Mutli-Metric Determination of the Ideal Source Surface Height for the WSA Coronal Model

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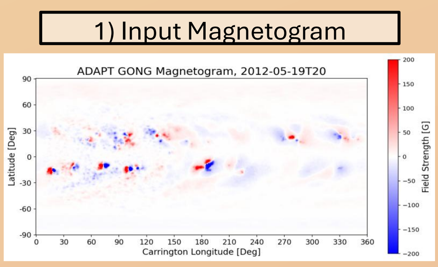
Introduction

Problem: The Sun's magnetic field can only be measured by remote observations on the photosphere or measured in situ at specific locations. However, to **accurately predict space weather**, we need to know what the global magnetic field is in the corona to predict the locations of **coronal holes**, which are the source of **fast solar wind streams**.

Solution: A coronal model can be used to estimate the coronal magnetic field using an observation of the photospheric magnetic field as input. In this case, we use the potential field source surface (PFSS) Wang-Sheeley-Arge (WSA) coronal model which depends on a single free parameter called the **Source Surface Height**. This poster presents a new analysis of the ideal value of the source surface height during two periods of differing levels of solar activity.

How WSA Works

1) Input Magnetogram

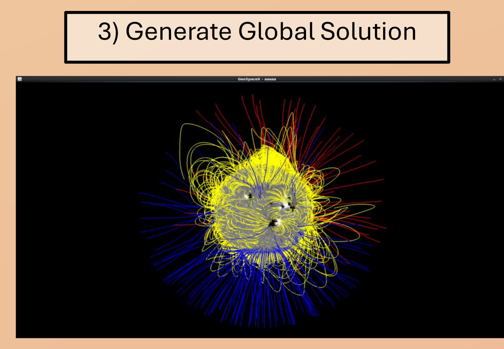


2) Solve Laplace's Equation (Assume Corona is current free)

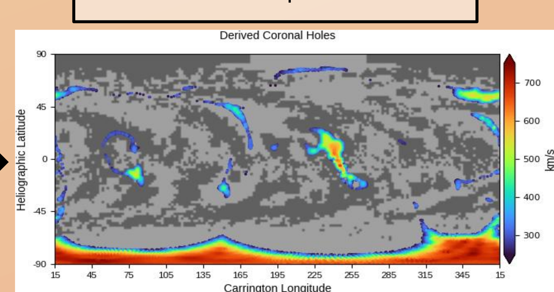
$$\nabla^2 \Phi = 0$$

$$\Phi(r,\theta,\phi) = R_\odot \sum_{l=1}^{\infty} \sum_{m=0}^{l} \left[\left(\frac{R_\odot}{r}\right)^{l+1} A_{lm} \right] Y_{lm}(\theta,\phi)$$

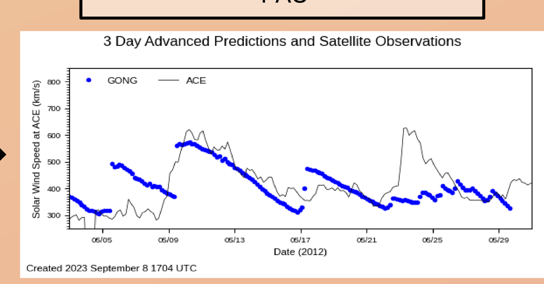
3) Generate Global Solution



4) Determine Location of Coronal Holes and Initial Solar Wind Speed



5) Propagate Wind Speed out to 1 AU



The Source Surface

The radius at which all modeled field lines are forced to be open. This is the outer boundary condition needed to solve Laplace's Equation, with the photospheric field acting as the inner boundary condition. Physically, it represents what on the real Sun is "The surface where the transverse magnetic energy density falls below the plasma energy density"[1]

