Space Weather of the Heliosphere: Processes and Forecasts
Proceedings IAU Symposium No. 335, 2017
C. Foullon & O.E. Malandraki, eds.

doi:10.1017/S1743921317009875

PFSS-Based Solar Wind Forecast and the Radius of the Source-Surface

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Abstract. The potential-field source-surface (PFSS) model of the solar corona is a widely used tool in the space weather research and operations. In particular, the PFSS model is used in solar wind forecast models which empirically associate solar wind properties with the numerically derived coronal magnetic field. In the PFSS model, the spherical surface where magnetic field lines are forced to open is typically placed at 2.5 solar radii. However, the results presented here suggest that setting this surface (the source-surface) to lower heights can provide a better agreement between observed and modelled coronal holes during the current solar cycle. Furthermore, the lower heights of the source-surface provide a better match between observed and forecasted solar wind speed.

Keywords. Sun: corona, Sun: magnetic fields, solar wind

1. Introduction

The potential-field source-surface (PFSS) model is an important model of the solar coronal magnetic field. Due to its numerical simplicity, the model is widely used in the space weather research and operations. The PFSS model is based on a current-free approximation and uses synoptic solar magnetograms to derive the magnetic field between the surface of the Sun and the so-called source-surface (Altschuler & Newkirk 1969, Schatten 1969). At the source-surface, which is typically placed at 2.5 solar radii (R_0) in PFSS applications, the coronal magnetic field is purely radial, i.e. "open". An important application of the PFSS model is for solar wind forecasting (Arge *et al.* 2003, Hakamada *et al.* 2005). In the PFSS-based solar wind models, solar wind properties are empirically associated with the coronal magnetic field. These models can be used as standalone solar wind forecast models, or to provide boundary conditions to heliospheric MHD codes (e.g., Shiota & Kataoka 2016, McGregor *et al.* 2011). In these implementations of the PFSS model, the source-surface is typically fixed at 2.5 R_0 as well. For example, this is also the case in the Wang-Sheeley-Arge (WSA) solar wind and ENLIL MHD model configuration, which is used for operational forecasting of coronal mass ejection arrivals (Steenburgh *et al.* 2014). However, there is a question on how well the PFSS-based solar wind models with the fixed source-surface perform as the solar activity changes (Reiss *et al.* 2016). This question is particularly important since the current solar cycle (cycle 24) is relatively weak in comparison with previous solar cycles. It has been suggested by Lee *et al.* (2011) and Arden *et al.* (2014), that changing the height of the source-surface should be considered in order to satisfy agreement between modeled and observed open magnetic flux. However, different conclusions about the height have been reported. Here, agreement between modeled and observed coronal holes (CH) and forecasted and observed solar wind speed is investigated for different heights of the source-surface in the PFSS model.

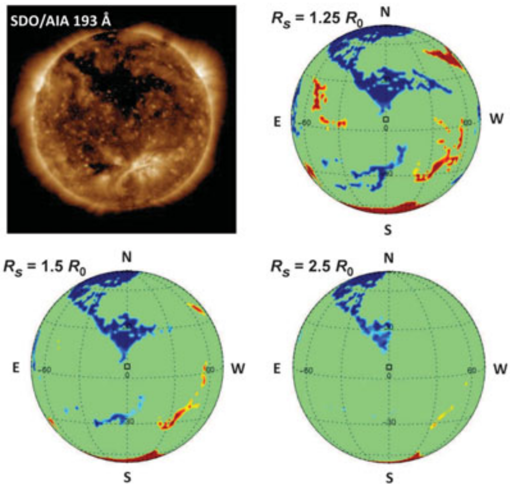

Figure 1. Observed (SDO/AIA 193 Å) and PFSS derived CH with $R_s = 1.25$, 1.5 and 2.5 R_0 for 22 August 2010. The red and blue color of modelled CH denote magnetic field lines which are pointed away from and toward the Sun, respectively.

