Calibration of Sunspot Numbers, II

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

<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.

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

## Die Beziehung zwischen der Sonnenflecken- relativzahl und der Gruppenzahl

Von

M. WALDMEIER

Hofflecken handelte. Später wurden den Flecken entsprechend ihrer Größe Gewichte erteilt: Ein punktförmiger Fleck wird einfach gezählt, ein größe- rer, 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 abgeleite-

Can we see this in the Historical Record?
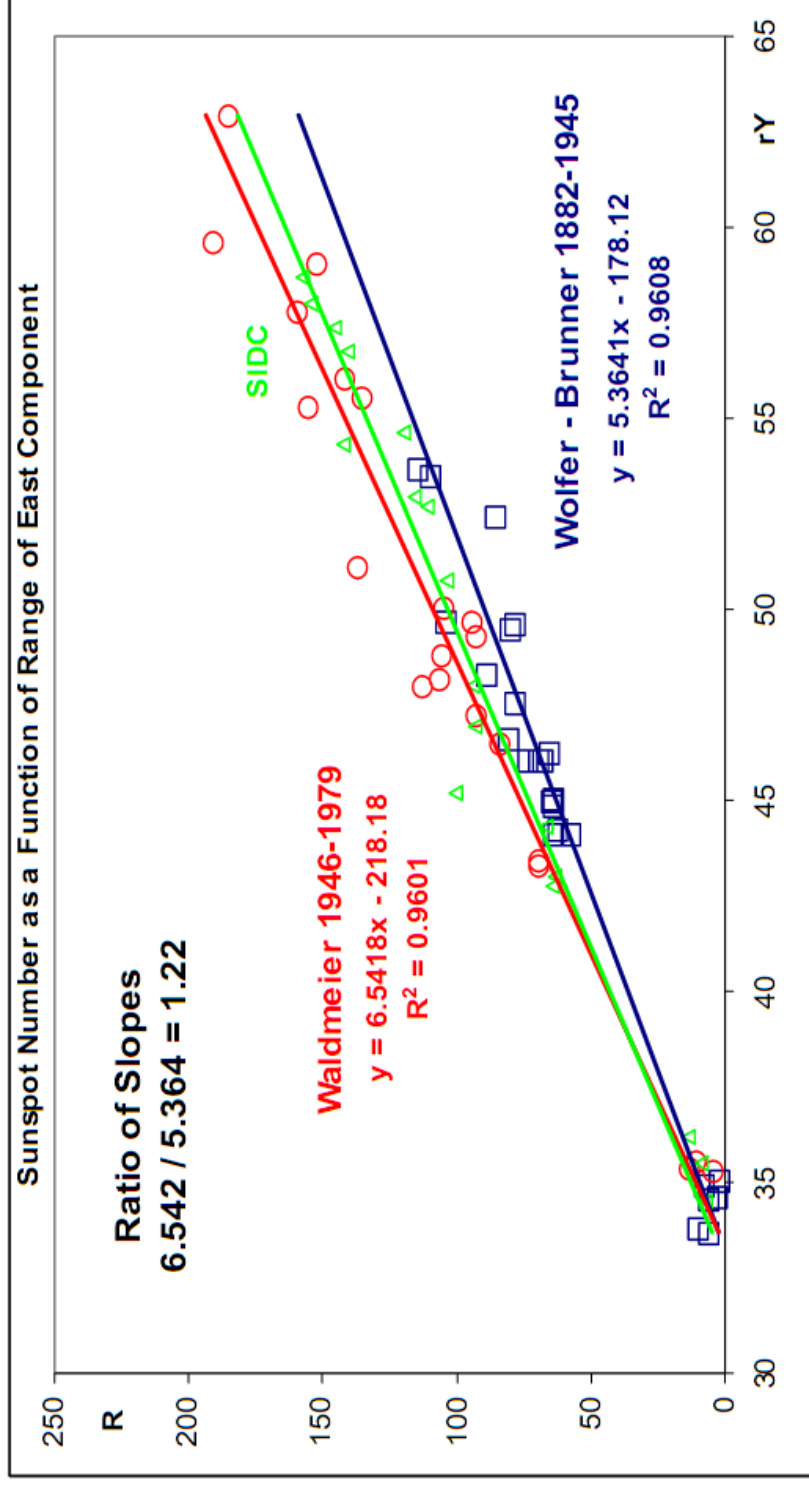
Wolf's Discovery: $rD = a + b\, R_W$