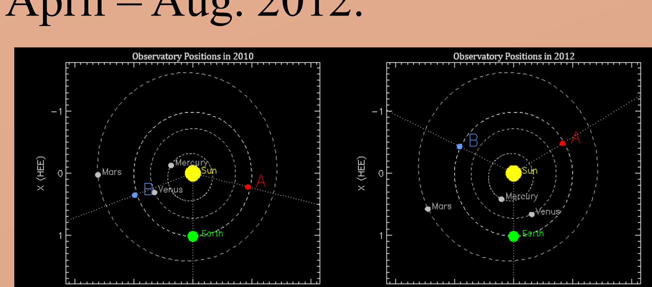
$$\frac{\mathbf{B}_T^2}{2\mu_0} < \mathrm{P_{ram}} + \mathrm{P_{gas}} = \frac{\rho V_{SW}^2}{2} + \rho k_B T$$

Transverse magnetic pressure → $\frac{\mathbf{B}_T^2}{2\mu_0}$; Plasma pressures → $\frac{\rho V_{SW}^2}{2} + \rho k_B T$

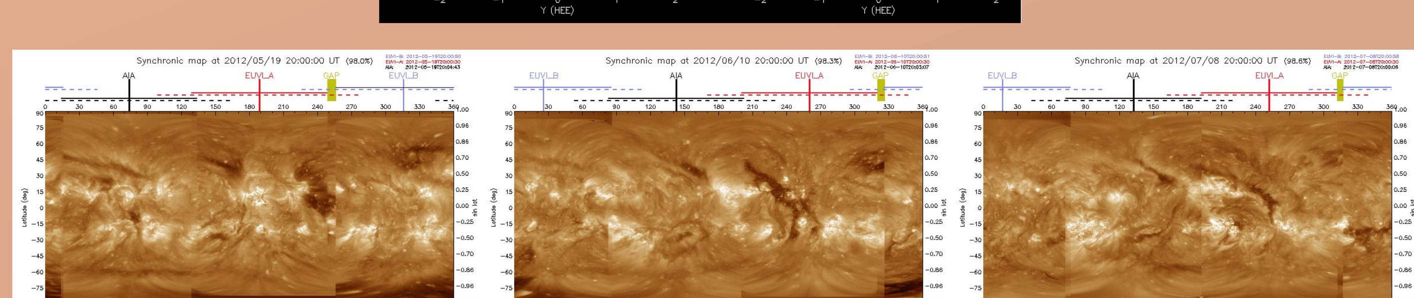
Typically, the source surface height is placed at 2.5 $R_\odot$, but is this always the best place for it? We use **multiple metrics** to analyze this question: solar wind and coronal holes.

Methodology – Synchronic and Modeled Coronal Hole Maps

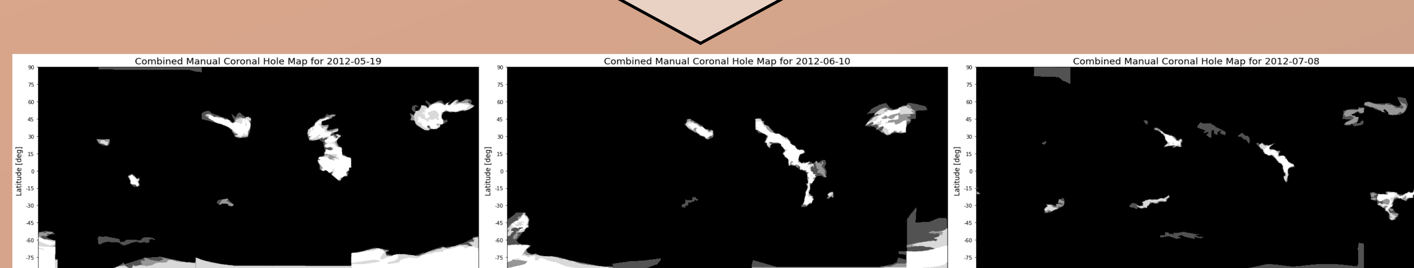
WSA provides a global coronal solution, so we use a global "synchronic" map made up of simultaneous observations from multiple instruments (STEREO A/B, SDO/AIA) for our ground truth coronal hole observations. We used the "labelme" software to **identify by eye** the coronal holes in each image (with four labelers), as automatic coronal hole detection schemes are not well constrained[2]. Meanwhile, we generate WSA coronal and solar wind predictions across a range of source surface heights in two periods of with varying activity levels, May – Aug. 2010 and April – Aug. 2012.



