The Waldmeier Discontinuity

Recalibration of the Zürich Sunspot Number

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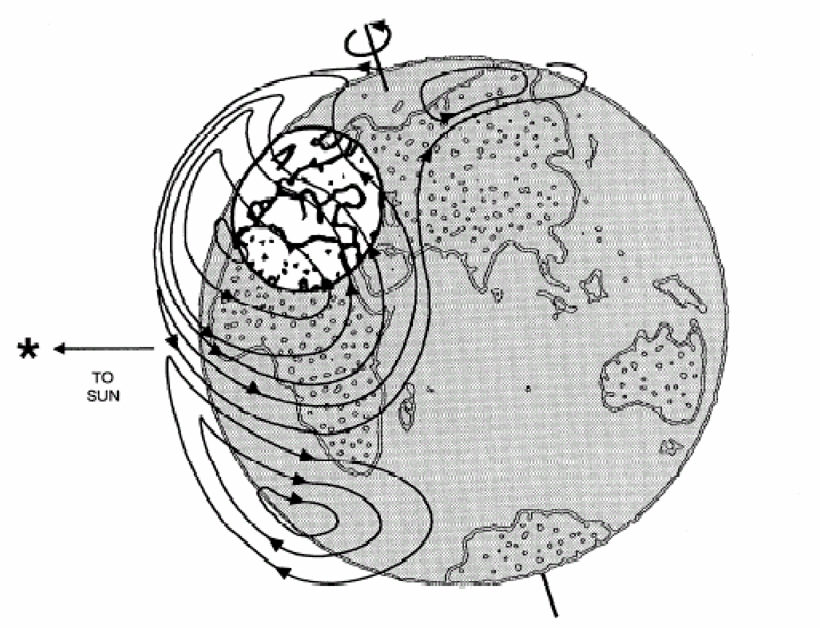
When Max Waldmeier took over the production of the Sunspot Number, Rz, in Zürich in 1945 he was relatively inexperienced in the art of divining sunspot numbers [Friedli, 2005] and he feared that the sunspot numbers may not have had the same 'calibration' as the existing series produced by the previous Zürich observers. We suggest that his fear was not unfounded and that the Zürich sunspot number be increased by 20% to match the modern record. In this poster we explore three reasons and methods on which we base this conclusion.

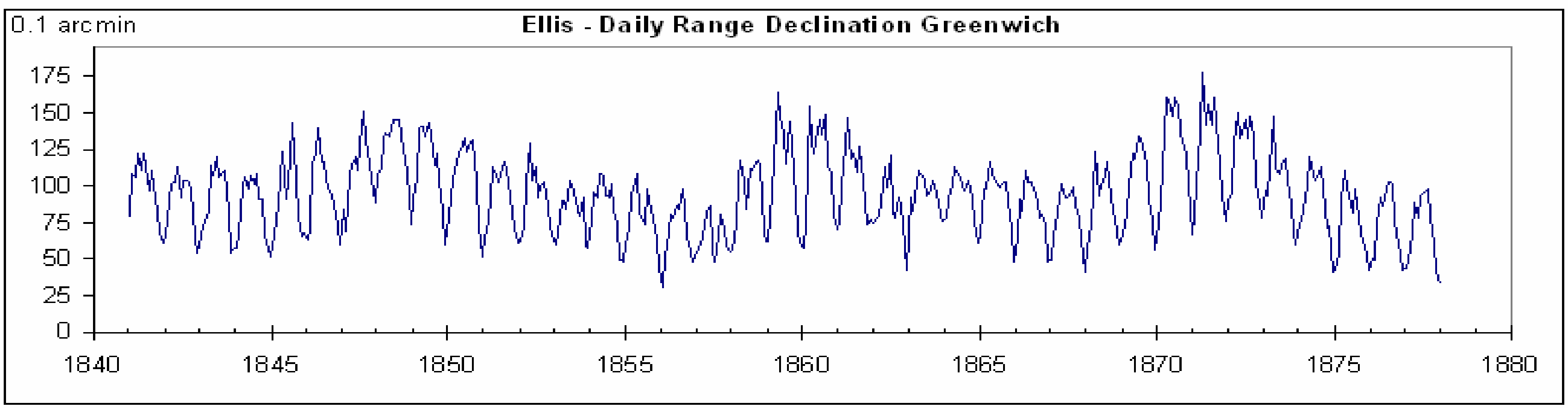
(1) The range of the diurnal variation of the East-component of the geomagnetic field controlled by FUV-induced conductivity of the day-side ionosphere is a strong proxy for solar activity, as already Rudolf Wolf had noted in 1856, and indicates a 22% increase of the sunspot number from 1946 onwards.
(2) The Greenwich Sunspot Areas (and the Group Sunspot Number, Rg, largely derived from the areas) indicate a 17.5% increase of Rz coincident with Waldmeier's tenure.
(3) The Ca II K-line index [see poster 15.16 by Bertello et al.] indicate a 20% increase in Rz.

