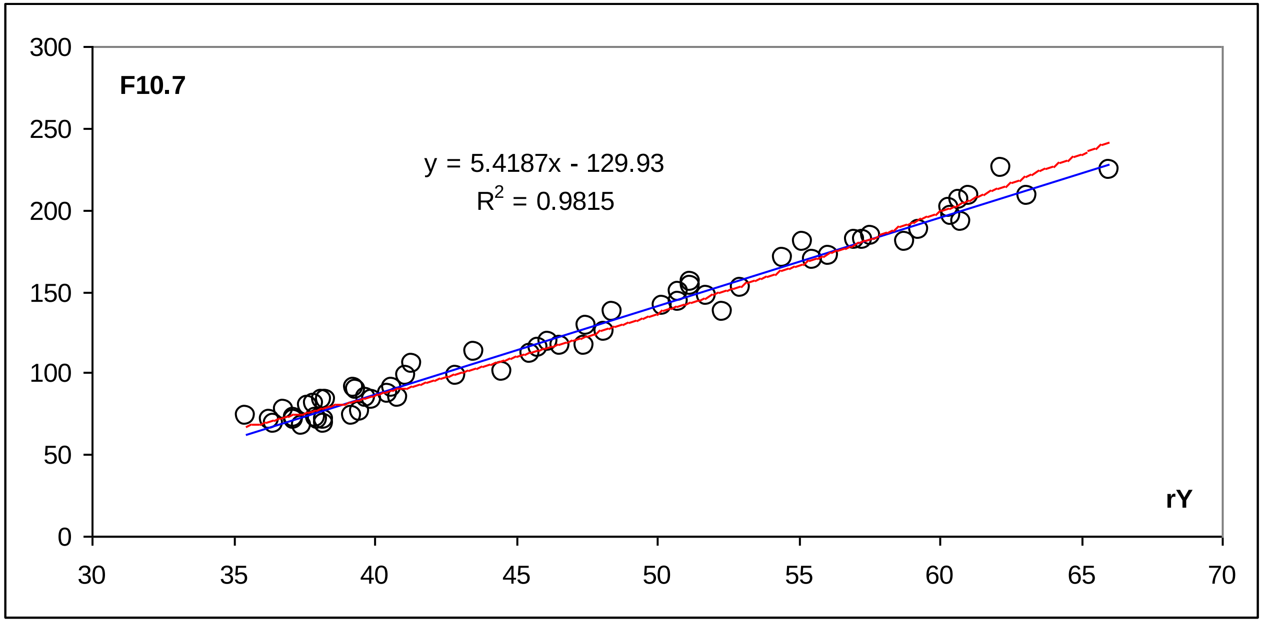
10 Days of geomagnetic variations



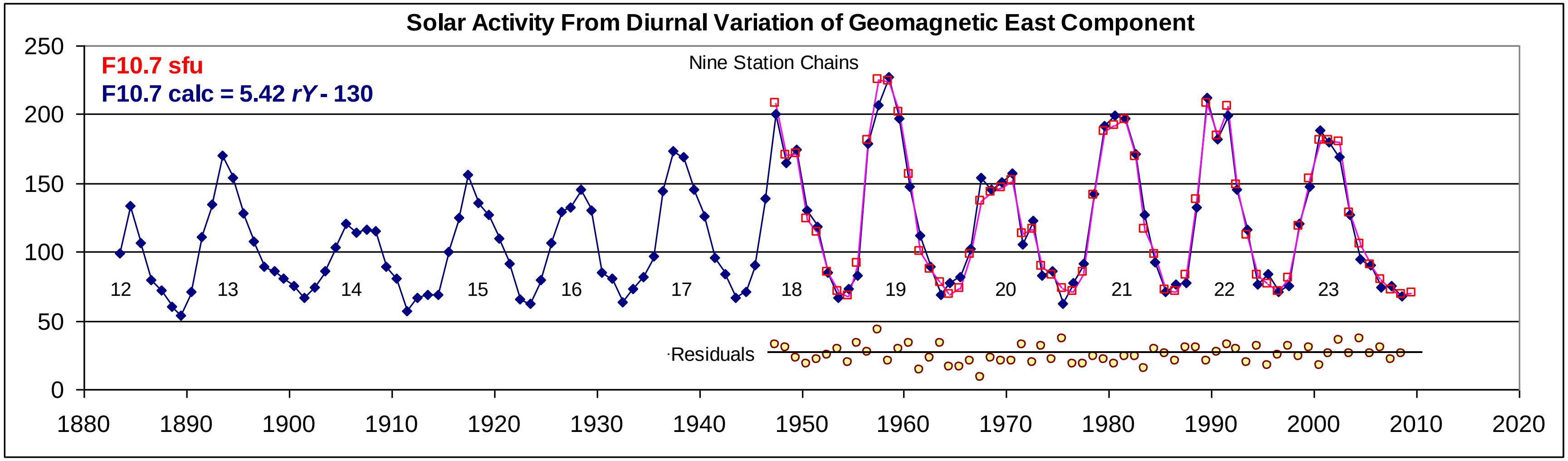
The Diurnal Variation of the Declination for Low, Medium, and High Solar Activity





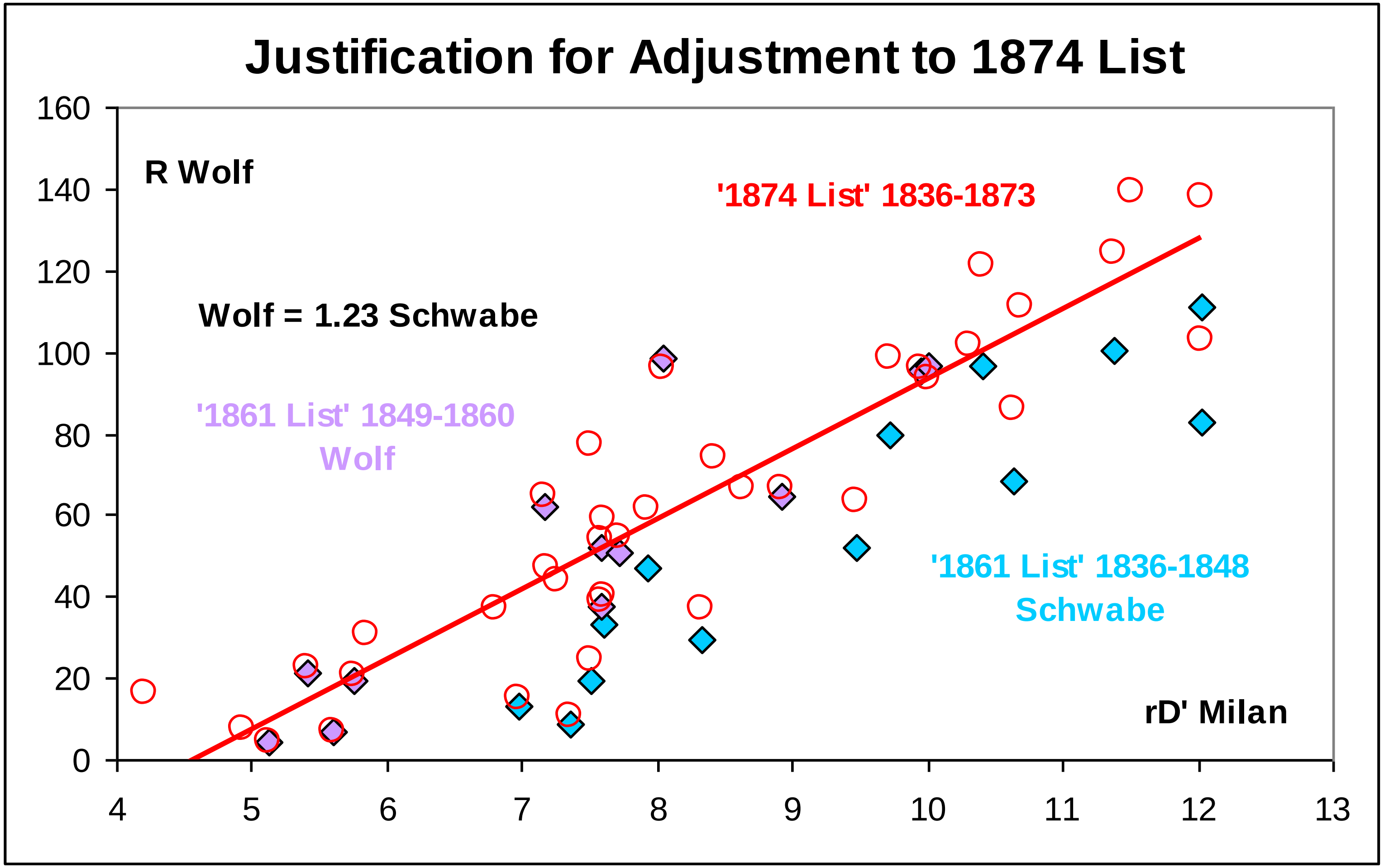


Using *rY* from nine 'chains' of stations we find that the **correlation** between *F10.7* and *rY* is extremely good (more than 98% of the variation is accounted for)



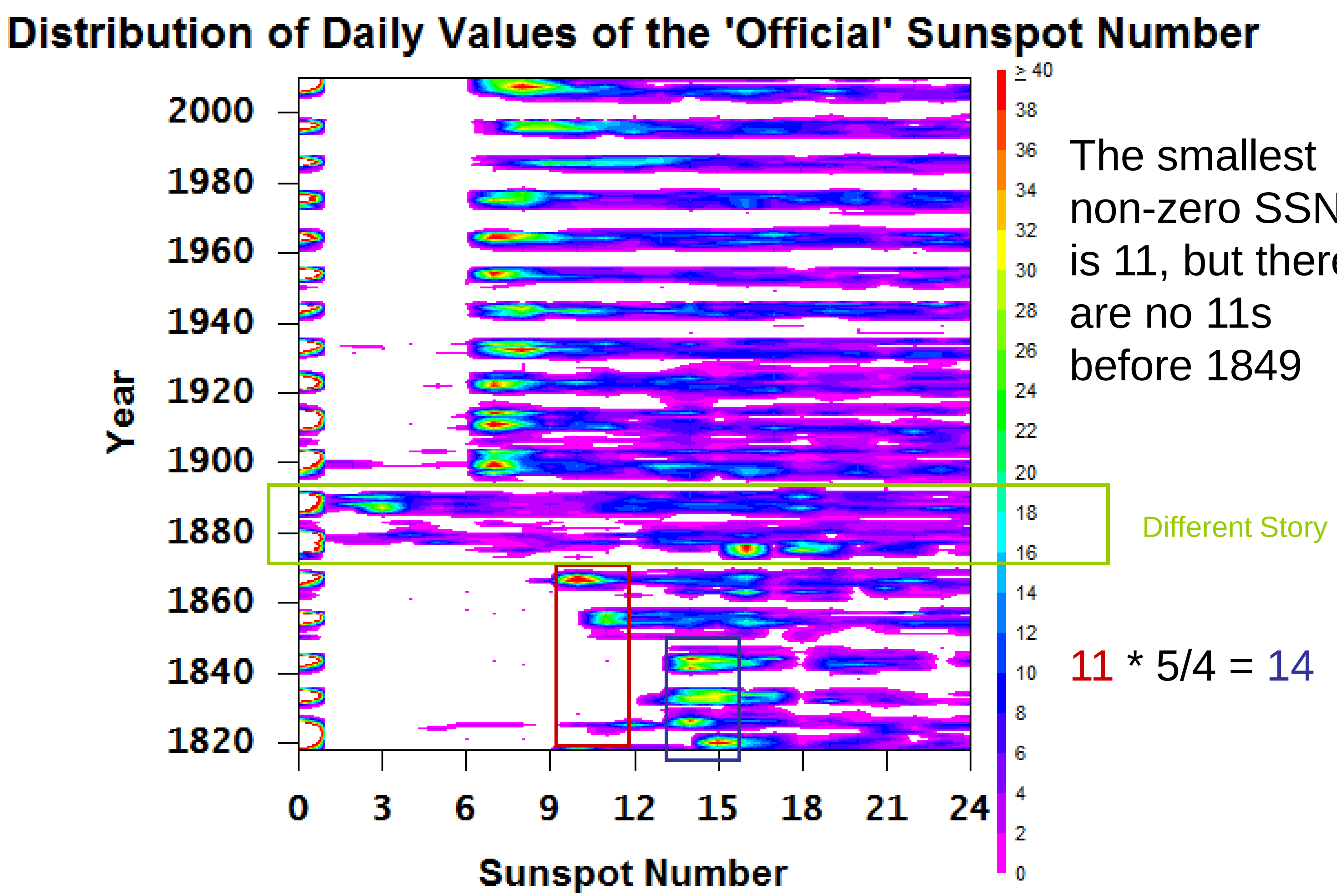
This establishes that Wolf's procedure and calibration are physically sound

Wolf got Declination Ranges for Milan from Schiaparelli and it became clear that the pre-1849 SSNs were too low