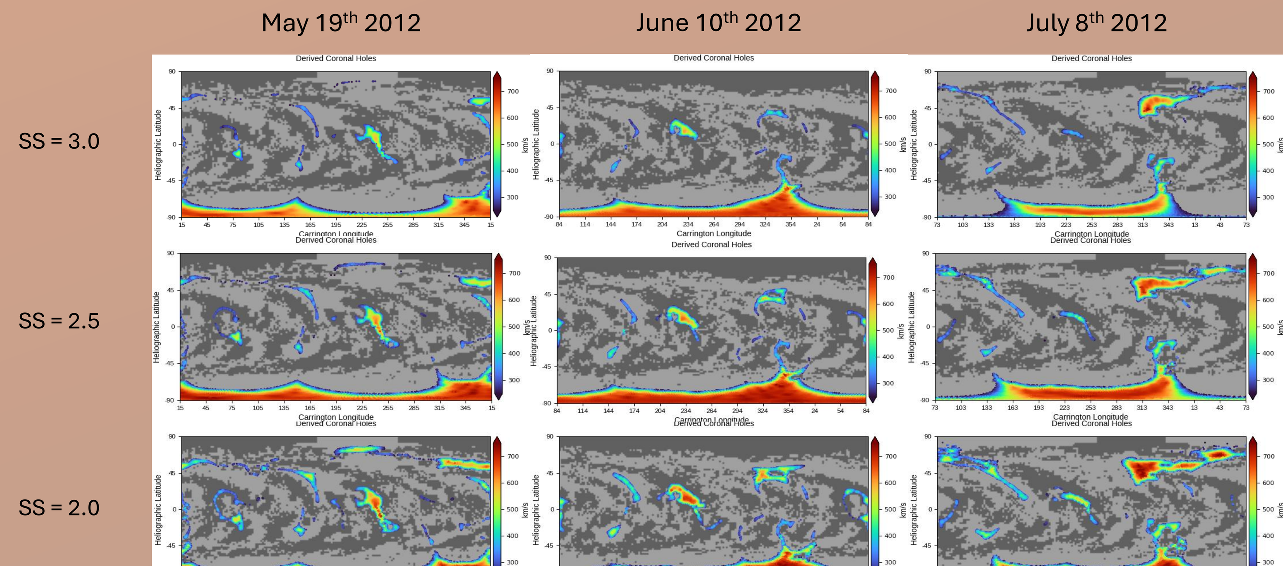
Alignment of observatories for the two periods analyzed on this poster



Hand Label



VS



A lower source surface height leads to larger coronal holes and therefore faster solar wind

Metrics

We use multiple metrics based on both coronal holes and solar wind predictions to validate the source surface. A single metric, such as solar wind which is only measured at a single point, may be unconstrained, but multiple metrics allow for more rigorous constraints while increasing confidence in the conclusions reached. We use the following metrics:

Three Coronal Hole Metrics

Jaccard Index[3]

$$J_W = \frac{\min(x_i, y_i)}{\max(x_i, y_i)}$$

(small scale)

Fractional Skill Score[4]

$$\mathrm{FSS} = 1 - \frac{\mathrm{fMSE}}{\mathrm{fMSE_{ref}}}$$

$$\mathrm{fMSE(n)} = \frac{1}{\mathrm{N_x N_y}} \sum_{x=1}^{N_x} \sum_{y=1}^{N_y} [f_o(x,y) - f_m(x,y)]^2$$

(intermediate scale)

Global Open Area

$$R = \frac{modeled\ area}{observed\ area}$$

(large scale)

