The Effect of Weighting in Counting Sunspots

‘The Waldmeier Discontinuity’

Leif Svalgaard

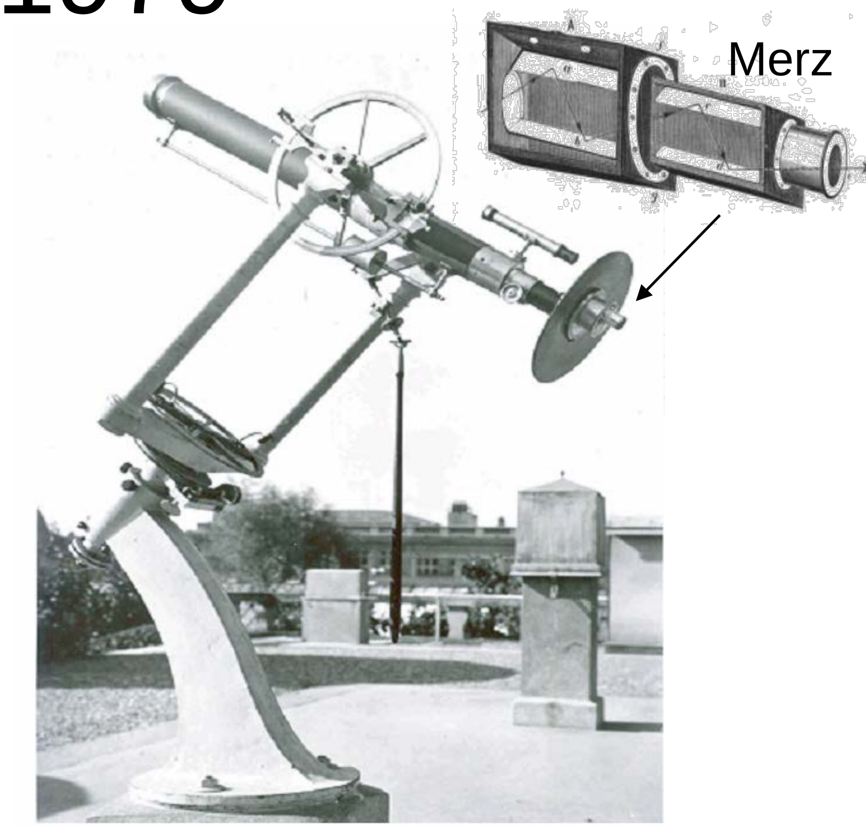
HEPL, Stanford University

Space Science Lab., Berkeley, Oct. 2011

Max Waldmeier's Tenure as Director of Zürich Observatory 1945-1979

Wolf's Relative Sunspot Number

R = k (10*Groups + Spots)



Rudolf Wolf's Telescope

Built by Fraunhofer 1822

Wolf's Telescopes, used by Wolf, Wolfer, Brunner, Waldmeier, Friedli

Still in use today [by T. Friedli] continuing the Swiss tradition [under the auspices of the Rudolf Wolf Gesellschaft]

Most of Wolf's observations (since the 1860s) were made with this telescope. Also still in use today

How does one count sunspots?

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

Astronomische Mitteilungen der Eidgenössischen Sternwarte Zürich
Nr. 285

1968

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 größerer, jedoch nicht mit Penumbra versehener Fleck erhält das statistische Gewicht 2, ein kleiner Hoffleck 3, ein größerer 5. Die Gruppen- und

"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.

Waldmeier claimed that the counting with weighting began in 1882:

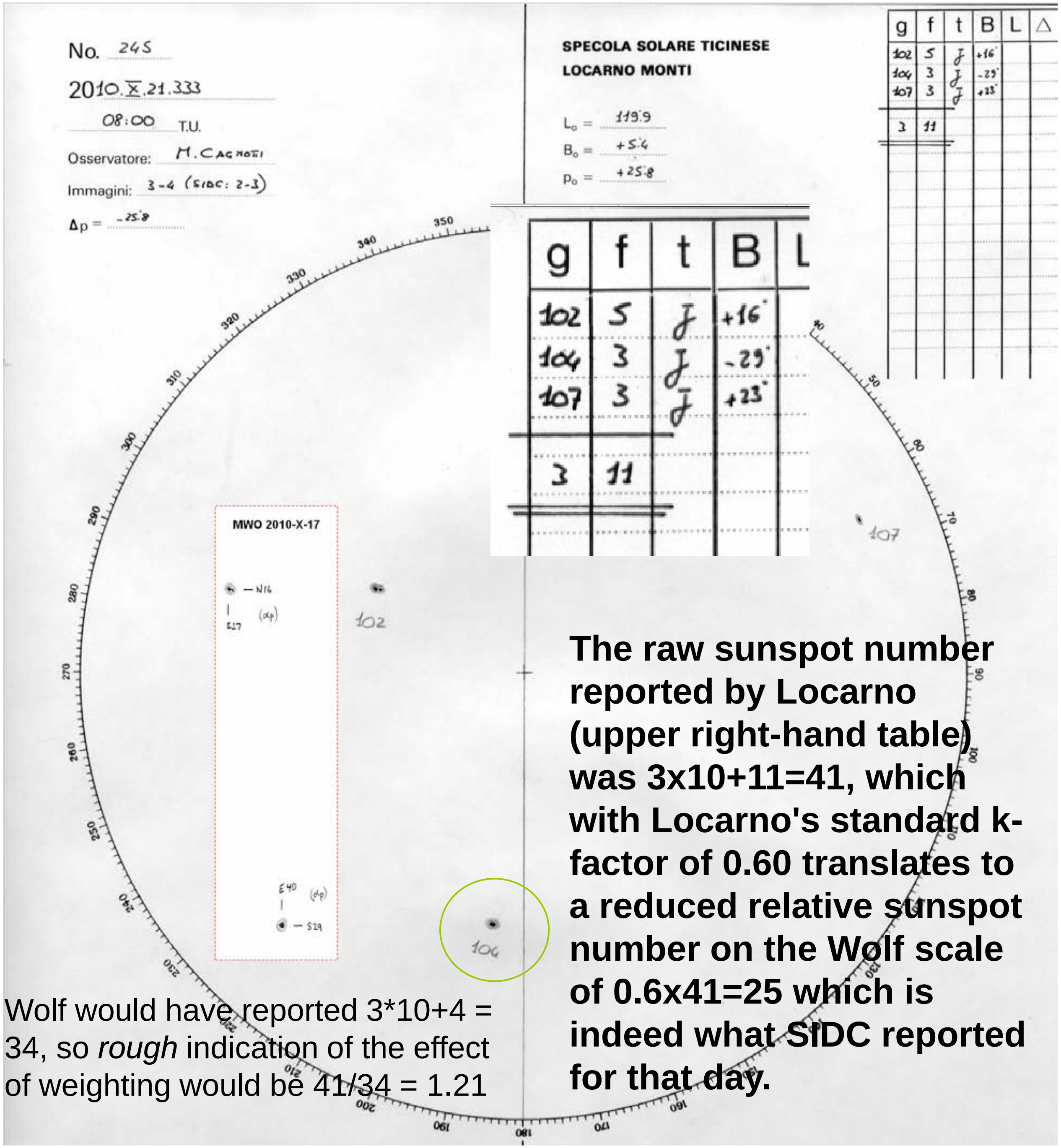
CHANGES TO THE COUNTING METHOD

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.

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



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.

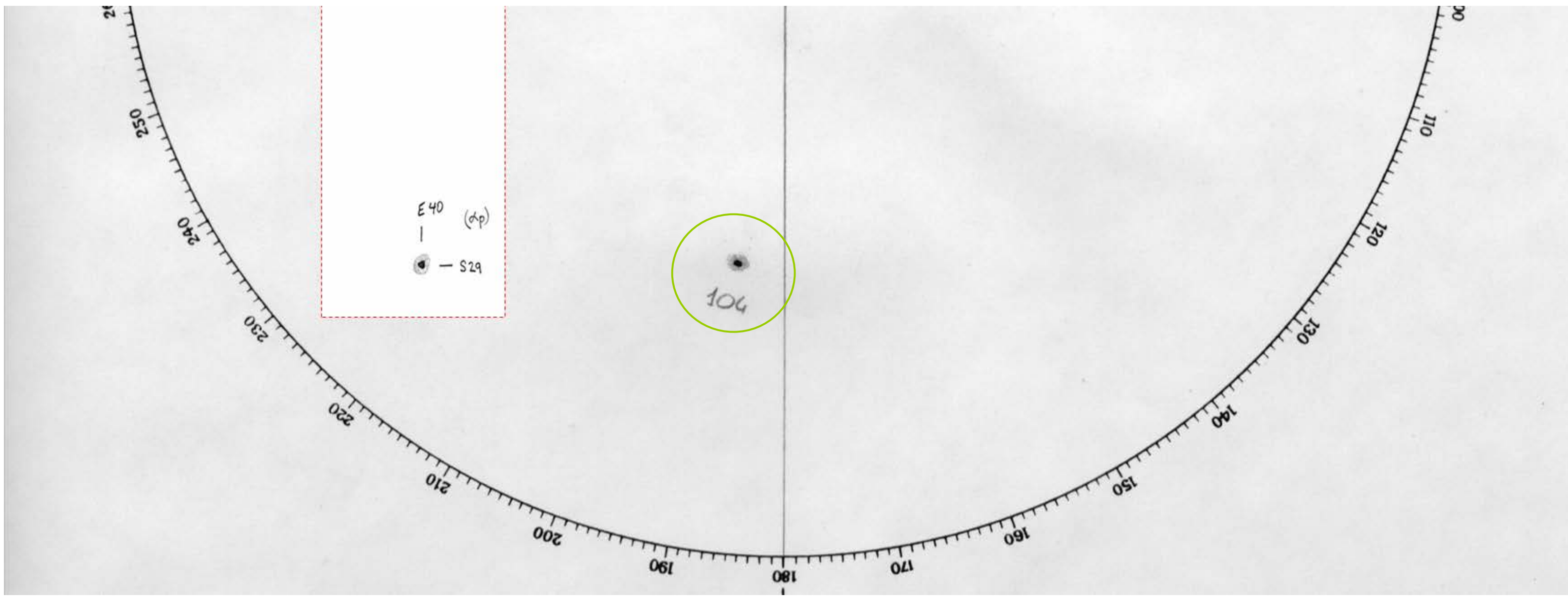
Wolf would have reported 3*10+4 = 34, so *rough* indication of the effect of weighting would be 41/34 = 1.21

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”

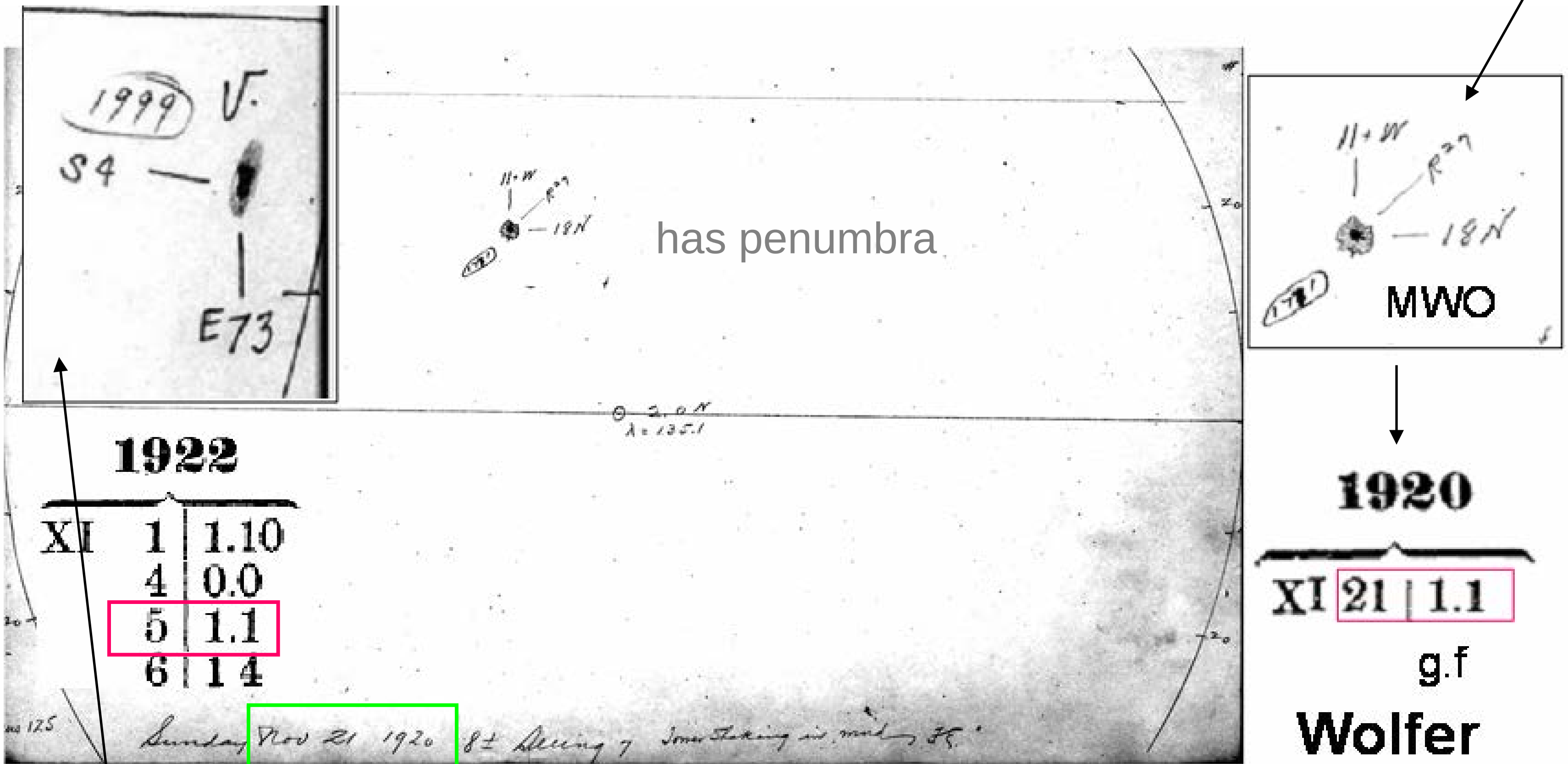
Sonnenfleckenbeobachtungen im Jahre 1849.

	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	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 $R = k * (10*12 + 58) = 178$

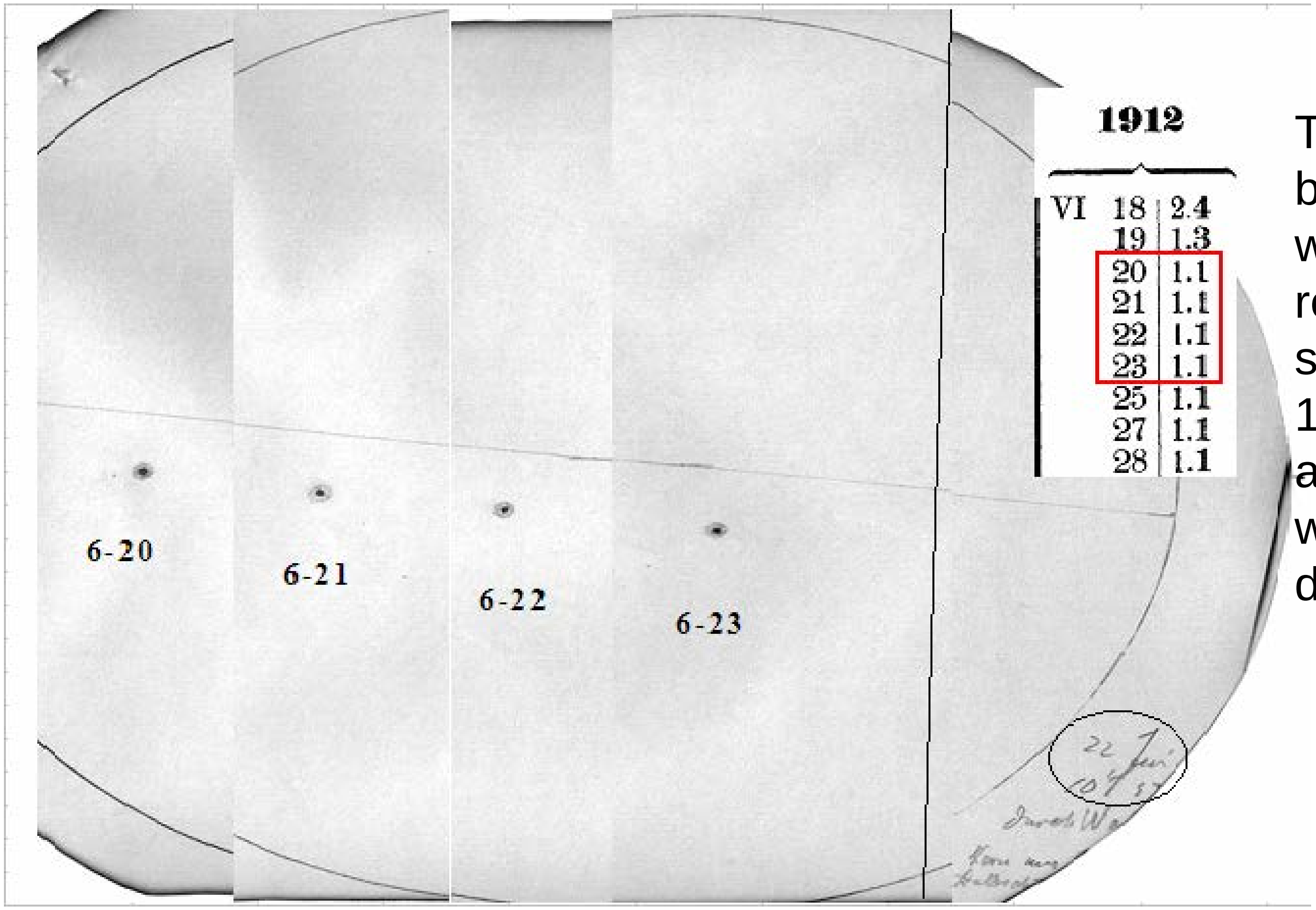
where the scale factor k is 1.00 for Wolf himself.

