What Geomagnetism can Tell Us about the Solar Cycle?

Leif Svalgaard
HEPL, Stanford University

Bern, 11 Nov., 2013
ISSI Workshop: The Solar Activity Cycle: Physical Causes and Consequences

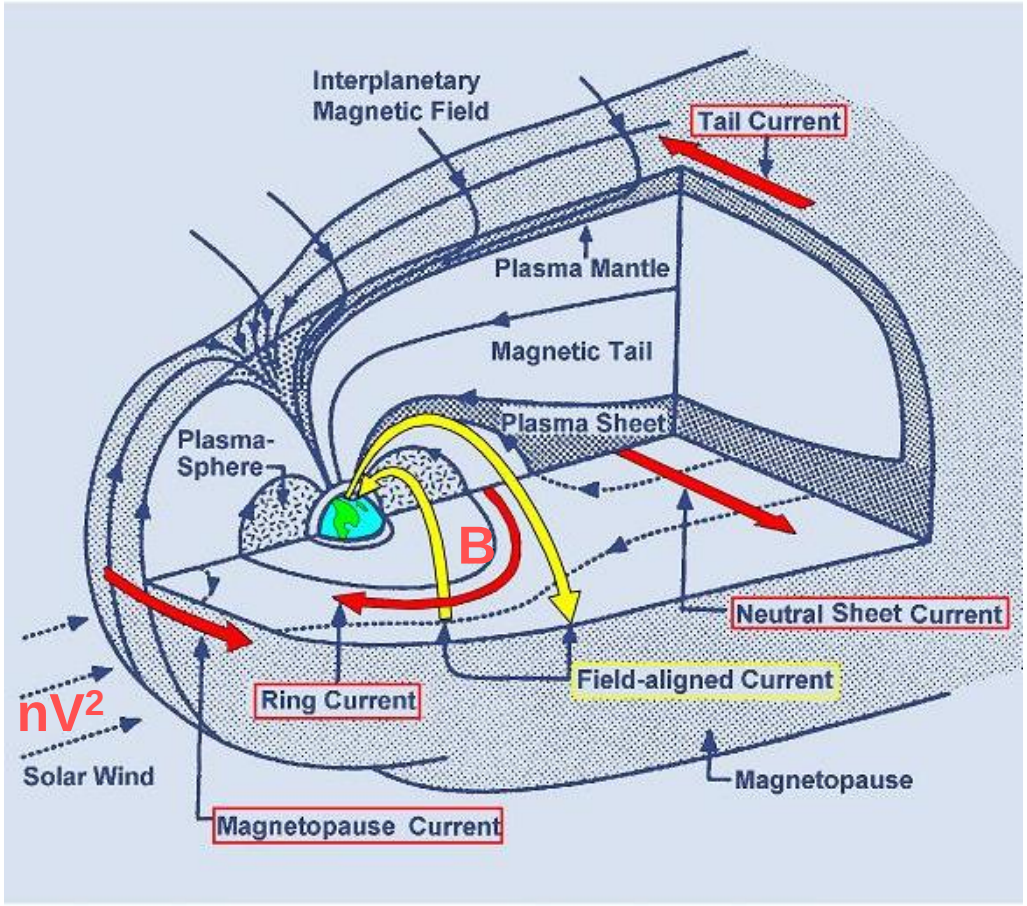
”Wer hätte noch vor wenigen Jahren an die Möglichkeit gedacht, aus den Sonnenfleckenbeobachtungen ein terrestrisches Phänomen zu berechnen?”
(J. R. Wolf, Bern, 1852)

‘Different Strokes for Different Folks’

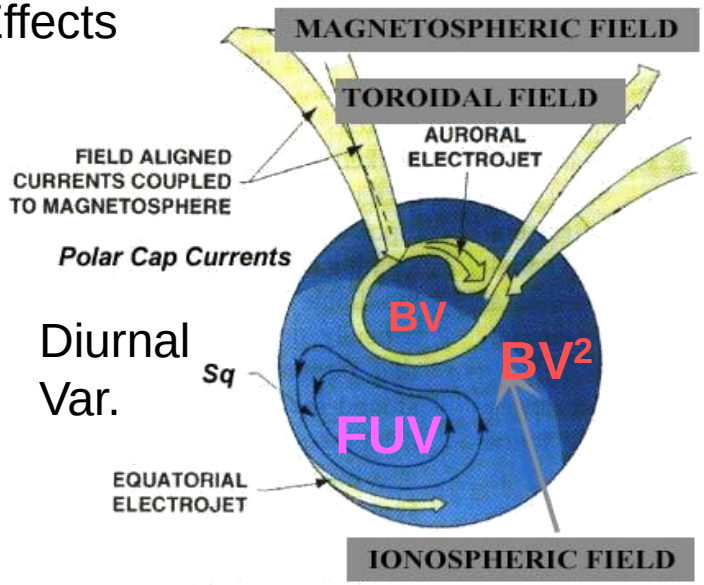
- The key to using geomagnetism to say something about the sun is the realization that geomagnetic ‘indices’ can be constructed that respond differently to different solar and solar wind parameters, so we can disentangle the various causes and effects
- In the last decade of research this insight has been put to extensive use and a consensus is emerging

Electric Current Systems in Geospace

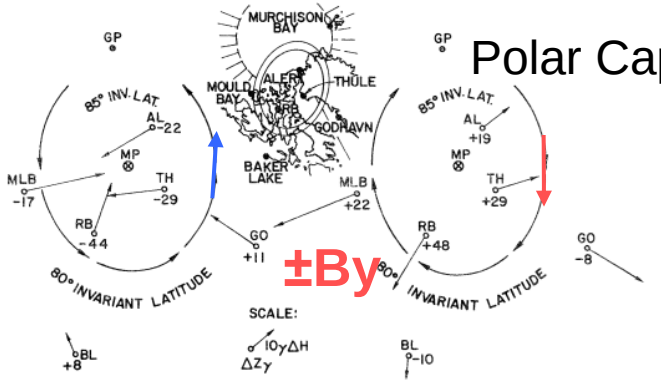
Different Current Systems ⇨ Different Magnetic Effects



Magnetospheric Currents

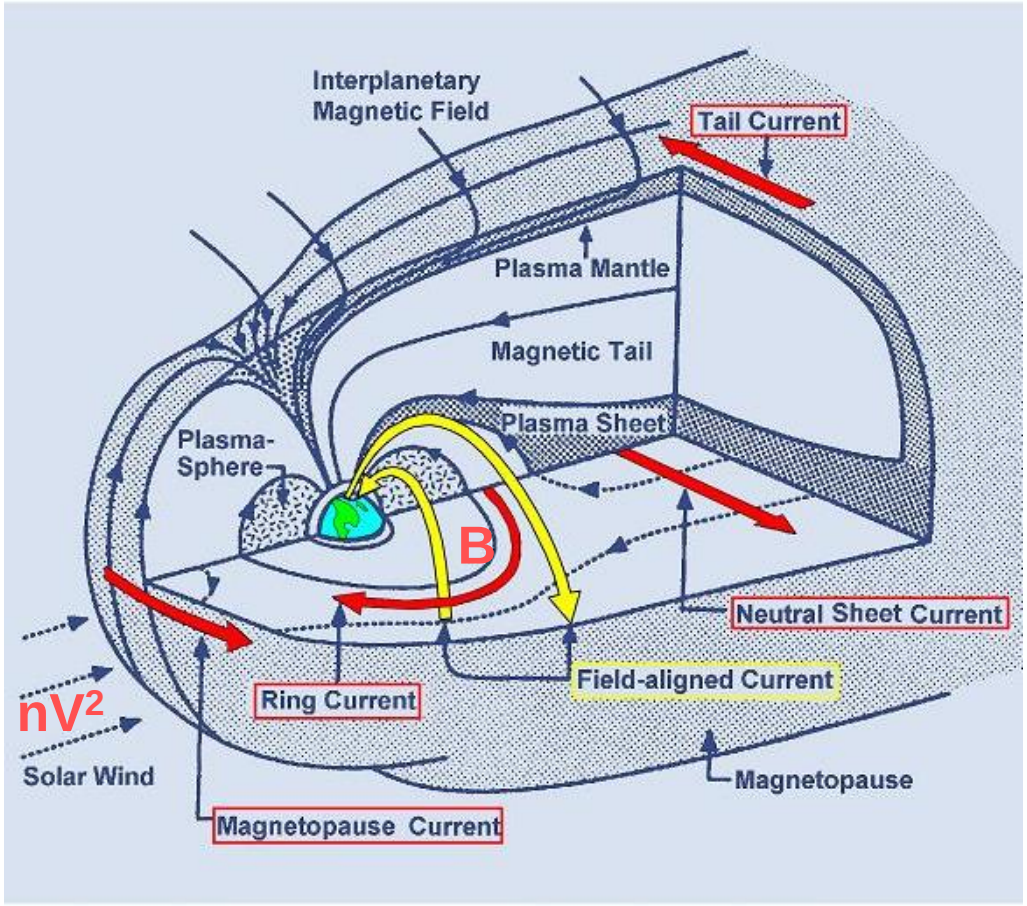


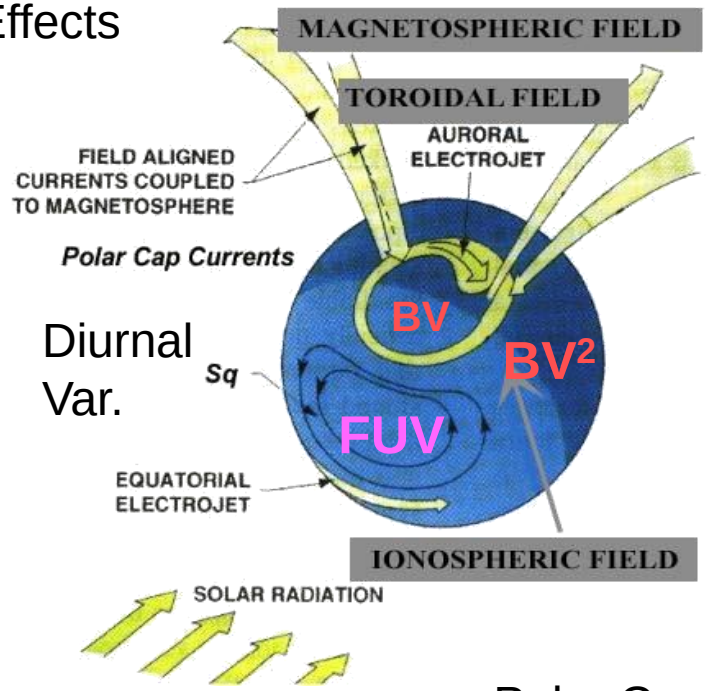
Polar Cap



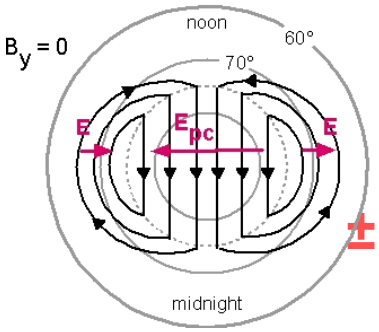
Electric Current Systems in Geospace

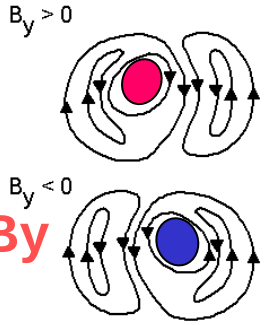
Different Current Systems ⇦ Different Magnetic Effects





Polar Cap

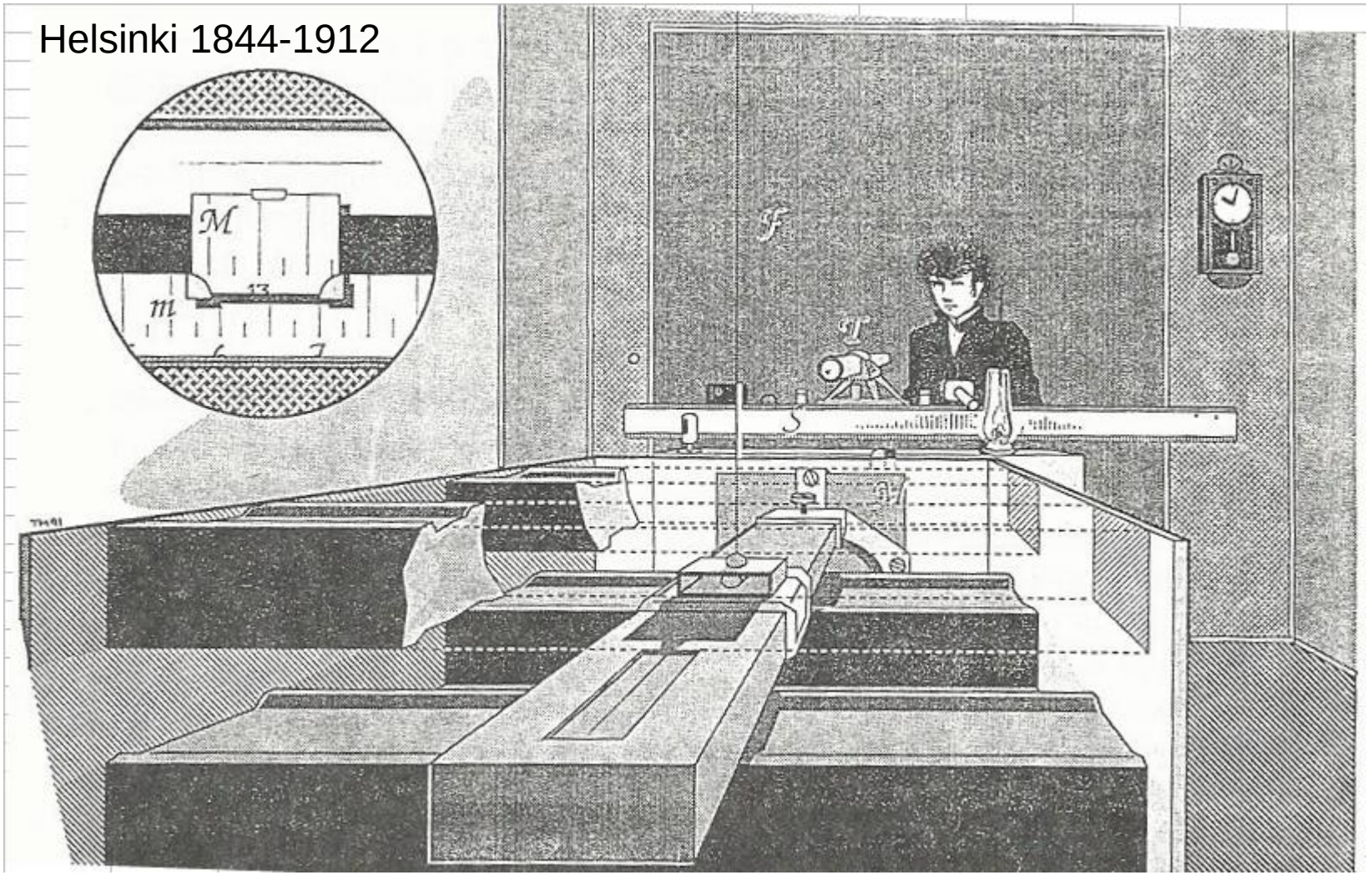




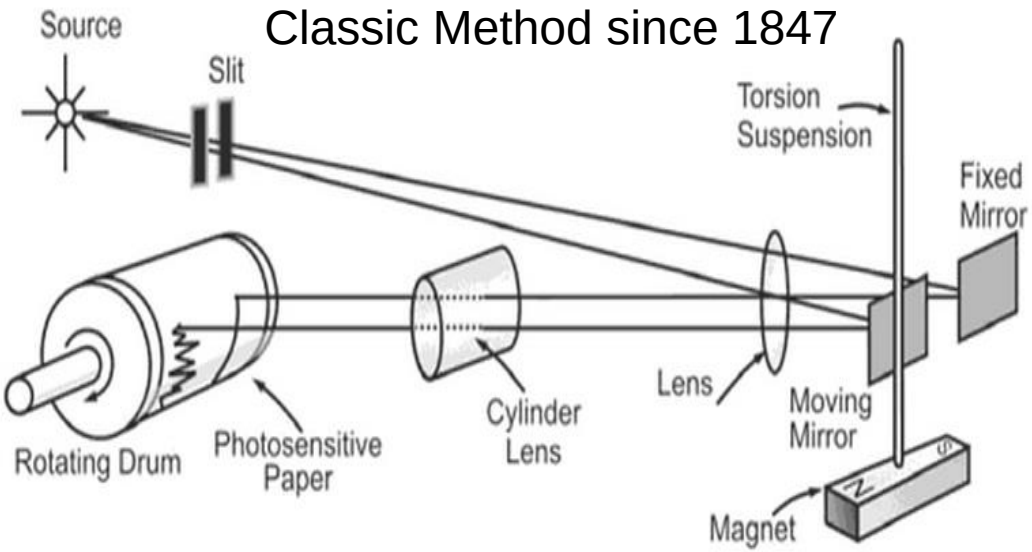
±By

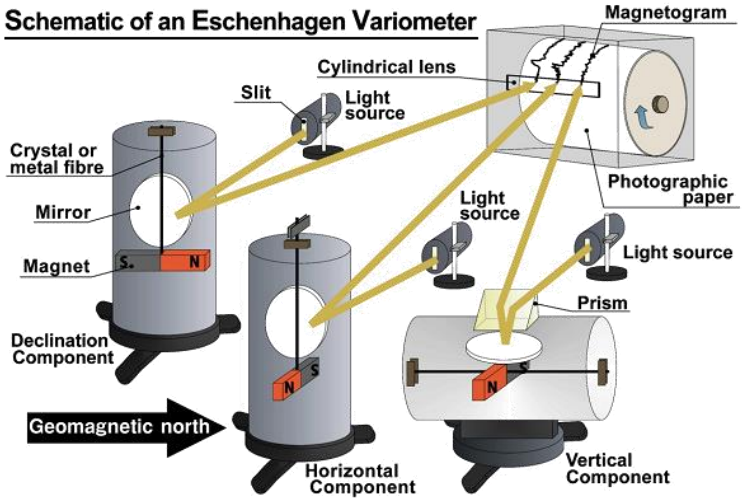
We can now invert the Solar Wind – Magnetosphere relationships…

Variometer Invented by Gauss, 1833

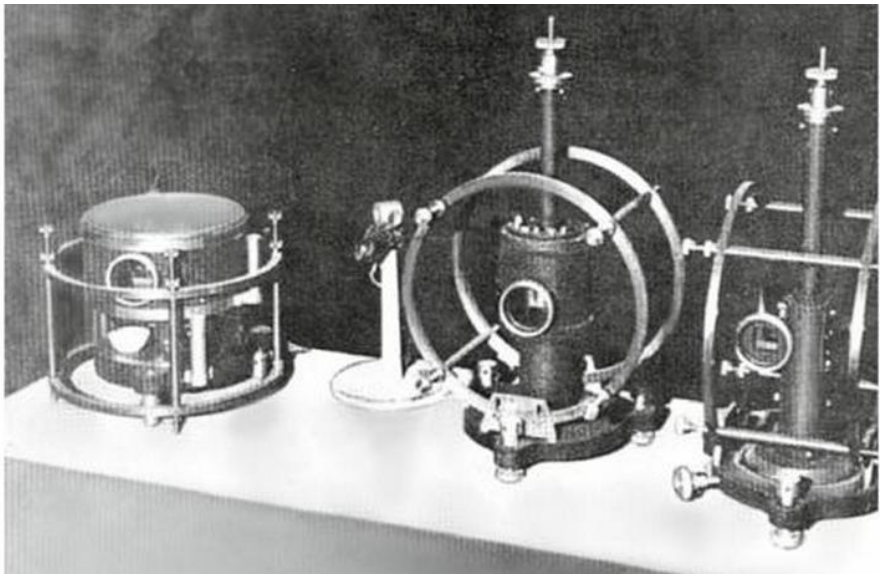


Nevanlinna et al.





