Modeling Solar Wind Using the Newly Calibrated MDI Magnetic Field: 1996-2008

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Introduction

• We use the newly calibrated MDI data (1996~2008) as input to the Wang-Sheeley-Arge (WSA) model to predict the solar wind parameters: speed and interplanetary magnetic field (IMF) polarity at 1 AU.

• We propose a new polar field extrapolation scheme for the input data.

• Results are statistically evaluated and compared with observation and results based on other sources.

• We study the dependence of WSA model on coronal field extrapolation method: the potential field source surface (PFSS) model, Schatten current sheet (SCS) model and horizontal-current current-sheet source-surface (HCCSSS) model.

WSA Model

• Solar wind comes from open field regions. Sources of high speed solar wind are usually located at the center of coronal holes or where the flux-tubes expand less.

• Two parameters are employed to depict these sources: flux-tube expansion factor (f) and the angular distance from flux-tube foot point to the coronal hole edge (θ).

• An empirical function (*Arge, 2004*) is used to predict solar wind speed near the sun:

$$v = 265 + \frac{1.5}{(1+f)^{0.27}}[6.1 - 1.4\exp(1-(\frac{\theta}{2.5})^{2.0})]^{3.4}$$

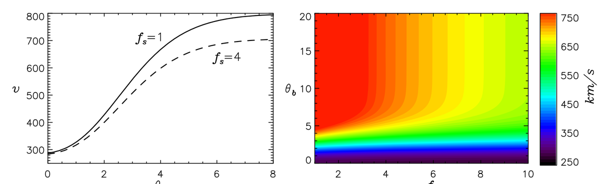

Fig1: WSA empirical function

• A simple dynamic model that considers the interaction between fast and slow streams is used to predict speed and IMF polarity at 1AU.

Coronal Field Models

• The essential parameters (f, θ) in WSA model are derived from coronal field extrapolation.

• Simple current-free extrapolation and its variations are widely used. We explore three of them here:

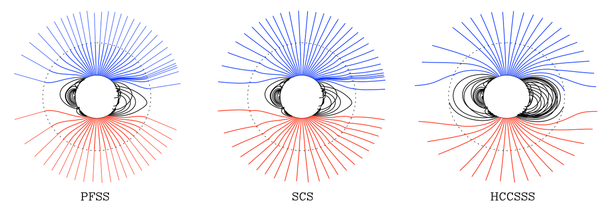

Fig2: Different coronal field configuration derived from three models (CR1922, MDI)

• PFSS: potential field everywhere; field becomes radial at source surface (SS).

• SCS: potential below SS; current sheet (CS) above SS.

• HCCSSS: SS placed near Alfven point; introduces cusp surface and streamer current sheet; introduces horizontal current (HS).

Input: MDI Synoptic Chart

• We use the newly calibrated MDI synoptic chart as photospheric input. Data is in radial format, with solar *b* angle corrected and converted to a 2.5º resolution..

• Data covers 11 years' range (*CR1911~CR2067*), roughly a solar cycle.

• We use a new polar field correction scheme, which is essential for WSA model.

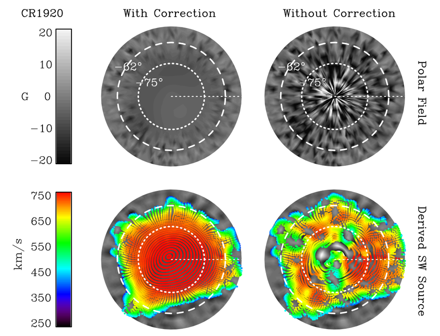

Fig3: Comparison of derived polar coronal hole from data with/without correction. Both location and predicted wind speed are very different.

New Polar Field Correction Scheme

• We take a set of well observed (Sep for N and Mar for S), smoothed polar data, together with a temporal interpolation to infer the missing data above 75º in any synoptic chart.

• The desired observation is then smoothed and combined with itself. Field above 75º is totally smooth; between 62º and 75º, the smoothed data linearly transits to the observed data.

• This polar field correction keeps the information in the original data as much as possible, while reducing the noise to a large extent. Missing values are also extrapolated resonably.