North X

Evening

Morning

TO SUN

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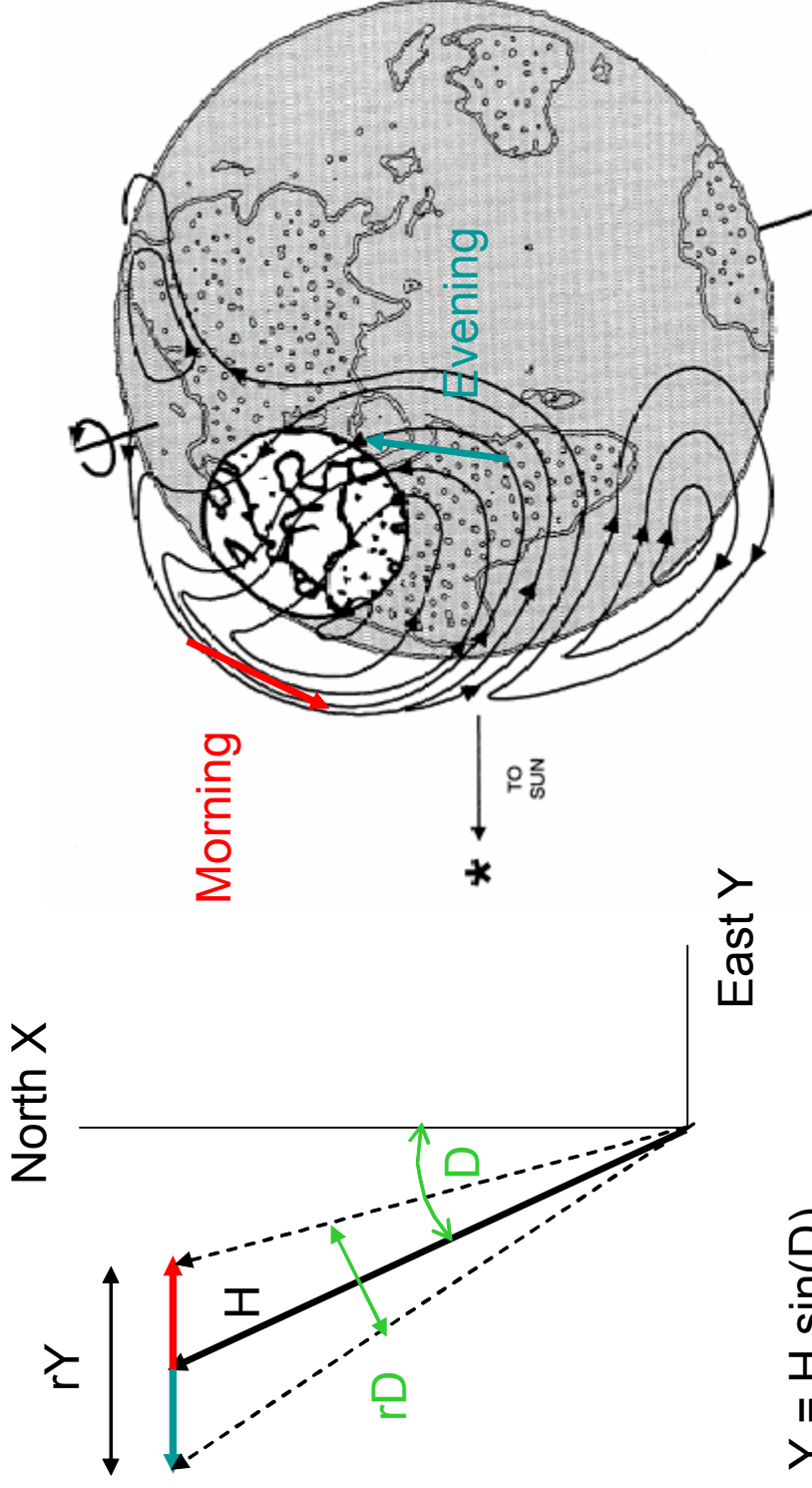
$Y = H \sin(D)$

