Spatial Structures of Polar Magnetic Field During the Last Solar Cycle

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Introduction

• We use 4 Carrinton rotations (CR) MDI radial synoptic maps from each fall/spring (1996-2008) to study the N/S polar field. We also use MDI campaign (1min cadence) magnetograms (Sep 1999) for detailed study.

• We compute the averaged flux density in different lat/longitudinal bins in synoptic maps and study the polar field structure. We give a classification of observed structures and describe its change over time.

• We use high cadence magetograms to explore the role of new flux coming from low-latitude "streams" in the formation of polar field structure. The structure is most pronounced during solar maximum.

Polar Field: Data and Method

• The Sun's polar fields are mostly concentrated in small uni-polar magnetic elements with strong flux density (Zhang et al., 1997, Benevolenskaya, 2007). They are not well observed due to geometry.

• The structure of polar field is determined by the spatial/temporal distribution of magnetic elements. It is depicted macroscopically by the averaged flux density in certain lat/longitudinal bins.

• The MDI synoptic maps use magnetogram data inside a window centered at central meridian (CM). The temporal signal, produced by continuous sampling of the longitudinal bins, reflects the large-scale spatial structure.

• MDI campaign magnetograms, after averaging, have a better signal to noise ratio (Liu, 2008). They help show the evolution of elements as well as the structure observed off central meridian.

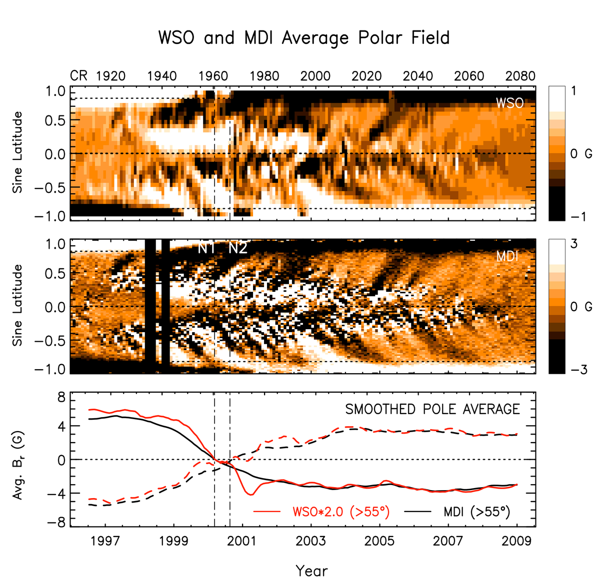


Fig1: Zonal field from WSO and MDI showing "flux streams" and polarity reversal. N_1 and N_2 are two streams marked for detailed study.

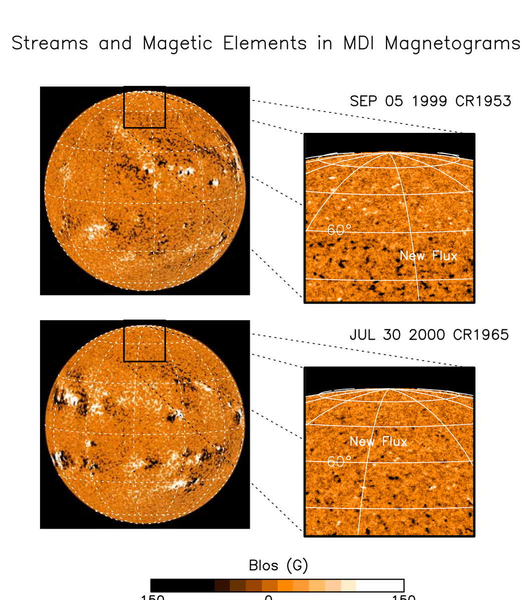


Fig2: Magneograms from fall 1999 and 2000, with a zoom-in at the north pole. Magnetic elements with new (negative) polarity rapidly moves into the polar region.