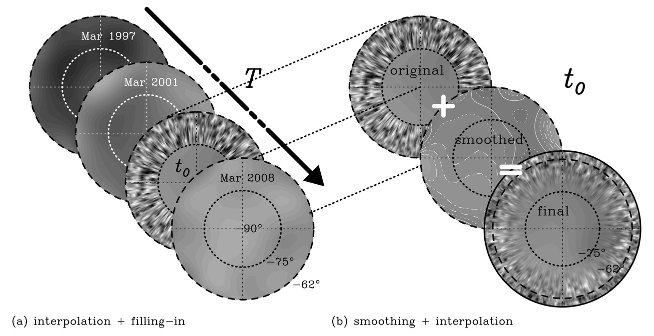

Fig4: Illustration of the new polar field correction scheme.

Tuning WSA for MDI Data

• Different input and coronal model requires different coefficients in the empirical function.

• We evaluate the result from each set of coefficients with observation, then pick the set that performs the best (i.e. has smallest error in solar wind speed prediction).

• We use a set of "trial" high speed events to validate the coefficients we choose.

• Proton data with low temperature is excluded for possible CME events (*Richardson, 1995*).

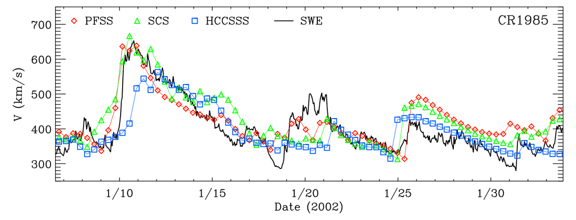

Fig5: One "trial" case with 1AU speed prediction from three coronal models.

Result (1): Derived CH and CS

• We trace the field line from 5 solar radii back to the photosphere. Coronal hole locations are inferred from open field line foot points; current sheet is located at the neutral line at 5R.

• Result simulates some global field features changing within a solar cycle: polar field reversal; disappearance and reappearance of polar coronal holes; warping of current sheet, etc.

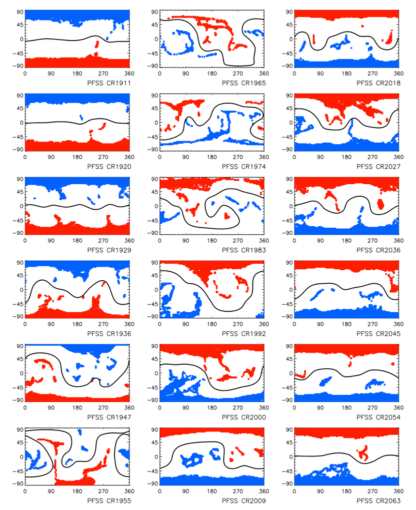

Fig6: Derived coronal hole and current sheet over a solar cycle. Blue means positive polarity, red negative.

Result (2): Global Speed Prediction

• During solar minimum and descending phase, fast wind mainly originates from polar regions. Speed prediction along the sub-earth line has less variation.

• During solar maximum, solar wind is more uniform globally. Sub-earth prediction has more variation and there are more transient events.

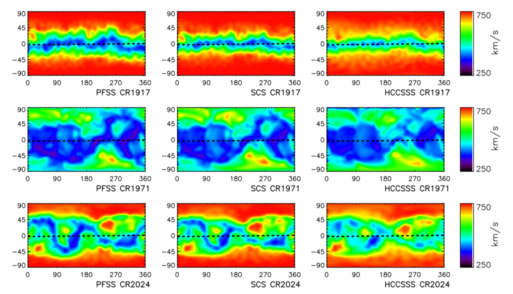

Fig7: Global wind speed prediction from three coronal models (minimum phase: CR1917; maximum phase: CR1971; descending phase: CR2024). The black line is the sub-earth line where the 1AU prediction is made.

Result (3): 1AU Prediction vs. Observation

• With the 2.5º input, we can use all three coronal models to make 4 hour average prediction of solar wind speed and IMF polarity at 1AU, up to 7 days in advance.

