Geomagnetic Calibration of Sunspot Numbers

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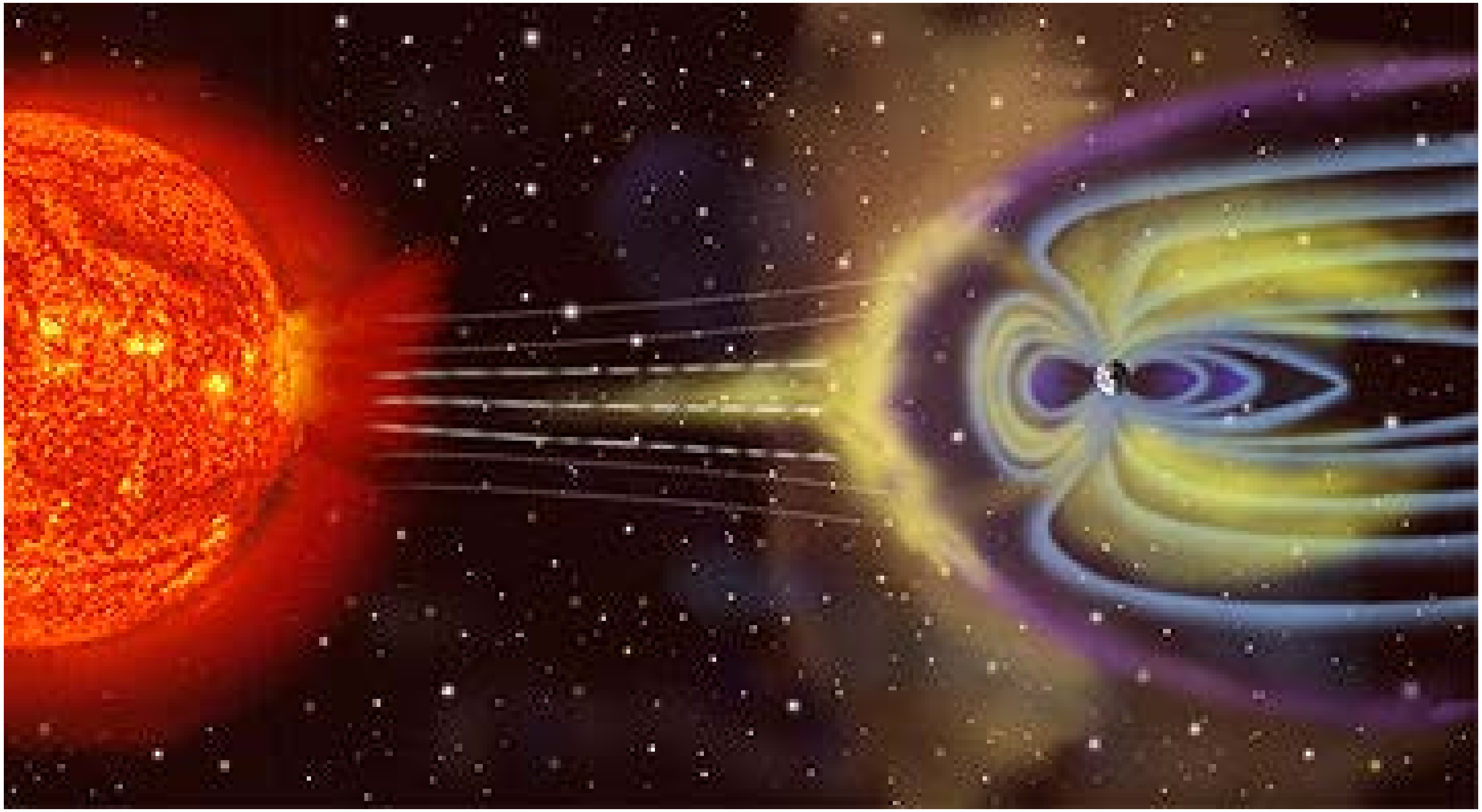
2nd SSN Workshop, Brussels, May 2012

Wolf’s Several Lists of SSNs

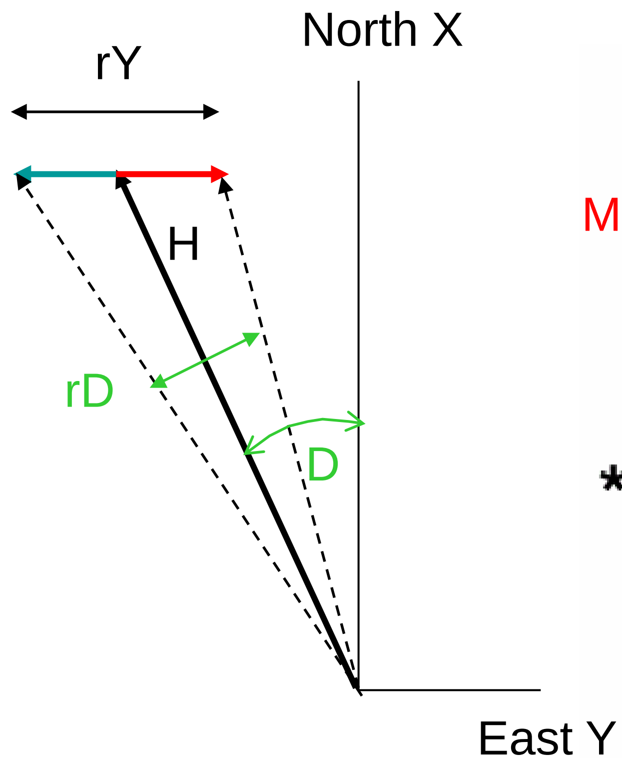
- During his life Wolf published several lists of his ‘Relative Sunspot Number’:
- 1857 Using Sunspot Drawings by Staudacher 1749-1799 as early SSNs
- 1861 Doubling Staudacher’s Numbers to align with the large variation of the Magnetic ‘Needle’ in the 1780s
- 1874 Adding newer data and published list
- 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

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

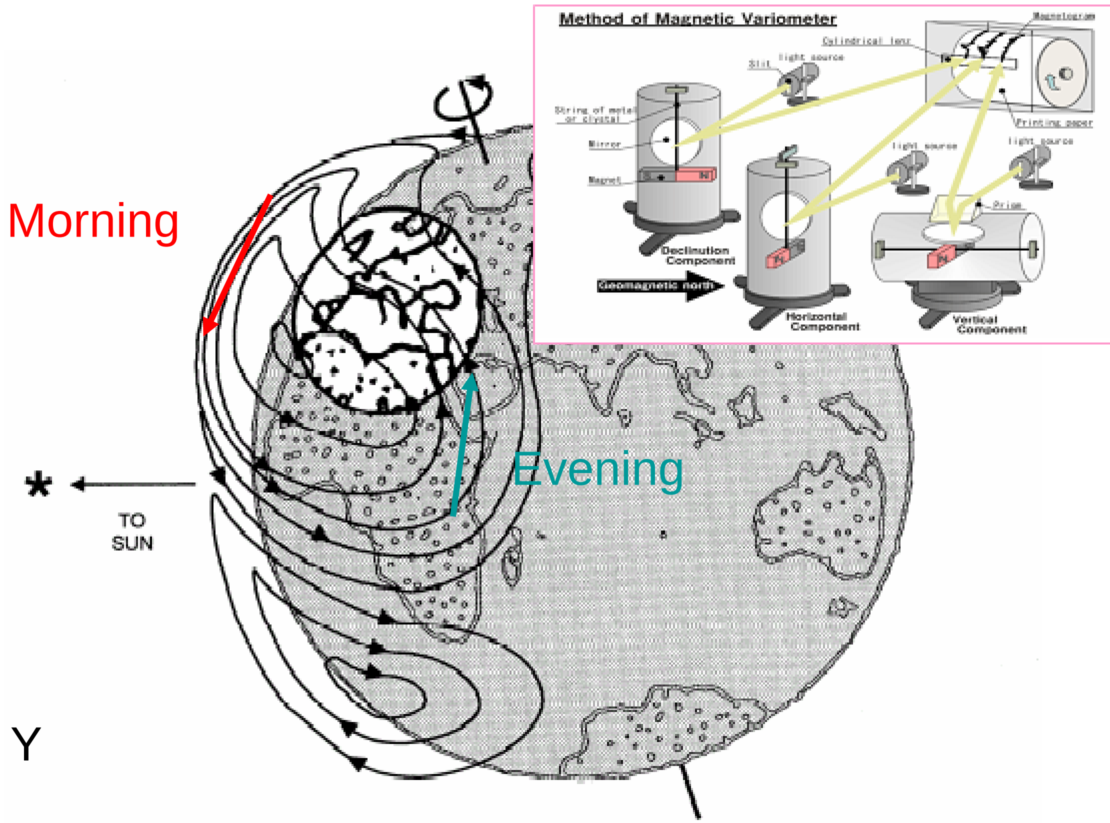
Justification of the Adjustments rests on Wolf's Discovery: $rD = a + b\ R_W$