The ‘1874’ list included the 25% [Wolf said 1/4] increase of the pre-1849 SSN

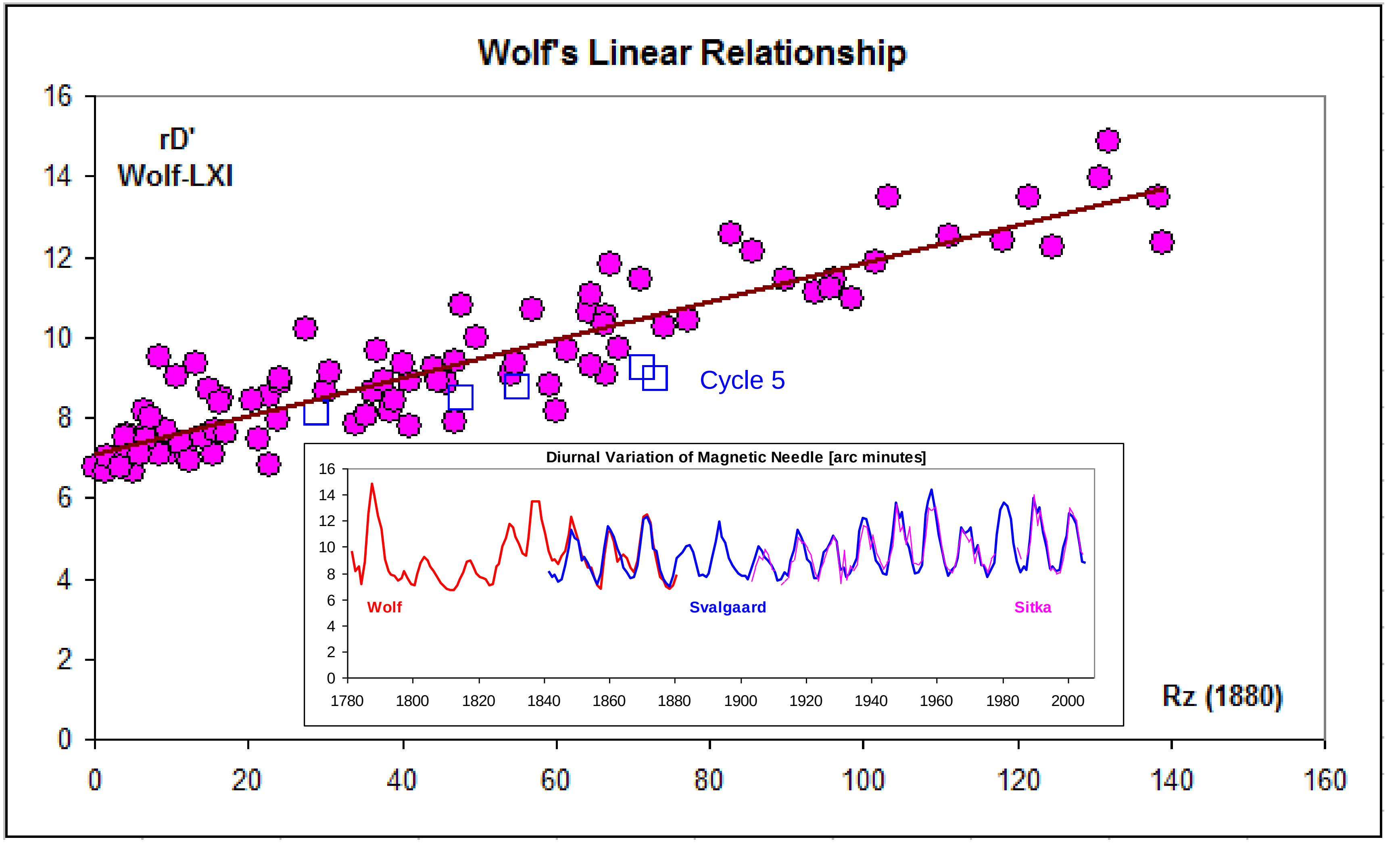
The Wholesale Update of SSNs before 1849 is Clearly Seen in the Distribution of Daily SSNs



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

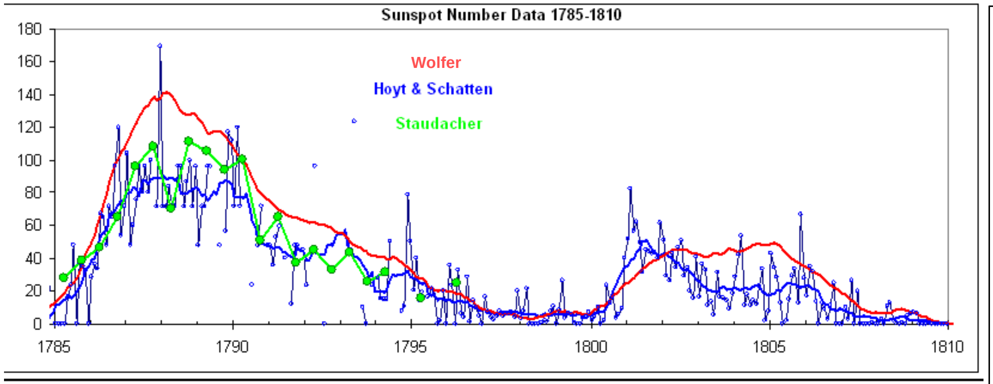
11 * 5/4 = 14

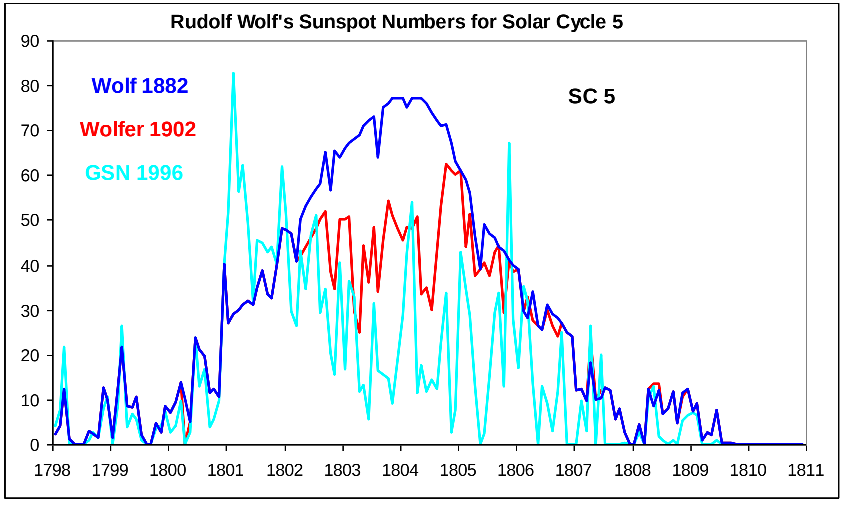
Wolf's SSN was thus now consistent with his many-station compilation of the diurnal variation of Declination 1781-1880

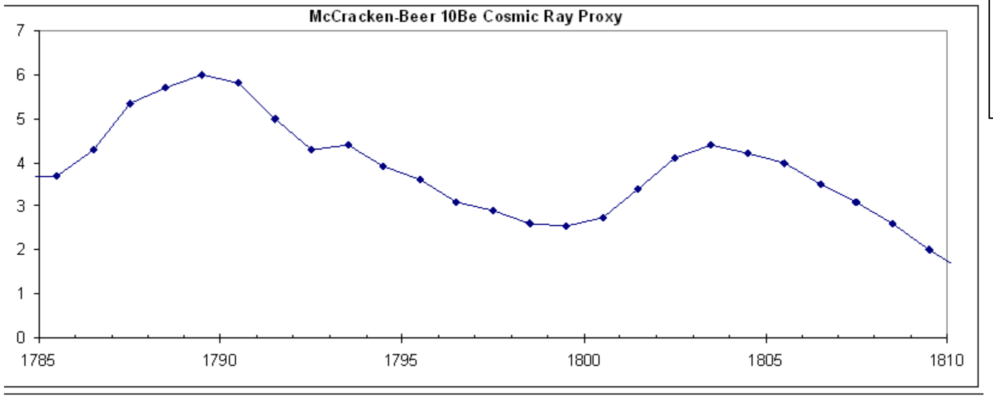


It is important to note that the relationship is *linear* for calculating averages

Wolfer’s Revision of Solar Cycle 5 Based on Observations at Kremsmünster

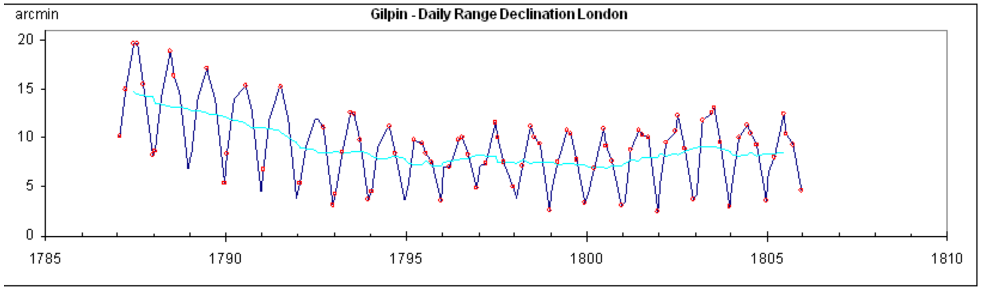






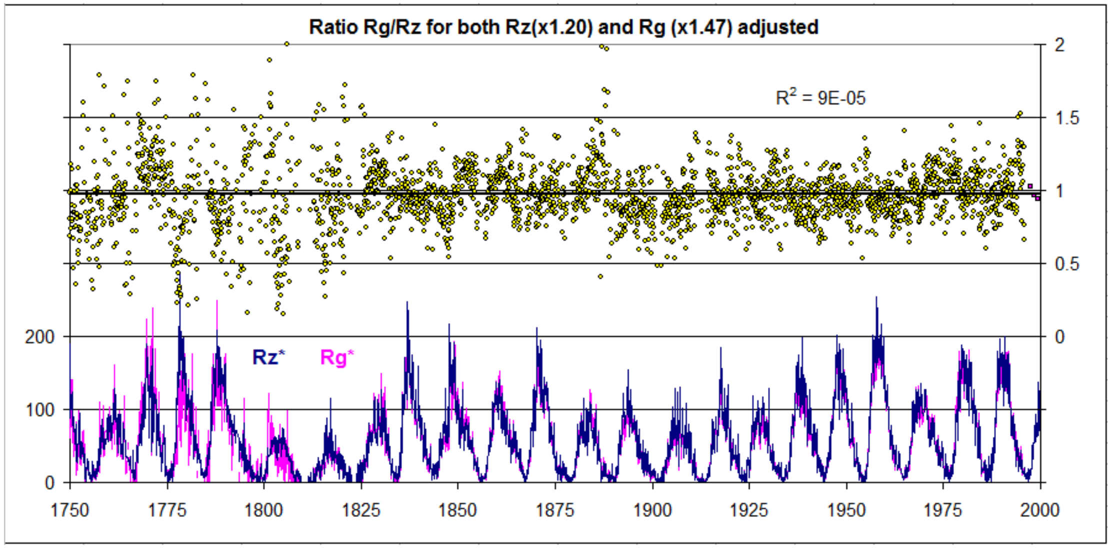
The Kremsmünster data is of very poor quality and consists of small sketches that were at times produced when there were notable spot activity.

We have precious little information about cycles 5 and 6. Those two cycles are on the target list for the next SSN workshop.



The Early ~1885 Discrepancy

- Since the sunspot number has an arbitrary scale, it makes no difference for the calibration if we assume Rg to be too 'low' before ~1885 or Rz to be too 'high' after 1885

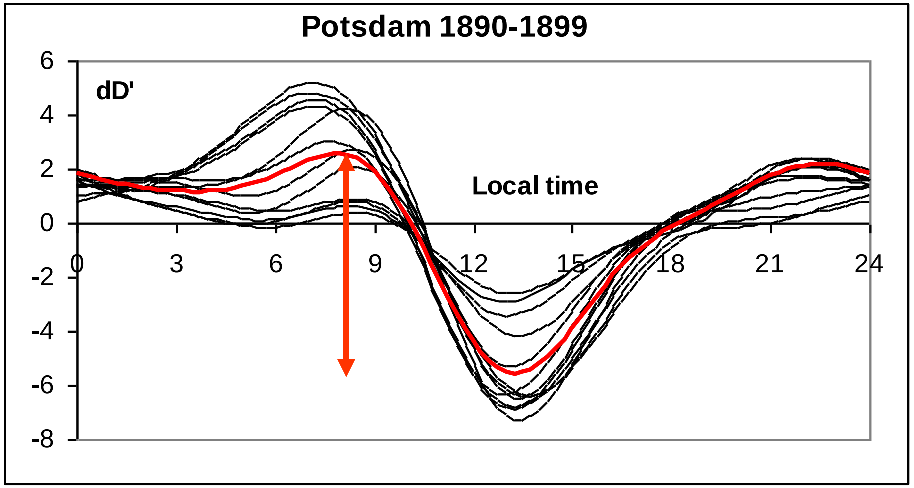


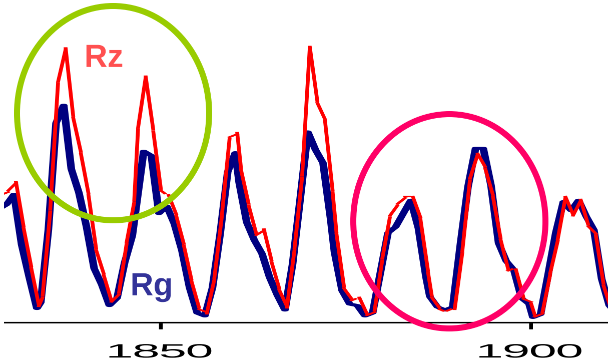
By applying Wolf's relationship between Rz and the diurnal variation of the Declination we can show that it is Rg that is too low

Adolf Schmidt's (1909) Analysis

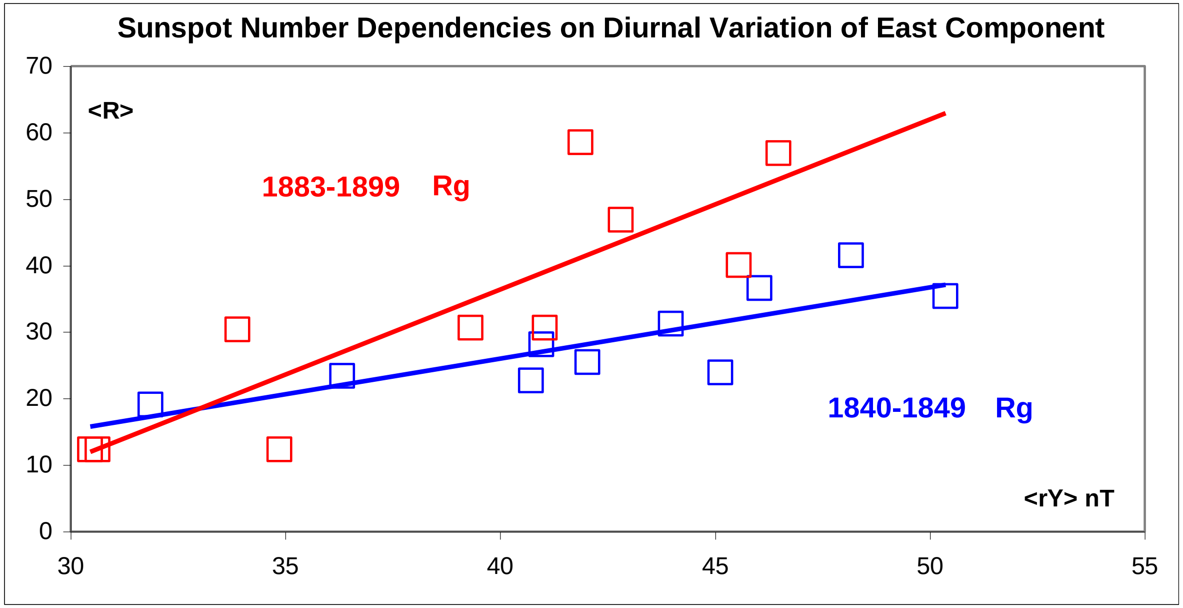
Schmidt collected raw hourly observations and computed the first four Fourier components [to 3-hr resolution] of the observed Declination in his ambitious attempt to present what was then known in an 'einheitlicher Darstellung' [uniform description]

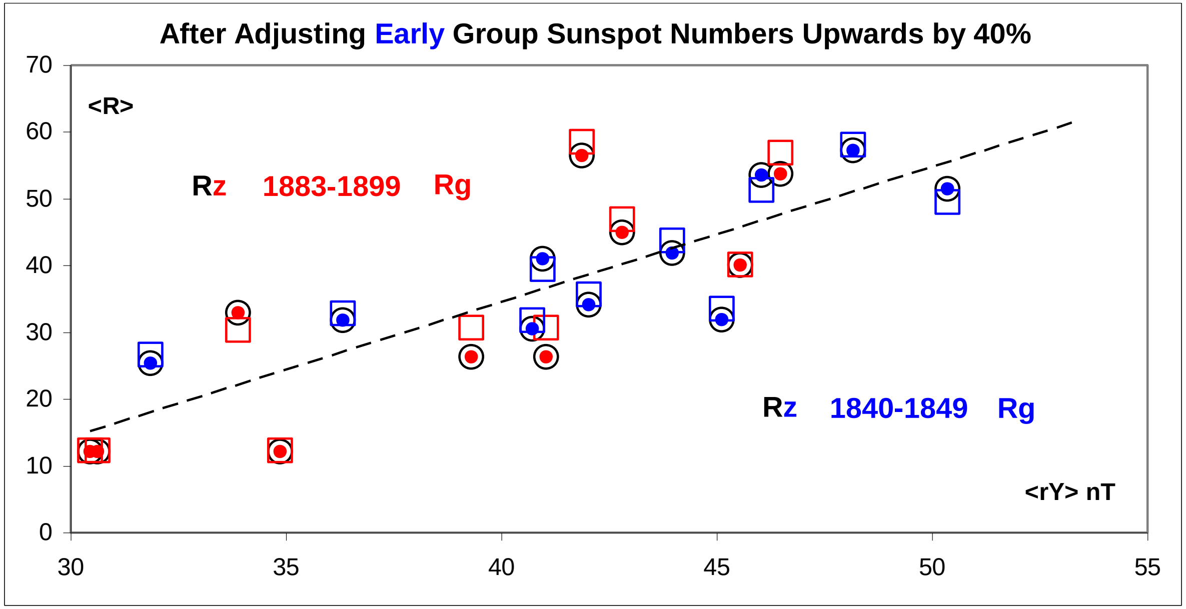
Observatory	Years	Lat	Long
Washington DC	1840-1842	38.9	282.0
Dublin	1840-1843	53.4	353.7
Philadelphia	1840-1845	40.0	284.8
Praha	1840-1849	50.1	14.4
Muenschen	1841-1842	48.2	11.6
St. Petersburg	1841-1845	60.0	30.3
Greenwich	1841-1847	51.5	0.0
Hobarton	1841-1848	-42.9	147.5
Toronto	1842-1848	43.7	280.6
Makerstoun	1843-1846	55.6	357.5
Greenwich	1883-1889	51.4	0.0
P. Saint-Maur	1883-1899	48.8	0.2
Potsdam	1890-1899	52.4	13.1
København	1892-1898	55.7	12.6
Utrecht	1893-1898	52.1	5.1
Odessa	1897-1897	46.4	30.8
Tokyo	1897-1897	35.7	139.8
Bucarest	1899-1899	44.4	26.1
Irkutsk	1899-1899	52.3	194.3
Zi-ka-wei	1899-1899	31.2	121.2





Engelenburg and Schmidt calculated the average variation over the interval for each month and determined the amplitude and phase for each month. From this we can reconstruct the diurnal variation and the yearly average amplitude, dD [red curve].



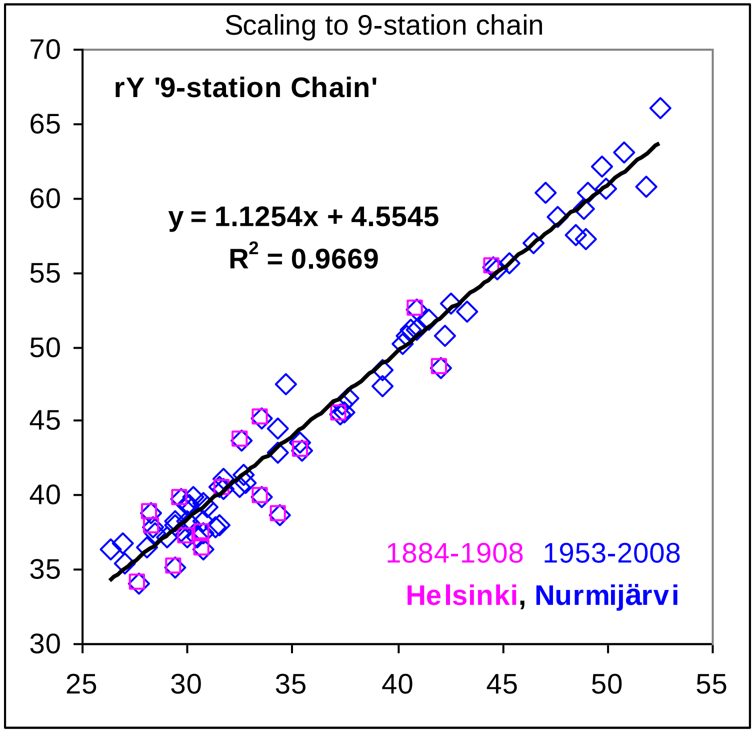


Procedure:

For each station we now compute the averages over the interval of <Rz>, of <Rg>, and of the diurnal range [converted to force units, nT, from arc minutes] and plot The Group Sunspot Numbers <Rg> as blue and red squares. It is clear that <Rg>s for the early interval fall significantly and systematically below <Rg> for the later.

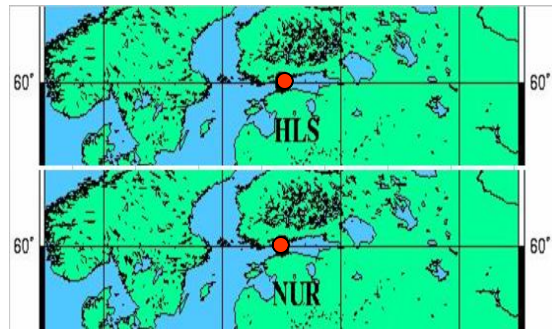
Increasing the early <Rg>s by 40% brings them into line with <Rz> before Waldmeier (Circles with dots).

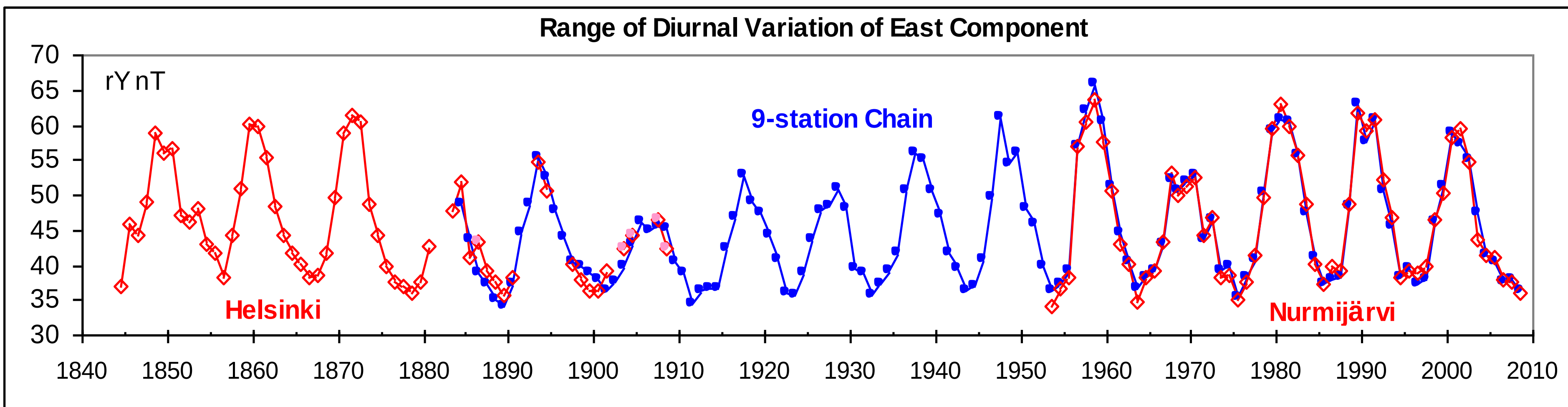
We conclude that the early Group Sunspot Numbers are too low, consistent with our analysis of the K-factors



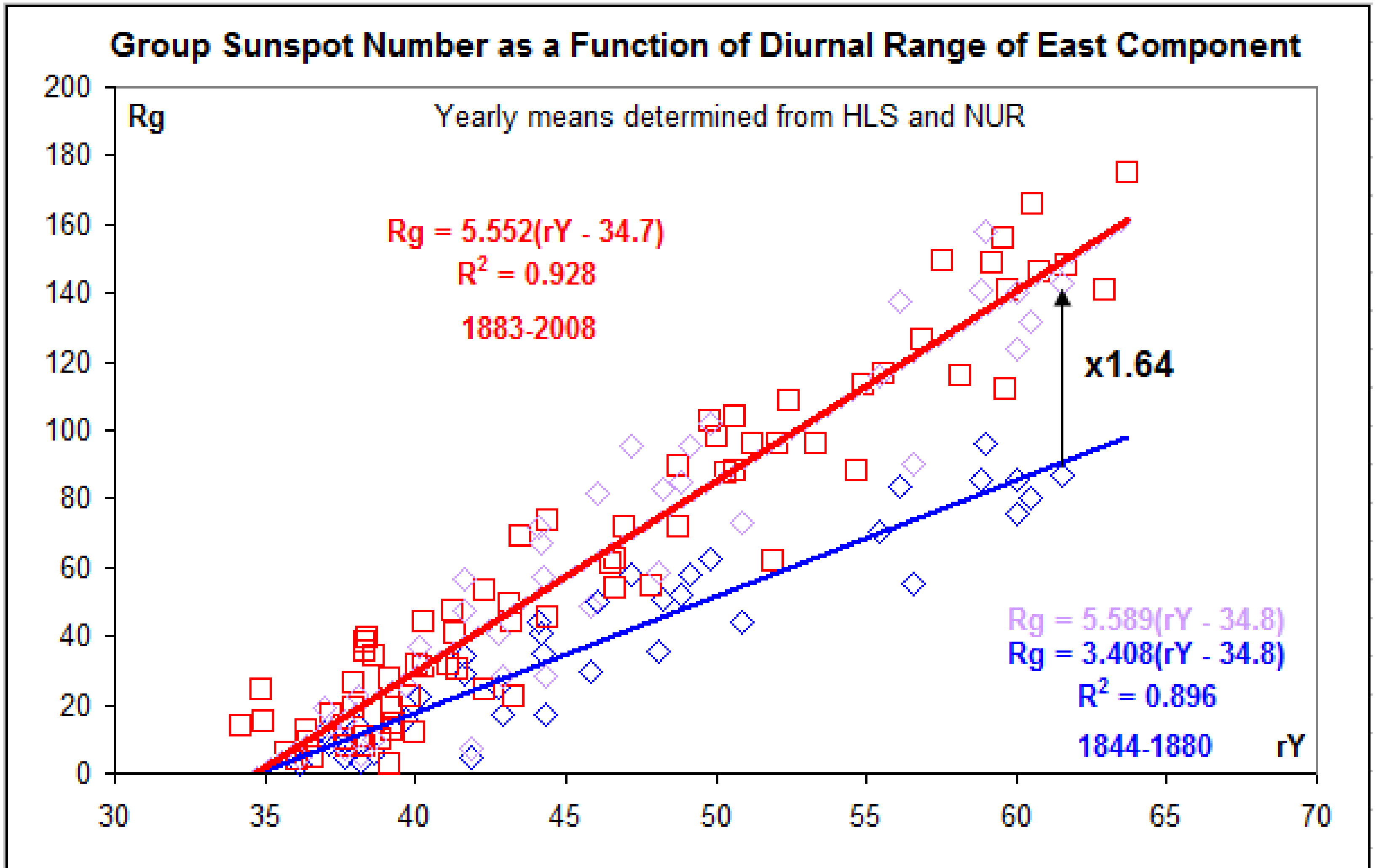
Helsinki-Nurmijärvi Diurnal Variation

Helsinki and its replacement station Numijärvi scales the same way towards our composite of nine long-running observatories and can therefore be used to check the calibration of the sunspot number (or more correctly to reconstruct the F10.7 radio flux)



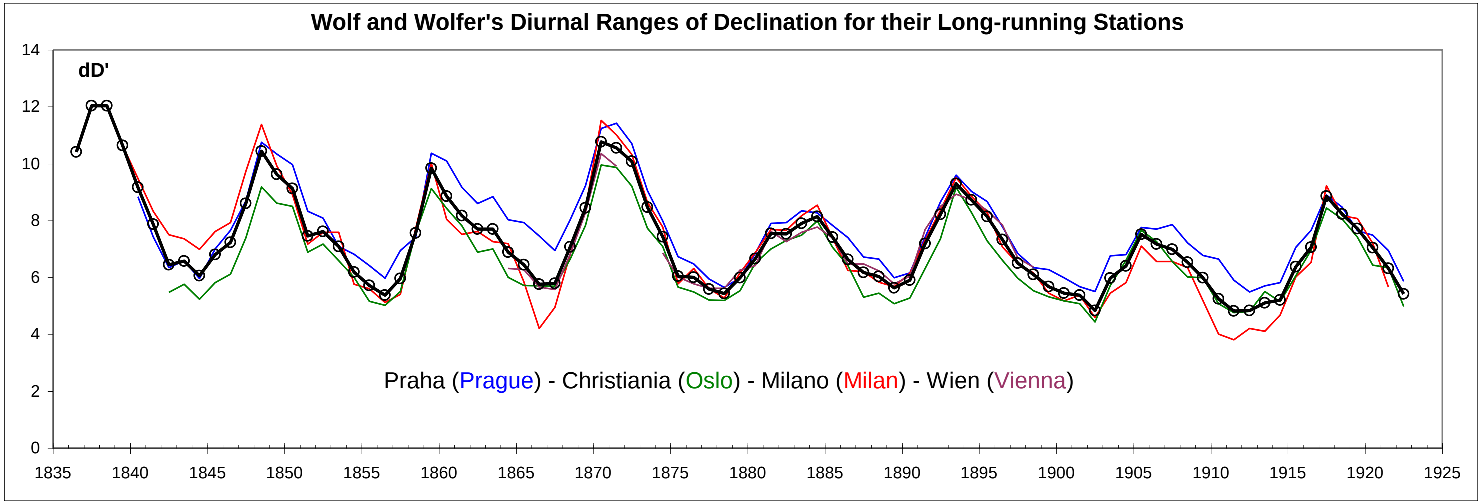


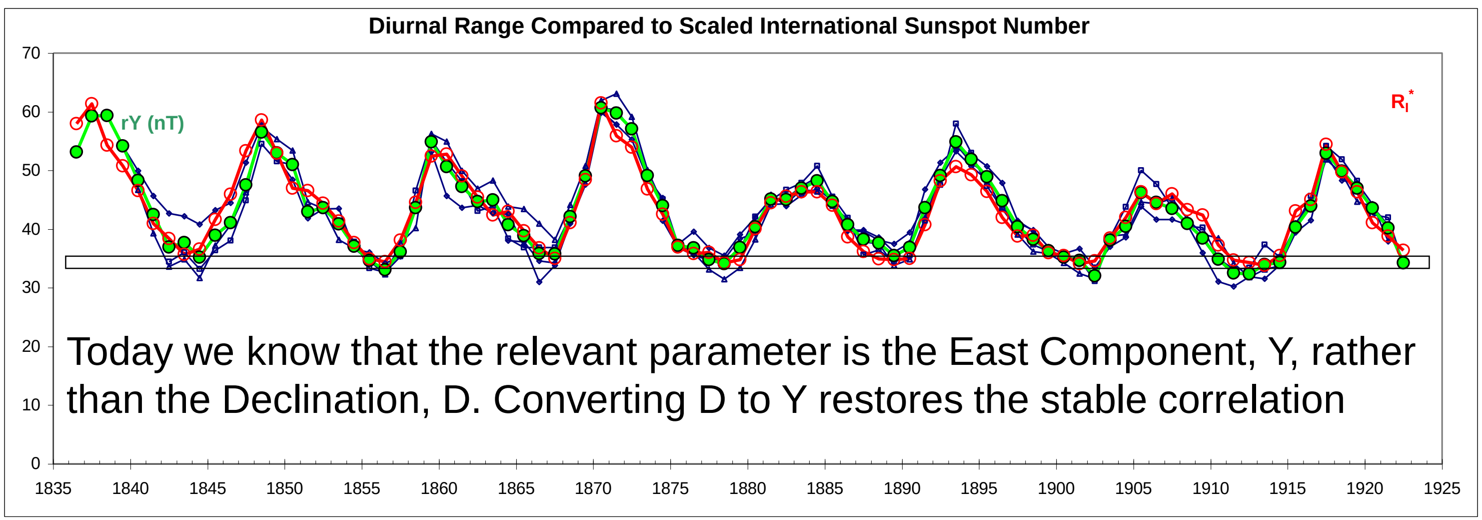
The HLS-NUR data show that the Group Sunspot Number before 1880 must be Increased by a factor 1.64±0.15 to match *rY* (F10.7)



This conclusion is independent of the calibration of the Zürich SSN, Rz

Wolf's Original Geomagnetic Data

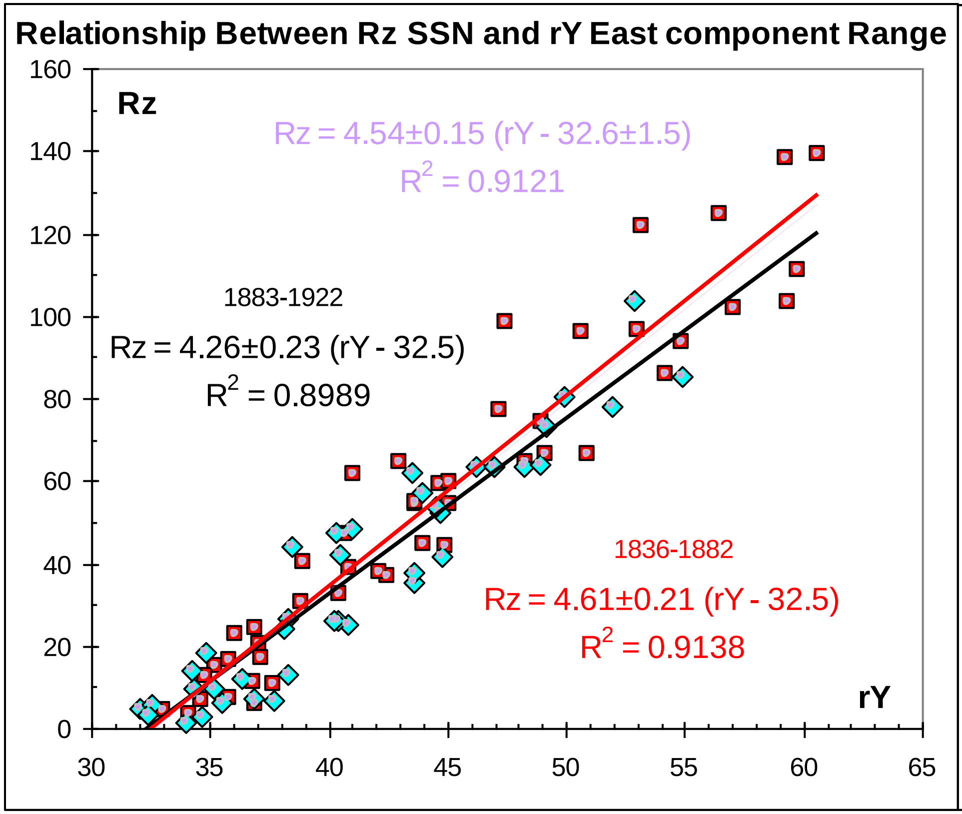


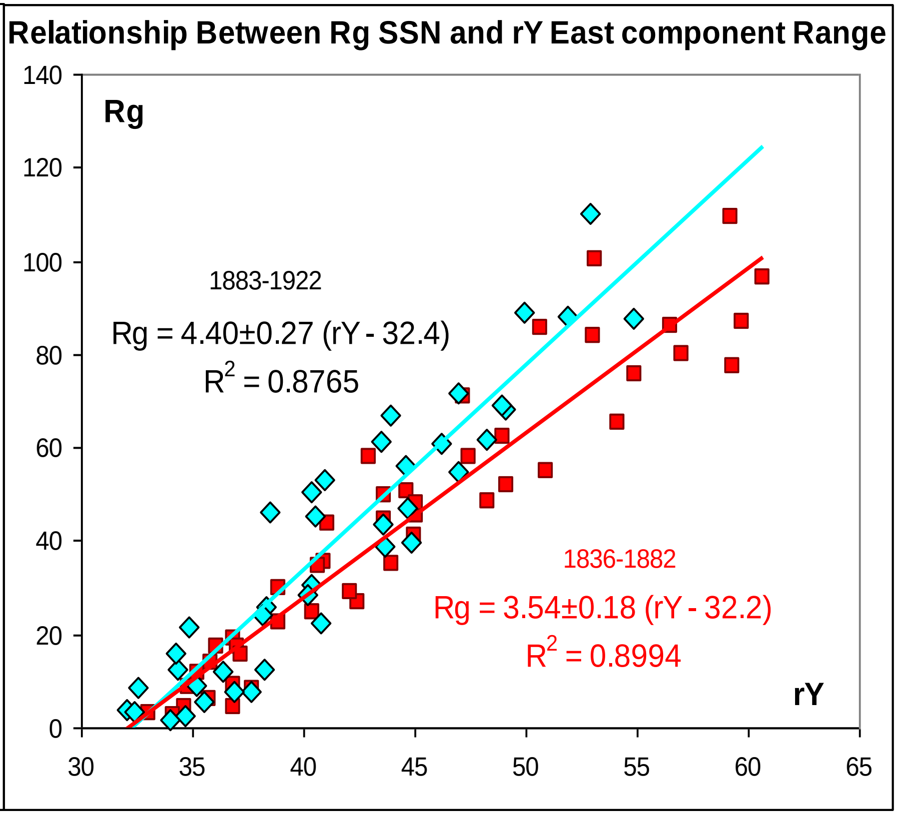


Wolf found a very strong correlation between his Wolf number and the daily range of the Declination.

Wolfer found the original correlation was not stable, but was drifting with time and gave up on it in 1923.

Using the East Component We Recover Wolf's Tight Relationship





The regression lines are identical within their errors before and after 1883.0. This means that likely most of the discordance with Rg ~1885 is not due to 'change of guard' or method at Zürich. It is also clear that Rg before 1883 is too low.

New paper on Eastward Component JGR, 2012

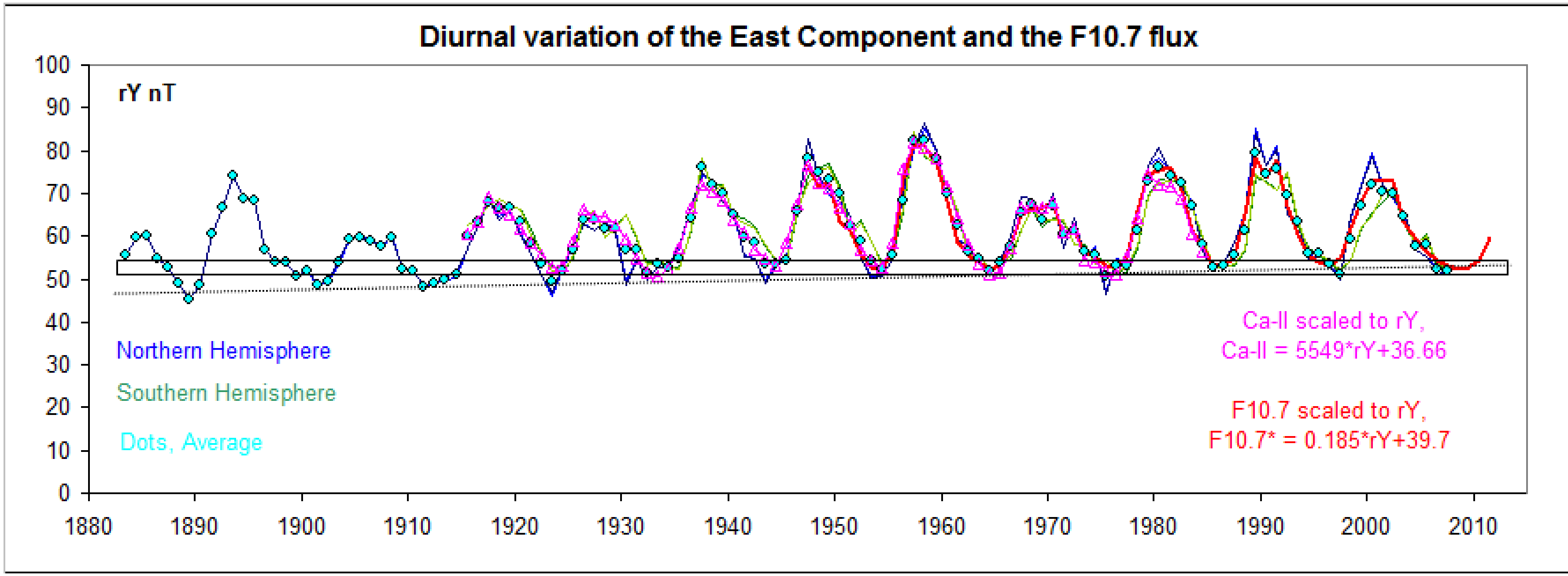
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 117, A05302, doi:10.1029/2012JA017555, 2012

The dependence of the coupled magnetosphere-ionosphere-thermosphere system on the Earth's magnetic dipole moment

Ingrid Cnossen,[1] Arthur D. Richmond,[1] and Michael Wiltberger[1]

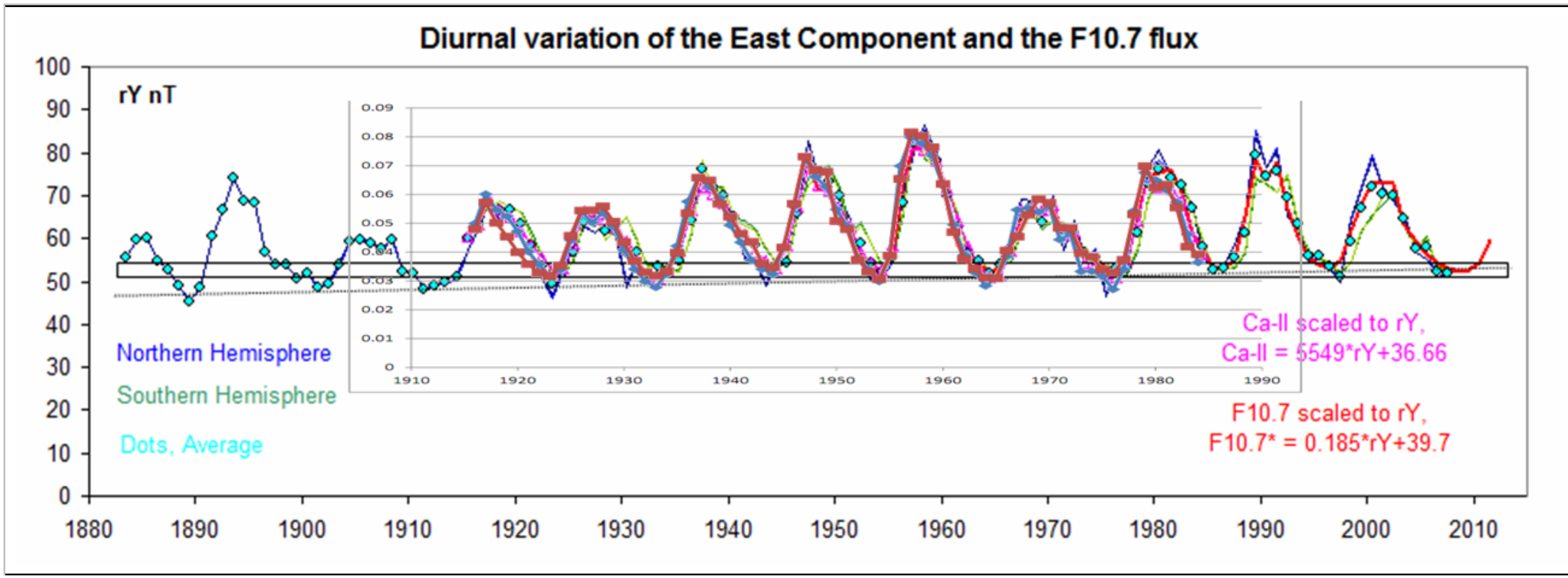
[39] *Svalgaard* [2009] noted that in particular the eastward component of the daily Sq variation is a useful indicator of solar activity, and may be used as a tool to calibrate the long-term sunspot number record. Clearly, if geomagnetic data are to be used in this way, the effects of the decreasing dipole moment on Sq variation must be considered and corrected for. Our scaling relations will be a first tool to do so, although local changes in the magnetic field over specific stations could also be important.

Putting the discovery to work



Variations of F10.7 microwave flux and Ca II K-line index (and thus solar activity) track the Diurnal Variation of the Geomagnetic Field.

Putting the discovery to work



Variations of F10.7 microwave flux and Ca II K-line index (and thus solar activity) track the Diurnal Variation of the Geomagnetic Field.

Overlay shows Peter Foukal's Ca II index scaled to fit.

What to do about all this?

The implications of this re-assessment of the sunspot record are so wide-ranging that the SSN community has decided on a series of Workshops to solidify this.

We have a Wiki giving details and presentations: http://ssnworkshop.wikia.com/wiki/Home

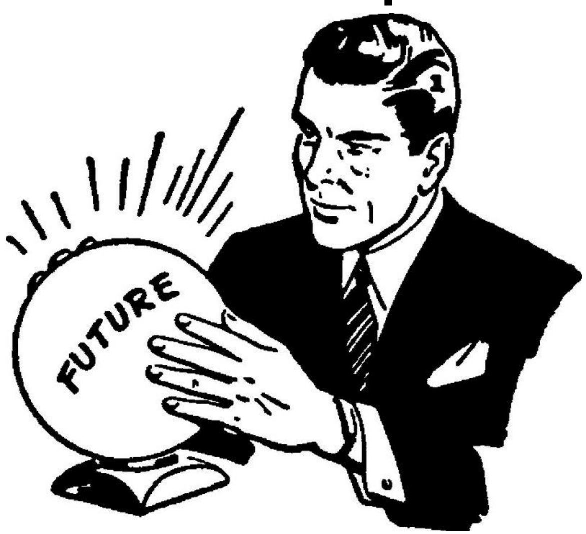
The goal is to arrive at a single, vetted series that we all agree on.

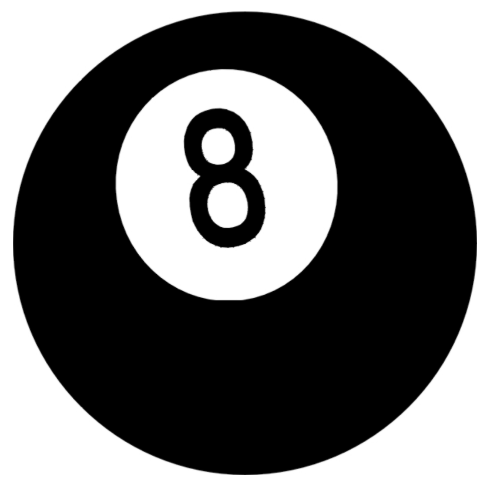
The SSN workshops are sponsored by the National Solar Observatory (NSO), the Royal Observatory of Belgium (ROB), and the Air Force Research Laboratory (AFRL).

Prediction of Future Activity

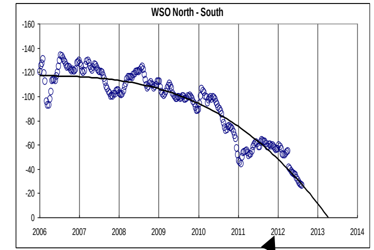
- Polar Fields Precursor
- Livingston & Penn Effect
- Grand Minima?

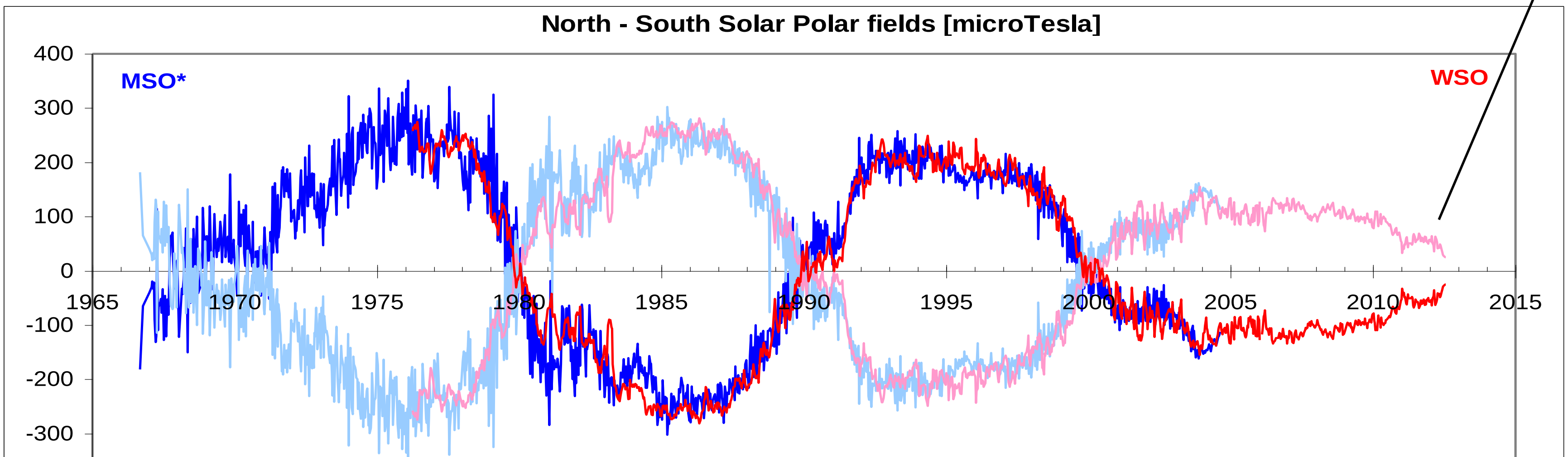
“It is difficult to predict, especially the future”

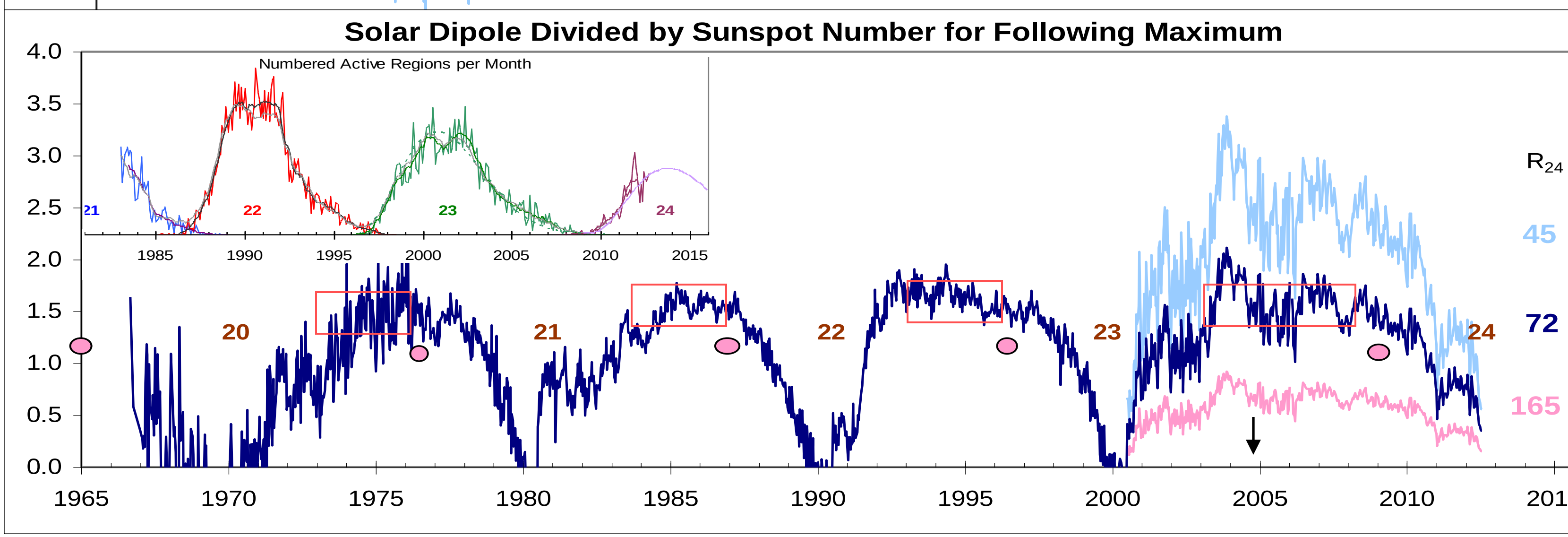


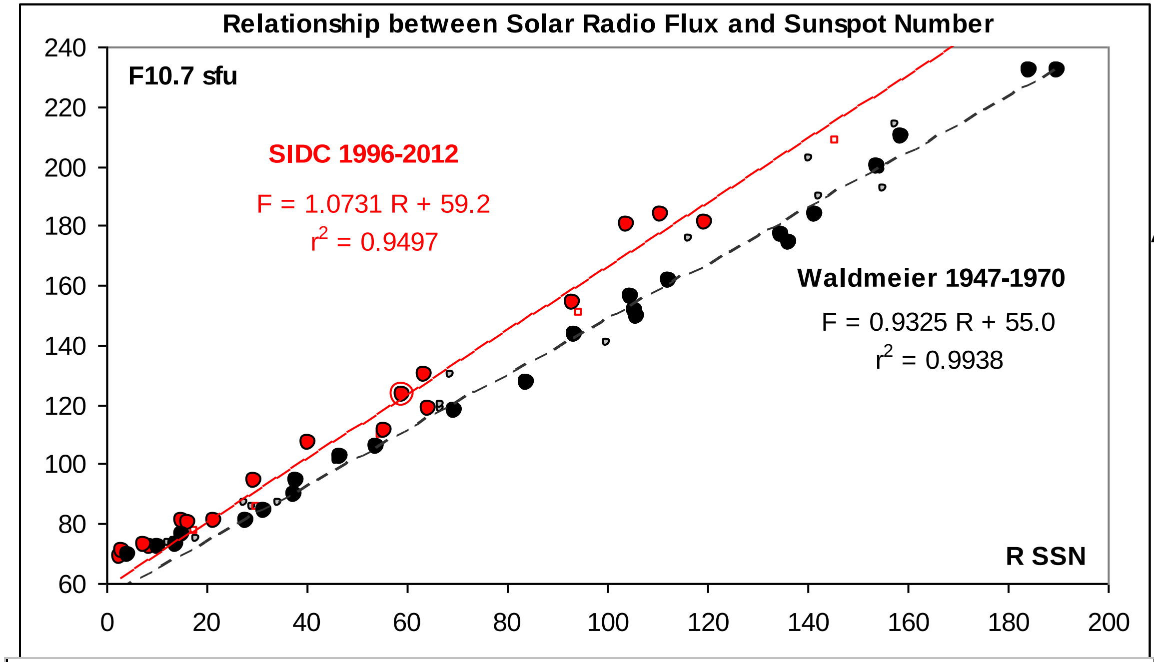


Polar Field Precursor

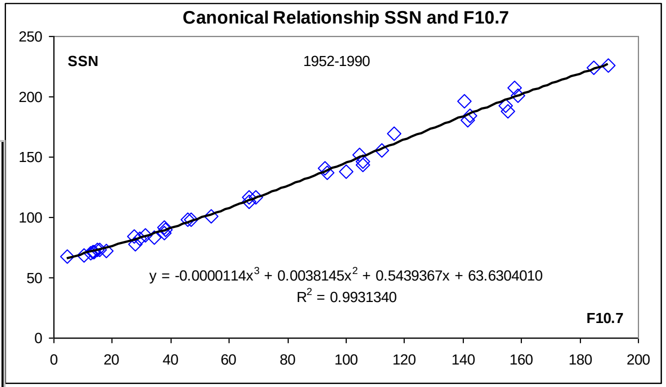


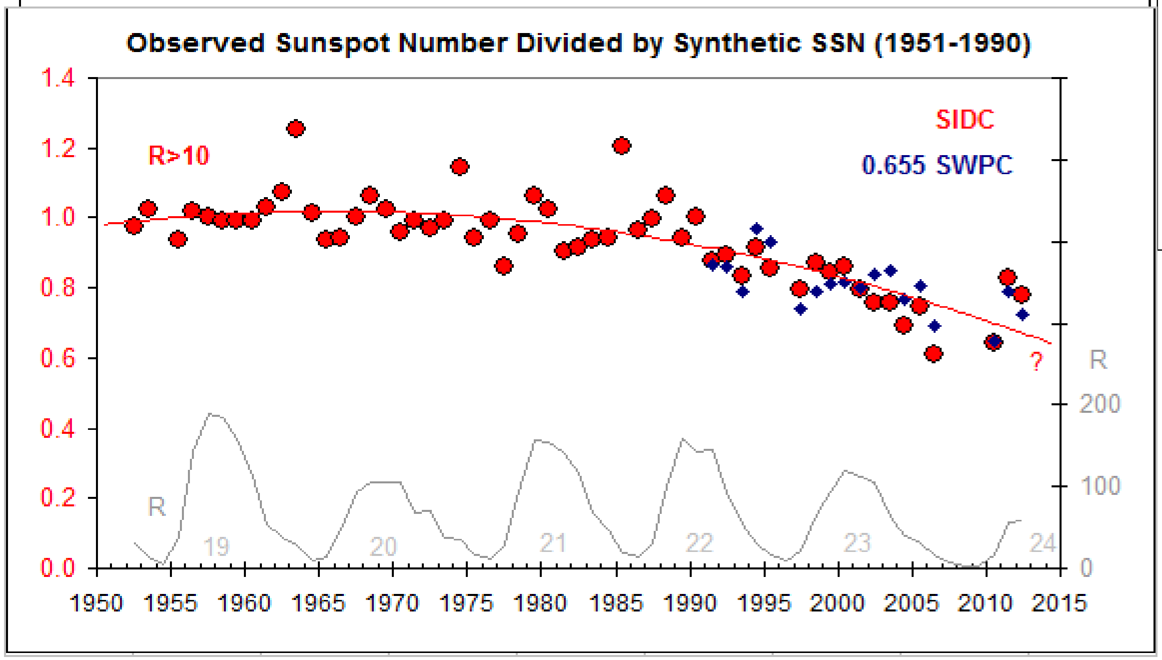






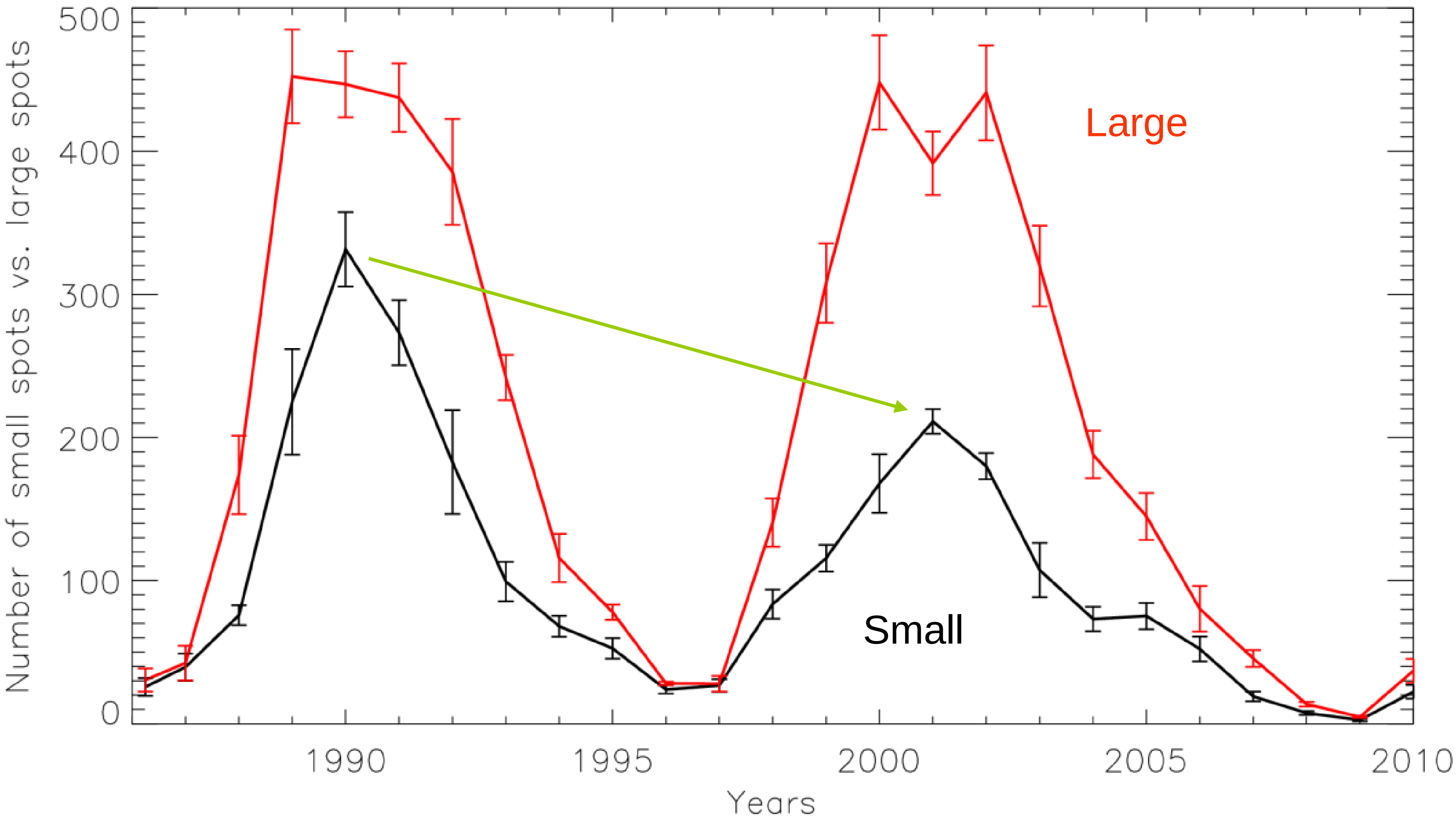
But is the SSN Always a Good Measure of Solar Activity?



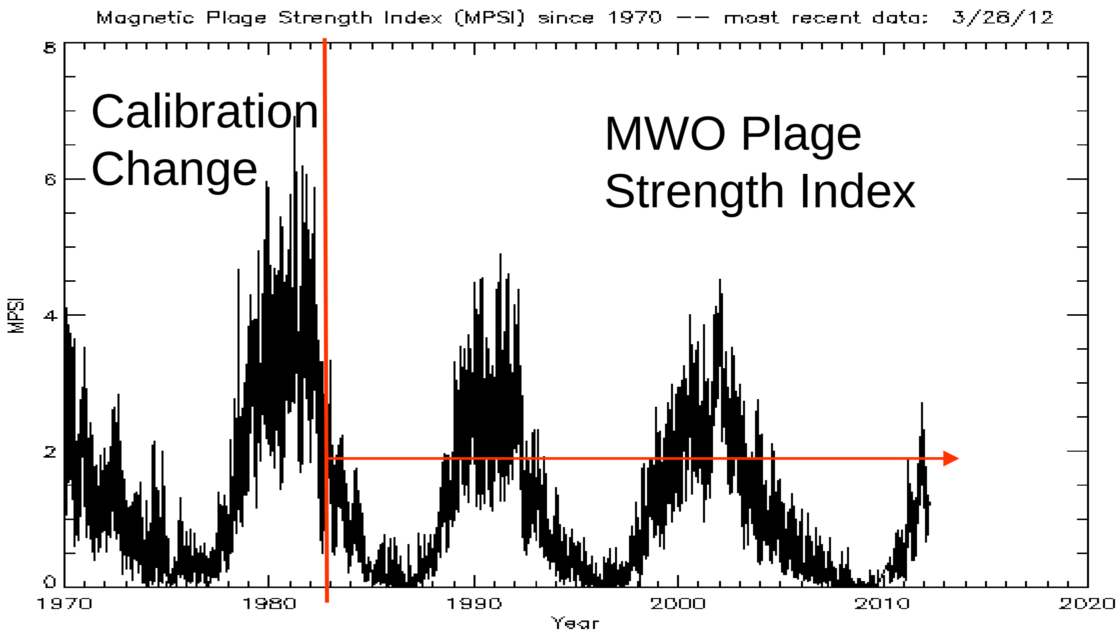


Since ~1990 we record progressively fewer sunspots than expected from observations of F10.7 microwave flux

We Observe a Deficit of Small Spots

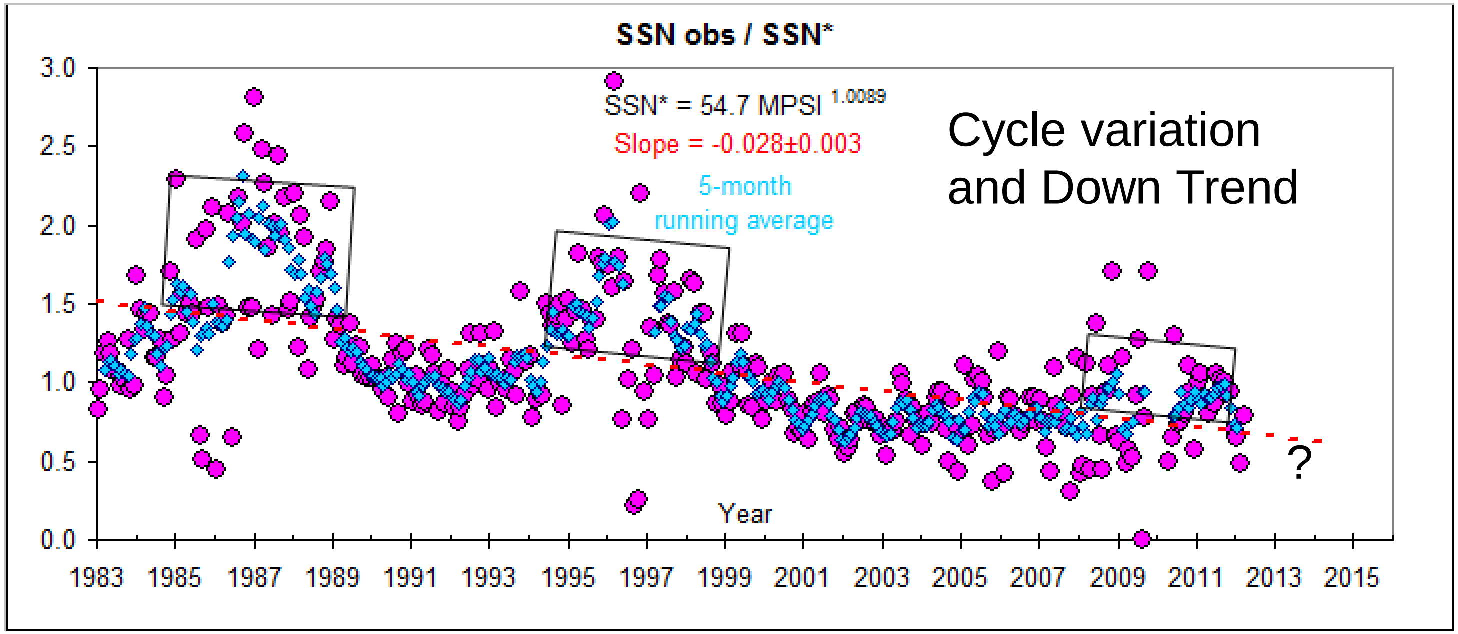


Lefevre & Clette, SIDC



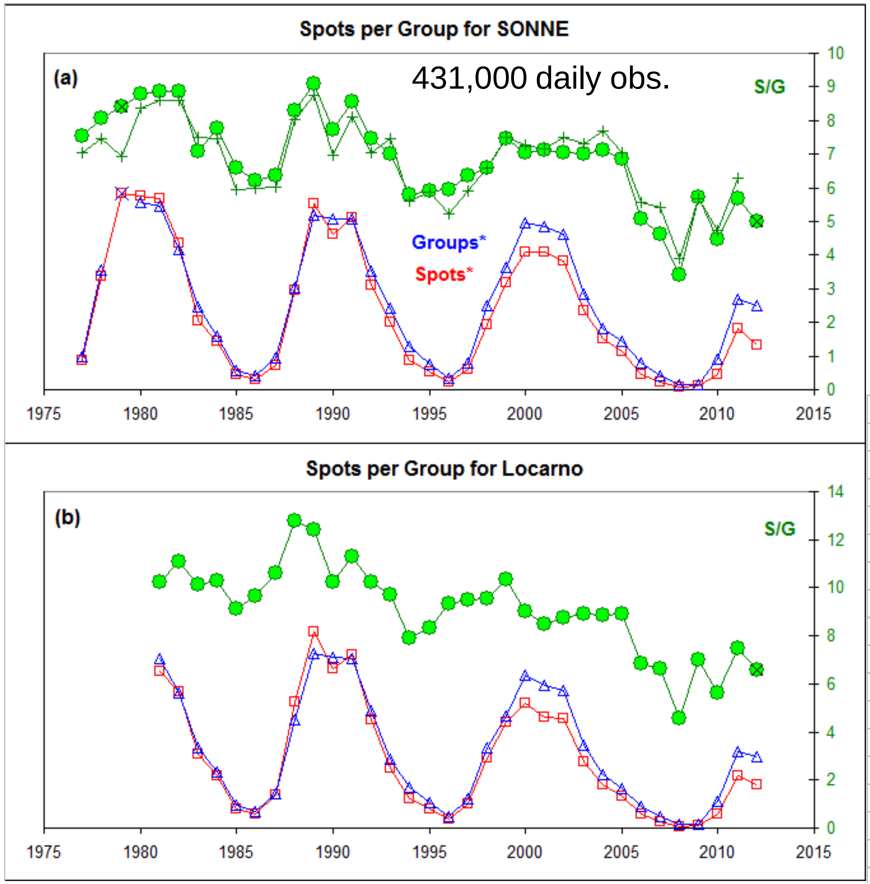
We see fewer sunspots for given MPSI

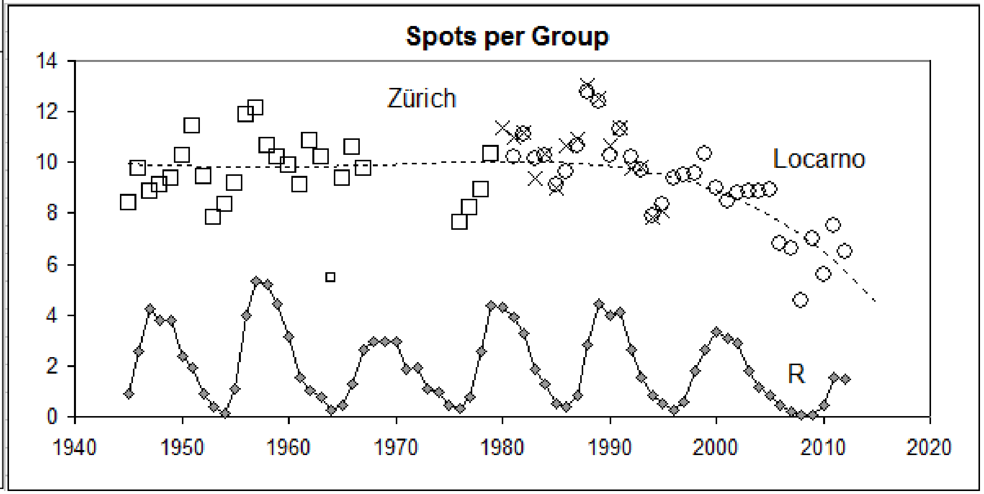
MPSI is the sum the absolute values of the magnetic field strengths for all pixels where that value is between 10 and 100 gauss. The sum is then divided by the total of number of pixels in the magnetogram.



Same result if Ca II index is used

We Observe Fewer Spots per Sunspot Group



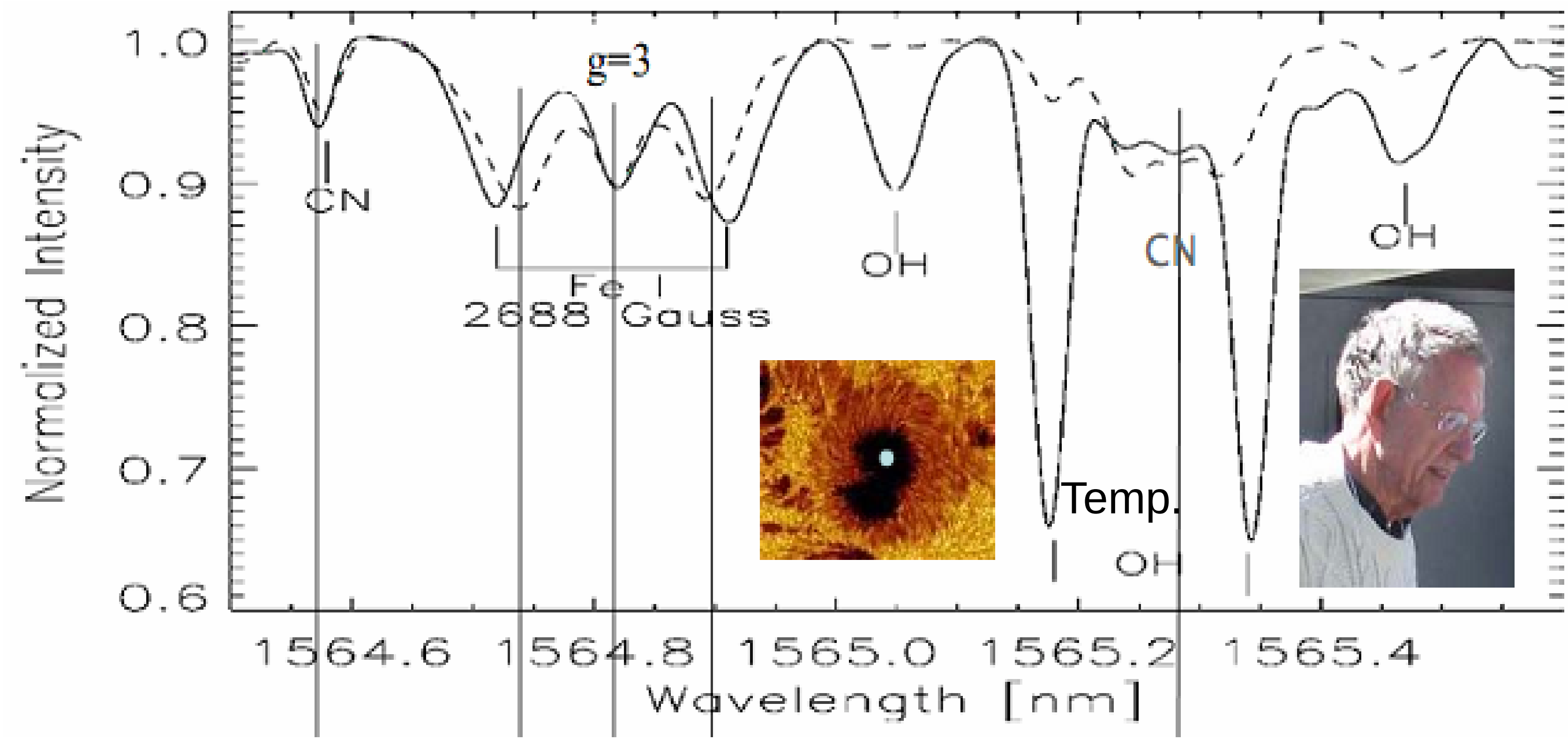


There is a weak solar cycle variation on top of a general downward trend seen by all observers

We are losing the small spots

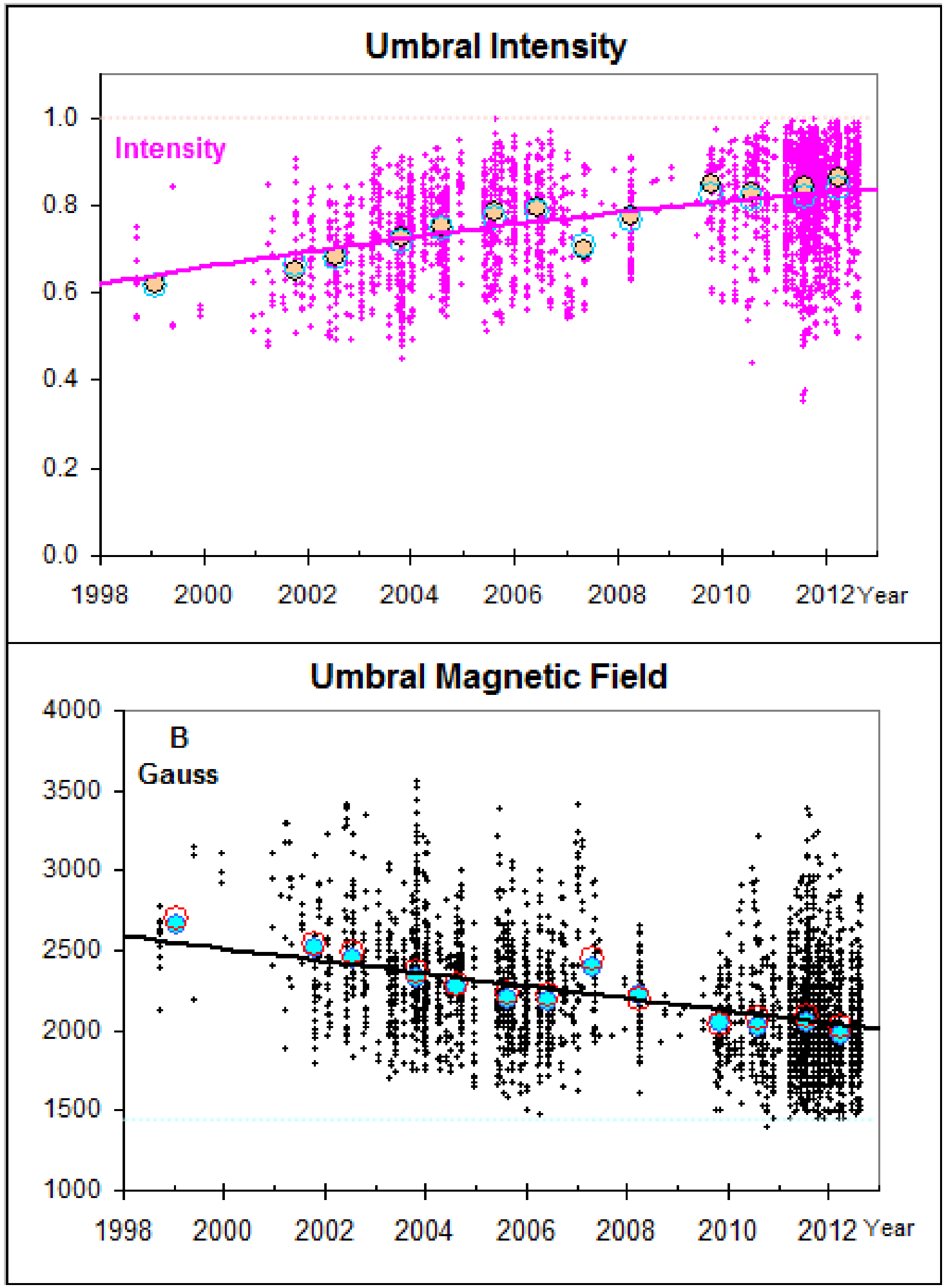
What could be the cause of that?

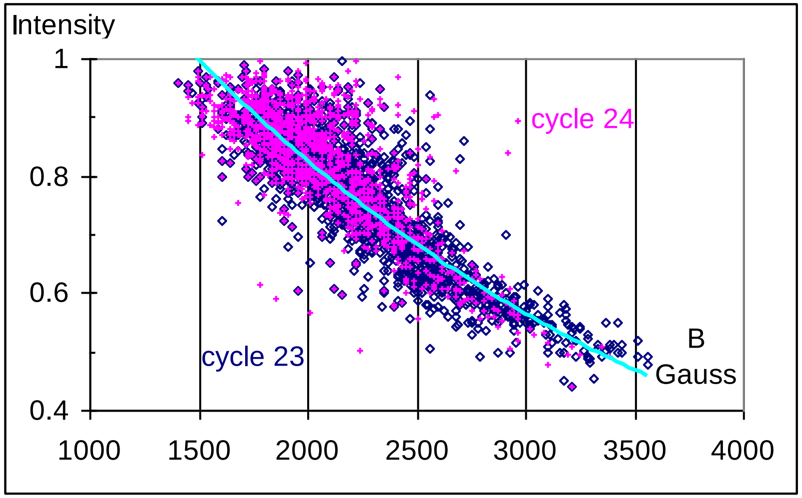
The Livingston & Penn Data



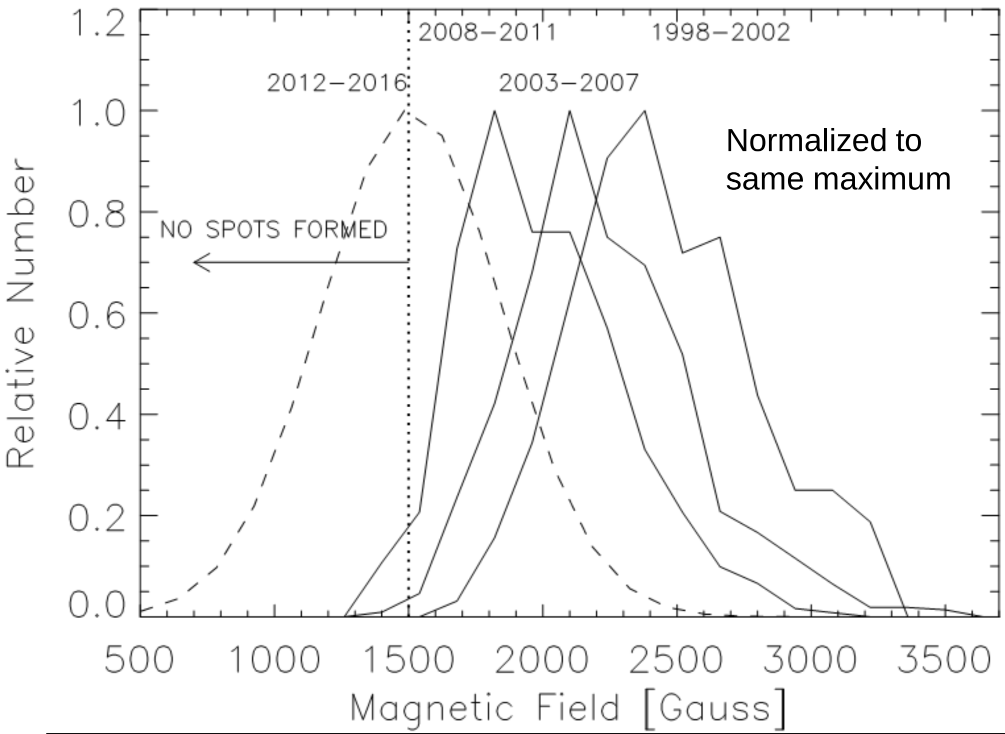
From 1998 to 2012 Livingston and Penn have measured field strength and brightness at the darkest position in umbrae of 3148 spots using the large Zeeman splitting of the infrared Fe 1564.8 nm line..

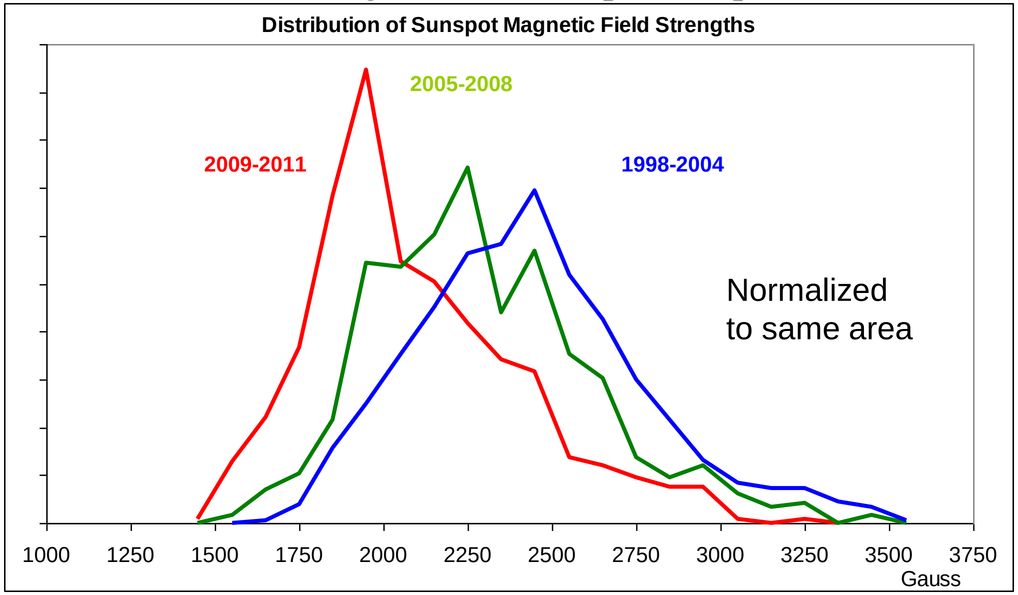
Spot Umbral Intensity [Temperature] and Magnetic Field Changing





Evolution of Distribution of Magnetic Field Strengths

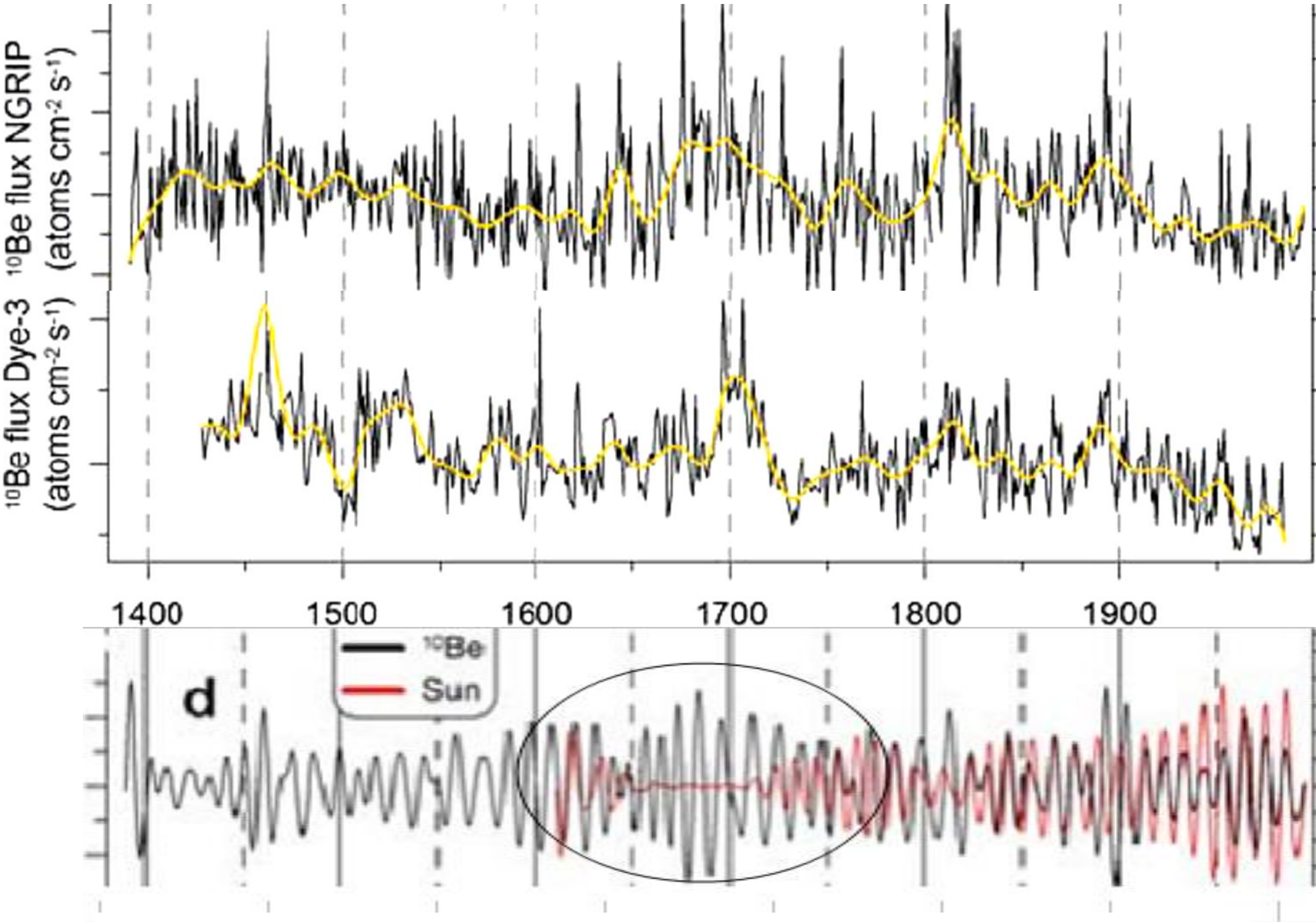




Sunspots form by assembly of smaller patches of magnetic flux. As more and more magnetic patches fall below 1500 G because of the shift of the distribution, fewer and fewer visible spots will form as observed

What to Predict? What to Use?

- So when predicting the solar cycle, do we predict F10.7 [or Ca II or MSPI or similar]
- Or should we predict SSN?
- As these diverge from each other, which is the ‘real’ activity?
- What do we do if SSN falls to near zero [while F10.7 does not] during the next cycle(s)?
- Is this how it was during the Maunder Minimum? [when the cycle was still operating and cosmic rays were still modulated. Magnetism was there, without the spots]



Cosmic Ray Proxy [Berggren et al.]

‘Burning Prairie’ => Magnetism

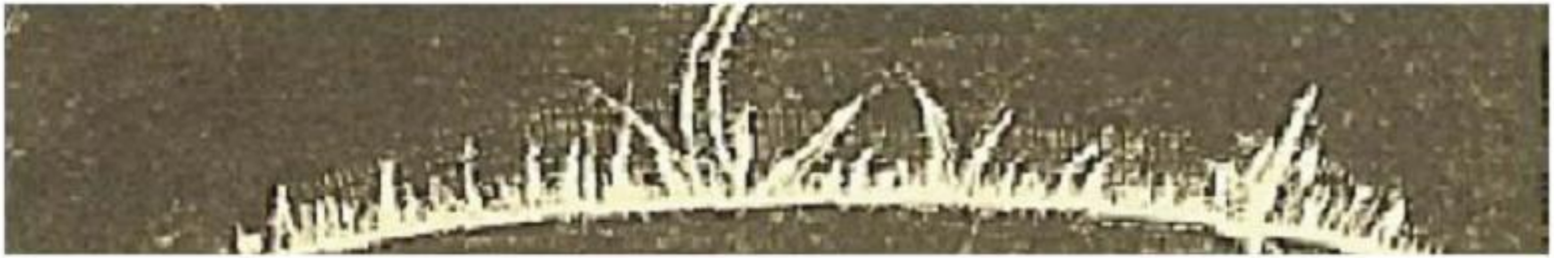


Figure 1 An early drawing of the “burning prairie” appearance of the Sun’s limb made by C.A. Young, on 25 July 1872. All but the few longest individual radial structures are spicules.

It is now well known (see, *e.g.*, the overview in Foukal, 2004) that the spicule jets move upward along magnetic field lines rooted in the photosphere outside of sunspots. Thus the observation of the red flash produced by the spicules requires the presence of widespread solar magnetic fields. Historical records of solar eclipse observations provide the first known report of the red flash, observed by Stannyan at Bern, Switzerland, during the eclipse of 1706 (Young, 1883). The second observation, at the 1715 eclipse in England, was made by, among others, Edmund Halley – the Astronomer Royal. These first observations of the red flash imply that a significant level of solar magnetism must have existed even when very few spots were observed, during the latter part of the Maunder Minimum.

Foukal & Eddy, Solar Phys. 2007, *245*, 247-249

Conclusions

- Wolf [International] SSN must be corrected by +20% prior to ~1945
- Group SSN should be abandoned and the data incorporated/merged with the Wolf SSN to a new standard
- The geomagnetic record can be used to calibrate/cross-check the early data
- No Modern Grand Maximum
- Meaning of the SSN in future is uncertain

Abstract

A hundred years after Rudolf Wolf's death, Hoyt et al. (1994) asked "Do we have the correct reconstruction of solar activity?" After a heroic effort to find and tabulate many more early sunspot reports than were available to Wolf, Hoyt et al. thought to answer that question in the negative and to provide a revised measure of solar activity, the Group Sunspot Number (GSN) based solely on the number of sunspot groups, normalized by a factor of 12 to match the Wolf numbers 1874–1991. Implicit in that normalization is the assumption or stipulation that the 'Wolf' number is 'correct' over that period. In this talk we shall show that that assumption is likely false and that the Wolf number (WSN) must be corrected. With this correction, the difference between the GSN and WSN becomes even more disturbing: The GSN shows either a 'plateau' until the 1940s followed by a Modern Grand Maximum [MGM], or alternatively a steady rise over the past three hundred years, while the (corrected) WSN shows no significant secular trend and no MGM. As the sunspot number is often used as the basic input to models of the future evolution of the Earth's environment and of the climate, having the correct reconstruction becomes of utmost importance, and the difference between GSN and WSN becomes unacceptable. By re-visiting the construction of the GSN we show how the GSN can be reconciled with the WSN, resolving the issue. We finally report on recent discrepancies between various indices of solar activity which raise the issue of the very meaning of the sunspot number and of the future evolution [and predictability] of solar activity. The talk is based on work in support of the Sunspot Number Workshops: http://ssnworkshop.wikia.com/wiki/Home