Comment on “The heliomagnetic field near Earth, 1428-2005” by K. G. McCracken

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McCracken (2007) inverted the galactic cosmic ray record for the interval 1428-2005 to estimate annual averages of the heliomagnetic field (HMF) near Earth during this interval. Quoting from his abstract, “There is good agreement with the results obtained by others using two independent methodologies based upon the sunspot [*Solanki, Schüssler, and Fligge*, 2002] and geomagnetic [*Lockwood, Stamper, and Wild*, 1999] records … There is disagreement with another method based on the geomagnetic record [*Svalgaard and Cliver*, 2005] that needs to be resolved.” In this comment, we address the reported disagreement of our long-term reconstruction of the HMF strength with that obtained in the other three studies. We show that a recent reconstruction of the HMF by *Rouillard, Lockwood, and Finch* [2007] agrees much more closely with that of Svalgaard and Cliver than that of Lockwood, Stamper and Wild. We also point out that the Solanki et al. model was developed to reproduce the Lockwood et al. HMF time variation; it does not provide independent support for the Lockwood et al. time series. We suggest that the discrepancy between McCracken’s cosmic-ray-based HMF reconstruction and those based on geomagnetic data originates in the Forbush and Neher ionization chamber data (1933-

1957) used to bridge the time gap between the ^{10}Be time series (1428-1930) and the Climax neutron monitor record (1951-present).

1. *The Lockwood et al. [1999] reconstruction has been superceded, largely resolving the disagreement with Svalgaard and Cliver [2005]*

McCracken's comparison of the four time series is shown in Figure 1. He noted that "the agreement between curves (1 [*Lockwood et al.*, 1999]), (3 [*Solanki et al.*, 2002]), and (4 [*McCracken*, 2007]) in (his) Figure 5 provides confidence in the overall validity of these three independent methods." After McCracken's paper was submitted, *Rouillard et al.* [2007] published an HMF time series that agrees substantially better with that of *Svalgaard and Cliver* [2005] than with that of *Lockwood et al.* [1999]. A comparison of the HMF reconstruction of *Rouillard et al.* [2007; red curve, based on the (corrected) *aa* index and their median (*m*) index], for their preferred derivation using Bayesian least squares regression, with that of *Svalgaard and Cliver* [2005; black curve, based on the interdiurnal variability (*IDV*) index][1] is given in Figure 2.

In the figure it can be seen that the agreement between the Rouillard et al. and Svalgaard and Cliver curves is quite good after ~1910 (RMS difference = 0.3 nT). The Rouillard et al. values before ~1910 are uncertain because of the paucity of available stations used to derive the *m*-index for those times and, in addition, their HMF value for 1901 is likely in error (both points, A. Rouillard, personal communication, 2007).

Both the *Rouillard et al.* [2007] and the *Svalgaard and Cliver* [2005] reconstructions give evidence for a "floor" in the solar wind IMF of ~4.5 nT [*Svalgaard and Cliver*,

[1] Yearly values of all time series plotted or otherwise used in this comment are given in electronic Table 1.

2007a] that is approached at each sunspot minimum. Figure 2 also contains an HMF series based on the polar cap potential index [*Le Sager and Svalgaard*, 2004; magenta curve], determined from magnetic observations within the polar cap from 1926-present and for a few isolated years from polar expeditions [*Svalgaard and Cliver*, 2007b] earlier in the 20th century. This index is highly correlated with the product of the HMF (*B*) and the solar wind speed (*V*). The *V* series reported in *Svalgaard and Cliver* [2007b] was used to deduce the plotted HMF strength; the *V* reconstruction of *Rouillard et al.* [2007] yields essentially the same result. In Figure 2, direct observations of the HMF strength, 1965-present are represented by a light blue curve.

We note that in Figure 1, from McCracken et al., the conversion from open flux on the left hand axis to field strength on the right hand axis is incorrect both with regard to scale and zero point. In Figure 3, we have recast correctly the *Lockwood et al.* [1999] open flux time series in terms of magnitude *B*. Also shown in Figure 3 are running 11-yr averages of the *Svalgaard et al.* [2005; green curve, based on *IDV*07], *Rouillard et al.* [2007; red curve], *Le Sager and Svalgaard* [2004; blue curve], and *McCracken* [2007] HMF strength time series, as well as 11-yr averages of direct observations of *B* (open black circles) for 1963-2007. The agreement between the three "upper" long-term curves is good except before ~1913 where the Rouillard et al. values begin to systematically dip below the IDV-based series (see above).

While the geomagnetic-based reconstruction of the solar open flux and HMF strength has sparked controversy (see the exchange between *Lockwood et al.* [2006] and *Svalgaard and Cliver* [2006]), Figure 3 reveals a strong convergence between the Lockwood/Rouillard and Svalgaard/Cliver/Le Sager reconstructions that is more impressive than the discrepancies that remain. For the intervals of overlap, the agreement between the *Le Sager and Svalgaard* [2004], *Svalgaard and Cliver* [2005], and *Rouillard et al.* [2007] series is significantly better than that of any of the three with the ^{10}Be-based HMF series of *McCracken* [2007] or with the superseded *Lockwood et al.* [1999] series.

2. *The Solanki et al. reconstruction is not independent of Lockwood et al.*

The *Solanki et al.* [2002] (see also *Solanki, Schüssler, and Fligge* [2000]) open flux model was developed in order to account for the doubling of the coronal magnetic field reported by *Lockwood et al.* [1999]. In this model, the open flux is a given fraction of the total magnetic flux over the Sun, which in turn is the sum of the flux from active regions (that falls to near zero at solar minimum), the flux from ephemeral regions, and the network flux. The decay time of the open magnetic flux in the model was adjusted in order to match the relative amplitudes of the cyclic flux to the doubling of the open flux reported by *Lockwood et al.* [1999] (also, observational evidence (from *Harvey* [1994]) regarding the sign of the contributions from active and ephemeral regions was discounted to maintain fidelity between the Lockwood et al. curve and the model output [see *Solanki et al.*, 2002, p. 710]). Presumably, the model could be similarly adjusted to reproduce the HMF time series of *Rouillard et al.* [2007] or *Svalgaard and Cliver* [2005]. Thus the *Solanki et al.* [2002] reconstruction does not provide independent support for the HMF reconstruction of *McCracken* [2007], and is not included in Figure 3.

3. *The McCracken 1428-2005 HMF reconstruction needs to be re-examined*

Figure 3 casts doubt on *McCracken's* [2007] 1428-2005 HMF time series. We suggest that re-analysis begin with the underlying galactic cosmic ray time series, specifically the 1933-1957 ionization chamber measurements used to link the Climax neutron monitor data (1951-present) to the ^{10}Be-based measurements (1426-1930). The 1933-1957 interval encompasses the largest step-like change (~1.7 nT, "…from 3.5 nT to ~5.2 nT between the sunspot minima of 1944 and 1954") in McCracken's ~600-yr HMF time series. We note that, in Figure 7 from *McCracken and Beer* [2007], both the anti-correlation of sunspot number with cosmic ray intensity [*Forbush*, 1954; *Cliver and Ling*, 2001] and the alternating peaked and flat-topped cosmic ray cycles [*Jokipii, Levy, and Hubbard*, 1977; *Smith*, 1990] are less apparent for years before 1951 than for later years. The compelling reason for questioning the 1933-1951 portion of the cosmic ray record, however, is the absence of a significant increase in the HMF strength during this time in the independent concordant reconstructions of *Le Sager and Svalgaard* [2004], *Svalgaard and Cliver* [2005], and *Rouillard et al.* [2007]. For each of these series, the HMF at the 1944 and 1954 minima is essentially constant at ~5 nT (Figure 2).

In closing, the disagreement between the *McCracken* [2007] reconstruction and the three upper curves in Figure 3 [*Le Sager and Svalgaard*, 2004; *Svalgaard and Cliver*, 2005; *Rouillard et al.*, 2007] will need to be resolved by McCracken to permit use of the long ^{10}Be series to confidently extend the HMF series back in time.

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Figure Captions

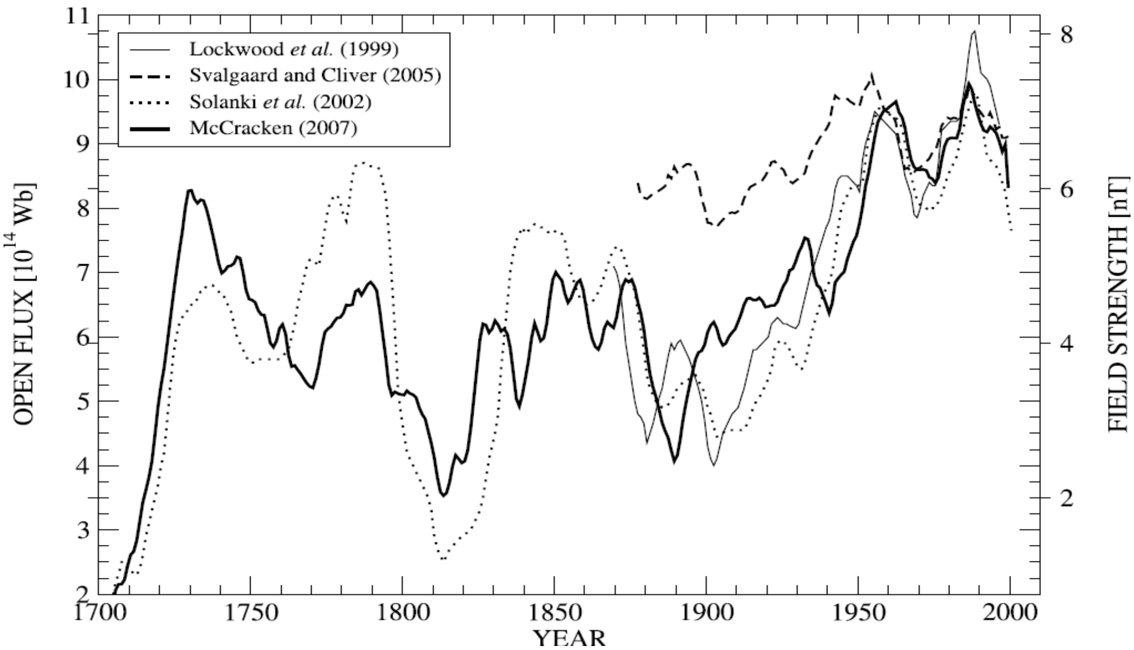

Figure 1. 11-yr running averages from 1700-2000 of the heliomagnetic field strength [HMF] near Earth based on three different methodologies. Curves 1 and 2 are obtained using the short-term fluctuations of the geomagnetic field. Curve 3 is one of several estimates based on the historical sunspot record. Curve 4 is derived from the cosmic ray record. This figure is from *McCracken* [2007; Figure 5 in that paper].

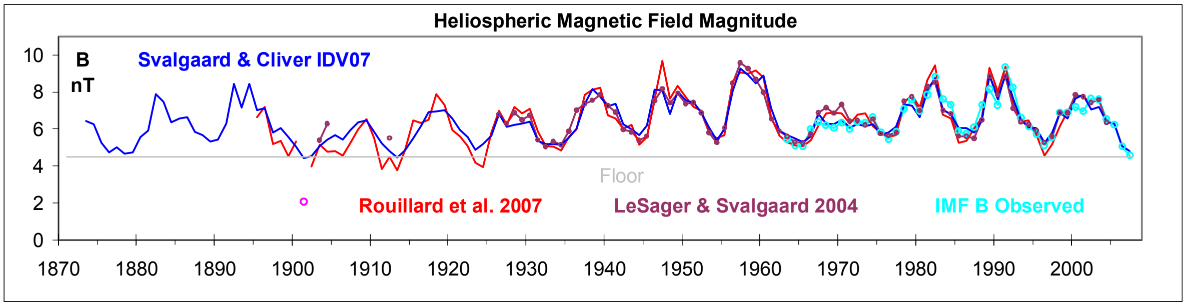

Figure 2. Three reconstructions of the HMF strength near Earth from 1873-2007 based on geomagnetic data: *Rouillard et al.* [2007; red curve], *Svalgaard and Cliver* [2005; blue curve, using IDV07], and *Le Sager and Svalgaard* [2004; magenta curve]. Direct solar wind observations of the HMF are also shown for 1965-present [*Omni data*, light blue curve].

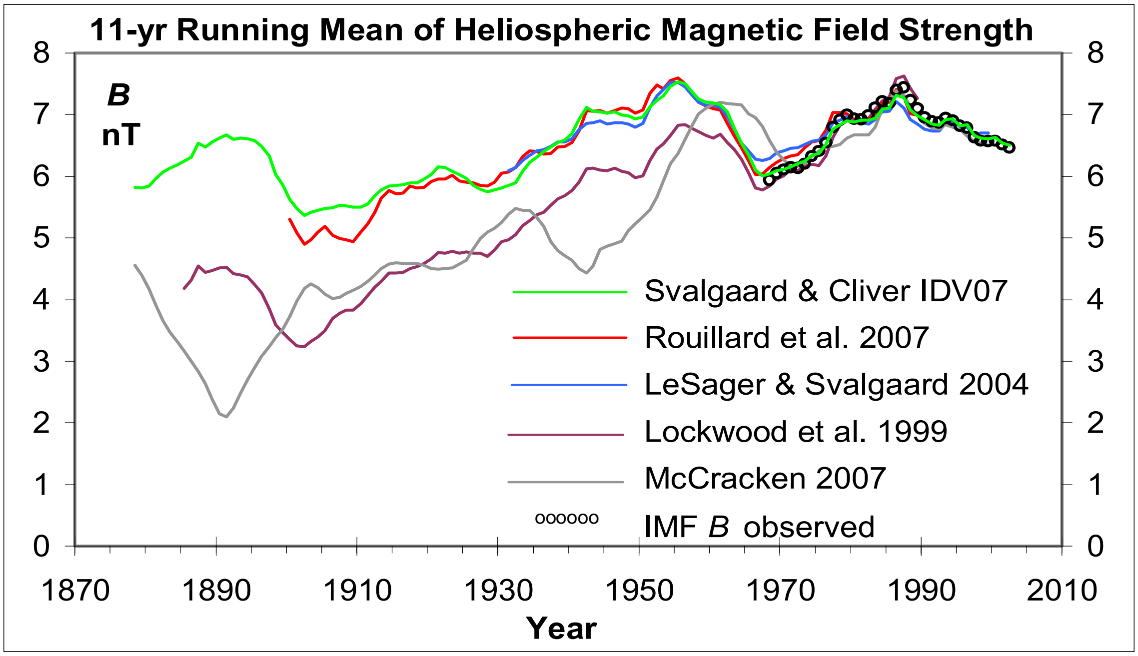

Figure 3. 11-yr running averages of the HMF reconstructions of *Svalgaard and Cliver* [2005; green curve, using IDV07], *Rouillard et al.* [2007; red curve], *Le Sager and Svalgaard* [2004; blue curve], *Lockwood et al.* [1999; magenta curve] (supplanted by *Rouillard et al.* [2007]), and *McCracken* [2007; gray curve]. Also shown are 11-yr averages of observed HMF strength values (open black circles) for 1963-2007.