

# Geomagnetic Indices

Regular Irregularity and Irregular Regularity

A Journey

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# Regular Variations



George Graham discovered [1722] that the geomagnetic field varied during the day in a regular manner. He also noted that the variations were larger on some days than on other days. So even the 'regular' was irregular...

# Disturbances and Aurorae



Pehr Wargentin [1750] also noted the regular diurnal variation, but found that the variation was 'disturbed' at times of occurrence of Aurorae. Graham, Anders Celsius, and Olaf Hjorter had earlier also observed this remarkable relationship.

# The First Index (Regular–Irregular)



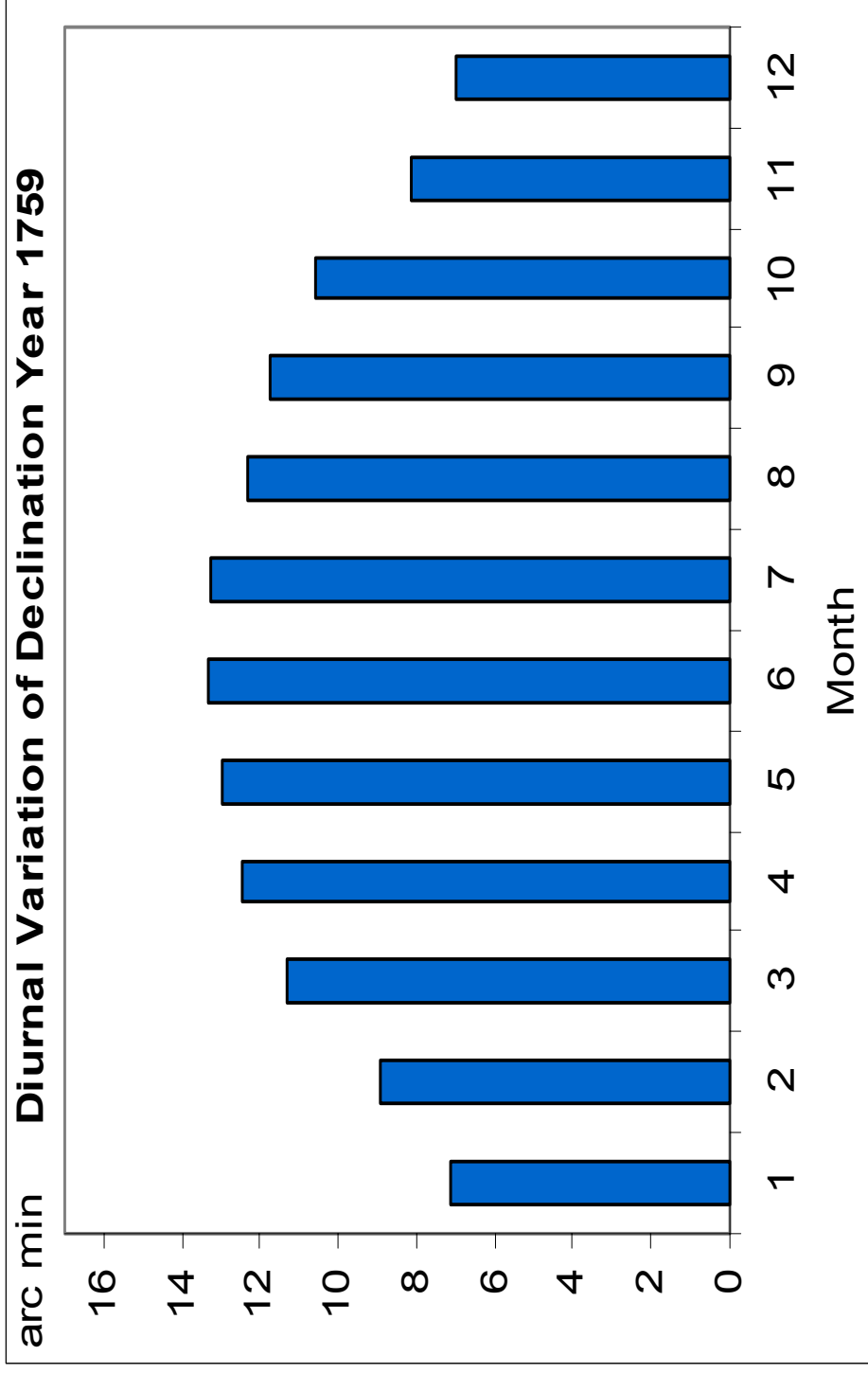
John Canton [1759] made ~4000 observations of the Declination on 603 days and noted that 574 of these days showed a ‘regular’ variation, while the remainder (on which aurorae were ‘always’ seen) had an ‘irregular’ diurnal variation.

# Classification - Character

The First Index was thus a *classification* based on the 'character' of the variation, with less regard for its amplitude, and the ancestor of the C-index (0=quiet, 1=ordinary, 2=disturbed) that is still being derived today at many stations.

The availability of the Character Index enabled Canton to discover another Regularity on Quiet days.

# The Regular Seasonal Variation



# More than One Cause

And to conclude that “*The irregular diurnal variation must arise from some other cause than that of heat communicated by the sun*”

This was also evident from the association of days of irregular variation with the presence of aurorae

# Another Regular Variation

George Gilpin sailed on the *Resolution* during Cook's second voyage as assistant to William Wales, the astronomer. He joined on 29 May 1772 as astronomer's servant. John Elliott described Gilpin as "a quiet yg. Man".

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.

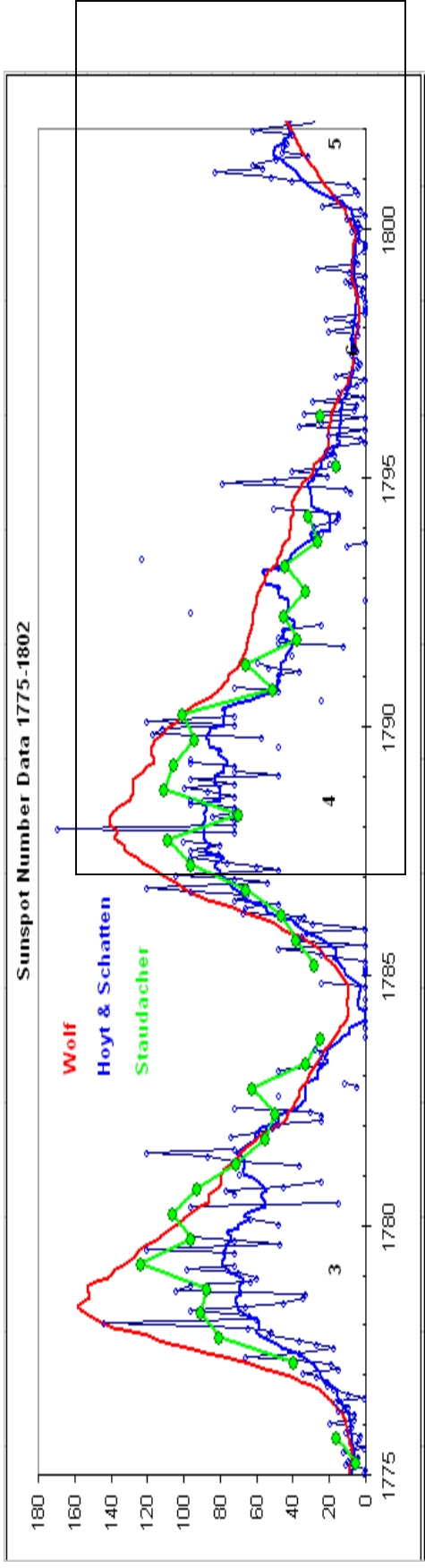
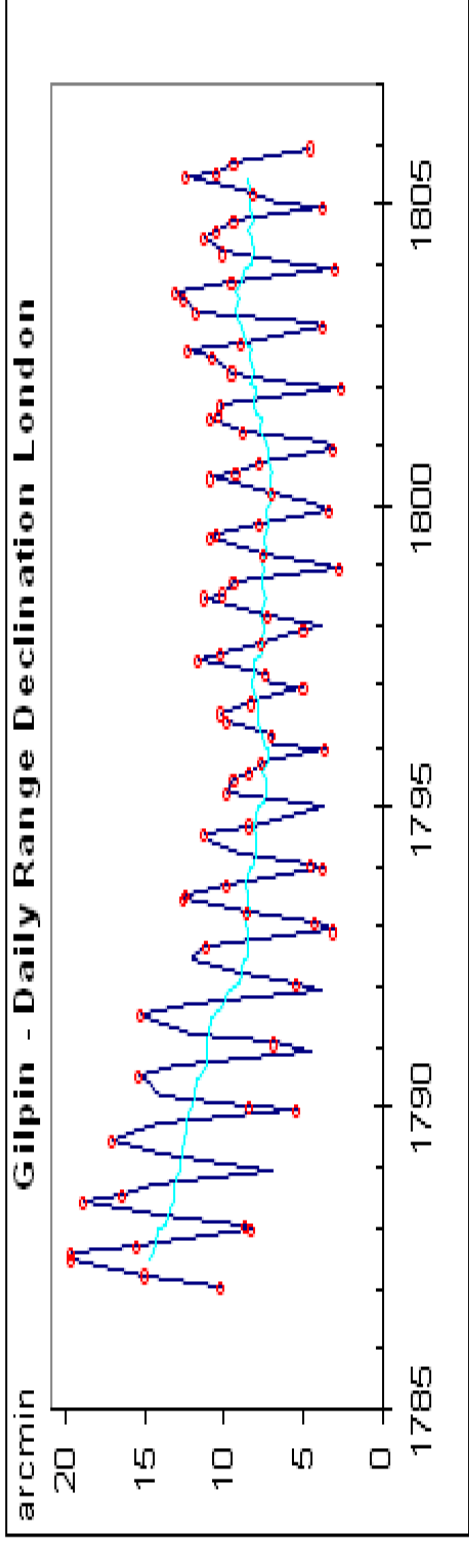
George Gilpin [1806] urged that regular measurements should be taken at fixed times during the day.