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

rD

D

H

rY

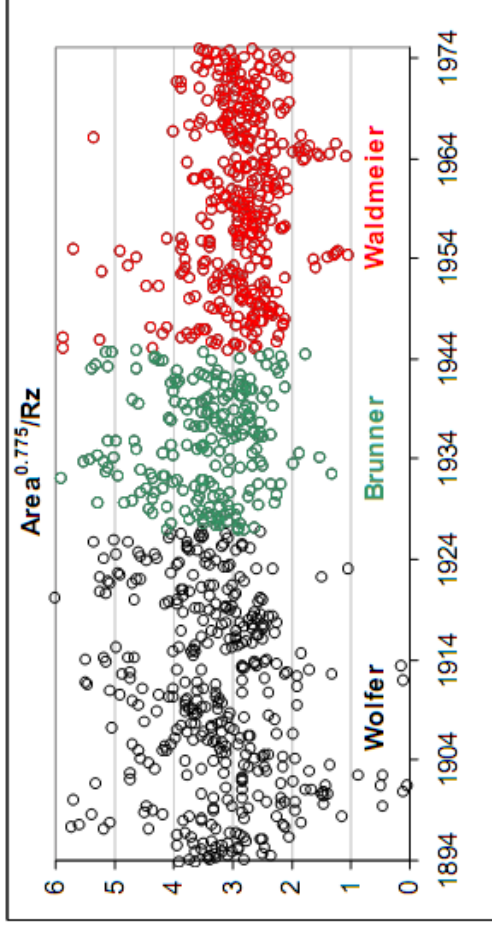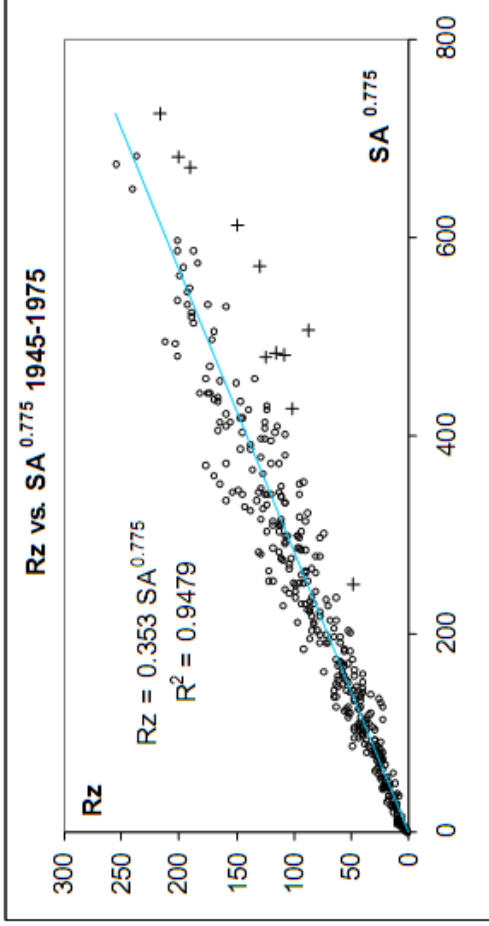A current system in the ionosphere is created and maintained by solar FUV radiation

Wolf realized that this relation can be used to check the sunspot calibration
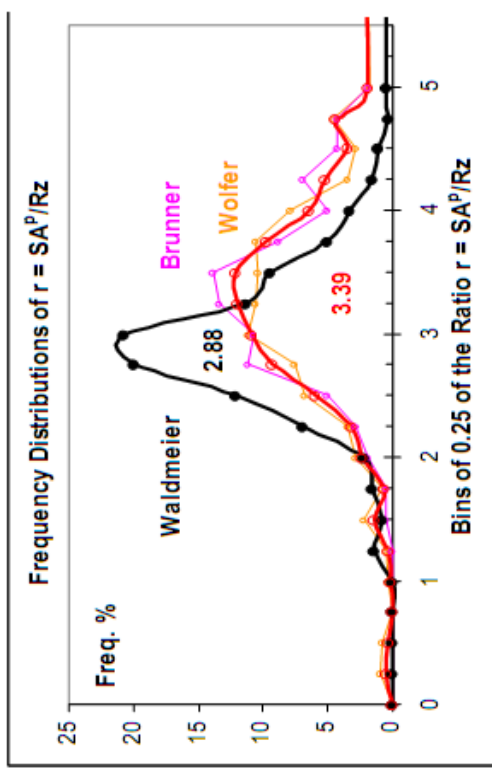
The Waldmeier Discontinuity, I