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

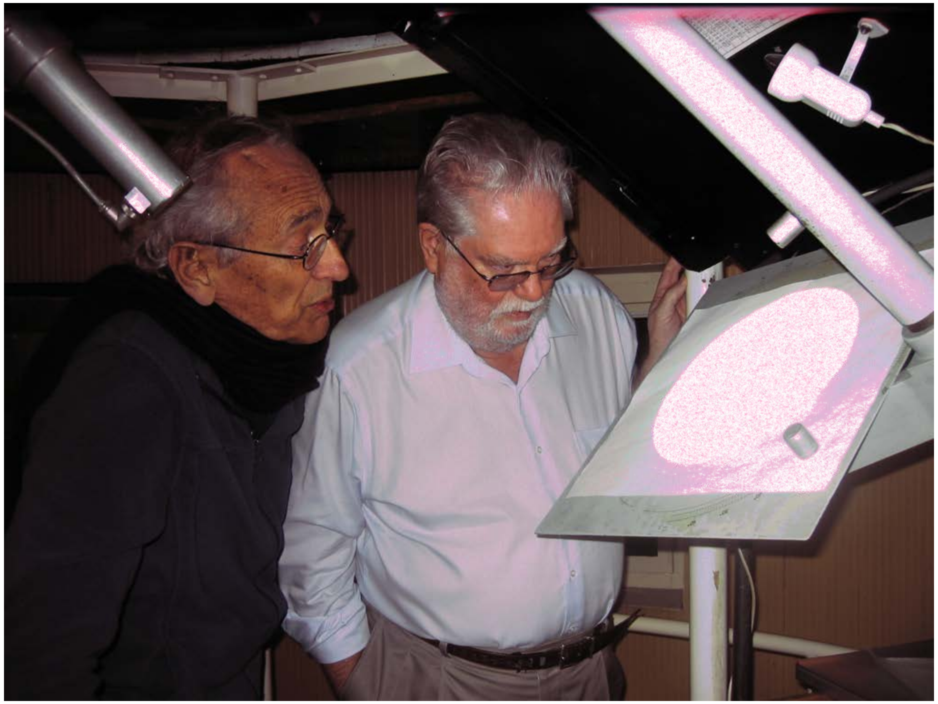
There are many other such examples, (e.g. 16th September, 1922 and 3rd March, 1924 for which MWO drawings are readily available).

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. 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.

The weighting is not generally known and was downplayed by Waldmeier

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)

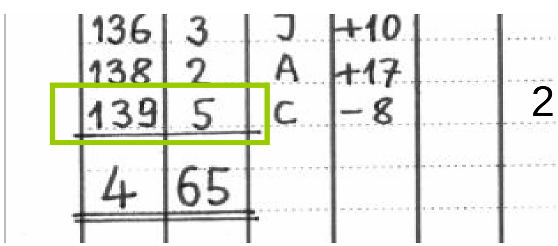
Sergio Cortesi started in 1957, still at it, and in a sense is the *real* keeper of the SSN, as SIDC normalizes everybody's count to match Sergio's

Estimating Unweighted Sunspot Count From Locarno Drawings

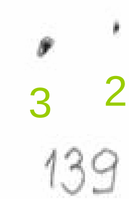
I look at the drawing of a group and from experience [I have looked at thousands of spots, 42025 at last count, on Locarno's drawings going back many years], assign a weight to each spot, then subtract the weight from the count given for the group and add 1 for the spot.

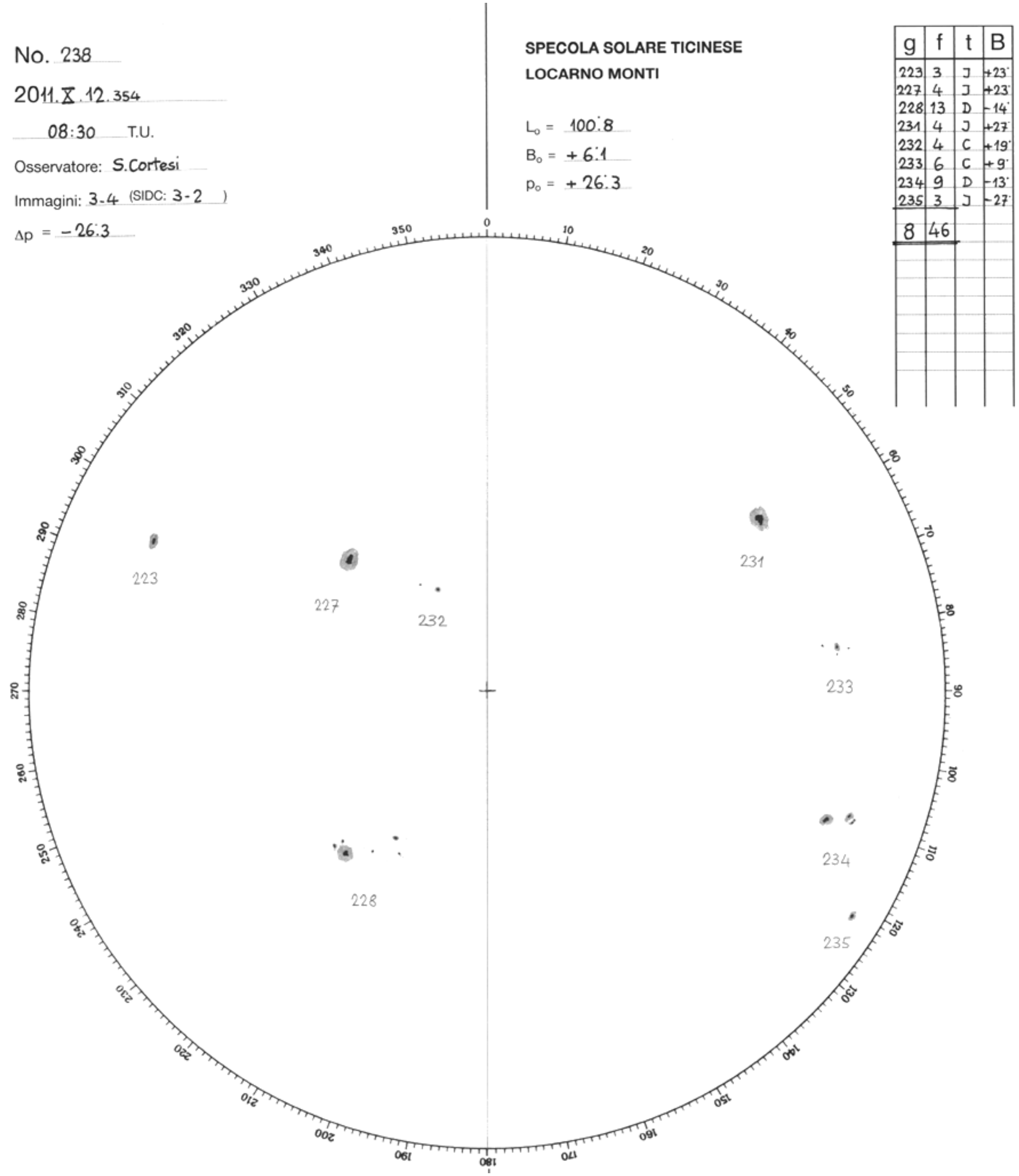
Example 1: A group has four spots on the drawing, one is large with weight 3, one is medium with weight 2 and two are small with weight 1. The total count given by Locarno was 6. That tells me that one of the small spots was not counted [otherwise the total would have been 3+2+1+1 = 7]. So, I subtract 3, 2, and 1 from their total: 6 - 3 - 2 - 1 = 0 and add 1 for each spot for a total of 3 as the unweighted count.

Example 2: Most of the time it is enough just to count the spots:



2004-8-12





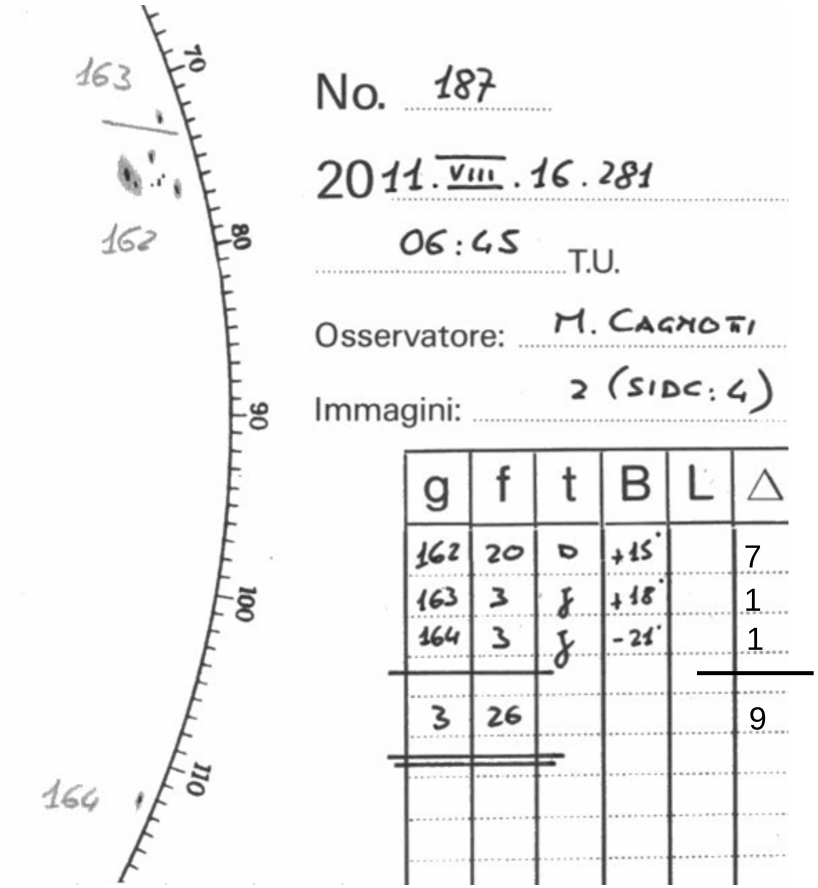
Oct. 12, Last Wednesday

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**
	126	**100**

26% inflated

Unweighted count red

More Examples



No. 187

2011.VIII.16.281

06:45 T.U.

Osservatore: M. Cagnoti

Immagini: 2 (SIDC: 4)

g	f	t	B	L	△
162	20	D	+15°		7
163	3	J	+18°		1
164	3	J	-21°		1
3	26				9

Just counting the spots regardless of size.

How does Marco get 20 for group 162?
My weighted count is 15 at most

Often there are more spots on the drawing than were included in the visual count at the eyepiece:

2006.IV.20.313

7.30 T.U.

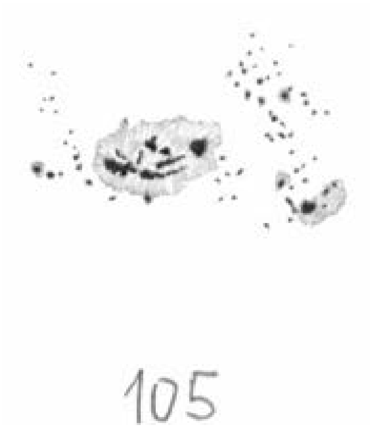
Osservatore: S. Cortesi

Immagini: 2-3

g	f	t	B	L
30	4	B	-1	
1	4			

3

Difficult (Rare) Cases



2005 . IX . 15 . 333

8.00 T.U.

Osservatore: S.Cortesi

Immagini: 3

74 spots

g	f	t	B	L
105	58	E	-11	
1	58			

36

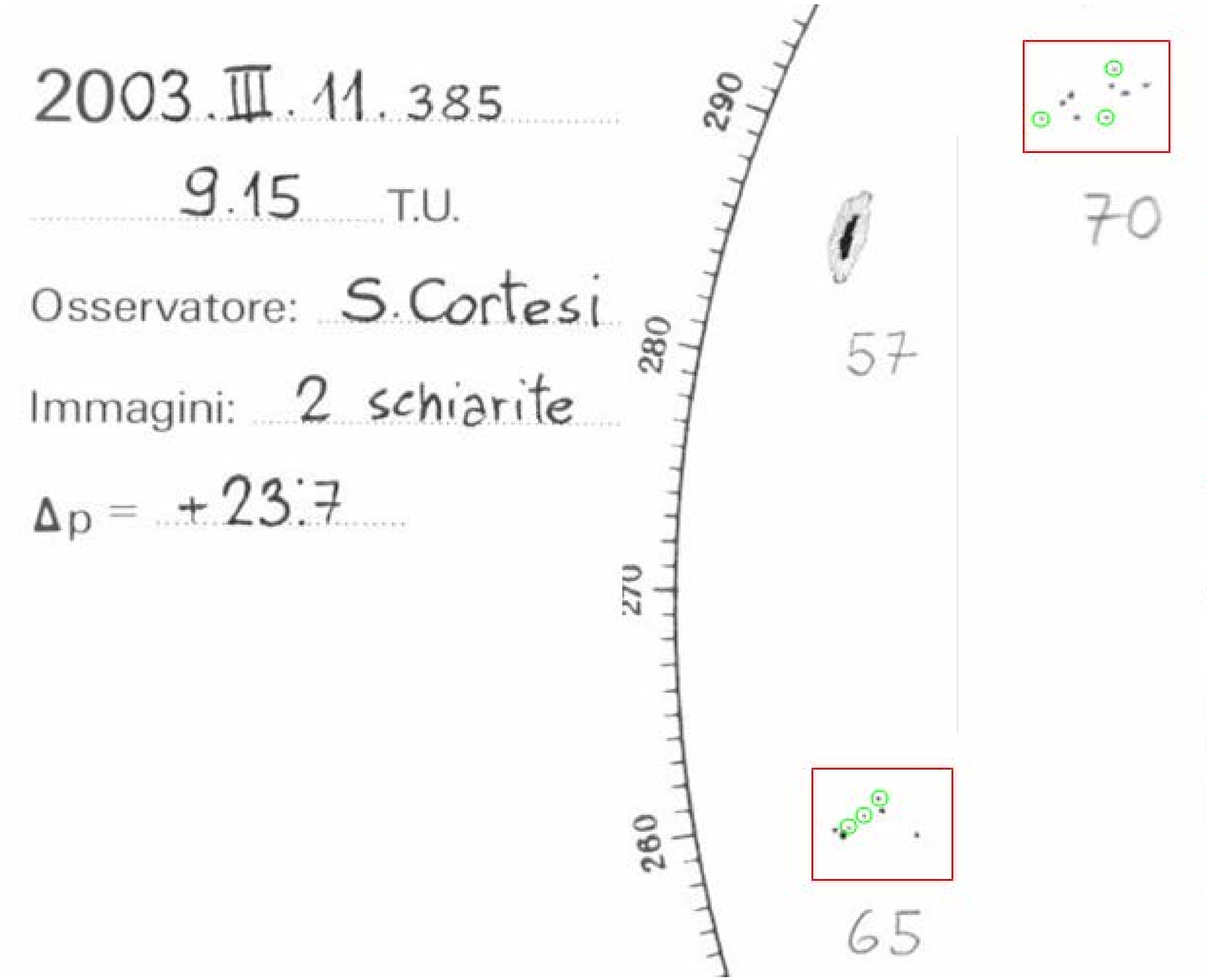
3,2,3,2,2,3,2,3,3,3,3,3,3: sum 35, 58-35+13 spots = 36

2004-08-12 (group 134)

g	f	t	B	L	△
134	55	E	-13		
136	3	J	+10		
138	2	A	+17		
139	5	C	-8		
4	65				

40
1
1
2
44

Examples of Spots Not Counted



g	f	t	B	L
57	4	H	+12°	1
65	4	B	−13	4
66	12	G	+6	
68	3	B	−24	
69	13	D	−12	
70	6	B	+15	6
6	42			

Details of My Analysis

(covering 2003-2011 so far)

