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SEMI-CENTENNIAL NORTH-SOUTH DISPLACEMENTS OF THE HCS BASED ON THE RECONSTRUCTED IMF SECTOR STRUCTURE

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Abstract. We present the analysis of the interplanetary magnetic field (IMF) sector structure reconstructed from geomagnetic data in the 19th and 20th centuries. During most of the 20th century the IMF polarity is inferred due to the Svalgaard-Mansurov effect using high latitude geomagnetic variations. The IMF polarity in the 19th century was inferred using mid-latitude observations. The latter is possible due to the ground magnetic effect of the field-aligned currents which are asymmetric during the IMF with non-zero By component. The reconstructed IMF sector structure reveals semi-centennial north-south displacements of the heliospheric current sheet (HCS). According to our results the dance of the "ballerina" was not bashful during 13(14)-19 solar cycles.

Introduction

Due to the solar wind, the dipole magnetic field of the Sun extends into interplanetary space, forming the interplanetary magnetic field (IMF). The IMF polarity is determined by the large-scale magnetic field of the Sun. The heliospheric current sheet (HCS) divides the IMF of opposite directions. Negative polarity is defined by the direction along the magnetic field lines toward (T) the Sun, and positive polarity – away (A) from the Sun.

To reconstruct an alternation of the IMF polarity prior the satellite era, geomagnetic data in the past can be used (*Svalgaard*, 1972; *Mansurov et al.*, 1973; *Vennerstroem et al*., 2001; *Berti et al.*, 2006). The IMF controls magnetospheric and ionospheric currents, which cause different variations of the ground magnetic field. In case of the IMF with non-zero By component, the high-latitude system of the field-aligned currents rotates either in clockwise, or in counterclockwise direction. This results in different variations of midlatitude geomagnetic field, especially during the IMF with negative Bz component. These findings allows us to infer the IMF sector structure from the old geomagnetic records made at Saint-Petersburg, Helsinki, Ekaterinburg, Potsdam and other stations since the middle of the 19th century (*Vokhmyanin and Ponyavin*, 2013, 2016).

Analyzing the IMF data at distances of 0.7-1.5 AU to the Sun, in the range of latitudes ±7.3° (satellites Mariner 2, 4, 5, and OGO 5), *Rosenberg and Coleman* (1969) found the predominance of one or another polarity. Due to the inclination of the solar axis of rotation to the plane of the ecliptic, during periods near the equinox the IMF predominates with the polarity of the hemisphere of the Sun which is inclined toward the observer (the Rosenberg-Coleman effect). The excess of one polarity is pronounced in case of poloidal solar magnetic field, i.e. within minima of solar activity. But besides clear evidence for the R-C effect (*Vokhmyanin and Ponyavin*, 2012, 2013) in fall and spring data, the reconstructed sector structure also show the consistent predominance of one IMF polarity on annual scale.

The difference in the widths of the two magnetic sectors was revealed in the simultaneous observations by Ulysses, Wind, and IMP-8. *Smith et al*. (2000) proposed a simple physical explanation of the offset of the sector structure in the ecliptic near solar minimum. The physical nature of this offset is a deflection of the HCS southward/northward, which makes it resemble a ballerina skirt. The average radial fields above and below the current sheet will be different depending on the solid angles that they occupy in the two hemispheres (*Smith*, 2011).

In this paper, we analyse the excess of the IMF polarities recovered from the geomagnetic data. This, in turn, characterizes the north-south HCS displacements since 1844.

N-S asymmetry in the IMF data

The IMF By effect is seen even outside the auroral oval, at mid and low latitudes. This allows inferring the IMF By polarities far more back in the past than it was when only high-latitude geomagnetic data were used. In *Vokhmyanin and Ponyavin* (2016), we estimated the success rate of the IMF sector structure inferred from old geomagnetic observations in Europe (middle latitudes) to be about 65% before 1880, 75% in 1885–1901 and more than 80% for 1902-2010. This assumes the reliability of the sector structure proxies.