Of course, it would be more convenient to increase the pre-1946 numbers by a similar amount rather than change the modern numbers which may be ingredients in operational forecast techniques.

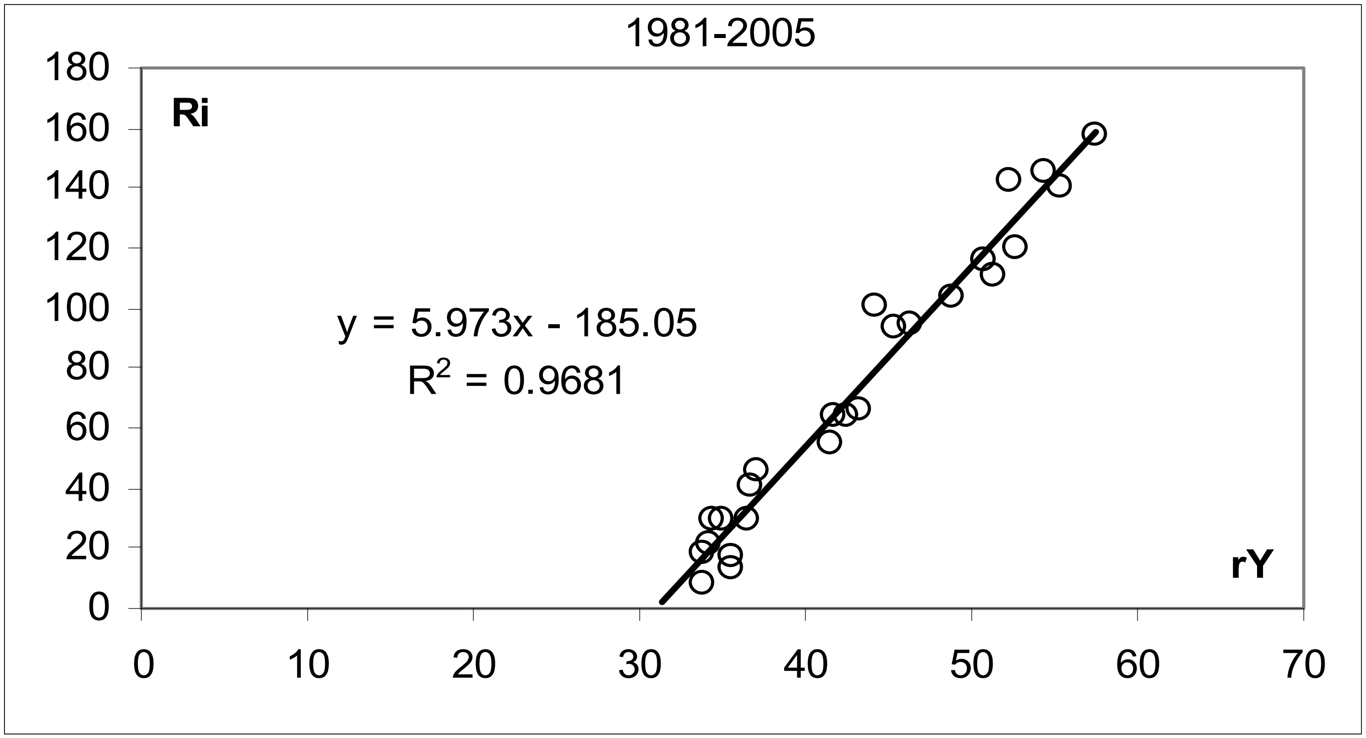
1: The Diurnal Range of the East-component (~Declination)