$Y = H \sin(D)$

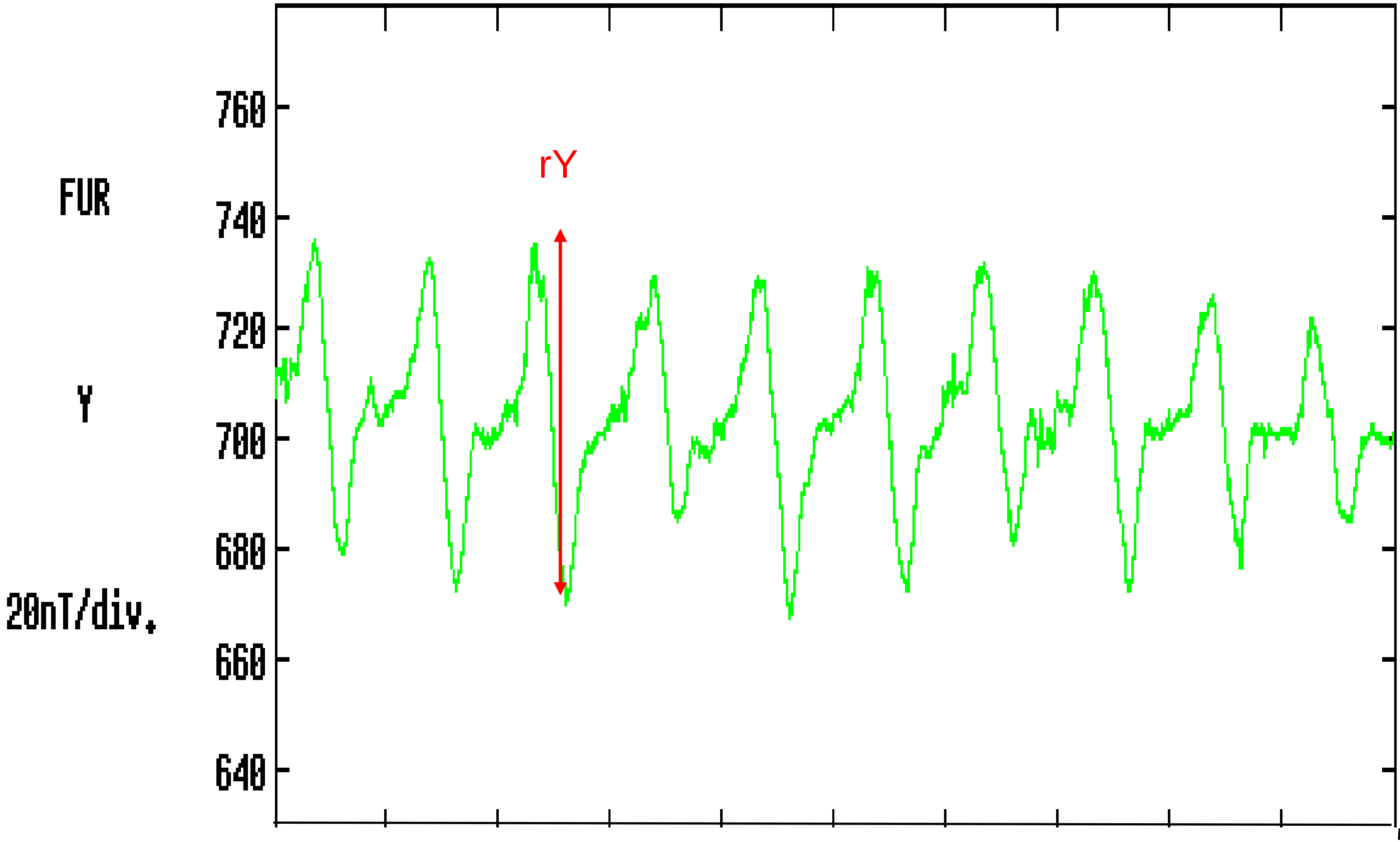
$dY = H \cos(D)\ dD$

For small D, dD and dH



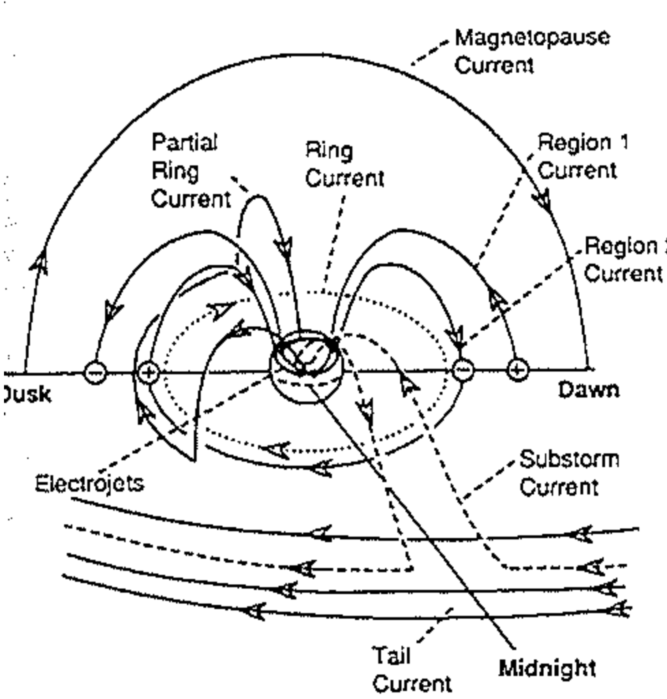
A current system in the ionosphere [E-layer] is created and maintained by solar FUV radiation. Its magnetic effect is measured on the ground.

10 Days of geomagnetic variations



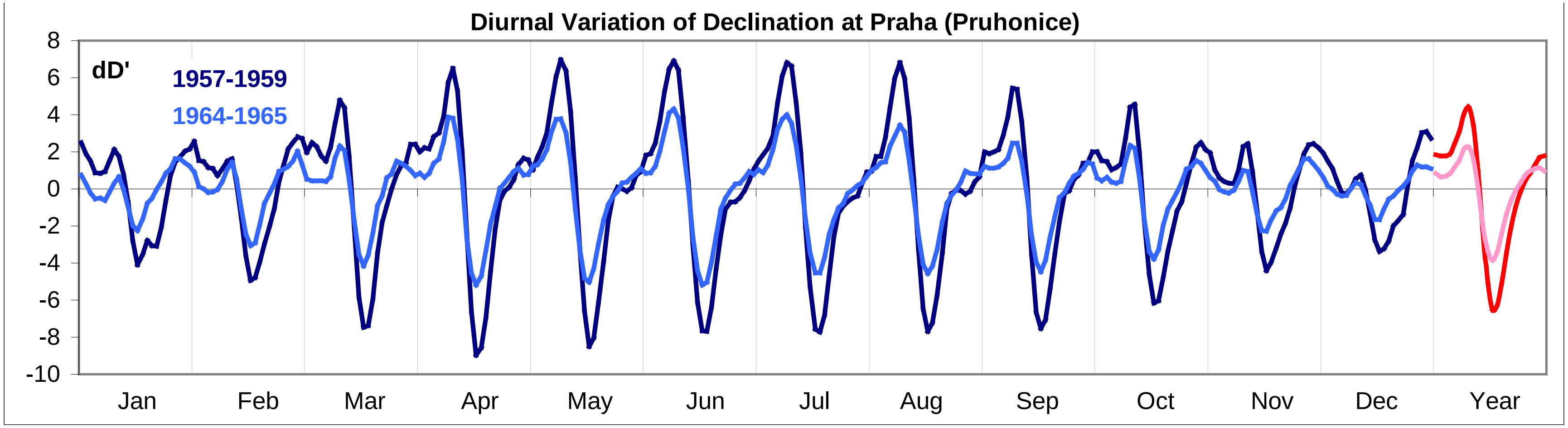
Disturbance Current Systems are East-West, thus their Magnetic Effects are North-South

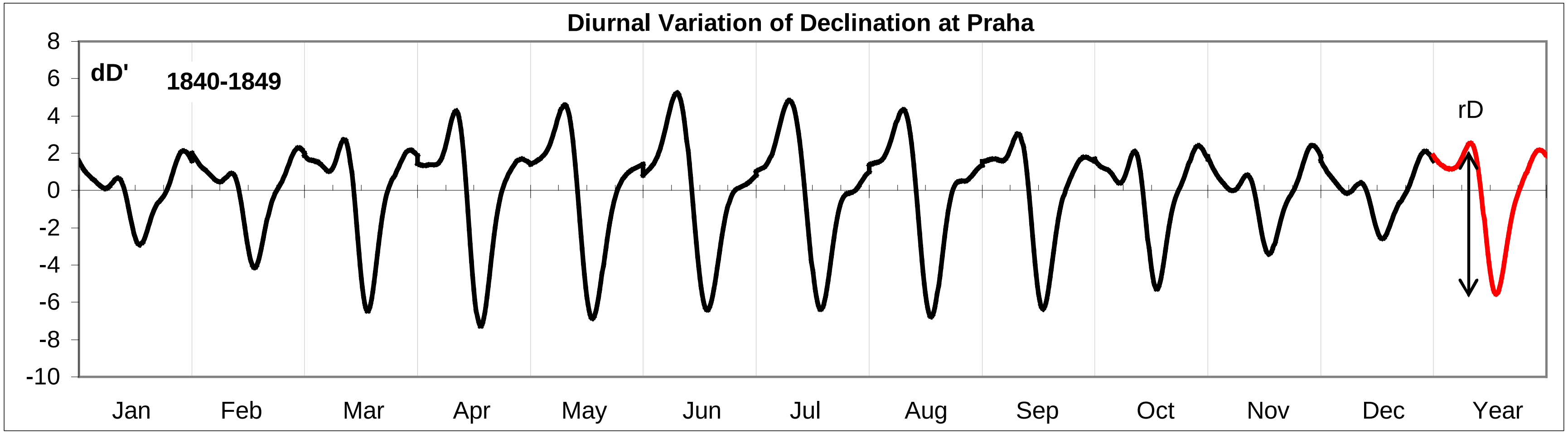
- Equatorial Electrojet
- Ring Current
- Auroral Electrojets

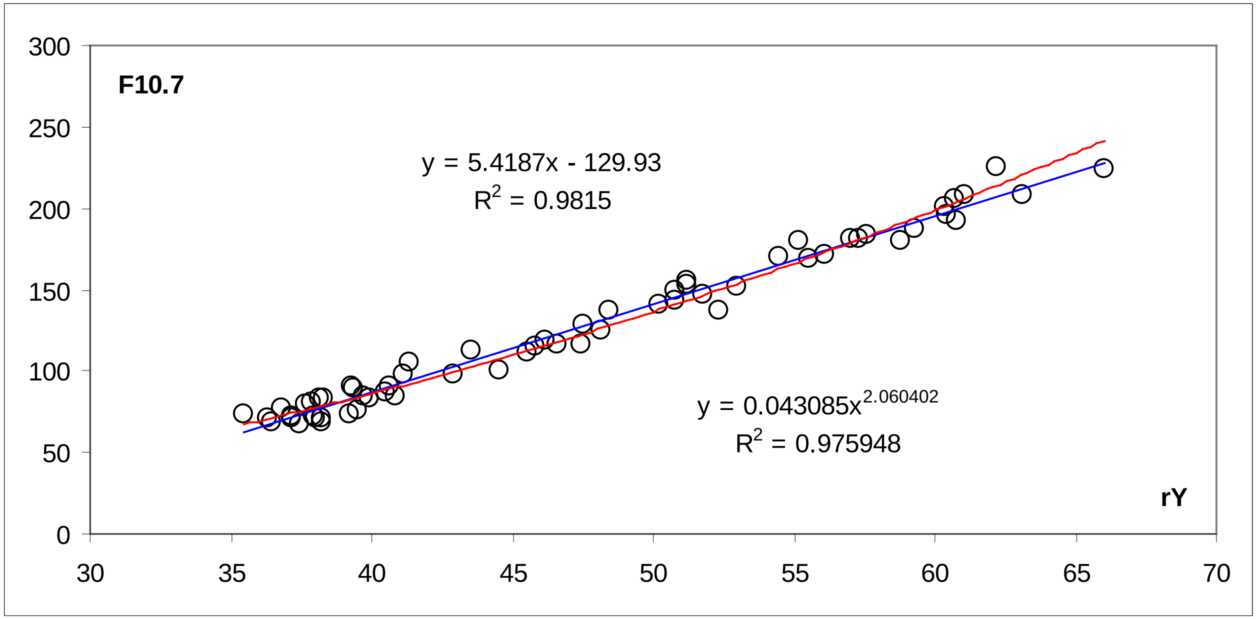


Disturbances are mainly a Nighttime phenomenon

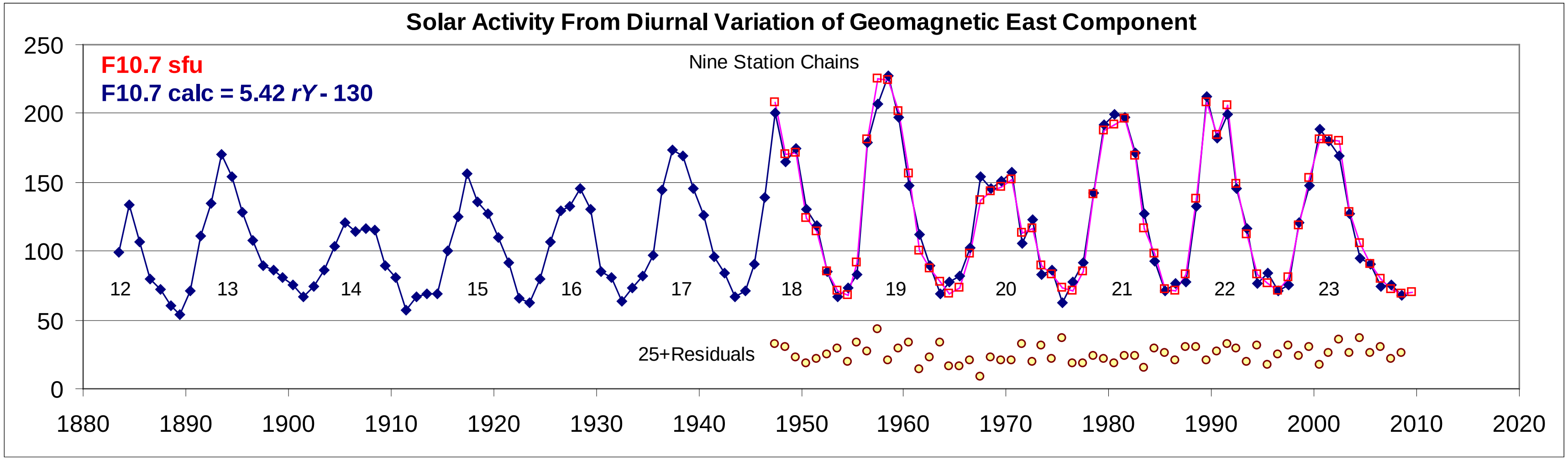
The Diurnal Variation of the Declination for Low, Medium, and High Solar Activity





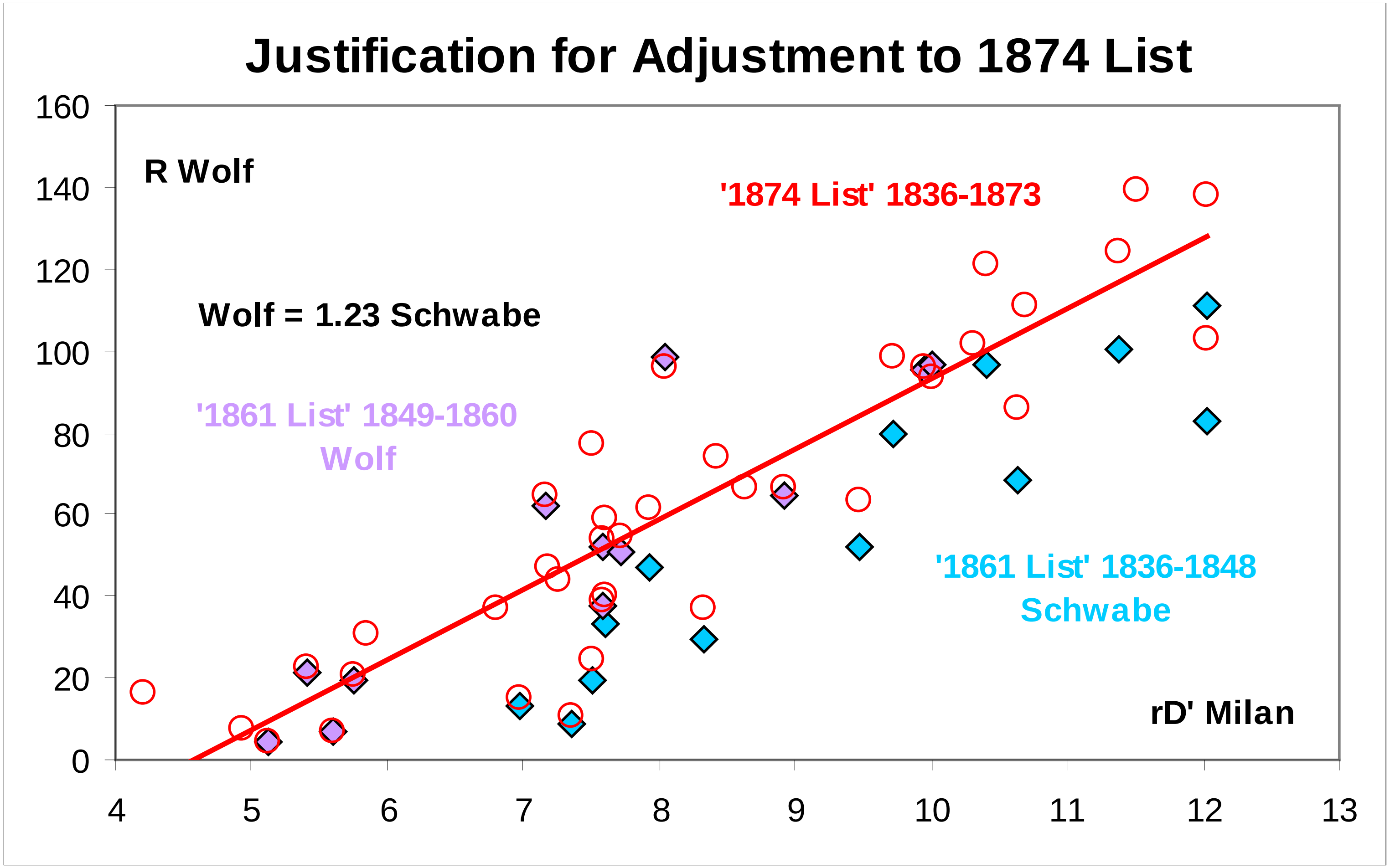


Using *rY* from nine 'chains' of stations we find that the **correlation** between *F10.7* and *rY* is extremely good (more than 98% of the variation is accounted for)



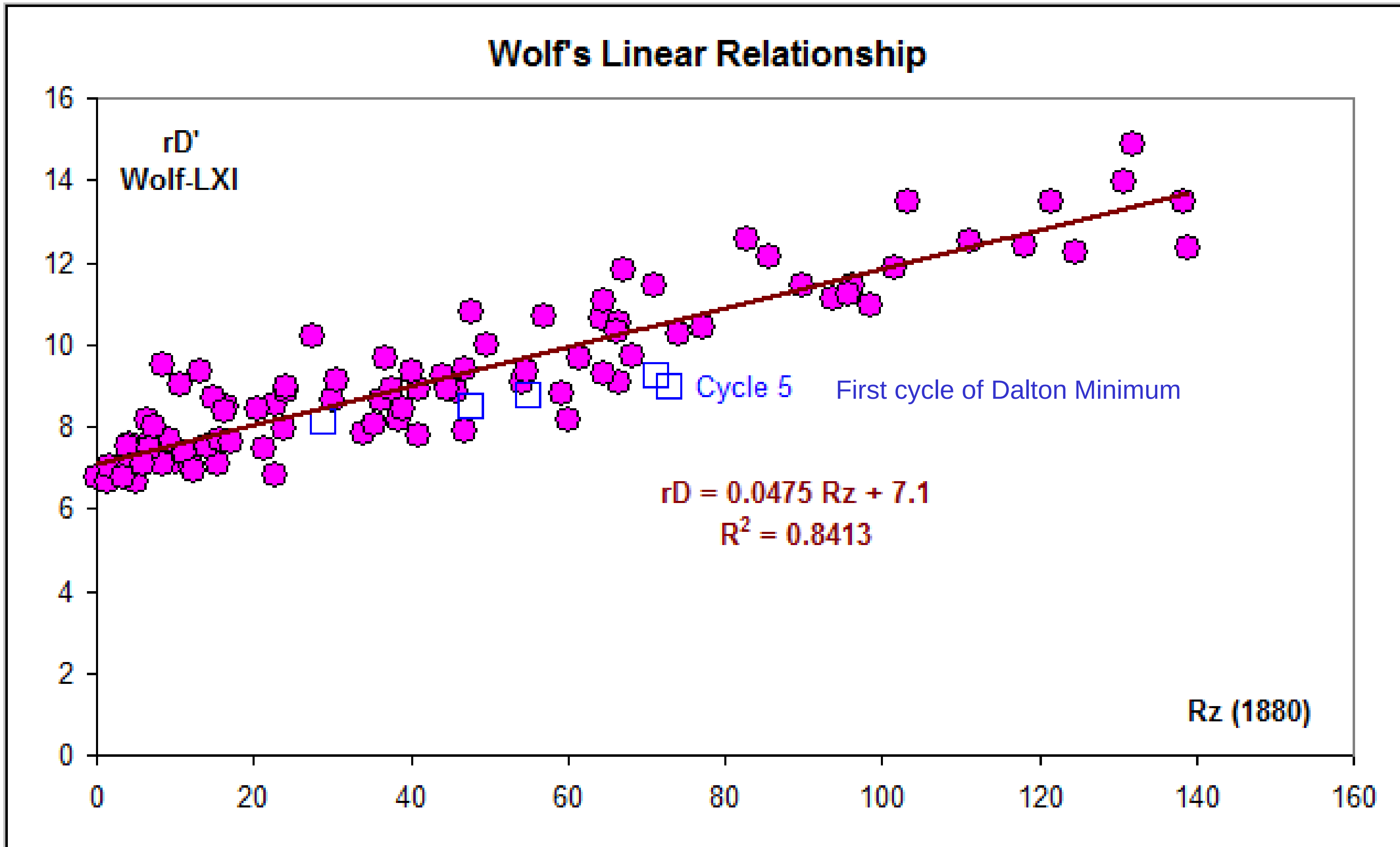
This establishes that Wolf's procedure and calibration are physically sound

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



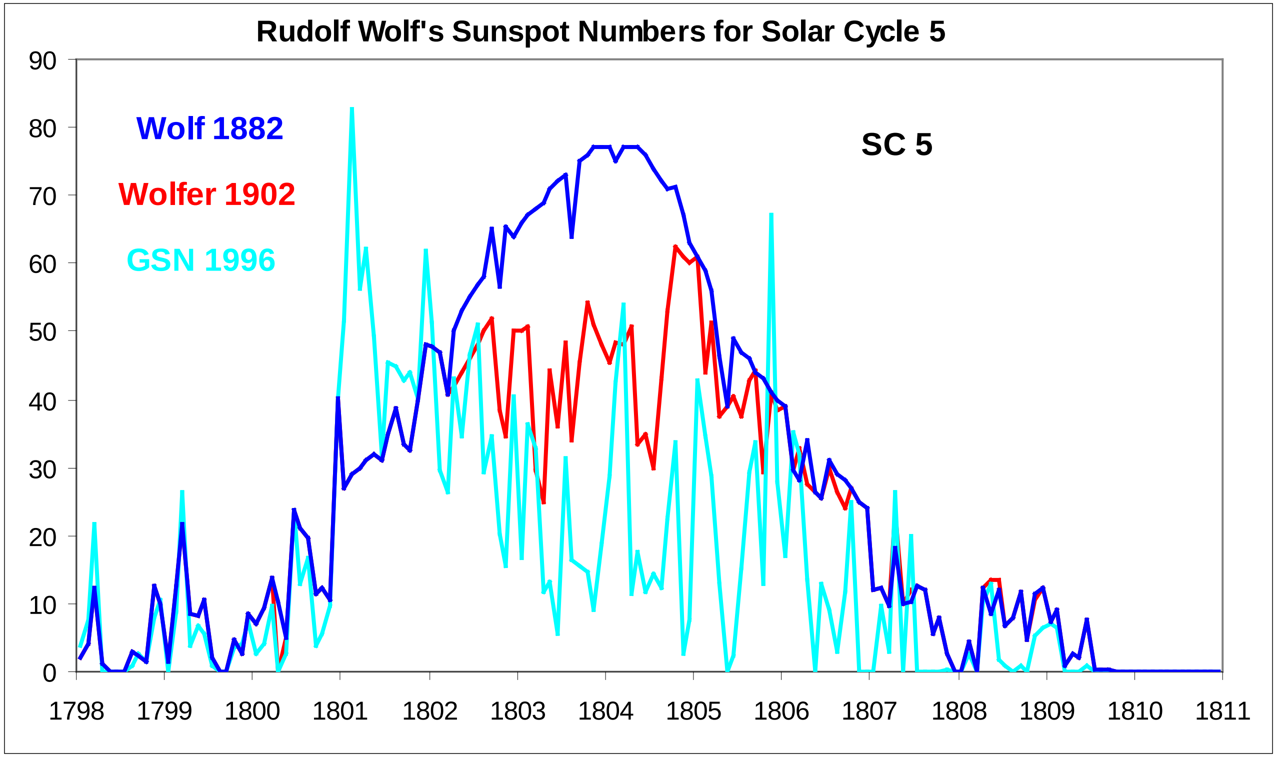
The '1874' list included the 25% [Wolf said 1/4] increase of the pre-1849 SSN

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



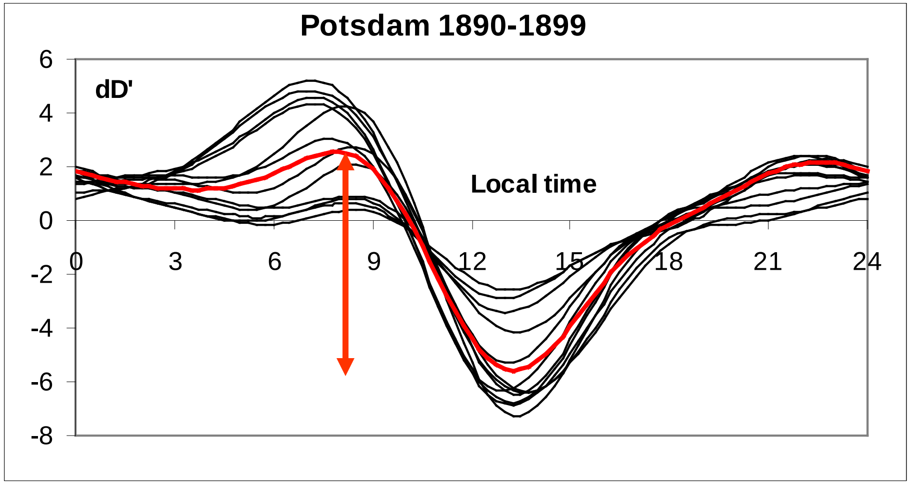
Comparing Diurnal Ranges

- 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

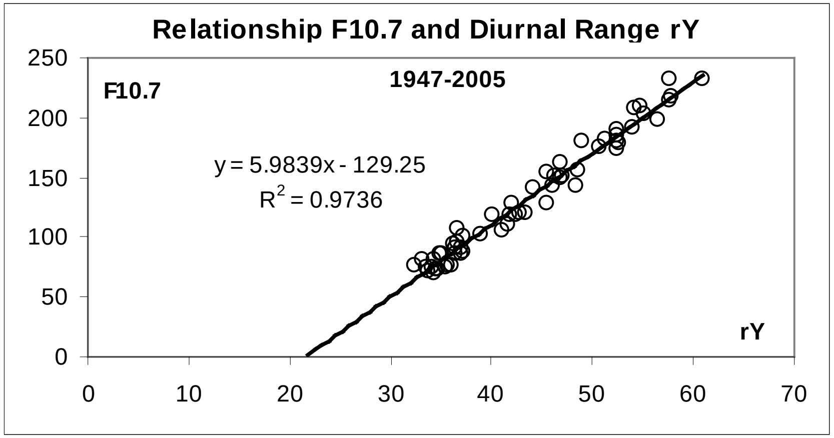
Schmidt collected raw hourly observations and computed the first four Fourier components [to 3-hr resolution] of the observed Declination in his ambitious attempt to present what was then known in an 'einheitlicher Darstellung' [uniform description]

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

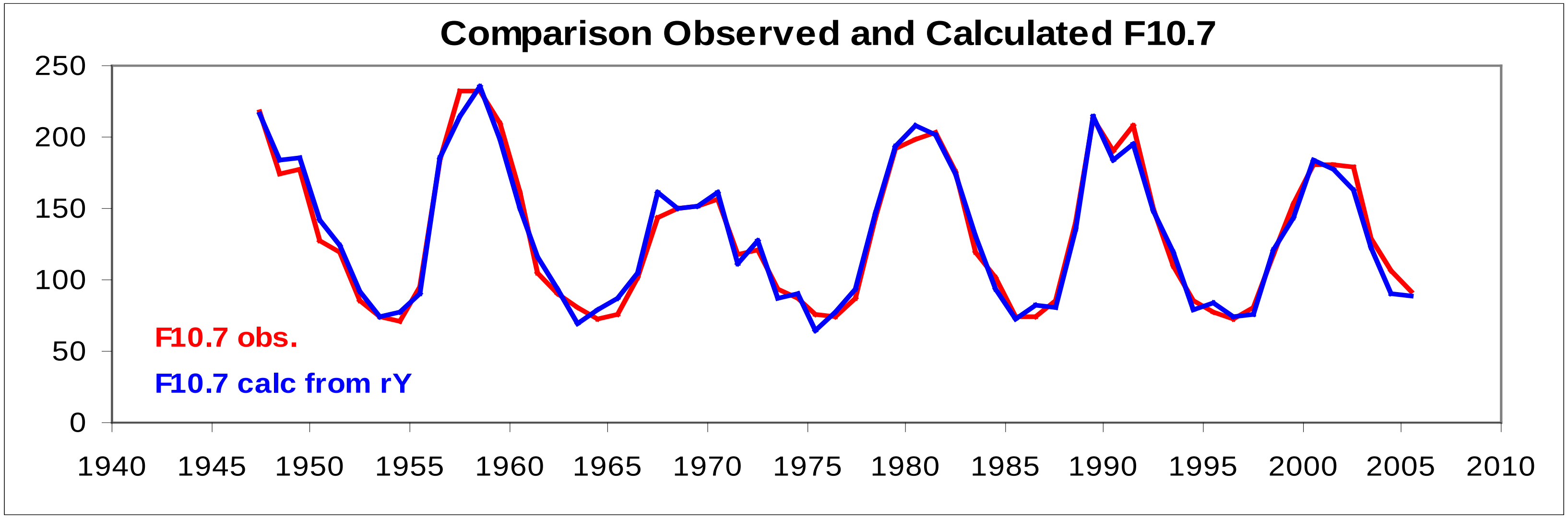


Engelenburg and Schmidt calculated the average variation over the interval for each month and determined the amplitude and phase for each month. From this we can reconstruct the diurnal variation and the yearly average amplitude, dD [red curve].

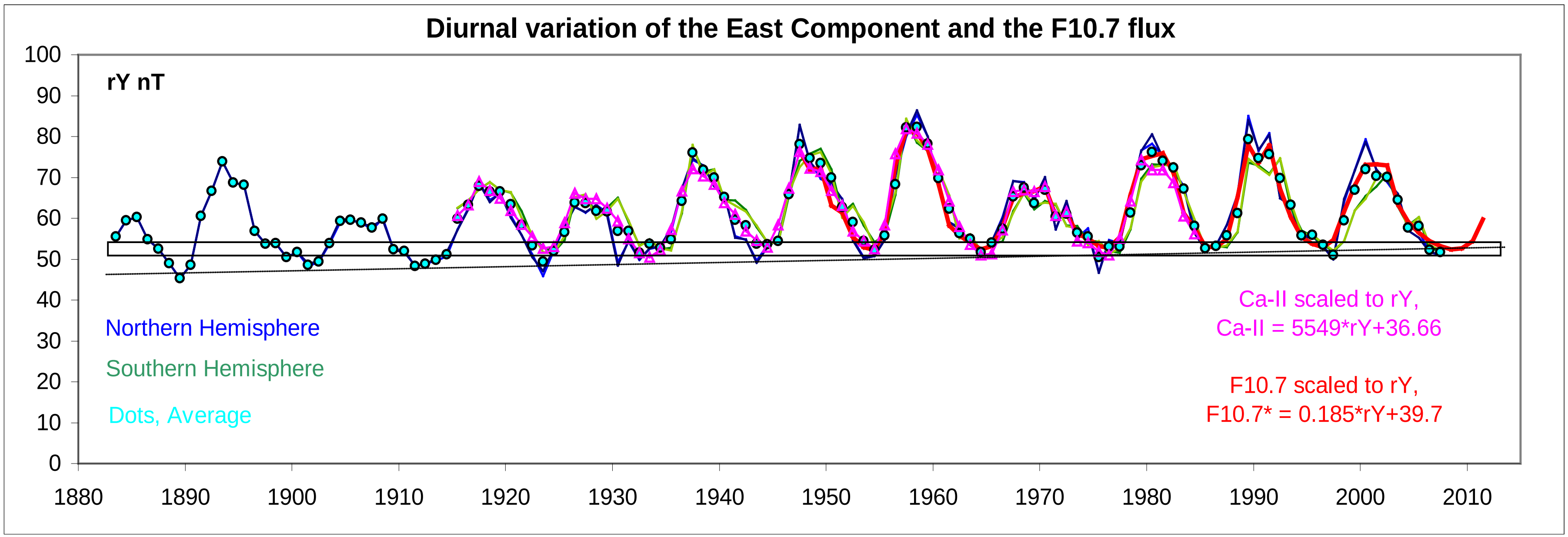
The Diurnal Range *rY* is a very good proxy for the Solar Flux at 10.7 cm



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



Compare with F10.7 Flux and Ca II Emission



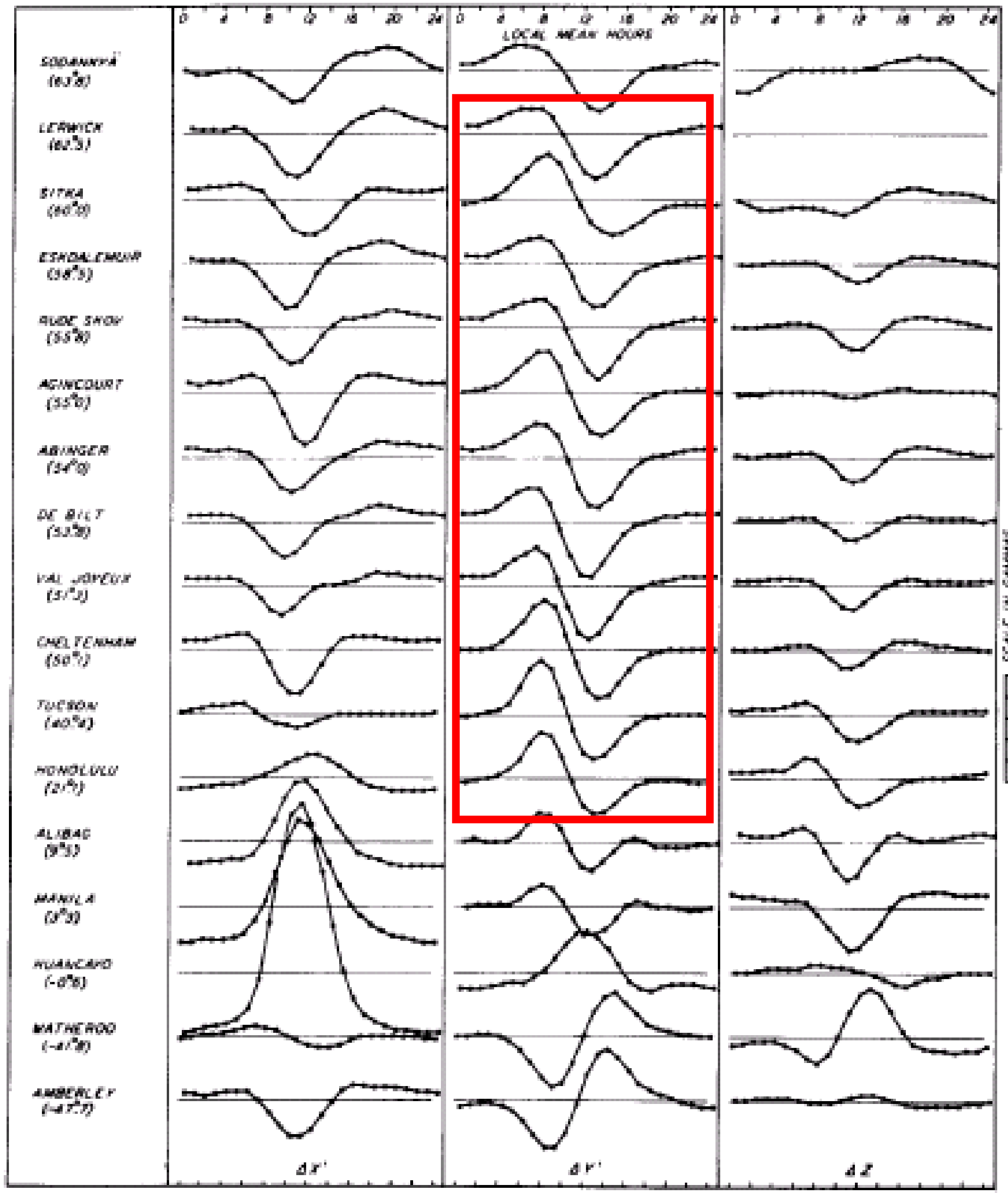
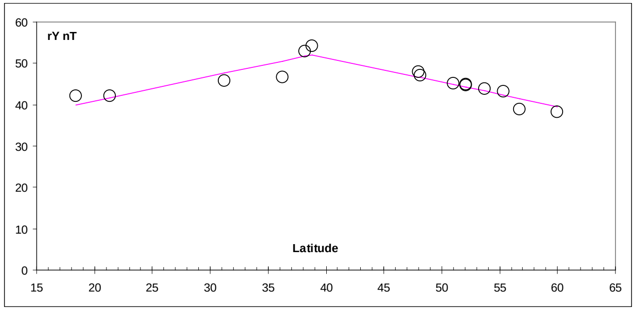


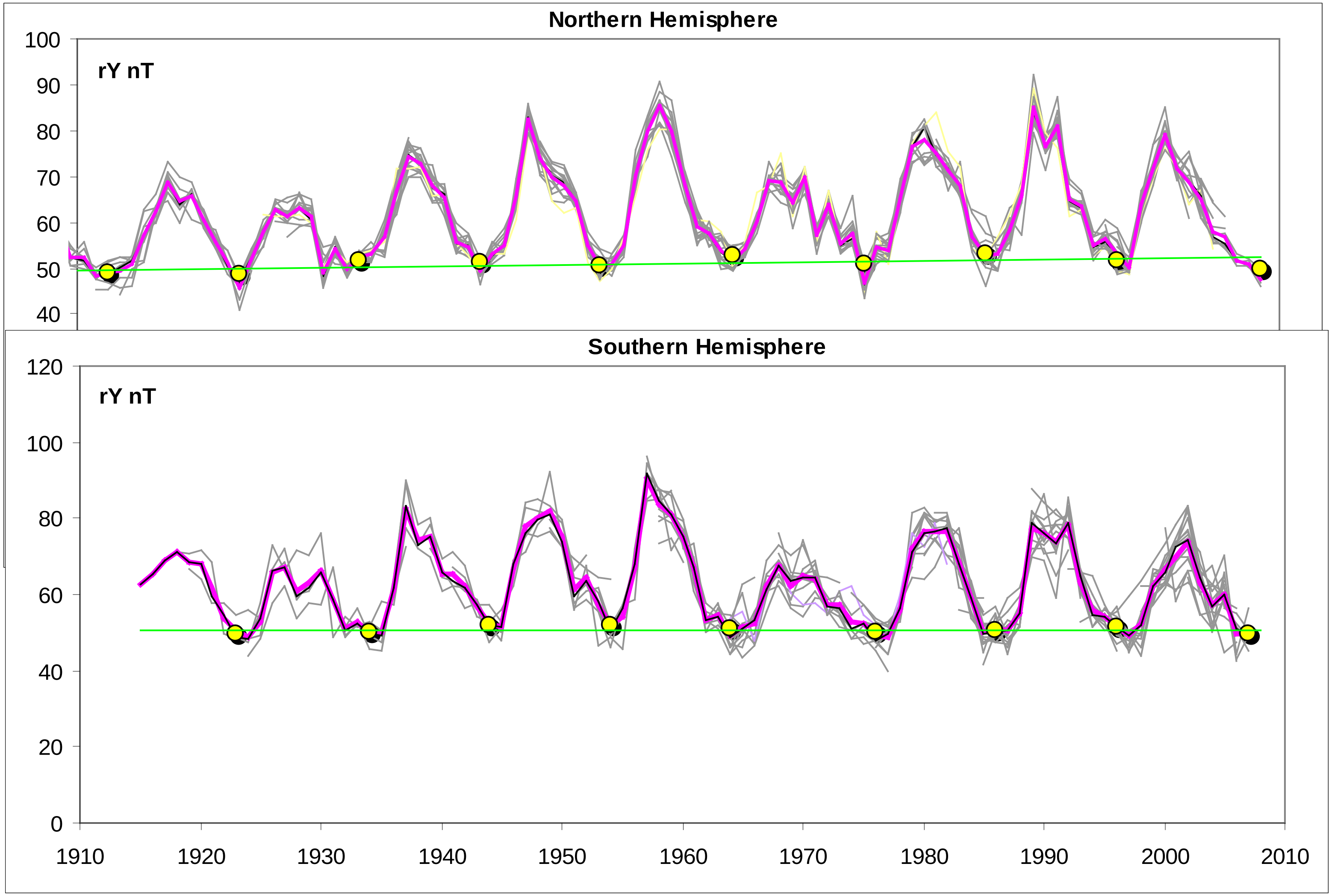
FIG. 69—SOLAR DAILY VARIATION ON QUIET DAYS (S_q), VARIOUS STATIONS, GEOMAGNETIC COMPONENTS, YEAR, 1922-33 (GEOMAGNETIC LATITUDES INDICATED IN PARENTHESES)

Diurnal Variation as a Function of Latitude

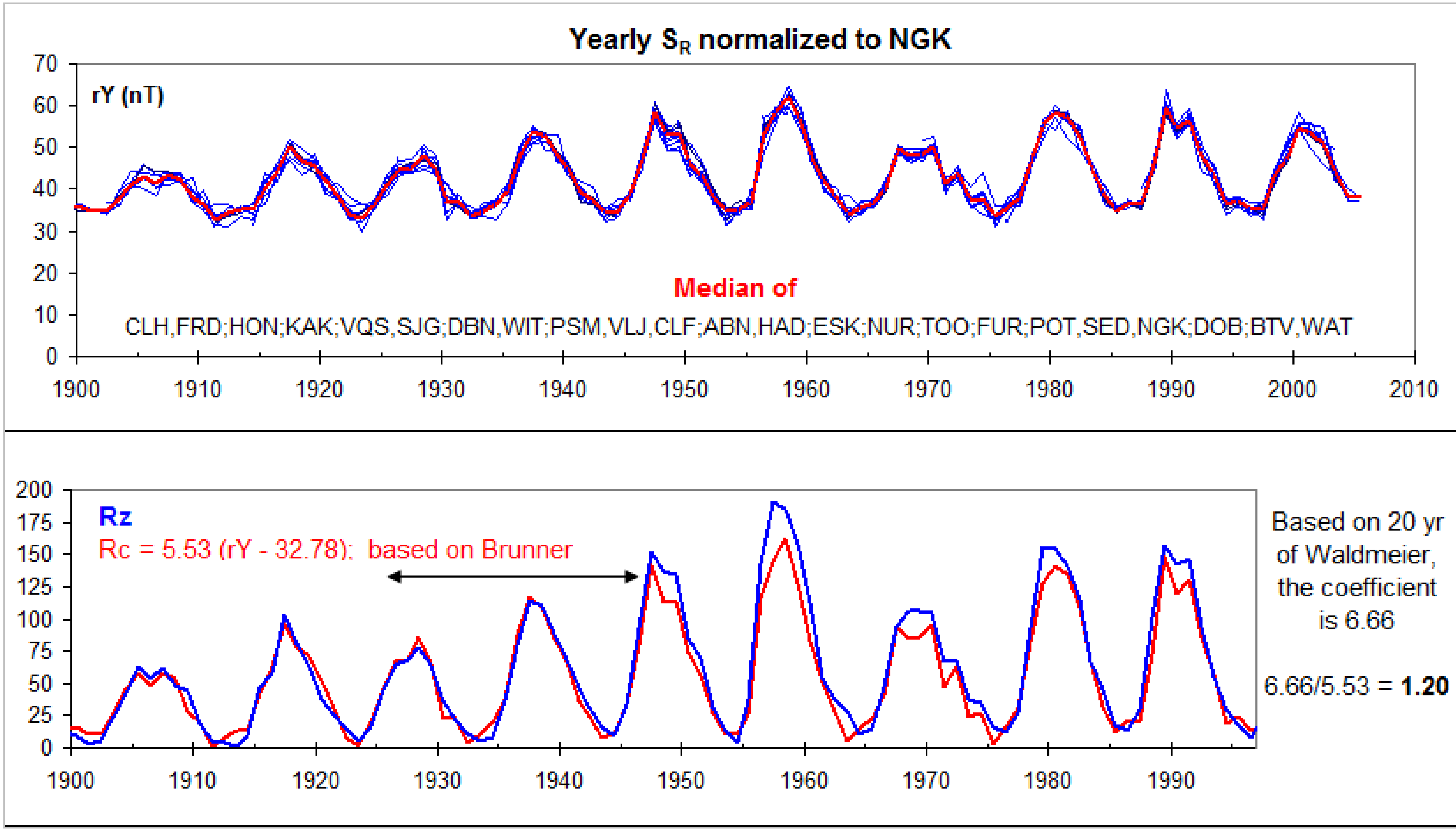


Only slight dependence

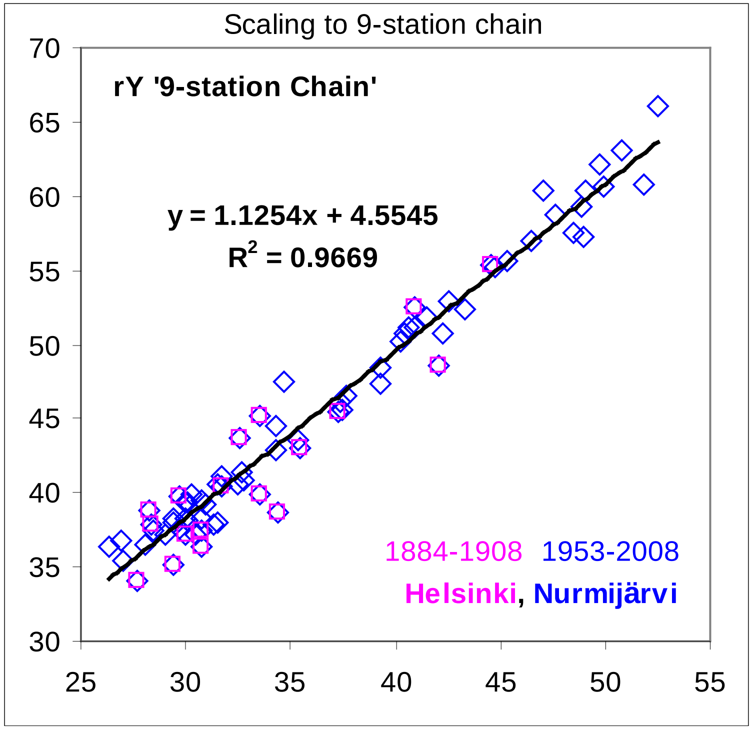
Hemispheric Variation



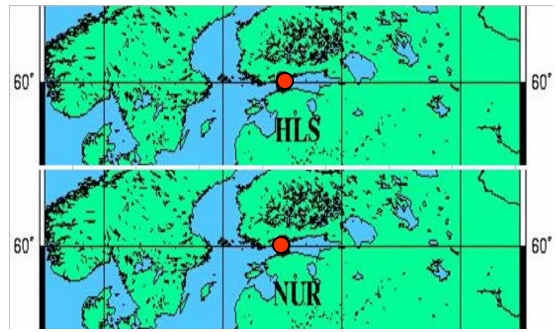
The Amplitude of the Diurnal Variation, *rY*, [from many stations] shows a Change in Rz ~1945

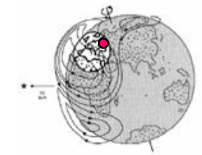


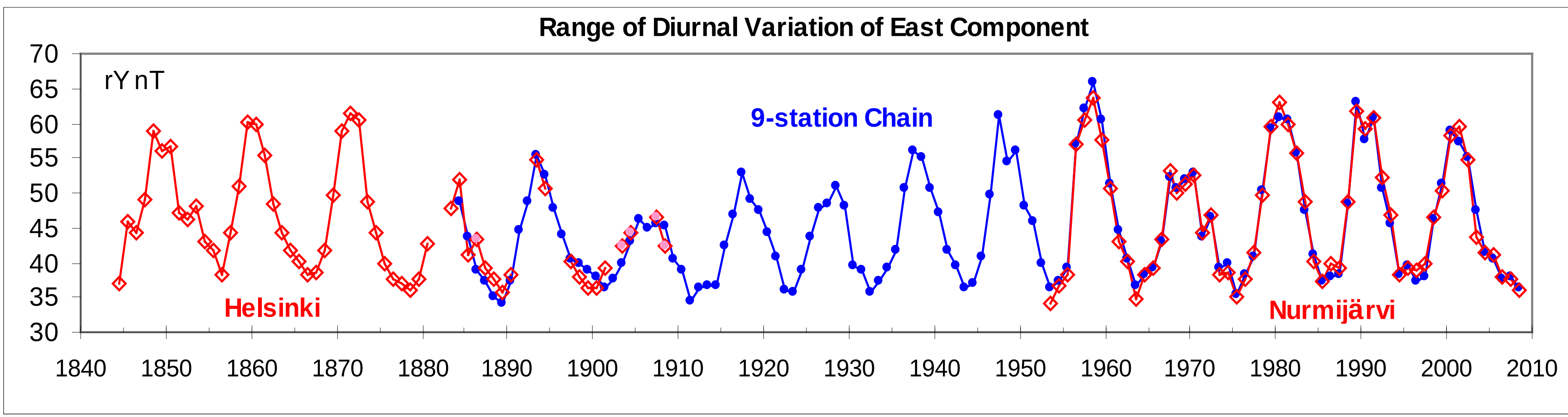
Helsinki-Nurmijärvi Diurnal Variation



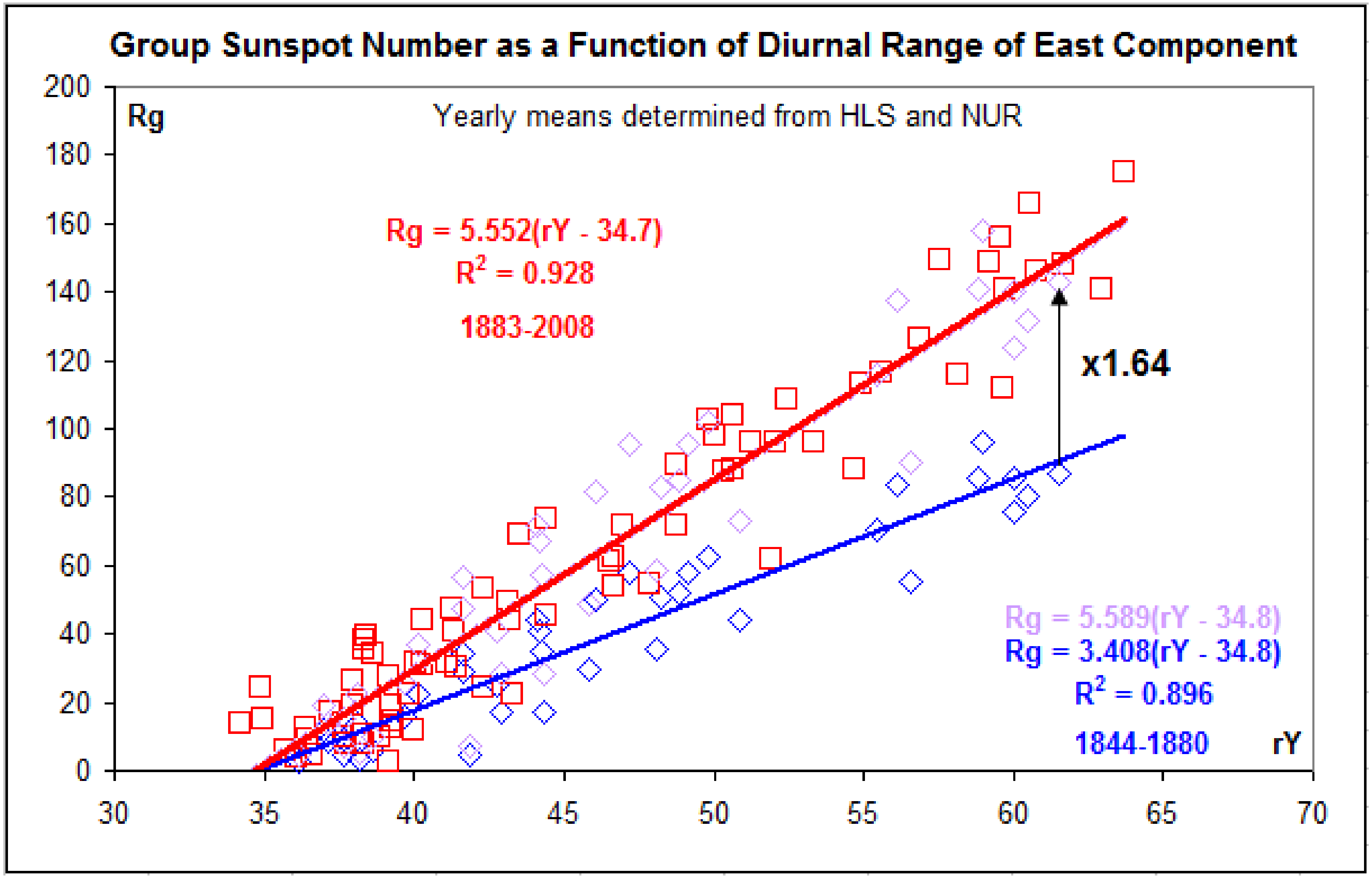
Helsinki and its replacement station Numijärvi scales the same way towards our composite of nine long-running observatories and can therefore be used to check the calibration of the sunspot number (or more correctly to reconstruct the F10.7 radio flux – see next slide)





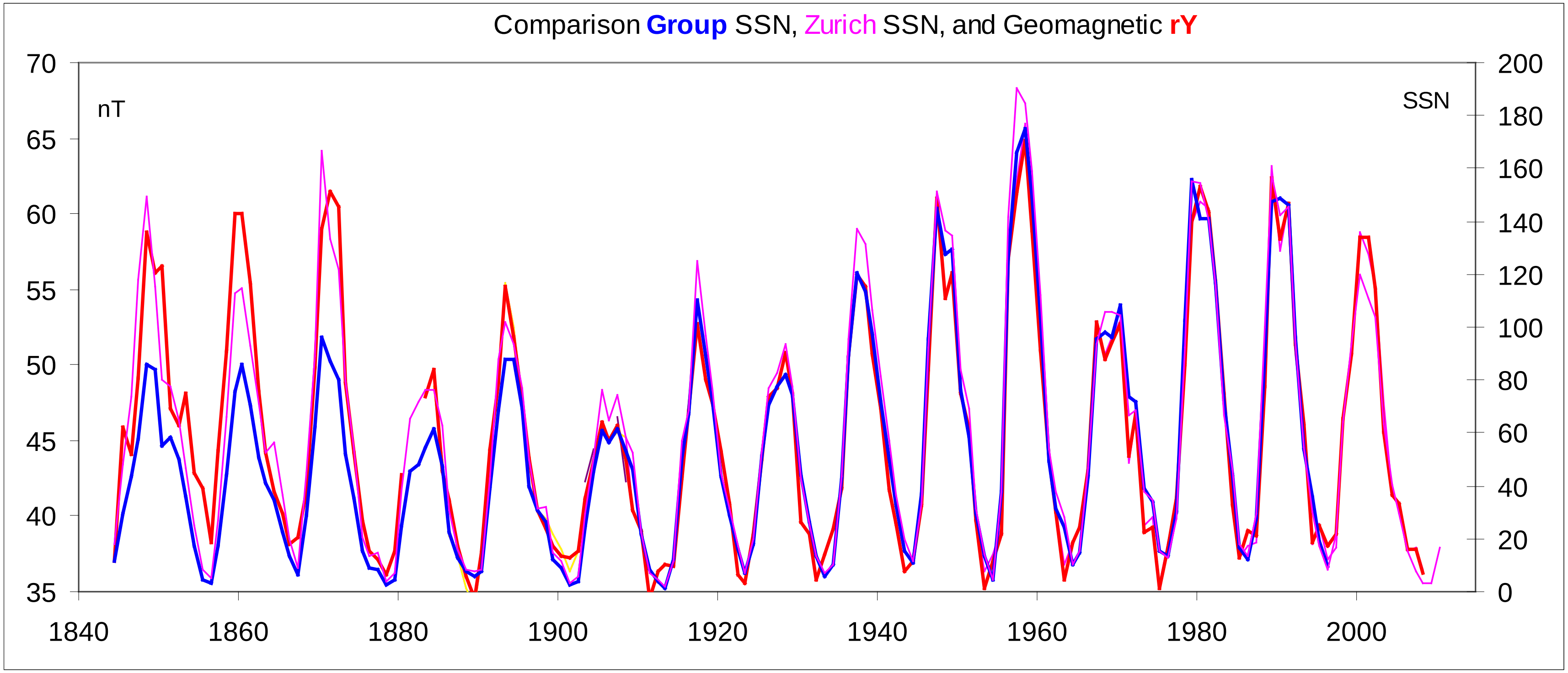


The HLS-NUR data show that the Group Sunspot Number before 1880 must be Increased by a factor 1.64±0.15 to match *rY* (F10.7)

