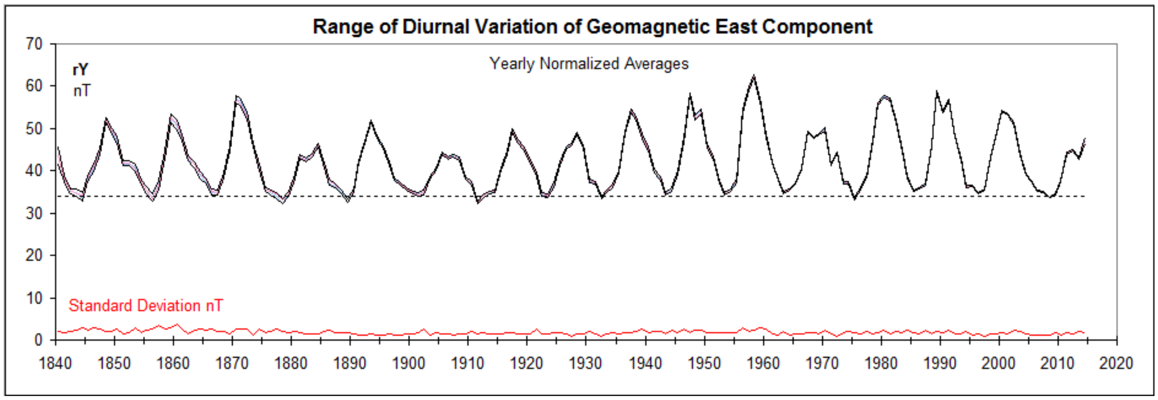
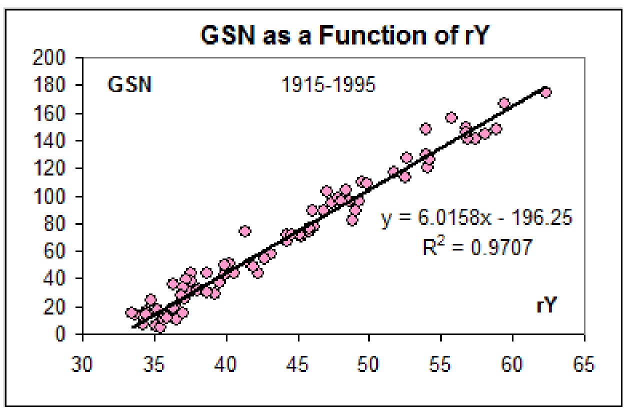
Sunspot Number Corrections

Let me try to say things a bit more clearly. Reconstruction of the EUV flux is on solid ground based on the range of the diurnal variation, rY, of the Geomagnetic East Component:

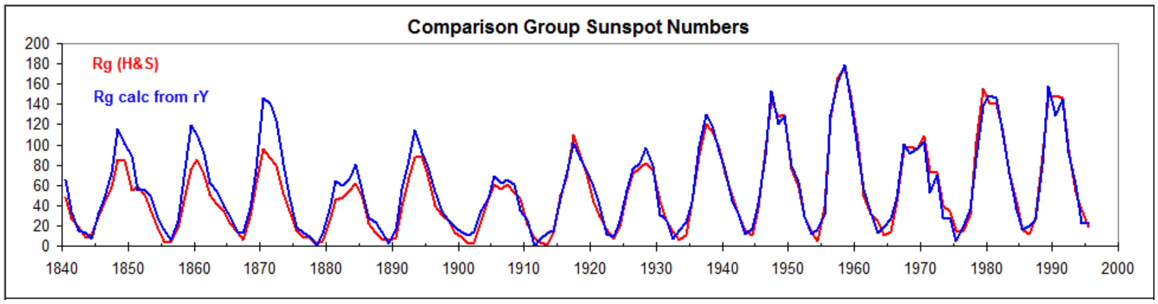


The process is described here http://www.leif.org/research/Reconstruction-Solar-EUV-Flux.pdf with more details here http://www.leif.org/research/Reconstruction-of-Solar-EUV-Flux-1840-2014.doc I believe that this reconstruction shows true solar activity back to 1840. This means that we have an absolute standard to compare with, rather than a series of moving targets.

