Updating the Historical Sunspot Record

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The Sunspot Record(s!)

- The Sunspot Record goes back 400 years and is the basis for many reconstructions of solar parameters (e.g. TSI)
- But, how good is it?
- And can we agree on which one [Wolf; Group]?
- Are the old values good?
- Are the new ones?
- What is a ‘good’ or ‘correct’ Sunspot Number?

Rudolf Wolf's 'Relative' Sunspot Number: R = 10·Groups + Spots

Abstract of his latest Results. By Prof. Wolf.

(*Translation communicated by Mr. Carrington.*)

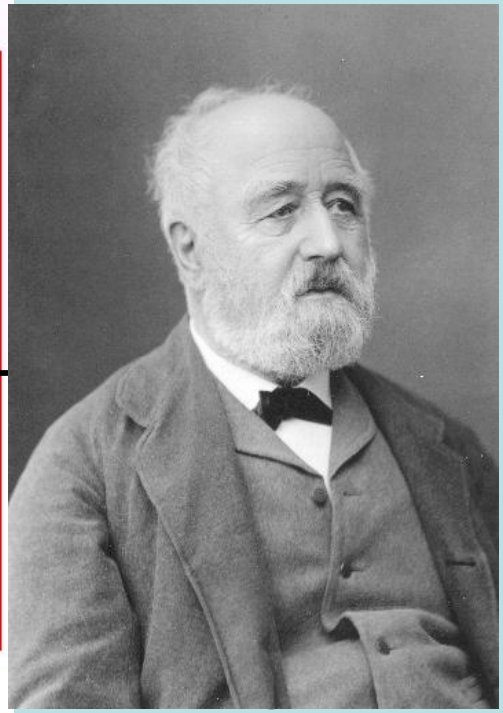
Some fine series of observations of Flaugergues, Adams, Arago, and others, have enabled me to fill in previous breaks, and to express in the same unit my Relative numbers (for the abundance of Solar Spots in successive years) for the years from 1749 to 1860. They are as follows:—

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

Wolf started his own observations in 1849



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Wolf started his own observations in 1849

Rudolf Wolf 1861

1837 111.0

Different !

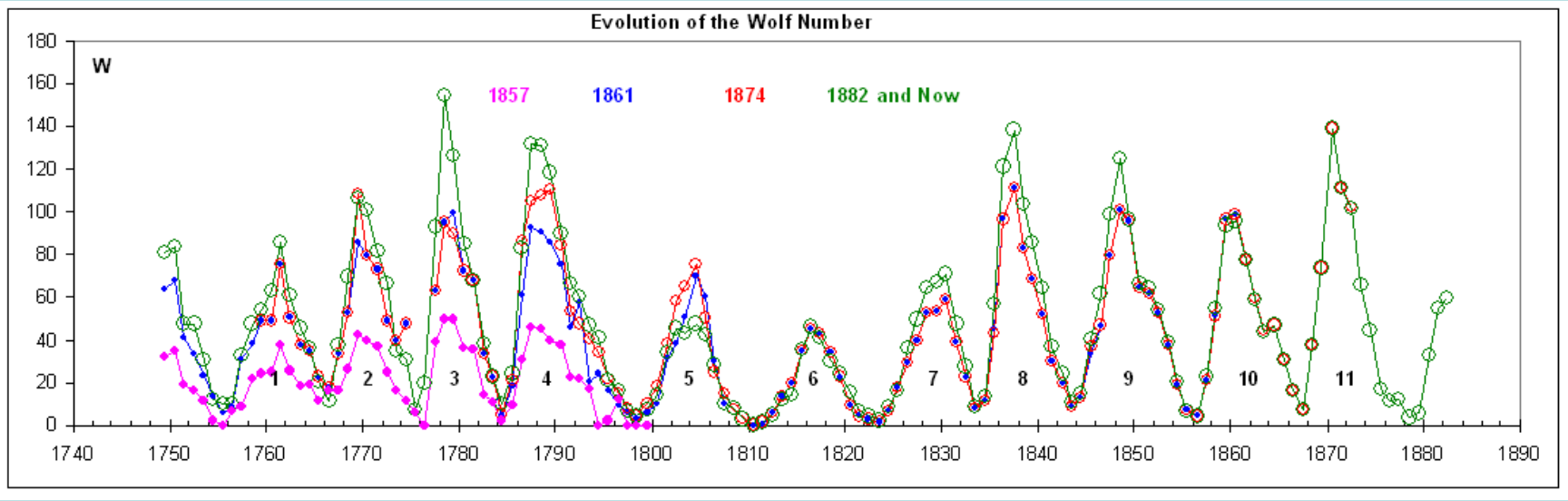
SIDC 2009

1837 138.3

25% higher

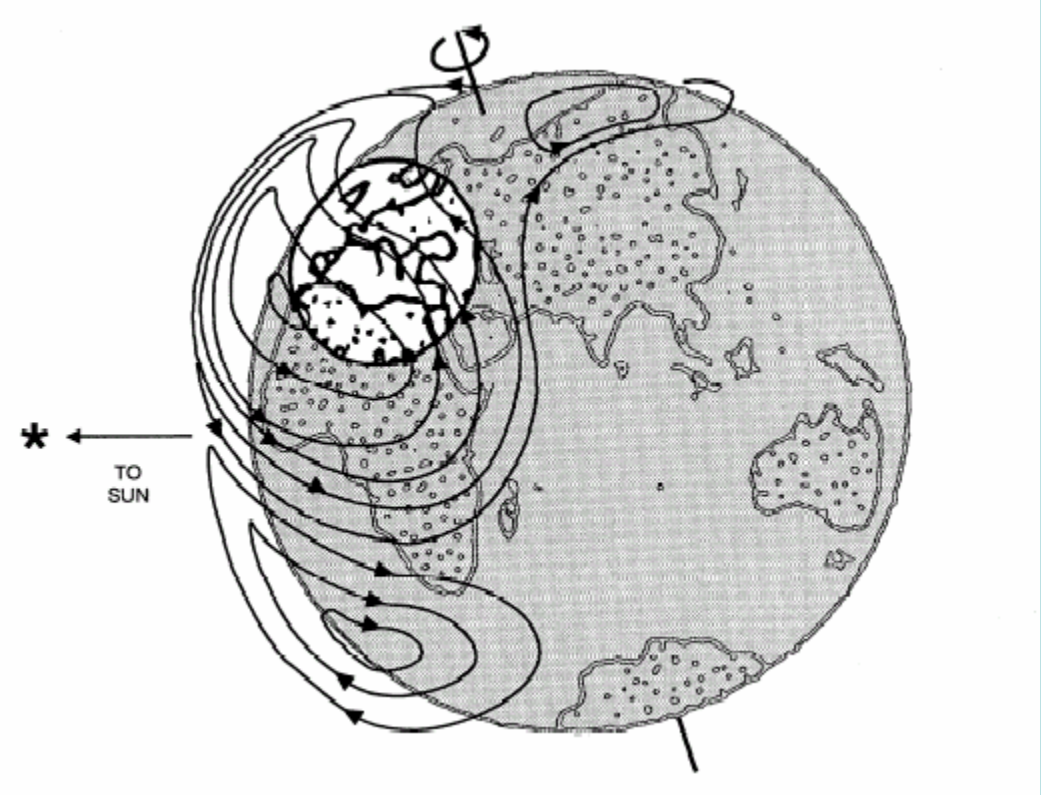
Evolution of Wolf Number (why the changes?)

Wolf published several versions of his celebrated ‘Relative’ Sunspot Numbers based on data gathered from many Observers both before and during Wolf’s own lifetime. How to ‘harmonize’ data from different observers?