In this work, we divide the IMF polarity proxies in six groups according to the availability of the geomagnetic data in the past. Data set 1 is based on the geomagnetic observations in Saint-Petersburg and Helsinki. In Set 2 we add results from Ekaterinburg and Potsdam, in Set 3 – from De Bilt and Sitka, in Set 4 – from Sodankyla and Eskdalemuir, in Set 5 – from Godhavn and Lerwick, in Set 6 – from polar station Thule.

For each set the daily IMF polarities P are calculated according to the following formula:

$$P = sgn(\sum_i (H_i + D_i))$$

i stands for the geomagnetic station, *H* and *D* are horizontal component and declination of the geomagnetic field.

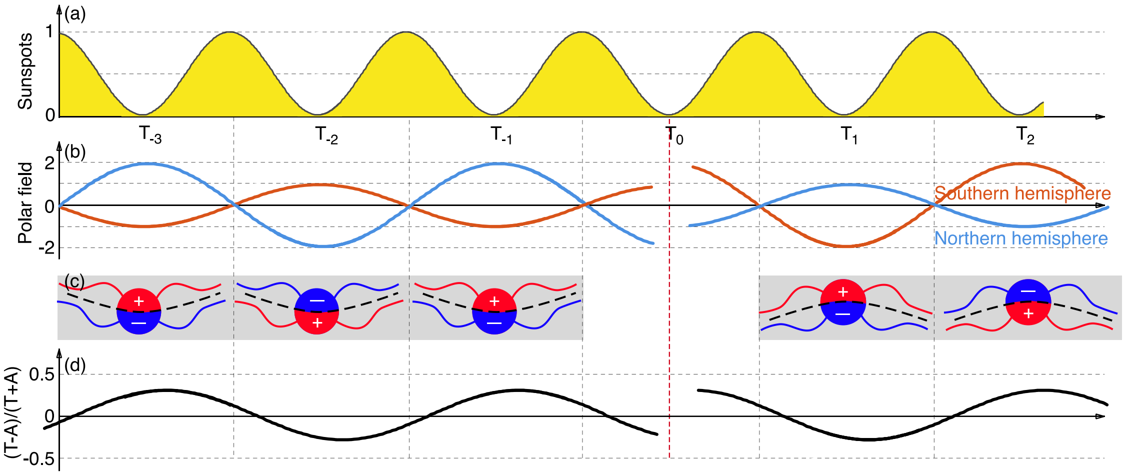

Figure 1. Schematic scenario of the sign change in the asymmetry of solar magnetic fields and offset of solar dipole. **(a)** Yellow fill color the sunspot numbers. Solar minima are marked as T. **(b)** Radial polar field component in the hemispheres. North is colored in light blue and south in light red. **(c)** Schematic asymmetric current sheet. **(d)** Asymmetry of days with negative (T) and positive (A) IMF polarities. Vertical dashed grey lines show solar minima. T_0 (dashed red line) defines the sign change of the asymmetry.

During satellite era, we determine the success rate of the polarity proxies as the percent of correct daily polarities. Assuming the 45 degree angle of the Parker spiral at 1 AU, the actual IMF polarity can be defined as the sign of the (By-Bx) expression in GSE coordinate system. For data sets 1 – 6, we obtain 79.5, 80.3, 82.4, 82.5, 85.4, and 87.9% success rates, i.e. the more geomagnetic variations are used to obtain polarity proxy the more correct result will be.

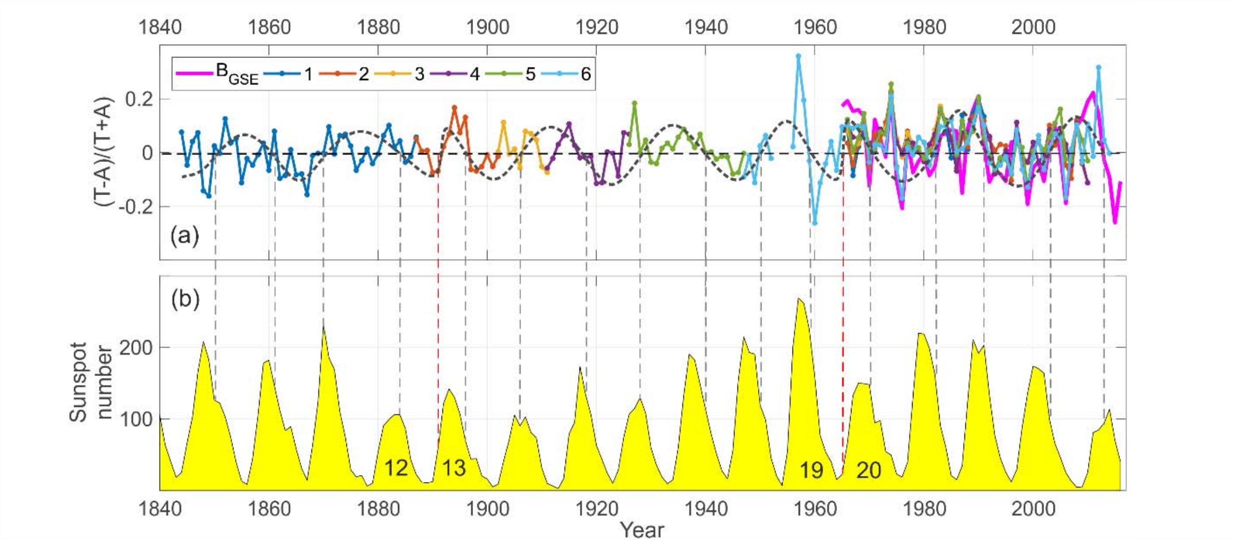

Figure 2. **(a)** Annual ratio of negative (T) and positive (A) polarity days according to polarity proxies Set 1-6 and from the satellite IMF data (B_{GSE}); dashed curve – approximate TA wave **(b)** Yellow fill color the annual sunspot numbers. Cycle numbers refer to the Zürich numbering.

To assess the superiority of one IMF polarity, we calculate the annual ratio according to the formula:

$$TA = \frac{T - A}{T + A}$$

A (away from the Sun) is the number of days with positive IMF polarities and *T* – with negative (toward the Sun). In Fig. 1, the cause of inequality between *T* and *A* is shown schematically. As *Smith et al.* (2000) explain, if southern polar field dominates (minima T_1 and T_2 on scheme), the HCS shifts southward and we observe more IMF with polarity of the northern hemisphere. At the ecliptic plane this is more clearly seen when solar magnetic field has poloidal and axisymmetric form, i.e. within the solar activity minima. In case of consistent HCS displacement and due to regular reversals of the solar magnetic field, the TA ratio has opposite signs within two consecutive minima of solar activity. Positive maxima between odd and even cycles indicate southern displacements of the HCS (due to negative polarity of the solar magnetic field in the northern hemisphere). In the opposite case, the TA indicates northern HCS displacements. In Fig. 1, the change occurs in minima T_0, resulting in phase shift of the TA wave.

The TA values obtained from polarity proxies are shown in Fig. 2 using different colors for different data sets. For satellite period 1967-2013, we use the IMF data from the OMNI data base (purple curve). It is seen that all polarity proxies are able to reproduce actual TA ratio fairly close. The approximate wave of the TA ratio during 1844-2016 is indicated with dashed grey curve. Red vertical lines denote changes in phase of the TA wave. Our results suggest the HCS is coned southward during cycles 9-12 and 20-24, and northward in cycles 13-19. *Hiltula and Mursula* (2006, 2007) also investigate reconstructed sector structure to find the HCS displacement. They use the polarity proxies obtained by *Svalgaard* (1972) and *Vennerstrom* (2001) and found that the HCS was shifted southward for the entire period of study, 1926 – 2006. We suggest that this result is wrong due to lower quality of the above polarity proxies. Besides, our assumption on the HCS displacements is supported by other studies of the north-south asymmetries: in differential rotation (*Zhang et al*. 2013, *Pulkkinen and Tuominen*, 1998) and in solar activity (*Verma* 1992, 1993).

Conclusions

The use of the midlatitude geomagnetic data allows us to infer the IMF sector structure and track the evolution of the north-south asymmetry of the solar magnetic field. We find that the HCS was shifted northward in cycles 13-19, and southward in cycles 9-12 and 20-24. The same N-S asymmetry is found in other solar data. We suggest that this asymmetry changes with the period of Gleisberg cycle where northern solar magnetic field dominates on the ascending phase and southern on the descending.

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