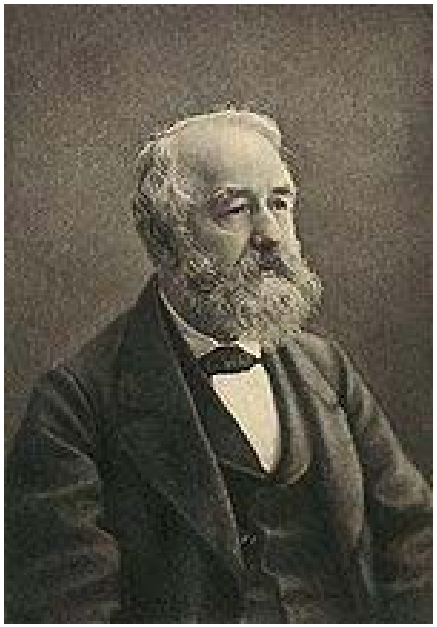
Objective Calibration of Sunspot Numbers



Rudolf Wolf, 1816-1893

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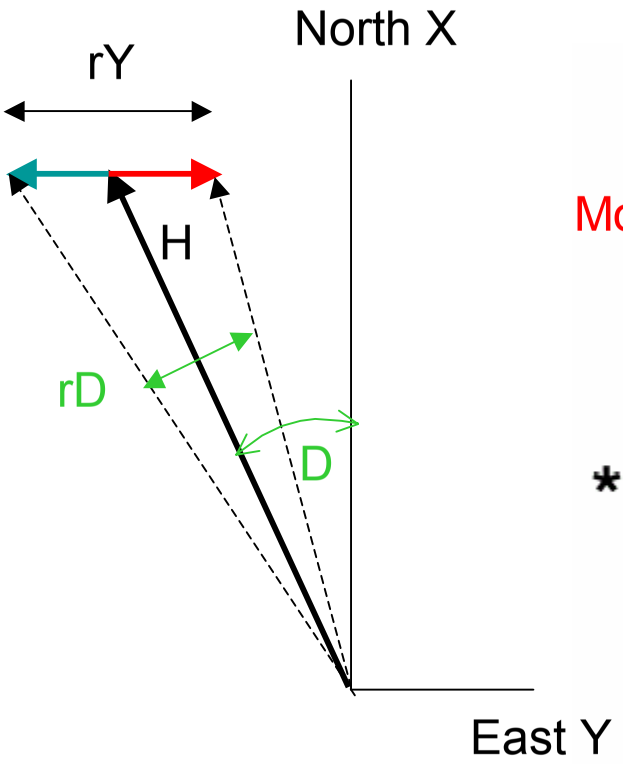
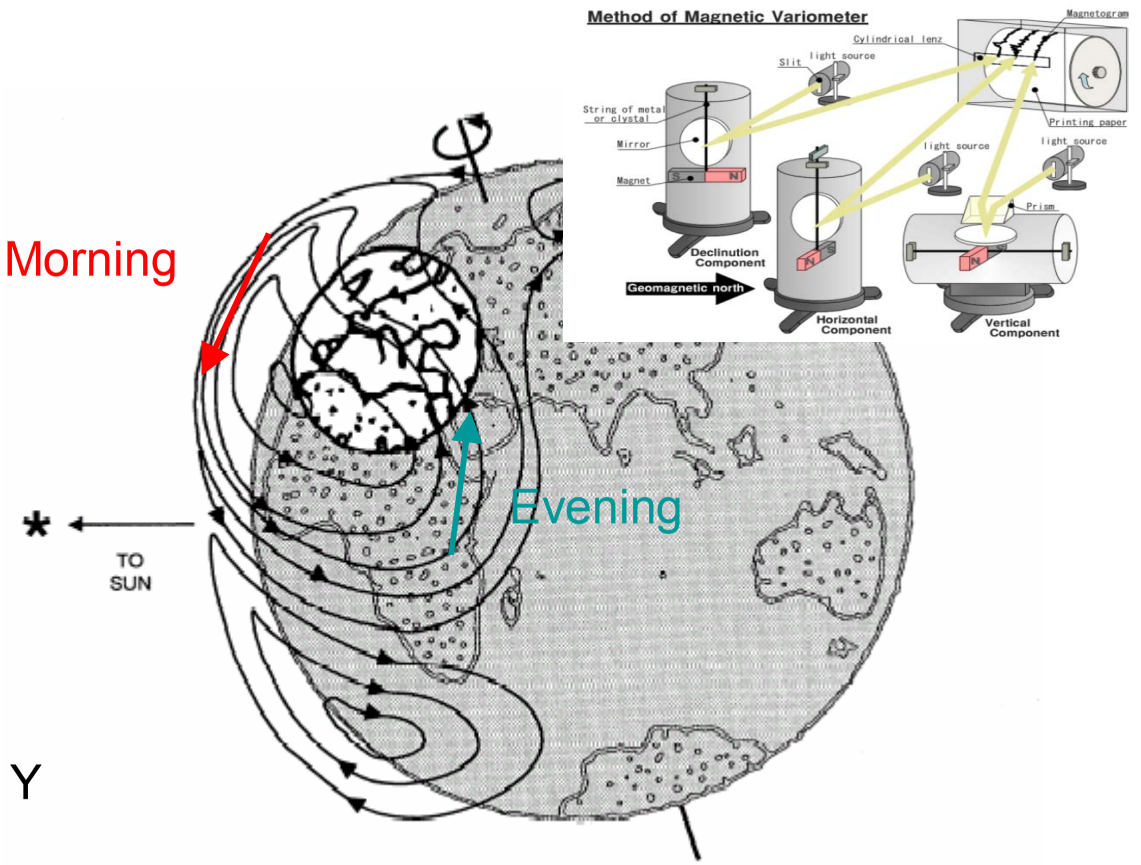
AGU Fall 2009, SH13C-03

Relative Sunspot Number
$R = k\,(10\,Groups + Spots)$

Wolf's Discovery: $rD = a + b\,R$





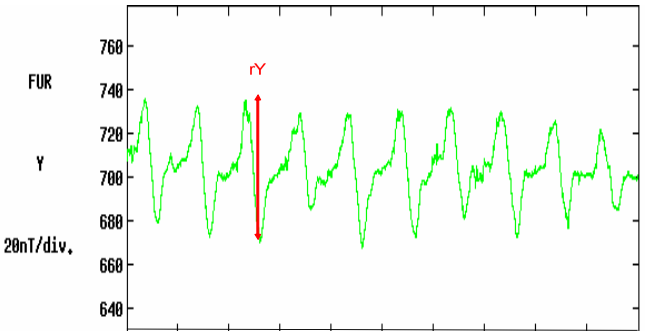
$Y = H \sin(D)$

$rY = H \cos(D)\, rD$ For small rD

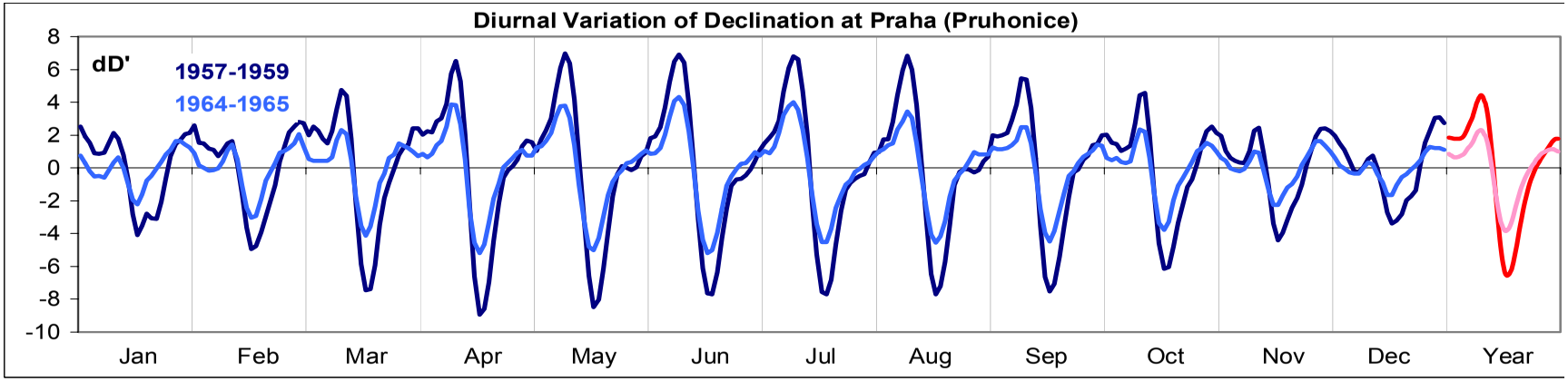
A current system in the ionosphere is created and maintained by solar FUV radiation