Wolf's Elegant Solution

$$rD = a + b\,R_W$$

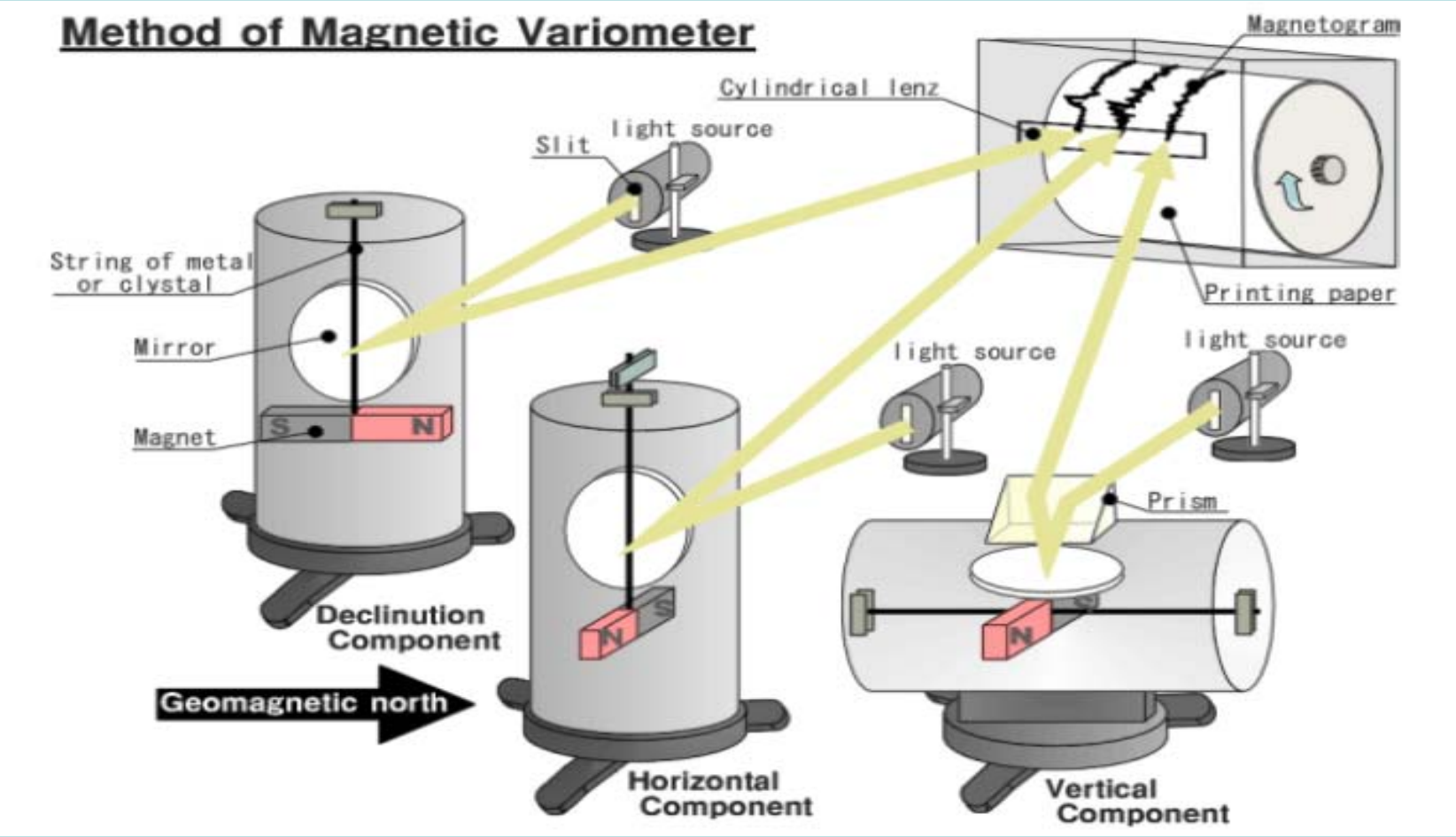


A current system in the ionosphere is created and maintained by solar FUV radiation.

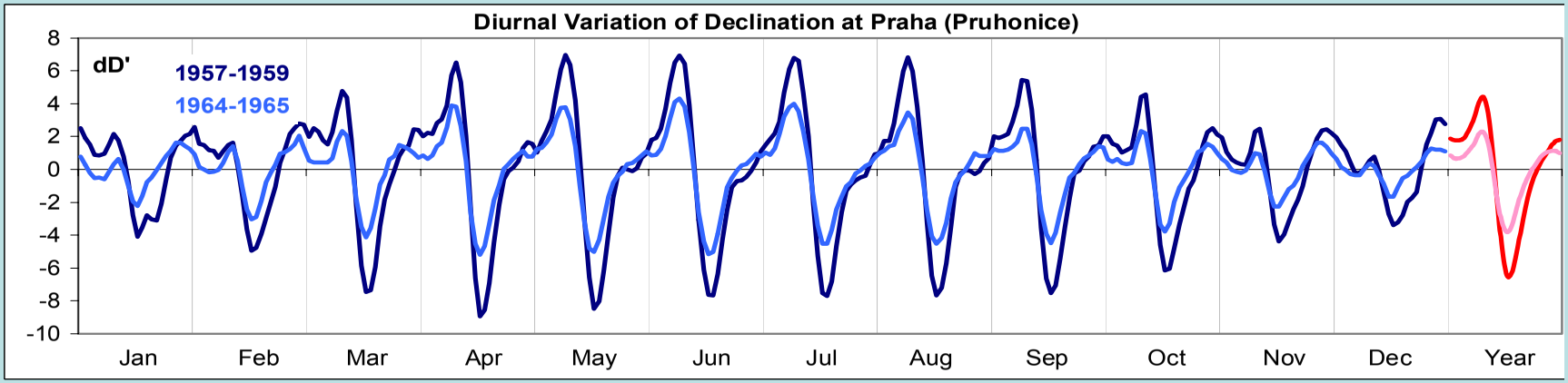
The current has a magnetic field of its own which is readily observed on the ground even with 18th Century technology.

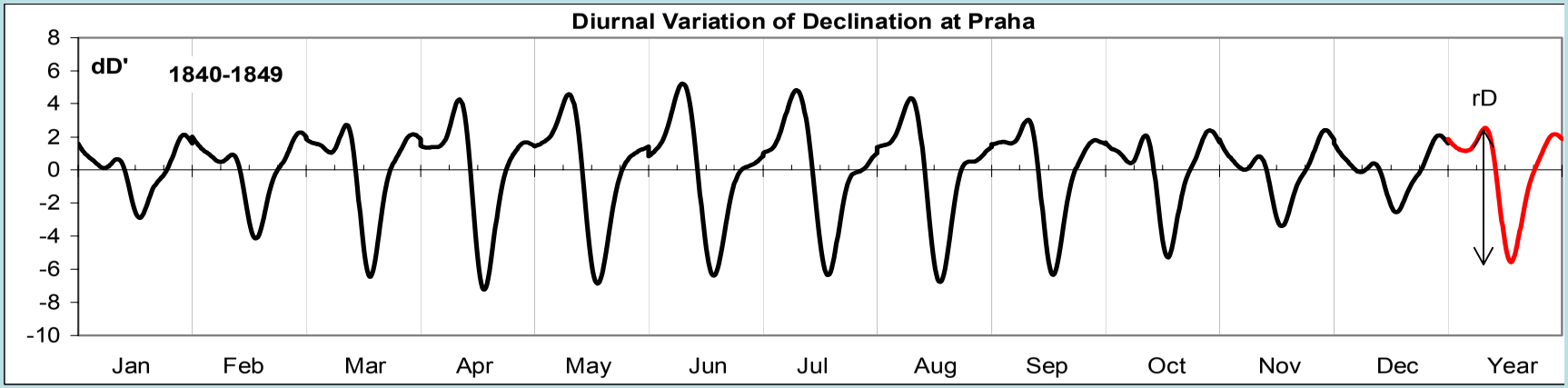
The amplitude [rD] of this variation is a proxy for FUV.