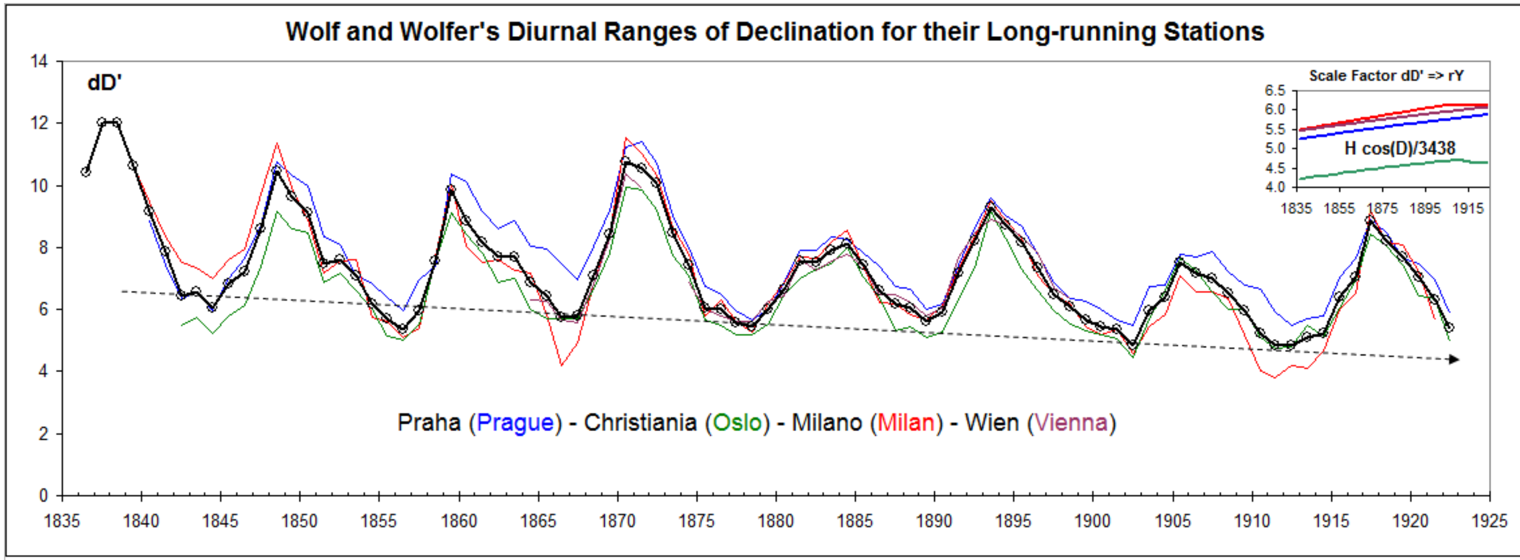


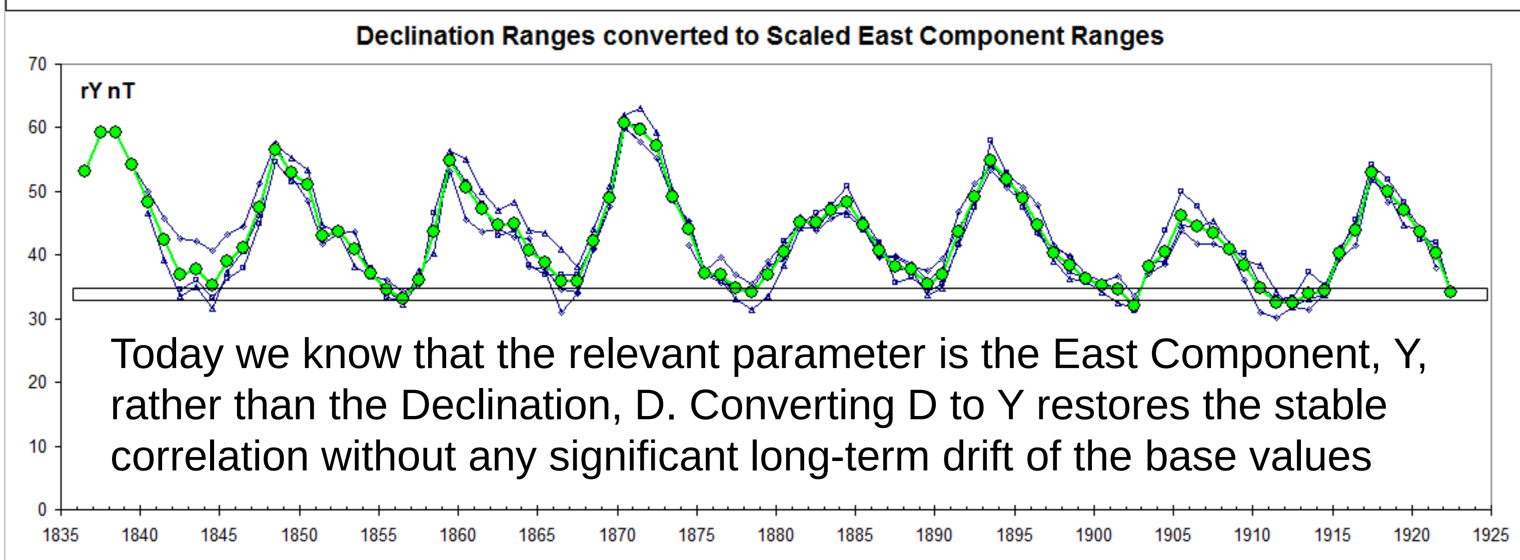
This conclusion is independent of the calibration of the Zürich SSN, Rz

Group SSN, Zurich SSN, and Diurnal Variation



Wolf's Geomagnetic Data

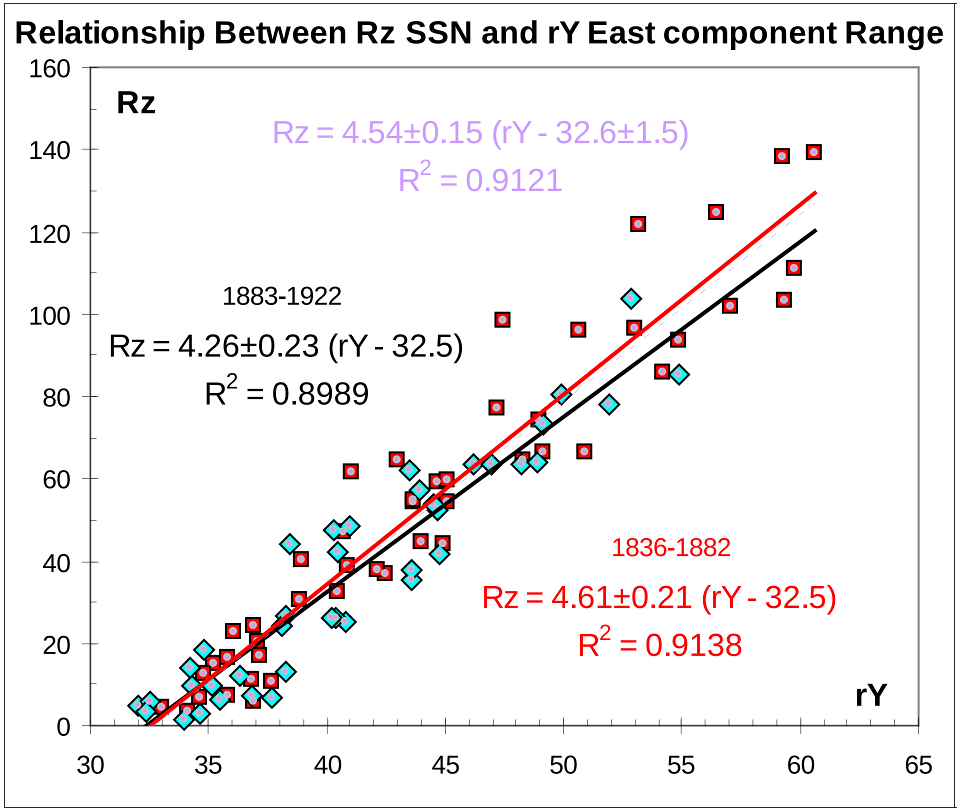


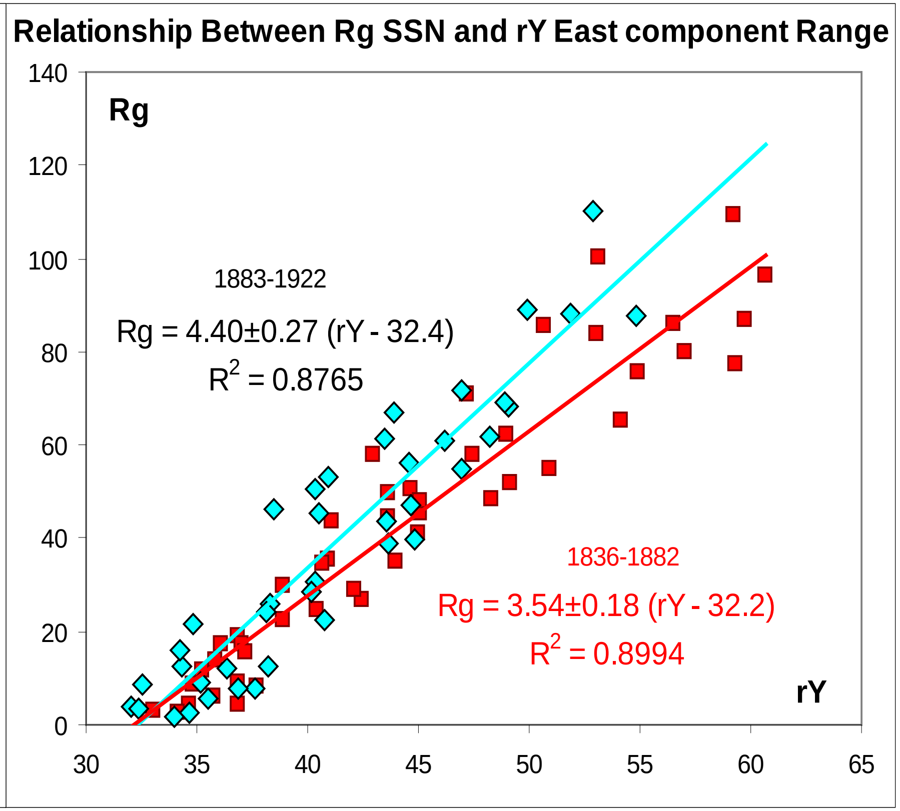


Wolf found a very strong correlation between his Wolf number and the daily range of the Declination.

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 ~1882 is not due to 'change of guard' or method at Zürich. It is also clear that Rg before 1883 is too low.

New paper on Eastward Component JGR, 2012

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 117, A05302, doi:10.1029/2012JA017555, 2012

The dependence of the coupled magnetosphere-ionosphere-thermosphere system on the Earth's magnetic dipole moment

Ingrid Cnossen,[1] Arthur D. Richmond,[1] and Michael Wiltberger[1]

[39] *Svalgaard* [2009] noted that in particular the eastward component of the daily Sq variation is a useful indicator of solar activity, and may be used as a tool to calibrate the long-term sunspot number record. Clearly, if geomagnetic data are to be used in this way, the effects of the decreasing dipole moment on Sq variation must be considered and corrected for. Our scaling relations will be a first tool to do so, although local changes in the magnetic field over specific stations could also be important. Further work with more

Where do we go from here?

- Find and Digitize as many 19th 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 Tucson, January 2013