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

Sunspot Number as a Function of Range of East Component

Ratio of Slopes
6.542 / 5.364 = 1.22

Waldmeier 1946-1979
y = 6.5418x - 218.18
$R^2 = 0.9601$

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Wolfer - Brunner 1882-1945
y = 5.3641x - 178.12
$R^2 = 0.9608$

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 $3.39/2.88 = 17.5\%$

Rz vs. $SA^{0.775}$ 1945-1975

$Rz = 0.353\ SA^{0.775}$
$R^2 = 0.9479$

Frequency Distributions of $r = SA^p/Rz$

Waldmeier 2.88
Brunner
Wolfer
3.39

Bins of 0.25 of the Ratio $r = SA^p/Rz$

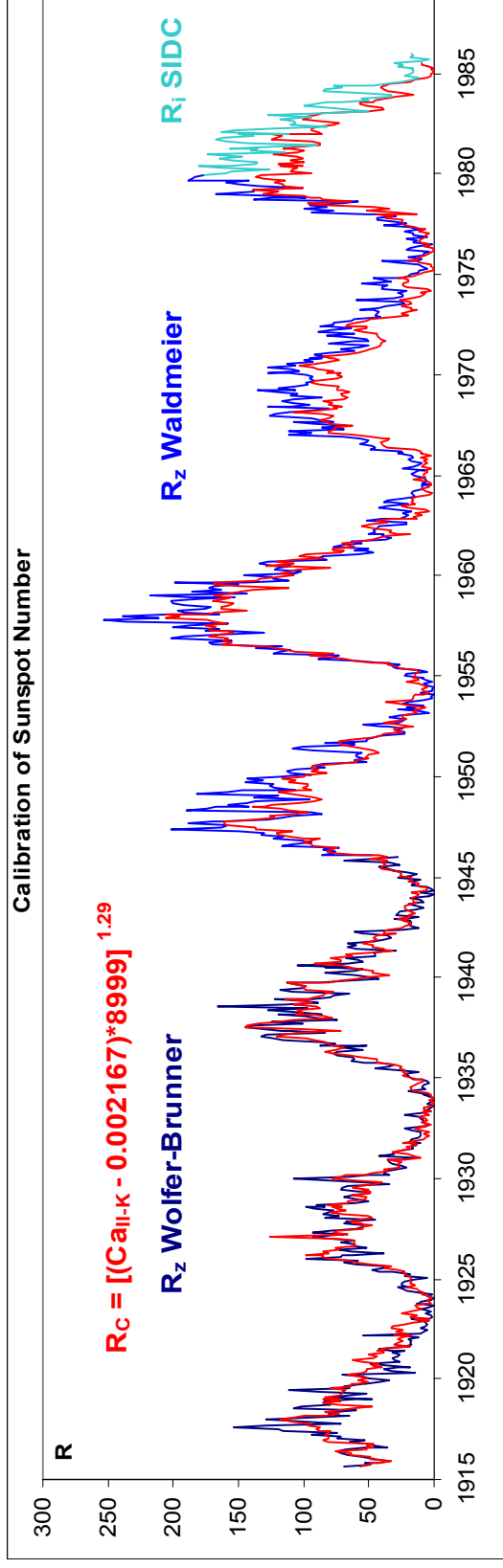$Area^{0.775}/Rz$

Wolfer   Brunner   Waldmeier

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.