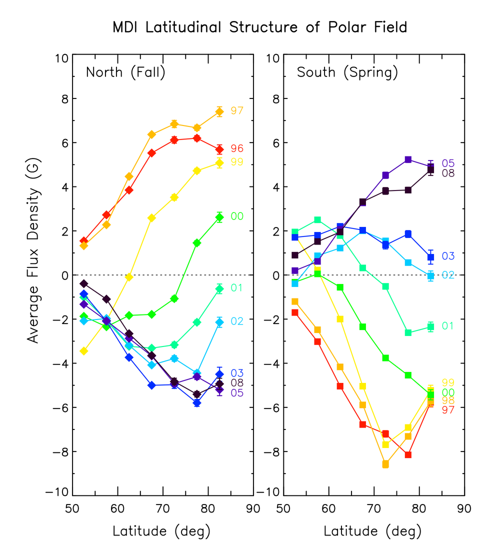
Latitudinal Structure

• Polarity reversal (*fig3*) at higher latitudes happen at later times (Sun et al., 2008), indicating the injection of new flux from lower latitudes. The time separation is about 1 year for 70° + band compared with 50°+ band.

• Flux density in each 5° latitudinal bin (*fig4*) indicates the polar field possibly peaks at around 80° during minimum (Raouafi et al., 2008).

• In ascending phase, flux density in the 50°-60° band switches rapidly to the opposite polarity due to the onset of active regions. It gradually gets balanced when coming into the minimum phase.

• The polarity reversal process in higher latitude bands follows the 50°-60° band, with lower latitudes slower than the higher ones.



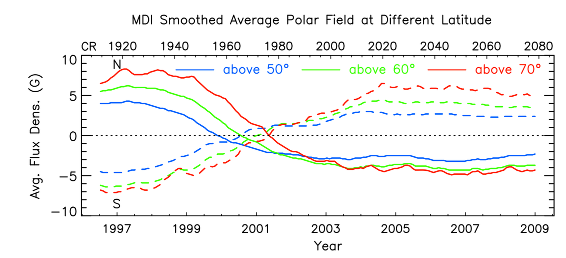


Fig3 (above): Smoothed average polar field strength. Polarity reversal happens at different time for different latitudinal bands.

Fig4 (left): Averaged polar field density in 5° latitudinal bins. Each year 4CRs are chosen during fall/spring for N/S pole.

Longitudinal Structure: Solar Min

• During solar minimum, there's not much longitudinal field structure in either 60°-70° or 70°-80° bin. Magnetic elements are distributed more uniformly in the polar cap (*fig5*).

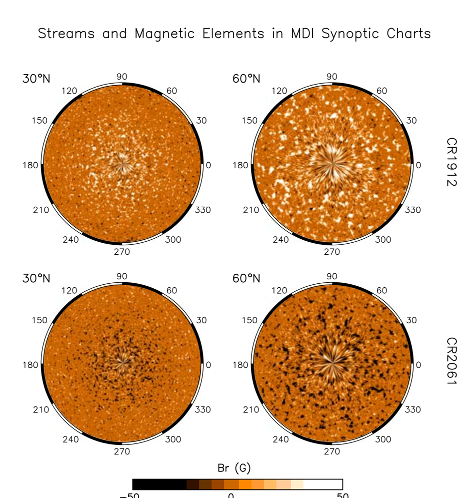


Fig5: North polar view of MDI synoptic map for CR1912 and CR2061, for the solar min. case. Left shows 30° and above, right 60° and above. The poles are dominated by elements of a single polarity.

Longitudinal Structure: Solar Max

• Averaged flux density in each longitudinal bin, plotted against central meridian passing time (*fig6*), shows a clear temporal periodicity during solar maximum.

• On synoptic maps, we are able to relate these local max/min of the signal to the concentration of new elements with opposite polarity (*fig7*).

• These new elements with opposite polarity can be related to spiral structured "flux streams" observed in synoptic maps (*fig8*).

• When new flux first reaches to the 60°-70° band, higher latitude has little response (1999). When it reaches the 70°-80° band (2000), new flux in the 60°-70° band already gets mixed and smeared (*fig6*).

