

# Calibration of Sunspot Numbers

Leif Svalgaard  
Stanford University

[leif@leif.org](mailto:leif@leif.org)

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# Waldmeier's Description of What he Believed was the Counting Method

## CHANGES TO THE COUNTING METHOD

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.

Waldmeier, 1961

I believe (2) is **incorrect**, having read all Wolfer's [and Brunner's] papers and not found any such description. Waldmeier may have believed that the spots were weighted by size and carried that belief into his count.

# Waldmeier's Own Description of his [?] Counting Method

Astronomische Mitteilungen der Eidgenössischen Sternwarte Zürich  
Nr. 285

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1968

Die Beziehung zwischen der Sonnenfleckenzahl und der Gruppenzahl

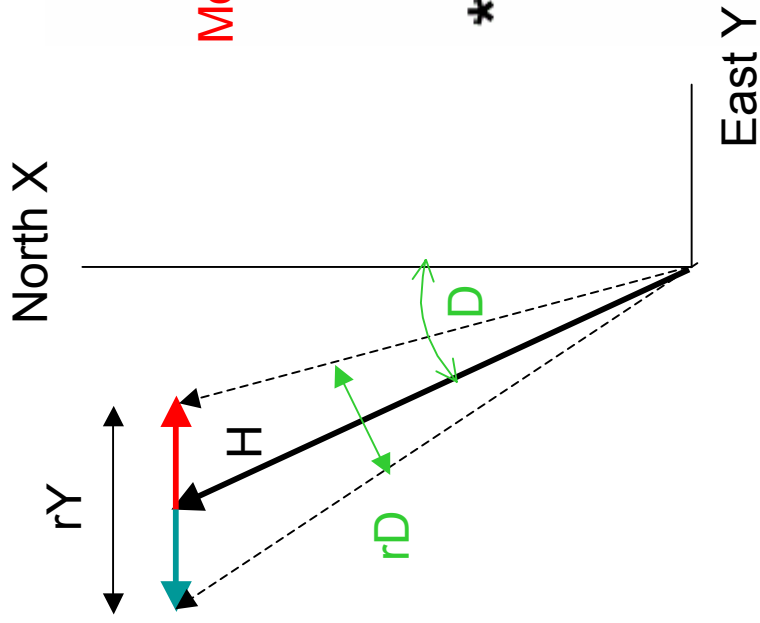
Von

M. WALDMEIER

Hofflecken handelte. 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. Die Gruppen- und Fleckenzahlen nach der neuen Zählart seien g und f. Die daraus abgeleiteten

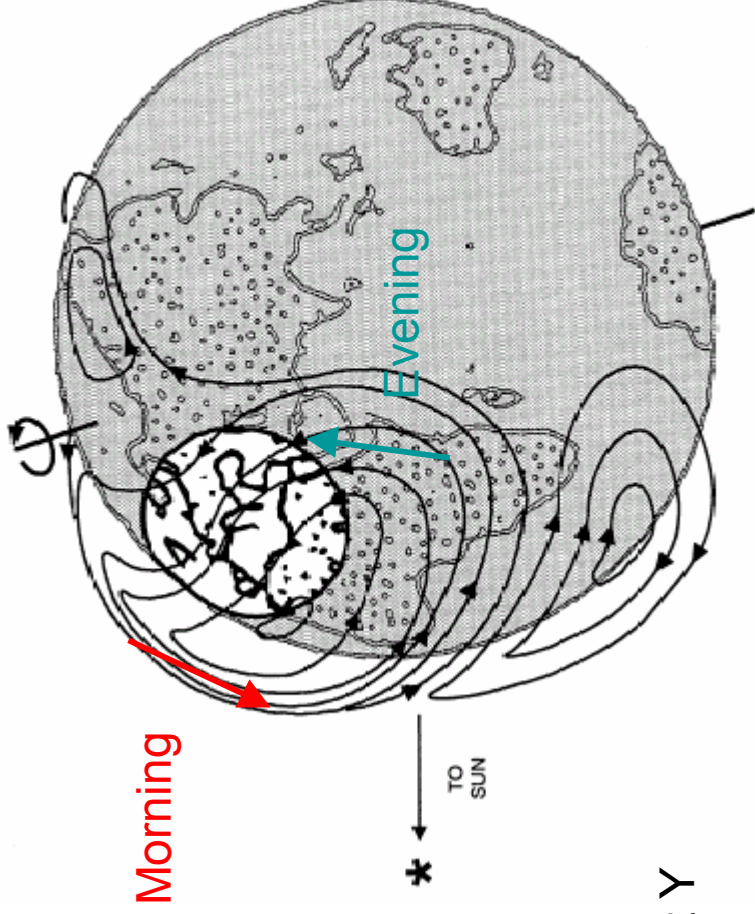
Can we see this in the Historical Record?

# Wolf's Discovery: $rD = a + b R_W$



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

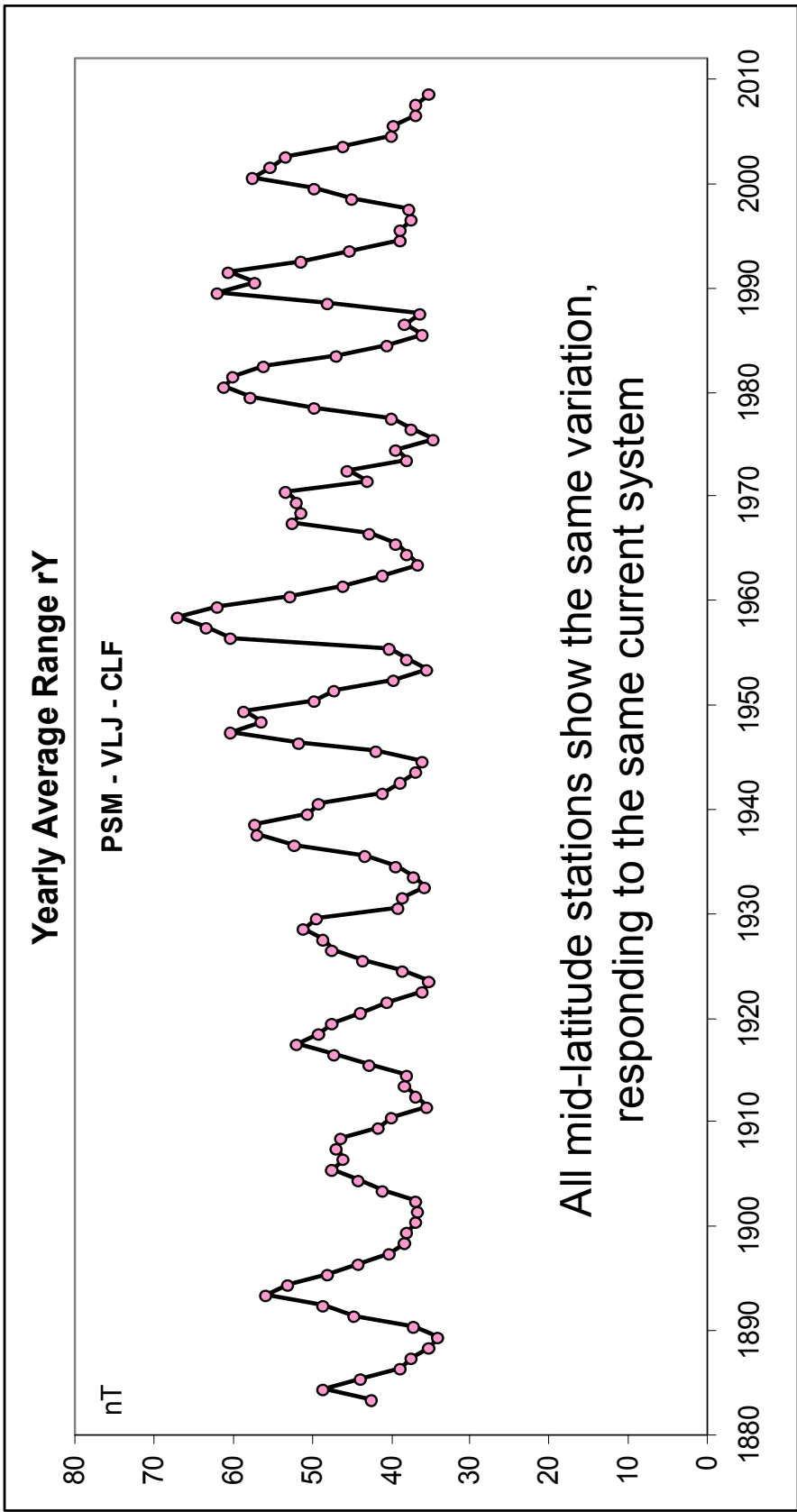
$dY = H \cos(D) dD$  For small  $dD$



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

**Wolf realized that this relation can be used to check the sunspot calibration**

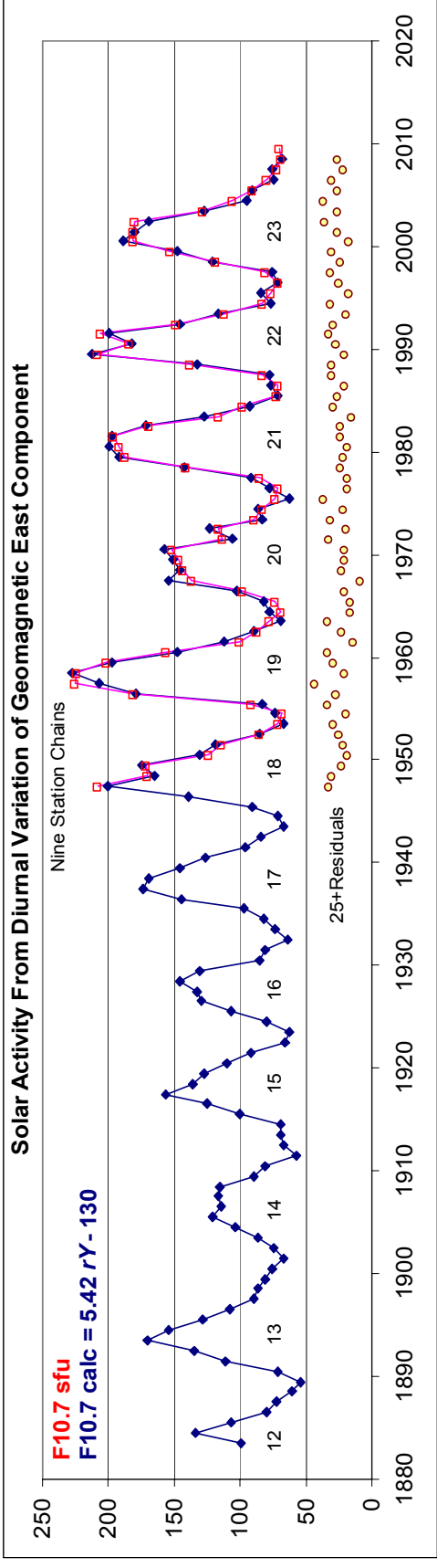
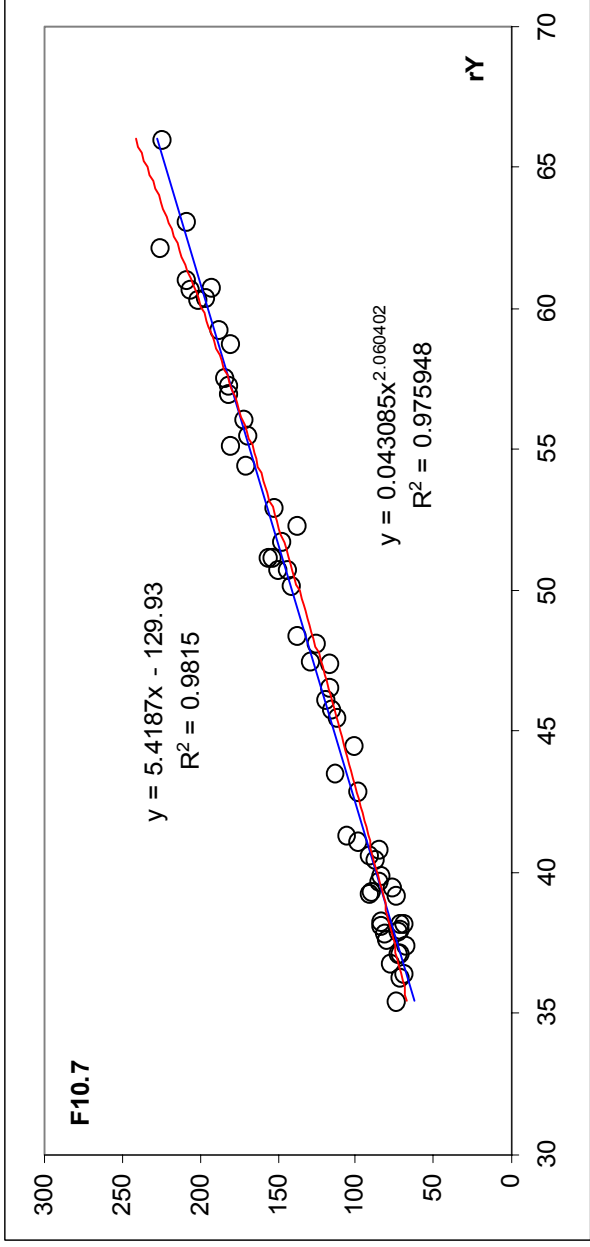
# The clear solar cycle variation of $r_Y$