And demonstrated that the seasonal variation itself varied in a regular manner

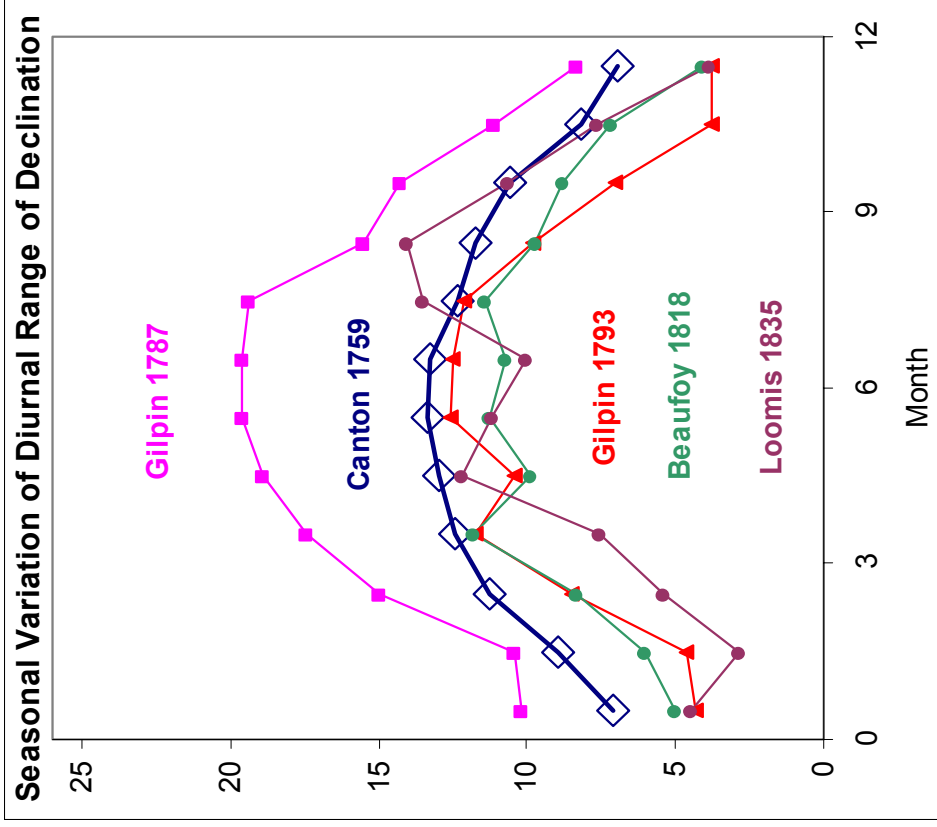


# Hint of Sunspot Cycle Variation

though unknown to Gilpin, who thought he saw a temperature effect



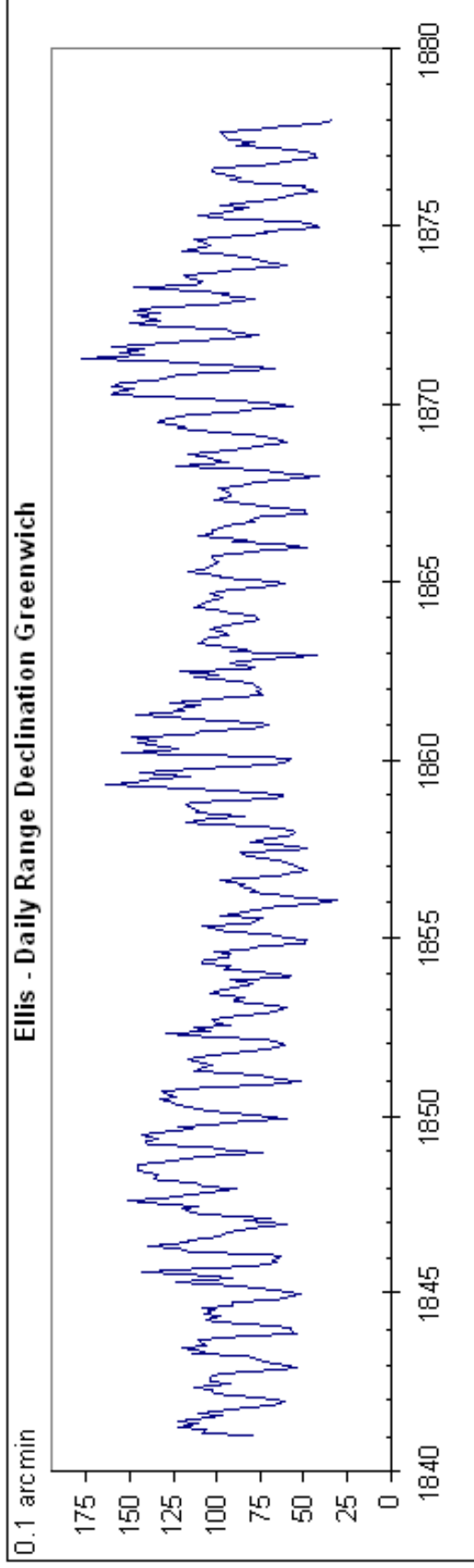
# Alas, Paradise Lost



Canton's great insight [that there were different causes of the variations during quiet and disturbed times] was lost with Gilpin and some later workers, and a new and simpler 'index' won acceptance, namely that of the *Daily Range*. The 'raw' *Daily Range* is, however, a *mixture* of effects.

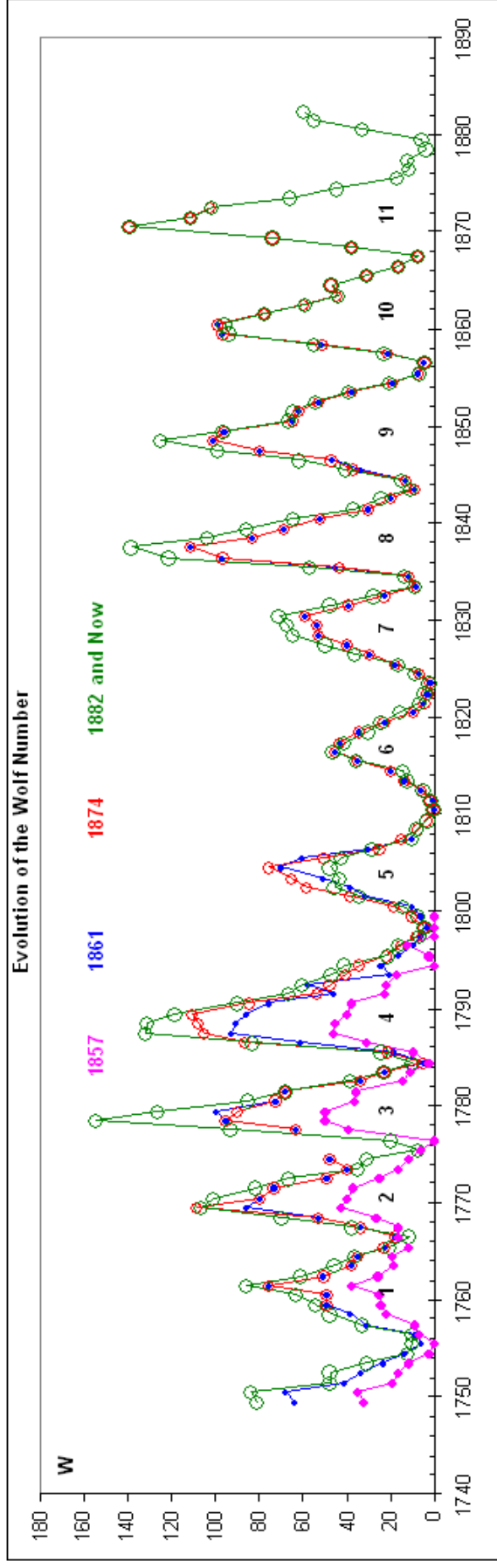
# The Daily Range Index

The Daily Range is simple to calculate and is an ‘objective’ measure. It was eventually noted [Wolf, 1854] that the range in the Declination is a proxy for the Sunspot Number defined by him.

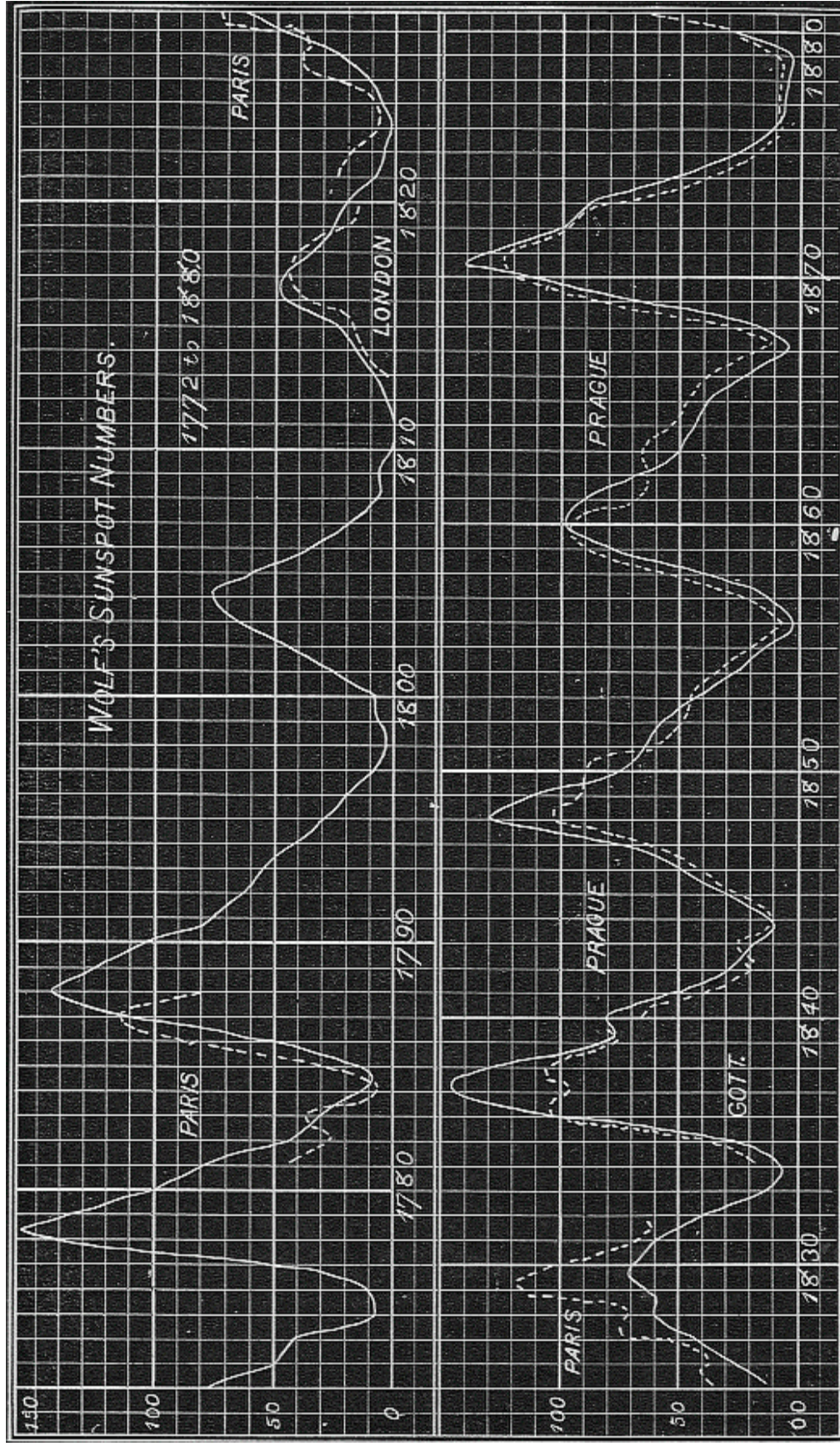


# Rudolf Wolf's Sunspot Number

Wolf used this correlation to calibrate the sunspot counts by other observers that did not overlap in time with himself



# Young's Version of the Correlation



# How to Measure Disturbance



Edward Sabine [1843],  
mindful of Canton's  
insight, computed the  
hourly mean values for  
each month, omitting  
'the most disturbed days'  
and defined Disturbance  
as the RMS of the  
differences between the  
actual and mean values.

# The Ever-present Tension

- ❑ Quiet time variations – their regular and irregular aspects
- ❑ Disturbance variations – their irregular and regular aspects

One cannot conclude that every regularity is a sign of ‘quiet’ and that every irregularity is a sign of ‘activity’. This is an important lesson.

# Quiet Time Variations

- Diurnal      25 nT
  - Focus      Change of sign (irregular)
  - Lunar Phase      X 0.1
  - Annual      X 2
  - Solar Cycle      X 3 (irregular)
  - Secular      10%/century (irregular)
- Mixture of regular and **irregular** changes



# Disturbance Variations

<input type="checkbox"/> Sporadic Storms	300 nT	
<input type="checkbox"/> Recurrent Storms	100 nT	(recurrent)
<input checked="" type="checkbox"/> Semiannual/UT var.	25%	(modulation)
<input checked="" type="checkbox"/> Annual	5%	(modulation)
<input type="checkbox"/> Bays	20-50 nT	
<input type="checkbox"/> Secular	?	

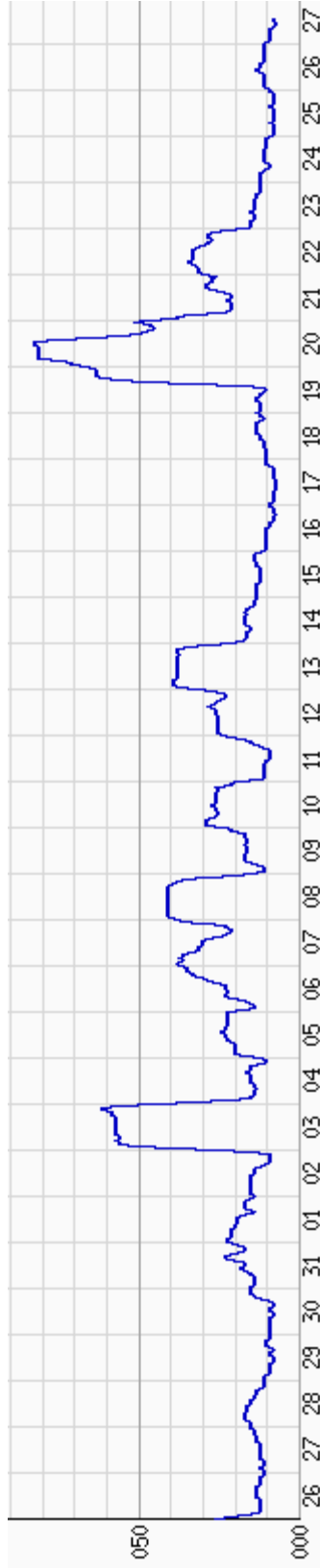
Mixture of irregular and **regular** changes

Note: As seen at mid-latitudes



# Quantitative Indices

We also use the word index as meaning a *quantitative* measure as a function of time of a *physical* aspect of the phenomenon, e.g. the Dst-index or the lesser known Tromsø Storminess-index:



# Model of Geomagnetic Variations

It is customary to decompose the observed variations of the field  $B$ , e.g. for a given station to first order at time  $t$ :

$$B(t) = B_o(t) + Q(l,d,t) + D(t) \cdot M(u,d)$$

where  $u$  is UT,  $d$  is day of year,  $l$  is local time, and  $M$  is a modulation factor. To second order it becomes a lot more complex which we shall ignore here.

# Separation of Causes

To define an index expressing the effect of a physical cause is now a question of subtraction, e.g.:

$$D(t) \cdot M(u,d) = B(t) - [B_o(t) + Q(l,d,t)]$$

or even

$$D(t) = \{B(t) - [B_o(t) + Q(l,d,t)]\} / M(u,d)$$

where M can be set equal to 1, to include the modulation, or else extracted from a conversion table to remove the modulation

# Fundamental Contributions



Julius Bartels [1939, 1949]

- ❑ Remove  $B_0$  and  $Q$  judiciously, no 'iron curve'
- ❑ Timescale 3 hours, match typical duration
- ❑ Scale to match station, defined by limit for  $K = 9$
- ❑ Quasi-logarithmic scale, define a typical class to match precision with activity level

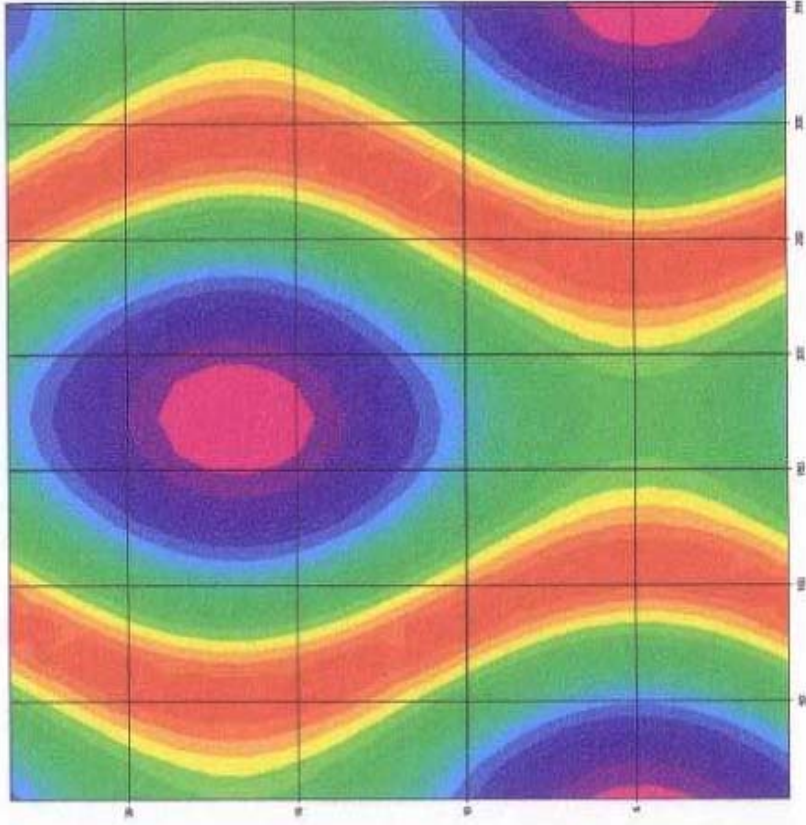
# The Expert Observer



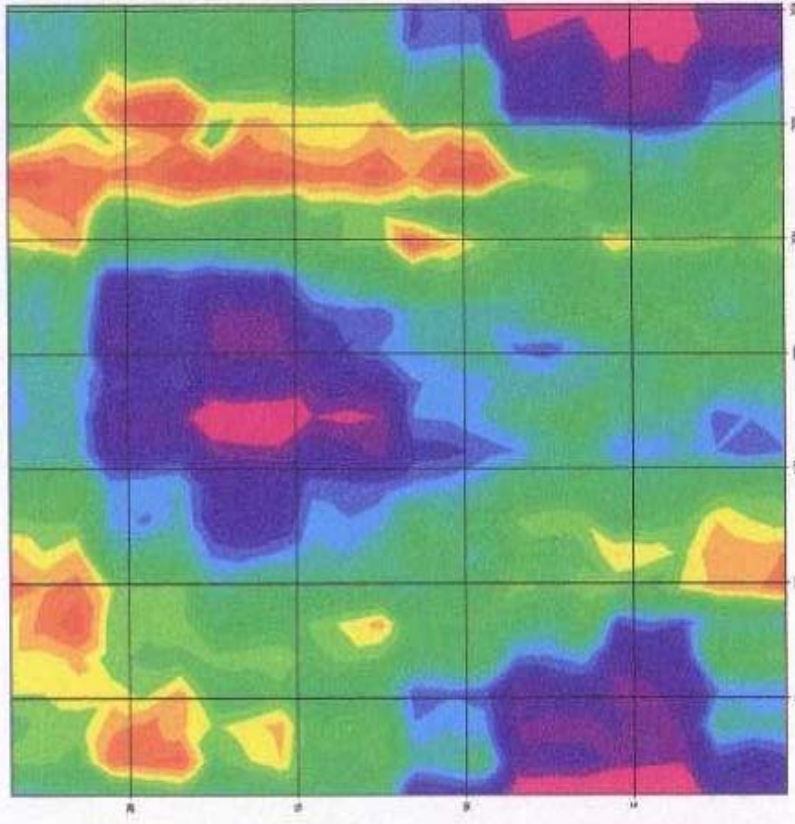
Pierre-Noël Mayaud, SJ [1967;1972] put Bartels' ideas to full use with the *am* and *aa*-indices.

A subtle, very important difference with Bartels' Ap is that the modulation, M, is *not* removed and thus can be studied in its own right.

# The Semiannual/UT Modulation



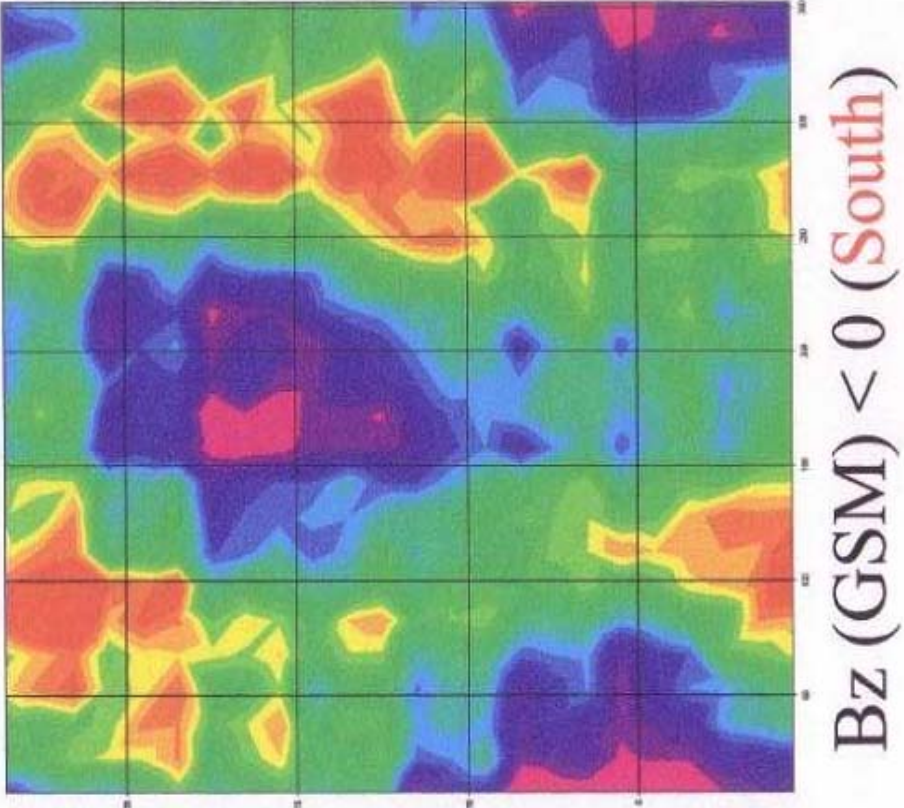
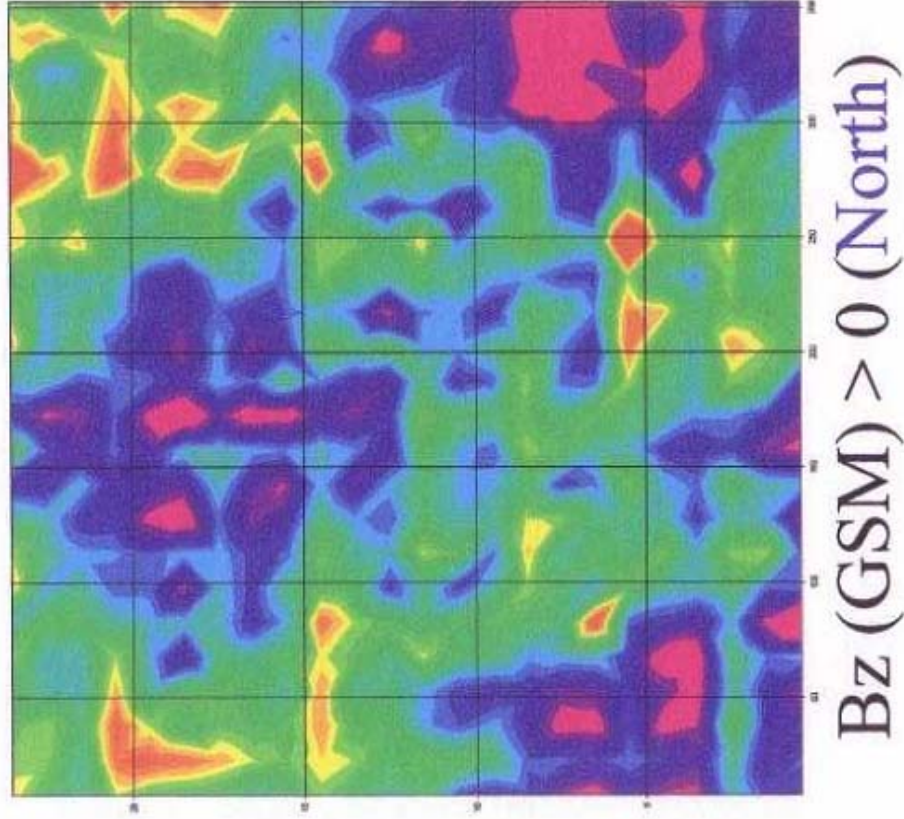
Dipole tilt,  $\Psi$



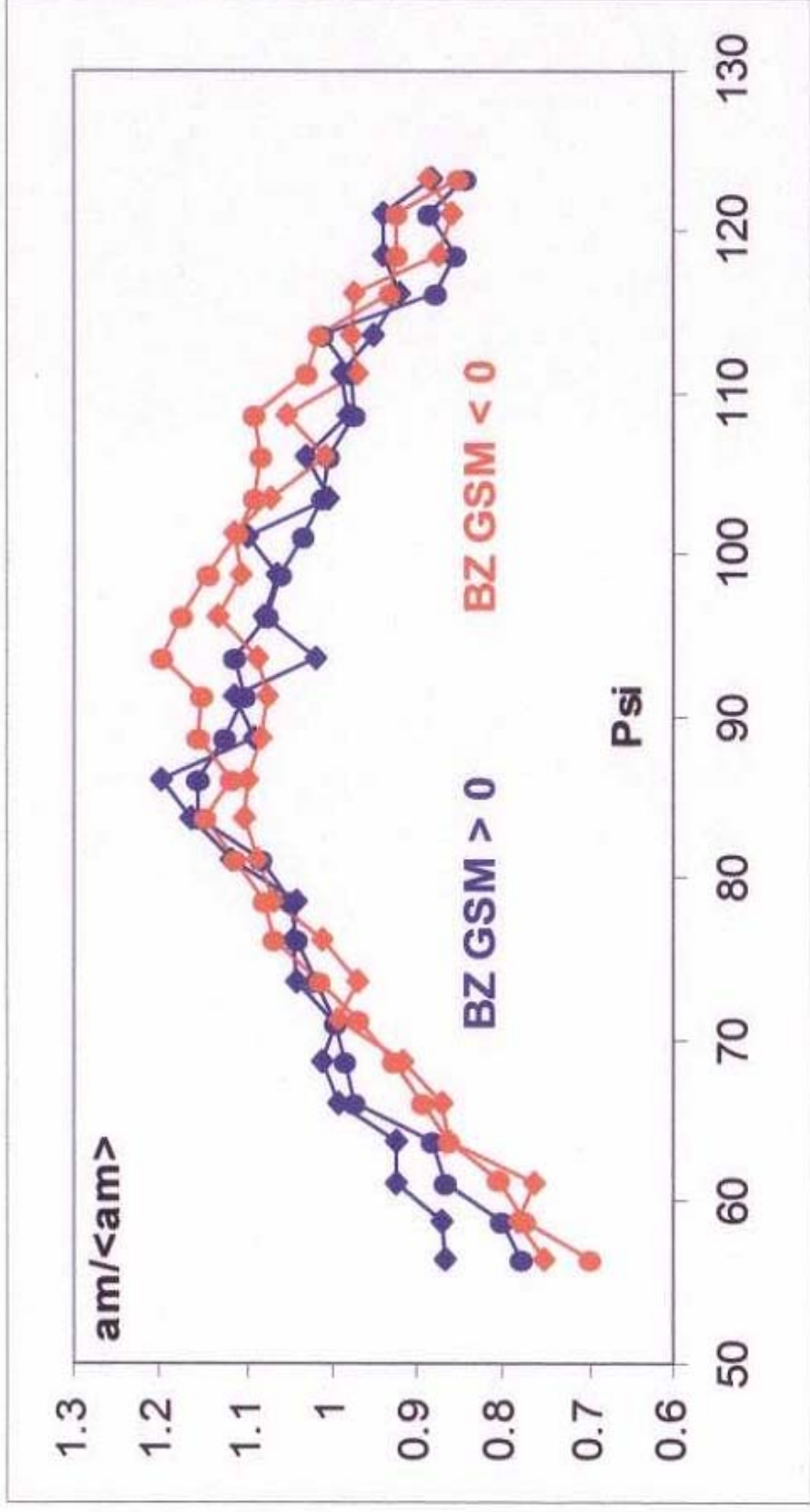
All orientations of  $\alpha$



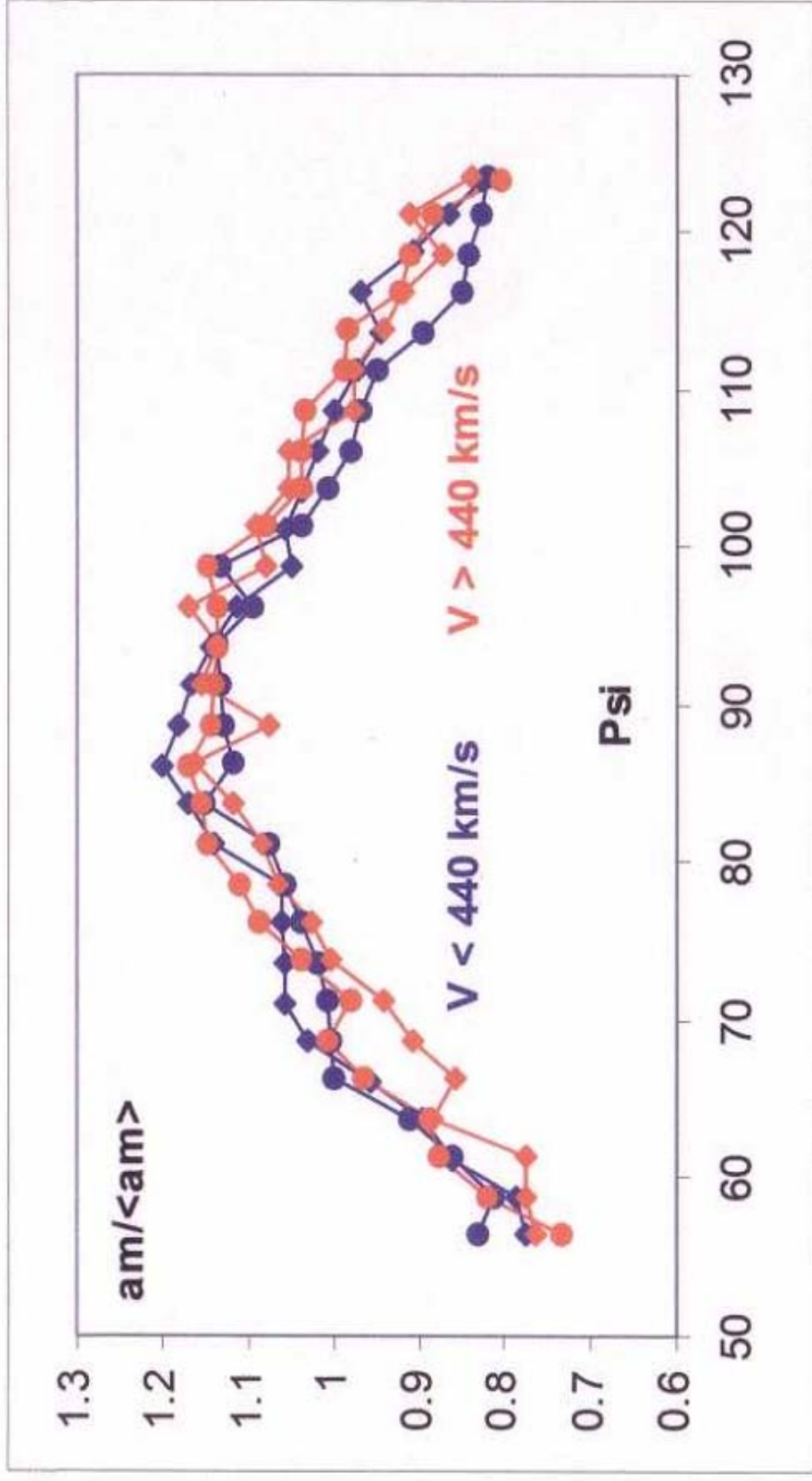
# Exists both for Southwards and for Northward fields (permanent feature)



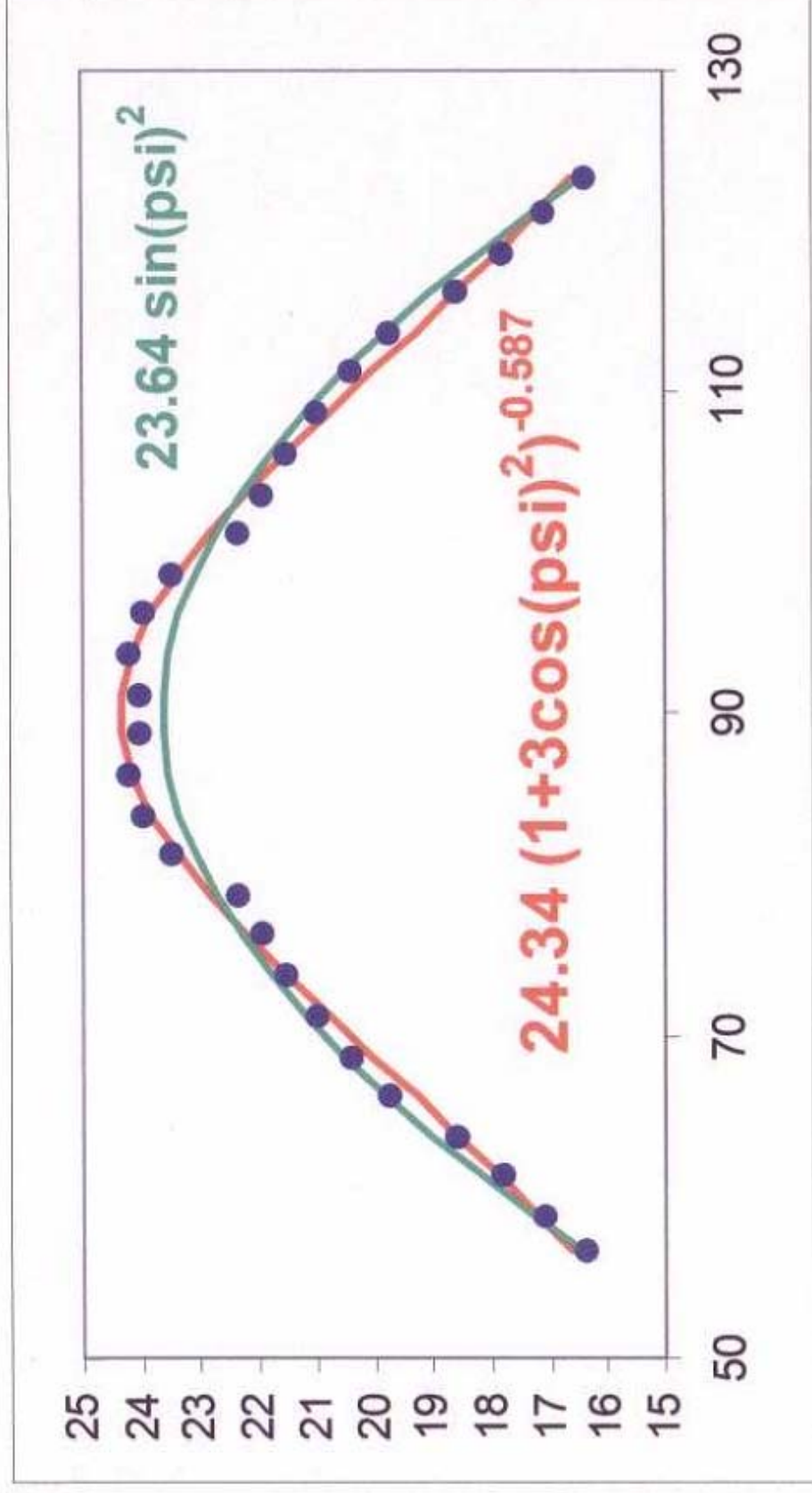
# Relative Magnitude Independent of Sign of Bz (Varies 30% or more)



# And does not Depend on Solar Wind Speed Either.



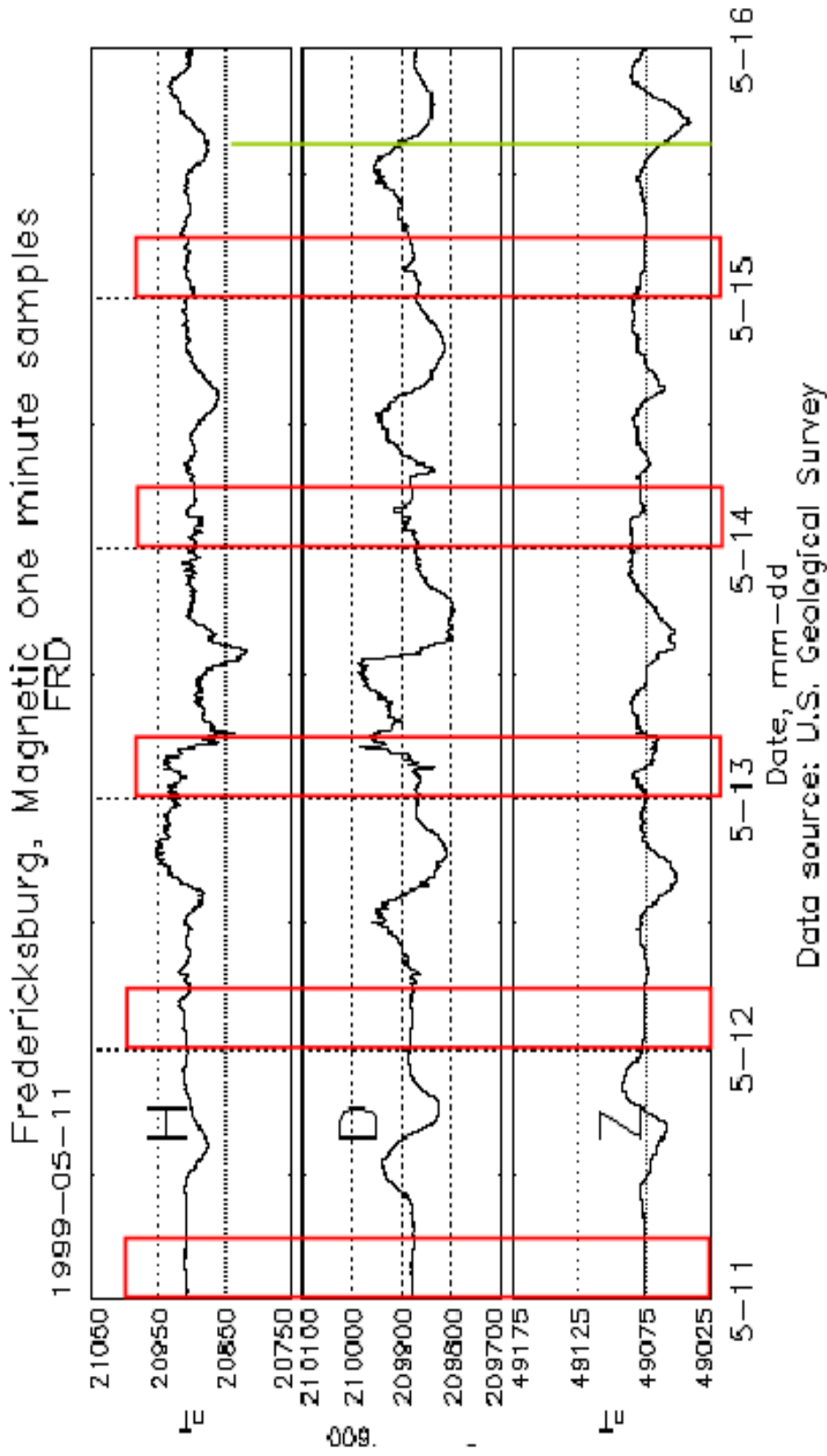
# $(1 + 3 \cos^2(\psi))$ is Basically Variation of Field Strength Around a Dipole



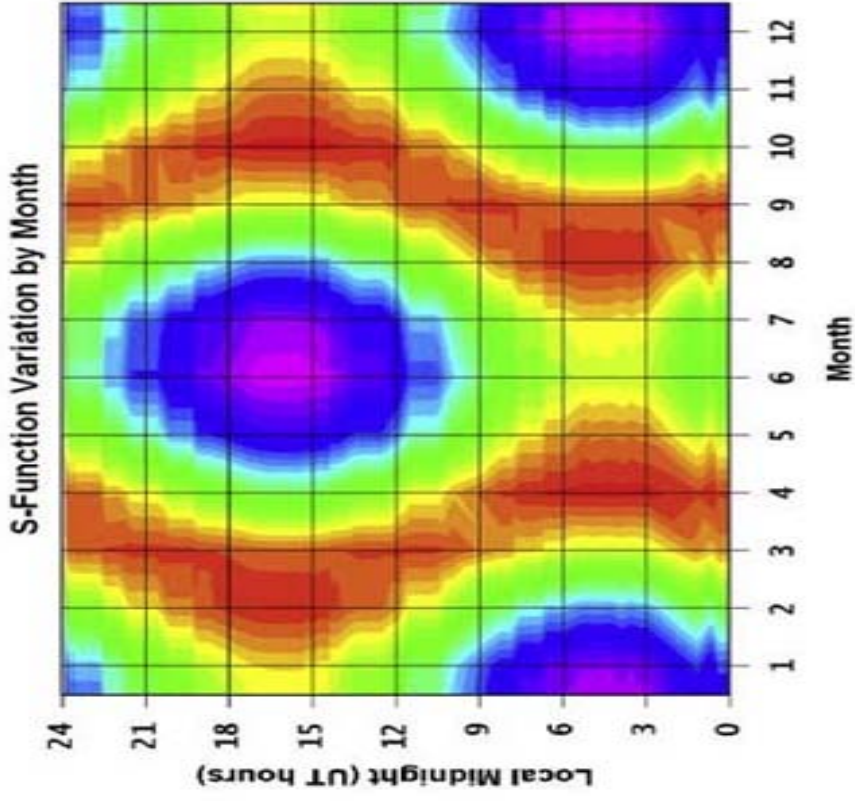
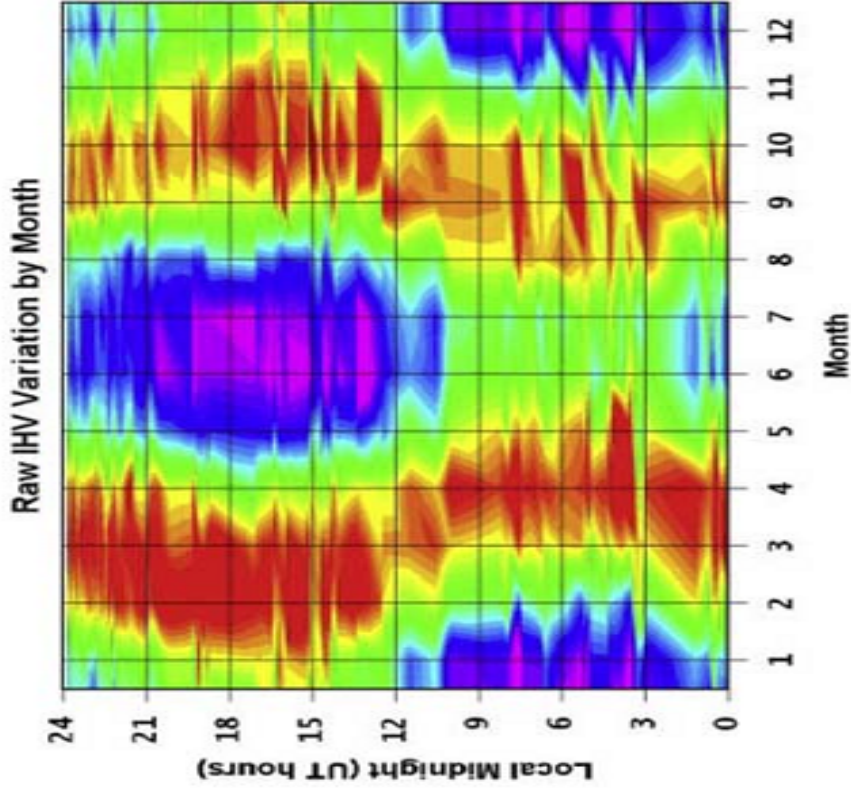
# The Lesson From Mayaud

- Mayaud stressed again and again not to use the ‘iron curve’, and pointed out that the observer should have a repertoire of ‘possible’ magnetogram curves for his station, and ‘*if in doubt, proceed quickly*’.
- He taught many observers how to do this. Unfortunately that knowledge is now lost with the passing of time [and of people].

# Since Determination of the Quiet Field During Day Hours is so Difficult, We Decided to Only Use Data Within $\pm 3$ Three Hours of Midnight (The IHV Index)



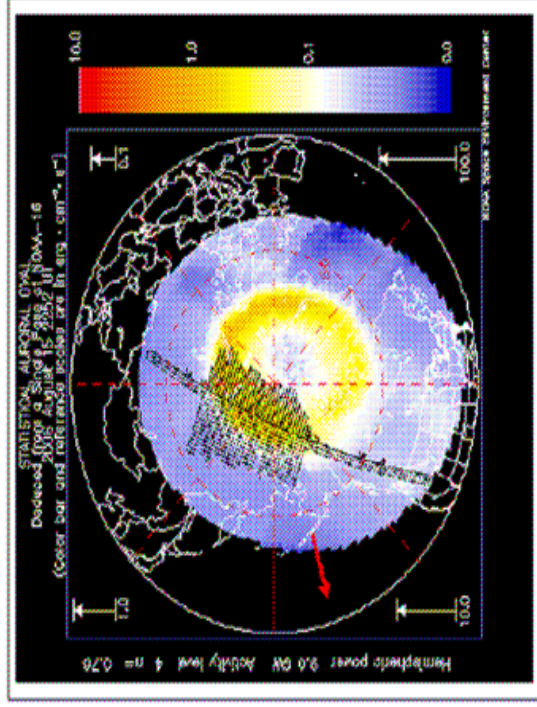
# The Midnight Data Shows the Very Same Semiannual/UT Modulation as all Other Geomagnetic Indices (The 'Hourglass')



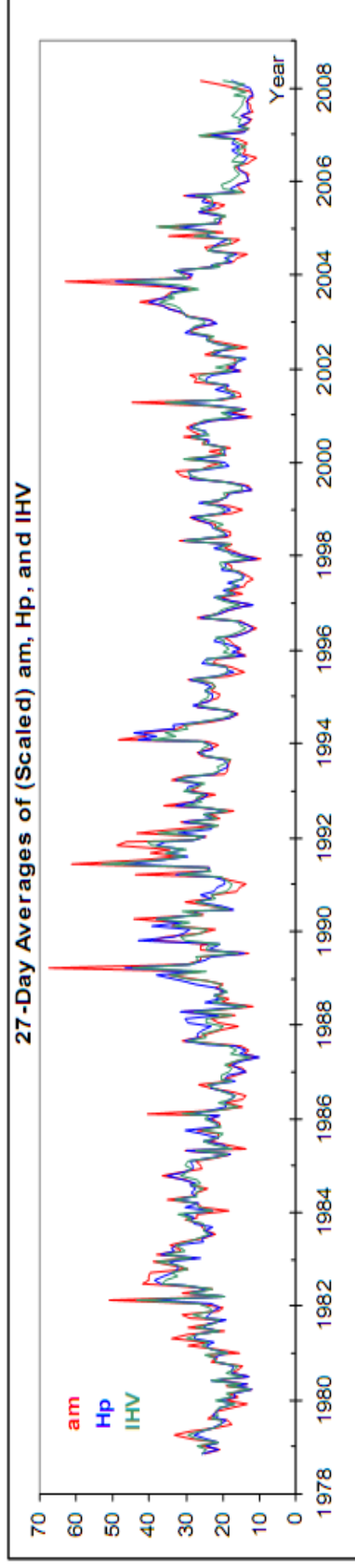
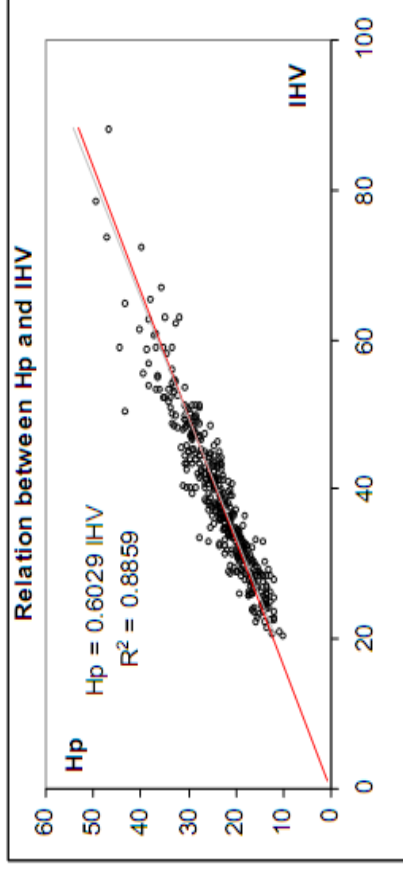




