Calibrating Sunspot Numbers Using Variations of "the Magnetic Needle"

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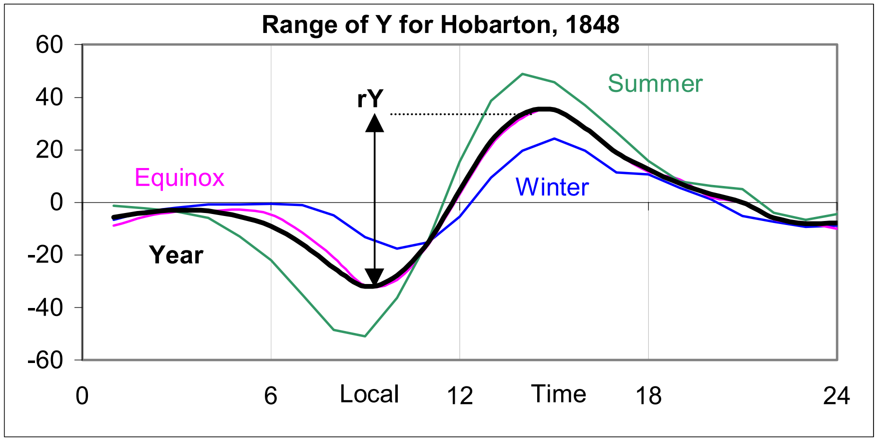
Abstract: Solar EUV creates and maintains the ionosphere. Thermal winds and solar tides drive a dynamo creating a current system whose magnetic effect is readily observed on the ground. Observations of this diurnal magnetic signature of the FUV flux (and indirectly the sunspot number) go back more that 250 years and can be used to estimate the sunspot number in the past, fording an independent calibration of the sunspot number time series. We show that both the Zurich and the Group Sunspot Numbers are too small before cycle 18 with the discrepancy growing larger as we go back in time reaching more than 50%.



Diurnal variation of the East component of the geomagnetic field at Hobarton (Tasmania, 42.9º lat. South) for the year 1848. The range *rY* (in nT) is defined as the yearly average peak to valley difference. Note the seasonal variation of the amplitude of the diurnal variation.

We have reliable measurements like the one shown above for many observatories (the number ranging from a handful in the 1840s to more than a hundred in the 21st century). Selecting stations that are away from the polar and auroral regions as well as from the equatorial electrojet, we find that the diurnal range, *rY*, in force units (nT) for each year does not vary much (less than about 15%) from station to station:

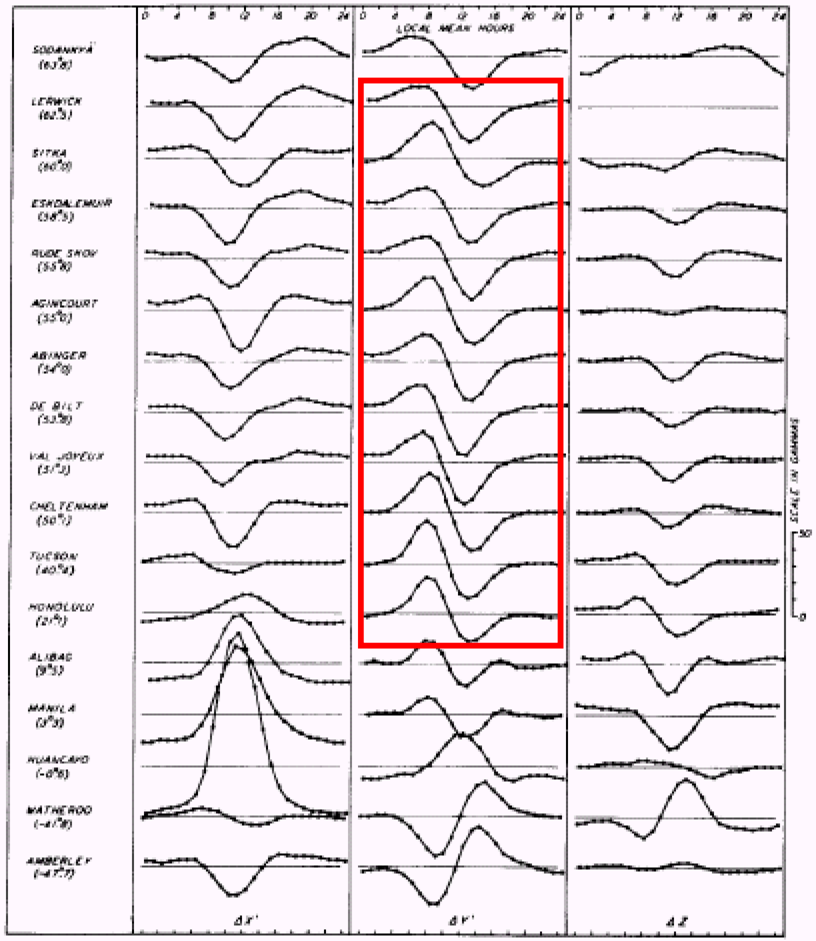
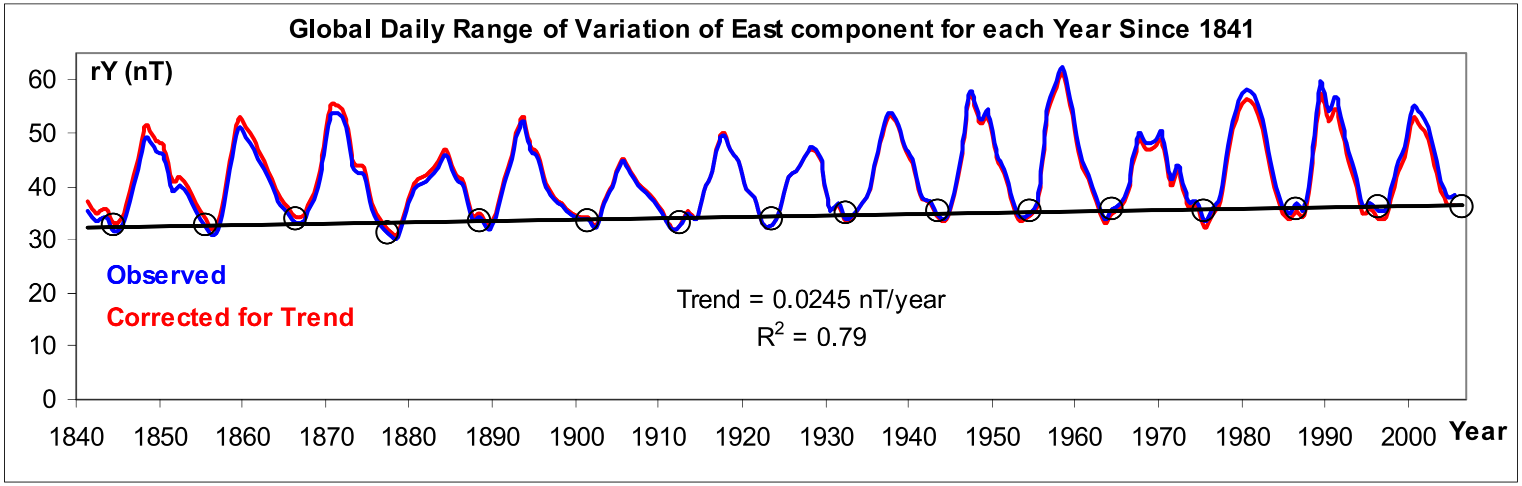


FIG. 69—SOLAR DAILY VARIATION ON QUIET DAYS (Sq), VARIOUS STATIONS, GEOMAGNETIC COMPONENTS, YEAR, 1922-33 (GEOMAGNETIC LATITUDES INDICATED IN PARENTHESES)

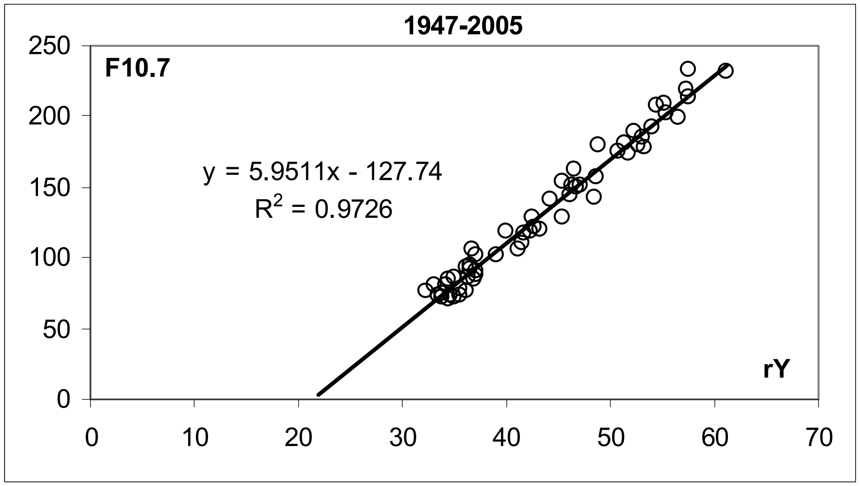
This has been known for along time. The plot shows data from 1922-1933 [*Vestine et al.*, 1959]. The red box covers GM latitude range 20º-60º.

Using overlapping data for many stations (after a certain point, ~5 stations, adding more stations does not make any difference) in that range, we normalize the yearly values of *rY* for each station to that of the Niemegk station (NGK) to remove the small local differences [*e.g.* in underground conductivity] and plot the average ‘global’ range as a function of time:



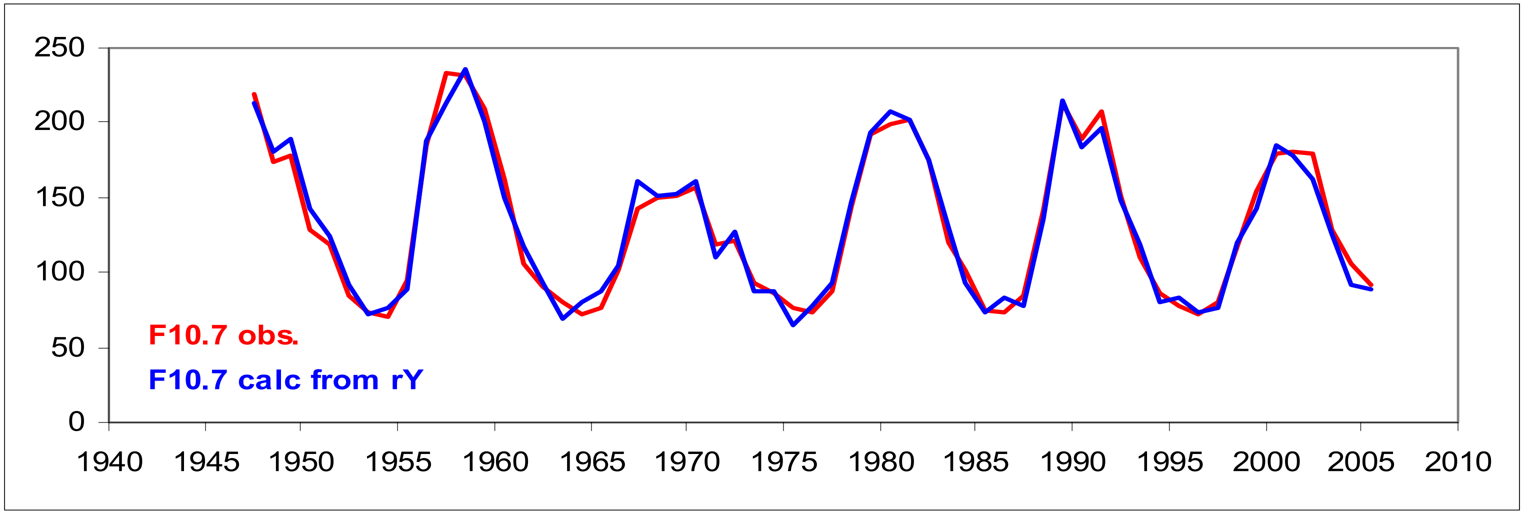
The circles show *rY* averaged over the three years around each sunspot minimum. There is a clear trend in these values (0.0245 nT/year) amounting to an increase of 9.8% over the 165-year interval 1841-2005. The red curve shows the ranges with this trend removed. It is very likely that the increase simply results from an increase of the ionospheric conductivity caused by the 9% decrease of the Earth's main dipole field over the same time interval. Simple theory predicts that the conductivity should be inversely proportional to the ambient magnetic field strength.

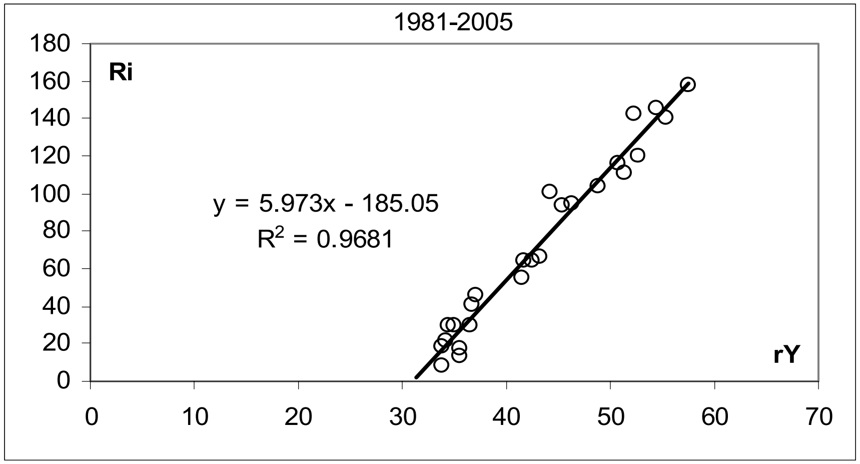
We now assume that the ~10% increase is due to a change in the response of the ionosphere due to the changing geomagnetic dipole field (*Clilverd et al.*, 2002). The alternative that the solar FUV flux at solar *minimum* has had a 10% secular change over 165 years we consider being too ‘radical’ at this point.



Using the F10.7 radio flux as a proxy for the FUV flux we now explore the relation between yearly means of the flux and the range of *Y* (left). We find a very tight correlation (R = 0.986) for the years since 1947 for which we have F10.7 measurements.

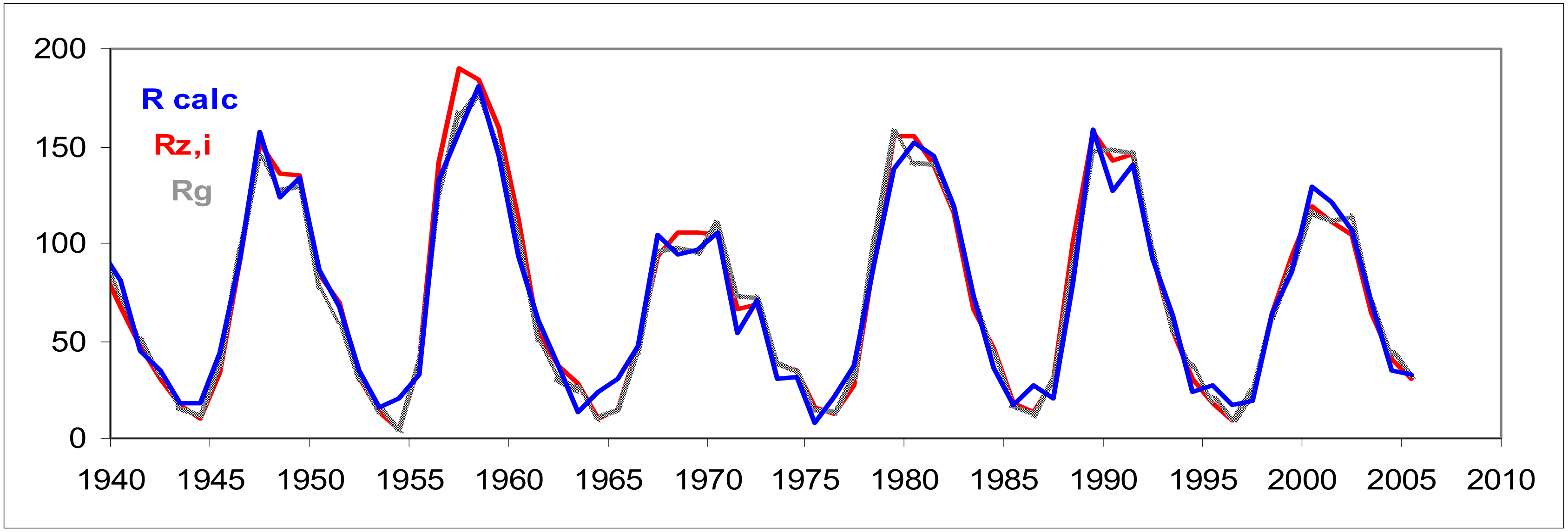
We can now calculate F10.7 (shown below) from *rY* using the regression established above. In a sense, the good correlation is a validation of the idea that F10.7 is a good proxy for the FUV emission.



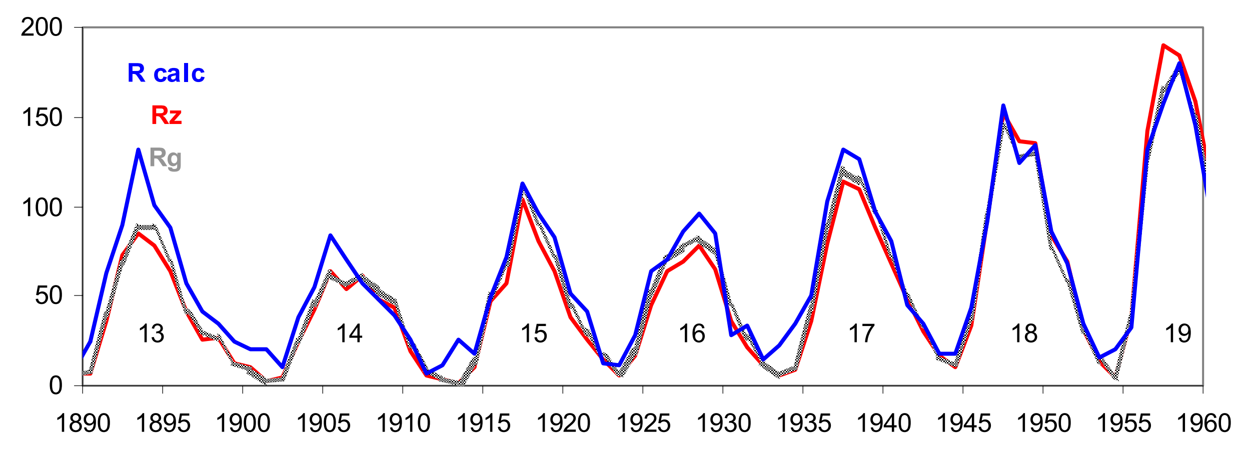


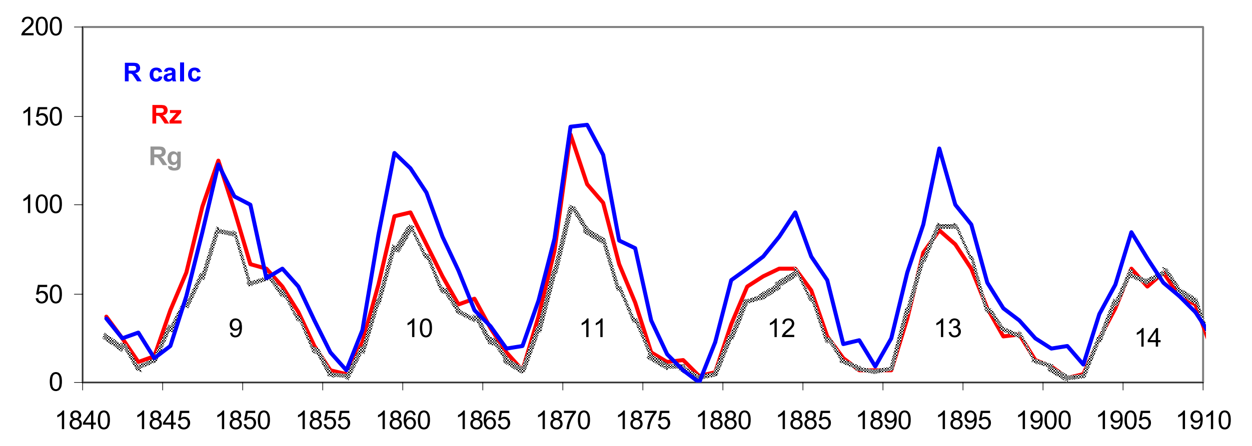
Because there is also a good correlation between the F10.7 radio flux and the sunspot number, we expect a good correlation between *rY* and R*β* (where the ‘*β*’ may be ‘*i*’ for the International sunspot number (shown at the left), ‘*z*’ for the Zürich sunspot number, and ‘*g*’ for the Group sunspot number.

The correlation is somewhat worse than for F10.7 (as we would expect), but is very high, nevertheless. Here is the Sunspot number calculated from *rY* using the regression for R*i* compared to the official, observed R*i* (*z* before 1981) and R*g*:



Although the agreement is less than for the F10.7 it is still very good. Interesting is the disagreements for some of the minima (e.g. 1965). We can extend the Figure to 1841:





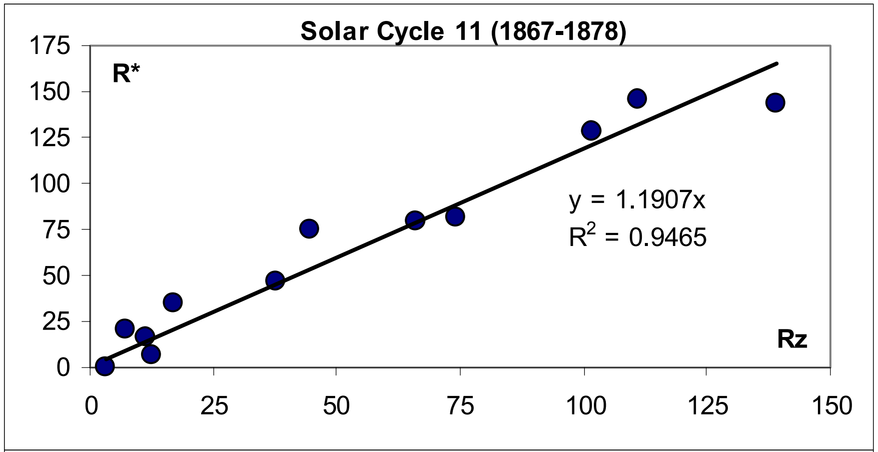
Notes on cycles:

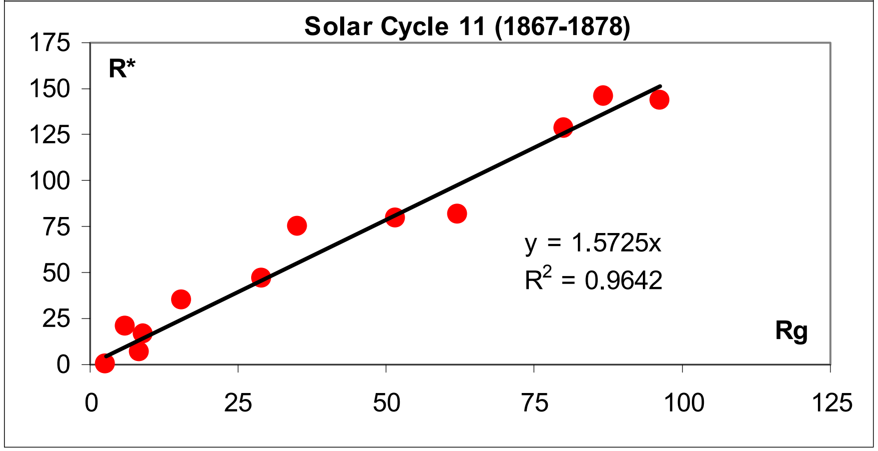
#19: R*z* may be too high.

#14, #13, #12, #10: R*z* and R*g* both too low.

#11 and #9: R*z* is a good match, R*g* is too low.

If anything, R*z* is a better match than R*g*.

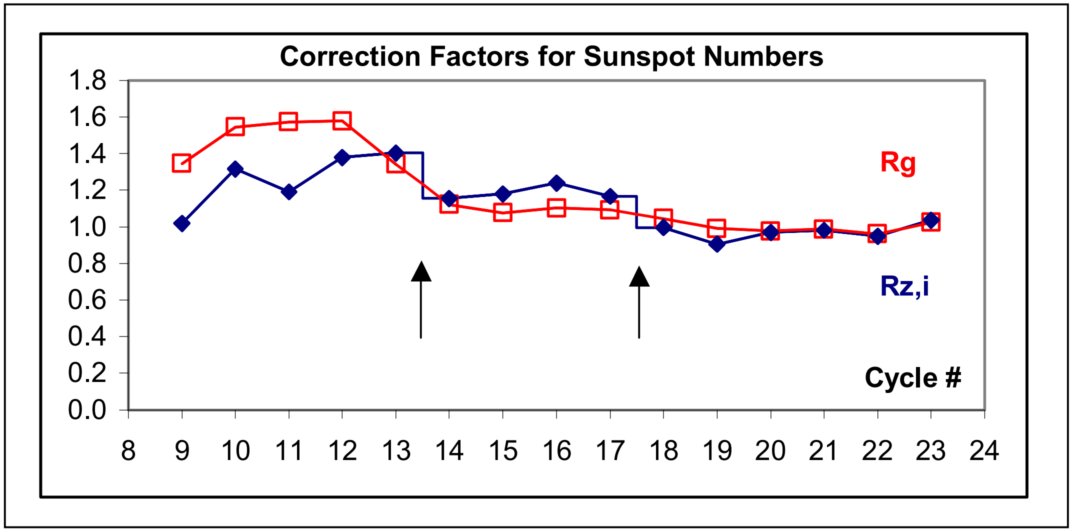




It is clear that the differences between the calculated sunspot number and the two observed series vary with time. No single trend is apparent, so we opt for finding a correction factor separately for each cycle by fitting the reconstructed and observed values by a straight line through the origin as shown at the left for cycle 11. We thus de-emphasize the influence of just the maximum value and spread the correction evenly (in the least-squares sense) over the entire cycle. We now construct a Table with the correction factors to be applied to each year (stipulating the same factor for monthly and daily values):

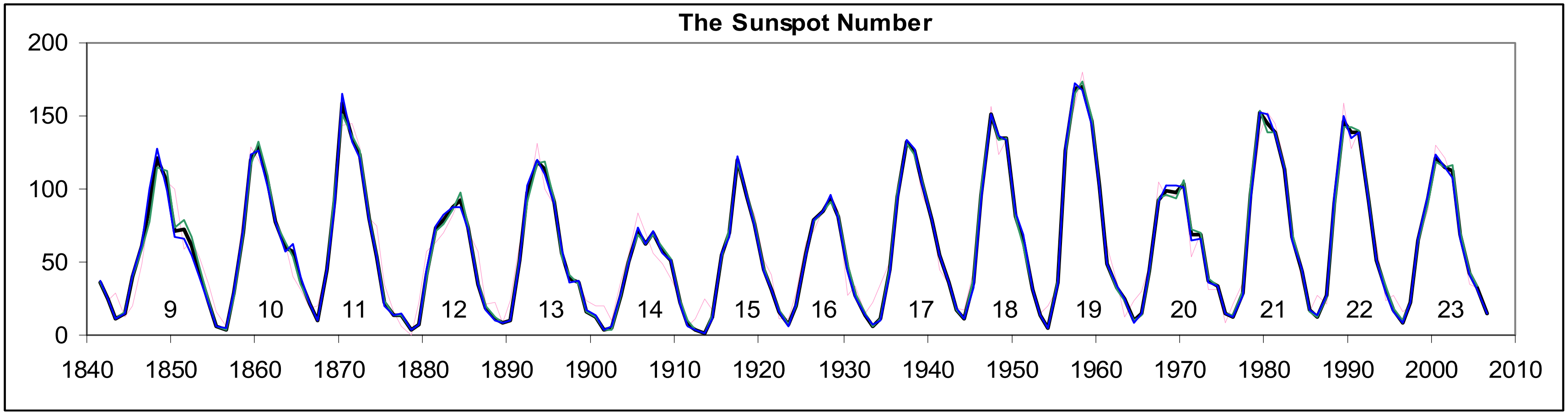
Cycle	Rg	Rz
9	1.347	1.020
10	1.545	1.317
11	1.572	1.191
12	1.580	1.379
13	1.343	1.403
14	1.121	1.156
15	1.075	1.180
16	1.103	1.238
17	1.093	1.166
18	1.046	0.996
19	0.991	0.905
20	0.978	0.970
21	0.986	0.982
22	0.961	0.948
23	1.026	1.036

Correction Factors for
reported sunspot numbers.

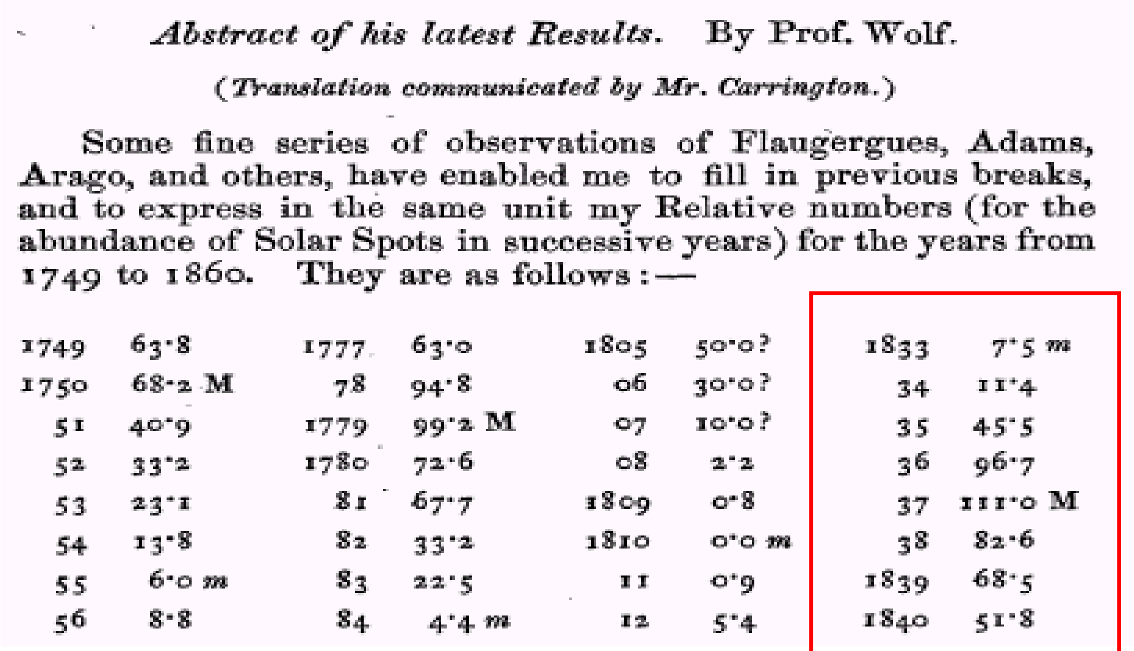


The counting method for small spots changed in 1893 when Wolf died and for groups in 1945 when Waldmeier took over. These changes seem to be duly reflected as discontinuities in the inferred correction factor for the Zürich sunspot

We can now plot the corrected sunspot number series since cycle 9. There is no real difference between the corrected Group sunspot numbers and Zurich sunspot numbers:



It is of interest to note that (corrected) cycles 11 and 10 were as active as the most recent cycles 22 and 23. We thus see no evidence in the sunspot number of a secular increase in solar activity over the last 165 years.



Abstract of his latest Results. By Prof. Wolf.

(*Translation communicated by Mr. Carrington.*)

Some fine series of observations of Flaugergues, Adams, Arago, and others, have enabled me to fill in previous breaks, and to express in the same unit my Relative numbers (for the abundance of Solar Spots in successive years) for the years from 1749 to 1860. They are as follows:—

1749	63·8	1777	63·0	1805	50·0?	1833	7·5 m
1750	68·2 M	78	94·8	06	30·0?	34	11·4
51	40·9	1779	99·2 M	07	10·0?	35	45·5
52	33·2	1780	72·6	08	2·2	36	96·7
53	23·1	81	67·7	1809	0·8	37	111·0 M
54	13·8	82	33·2	1810	0·0 m	38	82·6
55	6·0 m	83	22·5	11	0·9	1839	68·5
56	8·8	84	4·4 m	12	5·4	1840	51·8

1749	80.9	1777	92.5	1805	42.2	1833	8.5 m
1750	83.4 M	78	154.4	06	28.1	34	13.2
51	47.7	1779	125.9 M	07	10.1	35	56.9
52	47.8	1780	84.8	08	8.1	36	121.5
53	30.7	81	68.1	1809	2.5	37	138.3 M
54	12.2	82	38.5	1810	0.0 m	38	103.2
55	9.6 m	83	22.8	11	1.4	1839	85.7
56	10.2	84	10.2 m	12	5.0	1840	64.6

From MNRAS, 1861 and from the current dataset at SIDC in Brussels

Our methodology is not at all new. Already by 1859, Rudolf Wolf had noticed that the diurnal range, *rD*, of the Declination bore a strong, linear relation to his “relative” sunspot numbers:

$rD = a + b\,R_z$

In fact, sometime after 1880 Wolf quietly adjusted the original R_z before 1849 upward by 24% to get a better match with *rD*.

Later researchers were not so enthusiastic about Wolf's relationship; the 'constants' a and b seemed to change with location and possibly with time as well. Today we know that his scheme was sound, except that the proper physical parameter to use is rY in force units and not rD in angular units.

There are geomagnetic records going further back in time:

1740s	Olaf Hiorter (Uppsala, Sweden)
1760s	John Canton (London)
1780s-1800s	George Gilpin (London), Cassini (Paris)
1820s-1830s	François Arago (Paris)
1830s-1900s	Michele Rajna (Milano), Kreil (Praha)

and others.

The acquisition and analysis of these earlier data are ongoing.