Polar Magnetic Fields Observed During the Last Four Solar Minima

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Introduction

• We study the Sun's photospherical magnetic fields of the polar regions during the last four sunspot minima, using WSO and MDI synoptic charts.

• We use the potential-field source-surface (PFSS) model to infer the corona structures, and relate the features to the polar field strength.

• We use OMNI data to study the solar wind structures at 1AU, use the PFSS model to map for their sources, and relate them to the polar field strength.

• We propose a new polar field interpolation scheme which makes use of well-observed polar field data to estimate the missing polar data in MDI synoptic charts. The method improves the result of solar wind speed and IMF polarity prediction from the Wang-Sheeley-Arge (WSA) model, especially for minima..

Polar Field Observation

• The Sun's polar fields in the current minimum is the weakest in the past four minima, being about 30% weaker than the previous one. Its sunspot number is also the lowest.

• The Sun's dipole field strength is well-correlated with the polar field strength.

• Observed global weak-field flux during this minimum is also weaker.

• Modeled heliospheric current sheet warps more during this minimum; polar coronal hole shrinks; more large mid-low latitude coronal holes emerge.

• MDI and WSO polar fields correlate well with each other except for the early stage of cycle 23 where a small offset exists..

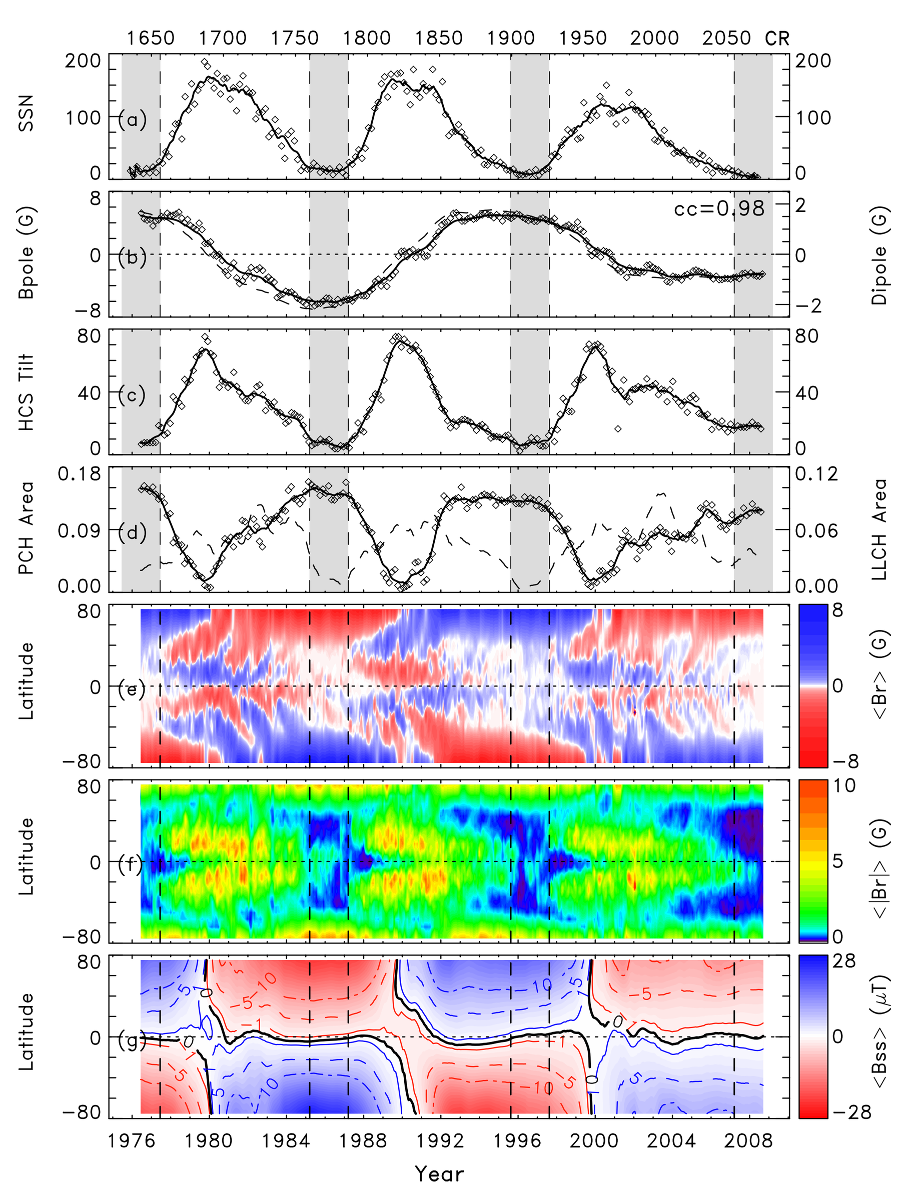

***Fig1** (a) monthly averaged SSN; (b) polar field strength (N-S)/2 and dipole field strength at pole; (c) modeled maximum heliospheric current sheet tilt angle; (d) modeled polar and mid-low latitude coronal hole area, with regards to the solar surface; (e) zonal net photospheric flux density; (f) zonal total photospheric density; (g) modeled zonal net flux density for the source surface. Plots (b) to (d) are based on WSO synoptic charts.*

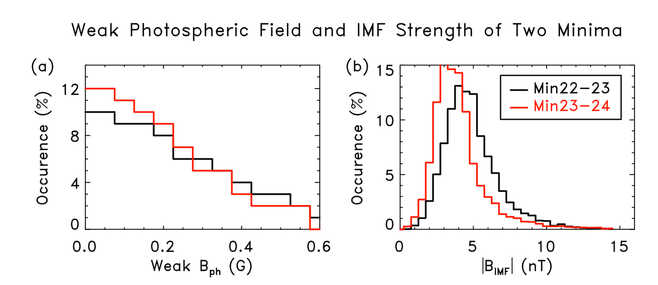

***Fig2** Histogram of (a) the weak photospheric field from WSO and (b) IMF strength from OMNI during the current and the last minimum.*

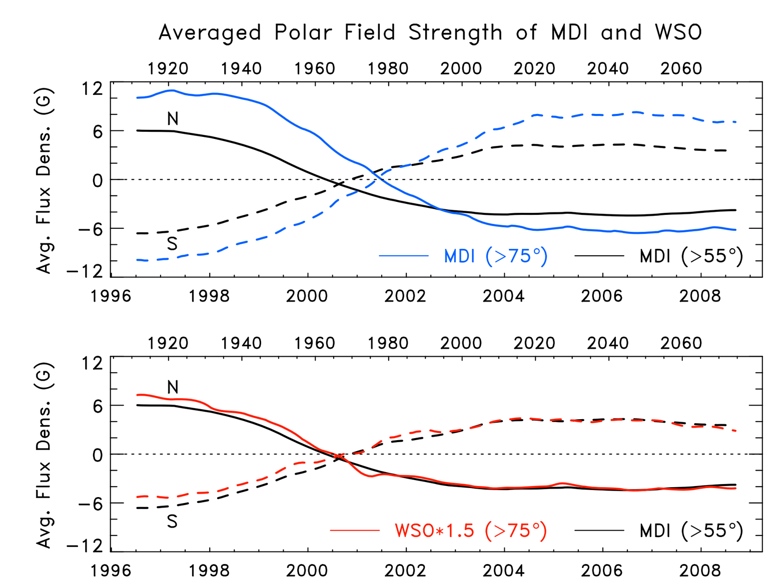

***Fig3** Averaged and smoothed radial polar field obtained from synoptic maps. Top: MDI (above 75d and 55d); Bottom: WSO*1.5 (above 75d) and MDI (above 55d).*

Corona Structure and Polar Field

• Observation (EIT) approves the modeled coronal structure: more warped HCS, shrunk polar CH and larger mid-low latitude CH.

• Polar field strength proves to be crucial to the global corona structure.