All mid-latitude stations show the same variation,  
responding to the same current system

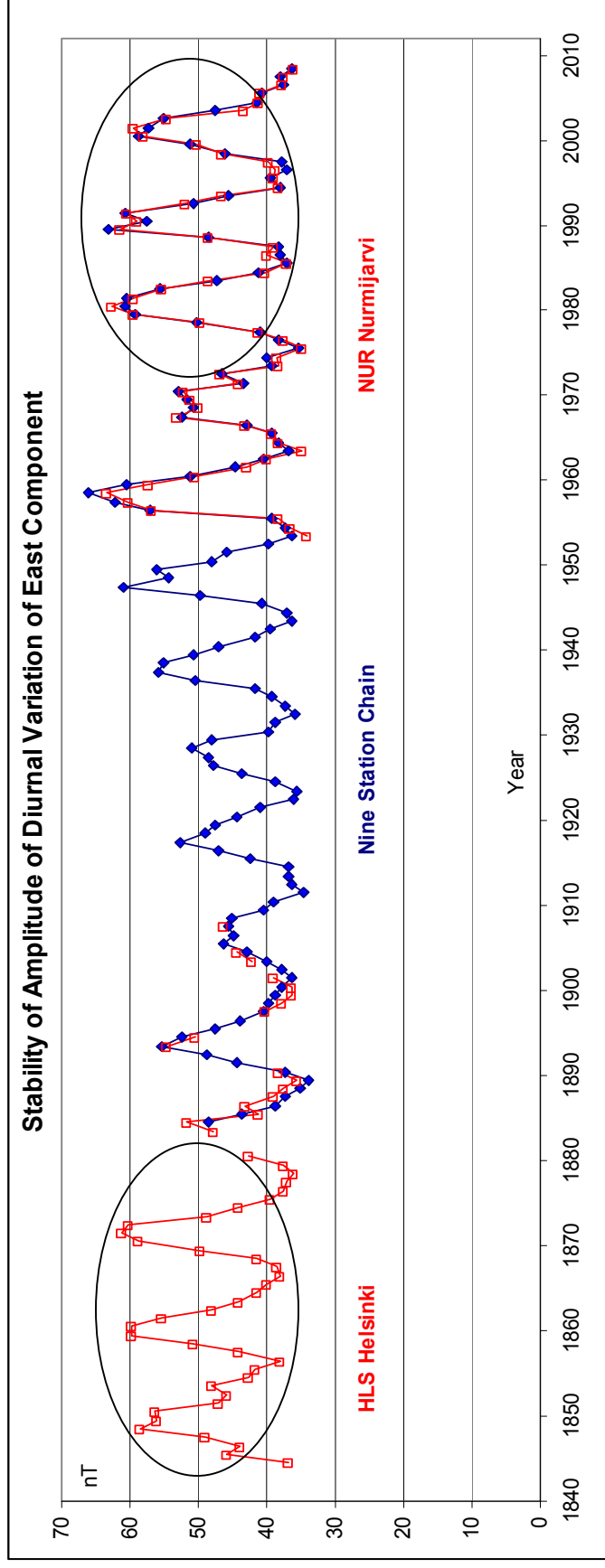
This was Wolf's justification for his calibration of the SSN

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

The diurnal range  $rY$  is thus an extremely good proxy for the F10.7 radio flux and [presumably] for ‘solar activity’ in general

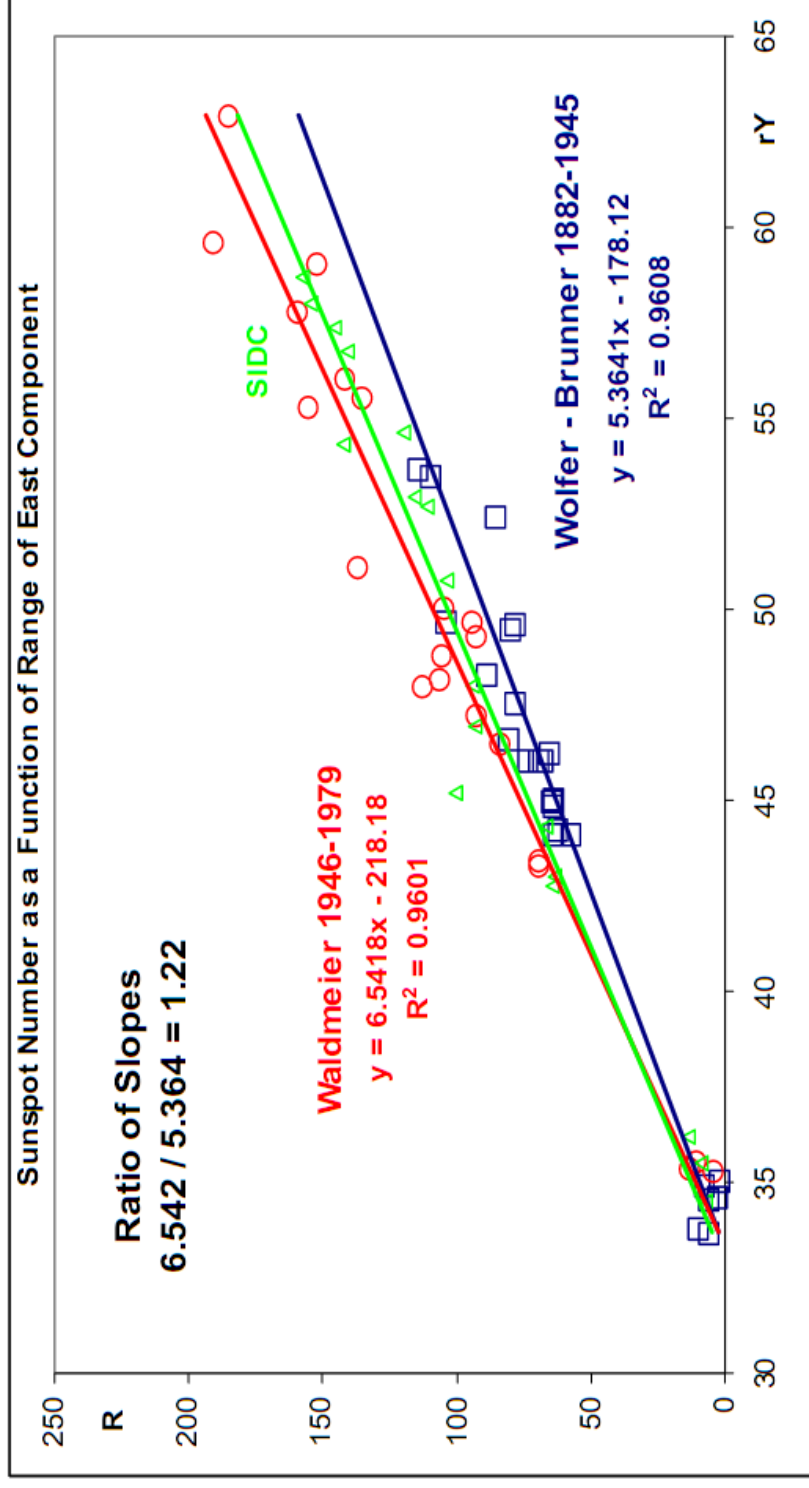


Here is the response at Helsinki and at its replacement station Nurmijärvi

*Note, that activity in the 1840s-1870s was similar to that in the 1970s-2000s*

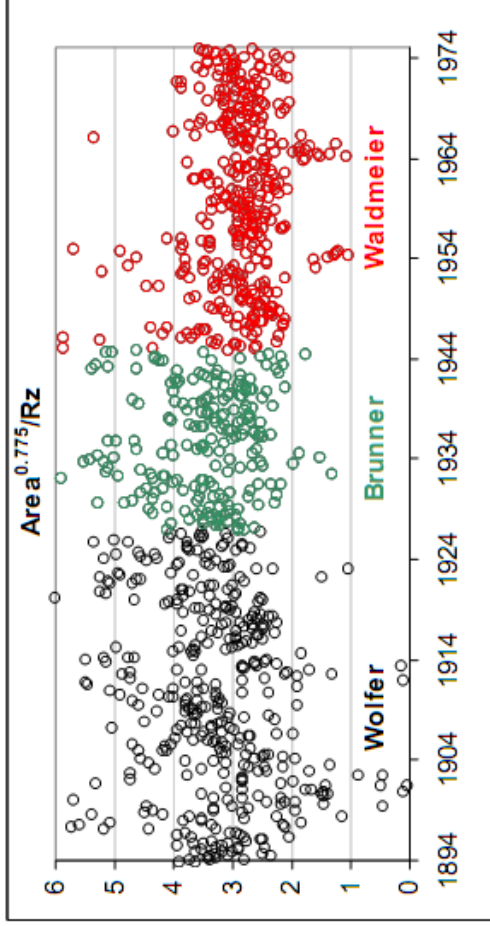
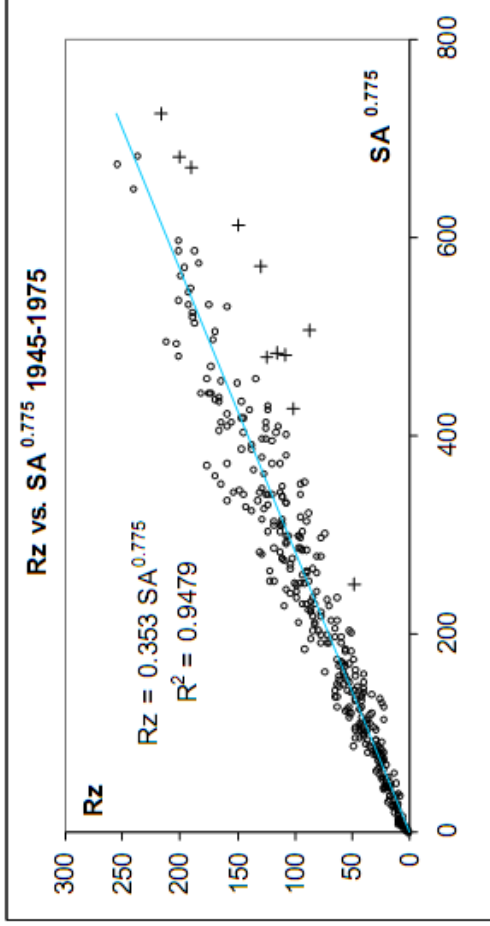
# The Waldmeier Discontinuity, I