				G Loc	S Loc	G Leif	S Leif	R Loc	R Leif	Loc/Leif	Obs	R SIDC	*k* Loc
2011	8	28	2011.657	5	22	5	15	72	65	1.1077	am	49	0.6806
2011	8	29	2011.660	6	19	6	12	79	72	1.0972	mc	43	0.5443
2011	8	30	2011.662	7	22	7	17	92	87	1.0575	mc	69	0.7500
2011	8	31	2011.665	9	57	9	35	147	125	1.1760	mc	96	0.6531
2011	9	1	2011.666	7	59	7	33	129	103	1.2524	mb	85	0.6589
2011	9	2	2011.669	8	72	8	52	152	132	1.1515	mc	91	0.5987
2011	9	3	2011.672	8	74	8	49	154	129	1.1938	mc	95	0.6169
2011	9	4	2011.674									70	
2011	9	5	2011.677	6	70	6	53	130	113	1.1504	mc	76	0.5846
2011	9	6	2011.680	5	37	5	25	87	75	1.1600	mc	58	0.6667
2011	9	7	2011.683									49	
2011	9	8	2011.685	3	24	3	12	54	42	1.2857	mc	36	0.6667
2011	9	9	2011.688	4	38	4	23	78	63	1.2381	mc	46	0.5897
2011	9	10	2011.691	5	36	5	25	86	75	1.1467	am	52	0.6047
2011	9	11	2011.694	7	44	7	28	114	98	1.1633	am	*59*	*0.5175*
										1.1677			**0.6303**

The SIDC numbers are preliminary and are updated as needed

Double-Blind Test

Email from Leif Svalgaard

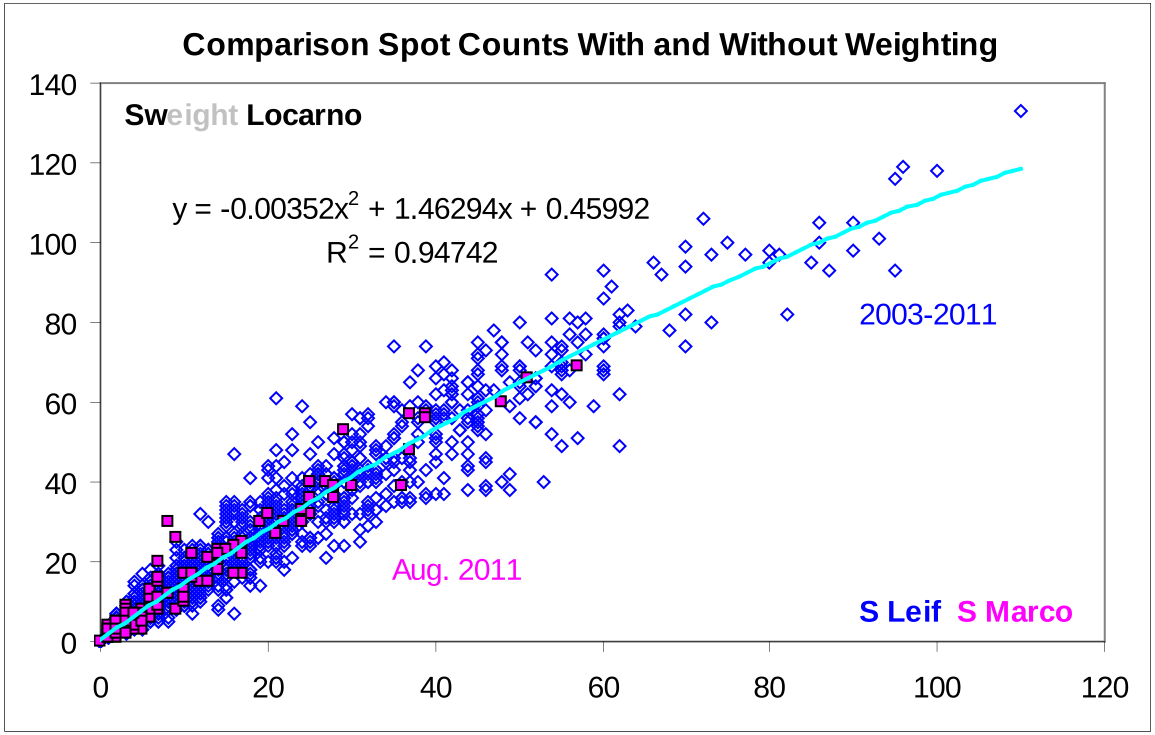
Sat, Jun 18, 2011 at 9:26 PM

Dear Everybody,

As you may know we are holding a sunspot workshop at Sunspot, New Mexico in September. For this I would like to propose a simple test, that hopefully should not put a great extra burden on everybody. I ask that the observer for each day writes down somewhere what the actual number of spots counted was without the weighting, but without telling me. Then in September you let me know what the counts for [rest of] June, July, and August were. This allows me to calibrate my method of guessing what your count was. It is, of course, important that the test be blind, that I do not know until September what you all are counting. I hope this will be possible.

My modest proposal was met with fierce resistance from everybody [incl. Frédéric], but since I persisted in being a pest, I finally got Locarno to go along

Current Status of the Test

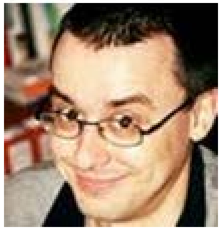


2nd degree fit

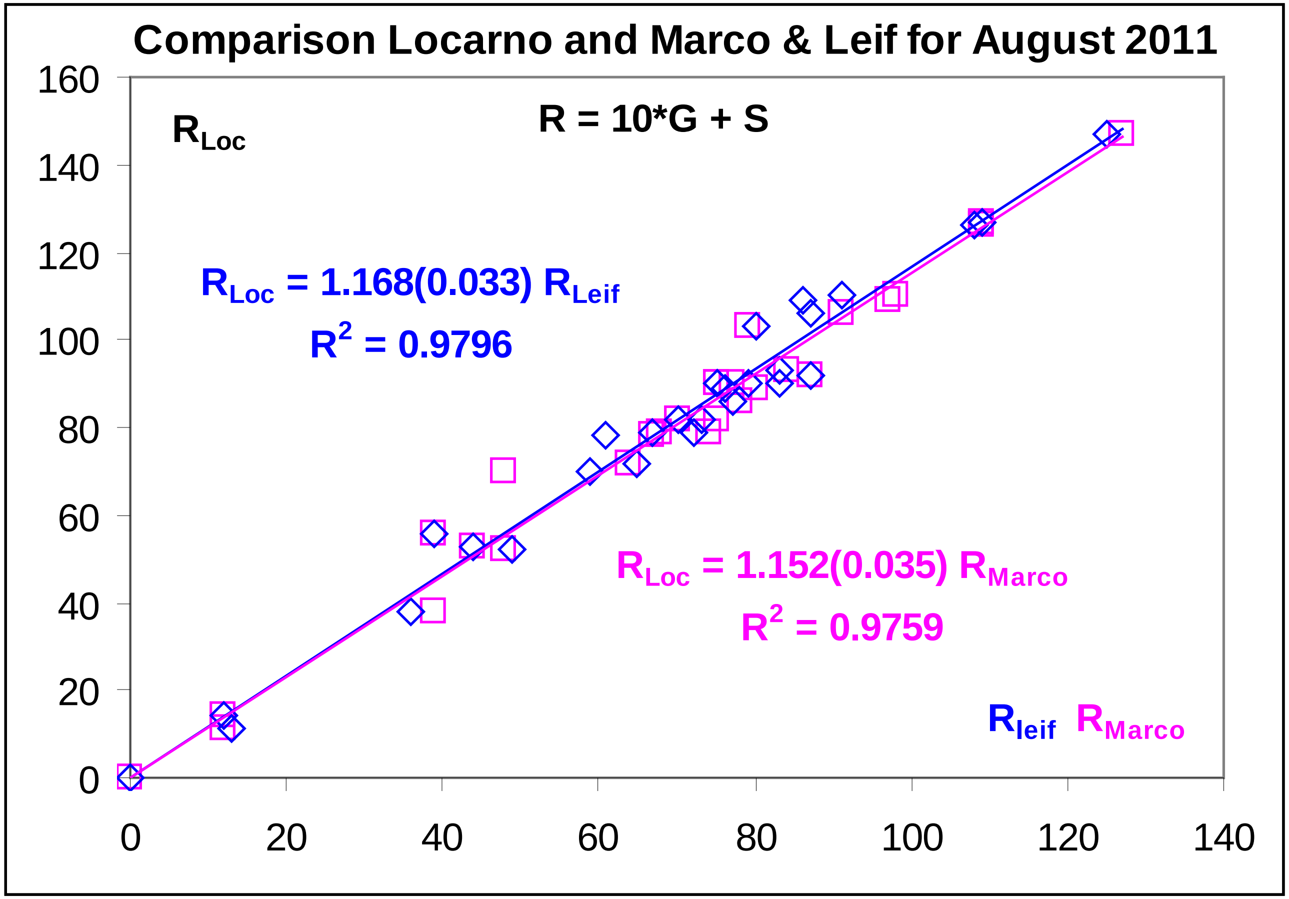
S	Sw	Sw/S
10	14.74	1.4737
25	34.83	1.3933
50	64.81	1.2961
75	90.38	1.2051
100	111.55	1.1155

For typical number of spots the weighting increases the ‘count’ of the spots by 30-50%

For the limited data for August 2011 Marco Cagnotti and Leif Svalgaard agree quite well with no significant difference. The test should continue as activity increases in the coming months.



Comparison of 'Relative Numbers'

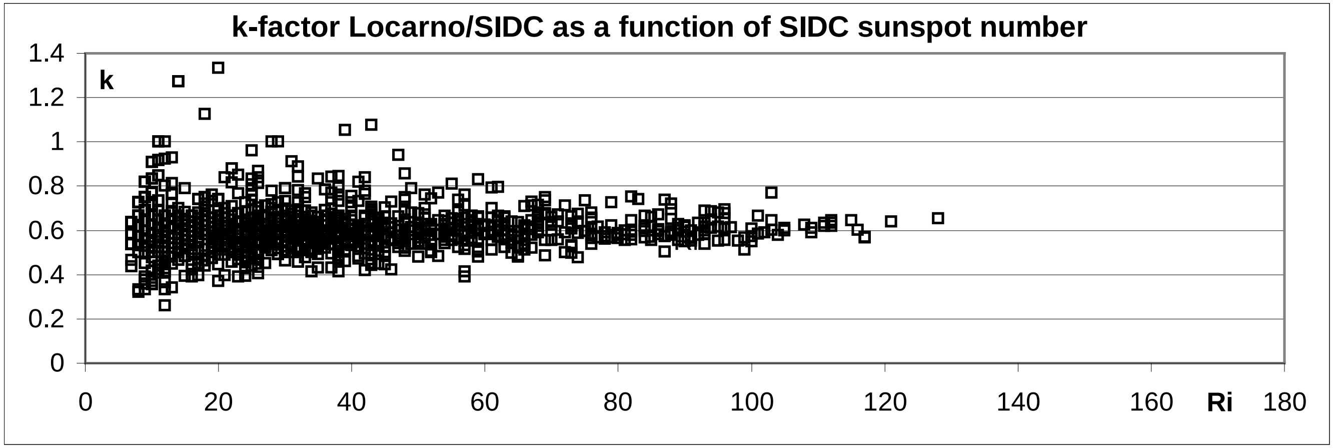


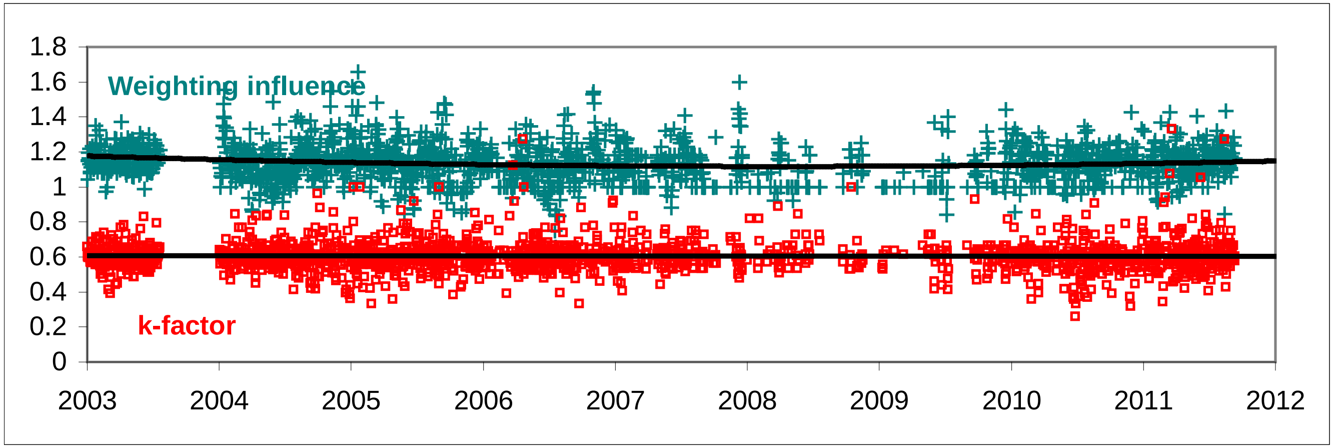
But we are interested in the effect on the SSN where the group count will dilute the effect by about a factor of two.

For Aug. 2011 the result is at left. There is no real difference between Marco and Leif.

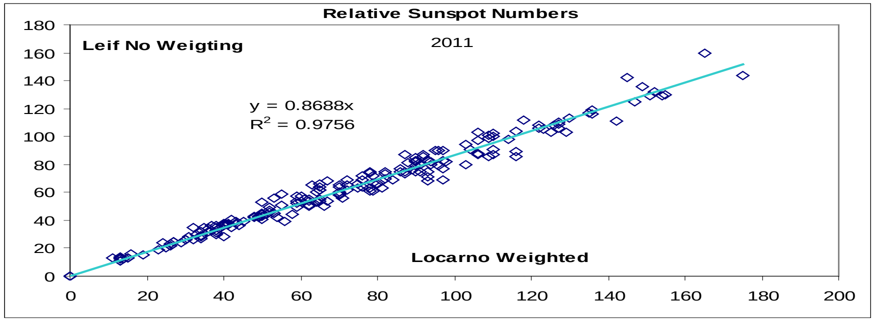
We take this a [preliminary] justification for my determination of the influence of weighting on the Locarno [and by extension on the Zürich and International] sunspot numbers

