The Effect of Weighting and Group Over-counting on the Sunspot Number

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Where the Story Plays Out

Observed 1849-1893

1849-1855 Bern

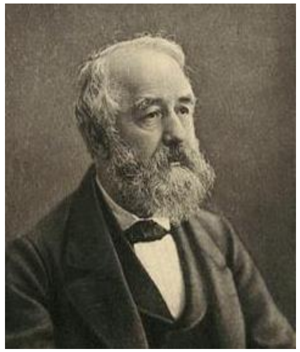
1856-1893 Zürich

- Wolf Number = k_W (10*G + S)
- G = number of groups
- S = number of spots
- k_W = telescope aperture + site + seeing + acuity + learning curve + age + counting method + …

Principal Actors and Observers

Samuel Heinrich Schwabe
1789–1875

(1825-1867)

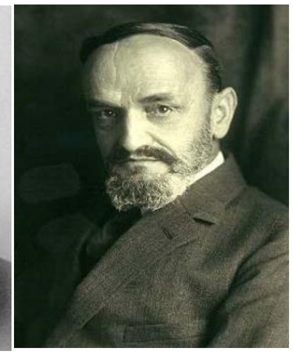


Johann Rudolf Wolf
1816-1893

(1849-1893)

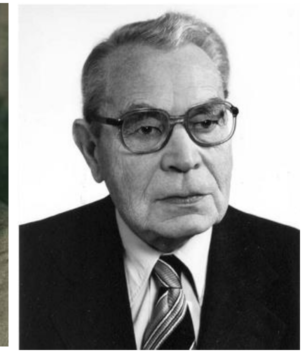
Alfred Wolfer
1854-1931

(1877-1928)



William Otto Brunner
1878-1958

(1926-1945)



Max Waldmeier
1912-2000

(1945-1980)

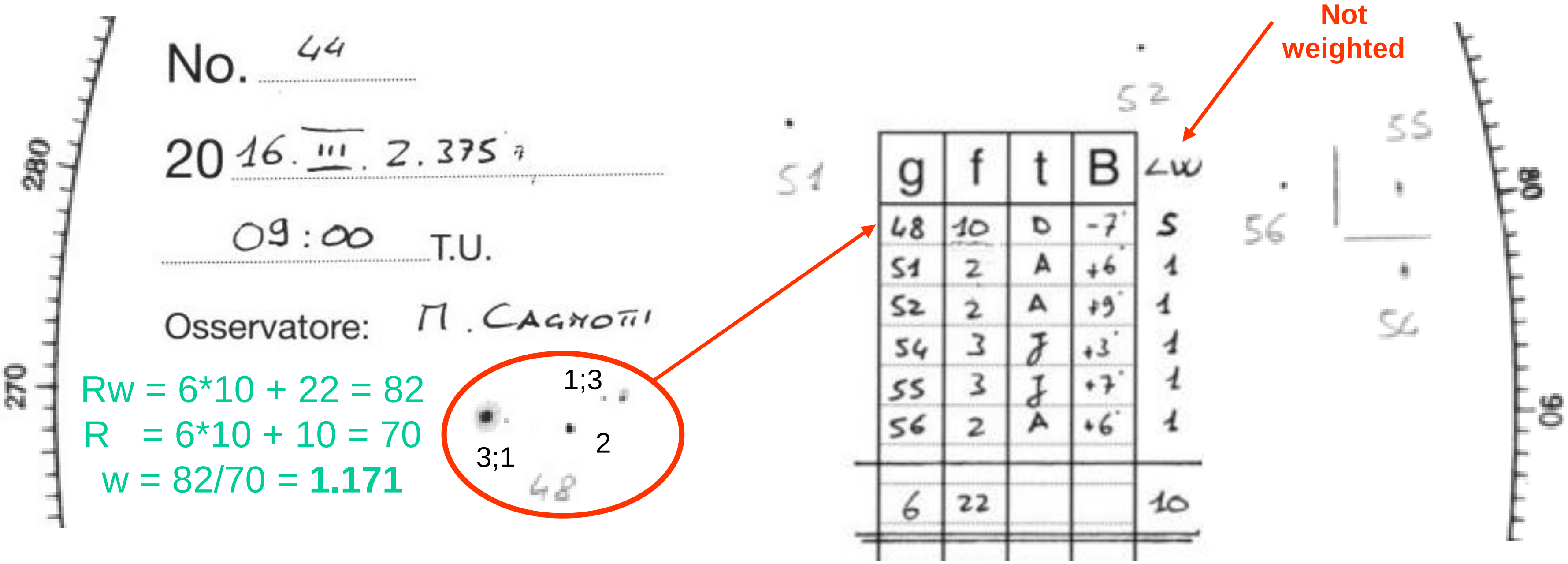
Sergio Cortesi
-

(1957-present)

Directors of Zürich Observatory

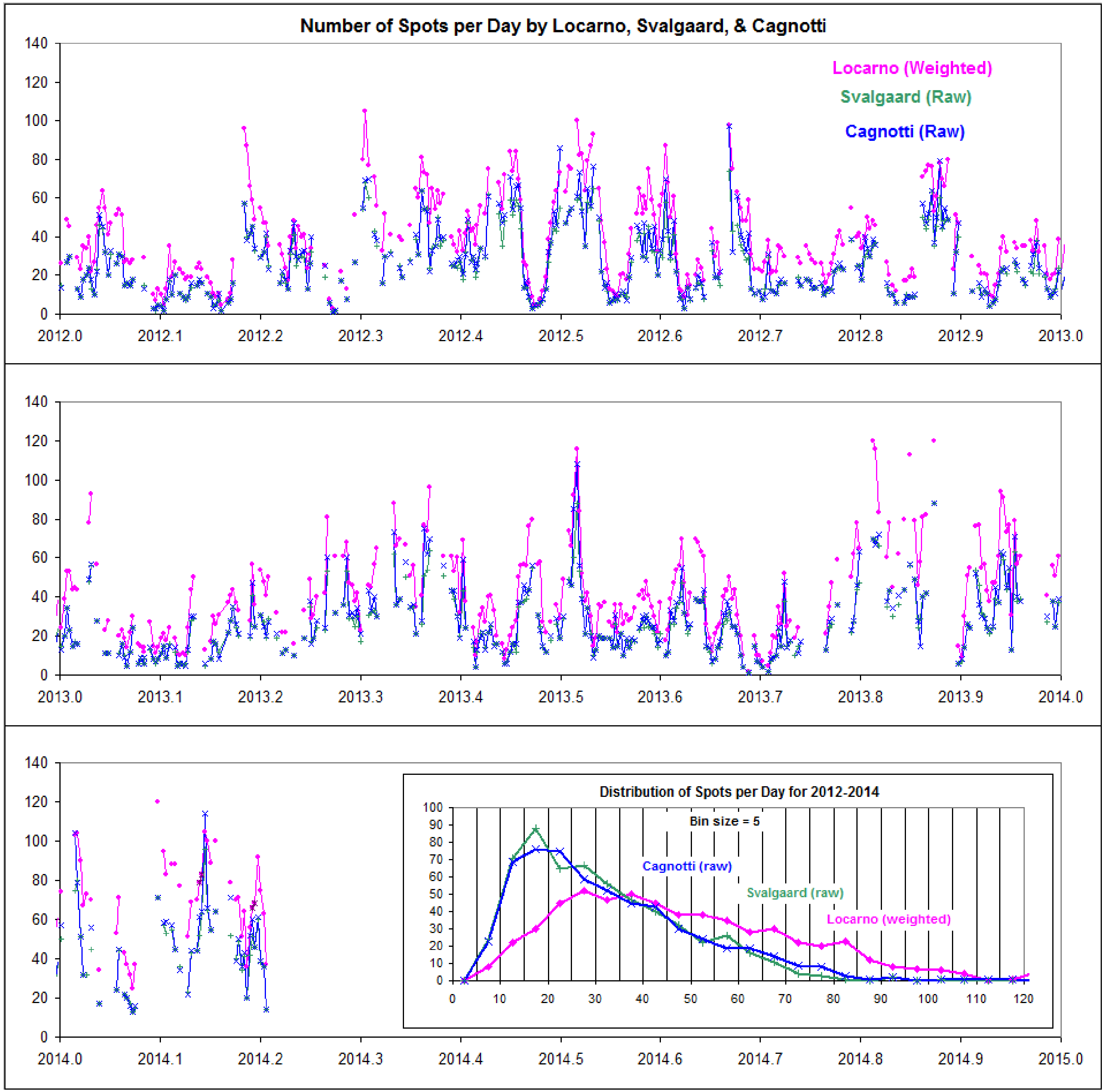
1825-1980 the Sunspot Number (SSN) was derived mostly from a single observer. Since then, the SSN is determined by SILSO in Brussels [Belgium] as an average of ~60 observers normalized to Cortesi in Locarno

It is now well Established that Locarno Observers Weight the Sunspot Count



Waldmeier's Weighting Rules: "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

The Locarno observers since August 3, 2014 report both weighted and un-weighted spot counts, but anybody can also determine the un-weighted count by simply counting spots on the drawings [back to 1957; since 1981 online]. I have done this since 2003.