FUV radiation from the Sun creates and maintains the ionospheric E-layer (105 km altitude) on the day-side. The Earth [and its magnetic field] rotates under this conductor and dynamo action creates an electrical current system which in turn has a magnetic effect measurable on the ground as a daily variation [the 'range'] of the direction of the compass needle. This effect was discovered in 1722 by Georges Graham. The East-component is the Horizontal component times the sine of the Declination, and has been measured [almost] ever since:

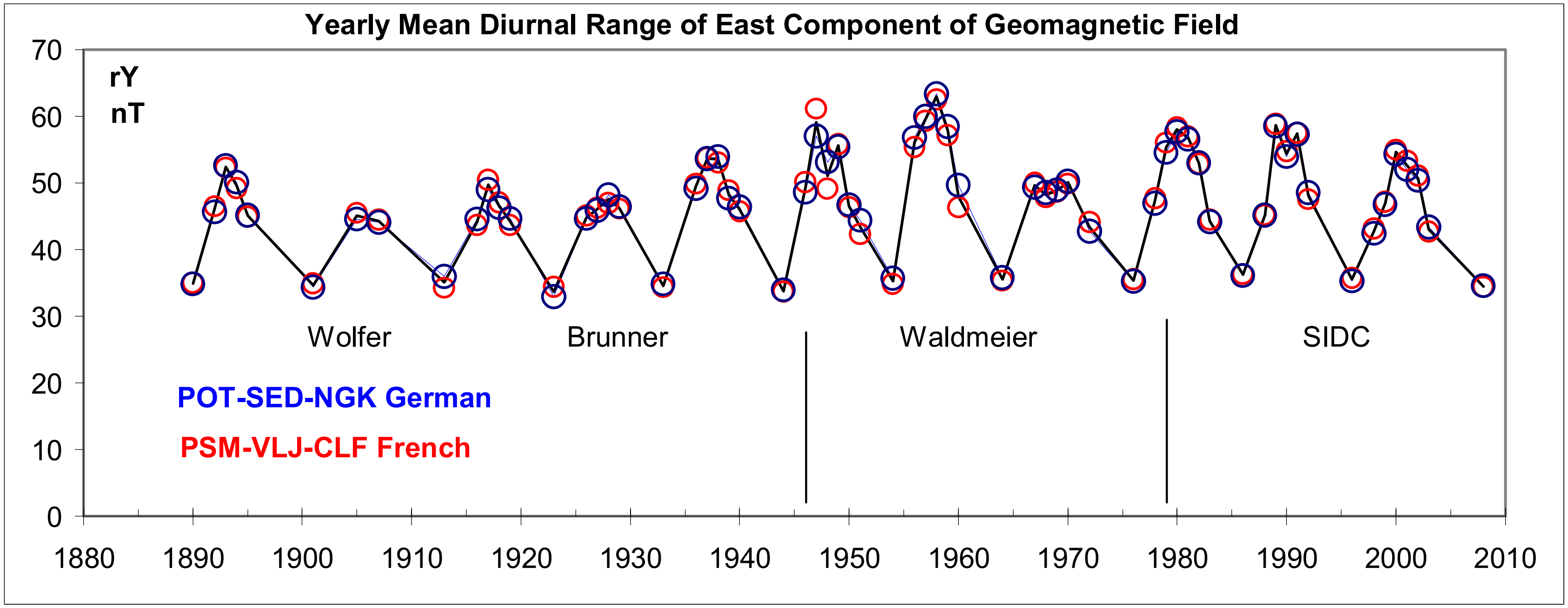


The range *rY* of the East component or [for a given station] equivalently, the declination has a daily and seasonal variation due to the variation of solar zenith angle, but more importantly, there is also an obvious solar cycle variation due to varying FUV flux. We can show that quantitatively using the modern sunspot number [the international sunspot number Ri from SIDC in Brussels]:



