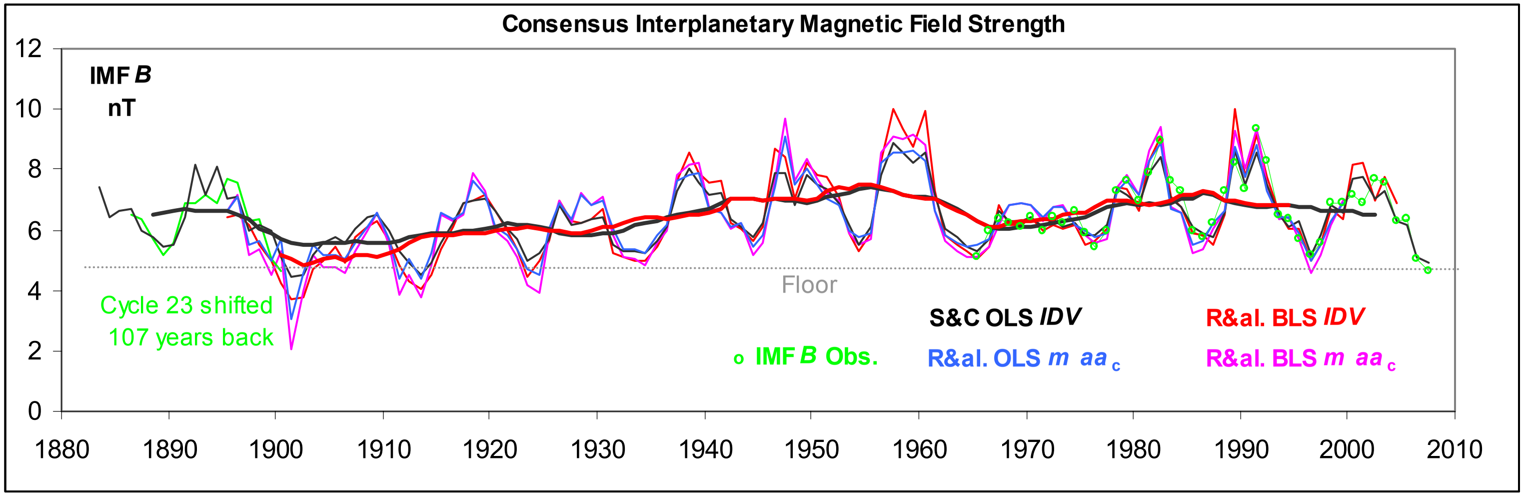
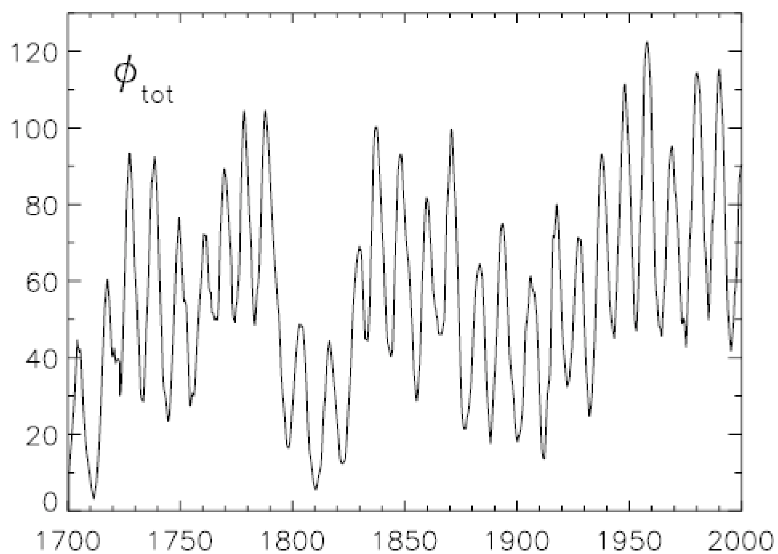
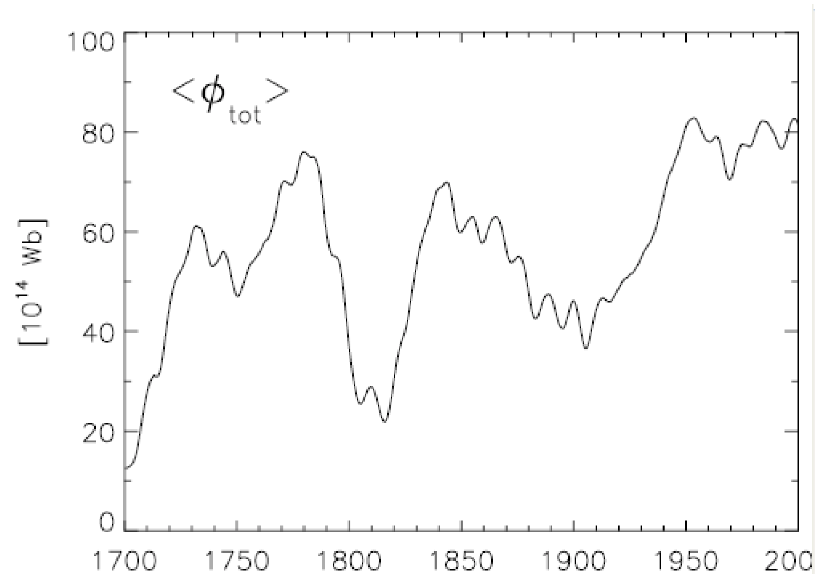