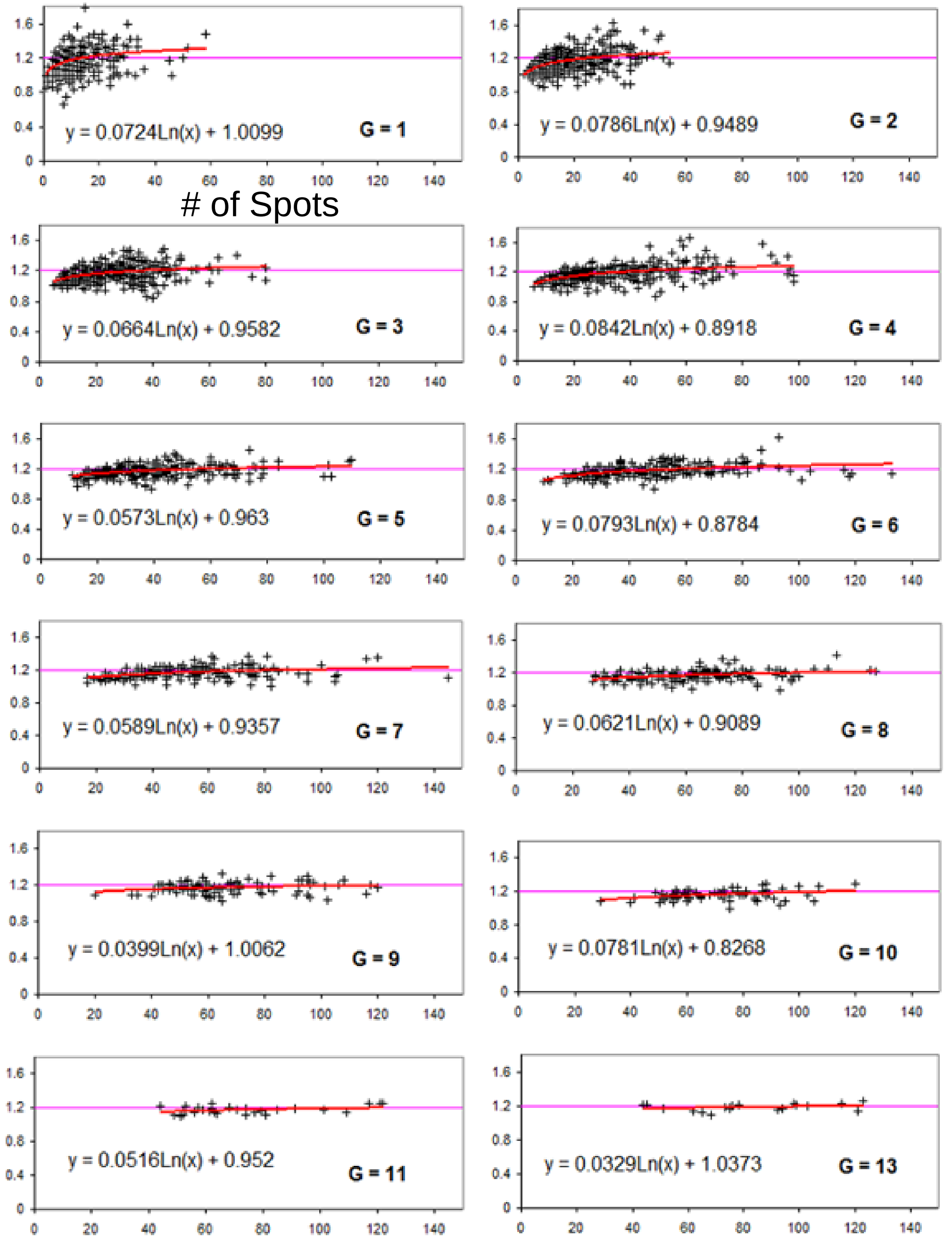


Comparing Direct Spot Counts by Marco Cagnotti & Leif Svalgaard

My raw counts match Marco's very well

I have recounted the ~60,000 spots for all observations since 2003 and the Locarno observers are now taking that back to the start of their series (1957).

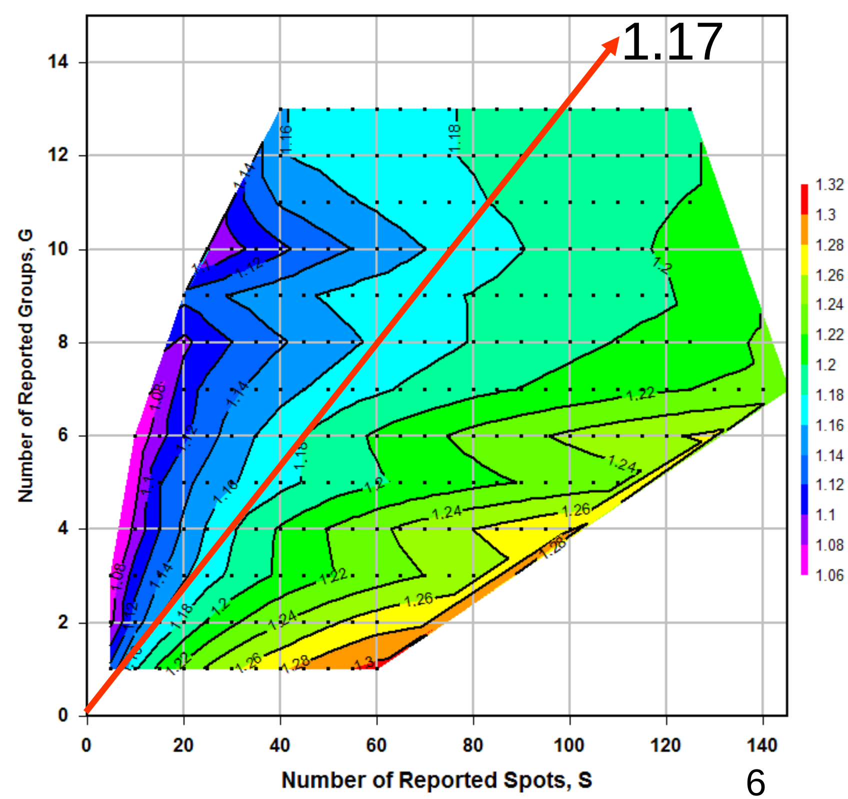
Sunspot Weight Factor as a Function of Number of Reported Spots for Different Bins of Number of Groups