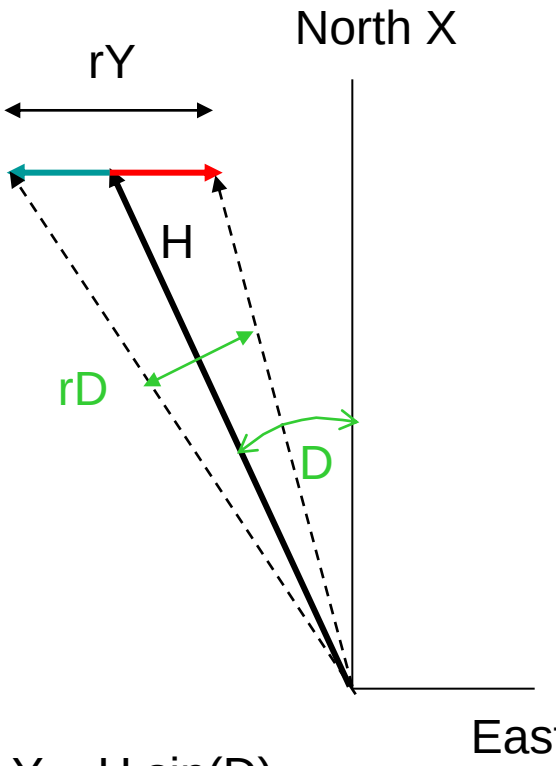
Magnetic Recorders



46 years ago, I used the Classic Instruments

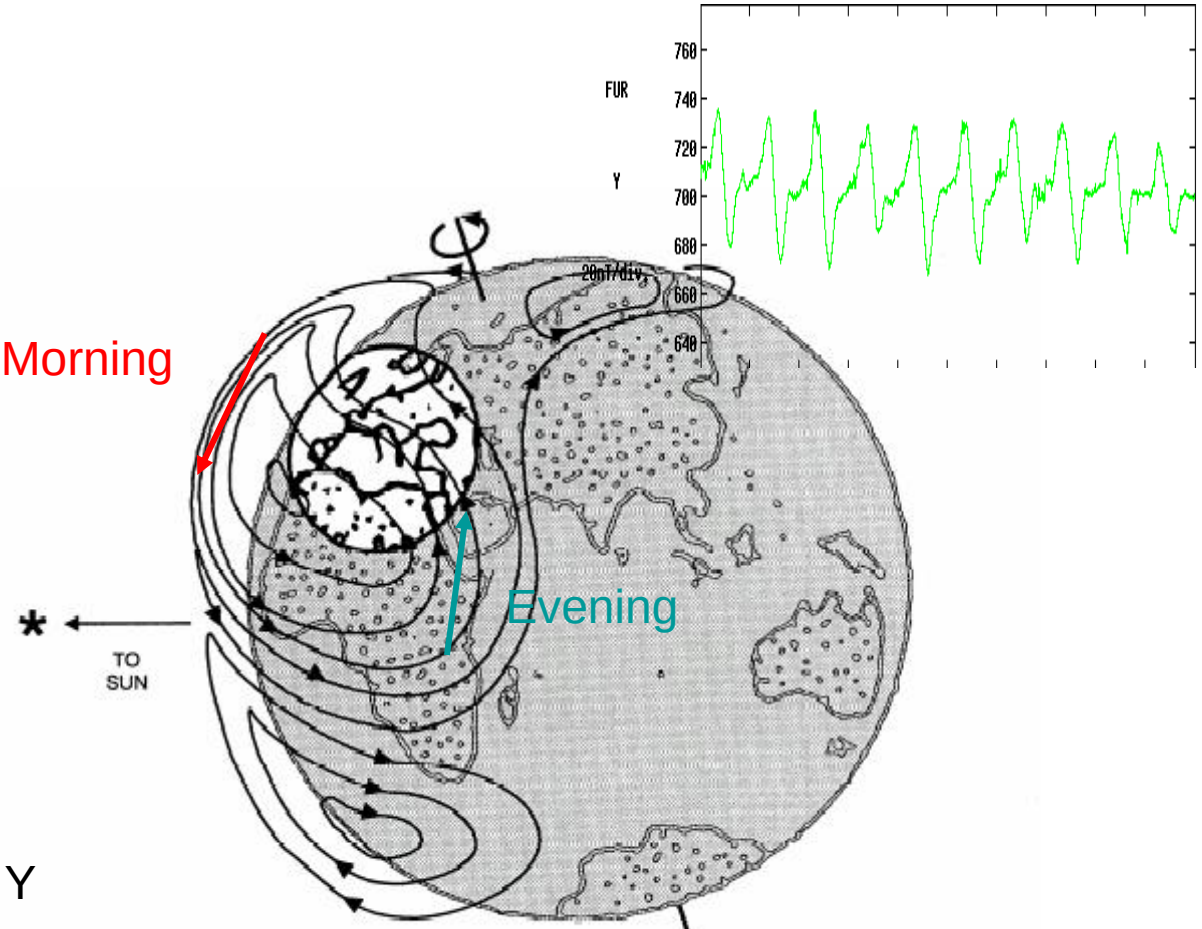
Modern Instrument

Wolf's Discovery (1852): $rD = a + b\,R_W$



$Y = H \sin(D)$

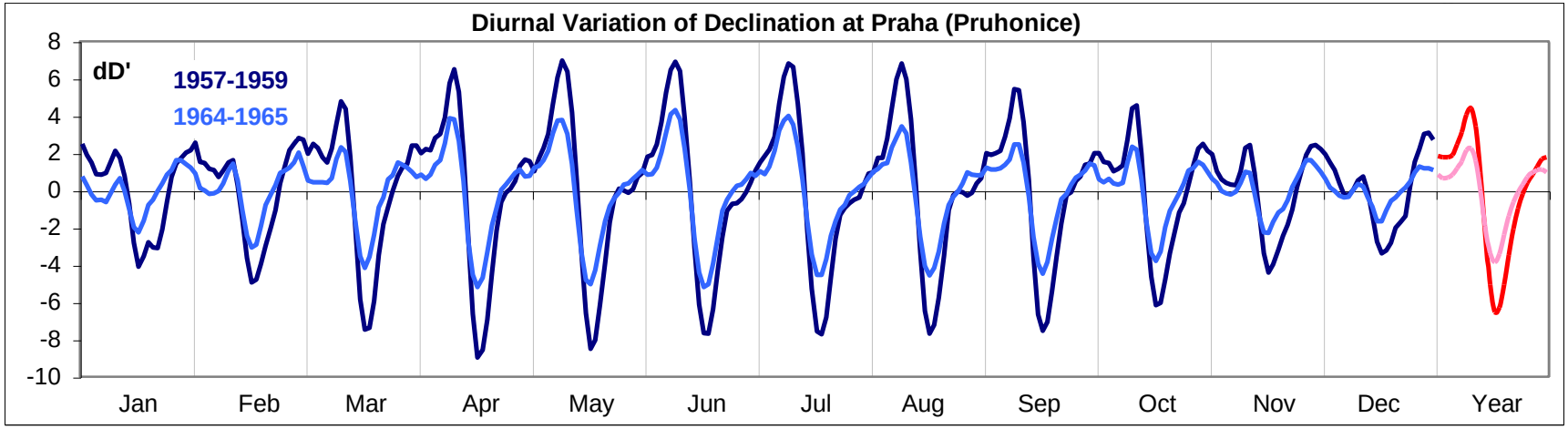
$dY = H \cos(D)\, dD$ For small dD

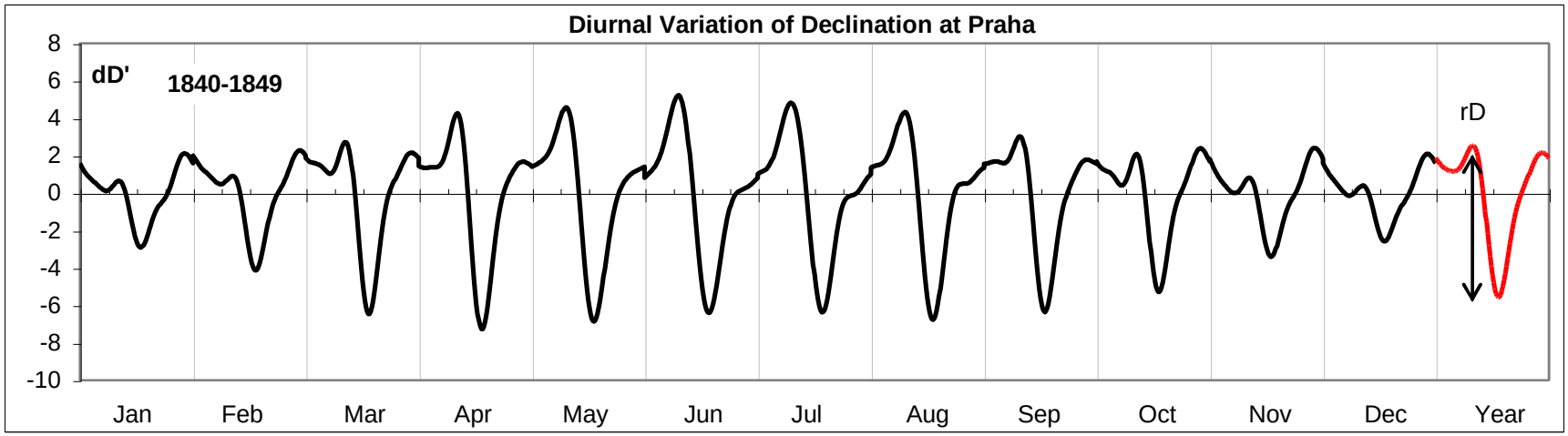


A current system in the ionosphere is created and maintained by solar FUV radiation

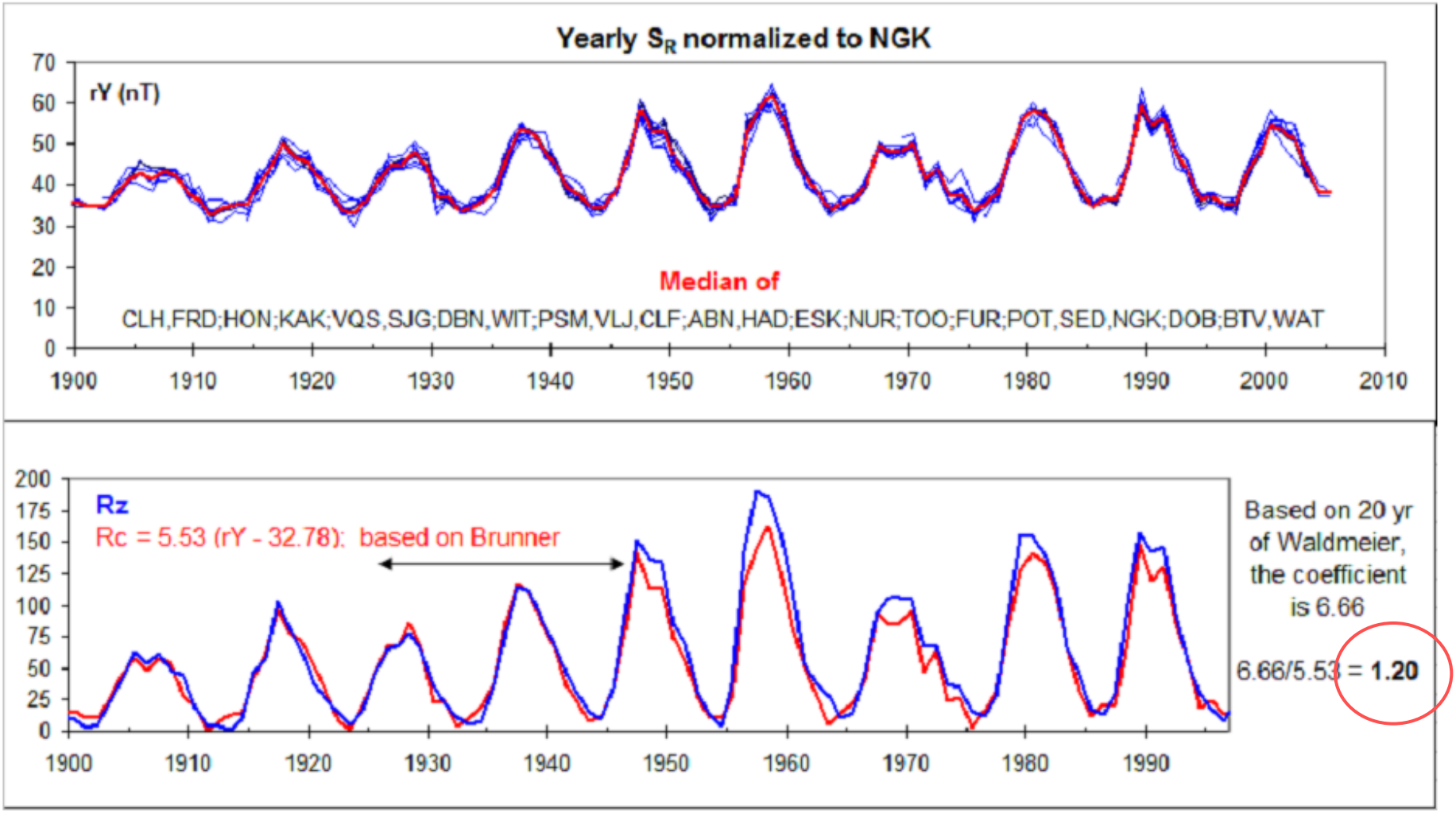
The magnetic effect of this system was discovered by George Graham in 1722