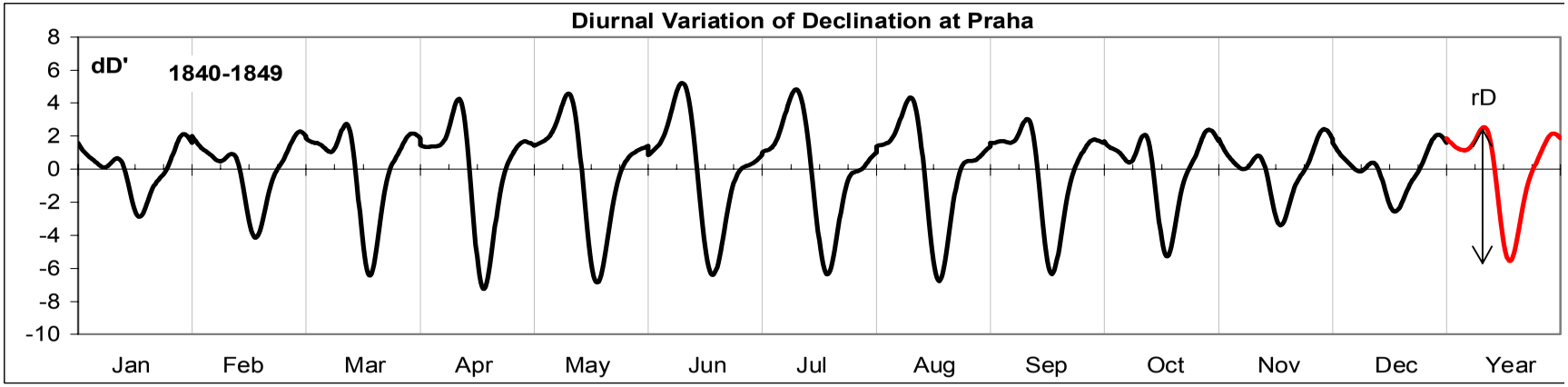
Wolf realized that this relation can be used to check the sunspot calibration

10 Days of geomagnetic variations

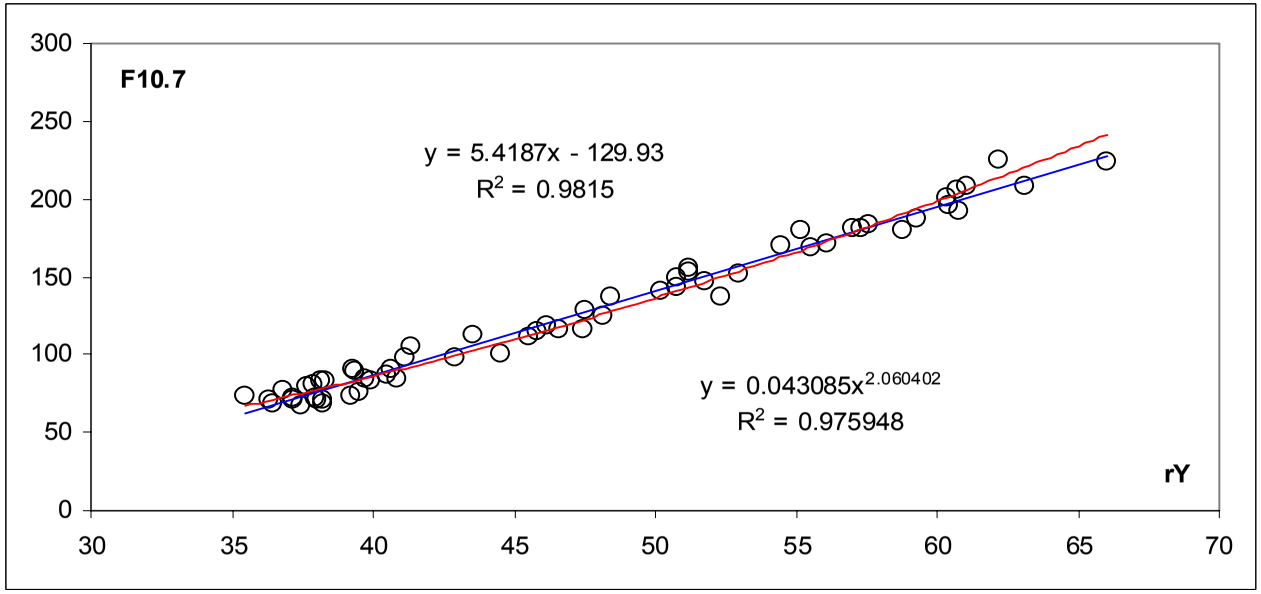


The regular diurnal variation of the ‘compass needle’