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

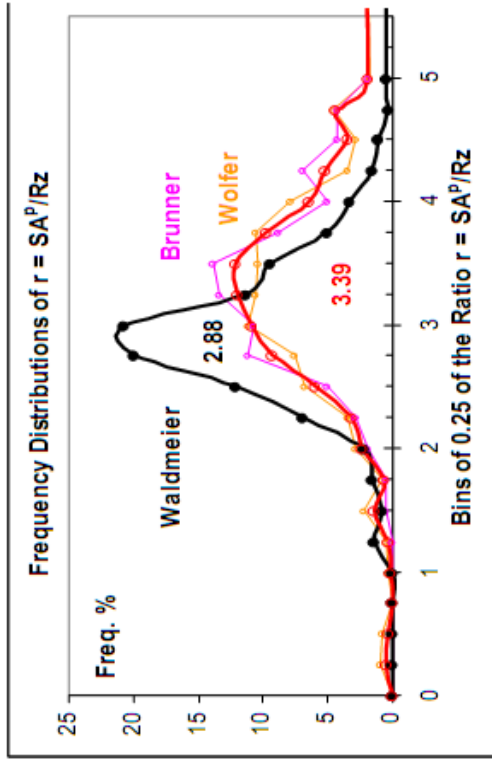




# The Waldmeier Discontinuity, II

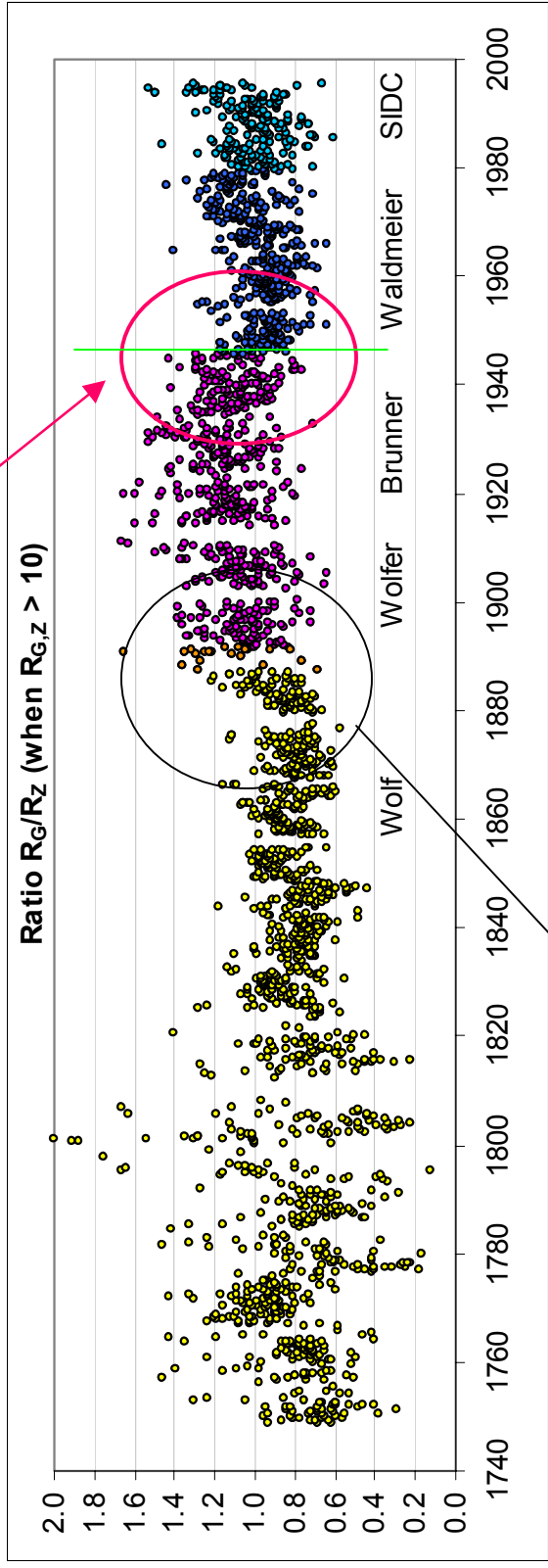


A linear relation going through the origin allows us to calculate the ratio between the [linearized] sunspot area  $SA^{0.775}$  and the sunspot number. We show here the ratio for each observer and histograms of the distributions of the ratios:



Assuming that the sunspot areas were not affected by Waldmeier taking over, the ratios indicate an increase of Rz of  $3.39/2.88 = 17.5\%$

The Group Sunspot Number  $R_G$  is derived from the RGO data after ~1874, so should show the same discontinuity, and it does:



Note, that I plot the inverse ratio, thus  $R_Z$  after 1945 is about 20% too high

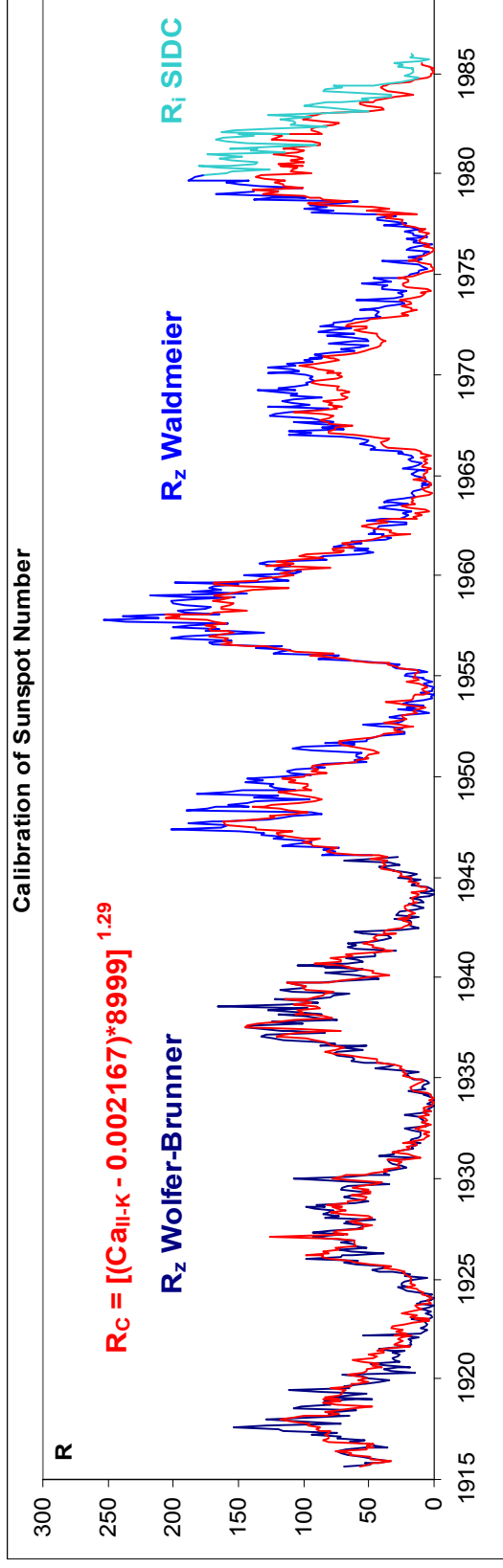
I'll come back to this discontinuity a bit later ...