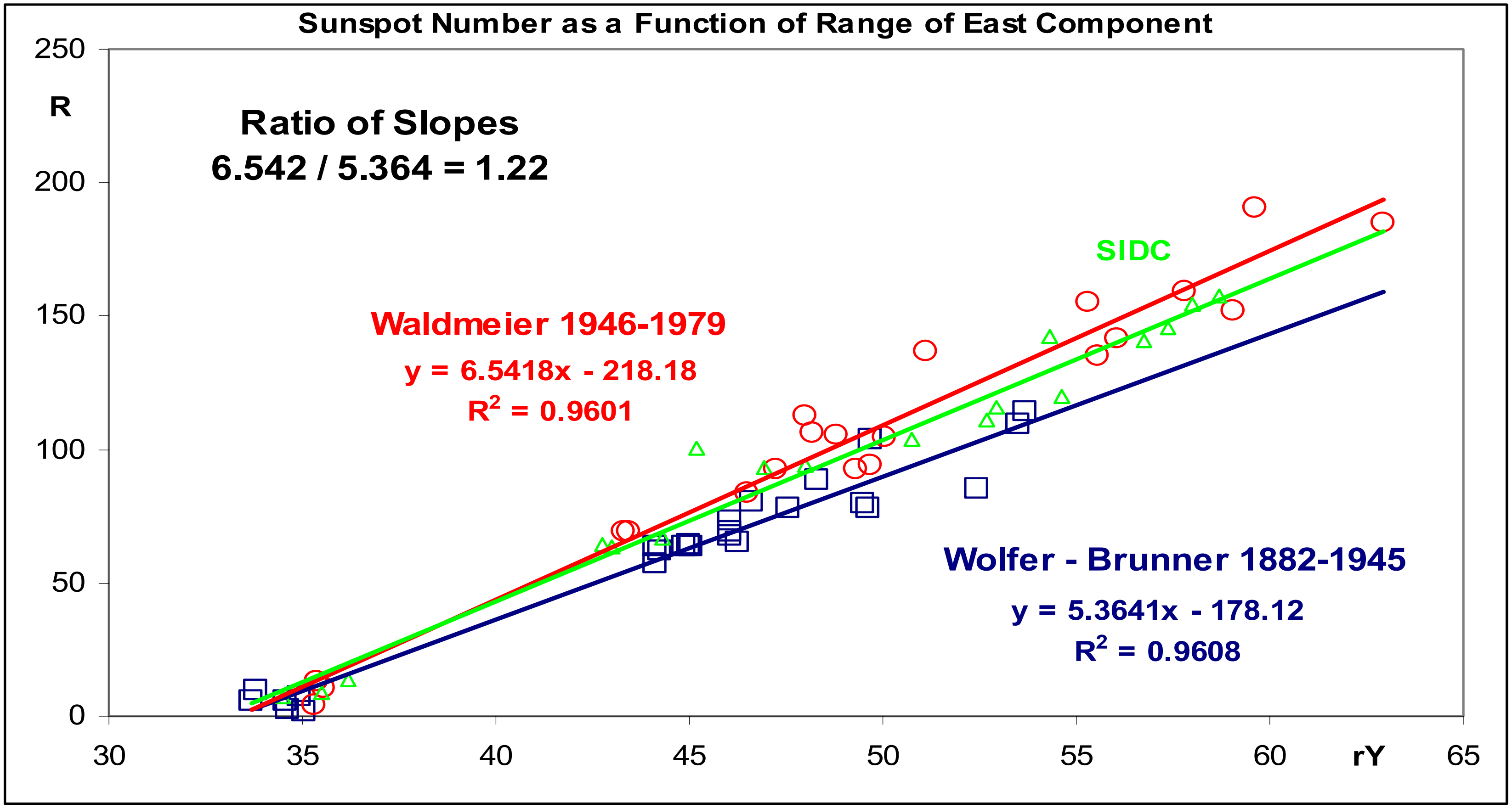
This relationship allows us to *calculate* Ri from the diurnal range, *rY* (in nanoTesla) using the mean of several stations. The plot uses yearly means of both variables, which averages out the seasonal variation.