Temporal Evolution of Weight Factor





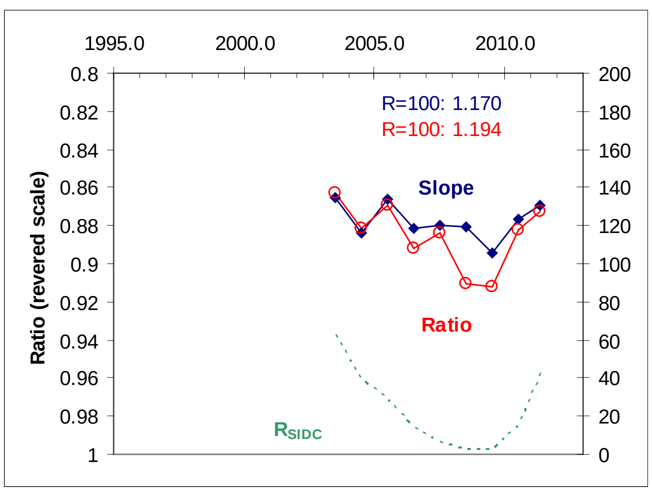
Daily values



The Average Weight Factor

1.13+0.00040*R		0.6176 Avg
R=100	1.17	**0.6088** Med

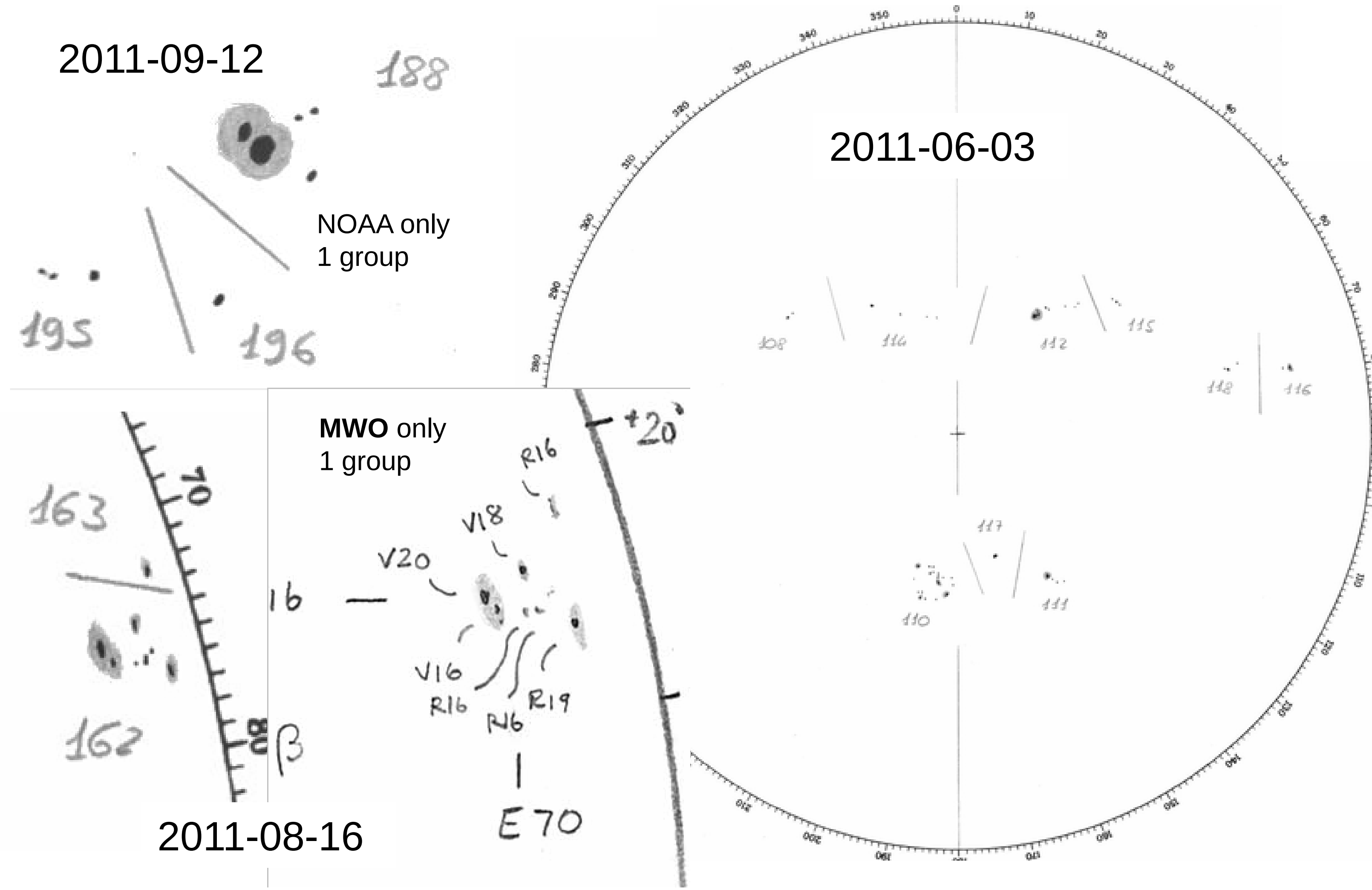
	slope					inv. Slope		
all	**0.8722**	<Rloc>	<Rleif>	ratio	<Rsidc>	**1.1465**	count Loc	k loc
2011.4	0.8691	70.29	61.36	0.8728	42.84	1.1506	211	0.6094
2010.5	0.8767	28.30	24.96	0.8822	16.47	1.1406	285	0.5819
2009.5	0.8945	4.74	4.32	0.9119	3.12	1.1179	309	0.6570
2008.5	0.8807	4.00	3.64	0.9107	2.85	1.1355	297	0.7137
2007.5	0.8801	12.33	10.90	0.8842	7.50	1.1362	332	0.6088
2006.5	0.8814	24.55	21.89	0.8919	15.22	1.1346	312	0.6200
2005.5	0.8662	50.37	43.80	0.8696	29.83	1.1545	318	0.5922
2004.5	0.8838	68.63	60.50	0.8816	40.45	1.1315	303	0.5894
2003.5	0.8654	108.69	93.83	0.8632	63.71	1.1555	190	0.5861



For yearly values there is an approximately (but weak) linear relation between the weight factor and the sunspot number. For a typical R of 100, the weighting increases the sunspot number by 17%.

How Many Groups?

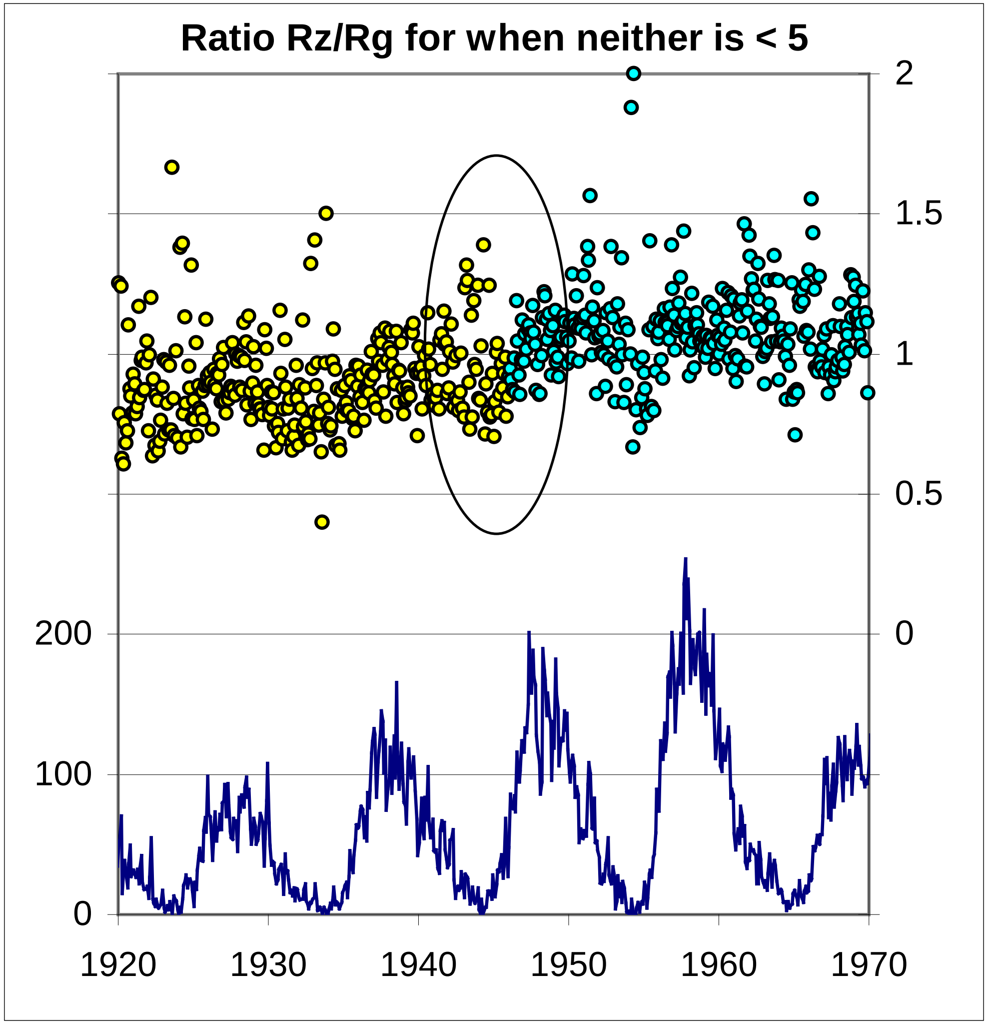
The Waldmeier Classification May lead to Better [larger] Determination of Groups



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 3% [?]
- This would increase the ‘Waldmeier Jump” to about 20%
- 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

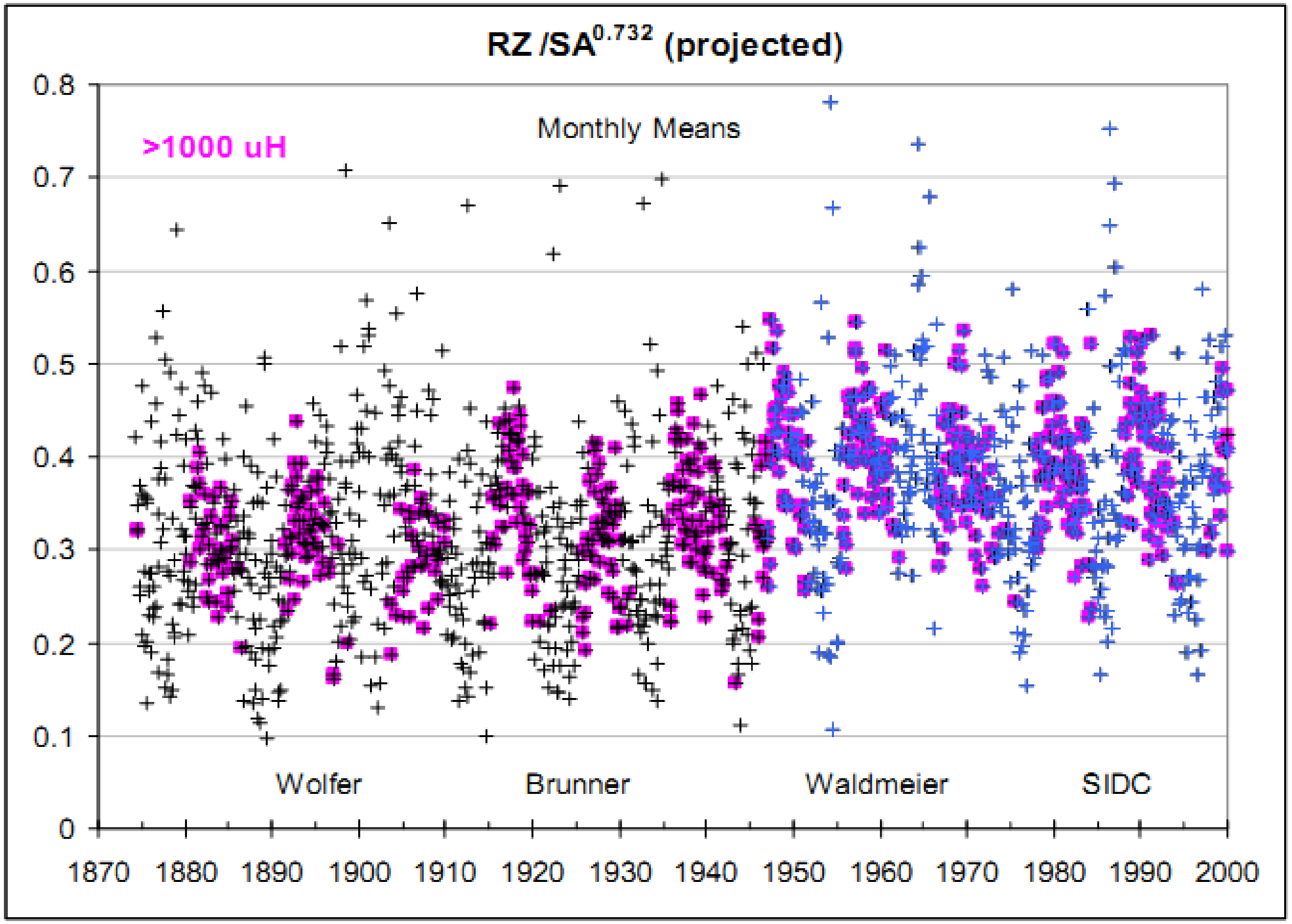
Can we see the Effect in the Data?



We can compute the ratio Rz/Rg [staying away from small values] for some decades on either side of the start of Waldmeier's tenure, assuming that Rg derived from the RGO data has no trend over that interval.

There is a clear discontinuity corresponding to a jump of a factor of 1.18 between 1945 and 1946. This compares favorably with the estimated size of the increase due to the weighting [with perhaps a very small additional influence from a greater group count]

Sunspot Areas vs. Rz

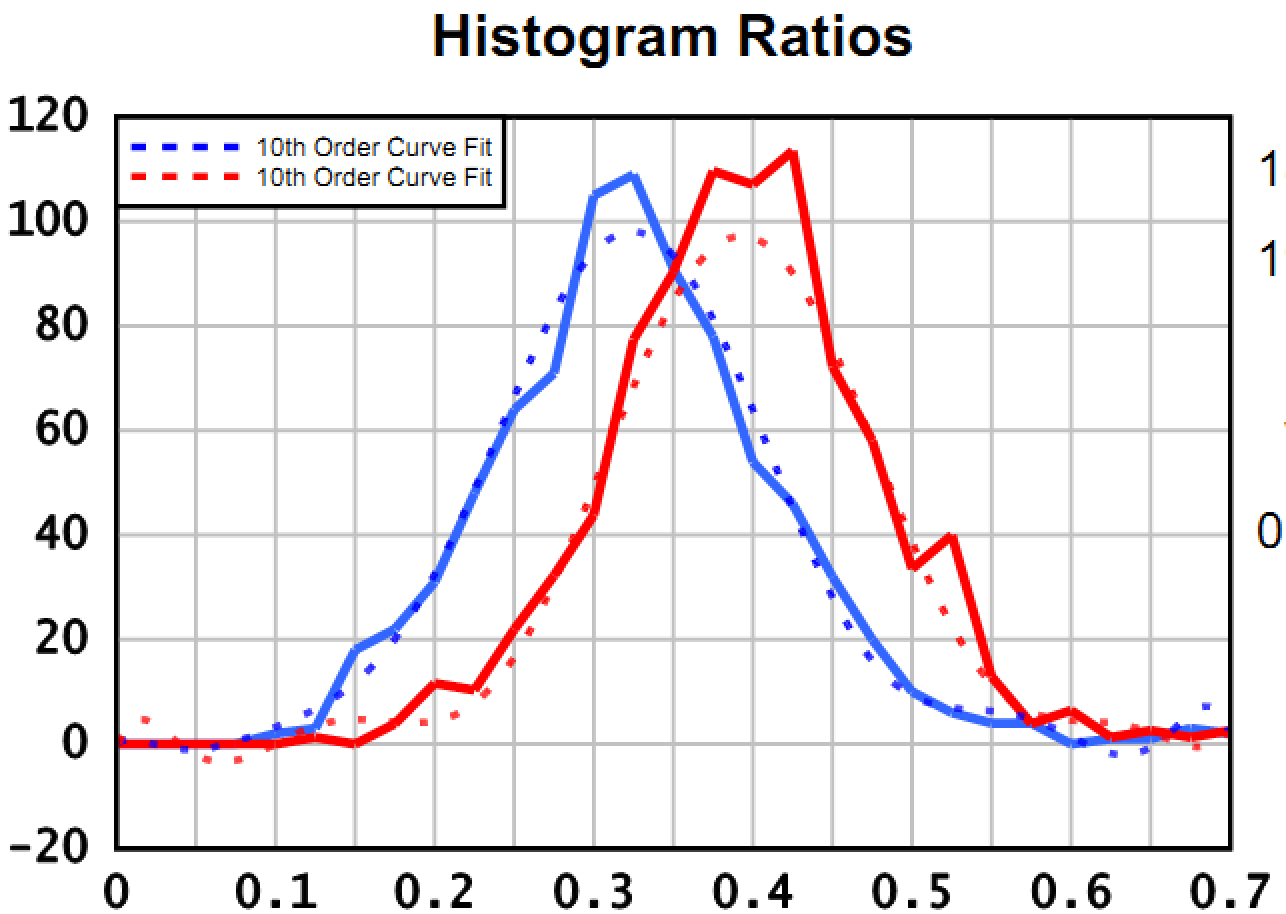


The relationship between sunspot number and sunspot area [SA, Balmaceda] is not linear, but can be made linear raising SA to the power of 0.732. Then taking the ratio makes sense.