# 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.

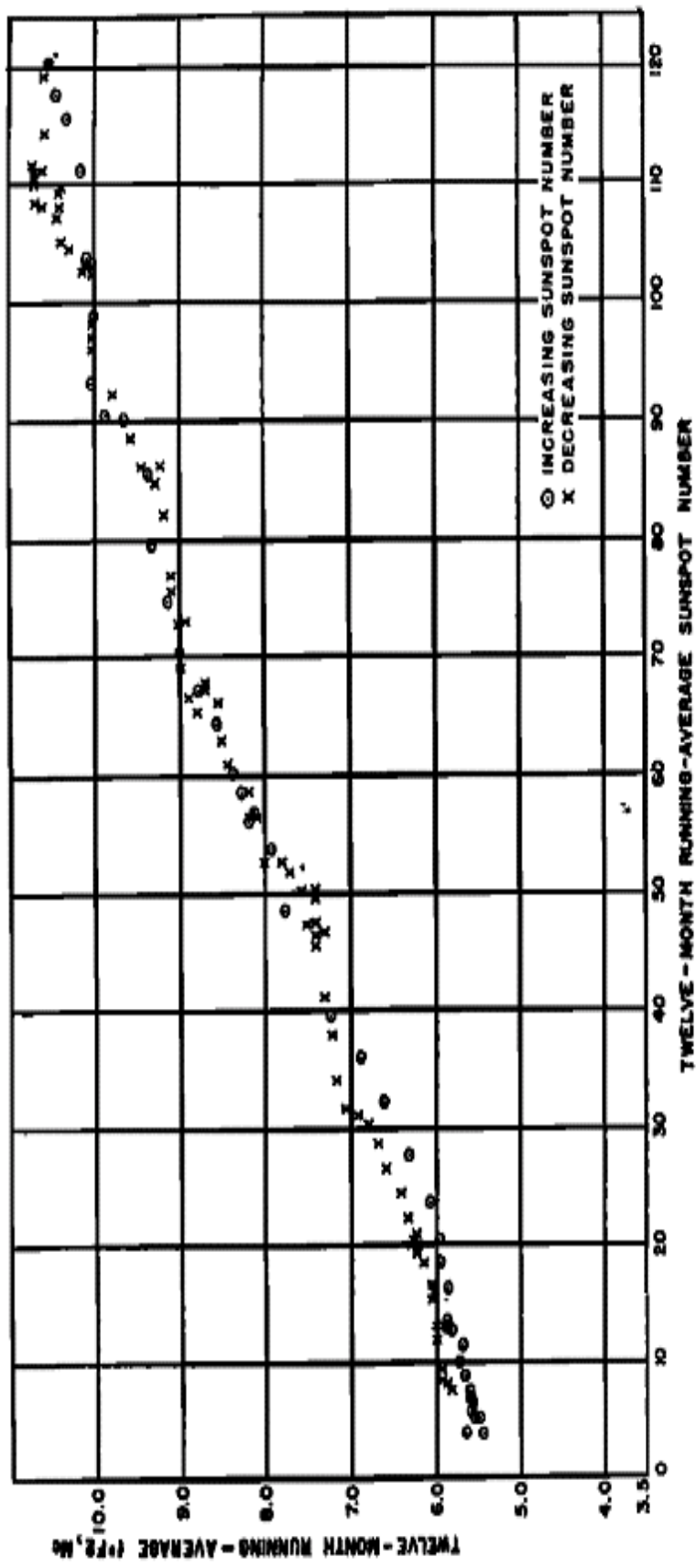
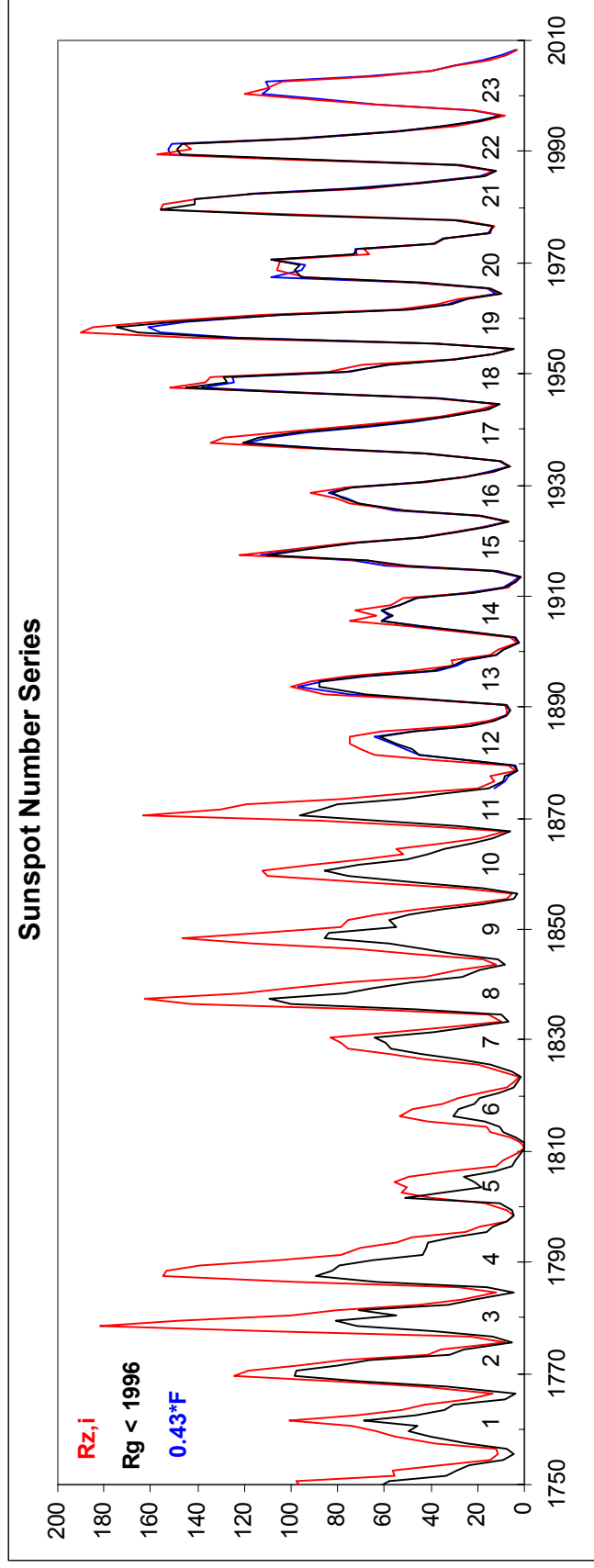


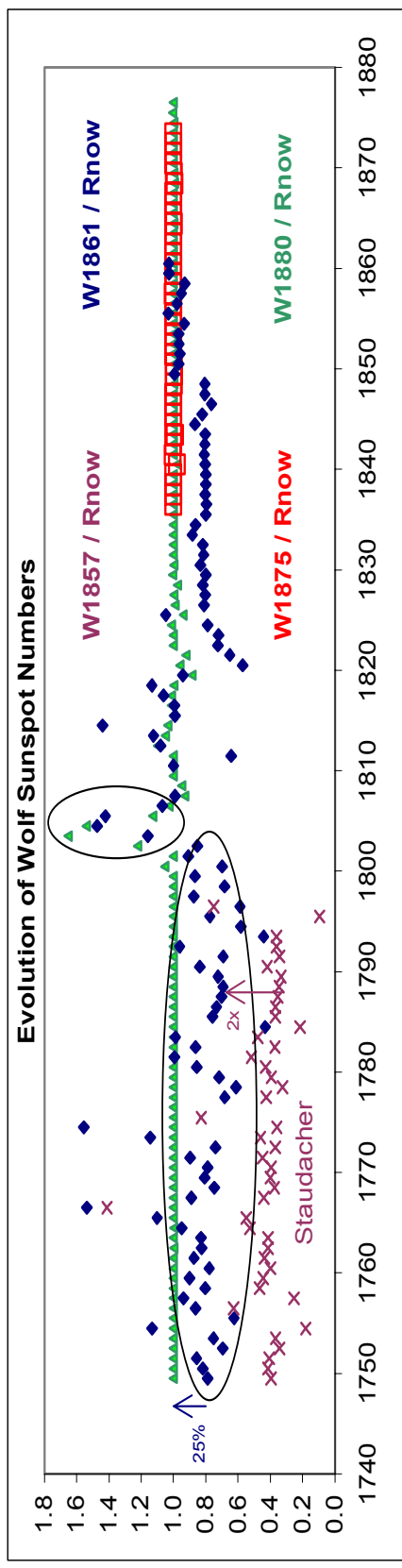
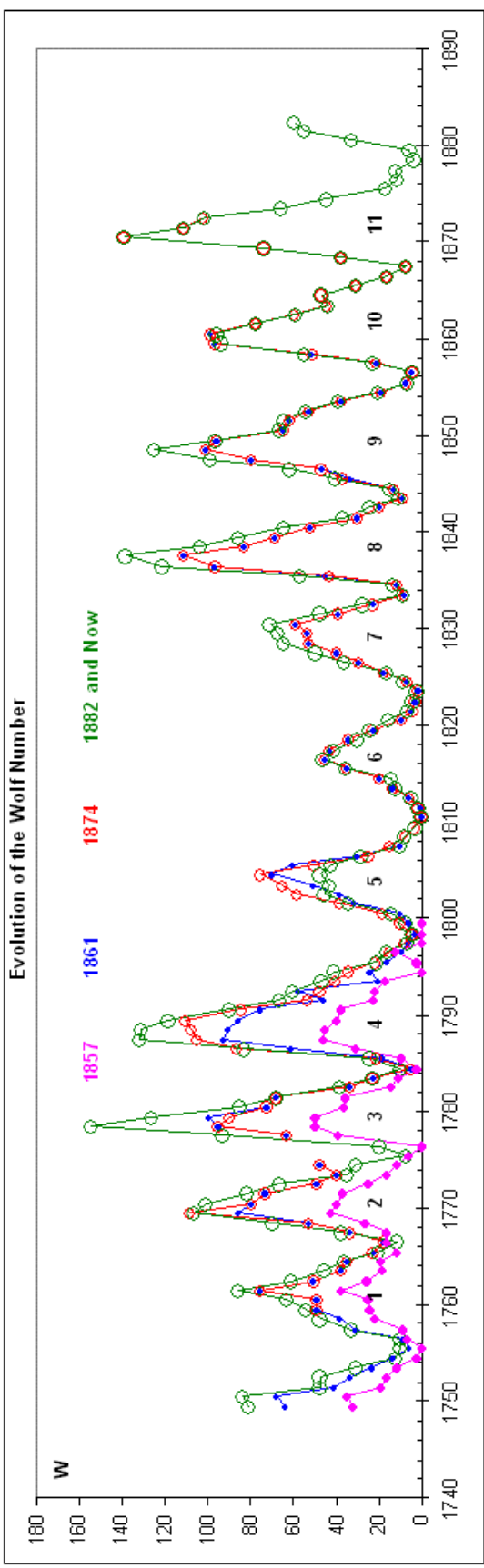
Fig. 5. VARIATION OF TWELVE-MONTH RUNNING-AVERAGE f°F2, 1200, AT WASHINGTON, D.C., WITH TWELVE-MONTH RUNNING-AVERAGE SUNSPOT NUMBER

If we accept the fidelity of the RGO sunspot observations [at least for a few decades around 1945] we must ascribe the artificial increase of Rz after 1945 to Waldmeier's inexperience [Friedli, 2005] as he struggled with learning how to construct the sunspot number [introducing the weights?]. Subsequent observers have strived to match Waldmeier, so in order to remove the 1945 discontinuity [and be consistent with modern counts] we must increase the pre-1945 Rz by ~20%:



This, of course, just makes the discrepancy with the Group Spot Number worse  
 [ $\langle Rz \rangle \sim 1.4 \langle Rg \rangle$  before 1875].

# Wolf himself was not afraid of such wholesale adjustments



# Rudolf Wolf's 'Relative' Sunspot Number values change over time...

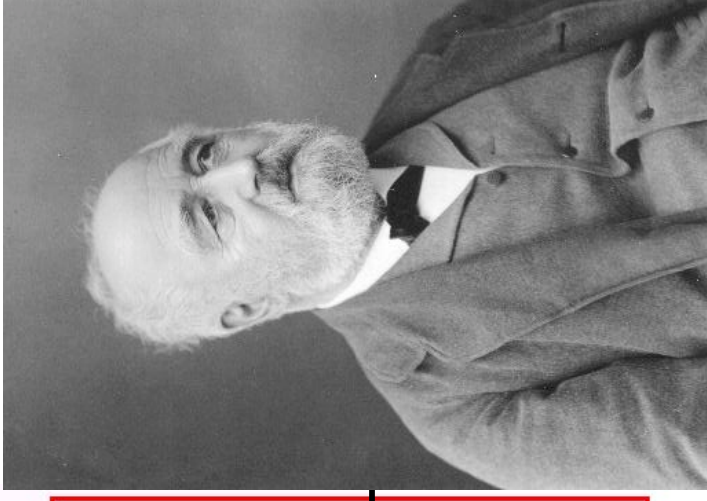
*Abstract of his latest Results. By Prof. Wolf.*