Recording Variations of the Geomagnetic Field

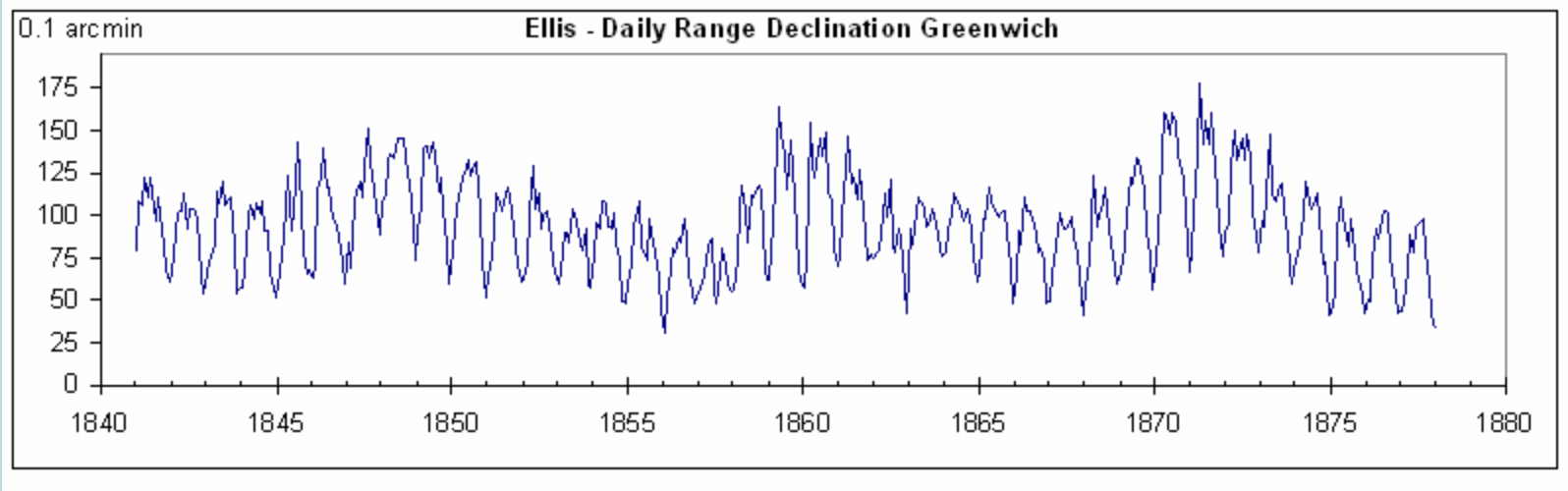


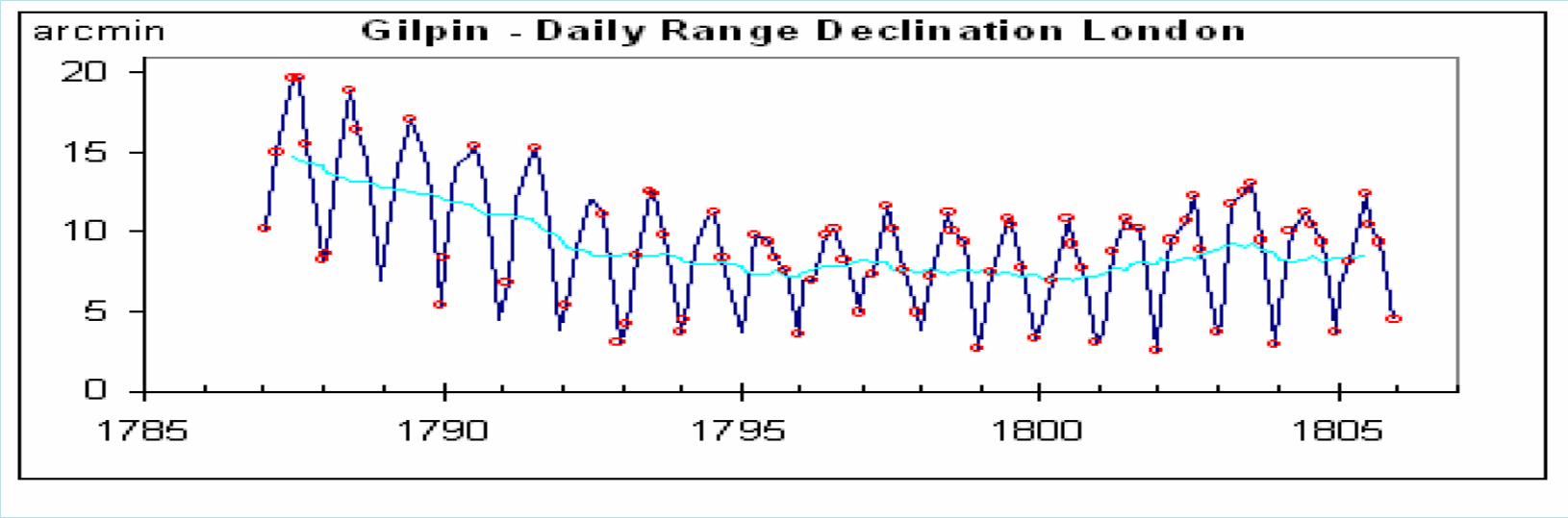
Amplitude Varies with Solar Zenith Angle and Solar Activity



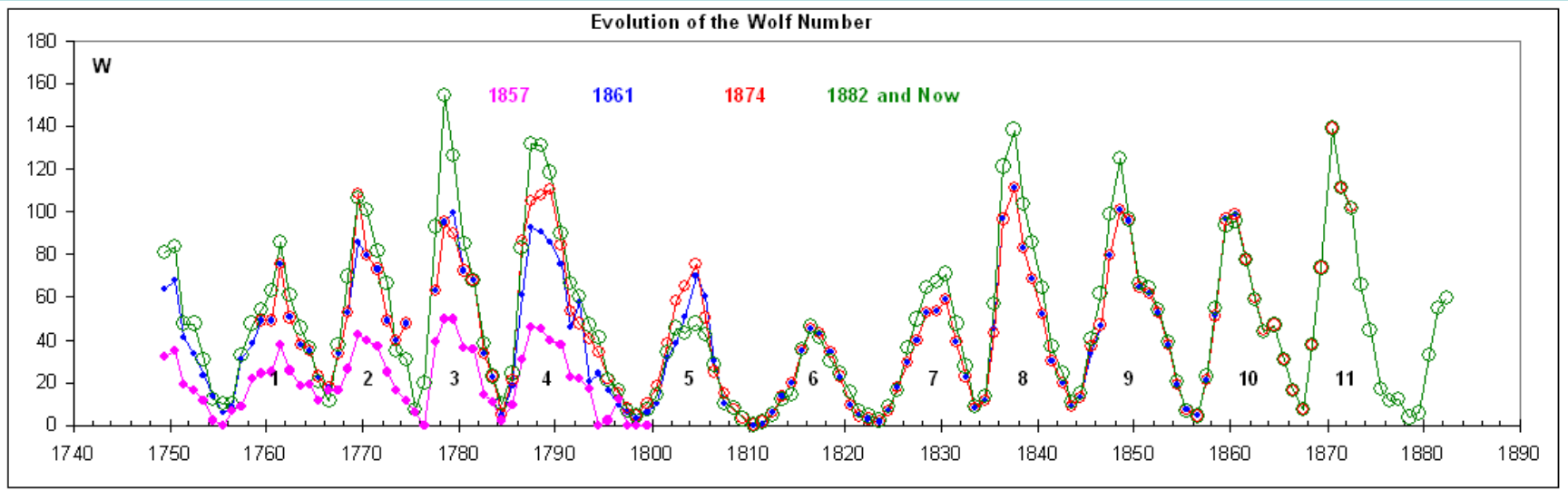


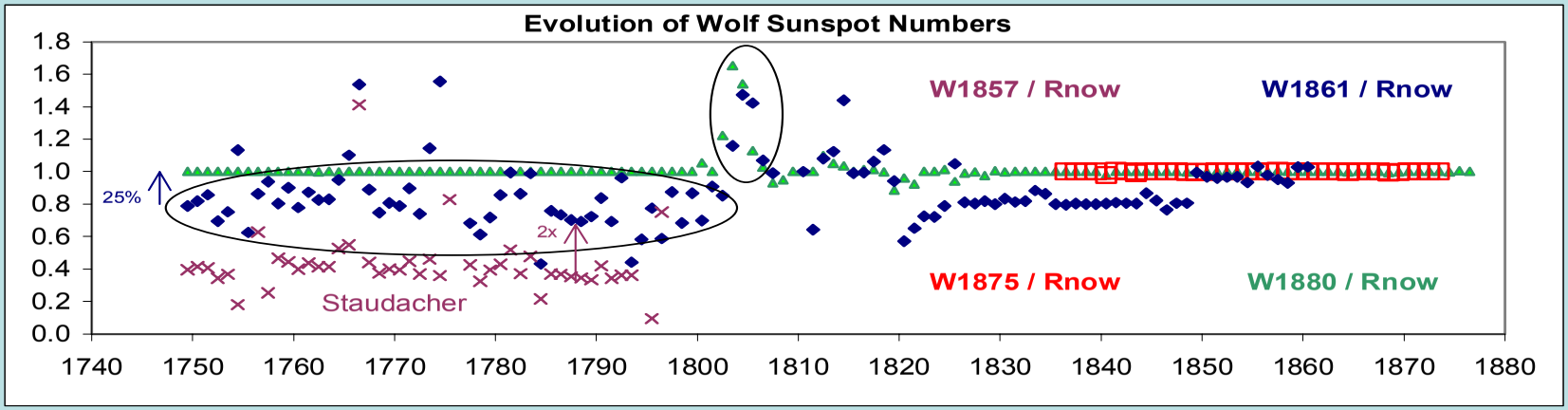
Clear Solar Cycle Variation





Evolution of Wolf Number (now the changes make sense)





The Group Sunspot Number

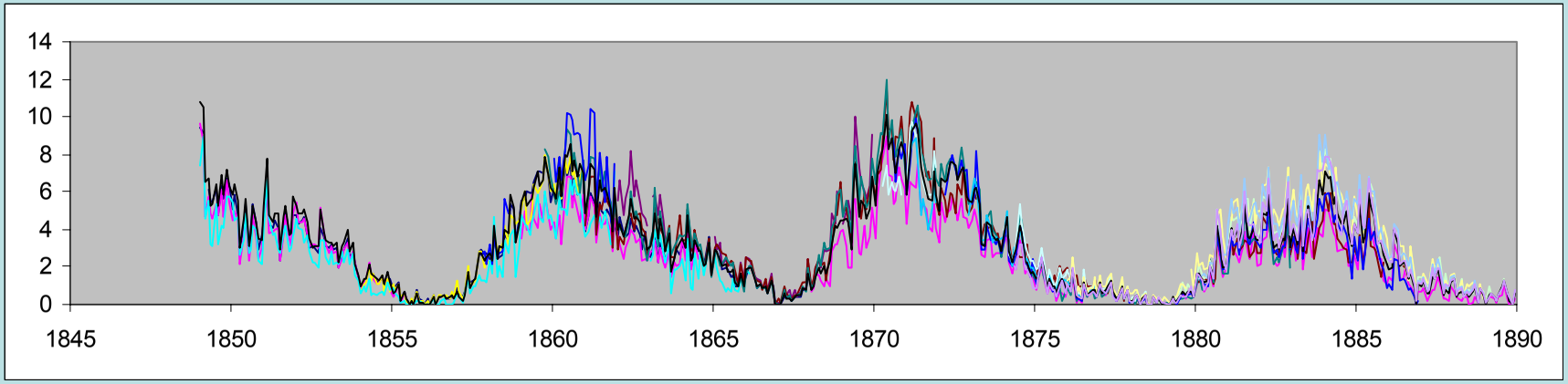
- Hoyt and Schatten proposed basing the Sunspot number on the Number of Groups reported by the observers:

$$GSN = 12\ Group$$

The calibration constant *12* was used to make the value of the GSN comparable to Wolf's Relative Sunspot Number