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

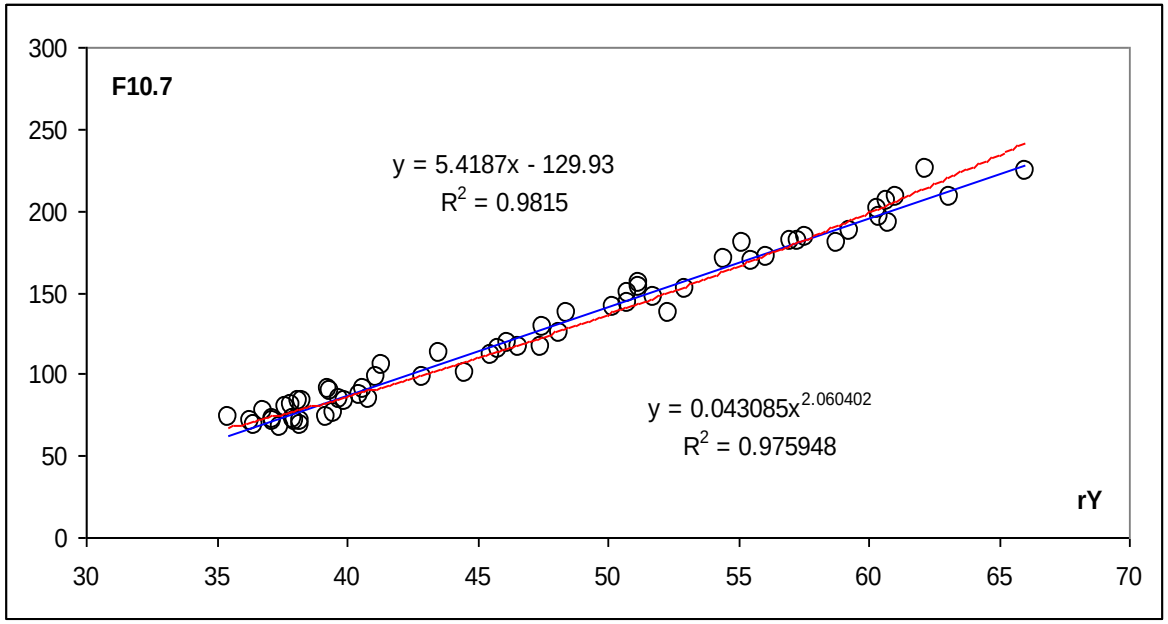




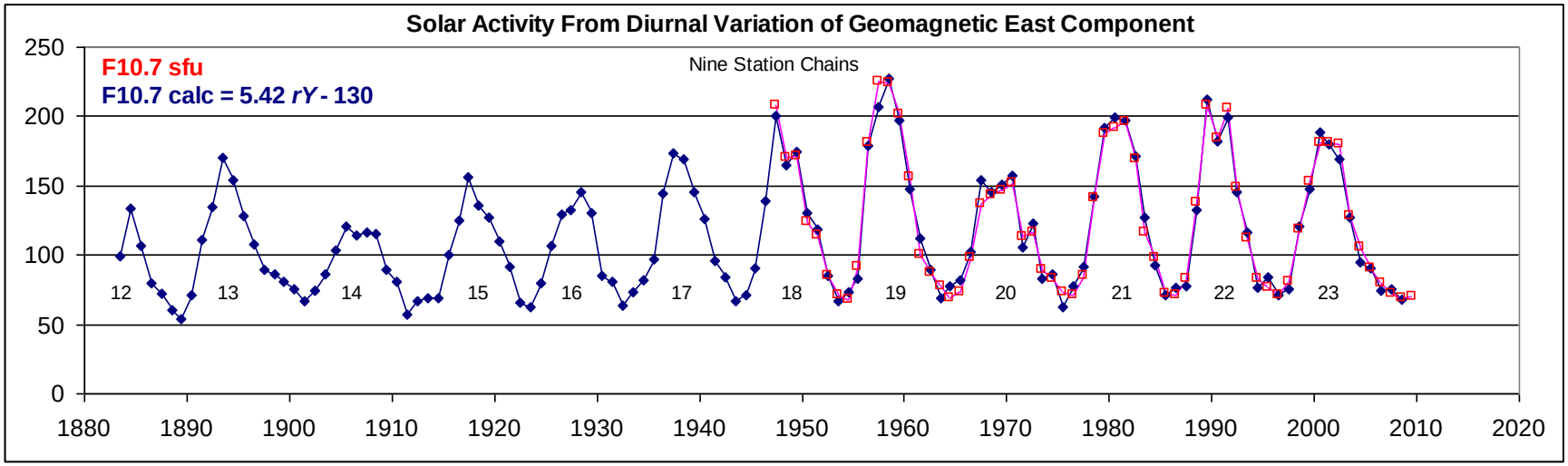
The Amplitude of the Diurnal Variation [from many stations] follows the Sunspot Cycle (can in fact be used to check the Sunspot Number calibration)

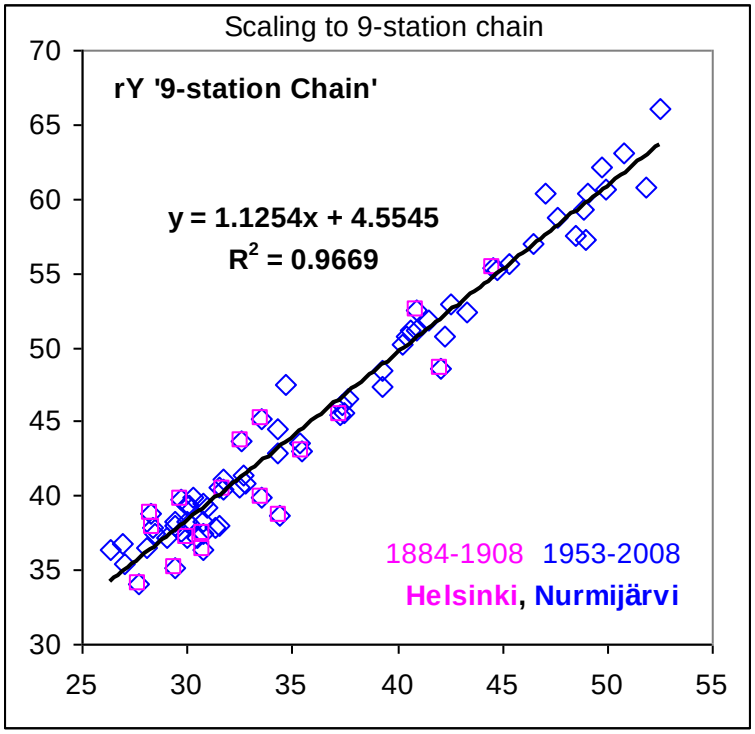


rY is a Very Good Proxy for F10.7 Flux



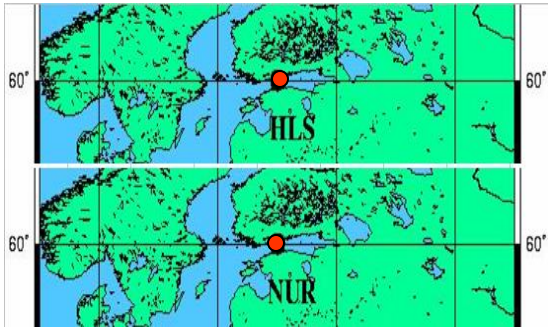
Using *rY* from nine ‘chains’ of stations we find that the correlation between *F10.7* and *rY* is extremely good (more than 98% of variation is accounted for)

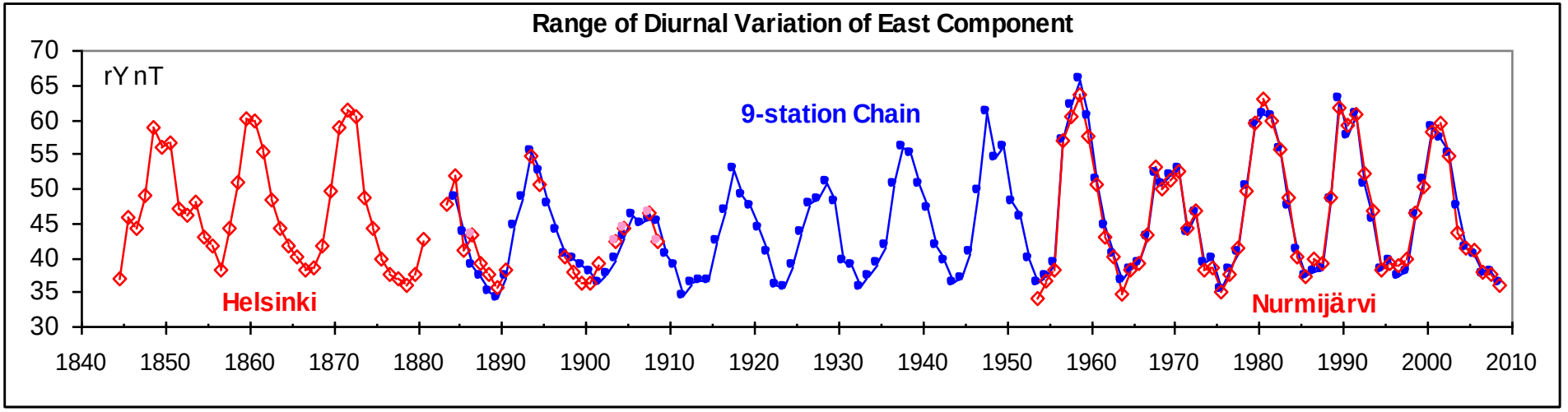




Helsinki-Nurmijärvi Diurnal Variation

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)





Sabine's Discovery about Geomagnetic Disturbances

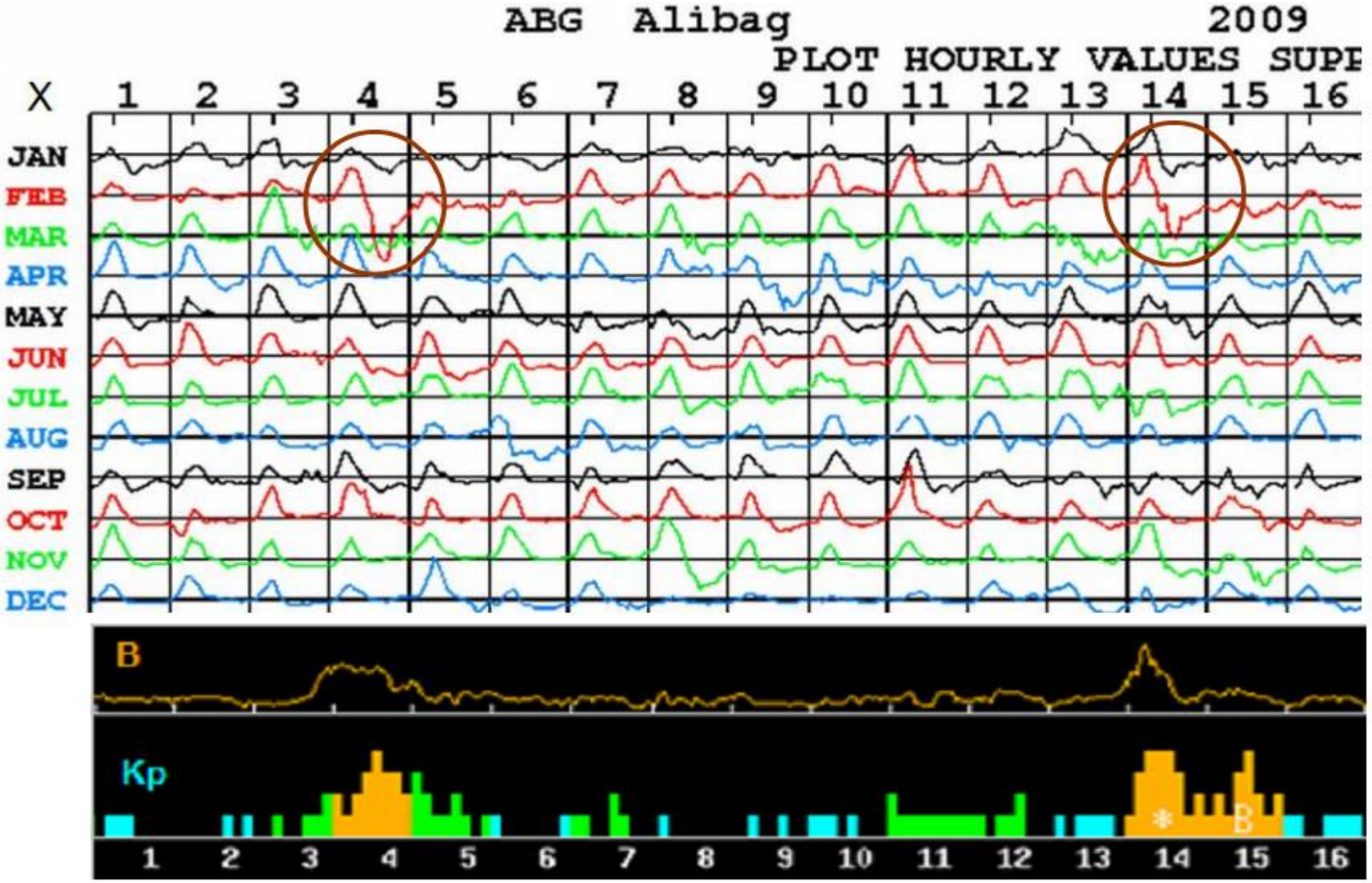
Sir Edward Sabine (1788-1883)

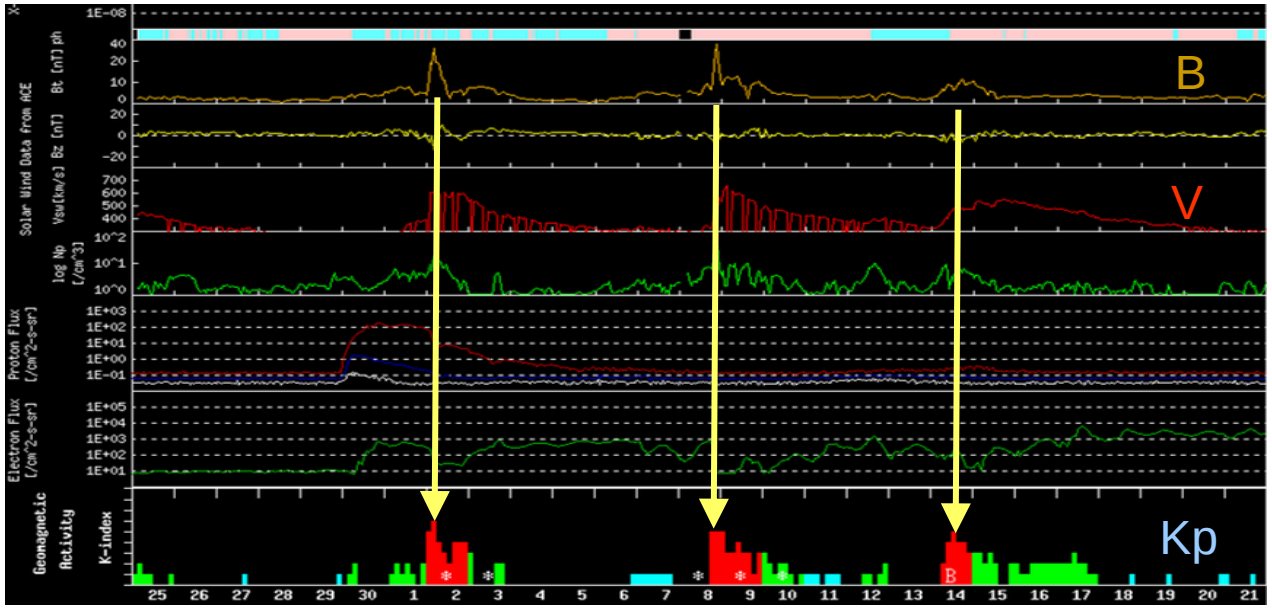
Edward Sabine [1843] computed the hourly mean values for each month and defined Disturbance as the RMS of the differences between the actual and mean values.

And discovered [1852] that minima in the average rate and size of magnetic disturbances at the widely separated Hobarton (SH) and Toronto (NH) observatories in 1843 corresponded to a minimum in sunspot numbers, while maxima in 1848 corresponded to a maximum in the decennial sunspot curve.

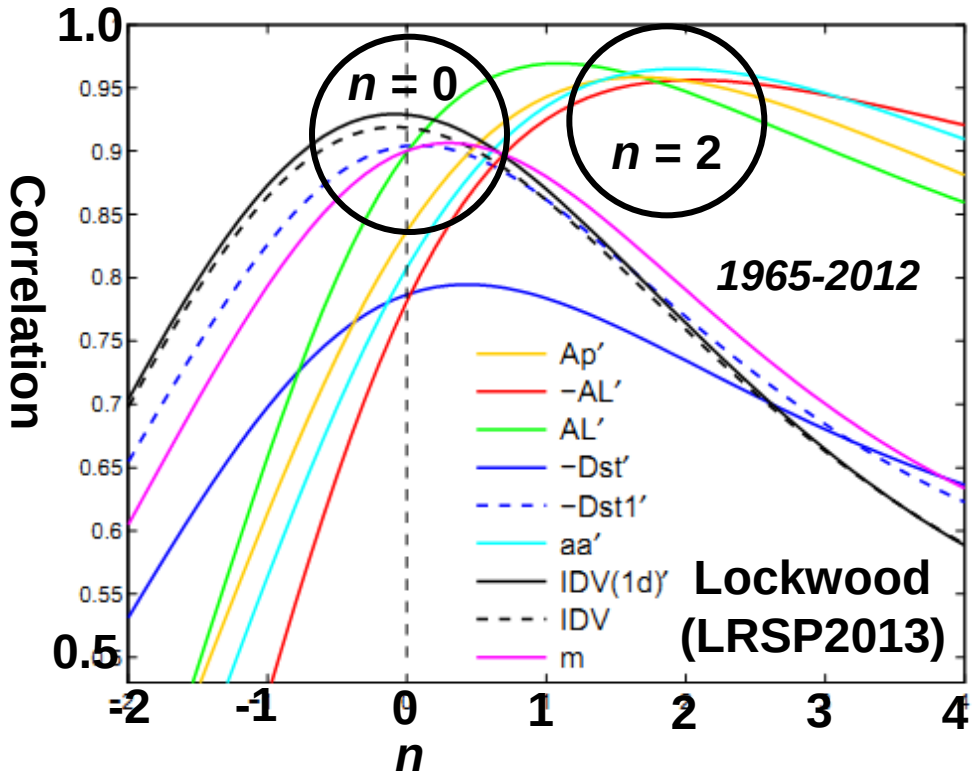
We use the IDV-index = unsigned difference from one day to the next