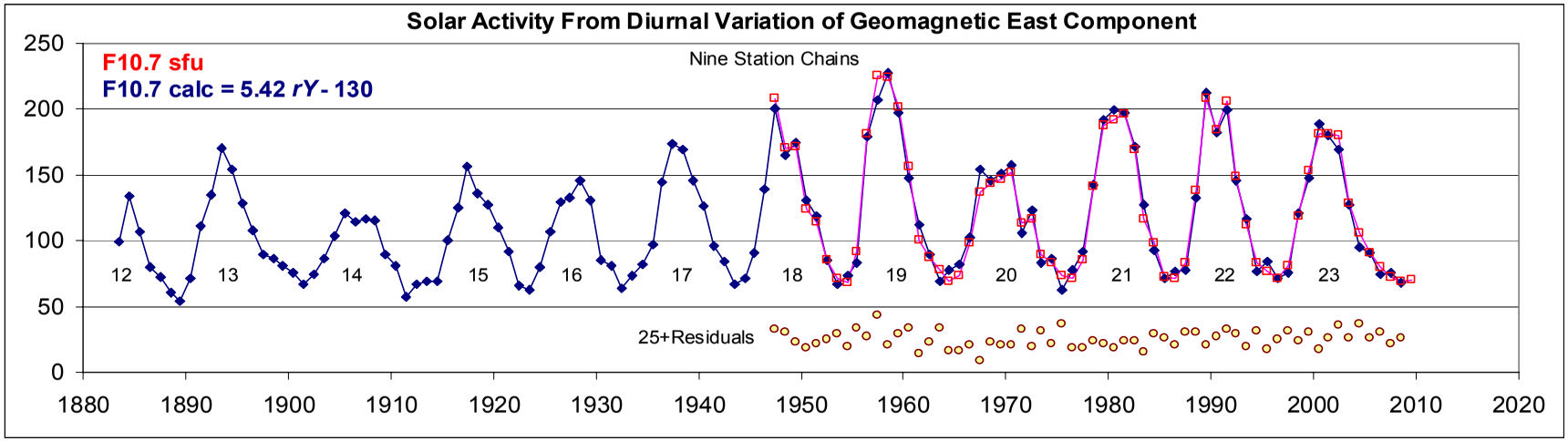




The F10.7 radio flux is a good proxy for solar UV and activity in general

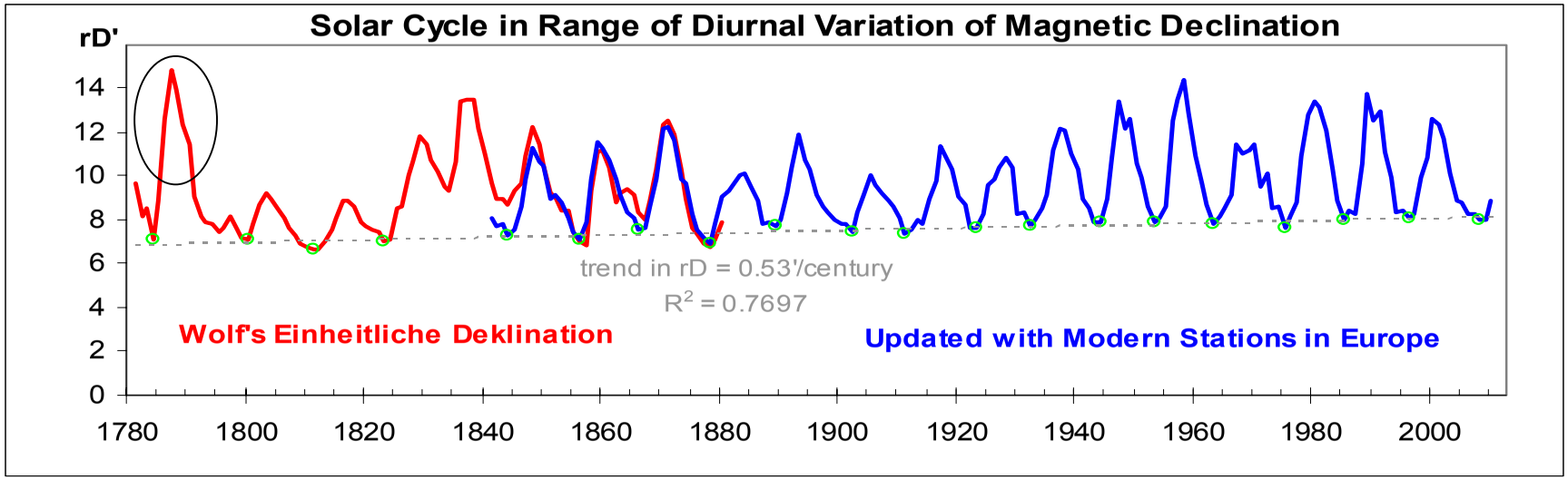


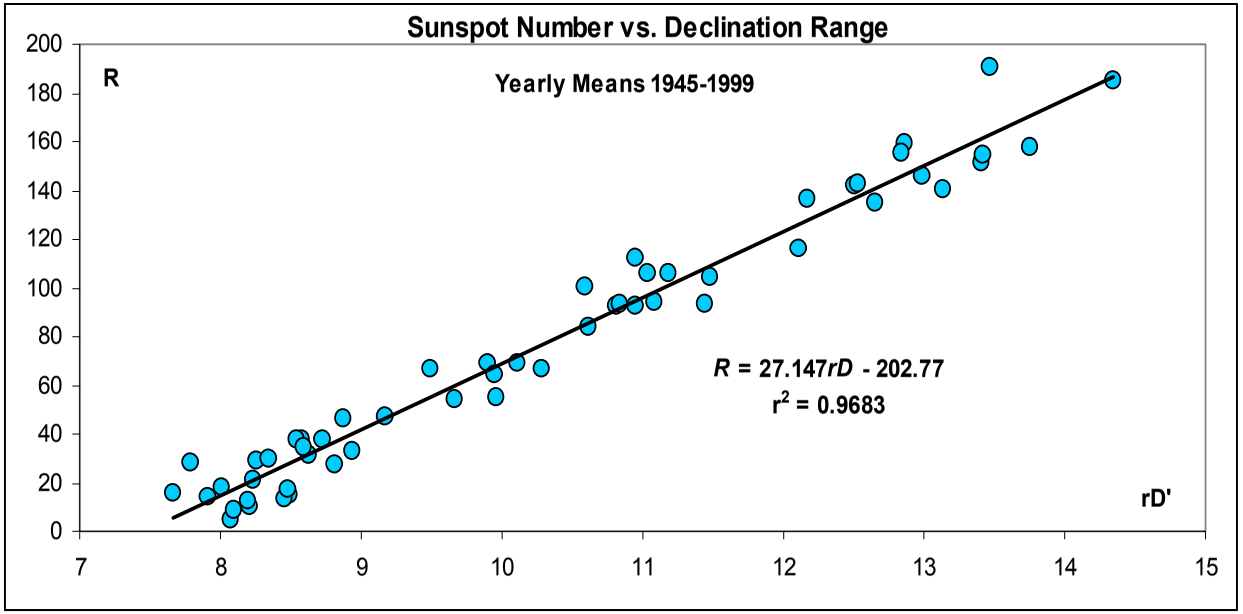
Using *rY* from nine 'chains' of stations we find that the relationship between *F10.7* and *rY* is extremely good (more than 98% of the variation is accounted for)



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

Wolf used the equivalent relation between sunspot number and magnetic declination





It makes no real difference if one uses F10.7 or the Sunspot number

Note the large range in the 1780-90s

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

Rudolf Wolf over time published several versions of his sunspot series

Compare his 1861 list with the modern official list

Rudolf Wolf's 'Relative' Sunspot Number values changed over time…

Abstract of his latest Results. By Prof. Wolf.

(*Translation communicated by Mr. Carrington.*)

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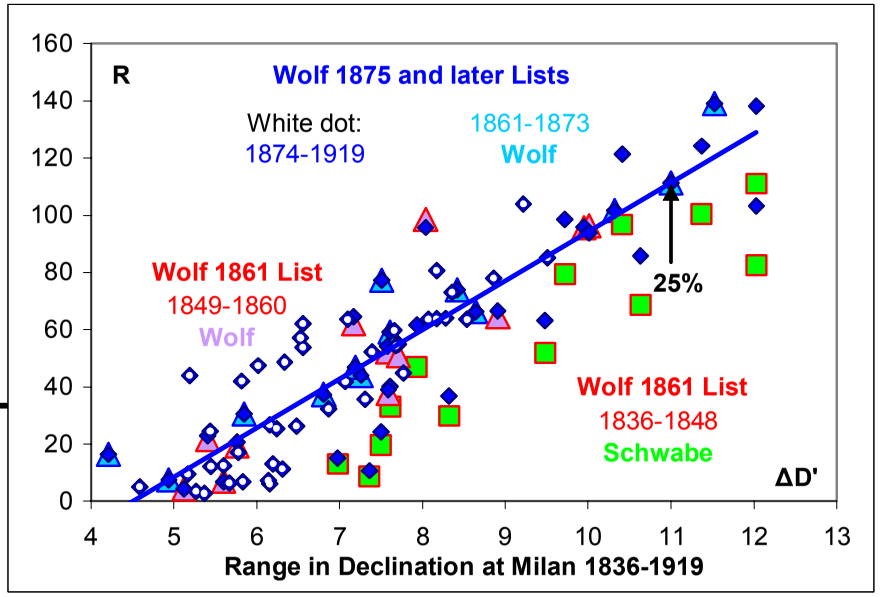
From MNRAS, 1861 and from the current dataset at SIDC in Brussels