But the Number of Sunspot Groups is However also Observer Dependent

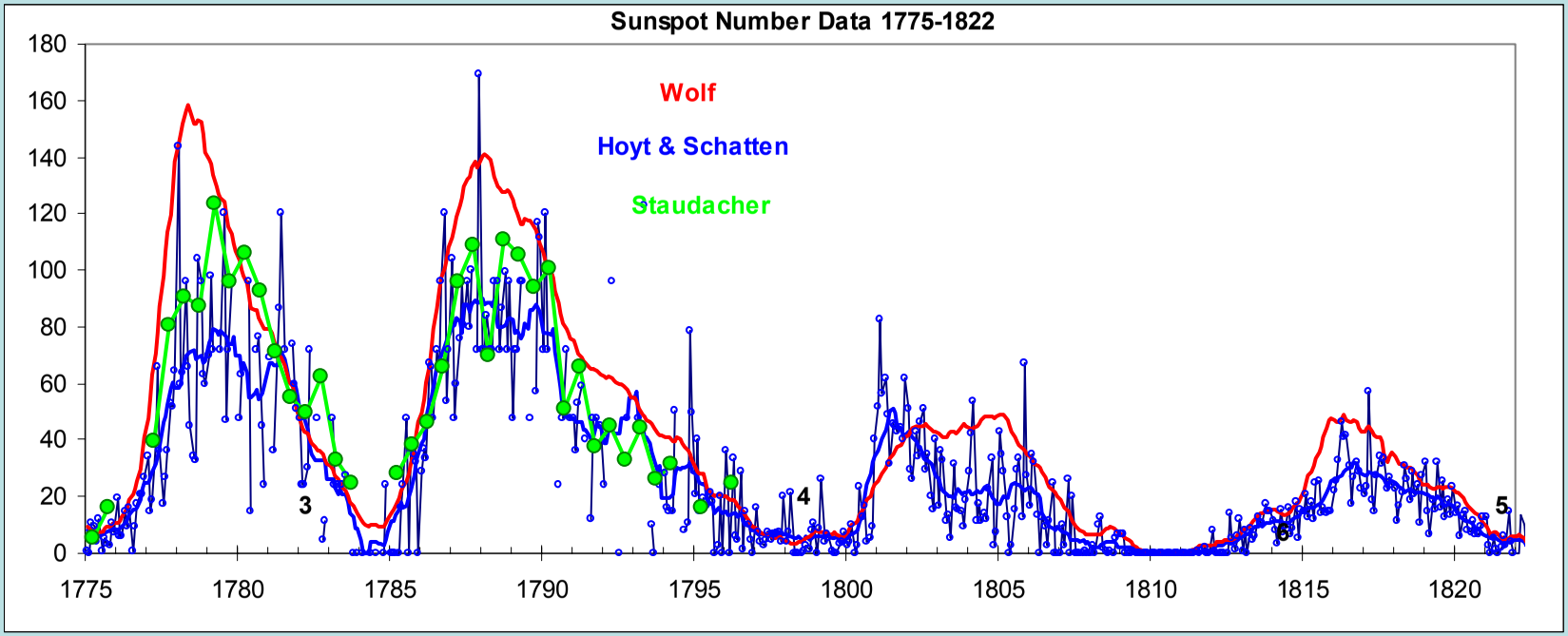
Schwabe	Wolf	Carrington	Shea
Peters	Spoerer	Weber	Schmidt
Secchi	Bernaerts	Wolfer	Aguilar
Ricco	RGO		



GSN = 12 k_G Groups

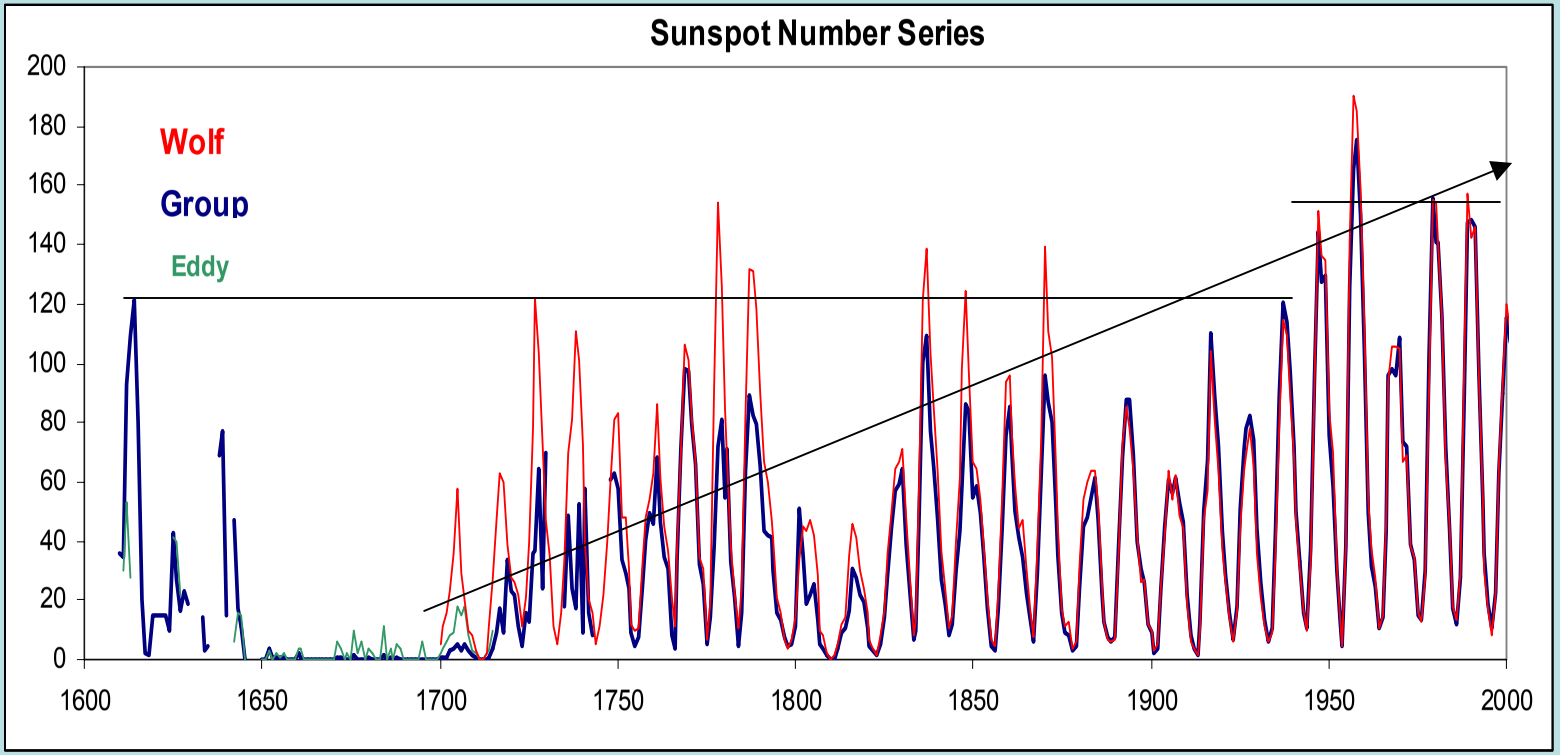
GSN is Comparable to old Wolf Numbers *before* Calibrating to Magnetic Declination

- Arlt [2008] has recently digitized Staudacher's drawings and derived Sunspot Areas that here just 'floats' between GSN and Wolf:

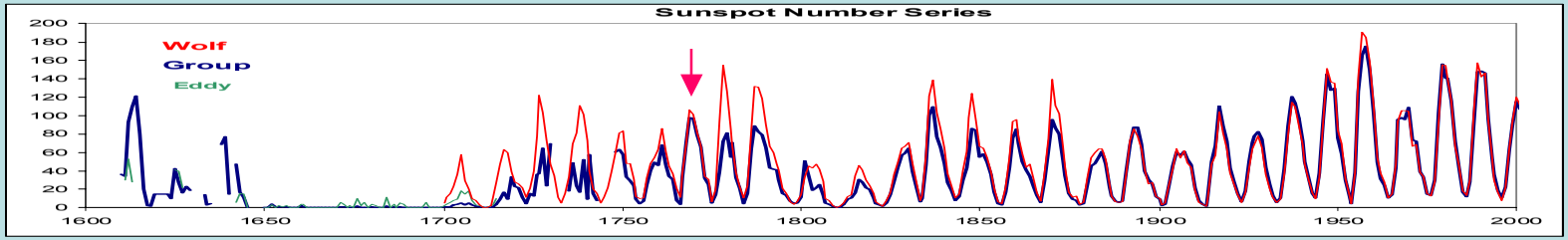


Qualitative Difference Between GSN and Wolf [SSN]

- Progressive increase vs. Step function



Modern Maximum?



Group and Wolf Sunspot Numbers

Even GSN has been 'adjusted'