As we think that the RGO group counts [used by Hoyt & Schatten] are good after ~1915, we can find the regression equation to convert rY to a GSN:

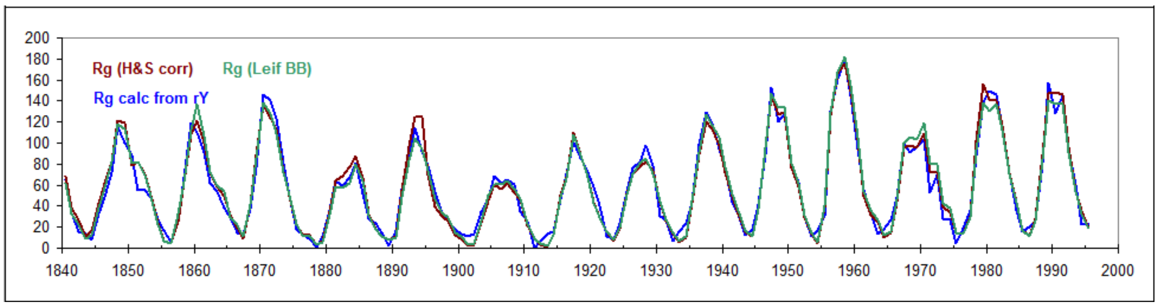


So *GSN* = (6.016±0.118)**rY* – (196.25±5.24) based on 1915–1995. We can thus calculate an equivalent GSN for that interval. We assume now that the Earth's response to EUV does not change on a timescale of two centuries [this is not quite true, but the issue is controversial and we take a conservative approach] and thus extend the calculation back to 1840:



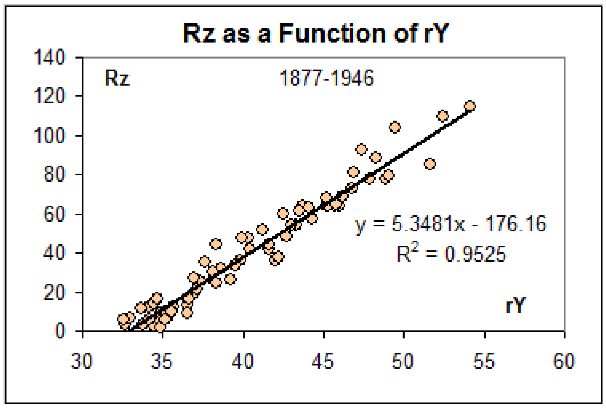
It is clear that the original H&S GSN (red curve) is too small before ~1900. The average correction factor is 1.43 to bring GSN(H&S) before 1900 up to GSN(rY). Although there *is* a 'ramp-up' from 1875 to 1915, we simplify matters a bit by using a constant correction before 1900. The difference is small [as the cycles are also small] and I don't like to introduce too many ad-hoc corrections.

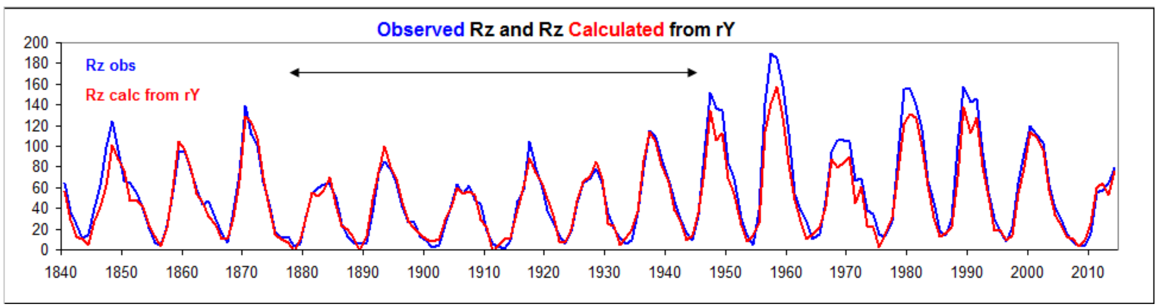
As a consistency check we can compare the so corrected GSN (brown curve on the next Figure with the GSN computed from rY (blue curve) and with the GSN derived from my backbone series (green curve; values multiplied by a scale factor of 13.5 – there is no a priori reason why we should use the canonical 12.08):