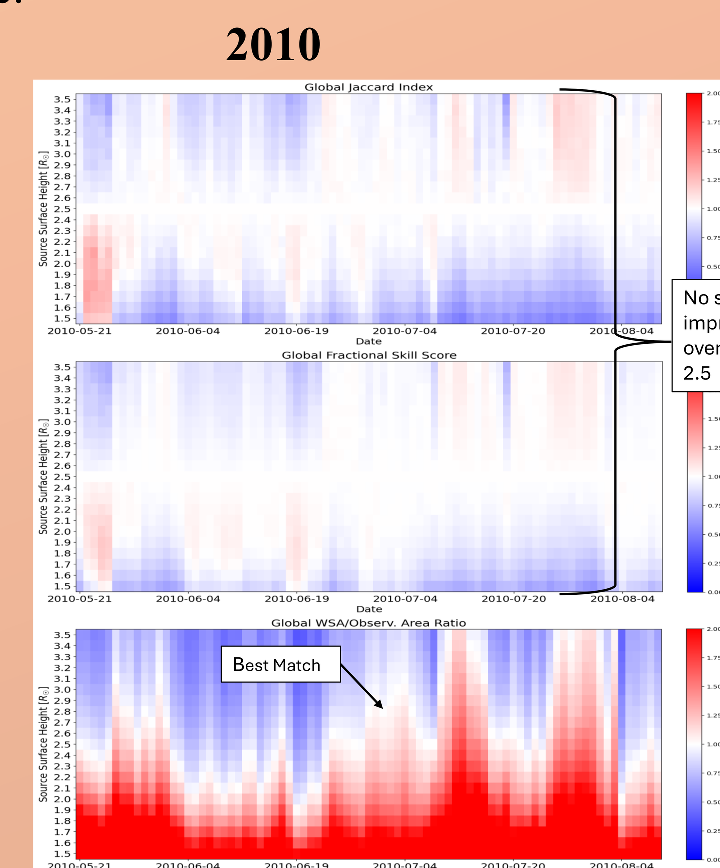
Solar Wind PM Score

$$WSA - PM(t) = \frac{\frac{1}{N}\sum_{i=1}^{N}[1 - \frac{1}{2}|P_{WSA}(t_i) - P_{Obs}(t_i)]}{\sqrt{\frac{1}{N}\sum_{i=1}^{N}[(V_{WSA}(t_i) - V_{Obs}(t_i))^2]}}$$

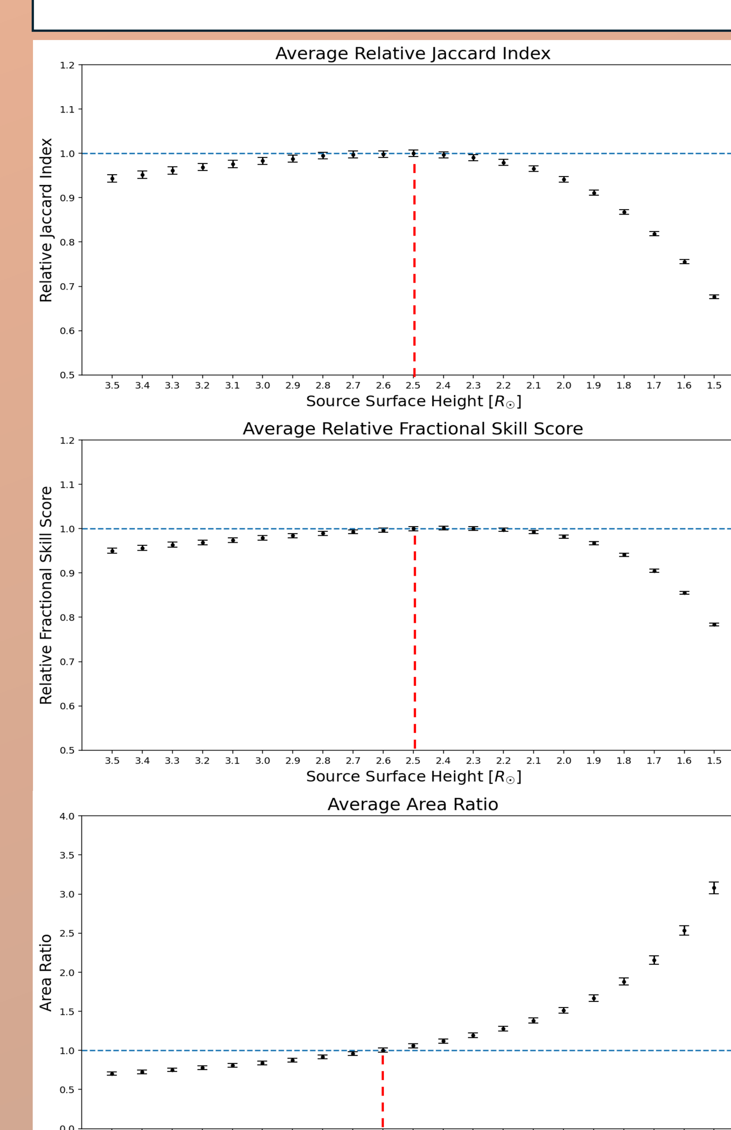
Results

As 2.5 $R_\odot$ has been the standard source surface height for most of the last sixty years, all scores are normalized by the score with a source surface height of 2.5 $R_\odot$ for the given date.