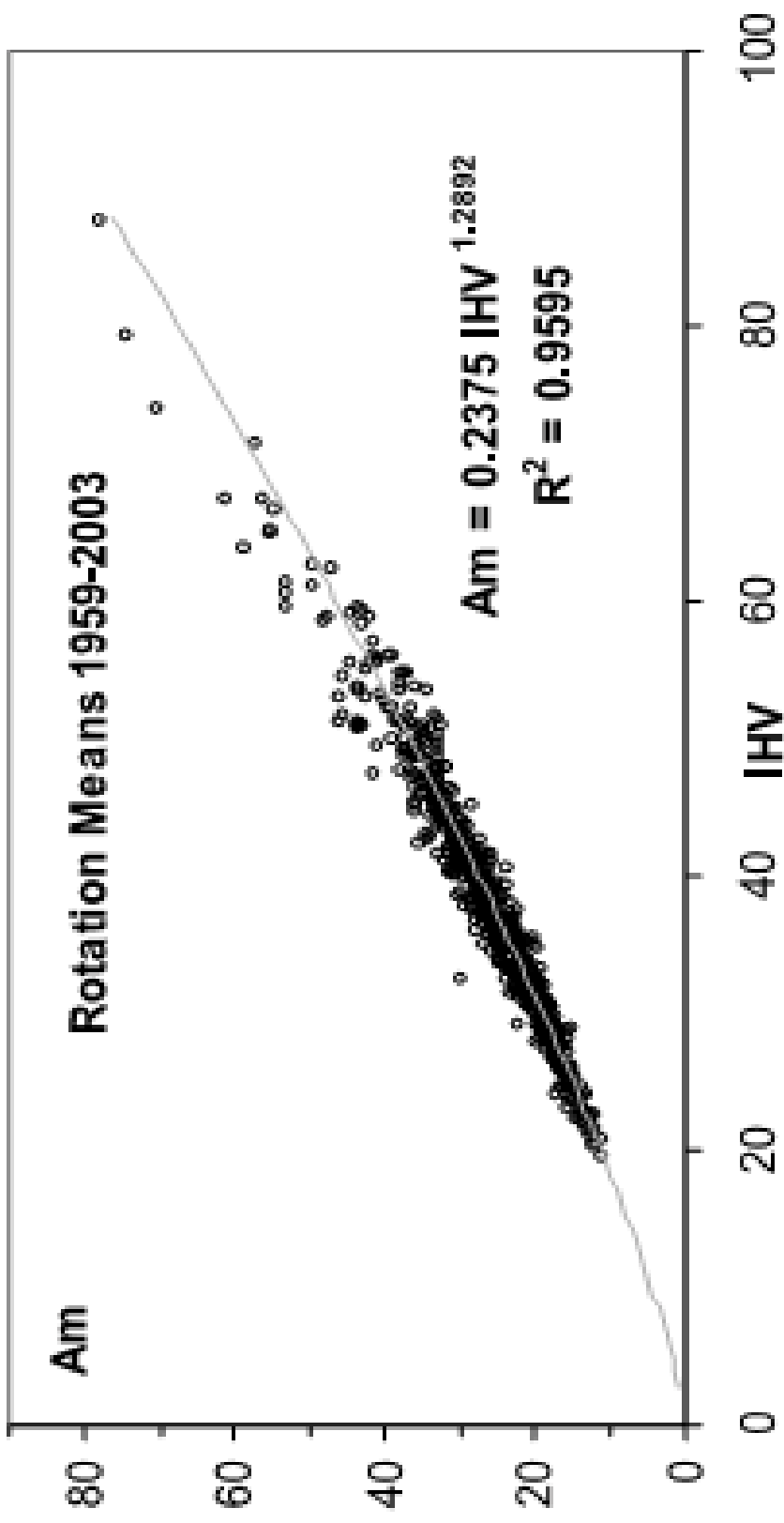
# IHV is a Measure of Power Input to the Ionosphere (Measured by POES)



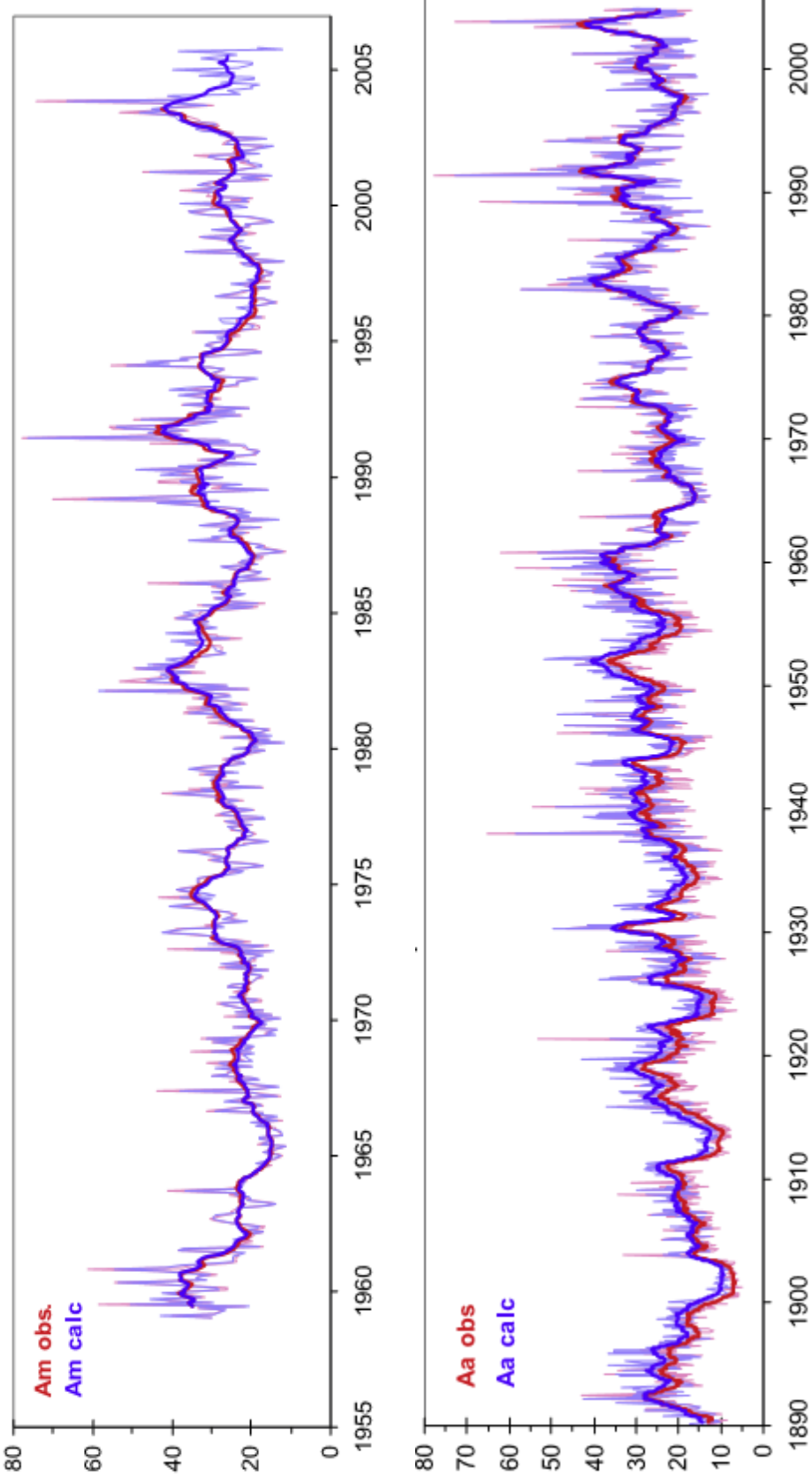
*IHV* is directly proportional to the power input (*Hp*) to the upper atmosphere:



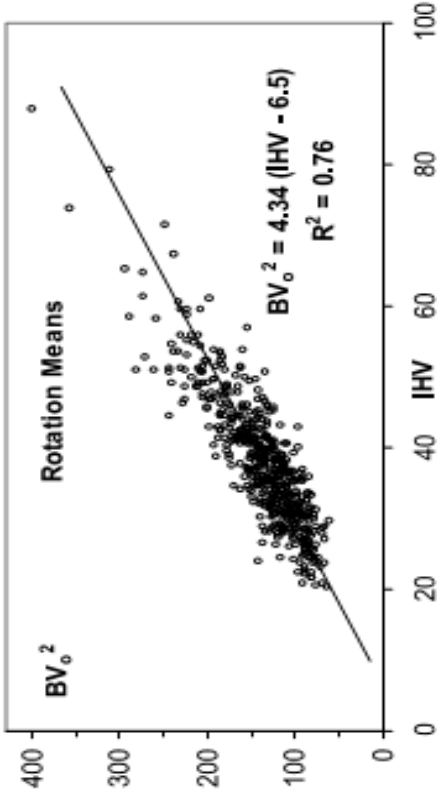
# IHV has Very Strong (Slightly Non-Linear) Relation with Am-index



