Reconstruction of Solar EUV Flux in Centuries Past

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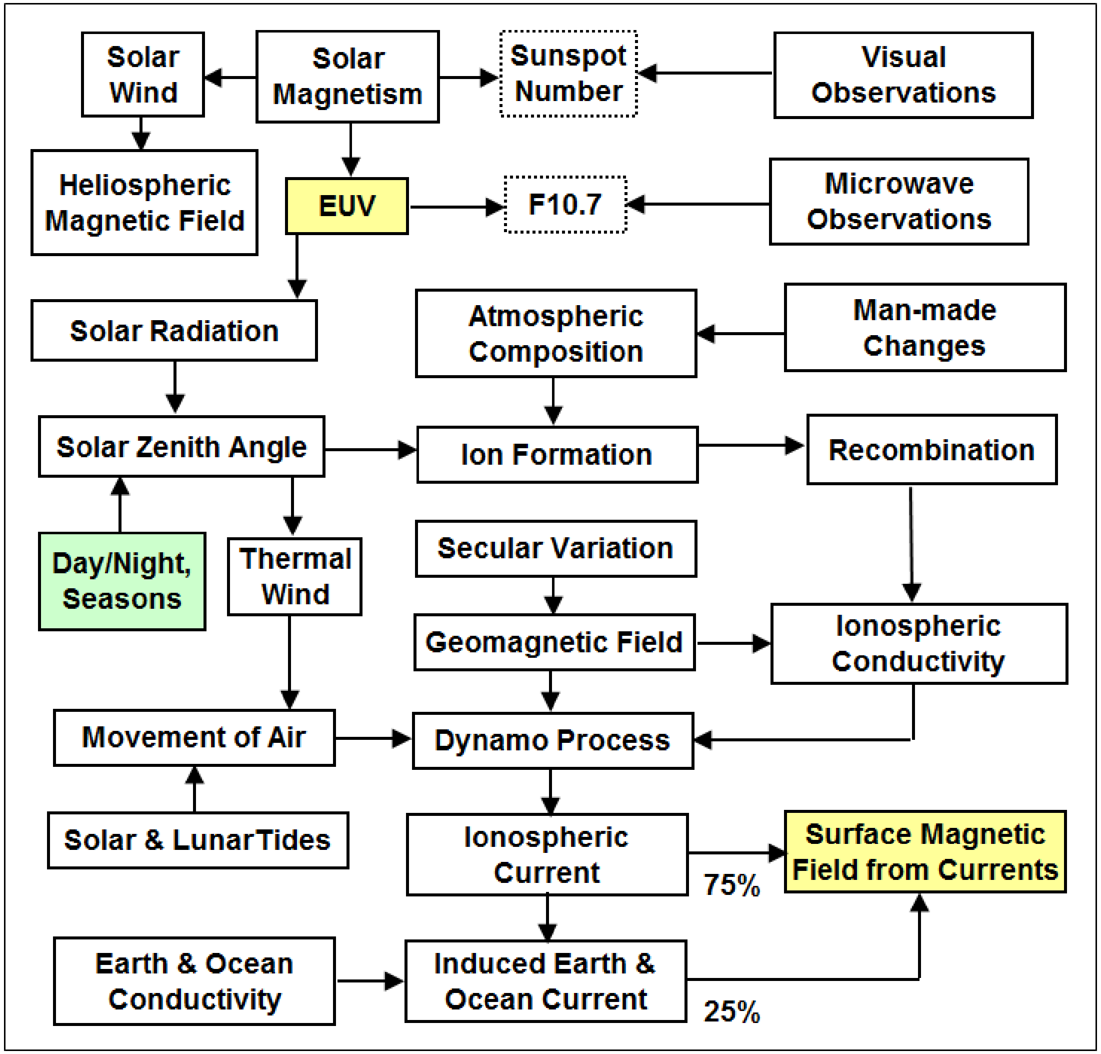
Stanford University

Big Bear Solar Observatory 23rd Sept. 2014
NSO, Sunspot, NM 3rd Oct. 2014

The Effect of Solar EUV

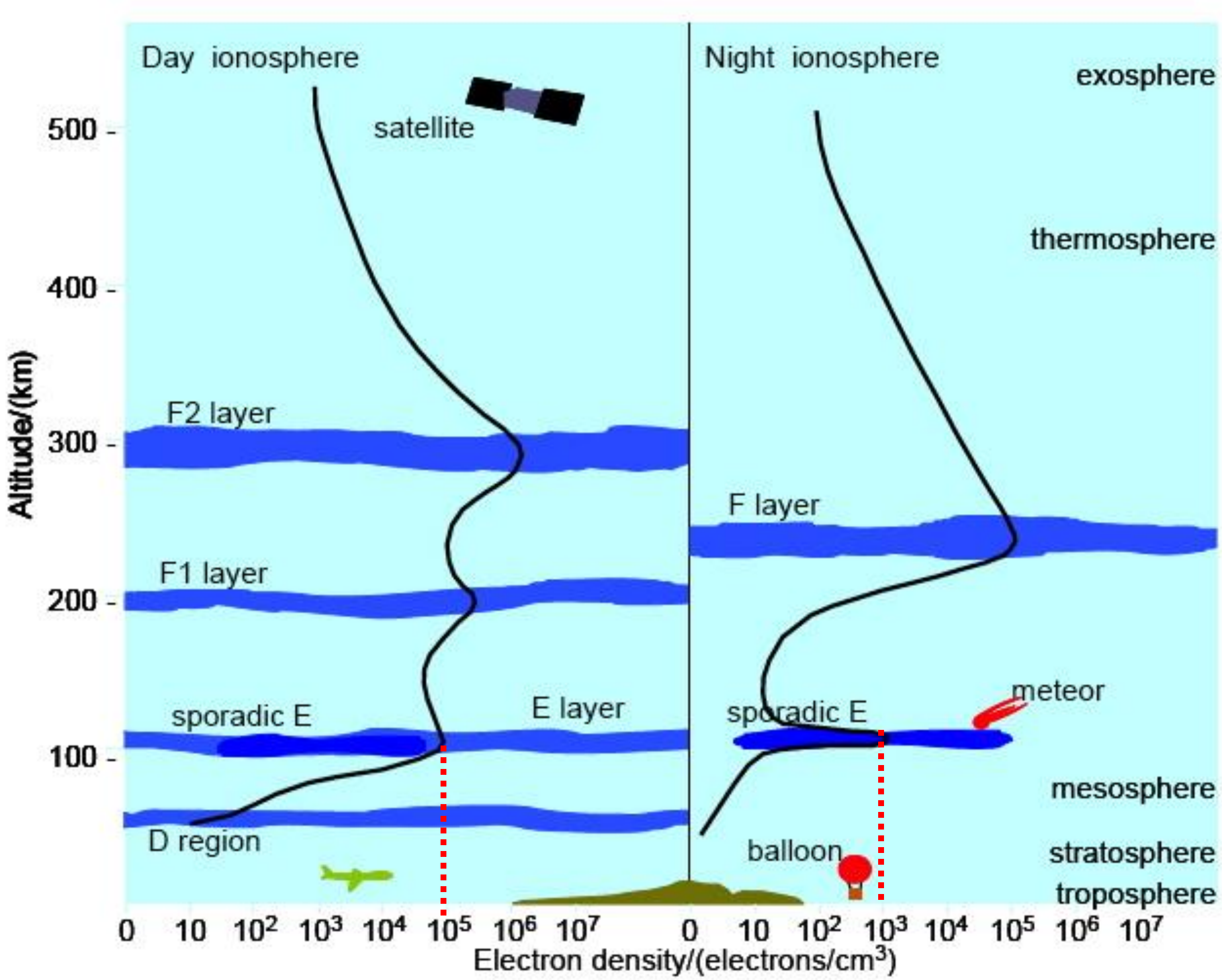


The EUV causes an observable variation of the geomagnetic field at the surface through a complex chain of physical connections.

The physics of each link in the chain is well-understood in quantitative detail and can be successfully modeled.

We'll use this chain in reverse to deduce the EUV flux from the geomagnetic variation.

Ionospheric Layers



An effective dynamo process takes place in the dayside E-layer where the density, both of the neutral atmosphere and of the electrons are high enough.

The geomagnetic response is thus due to electric currents induced in the E-layer.

Electron Density due to EUV

< 102.7 nm

$$O_2 + h\nu \xrightarrow{J} O_2^+ + e^-$$

$$O_2^+ + e^- \xrightarrow{\alpha} O + O$$

The conductivity at a given height is proportional to the electron number density N_e. In the dynamo region the ionospheric plasma is largely in photochemical equilibrium. The dominant plasma species is O^+_2, which is produced by photo ionization at a rate J (s^{-1}) and lost through recombination with electrons at a rate α (s^{-1}), producing the Airglow.

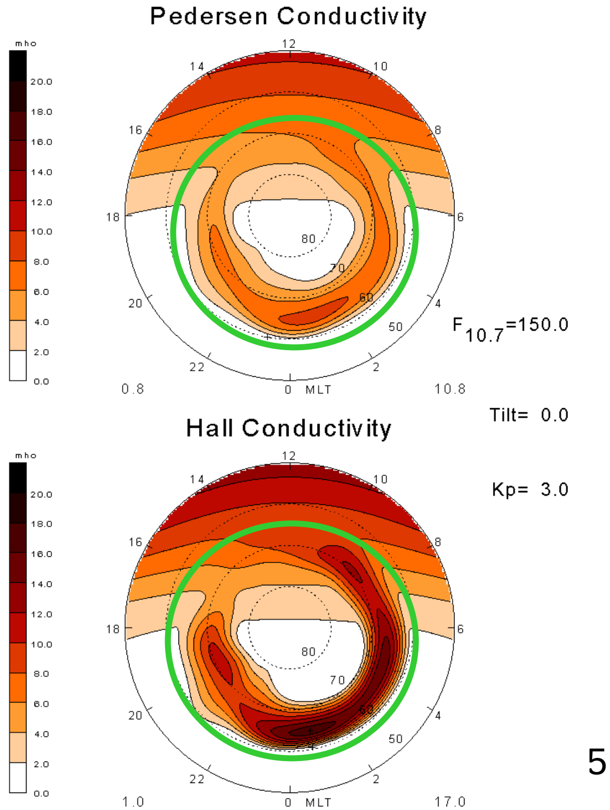
The rate of change of the number of ions N_i, dN_i/dt and in the number of electrons N_e, dN_e/dt are given by $dN_i/dt = J \cos(\chi) - \alpha N_i N_e$ and $dN_e/dt = J \cos(\chi) - \alpha N_e N_i$. Because the process is slow (the Zenith angle χ changes slowly) we have a quasi steady-state, in which there is no net electric charge, so $N_i = N_e = N$. In a steady-state $dN/dt = 0$, so the equations can be written $0 = J \cos(\chi) - \alpha N^2$, and so finally $N = \sqrt{(J \alpha^{-1} \cos(\chi))}$, (the Chapman Function, first derived by Sidney Chapman).

Since the conductivity, Σ, depends on the number of electrons N, we expect that Σ scales with the square root $\sqrt{(\boldsymbol{J})}$ of the overhead EUV flux with $\lambda < 102.7$ nm.

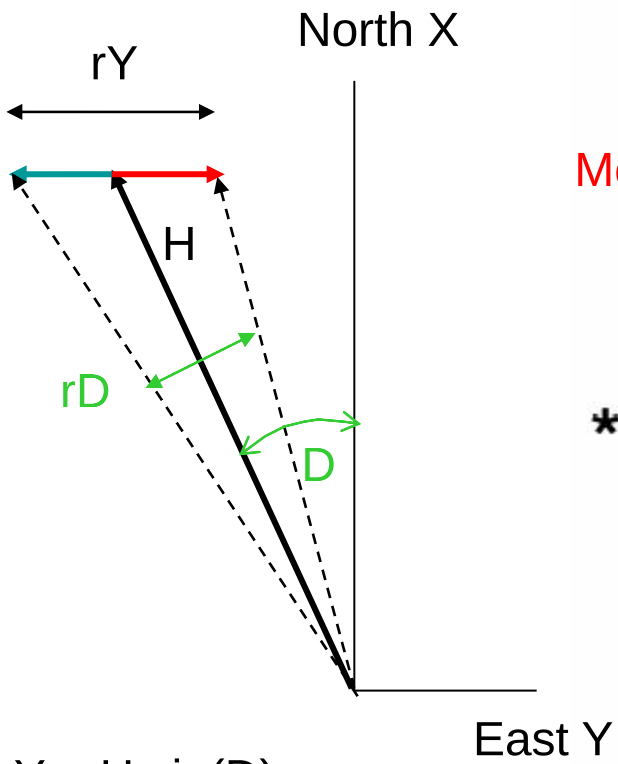
Magnitude of Magnetic Effect

The magnitude, A, of the variation of the East Component due to the dynamo process is given by $A = \frac{3}{4} \mu_o \Sigma U B_z$ where μ_o is the permeability of the vacuum ($4\pi\times 10^{7}$), Σ is the effective ionospheric conductivity (S), U is zonal neutral wind speed (m s^{-1}), and B_z is the vertical geomagnetic field strength (nT).

In the E-layer the conductivity is a tensor and highly anisotropic. To first approximation Σ depends on N and inversely on B: $\Sigma \sim N/B$, such that the magnitude A only depends on the electron density and the zonal neutral wind speed. The cancellation of B is not perfect, though, depending on the precise geometry of the field. In addition, the ratio between internal and external current intensity varies with location. The net result is that A can vary somewhat from location to location even for given N and U. Thus a normalization of the response to a reference location is necessary

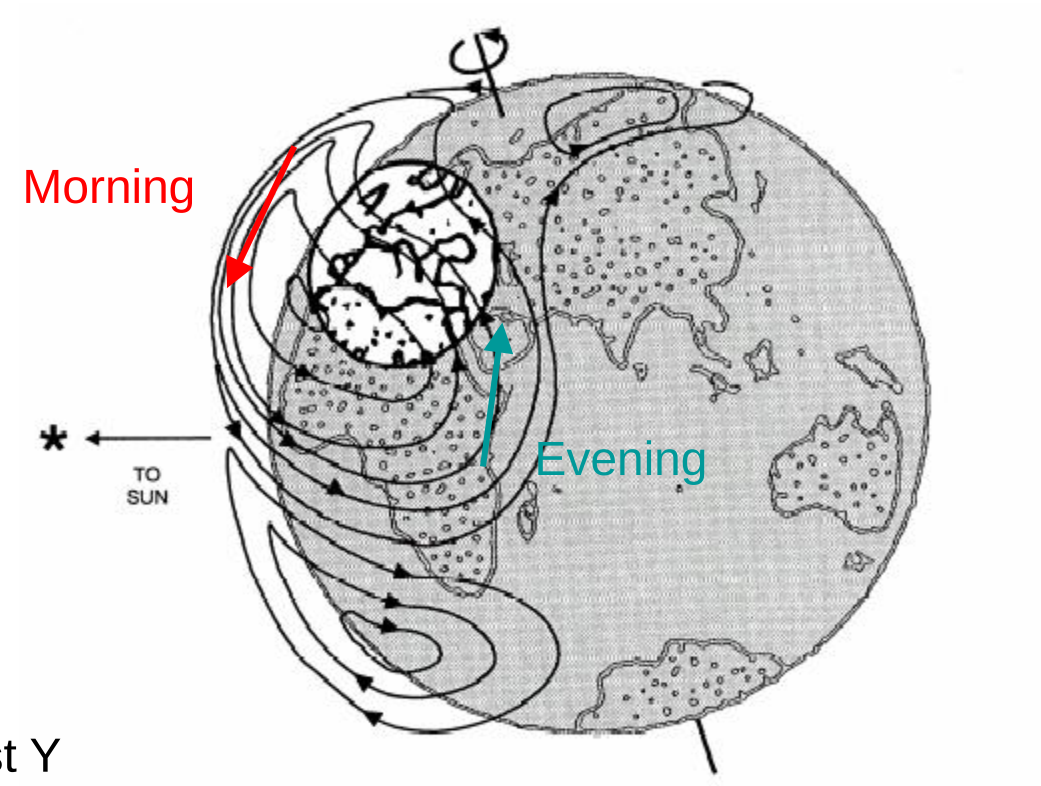


The E-layer Current System



$Y = H \sin(D)$

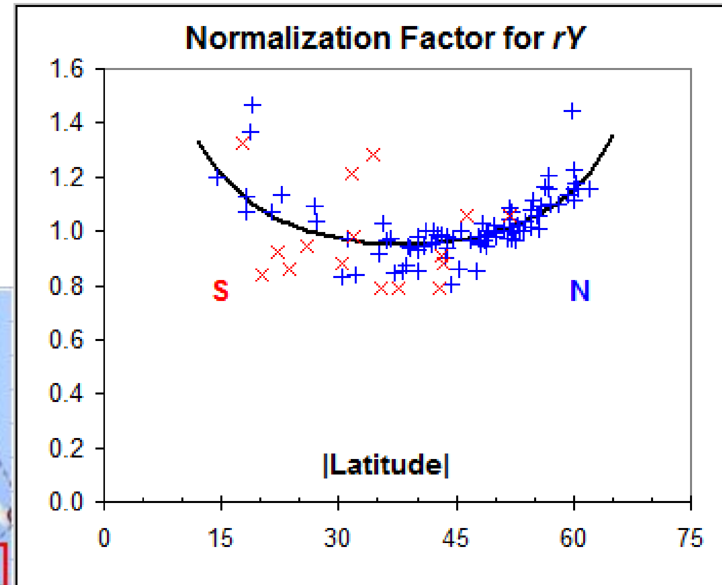
$dY = H \cos(D)\, dD$ For small dD

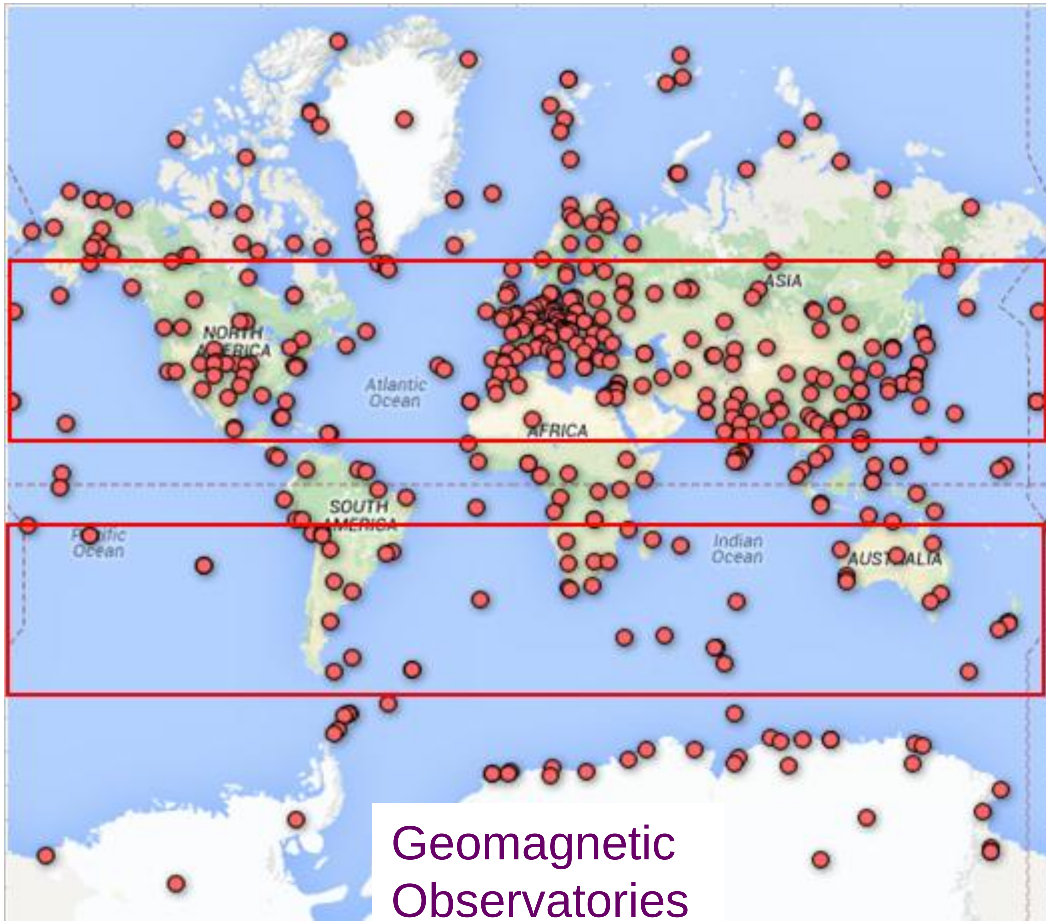


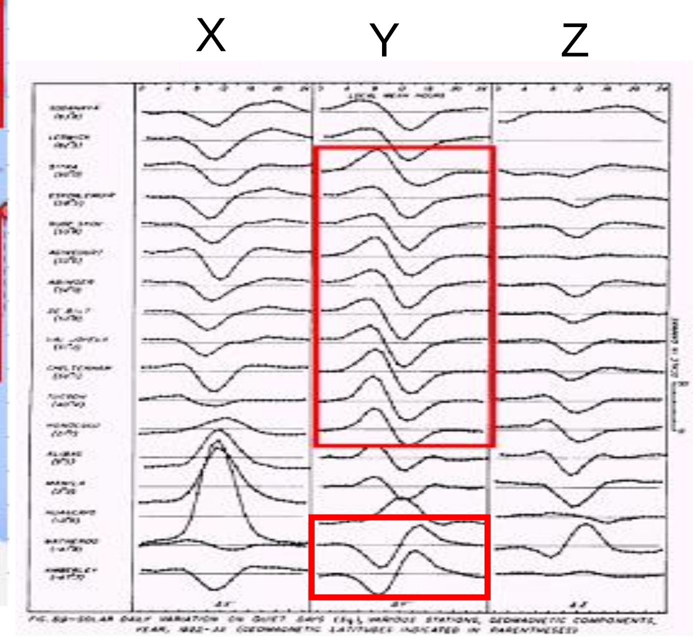
A current system in the ionosphere is created and maintained by solar EUV radiation