Relation to HMF Strength B





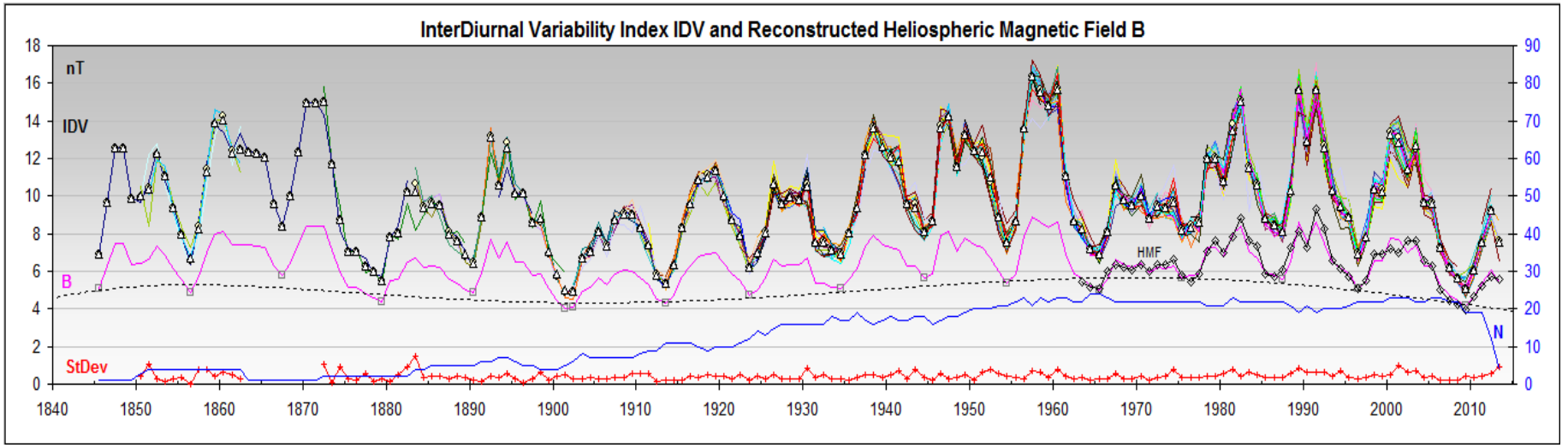
Latest 27-day Bartels Rotation showing *B* and *Kp* peaks

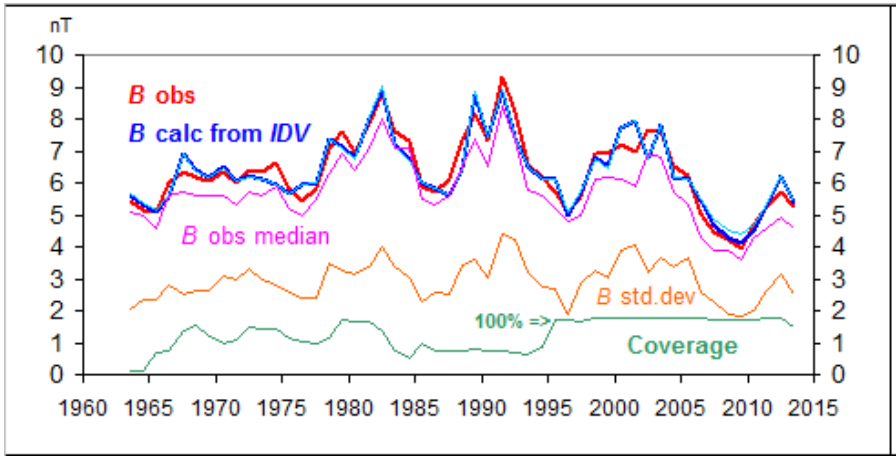


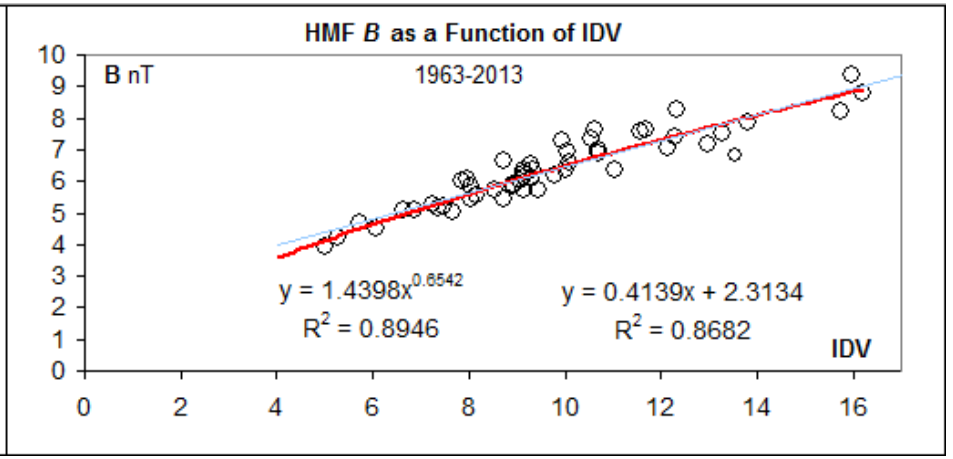
Correlation between IMF BV^n and several geomag. indices as a function of *n*

The IDV indices are not significantly different from having a dependence on **B** only. Thus, the negative part of **Dst** (i.e. ring current enhancement) is closest to explaining the behavior of IDV

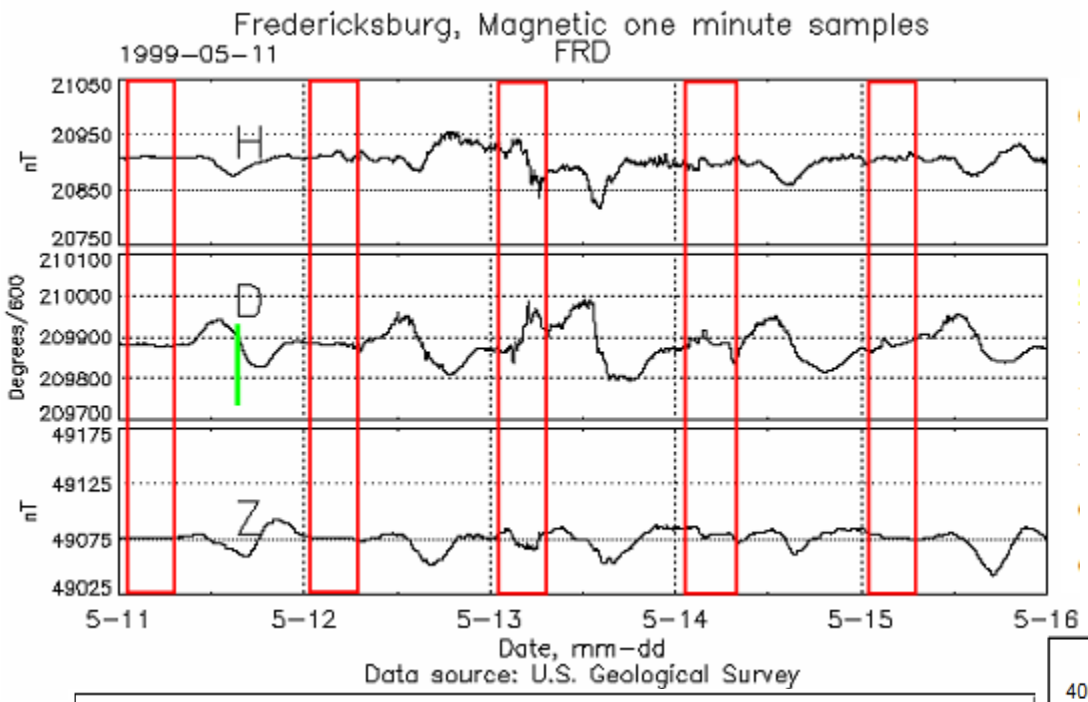
Latest Reconstruction of HMF *B*



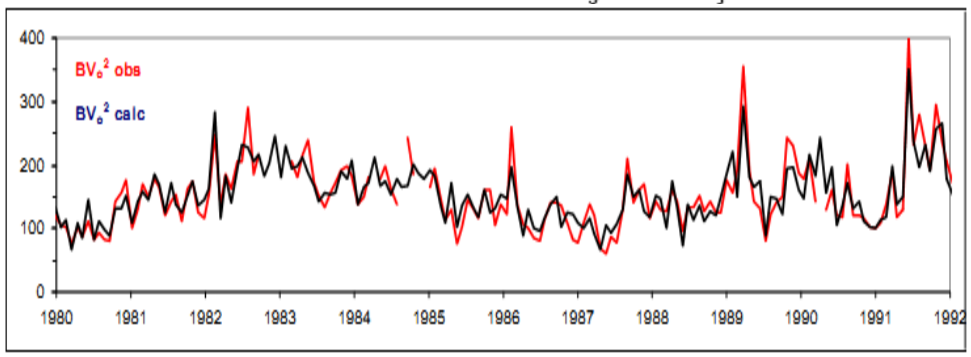


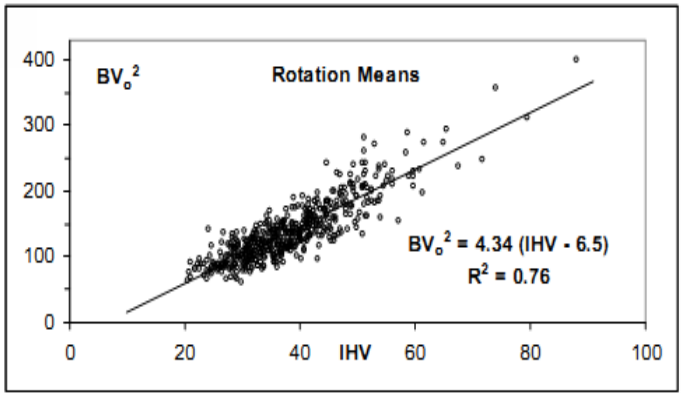


The *IHV* Index gives us BV^2

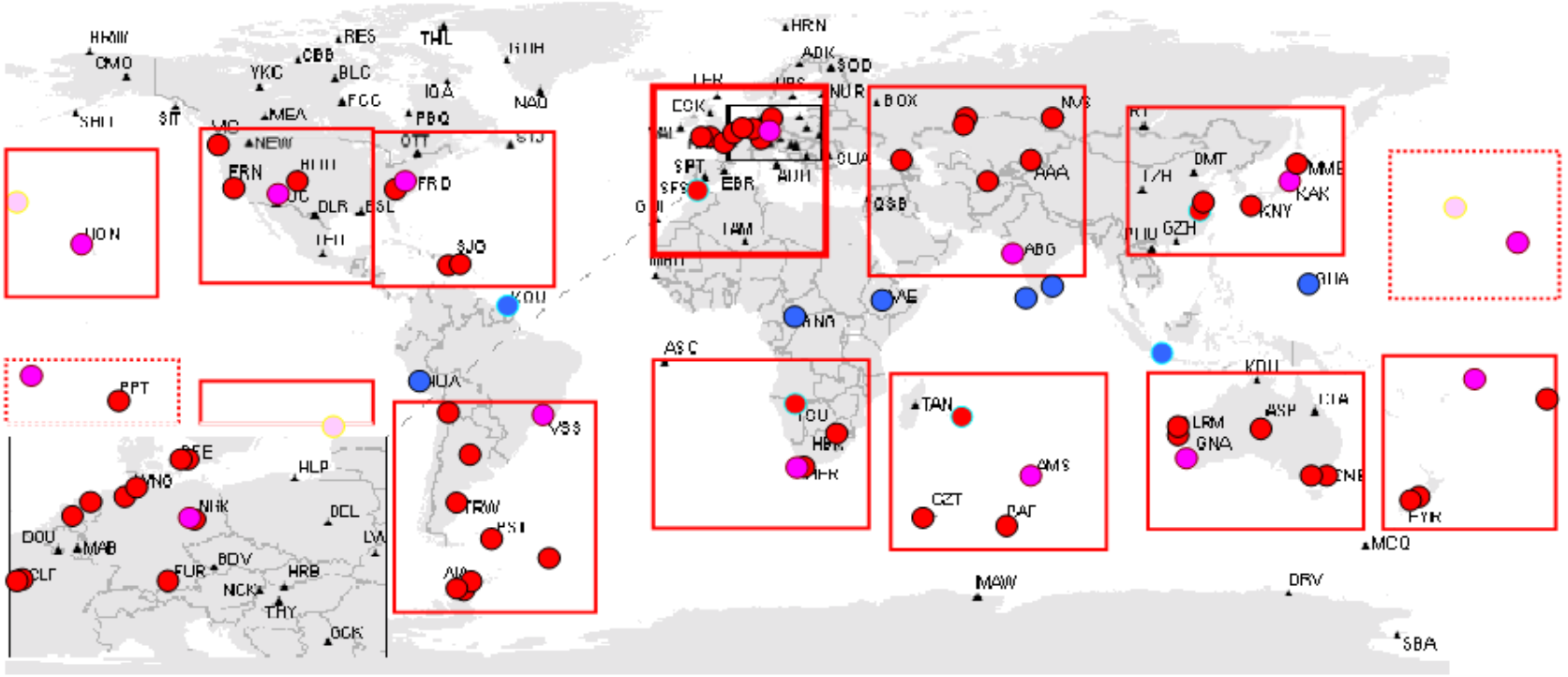


Calculating the variation (sum of unsigned differences from one hour to the next) of the field during the night hours [red boxes] from simple hourly means (the Interhourly Variation) gives us a quantity that correlates with BV^2 in the solar wind

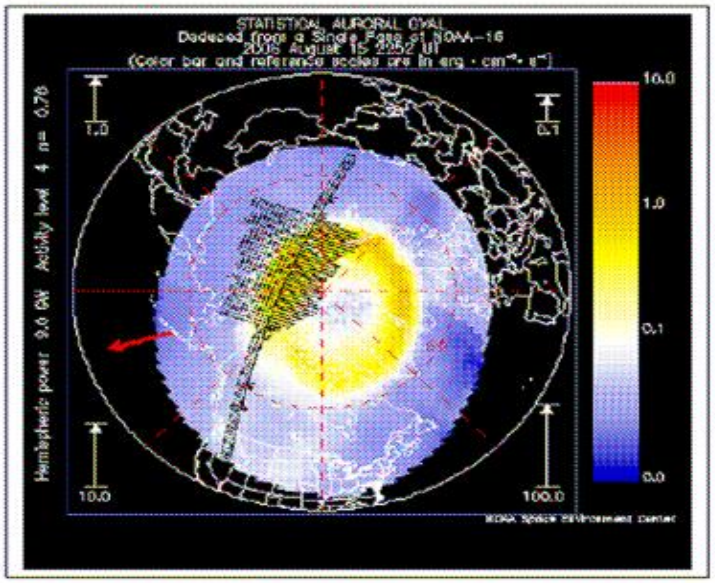




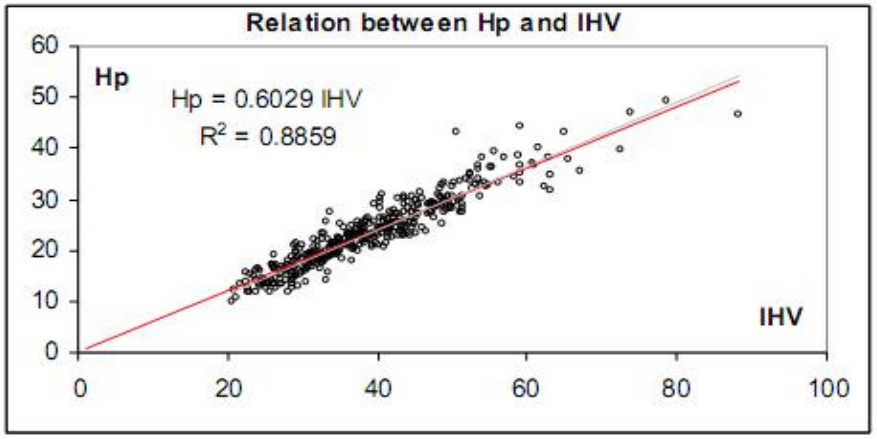
The Many Stations Used for IHV in 14 ‘Boxes’ well Distributed in Longitude, Plus Equatorial Belt

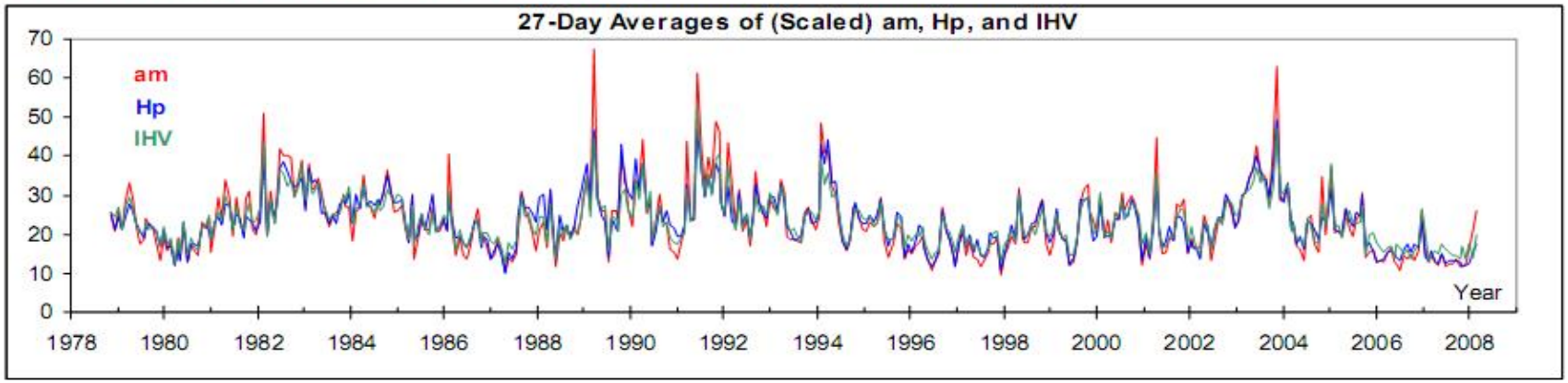


IHV is a Measure of Power Input to the Ionosphere (Measured by POES)