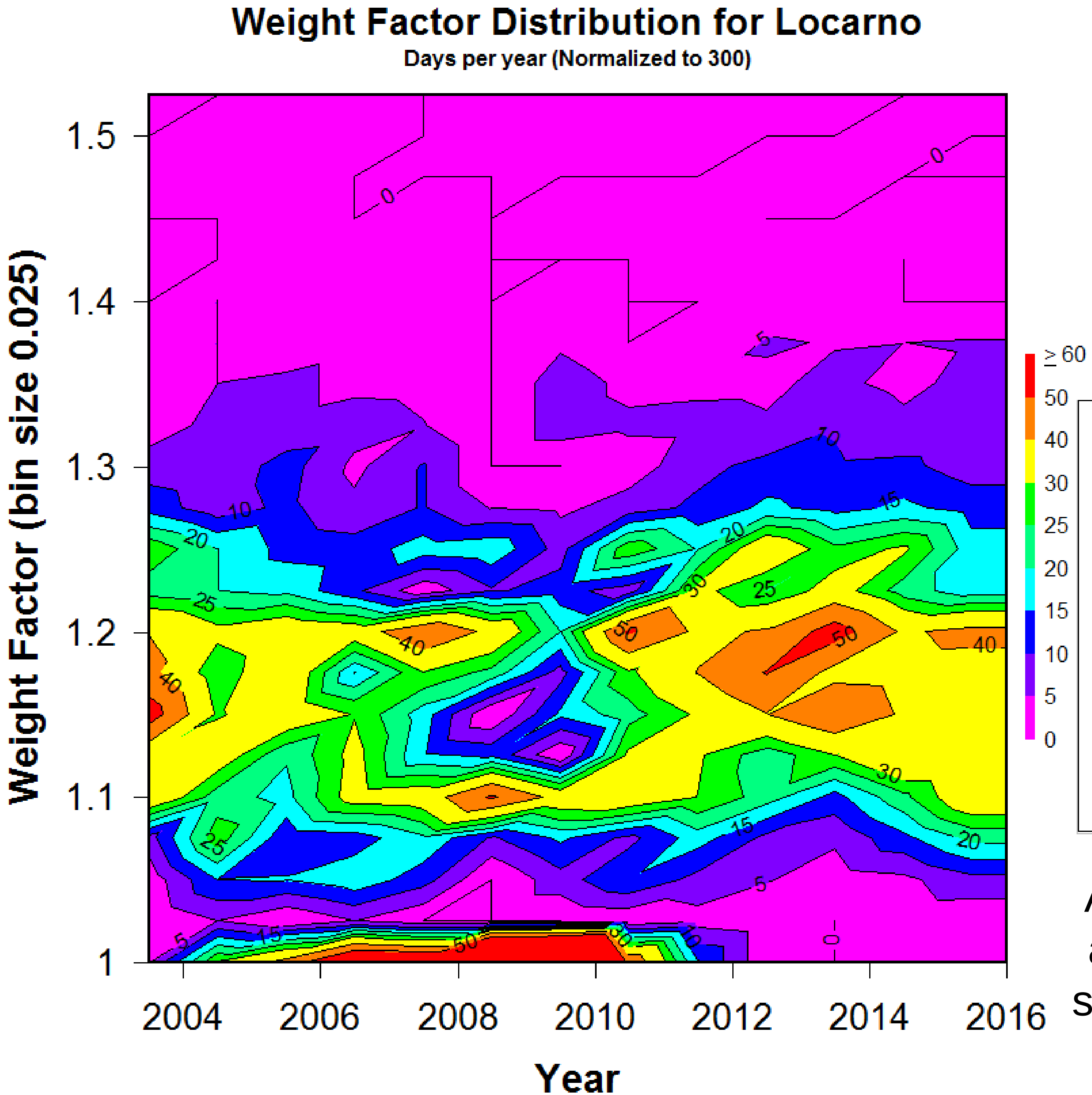


On average a constant weight factor (of 1.17) seems to work well, but it is more complicated than that. The weight factor depends on both the number of spots and on the number of groups, approaching 1.2 at high activity (pink lines). Daily values shown.

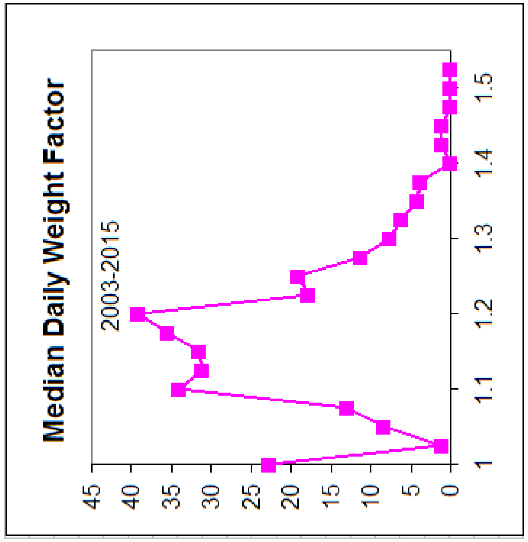
Weight Factor as a Function of S(reported) and G(reported)

Locarno 1997-2015



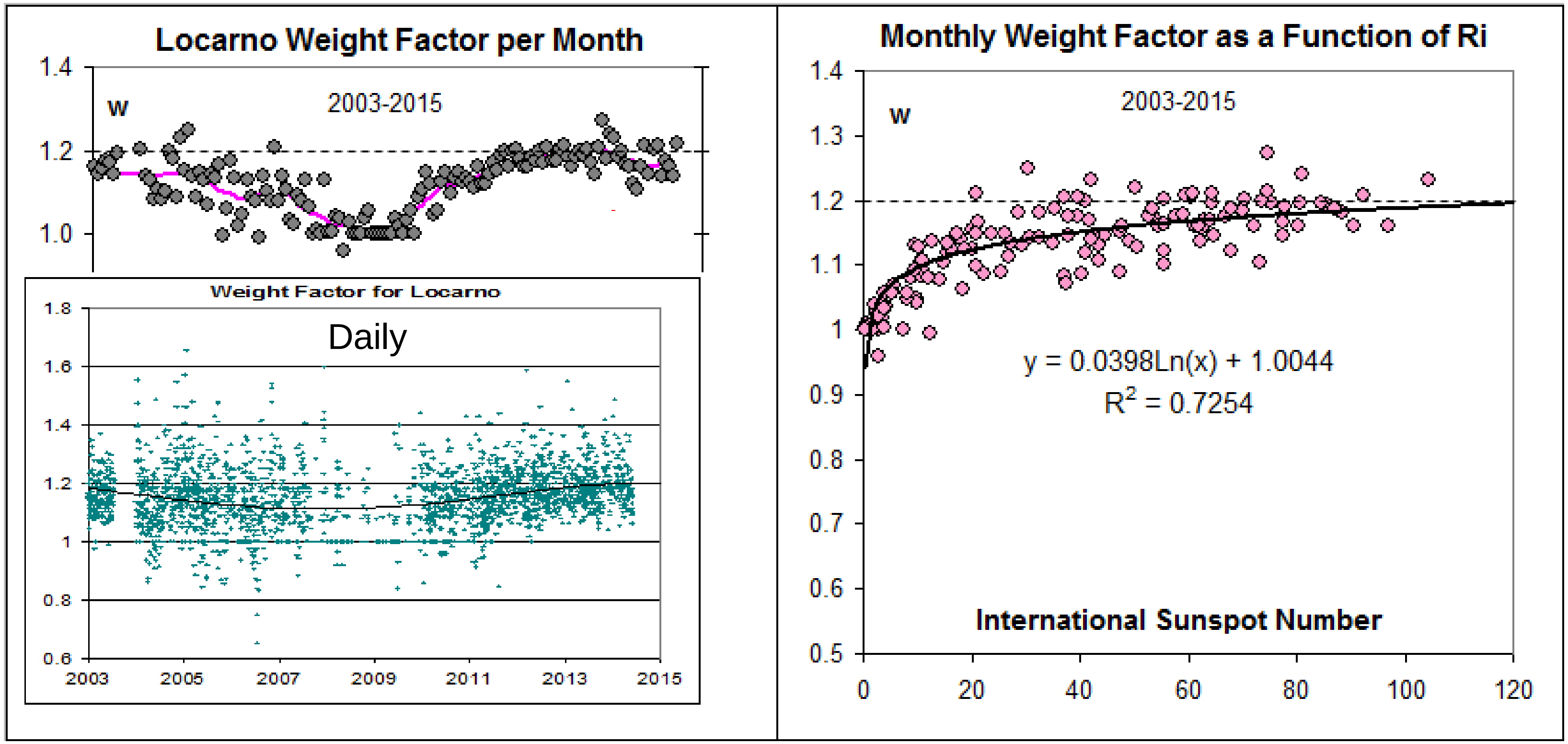


Distribution of Daily Weight Factors



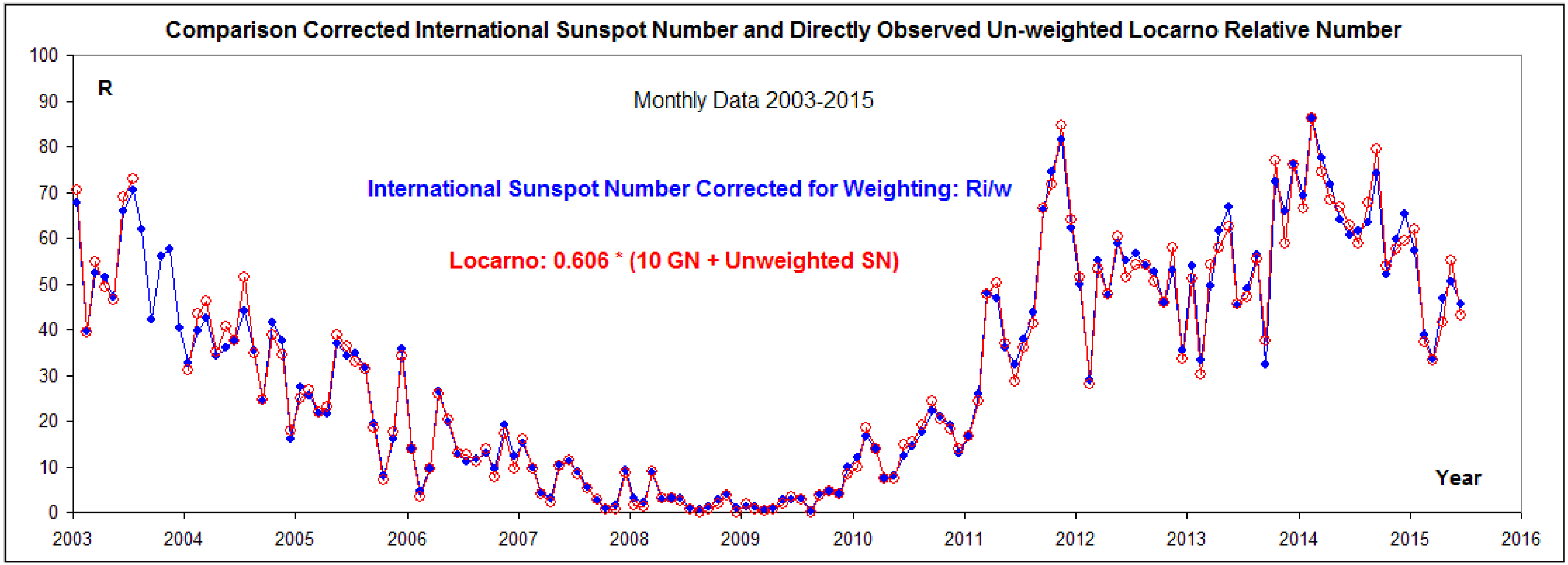
At low activity there are few large spots so weighting is slight

If monthly averages are used, the dependence on Group Number is much reduced



The non-linear relationship $w = 1.00 + 0.0398 \ln(R_i)$ is a good fit [$R_i > 0.1$]

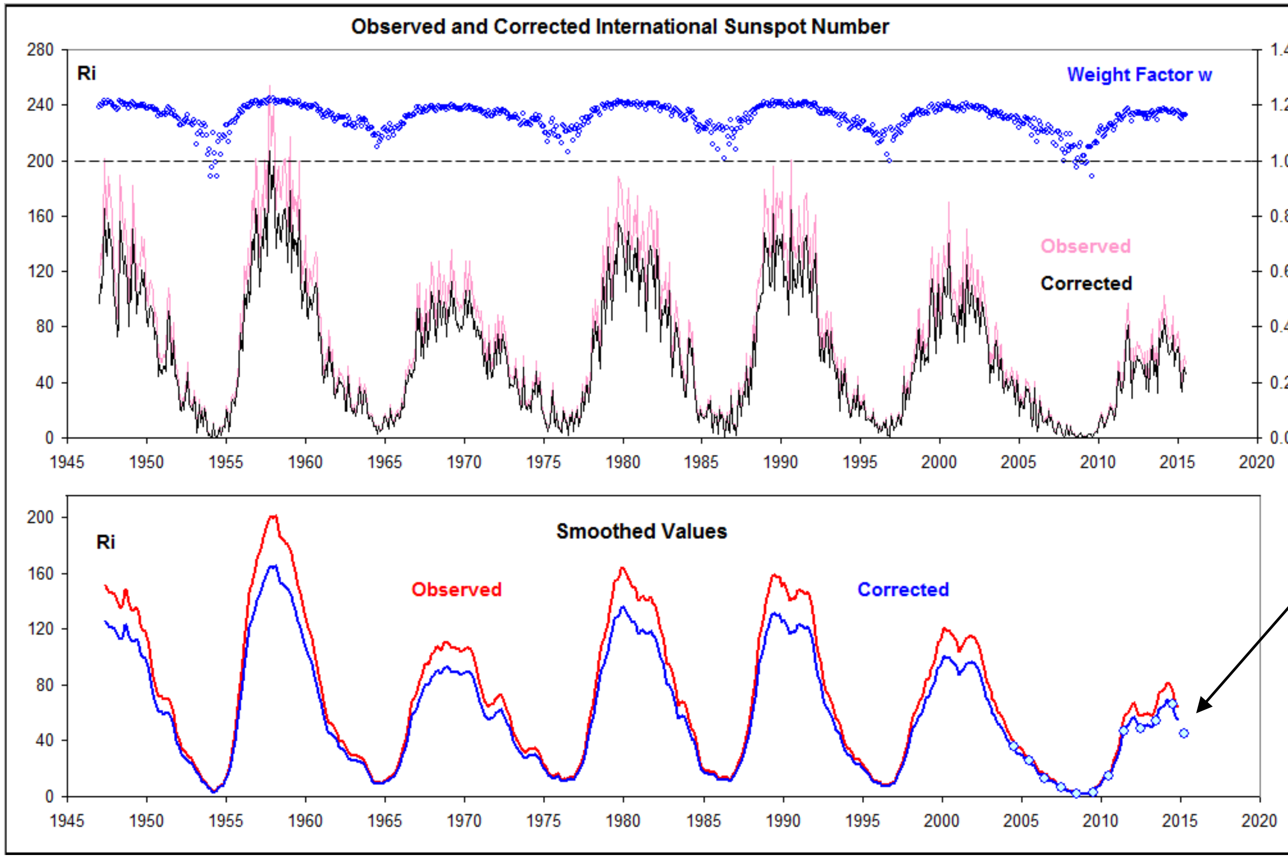
How well can we correct R_i? Very well, indeed



Conclusions on Weighting (1):

1) We have determined the weight factor by **direct** observation
2) We can correct for weighting with high precision (R^2 = 0.991)
3) Weighting is non-linear and simple-minded analysis will not do
4) Going forward, no more weighting in SSN Version 2

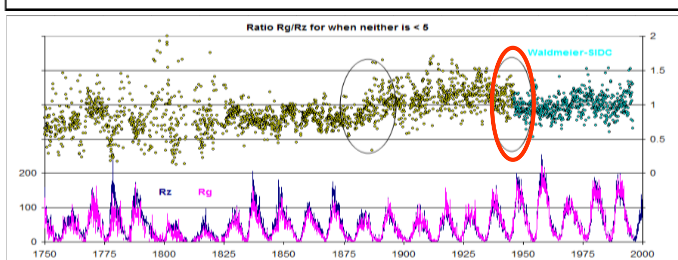
SSN with/without Weighting



The weight (inflation) factor

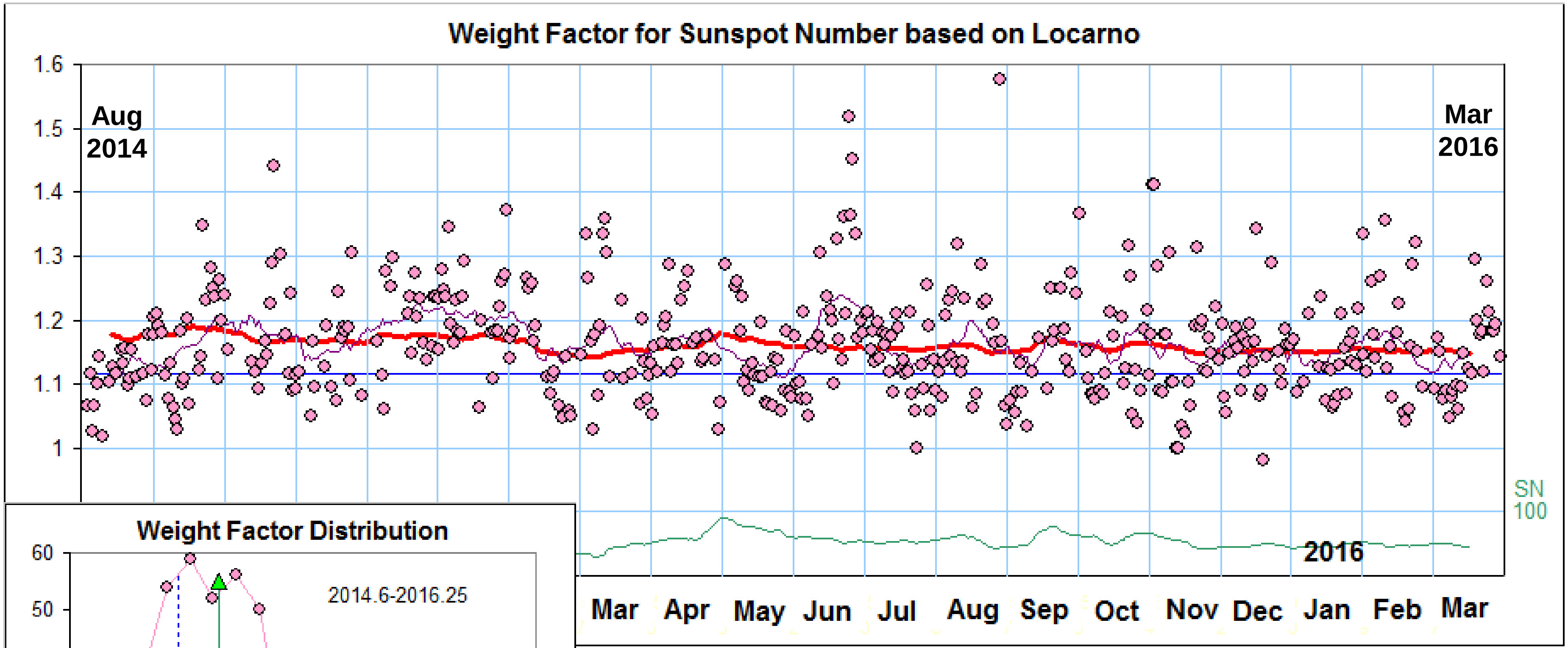
The observed (reported) SSN (pink) and the corrected SSN (black)

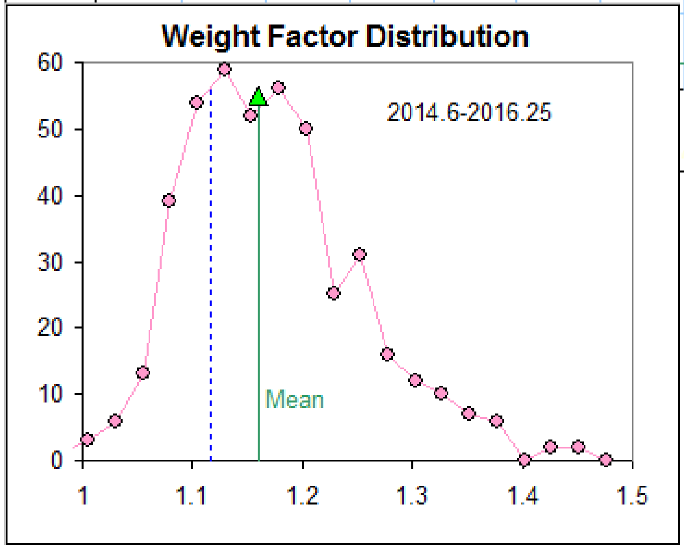
Light blue dots show yearly values of un-weighted counts from Locarno, *i.e.* not relying on the weight factor formula. The agreement is excellent



The inflation due to weighting largely explains the second anomaly in the ratio between the GSN and the SSN

We Still Keep Track of the Locarno Weight Factor for Historical Reasons





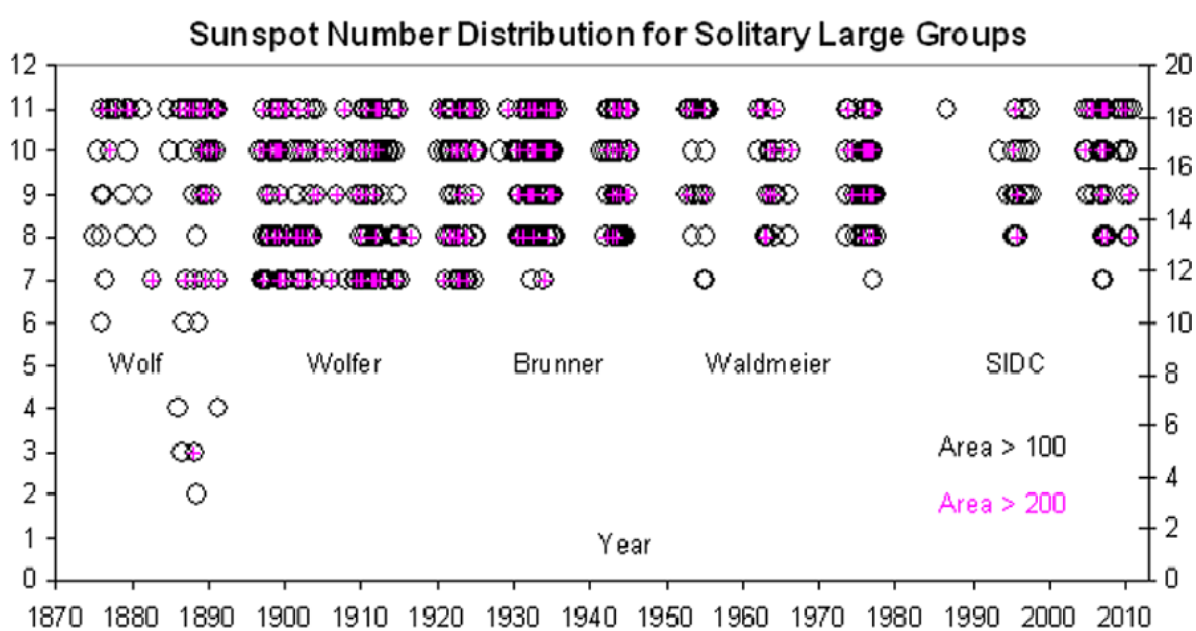
Thin blue line is the claim by Lockwood et al. that clearly is not a good fit to reality, but we don't need to agonize over this as we have **direct** measurements of the weight factor. The red curve is 27-day mean calculated from SN

When Did Weighting Begin?

Waldmeier (1948, 1961) said that wholesale weighting began in 1882 (by Wolf's successors).

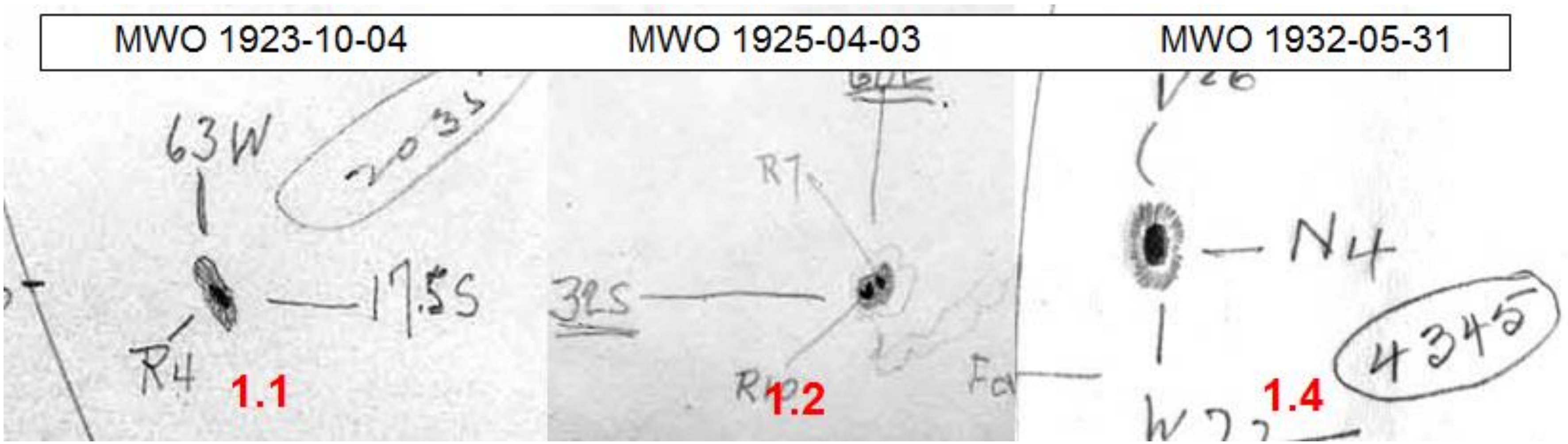
Wolfer (1907) explicitly stated that spots were counted "singly, without regard to their size".

Brunner (1936) hinted that "In large centers of activity one is inclined – and this perhaps rightly – to give some single spots according to their sizes a different weight".



For days where only one group was observed, the sunspot number (if less than 12) for that day (i.e. for that solitary group) is plotted if the projected area of the group is larger than 100 μHemisphere (circles) and larger than 200 μH (pink "+" symbols). The right-hand scale is for sunspot number divided by 0.6, i.e. on the original Wolf scale [Clette 2014, Fig. 33]

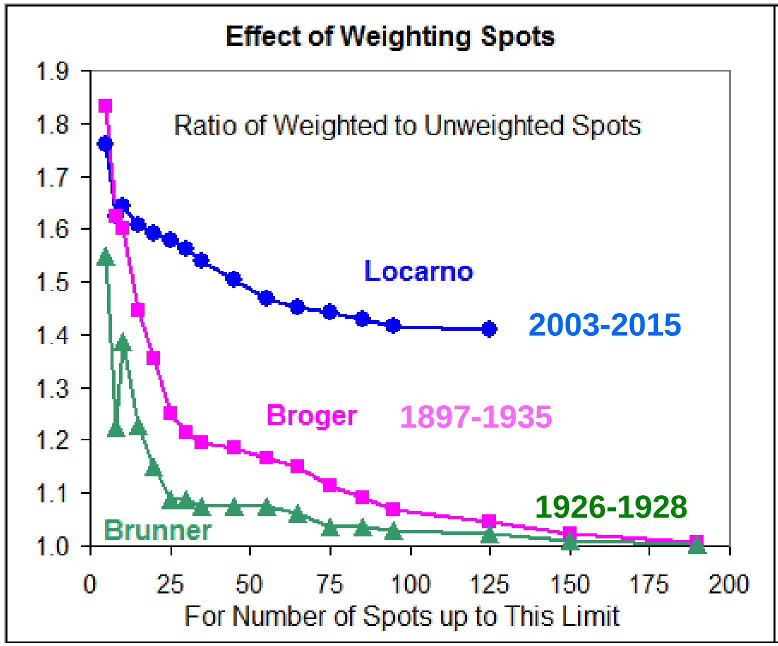
Weighting of Very Large Spots: Wolfer 'No', Brunner 'Yes'



