Relationship between the High and mid latitude Solar Magnetic Field

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Introduction

The discussion of a relationship between high-latitude and mid-latitude activity has deep roots since Sheeley has published a time series of the polar faculae (Sheeley, 1964, 1966). He found that the number of polar faculae (a proxy of the polar magnetic fluxes) varies cyclically with time, approximately 90 deg out of phase with the variation of the alternating sunspot number (plotted with polarity) during the period 1905-1964.

According to the Babcock's polar magnetograms the faculae "streams" generally correspond to magnetic field having the polarity of the following sunspots of the corresponding hemisphere and it led Babcock (1961) to the understanding of the polar magnetic field as a result of the transport magnetic field from activity belts in the mid-latitude to the poles due to the meridional circulation.

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. These "streams" correspond to the unipolar magnetic regions (Bumba, Howard, 1965) stretched eastward and poleward by differential rotation, and drift toward the pole. For describing the transport of the magnetic energy from the mid-latitude to the high-latitude Leighton (1964, 1969) applied a random-walk process associated with the convective supergranulation.

All these investigations has become a base for the modern solar cycle transport models, in which the polar magnetic field is a result of acting the turbulent diffusion, differential rotation and meridional circulation.

Recent investigations of Carrington maps of the upper photosphere during the years 1996 –- 2005 obtained in the 6767 A continuum with the Michelson Doppler Interferometer **(MDI**) on the Solar and Heliospheric Observatory (**SOHO**) by **Sheeley and Warren (2006)** reveal a facula-free zone in each hemisphere between the old-cycle polar field and the trailing-polarity flux that was migrating poleward from the sunspot belts. This facula-free zone coincides with the zone of polar prominences (**Secchi, 1877; d'Azambuja, 1945; Makarov & Sivaraman, 1989**).

Coronal emissions, also, display the butterfly distribution in latitude-time diagram, and point out on the poleward activity waves (e.g. **Bumba, Rusin, & Rybanskii, 1990; Bortsov, Makarov, & Mikhailutsa 1992; Altrock 1998; Rusin, Rybanskii & Minaroevich, 1998**).

A study of the **EUV** from **SOHO/EIT** and the **X-ray** from **YOHKOH** data has revealed a large scale connectivity in the corona between polar regions and the following parts of complexes of solar activity in the rising phase of the solar cycle **(Benevolens-kaya,Kosovichev, & Scherrer, 2001; Benevolenskaya, Kosovichev, Lemen, Slater & Scherrer, 2002**).

This connectivity or "giant loop“ (**Figure 1 on the next page**) structure can provide an additional dissipation of the magnetic energy, which together with turbulent diffusion, meridional circulation and differential rotation lead to the changing polarity of the polar magnetic field on the Sun.

Gopalswamy, Lara, Yashiro & Howard (2003) proposed that coronal mass ejections associated with closed configurations of the magnetic field connecting the following parts of complexes of solar activity with the open magnetic flux of polar regions may be also an important mechanism for magnetic field decay for the polar reversals.

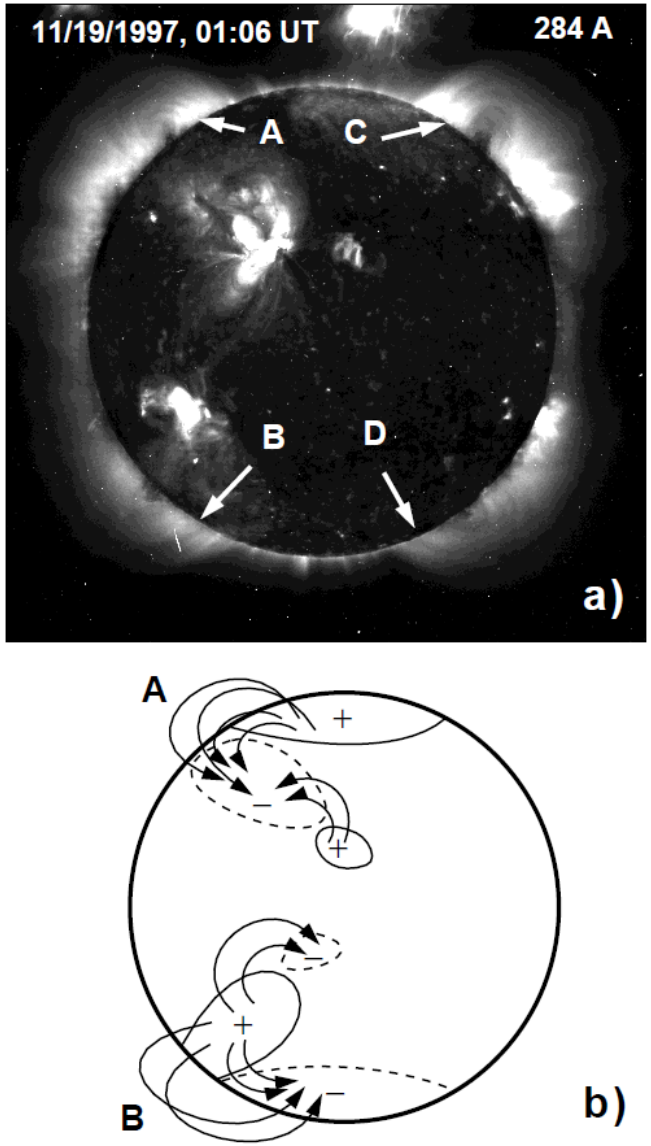


Figure 1. The EIT image in 284 A line on 11/19/1997, 01:06 UT. The arrows identify structures (A-D) which are parts of the longitudinally extended high latitude high-latitude structures.

Zonal Structure of the Solar cycle 23

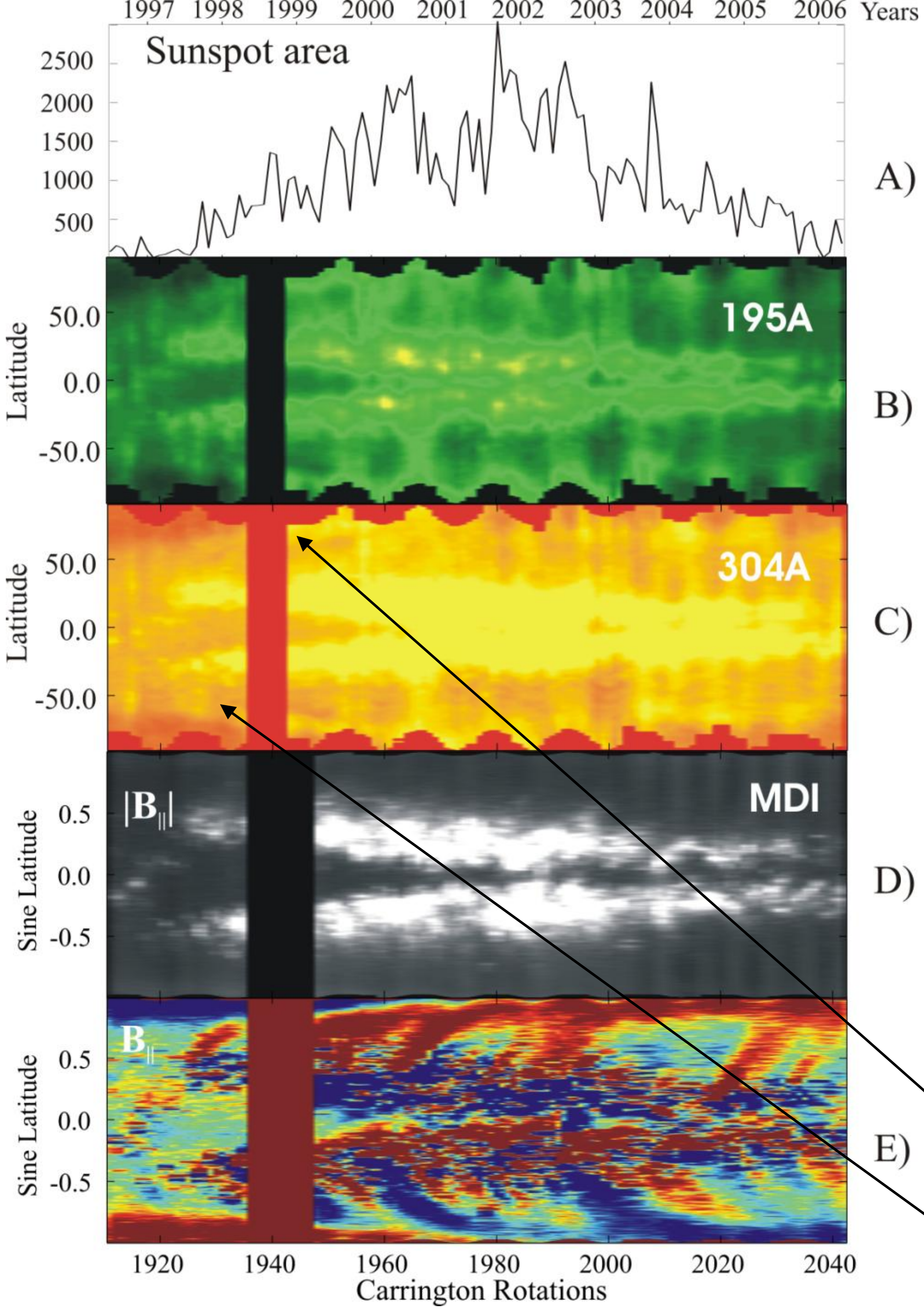


Figure 2. A) Sunspot area as a function of time from June 1996 to May 2006 (Carrington rotations from 1911 to 2042); Axisymmetrical distributions as a function of latitude and time for:

B) EUV flux in Fe XII and **C**) He II lines ;

D) Unsigned magnetic flux [0 20G], MDI (old calibration).

E) B||- component of the magnetic field, in the blue-red color map is [-1G 1G], MDI (old calibration);

The 3-point Gaussian smoothing is applied.

In the coronal **EUV** axisymmetrical distribution , we see two sets of activity waves :

In the coronal EUV maps, we see in each hemisphere two sets of migrating structures: low-latitude structures which migrate towards the equator following **$|B_{||}|$,** and high-latitude structures which migrate towards the poles parallel to the magnetic neutral lines.

The coronal structures associated with the high-latitude waves are easily identified on the EUV synoptic charts as longitudinally extended bright structures at **50º - 70º** latitude.

Polar magnetic field, its reversals

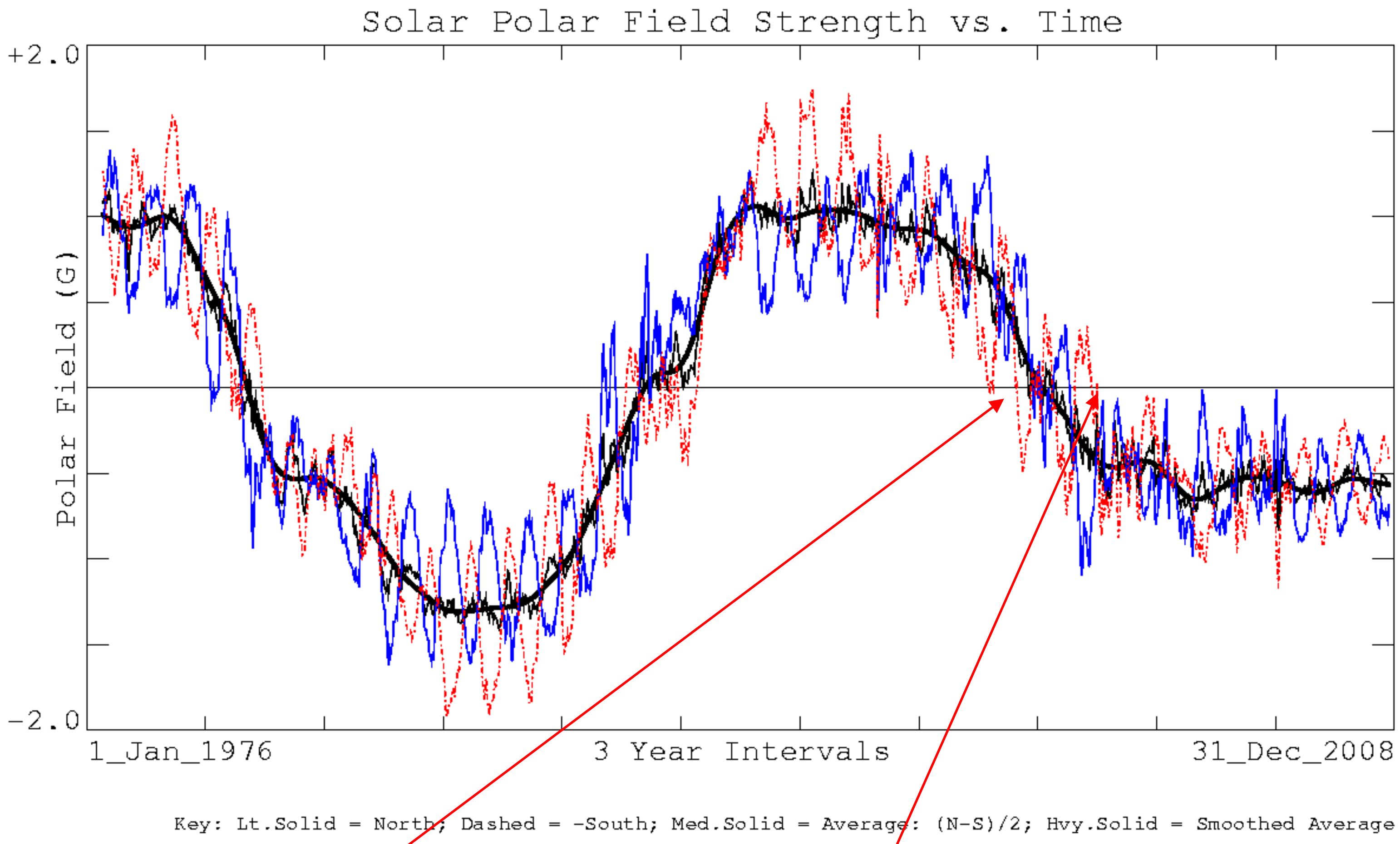


Figure 3. Polar magnetic field (at 55°) from Wilcox Solar Observatory. North hemisphere Is marked by the blue color, South hemisphere is marked by the red color.

