SH24A-01

Towards a Consensus View of the Heliospheric Magnetic Field Strength Since 1900

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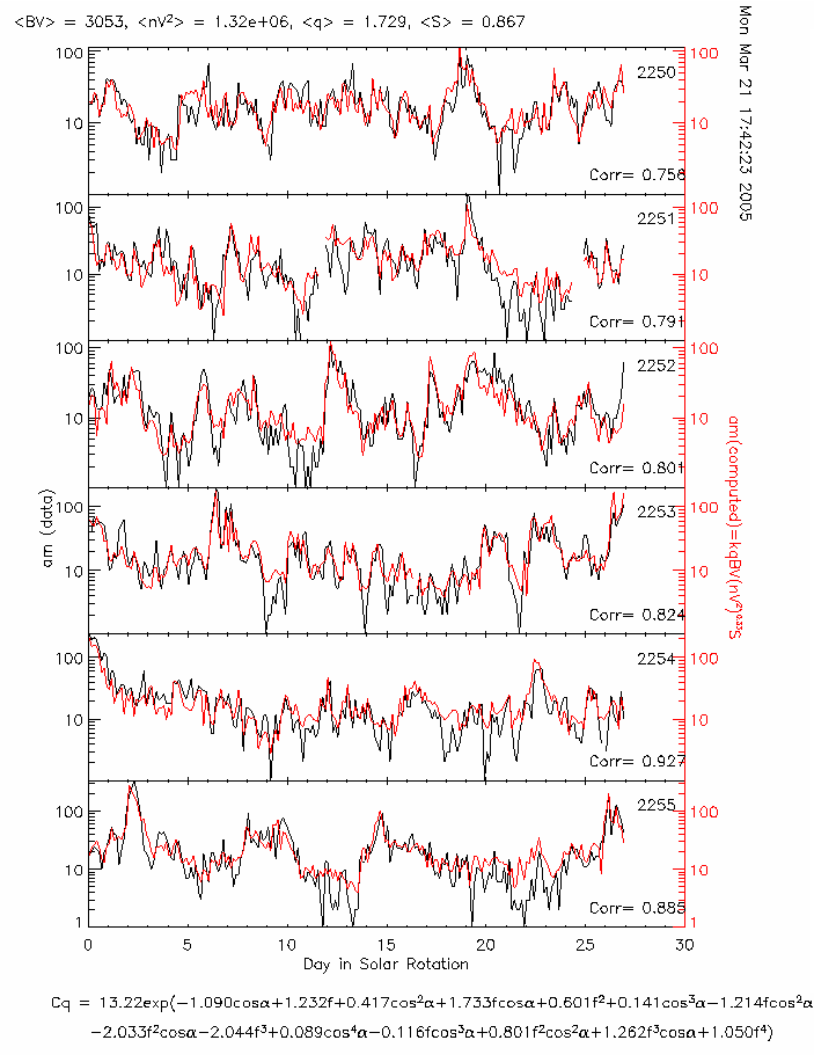
The Heliospheric Magnetic Field (HMF ***B***) is of fundamental importance for the effect of the solar wind on solar system bodies and for cosmic ray transport processes. It has become possible to reliably infer ***B*** back 170+ years using the Geomagnetic Record.

On physical grounds it is clear that the response of the Earth's magnetosphere to the varying solar wind is some function of solar wind parameters. Different *coupling functions* have been proposed. And people bicker about what the *best* coupling function is or which function is based on the most correct 'physics'. All these functions allow one to calculate various *geomagnetic indices* from solar wind parameters, with some [varying] success. The key point is that geomagnetic activity can be ***calculated*** with some precision.

Here is one that I [LS] proposed in 1977:

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

where the various factors have meaning of Momentum flux, Magnetic Reconnection, and Geometric Modulation, and where B is the Heliospheric Magnetic Field strength [at Earth], V is the Solar Wind Speed, n is solar wind density, q is a function of the angle α between the HMF and the Earth's magnetic field at the 'nose' of the magnetopause, and the relative variability $f = \sqrt{(\sigma Bx^2 + \sigma By^2 + \sigma Bz^2)}/\sigma B$. The geometric modulation function $S(\Psi) = 1/(1 + 3\cos^2(\Psi))^{2/3}$ is controlled by Ψ, the angle between the solar wind direction and the direction of the Earth's magnetic dipole, and is responsible for semiannual and Universal Time variations of geomagnetic activity, here measured by the *am*-index.



This coupling function does an outstanding job in reproducing the *am*-index even on a time scale as short as three hours (except for the very smallest values where the index is very difficult to measure).

For averages over a solar rotation or more, the function simplifies to $am \sim BV^2$ (first removing the *S*-function).

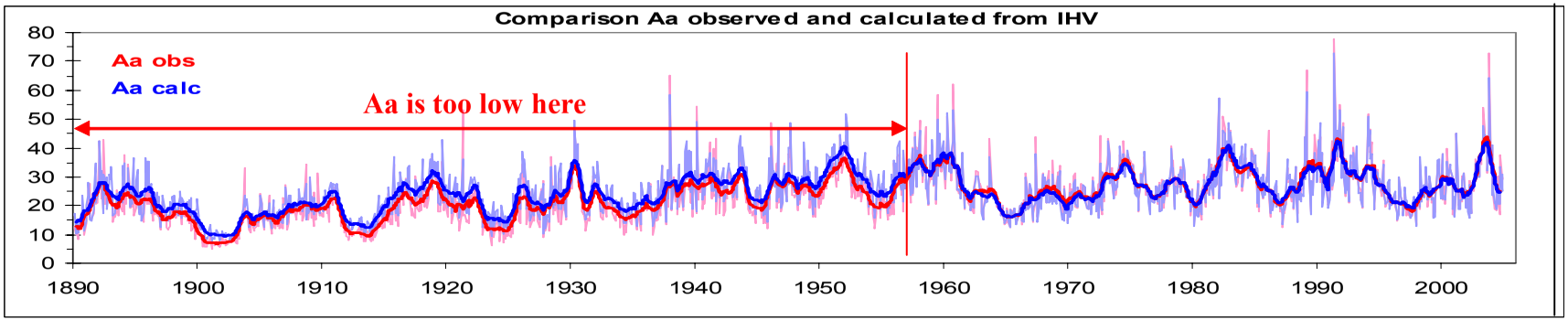
We can calculate *am* from *B* and *V*, or by inversion of the formula, the quantity $BV^{.2}$ from *am*. But we need to separate *B* and *V*, and *am* only goes back to 1959. The long-term index *aa* (back to 1868) can be used instead, if we have confidence in its stability and calibration, but *aa* cannot realistically be recreated, so it is difficult to gauge that trends are quantitatively correct.

The *am*-index and similar indices *aa* and *ap* are derived from data from mid-latitude or subauroral zone geomagnetic observatories. Other geomagnetic indices (*Dst*, *u*, *PCI*, etc) are derived from stations at low-latitudes or polar latitudes and are responses to different physical processes and have different coupling functions, where *B* and *V* appear to different powers.

Geomagnetic index	**Function of**	$B\,V^{\alpha}$	**Proponents**
IDV; [D_{st}<0]; u	B	$\alpha = 0$	Svalgaard & Cliver; Love; Bartels
m	$B\,V^{0.5}$	$\alpha = 0.5$	Lockwood et al.
PCP	$B\,V$	$\alpha = 1$	Le Sager & Svalgaard
IHV	$B\,V^{2}$	$\alpha = 2$	Svalgaard & Cliver
am, aa; ap	$B\,V^{2}$	$\alpha = 2$	Mayaud; Bartels

The indices depend on different functions of B and V, so we can infer both B and V in the past, having, when using several indices in combination, in fact, an over-determined system that inspires confidence. Several new indices (*IDV*, *m*, *IHV*, *PCP*) have been recently introduced that can be constructed from simple hourly

averages of the geomagnetic field, thus opening up the total geomagnetic record back to the 1830s for automated analysis. One of these indices (*IHV*) is very strongly correlated with the *am*, *aa*, *ap* type of indices and allows an independent check on the calibration of these indices:



It is evident that the *aa*-index is systematically too low before 1957 [we know why, but this is a short talk…]

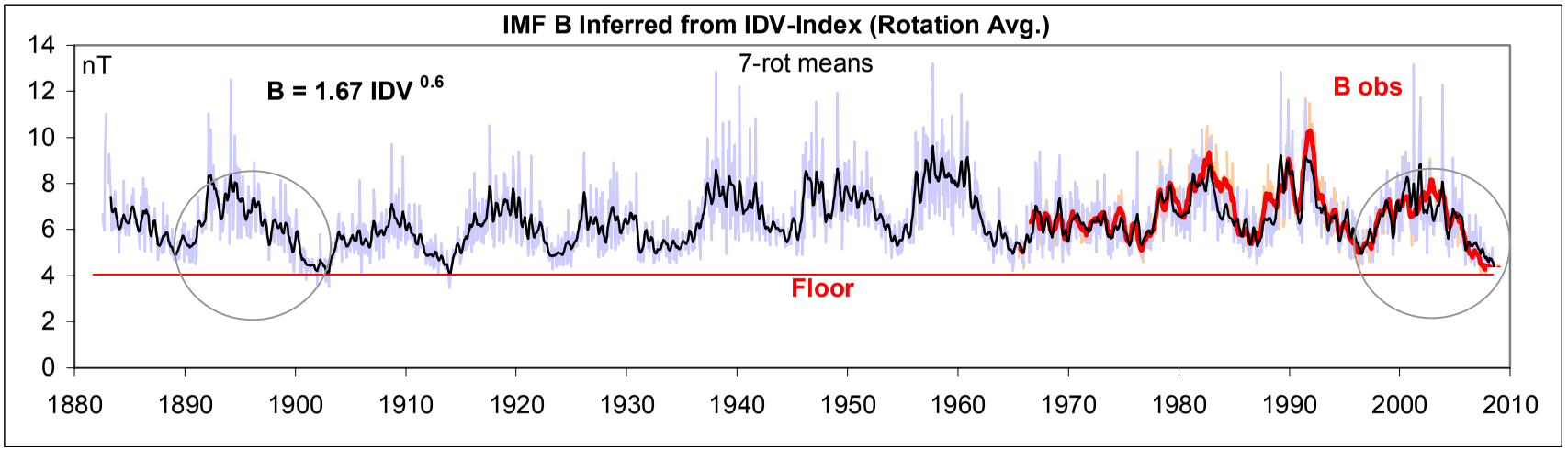
The following advances have been key:

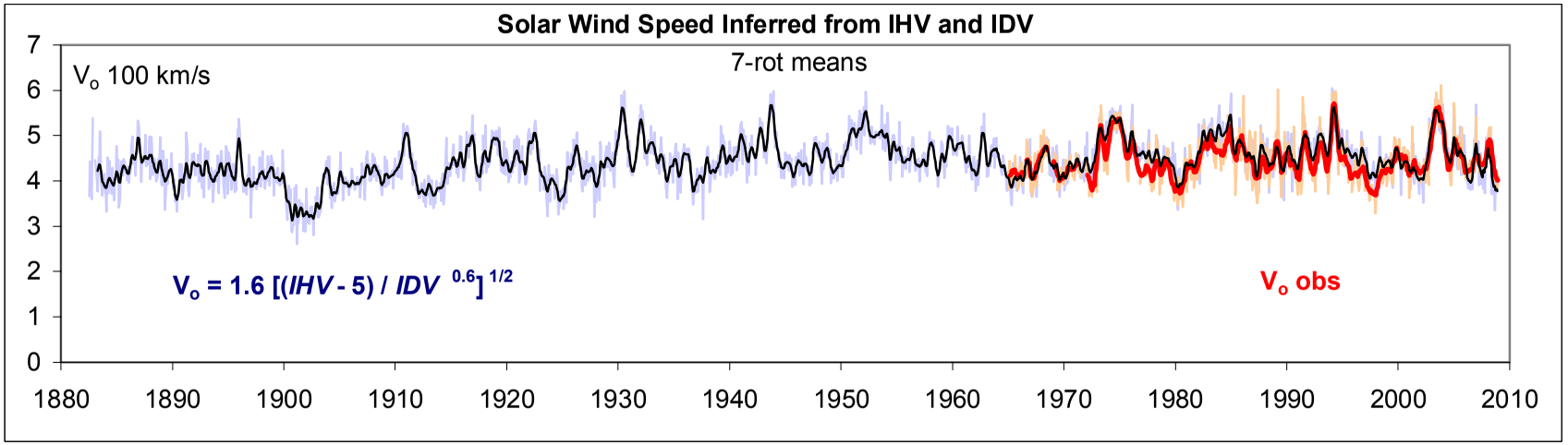
(1) Realization that high-quality indices can be constructed from hourly averages of the geomagnetic field available in 'yearbook' form since the 1830s

(2) Realization that our traditional long-term indices [*aa* and possibly *Dst*] must be [and can be] corrected

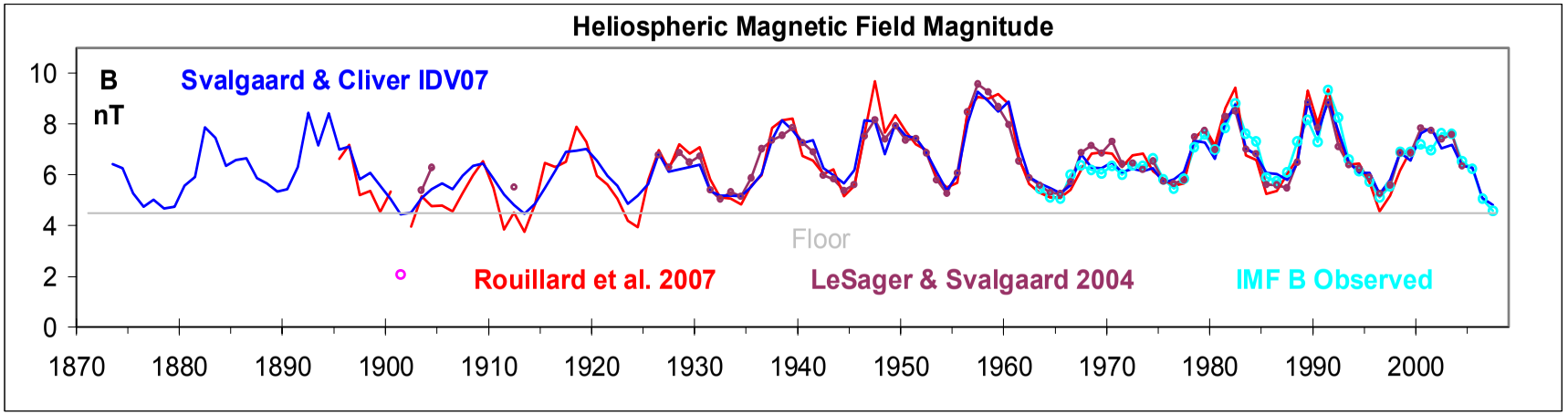
(3) Realization that different indices are responses to different physical processes [current systems] with different coupling functions with different dependencies on *B* and *V* thus allowing *B* and *V* to be determined separately and cross-checked with *B* and *V* from a different combination of indices.

Here is one result of these points [using the *IDV* and *IHV* indices]:


IMF B Inferred from IDV-Index (Rotation Avg.)
nT
7-rot means
B = 1.67 IDV 0.6
B obs
Floor
14
12
10
8
6
4
2
0
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010


Solar Wind Speed Inferred from IHV and IDV
Vo 100 km/s
7-rot means
Vo = 1.6 [(IHV - 5) / IDV 0.6] 1/2
Vo obs
7
6
5
4
3
2
1
0
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

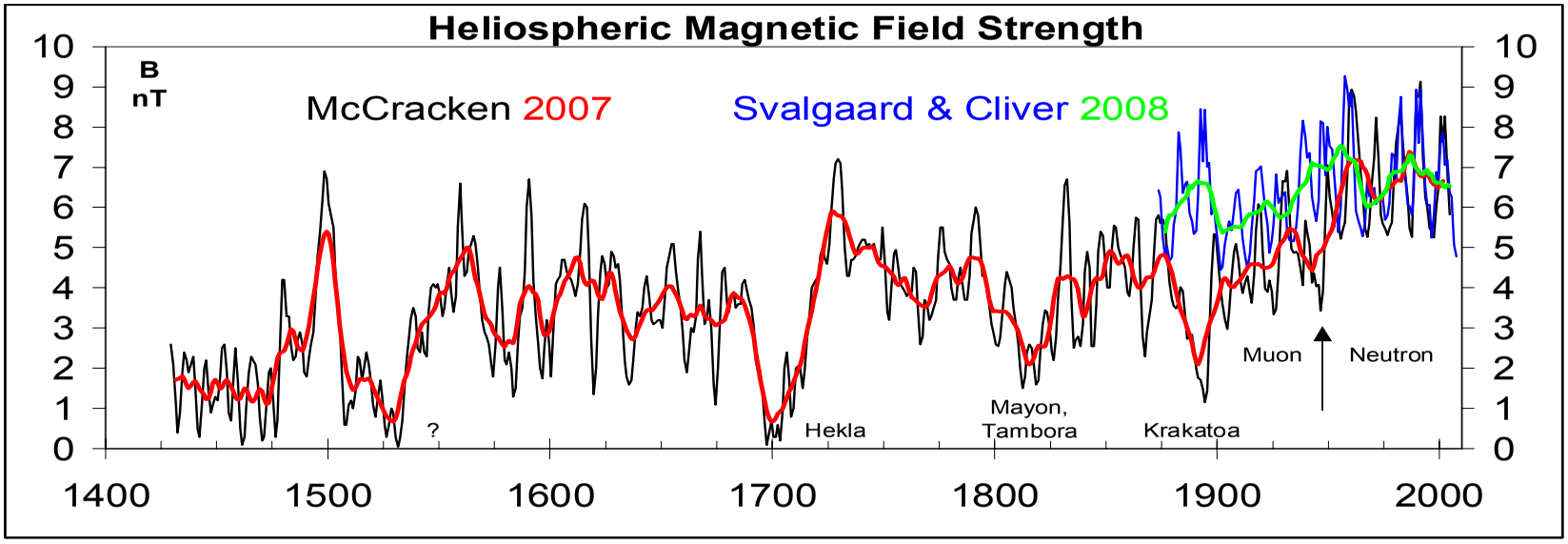
Using different combinations of indices [including a corrected *aa*-index] several groups have reconstructed HMF *B* with very comparable results:



It is clear that *B* is well constrained over the past 135+ years and that there is good general agreement between the various reconstructions, in particular during the interval 1930-1960.

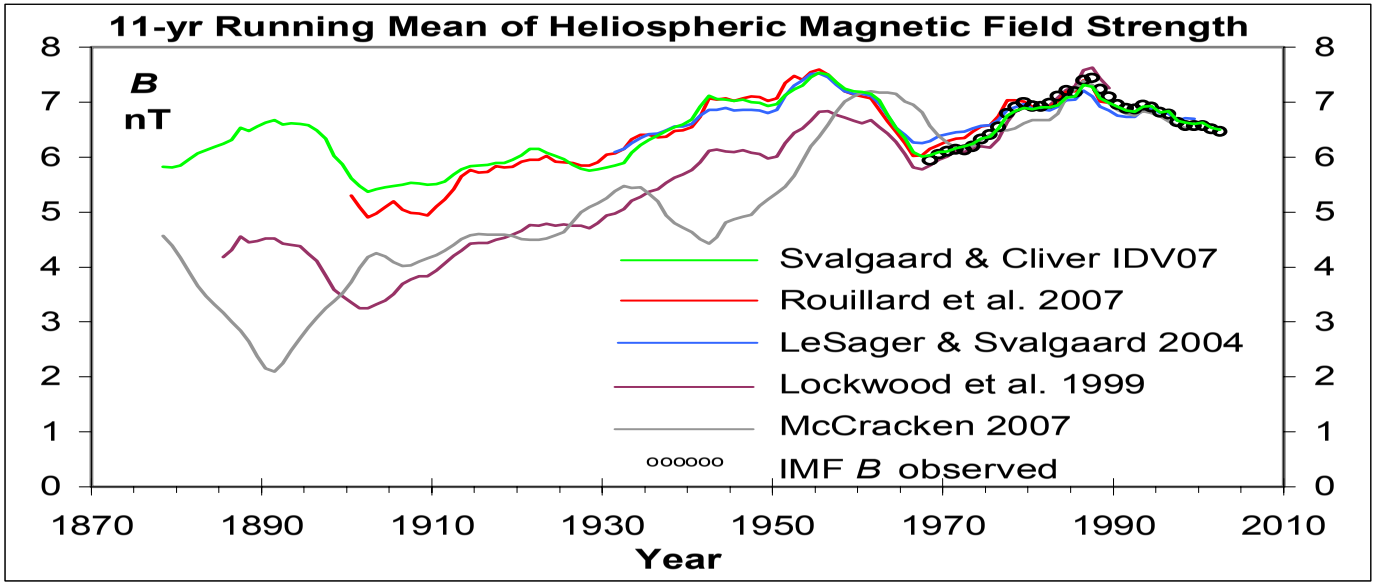
We argue that other proxies should agree with this ‘consensus’ *B*.

One example is McCracken [2007] who inverted the cosmic ray flux (inferred from ^{10}Be fitted to the secular change) to calculate HMF *B*:



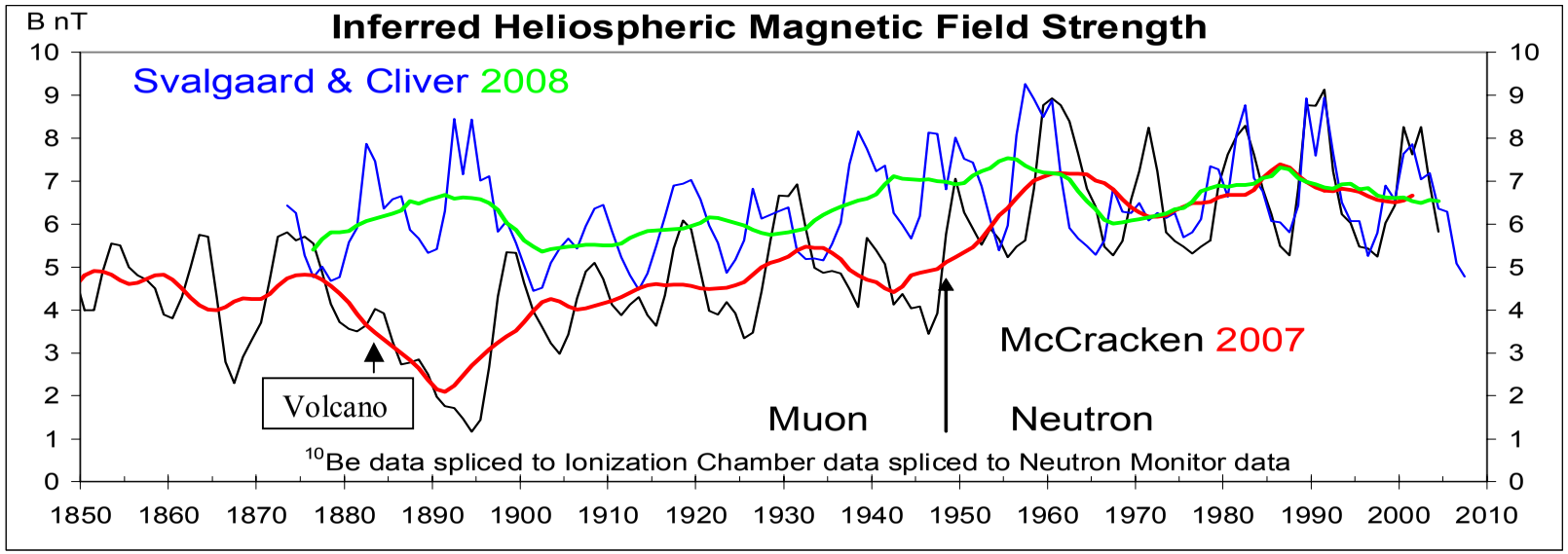
Back to ~1948 there is good agreement [as there must be because the reconstruction is adjusted to fit recent data], but not before.

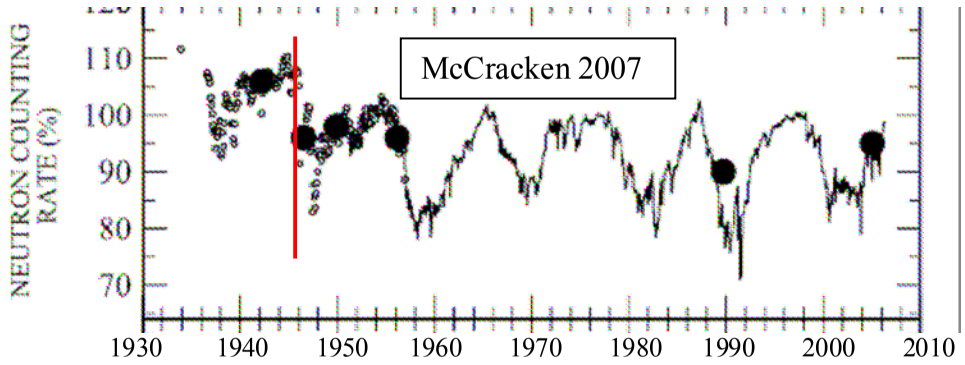
An 11-year running mean attenuates the solar cycle and shows the trend more clearly:



It is clear that McCracken [2007] HMF does not agree with the 'consensus' *B*, although agreement was claimed with an earlier [and now superseded] reconstruction by Lockwood *et al.* [1999 – "more than doubled during the last century"]

A more detailed look at the disagreement:





Neher's balloon data was used to carefully calibrate the old ionization chamber data into 'equivalent' neutron monitor counts. The 'jump' around 1945 is what caused the inferred HMF *B* to drop by 1.7 nT.

It is evident that the inferred HMF *B* from the reconstructed cosmic ray flux is at variance with the 'consensus' *B*. We urge a critical re-examination of the reconstructed cosmic ray flux and associated HMF *B*. before any conclusions are drawn from that data.

The End