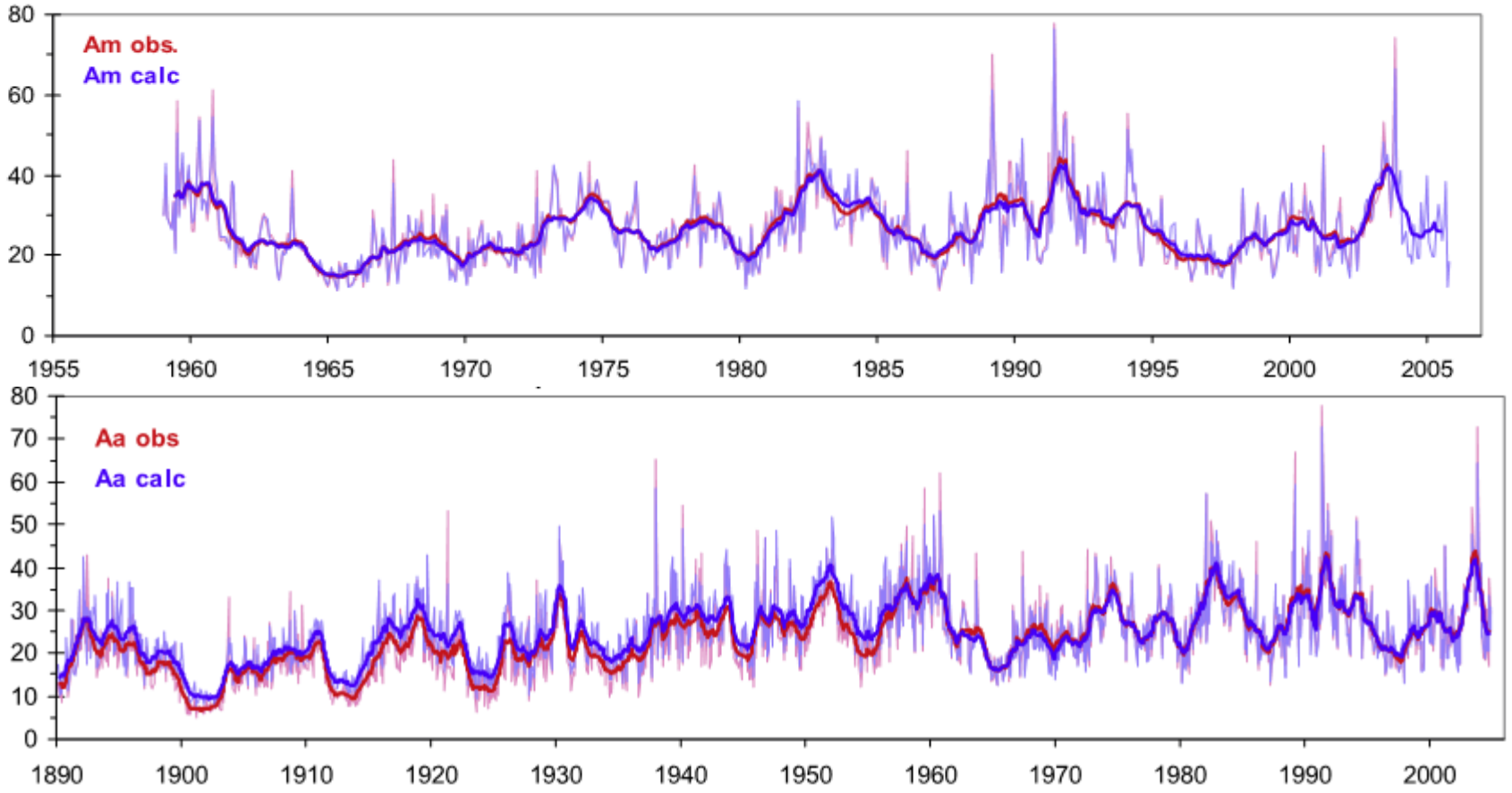


IHV is directly proportional to the power input (*Hp*) to the upper atmosphere:





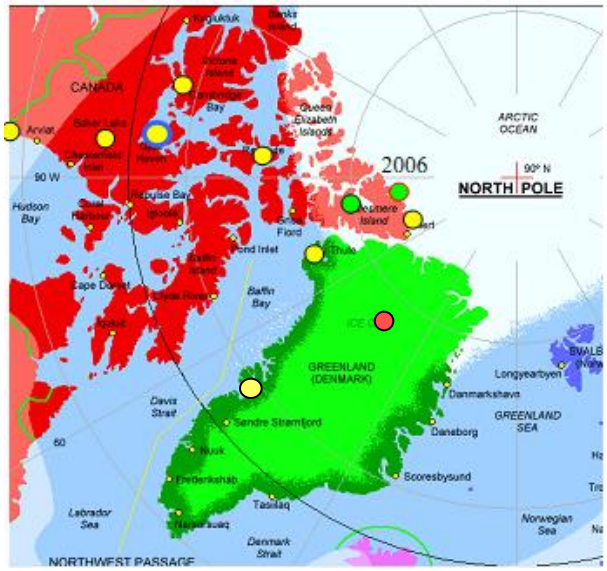
We can calculate Am [and Aa] from IHV



From IDV we get B. From IHV we get BV^2.

Thus we can get V

Polar Cap Geomagnetic Observatories



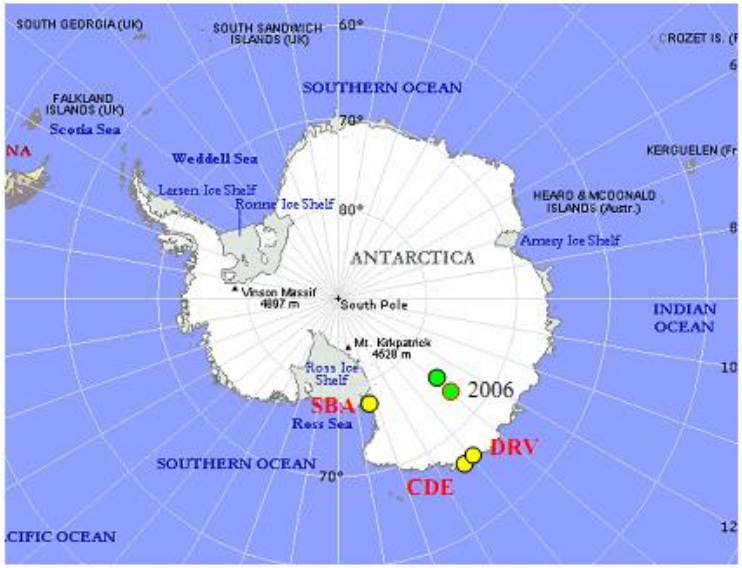
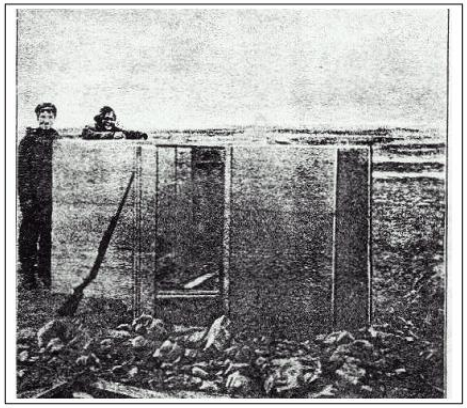


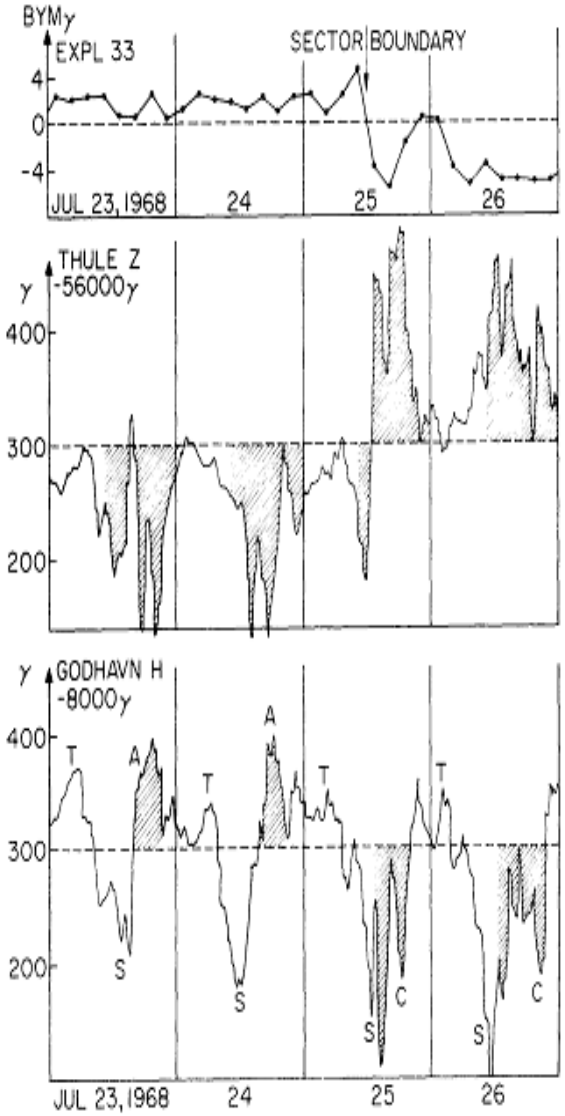
Fig. 4.—Entrance to the Magnetograph House on a fine Spring Day. E. N. Webb climbing

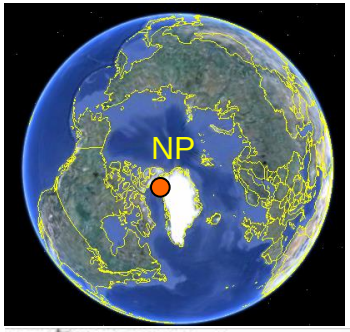
One of my observers enjoying a fine spring day at Cape Denison close to Dumont d'Urville, 1912.

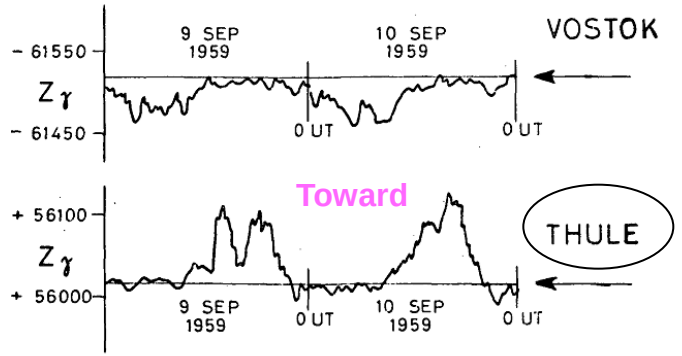


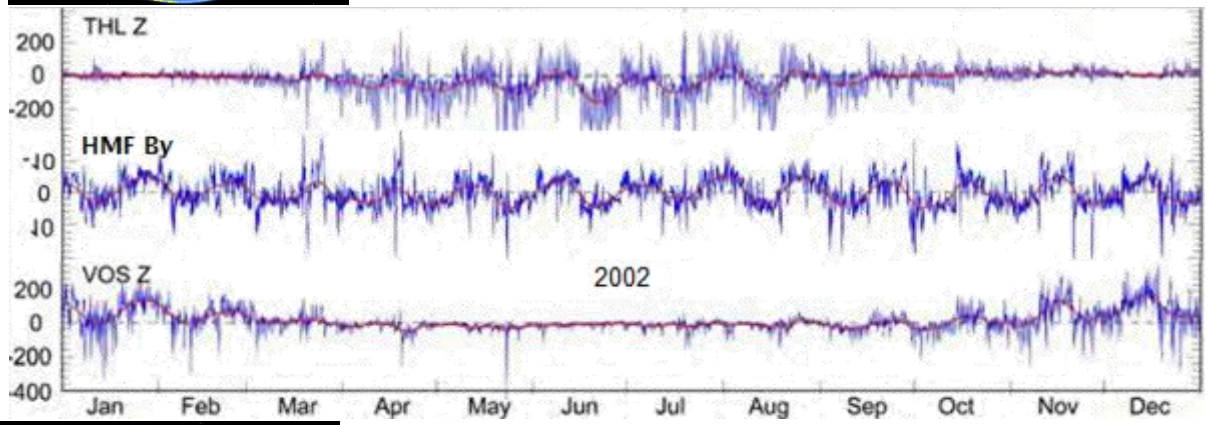
Magnetic variometer hut at Gjoahavn

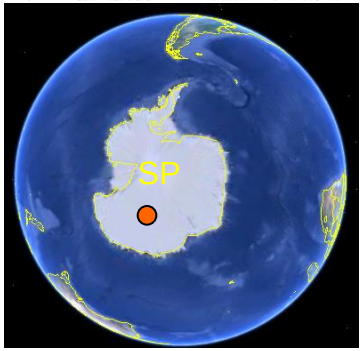
Svalgaard-Mansurov Effect

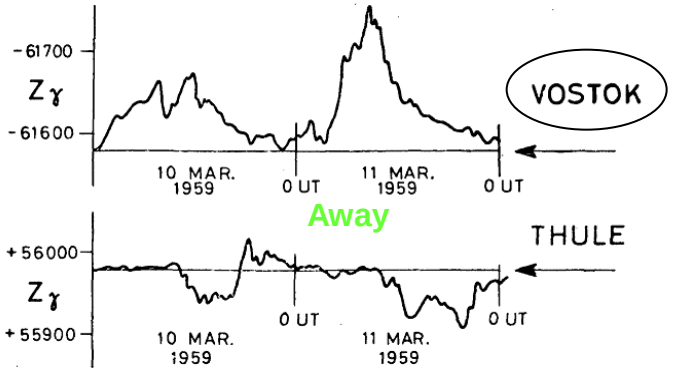




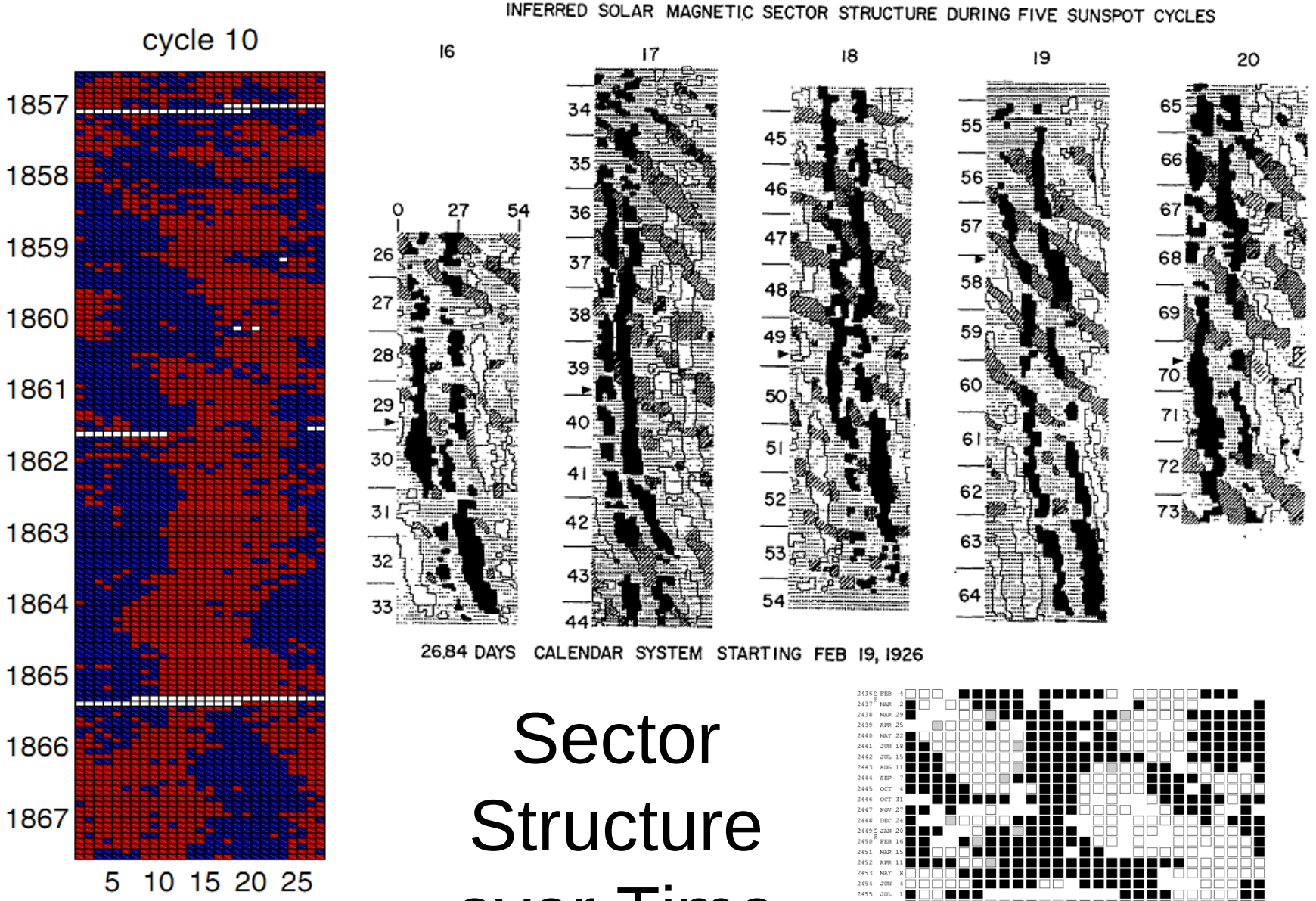








Not a subtle effect…

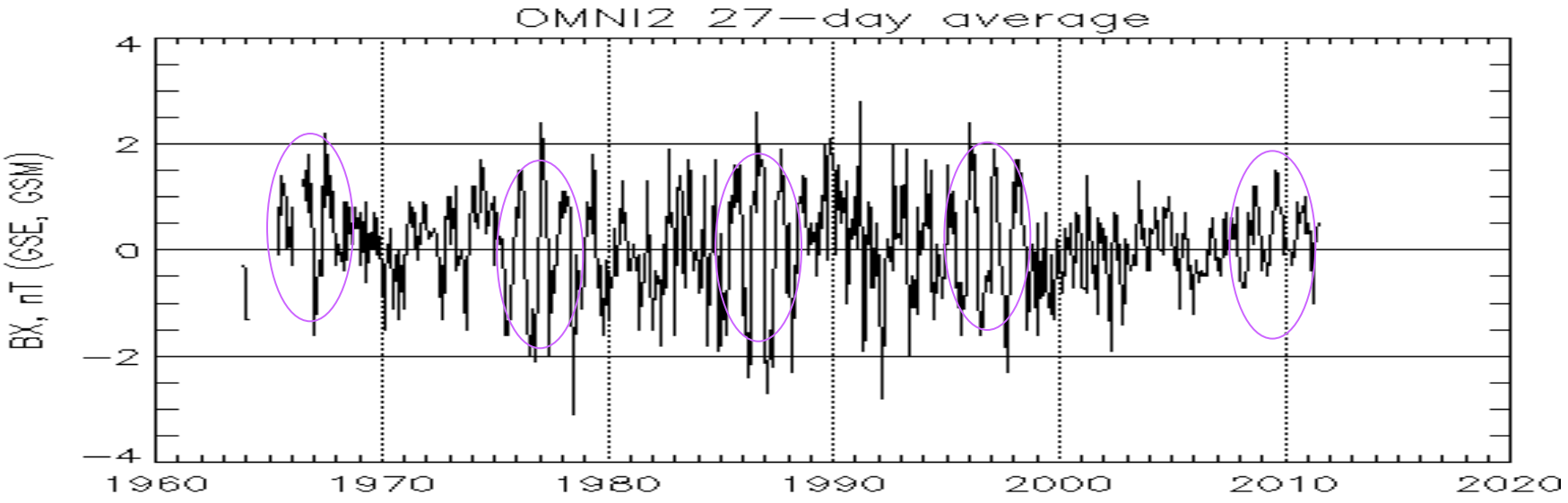


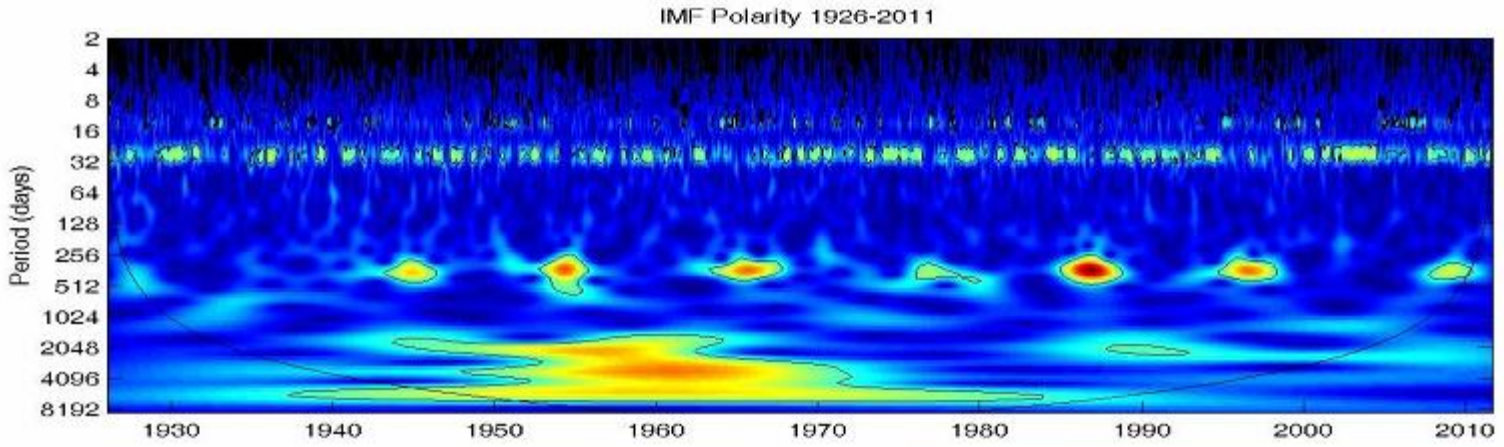
Sector Structure over Time

Vokhmyanin & Ponyavin, 2013

Now

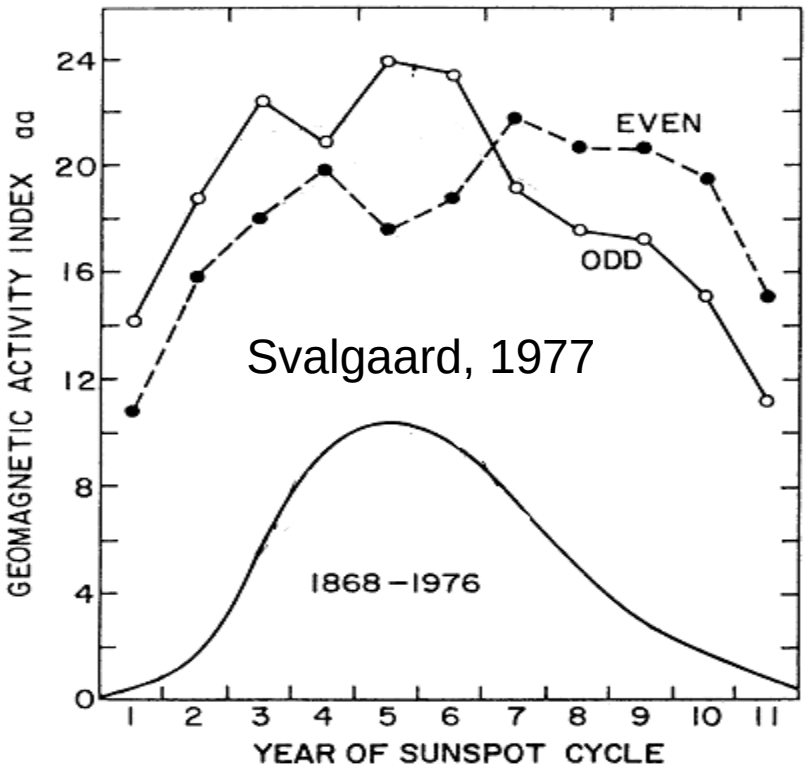
Dominant Polarity: Rosenberg-Coleman Effect





Proves Polar Field Reversals in the Past

How do we Know that the Poles Reversed Regularly before 1957?

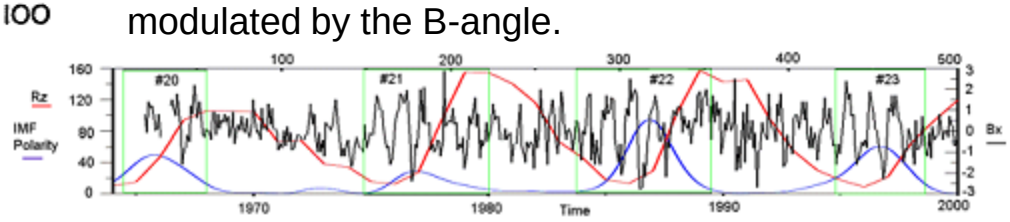


Svalgaard, 1977

"Thus, during last eight solar cycles magnetic field reversals have taken place each 11 year period". S-M effect. Vokhmyanin & Ponyavin, 2012

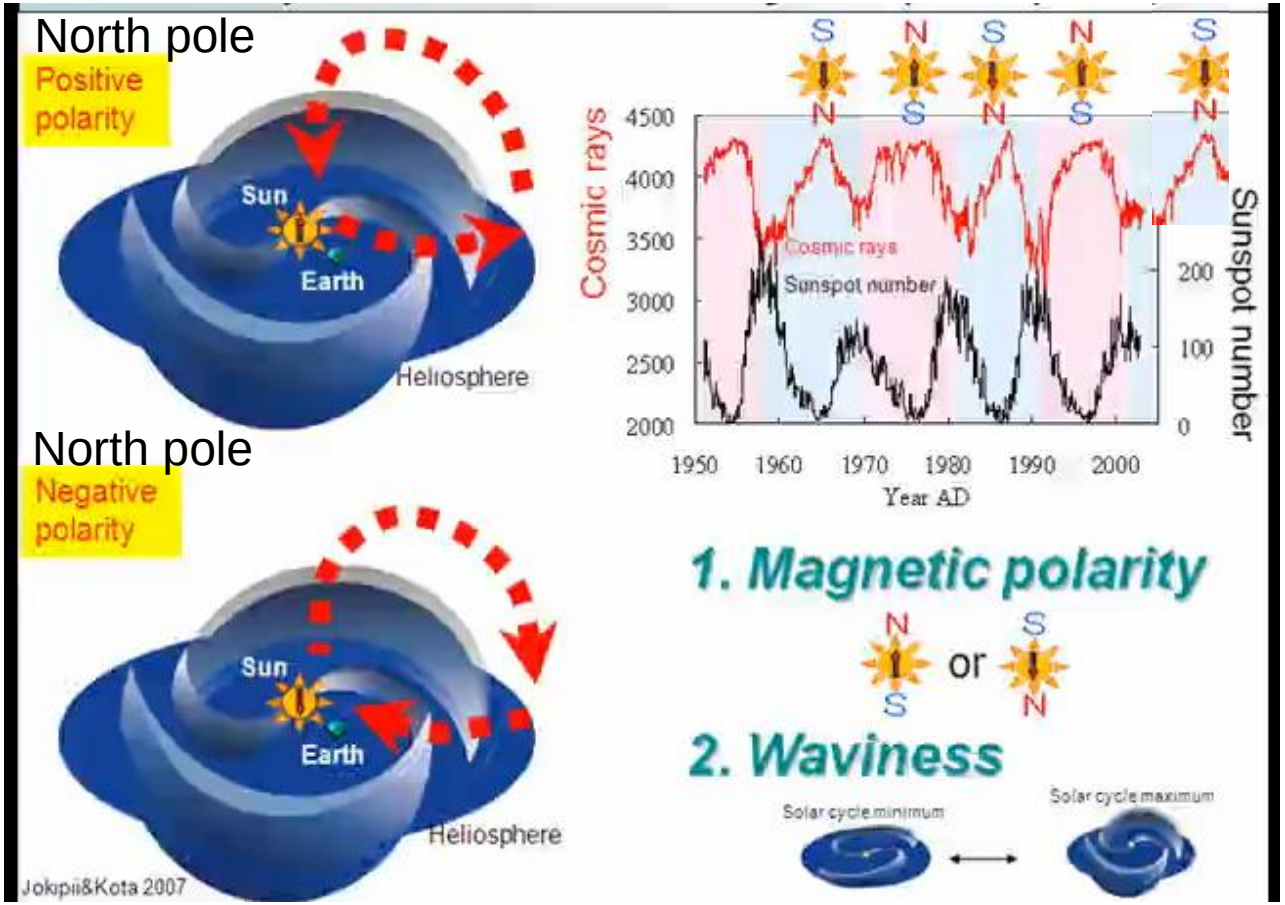
In any case, our result over a 45-year interval is probably the most direct evidence for a continuing change of the predominant polarity of the large-scale solar-magnetic field with a period equal to the sunspot magnetic cycle, i.e., ~20 years during this century. Wilcox & Scherrer, 1972

The predominant polarity = polar field polarity (Rosenberg-Coleman effect) annually modulated by the B-angle.

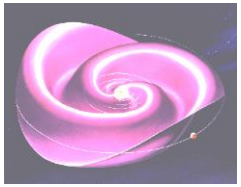


This effect combined with the Russell-McPherron effect [geomagnetic activity enhanced by the Southward Component of the HMF] predicts a 22-year cycle in geomagnetic activity synchronized with polar field reversals, as observed (now for 1840s-Present).

Cosmic Ray Modulation Depends on the Sign of Solar Pole Polarity



Miyahara, 2011

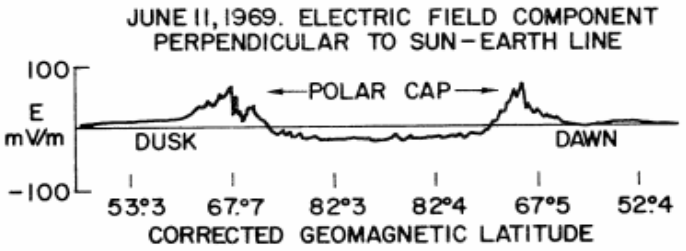


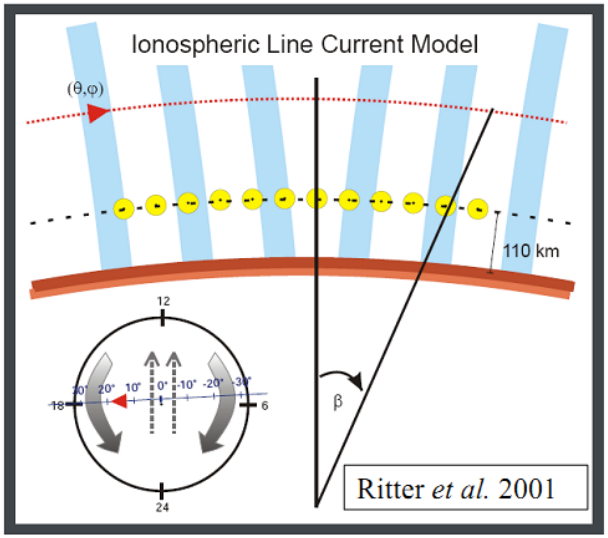
Svalgaard & Wilcox, 1976

The shape of the modulation curve [alternating 'peaks' and 'flat tops'] shows the polar field signs.

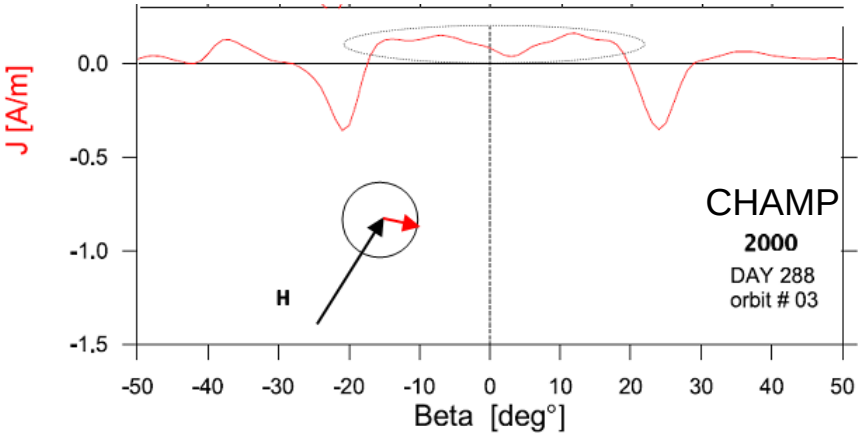
Ice cores contain a long record of 10Be atoms produced by cosmic rays. The record can be inverted to yield the cosmic ray intensity. The technique is not *yet* good enough to show peaks and flats, but might with time be refined to allow this.

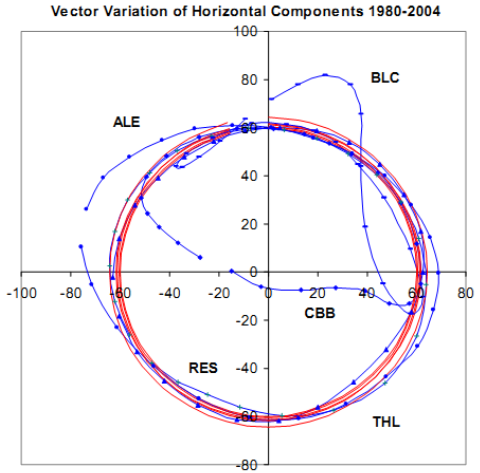
Cross Polar Cap Hall Current



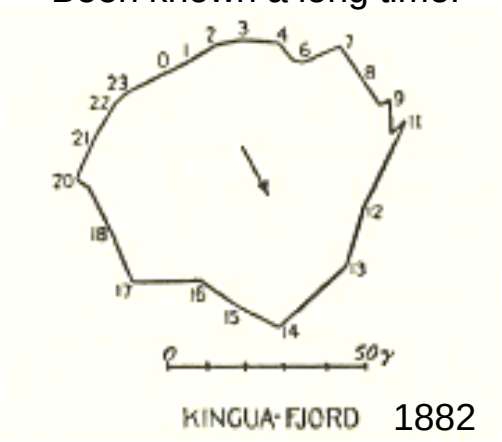


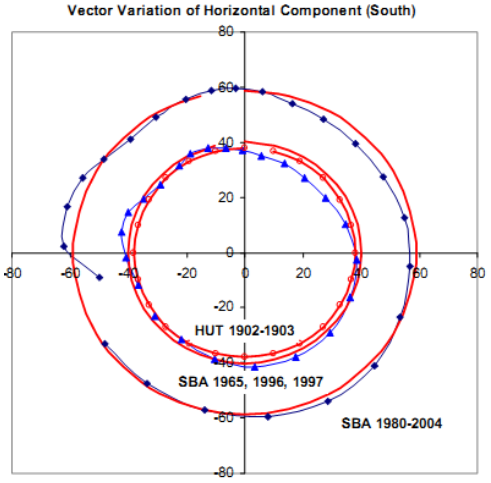
Ionospheric Hall Current across Polar Cap