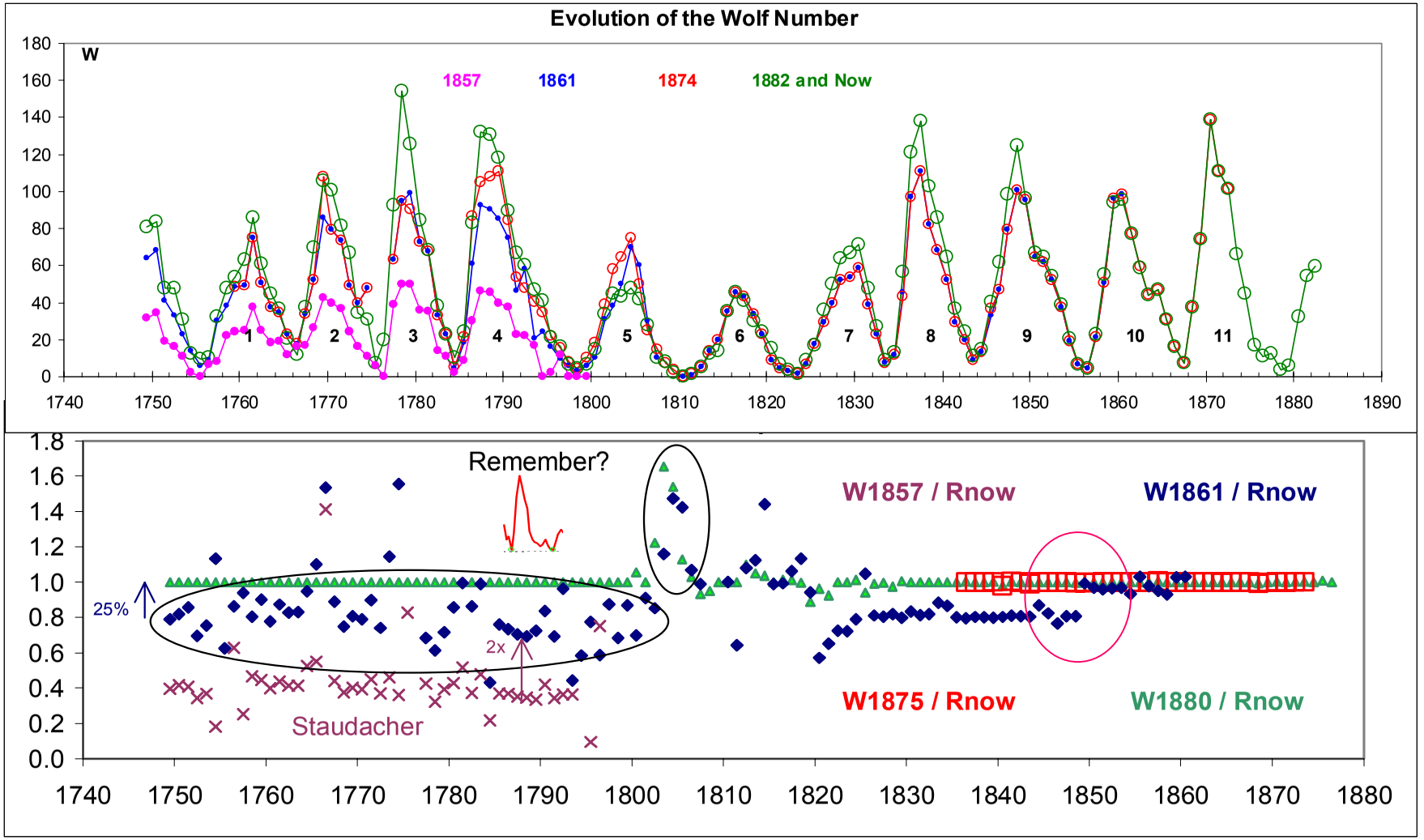
Wolf started his own observations in 1849



25% difference

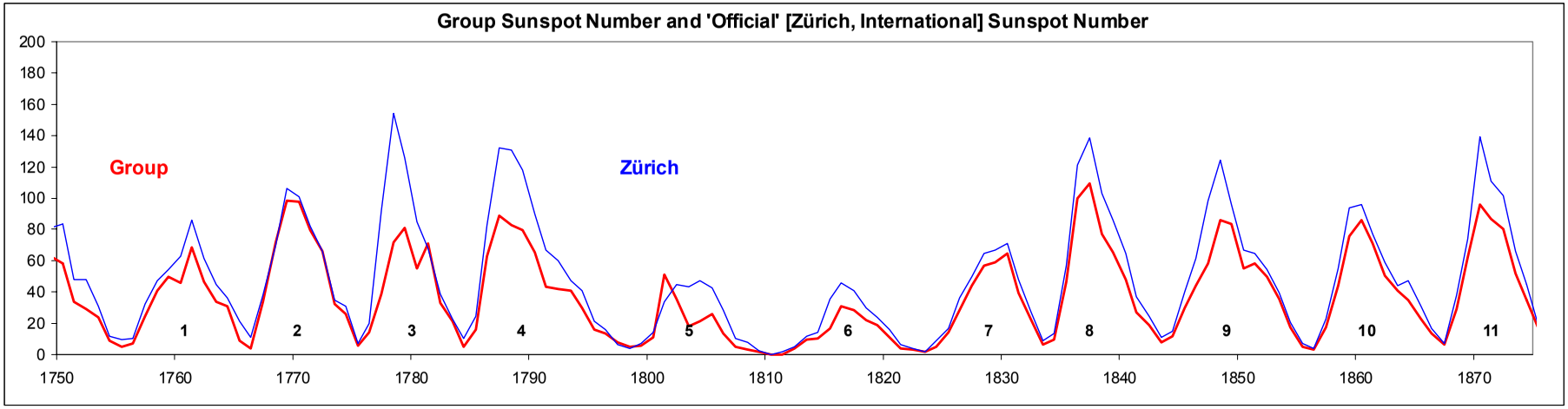
Wolf noted that the points before 1849 fell consistently below the regression line for values after that time; he therefore decided to adjust the early values upwards

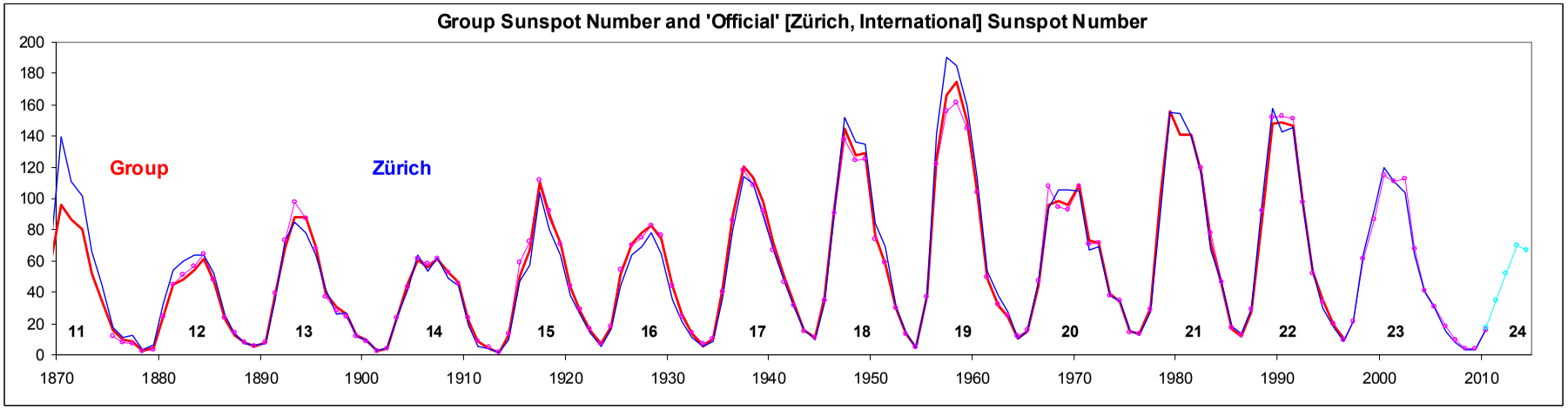
Comparing Wolf's various lists we can trace the evolution of the sunspot number calibration



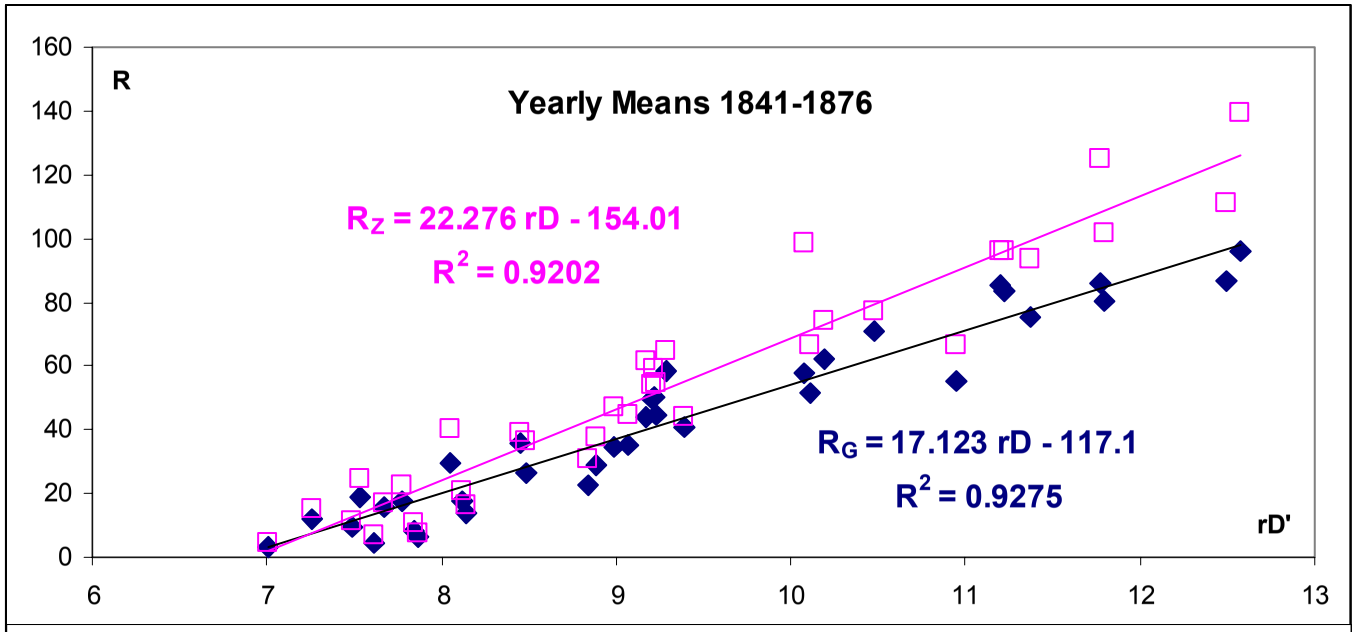
Doubling of Staudacher values. Raising all value before 1861 by 25%

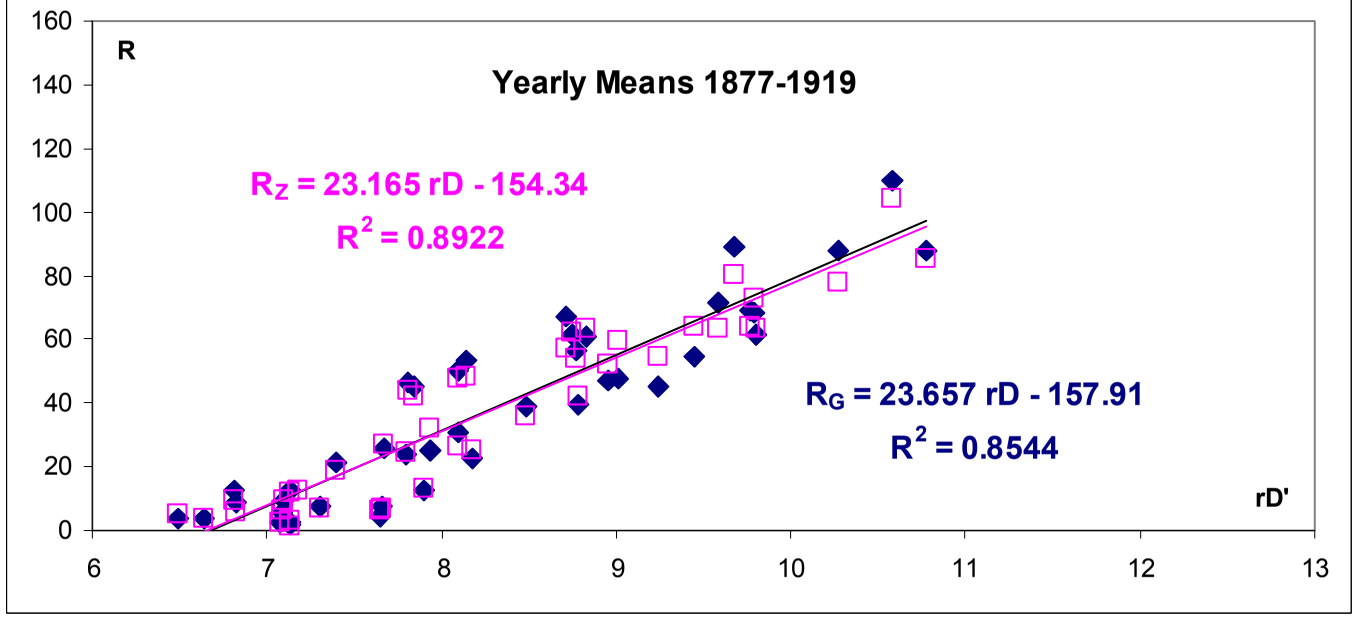
Hoyt & Schatten: Group Sunspot Number R_G = 12 *Groups*





Decent match after ~1875 [by design]. R_{Group} much lower than R_{Wolf} before that





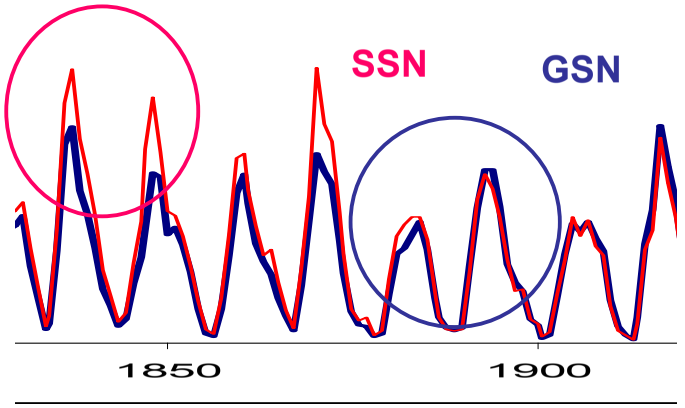
Having established that the calibration of the Wolf number is sound, we can check the Group number against the same standard and find that R_G is too low before ~1877

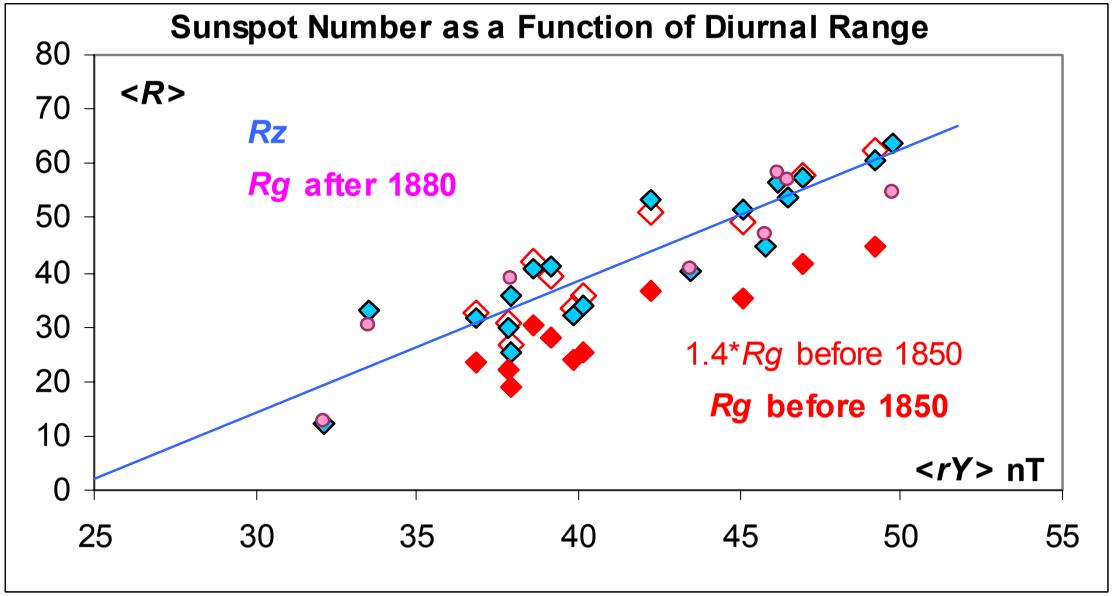
$$R_Z = 21.69 \pm 0.81) * rD - (145.0 \pm 7.2)$$