Pink squares show the ratios for SA exceeding 1000 micro-hemispheres

Clear change in the relationship around 1945

Quantifying the Waldmeier 'Jump'



Plotting Histograms of the ratio $Rz/SA^{0.732}$

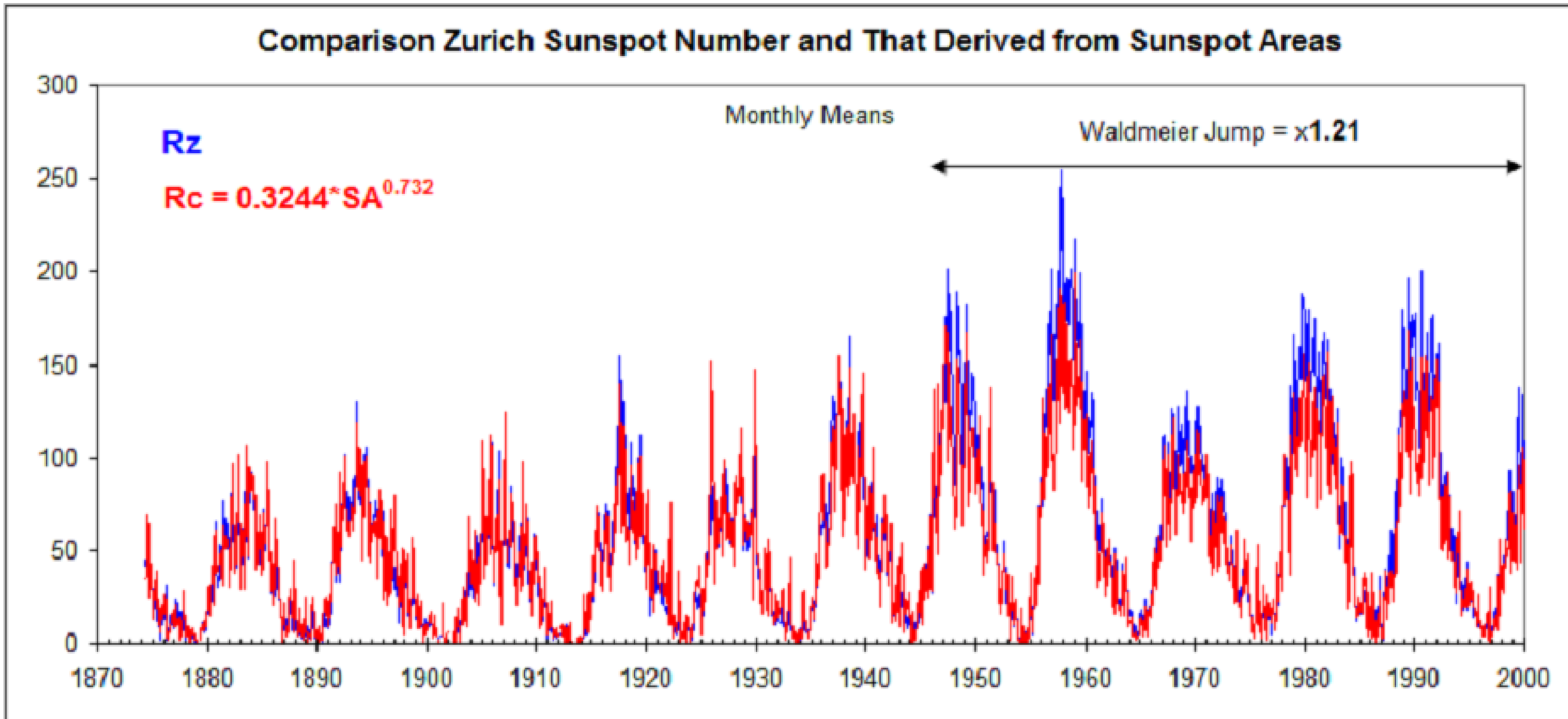
1874-1944 0.3244

1945-2000 0.3921

Waldmeier Jump

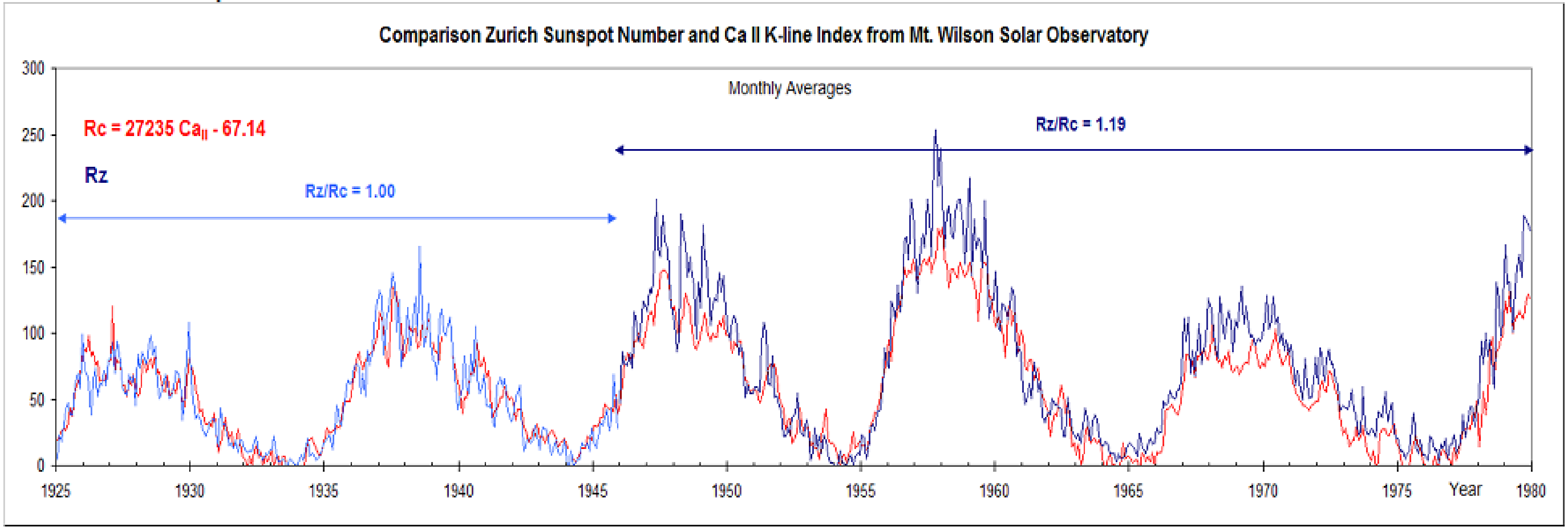
0.3921/0.3244 = **1.212**

Illustrating that Observed Rz after 1945 is Higher than Deduced from Sunspot Areas



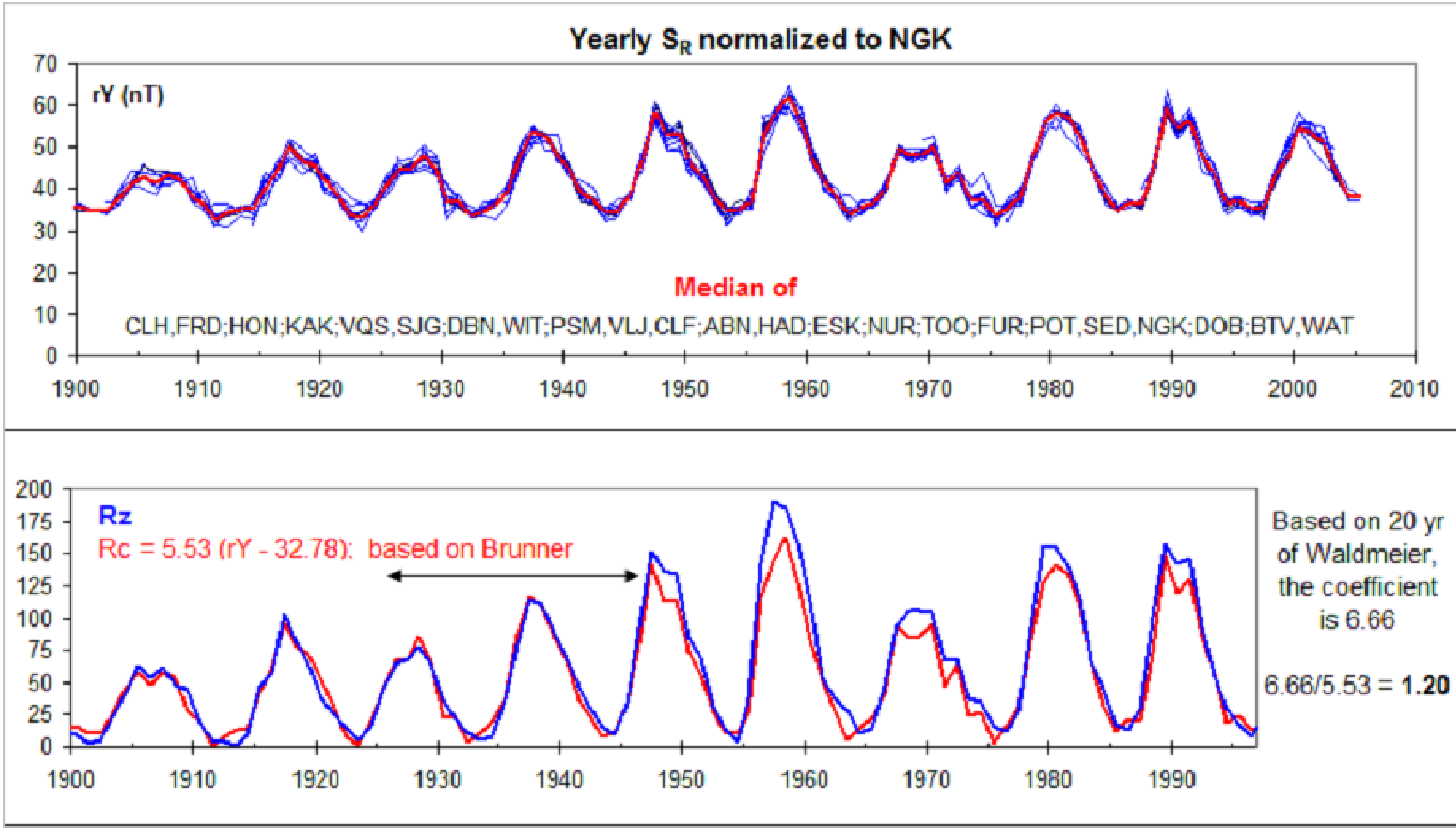
Ca II K-line Data Scaled to Rz shows similar Jump in Rz Sunspot Number after 1945

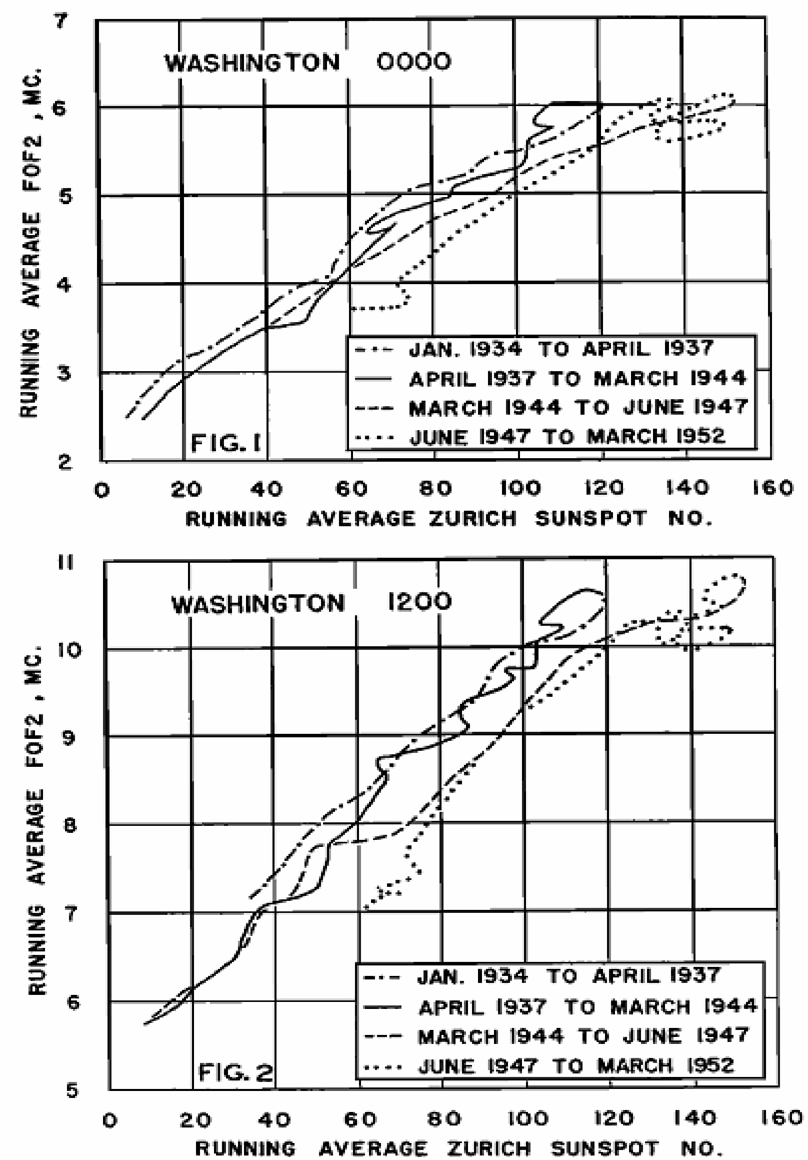
From ~40,000 CaK spectroheliograms from the 60-foot tower at Mount Wilson between 1915 and 1985, a daily index of the fractional area of the visible solar disk occupied by plages and active network has been constructed [Bertello et al., 2008]. Monthly averages of this index is strongly correlated with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





FIGS. I 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

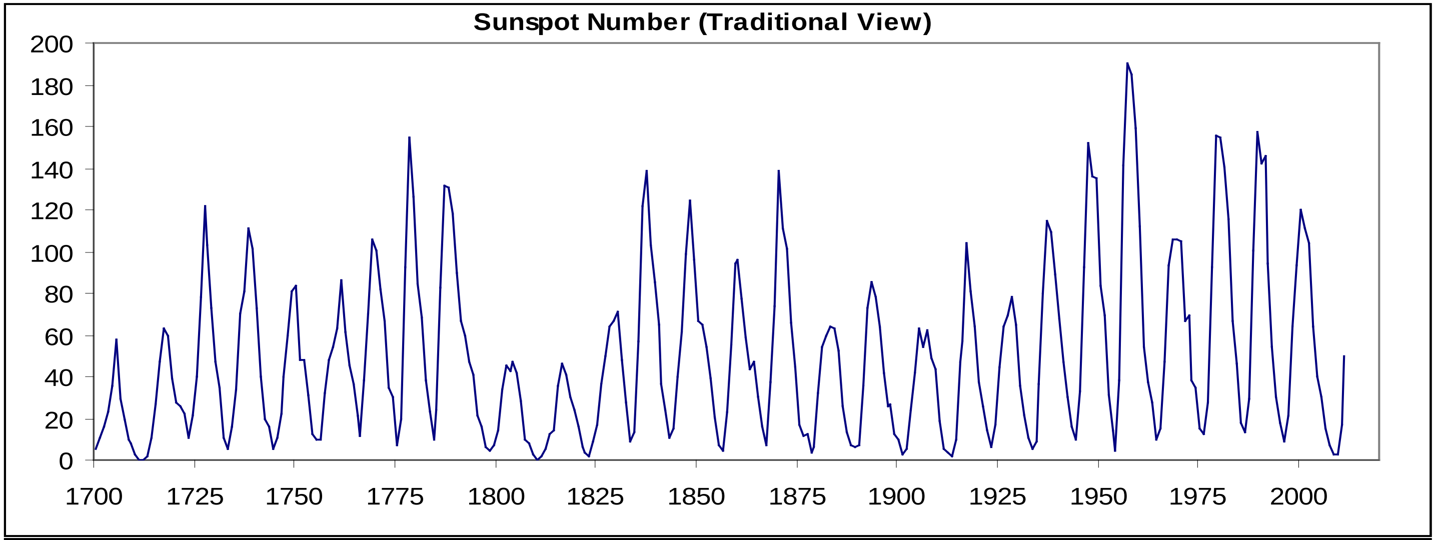
foF2

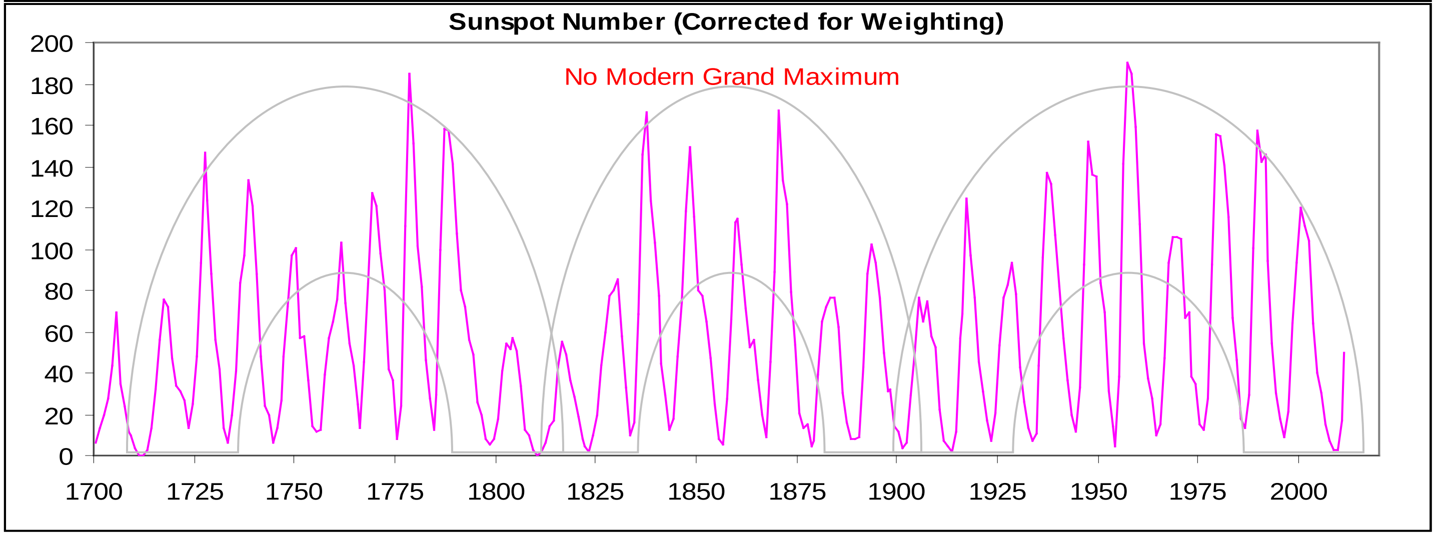
F2-layer critical frequency. This is the maximum radio frequency that can be reflected by the F2-region of the ionosphere at vertical incidence (that is, when the signal is transmitted straight up into the ionosphere). And has been found to have a profound solar cycle dependence.

The shift in SSN to bring the curves to overlap is 21%

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

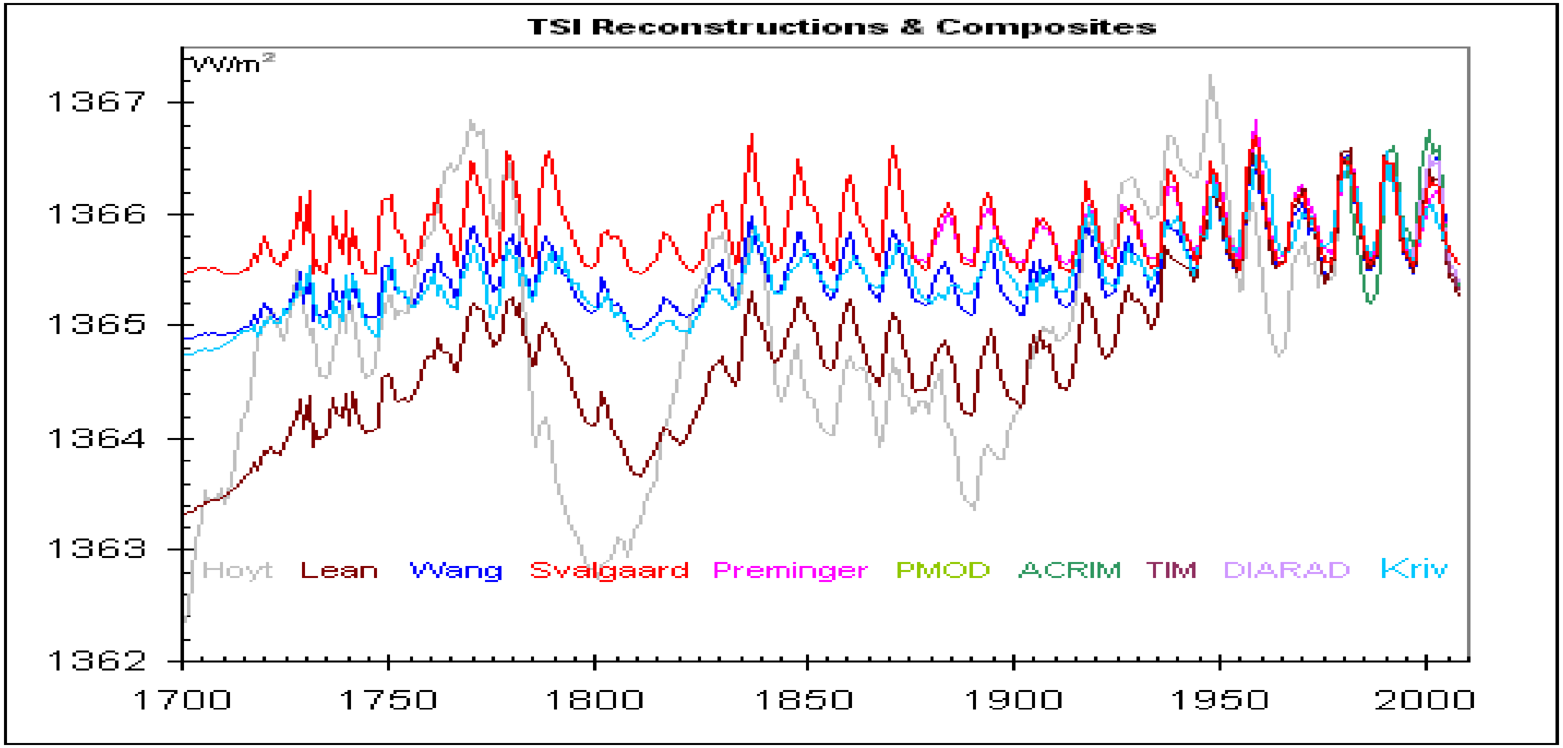
The Effect on the Sunspot Curve





No long-term trend the last 300 years

Implications for Total Solar Irradiance

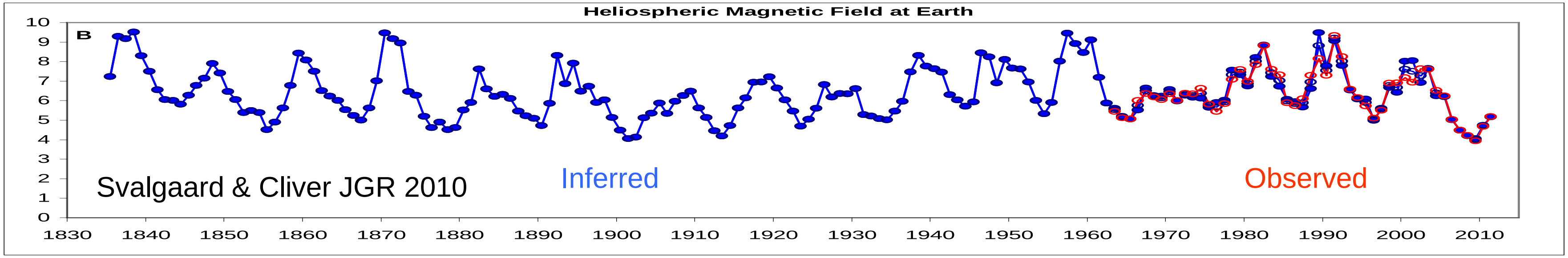


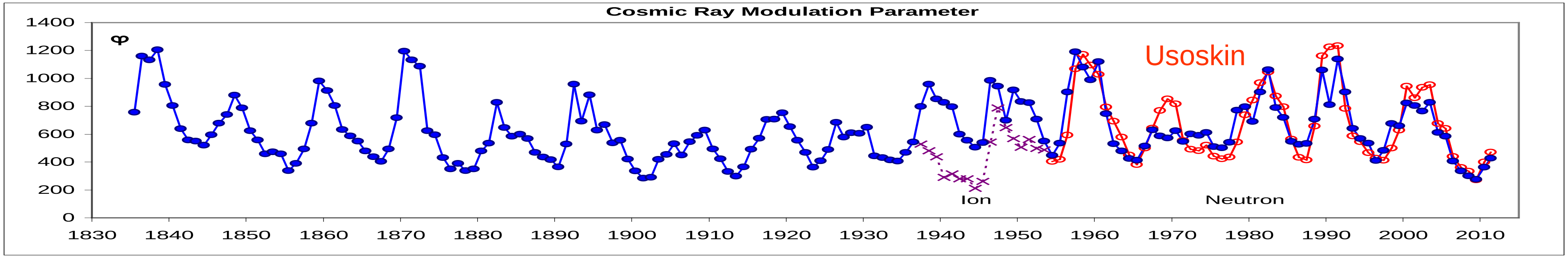
If no long-term trend, then no rationale for a background trend in TSI

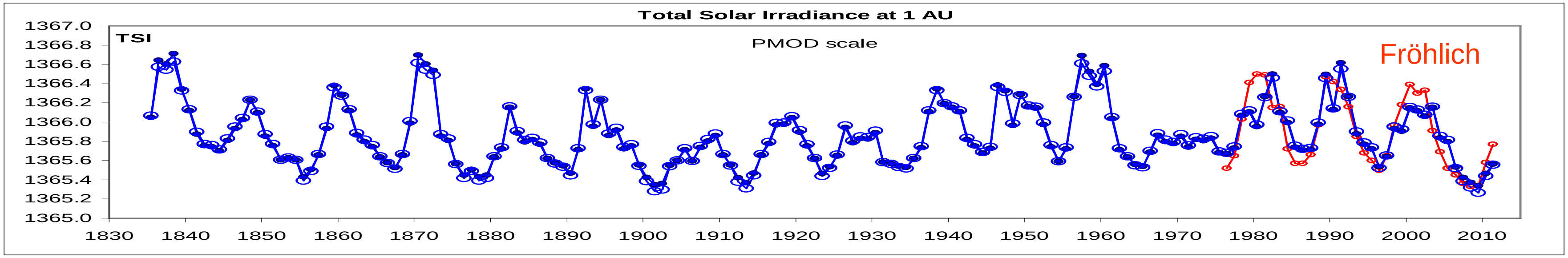
The ‘No Background’ TSI

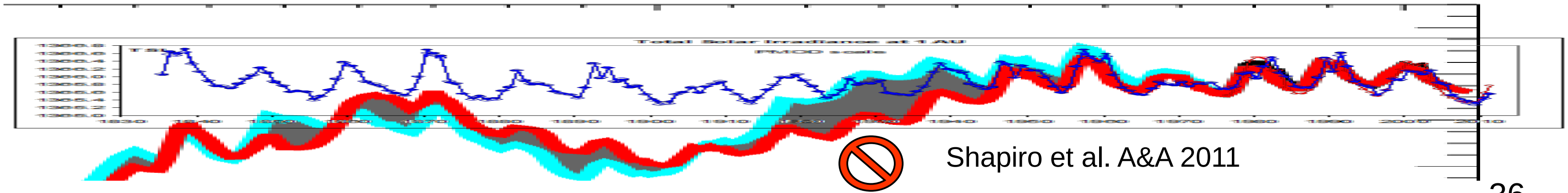
- In 2011GL046658 Schrijver et al discuss TSI without the background:
- [19] The TSI appears to be mostly, if not entirely, set by the counteracting effects of dark pores and sunspots and the bright small concentrations of magnetic field (the faculae) on an otherwise constant background [Lean and Woods, 2010]. In view of the above, the observational records suggests that the network faculae associated with the ephemeral regions were the same in early 2009 as at any very quiet time in the past, and that this is consequently true also for the TSI during the Maunder Minimum.

The Shapiro et al. Reconstruction

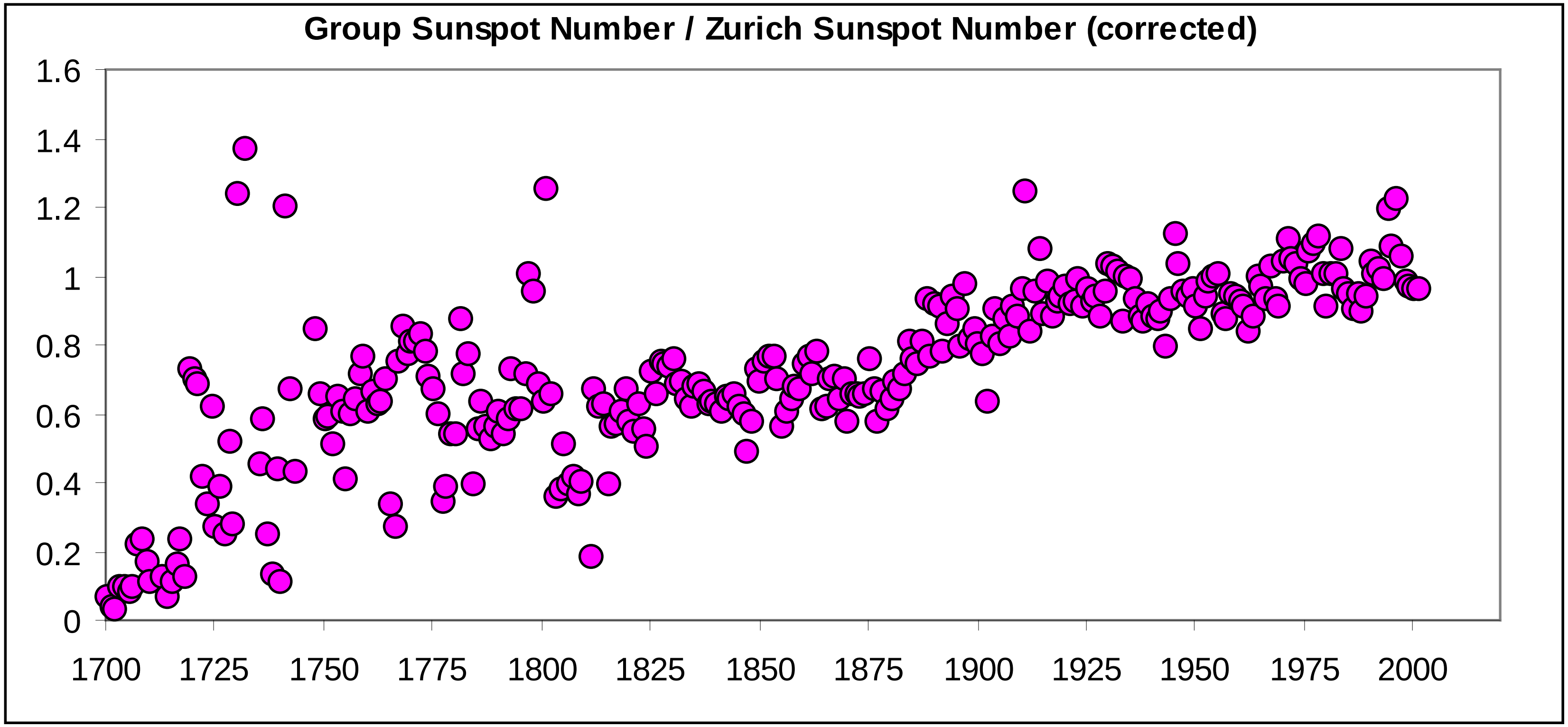


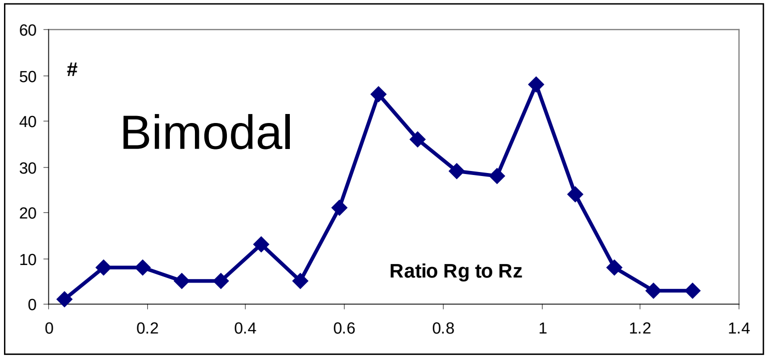






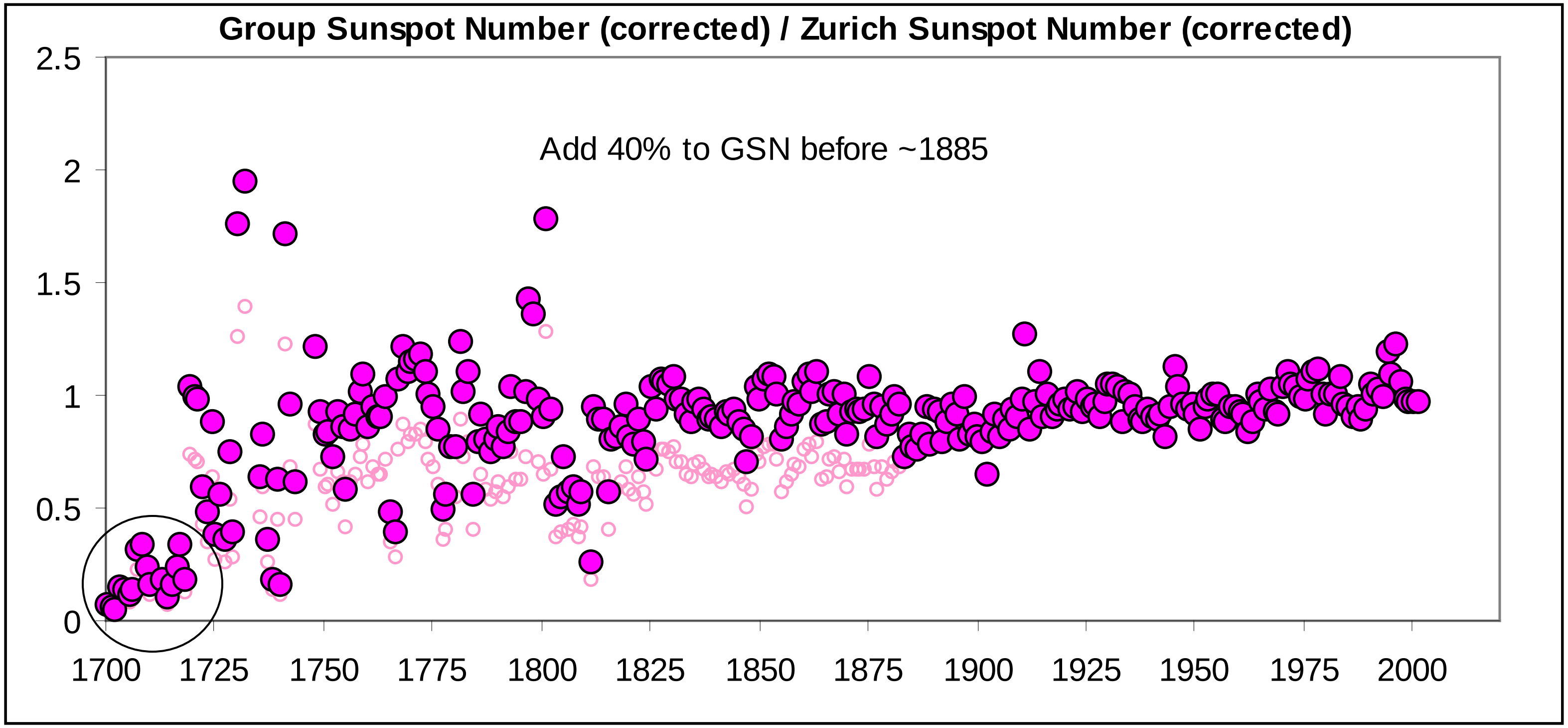
What About the Group Sunspot Number?





The Group Sunspot Number (Rg = 12 G) is systematically lower that the Zurich Number before ~1885

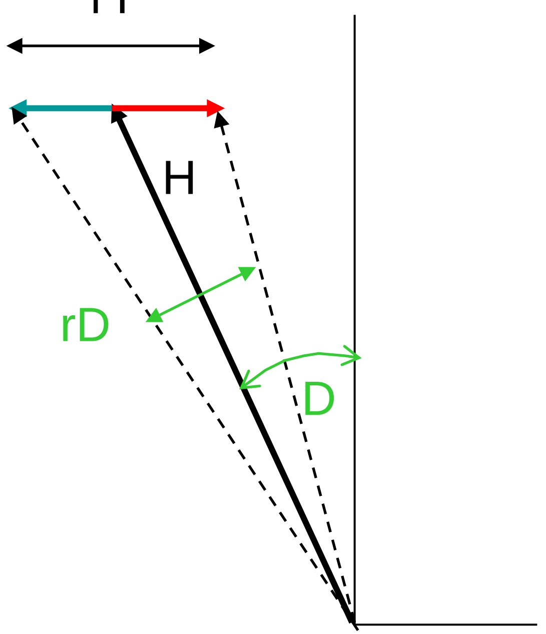
What About the Group Sunspot Number?

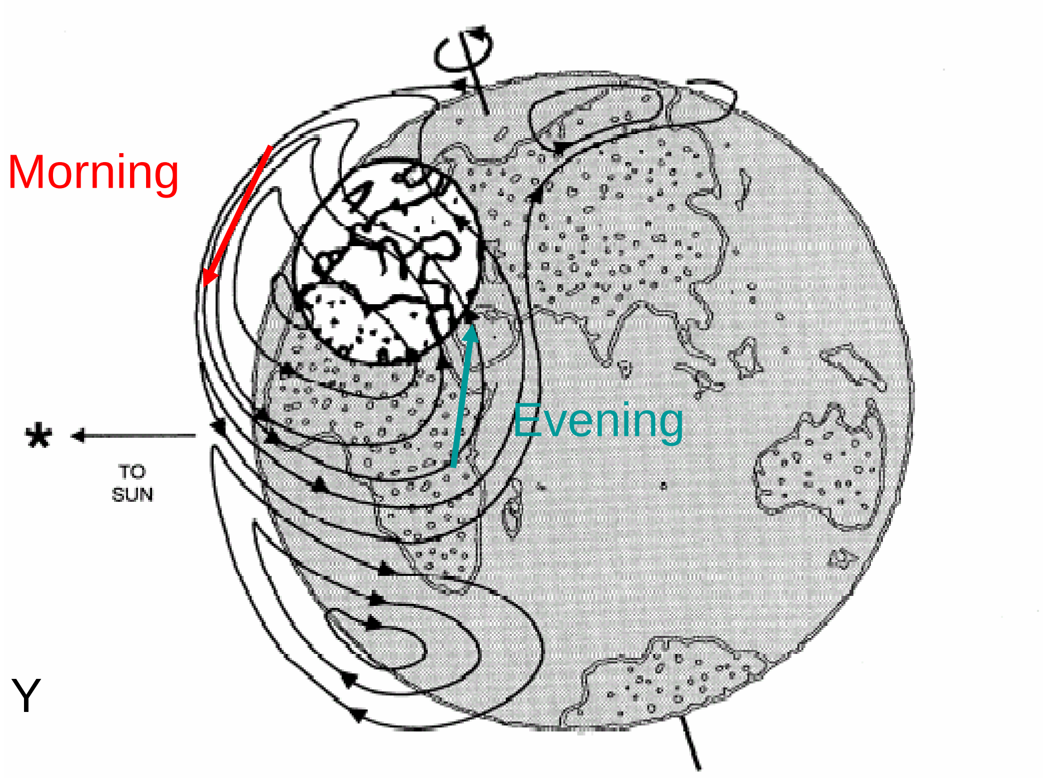


Adding ~40% to the Group Sunspot Number before ~1885 puts the Rg on the same scale as the (corrected) Zurich Number Rz.

How do we know that it is Rg that needs correcting and not Rz?

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



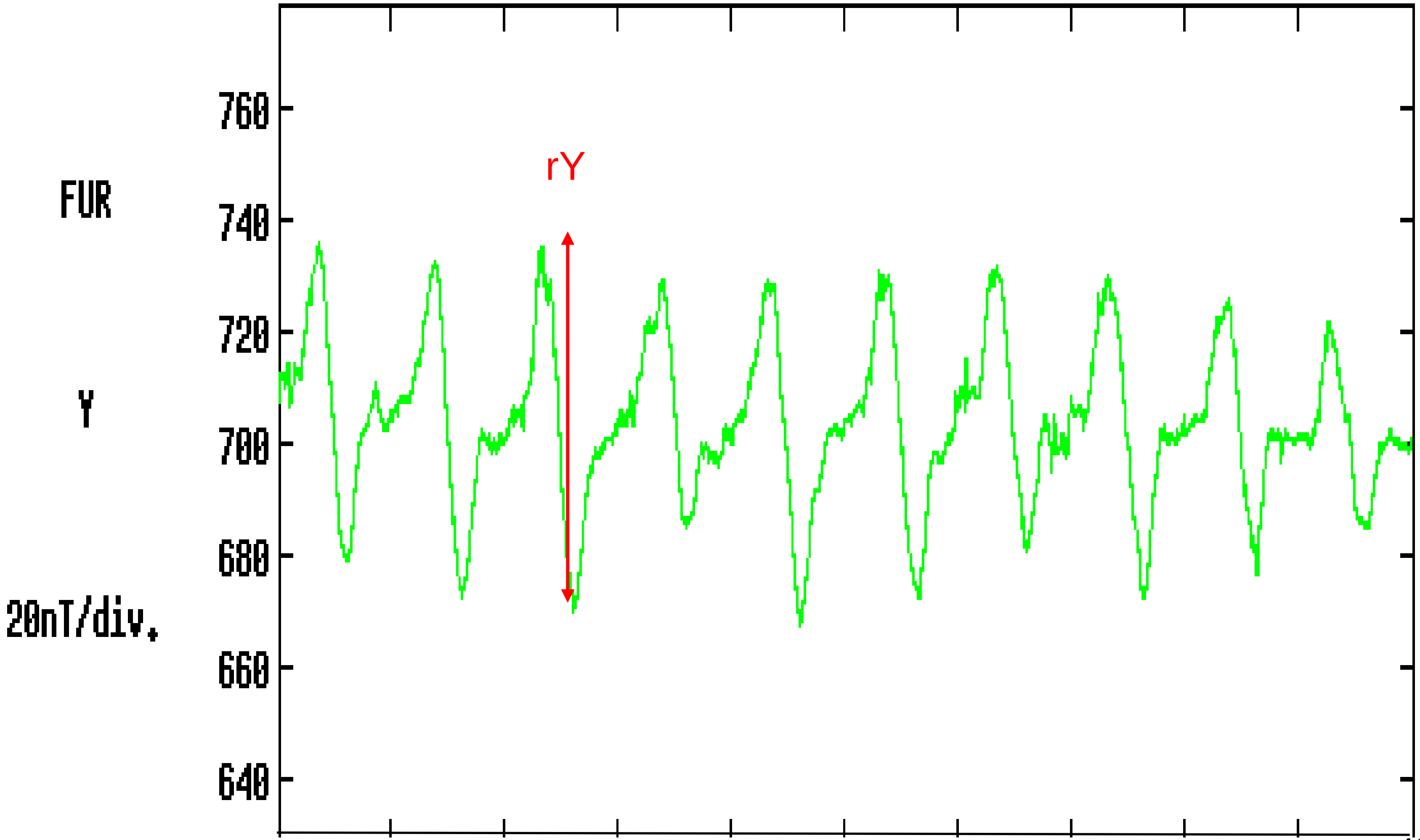


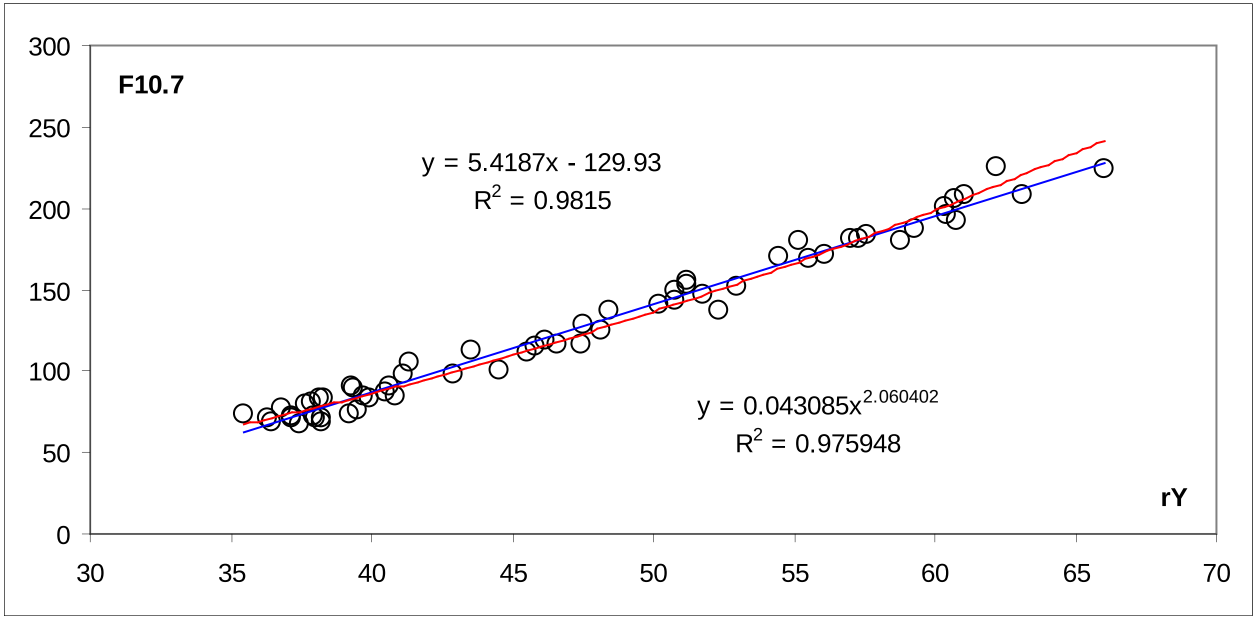
$Y = H \sin(D)$

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

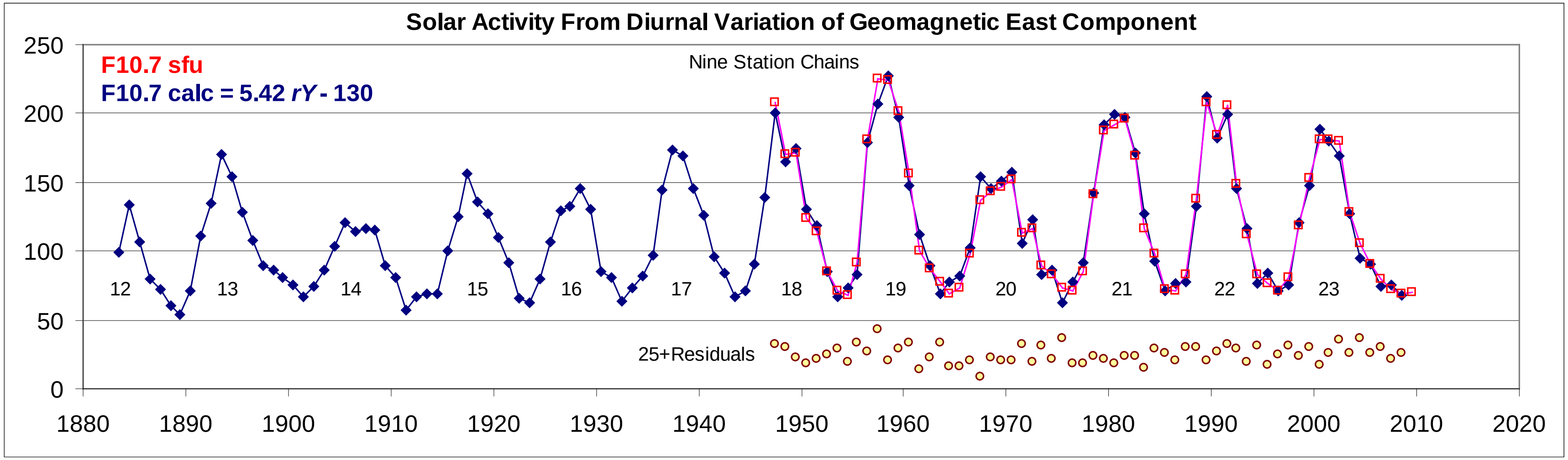
A current system in the ionosphere is created and maintained by solar FUV radiation

10 Days of geomagnetic variations



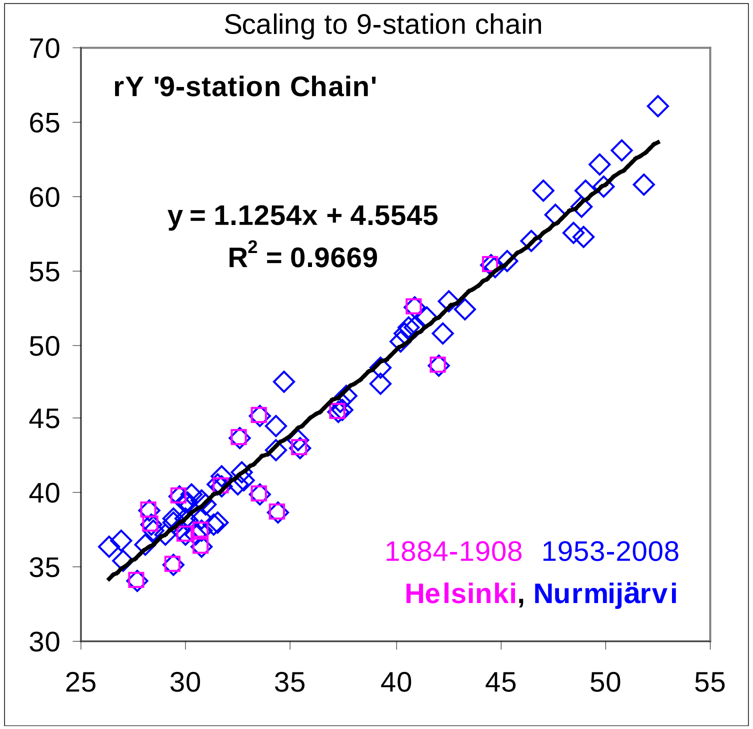


Using *rY* from nine 'chains' of stations we find that the **correlation** between *F10.7* and *rY* is extremely good (more than 98% of the variation is accounted for)

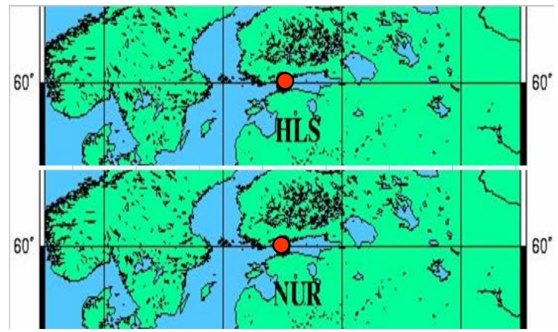


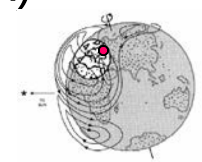
This establishes that Wolf's procedure and calibration are physically sound

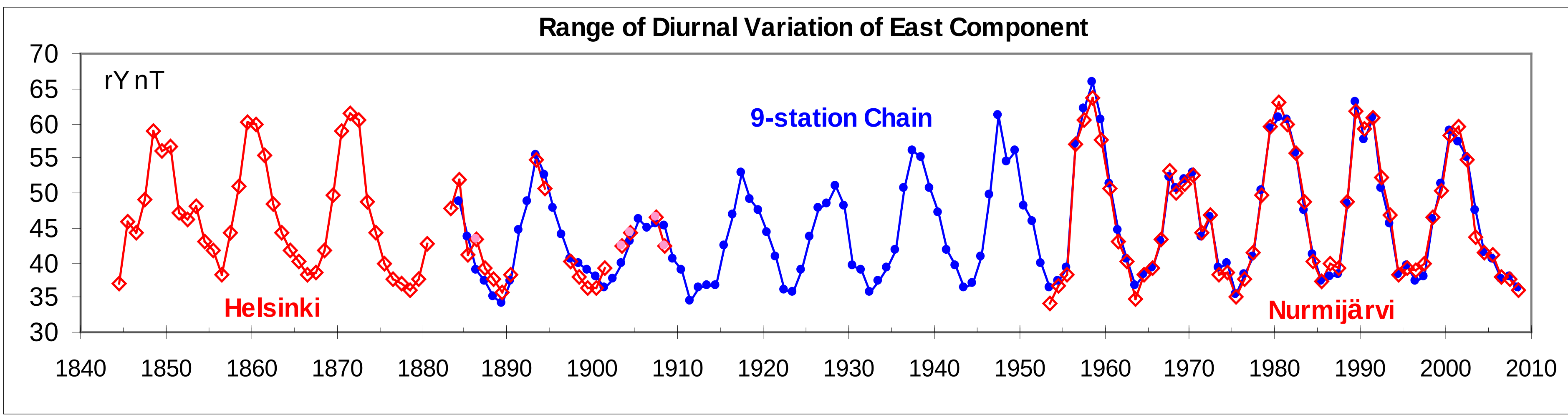
Helsinki-Nurmijärvi Diurnal Variation



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)