The magnetic effect of this system was discovered by George Graham in 1722

The Magnetic Signal at Midlatitudes

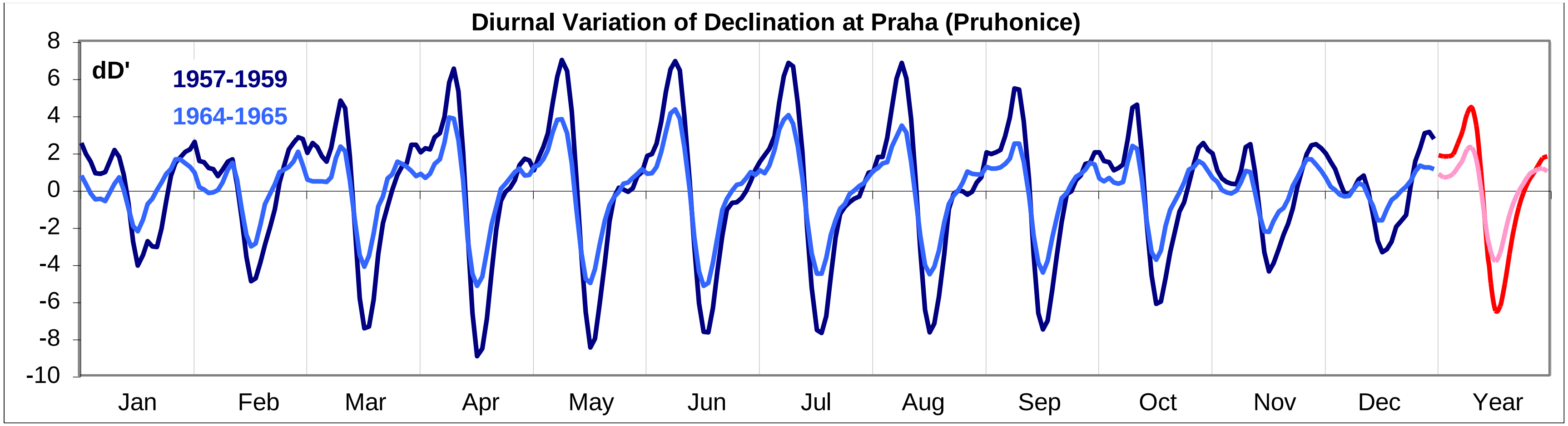


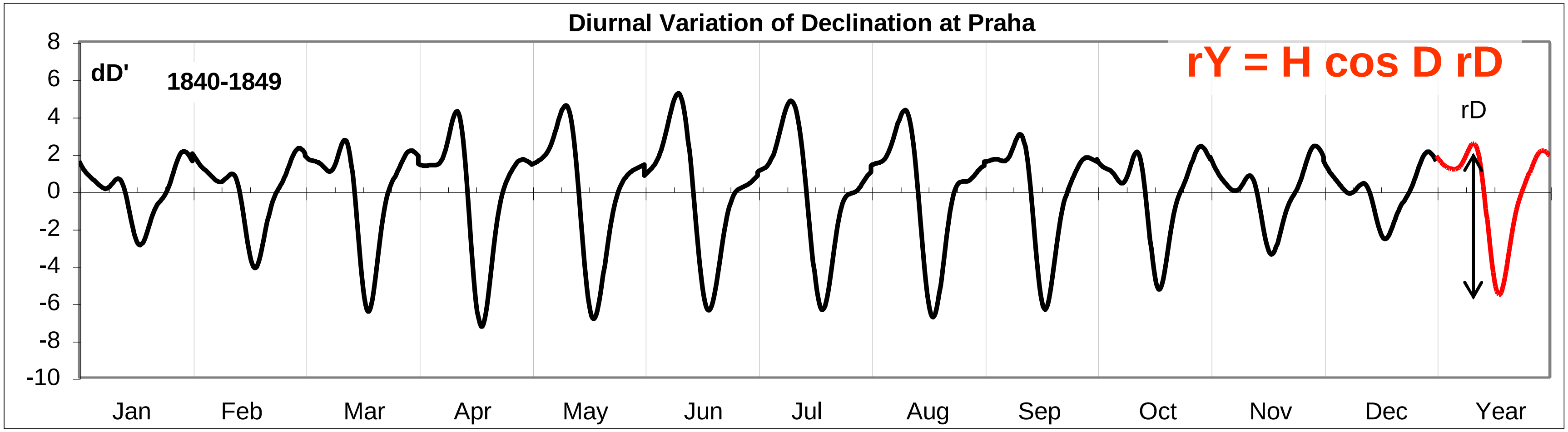




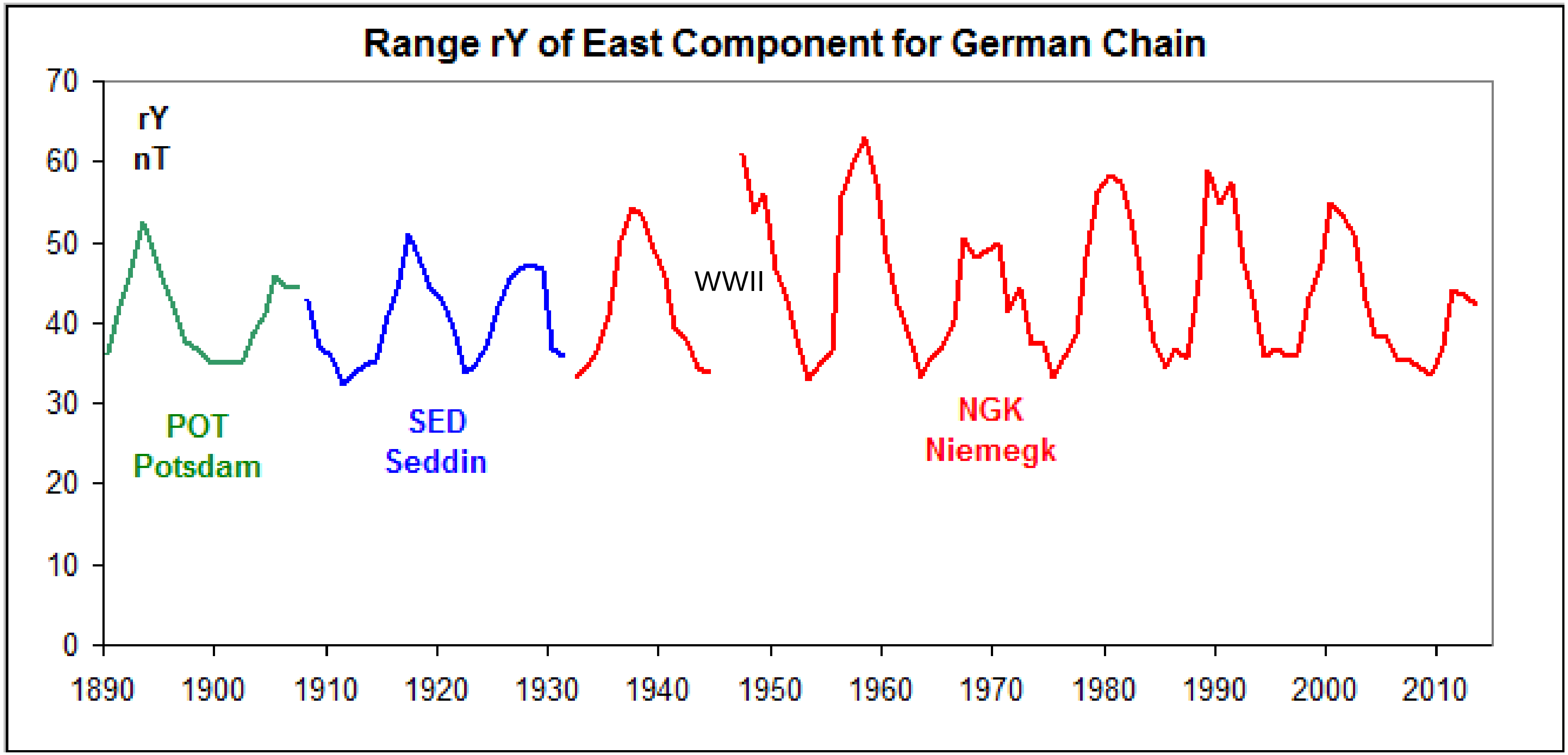
The effect in the Y-component is rather uniform for latitudes between 20º and 60º

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

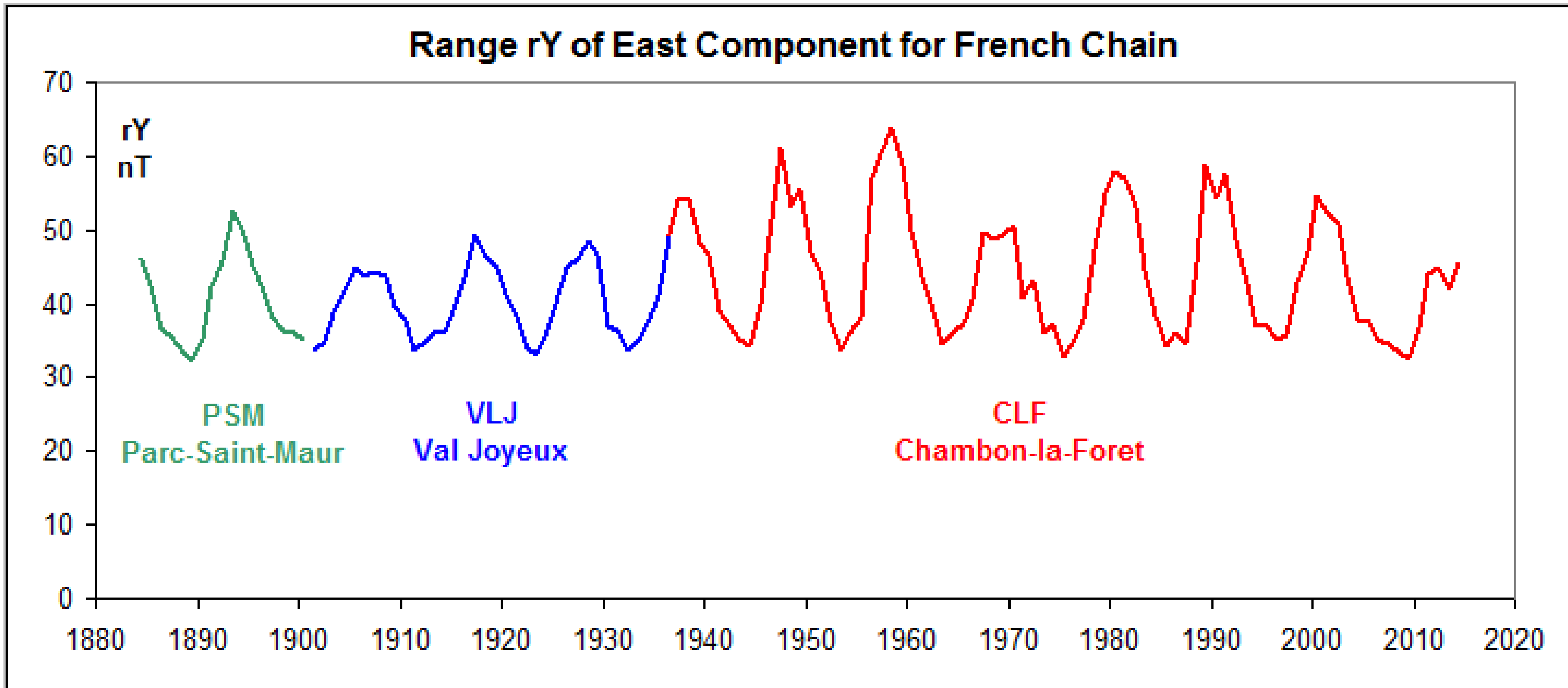




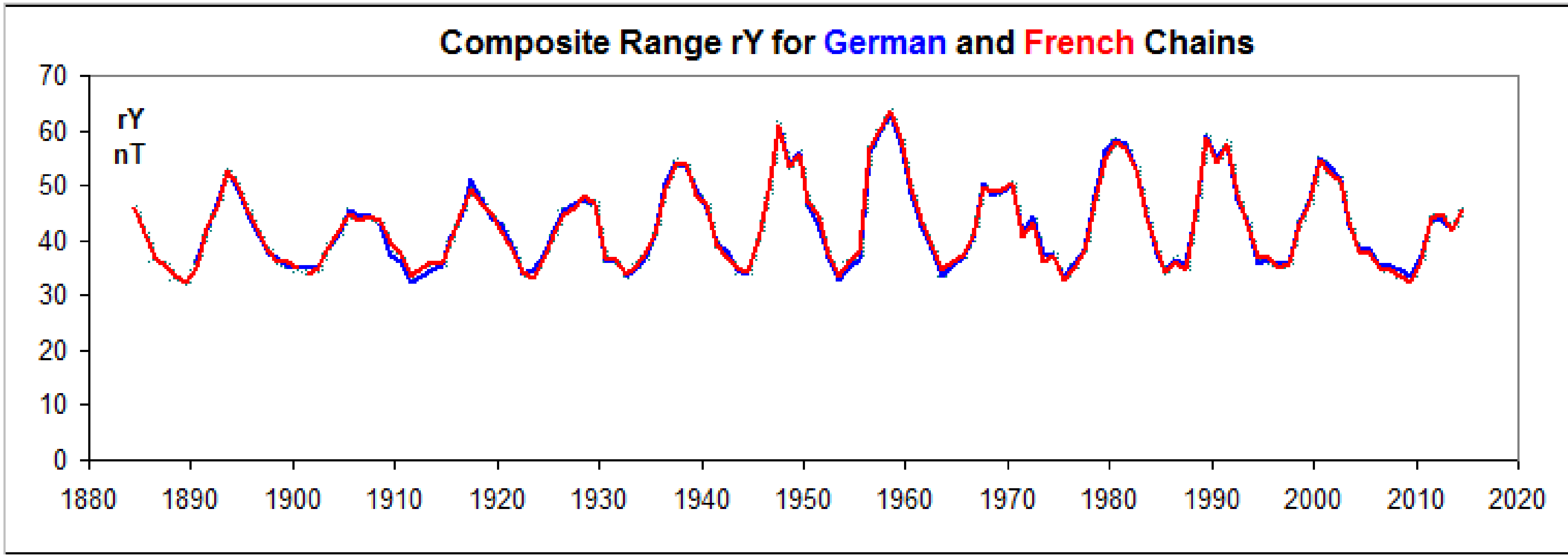
POT-SED-NGK
1890-2013



PSM-VLJ-CLF
1884-2014

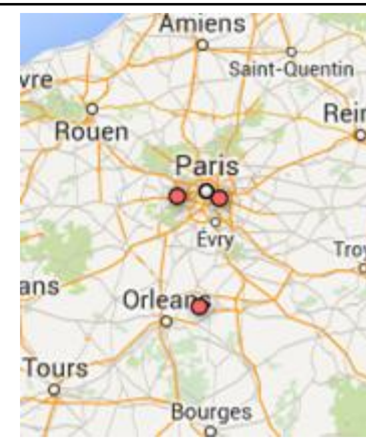


PSM-POT-VLJ-SED-CLF-NGK

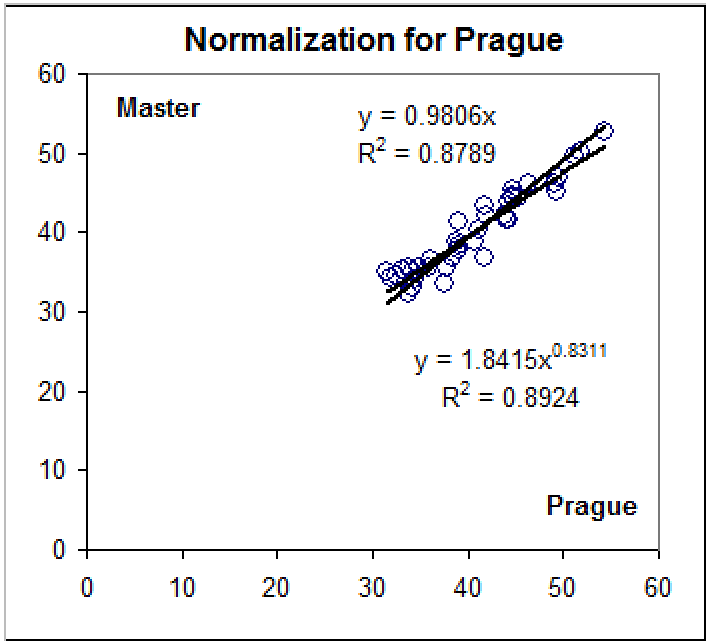


A ‘Master’ record can now be build by averaging the German and French chains.

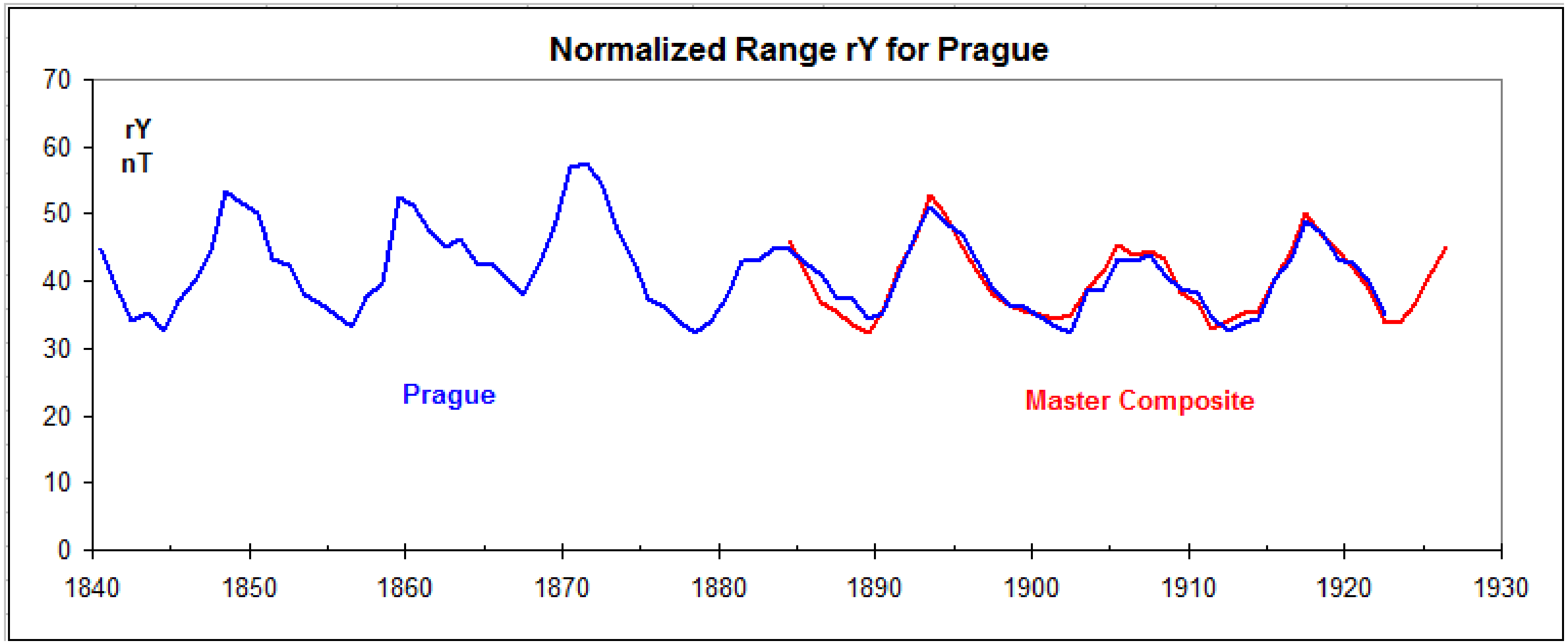
We shall normalize all other stations to this Master record.