2010

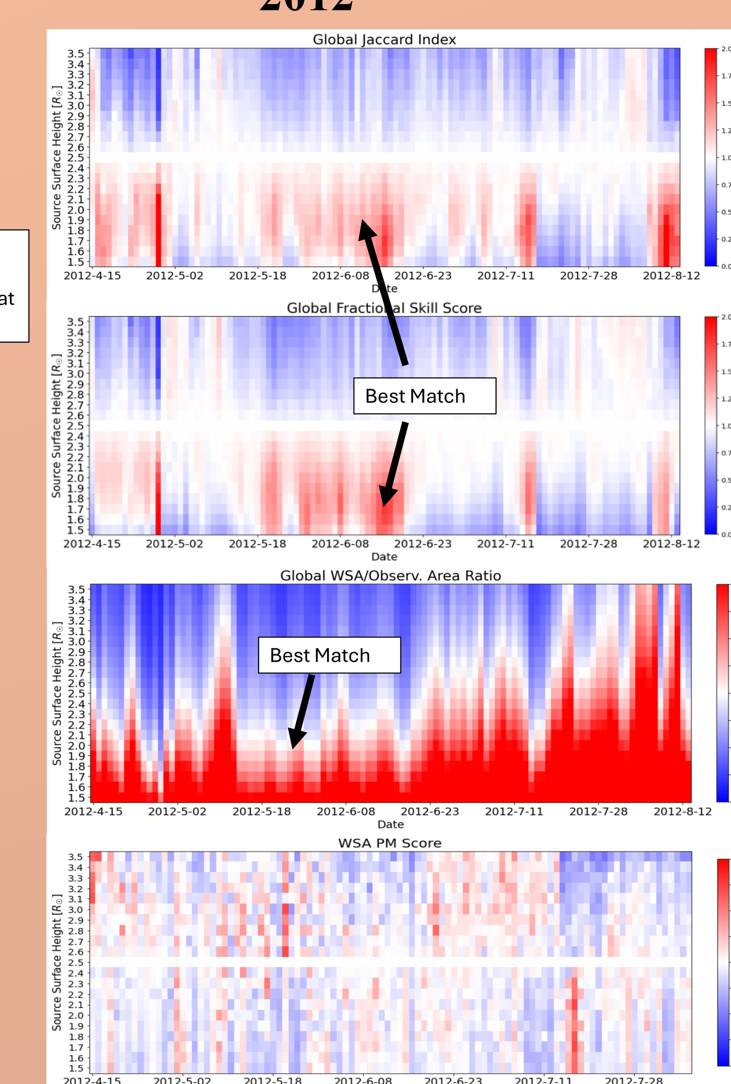


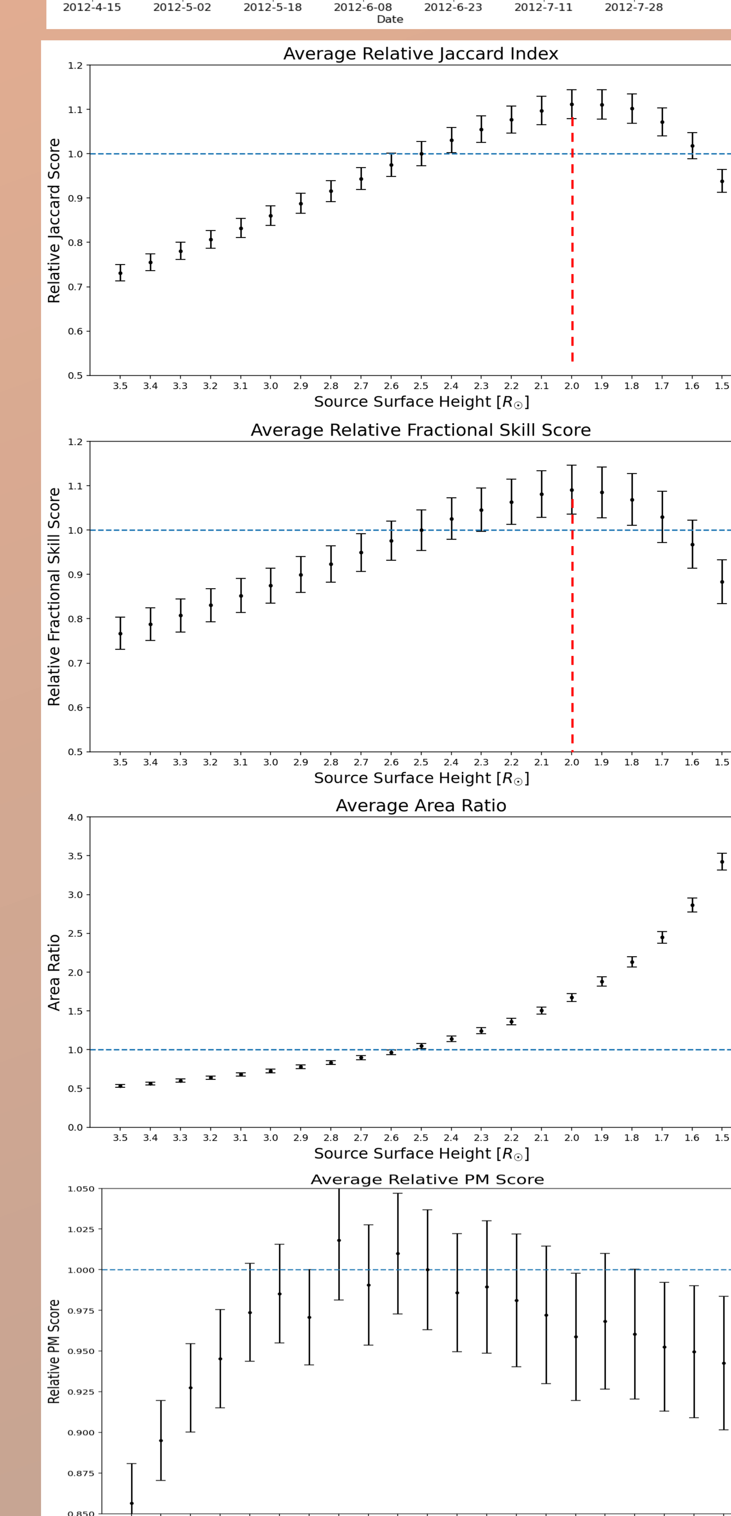
Solar Wind Results from 2010 TBD!
(see final results at SHINE 2026)



Solar Wind Results from 2010 TBD!
(see final results at SHINE 2026)

2012





Conclusions

1. The ideal source surface height is lower (i.e. around 2.0 $R_\odot$) during a more active period and higher (i.e. around 2.5 $R_\odot$) a less active period. This agrees with several other source surface height studies[5]
2. Using **both** coronal holes and solar wind as metrics gave more concrete results than just using solar wind. These metrics can also be used in other model analysis studies (e.g. the improvement resulting from including far side magnetic field data in the input maps)
3. This study needs to be extended to cover an entire solar cycle while also including more metrics (e.g. total open flux, white light field line configuration)

Acknowledgments

We would like to acknowledge the NSF Division of Atmospheric and Geospace Sciences for supporting this work, as well as the multi-messenger astronomy supplemental funding to NSO's award AST-0946422.

References

(1) Schatten, K. H., Wilcox, J. M., & Ness, N. F. 1969, Solar Physics, 6, 442
(2) Reiss et. al. 2024, The Astrophysical Journals, 271, 6
(3) Chierichetti, F., et. al., 2010, Finding the Jaccard Median , 293-311
(4) Mitteermaier, M. P., 2021, Monthly Weather Review, 149, 3491
(5) e.g. Lee, C. O. et. al., 2011, Solar Physics, 269, 367

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