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The Semiannual Variation of Geomagnetic Activity: Protons or Photons?

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The Semiannual Variation of Geomagnetic Activity (SAV) has been known for a long time (Broun, 1848: Sabine, 1856). We still don't know what causes it. Several explanations have been put forward:

1: The "Axial" hypothesis, AX, (Cortie, 1912) invoking driving forces varying with heliographic latitude of the Earth.

2: The "Equinoctial" hypotheses, EQ, (Bartels, 1925) asserting that activity is modulated by an unknown process sensitive to the angle between the geomagnetic dipole and the direction to the sun.

3: The "R-M Effect", RM, (Russell & McPherron, 1973) leading to enhanced GSM-Southward IMF at the equinoxes resulting in stronger reconnection at the magnetopause and thus increased energy input to the magnetosphere.

4: Lack of "Solar Illumination", SI, (Lyatsky *et al.*, 2001) on one polar region ionosphere at each solstice, inhibiting or reducing geomagnetic activity.

Several other mechanisms (including variations of the above) have been suggested. It is possible (indeed, likely) that the observed SAV is a combination of several causes.

The mechanisms fall in two categories:

A: "Excitation", where the effects directly "produce" geomagnetic activity (possibly hypotheses 1 and 3).

B: "Modulation", where the effects modulate "existing" activity (possibly hypotheses 2 and 4).

"Geomagnetic Activity (including auroral activity)" is a very complicated phenomenon. To reduce the complexity, we commonly resort to study geomagnetic "indices" instead.

Many indices exist (Ci, u, Dst, AE, Kp, aa, am, IHV, *etc*). Several are obsolete and the details of most are poorly understood by many researchers. Different indices describe different aspects (and related physical processes) of geomagnetic activity and the SAV could very well have different (mixes of) causes for different indices.

The "mid-latitude" indices (Kp, aa, am, IHV) are a kind of compromise between the polar or auroral indices (PC, AE, AU, AL) and the low-latitude indices (u, Dst) and are perhaps more representative of the elusive "global" index.

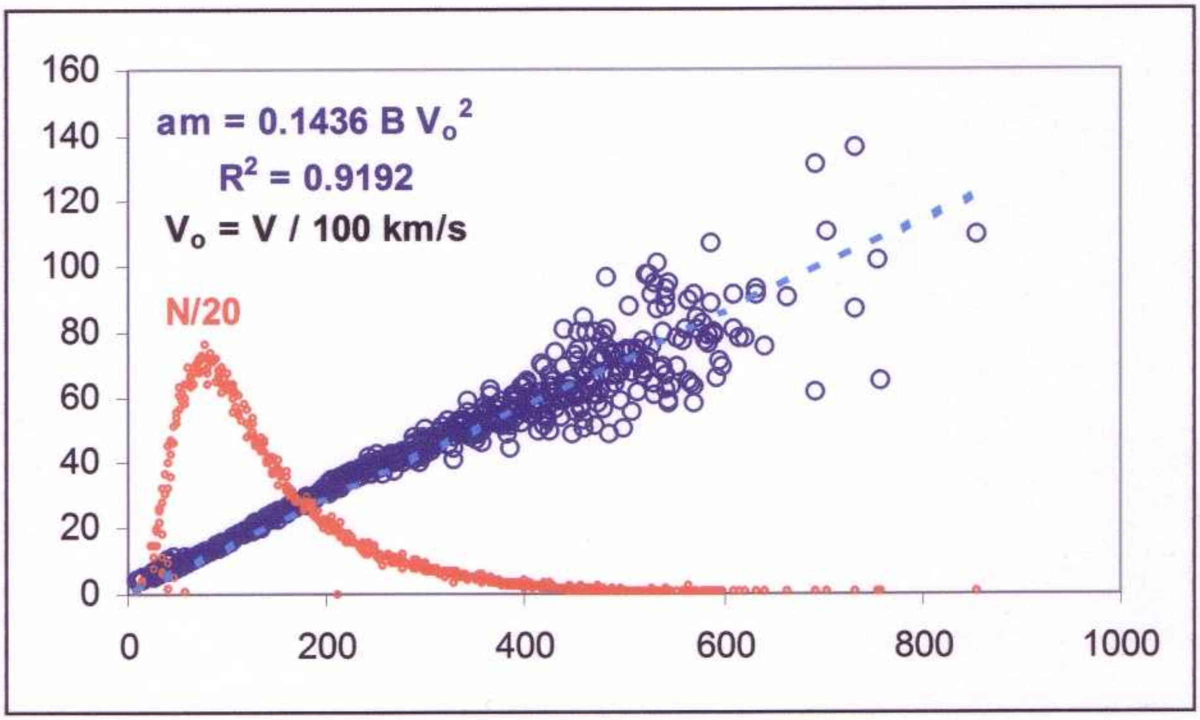
The "**am**"-index is constructed from K-indices from a global network of stations with reasonable coverage in longitude and latitude and is the best we have at present (*i.e.* is believed to be a suitable approximation to a true "global" index).

A somewhat surprising fact is that we can predict several indices from solar wind properties with amazing accuracy (*e.g.* Dst: Temerin & Li, 2002; am: Svalgaard, 1977). One might conclude from this that the goal of constructing indices with real physical content has been reached (perhaps even exceeding the aspirations of the index originators). In other words: "these indices are ***good***".

Several studies have shown that the am-index can be predicted as

$$am = k\, q(\alpha, \mathrm{DOY}, \mathrm{UT})\, B\, V^2 \qquad (1)$$

where k is a scale factor, q is a geometrical factor depending on the IMF clock angle (α), on Day of Year (DOY) and on Universal Time (UT), B is the total IMF field strength, and V is the solar wind speed.



(Just a reminder of the $am \sim B\,V^2$ relation; data for 1963-2003, binned in $B\,V^2$)

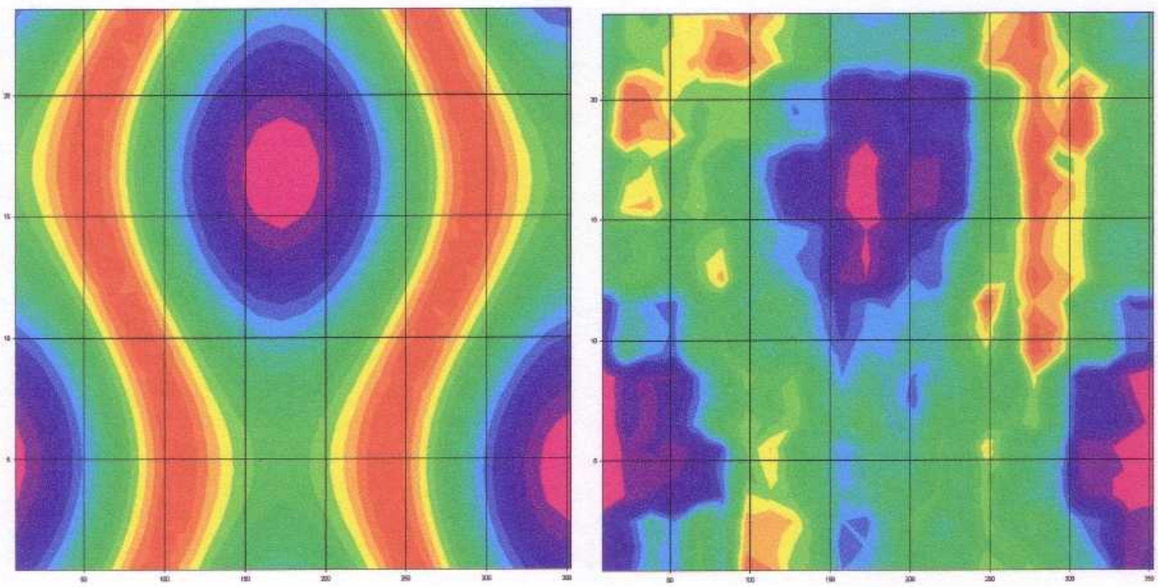
We can now normalize *am* for the effect of *B* and *V*. This removes any "axial" effects and brings the geometrical factor into focus:

$$am' = am \langle B\,V^2\rangle / (B\,V^2) \qquad (2)$$

If we average over many years, α drops out and we should have:

$$\langle am'\rangle \sim q(\text{DOY, UT}) \qquad (3)$$

This is what we get:



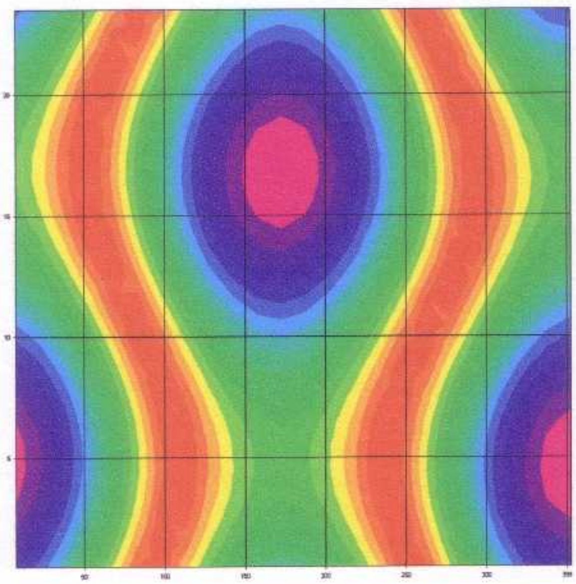
(a) (b)

(a) Dipole tilt, Ψ, as a function of UT (vertical) and of DOY (horizontal).

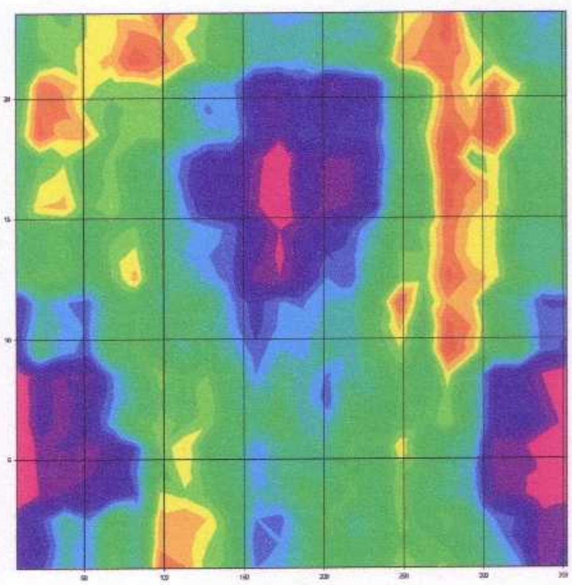
(b) normalized <*am'*> as a function of UT (vertical) and of DOY (horizontal). All plots are for the interval 1963-2003 where we have both *B* and *V* data.

It is clear that the geometrical factor has a strong resemblance to the dipole tilt, especially in the UT-variation.

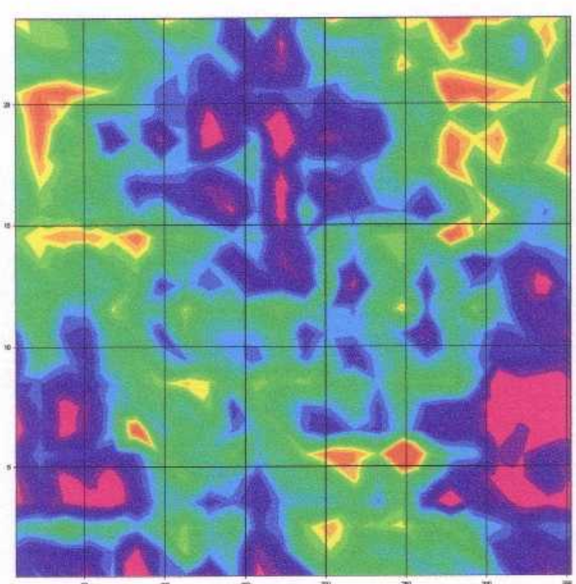
That the influence of α has averaged out can be seen if we analyze separately for times where Bz (GSM) is positive and negative, respectively:



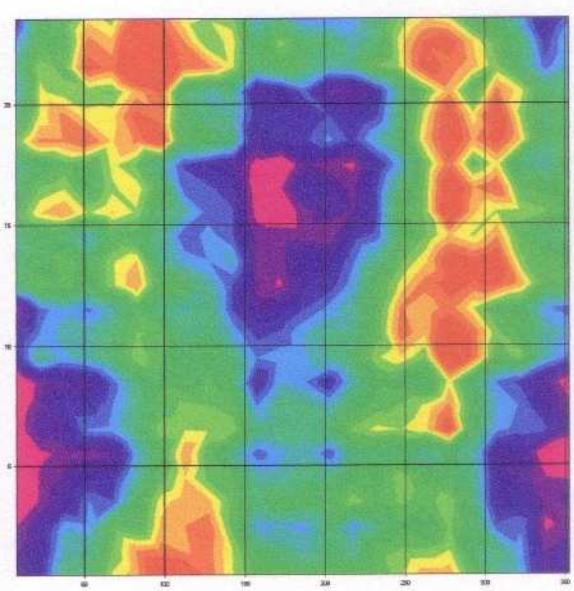
Dipole tilt, Ψ



All orientations of α

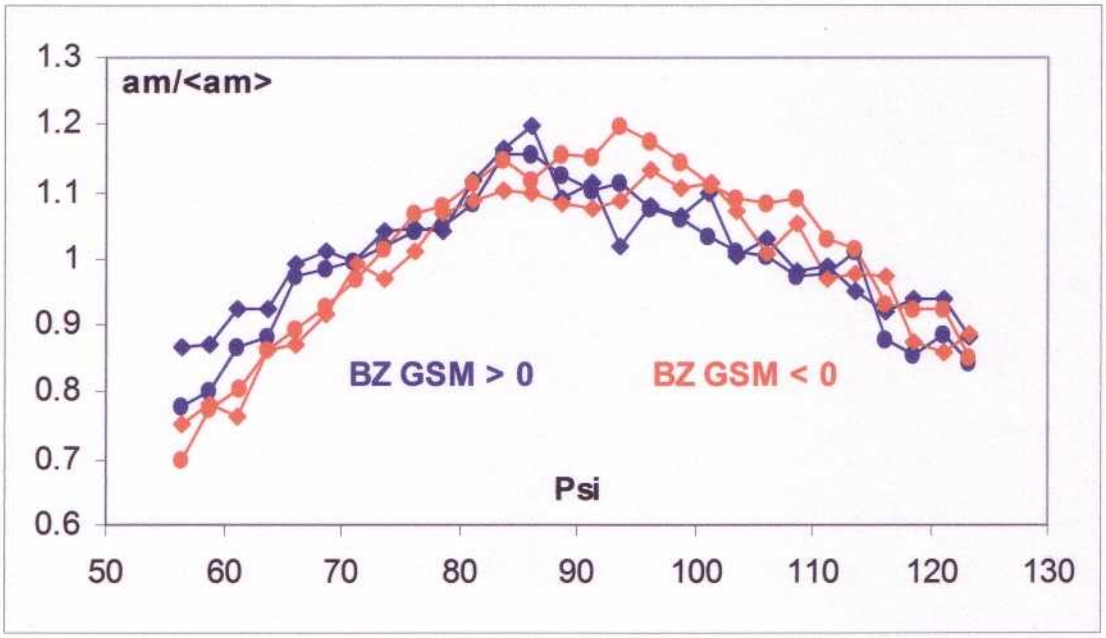


Bz (GSM) > 0 (North)

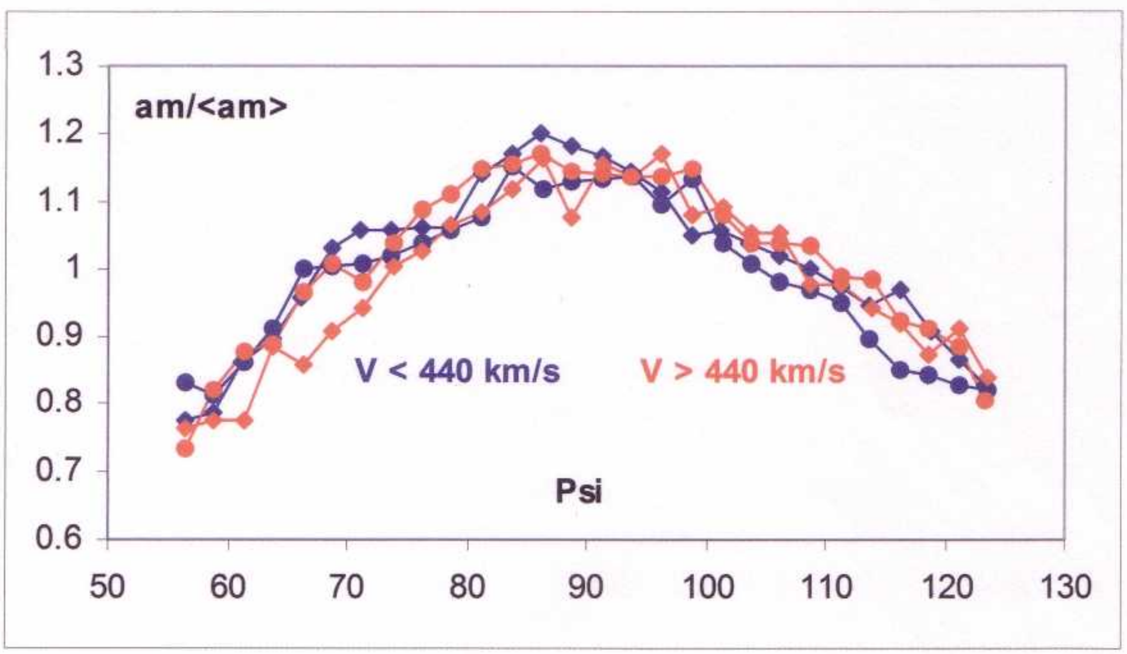


Bz (GSM) < 0 (South)

The "hour-glass" dependence on Ψ is a *permanent* feature, independent of the orientation of the IMF.

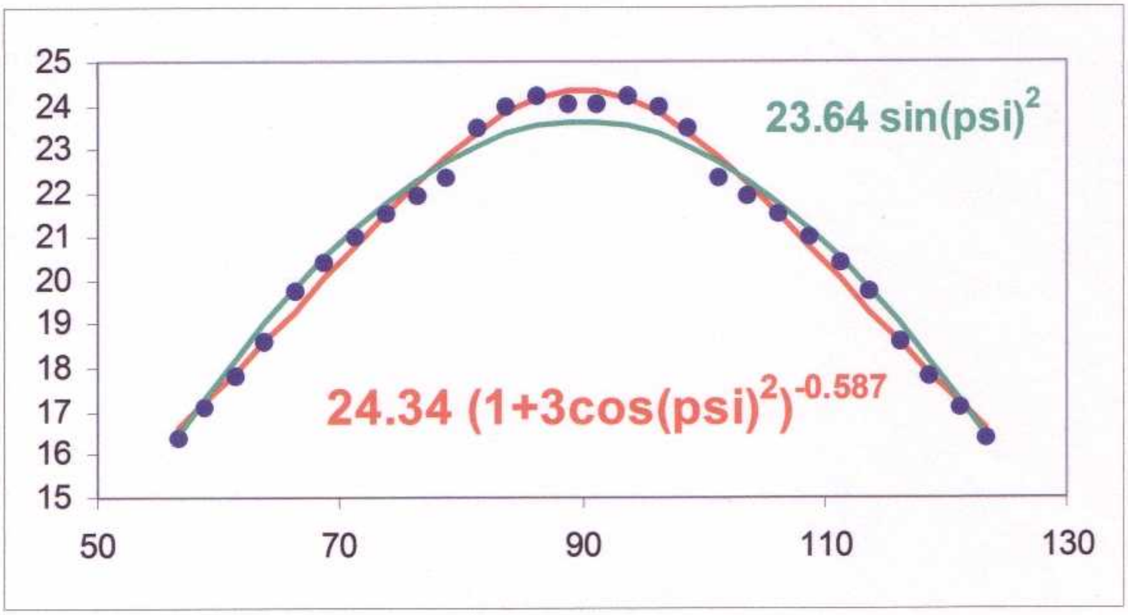


Relative variation of *am* (*i.e.* divided by the mean <*am*>) as a function of dipole tilt, separately for Northward and Southward IMF, and for odd/even years (diamonds/circles). Same, but for low/high solar wind speed:



We can thus describe the Ψ-dependence as a *modulation* that works with existing activity in a manner simply proportional to the activity level, *i.e.* with the same relative effect.

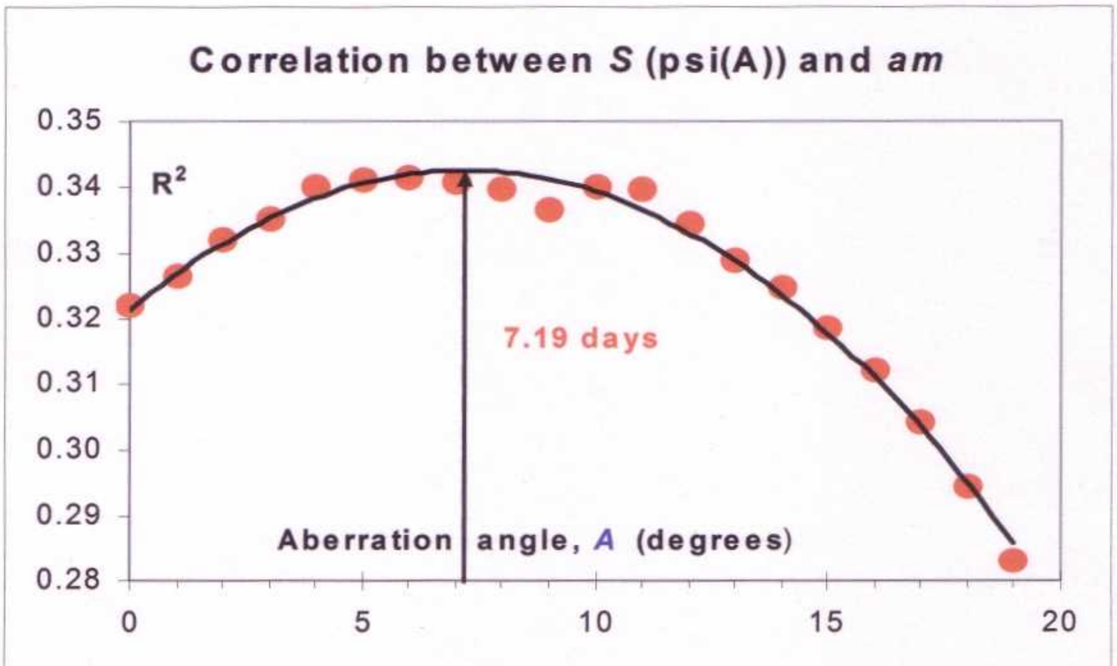
Since we don't know the mechanism, we can only suggest an *ad hoc* empirical functional relationship describing the modulation:



The "$\sin^2$(psi)" function (suggested by Mayaud, 1975) is a slightly worse fit, but has the virtue of simplicity. Within the observed range of Ψ, there is not much difference between the two formulae, but they have dramatically different behavior for $\Psi \rightarrow 0$. We can also write the modulation function as:

$$S(\Psi) = 1/(1 + 3\cos^2(\Psi))^{0.587} \qquad (4)$$

Calculating the dipole tilt angle for various amounts of solar wind aberration allows us to search for the aberration angle, *A*, that gives the highest correlation (we calculated the square of the correlation coefficient, R^2) between the aberrated modulation function $S(\Psi(A))$ and *am*.



There is a clear aberration. It is, in actual fact, embarrassingly large, 7.2 degrees. It is possible that a residual RM-effect (with its maximum near April 6) is skewing the result. An indication that this is happening is that the aberration angle for highest correlation with *am* during intervals of southward Bz is even larger, 12.2 degrees.

Conclusions:

1) The dominant component of the SAV is a modulation of existing activity depending on the dipole tilt, Ψ, with a suggested functional form involving the quantity $(1 + 3\cos^2\Psi)$, and independent of the direction of the IMF.

2) The sharpest modulation is obtained for an aberration of about 7 degrees (~days), suggesting that protons and not photons (which would presumably show negligible aberration due to the high speed of light) are responsible for the SAV.