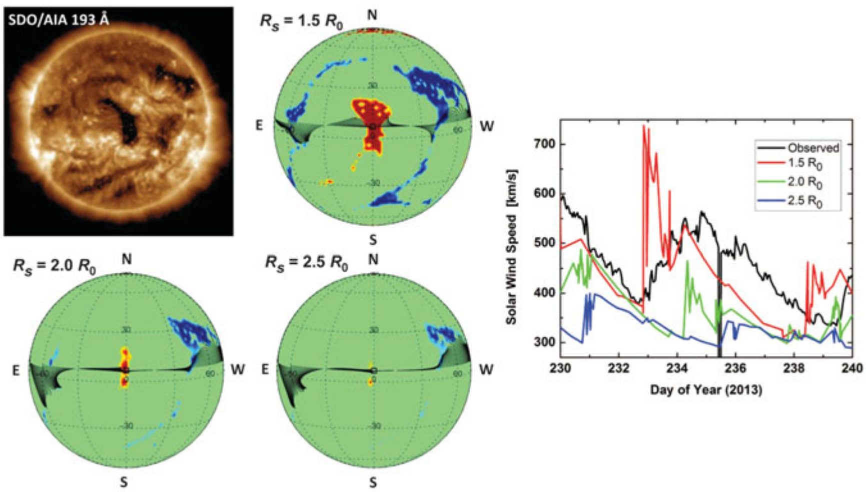

Figure 2. Observed (SDO/AIA 193 Å) and PFSS derived CH with $R_s = 1.5$, 2.0 and 2.5 R_0 for 18 August 2013 (230 day of year), and the observed and forecasted solar wind speed at Earth with different heights of the source-surface. The red and blue color of modelled CH denote magnetic field lines which are pointed away from and toward the Sun, respectively, while the black lines represent open magnetic field lines which connect to projected positions of Earth on the source-surface.

2. Results and Discussion

The PFSS and solar wind forecast code are developed at the Canadian Space Weather Forecast Center. Here, Global Oscillation Network Group (GONG) synoptic maps are used in the PFSS model to derive the coronal magnetic field for various heights of the source-surface.

To illustrate the dependence of the results on the height of the source-surface, in Figure 1 observed and PFSS modelled CH are shown for 22 August 2010. The observations are from the Solar Dynamics Observatory satellite (AIA 193 Å) and modelled CH are

https://doi.org/10.1017/S1743921317009875 Published online by Cambridge University Press

obtained with the source-surface radius (R_s) of 1.25, 1.5 and 2.5 R_0. Although identification of CH from observations is challenging (e.g., de Toma 2011), from Figure 1 we can see that the PFSS model with customary used $R_s = 2.5$ R_0 does not provide a good resemblance to the large northern CH. The lower heights of the source-surface provide a better match. It is found that, in particular around the solar cycle 24 maximum, instead of 2.5 R_0, the source-surface with a radius of 1.5 - 1.8 R_0 provides better agreement between the model and observations. This can be seen also in Figure 2 where observed and modelled CH with $R_s = 1.5$, 2.0 and 2.5 R_0 are shown for 18 August 2013.

Since CH are the source of high-speed solar wind streams, the CH properties can be used to forecast the solar wind. Therefore, the fact that numerical modelling of CH can be improved by changing the source-surface height has implications on the PFSS-based solar wind models. In the WSA model, for example, the solar wind speed is empirically associated with open magnetic field lines, which form CH. In particular, in the WSA model, the solar wind speed depends on the flux tube expansion factor f_s, and the distance of the open magnetic field line foot-point from the CH boundary θ_b (Arge *et al.* 2003). Since the centrally located CH in Figure 2 is not represented well with $R_s = 2.5$ R_0, the standard WSA solar wind relation (see Reiss *et al.* 2016) does not provide a good agreement between observed and derived solar wind speed. As we can see from Figure 2, using the same solar wind relation, but with lower heights of the source-surface, one could obtain an increased value of the solar wind speed. However, to obtain a better quantitative agreement, empirical coefficients used to associate the solar wind speed with f_s and θ_b should be tuned for lower source-surface heights. Since the tuning of the coefficients in the standard WSA relation for different heights of the source-surface poses a significant challenge, further research is needed to investigate and simplify the empirical relation between the coronal magnetic field and solar wind properties.

3. Summary

The obtained results suggest that changing the source-surface height in the PFSS model could improve agreement between observed and modelled CH. In general, during the current solar cycle, the source-surface location lies well below the customary used heights of 2.5 R_0. These results also suggest that the solar wind models with the solar activity dependent source-surface could provide better forecast of solar wind conditions.

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