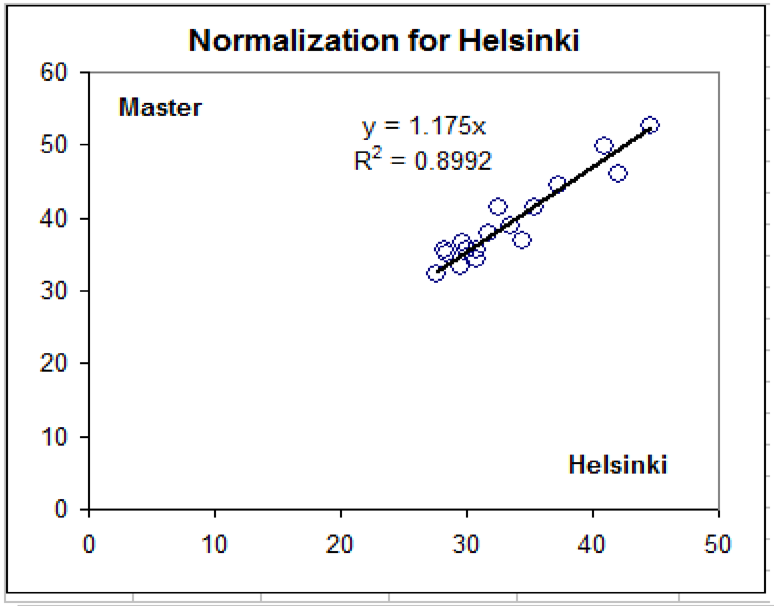


Adding Prague back to 1840

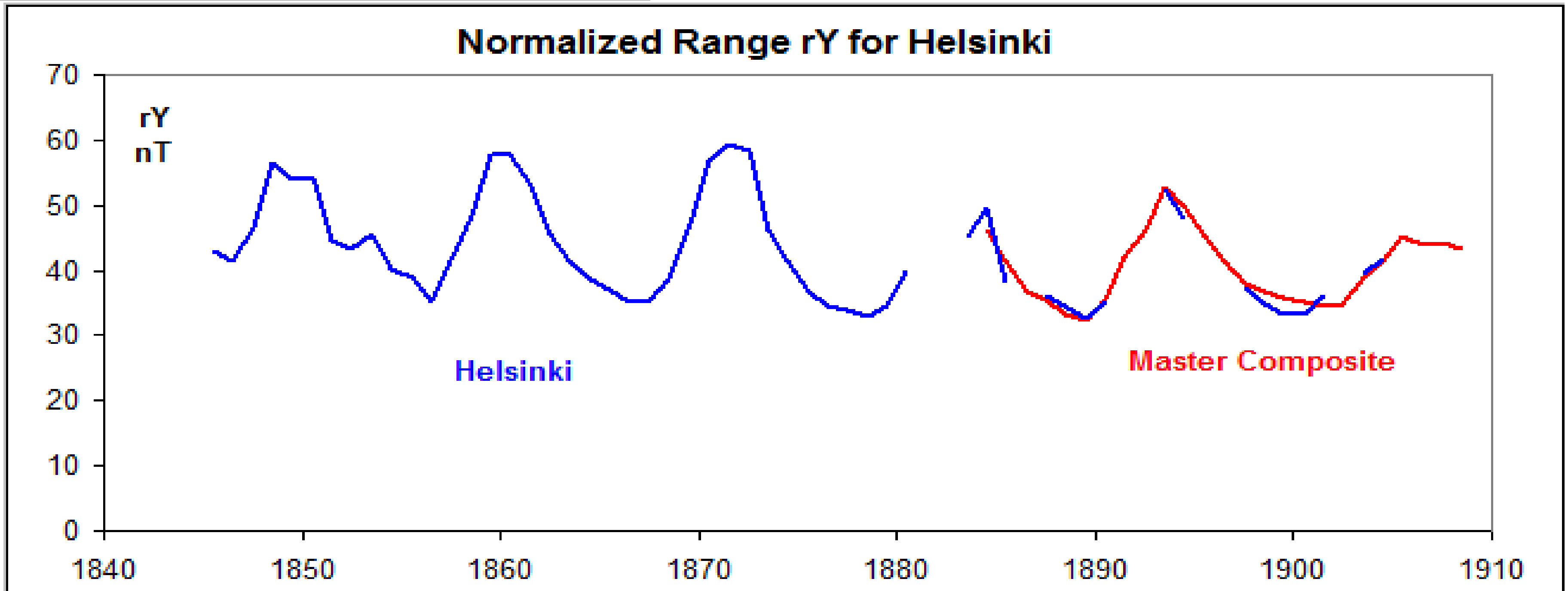


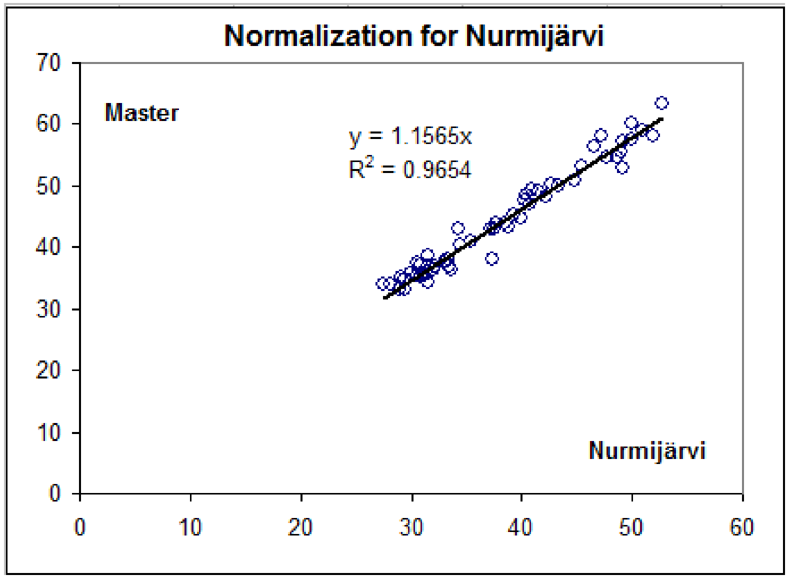
If the regression against the Master record is not quite linear, a power law is used.



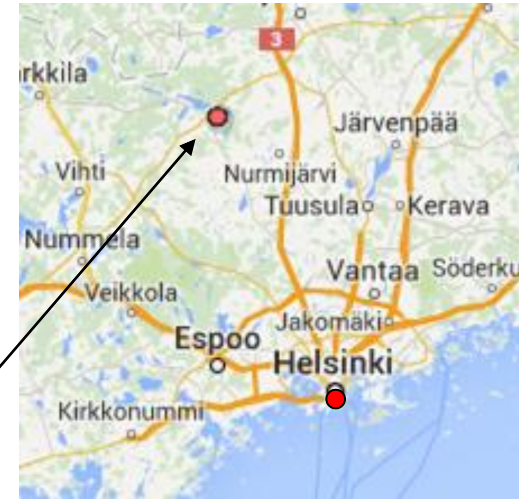


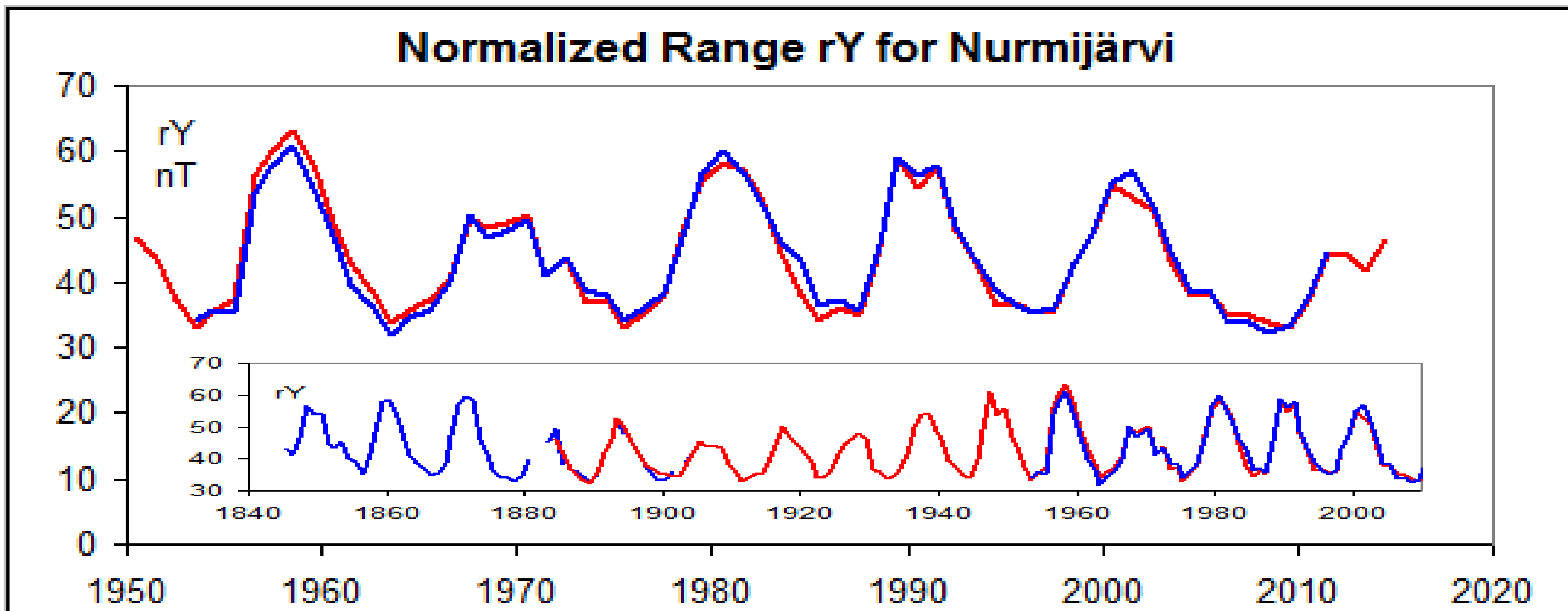
Adding Helsinki back to 1845



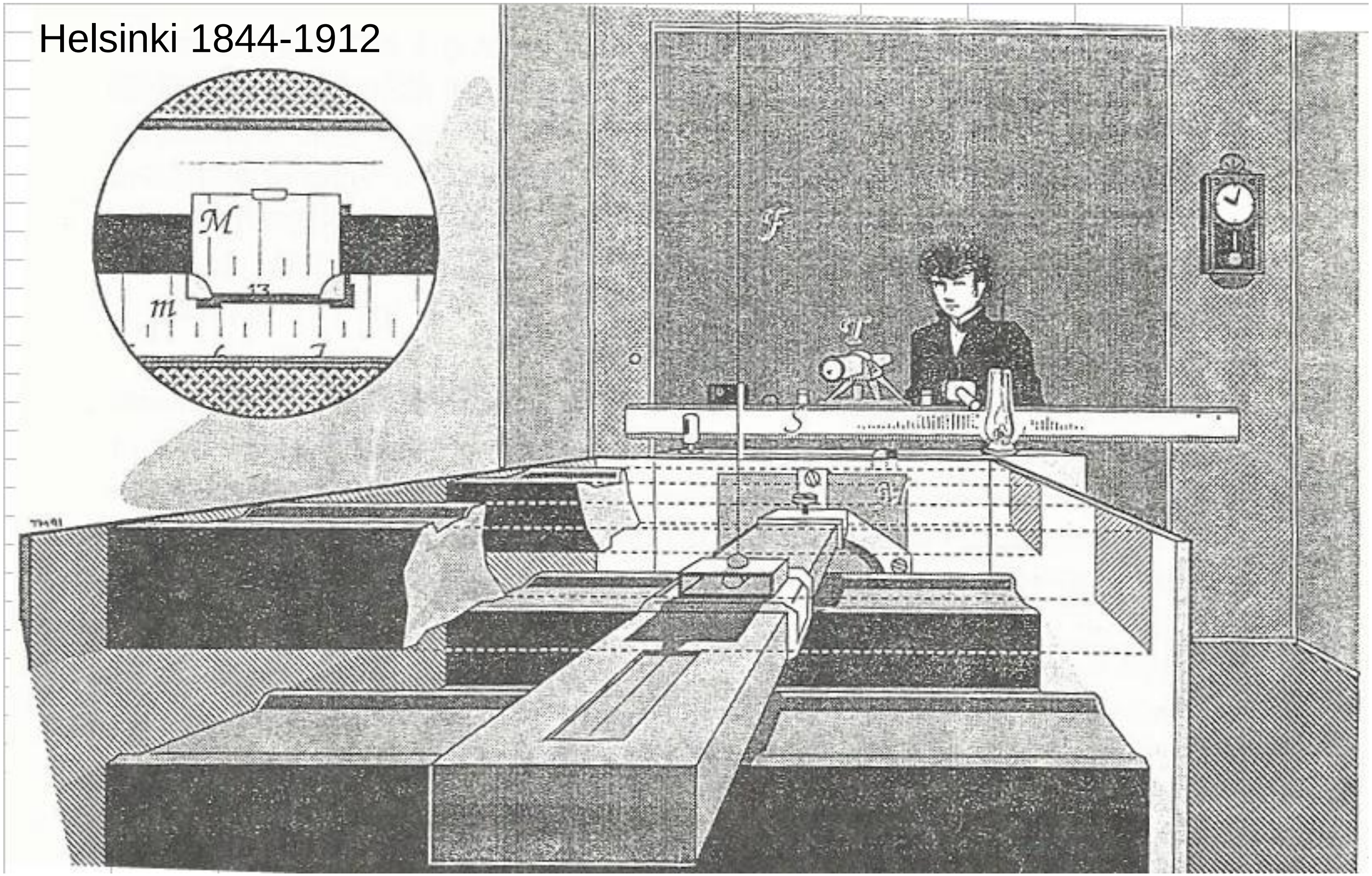


Adding its replacement observatory Nurmijärvi



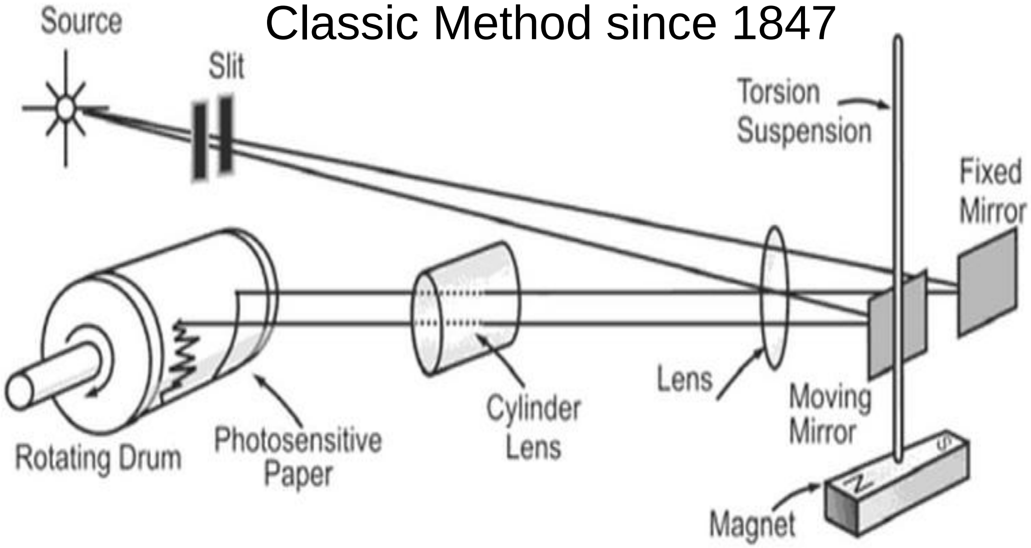


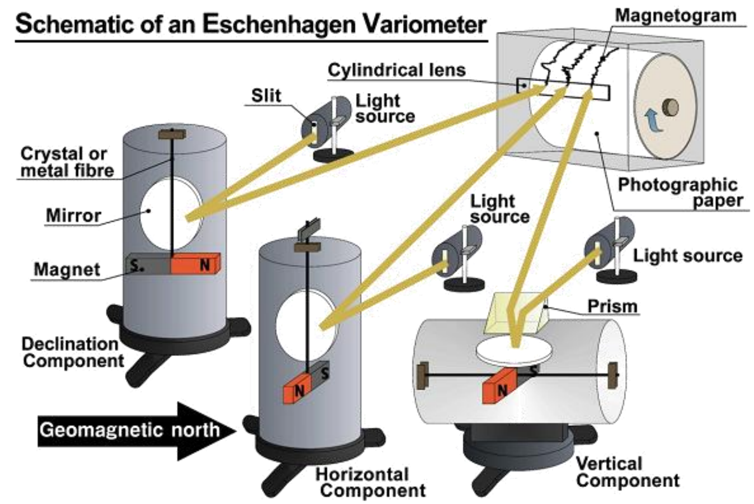
Variometer Invented by Gauss, 1833



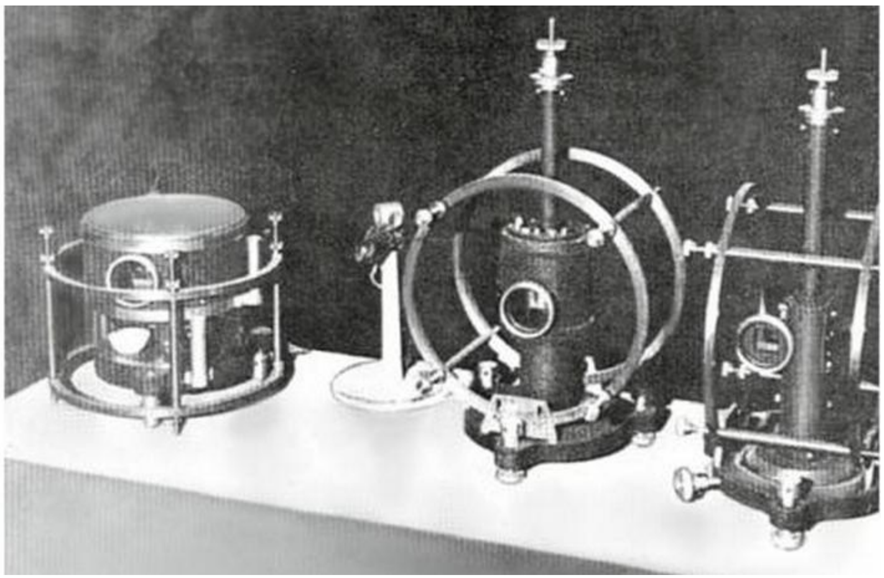
Nevanlinna et al.

