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Regularities of the IMF Sector Structure in the Last 170 Years

Mikhail V. Vokhmyanin, Nadezhda V. Zolotova and Dmitry I. Ponyavin†

St. Petersburg State University,
7/9 Universitetskaya nab., St. Petersburg, 199034 Russia
email: m.vokhmyanin@spbu.ru; ned@geo.phys.spbu.ru

Abstract. The interplanetary magnetic field (IMF) controls magnetospheric currents which cause variations of the ground-based magnetic field. Regular magnetic observations made in the 19th century allow us to infer daily IMF polarities back to 1844. The results coincide with satellite data in about 79% days. Moreover, for the most part of the 19th and 20th centuries, proxies obtained from various geomagnetic data (Helsinki, Saint-Petersburg, Potsdam, and Ekaterinburg) show the same patterns. This suggests that the reliability of the proxies is sufficient to study the IMF in the past. The large-scale organization of the IMF polarities, the so-called sector structure, reveals semi-centennial north-south displacements of the heliospheric current sheet (HCS).

Keywords. Sun: magnetic fields, solar wind, evolution

1. Introduction

Continuously extending solar corona forms the interplanetary magnetic field (IMF). This field is stretched out along the Parker spiral and is directed either away (positive polarity) or toward (negative polarity) the Sun depending upon the source field. The IMF of one polarity is usually observed for several days reflecting the sectoral organization of the IMF at the ecliptic plane. Heliospheric current sheet (HCS) divides areas of opposite IMF. It has been found that one of the IMF polarity may dominate over the other for long periods. On a seasonal scale, this happens due to higher heliographic latitudes of the Earth in Fall and Spring. Thus, when solar dipole is axisymmetric, we observe more IMF with the polarity from the corresponding hemisphere (Rosenberg & Coleman 1969). Observations made on board of Ulysses spacecraft in 1994 – 1995 revealed southward inclination of the HCS (Crooker *et al.* 1997; Smith *et al.* 2000). At the ecliptic plane, this causes the overall excess of the IMF from the northern solar hemisphere. According to the IMF polarities derived in Echer & Svalgaard (2004), the north-south asymmetry of the HCS exists at least from 1926 (Hiltula & Mursula 2006, 2007). This result is based on a combination of three polarity proxies obtained in Svalgaard (1972), Mansurov (1969), and Vennerstroem *et al.* (2001).

In the present work, we analyze reconstructed IMF polarities from Vokhmyanin & Ponyavin (2016). This data set covers additional 80 years allowing to investigate long-term changes of the N-S asymmetry.

2. Results and discussion

The IMF polarity is generally defined by the sign of the IMF By component in GSM coordinate system. Depending upon the IMF By sign, the ionospheric field-aligned current

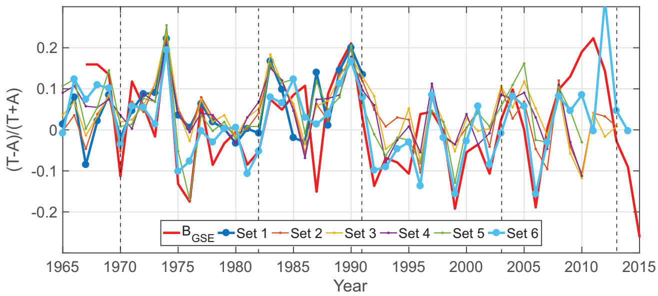

Figure 1. The annual ratio of days with negative (T) and positive(A) IMF polarities according to satellite observations (red) and from geomagnetic data sets 1–6.

Table 1. Reliability of the inferred IMF polarities.

	Set 1	**Set 2**	**Set 3**	**Set 4**	**Set 5**	**Set 6**
Success rate, %	79.5	80.3	82.4	82.5	85.4	87.9
$< \|\Delta TA\| >$	0.10	0.10	0.10	0.09	0.07	0.06

system rotates to dawn or dusk causing a mid-latitude geomagnetic effect (Vennerstrom *et al.* 2007). So the IMF polarity can be inferred in the pre-satellite era. Using the prolonged observations at the first European magnetic stations, we inferred the IMF sector structure back to 1844 (Vokhmyanin & Ponyavin 2013, 2016). Here, we divide the IMF polarity proxies into six groups to estimate their reliability in the past. Data Set 1 is based on geomagnetic observations from Saint-Petersburg and Helsinki (available since 1844). In Set 2, we add results from Ekaterinburg and Potsdam (1896), in Set 3 from De Bilt and Sitka (1902), in Set 4 from Sodankyla and Eskdalemuir (1911), in Set 5 from Godhavn and Lerwick (1926), and in Set 6 from polar station Thule (1947). The success rate over 1965 – 2010 is presented in Table 1. It is defined as the relative number of coincidences with actual IMF polarity — the sign of the (By-Bx).

In order to estimate the HCS state, we calculate the $(T - A)/(T + A)$ ratio (hereinafter referred to as TA), where T and A are the annual numbers of days with negative and positive IMF polarities, respectively. In Figure 1, the ratio calculated for the IMF polarities from satellites is shown by the red curve, and for the reconstructed polarities by orange, yellow, violet, green, and blue colors. Near the solar magnetic field reversals (dashed vertical lines) the average TA and, thus, the dominant polarity change sign. Regularity of such alterations means the direction of the HCS shift stays the same. The largest difference between the actual and inferred TA is observed within the periods of low geomagnetic activity, when the success of the reconstruction decreases (Vokhmyanin & Ponyavin 2016). The average of the absolute difference is presented in Table 1. Although, it is about 0.10 for the proxies based on data sets 1–4, we still can discern the wavy evolution of the TA ratio.

In Figure 2, we show TA from 1844 to 2017. The years of solar magnetic field reversal are arbitrary indicated with vertical dashed lines. For more clarity, we also show prospective wave of TA (purple curve) drawn by hand. The maxima of this wave lie within the solar activity minima, when solar dipole is presumably axisymmetric. Significant deviations from the purple curve in 1856 – 1858, in 1876 – 1879, and in 1897 – 1901 coincide with extremely low geomagnetic activity. As we mentioned, this could be the cause of low success rate and hence unreliable TA estimation. Thus, the purple curve was drawn according to the TA values at the declining and growing phases of solar cycles. The

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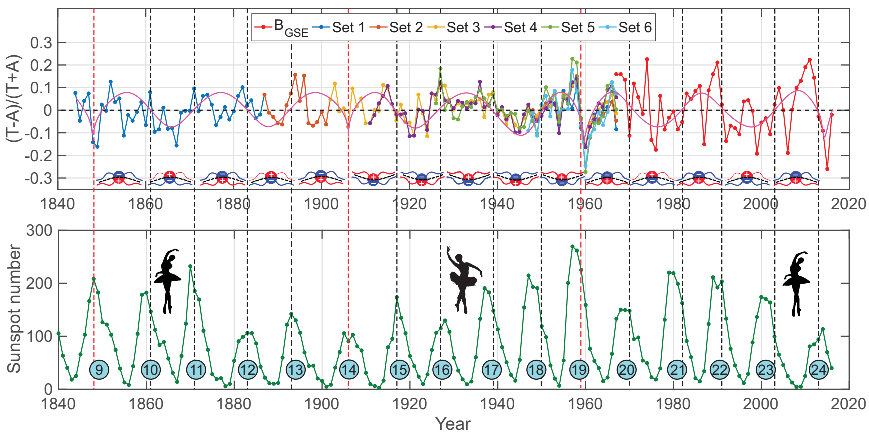

Figure 2. *Top*: TA ratios similar to Figure 1; purple wave – approximate TA wave; *bottom*: the annual sunspot numbers from the WDC-SILSO; the HCS asymmetry is illustrated by the ballerina's skirt.

assumed wave stutters around maxima of solar cycles 14 and 19. This means that before solar cycle 19 the HCS was shifted northward, while before solar cycle 14 — southward (see schematic illustration under the top plot). Therefore, the polar field was stronger in the northern hemisphere during solar cycles 15 – 19, and in southern during cycles 10 – 14 and 20 – 24. Our result on the HCS displacements is supported by other studies of the north-south asymmetries found in differential rotation (Pulkkinen & Tuominen 1998; Zhang *et al.* 2013) and solar activity (Verma 1993). If this scenario consistently repeats and the N-S asymmetry indeed has periodic behavior, we might expect northward solar field strengthening in the upcoming solar cycle 25.

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