

SH21A-0313

Leif Svalgaard

A Floor in the Open Flux IMF Strength:
Constant in Time (Centuries?)
and Space (Latitude)

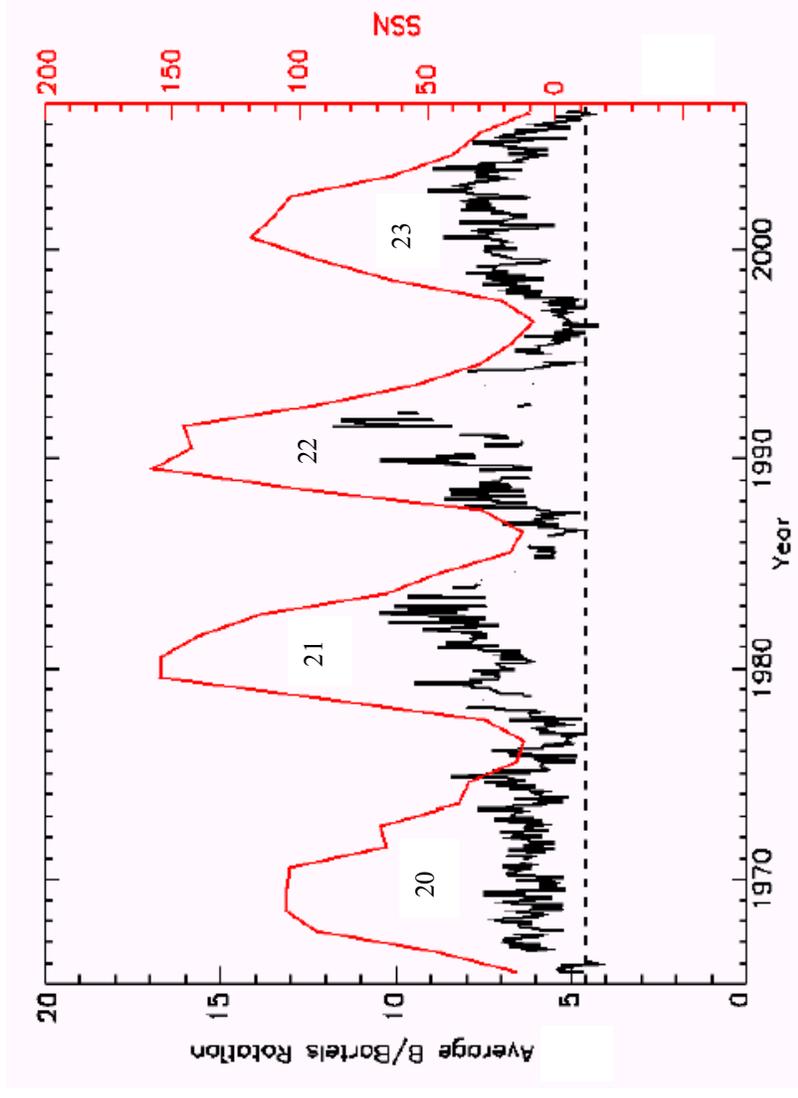
AGU 2006 Fall

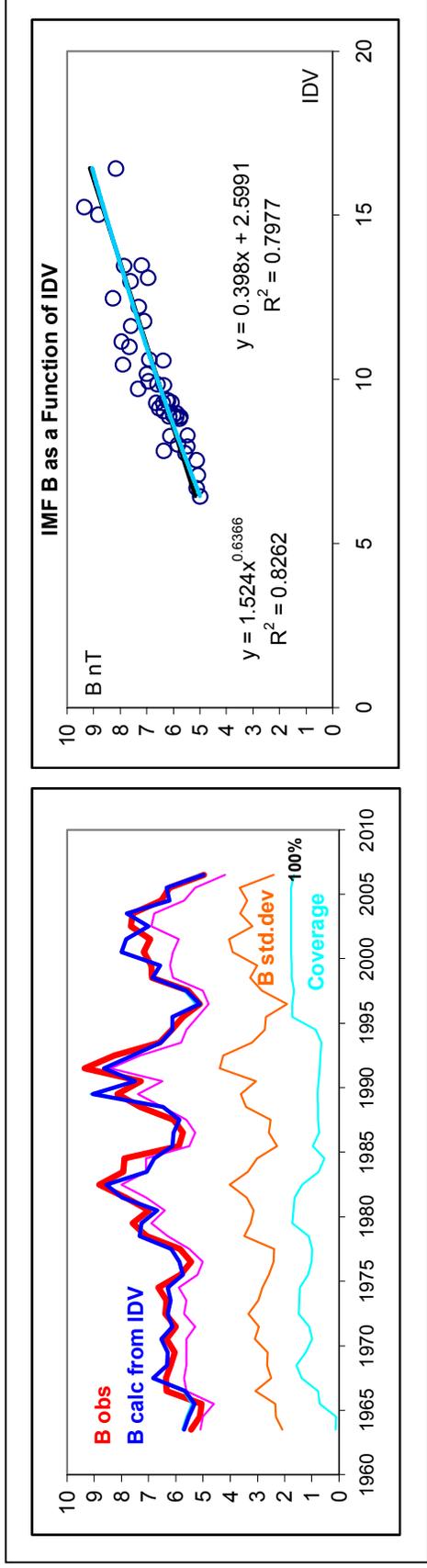
Abstract

The Interplanetary Magnetic Field (IMF) is with some success often modeled by assuming a spherical "source surface" near the sun where the magnetic potential is constant giving rise to the "open flux" of a radial IMF (eventually turning into a coned helix by solar rotation). 150 years of geomagnetic activity measurements suggest that the solar cycle variation of the IMF strength can be expressed as a constant component ($B_r \sim 3$ nT at 1 AU near the Earth) plus a component that varies with the square root of the sunspot number (a proxy for the frequency of CMEs). There is growing evidence that CMEs represent "closed flux" with both foot-points in close proximity at the sun. If so, the remaining IMF (subtracting flux added by CMEs) varies little over the solar cycle. We suggest (and present evidence for) that there exists a "floor" in the IMF that is nearly constant over time (centuries?) and space (latitude) reviving an old idea of Schulz et al. (1978) that the source surface might be thought of as a (prolate) surface of constant field strength rather than of constant potential. A consequence of this view is that the IMF strength does not depend on the solar polar fields.

Direct Interplanetary Measurements of the 'Near Earth' Magnetic Field:

Interplanetary Magnetic Field strength, B , averaged over full 27-day Bartels rotations. At each sunspot minimum, the IMF B reaches the same low value (~ 4.6 nT). On top of that there is a component that seems to follow solar activity (a bit poorly during cycle 20).

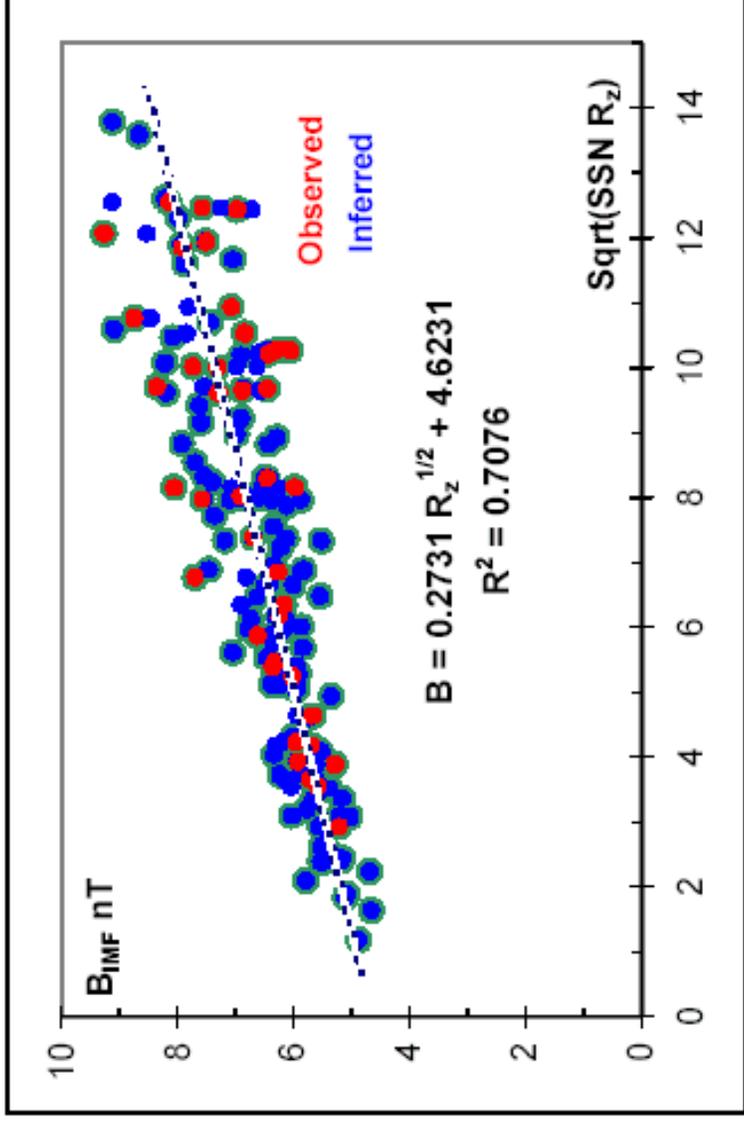




The geomagnetic *IDV*-index [Svalgaard & Cliver (2006) *JGR 110*, A12103; *111*, A09110] is a close measure of the IMF *B* (correlation coefficient $R = 0.9$ for yearly averages), and is conveniently uncorrelated with the solar wind speed. This allows us to estimate *B* as far back in time as regular geomagnetic records go (1830s, with high-quality records to at least 1872).

IDV is defined as the average over some time (months to a year) of the *unsigned* difference between successive midnight values of the geomagnetic Horizontal component for a number of mid- and low-latitude observatories. Akin to Bartels' *u*-measure.

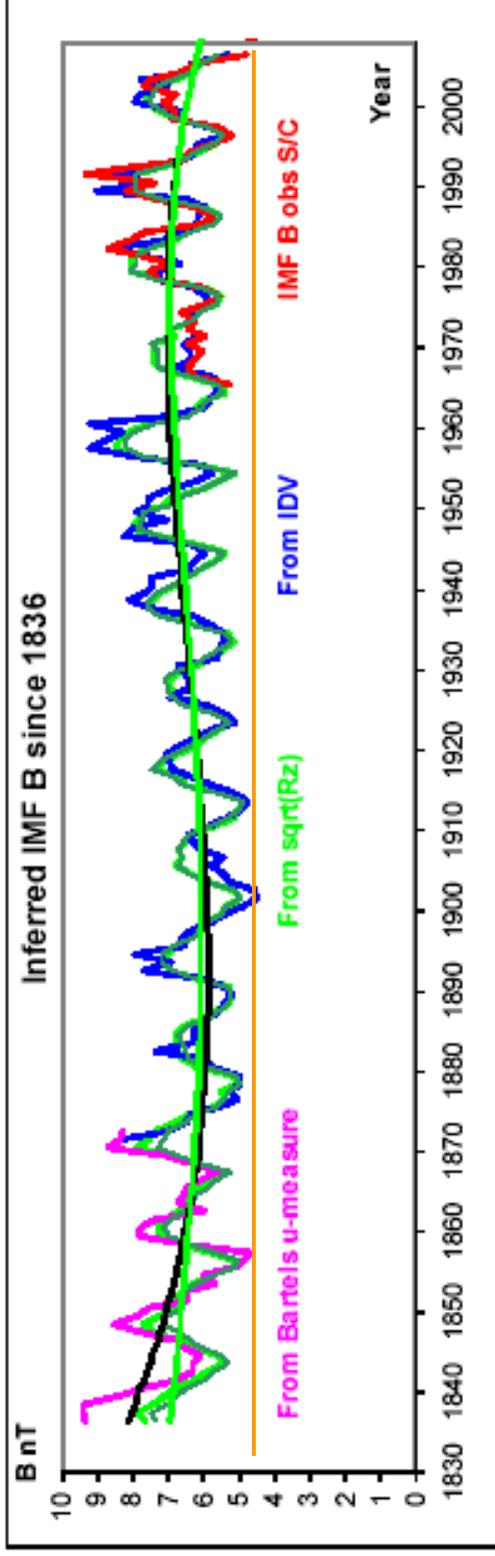
Although it came as a surprise that there was no clear solar cycle dependence of IMF B during the first decade of spacecraft measurements, data from later cycles *do* show a strong solar cycle relationship. Having 13 cycles worth of B (inferred and observed) permits a study of this relationship with much improved statistics. The main sources of the equatorial component of the Sun's large-scale magnetic field are large active regions and especially their remnants. If these active regions emerge at random longitudes, their net equatorial dipole moment will scale as the square root of their number. Thus their contribution to the average IMF strength will tend to increase as $SSN^{1/2}$ [Wang & Sheeley (2003) *Ap. J.* 590(2), 1111]. We found, indeed, that there is a linear relation between B and the square root of the SSN [Svalgaard & Cliver (2005) *JGR* 110, A12103]. This allows us to estimate the contribution to IMF B from activity (such as CMEs, magnetic clouds, ropes, etc) related to the sunspot number:

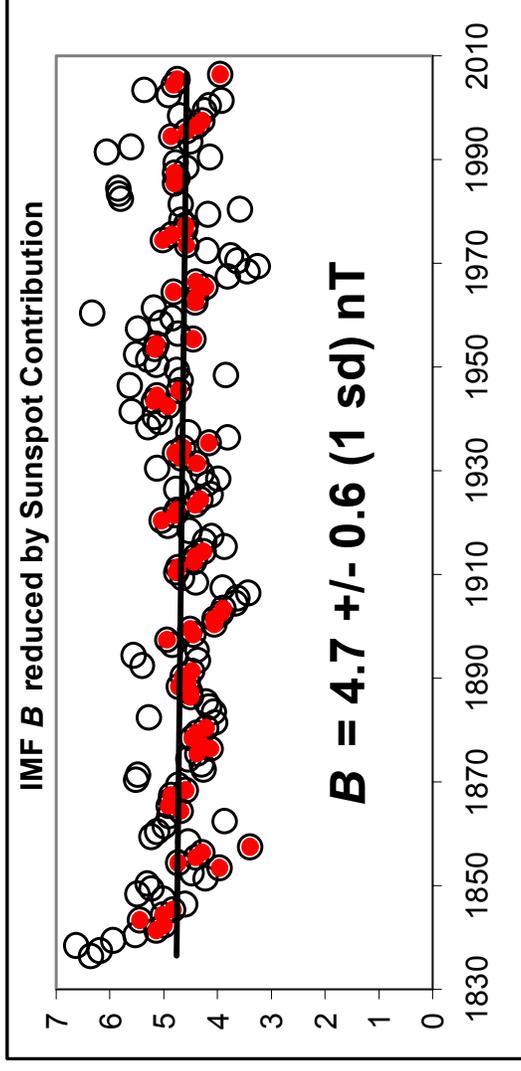


Yearly average IMF B as a function of the square-root of the SSN=Zürich sunspot number.

Observed in situ (red) after 1964 and inferred (blue) from IDV before that. Note that B tends to 4.62 nT as the SSN tends to zero.

Combining B inferred from IDV (blue and pink) and from SSN (green) we get the Figure below. Observed B is in red. Of note is that the long-term variation of B is slight ($\pm 12\%$ for cycle averages), basically following a long wave in the cycles. The minima are close to the same value (orange line); the small deviations from the line are caused by a varying non-zero sunspot number at minimum.





We can also simply subtract $0.273 \text{ SSN}^{1/2}$ to remove the sunspot-related contribution. The red dots mark minimum-condition years (with $\text{SSN} < 40$). Again, we see little variation with time of the result.

In SH21A-0318 (this meeting) Owens *et al.* remark that “*the total amount of open flux on the Sun is conserved*” because interplanetary-CMEs basically contain closed flux (with frequency following the sunspot number). What we suggest here is that the open flux is not only conserved within a solar cycle, but across cycles for possibly centuries.

Now, this presents a puzzle. Traditional wisdom asserts that the polar fields of the Sun at minimum are the remnants of active regions of the previous cycle and likely the seed for the next cycle. In any case, we expect that there be a relationship between the solar polar fields and the size of - either the previous or the next - cycle. As the cycles vary very much in size, by a factor of four in recent centuries and much more if we include the Maunder minimum, we would expect the polar fields to vary accordingly. Direct observations since the 1950s bear this expectation out and show simple, approximate proportionality between polar field strength and the maximum (smoothed) sunspot number for the (following) solar cycle [*Svalgaard et al.* (2005) *GRL* 32, L01104].

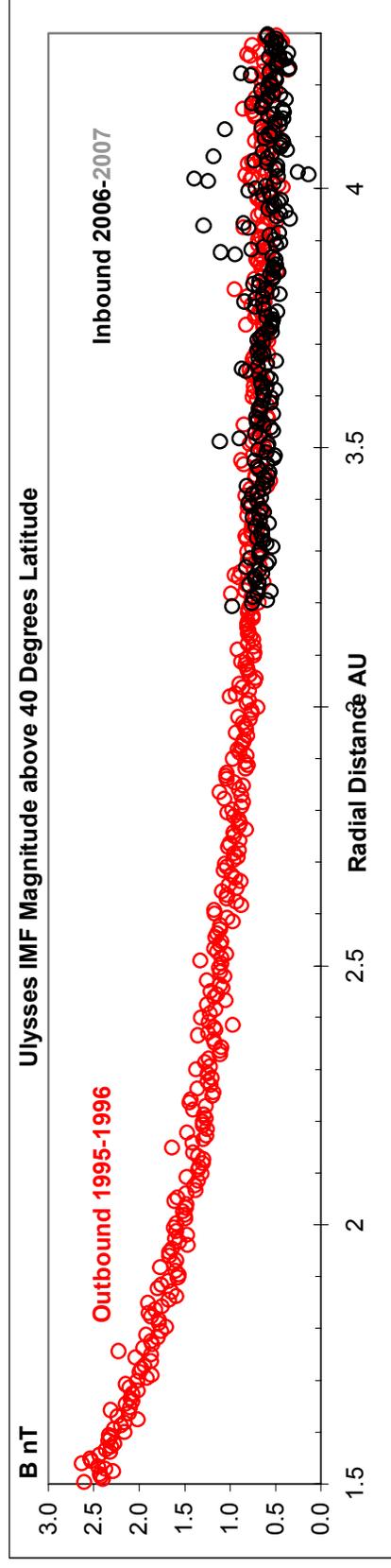
Traditional wisdom also asserts that at solar minimum most (all?) of the open flux in the heliosphere comes out of the polar cap coronal holes. In that case we would expect that the IMF strengths at minimum conditions should mirror the strength of the polar fields, so the puzzle is that they do not.

We illustrate the situation using the operational (and somewhat successful) *Wang-Sheeley-Arge* solar wind model (results generously provided by Leslie Mayer and Nick Arge). We examine the calculated IMF magnitude over the solar poles (at 1 AU) using magnetograms from the Wilcox Solar Observatory:

Year	Carrington rot.	$ B_{\parallel} $ polar field	$ B_{\parallel} $ WSO corr.	$ B_{\parallel} $ MWO corr.
1995	1887, 1898	103 uT	2.06 nT	2.62 nT
2006	2049	59 uT	0.99 nT	1.45 nT

As there is some controversy about which “saturation factor” to use, the model was run with both the constant WSO factor (1.86) and with the inappropriate position-on-the-disk dependent MWO correction (approx. 2 at the limb). In any case, the calculated field strengths scale approximately with the measured line-of-sight polar fields for the current near-minimum and the previous near-minimum as we would expect, with the current fields being about half of what the fields were a solar cycle ago. Yet the IMF strength near the Earth is currently close to its value of one (and indeed any number of cycles) ago.

One might argue that there is something special about the Earth being near the current sheet and not directly in the “regime” of the polar fields. The Ulysses spacecraft near the previous minimum went almost over the poles, so the field it measured then ($|B_r| = 3 \text{ nT}$) can directly be compared to what it is measuring right now when it again is going over the poles. Based on the foregoing we would expect the current field to be down to about half of the 1995 field. Since the orbit of Ulysses is (almost) fixed in space we can compare the total field magnitudes then and now rather than the radial components that depend on averaging interval and polarity determination. The field magnitudes are equal:



We shall not comment on the fact that the observed field *values* do not match the model calculations. Balogh *et al.* SH44A-05 (this meeting) discuss this surprising result in more detail. There is, however, little doubt that in spite of the polar fields being only half, and in spite of the WSA-model (and presumably all the others) predicting a field at Ulysses that should be only half, the observations show otherwise. We take this as support for our contention that ***the polar fields do not determine the magnitude of the IMF.*** Rather, the observations are consistent with the notion that the ‘source surface’ may be a surface of constant field instead of constant potential. If that were so, then one might use this as a constraint to determine the (variable) source surface radius that would keep the field constant and use that in the model calculations.

An ad hoc explanation for each of the observational facts that we have presented might be given. We prefer the simpler suggestion that the open flux simply does not change much with time (and location when away from the change of sign in the current sheet).