Classic Method since 1847





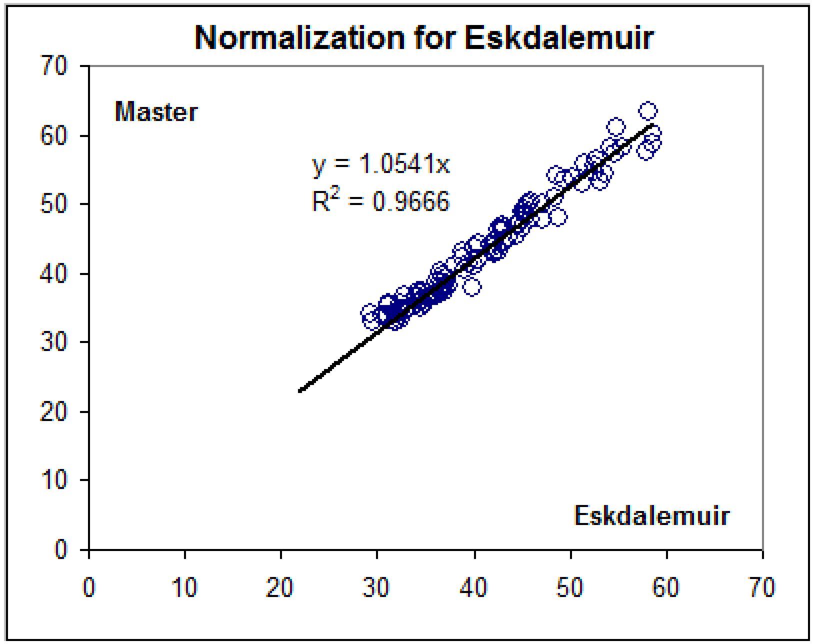
Magnetic Recorders

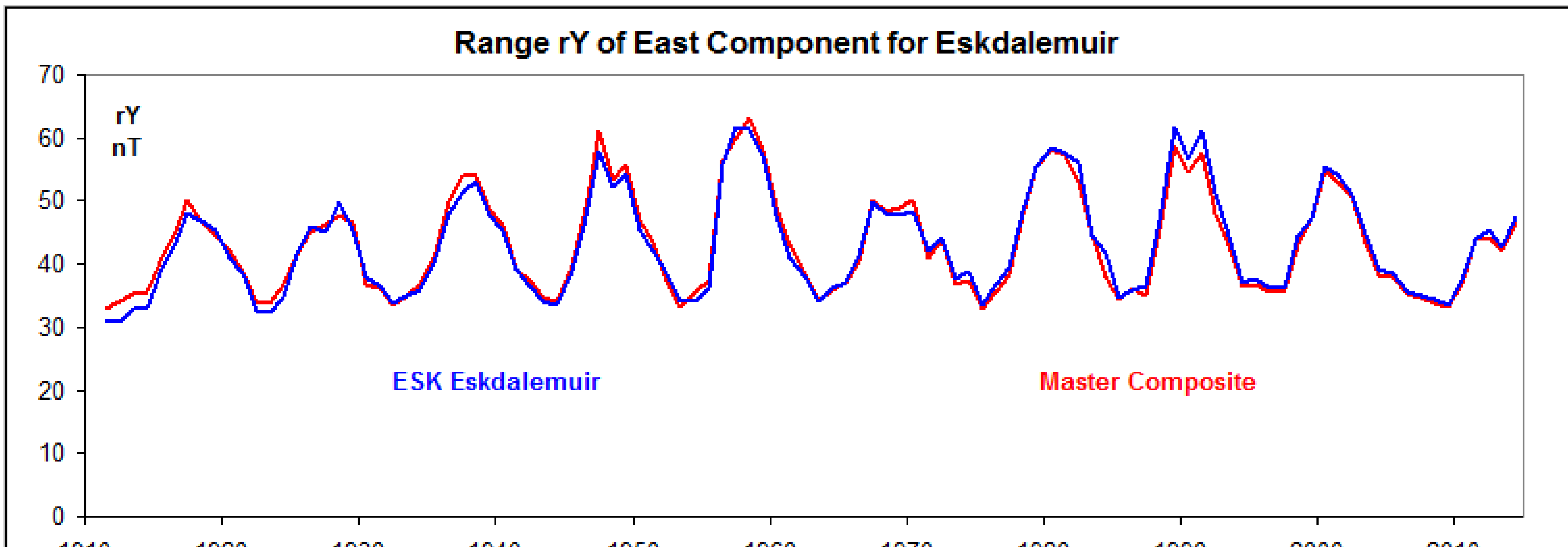


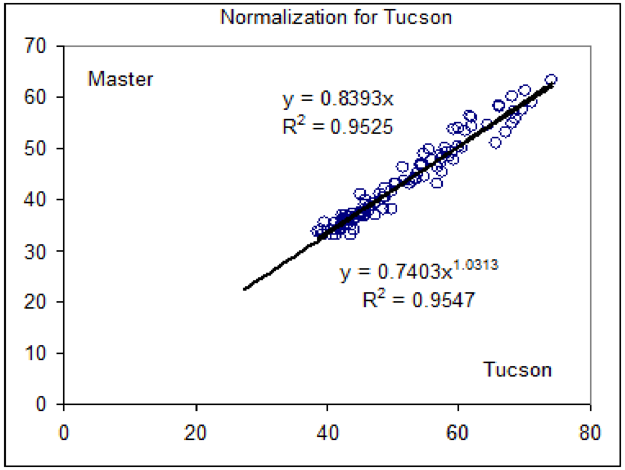
Classic Instruments circa 1900

Modern Instrument

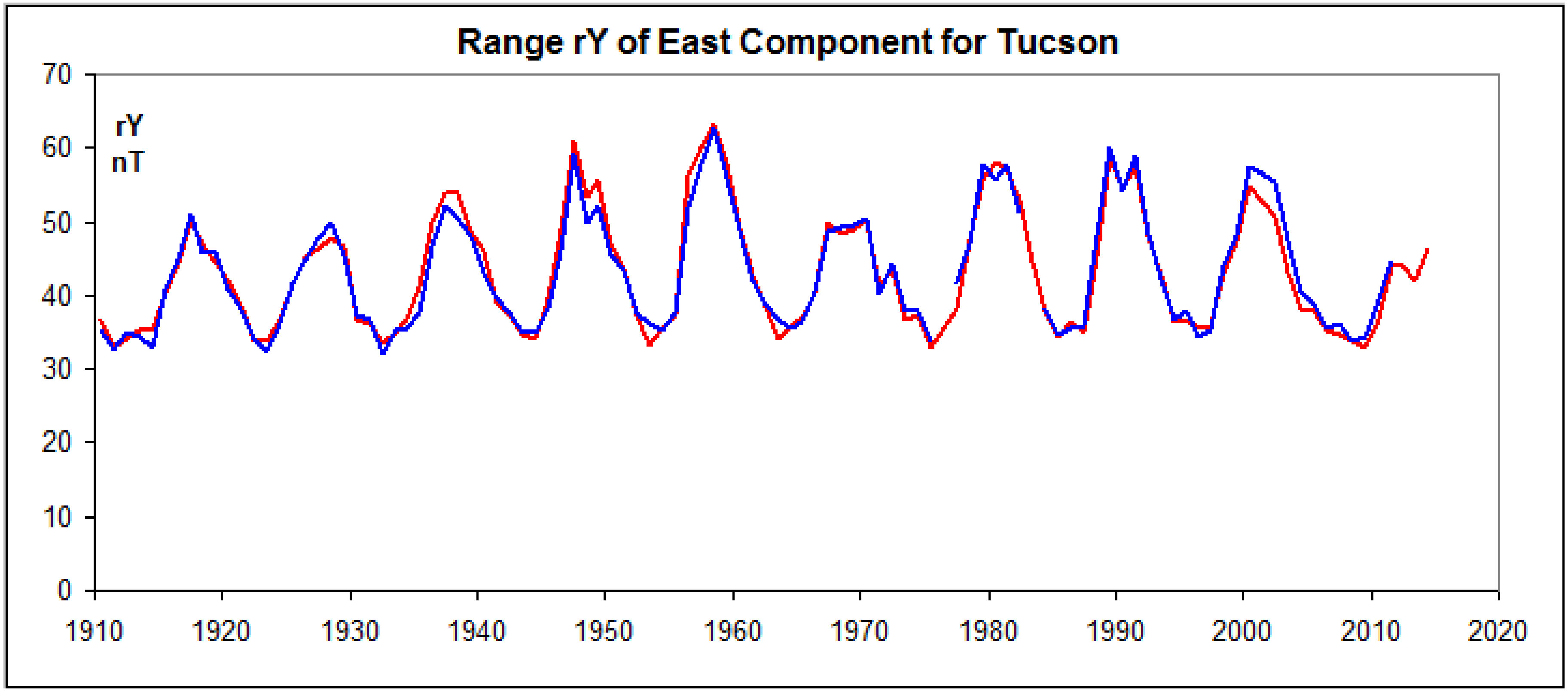
An Example of an Unbroken Series: Eskdalemuir







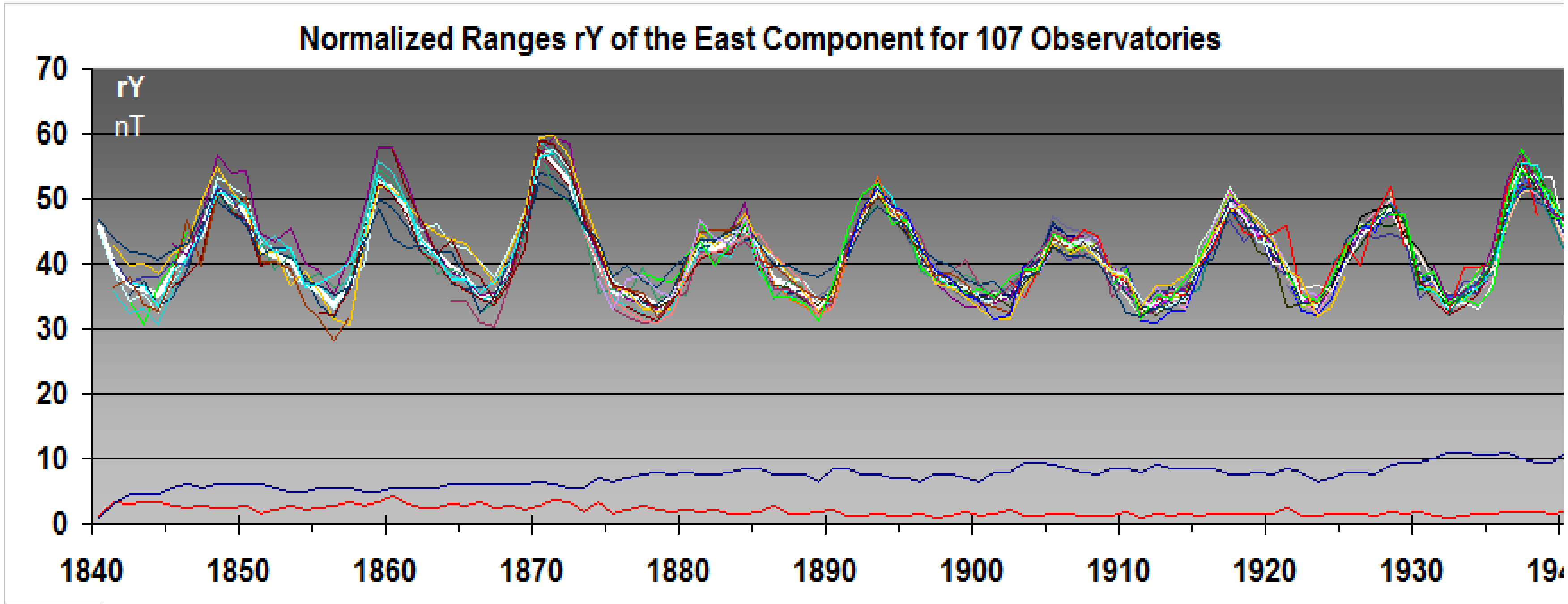
Add Tucson, AZ

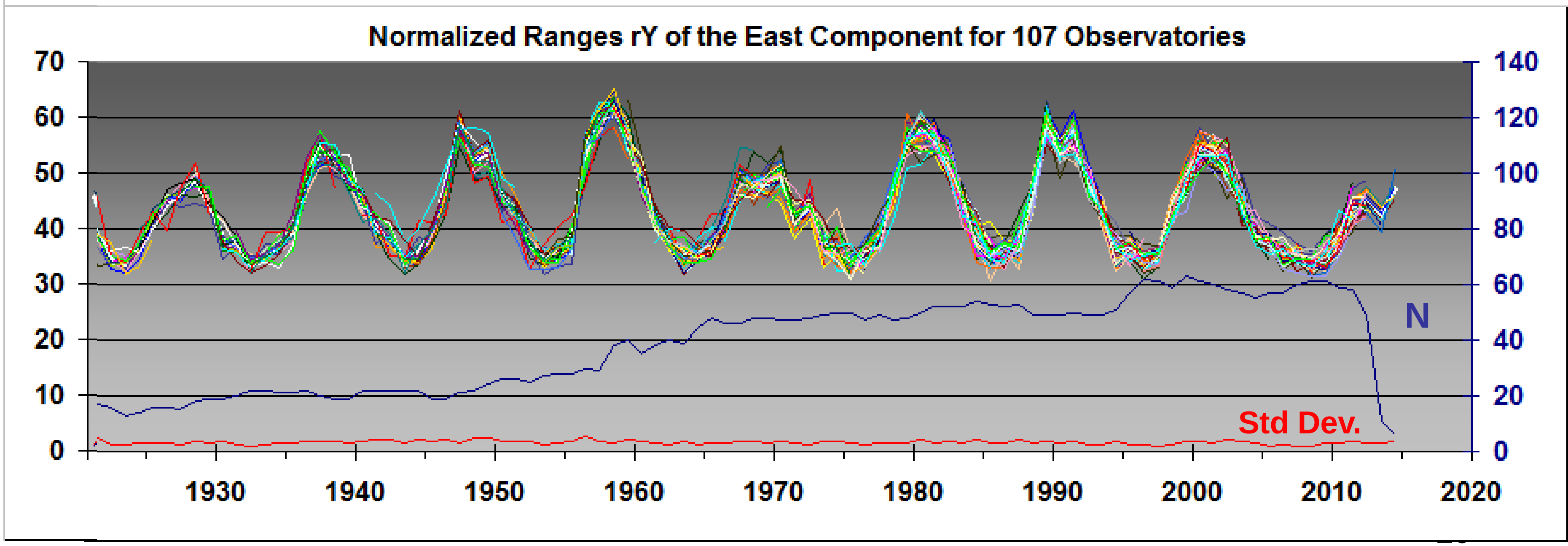


And So On: For 107 Geomagnetic Observatories with Good Data

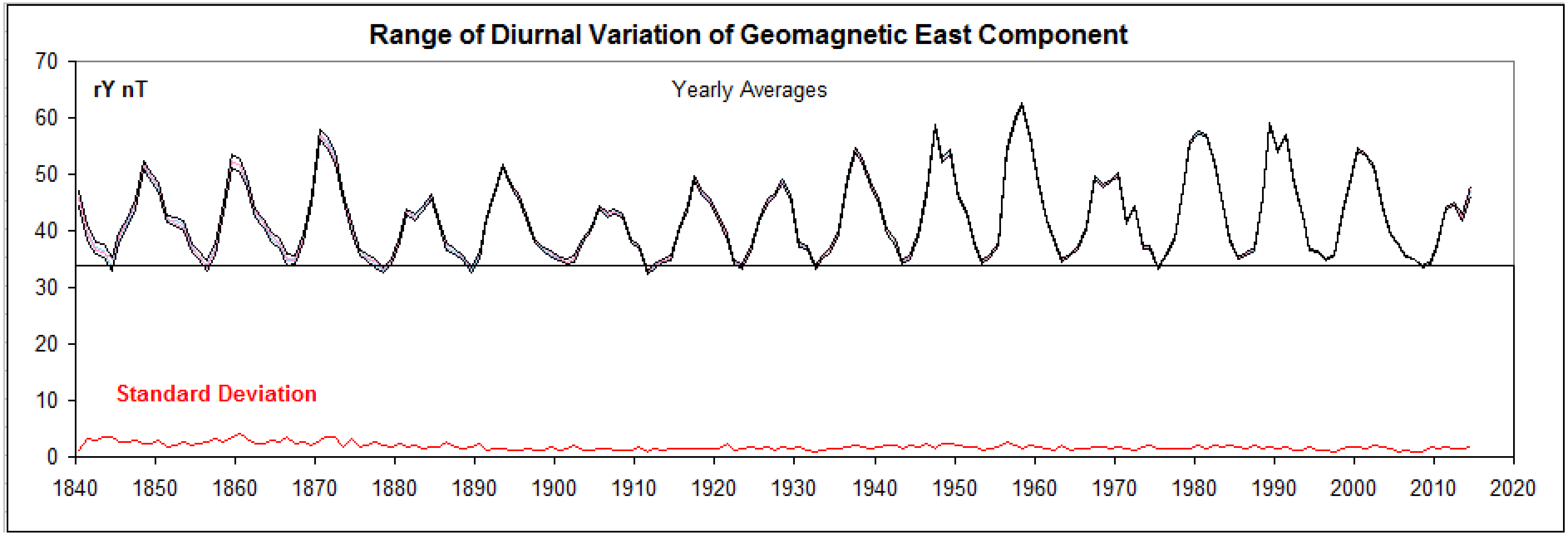
POT	COI	WIK	BSL	DBN	VAL
SED	WNG	AAA	TOR	WIT	VIC
NGK	TOK	ARS	MON	FUR	YAK
PSM	HRB	ASP	AML	WLH	SPE
VLJ	TOO	BDV	AQU	EKT	MIL
CLF	WAT	BEL	BTV	BAL	BER
KAK	SIT	BJI	PET	OSL	TFS
ESK	SSH	BOU	ROM	CLA	MBO
HLS	PIL	BOX	EYR	ABG	CBI
NUR	LOV	SFS	FRN	WIE	LRM
CLH	RSV	CDP	GNA	GRW	NVS
FRD	BFE	CNB	HLP	MNH	PAG
HON	HER	CTA	EBR	KLT	PPT
TUC	SVD	HBK	MIZ	GEN	PST
VQS	AGN	ISK	GCK	MNK	THY
SJG	OTT	LNN	IRT	KNZ	STJ
ABN	HBT	TAM	JAI	DOU	CZT
HAD	PRA	MMB	LER	LVV	

Next slide shows all [normalized] stations in a combined graph


Normalized Ranges rY of the East Component for 107 Observatories
rY
nT
70
60
50
40
30
20
10
0
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
194