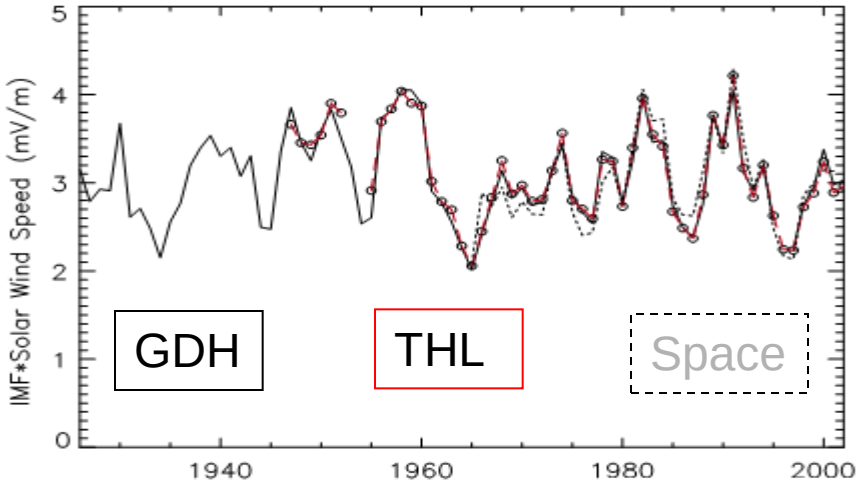


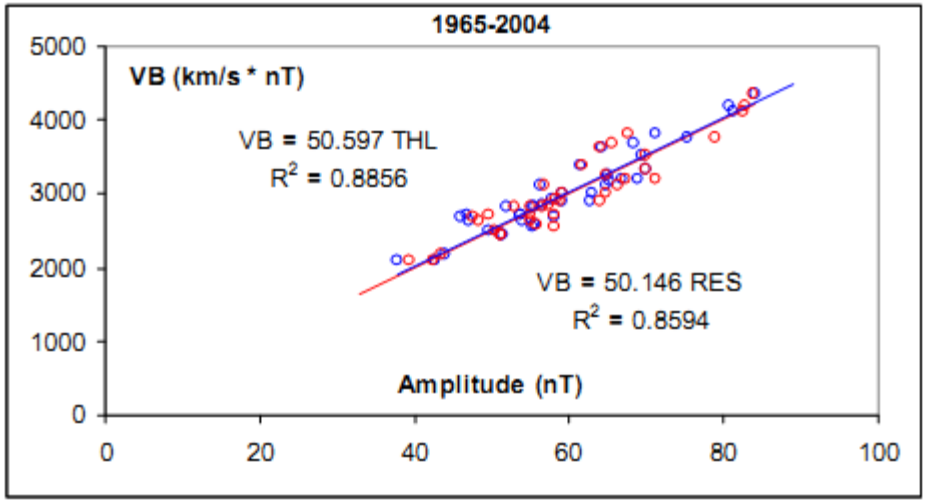
Been known a long time:

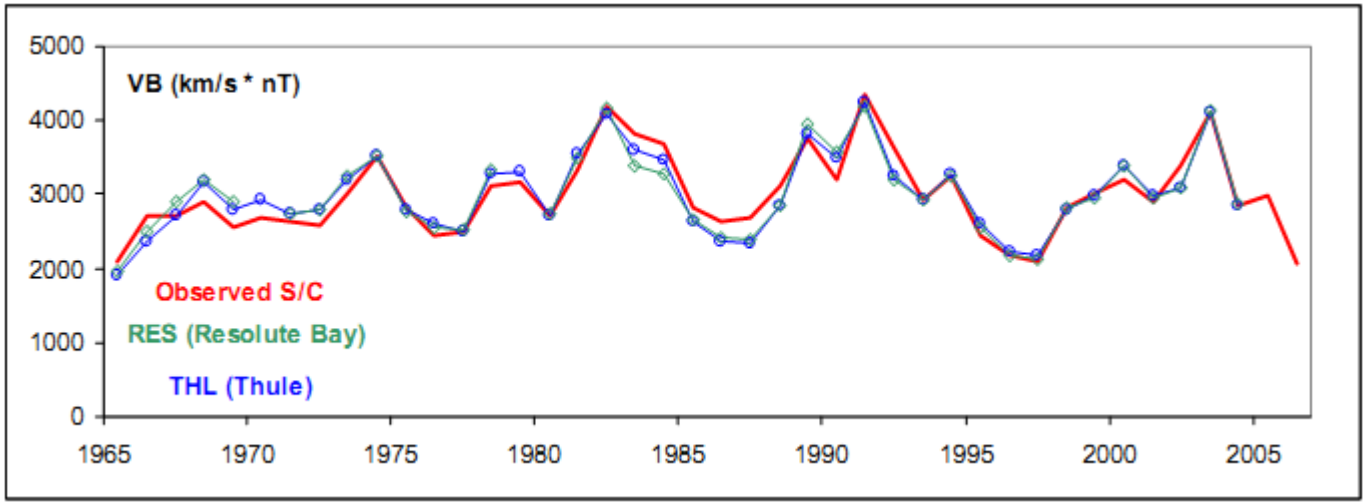




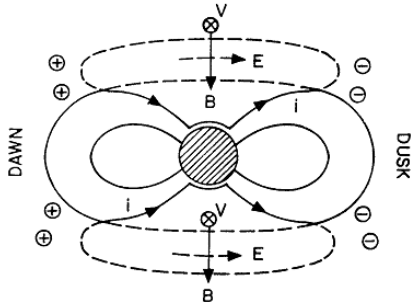
Cross Polar Cap Potential Drop

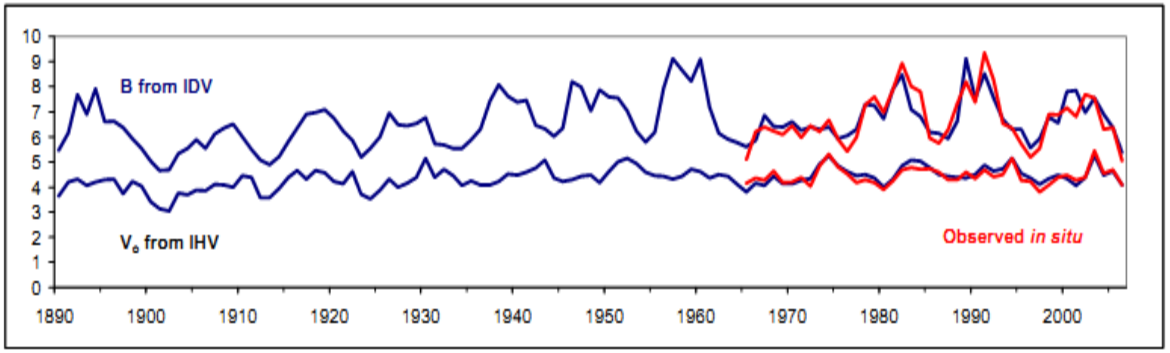


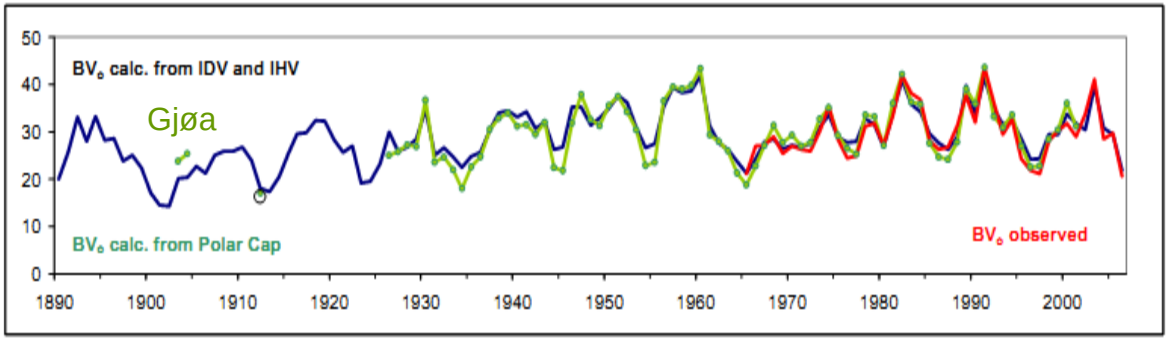




$$E \sim -V \times B$$







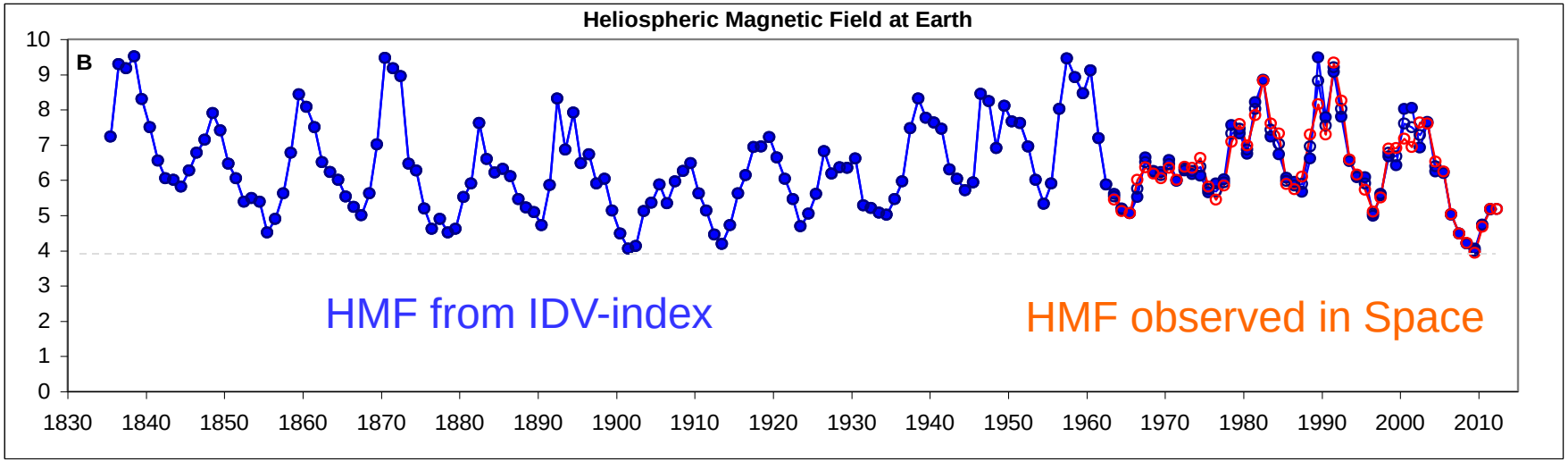
Overdetermined System: 3 Eqs, 2 Unknowns

B = p (IDV)

BV^2 = q (IHV)

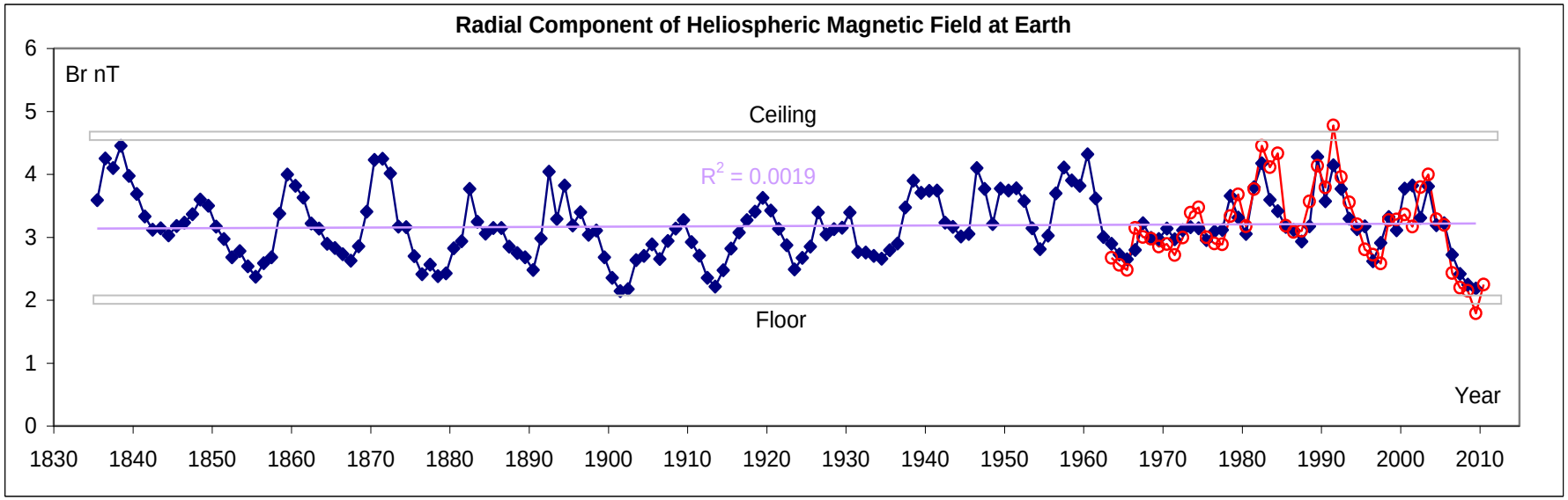
VB = r (PCap)

Here is B back to the 1830s:



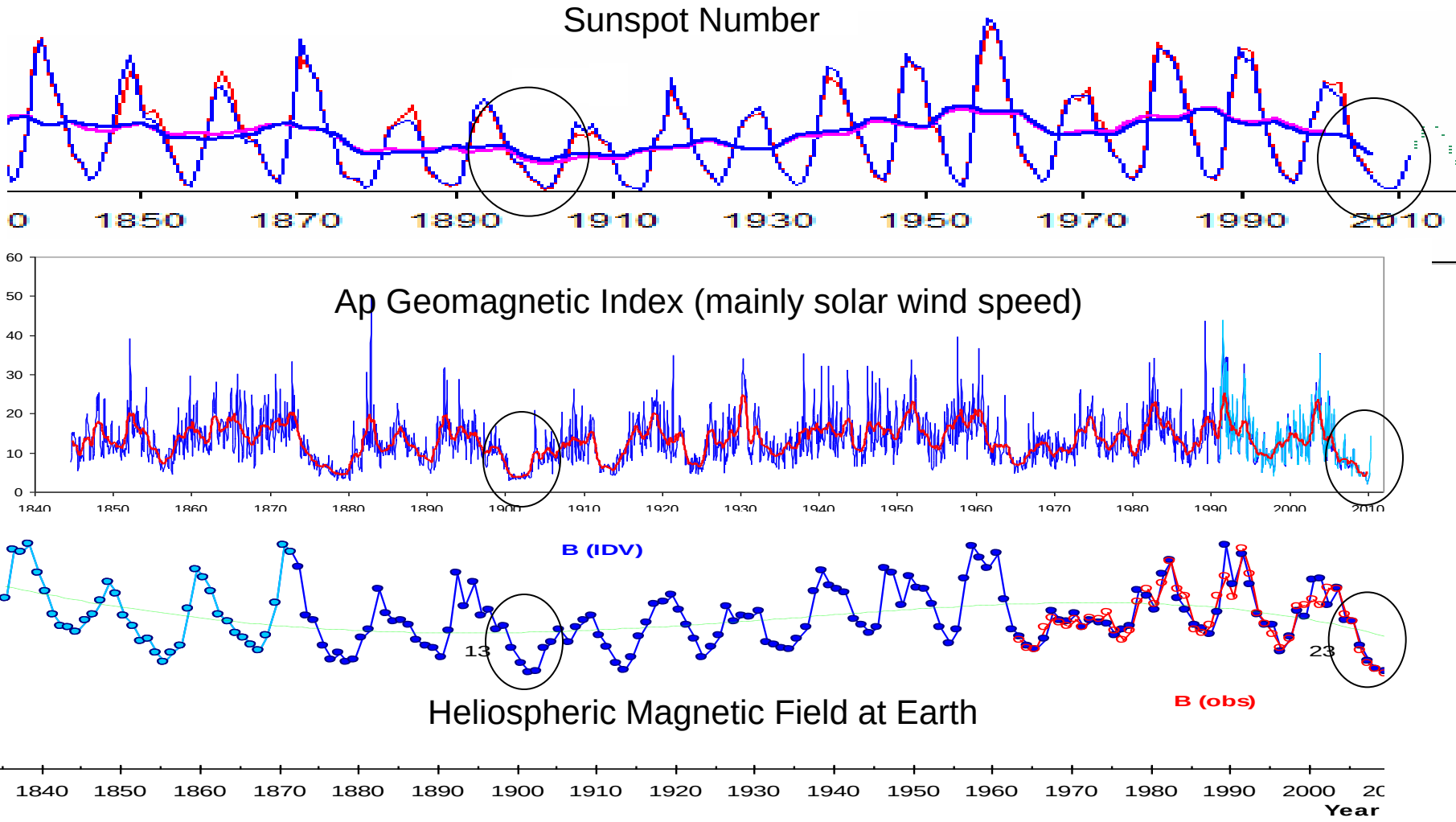
Radial Magnetic Field (‘Open Flux’)

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



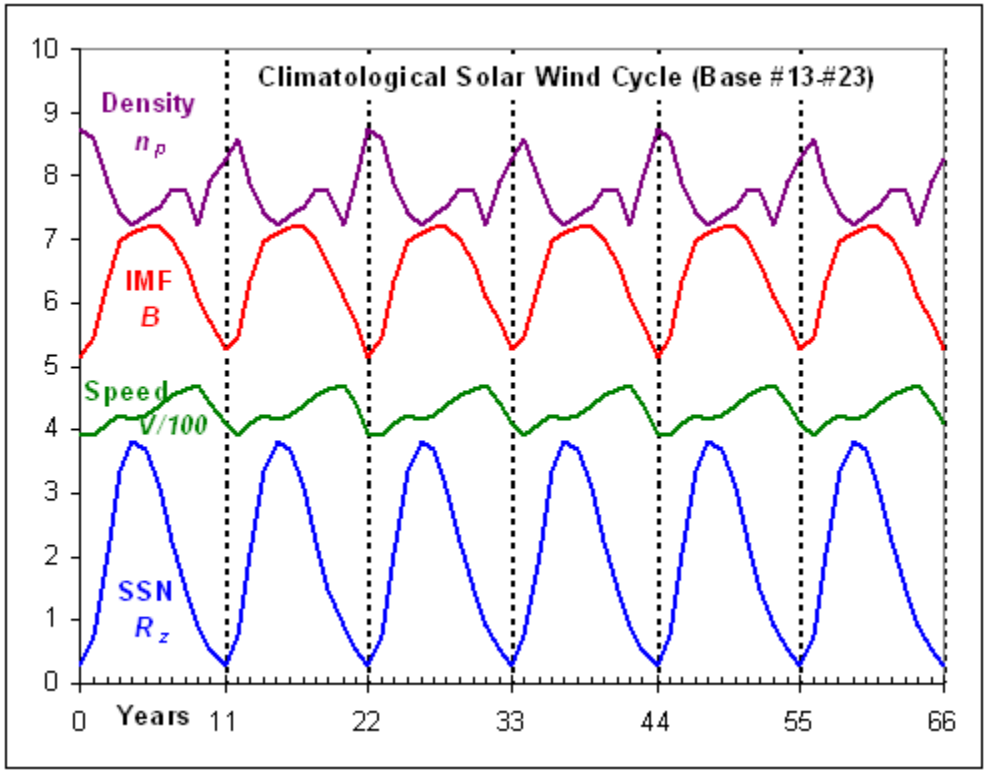
There seems to be both a Floor and a Ceiling and most importantly no long-term trend since the 1830s. Thus no Modern Grand Maximum.