# So We can calculate Am [and Aa] from IHV



# We can also Determine $BV^2$

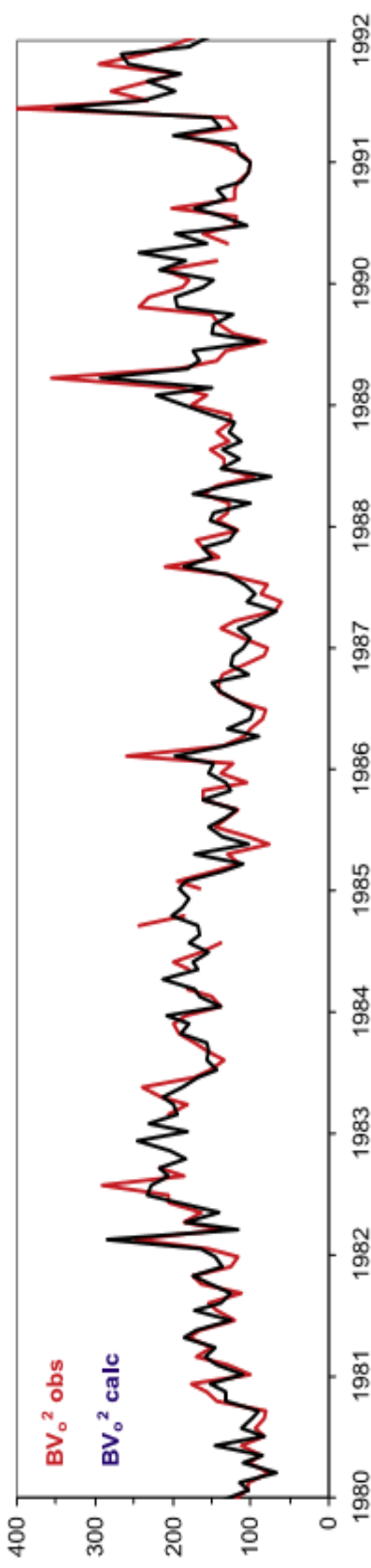


Solar Wind Coupling Function

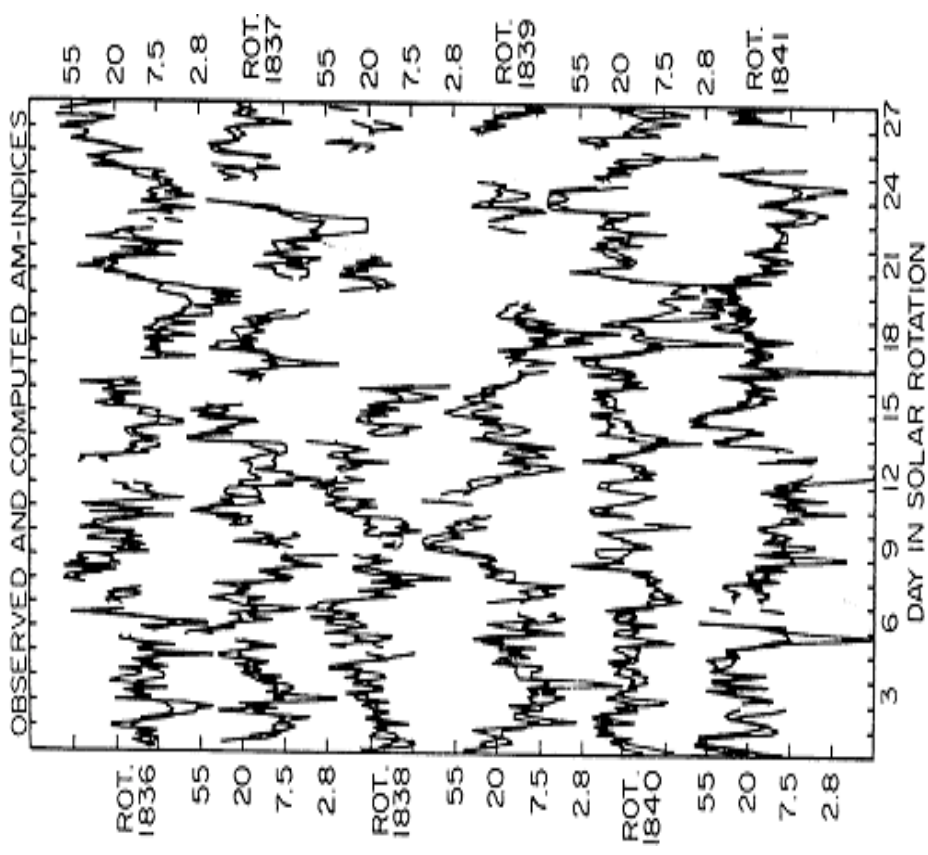
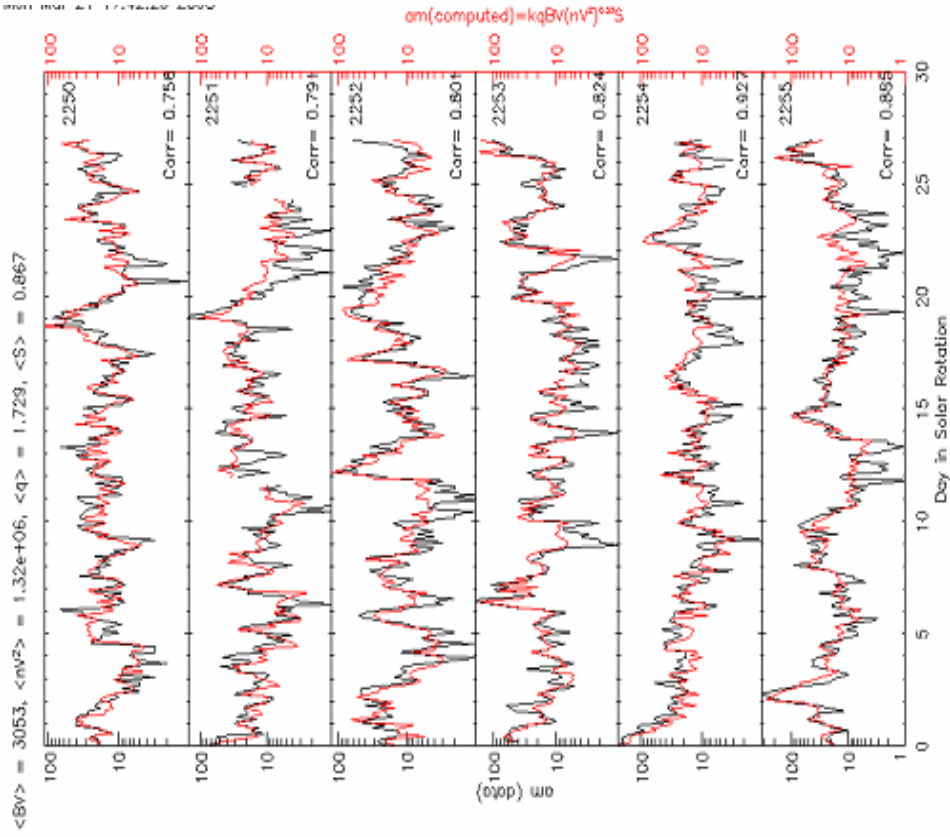
[Momentum, Reconnection, Modulations]

$$am = k (nV^2)^{1/3} (BV) q(\alpha, f) S(\Psi)$$

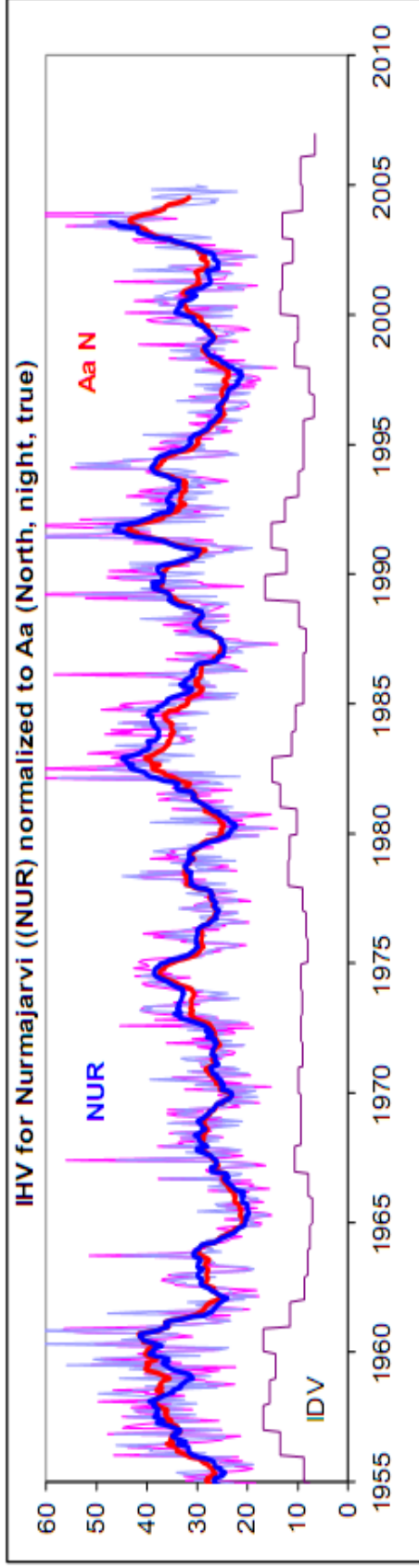
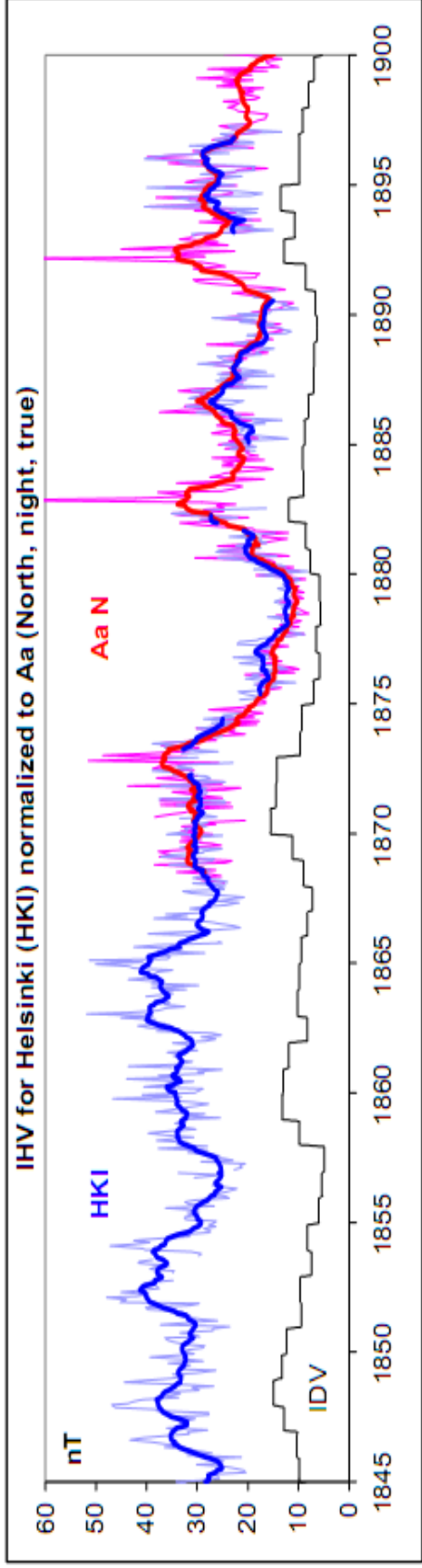
$$Am \sim BV^2$$



# The Coupling Function is a Very Good Description of Am



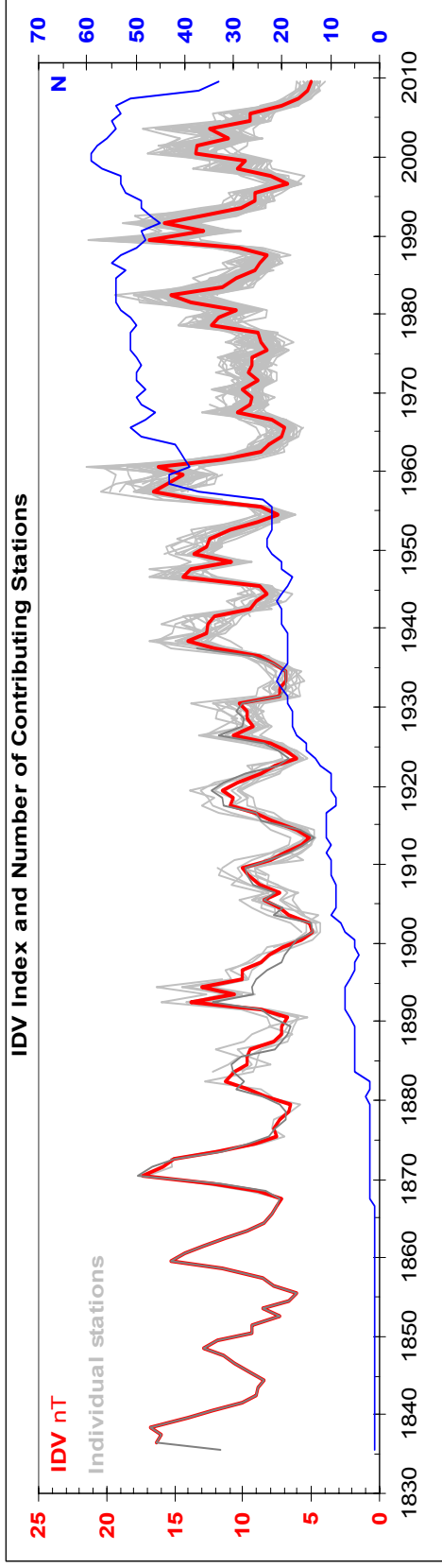
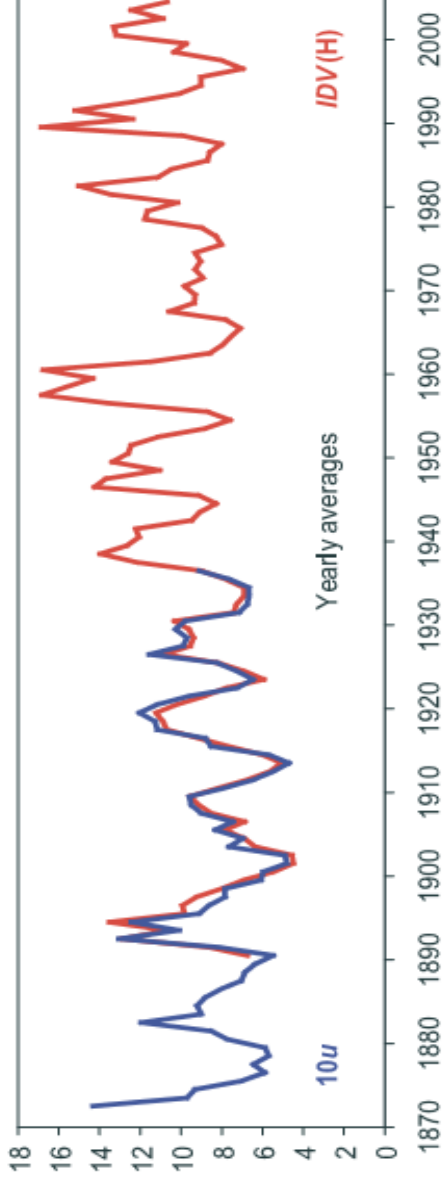
# Here We Compare [Corrected Aa] with Aa computed from IHV