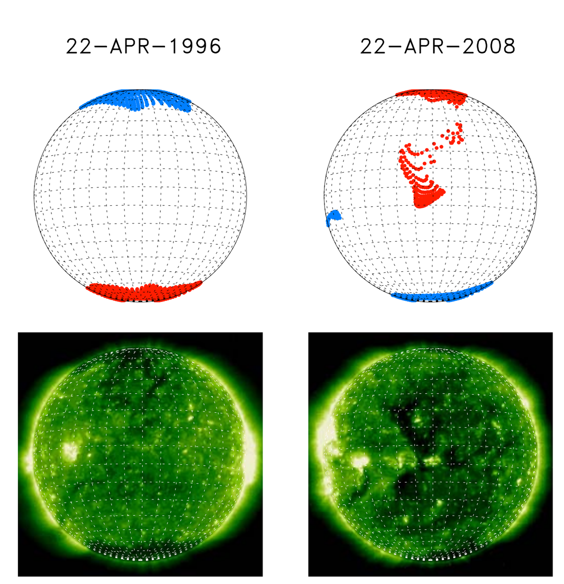

***Fig4** Modeled and observed (EIT 195A) coronal hole during the current and last minima.*

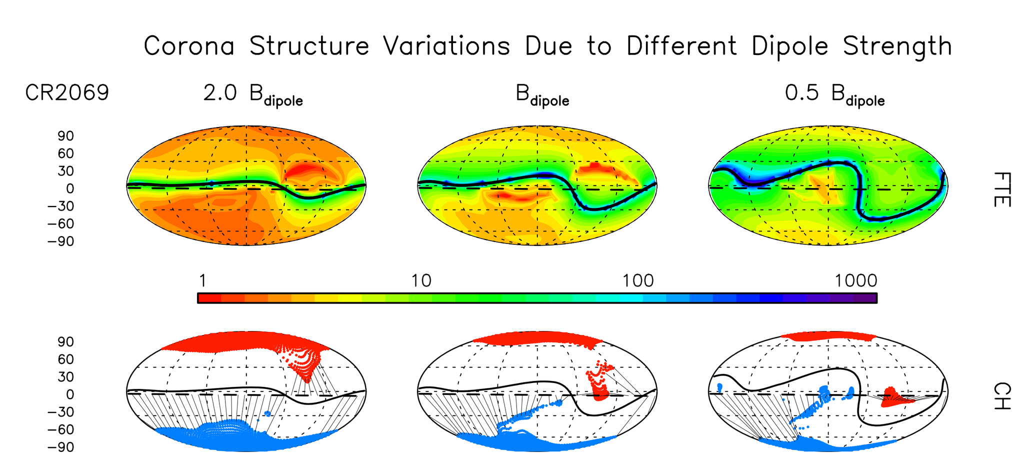

***Fig5** Modeled coronal structure of CR2069 with different dipole field. Top: flux-tube expansions (correlated with solar wind speed); Bottom: open field foot points, current sheet and the sources of solar wind. Left: doubled dipole field; middle: original input; right: halved dipole field.*

Solar Wind and Polar Field

• Solar wind stream structure is well correlated to corona open field structure, which is in turn closely related to the dipole (polar) field.

• Minimum 21-22 has abundant high speed streams that come from large polar coronal hole extensions, which are caused by a "tilted dipole".

• Minimum 22-23 has very few high speed streams. The dipole field is strong for a long time, which oppresses the polar CH extensions and low latitude CHs.

• Minimum 23-24 has many long-lived high speed streams. The dipole field is weak, so many large mid-low latitude appear as the fast wind source.