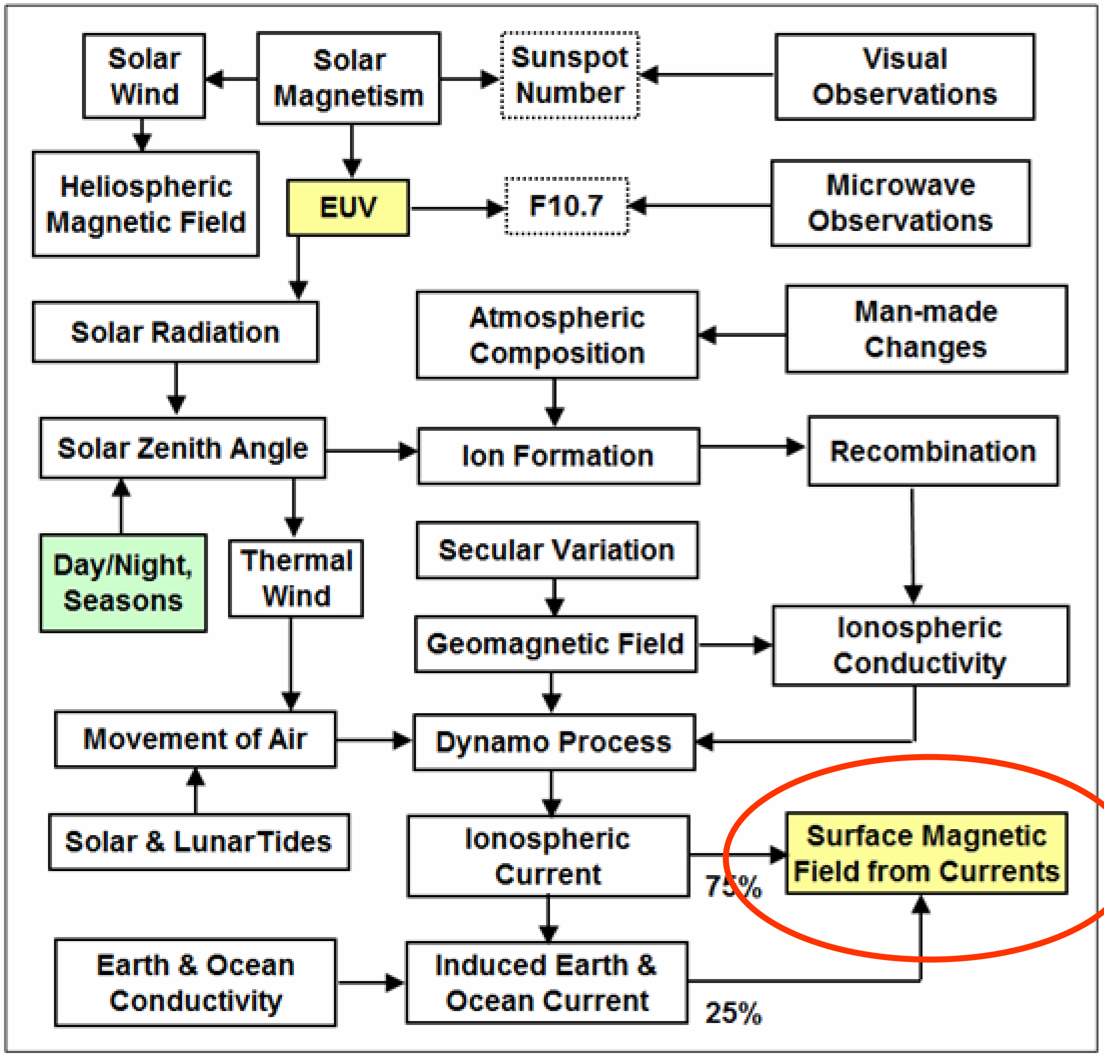

Normalized Ranges rY of the East Component for 107 Observatories
70
60
50
40
30
20
10
0
140
120
100
80
60
40
20
0
N
Std Dev.
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

Composite *rY* Series 1840-2014



From the Standard Deviation and the Number of Station in each Year we can compute the Standard Error of the Mean and plot the ±1-sigma envelope

The Effect of Solar EUV



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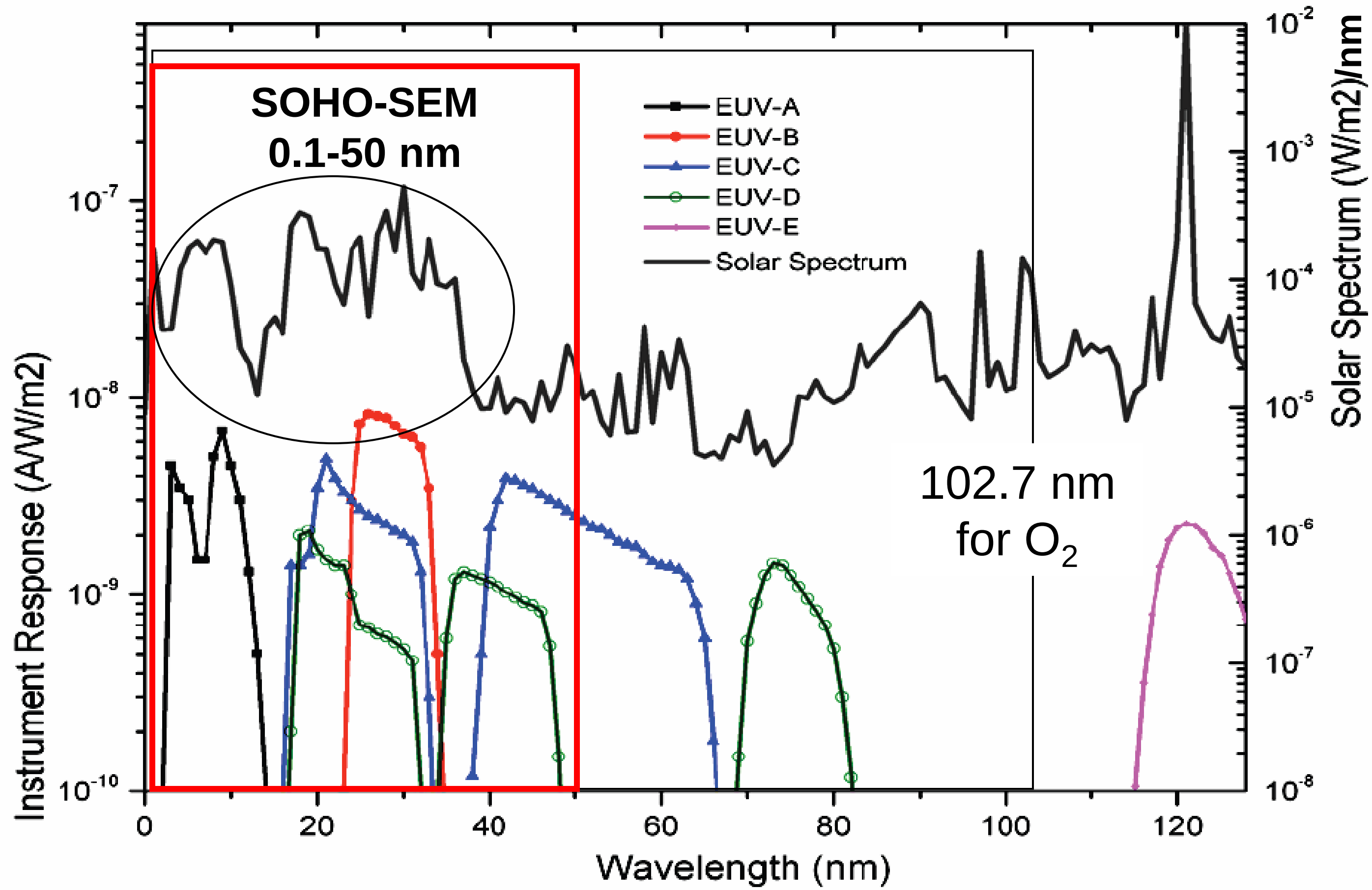
The physics of each link in the chain is well-understood in quantitative detail and can be successfully modeled.

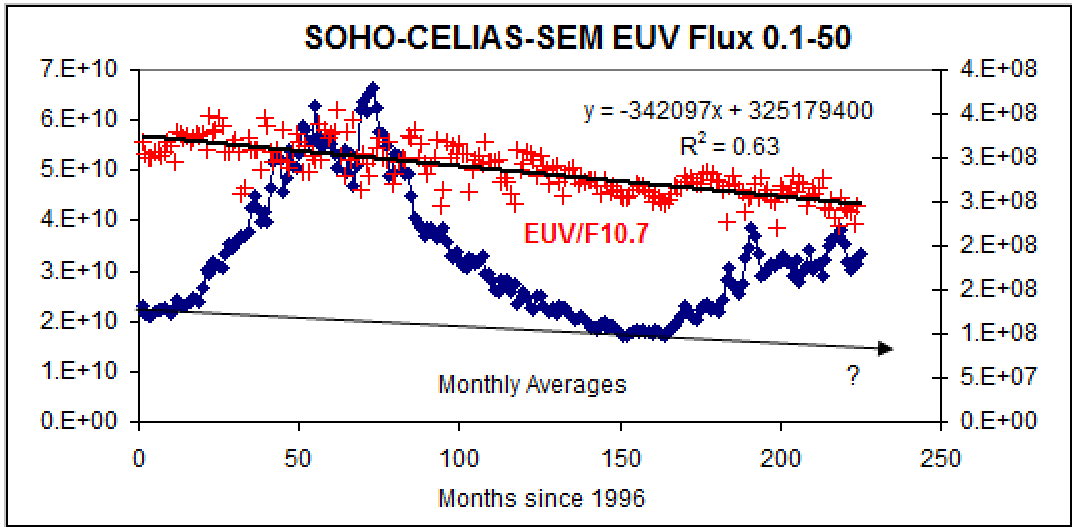
We'll use this chain in reverse to deduce the EUV flux from the geomagnetic variation.

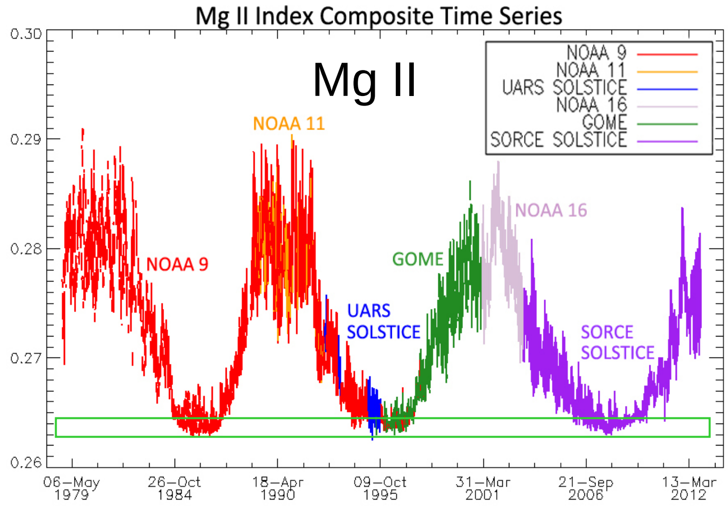
EUV Bands and Solar Spectrum

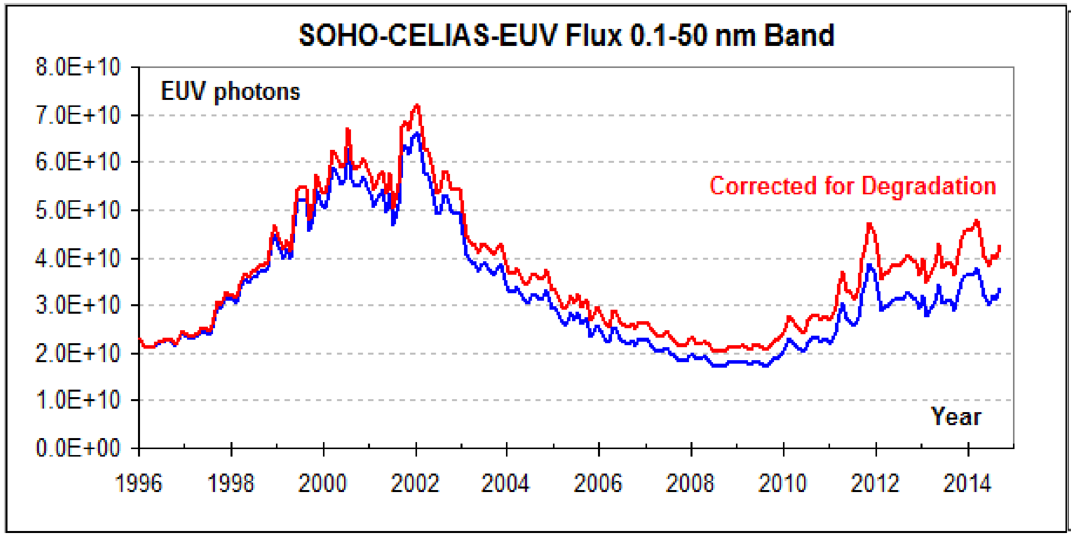
Most of the Energetic Photons are in the 0.1-50 nm Band

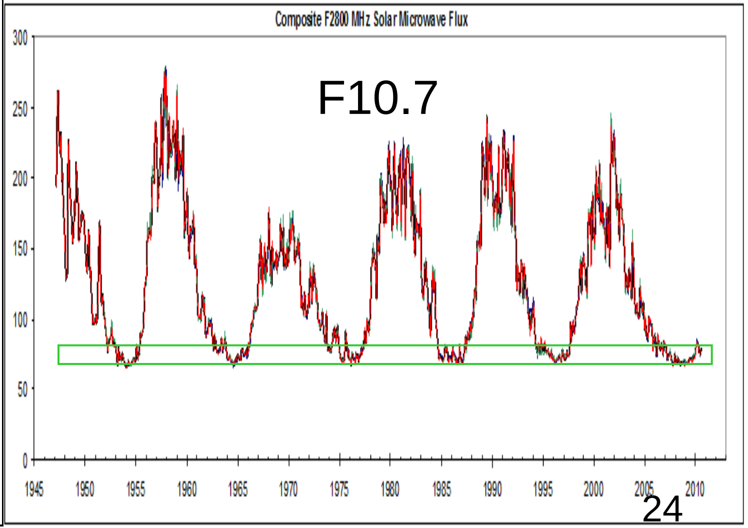


We Correct the SEM-series for Degradation Comparing with F10.7 and Mg II Indices

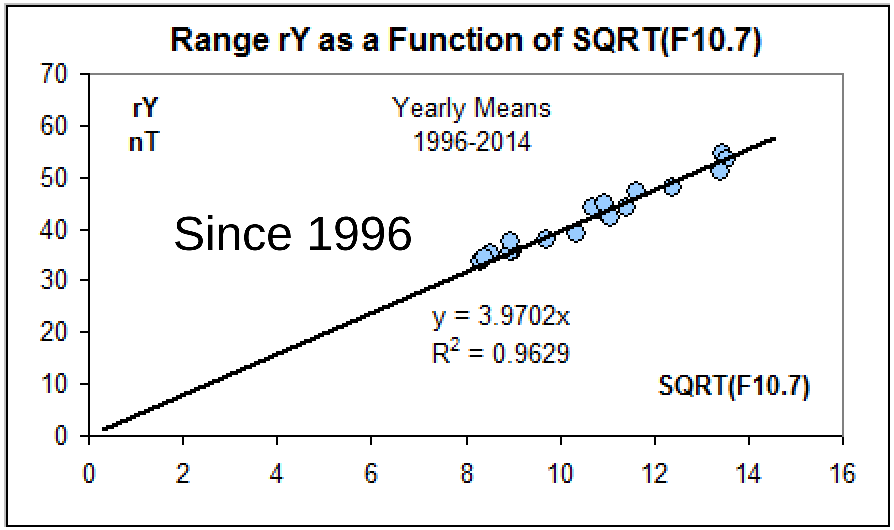


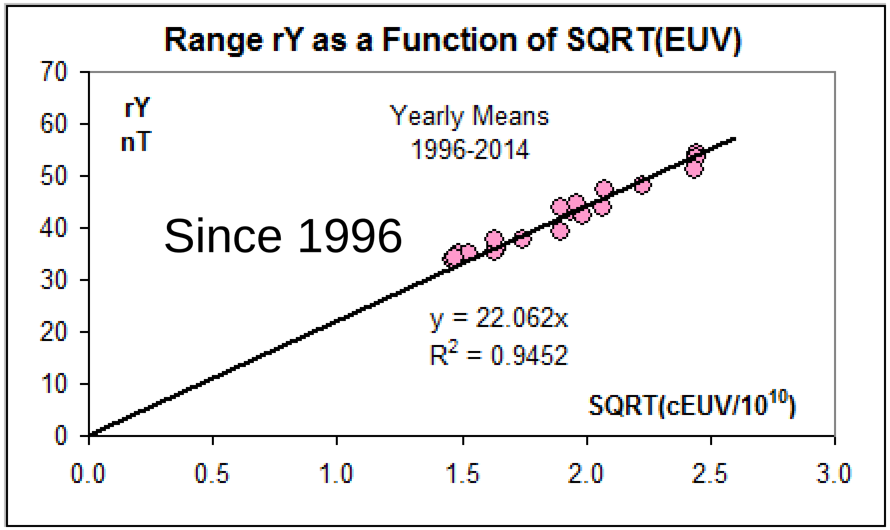


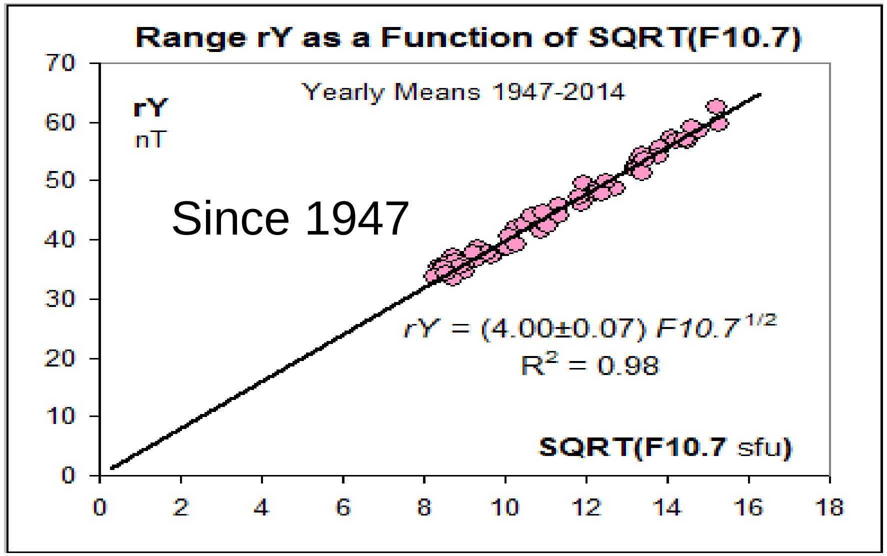


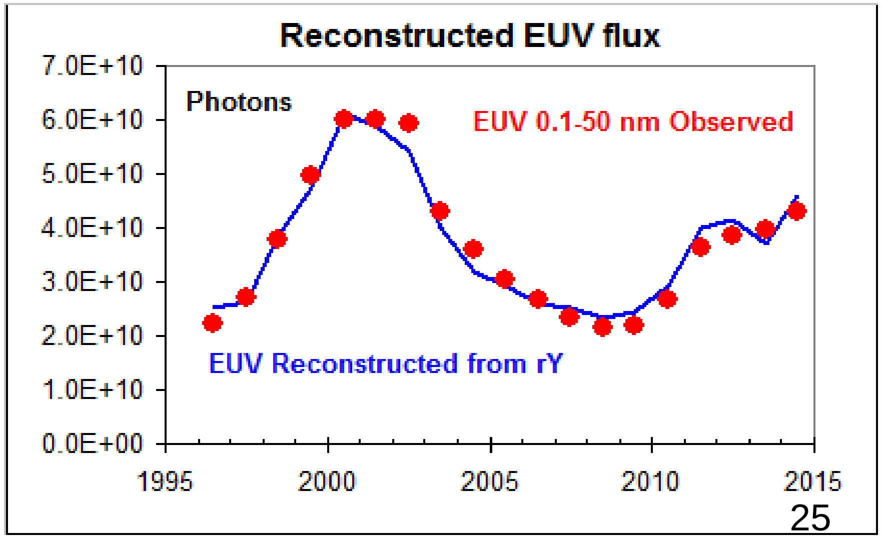


rY and F10.7$^{1/2}$ and EUV$^{1/2}$

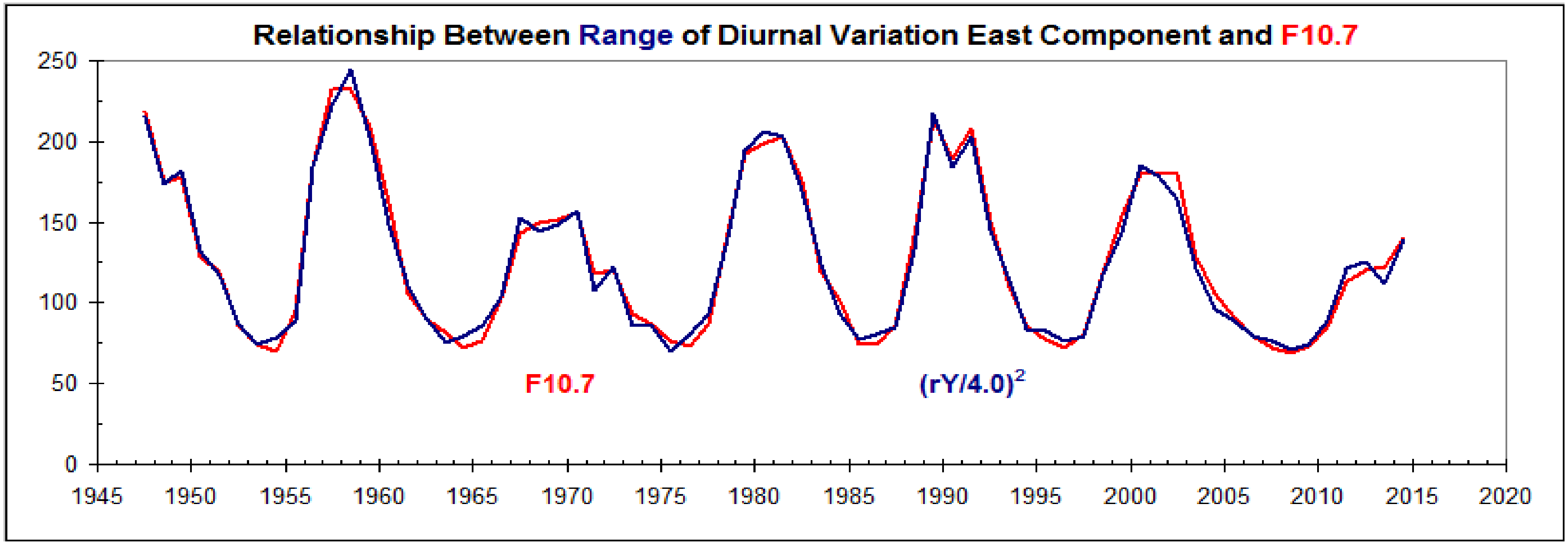


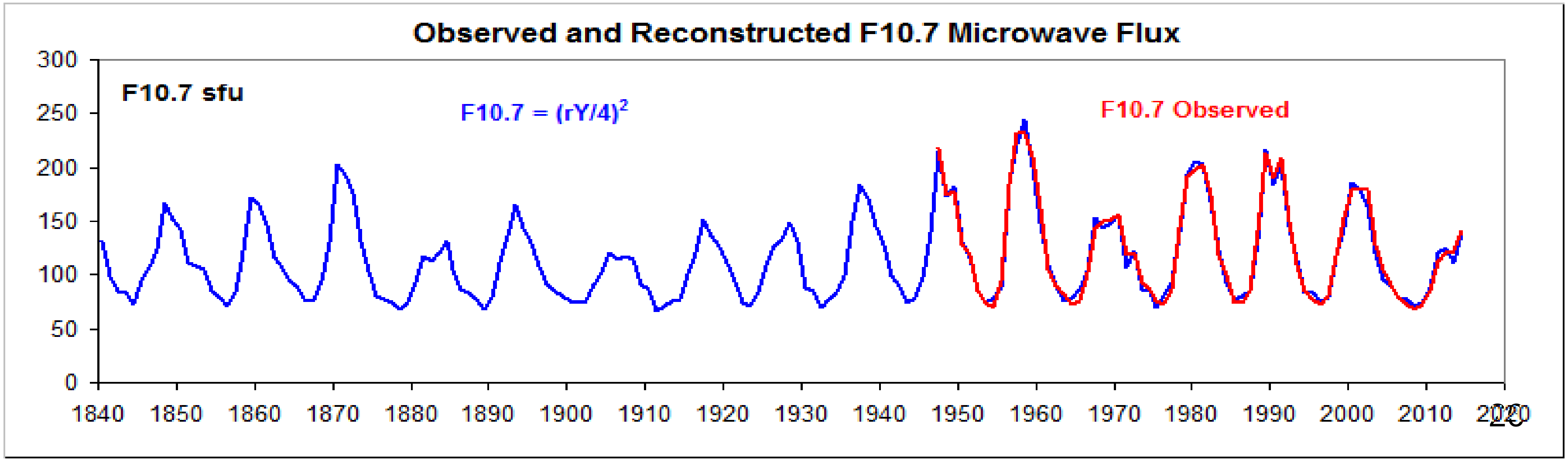




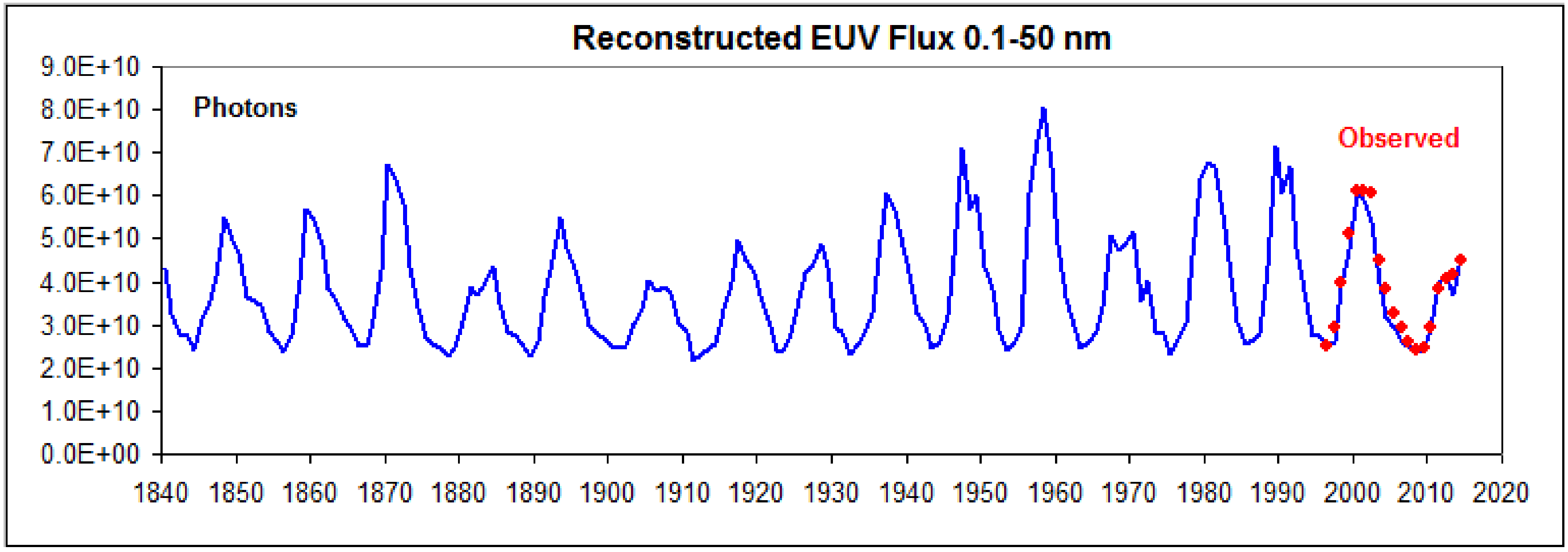


Reconstructed F10.7 [an EUV Proxy]



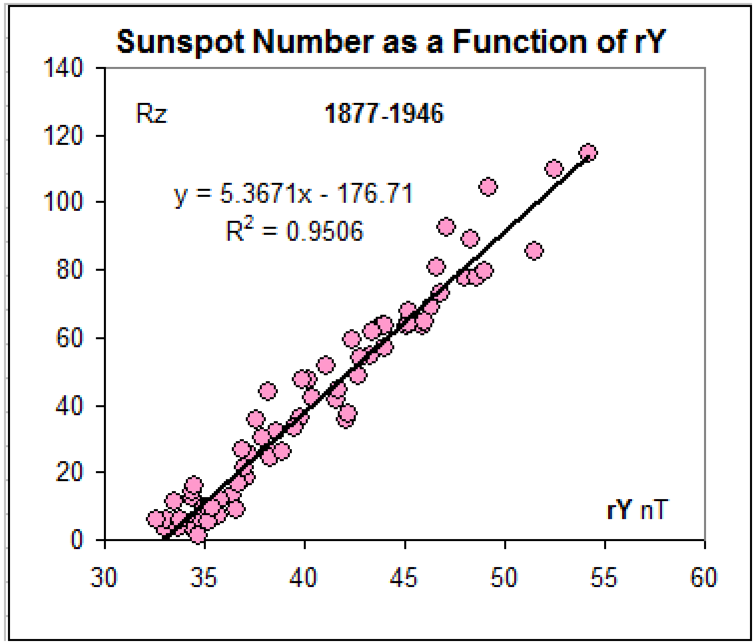


Reconstructed EUV Flux 1840-2014



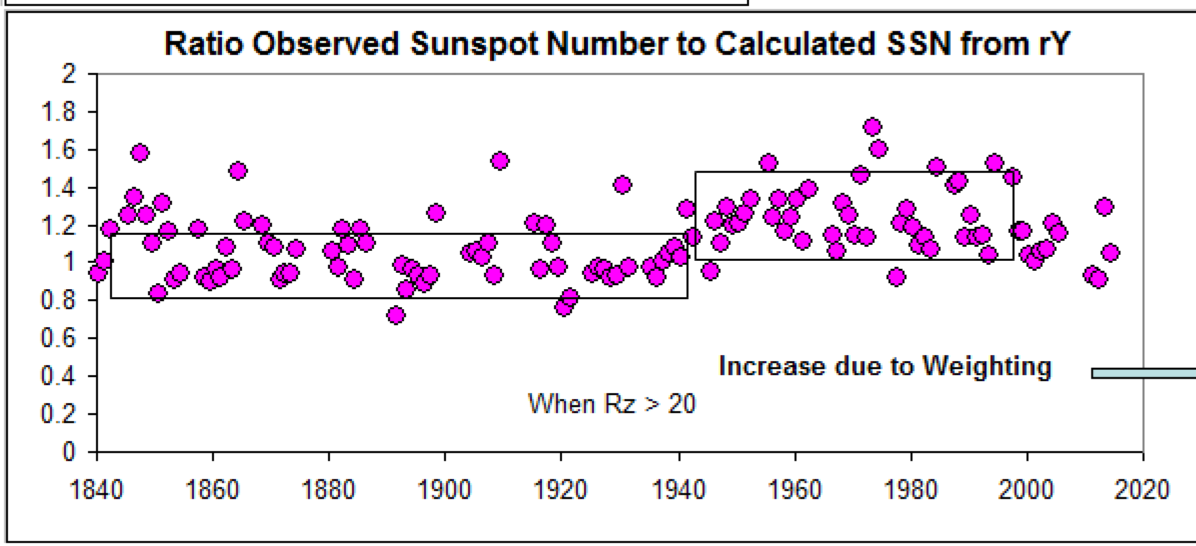
This is, I believe, an accurate depiction of true solar activity since 1840

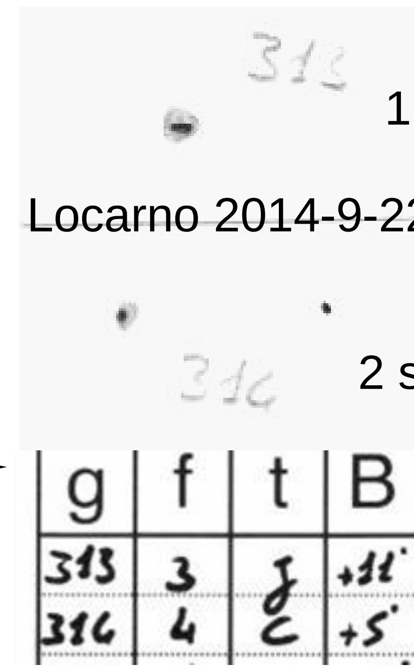
We can compare that with the Zurich Sunspot Number



	ratio
1840-1876	1.052
1877-1946	1.000
1947-1999	1.210
2000-Now	1.022

Wolfer & Brunner



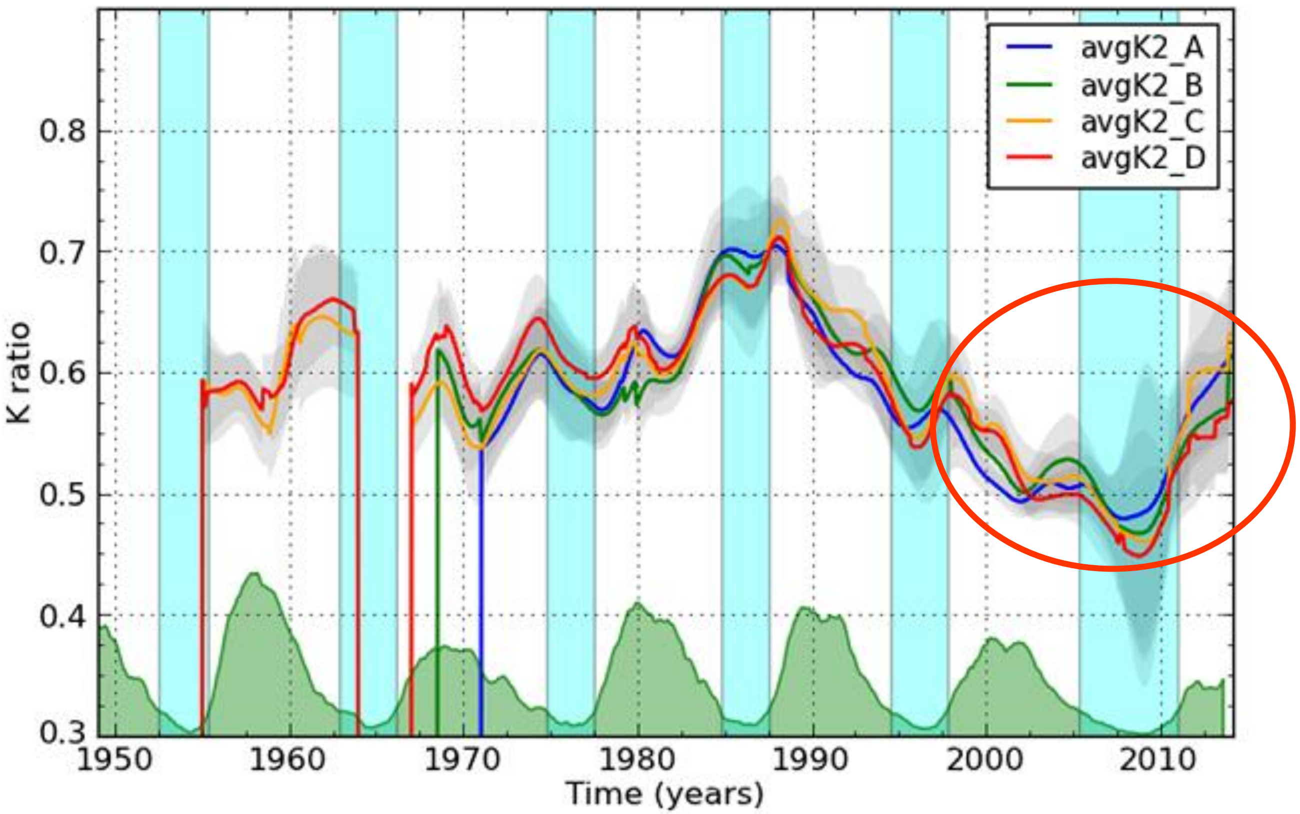


1 spot

Locarno 2014-9-22

2 spots

Recent Drift of International Sunspot Number k-values

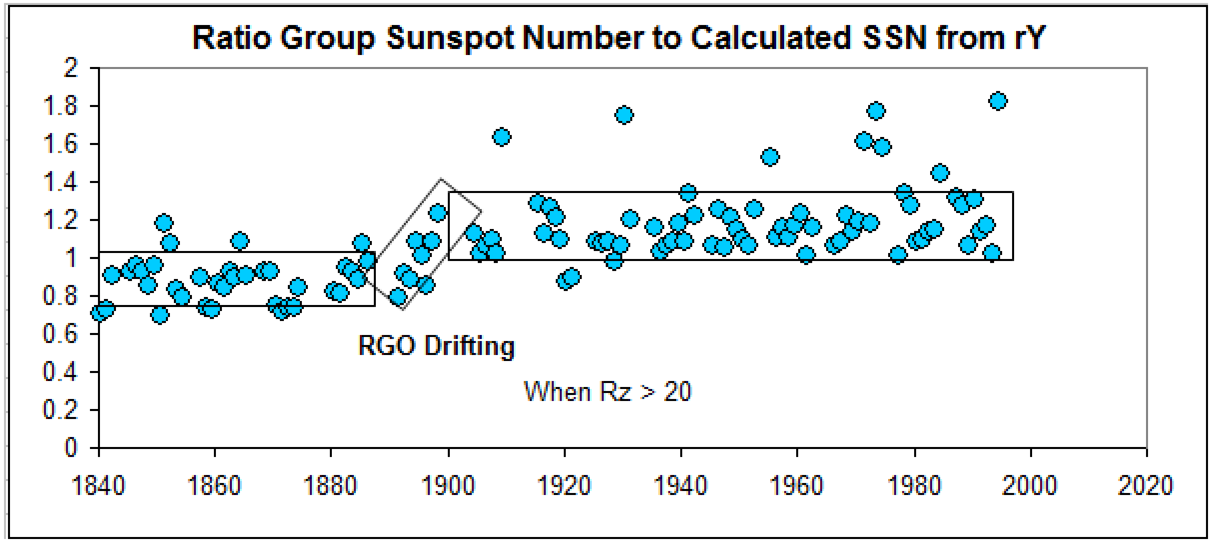


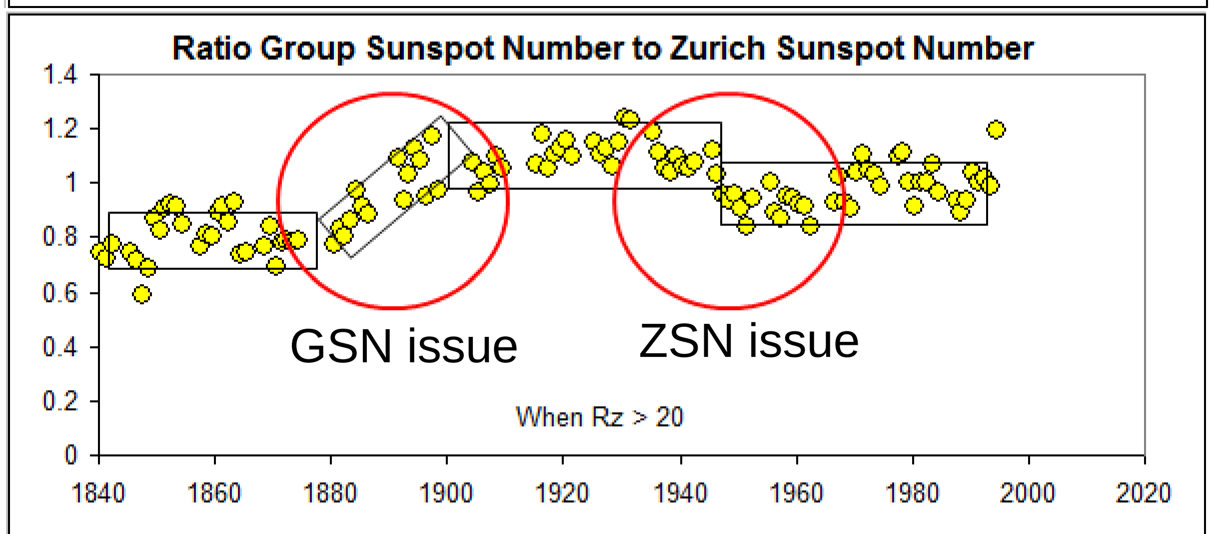
Plot of different multi-station average k ratios spanning the 1955–2013 interval, for 4 different subsets of stations

(A: 3 best stations; B: 6 stations; C: 16 stations; D: 22 stations).

Effect is under way to re-examine the International Sunspot Number: Clette et al., Space Science Reviews, 2014

How About the Group Sunspot Number?

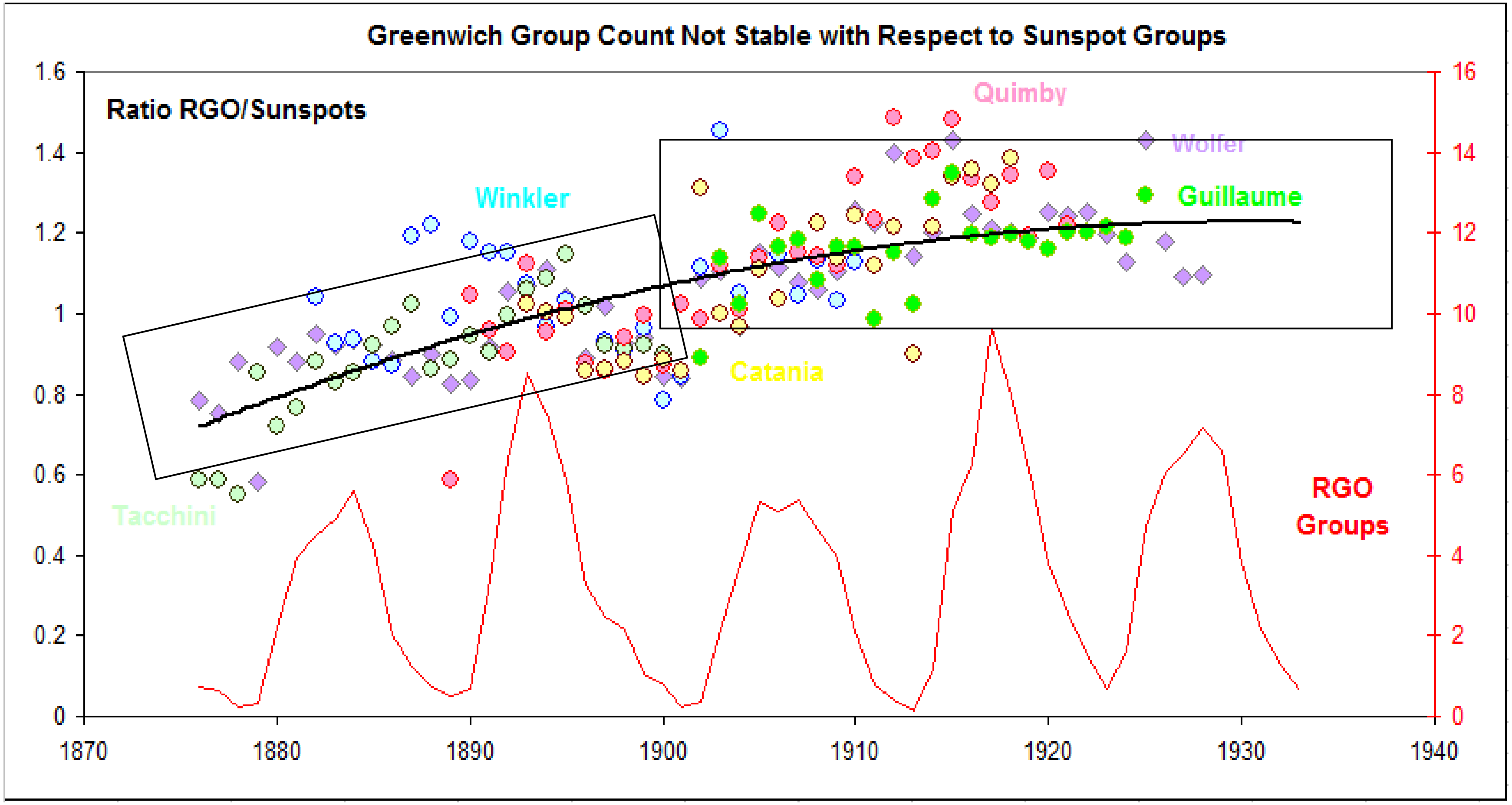




The main issue with the GSN is a change relative to the ZSN during 1880-1900. This is mainly caused by a drift in the reference count of the standard (Royal Greenwich Observatory)

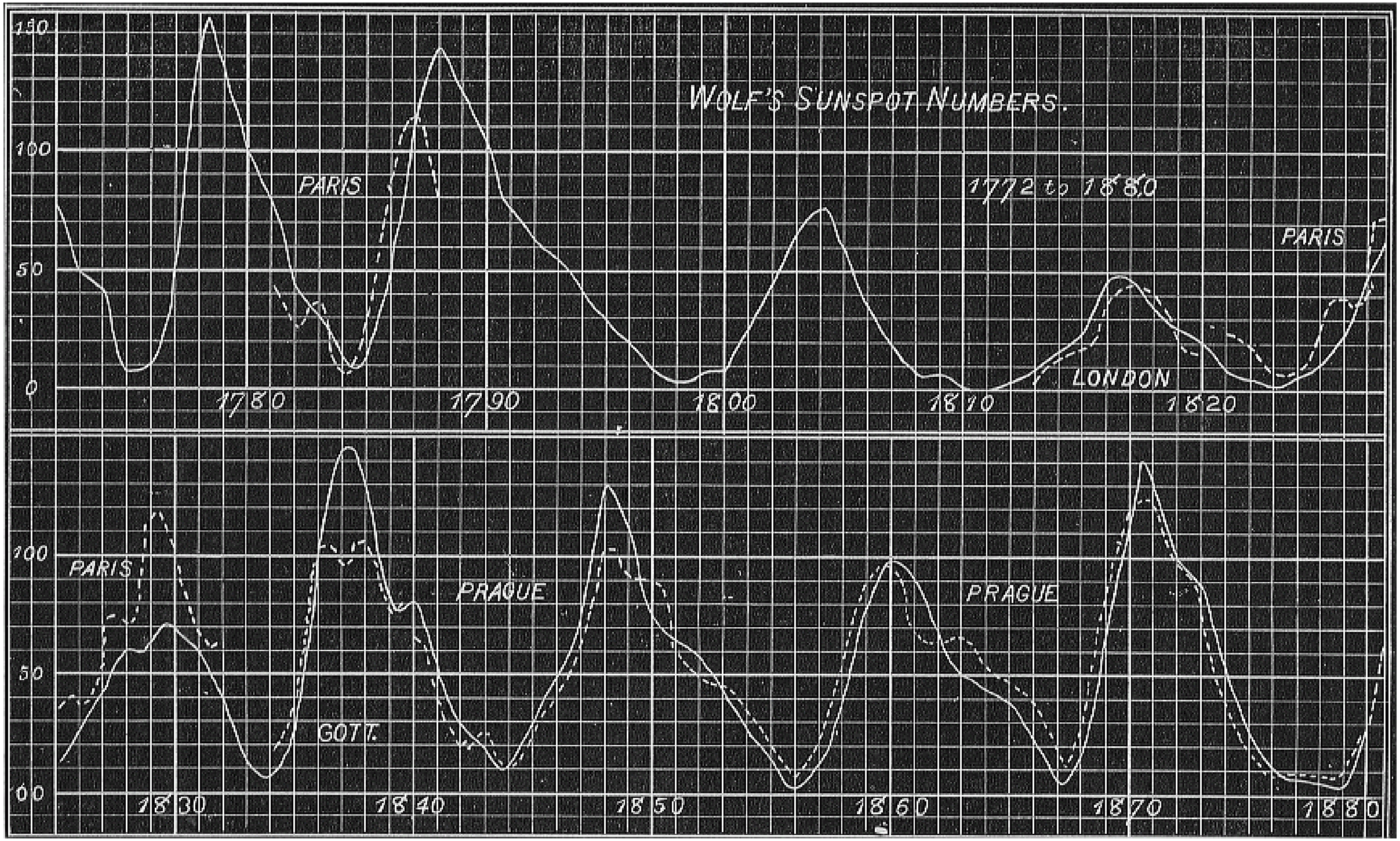
The ratio between the Group Sunspot Number reveals two major problem areas. We can now identify the cause of each

RGO Groups/Sunspot Groups



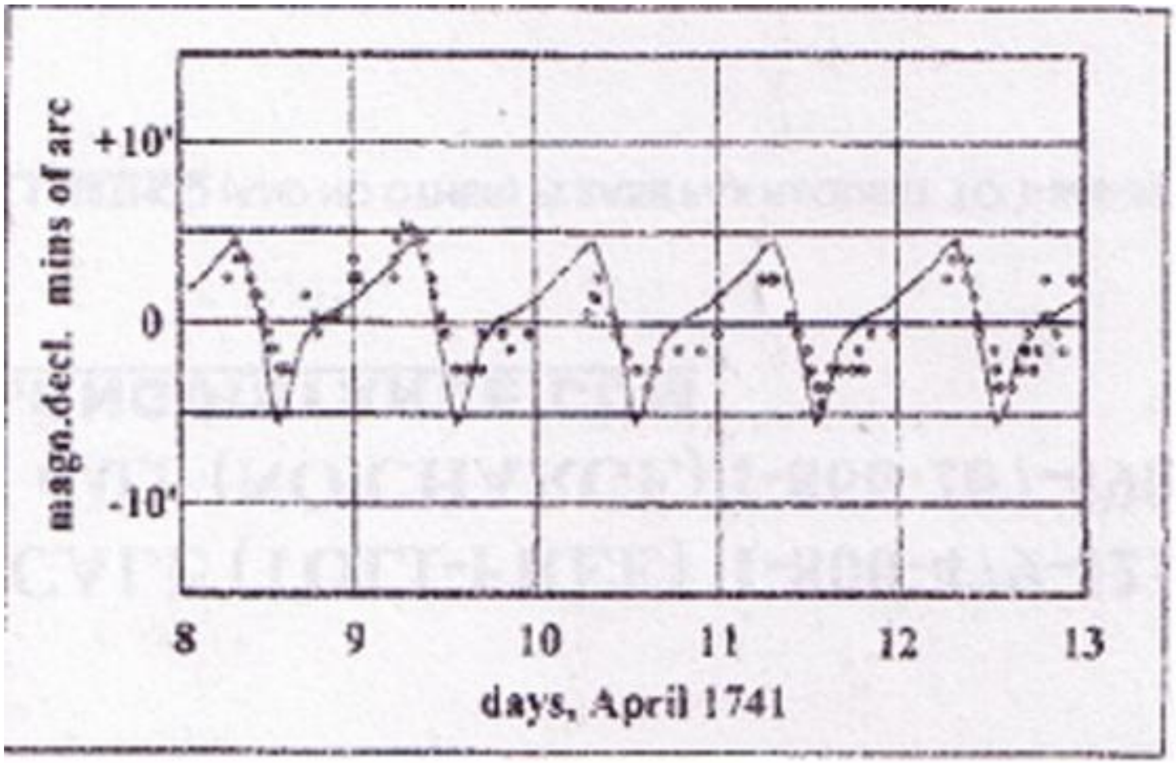
Early on RGO counts fewer groups than Sunspot Observers

Rudolf Wolf Discovered the Effect in 1852. Today We Know the Cause



A.C. Young: The Sun (revised edition, 1897).

Observations in the 1740s



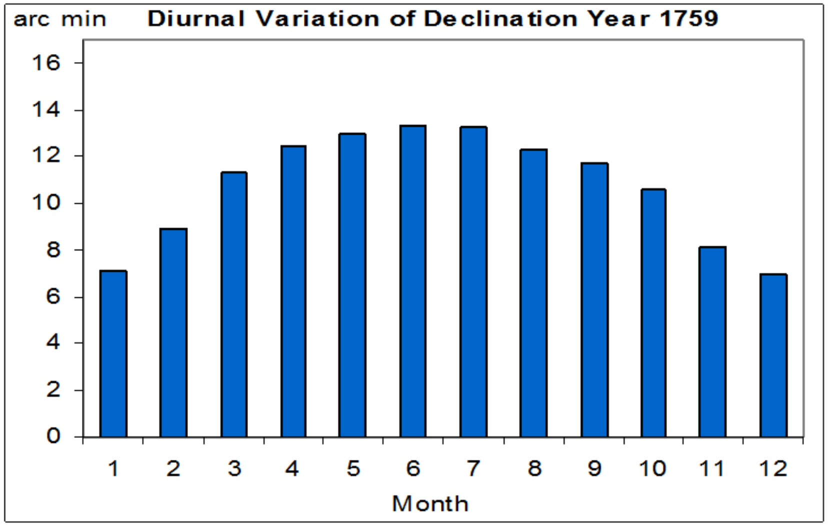
Olof Petrus Hjorter was married to Anders Celsius' sister and made more than 10,000 observations of the magnetic declination in the 1740s.

The data is available and I'm trying to find time to work on them.

Hjorter's measurements of the magnetic declination at Uppsala during April 8-12 1741 (old style). The curve shows the average variation of the magnetic declination during April 1997 at nearby Lovö (Sweden).

Observations in the 1760s

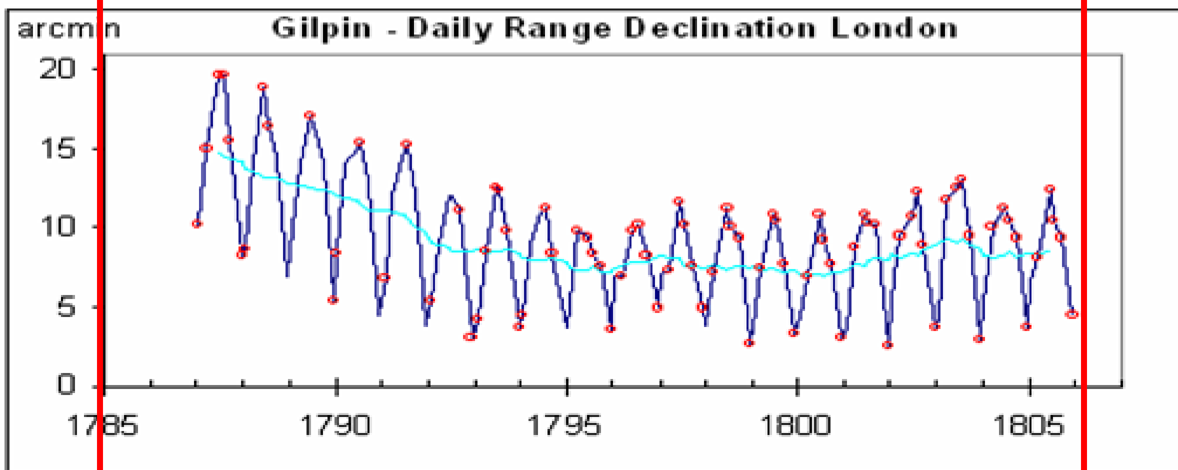
John Canton [1759] made ~4000 observations of the Declination on 603 days and noted that 574 of these days showed a ‘regular’ variation, while the remainder (on which aurorae were ‘always’ seen) had an ‘irregular’ diurnal variation.

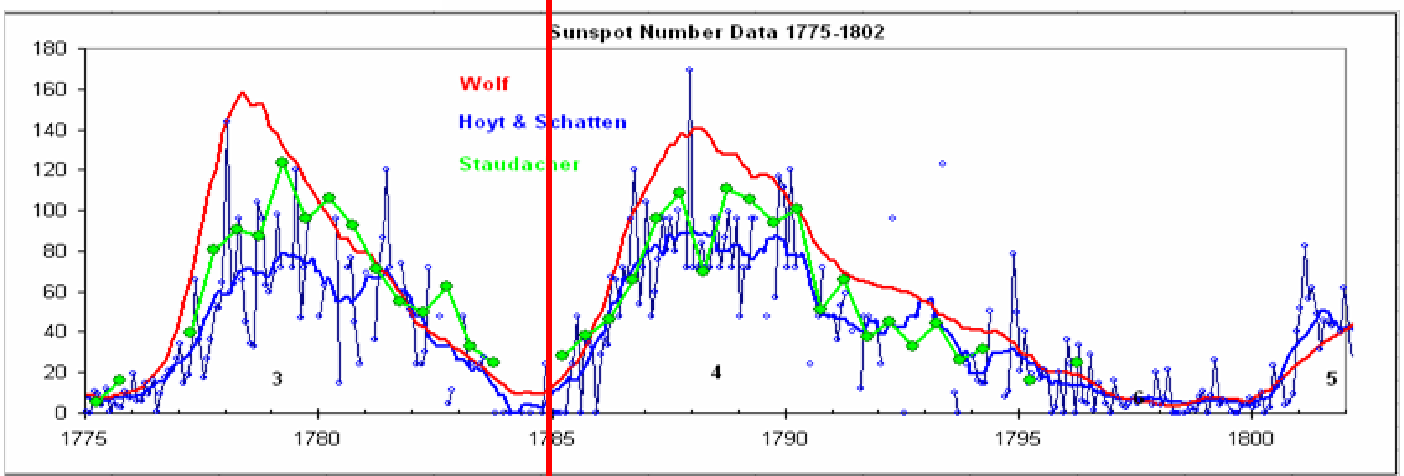


Observations in 1787-1805

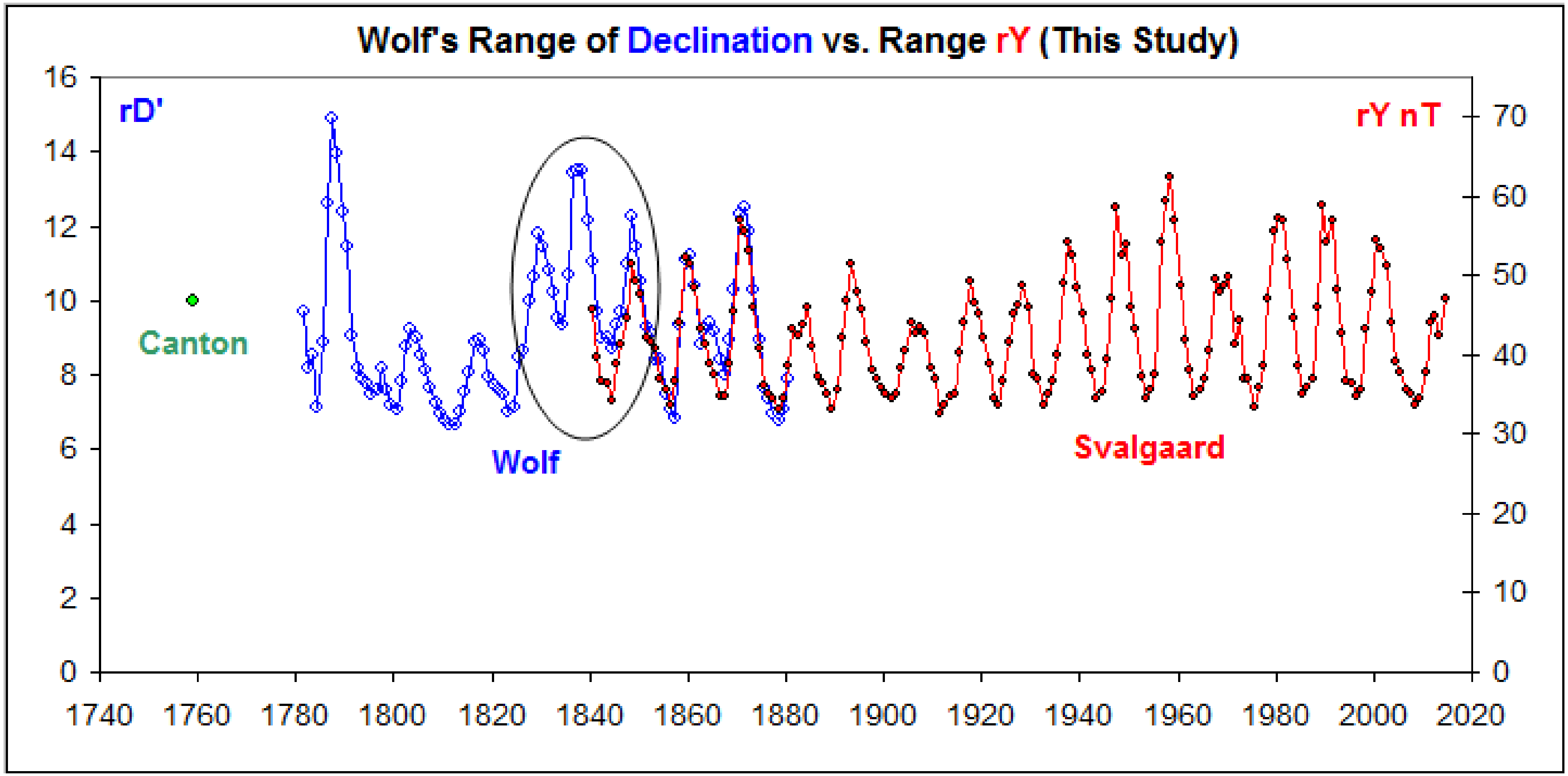
George Gilpin sailed on the *Resolution* during Cook's second voyage as assistant to William Wales, the astronomer.

Gilpin was elected Clerk and Housekeeper for the Royal Society of London on 03 March 1785 and remained in these positions until his death in 1810.



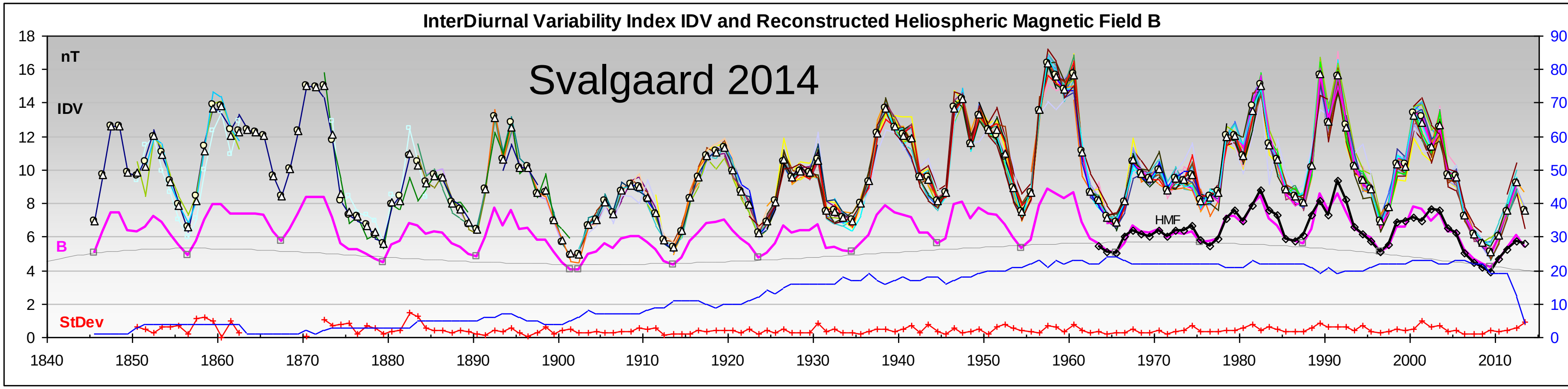


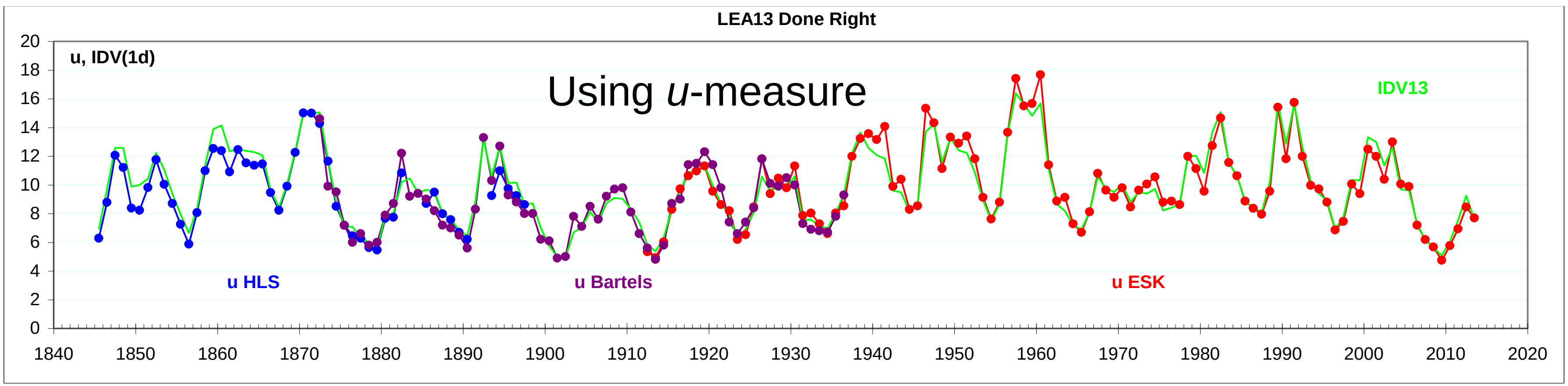
Wolf’s Series of Declination Ranges



Next Task: to critically resolve the discrepancy (in oval)

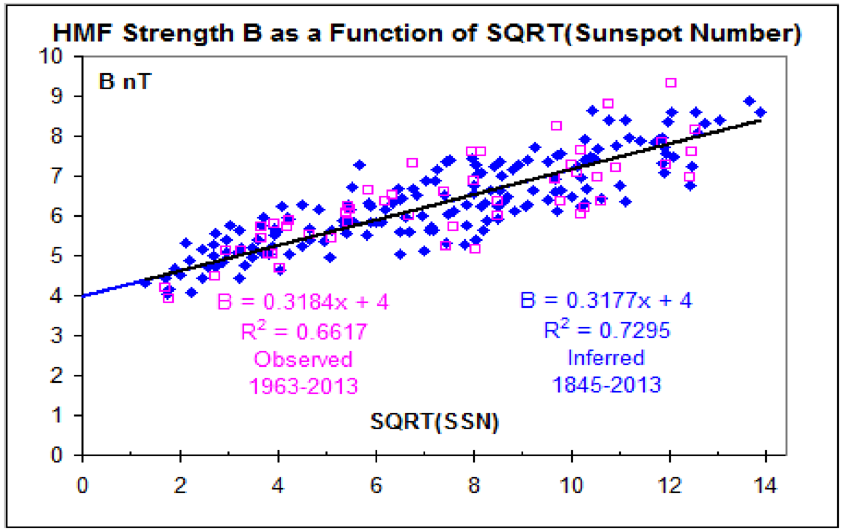
Progress in Reconstructing Solar Wind Magnetic Field back to 1840s

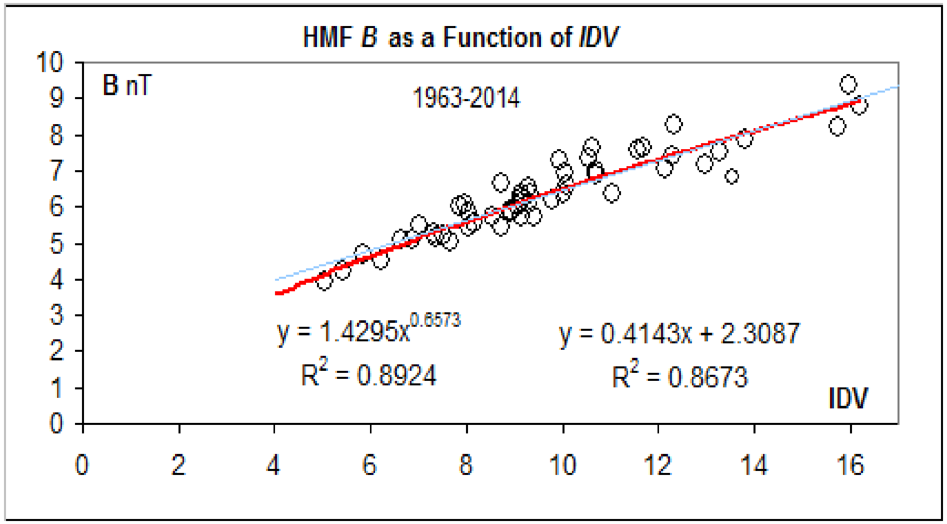


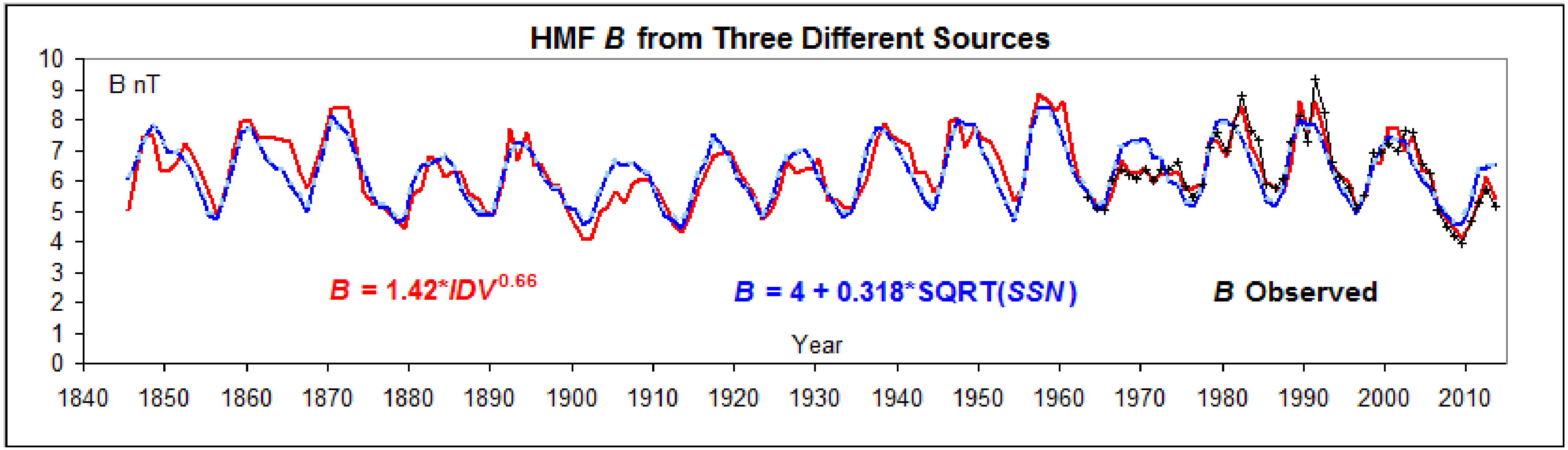


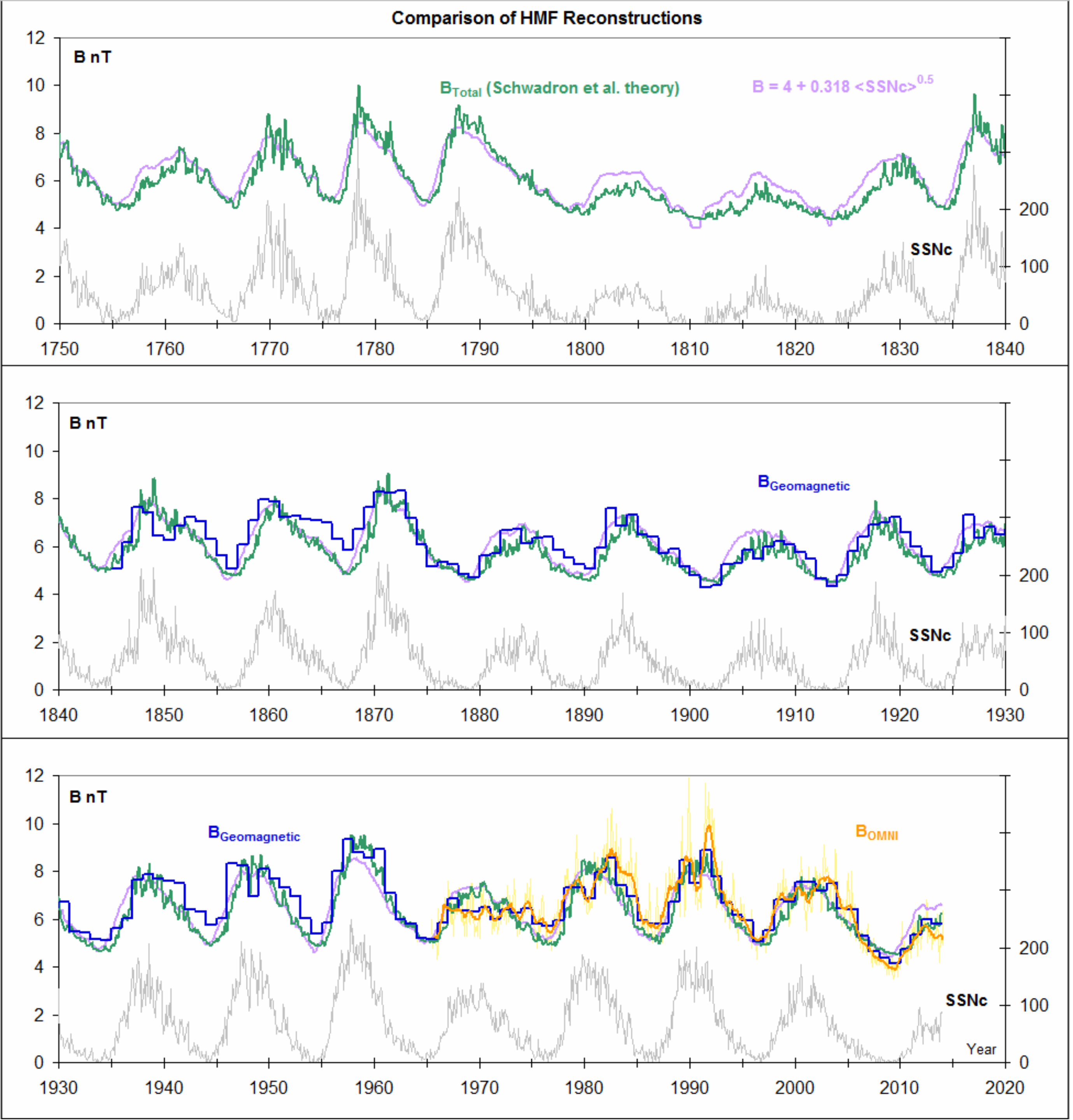
Even using only ONE station, the 'IDV' signature is strong enough to show the effect

Different Ways of Reconstructing HMF B









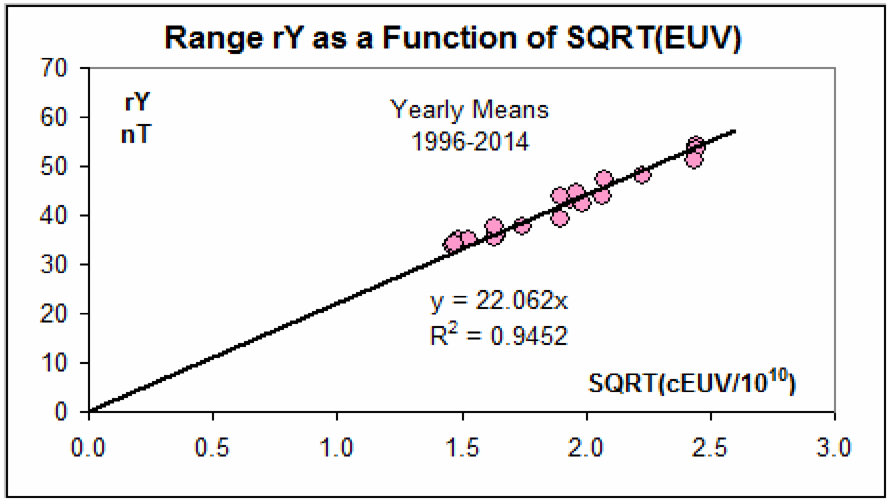
Schwadron et al. (2010) HMF B Model with my set of parameters with a 'Floor'

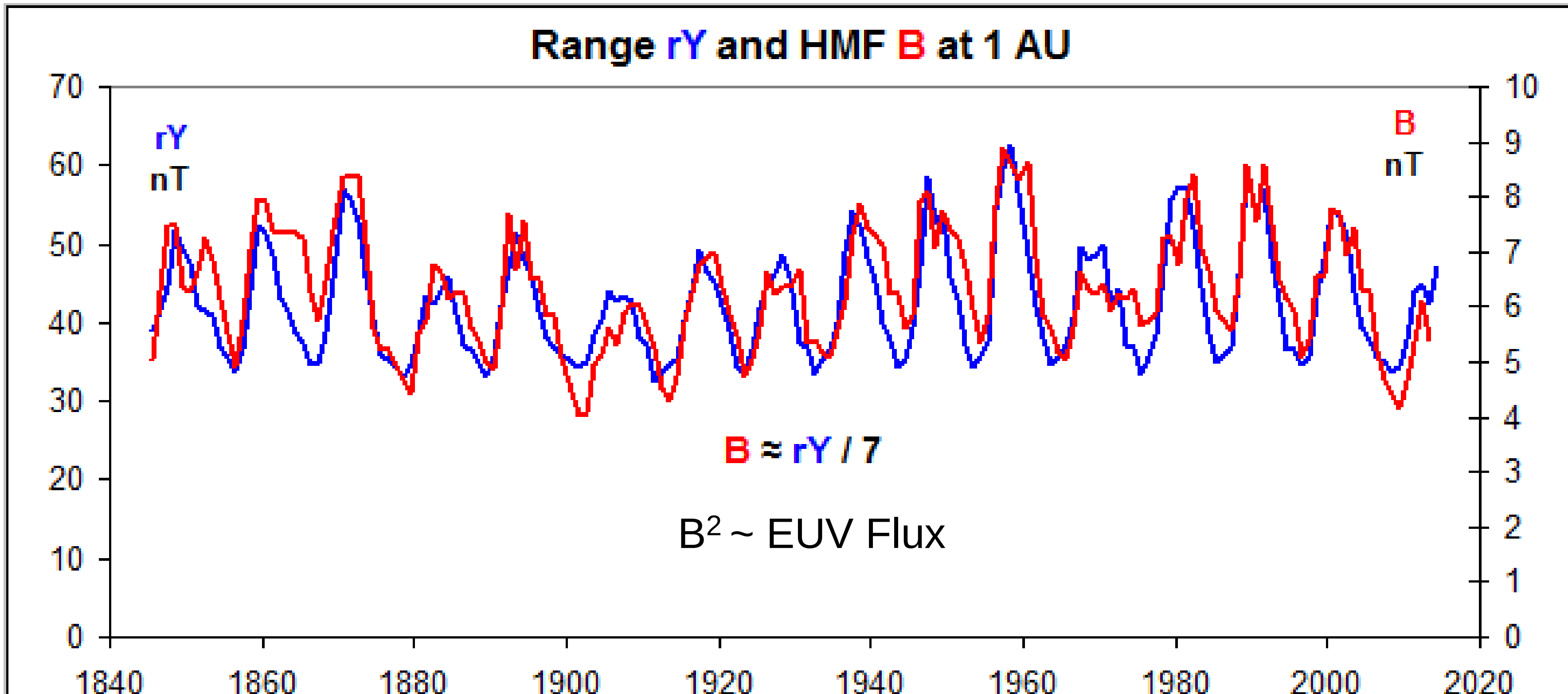
von Neumann: "with four parameters I can fit an elephant, and with five I can make him wiggle his trunk"

This model has about eight parameters…

$B = 4 + 0.318\ SSNc^{1/2}$

HMF B Scales with the Sqrt of the EUV flux





Conclusions

- We can reconstruct with confidence the solar EUV flux [and its proxy F10.7] back to 1840
- The reconstructed EUV flux confirms the discontinuities in the Sunspot Records reported by Clette et al., 2014
- There is more geomagnetic data earlier than 1840, and it now seems important to acquire and process the earlier data.
- The EUV flux is concordant with the revised Sunspot Number and the Solar Wind Magnetic Flux
- There is no Modern **Grand** Solar Maximum
- Some of this may still be controversial. Aggressive and serious opposition is welcome

Abstract

Solar EUV creates the conducting E-layer of the ionosphere, mainly by photo ionization of molecular Oxygen, governed by the so-called Chapman function. Solar heating of the ionosphere creates thermal winds which by dynamo action induce an electric field driving an electric current having a magnetic effect observable on the ground, as was discovered by G. Graham in 1722. The current rises and sets with the Sun and thus causes a readily observable diurnal variation of the geomagnetic field, allowing us the deduce the conductivity and thus the EUV flux as far back as reliable magnetic data reach. High quality data go back to the 1840s and less reliable, but still usable, data are available for the hundred years before that. R. Wolf and, independently, J-A. Gautier discovered the dependence of the diurnal variation on solar activity, and today we understand and can invert that relationship to construct a reliable record of the EUV flux from the geomagnetic record. We compare that to the F10.7 flux and the sunspot number, and find that the reconstructed EUV flux reproduces the F10.7 flux with great accuracy and that the EUV flux clearly shows the discontinuities of the sunspot record identified by Clette et al, 2014.