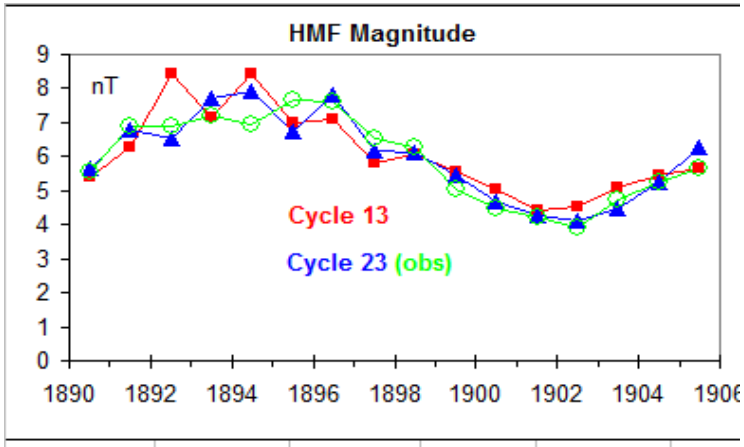
Solar Activity 1835-2011

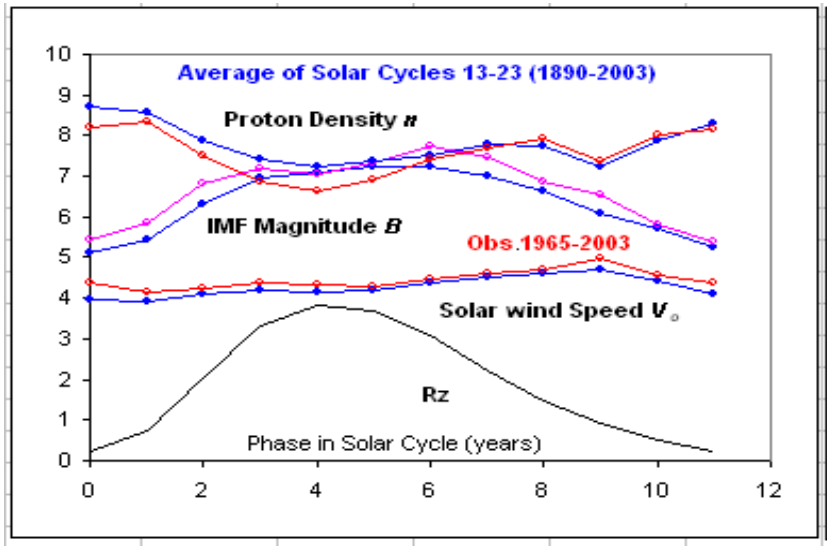


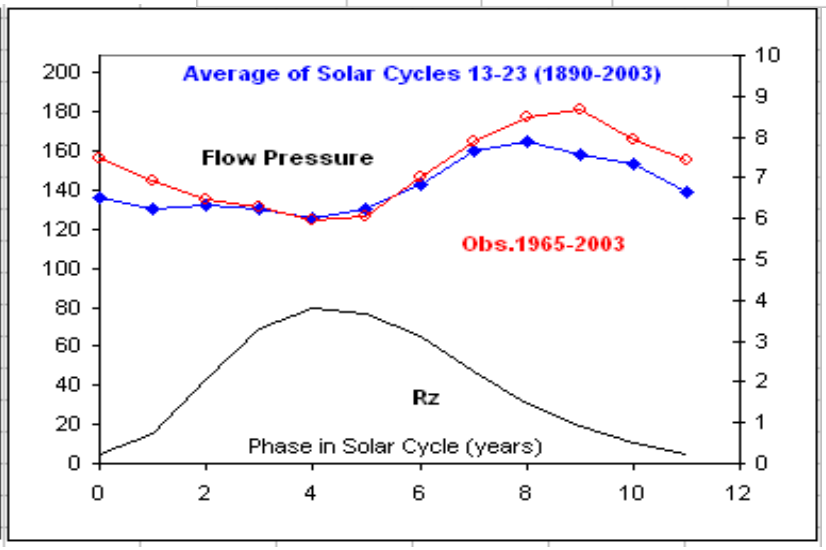
Activity now is similar to what it was a century ago

Space Climate

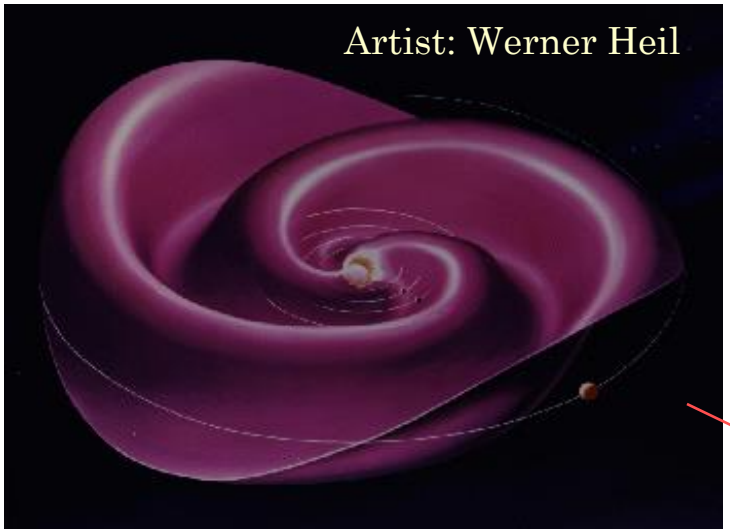


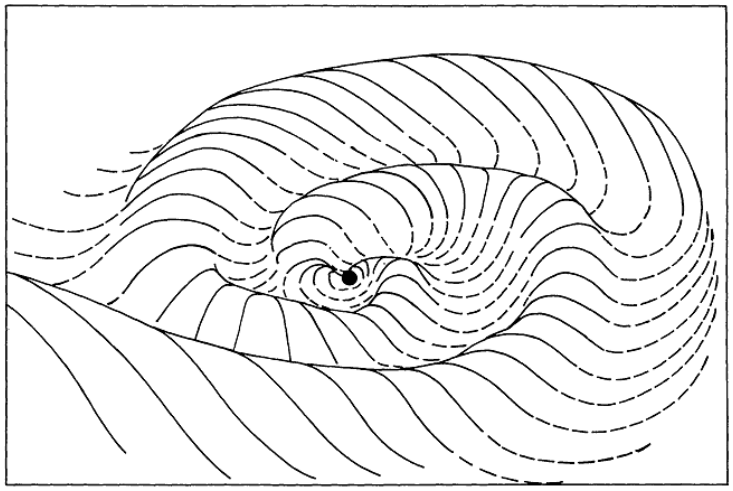


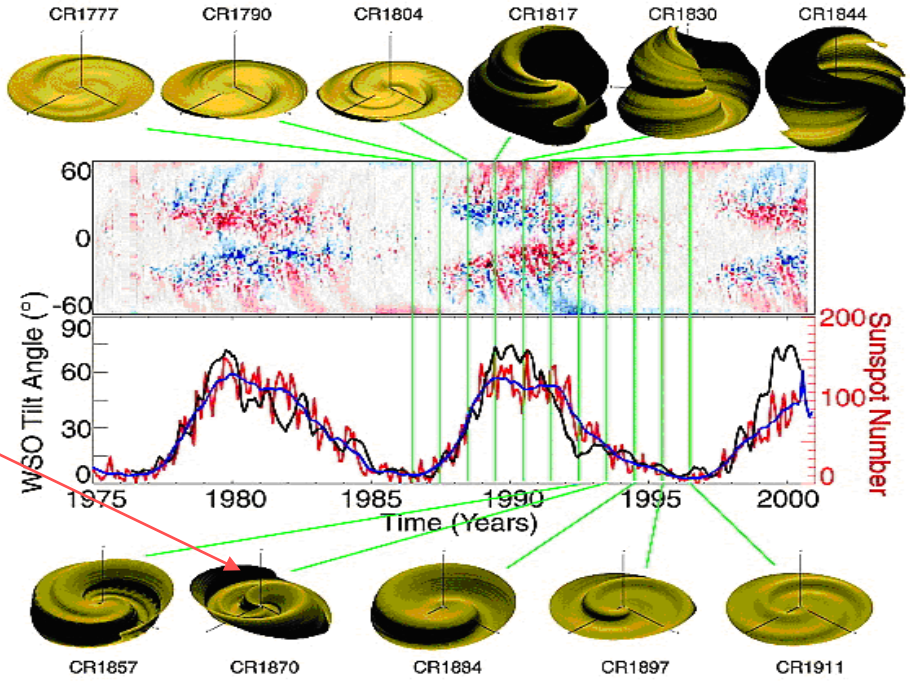


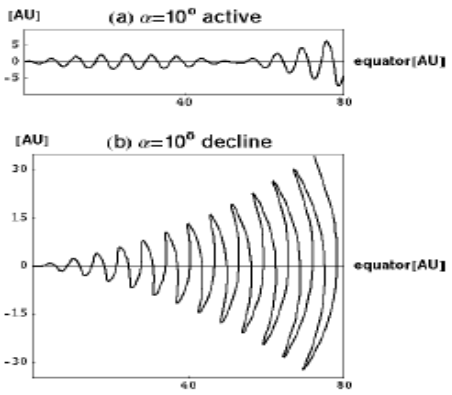


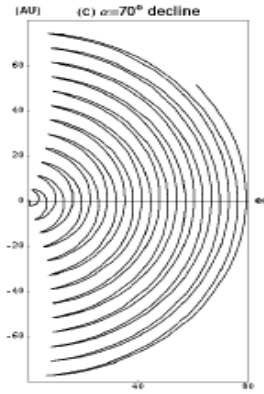
The Heliospheric Current Sheet







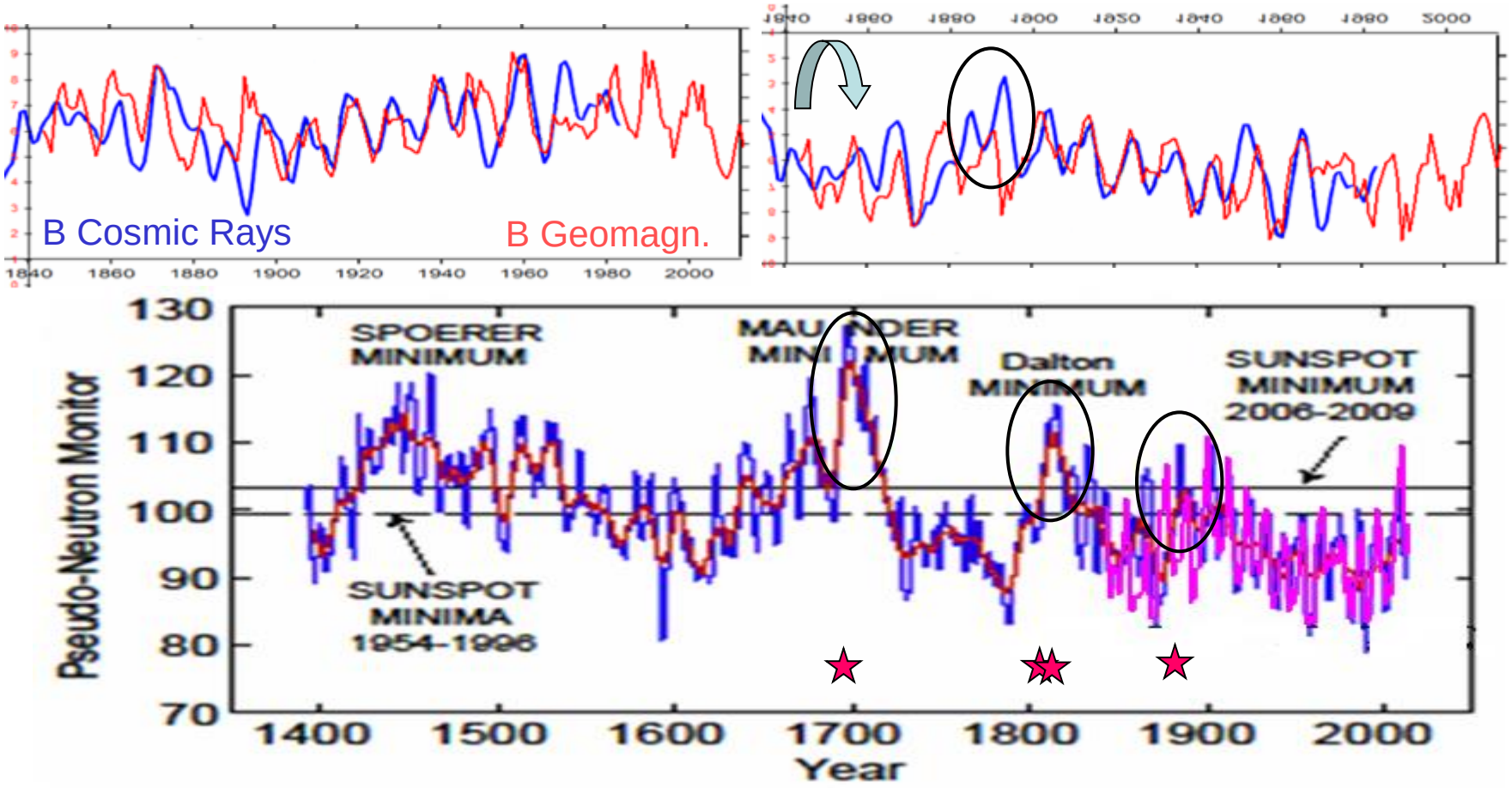




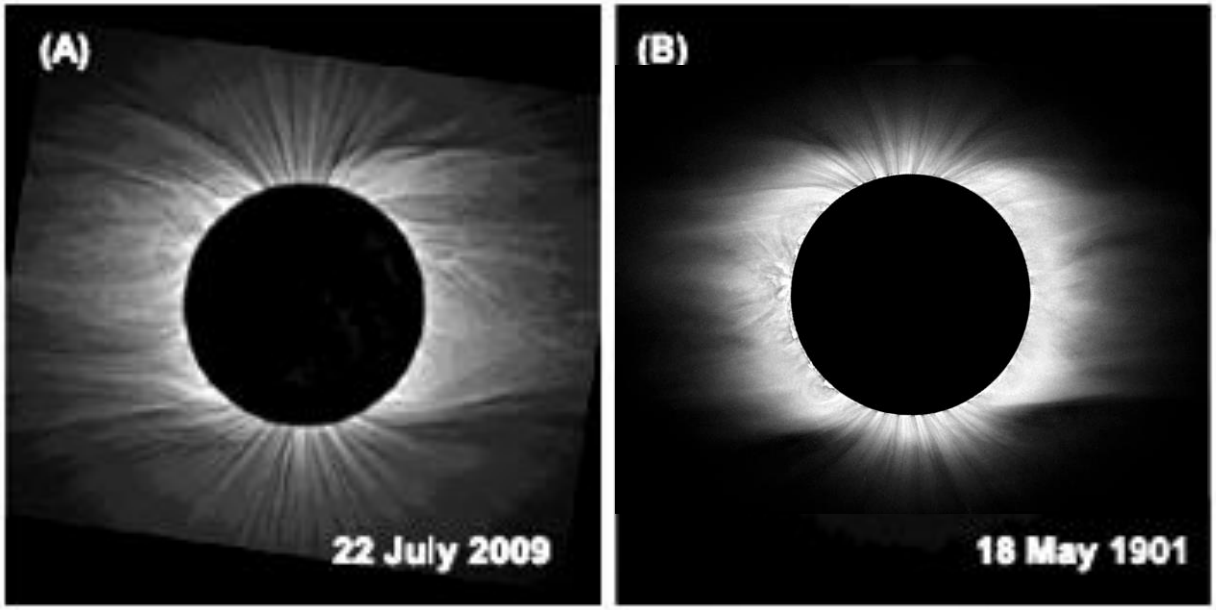
Cosmic Ray Modulation caused in part by latitudinal variations of HCS, CIRs, CMEs, and B

Svalgaard & Wilcox, *Nature*, 1976

The Cosmic Ray Connection



Back to the Future



2008-2009 HMF *B* = 4.14 1901-1902 HMF *B* = 4.10 nT

Sunspot Number, Ri = 3 Sunspot Number, Rz = 4

Showing very similar conditions of the HMF *B* at the recent minimum and the minimum 108 years before as deduced from the Geomagnetic Record.

The first known report of the red flash, produced by spicules requiring the presence of widespread solar magnetic fields, comes from Stannyan observing the eclipse of 1706 at **Bern**, Switzerland. The second observation, at the 1715 eclipse in England, was made by, among others, Edmund Halley. These first observations of the red flash imply that a **significant level of solar magnetism must have existed even when very few spots were observed, during the latter part of the Maunder Minimum** (Foukal & Eddy, 2007)

Conclusions

- We can determine B, V, and n back to 1830s
- Polar field reversals occurred that far back
- No Modern Grand Maximum
- FUV radiation varies with Sunspot Number
- Solar Cycle Variations can be tracked with Geomagnetism
- Caveat: The Earth's main field is decreasing and we don't know how that affects the geomagnetic inferences