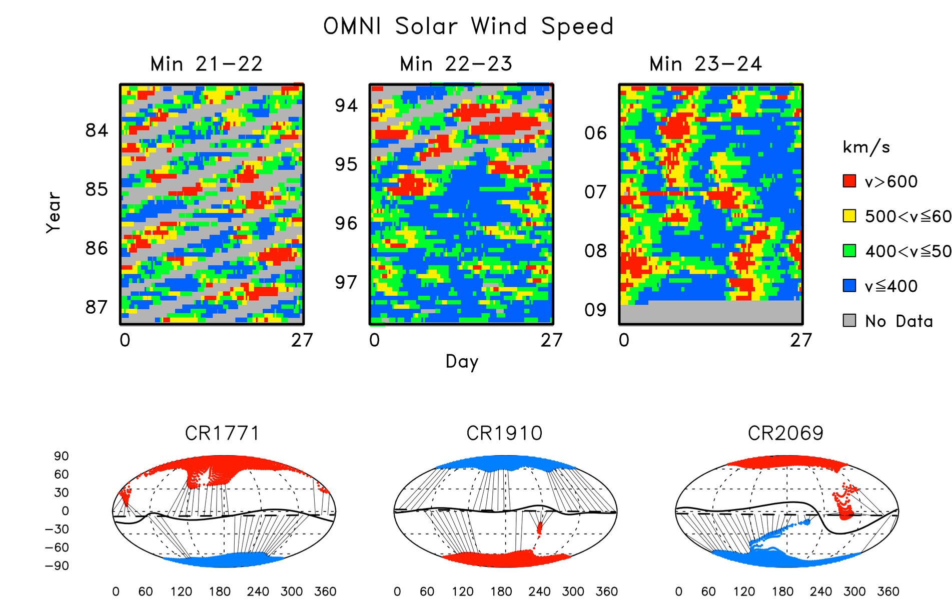

***Fig6** Top: solar wind speed structure of three minima from OMNI; Bottom: modeled open field foot points as solar wind sources.*

MDI: Polar Field Interpolation

• The Sun's polar field is not well observed due to its tilted rotation axis; the edge of each magnetogram is discarded due to high noise. Thus, there will be missing data at polar region of synoptic maps.

• The WSA model for solar wind and IMF polarity prediction is sensitive to polar field strength.

• We propose a new polar field interpolation scheme that makes use of favorably oriented synoptic maps to estimate the missing data.

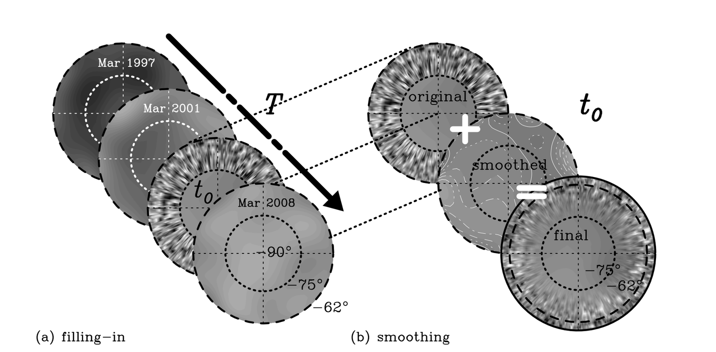

***Fig7** Illustration of polar field interpolation scheme for MDI synoptic maps.*

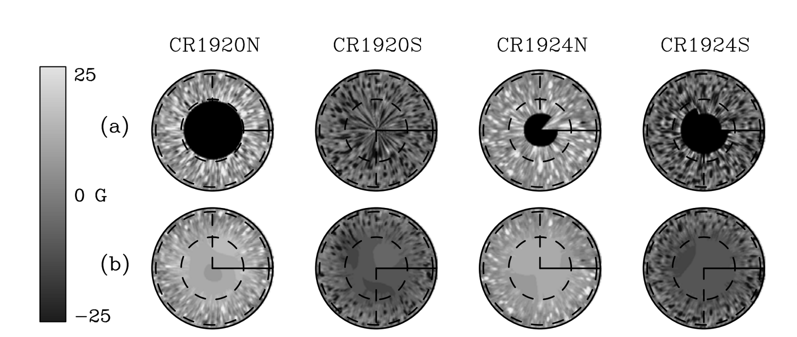

***Fig8** Polar view of MDI synoptic maps before and after interpolation.*

Improvement of Solar Wind Modeling

• We use MDI synoptic maps with/without polar field interpolation to predict 3-day-advance solar wind speed and IMF polarity. Results are evaluated statistically against OMNI data.

