An Analysis of Heliospheric Magnetic Field Flux Based on Sunspot Number from 1750 to Today and Prediction for the Coming Solar Minimum

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Introduction

The Heliospheric Magnetic Field (HMF) intensity has been shown by observation to rise and fall with the solar cycle. In situ observations have only been available from 1963 onward. This work takes the model of Schwadron et al. (2010) and uses it to model the HMF using sunspots as a proxy for flux injection. This allows us to project the HMF intensity as far back as 1749.

As a comparison, the level of the cosmogenic isotope ^{10}Be has been shown to vary with the HMF. McCracken et al. (2013) used the ^{10}Be in ice core samples to make a model for the HMF. We compared the sunspots with the ice cores to determine validity of the sunspot predictions.

Predictions for Coming Solar Cycle

After reconciliation with the ^{10}Be data and in situ measurements in more recent years, we make a prediction for the HMF in the coming solar cycle. We note that 2013 marks the peak of Cycle 24 and the sunspot numbers bear remarkable similarity to the Dalton Minimum. Therefore, we have used the data for 1805 onward as a prediction for the next seven years of solar activity. Figure 3 shows this, with the vertical line representing the present and the data to the right being from the Dalton Minimum.

If this analysis proves accurate, then the hysteresis effect will mean the the HMF intensity will be falling from a much lower level and will reach a lower final value than the last protracted solar minimum. The Parker field will reach as low as 0.5 nT, and |B| as low as 1.5 nT, due to the smaller difference in the two during solar minimum.

Equations

$$\Phi_m(R) = 4\pi R^2 \left\langle |B_r| \right\rangle$$

$$\frac{d\Phi_{ej}}{dt} = f(1-D)\phi_{CME} - \Phi_{ej}\left(\frac{1}{\tau_{ic}} + \frac{1}{\tau_d} + \frac{1}{\tau_o}\right)$$

$$\frac{d\Phi_0}{dt} = -\frac{\Phi_0 - \Phi_{flr}}{\tau_d} + \frac{\Phi_{ej}}{\tau_o}$$

$$\frac{d\Phi_{tot}}{dt} = -\frac{\Phi_{tot} - \Phi_{flr}}{\tau_d} + f(1-D)\phi_{CME} - \frac{\Phi_{ej}}{\tau_{ic}}$$

Equations used in Schwadron et al. (2010) to compute flux based on monthly averages of sunspot numbers.

^{10}Be Data

At times of lower solar activity, more radionuclides are produced and subsequently more are trapped in the polar ice. Ice cores layers can be used to determine the level of solar activity with a resolution as high as one year. It has been shown with sunspot data and recorded HMF intensities that sunspot minima and the corresponding changes to the HMF increase ^{10}Be levels, from which the historic HMF can be modeled.

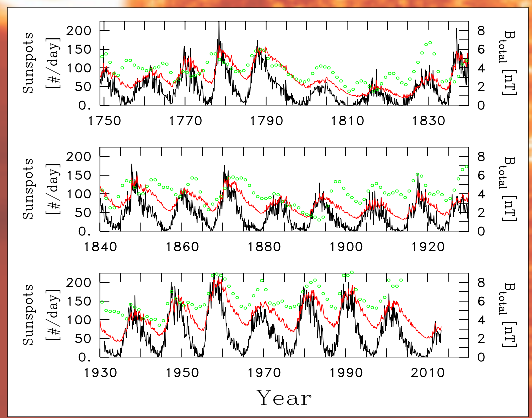

Figure 1. (black) Plot of monthly average sunspot number from 1749 to the present. (red) Corresponding predicted Parker component of the HMF intensity at 1 AU. (green) Yearly average value of |B| derived from ^{10}Be data.

Data Analysis

Figure 1 shows the sunspot number, B_p as computed from sunspot data and the B as computed from ^{10}Be data. The most important feature of this figure is the hysteresis visible. The HMF rises quickly with the sunspot number, but falls off at a lower rate. This is further visible in Figure 2, where a 7 month running boxcar average has been applied and the data smoothed over a smaller set of years.

Comparing Flux and Total Field Intensity

Looking at Figure 1, it is evident that there is a systematic difference between the results obtained from sunspots and from ^{10}Be. The reason for this is that the Schwadron et al. (2010) model predicts the Parker component of the field , $|B_p|$, and the McCracken et al. (2013) predicts the average total field intensity, |B|. Therefore, since $|B_p|$ neglects the azimuthal components of the field, is it expected and shown to be consistently less than |B|.

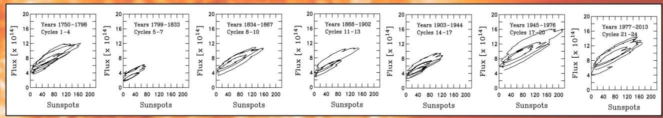

Figure 2. Hysteresis plots for given years and cycles plotting smoothed sunspot numbers vs. smoothed computed HMF flux as derived from the above theory.
Because the flux rises quickly with sunspots, which we use as a proxy for CME activity, and falls more slowly as sunspot activity decreases, there is a noted hysteresis effect.

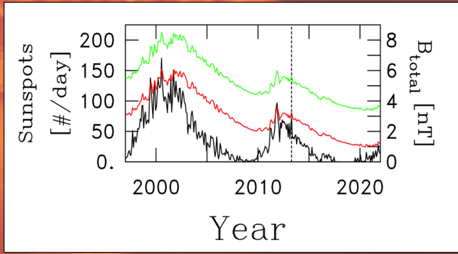

Figure 3. Analysis of recent solar cycle. From year 2013 onward the sunspot number is from the historical record 1805 onward. Resulting $|B_p|$ is 1 nT lower than in the last protracted solar minimum.