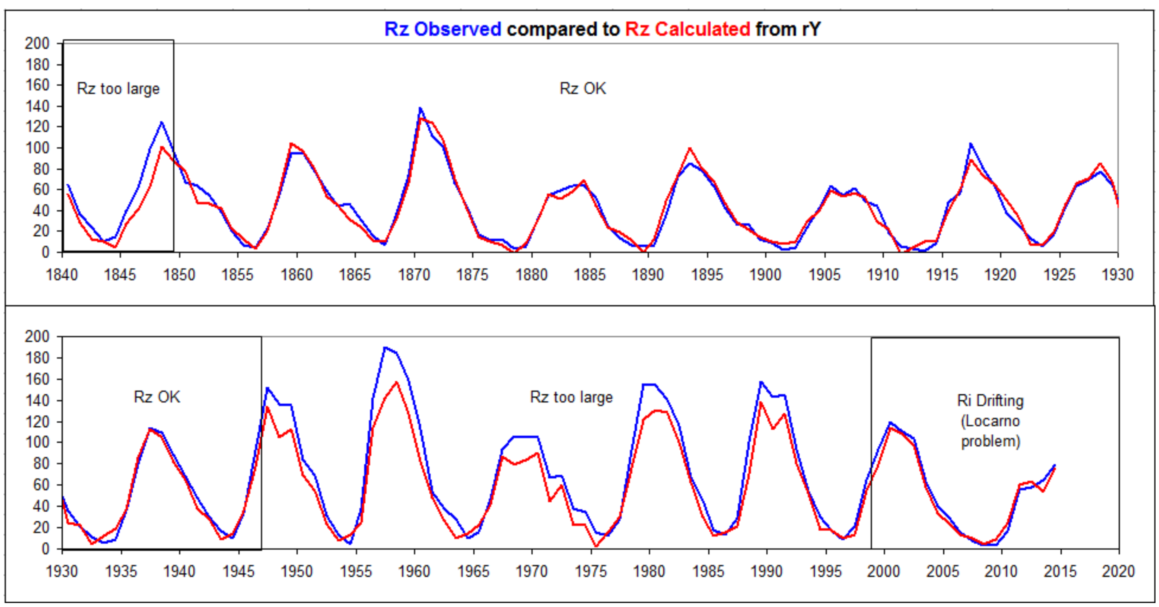
All reconstructions match very well [the expected error bar is ±8 units]. Now, I'm not advocating that GSN be used for anything [it should be abolished], but it seems that the H&S GSN can, at least with our correction, be reconciled with both rY and the independent [solely solar-based] backbones, lending credence to our claim that we are on the right track.

We can do the same procedure for the Zürich (International) sunspot number. As we have the original data on which Wolfer's and Brunner's relative sunspot numbers are based, it makes sense to use the interval 1877-1946 as the base-interval to regress against rY in order to get the conversion equation for ZSN (or Rz or whatever we want to call it). We find $ZSN = (5.348\pm0.145)*rY - (176.16\pm5.91)$ based on 1877–1946. We can thus calculate an equivalent ZSN for that interval. We assume again that the Earth's response to EUV does not change on a timescale of two centuries and extend the calculation to the entire dataset since 1840. The vertical component in Central Europe over the last 150 years has increased by some 3%. We would expect a corresponding 2% decrease of the magnetic effect of the S_R system over that time, or a 1.3 nT/century *decrease* that, however, does not seem to be visible in the data at sunspot minima. Other stations seem to show an *increase* of a similar amount [*Macmillan and Droujinina*, 2007; *Yamazaki and Kosch*, 2014] or no increase at all ("Sq(Y) did not increase significantly at observatories where the main field intensity decreased" [*Takeda*, 2013]). The issue is still open and several other variables could be in play, such as variation of the upper atmospheric wind patterns, changes in atmospheric composition, and changes in the altitude and/or density of the dynamo region (affecting the mix of Hall and Pedersen conductivities). Our position here shall be not to try to make ad–hoc corrections for the change of the main field.



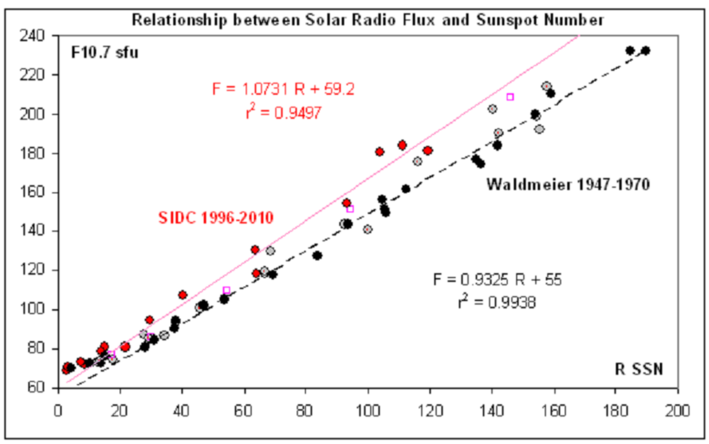


Or on an expanded time axis:



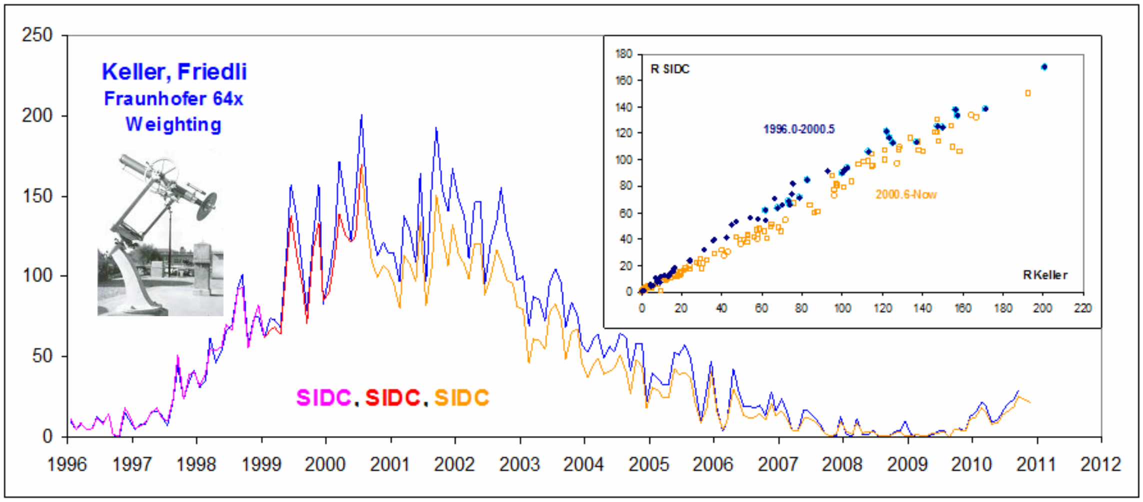
It would seem that Rz [or ZSN or Ri or …] is consistent with rY [which in turn was validated by comparing with the Backbone GSN] over the interval 1849–1946. For 1840–1848, Rz is too high [as pointed out by Leussu, but that does not mean that the GSN is 'better' or that one can make the claim that their comparison extends all the way back to 1700]. It is clear that cycle 10 [in the 1860s] does not need any correction of ZSN as it matches the rY-data very well. For 1947–1999 (or so), the effect of the Waldmeier weighting is evident. The average weight factor is 1.22. From 2000 on, Locarno is still weighting but the effect of that is completely offset by a curious [and perhaps unexplained] decrease of the Locarno *k*-factor. It is a travesty that the Locarno observers refuse to participate in determining the weight factor going forward and that we do not seem to have the balls to tell them that in strong enough terms.

In a short 1971 paper, Max Waldmeier [*Waldmeier*, 1971] pointed out that the "Zürich standard scale [of the relative sunspot numbers] has never been calibrated in an objective way". He went on to note that the close correlation between monthly, and especially yearly, means of the solar microwave emission at 10.7 cm wavelength and the sunspot numbers yields a possibility of an objective calibration of the scale of the relative sunspot numbers. The following Figure shows the tight relationship (linear for sunspot number greater than 25) deduced by Waldmeier for the interval 1947-1970 (black dots).



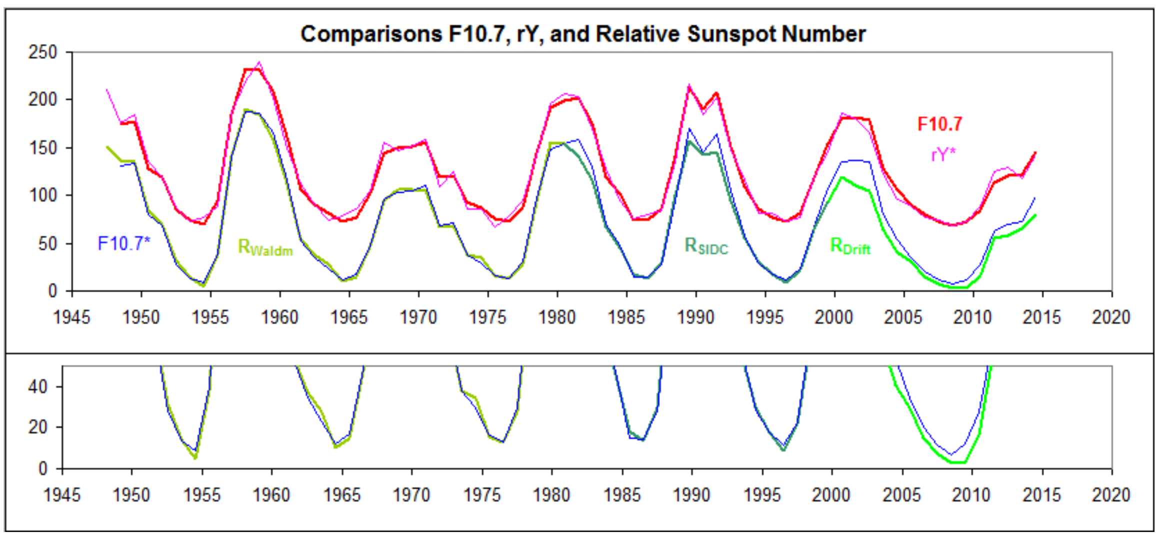
He remarks that "As long as this relation holds, the Zürich series of sunspot-numbers may be considered to be homogeneous. If this relation should be subject to changes in the time to come, then the reduction factor used hitherto ought to be changed in such a way that the old R-F relation is reestablished". The Figure also shows the relation since 1996 derived from the International Sunspot Number as determined by SIDC (red dots, http://sidc.be/silso/DATA/monthssn.dat). The data for the intervening interval 1971-1995 are shown as gray dots and open red squares. It is clear that the recent sunspot numbers no longer follow the relationship found by Waldmeier and that therefore, perhaps, "the reduction factor used hitherto ought to be changed in such a way that the old R-F relation is reestablished". On the other hand it is also possible that the sunspot number as currently defined simply is no longer a suitable measure of solar activity, given the progressive discrepancy with the F10.7 flux. A similar conclusion was reached by *Svalgaard and Hudson* [2010] and *Tapping* [2010].

The [artificial] decrease of the SIDC SSN is also clear when comparing with other observers, e.g. with Keller [a former Waldmeier assistant] and Friedli using the original Wolf large telescope and [presumably – at least they said so] the same weighting rules:



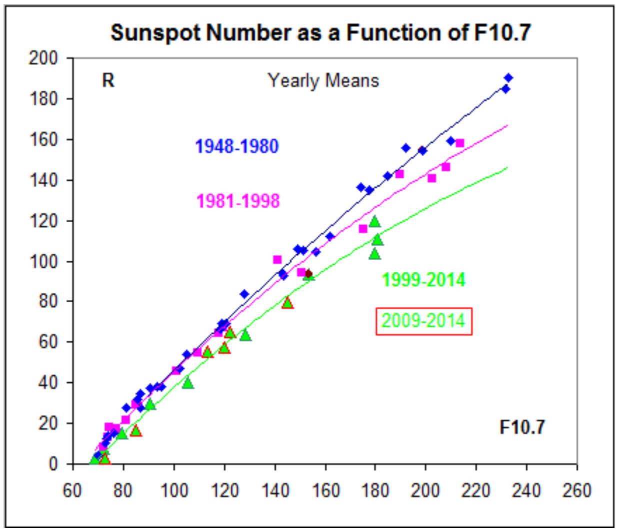
I think that the planned [and promised] re-evaluation of the sunspot number for the recent past cycles should have high priority.

I'll continue the comparison with F10.7. The next Figure compares the sunspot number, R, with F10.7 (blue curve) scaled to match R (**green** curve) during the Waldmeier epoch [1948-1980]. I omit 1947 because the coverage of F10.7 for that year was not complete. Also shown are observed F10.7 (**red** curve) and rY scaled to match F10.7 (pink curve). The close agreement between rY and F10.7 lends credence to the accuracy of both:



It is clear that SIDC slightly undercounts compared to Waldmeier during the interval 1981-1998 (**dark green** curve) and that, beginning in 1999, the undercount becomes much worse (**bright green** curve), consistent with the Keller-Friedli counts. This extends even to the 'unusual' mimimum 2008-2009 (lower panel).

An alternative way of showing that R has been undercounted is to regress directly against F10.7 for each of the three intervals, 1948-1980, 1981-1998, and 1999-2014:



Cycle 24 data are marked by a red outline of the green symbols. The average 'degradation' of the 1999-2014 count is 0.8 [or 25%] compared to Waldmeier's. I think that this type of analysis is superior to looking at *k*-values as those are difficult to determine when R approaches zero.