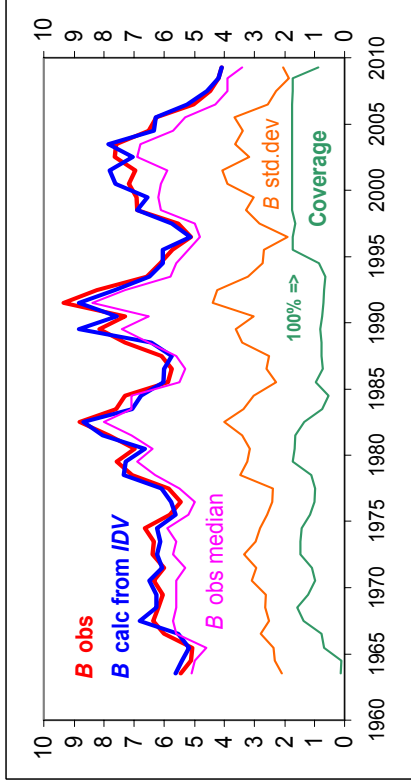
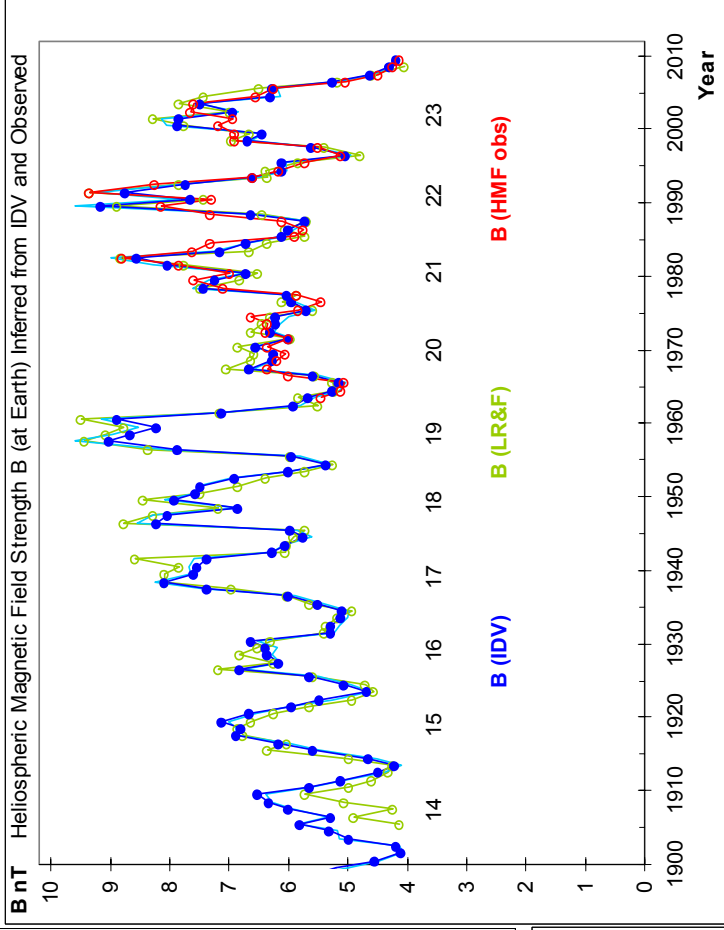
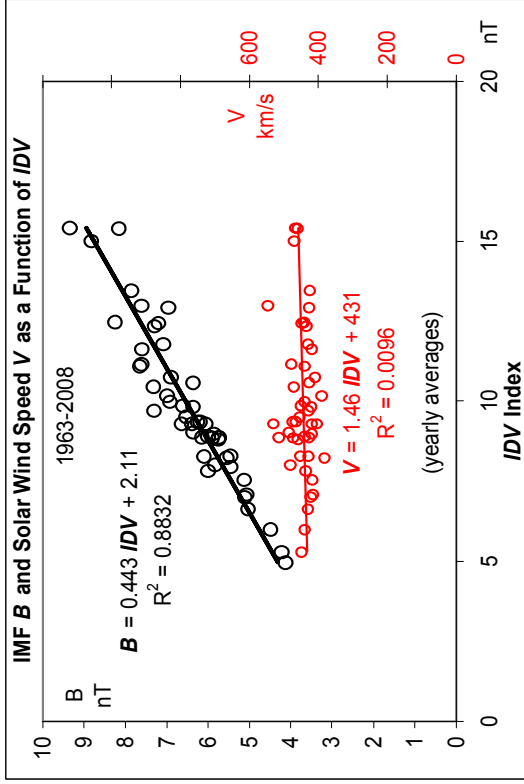
# Bartels' $u$ -measure and our $IDV$ -index

$u$ : all day |diff|,  
1 day apart

$IDV$ : midnight  
hour |diff|,  
1 day apart



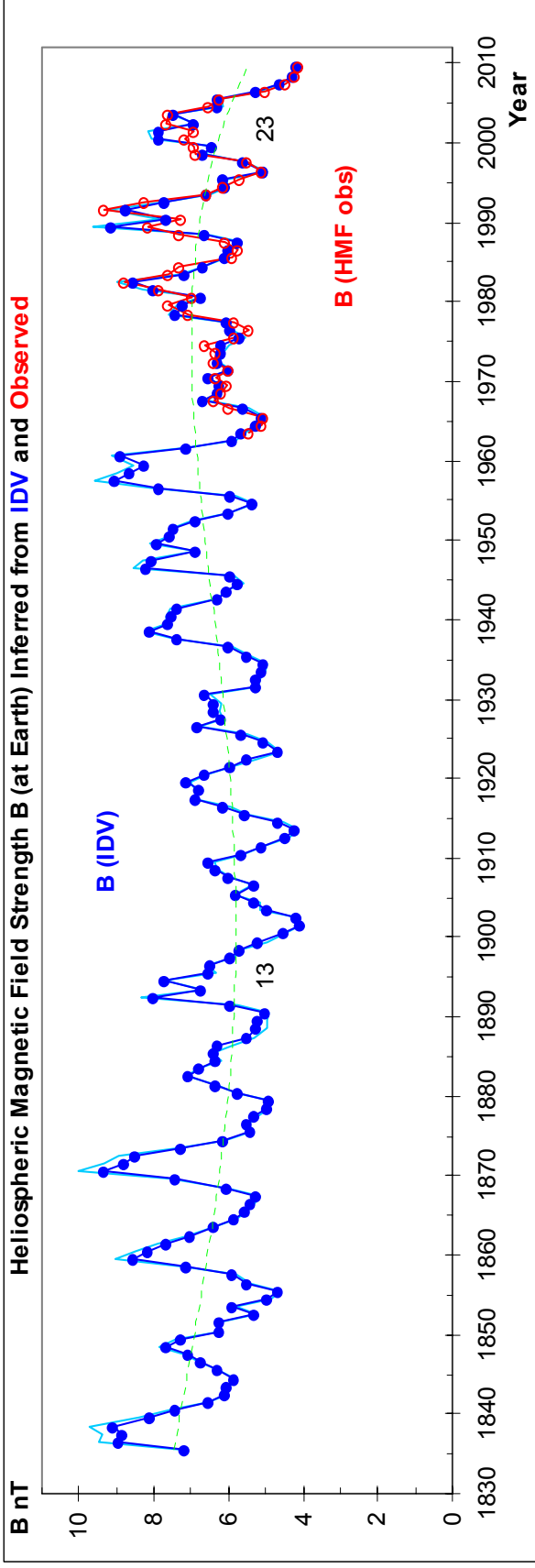
# IDV is Blind to $V$ , but has a Significant Relationship with HMF $B$



The HMF back to 1900 is strongly constrained



# We Can Even [With Less Confidence] Go Back to the 1830s



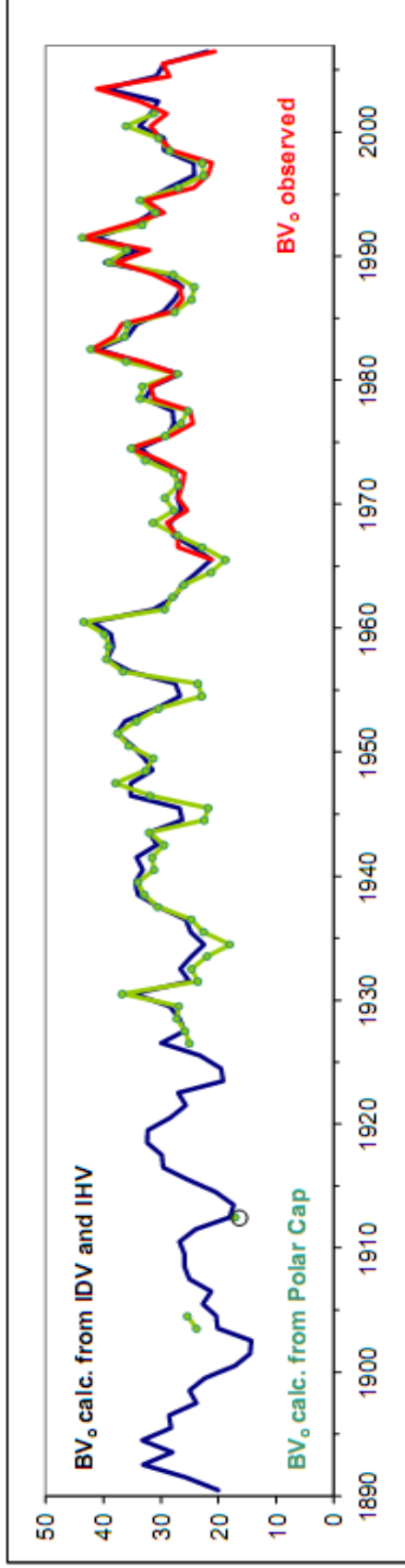
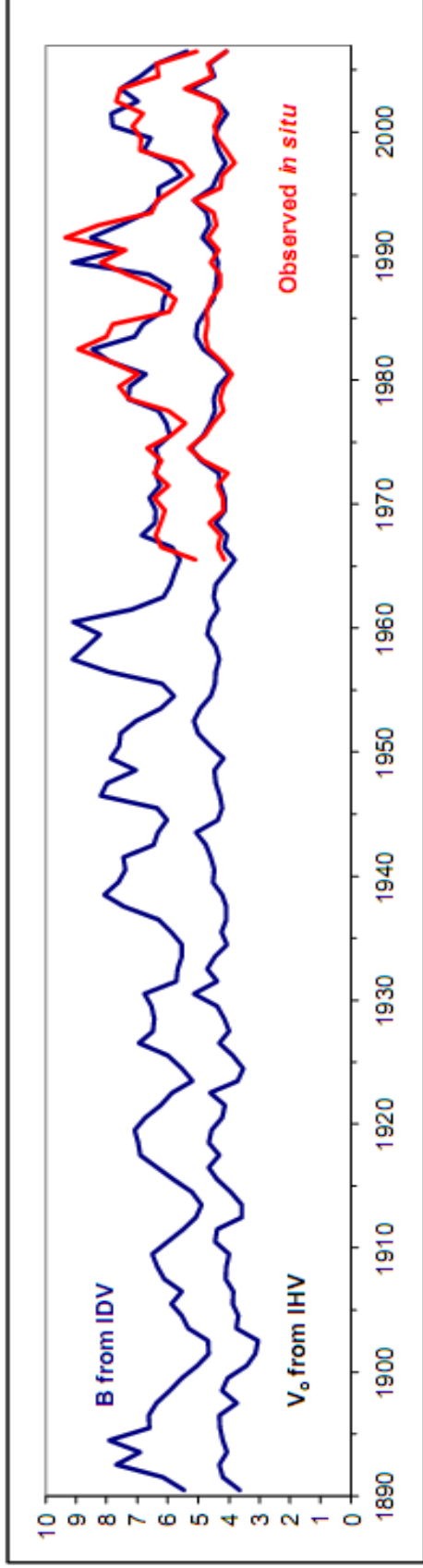
From IHV-index we get  $BV^2 = f(IHV)$

From IDV-index we get  $B = g(IDV)$

From PC-index we get  $BV = h(PCI)$

Which is an over-determined system allowing B and V to be found and cross-checked →

# With Good Agreement



# Conclusion

- From Canton, Sabine, Wolf, Bartels, and Mayaud, the patient recording [by many people] and growing physical insight have brought us to heights that they hardly could have imagined, but certainly would have delighted in. From their shoulders we see far.

“Ban the iron curve, whether wielded by human  
or by machine”

The End

# Abstract

Geomagnetic variation is an extremely complicated phenomenon with multiple causes operating on many time scales, characterized by 'regular irregularity, and irregular regularity'. The immense complexity of geomagnetic variations becomes tractable by the introduction of suitable geomagnetic indices on a variety of time scales, some specifically targeting particular mechanisms and physical causes. We review the historical evolution of the 'art of devising indices'. Different indices [by design] respond to different combinations of solar wind and solar activity parameters and in Bartels' [1932] words "yield supplemental independent information about solar conditions" and , in fact, have allowed us to derive quantitative determination of solar wind parameters over the past 170 years. Geomagnetic indices are even more important today as they are used as input to forecasting of space weather and terrestrial responses.