The Solar Wind - Magnetosphere Coupling Function and Nowcasting of Geomagnetic Activity

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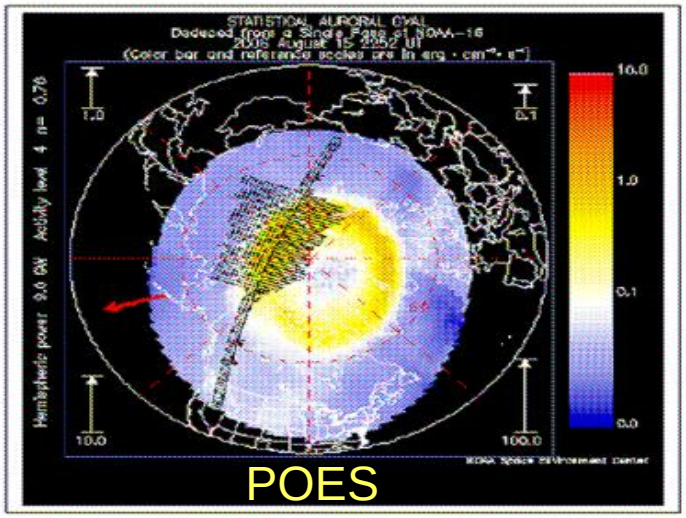
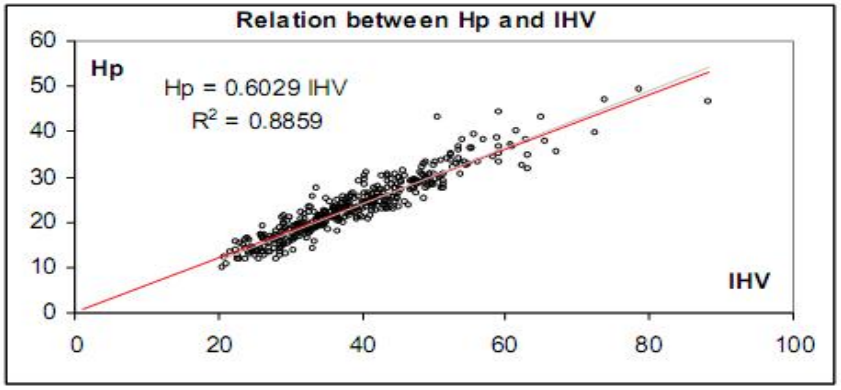
AMS-93, Austin, Jan. 2013

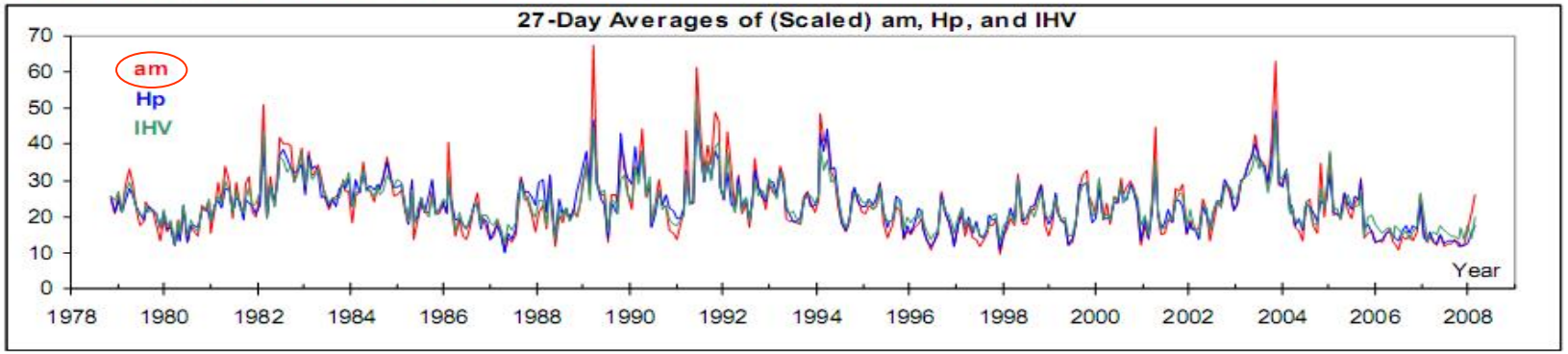
Geomagnetic Indices have been Constructed which are Measures of Power Input to the Ionosphere (Magnetosphere)

and *am*



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





One of the best on short time scales (3 hours) is the *am*-index based on many stations with good longitudinal coverage in both hemispheres

The Coupling Function:

How to calculate the power input from solar wind parameters

Geomagnetic activity as given by the three-hour *am*-index has been found [Svalgaard 1978] to depend on solar wind parameters and the geometry of their interaction with the Earth as this:

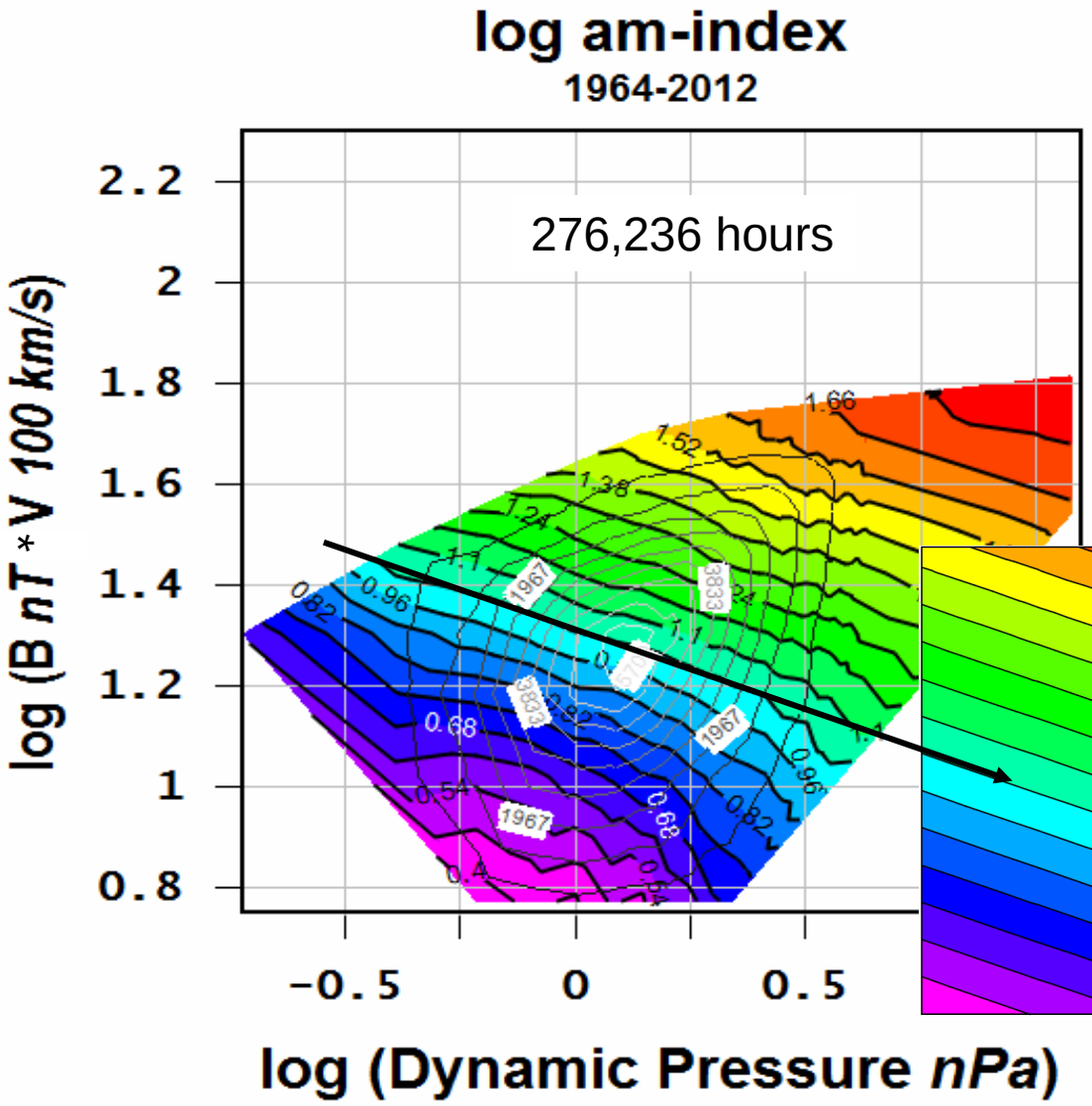
$$am = k\,(nV^2)^{1/3}\,(BV)\,q(\alpha, f)\,S(\Psi)$$

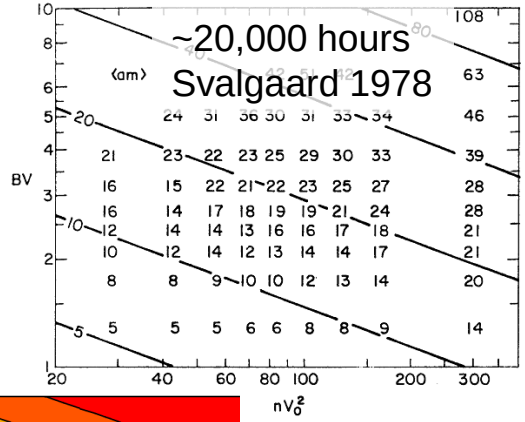
where the various factors have meaning of Momentum flux, Magnetic Reconnection, and Geometric Modulation, and where B is the Interplanetary Magnetic Field (IMF) strength, V is the Solar Wind Speed, q is a function of the angle α between the IMF and the Earth's magnetic field at the 'nose' of the magnetopause, and the relative variability f is defined as $\sqrt{(\sigma_{Bx}^2 + \sigma_{By}^2 + \sigma_{Bz}^2)}/\sigma_B$. n is the solar wind density and S is a function of the dipole tilt, Ψ, against the solar wind flow.

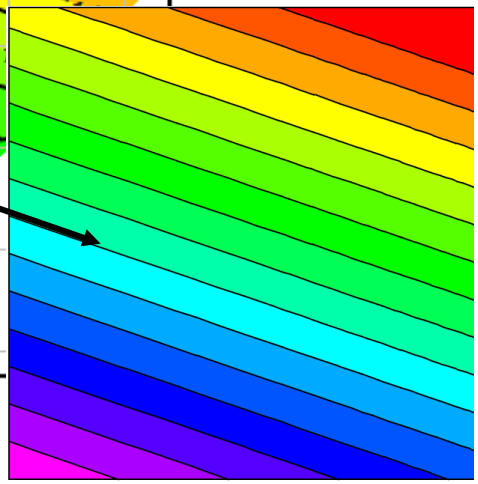
The above finding was based on ~20,000 hours of Interplanetary data. Today we have an order of magnitude more data, so it is of interest to see how well the finding holds up.

Being able to determine geomagnetic activity from upstream Interplanetary Solar Wind properties obviously gives us Nowcasting and [short-term] Prediction capabilities. Inversion of the process provides monitoring of long-term solar wind properties due to the centuries-long observations of geomagnetic activity.

am ~ $(BV)(nV^2)^{1/3}$







Plot of the function:

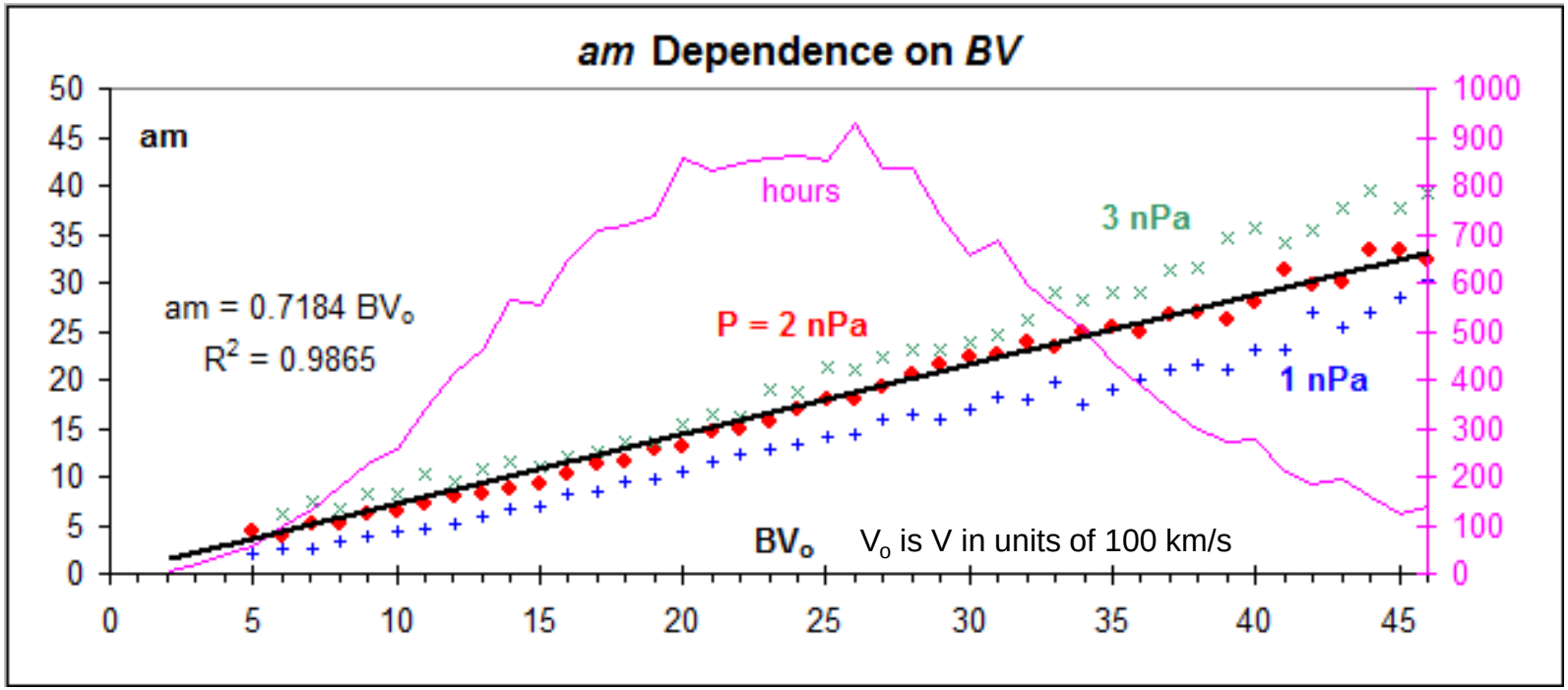
$Z = Y X^{1/3}$

On log scales

So the relationship is strongly confirmed

Dynamic Pressure ~ m nV^2

The *am*-index scales with *BV*

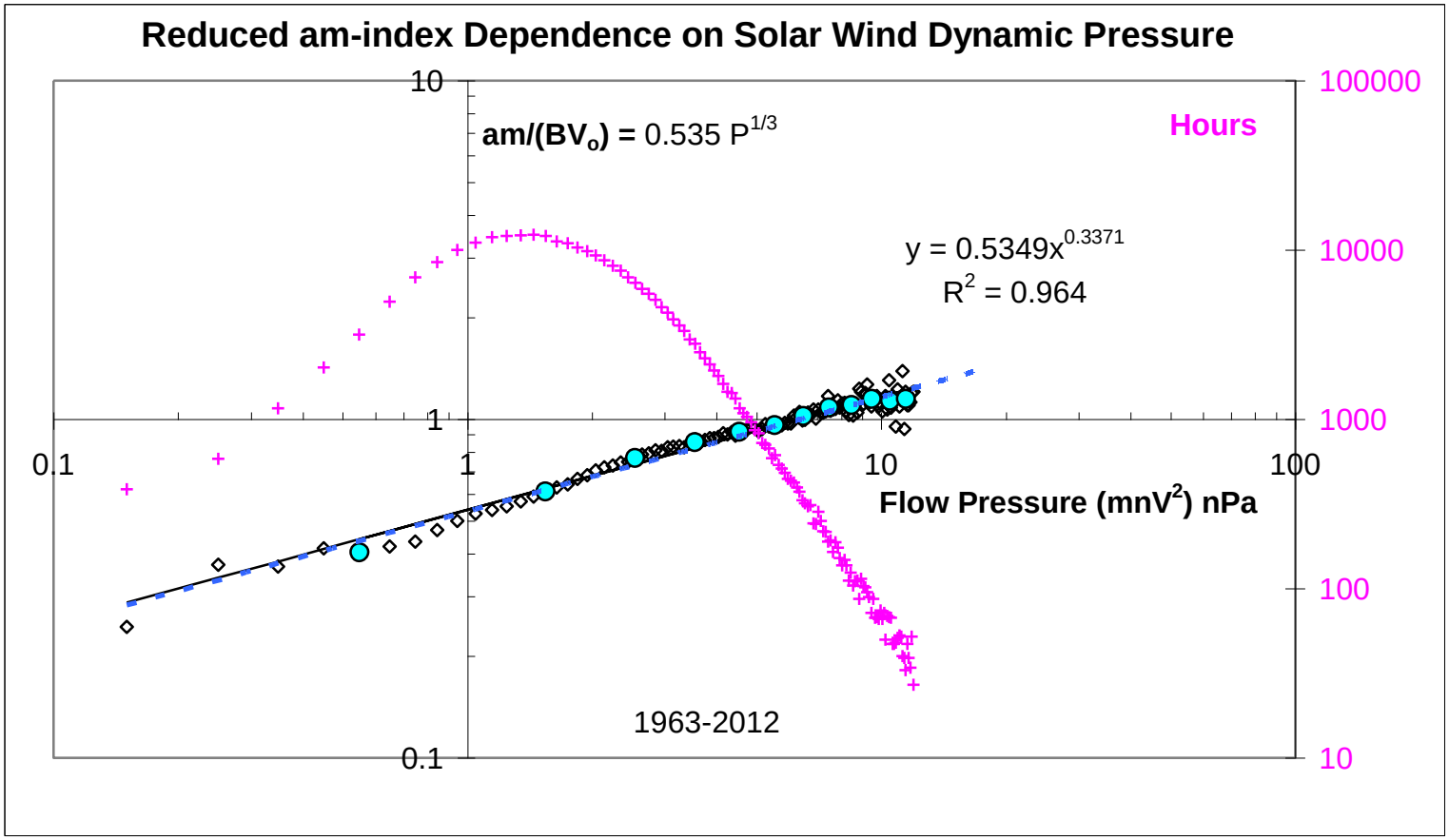


For a given level of dynamic pressure, *am* is proportional to *BV*

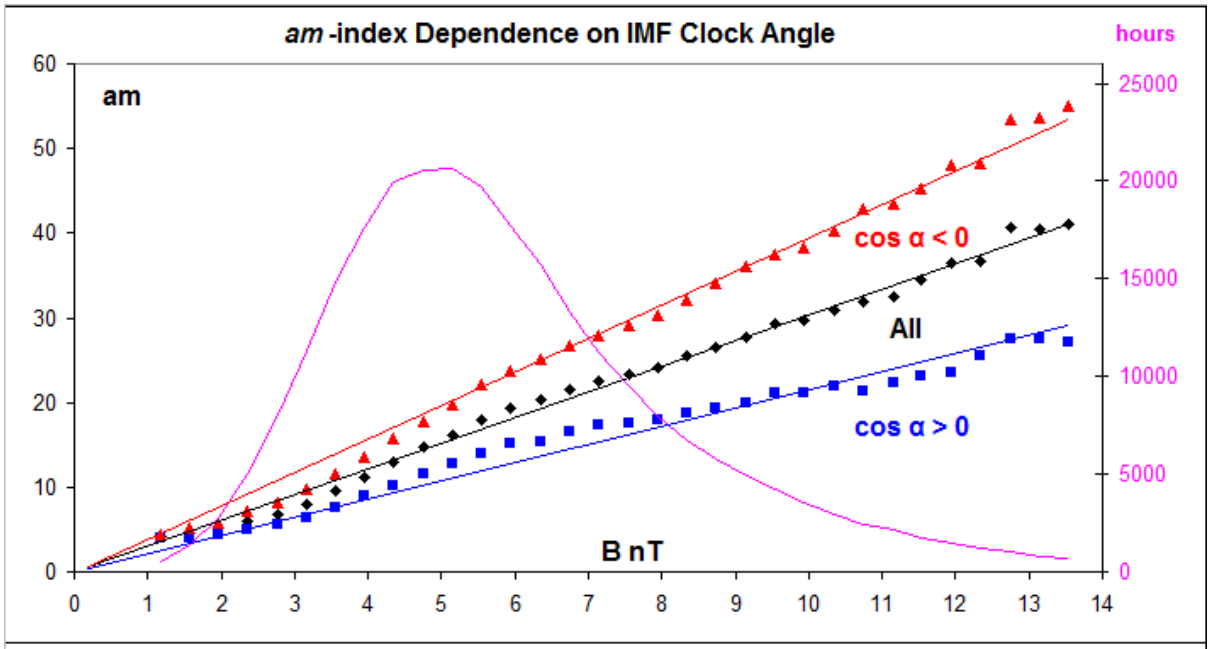
The 'hours' is the number of hours of data in each binned data point.

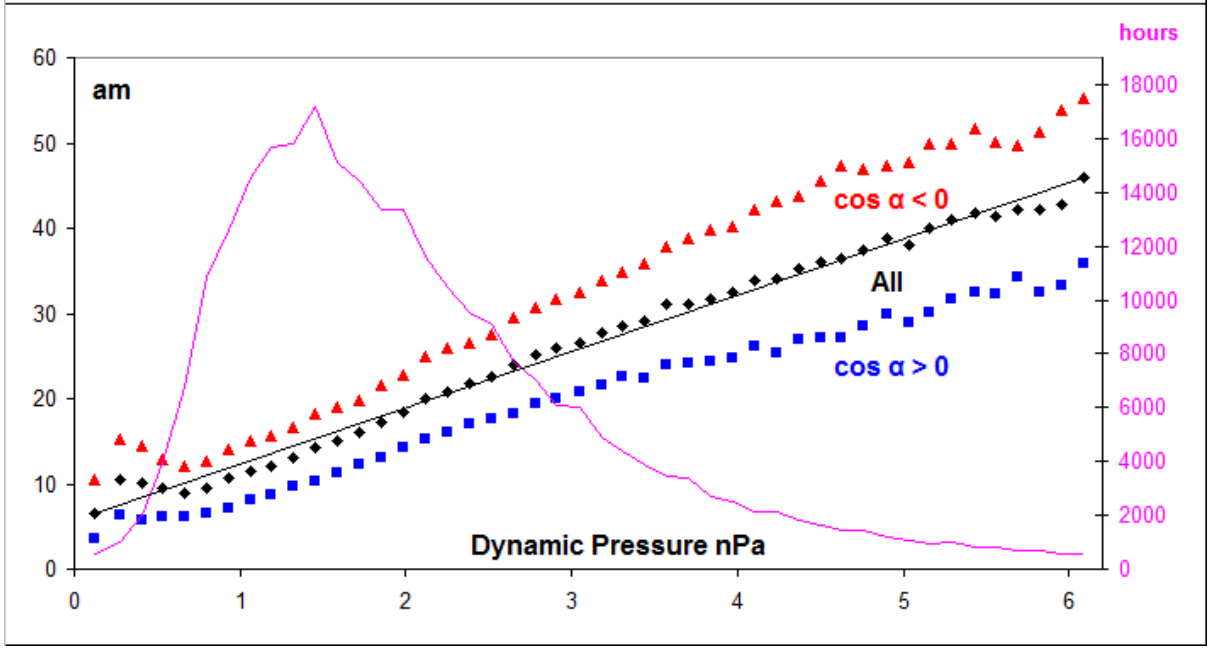
Note: the 3-hour am-index has been interpolated to 1-hour resolution. In the 1978 analysis, the solar wind data were averaged to 3-hour resolution. It does not make any difference. The results are the same.

We can remove the dependence of *am* on *BV* by dividing *am* by *BV*:

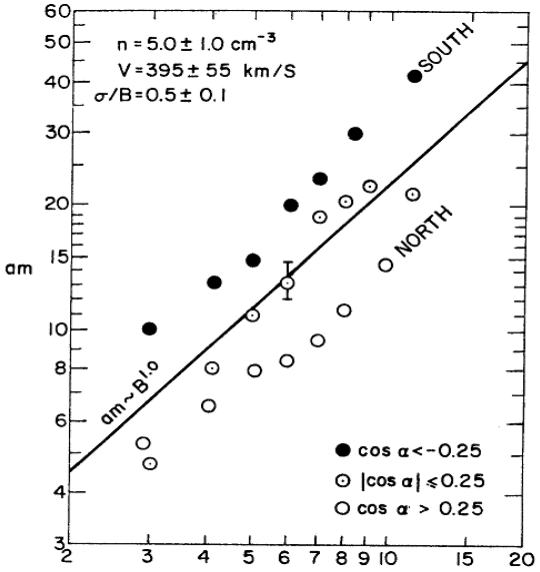


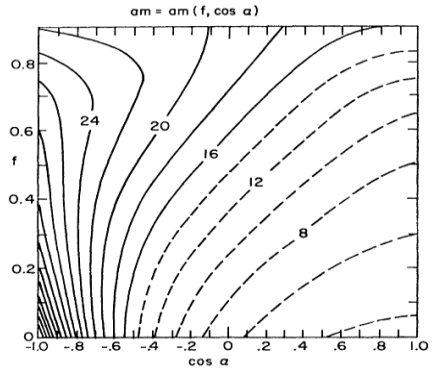
Showing the clear dependence on the dynamic pressure (P). The 1/3 power reminds me of the famous Hopkinson-Cranz-Sachs 'cube root scaling law' for shock waves





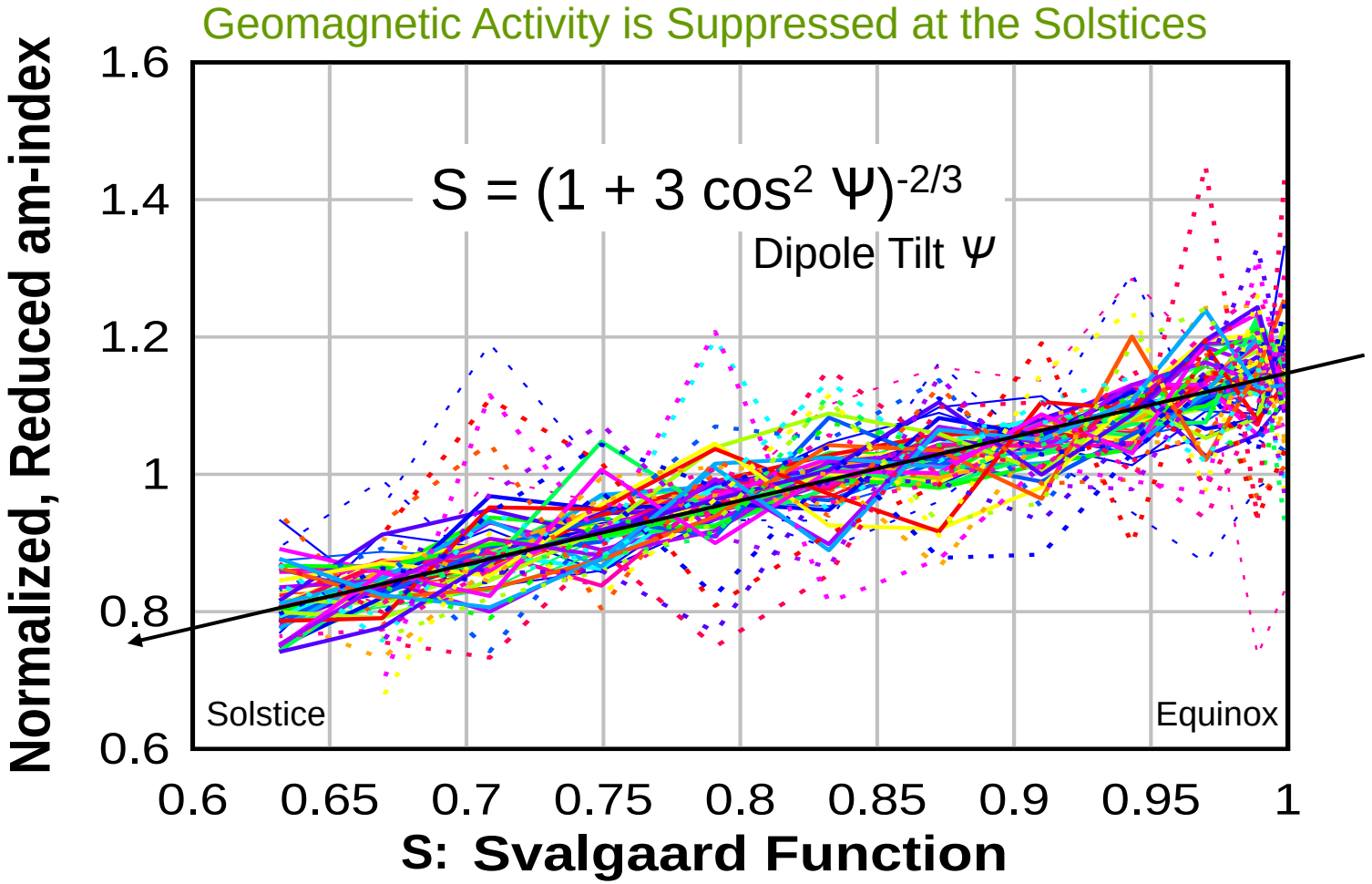
The Dependence on IMF Clock Angle hasn't changed



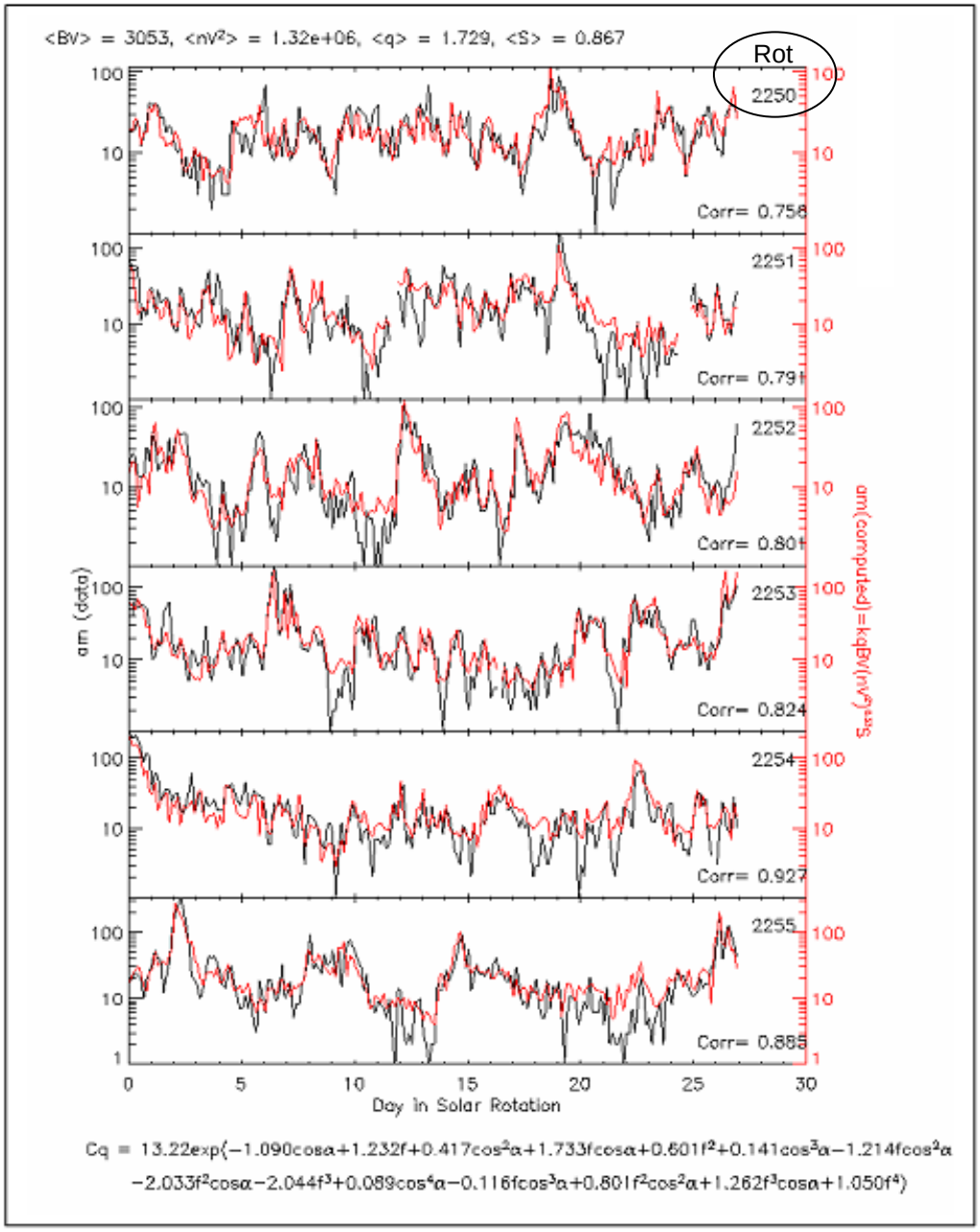


q-function depends both on *f* and on cos *α*

If we remove the effect of the Merging Electric Field [qBV] and the Dynamic pressure [mnV^2] by dividing am by $\{(BV)[nV^2]^{1/3}\}$ one effect remains: the Semiannual/UT variation



Describes well the modulation depending on Ψ, completing the expression for the Coupling Function



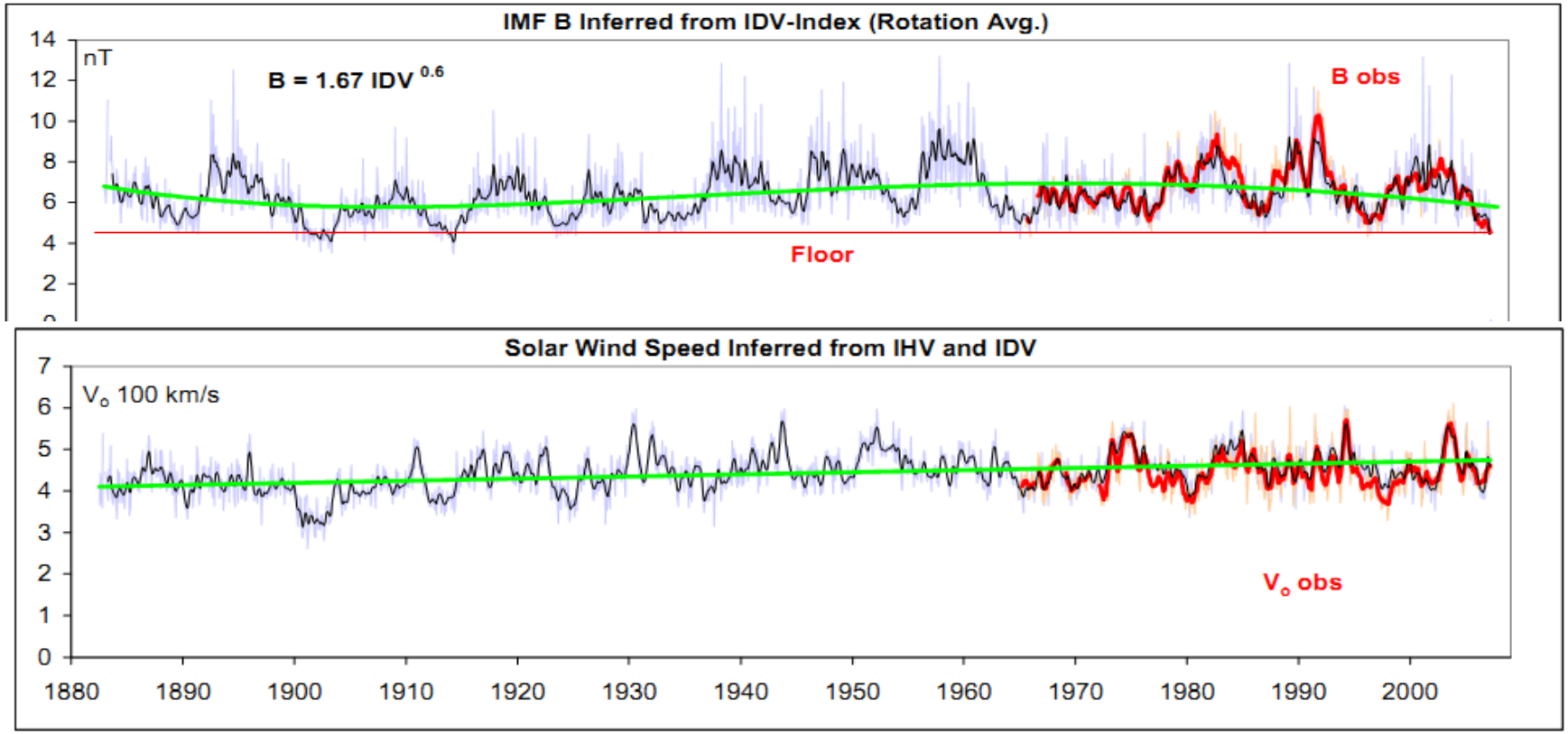
The Original Coupling Function and its Verification here calculate Geomagnetic Activity very precisely on 3-hour resolution

The red curve is the calculated *am*-index over six 27-day Bartels Rotations, while the black curve is observed *am*. The scale is logarithmic to show how well the curves match at all levels of activity.

The match is very good, except for very low values of *am* where the index is very difficult to measure [and where the activity doesn't matter much anyway].

Conclusions

- $am = k\,(BV)\,q(f,\alpha)\,(nV^2)^{1/3}\,S(\Psi)$
- As f depends weakly on V we find that on timescales of several rotations
  $am \sim BV^2$ [similarly for the *IHV* index which is a proxy for *am*]
- This in combination with other indices [e.g. *IDV*] that are proxies for *B* alone, allows us to reconstruct *B* and *V* for times past:



Abstract

We present an semi-empirical derivation of a solar wind - magnetospheric coupling function depending on solar wind parameters and the geometry of their interaction with the Earth including Momentum Flux, Magnetic Reconnection, and Geometric Modulation. The coupling function performs well at all levels of geomagnetic activity at time-scales from one hour and up. We also show how to invert the coupling function, allowing us to infer solar wind parameters in the past ~180 years from the historical geomagnetic record.