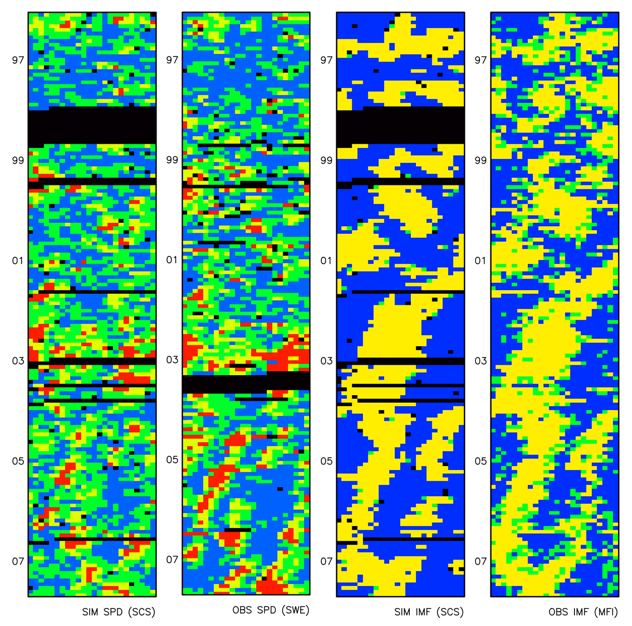

Fig8: 11 years of simulated vs. observed daily solar wind speeds, and simulated vs. observed daily IMF polarity patterns. Results are arranged in 27-day rows. For speed prediction, red (v>600km/s), yellow (500km/s<v<600km/s), green (400km/s<v<500km/s), blue (v<400km/s). For IMF polarity prediction, yellow means the field is pointing toward the sun, blue means away from the sun, green means mixed polarity. Black indicates missing data.

Discussion

1. Results are compared with WIND data. For speed prediction, we evaluate root mean square error (RMSE), average fractional deviation (AFD), and correlation coefficient (CC). For IMF polarity prediction, we compute the success rate (P_{IMF}). Results from all three coronal models are listed here. We also include the prediction from NSO data using SCS model as comparison. The results are similar.

4 hr avg.	RMSE (km/s)	AFD (%)	CC	P(IMF) (%)
PFSS	109.1	17.4	0.365	77.4
SCS	111.4	17.7	0.358	77.8
HCCSSS	114.1	18.4	0.282	77.6
SCS (NSO)	106.3	18.1	0.385	73.1

2. Three coronal models give different coronal field configuration (*fig2*). PFSS model requires the field to be radial above the source surface, while the current sheet in HCCSSS model draws the polar open flux towards low latitude. This leads to greater expansion factor in polar regions and smaller polar coronal holes. However, this does not seem to affect the prediction, after we carefully tune the coefficients for each case.

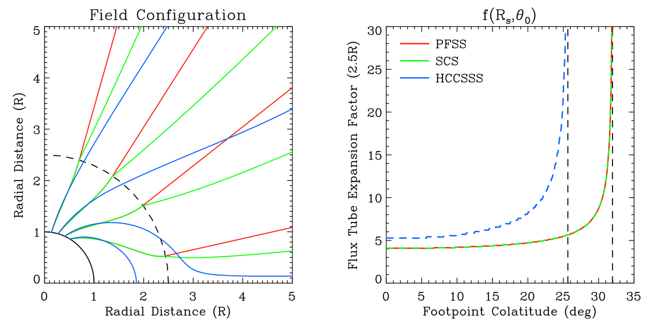

Fig9: Coronal field configuration and expansion factors for an artificial input: B=(cosθ)^7.

Conclusion

• Newly calibrated MDI synoptic chart can be successfully incorporated into WSA model and be used for routine solar wind speed and IMF polarity prediction.

• Polar field correction proves to be crucial and we propose a new scheme that works well for solar wind modeling with WSA model.

• Over solar cycle 23, 4 hour average speed prediction yields an average error ~18% and IMF polarity prediction success rate around ~77.5%. They are similar to the result from NSO data.

• For the three cases we explore, WSA does not appear to have a strong dependence on coronal models. After tuning the parameters for each case, we get similar results.

References

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