Consensus Interplanetary Magnetic Field Strength
IMF B
nT
12
10
8
6
4
2
0
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Floor
Cycle 23 shifted
107 years back
S&C OLS IDV
R&al. BLS IDV
o IMF B Obs.
R&al. OLS m aa c
R&al. BLS m aa c

The Solanki et al. (2000, 2002) models were constructed to account for Lockwood's "doubling".

Here is Solanki's model result (2002). Total flux on the left, 20-year running average on the right. The open flux is some fraction (e.g. 1/10th of the total flux)

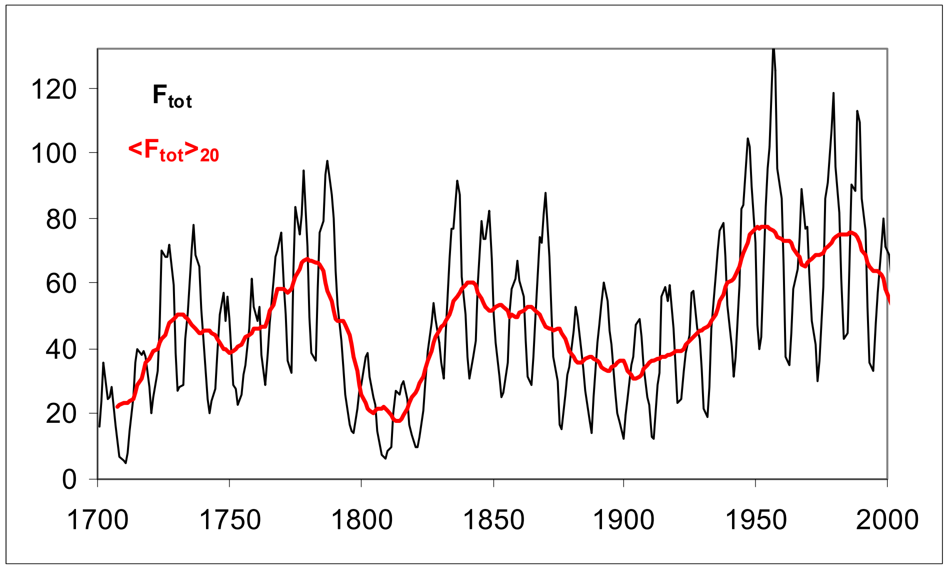




If you cut through all the voodoo and flim-flam, the model can be expressed thus:

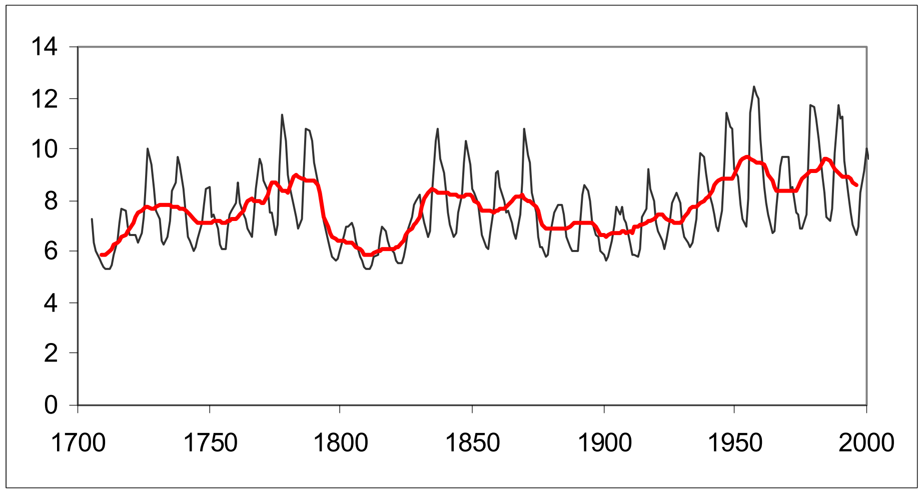
$$F_{total}(t) = R(t) / 3 + R(t+3) / 2 + \langle R(t) \rangle_{11} / 5 \qquad (\times 10^{14} \text{ Wb})$$

Where R is the sunspot number. Here is the result (compare with Solanki's):

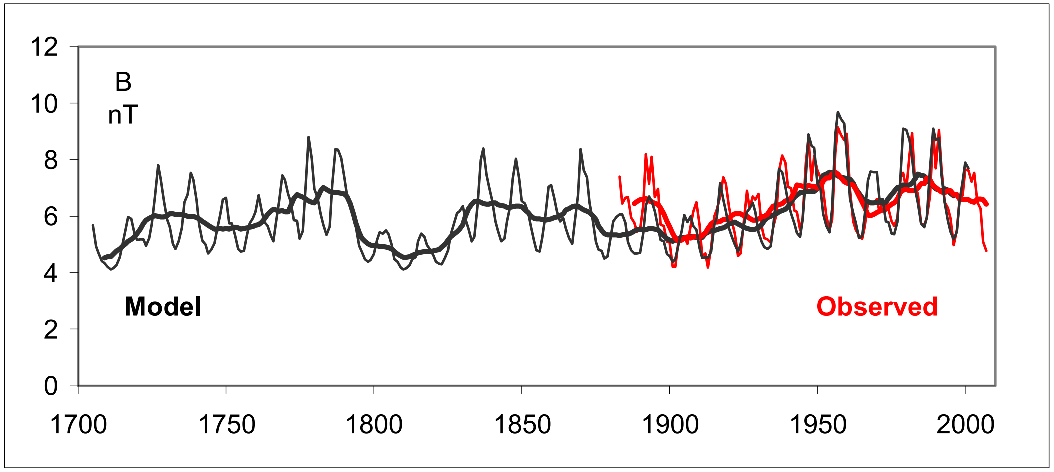


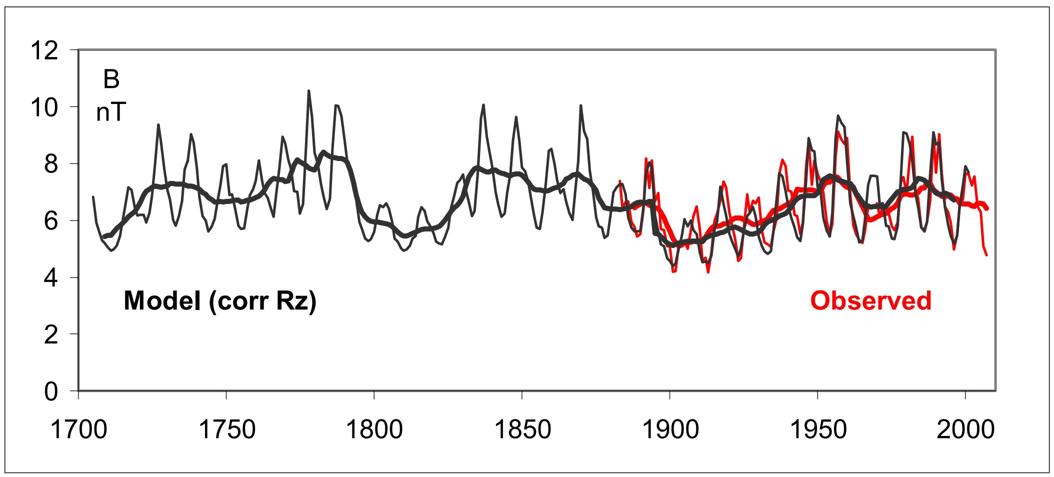
The first term is simply the flux from the sunspot regions. The second and third terms serve to "fill up" the minima, making sure that the long-term trend of the total (and of the "background") will resemble the long-term trend of the sunspot activity itself. With this device the open flux at minima should reflect that the following cycle (or at least three years into the next cycle). Empirically that is not what is seen: we see a "floor" at minima (possibly with a weak "Gleissberg" cycle contribution - the third term).

It is the middle term {R (t+3) / 2} that provides the most of the secular change. Setting it to be constant {50 for average sunspot number of 100}, yields the following result, with little secular change, and much closer to what we have. Plotted is $F_{open} = F_{total} / 10$:



We can compare this with our "observed" IMF B. I'll simply take the average of Alexis' and our series and plot them in on the above Figure (first scaling it by a factor of 1/1.41 = 0.71. Remember that $F_{open} = 1.41 \times 10^{14}\ B$. [I cheat a little bit: the best match factor is 0.7773, but then the 1/10 was only approximate]). The result is shown as the upper panel of this Figure:


12
10
8
6
4
2
0
B
nT
Model
Observed
1700
1750
1800
1850
1900
1950
2000

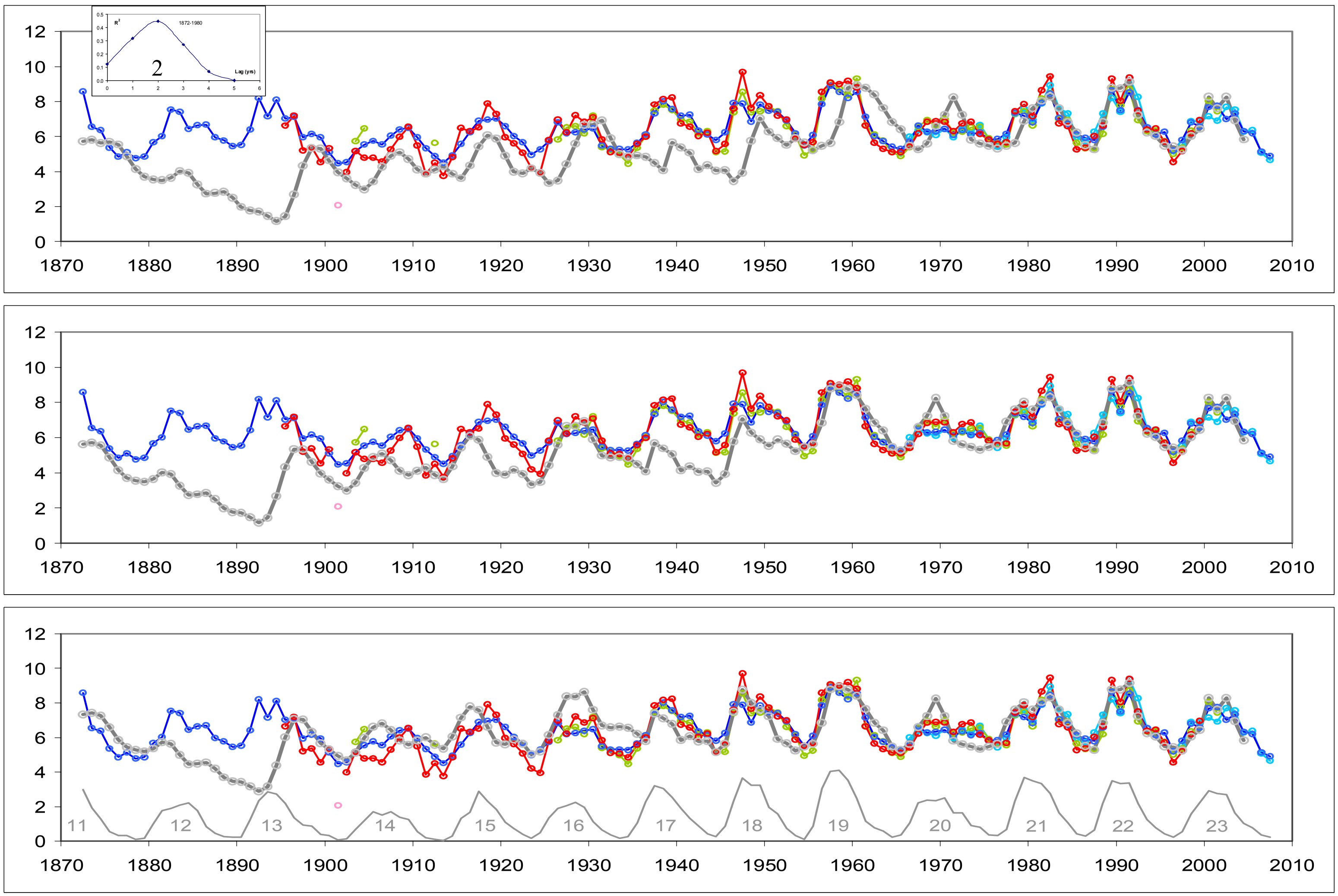

12
10
8
6
4
2
0
B
nT
Model (corr Rz)
Observed
1700
1750
1800
1850
1900
1950
2000

But wait, there is more. There seems to be a good fit except in the 1890s. Remember that Rz is wrong before ~1900. The correction factor between pre-1900 and post-1900 Rz is ~1.2 (our sunspot reconstruction). Applying the factor 1.2 results in the lower panel. As I have said many times: ***everything must fit***.

The HMF deduced by McCracken is based on what he calls a "pseudo-Climax neutron monitor record". In constructing this record he merges 10Be with neutron monitor data. But he is mixing oranges and apples. He forgets (or does not know - although Beer should) that the 10Be data lags 2 years behind the sunspots and the HMF (mainly because of the residence time of 10Be in the atmosphere). Thus all his data from before ~1980 (where the 10Be series from Dye-3 in Greenland stops) should be shifted 2 years earlier. This louses up any detailed comparisons of single years. I discovered this by painstakingly making a large magnification (3 feet across) copy of his Figure showing HMF as a function of time.

When shifting the HMF(10Be) data 2 years it becomes evident that they are too low before ~1950 by 1.7nT. When adding 1.7 nT before 1950, his data now agrees well with S&C, RL&F, and L&S.

There is a strong disagreement 1883-1896 (the "crack" in the floor). There are other cracks: 1694-1710, 1809-1820, and a smaller one ~1766. 10Be is deposited by adhering to stratospheric aerosols which then drift down and rain out. The amount of aerosols in the stratosphere is controlled mainly by volcanic eruptions. There were such strong eruptions in 1693 (Hekla on Iceland, having large effect on nearby Greenland), 1766 (Hekla), 1809 (see J. Dai et al., JGR vol 96, p 17361-17366, 1991), 1814 (Mayon), 1815 (Tambora), 1883 (Krakatoa). I suggest (although will have to study the mechanism) that these events are the reason for the cracks.



12
10
8
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0
1870
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2010
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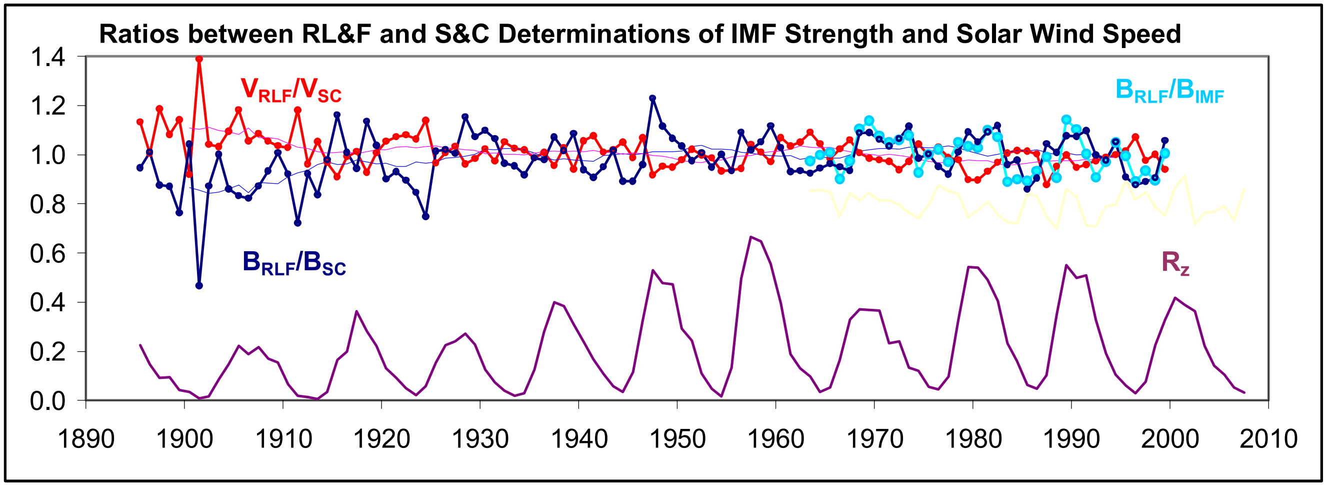

One way to compare the various determinations of B and V is to form the ratio between values for each year determined by the different methods. The above Figure shows the ratio B_{RLF}/B_{IMF} (light blue with dots) and the sunspot number (purple at bottom). It is clear that there is a solar cycle modulation in the ratio. The ratio should be constant 1.000 if B_{RFL} were correctly determined. Instead, solar maximum values are too high and solar minimum values are too low. To first order we might ignore this discrepancy as it is only of the order of 15%. Since B_{SC} does not show a similar solar cycle dependence, we would expect B_{RLF}/B_{SC} to show the modulation and so it does (dark blue with small dots). But, again, the effect is small (~15%) and not systematic after ~1915. Note how V_{RLF}/V_{SC} (red with small dots) generally is anti-correlated with B_{RLF}/B_{SC}, and about half the size, as it should be because $\delta B/B = -2\ \delta V/V$. 11-yr running means are shown with thin pink and light-blue curves.

Here are some “technical assault” notes that we may need for the referee:

Solanki et al. [2002, p. 703] note that "One of the major advances in solar and heliospheric physics of recent years has been the reconstruction of the heliospheric magnetic feld (i.e., the Sun's open magnetic flux) from the geomagnetic aa-index by Lockwood et al. (1999). The surprising outcome of this work was the discovery of a secular variation of the heliospheric magnetic feld, upon which is superimposed a modulation by the 11-year solar activity cycle: on average, the open flux has doubled since roughly 1900". Svalgaard and Cliver [2005] utilized their IDV geomagnetic activity index to infer the strength, B, of the interplanetary magnetic field (IMF) near Earth employing Ordinary Least Squares (OLS) regression analysis, and could not confirm the doubling of the IMF.

Recently, Rouillard et al. [2007] have conceded that the aa-index does not have constant calibration over time and should be corrected. Using their corrected aa-index and a new index, their m-index, Rouillard et al. [2007] reconstructed IMF B by employing a least squares regression based on Bayesian statistics (BLS).

The key difference between the OLS regression of Svalgaard and Cliver [2005] and the BLS regression of Rouillard et al. [2007] is that the least squares minimization for BLS is applied to the residuals in the geomagnetic activity index, rather than in IMF B, even when predicting the latter. In other words, IMF B is considered to be error-free, rather than the geomagnetic index, in spite of the fact that for most of the time, the yearly average IMF B is calculated from data where measurements are missing more than half of the time. As long as we stay within the observed range of B, the difference between results obtained with OLS and BLS is but minor as can be clearly seen in Figure 1. The BLS-method tends to overshoot for high values and undershoot for low values, including the extreme outlier in the single year 1901. In spite of such problems, the various series of Rouillard et al. [2007] now all agree with the result of Svalgaard & Cliver [2005] to better than 8% (rms). As can be seen in Figure 1, it is now clear that the long-term variation of the strength of IMF over the last ~125 years can be described as a constant "floor" value upon which is superimposed a robust contribution from the 11-year solar activity cycle, i.e., there has been no secular variation of the base value of IMF.

In the model of Solanki et al. [2002], the total magnetic flux over the Sun is the sum of the flux from active regions (that falls to near zero at solar minimum), the flux from ephemeral regions, and the open flux. The value of the decay time of the open network flux was adjusted in order to make the model match the relative amplitudes of the cyclic flux to the doubling of the open flux reported by Lockwood et al. [1999] (proportional to B because Lockwood et al. [1999] used a constant ratio (0.56) of the IMF radial field Br to the total field B). Since Svalgaard and Cliver [2005] and Rouillard, Lockwood, and Finch [2007] now agree that there is no secular trend in the IMF, the conclusion would be that there is therefore also no secular trend in the ephemeral region flux. The Solanki et al. [2000, 2002] model would then be moot as it was constructed to “explain” the Lockwood et al. result.

Lockwood, M., R. Stamper, and M. N. Wild, A doubling of the Sun's coronal magnetic field during the past 100 years, Nature, 399(6735), 437-439, doi: 10.1038/20867, 1999.

Rouillard, A. P., M. Lockwood, and I. Finch, Centennial changes in the solar wind speed and in the open solar flux, J. Geophys. Res., 112(5), A05103, doi:10.1029/2006JA012130, 2007.

Solanki, S. K., M. Sch¨ussler, and M. Fligge, Secular variation of the Sun's magnetic flux, Astron. & Astrophys., 383, 706-712, doi:10.1051/0004-6361:20011790, 2002.

Svalgaard, L. and E. W. Cliver, The IDV index: Its derivation and use in inferring long-term variations of the interplanetary magnetic field strength, J. Geophys.Res., 110(A12), A12103, doi:10.1029/2005JA011203, 2005.