Reconstruction of Heliospheric Magnetic Field Strength 1835-2014

180 Years of HMF B

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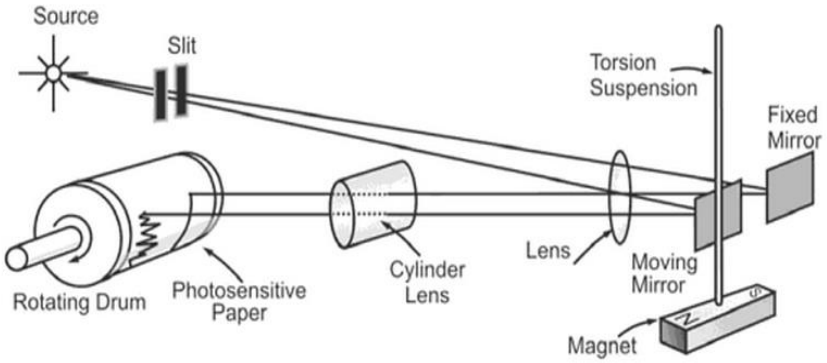
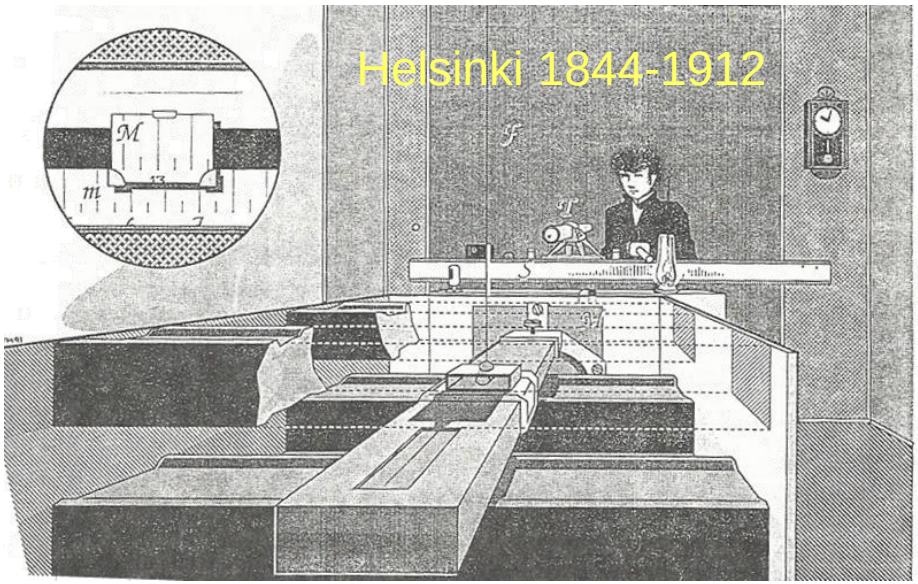
Stanford University

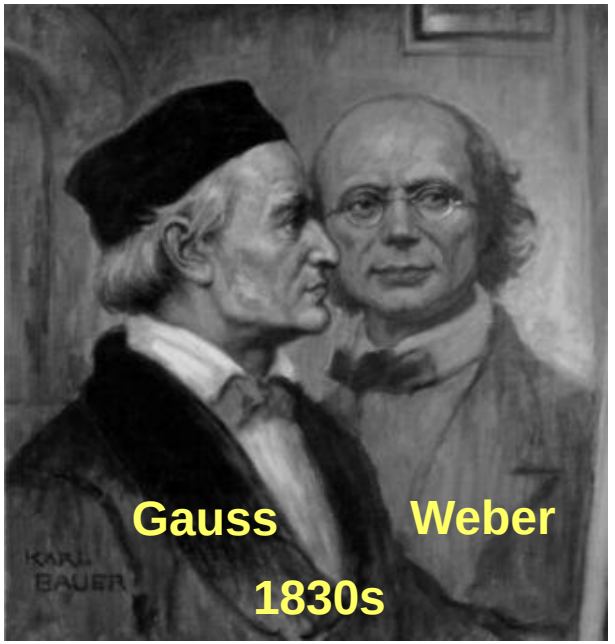
LWS Session S-16 (1a)

Portland, OR, Nov. 6, 2014



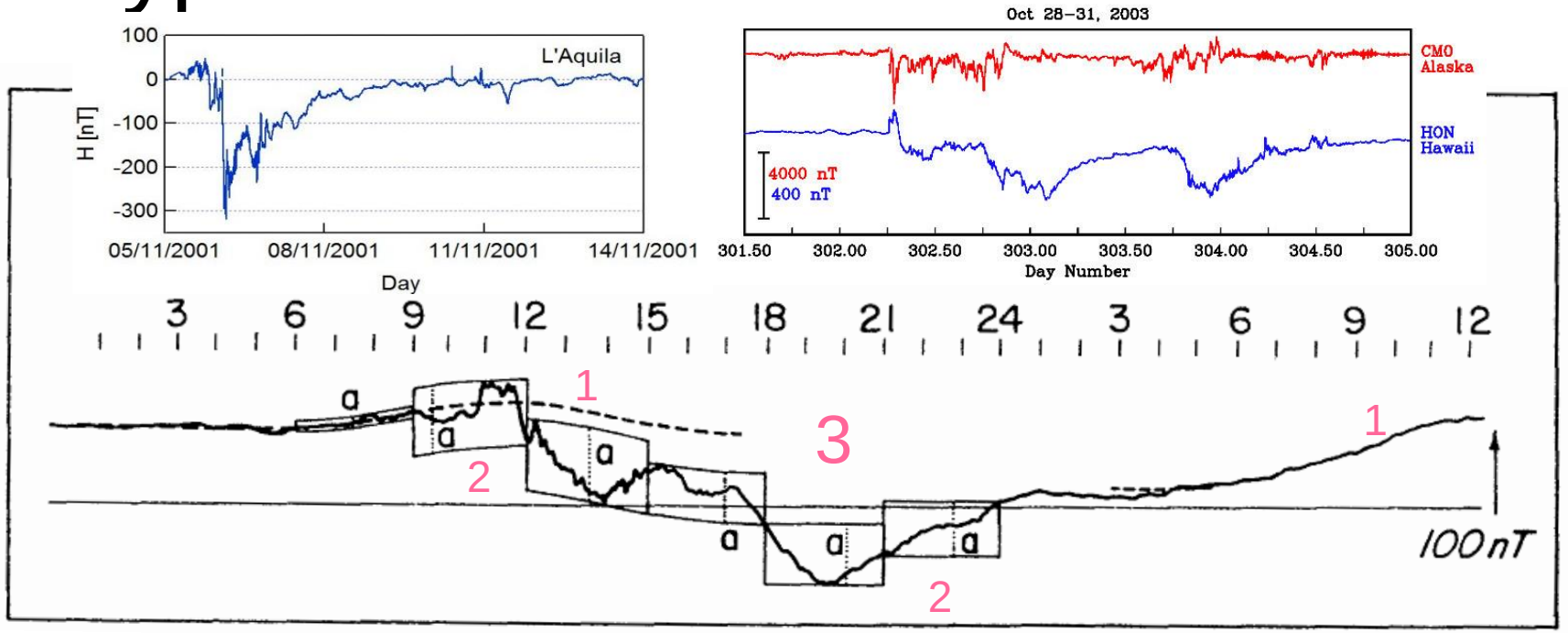
Classic Method since 1846





Magnetic Recording over Time

Typical Recording over 36 Hours



Three simultaneous features:

1: A Regular Daily Variation [it took ~200 years to figure out the cause]

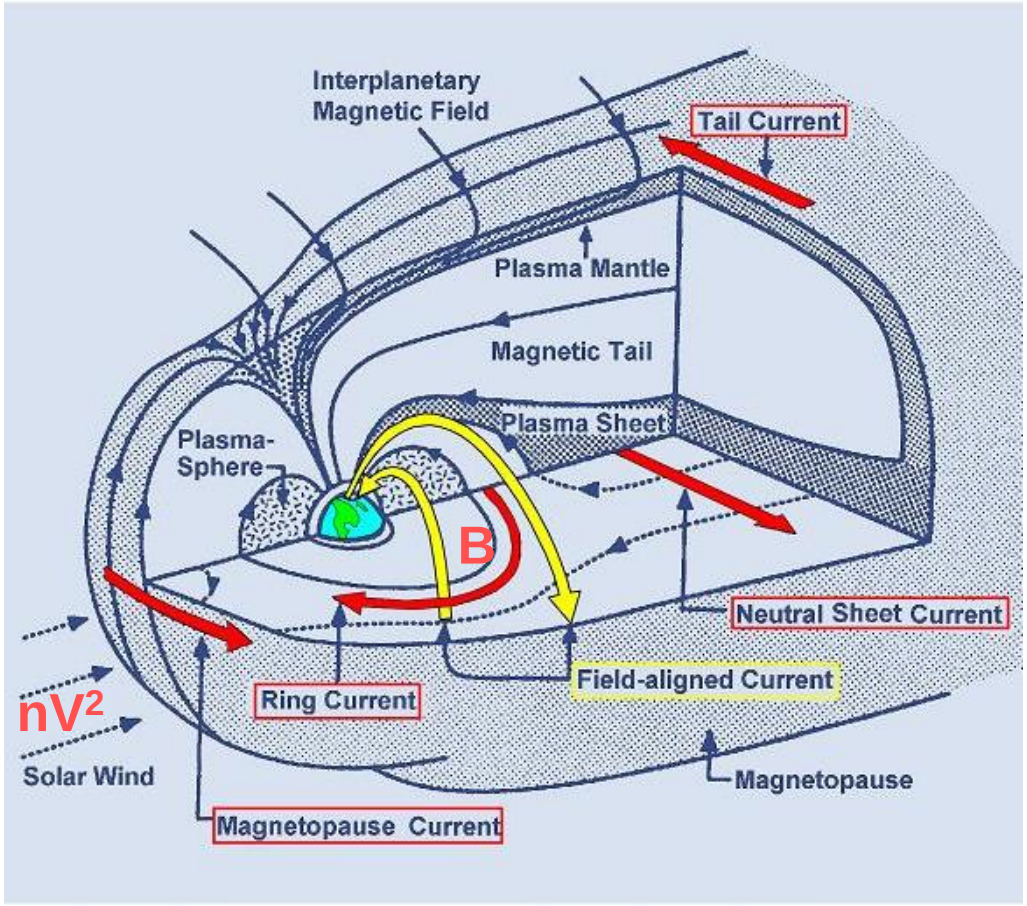
2: Shorter-term [~3 hour] fluctuations ['substorms' recognized in 1960s]

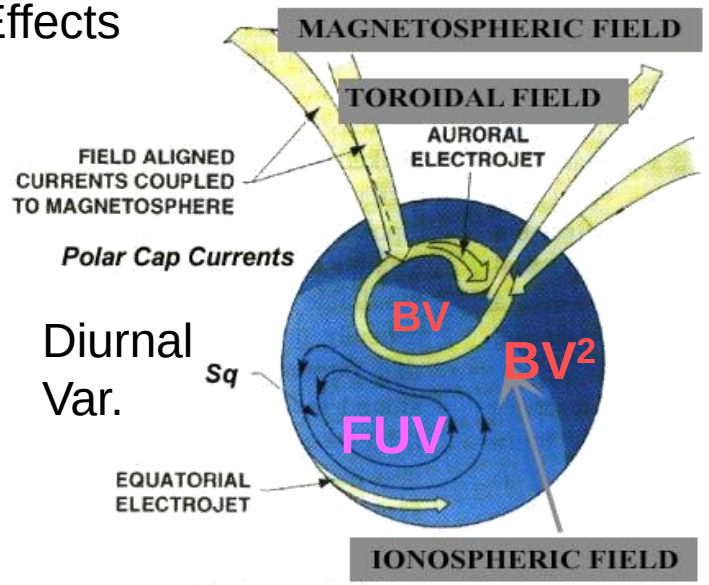
3: Large disturbances ['geomagnetic storms' explained in the 1960s]

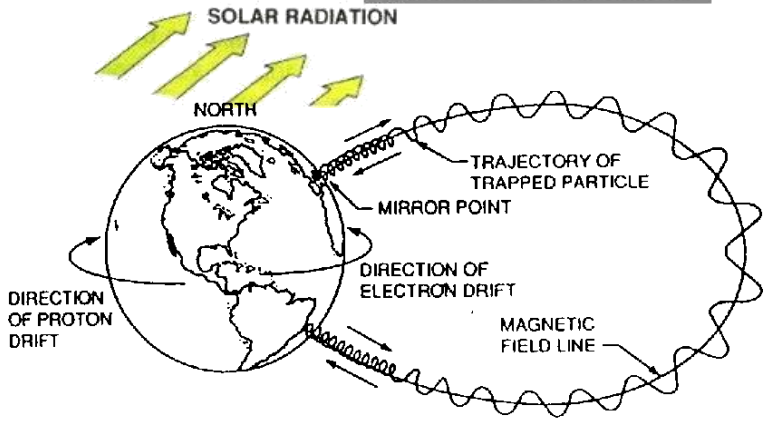
The complicated, simultaneous effects withstood understanding for a long time

Electric Current Systems in Geospace

Different Current Systems ⇄ Different Magnetic Effects



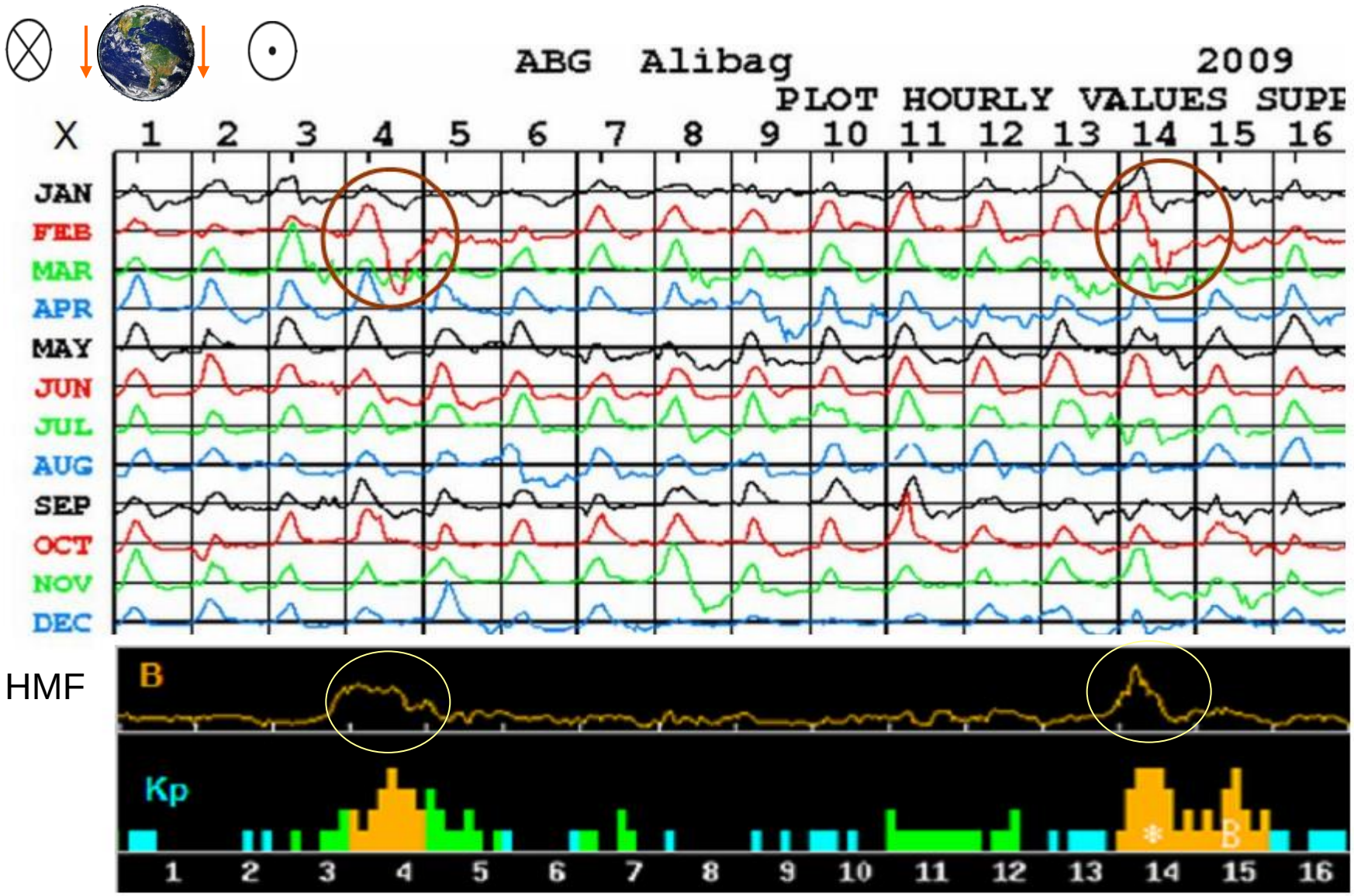




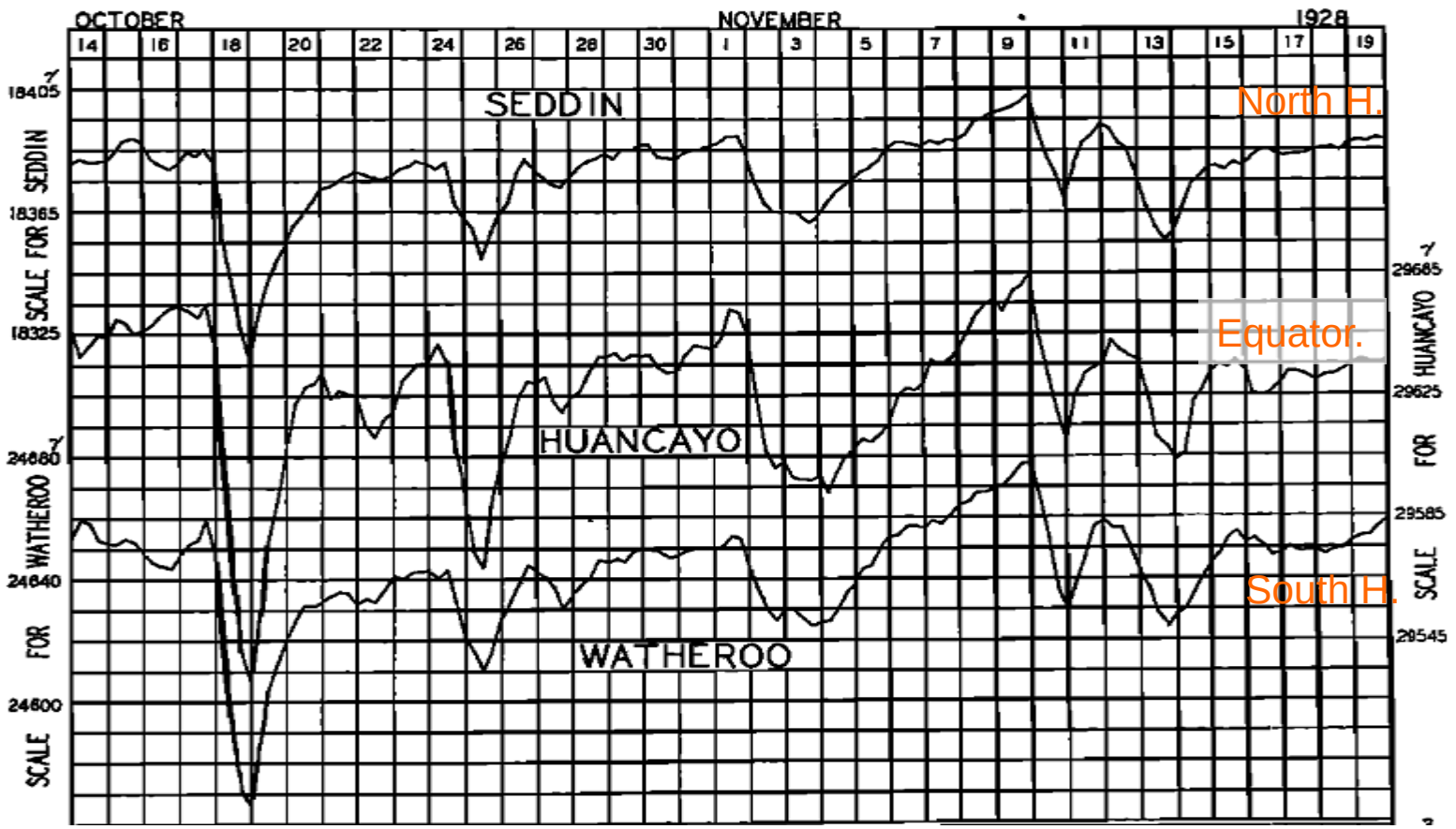
We can now invert the Solar Wind – Magnetosphere relationships…

Oppositely charged particles trapped in the Van Allen Belts drift in opposite directions giving rise to a net westward 'Ring Current'.

Relation to HMF Strength B



24-hour running means of the Horizontal Component of the low- & mid-latitude geomagnetic field remove most of local time effects to show the Ring Current imprint:

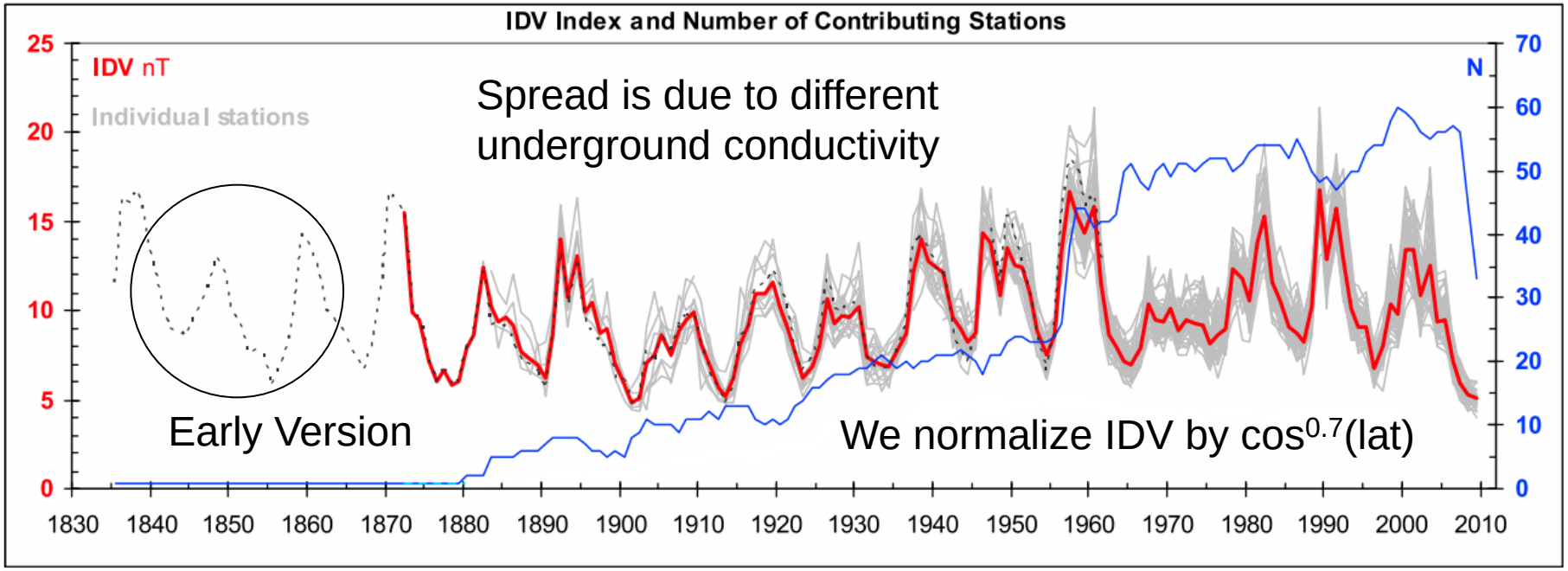


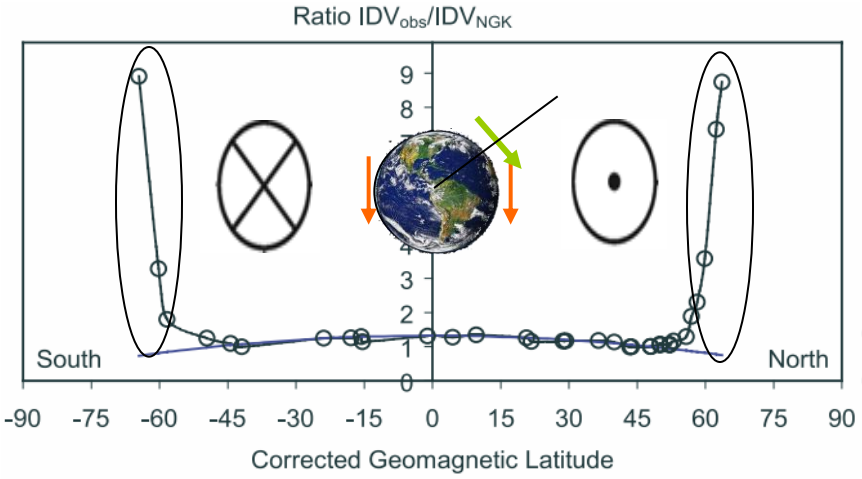
Latitude effect can be corrected for

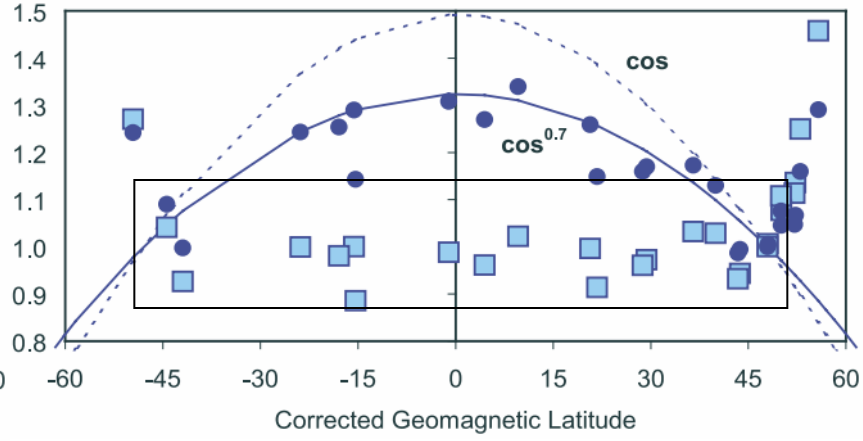
The IDV Geomagnetic Index

- Since the daily variation is fairly regular from day to day we can eliminate it by considering the difference between consecutive days
- Further suppression of the daily variation can be achieved by working only with the field during night hours or the average over a whole day
- That led to the definition of the Interdiurnal Variability Index [IDV] as the unsigned difference between the geomagnetic field component on consecutive local nights
- IDV is a Global index
- IDV is a modern version of the *u*-measure

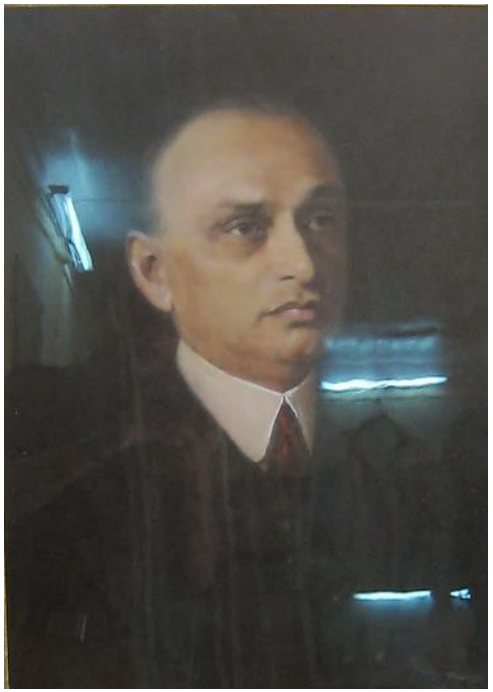
IDV Derived from Many Stations (Observatories)







The *u*-measure



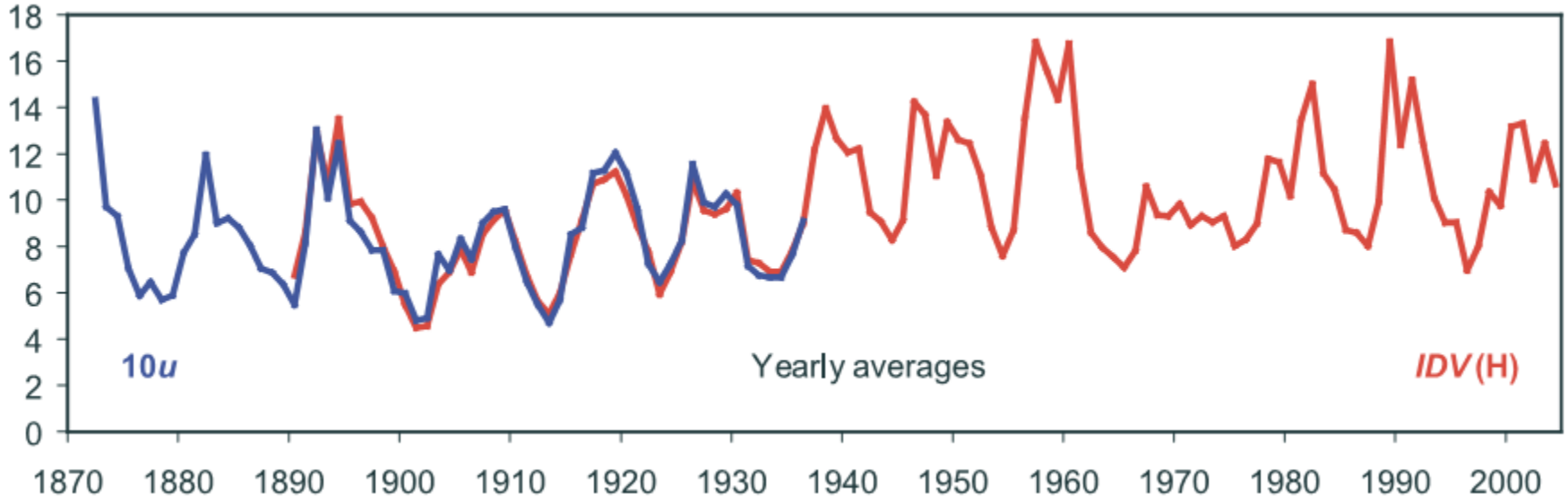
N.A.F Moos (1859-1936)

Adolf Schmidt (1860-1944)

Julius Bartels(1899-1964)

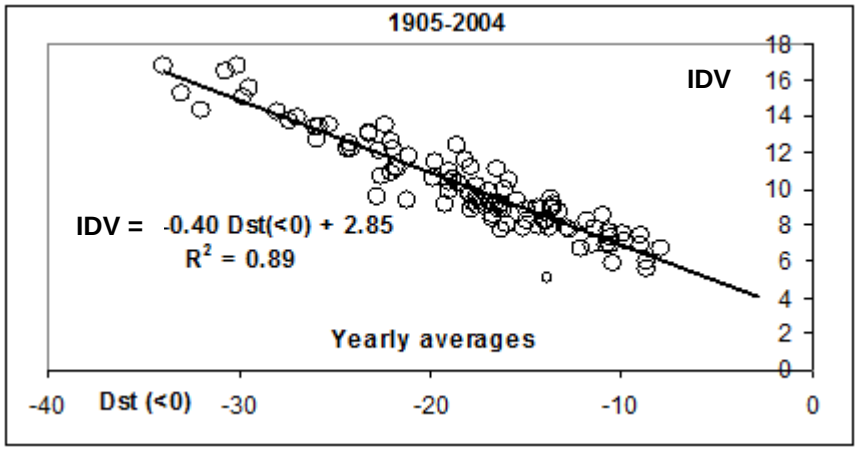
The u-measure was an index defined as the unsigned difference of the daily **means** of the horizontal component from one day to the next

Comparing the *u*-measure and IDV

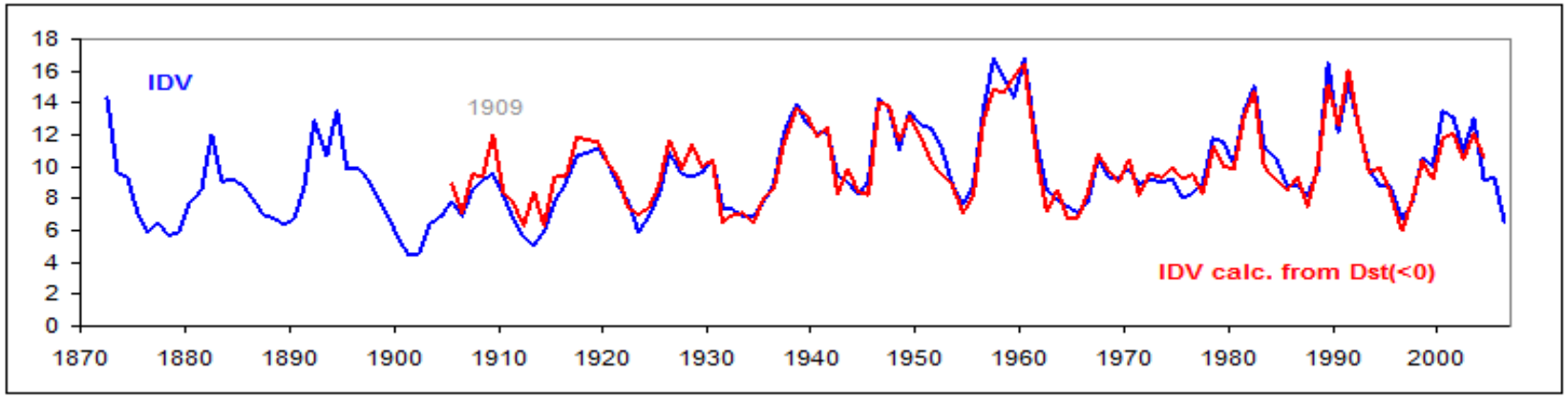


The IDV index and the *u*-measure track each other so well that either one can be used. We introduced the IDV based on only one hour per day because in the 19th century many stations did not observe at all hours throughout the day [not to speak about the night] so we wanted to see if only a few [as few as 1] hours worth of observations would be sufficient. As you can see, this hope seems fulfilled.

IDV measures the same as the Negative part of Dst Index

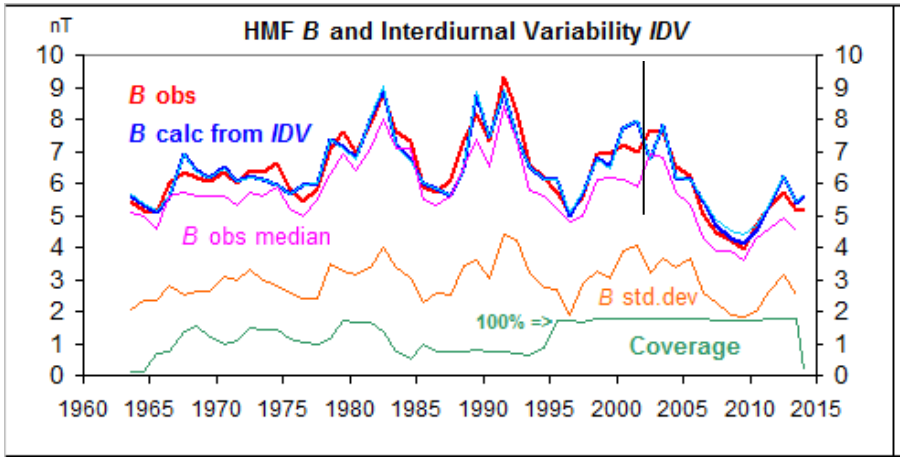


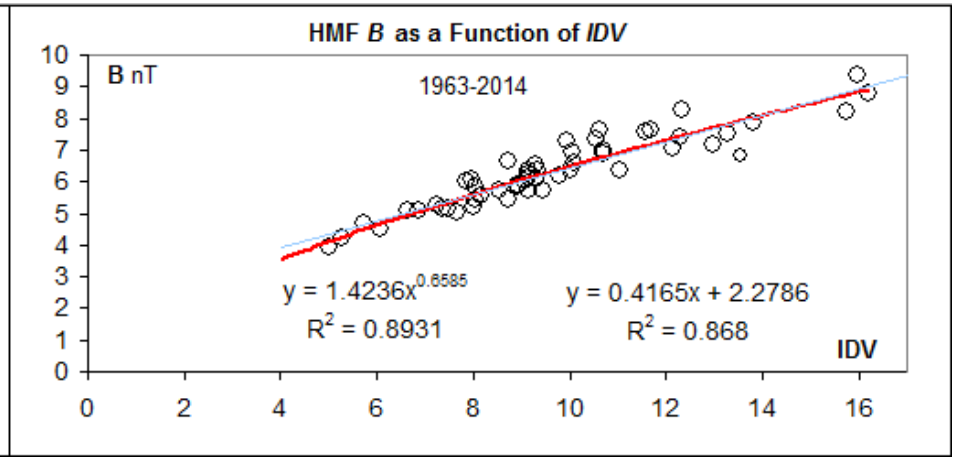
Coronal Mass Ejections (CMEs) add (closed) magnetic flux to the IMF. CMEs hitting the Earth create magnetic storms feeding energy into the inner magnetosphere ("ring current"). The Dst-index is aimed at describing this same phenomenon, but only the negative contribution to Dst on the nightside is effectively involved. We therefore expect (negative) Dst and IDV to be strongly related, and they are

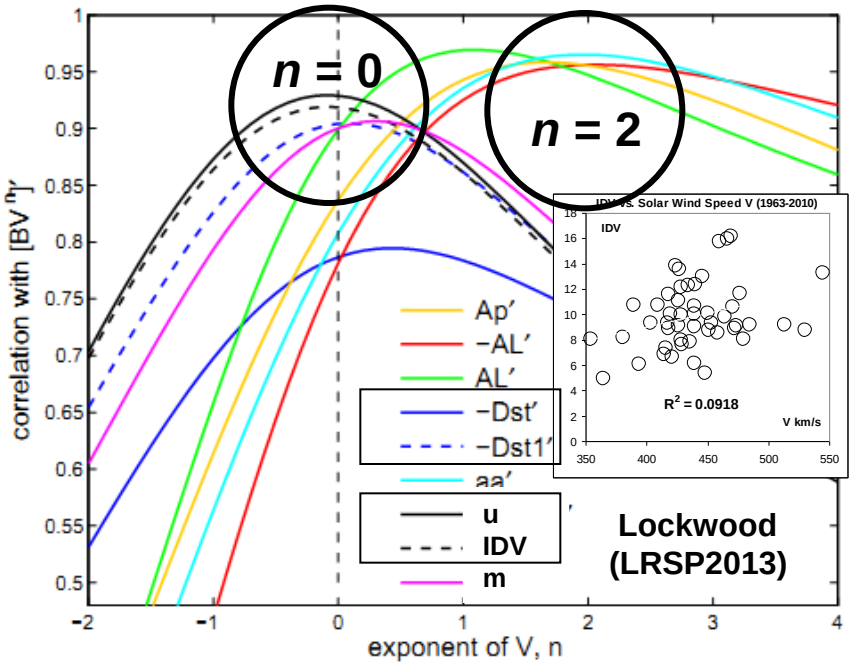


We used a derivation of Dst by J. Love back to 1905. Similar results are obtained with the Dst series by Mursula et al. (to 1932) or with the "official" Dst series (to 1957). The very simple-to-derive IDV series compares favorably with the much more elaborate Dst(< 0).

Relationship between HMF *B* and *IDV*





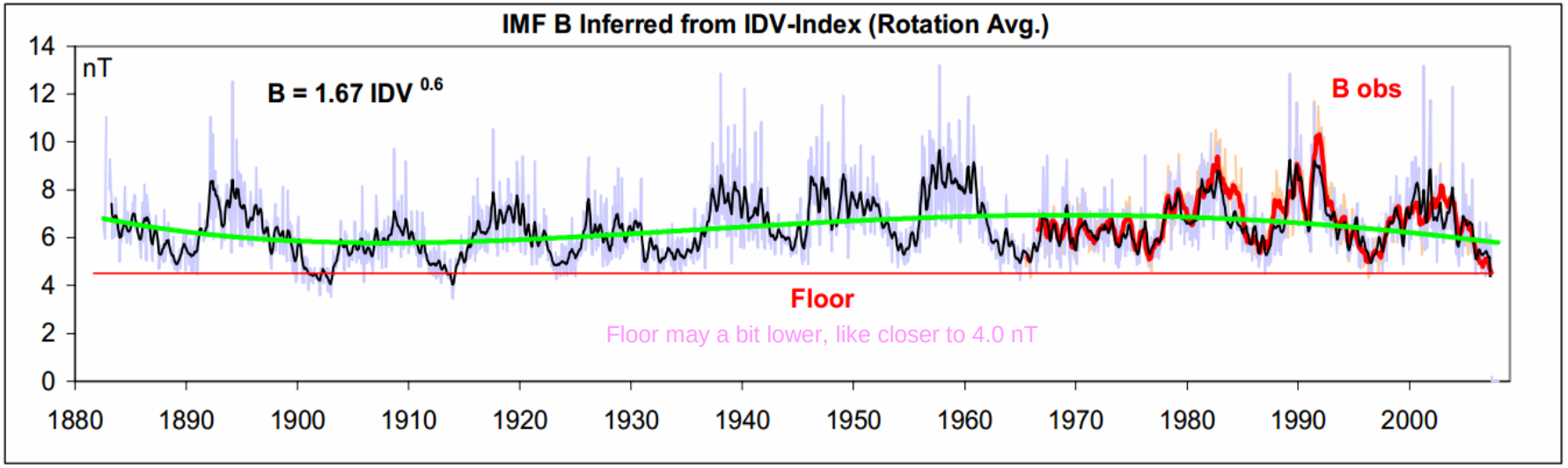


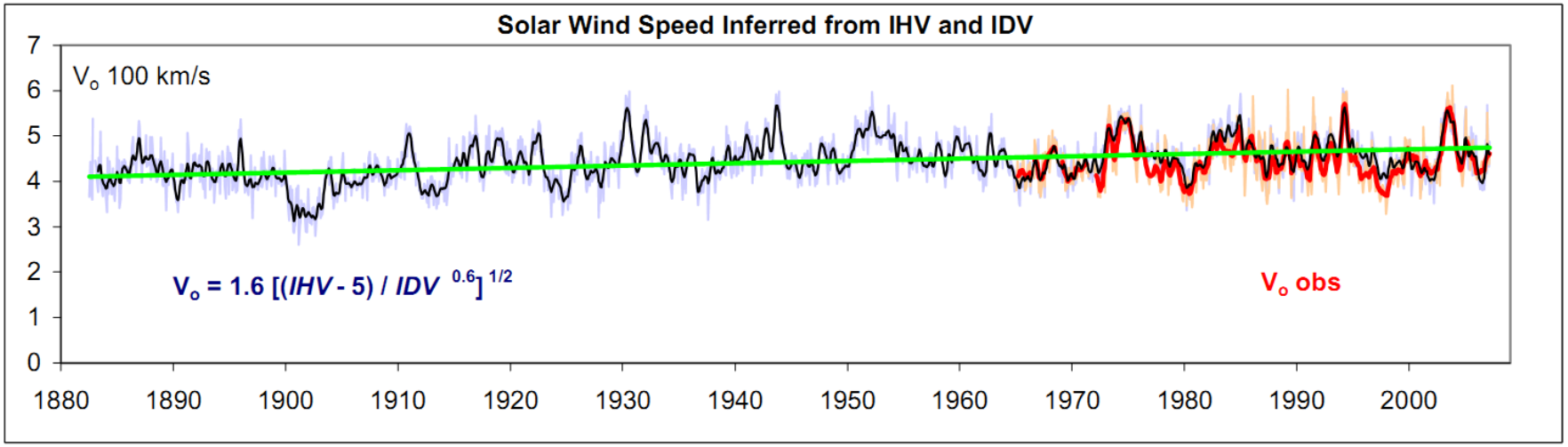
Correlation between Heliospheric BV^n and several geomagnetic indices as a function of *n*

The IDV and Dst indices thus depend on ***B*** only (*n* = 0). IDV is strongly correlated with HMF ***B***, but is blind to solar wind speed ***V***

Substorm indices [e.g. *aa* and *IHV*] depend on BV^2

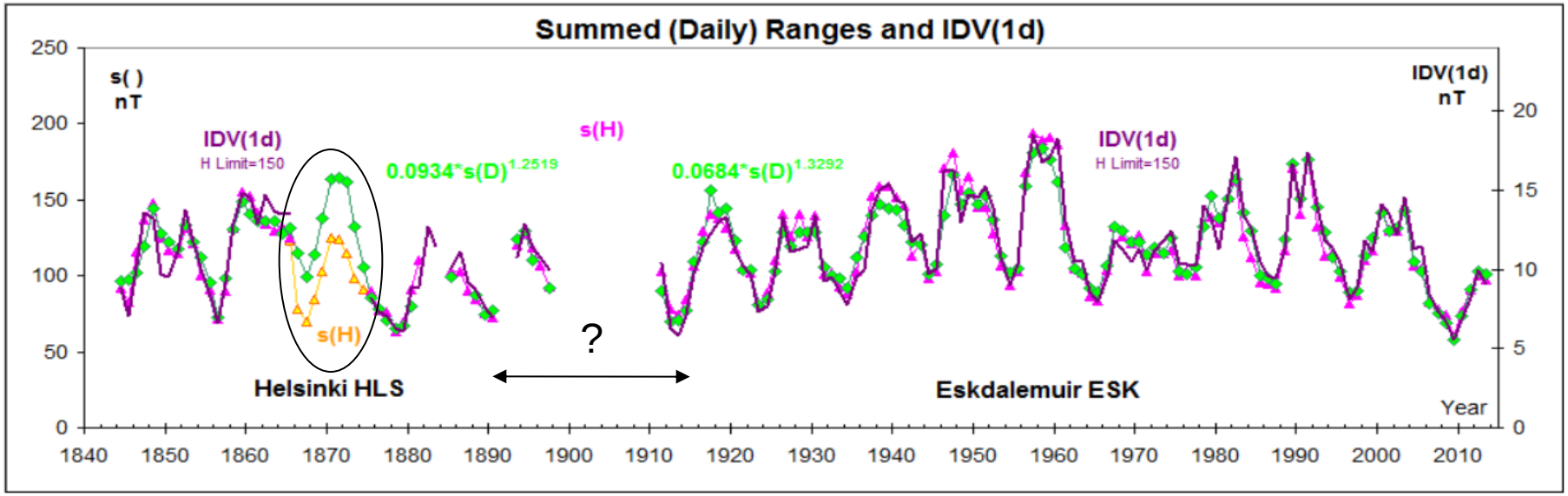
Also holds on timescales shorter than one year

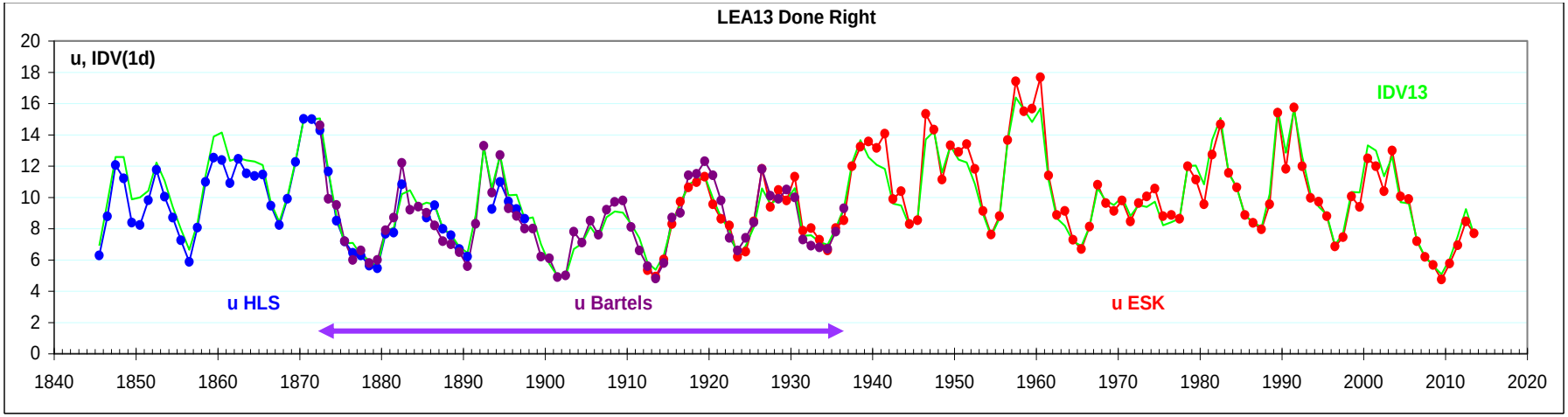




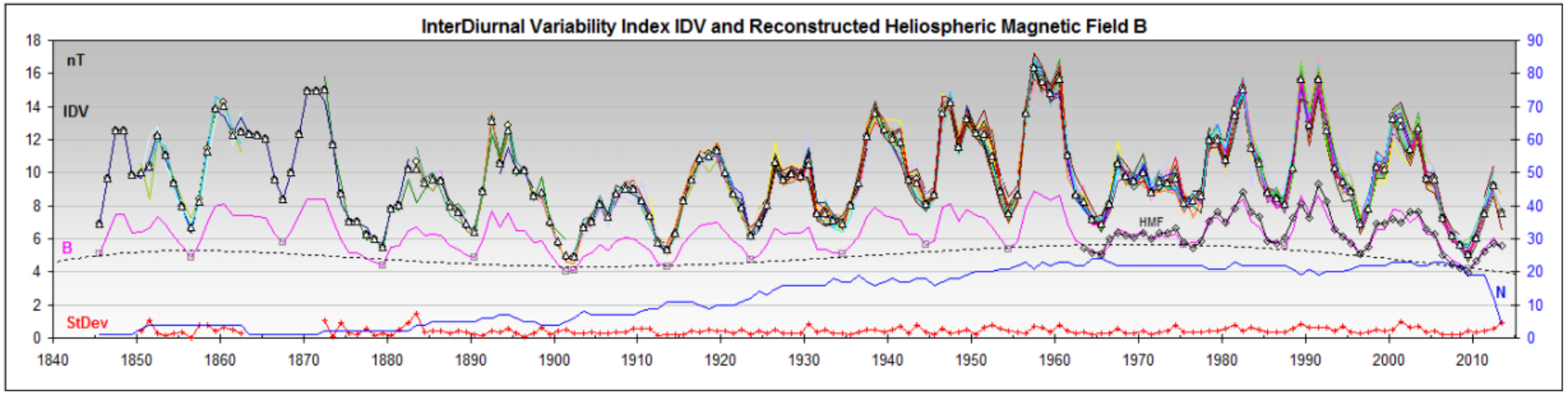
We can even infer the solar wind speed

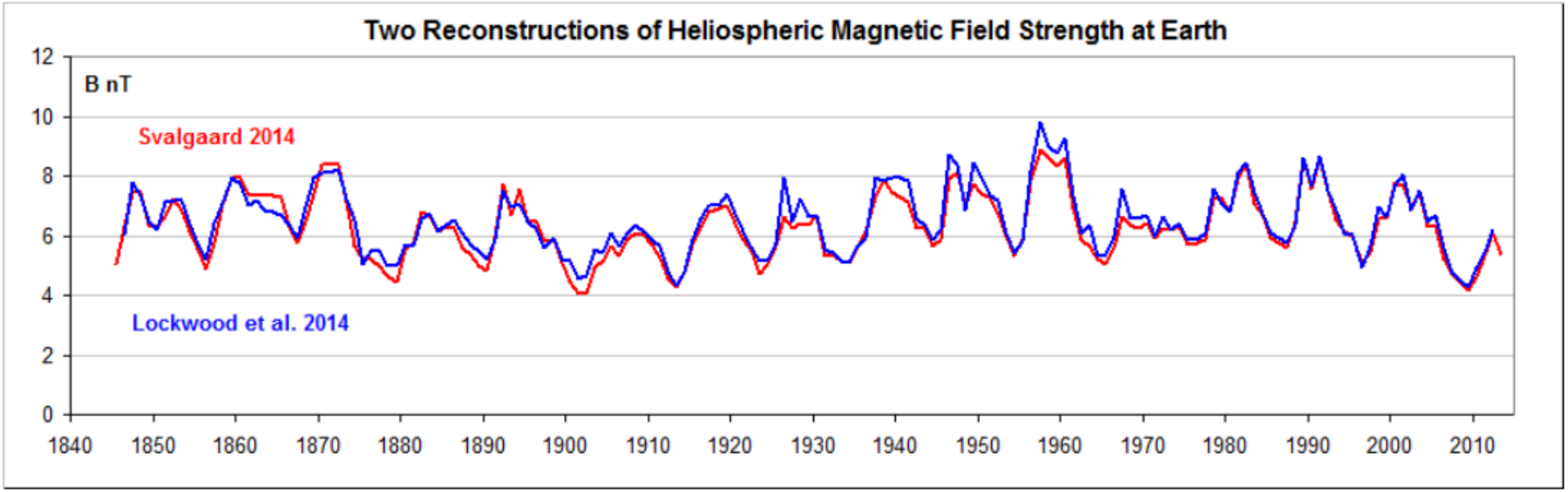
Lockwood et al. suggest to use the u-measure from HLS and ESK





Applying the methods described above we can reconstruct HMF B with Confidence:

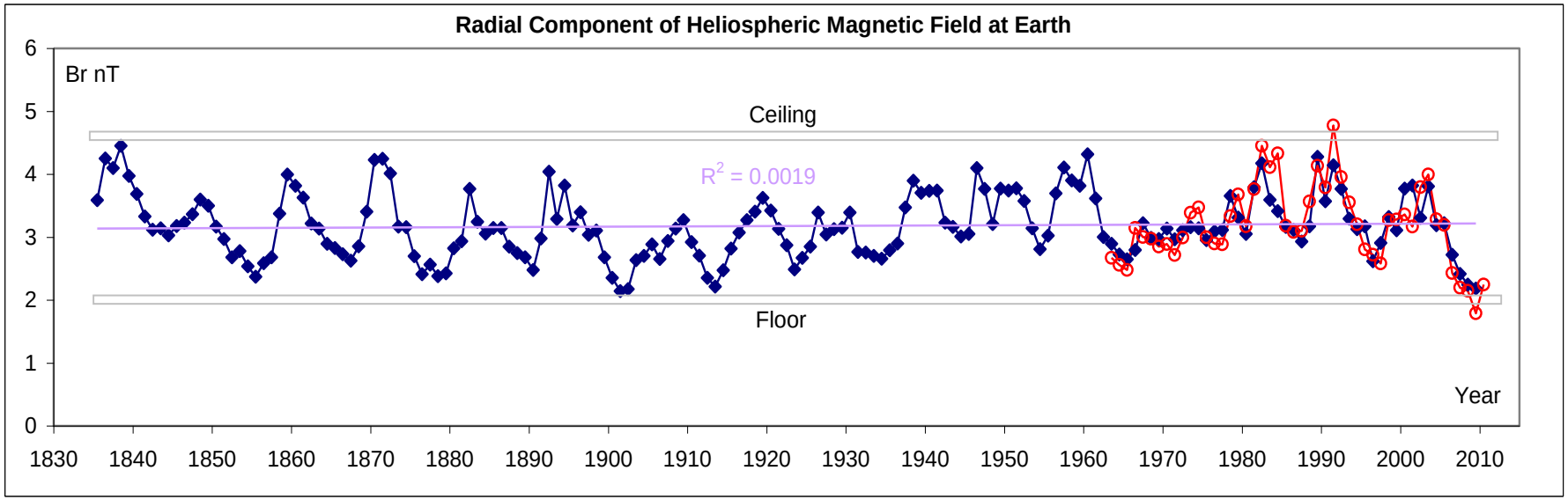




Lockwood et al. have conceded that their finding should be corrected and everybody now agree.

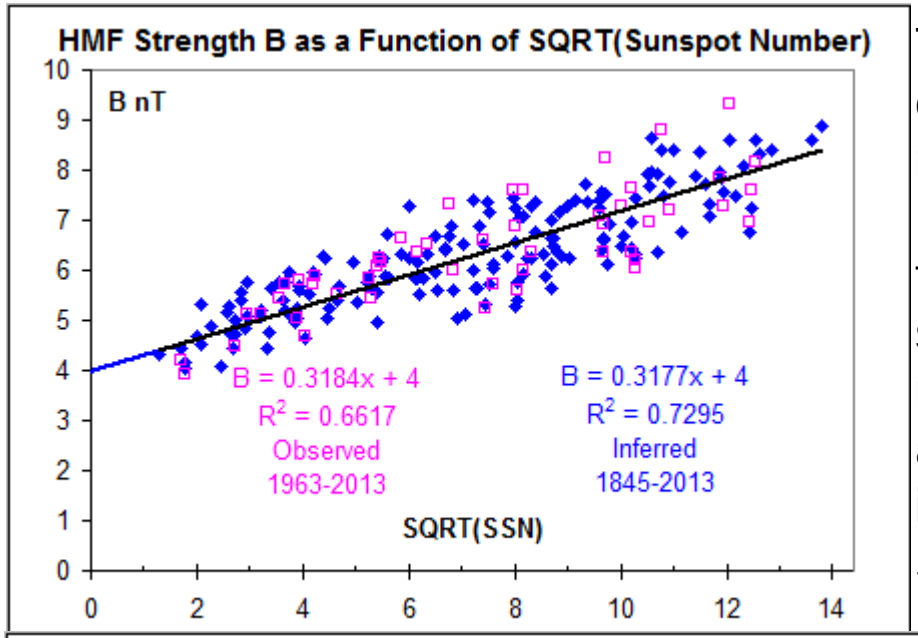
Radial Magnetic Field (‘Open Flux’)

Since we can also estimate solar wind speed from geomagnetic indices [IHV, Svalgaard & Cliver, JGR 2007] we can calculate the radial magnetic flux from the total *B* using the Parker Spiral formula:

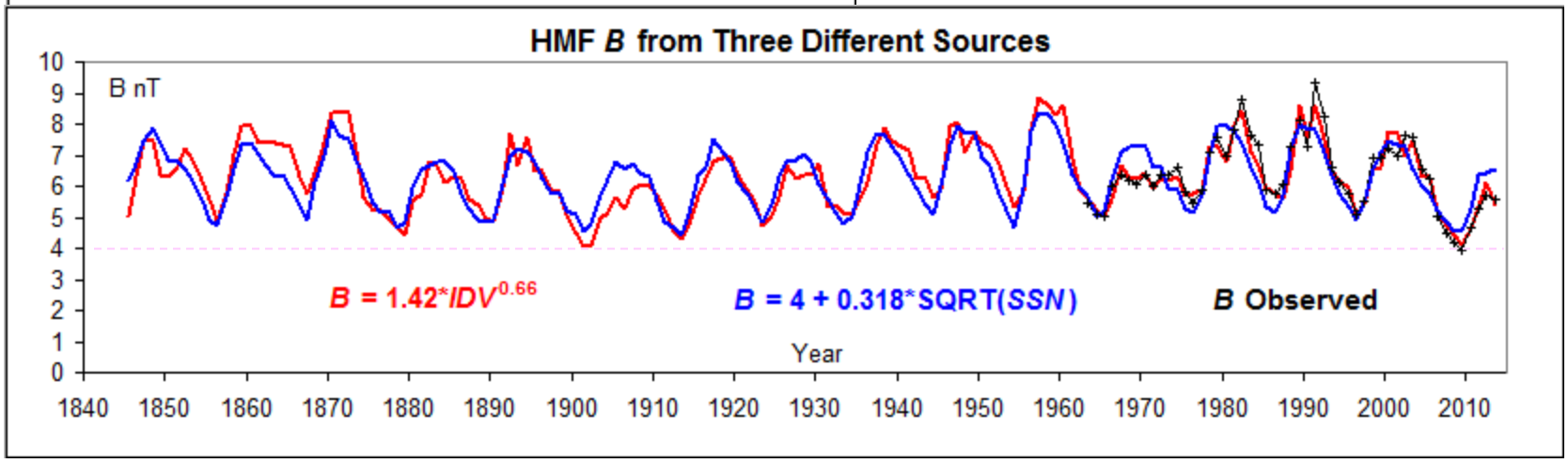


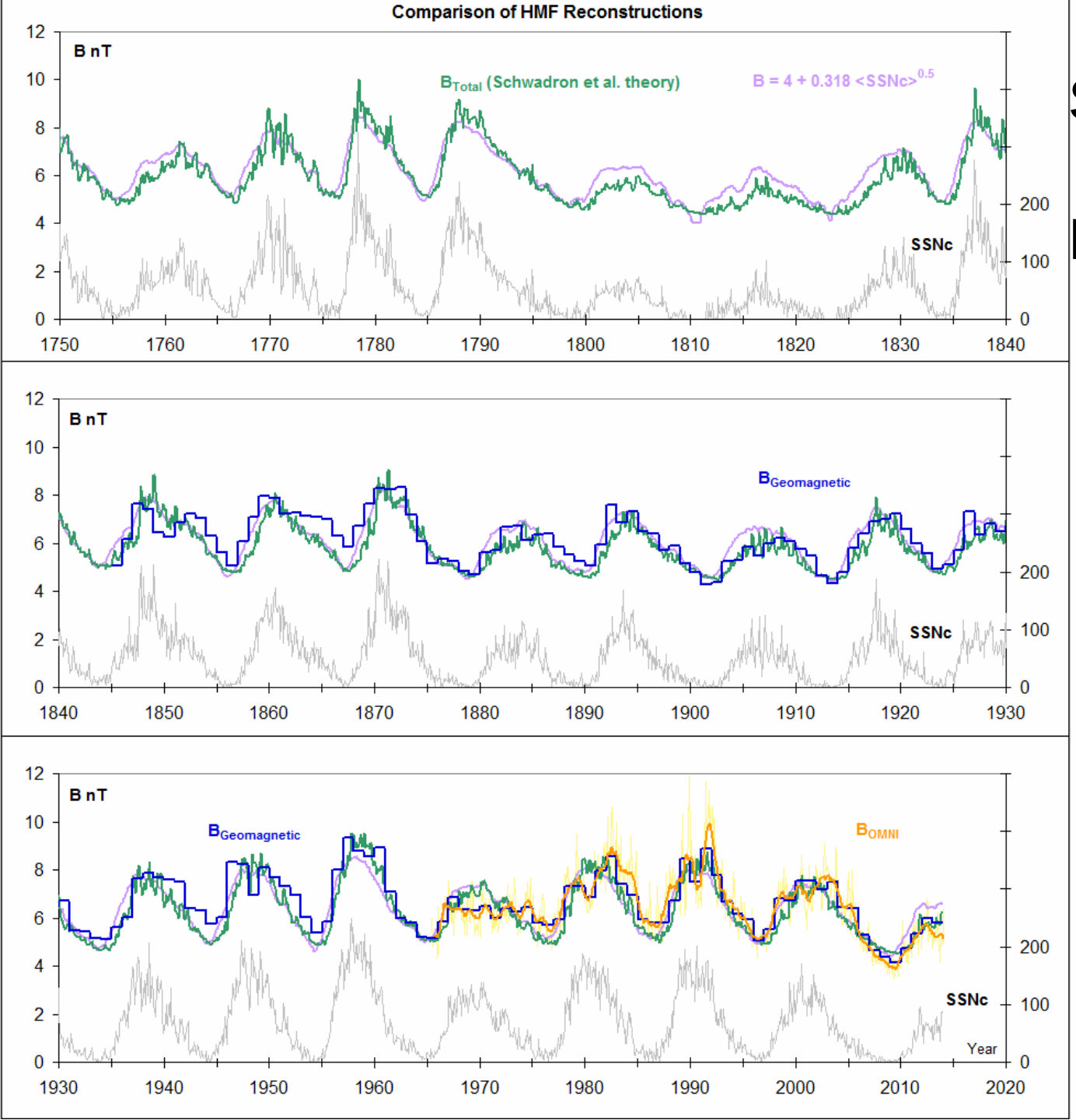
There seems to be both a Floor and a Ceiling and most importantly no long-term trend since the 1830s. Thus no Modern **Grand** Maximum.

HMF *B* related to Sunspot Number



The main sources of the equatorial components of the Sun's large-scale magnetic field are large active regions. If these emerge at random longitudes, their net equatorial dipole moment will scale as the square root of their number. Thus their contribution to the average HMF strength will tend to increase as $SSN^{1/2}$ (see: Wang and Sheeley [2003]; Wang et al. [2005]).



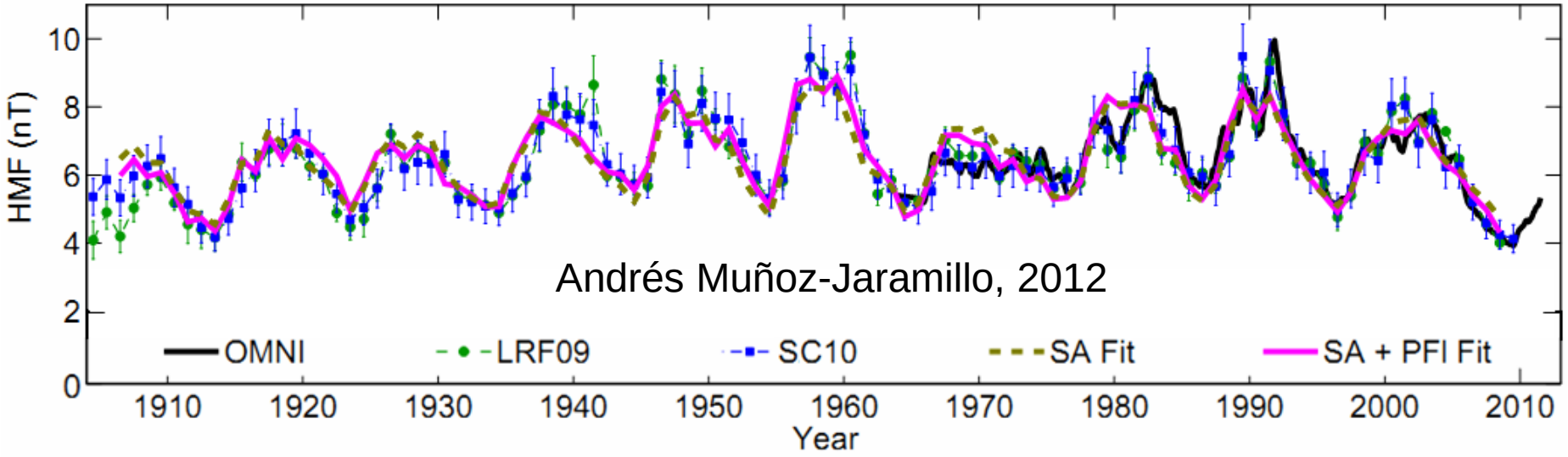


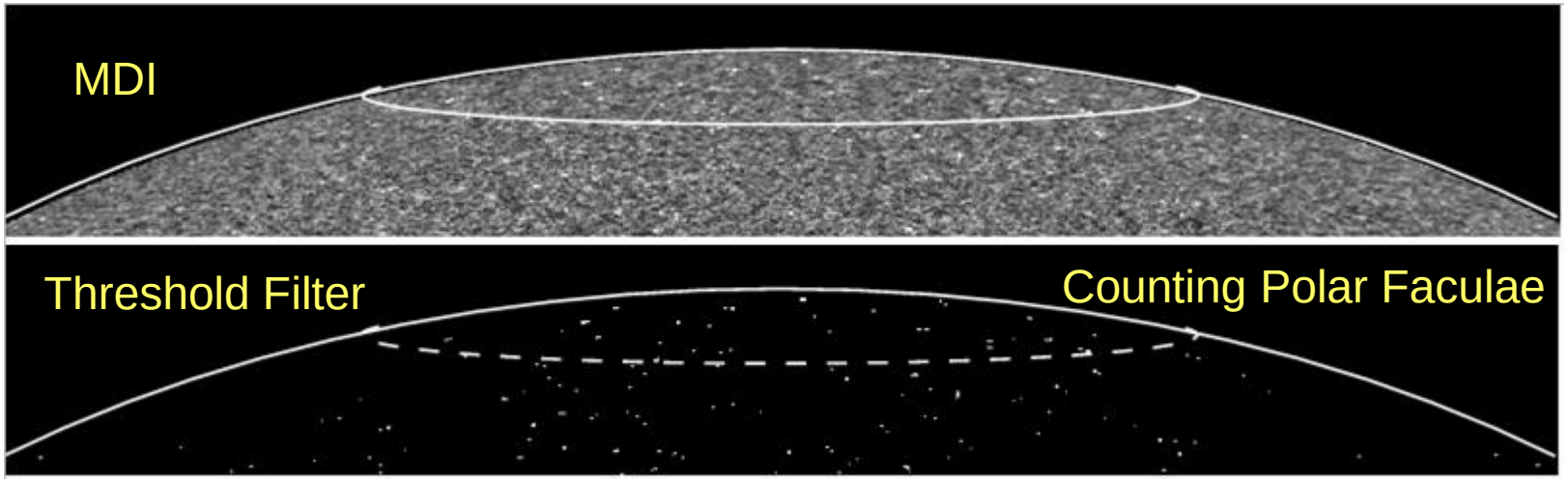
Schwadron et al. (2010) HMF B Model, with my set of parameters, including a 'floor' in B

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…so perhaps we can make him wiggle both ears and the tail, too

Combining Polar Faculae and Sunspot Areas can also give HMF B





Conclusions

- We can compute IDV, *u* back to 1835
- We can compute IDV, *u* from H and D
- We can calibrate IDV in terms of HMF B measured by spacecraft since 1963
- We can thus estimate HMF B from IDV
- We find that HMF B depends on the $SSN^{½}$ above a ‘floor’ at about 4 nT
- We can also model HMF B from estimated polar faculae and from the Schwadron Theory
- All of these methods agree to ~10%
- So we know HMF B for the past 180 years

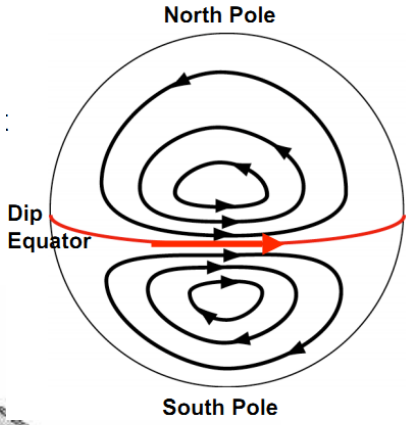
End

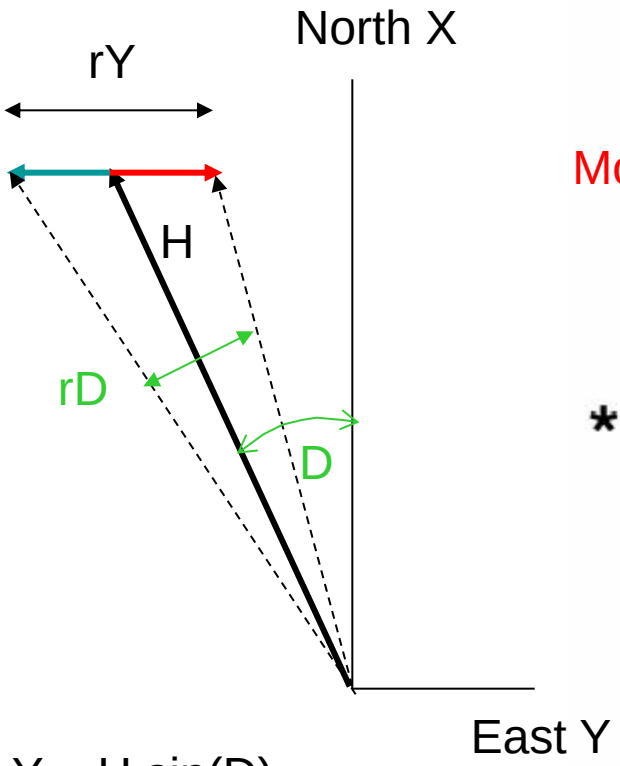
Abstract

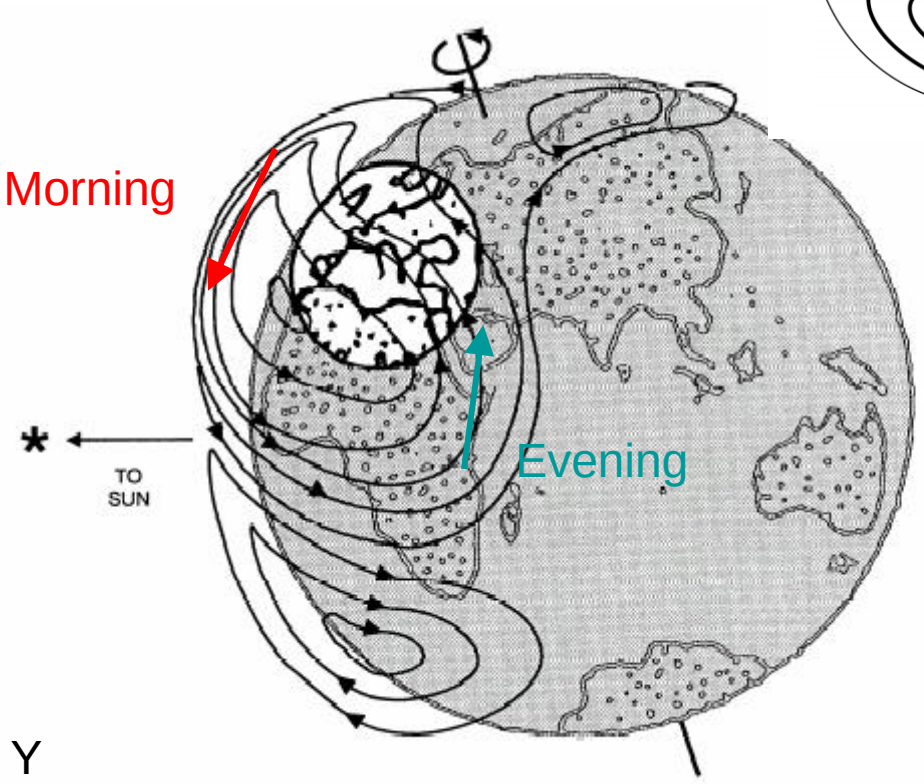
After C. F. Gauss and W. E. Weber's invention of the Magnetometer in 1833 systematic [e.g. hourly] measurements of the variation of the Earth's magnetic field were begun at several newly erected observatories around the World ["the Magnetic Crusade"]. These observations [greatly expanded] continue to this day. Magnetometers on the first spacecrafts to explore interplanetary space in 1962 showed that the, long hypothesized and then detected, solar wind carried a measurable magnetic field, which was soon identified as the main driver of disturbances of the magnetic fields observed at the Earth. Vigorous research during the last decade has shown that it is possible to 'invert' the causative effect of the magnetic field in near-Earth interplanetary space [the near-Earth Heliospheric Magnetic Field] and to infer with good accuracy the value of that field [and also of the solar wind speed and density] from the observed magnetic changes measured at the surface of the Earth. In this talk we describe the remarkable consensus reached by several researchers of the variation of the Heliospheric Magnetic Field (and thus of its source: the solar magnetic field) since the 1830s to today.

For Q/A

The E-layer Current System







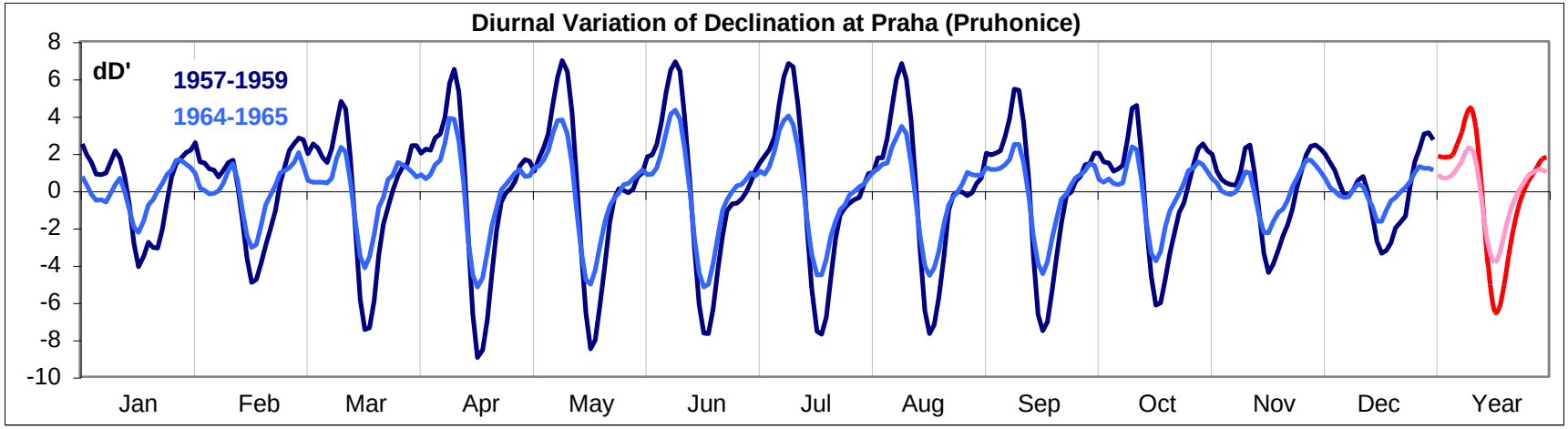
$Y = H \sin(D)$

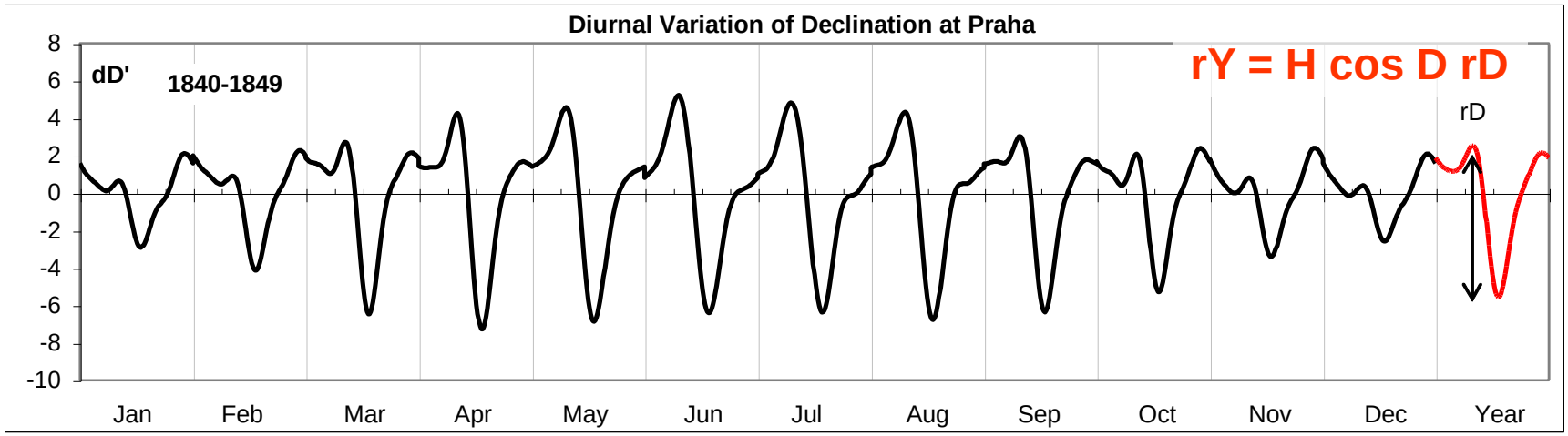
$dY = H \cos(D)\, dD$ For small dD

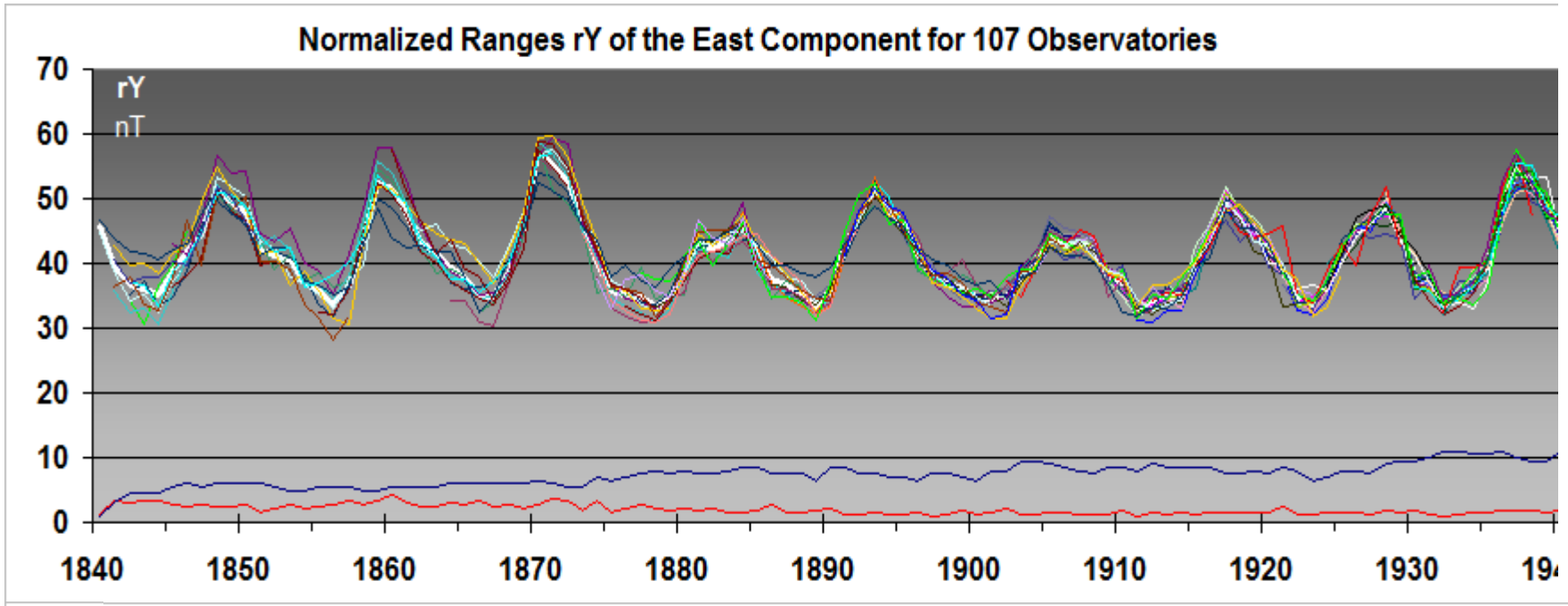
A current system in the ionosphere is created and maintained by solar EUV radiation

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

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






Normalized Ranges rY of the East Component for 107 Observatories
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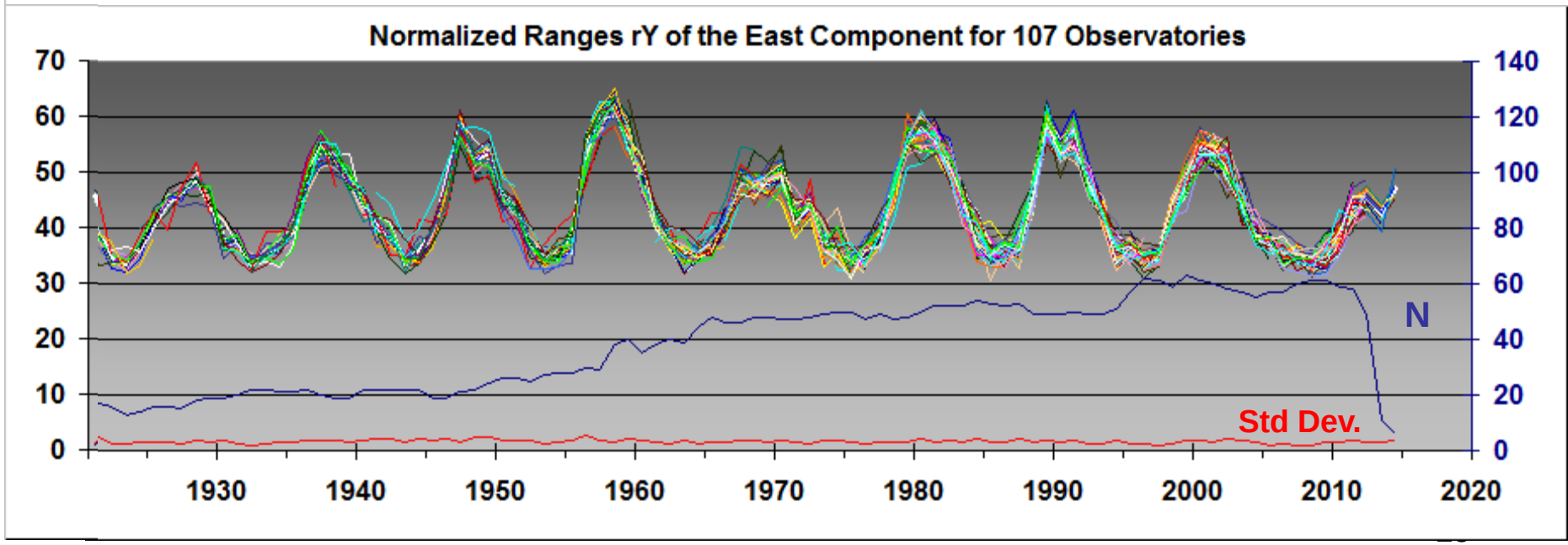
Normalized Ranges rY of the East Component for 107 Observatories
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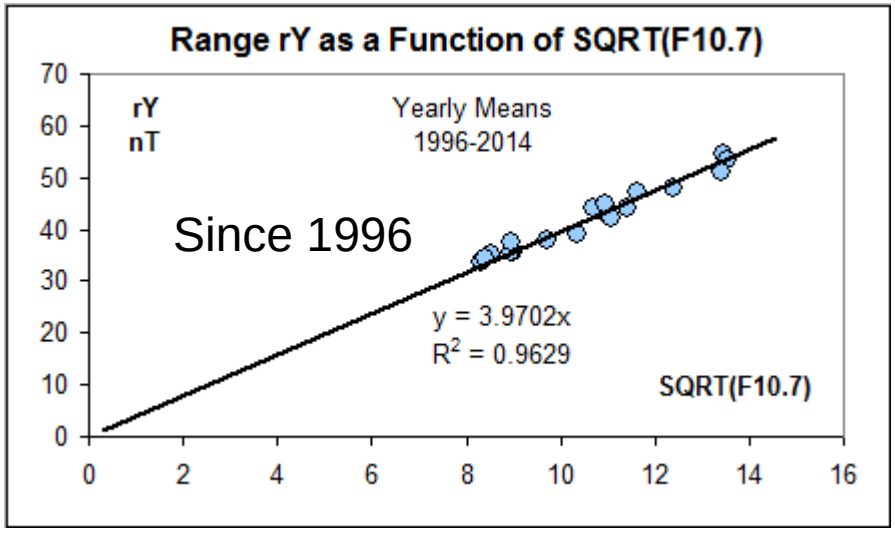
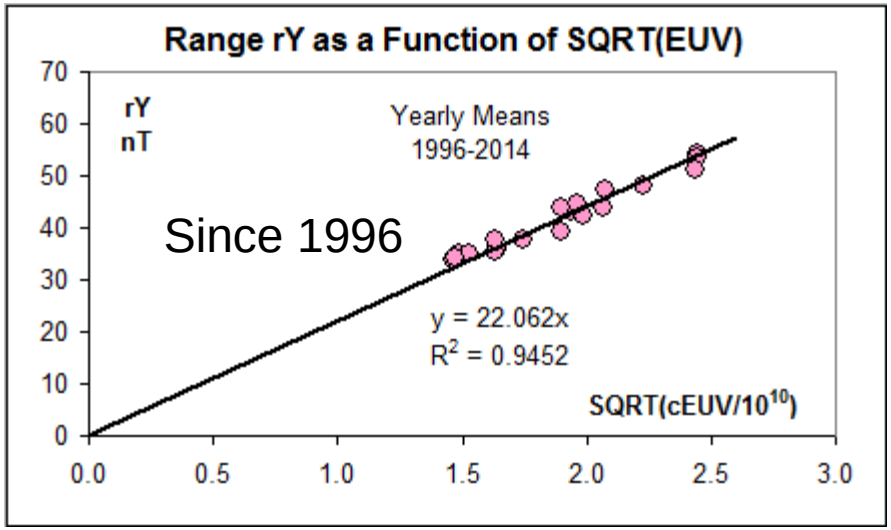
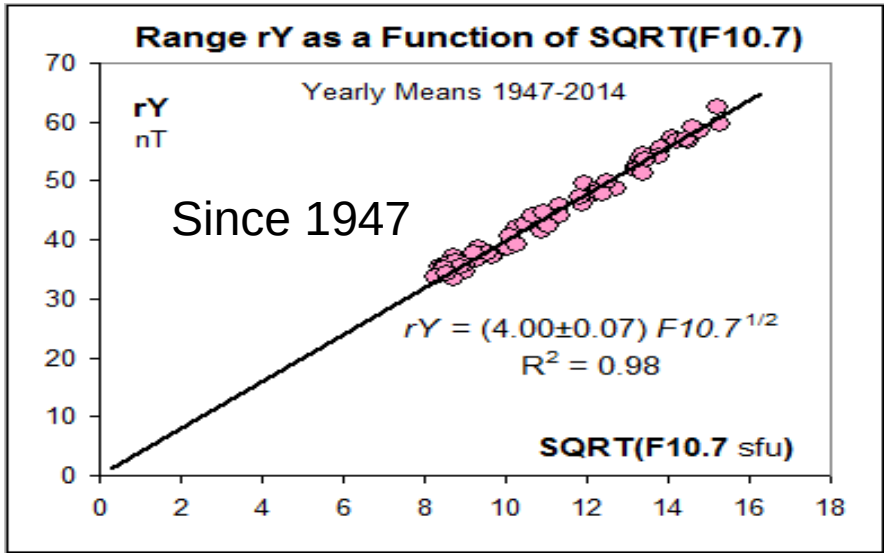
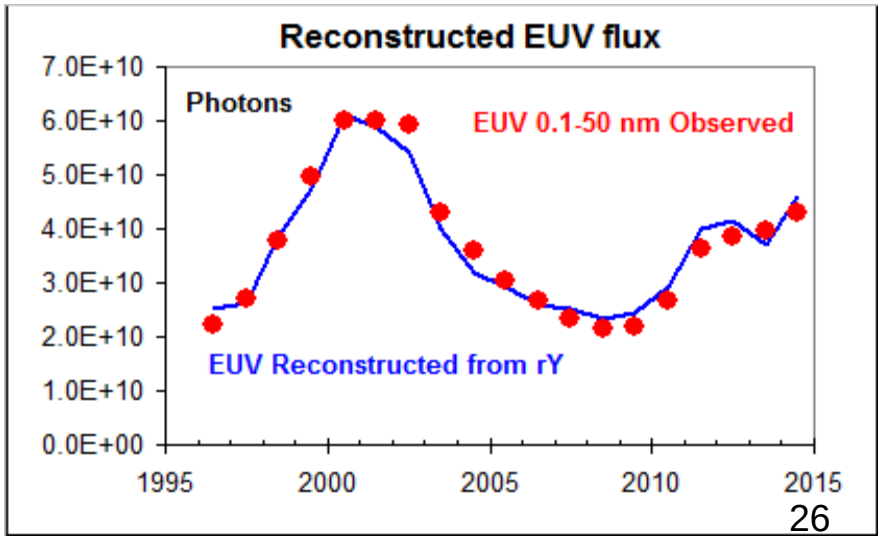
rY and $F10.7^{1/2}$ and $EUV^{1/2}$

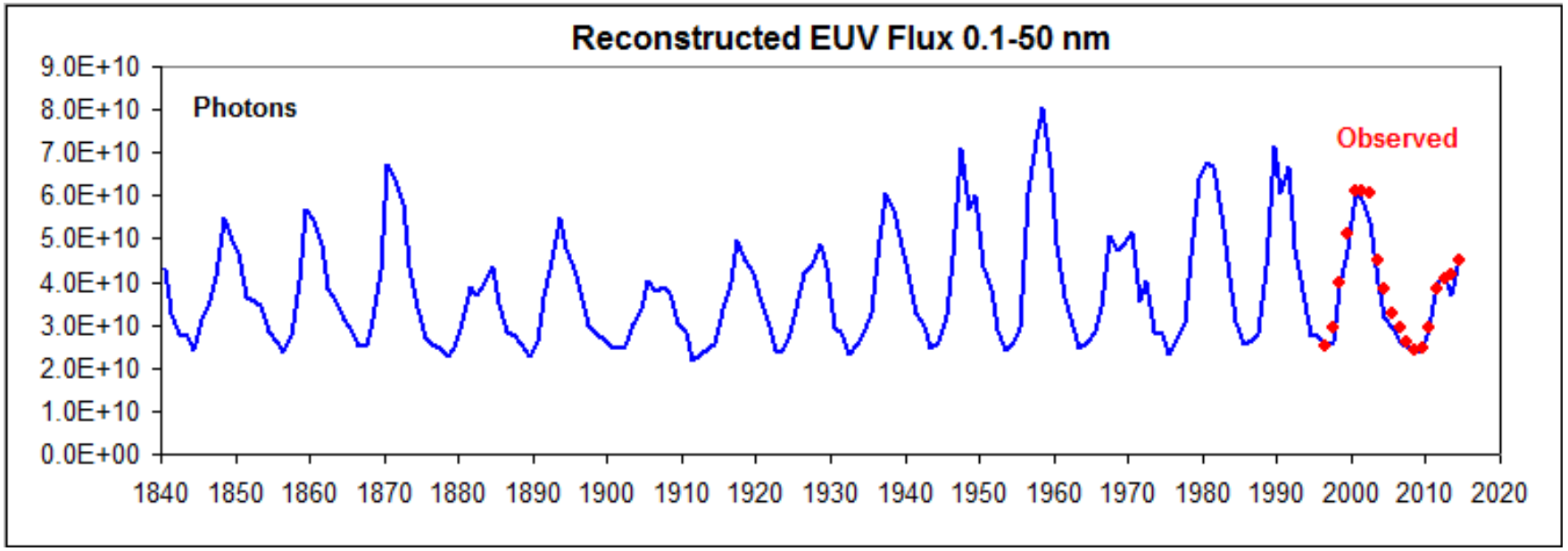




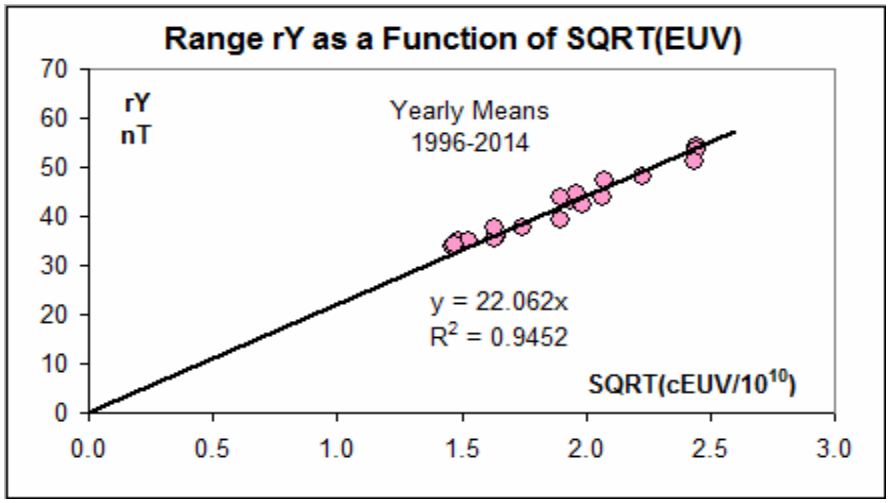




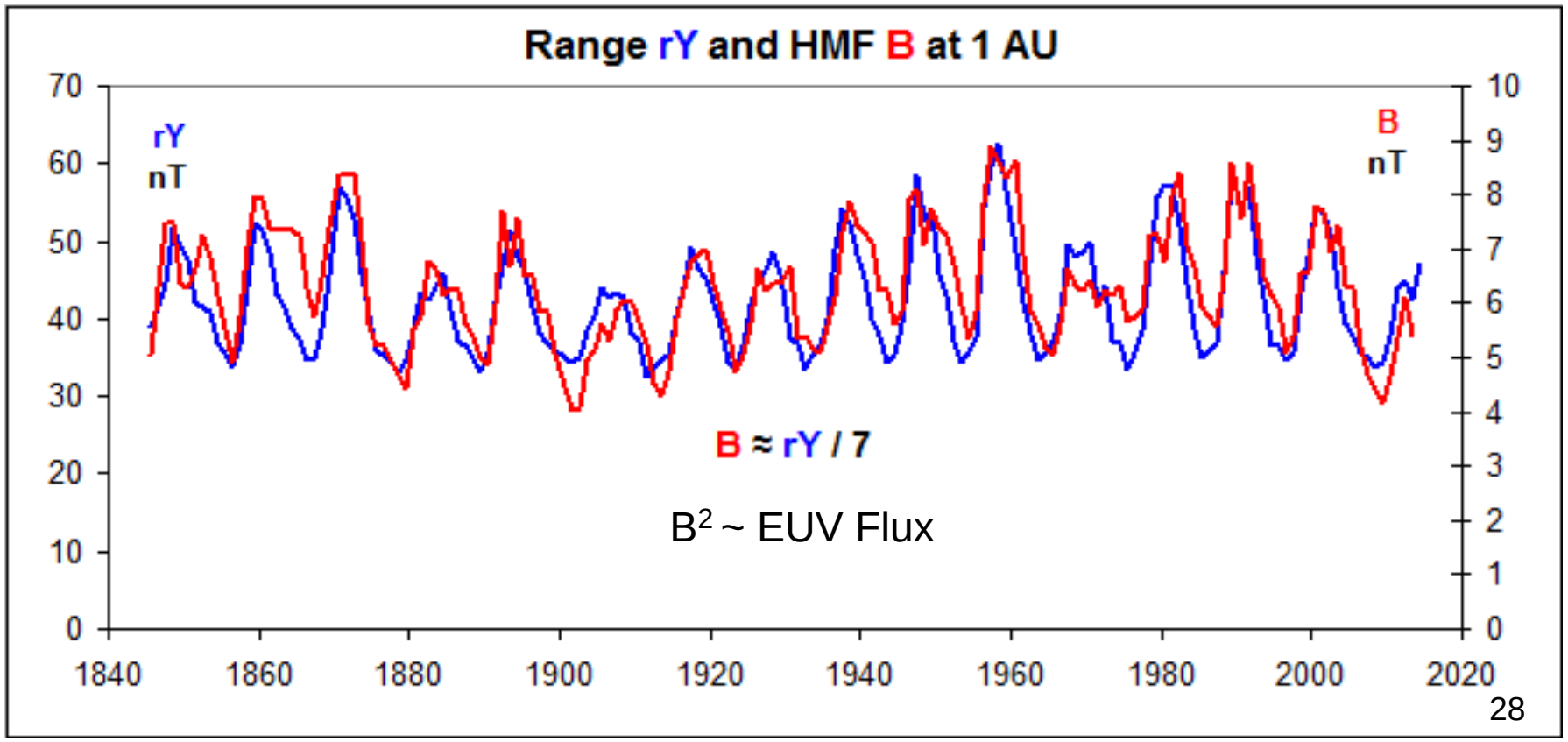
Reconstructed EUV Flux 1840-2014



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



HMF B Scales with the Sqrt of the EUV flux



Done Q/A