Start of reversal at 55° in South

End of reversal at 55° in South

Δt~ 2 years

Time of polar magnetic field reversals

L. Svalgaard And E. W. Cliver, ApJ, 2007

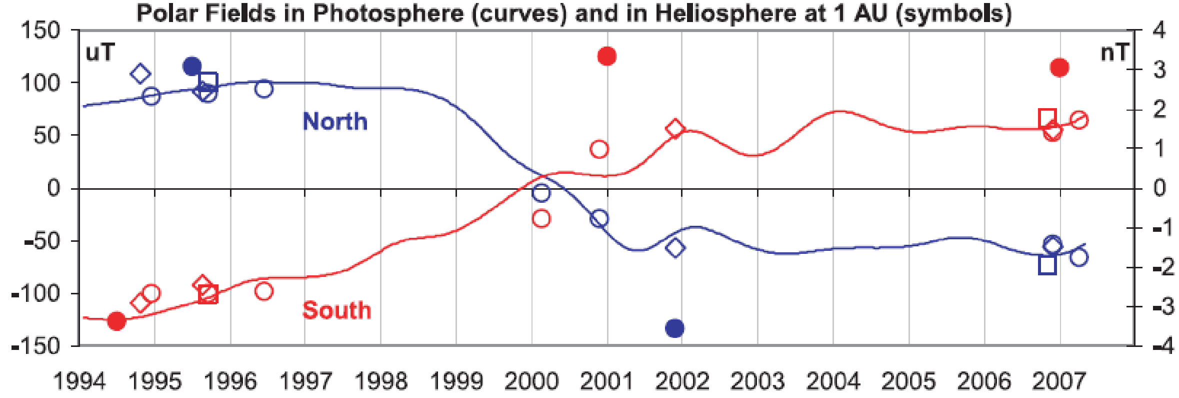


FIG. 4.—*Curves*: WSO polar fields (*left scale*, in units of microtesla) with the annual variation due to the 7.16° tilt of the solar equator from the ecliptic plane suppressed by a 20 nHz filter. *Symbols*: IMF strength, radial component over the poles normalized to 1 AU (*right scale*, in units of nanotesla). *Diamonds*: WSA model with WSO (MWO correction). *Squares*: MHD with WSO (MWO correction). *Open circles*: MAS model with NSO/SOLIS. *Filled circles*: *Ulysses* $B_r r^2$ (average of all five = 3.27 nT).

Durrant and Wilson (2003) found time of reversals using The Kitt Peak data:
CR1975 2 in North and **CR1981 1** in South.
MDI data confirmed this results.

What contributes these uncertainties?
Line of sight component? Radial field approximation?
Space scale of the averaged magnetic field?

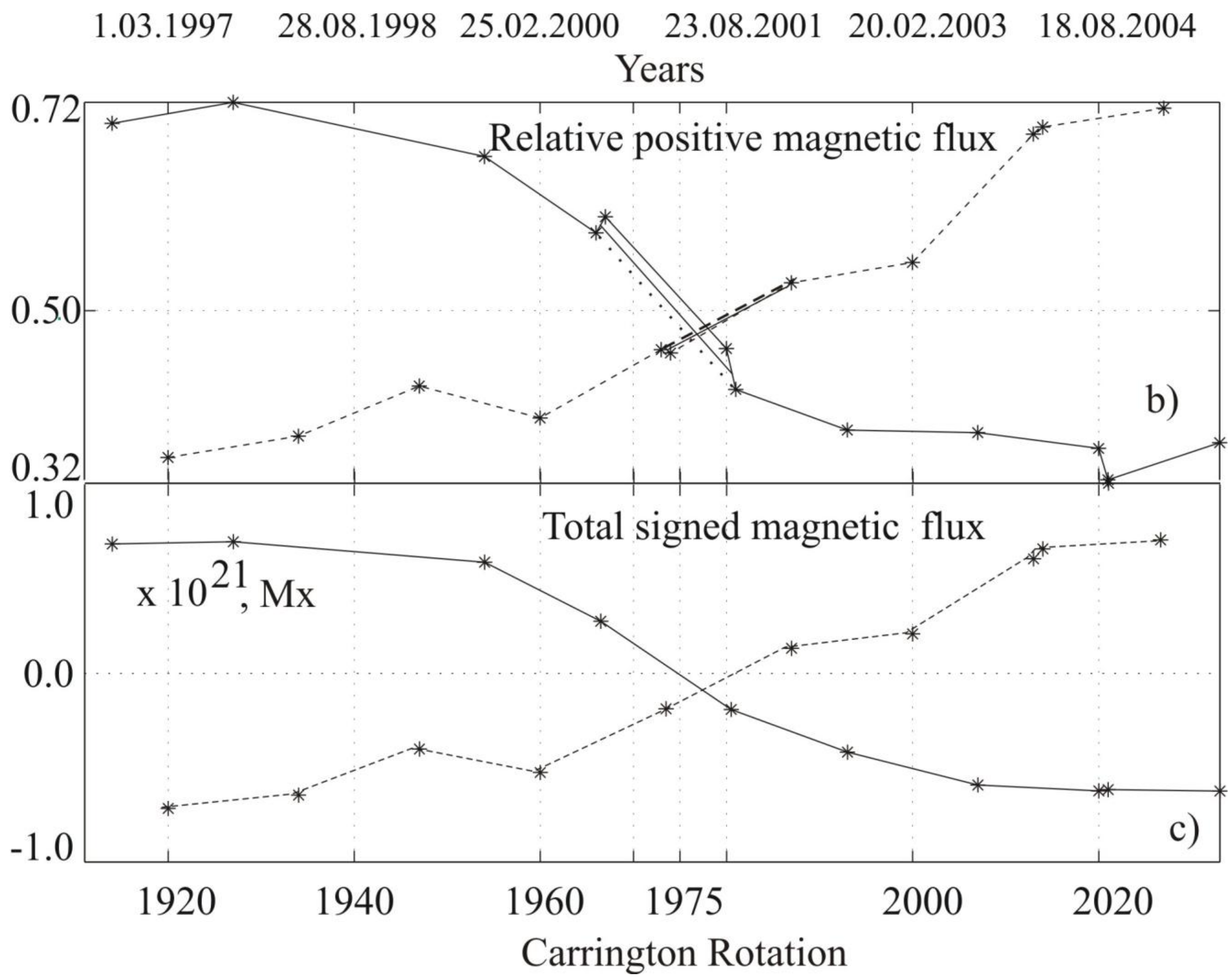
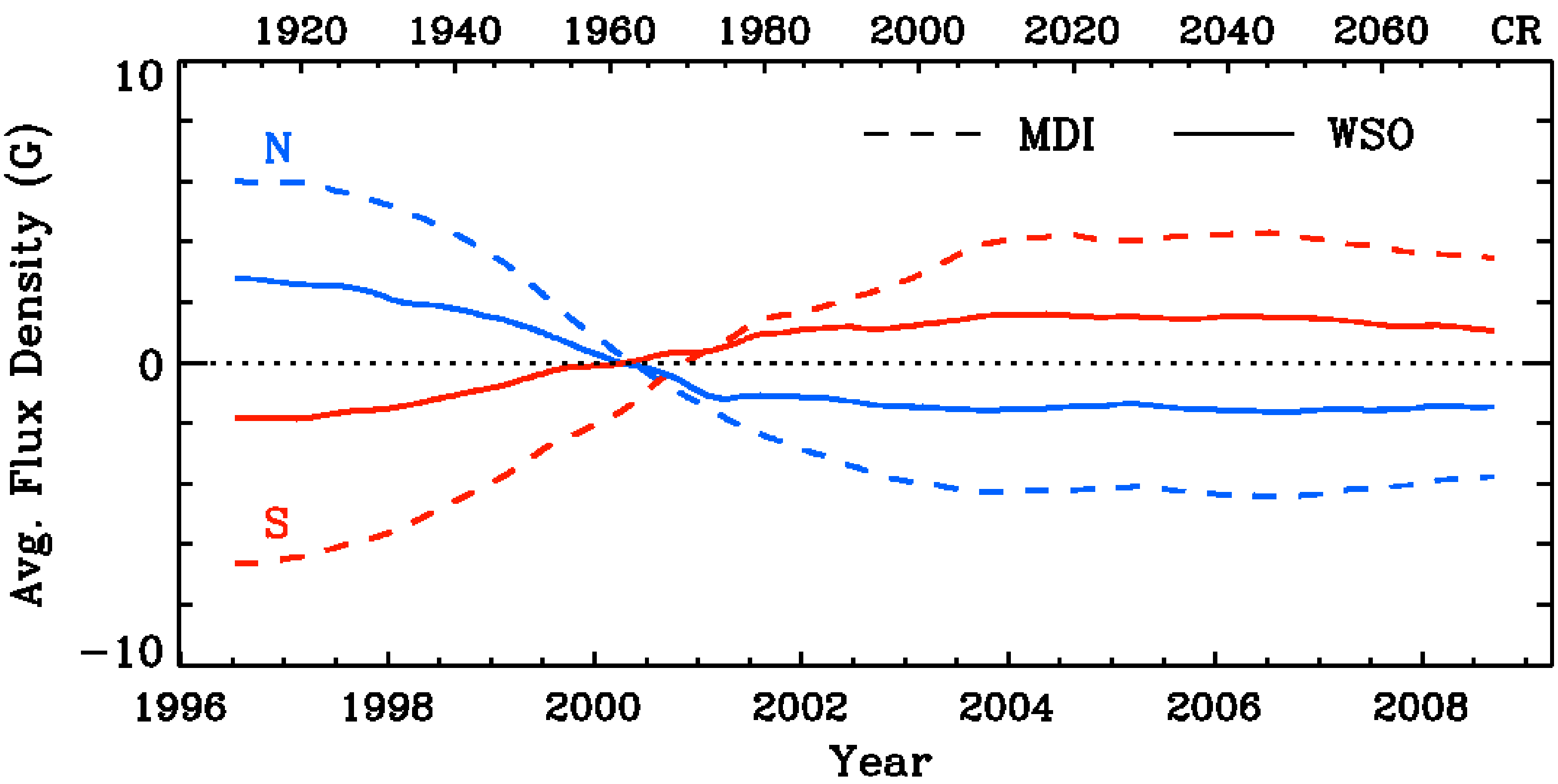


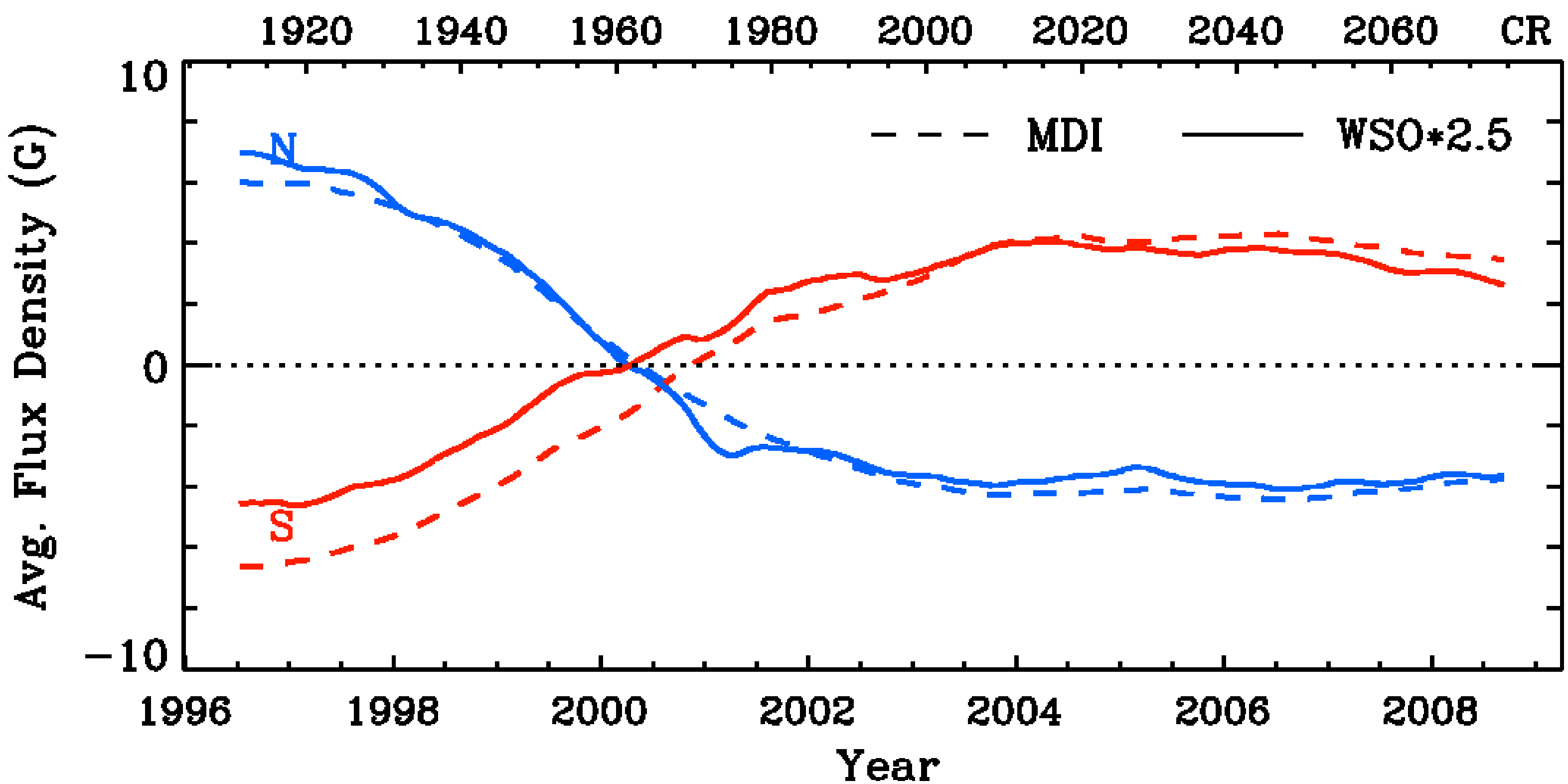
Figure 5. The total MDI unsigned magnetic flux of the radial field component in the latitude zones from 78o to 88o in Northern (solid line) and Southern Hemispheres (dash lines); b) The relative positive polarity parts of magnetic flux in Northern (solid line) and Southern (dash line) hemispheres ; c) The total signed magnetic flux. The polar magnetic field reversal was in CR1975 2 (March 2001) in the North and in CR1980 2 (September 2001) in South.

Synoptic Comparison of WSO & MDI

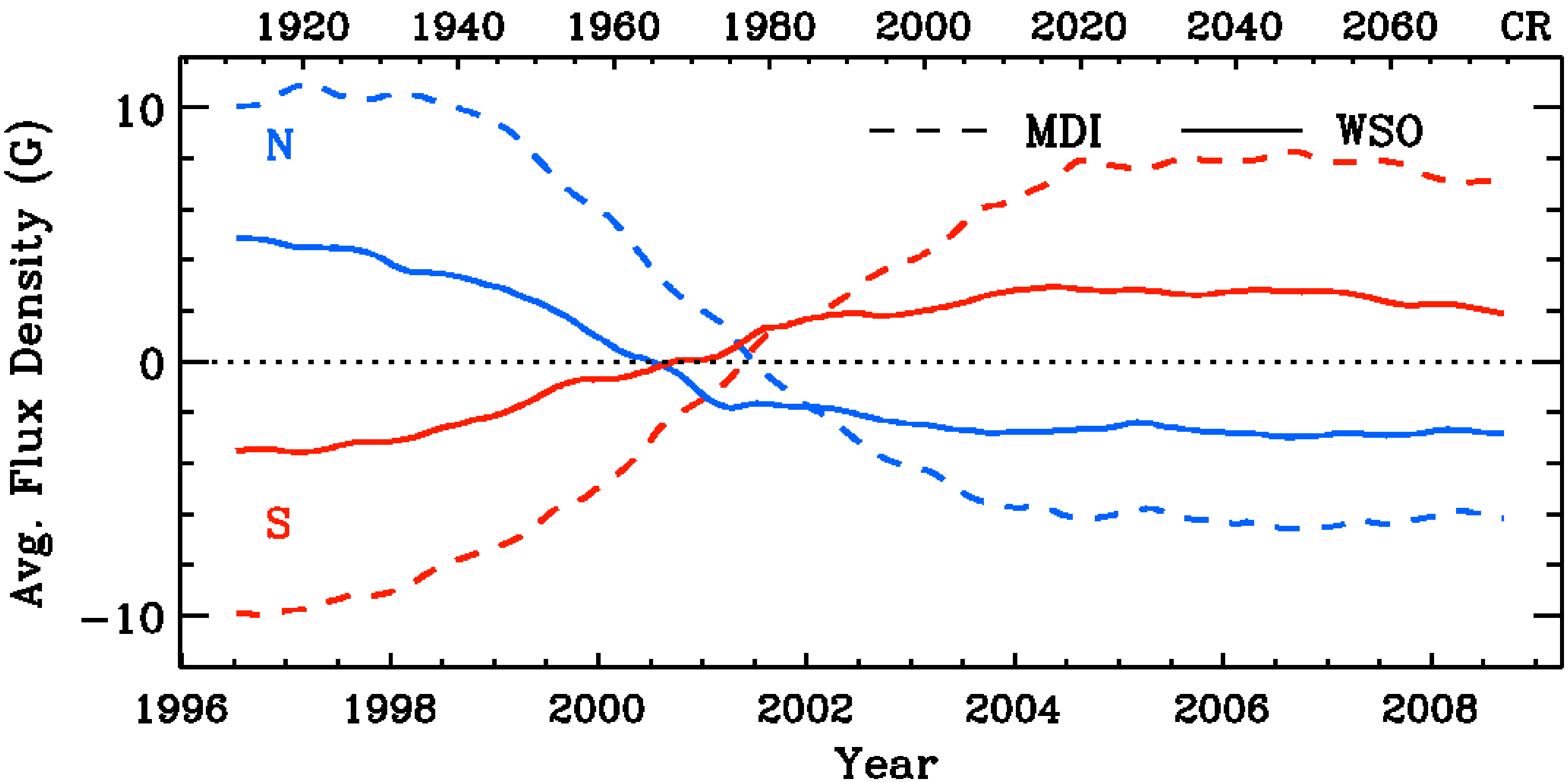
Magnetic Field Reversal 55+



Same WSO-MDI Comparison
WSO multiplied by 2.5



MDI at 75 degrees + WSO at higher synoptic latitude



Mid-latitude and high-latitude magnetic fields.

Dynamics of the small-scale magnetic field which forms the streamers or 'surges' is very complicated. Near the pole we did not observe continually latitudinal motion for individual magnetic elements and it may be related to slow down of the meridional circulation (Raouafi, Harvey, 2007).

Example for one magnetic element in High latitude (about 80º)

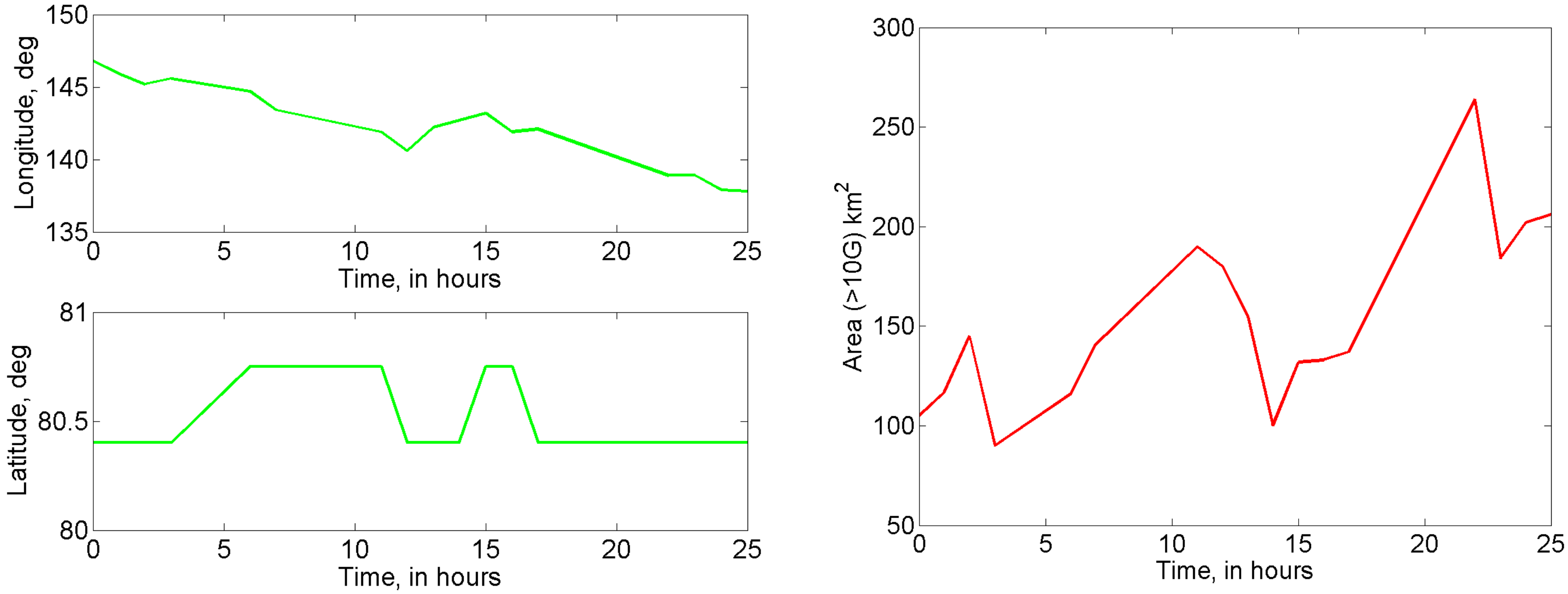
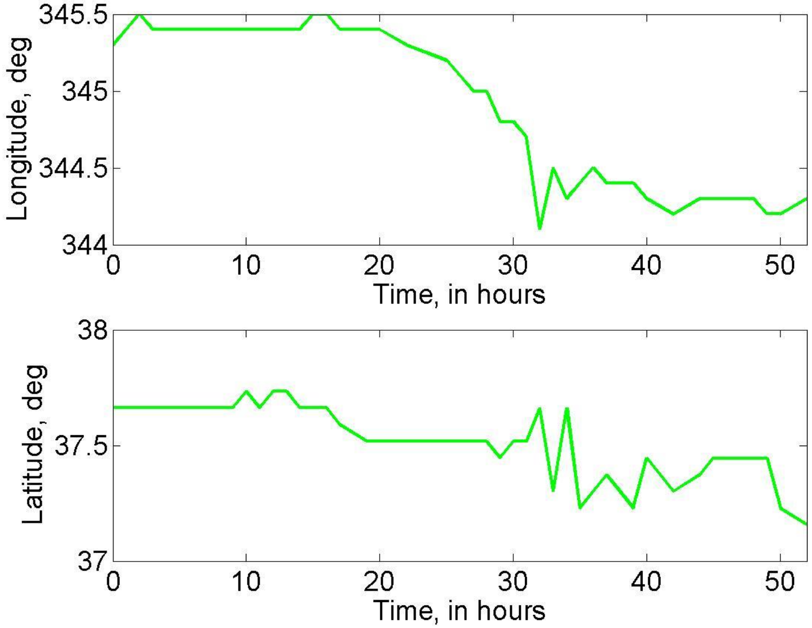


Figure 6. Left panels: Displacement of the magnetic element in longitude and in Latitude. Right panel: Area of magnetic element >10 G.

And in the activity belt,
we observe the motion to the lower latitude.

Example for one magnetic element in Mid latitude



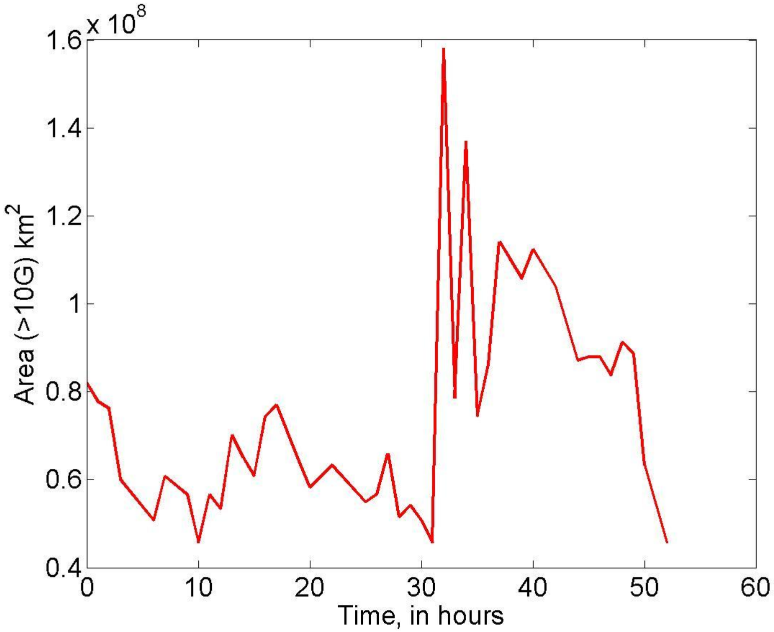


Figure 7. Left panels: Displacement of the magnetic element in longitude and in Latitude. Right panel: Area of magnetic element >10 G.

Conclusions

- The zonal or axisymmetrical structure of the solar cycle reveals the transport of the magtetic flux from the mid to high latitude.
- Migration of the zonal neutral line defines the reversal of the magnetic field during the solar cycle.
- The transport of the magnetic energy is a complex process related to the surface, subsurface and coronal processes.