• New polar field interpolation improves the accuracy in every statistical category. The improvement is the most significant during sunspot minima, some times can be as high as 30% in terms of MSE in speed.

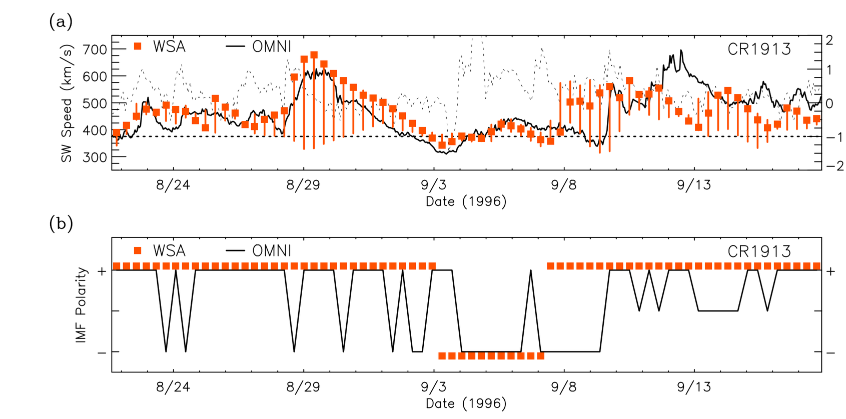

***Fig9** Example of 3-day-advance solar wind speed (top) and IMF polarity (bottom) prediction, using MDI synoptic maps and WSA model with polar field interpolation.*

4 hr avg.	RMSE (km/s)	AFD (%)	CC	P(IMF) (%)
With Interp.	99.6	16.0	0.451	80.9
No Interp.	102.9	16.8	0.401	79.6

***Table1** Statistical evaluation of solar wind prediction for 1996-2008 against OMNI, using MDI synoptic maps with/without polar field interpolation.*

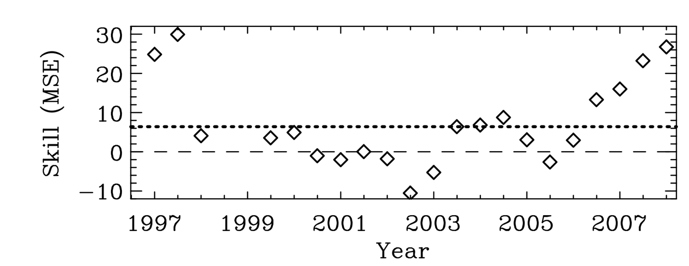

***Fig10** Skill score (improvement) of speed prediction.*

RMSE: root-square of prediction's mean-square-error.

AFD: average fractional deviation of speed prediction.

CC: correlation coefficient between predicted and observed speed series.

P(IMF): accuracy of IMF polarity prediction.

Skill Score: (MSE1 – MSE2) / MSE2.

Conclusion

• Using WSO and MDI synoptic maps, we find that the Sun's polar field during this minimum is about 30% weaker than the previous, and is the weakest amongst the last four. Sun spot number, dipole field, observed weak field flux and IMF strength are all relatively weaker compared to the previous ones.

• From both coronal hole observation and modeling (WSO+PFSS), we find some distinctive corona structures of this minimum: more warped current sheet, smaller polar coronal holes and a greater number of large mid-low latitude coronal holes. They can be related to a weaker polar field.

• From OMNI we find some distinctive solar wind stream structures. Minimum 22-23 has much fewer long-lived high-speed streams. This can be explained by the absence of large polar coronal hole extensions (min 21-22) or large mid-low latitude coronal holes (min 23-24). They can also be related to the polar fields.

• We propose a new polar field interpolation scheme for the MDI synoptic maps to fill in the missing data due to the Sun's tilt angle. It makes use of well-observed poles during Mar/Sep. The interpolation proves to be important during minima, improving the solar wind speed prediction as much as 30%.

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