*(Translation communicated by Mr. Carrington.)*

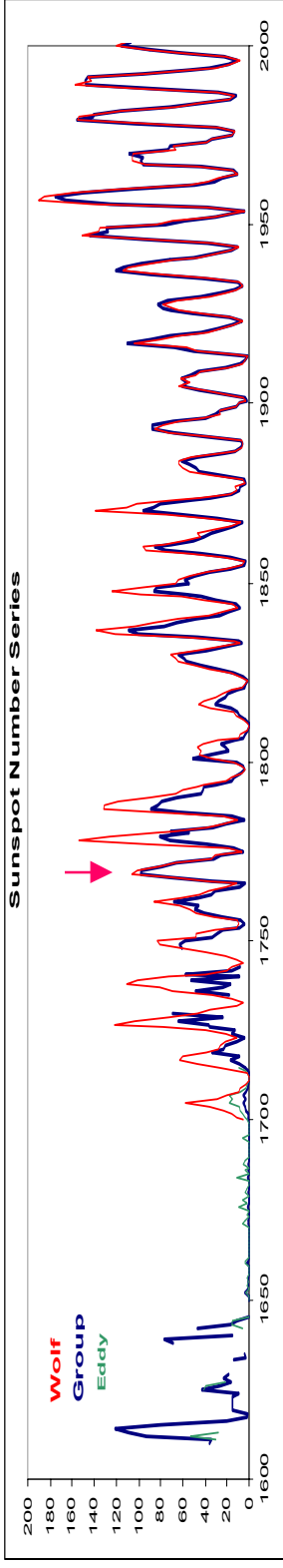
Some fine series of observations of Flaugergues, Adams, Arago, and others, have enabled me to fill in previous breaks, and to express in the same unit my Relative numbers (for the abundance of Solar Spots in successive years) for the years from 1749 to 1860. They are as follows:—

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

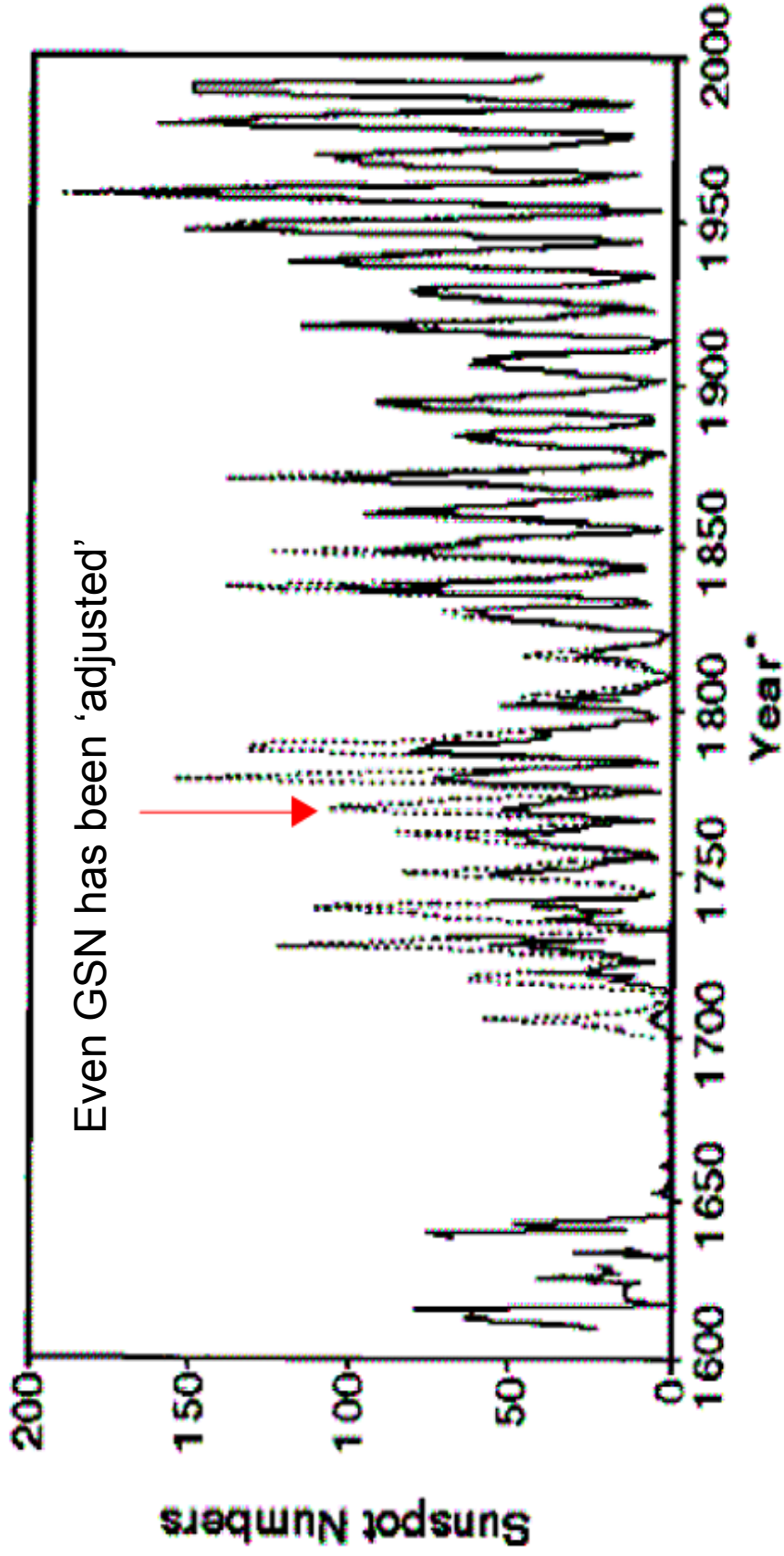
Wolf started his own observations in 1849



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

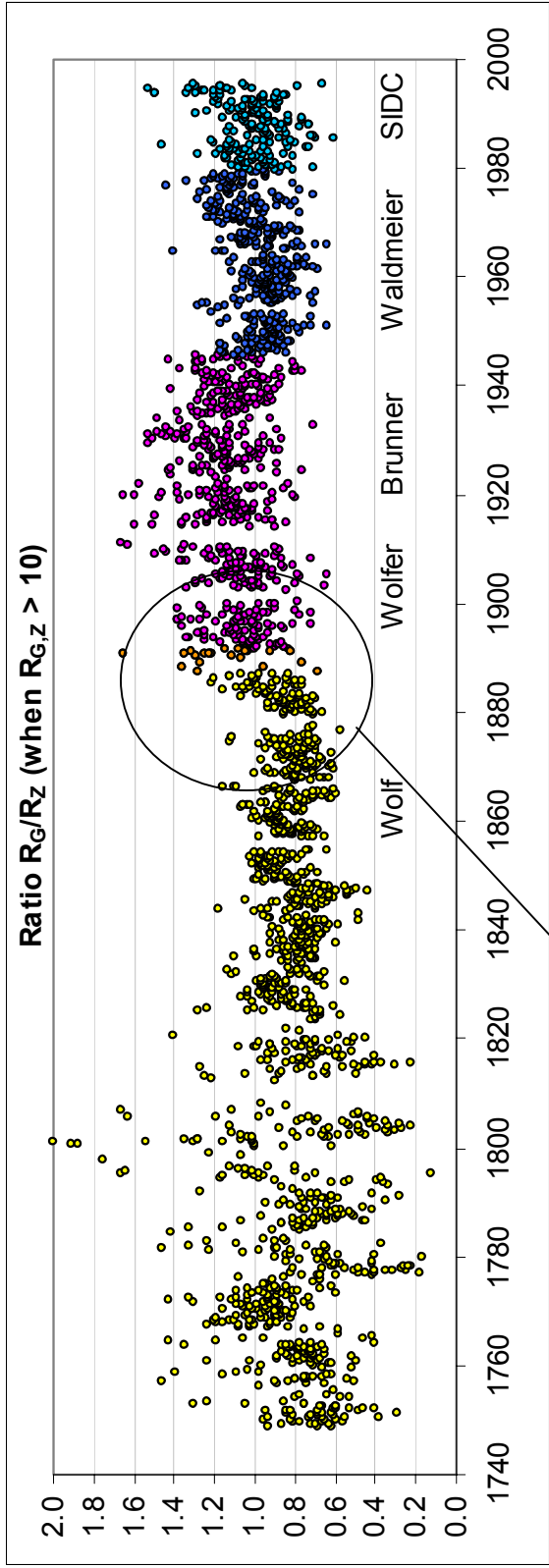


# Group and Wolf Sunspot Numbers





The Group Sunspot Number  $R_G$  is derived from the RGO data after ~1874



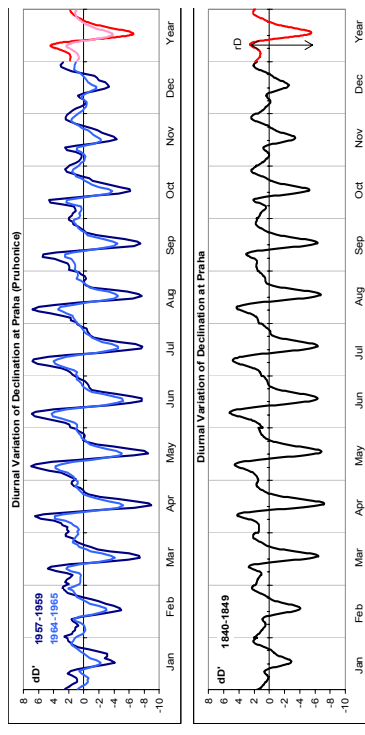
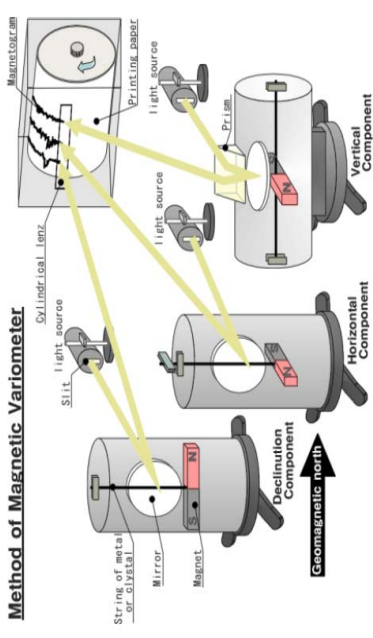
Note, that I plot the inverse ratio, thus  $R_G$  before ~1880 is about 40% too low

I'm back at this discontinuity as promised...

# The Discontinuity in the 1880s between Group and Zurich Sunspot Numbers, I

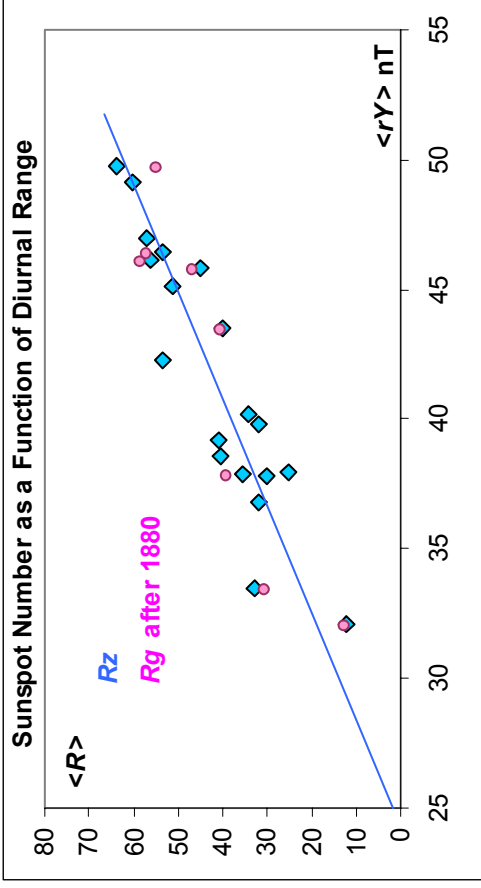
Adolf Schmidt [ $\sim 1900$ ] had analyzed the data for two intervals on either side of the start [1875] of the RGO sunspot observations for several stations and determined the diurnal ranges:

obs	name	lat	long	interval
WDC	Washington D.C.	38.9	283.0	1840-1842
DUB	Dublin	53.4	353.7	1840-1843
MNH	Munich	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

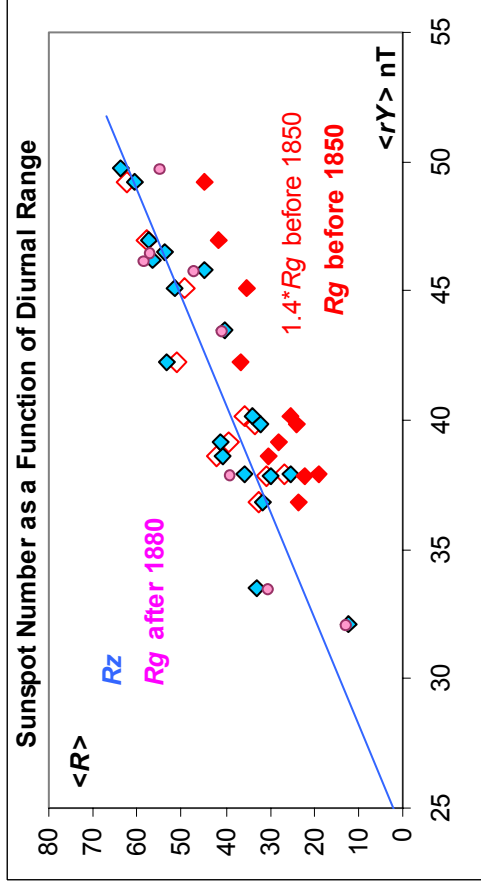


WLH	Wilhelmshaven	53.7	7.8	1883-1883
GRW	Greenwich	51.5	0.0	1883-1889
WDC	Washington D.C.	38.9	283.0	1891-1891
PSM	Parc Saint-Maur	48.8	0.2	1883-1899
POT	Potsdam	52.4	13.1	1890-1899
COP	Kobenhavn	55.7	12.6	1892-1898
UTR	Utrecht	52.1	5.1	1893-1898
IRT	Irkutsk	52.3	104.3	1899-1899

# The Discontinuity in the 1880s between $R_G$ and $R_Z$ explained and resolved

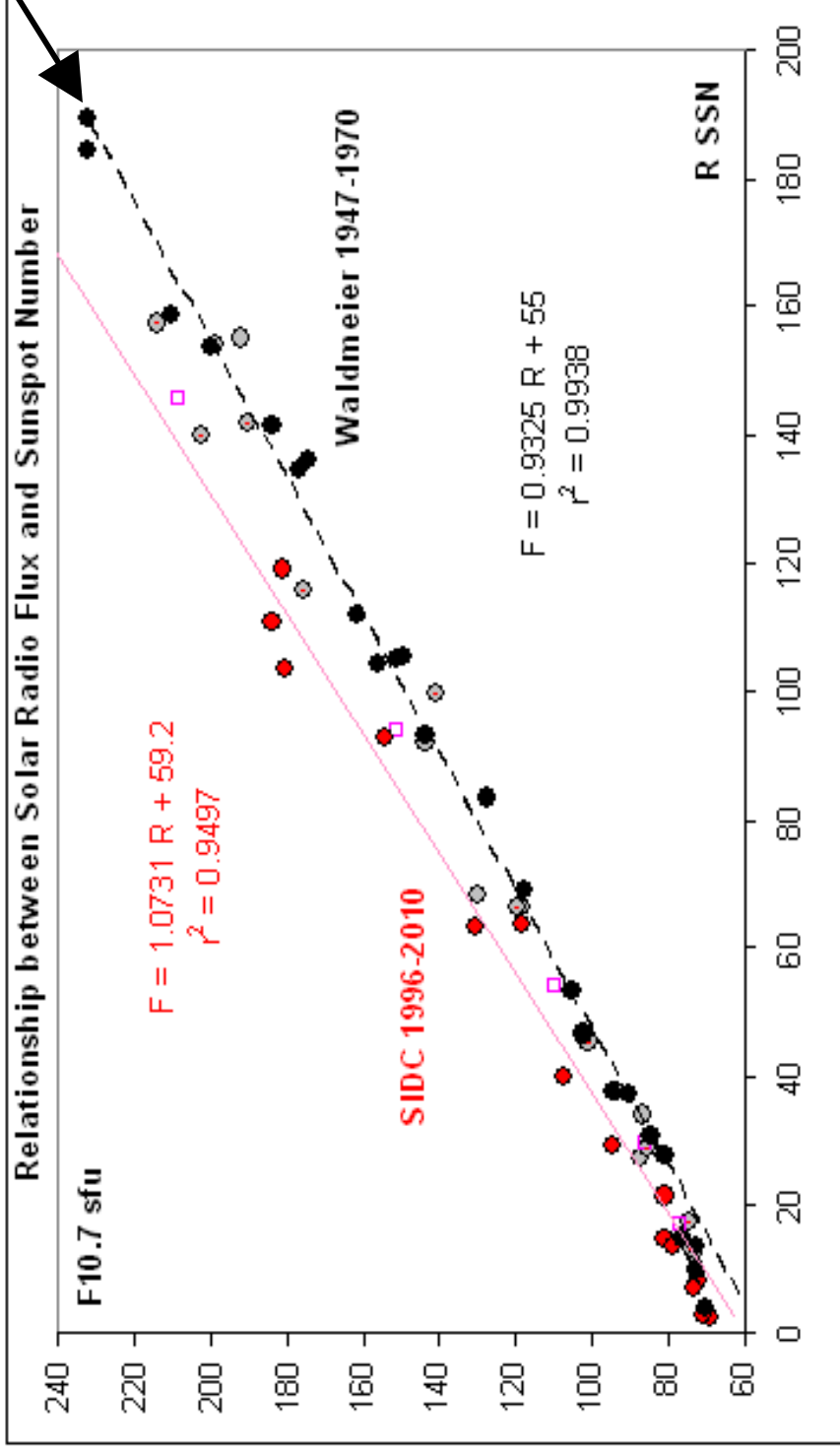


For each station we now compute the average  $\langle R_Z \rangle$ ,  $\langle R_G \rangle$ , and diurnal range [converted to force units,  $nT$ , from arc minutes] and plot  $\langle R_Z \rangle$  against the range  $\langle rY \rangle$  [blue diamonds, left]. You can see Wolf's linear relationship in action. For the eight stations with data after 1880, the  $\langle R_G \rangle$ s are also plotted [pink dots] and they match the  $\langle R_Z \rangle$  points reasonably well.



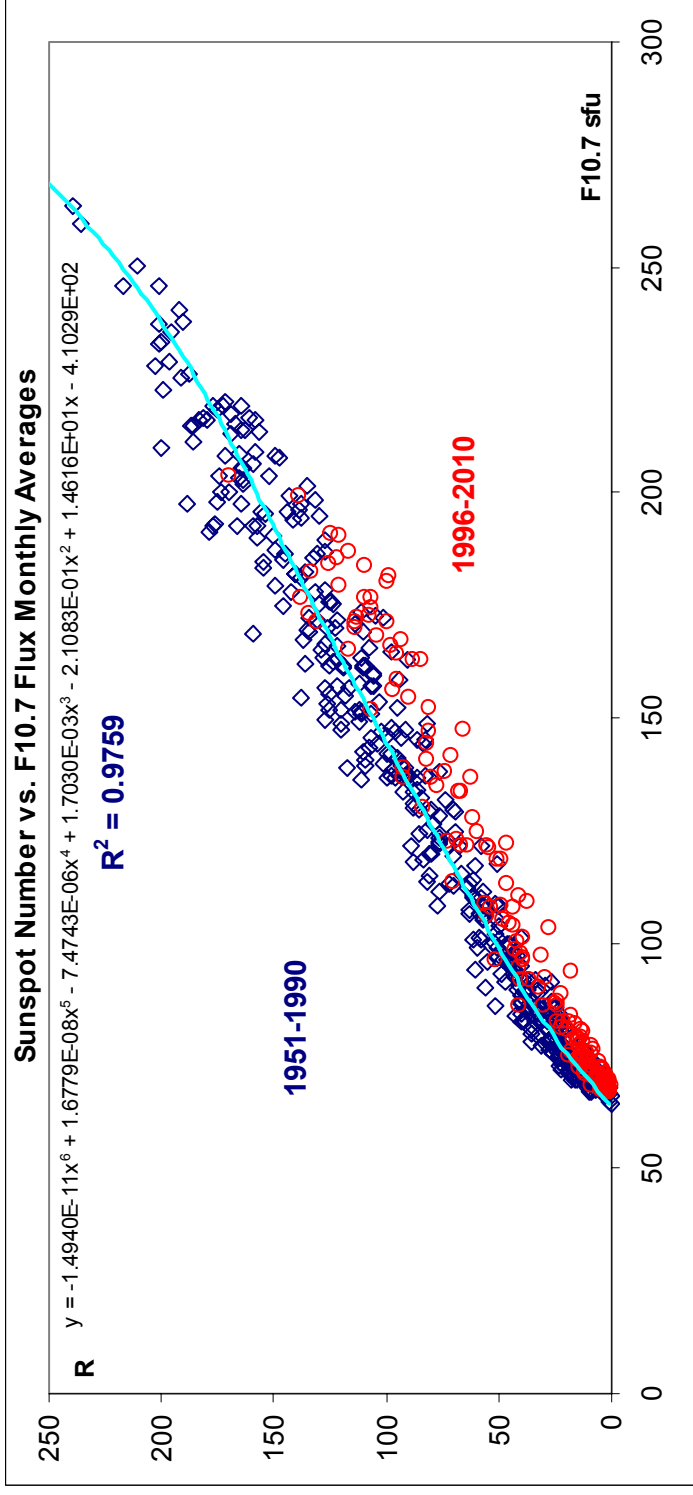
This is, however, not the case for the eleven stations from 1850 and before. Their  $\langle R_G \rangle$  [red diamonds] lie well below the fitted line. To make them fit it suffices to multiply their values by 1.4 [giving red open diamonds].

Waldmeier [1971] already noticed that the tight correlation between the solar microwave flux F10.7 and the sunspot number could be used as a calibration tool



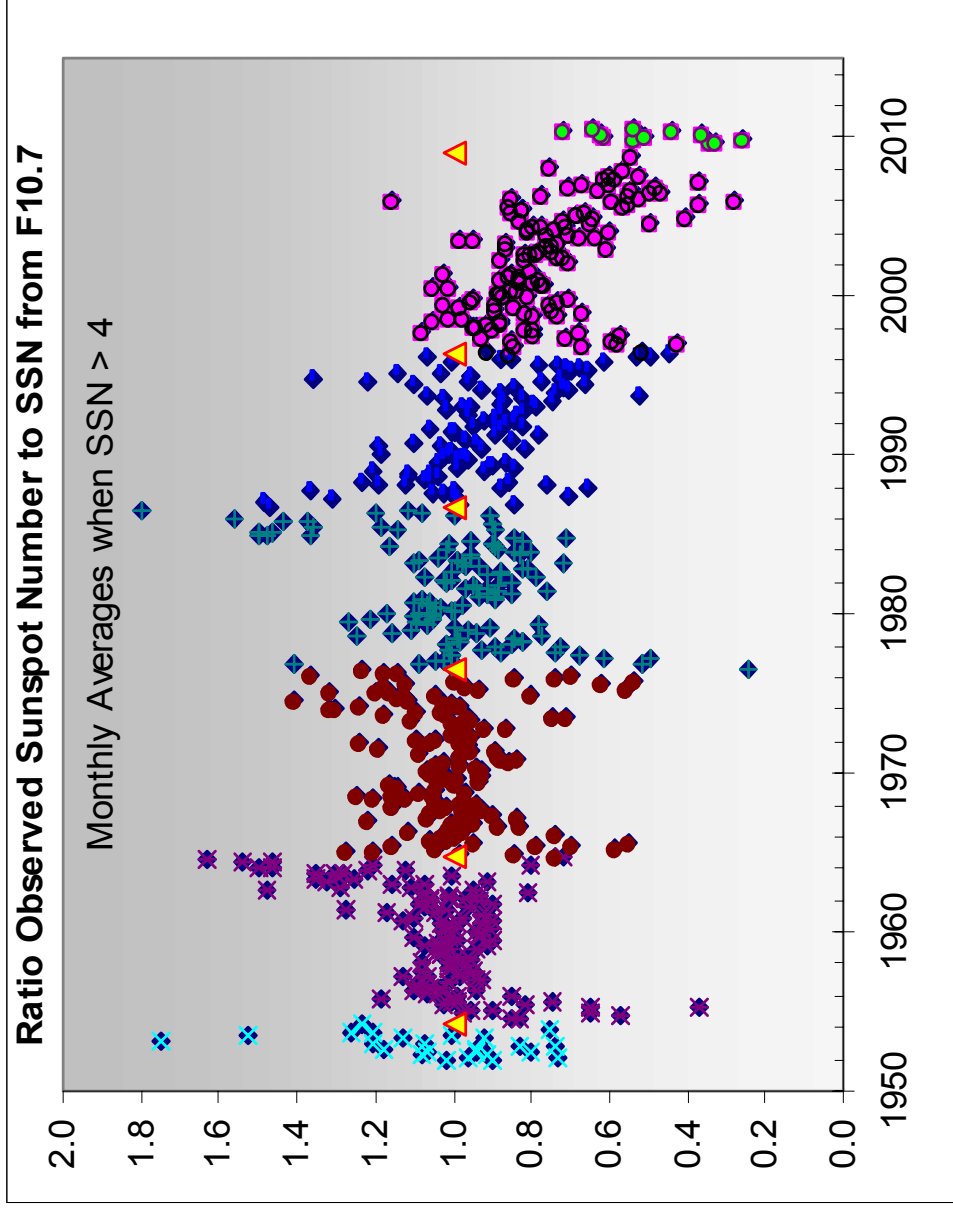
Waldmeier: “As long as this relation holds, the Zürich series of sunspot-numbers may be considered to be homogeneous. *If this relation should be subject to changes in the time to come, then the reduction factor used hitherto ought to be changed in such a way that the old R-F relation is reestablished*”

# The change in relationship is perhaps clearer in monthly values



We know that the F10.7 measurements themselves [which are absolute flux values] have not changed because of the agreement between Canadian [since 1947] and Japanese [since 1951] measurements.

# Comparing Observed and Synthetic SSN from F10.7



The growing discrepancy could be due to a drift in the SIDC calibration or to a real change in the Sun, or both! Waldmeier did not consider the possibility of a solar change...  
Do we?

# Some other organizations that have kept a keen eye on the Sun, making their own sunspot number series:

<http://www.vds-sonne.de/gem/res/results.htm>

SIDC: Solar Influences Data Analysis Center, Brussels  
(International sunspot numbers)

SONNE prov.: SONNE network, provisional sunspot numbers

SONNE def. : SONNE network, definitive sunspot numbers

AAVSO: American Association of Variable Star Observers - Solar Division

AKS: Arbeitskreis Sonne des Kulturbundes e.V., Germany

BAA: The British Astronomical Association - Solar Section, UK

GFOES: G.F.O.E.S. Commission "Nombre de Wolf", France

GSRSI: GruppoSole Ricerce Solari Italia, Italy

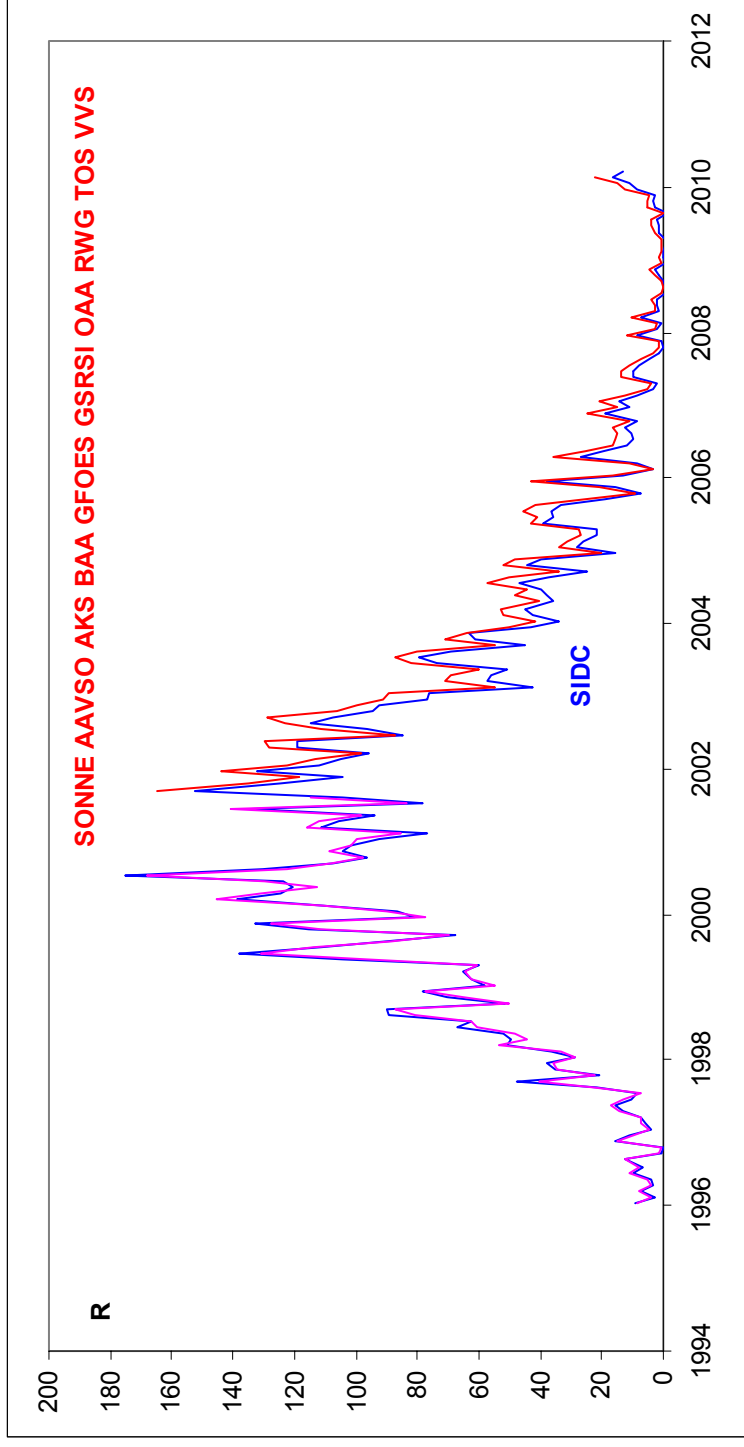
OAA: The Oriental Astronomical Association - Solar Division, Japan

RWG: Rudolf Wolf Gesellschaft - Solar Obs. Group of Swiss Astron. Society

TOS: Towarzystwo Obserwatorow Slonca - Solar Observers Society, Poland

VVS: Vereniging voor Sterrenkunde, Werkgroep Zon, Belgium

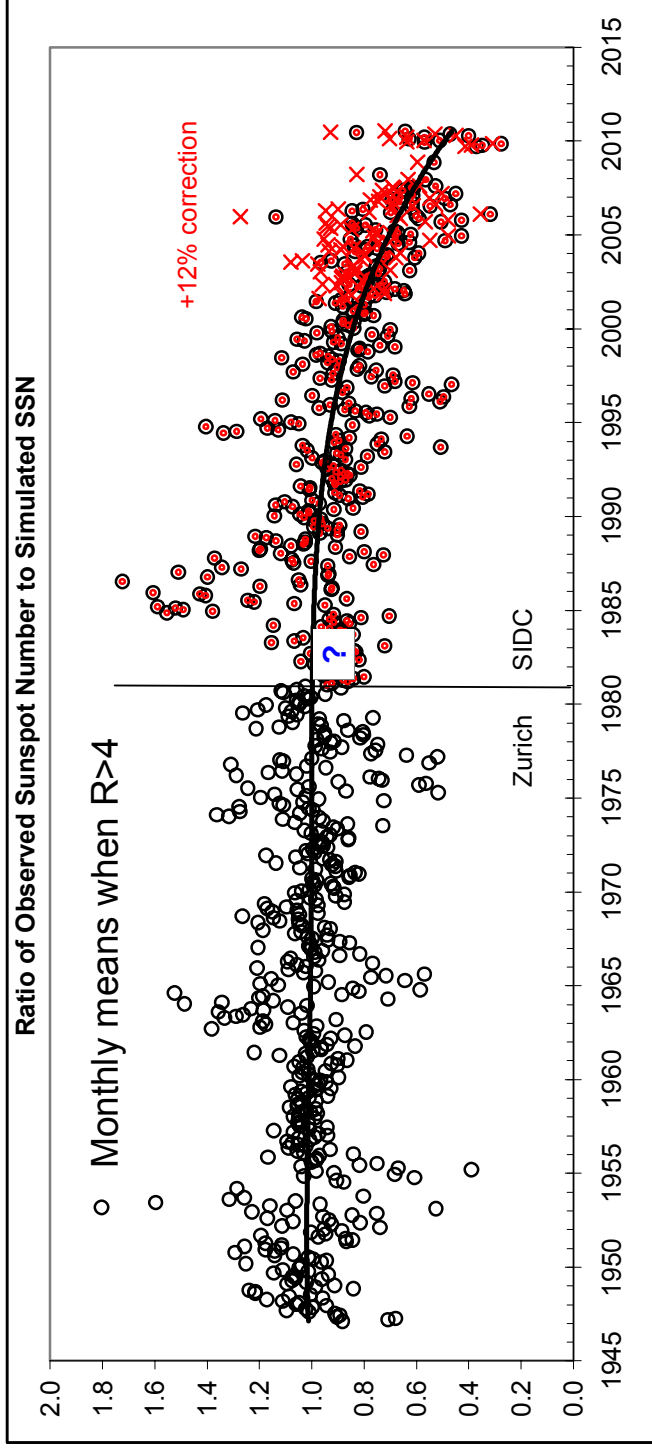
# All these series can be successfully scaled to SIDC before ~2001



But the same scaling relation yields a sunspot number after that time that is systematically 12% higher than SIDC's. Did all these organizations somehow change their procedures and/or observer cadre? Or did SIDC?

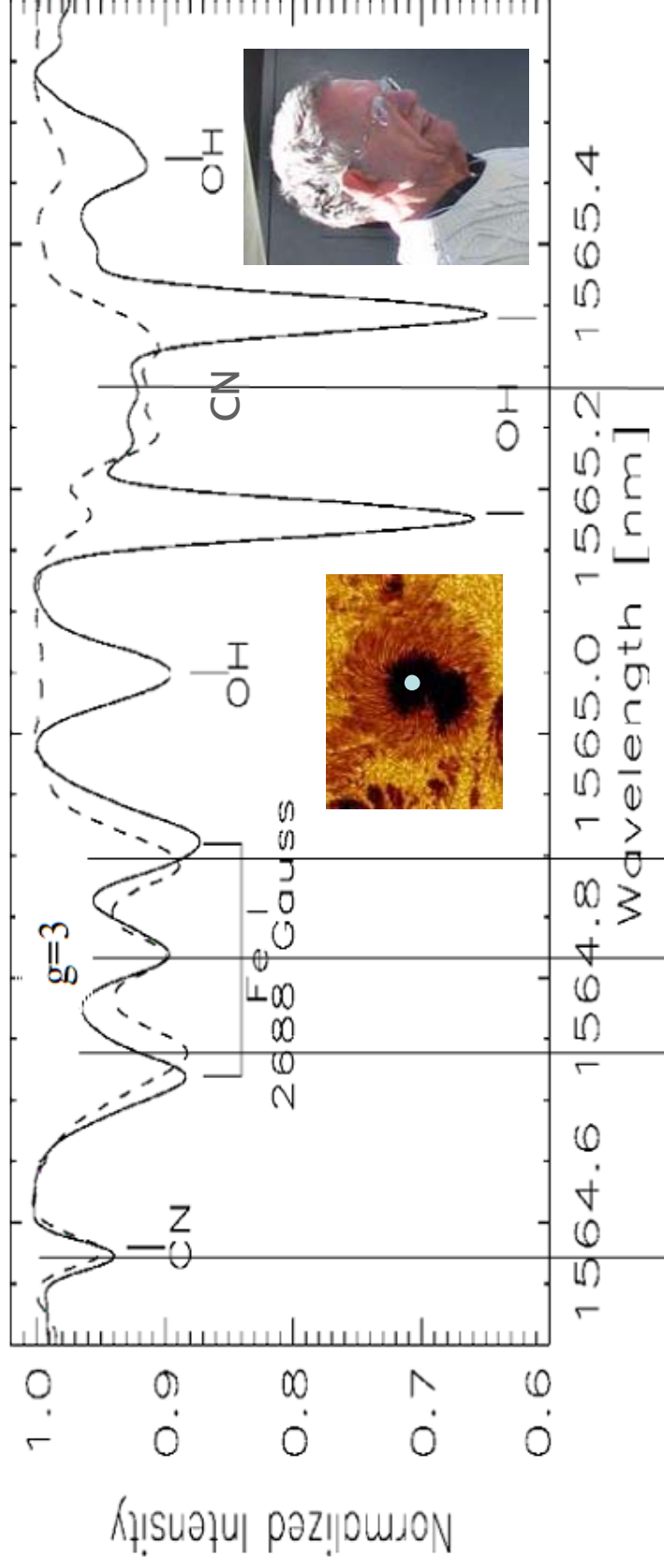


It seems that we increasingly see 'fewer spots' for the same amount of microwave flux. We can quantify that by the ratio between observed spots and expected spots from the pre-1991 relationship:



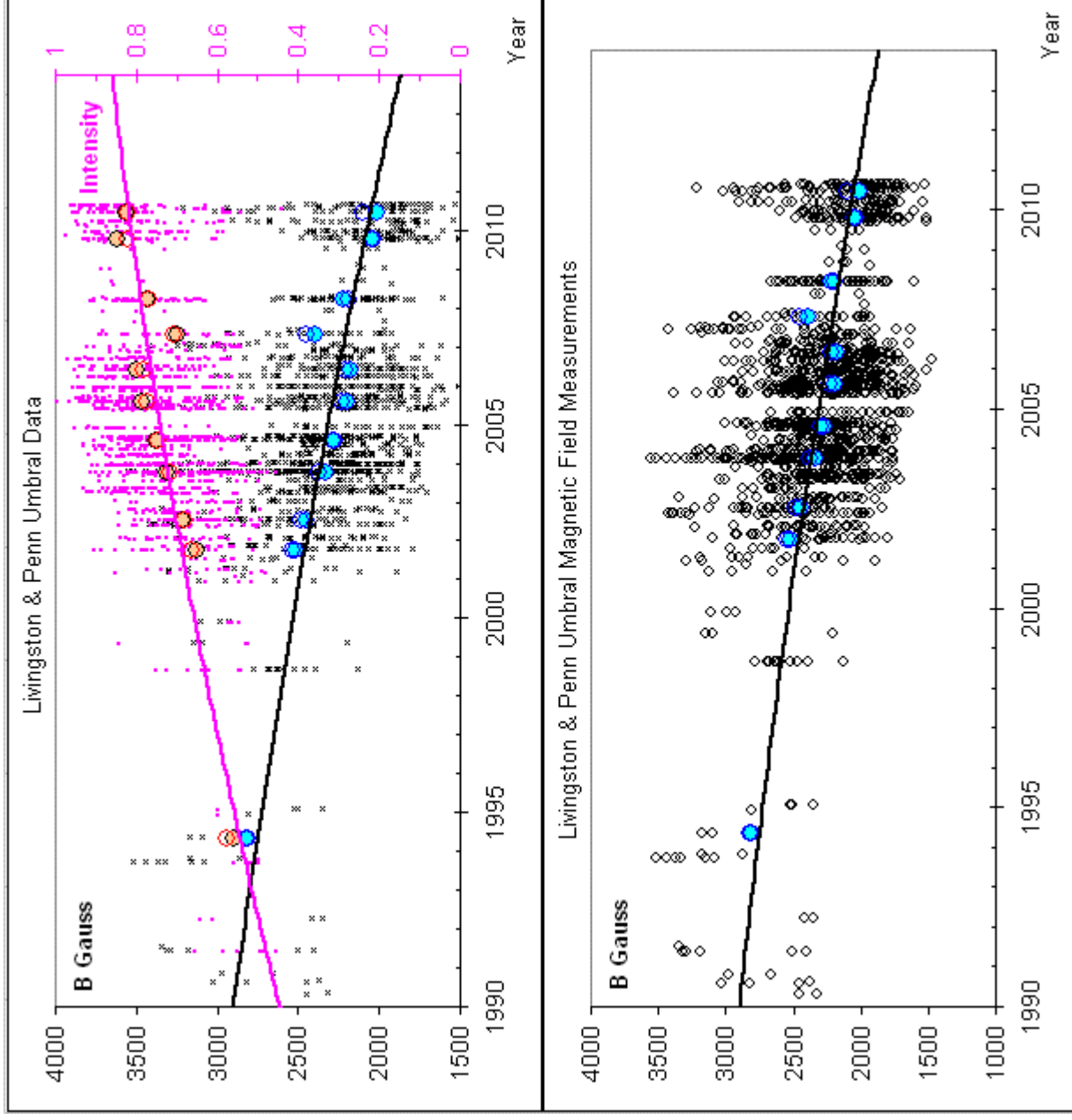
Adding 12% [assuming that SIDC has a problem from ~2001] does not materially alter this conclusion (red crosses).

The Fe I line at 1564.8 nm has a very large and easily measured Zeeman splitting. The Hydroxyl radical OH is very temperature sensitive and the lines weaken severely at higher temperatures.



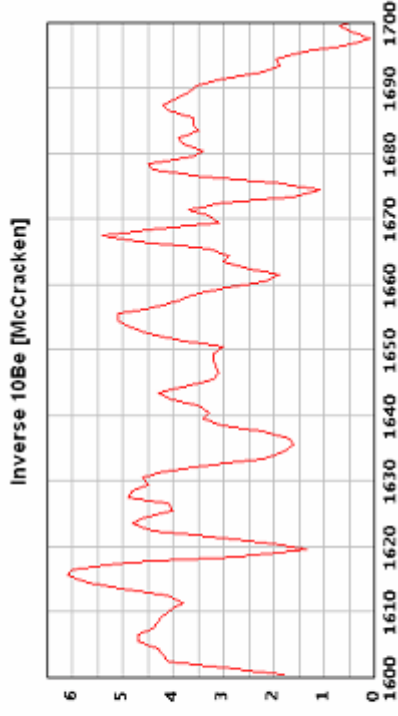
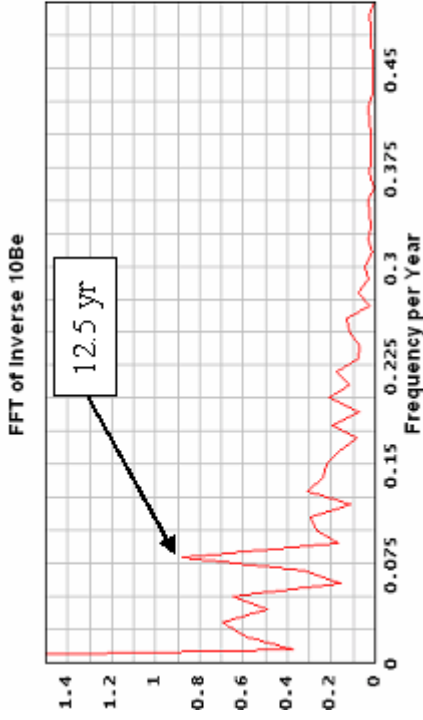
Courtesy Bill Livingston

Livingston finds that the magnetic fields of sunspots have been decreasing the past ~15 years. This means that the spots have become warmer, their contrast with the surrounding photosphere weaker making them harder to see perhaps leading to an undercount of small spots and a lower SSN.



# Was the Maunder Minimum Just an Example of a Strong L&P Effect?

Cosmic Ray proxies show that during both the Maunder Minimum and the Spörer Minimum, the modulation of cosmic rays proceeded almost as 'usual'. So the Heliosphere was not too different then from now, and perhaps the spots were there but just much harder to see because of low contrast because of  $B \approx 1500$  G.



# Conclusions

- The current sunspot number is not correctly calibrated. SIDC 'undercounts' since 2001
- Waldmeier introduced an artificial upwards jump ~1945
- The Group Sunspot Number is too low before ~1880. There is no long-term change in the SSN. No 'Modern Grand Maximum'
- Sunspots are becoming harder to see and may become effectively 'invisible' in a few years