Sunspot Numbers

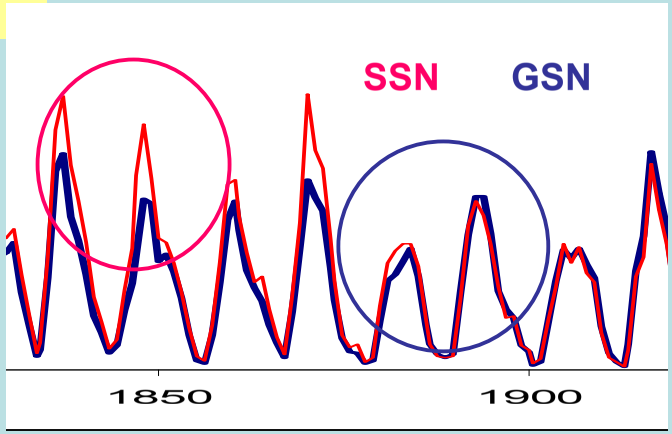
200
150
100
50
0

1600 1650 1700 1750 1800 1850 1900 1950 2000

Year

Probing Difference Between GSN and Wolf SSN

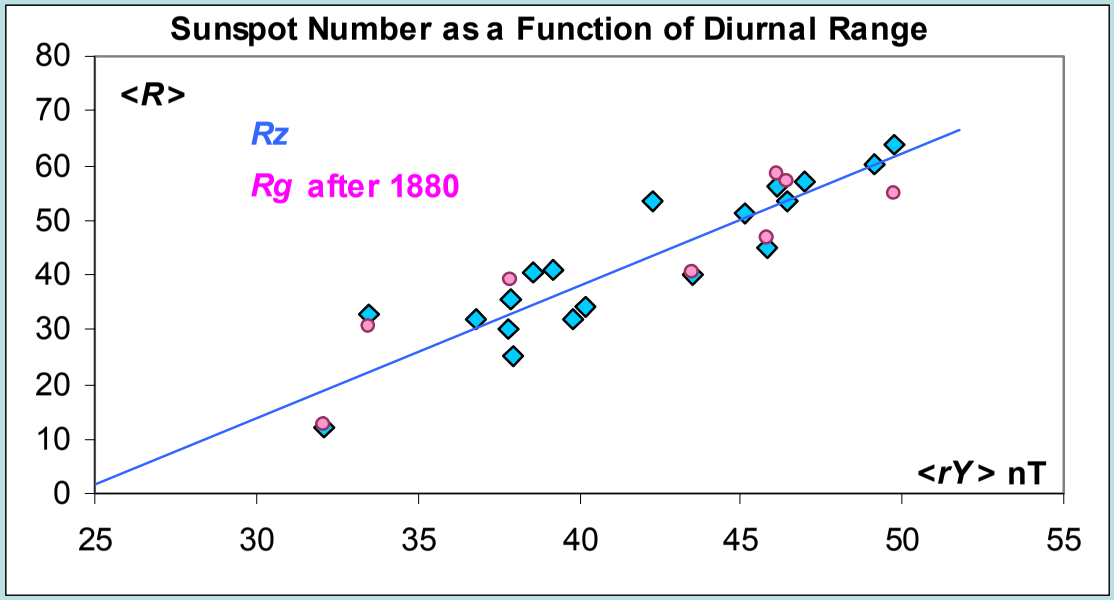
obs	name	lat	long	interval
WDC	Washington D.C.	38.9	283.0	1840-1842
DUB	Dublin	53.4	353.7	1840-1843
MNH	Munchen	48.2	11.6	1841-1842
PGC	Philadelphia	40.0	284.8	1840-1845
SPE	St. Peterburg	60.0	30.3	1841-1845
GRW	Greenwich	51.5	0.0	1841-1847
PRA	Praha	50.1	14.4	1840-1849
HBT	Hobarton	-42.9	147.5	1841-1848
MAK	Makerstoun	55.6	357.5	1843-1846
KRE	Kremsmunster	48.1	14.1	1839-1850
TOR	Toronto	43.7	280.6	1842-1848
WLH	*Wilhelmshaven*	53.7	7.8	*1883-1883*
GRW	*Greenwich*	51.5	0.0	*1883-1889*
WDC	*Washington D.C.*	38.9	283.0	*1891-1891*
PSM	*Parc Saint-Maur*	48.8	0.2	*1883-1899*
POT	*Potsdam*	52.4	13.1	*1890-1899*
COP	*Kobenhavn*	55.7	12.6	*1892-1898*
UTR	*Utrecht*	52.1	5.1	*1893-1898*
IRT	*Irkutsk*	52.3	104.3	*1899-1899*



There are good geomagnetic data for many stations during the intervals marked by ovals when there is a systematic difference between GSN and SSN

Sunspot Number as a Function of the Diurnal Range for the Stations

- After 1880, GSN [pink, for stations after 1880] and SSN [blue, all stations] agree and cluster neatly along a common regression line



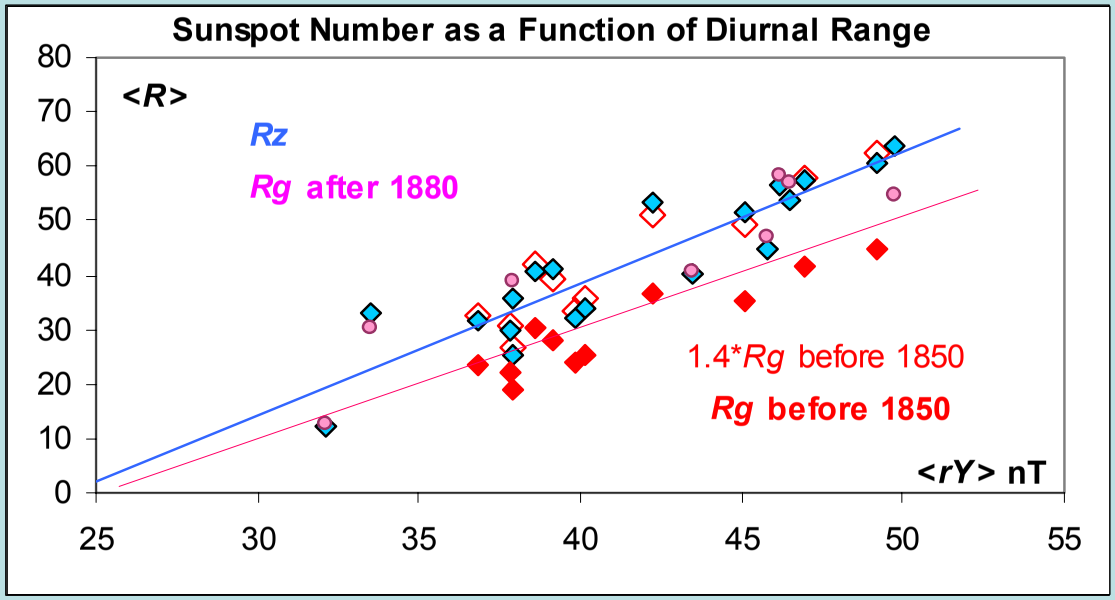
Technical Detail:

Y = H sin(D)

The East component Y is really what varies during the day rather than Declination D. The Horizontal component varies from place to place causing D to vary.

Sunspot Number as a Function of the Diurnal Range for the Stations

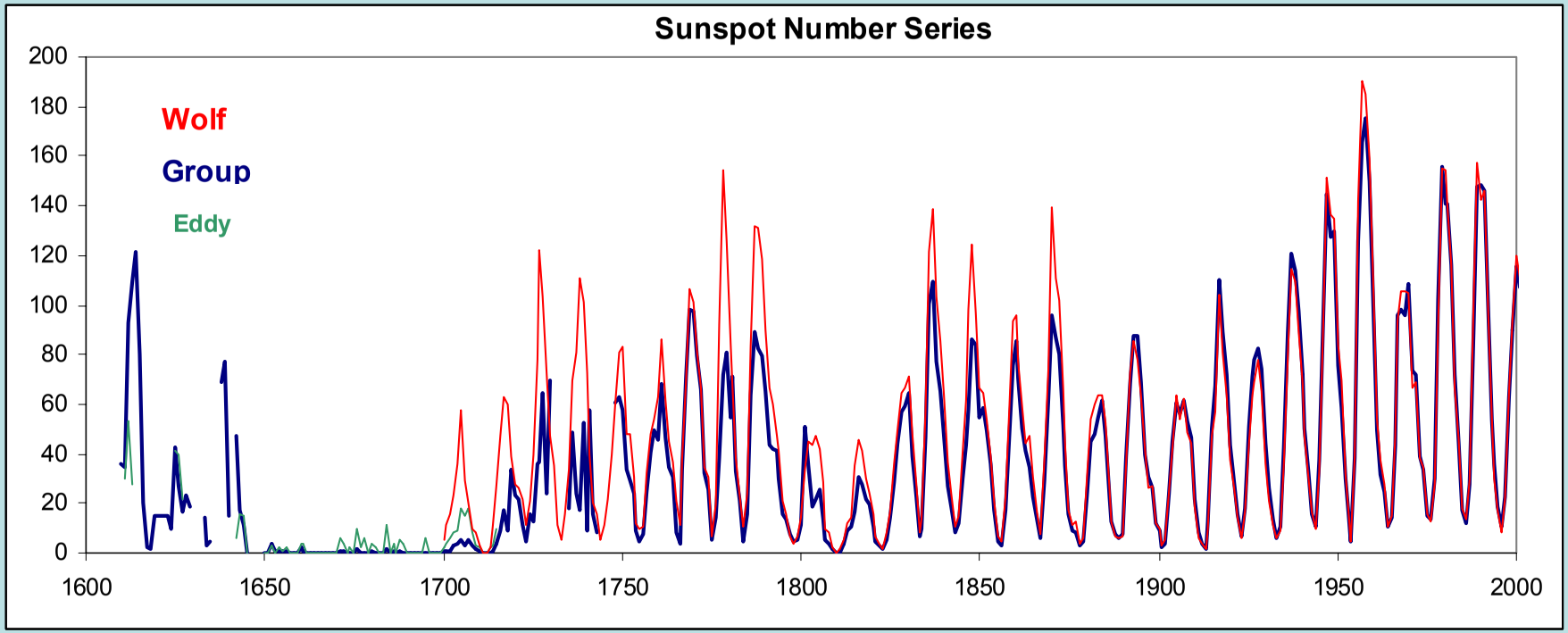
- The stations before 1850 [red diamonds] fall systematically below the regression line



Multiplying GSN [Rg] by a factor 1.4 brings them up into good conformance with the SSN [Rz], open red diamonds

Original GSN

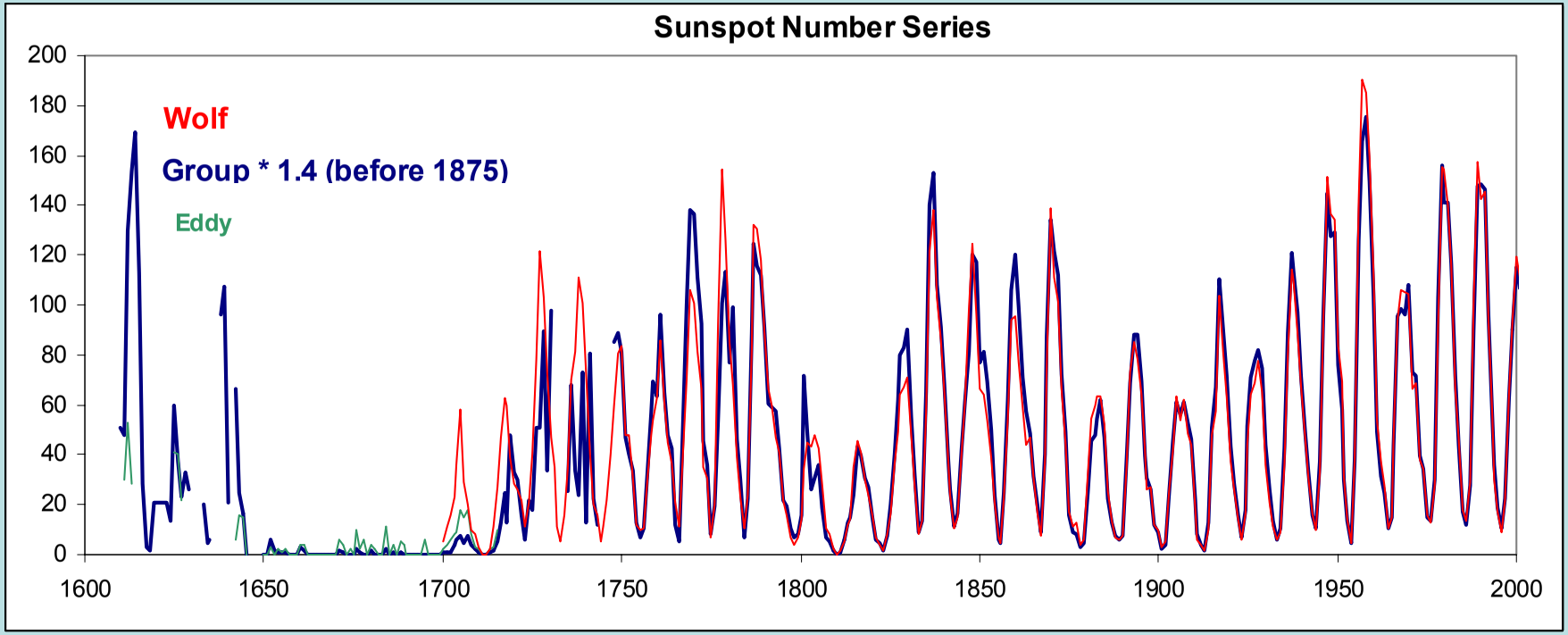
Compared with Wolf SSN



Adjusted GSN

Compared with Wolf SSN

Both series now calibrated to Geomagnetic Response



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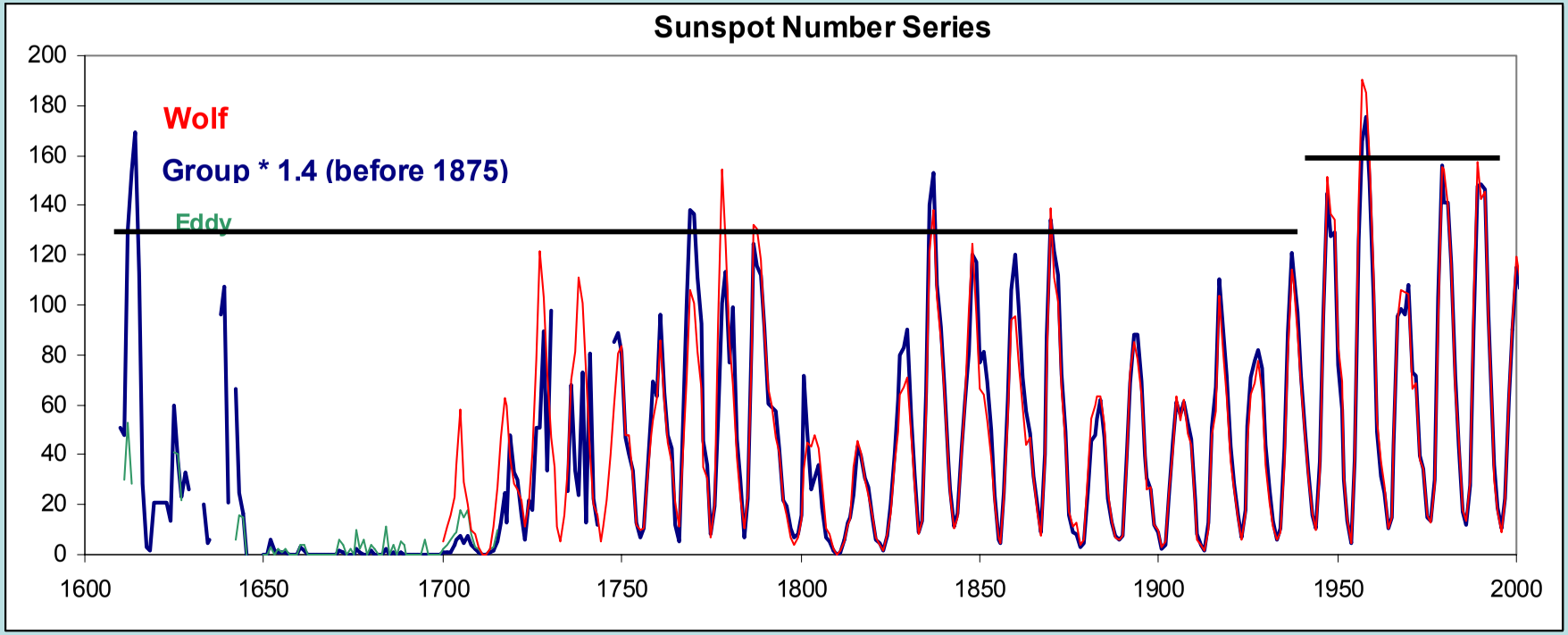


We still have the step function up to the 'Modern Maximum'

Wolfer Changed Counting Method

- Wolf did not count pores and the smallest spots. His assistant [and successor] Alfred Wolfer disagreed and argued that all spots, no matter how small, should be counted, and of course won the argument by staying longer on the right side of the grass. He introduced a correction factor, *k*, to bring his counts into conformance with Wolf's [the tyranny of installed base]

The Confusing Coefficient *k*

Wolfer compensated for his change in counting method by calculating an equivalent ‘Wolf Number’ as

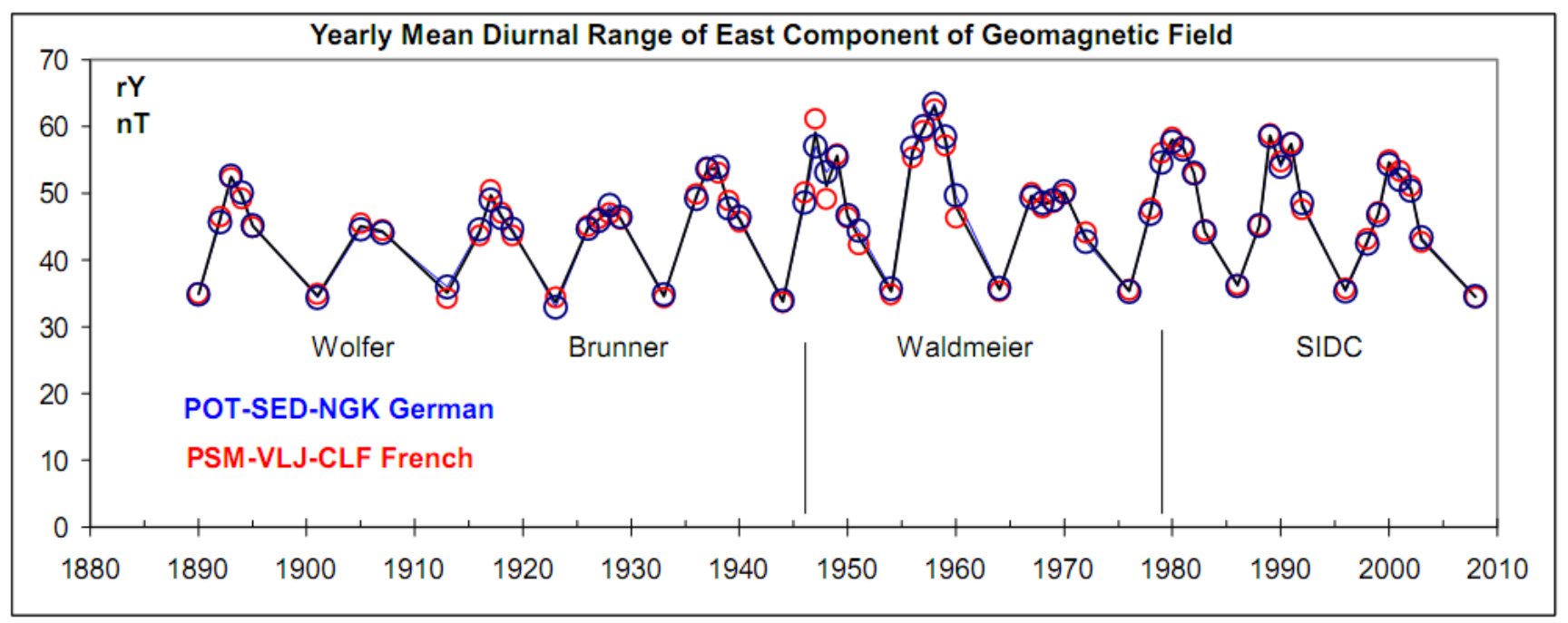
$$SSN = k\,(10\,G + S), \text{ with } k = 0.6,$$

but since G is only rarely influenced by the change in counting the smallest spots, the equation should really have been

$$SSN = 10\,G + \kappa\,S$$

Post Wolf Sunspot Numbers

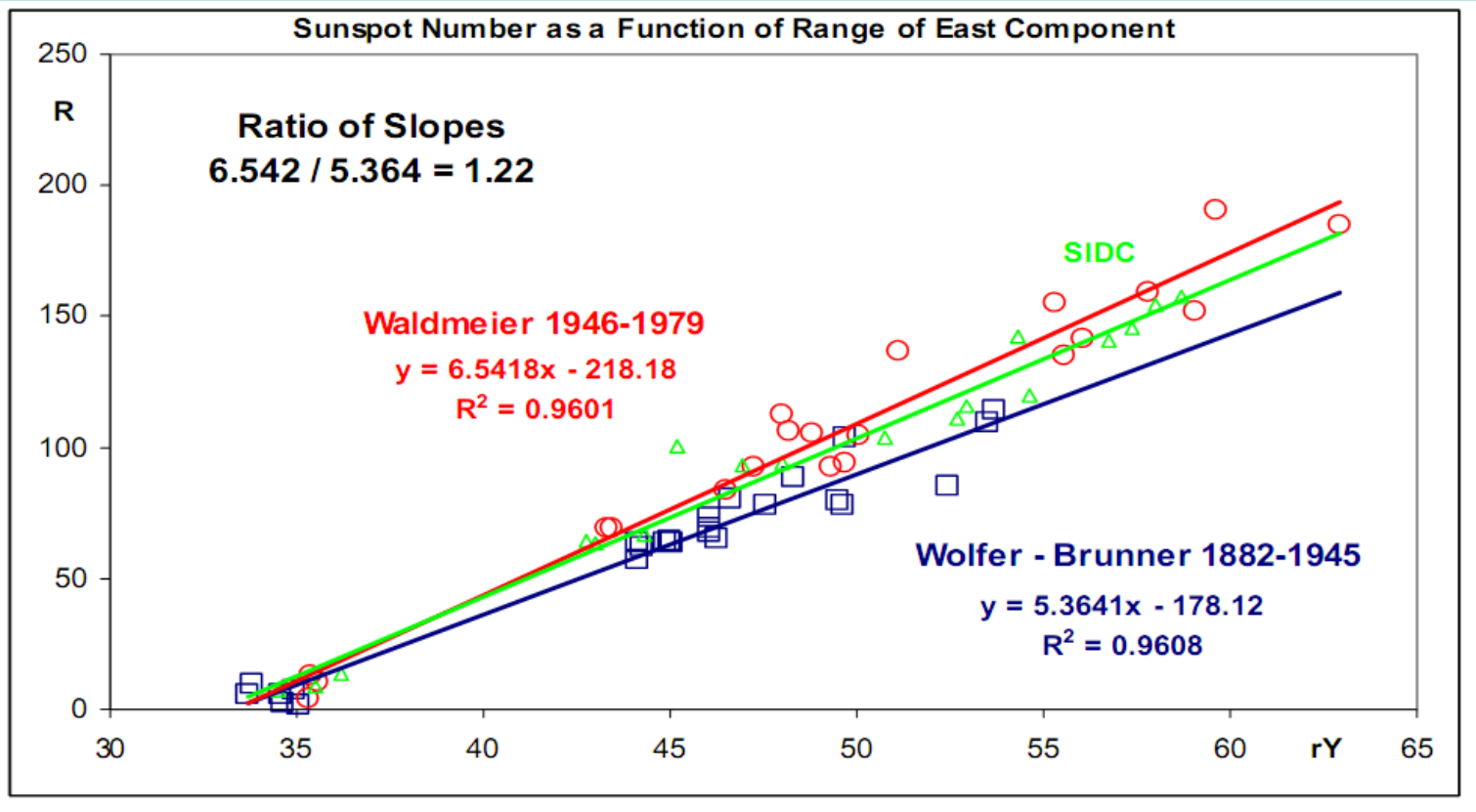
- This is NOT a graph of the SSN, but of the East Component [looks very much like the SSN]



The Observers and their tenure intervals are indicated on the graph

The Waldmeier Discontinuity, I

- Waldmeier's counts are 22% higher than Wolfer and Brunner's, for the *same* amplitude of the Diurnal Geomagnetic Variation.



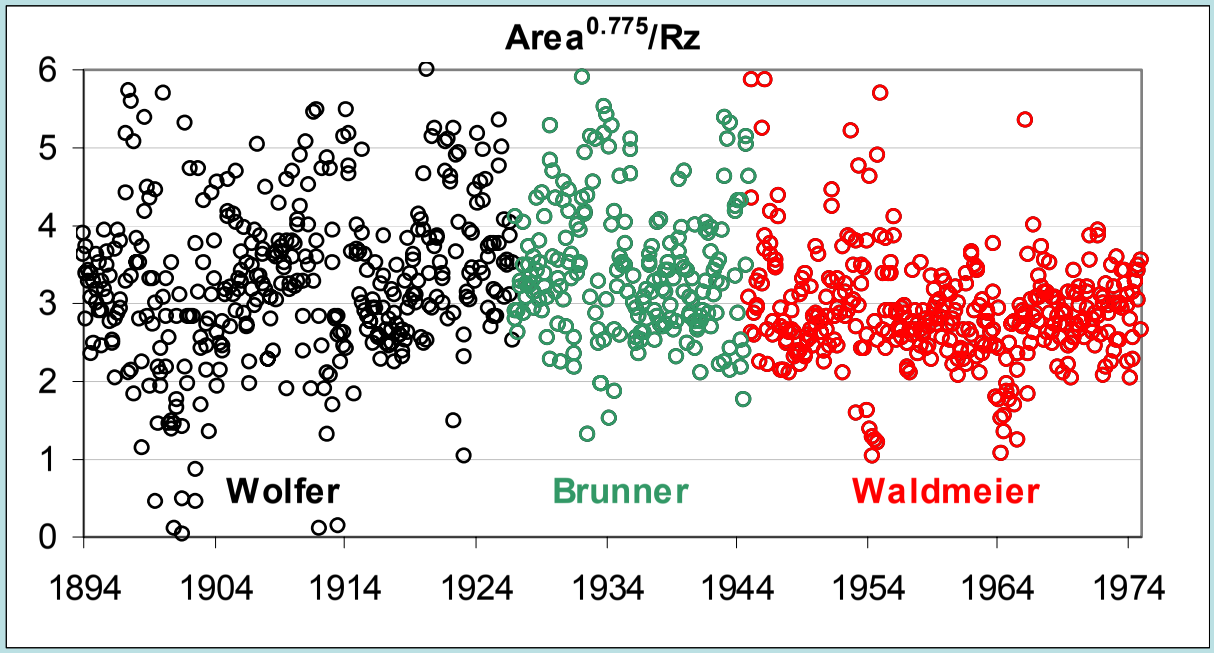
Waldmeier was Inexperienced

- Friedli [2005] writes:
- “Zum Einen war Waldmeier vor seiner Ernennung zum Direktor der Eidgenössischen Sternwarte jahrelang der Leiter der Aussenstation in Arosa und hatte kaum Beobachtungserfahrung am Wolfschen Normalrefraktor in Zürich, zum Anderen hat Waldmeiers Vorgänger William Brunner nach seiner Emeritierung nicht mehr weiterbeobachtet und auch dessen langjähriger Assistent hat die Eidgenössische Sternwarte schon ein Jahr nach Waldmeiers Amtsantritt verlassen. Das neue Beobachtungsteam in Zürich war also relativ unerfahren und musste zudem noch während der Minimumsphase beginnen. Erschwerend kam hinzu, dass die beiden nachfolgenden Zyklen die intensivsten je direct beobachteten waren, mit bis zu 100 Einzelgruppen pro Sonnenrotation in den Maximumsphasen. Waldmeier hat denn auch selber befürchtet, sein als konstant angenommener Skalenfaktor könnte variieren.”

- “The new observer-team in Zurich was thus relatively inexperienced” and “Waldmeier himself feared that his scale factor could vary”. We now know that his fear was not unfounded.

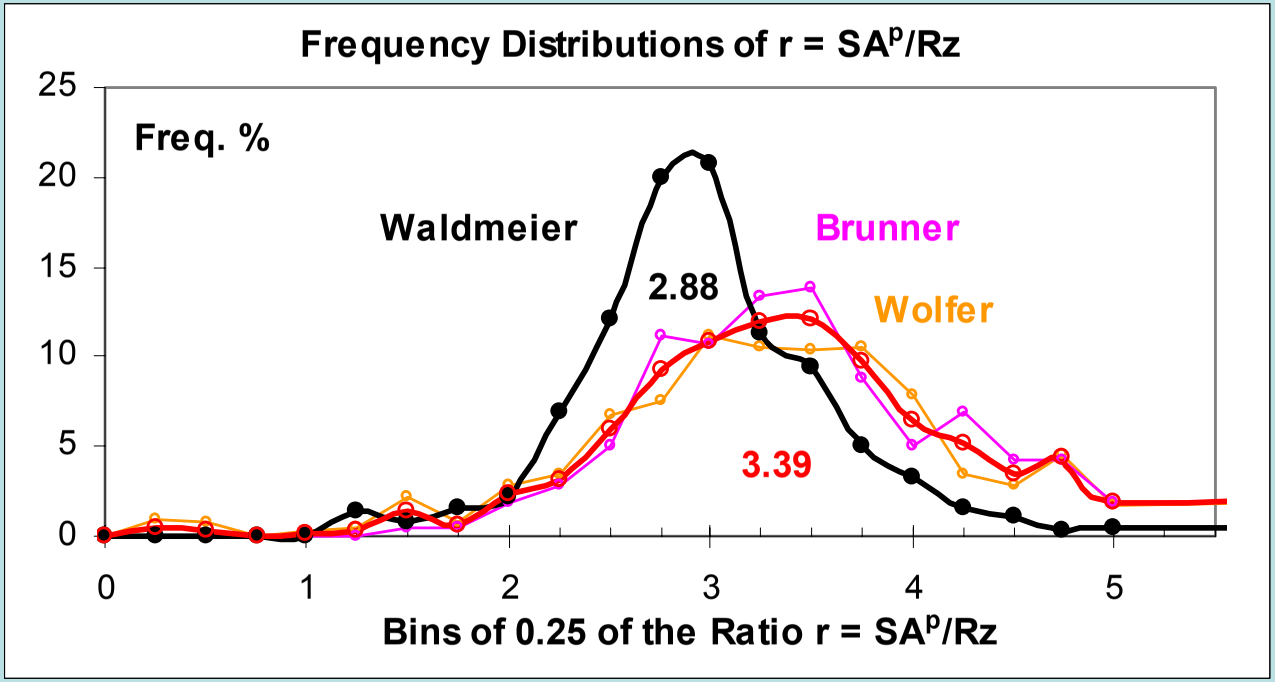
The RGO Sunspot Area Series

- There is a strong correlation [with zero offset] between the Sunspot area [SA] and Rz = (1/r) • $SA^{0.775}$. The ratio $SA^{0.775}$/Rz is observer dependent. We see the same ~20% difference for Waldmeier



The Waldmeier Discontinuity, II

- Histograms of the ratio values indicate that Waldmeier's Rz are a factor of 3.39/2.88 = 1.18 too high

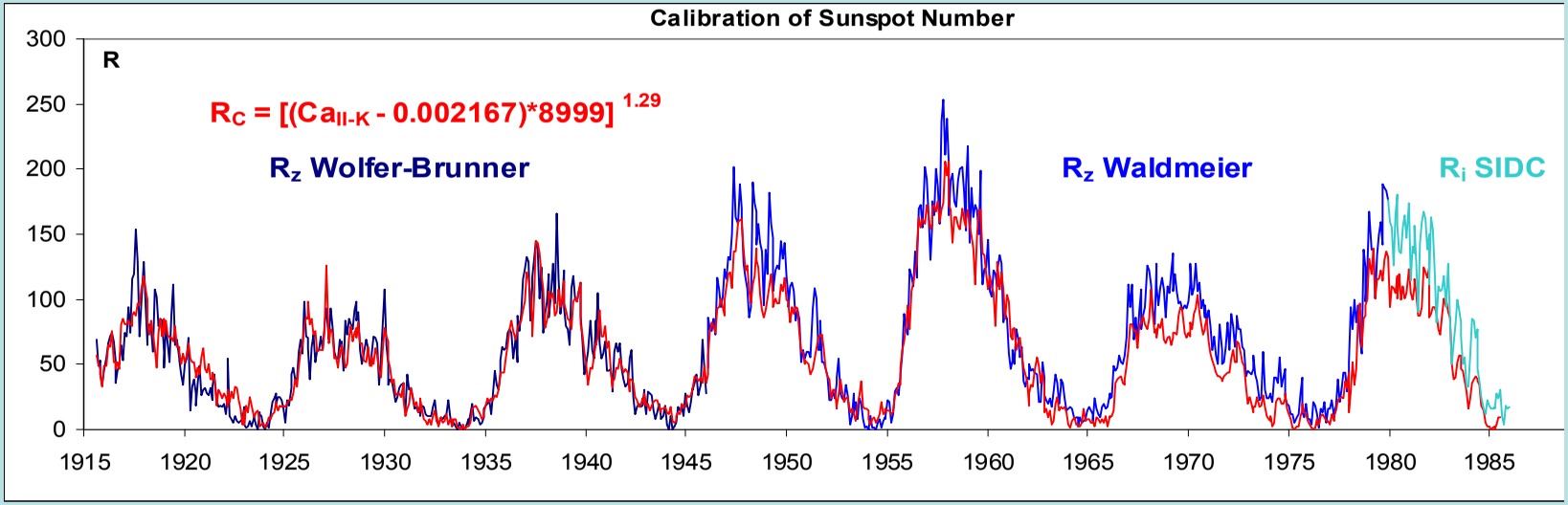


The Waldmeier Discontinuity, III

- 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. The relationship is not linear, but can be represented by the following equation:

$$R = [(CaK - 0.002167)*8999]^{1.29}$$

using data from 1910-1945, i.e. the pre-Waldmeier era.



The SSN observed by Waldmeier is 20% higher than that calculated from CaK using the pre-Waldmeier relation.

The Waldmeier Discontinuity, IV

- The value of the Ionospheric Critical Frequency foF2 depends strongly on solar activity. The slope of the correlation changed 20% between sunspot cycle 17 and 18 when Waldmeier took over.

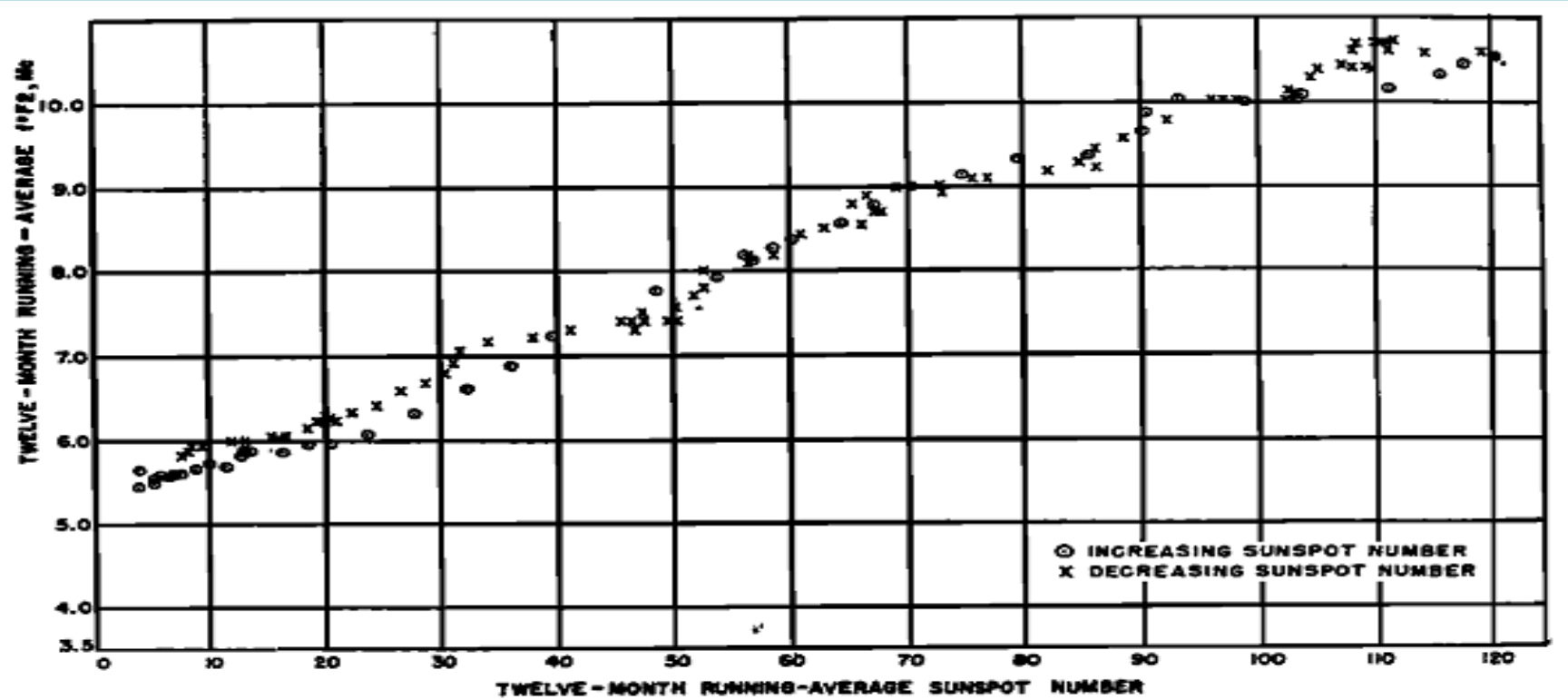


Fig. 5. VARIATION OF TWELVE-MONTH RUNNING—AVERAGE f°F2, 1200, AT WASHINGTON, D.C., WITH TWELVE-MONTH RUNNING-AVERAGE SUNSPOT NUMBER

Waldmeier Introduced a Discontinuity of 20% in the Zurich Sunspot Number. Correcting for this by increasing pre-Waldmeier SSN by 20% yields this suggested Sunspot Series: