# Geomagnetic Calibration of Sunspot Numbers

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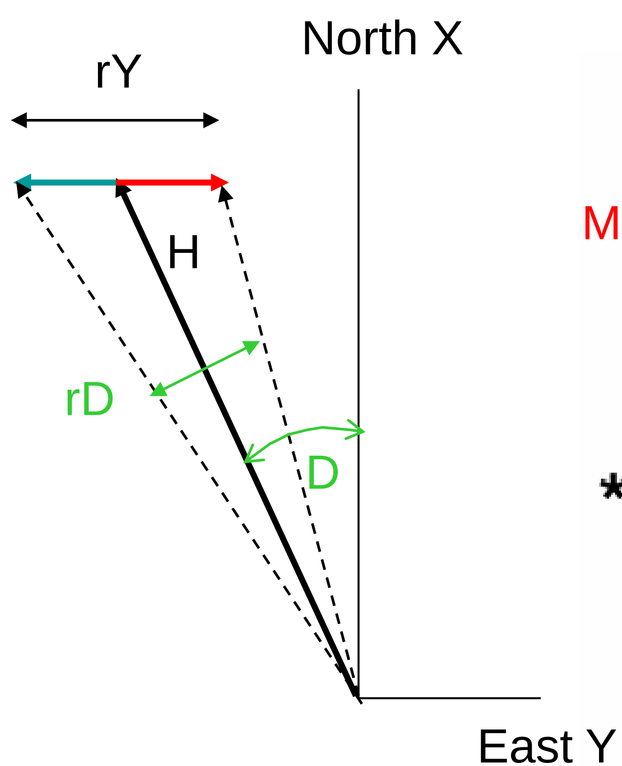
# Wolf’s Several Lists of SSNs

- During his life Wolf published several lists of his ‘Relative Sunspot Number’:
- 1857 Using Sunspot Drawings By Staudacher 1749-1799 as early SSNs
- 1861 Doubling Staudacher’s Numbers to align with the large variation of the Magnetic ‘Needle’ in the 1780s
- 1874 Adding newer data and published list
- 1880 Increasing all values before his own series [beginning 1849] by ~25% based on Milan Declination
- 1902 [Wolfer] reassessment of cycle 5 reducing it significantly, obtaining the ‘Definitive’ List in use today

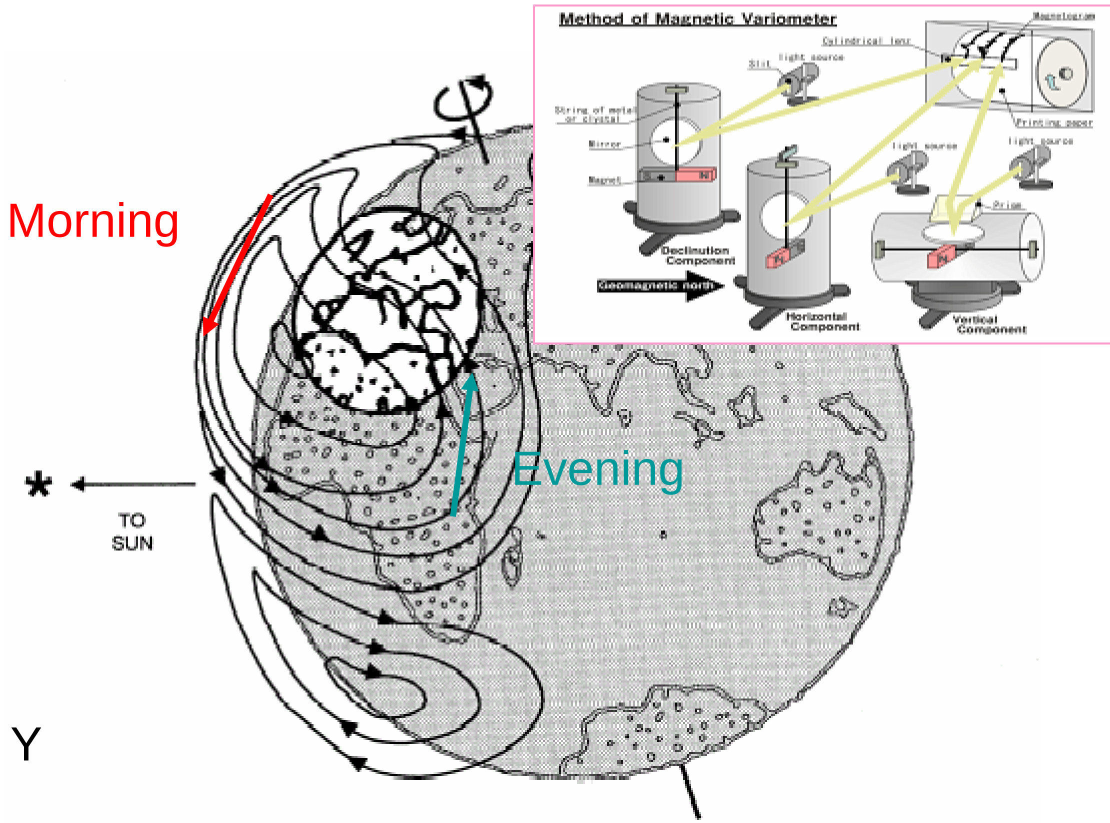
# Justification of the Adjustments rests on Wolf's Discovery: $rD = a + b\ R_W$




$Y = H \sin(D)$

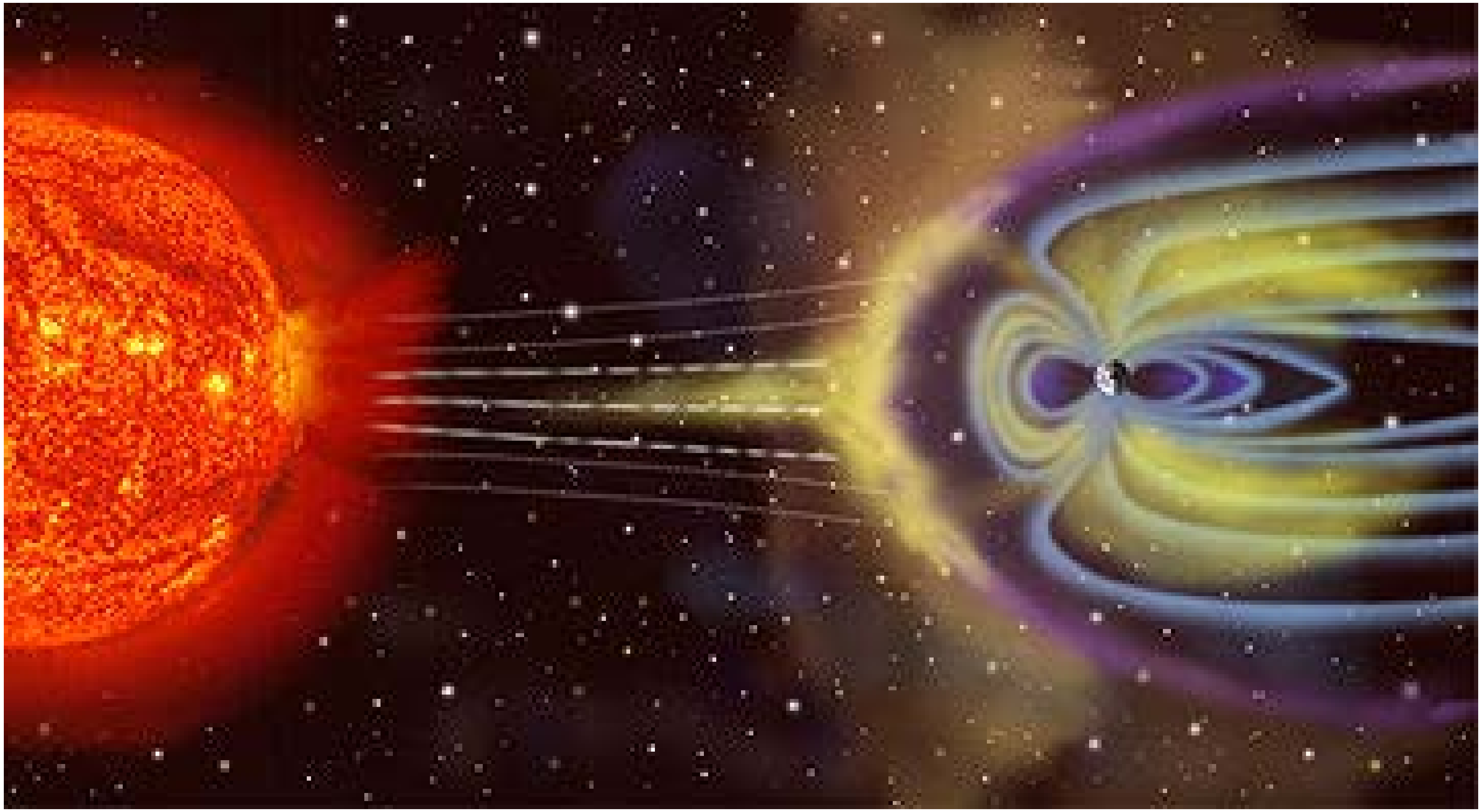
$dY = H \cos(D)\ dD$

For small D, dD and dH



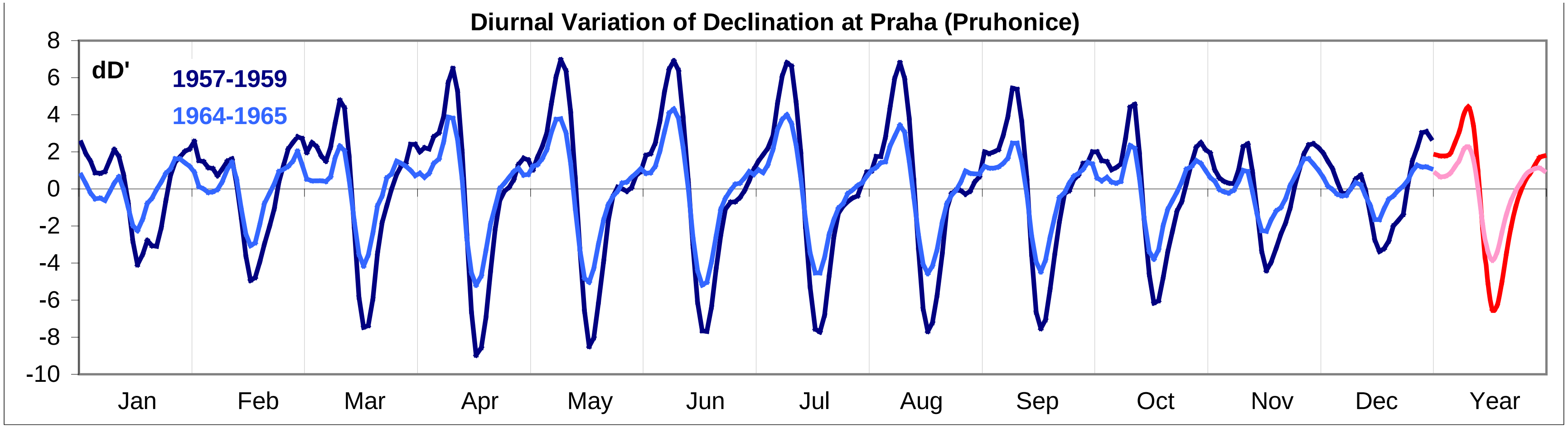

A current system in the ionosphere [E-layer] is created and maintained by solar FUV radiation. Its magnetic effect is measured on the ground.

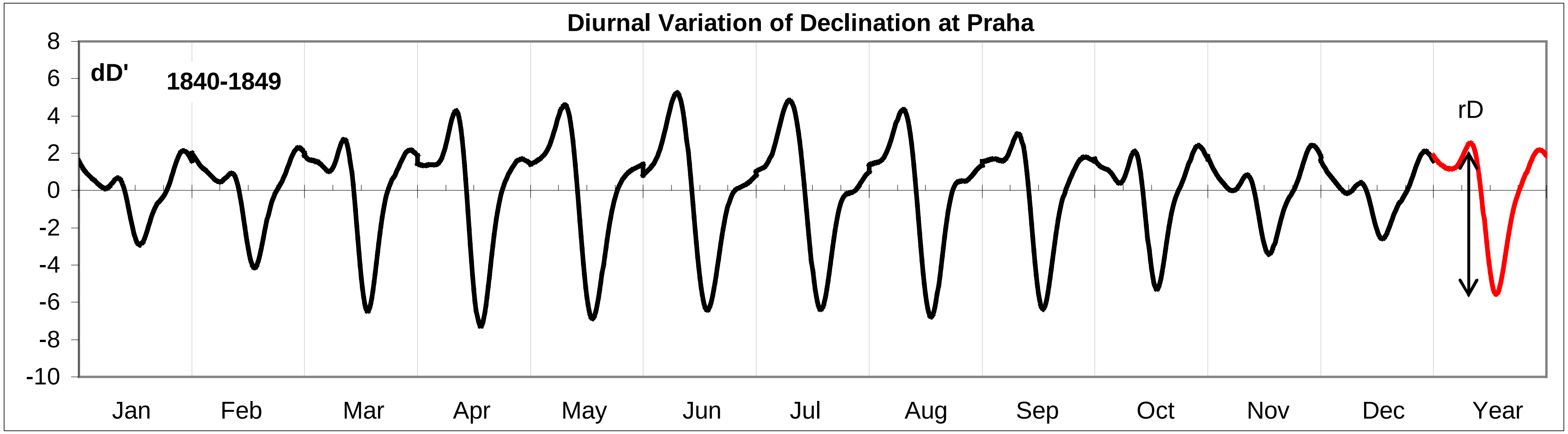
# Geomagnetic Regimes



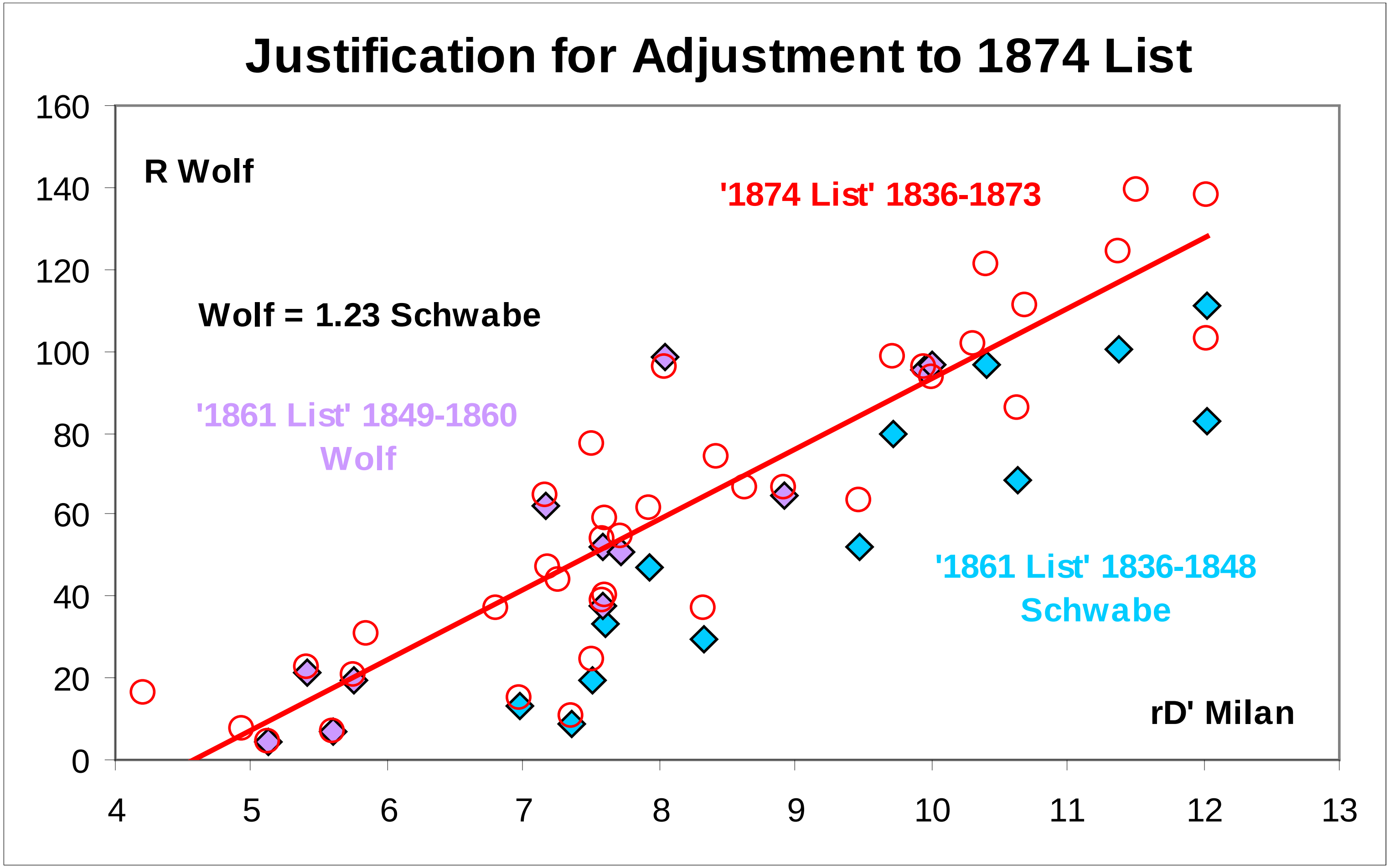
1) Solar FUV maintains the ionosphere and influences the daytime field.
2) Solar Wind creates the magnetospheric tail and influences the nighttime field

# The Diurnal Variation of the Declination for Low, Medium, and High Solar Activity



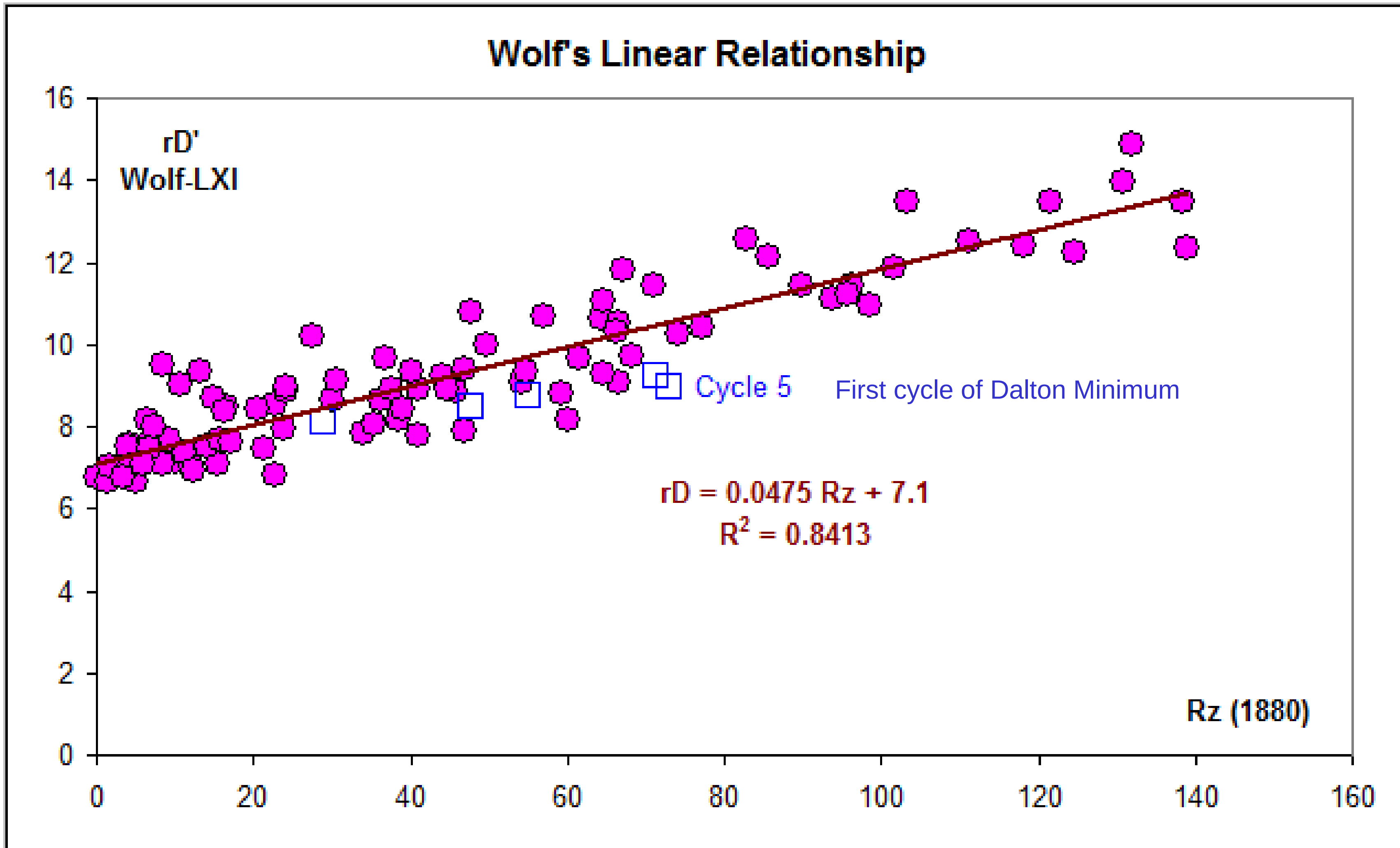



# Wolf got Declination Ranges for Milan from Schiaparelli and it became clear that the pre-1849 SSNs were too low



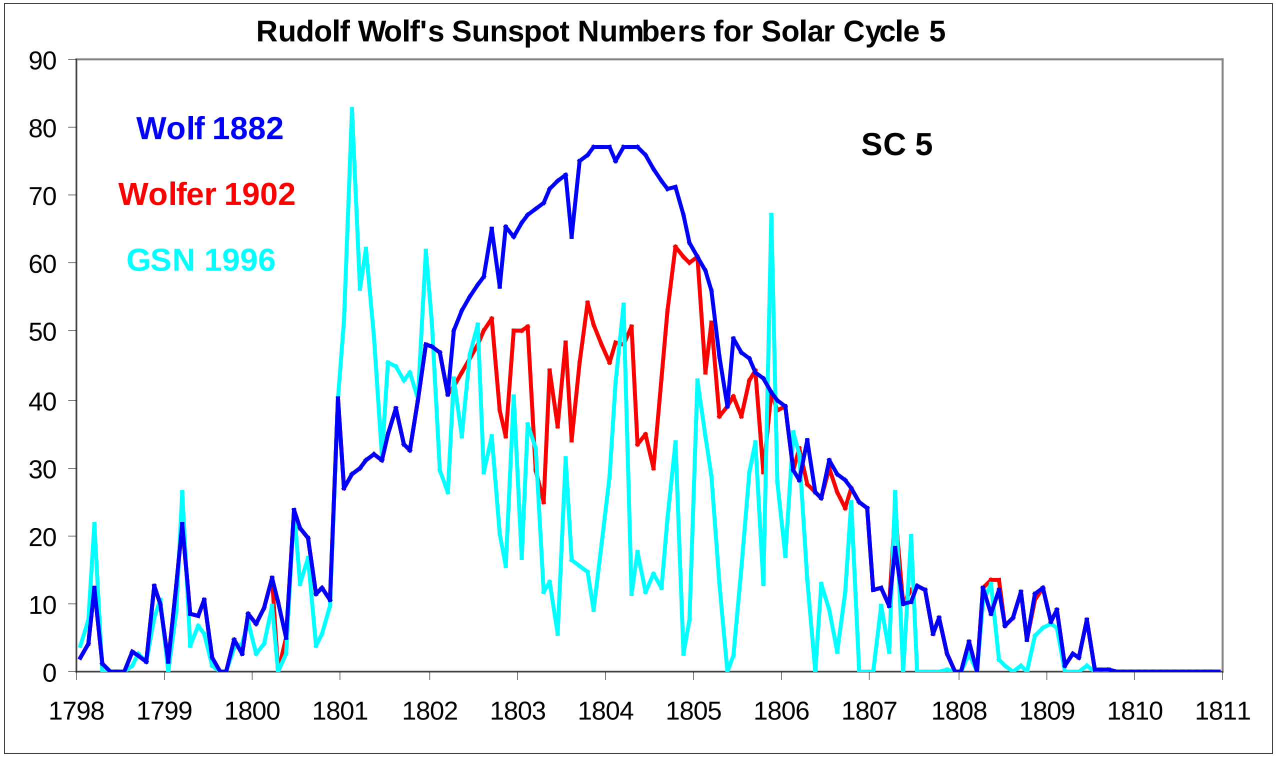

The ‘1874’ list included the 25% [Wolf said 1/4] increase of the pre-1849 SSN

# Wolf's SSN was thus now consistent with his many-station compilation of the diurnal variation of Declination 1781-1880




It is important to note that the relationship is *linear* for calculating averages

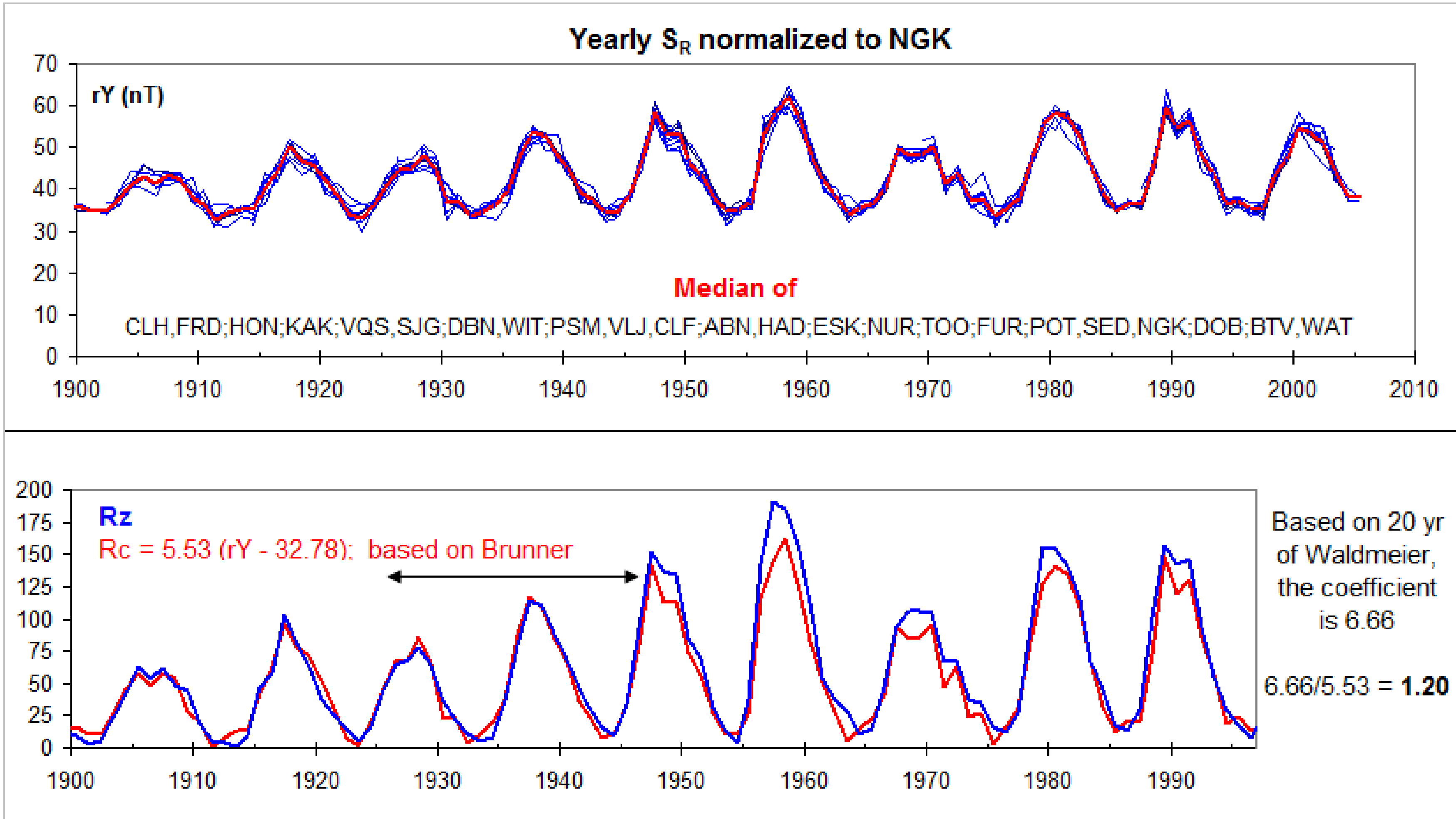
# Wolfer's Revision of Solar Cycle 5 Based on Observations at Kremsmünster



# Alfred Wolfer became Wolf’s Assistant in 1876 and Used a Different Counting Method

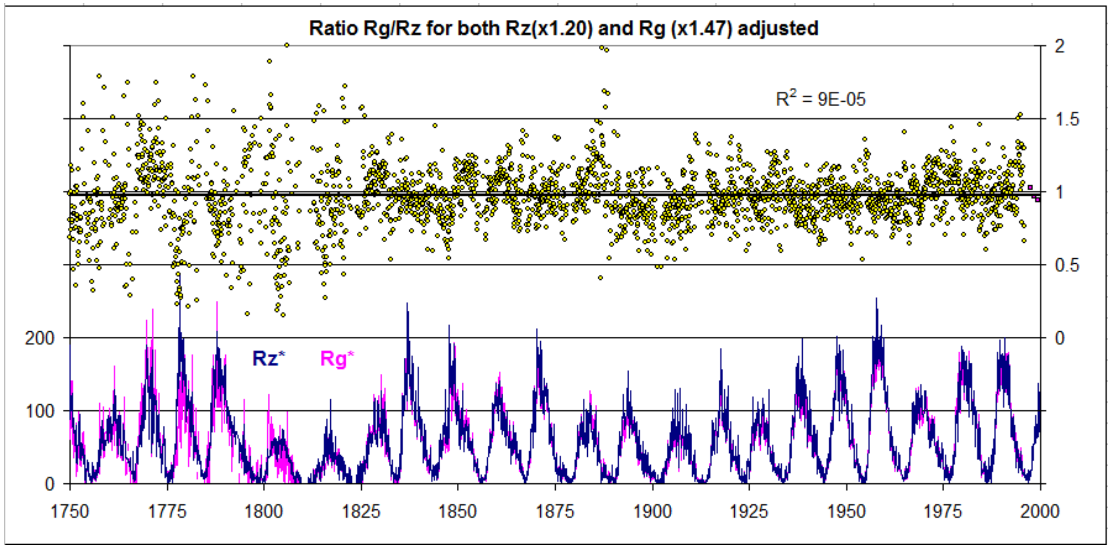
- Wolf did not [with the 80mm] count small spots and pores that could only be observed under good ‘seeing’
- With the smaller Handheld Telescope this was really not an issue because those small spots could not been seen anyway
- Wolfer insisted on counting ALL the spots that could be seen as clearly black with the 80mm Standard Telescope [this has been adopted by all later observers]
- During 16 years of simultaneous observations with Wolf, it was determined that a factor of 0.6 could be applied to Wolfer’s count to align them with Wolf’s [actually to 1.5 times the ‘Handheld’ values]
- All subsequent observers have adopted that same 0.6 factor to stay on the original Wolf scale for 1849-~1860

# The Amplitude of the Diurnal Variation, *rY*, [from many stations] shows the same Change in Rz ~1945



# The Early ~1885 Discrepancy

- Since the sunspot number has an arbitrary scale, it makes no difference for the calibration if we assume Rg to be too ‘low’ before ~1885 or Rz to be too ‘high’ after 1885




By applying Wolf’s relationship between Rz and the diurnal variation of the Declination we can show that it is Rg that is too low

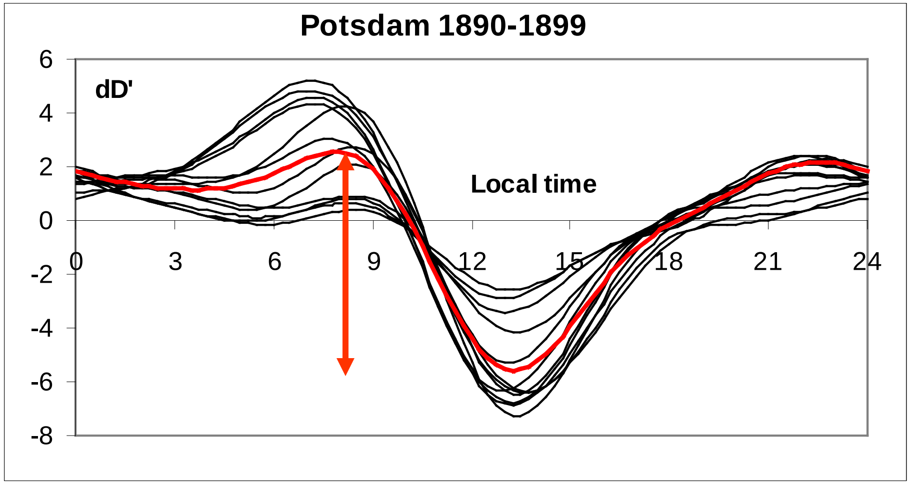
# Comparing Diurnal Ranges

- A vast amount of hourly [or fixed-hours] measurements from the mid-19th century exists, but is not yet digitized
- We often have to do with second-hand accounts of the data, e.g. the monthly or yearly averages as given by Wolf, so it is difficult to judge quality and stability
- Just measuring the daily range [e.g. as given by Ellis for Greenwich] is not sufficient as it mixes the regular day-side variation in with night-time solar wind generated disturbances

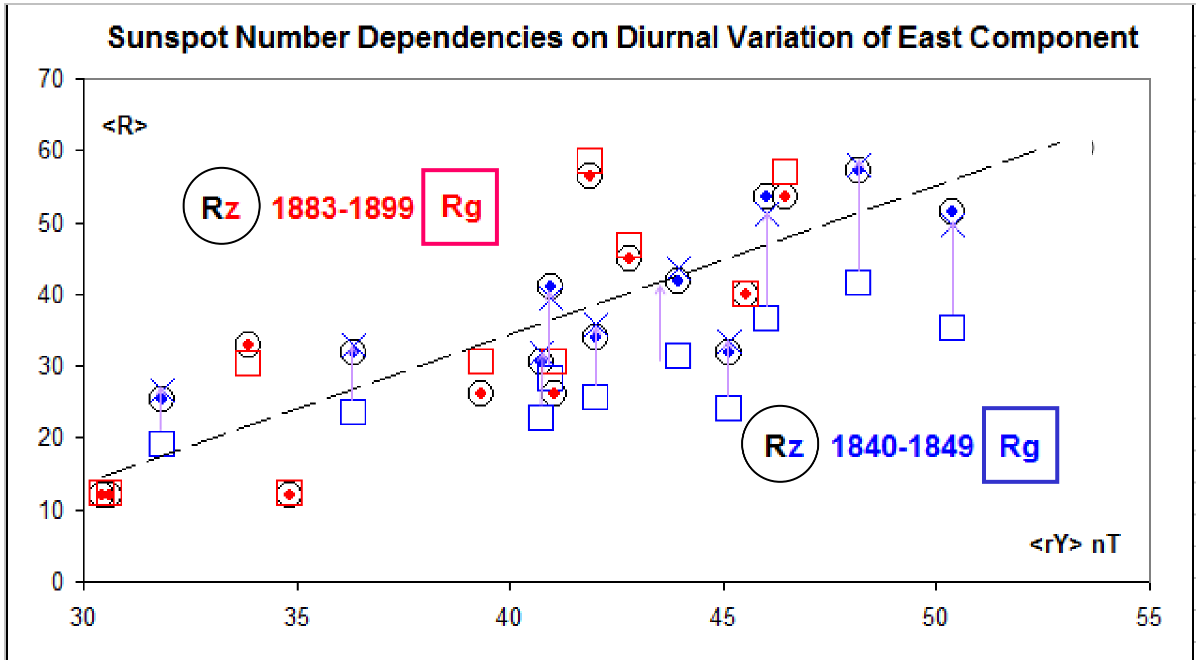
# Adolf Schmidt's (1909) Analysis

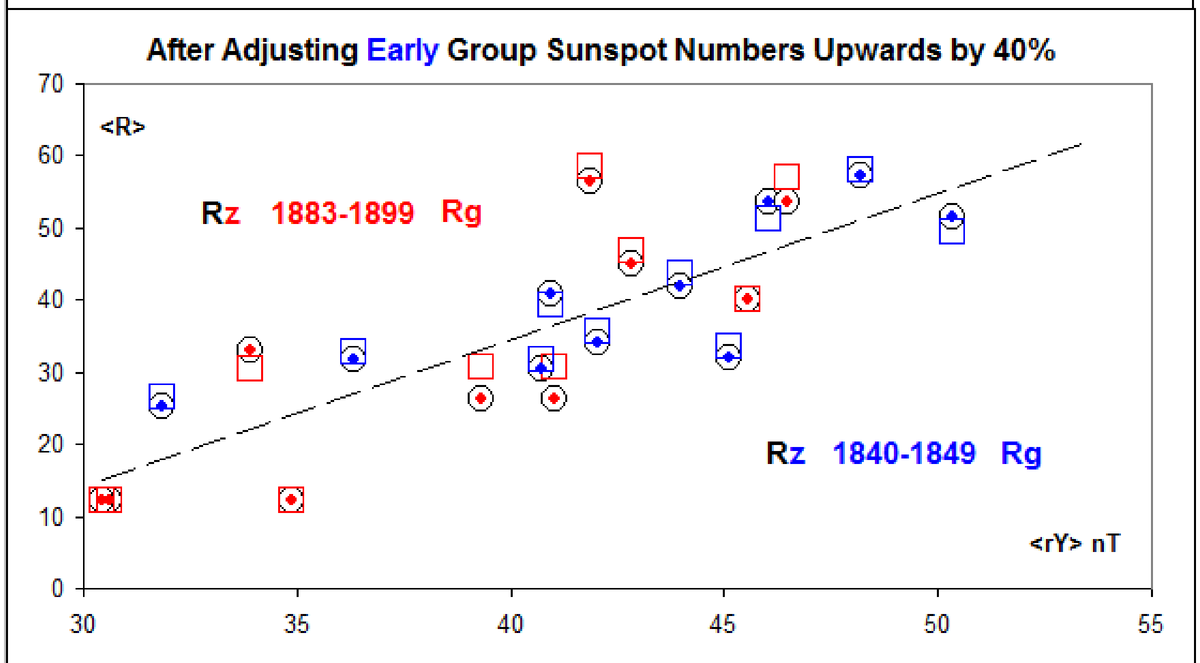
Schmidt collected raw hourly observations and computed the first four Fourier components [to 3-hr resolution] of the observed Declination in his ambitious attempt to present what was then known in an 'einheitlicher Darstellung' [uniform description]

| Observatory | Years | Lat | Long |
|---|---|---|---|
| Washington DC | 1840-1842 | 38.9 | 282.0 |
| Dublin | 1840-1843 | 53.4 | 353.7 |
| Philadelphia | 1840-1845 | 40.0 | 284.8 |
| Praha | 1840-1849 | 50.1 | 14.4 |
| Muenschen | 1841-1842 | 48.2 | 11.6 |
| St. Petersburg | 1841-1845 | 60.0 | 30.3 |
| Greenwich | 1841-1847 | 51.5 | 0.0 |
| Hobarton | 1841-1848 | -42.9 | 147.5 |
| Toronto | 1842-1848 | 43.7 | 280.6 |
| Makerstoun | 1843-1846 | 55.6 | 357.5 |
| | | | |
| Greenwich | 1883-1889 | 51.4 | 0.0 |
| P. Saint-Maur | 1883-1899 | 48.8 | 0.2 |
| Potsdam | 1890-1899 | 52.4 | 13.1 |
| København | 1892-1898 | 55.7 | 12.6 |
| Utrecht | 1893-1898 | 52.1 | 5.1 |
| Odessa | 1897-1897 | 46.4 | 30.8 |
| Tokyo | 1897-1897 | 35.7 | 139.8 |
| Bucarest | 1899-1899 | 44.4 | 26.1 |
| Irkutsk | 1899-1899 | 52.3 | 194.3 |
| Zi-ka-wei | 1899-1899 | 31.2 | 121.2 |




Engelenburg and Schmidt calculated the average variation over the interval for each month and determined the amplitude and phase for each month. From this we can reconstruct the diurnal variation and the yearly average amplitude, dD [red curve].

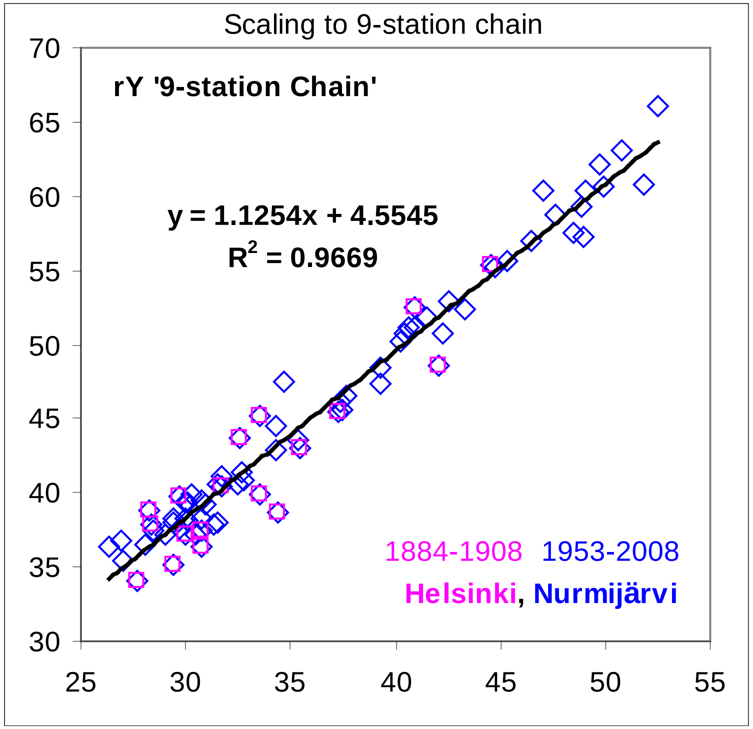


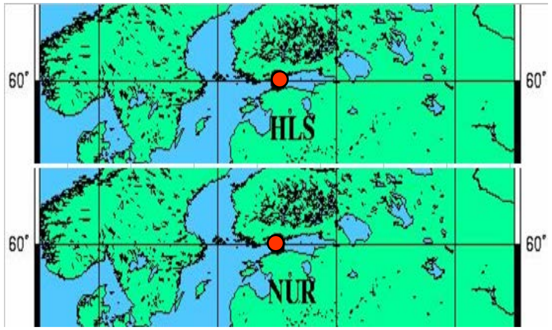

**Procedure:**
For each station we now compute the averages over the interval of <Rz>, <Rg>, and of the diurnal range [converted to force units, nT, from arc minutes] and plot <Rz> against the range <rY> (calculated from dD) as the black circles with a color dot at the center. The color is blue for the early interval and red for the later interval.

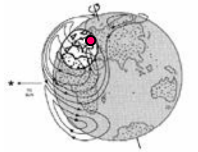
The Group Sunspot Numbers <Rg> is plotted as blue and red squares. It is clear that <Rg>s for the early interval fall significantly and systematically below corresponding <Rz>s. Increasing the early <Rg>s by 40% [the arrows to the blue crosses] brings them into line with <Rz> before Waldmeier.

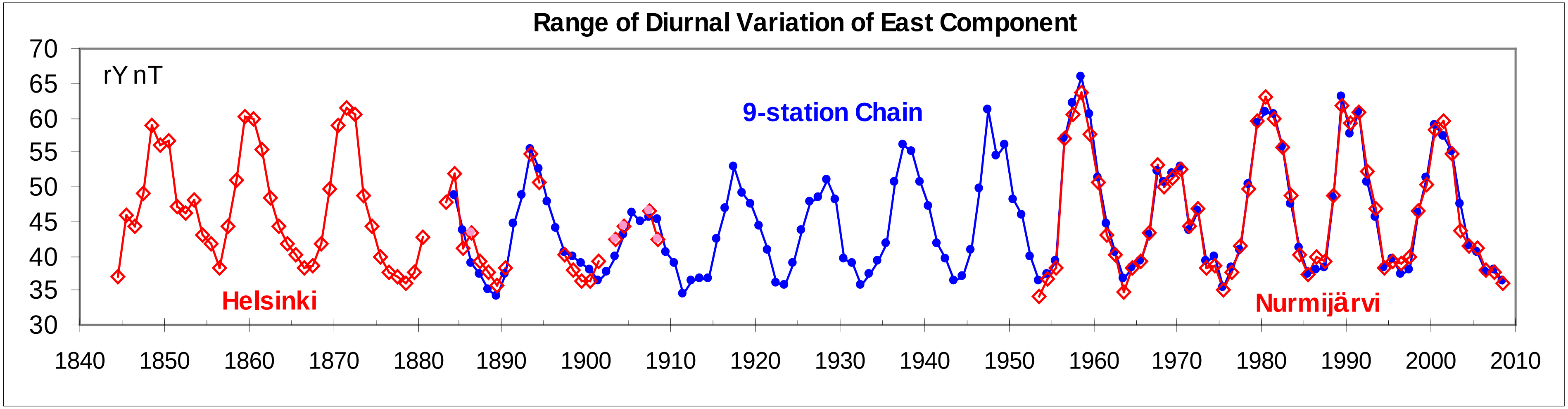
# Helsinki-Nurmijärvi Diurnal Variation



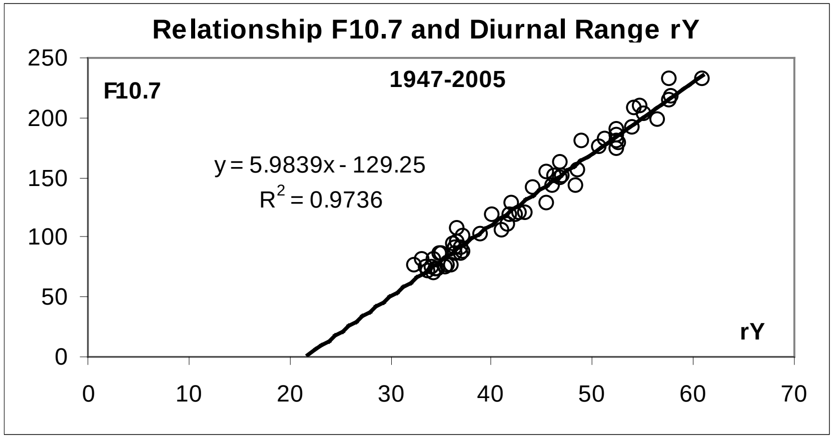

Helsinki and its replacement station Numijärvi scales the same way towards our composite of nine long-running observatories and can therefore be used to check the calibration of the sunspot number (or more correctly to reconstruct the F10.7 radio flux – see next slide)



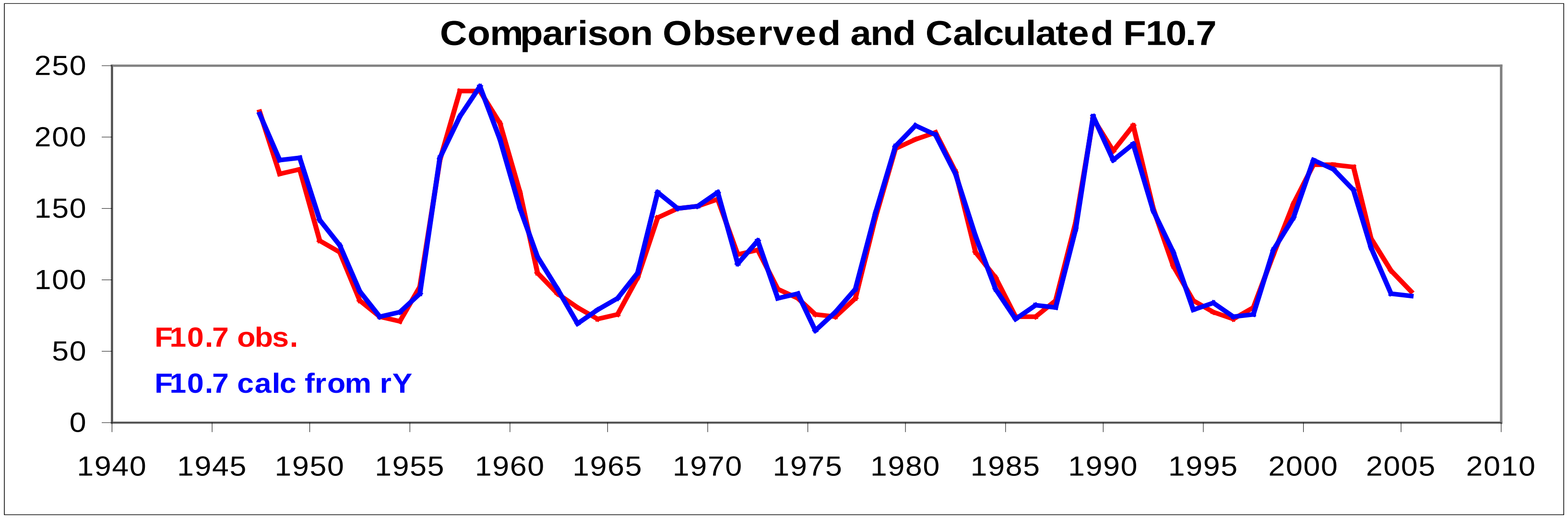





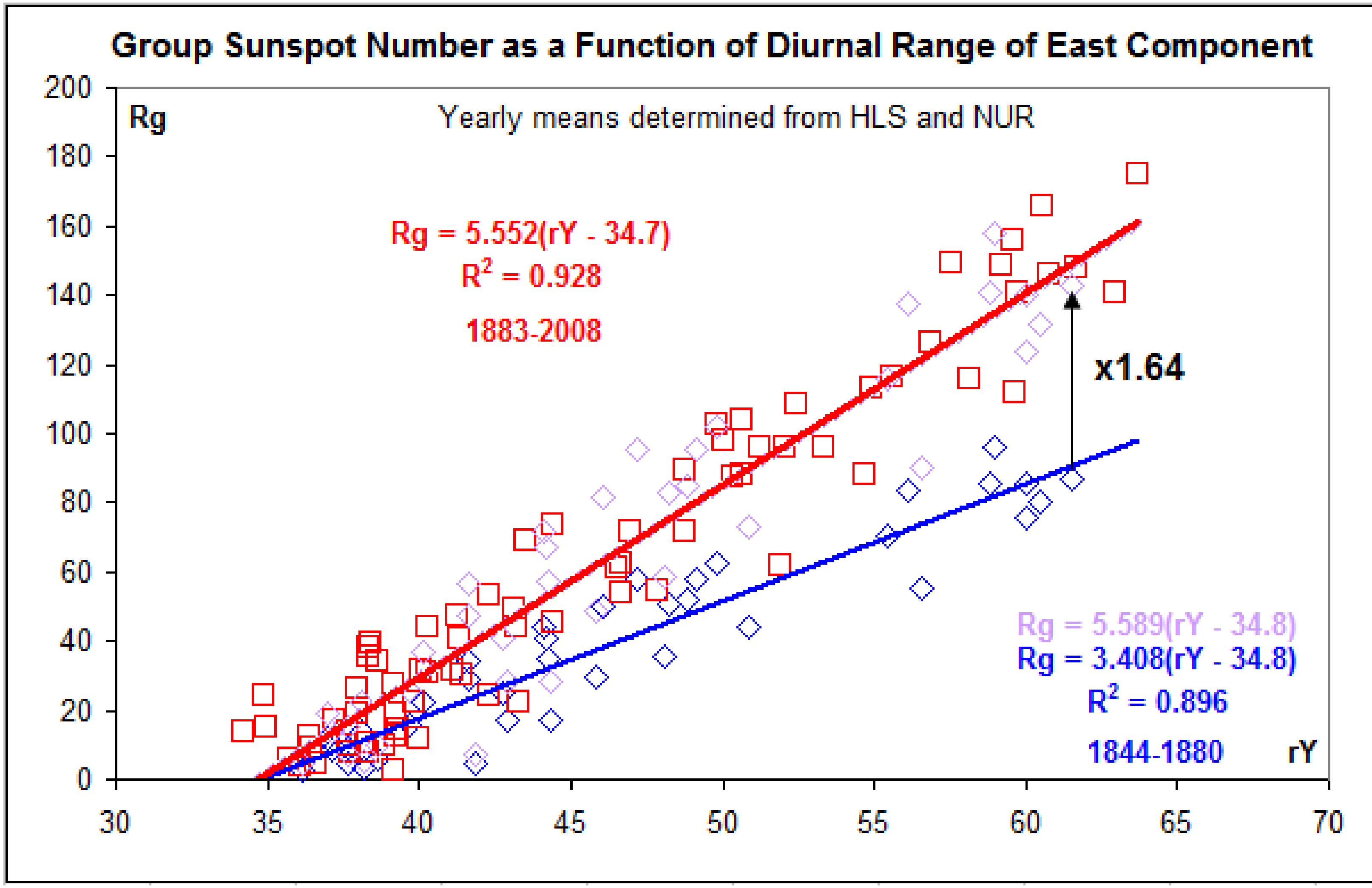
# The Diurnal Range *rY* is a very good proxy for the Solar Flux at 10.7 cm




Which itself is a good proxy for solar Ultraviolet radiation and solar activity in general [what the sunspot number is trying to capture].

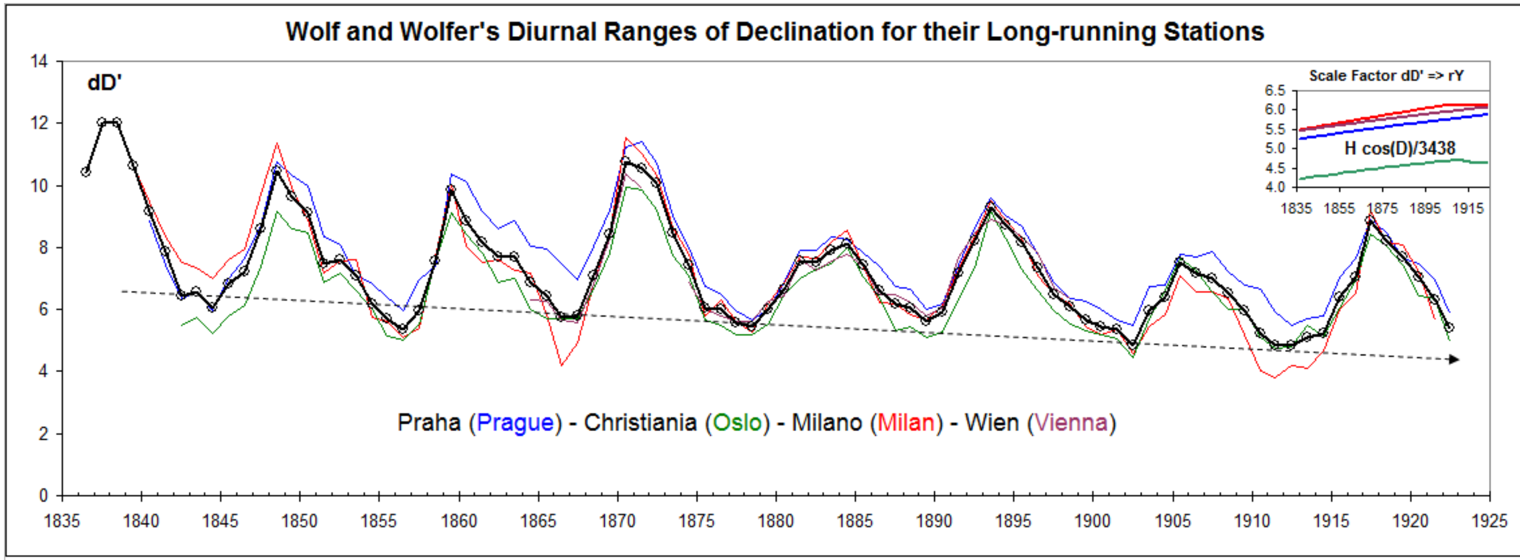


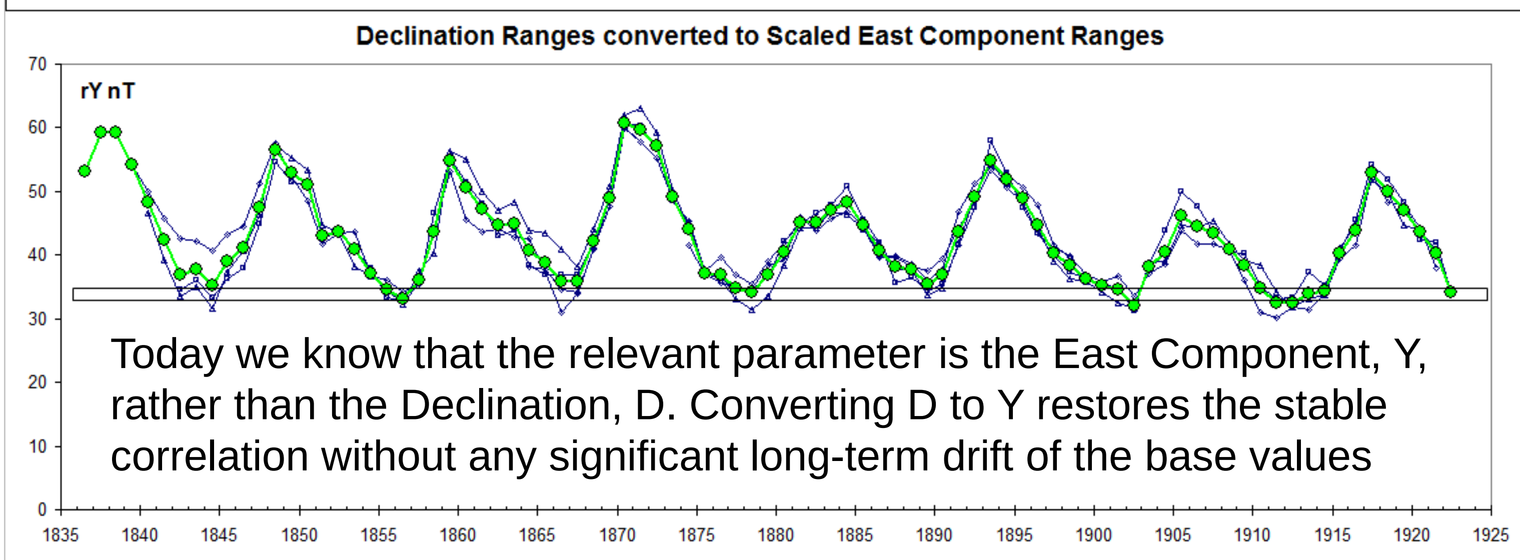
The HLS-NUR data show that the Group Sunspot Number before 1880 must be Increased by a factor 1.64±0.15 to match *rY* (F10.7)




This conclusion is independent of the calibration of the Zürich SSN, Rz

# Wolf's Geomagnetic Data

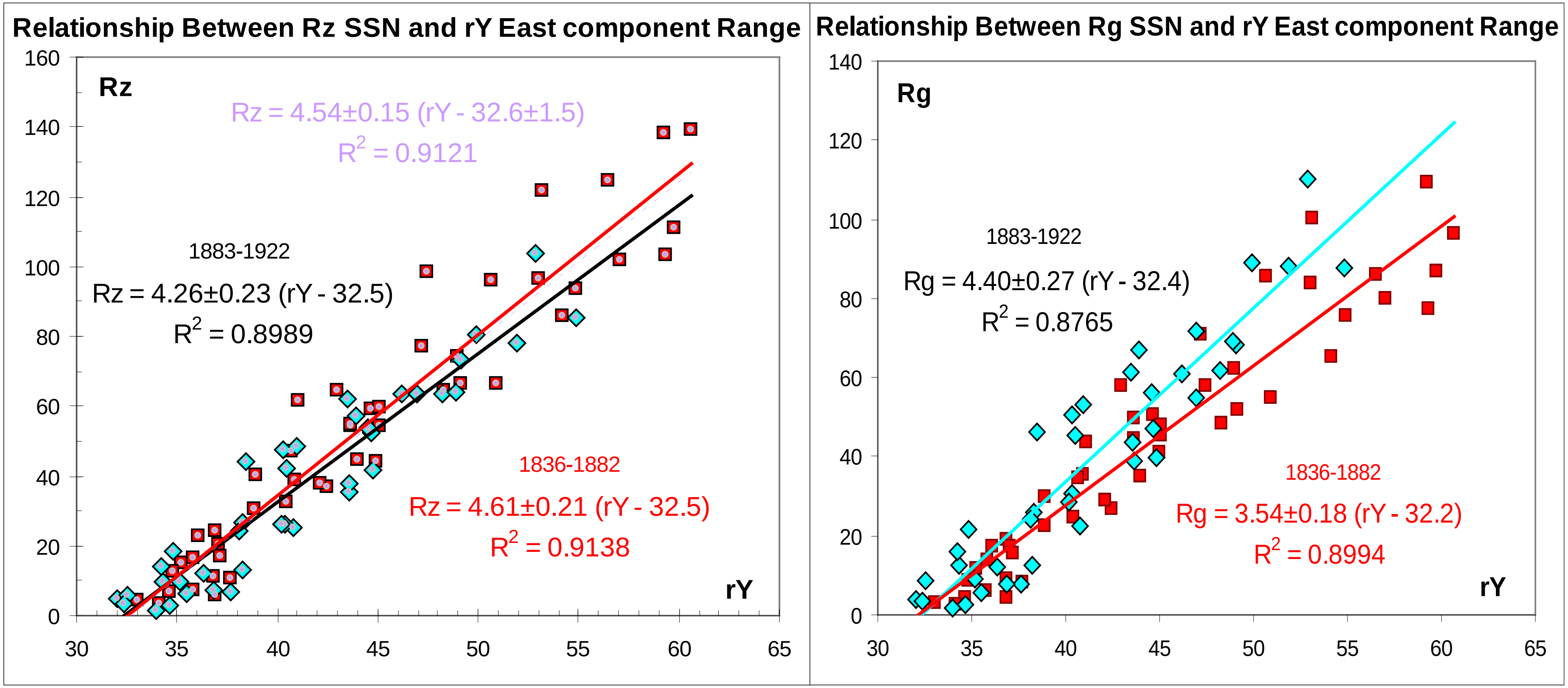



Wolf found a very strong correlation between his Wolf number and the daily range of the Declination.

Wolfer found the original correlation was not stable, but was drifting with time and gave up on it in 1923.

# Using the East Component We Recover Wolf's Tight Relationship




The regression lines are identical within their errors before and after 1883.0. This means that likely most of the discordance with Rg ~1885 is not due to 'change of guard' or method at Zürich. It is also clear that Rg before 1883 is too low.

# Where do we go from here?

- Find and Digitize as many 19$^{th}$ century geomagnetic hourly values as possible
- Determine improved adjustment factors based on the above and on model of the ionosphere
- Co-operate with agencies producing sunspot numbers to harmonize their efforts in order to produce an adjusted and accepted sunspot record that can form a firm basis for solar-terrestrial relations, e.g. reconstructions of solar activity important for climate and environmental changes
- Follow-up Workshop in Brussels, May 2012