A series of German and French geomagnetic stations provide *rY* means well into the 1880s. In this plot we omit the years when solar activity changes rapidly [and also stay away from the years with strong coronal holes just before solar minimum:



Several other series of long-running geomagnetic stations give very similar results. There is a very slight increase of the solar minimum values that is caused by the slow secular decrease of the Earth magnetic field, which leads to a corresponding slight increase of the conductivity of the ionosphere [a weaker magnetic field increases the mobility of the ions], as this is a very small over the time span of the observations. For data going back yet another century, this effect must be taken into account.

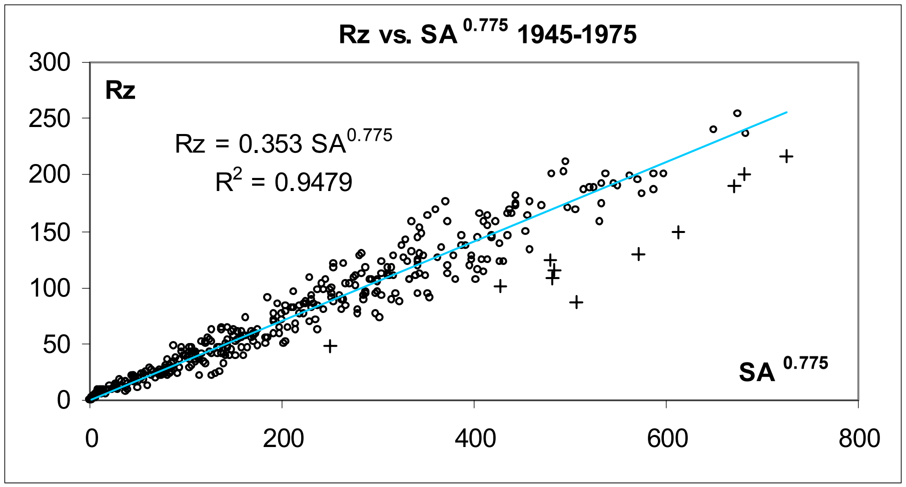
Plotting the sunspot number as a function of station-averaged ranges separately for the Wolfer-Brunner era [1882-1945] and the Waldmeier era [1946-1979] we get that the two relationships are linear [as Wolf discovered back in 1856], but have different slopes:

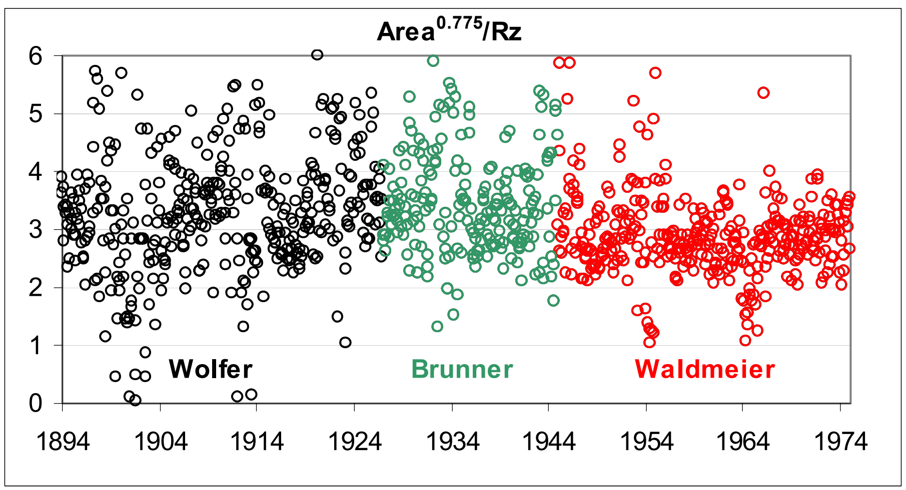


So, we conclude that the geomagnetic data suggests that Waldmeier introduced a 22% increase of the sunspot number. The SIDC numbers follow Waldmeier's as SIDC has striven so hard to do.