$$rD = (6.45 \pm 0.32) + (0.046 \pm 0.002) * R_Z$$

Resolving Difference Between H&S GSN and Wolf SSN

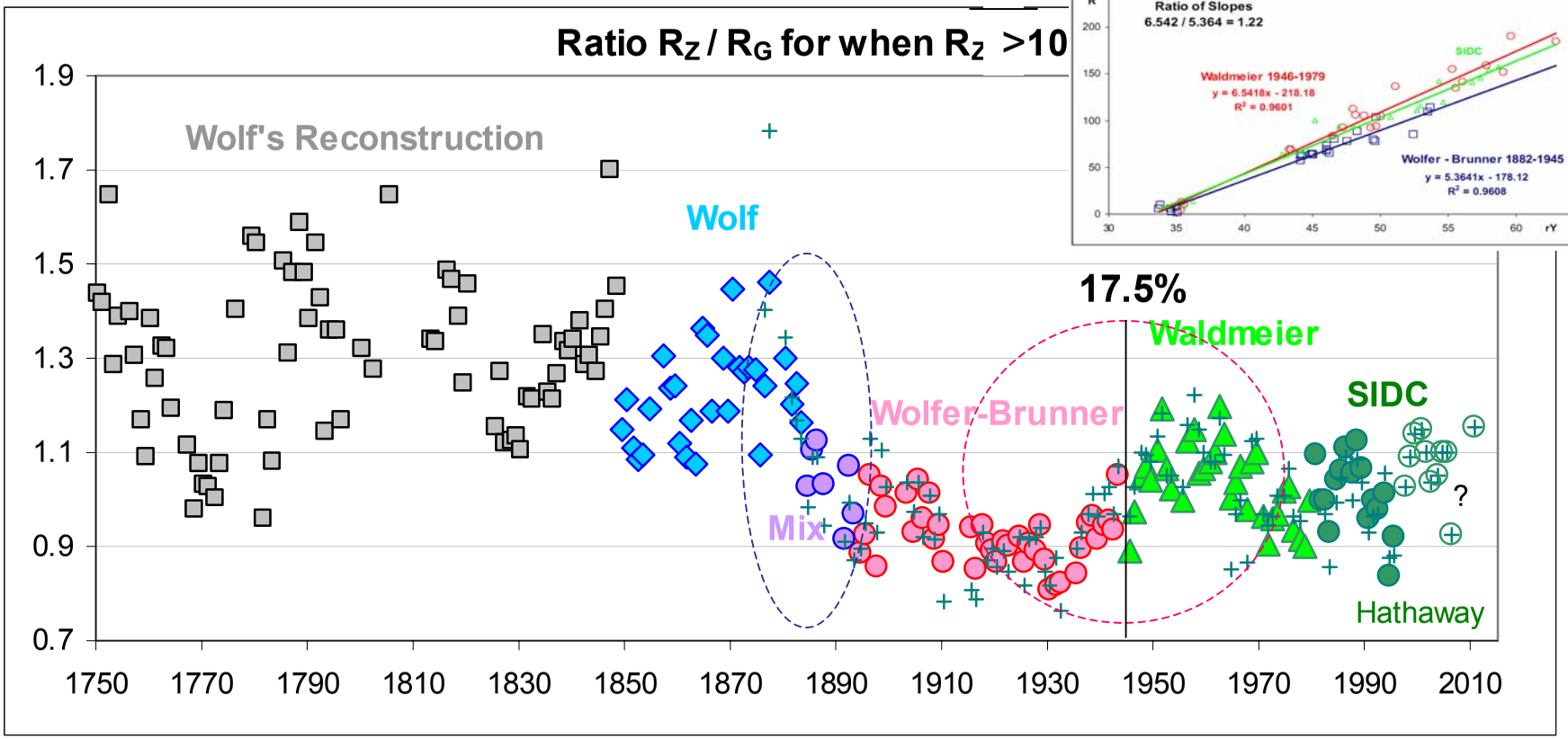
obs	name	lat	long	interval
WDC	Washington D.C.	38.9	283.0	1840-1842
DUB	Dublin	53.4	353.7	1840-1843
MNH	Munchen	48.2	11.6	1841-1842
PGC	Philadelphia	40.0	284.8	1840-1845
SPE	St. Peterburg	60.0	30.3	1841-1845
GRW	Greenwich	51.5	0.0	1841-1847
PRA	Praha	50.1	14.4	1840-1849
HBT	Hobarton	-42.9	147.5	1841-1848
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*





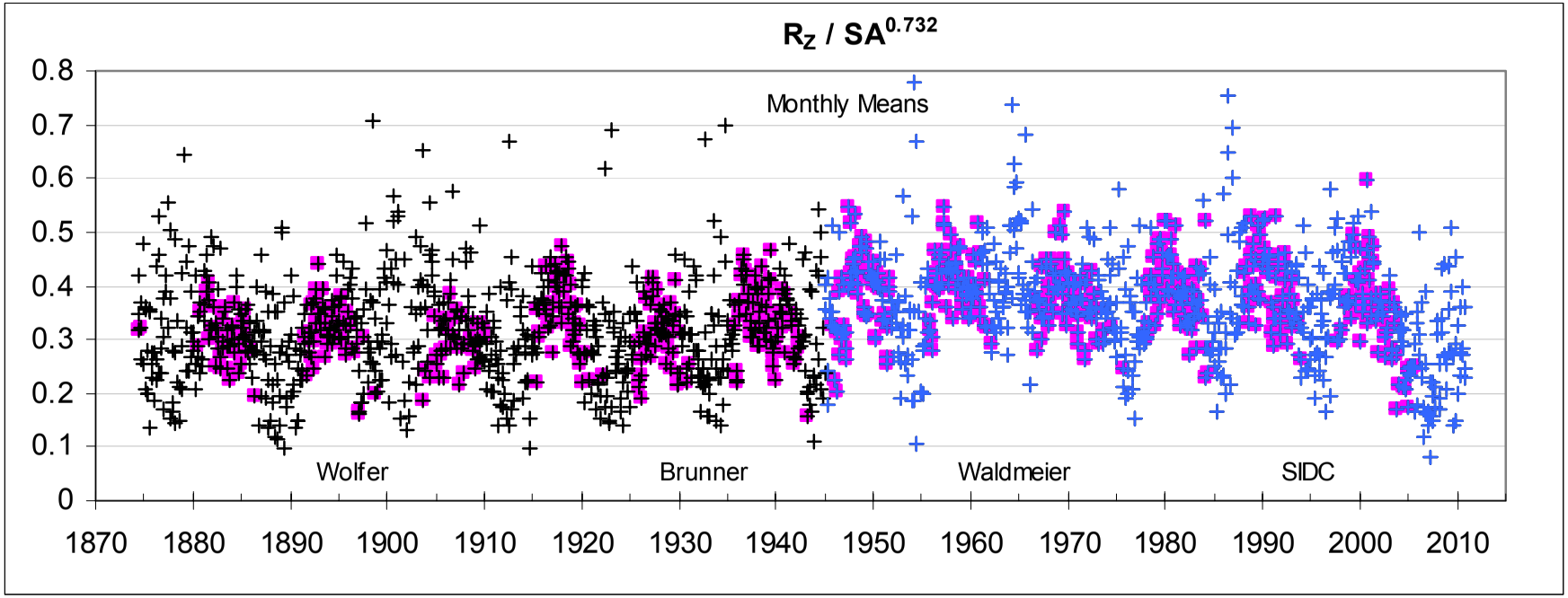
Multiplying GSN [Rg] by a factor 1.4 brings them up into good conformance with the SSN [Rz], open red diamonds

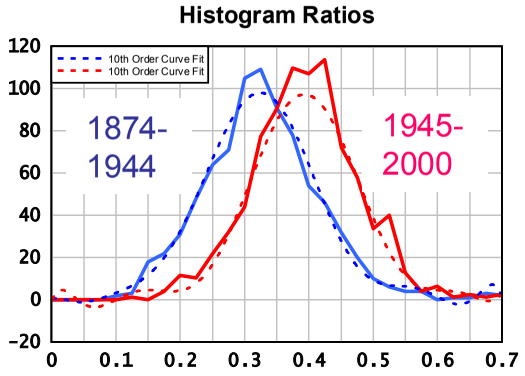
We can quantify the difference between R_Z and R_G for the different observers



We now see clearly the factor 1.4 before ~1875. But there is another jump ~1945 when Max Waldmeier took over: the numbers since then are ~20% higher than the Wolfer-Brunner standard [pink]. R_z vs. *rD* also shows this.

The *ratio* between the Zürich sunspot number and the sunspot area (Balmaceda et al.) also clearly shows this 'Waldmeier' discontinuity:





The jump in R_Z is 21% in 1945 and was maintained by SIDC when they took over as they relied on the Swiss station Locarno as their reference observer. Lately, the influence of Locarno is diminishing because of the large number of contributing stations

The pre-Waldmeier observers carefully documented the group count and spot count separately. This was lost with Waldmeier.

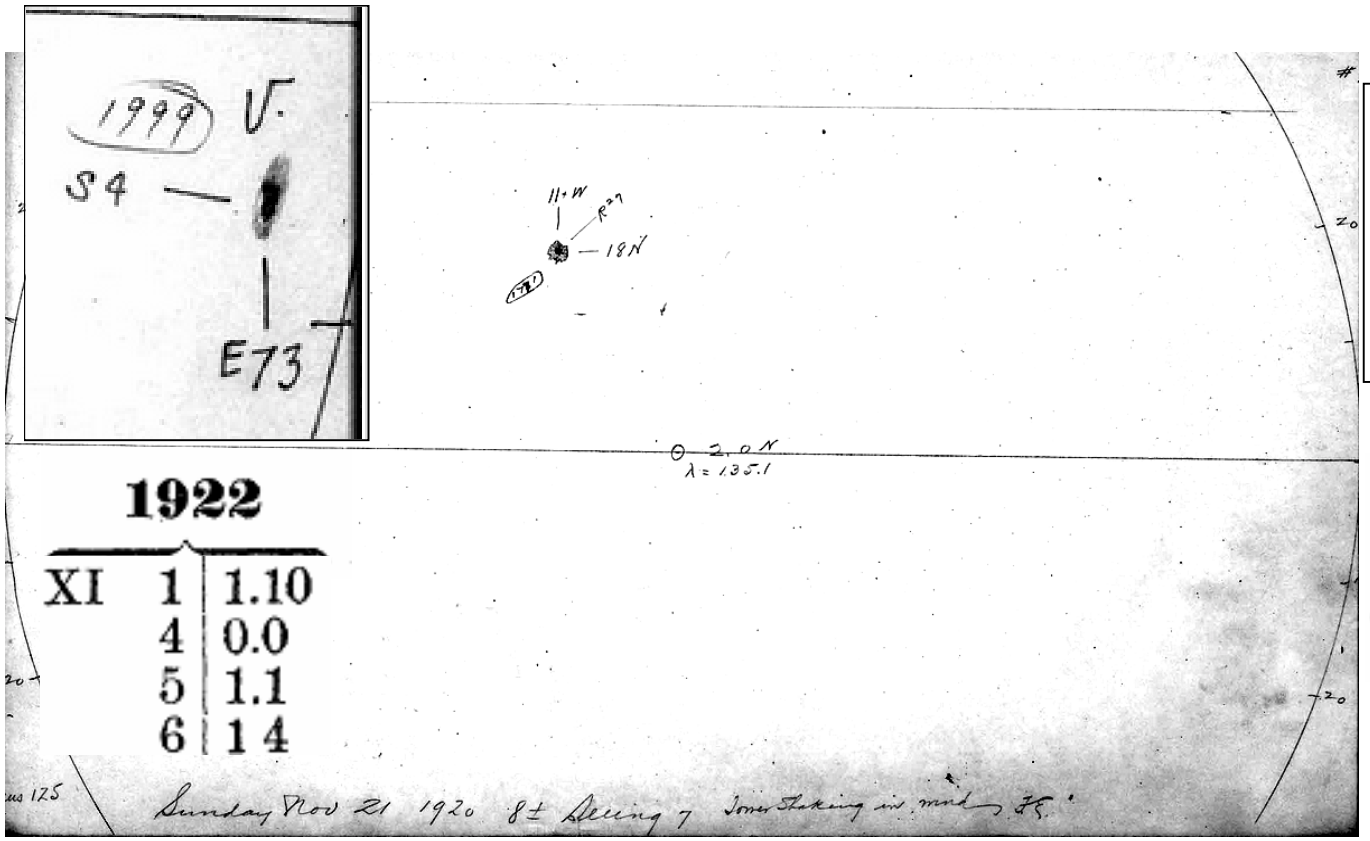
685) Rudolf Wolf, Beobachtungen der Sonnenflecken auf der Sternwarte in Zürich im Jahre 1893. (Forts. zu 664).

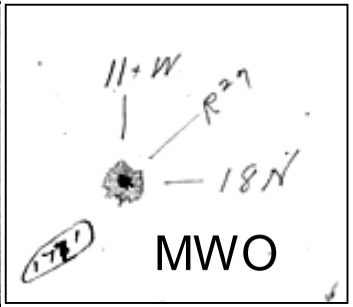
1893			1893			1893			1893			1893		
I	1	7.10	II	23	3.12	III	31	2.8	V	6	5.8	VI	13	4.8
–	2	5.8	–	24	3.10	IV	1	3.12	–	7	5.12	–	14	4.10
–	5	5.8	–	25	4.14	–	2	3.12	–	8	5.12	–	15	3.8
–	9	2.2	–	26	4.14	–	3	4.10	–	9	5.8	–	16	5.16
–	11	2.4	–	27	4.10	–	4	3.4	–	10	6.8	–	17	5.14
–	12	2.4	III	1	5.14	–	5	3.4	–	11	4.6	–	18	2.4
–	6	9.28	–	24	8.14	–	12	3.8	–	8	4.6	X	28	6.12
–	7	11.36	–	25	5.8	–	13	4.8	–	9	4.10	–	29	4.8
–	8	12.30	–	26	4.8	–	14	4.6	–	10	4.10	–	30	3.4
–	9	11.24	–	27	3.6	–	15	4.6	–	11	4.6	–	31	2.4
–	10	11.26	–	28	3.8	–	18	2.4	–	12	4.8	–		

G.S

Wolf's last observation R=2*10+4=24

Wolf, Wolfer, and Brunner counted single spots as one, regardless of size





1920

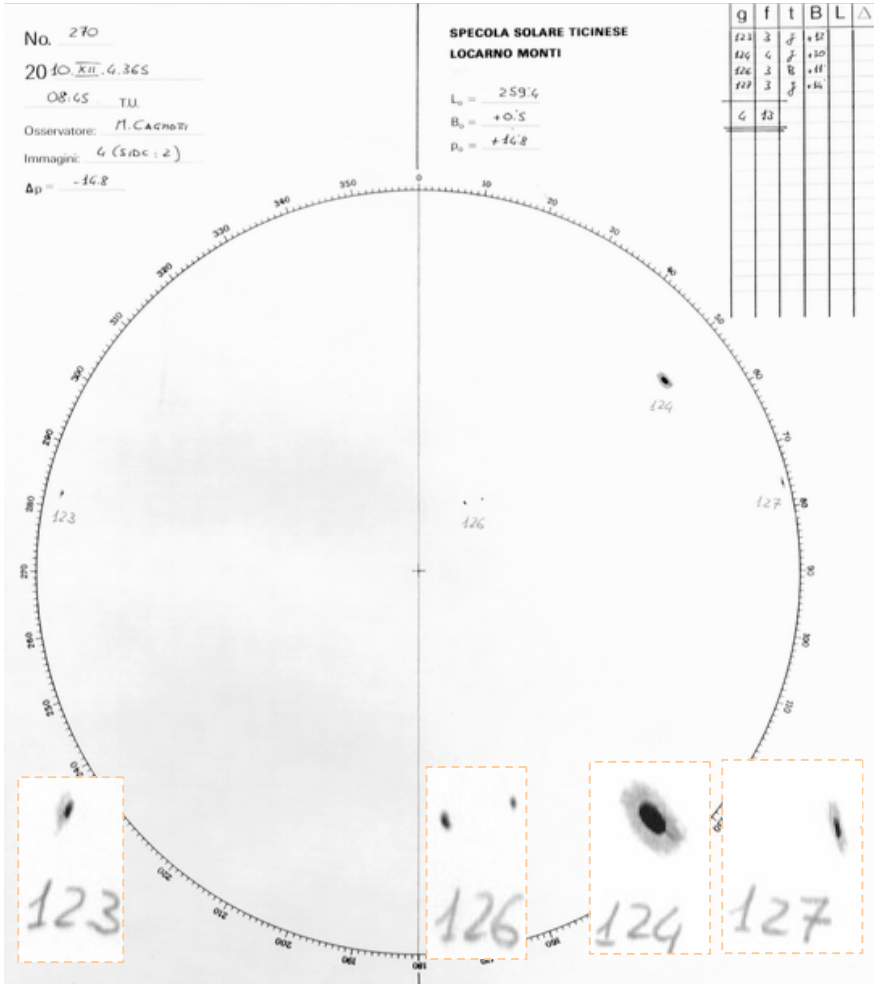
XI	21	1.1

G.S

Wolfer

The large spot on 1920, Nov. 21 was counted as one spot by A. Wolfer

But Locarno counts larger spots with a higher weight



g	f	t	B	L	Wolfer, Brunner
123	3	J	+12°		1
124	4	J	+30°		1
126	3	B	+11°		2
127	3	J	+14°		1
4	13			4	5
	53	53/45 = 1.18			**45**