Calibration of Sunspot Number

$$R_C = [(Ca_{II-K} - 0.002167)*8999]^{1.29}$$

R_z Wolfer-Brunner

R_z Waldmeier

R_i SIDC

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.
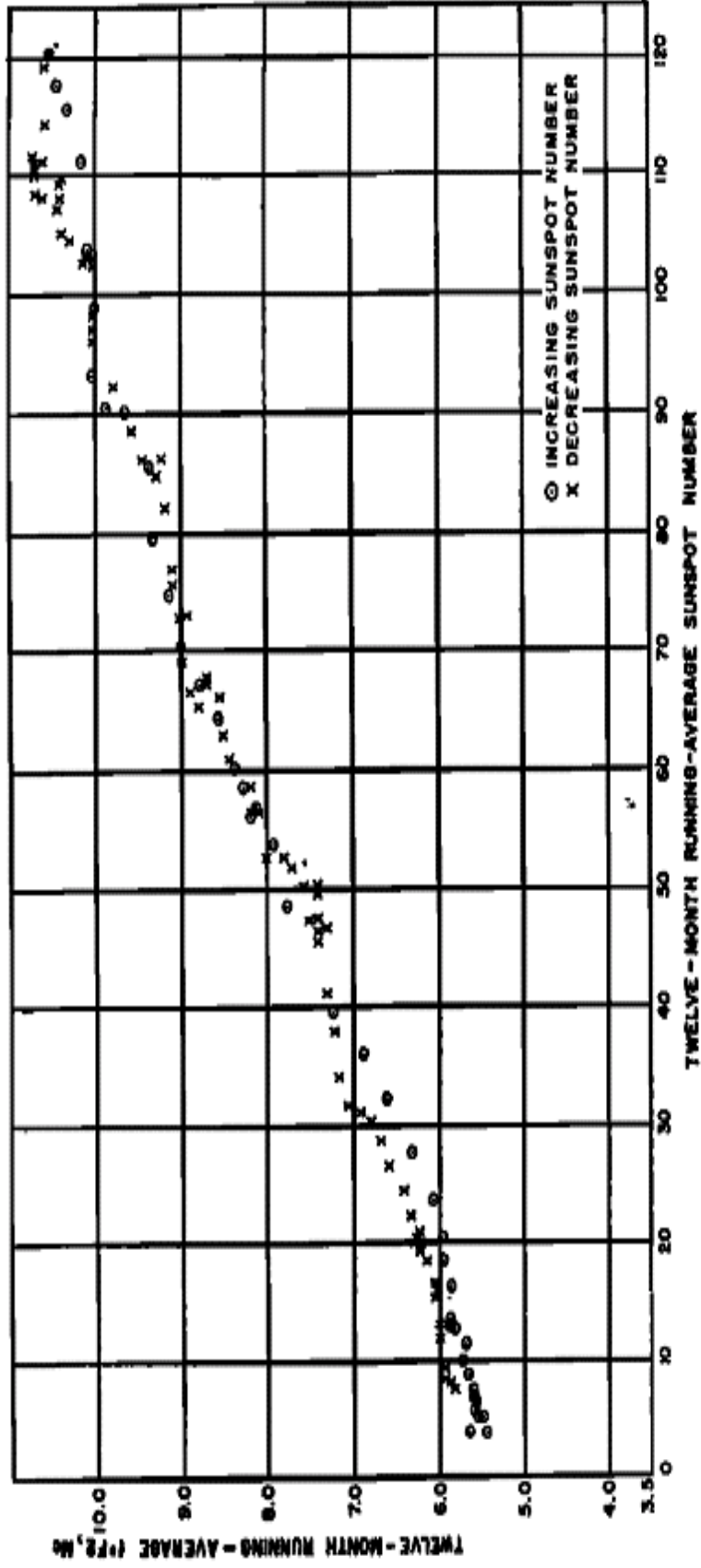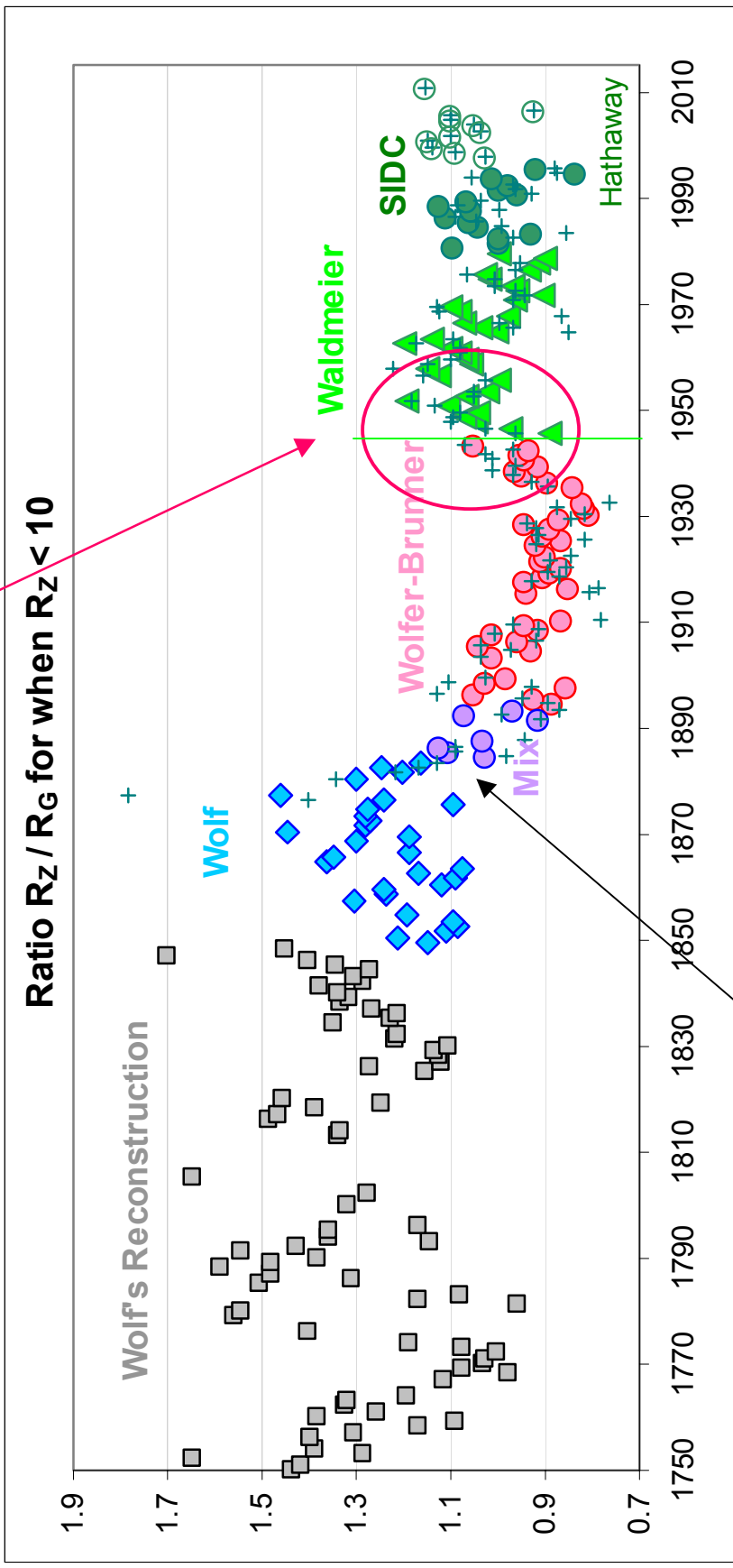

Fig. 5. VARIATION OF TWELVE-MONTH RUNNING—AVERAGE f"F2, 1200, AT WASHINGTON, D.C., WITH TWELVE-MONTH RUNNING—AVERAGE SUNSPOT NUMBER

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

I'll not discuss this jump today (defect in R_G, not in R_Z)

What did Waldmeier actually say about how to count sunspots?

I have [and have read] ALL the *Mitteilungen* from 1855 on through 1978 and every paper and book Waldmeier has ever written.

Let's have a look:

After Waldmeier took over the production of the sunspot series he stated {*100 Jahre Sonnenfleckenstatistik, Astron. Mitt. Eid. Sternw. Zürich, 152, 1948*}:

[…] Allerdings hat Wolfer, während seiner Assistentenzeit 1877-1893 eine andere Zählweise wervendet […] dass die Hofflecken, die bei Wolf nur als **ein** Fleck galten, je nach ihrer Grösse und Unterteilung mehrfach gezählt werden.

([…] Though Wolfer used an different counting method during his tenure as assistant 1877-1893 […] that spots with penumbra, that by Wolf was counted as **one** spot, would be counted multiple times according to size and complexity).

The sunspot-activity in the years 1610-1960, Schulthess, Zürich, 1961:

Around 1882 Wolf's successors changed the counting-method, which since then has been in use up to the present. This method counts also the smallest spots, and those with a penumbra are weighted according to their size and structure of the penumbra.

In 1882 Wolf was very much alive and running the show

Die Beziehung zwischen der Sonnenflecken-relativzahl und der Gruppenzahl, Astron. Mitt. Eid. Sternw. Zürich, 285, 1968:

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.

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

Interesting that there is no mention of a weight of 4…

Kopecký et al. (*On the relative inhomogeneity of long-term series of sunspot indices, Bull. Astron. Inst. Czech., 31, 267-283, 1980*) essentially quote Waldmeier with a twist:

[…] beginning with Wolfer, a "modified" method of calculating the number of sunspots, but **without mentioning it** {matches that I have not seen any either}, is being used in Zürich.

They speculate that perhaps using the new Zürich classification of groups might introduce an inhomogeneity, quoting Zelenka [Memorandum and personal communication]. I'll show it does not

This 'modified' counting method is still in use at the reference station Locarno used by SIDC . As a typical example we take the drawing made at Locarno on 21st October, 2010 [next slide]. Three sunspot groups are visible, numbered by Locarno as 102, 104, and 107, corresponding to NOAA active region numbers 11113, 11115, and 11117.

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 this spot of the same size: -
1920 11 21.55  9263 MWO   223 μH
```

Drawing from Locarno 21 October, 2010 showing the three Locarno Regions 102, 104, and 107. The table at the upper right 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).

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 is indeed what SIDC reported for that day.

SPECOLA SOLARE TICINESE
LOCARNO MONTI

$L_0 = 119.9$
$B_0 = +5.4$
$P_0 = +25.8$

No. 245
2010.X.21.333
08:00 T.U.
Osservatore: M. CAGNOTTI
Immagini: 3-4 (SIDC: 2-3)
$\Delta p = -25.8$

g	f	t	B	L	△
102	5	𝛿	+16		
104	3	𝛿	-25		
107	3	𝛿	+15		
3	11				

MWO 2010-X-17

SIDC International Sunspot Number

- 2010 10 18 2010.795 42
- 2010 10 19 2010.798 44
- 2010 10 20 2010.801 36
- 2010 10 21 2010.804 25
- 2010 10 22 2010.806 25
- 2010 10 23 2010.809 31
- 2010 10 24 2010.812 42

Is there any way we can check what was actually done?

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	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

$$R = 10*12 + 58 = 178$$

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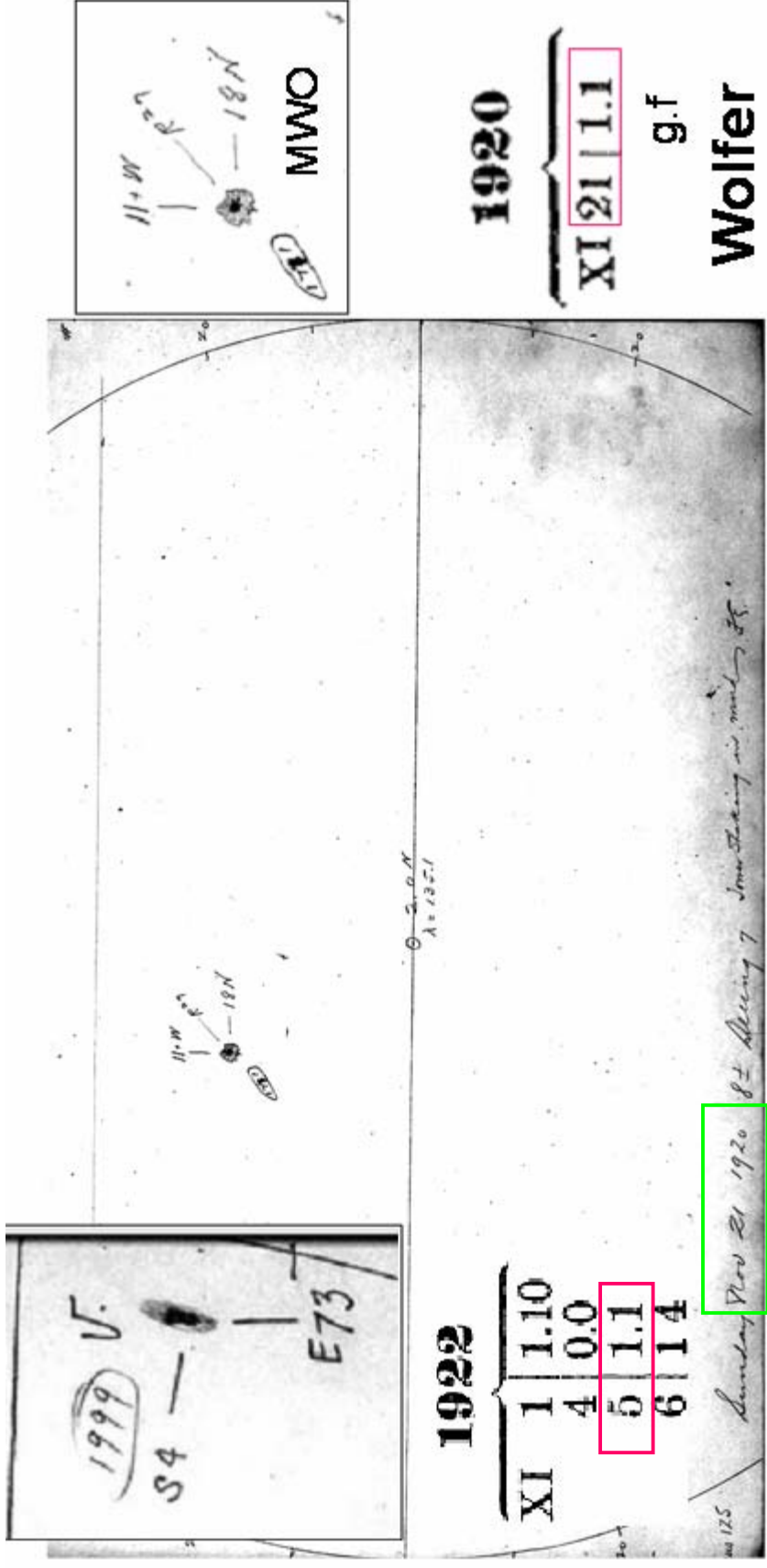
An insert shows a similar group observed at MWO on 5th Nov., 1922. For both groups, Wolfer should have recorded the observation as 1.3 if he had used the weighting scheme, but they were recorded as 1.1, clearly counting the large spots only once (thus with no weighting). The recorded (in the historical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

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There are many other such examples, (e.g. 16th September, 1922 and 3rd March, 1924 for which MWO drawings are readily available). 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. Furthermore, Wolf was still very much alive in 1882 and in charge of things, and was not 'succeeded' at that time. We shall not here speculate about the motive or reason for Waldmeier ascribing the weighting scheme to Wolfer. Waldmeier himself was an assistant to Brunner since 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 will provide a resolution of the conundrum.

Conclusions

- Waldmeier introduced an artificial upwards jump ~1945 by introducing a weighting of sunspots by size and appearance

- Since Locarno counts with the same weighting scheme and since Locarno is the reference station used by SIDC, this 'Waldmeier Discontinuity' carries over into today's International Sunspot Number which is then ~20% too high compared with Wolf's historical standard sunspot series

- Suggested [simple] solution: increase all values before 1945 by 20%, and then remove the 0.6 k-factor [the latter to be compatible with NOAA]. More complicated procedure can be contemplated, if needed.