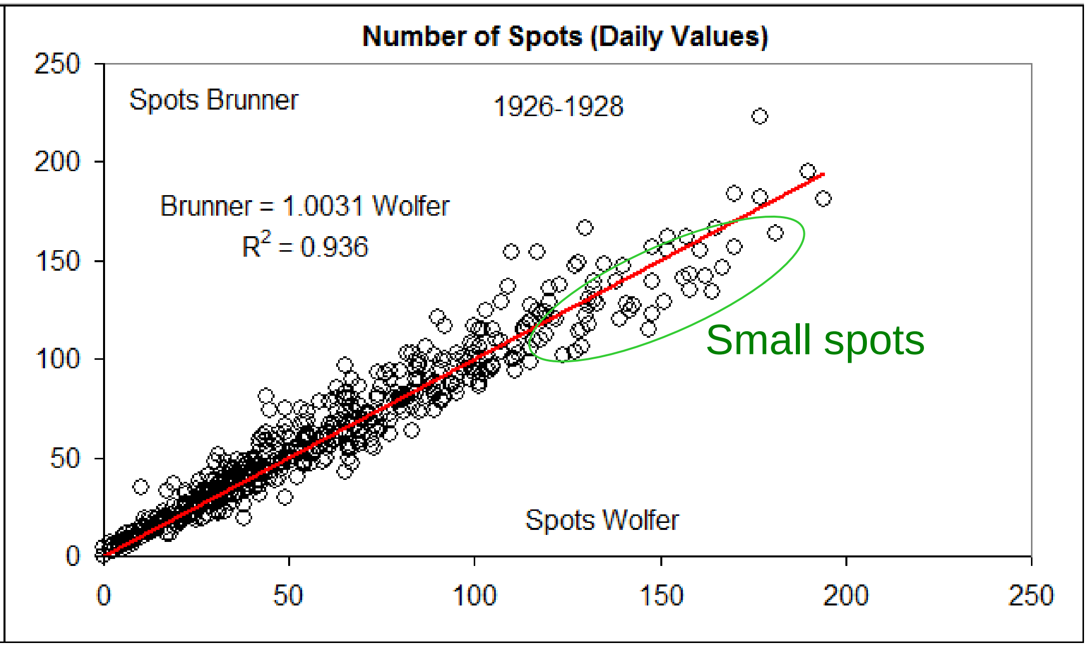
Wolfer Wolfer Brunner

So, we must consider it established that Brunner weighted at least *some* of the spots, perhaps especially very large solitary spots, which would explain the dearth of 7's for Brunner on the previous slide. The questions are now (1) how large the effect of this would be on the sunspot number and (2) how consistently the weighting was performed.

Brunner's weighting had no influence on the [average] sunspot number



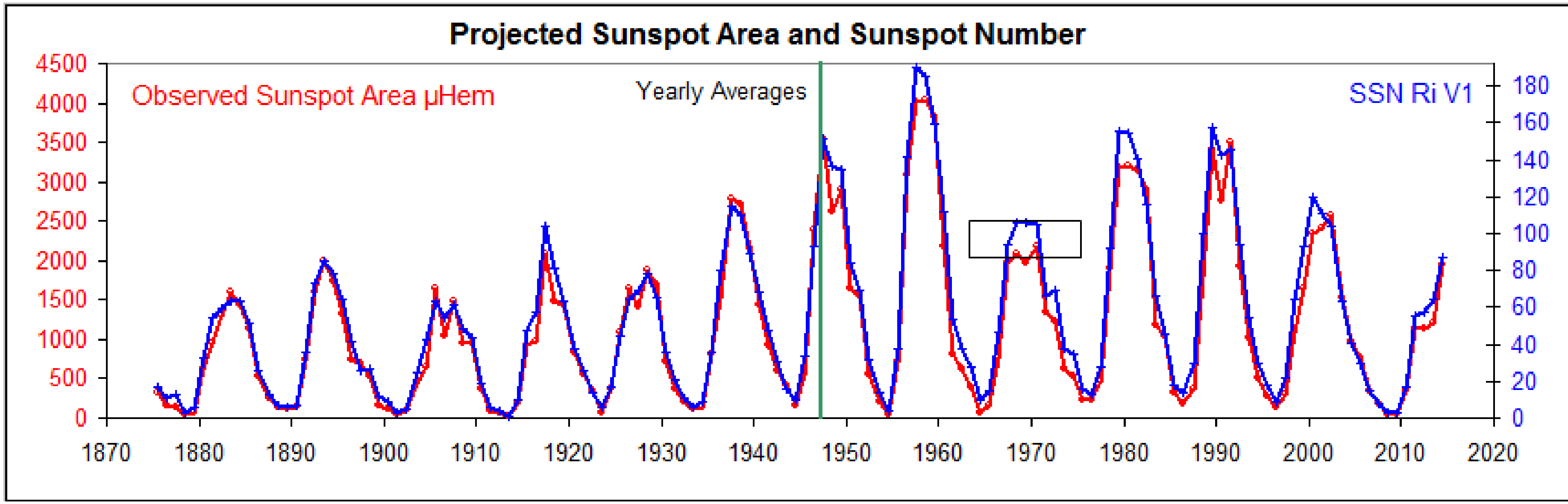
The slope of the correlation between weighted spots and un-weighted spots

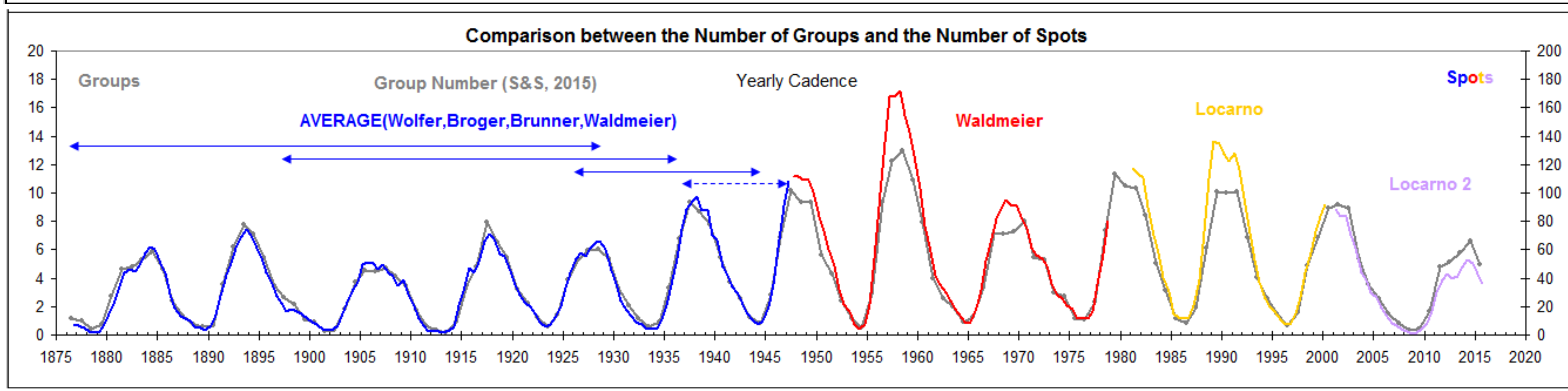


Correlation between daily values of Brunner's reported weighted spot count and Wolfer's reported un-weighted count.

In spite of Brunner's weighting of very large spots, he reports the same *k*-factor (0.60) as Wolfer, so the weighting of large spots must be precisely compensated by counting fewer small spots in order to keep the *k*-factor constant, and hence does not influence the average sunspot number

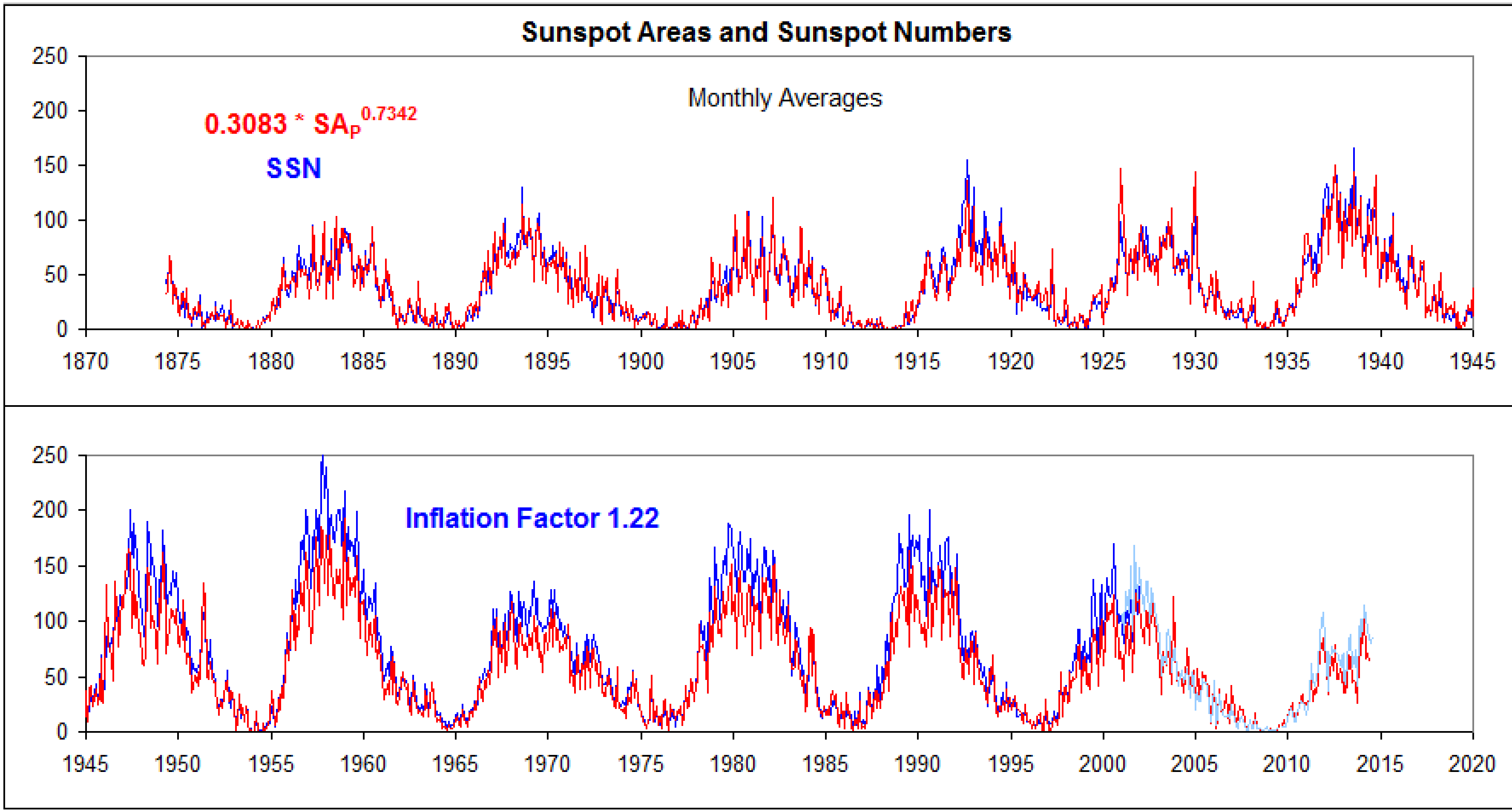
This is also clearly seen in the Record





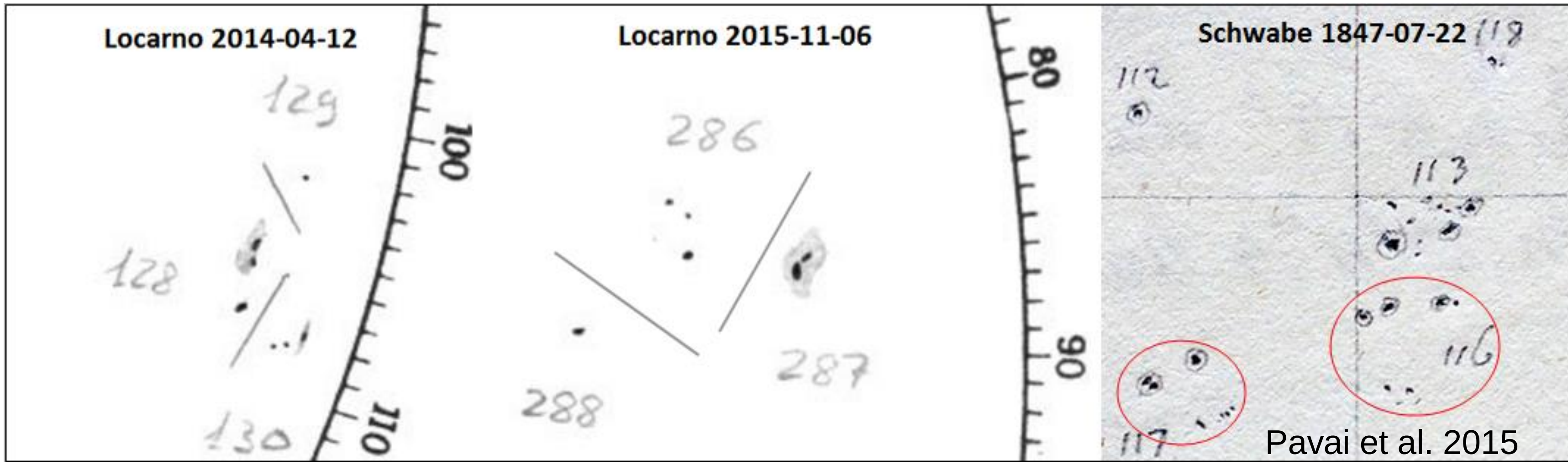
The number of groups and the sunspot areas are not influenced by the weighting

And in a Closer Look at the Sunspot Areas



Areas: Balmaceda et al. 2009 updated from Hathaway 2016 website

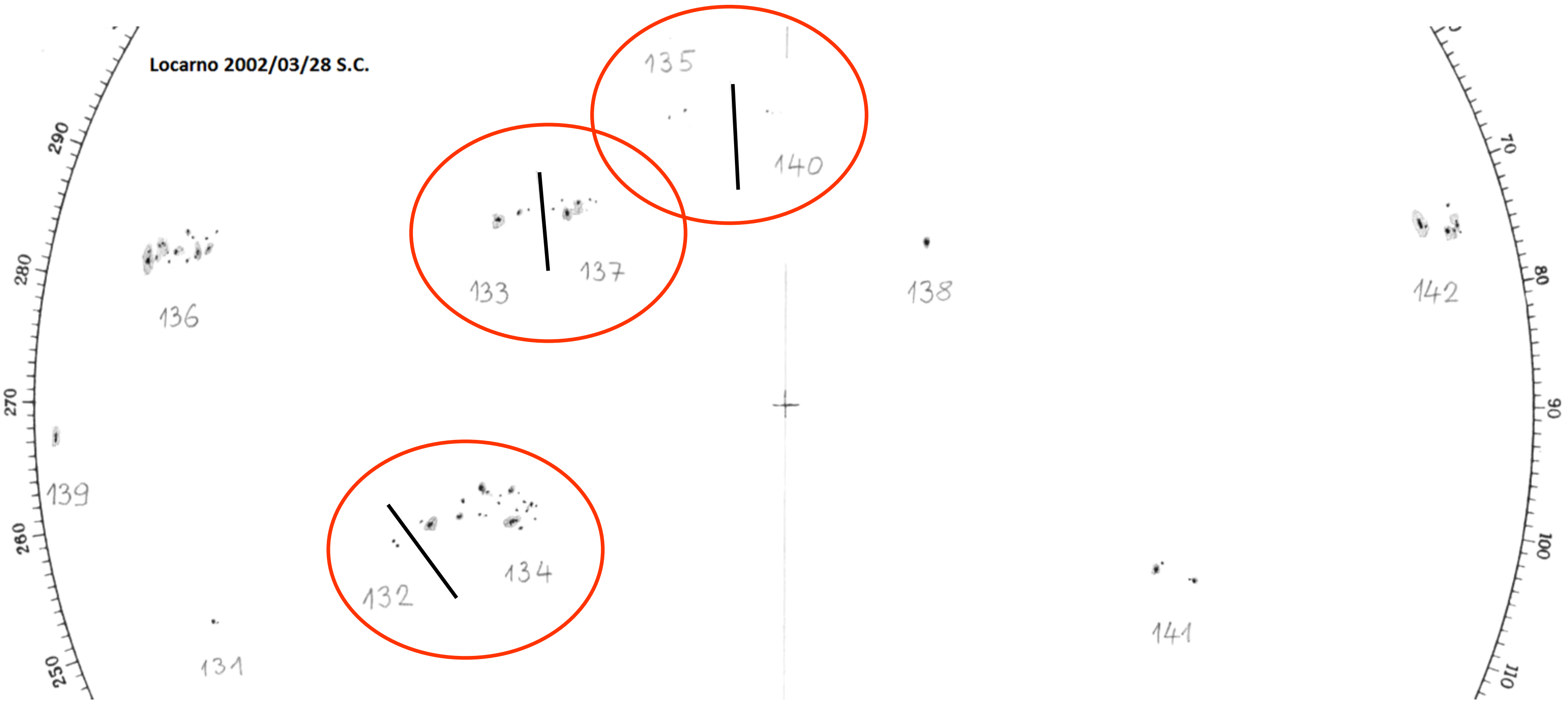
What is a Group?
Groups are HARD to determine



Kopecký et al. (1980) cite the Zürich observer Zelenka drawing attention to the possible inflationary effect of the introduction of the Waldmeier Group Classification around 1940. The Classification offered a unified definition including taking into account the temporal evolution of the group.

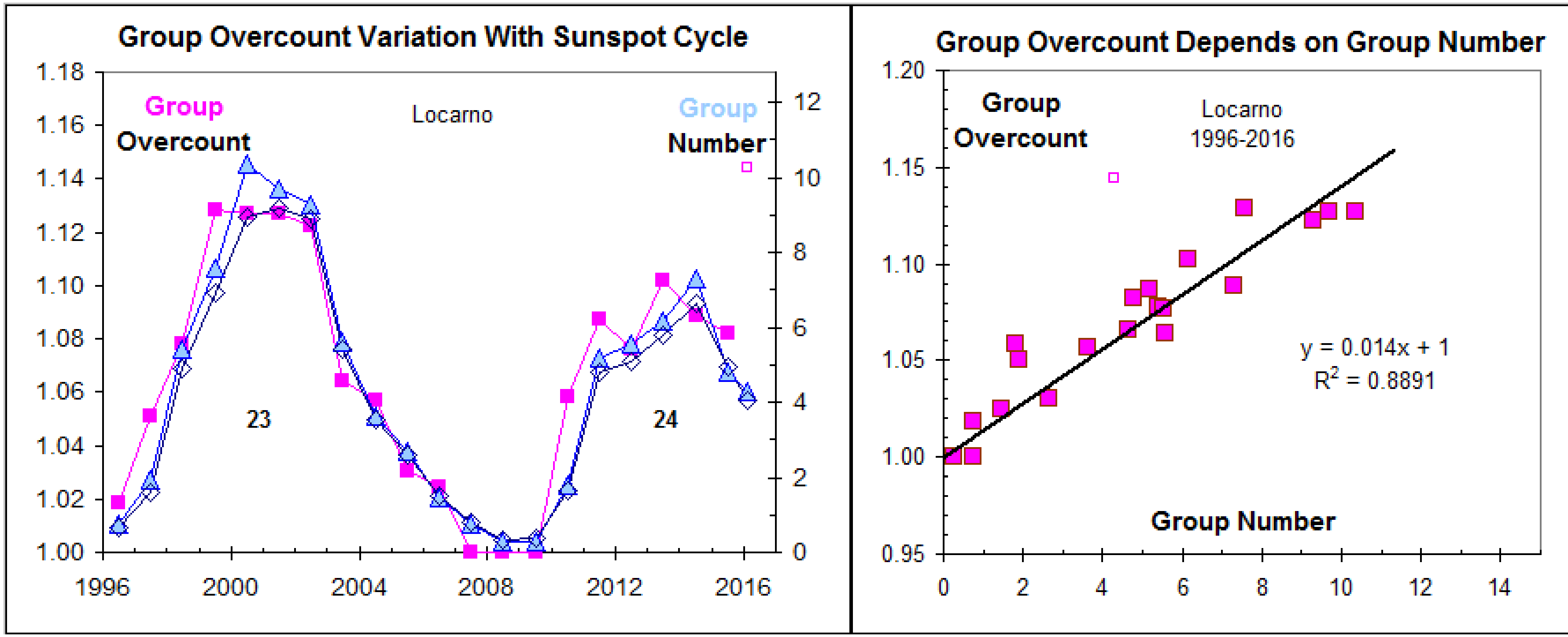
Early on, a sunspot group was defined solely on the basis of its morphology and location relative to other groups. Sunspot groups were at first considered just to be spatially separate assemblies of sunspots.

Modern (Locarno) Overcount of Groups



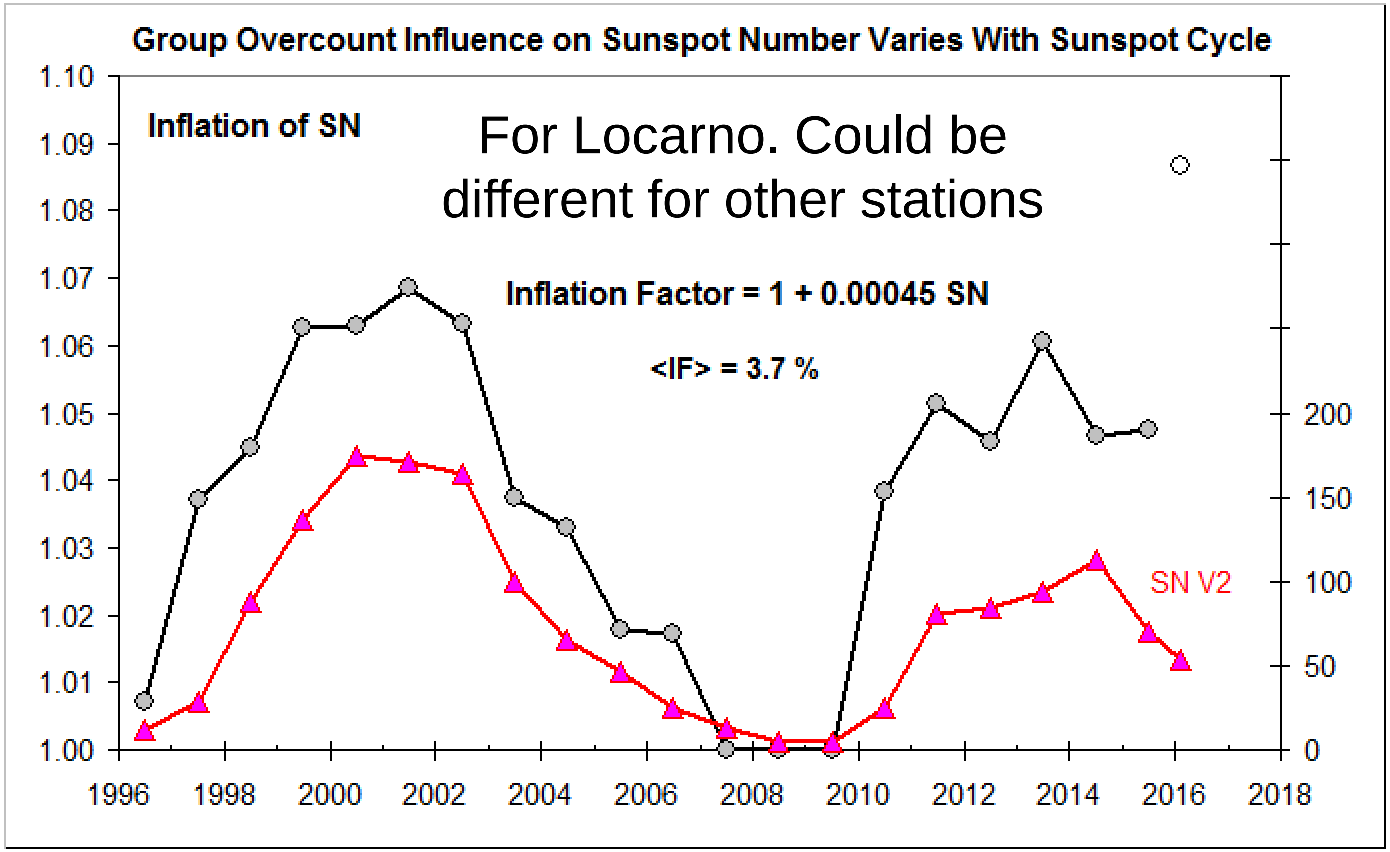
Locarno counted 12 groups. Applying the morphological criteria, I see only 9 groups. I have recounted the groups on Locarno's 6025 drawings since 1996 using the older morphological criteria. A database with the counts is available on my website http://www.leif.org/research

Overcount Dependence on Activity



As expected, the more groups there are on the disk, the greater is the difficulty of apportioning spots to groups blending into each other, and the greater is the overcount (on average for 26750 groups: 9%). The Group Number in our reconstruction (Svalgaard & Schatten, 2016) had already been corrected for an overcount (of 7%, at the time – we can do better now).

How Much Does the Group Overcount Inflate the Sunspot Number?



We can now simply calculate what influence the overcount has on the sunspot number (10*G+F). On average, the inflation is 3.7%. I suggest that the sunspot number be corrected for this since the 1940s

Conclusions

- The Weight factor *w* is not constant, but depends [for monthly data] on the International Sunspot Number: $w = 1.00 + 0.0398 \ln(R_{iV1})$ approaching and even slightly exceeding 1.2 for high solar activity
- We don't need to guess or argue much as we have direct measurements of the weight factor
- Although Brunner weighted large spots he compensated by omitting enough small spots to keep his k-value equal to Wolfer's [the canonical 0.6] such as to leave negligible net effect on the sunspot number
- We should only apply the effective weighting formula for times since 1947 where we don't have direct measurements and neither should be applied going forward
- The Waldmeier Classification of active regions makes recognition of groups more secure than the older purely morphological criteria and have led to an inflation of the number of groups by a factor of $1 + 0.00045\, SN_{v2}$ (several percent). This should be corrected for
- It is encouraging that the whole question of the calibration of the sunspot and group numbers is finally being vigorously pursued, but it should be done right, building on the progress already made

The end