This increases the sunspot number

After more than 20 years, Waldmeier reveals that he introduced a weighting scheme according to size

Astronomische Mitteilungen der Eidgenössischen Sternwarte Zürich
Nr. 285

1968

Die Beziehung zwischen der Sonnenflecken-relativzahl und der Gruppenzahl

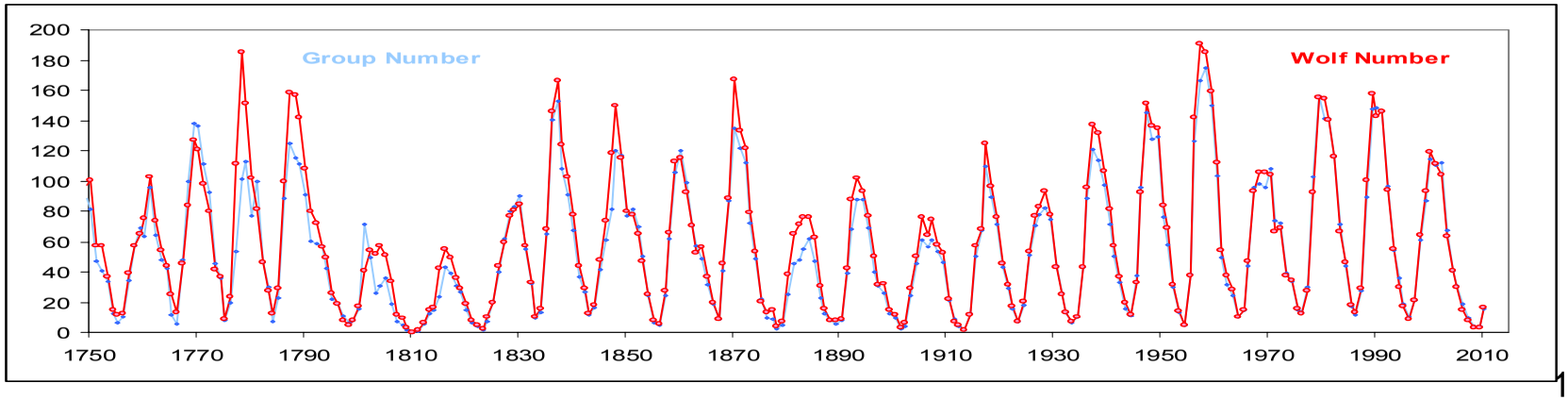
Von
M. Waldmeier

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. Die Gruppen- und Fleckenzahlen nach der neuen Zählart seien g und f.

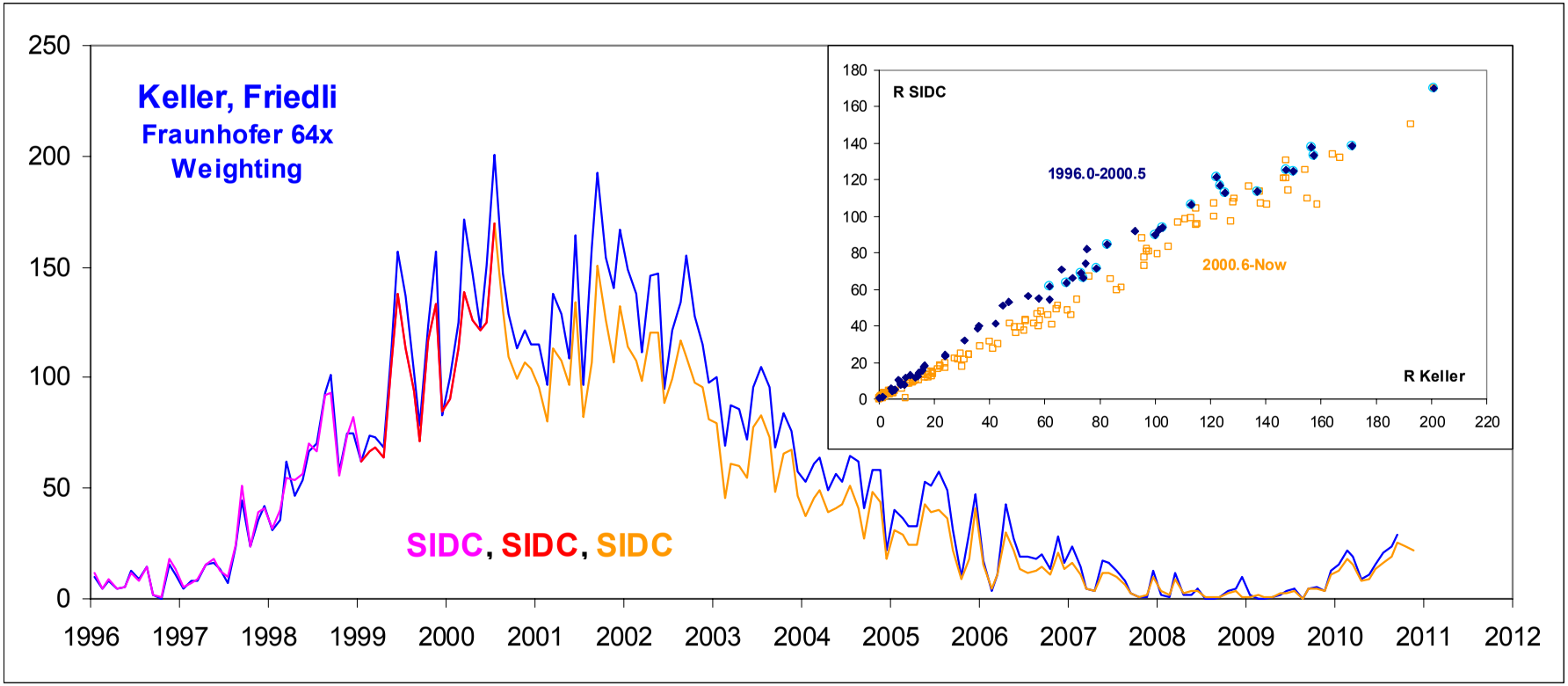
Later the spots were weighted according to size: A pore was counted as one, a larger spot but still without penumbra got a statistical weight of 2, a small group-forming spot one of 3, and a larger of 5.

Conclusions

- It is possible to calibrate the sunspot number using the diurnal variation of the geomagnetic field [as Wolf did himself]
- The group sunspot number should be increased by 40% before ~1875
- The Zurich sunspot number should be increased by 20% before 1945
- There has been no particularly Grand Maximum



Comparison between SIDC and Keller/Friedli [with Wolf telescope]



The original telescope used by Wolf is still in use

The 80/1100 mm Fraunhofer Refractor (64x) used by Wolf, Wolfer, Brunner, Waldmeier, Keller, and (now) Friedli

The sunspot-activity in the years 1976 - 1995.
Keller, H. U.; Friedli, T. K.
Mitt. Rudolf Wolf Ges., Jahrg. 3, Nr. 7, p. 1 - 46
The paper contains the last twenty years of sunspot relative and group numbers as observed by the standard observers M. Waldmeier, A. Zelenka and H. U. Keller in Zurich. Starting with January 1996 a new series of sunspot countings called Swiss Wolf Numbers RS will be initiated using standard observations made by T. K. Friedli at the original Fraunhofer Refractor used by Wolf and an international network of professional and amateur astronomers.

Die Sonnenfleckenaktivität 1993.
Keller, H. U.,
Mitt. Rudolf Wolf Ges., Jahrg. 2, Nr. 4, p. 3 - 13
[…] In autumn 1993 a new series of sunspot counts with Wolf's portable telescopes has been commenced, aiming to verify the historical reduction factors k of these instruments compared with today's counting mode at the standard Fraunhofer telescope.