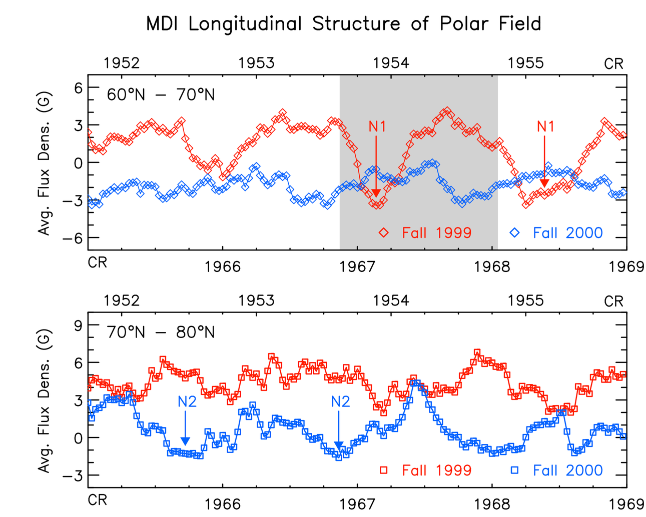
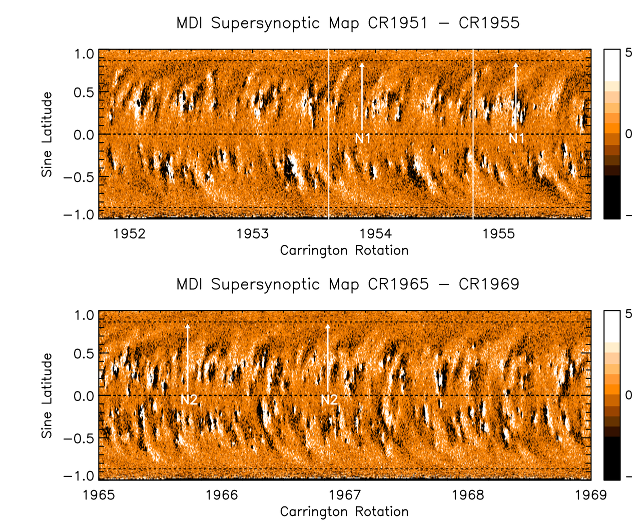


Fig6: Averaged polar flux density in each 5° longitude bin vs CMP time. Two sets of synoptic maps are used (fall 1999 and 2000). Shaded region are also studied by using magnetograms.

Fig7: Sets of synoptic maps used for study. Time goes from left to right and 4CRs are concatenated to show the evolution of flux streams (N_1 and N_2).



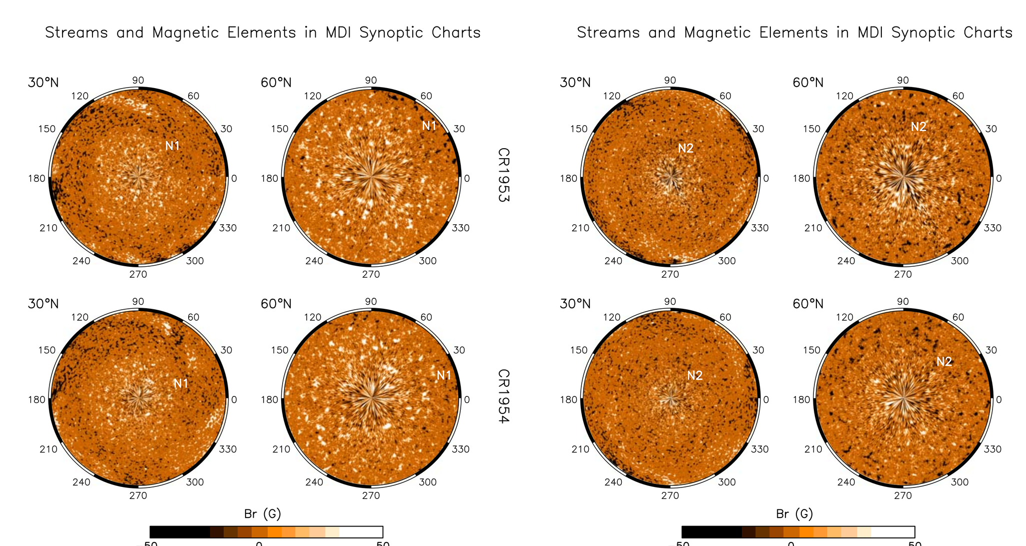


Fig8: Same as fig5, for 2CRs during fall 1999 and 2000. "Flux streams" appear as spiral structure due to the differential rotation. In 2000, new negative flux reaches a much higher latitude and starts to effect the structure above 70°.

Longitudinal Structure: A Classification

New Flux: Signal	60° - 70°	70° - 80°
Ascend.	Just arrived: strong	Not yet arrived: weak
Max. I	Not yet smeared: less strong	Just arrived: strong
Max. II	Smeared: moderate	Just smeared: less strong
Descend. Min.	Dominated by one polarity: weak	

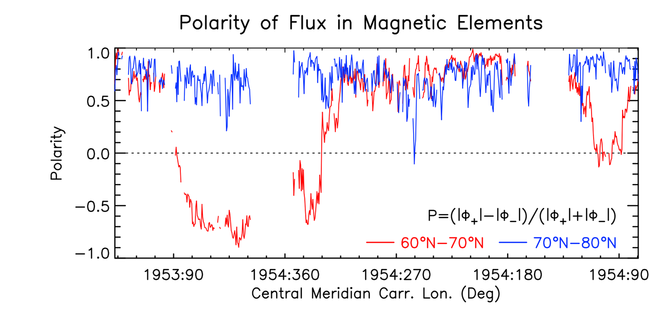
From High Cadence Magnetograms

• ~32 days of 1min MDI magnetograms (Sep 1999) are studied.

• A study of the total flux coming from positive and negative elements (Lin et al., 1994) shows that negative flux stream intrudes from the edge of 60°-70° band, during the time marked by two red lines in *fig9*.

• Signal from 30° E/W off CM shows that signal "travels" at a speed faster than differential rotation rate, giving signs of meridional motion of the stream. Random large elements can also dominate local polarity (*fig10*, *11*).

Fig9: "Polarity" of flux inside magnetic elements (above 25G for radial field). Signal in the 60°-70° band shows the effect of the negative flux stream.



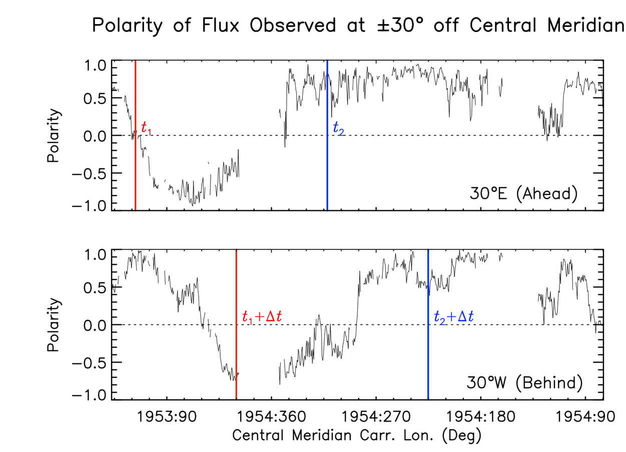


Fig10: "Polarity" of flux observed in windows (fig11) 30° E/W off central meridian, plotted against Carrington longitude of CM. The time separation Δt between solid vertical lines represents differential rotation rate at 62° latitude (Meunier 2005).

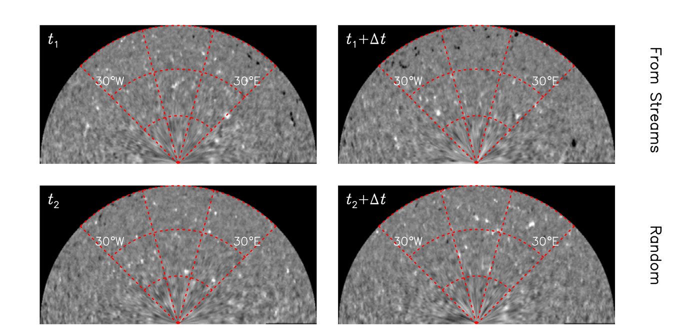


Fig11: North polar view of remapped magnetograms (above 60°) corresponding to the marked times in fig10. The Sun rotates CCW; red dotted lines are 30° lon. and 10° lat. apart. Upper column shows the intrusion of negative flux stream; bottom shows random appearing of strong elements.

Conclusions and Next Step

• Polar field structure is determined by the distribution of magnetic elements.

• Latitudinally, polar field increases toward the pole, but peaks somewhere near the pole instead during solar min. New flux from low latitude reverses its polarity, first in lower latitudes then higher ones, over a period of ~1 year.

• Longitudinally, polar field demonstrates quasi periodic structure that is related to low-latitude new "flux streams" during solar maximum. Streams and elements evolve with time, as new flux is injected into the polar region. The spatial structure is weak during solar minimum.

• Detailed, quantitative study of the evolution of magnetic elements and flux transport will be the next step. High cadence magnetograms will be used to describe the formation of new polar field.

References

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