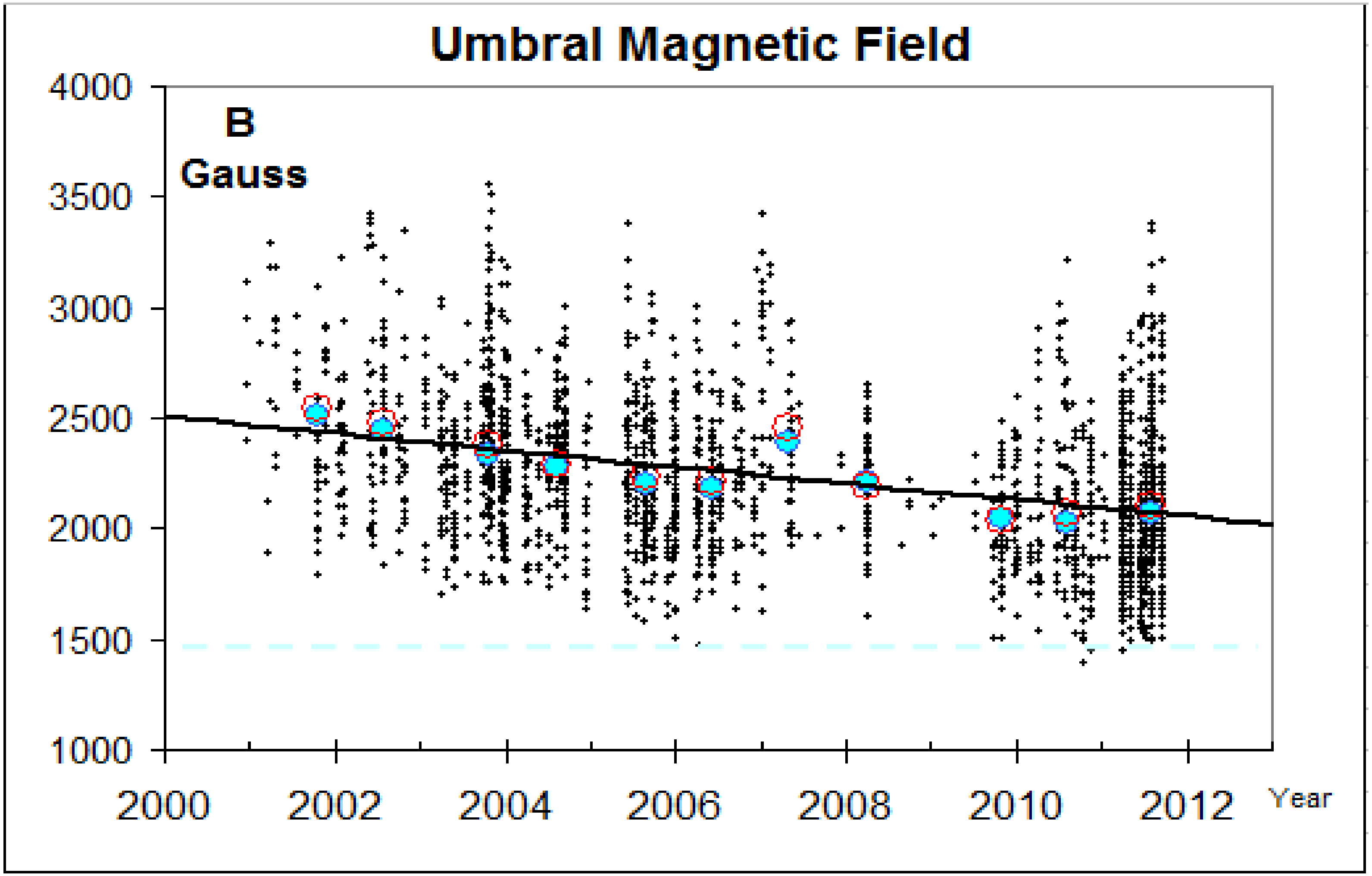






This is how we know that Rz is correct

Since at least 2000 the magnetic field of spots have steadily decreased

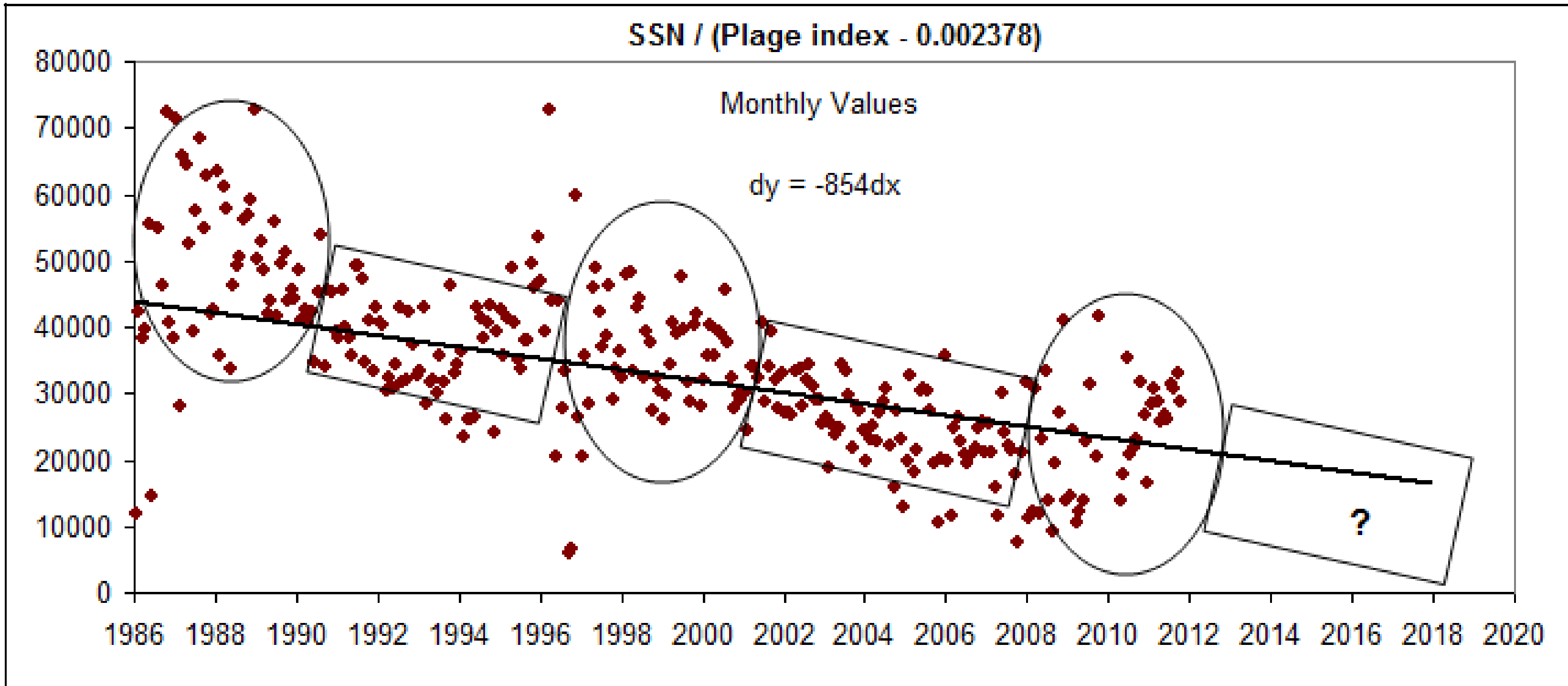


Livingston & Penn Effect

Speculation: Perhaps the Maunder Minimum was just an extreme L&P effect. The dynamo was still working, but the magnetic field did not [for unknown reasons] assemble into visible spots, just what seems to be happening now

- This might explain why there still was a strong cosmic ray modulation during the MM.
- I mention this at Lunch with Jürg Beer, Karel Schrijver, and Allan Title last Friday. Allan suggested a test: All that magnetic field should be around as plages, so plotting sunspots vs. plage areas should show a progressive deficiency of spots.

For a given CA II K-line index there are progressively too few sunspots

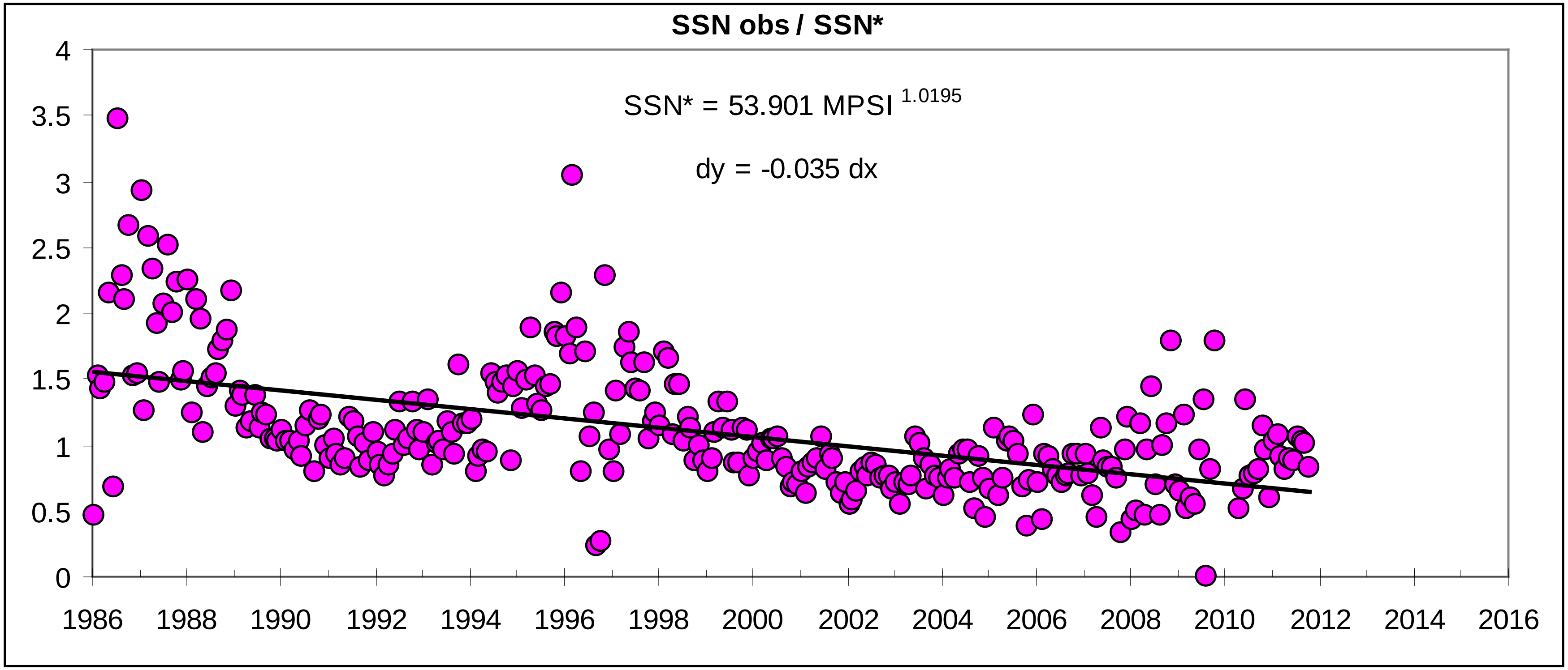


The Plage index is MWO's Magnetic Plage Strength Index MPSI:

For each magnetogram taken at the 150-Foot Solar Tower, a Magnetic Plage Strength Index (MPSI) value is calculated. To determine MPSI we sum the absolute values of the magnetic field strengths for all pixels where the absolute value of the magnetic field strength is between 10 and 100 gauss. This number is then divided by the total of number of pixels (regardless of magnetic field strength) in the magnetogram. The MPSI has been scaled by Luca Bertello to match the Ca II K-index. The calibration after 1986 is believed to be good.

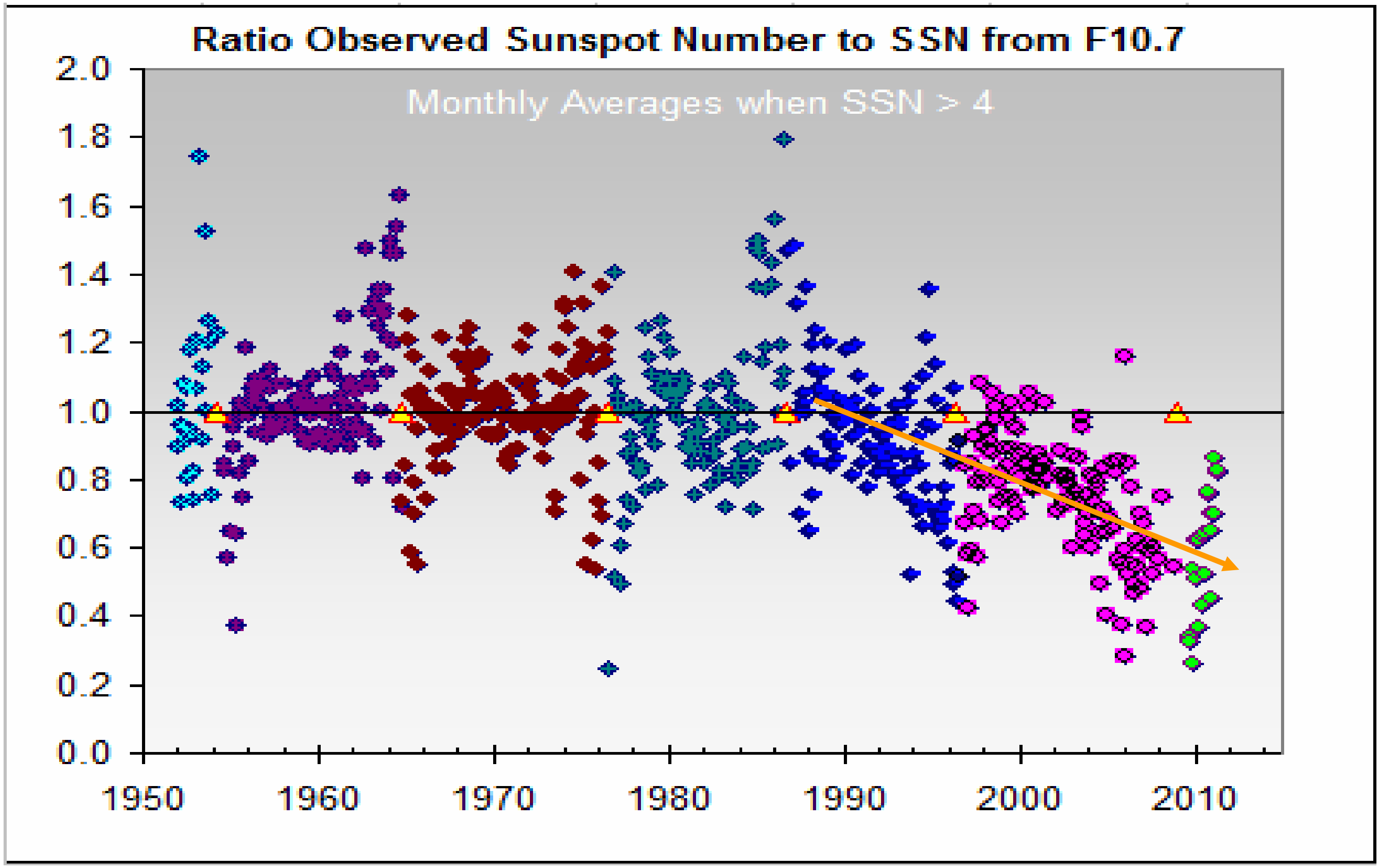
The rising phase seems to be slightly higher than the declining, but the overall trend is a decline of sunspot numbers compared to the plage index.

Same result if using MWO’s MPSI directly: The Sunspot Number is dropping



We show the ratio between observed SSN and the linearized MWO Plage Index

For a given F10.7 flux there are also progressively too few sunspots



What to do about all this?

Credit line: *Dave Dooling, NSO/AURA/NSF*

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.

The first was in Sunspot, NM, Sept. 2011. The next in Brussels, Belgium, May 2012

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