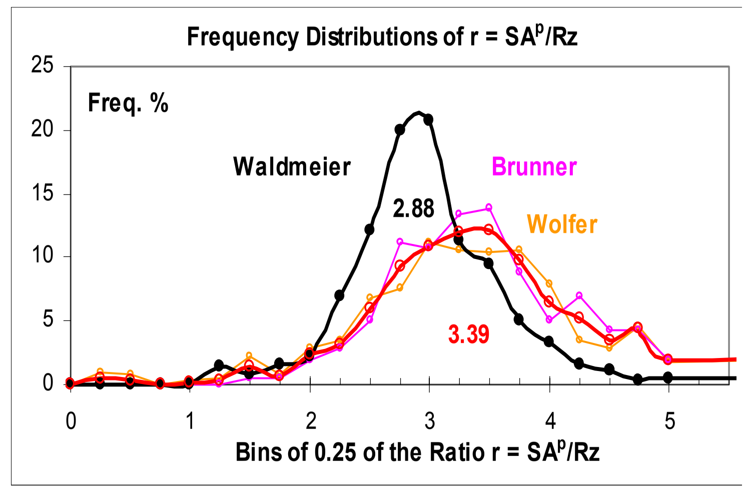
2: The Sunspot Area Correlation

Sunspot areas measured at the Greenwich Observatory are our second indicator. The relationship is slightly non-linear, but a power-law relation with exponent 0.775 linearizes the relation:



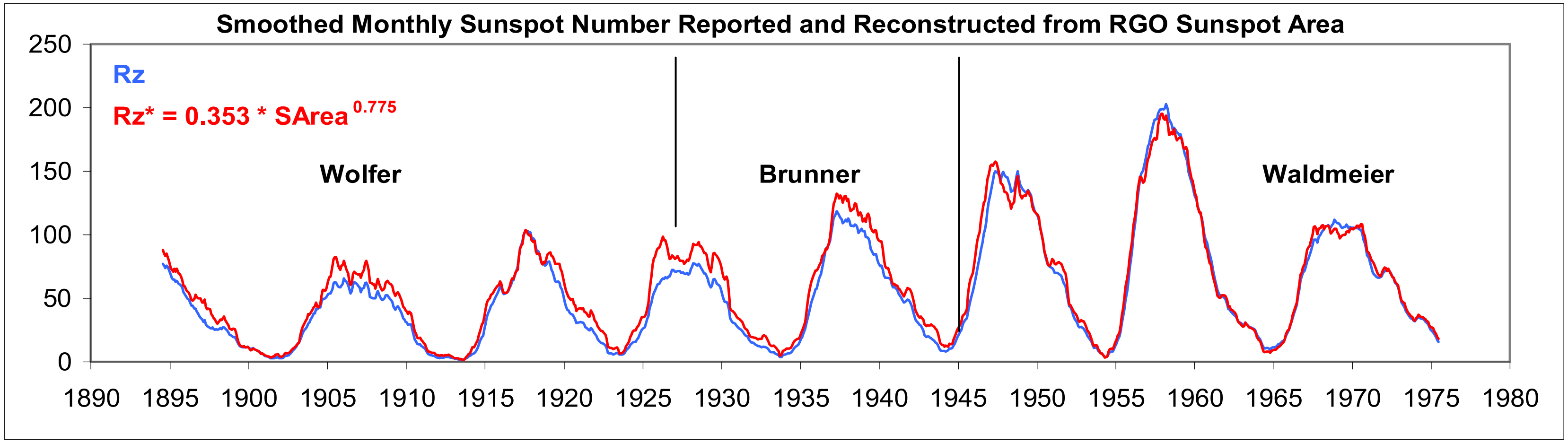


A linear relation going through the origin allows us to calculate the ratio between the [linearized] sunspot area $SA^{0.775}$ and the sunspot number. We show here the ratio for each observer and histograms of the distributions of the ratios:



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%

Another way of showing the discontinuity is to reconstruct the sunspot number from the relation between SA and R:



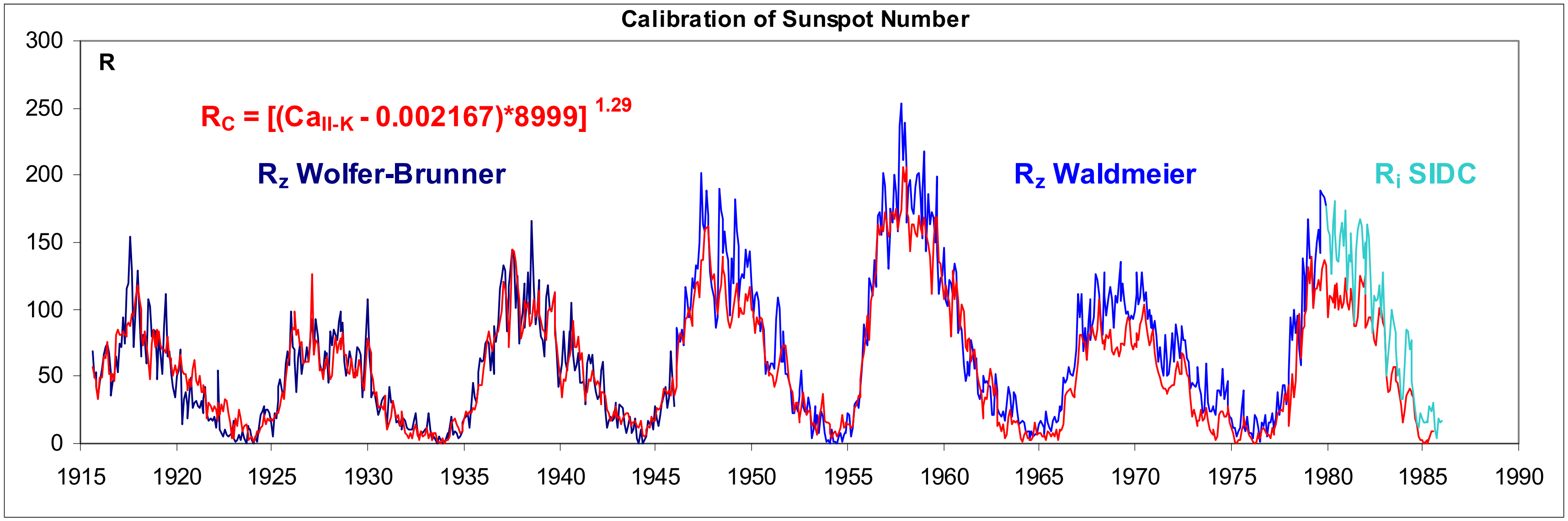
3: The Ca II K-line Correlation

The magnetic field of the Sun manifests itself in plage areas clearly visible in Ca II K-line images. A recent digitization effort of ~40,000 CaK spectroheliograms from the 60-foot tower at Mount Wilson between 1915 and 1985 has permitted the calculation of a daily index of the fractional area of the visible solar disk occupied by plages and active network as described by Bertello et al. in poster 15.16. Monthly averages of this index is strongly correlated with other solar indices, e.g. 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.

Here we show the comparison between the calculated sunspot number and the sunspot numbers reported by the different observers:



It is clear that the correspondence is excellent, but that there is a marked discontinuity at the beginning of the Waldmeier-era. Average values for different intervals are as follows:

	1915-45	1946-79	1980-85	1946-85
R, CaII K	48.07	65.20	67.65	65.55
Rz.i	47.57	78.12	96.04	80.65
Rz/CaK	0.9896	1.1982	1.4197	1.2304

Giving a discontinuity of 20% for the Waldmeier-era, or 23% for the entire period until 1985.

A long-neglected paper by Peter Foukal [Extension of the F10.7 index to 1905 using Mt. Wilson Ca K spectroheliograms, Geophysical Research Letters, Volume 25, Issue 15, p. 2909-2912, 1998] comes to a similar [if even greater factor] conclusion: “The behavior of this extended index indicates that UV irradiance levels achieved near the peaks of sunspot cycles 15, 16, and 17 between 1915-1945, were 25-40% higher than would be estimated from behavior of the Zurich sunspot number, Rz”. We suggest that the reason for this is not that the UV level has changed, but that the sunspot number calibration underwent a discontinuity when Waldmeier took over the production of the Zürich sunspot number.

Adopting the 20% change of values before 1946, leads to a different picture of solar activity that the commonly held view: