A New Source Surface Radius in Potential Field Modeling During the Current Weak Solar Minimum?

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Introduction

• The potential-field source-surface (PFSS) model is widely used to extrapolate field in corona from the photosphere. It is very useful for describing large-scale coronal structures.

• A 2.5 solar radii source surface (*Hoeksema et al, 1983*) successfully reproduces the interplanetary magnetic field (IMF) polarity at 1AU. It gives a good description of the streamer belt topology and coronal hole location too for the last minimum.

• The current minimum shows an overall weaker field (*fig 1*). A smaller source surface is needed (*Luhmann et al, 2009*) to produce the observed coronal structures and to keep the model self-consistent in terms of open flux.

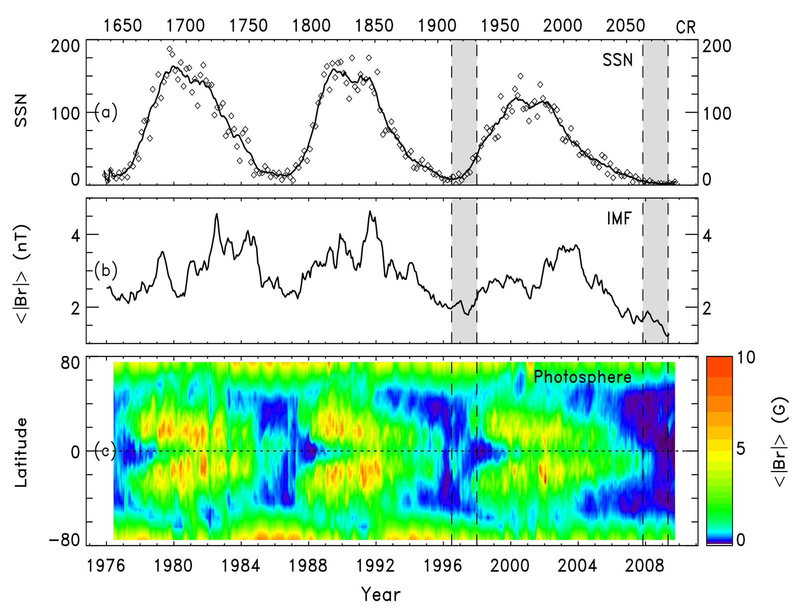


***Fig 1** Sunspot number (top), IMF Bx component from OMNI (mid) and total flux on photosphere from WSO (bot) over the last three cycle. Dashed lines show the period we study. A decrease in value is found in all three panels during this min compared with the last.*

Modeling Heliospheric Current Sheet

• Bright stripes in LASCO C2 and STEREO COR coronagraphs show the streamer belt structure. The helmet streamer structures whose core at the source surface define the base of the heliographic current sheet. The zero isosurface of radial field in PFSS model describes the inferred location of the current sheet.

• For the last minimum, a 2.5 solar radii source surface produces a relatively flat current sheet and fits observation well. For the current minimum where the current sheet looks more warped, a source surface of 1.8 solar radii seems better (*fig 2*).

• However, for modeled IMF polarity where solar wind stream interactions are involved, the 2.5 solar radii source surface yields better result for both periods (*fig 3*).

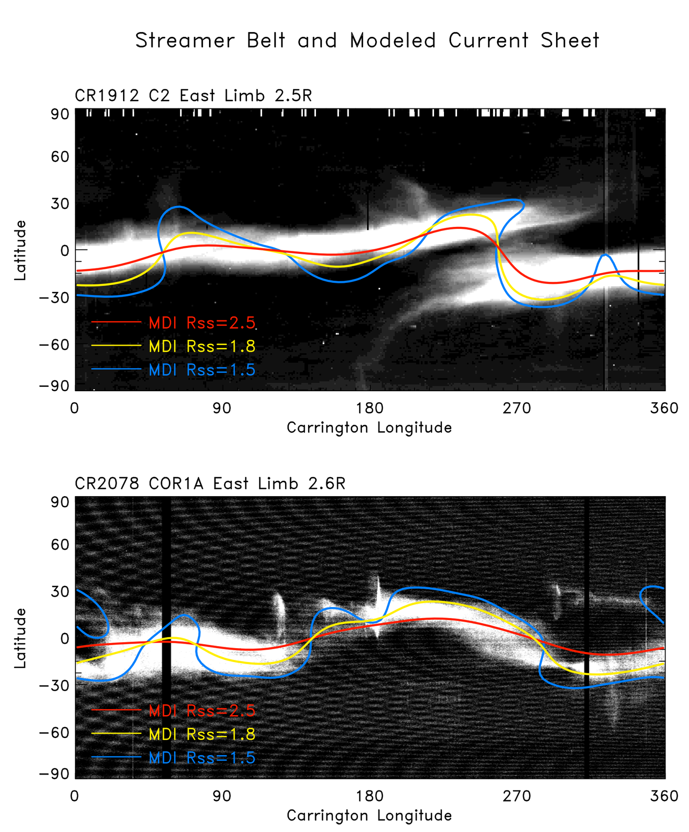


***Fig 2** Synoptic maps made from LASCO C2 coronal graph at 2.5R on east limb for CR1912 (top); and from STEREO COR1A at 2.6R on east limb for CR2078 (bot). Overplotted are zero isosurface of Br at 2.5R as current sheet location, computed from PFSS with different source surface radius.*

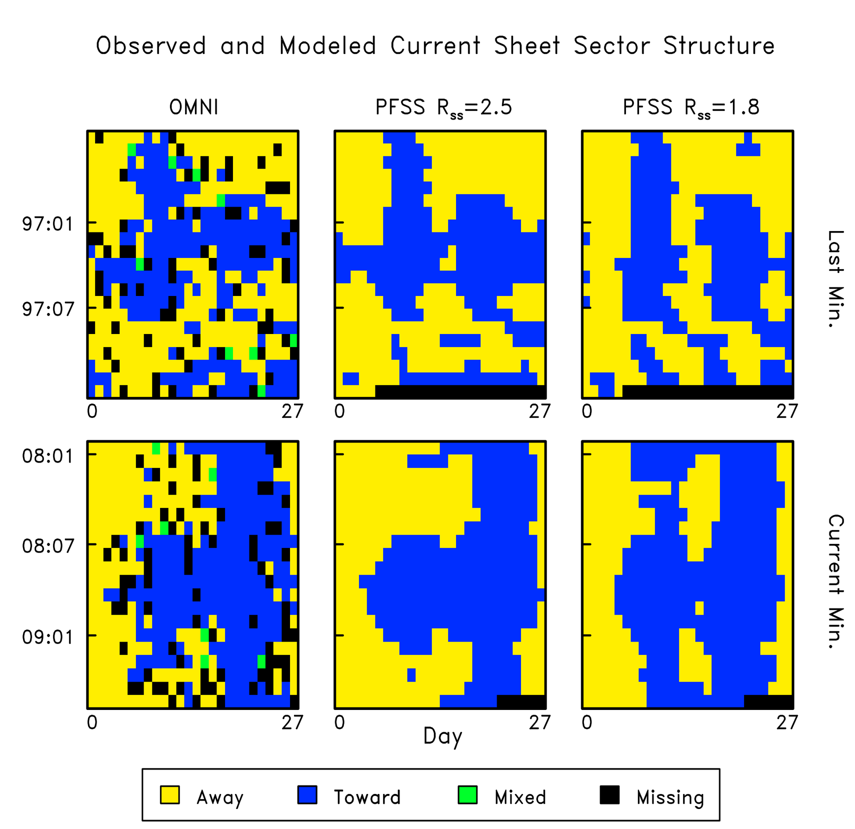


***Fig 3** (Left) IMF polarity from OMNI data set, daily averaged, stacked in a 27-day per row Bartel format to show the heliographic current sheet sector structures. (Middle) Modeled result using 2.5R source surface, assuming a uniform 5-day solar wind transition time to Earth. (Right) result from 1.8R source surface.*

Modeling Coronal Hole Location

• Dark regions in EIT and STEREO SECCHI EUVI 195A observations indicate open field structures, in the lower corona, which show the location of coronal holes. In PFSS, we can specify the open field foot points by field line tracing.

• During the previous minimum, there are few mid-low latitude coronal holes, and a 2.5 solar radii source surface correctly shows that most open flux comes from the polar region. For the current minimum, we see more large middle and low latitude coronal holes. The 2.5R source surface fails to reproduce them, while a source surface of about 1.8 solar radii works better (*fig 4*).

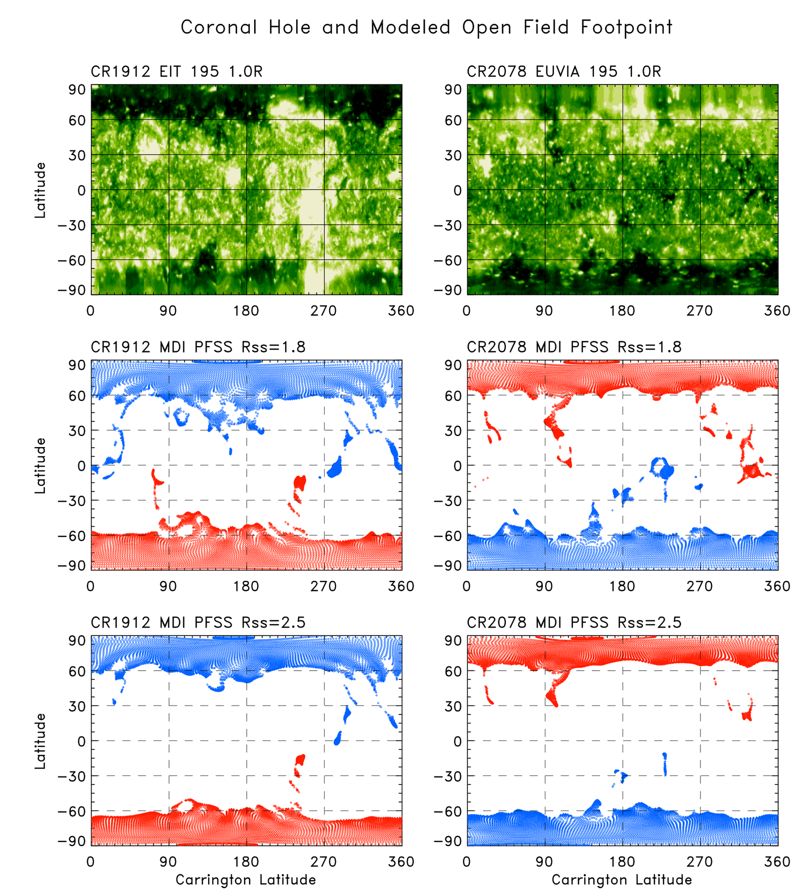


***Fig 4** Top left: EIT 195A synoptic map for CR1912; top right: STEREO SECCHI EUVIA 195A for CR2078. Mid: open field foot points from PFSS with 1.8R source surface, red for negtive, blue positive. Bot: foot points from PFSS with 2.5R source surface.*

Estimate R_{SS}: Inferred Open Flux?

• Ulysses latitudinal scan of the heliosphere during two solar minima shows no apparent latitudinal gradient in IMF strength (*Smith and Balogh, 2008*). Thus, we can use the in-situ IMF measurement at the L1 point to estimate the open flux from the Sun in the heliosphere.

• The OMNI data set (*King and Papitashvili, 2005*) provides an IMF strength. The average |Br| during the current minimum is smaller than the last one. The average from Jul 1996 to Nov 1998 is about 82% of that from Nov 2007 to Apr 2009 (*fig 5, 6*).

• The averaged open flux from PFSS, using WSO data set, matches well with observation during last minimum, but is only about 58% this minimum compared to the last if we use the same 2.5R source surface (*fig 5, 6*). Modeled values are off during maximum due to injected fluxes from ICME, etc (*Riley, 2007*). Similar result for MDI.

• We will need to decrease the source surface height to about 1.7 solar radii for the model to be consistent with the observed change in flux (*fig 6*).

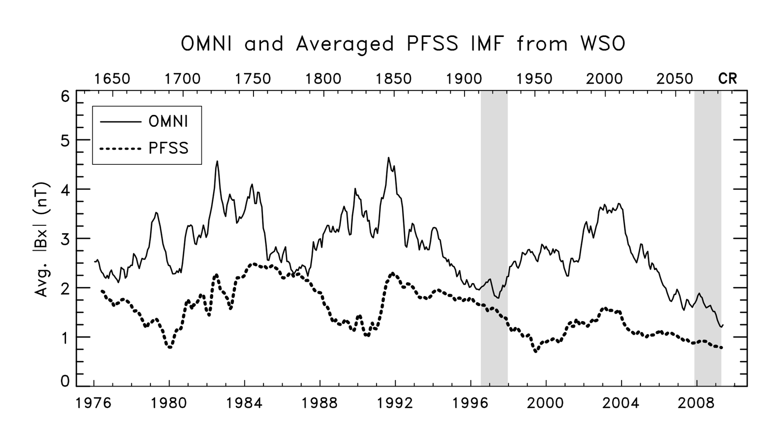


***Fig 5** Solid line: 27-day averaged IMF |Br|. Dotted line: averaged |Br| at 1AU, modeled by PFSS with a 2.5R source surface, using the WSO data. Both lines are smoothed by a 20nHz filter. Shaded area shows the two minima we study.*

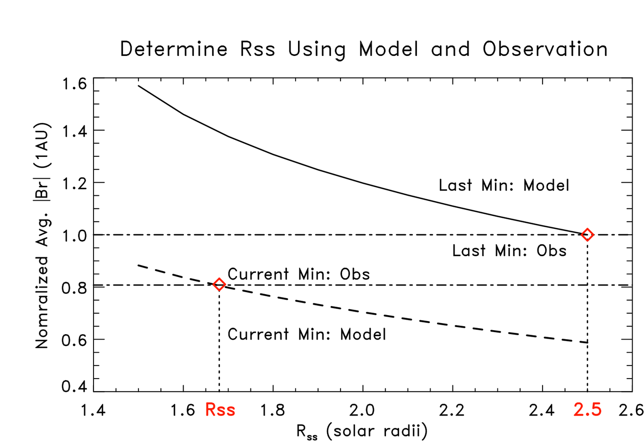
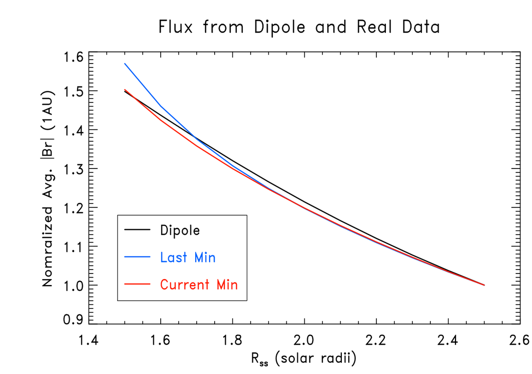


***Fig 6** Illustration of how to determine source surface radius in terms of open flux. Solid: open flux from different Rss for last min. Dashed: this min. All normalized to 2.5R for last min. Horizontal lines show observed |Br|. If 2.5R is used for last min, 1.7R is needed for the current one.*

Estimating the Source Surface Radius:

During solar minimum, the open flux inferred from PFSS model is primarily determined by the dipole component (*fig 7*). The dipole flux is proportional to dipole strength ($\Phi \propto D$) and approximately inversely proportional to the source surface radius ($\Phi \propto 1/R_{ss}$). On the other hand, the flux should be proportional to observed IMF ($\Phi \propto B_r$). Therefore,



$$R_{ss} \approx R_{ss0} \times (D/B_r) / (D_0/B_{r0})$$

where 0 denotes the reference value (from last minimum). For the current minimum, $R_{ss} \approx 2.5 \times 0.58 / 0.82 \approx 1.8$

***Fig 7** Open flux from dipole field and PFSS, vs. source surface radius from two minima.*

HCCSSS: An Improved Approach

• The PFSS model assumes that field lines are radial outside the source surface, which does not fit the observations well. It also assumes there is no current flowing in the corona. Therefore, inferred coronal field at low latitude are significantly lower than high latitude, causing a false latitudinal field gradient (*fig 8*).

• By introducing a horizontal current sheet (*Schatten, 1971*), the flux is more uniformly distributed over latitude. The horizontal-current current-sheet source-surface (HCCSSS) model (*Zhao and Hoeksema, 1995*) introduces horizontal current to the system, while also satisfying the magneto-static equations (*Dogdan and Low, 1986*). It gives a more realistic description of the corona, while predicts IMF strength at higher accuracy (*fig 8*).

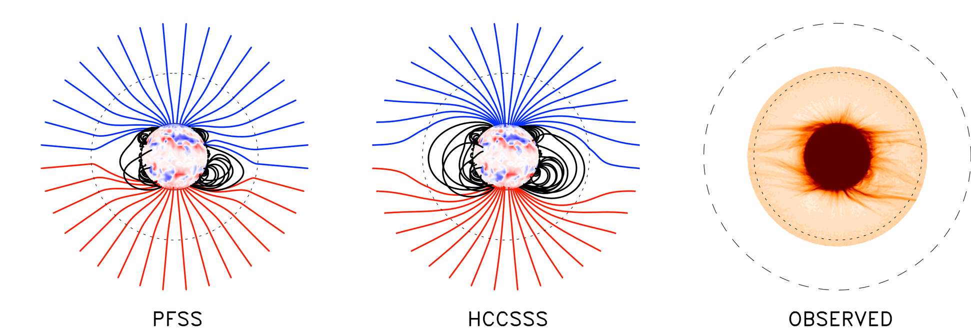


***Fig 8** Illustration of coronal field structures derived from PFSS and HCCSSS, and corona image of Feb 1998 eclipse (courtesy POISE, HAO). CMP is about CR1933, 260 degree.*

Conclusions

• The PFSS model with a 2.5 solar radii source surface models the corona structures well during the last minimum.

• During the current weak minimum, the current sheet is more warped; there're more large mid-low latitude coronal holes; the photospheric field and IMF are both weaker than the last but by a different factor. A source surface of about 1.8 solar radii yields a better result.

• The current sheet sector structure at 1AU, however, is better reproduced by the 2.5 solar radii source surface in both minimum.

References

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