Solar Wind Parameters in Periods of Solar Large-Scale Magnetic Field Reversals

Simeon Asenovski
Space Research and Technology Institute, Bulgarian Academy of Sciences, BG-1000, Sofia
asenovski@space.bas.bg

(Submitted on 09.08.2018. Accepted on 07.11.2018)

Abstract. The present paper investigates the behavior of solar wind basic parameters during the large-scale solar magnetic field reversal. Using the superposed epochs method for monthly averaged values of the different solar wind parameters for the last four large-scale magnetic field reversal, it is shown that during the periods of different polarities, some of the parameters as magnetic field B_x and B_y components, as well as B_{scalar} and solar wind speed have seasonal trend. Plasma density and pressure have differences in their magnitude during the different periods.

Key words: Solar wind parameters, Positive and negative polarity

Introduction

Solar Wind (SW) streams, directed away from the Sun, are not uniform. They rapidly change their basic parameters – speed V, temperature T, direction and magnitude of the carried magnetic field B, density ρ, pressure P, etc. Studies of the physical processes related to these changes or just observational and statistical comparison between different periods of solar activity, have significant importance for understanding how the solar present state can influence Earth's environment. One of the main factors causing variations and changes of the solar wind parameters is the 11-year solar magnetic field reversal.

Since 1959, when for the first time Babcock (1959) reported that the general magnetic field of the Sun had reversed polarity, numerous observation and theory models have vastly improved our understanding about this phenomenon.

The polarity of the solar magnetic field is directly related to the B_z-component of the interplanetary magnetic field (IMF) (Lyatsky et al., 2003; Youssef et al., 2012) and has influence on the geomagnetic activity (Xu et al., 2009). Also it is important for the cosmic ray drift (Jokipii et al., 1977), as solar cyclic magnetic field modulates the long-term variations of the galactic cosmic rays differential spectrum (Cliver and Ling, 2001; Gushchina et al., 2009). Furthermore, there is a possible link between multi-decadal climate cycles and periodic reversals of solar magnetic field polarity (Miayahara et al., 2008). Based on measurements stored in OMNI data base of the National Space Science Data Center, Kirov et al., (2003) investigate the behavior of the IMF components during negative and positive solar cycles. They show statistically significant difference in the IMF B_x, B_y, B_{long} components in positive and negative polarity solar cycles. Considering the possible relation between the 22-year Earth rotation variation and 22-year periodicity in solar wind parameters, they also suggest that SW mediates the transfer of angular momentum from Sun to Earth.

It is important to note that the unique Ulysses measurements have exposed how the IMF and heliospheric current sheet are influenced by solar cycle variations and magnetic field reversal. Observations of the sector structure throughout the solar cycle show that a correlation between the sector structure and the periodic transitions between slow and fast SW exists (Smith, 2011).

All these facts encourage an investigation on the relation between SW parameters and polarity of the solar cycles and try to answer the question: How does the large-scale magnetic field reversal modify the different parameters characterizing the solar wind? This paper presents a statistical study of the solar wind speed, temperature, magnetic field, density and pressure during positive and negative polarity of the solar magnetic field.

1. Data and methods

In this paper it is assumed that solar magnetic field polarity for the Northern Hemisphere refer to abbreviations PPSC (positive polarity solar cycle) or NPSC (negative polarity solar cycle). When the dominating magnetic field for the Northern Hemisphere is positive then we have PPSC or if dominating magnetic field for the Northern Hemisphere is negative then we have NPSC. The exact time of the large-scale solar magnetic field reversals has been estimated using solar polar field data from Wilcox Solar Observatory (WSO)(http://wso.stanford.edu/) and Mount Wilson Observatory (MWO) (Fig. 1).

There are several catalogues for solar wind (SW) parameters, covering the last four solar cycles. Using the experimental data presented in OMNIWeb Data Explorer (http://omniweb.gsfc.nasa.gov), we can study different parameters characterizing the SW state near Earth in conditions of NPSC and PPSC. From a physical point of view and for the purpose of this investigation the data is grouped according to the solar magnetic field reversal in two different sets – those which are measured during negative polarity and those during positive polarity. Makarov et al., (2003) report that the reversal occurs on average 5.8 ± 0.6 years from sunspot minimum (polar fields reverse polarity at about the time of the cycle maximum). The time intervals of the reversal are not the same for even and odd cycles (Makarov et al., 2001). Moreover, a clear asymmetry of the solar polar field reversal during the 24 Solar cycle was observed, as the northern pole coronal hole had already disappeared, while the South polar flux had only slightly decreased (Gopalswamy et al., 2012; Hoeksema, 2012; Shiota et al., 2012).

The time periods representing the Northern Hemisphere different polarity for the last four solar reversals are shown in Table 1.

The evolution of the solar wind parameters, including IMF polarity during the time of large-scale solar magnetic field reversal does not contribute to adequate assessment for the general picture. At the time of solar maximum activity, when the solar magnetic dipole field is not well determined, the IMF is characterized with a complex structure. Wang et al., 2002, examine the polarity reversal during the solar maximum of cycle 23 and show that the total area of the solar surface with open magnetic fields is decreasing to $\sim 5\%$ (during solar minimum it is 20%). They point out that during

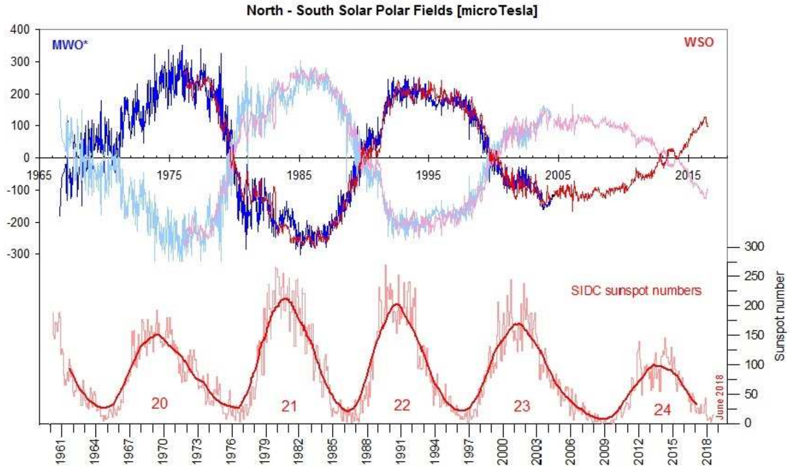

Fig. 1. The North and South solar magnetic fields reversing (Chart by Leif Svalgaard from http://www.leif.org/research/) compared with sunspot number (http://www.ngdc.noaa.gov/ngdc.html). The upper graph represents solar polar field strength for northern polar field - dark red (Wilcox Solar Observatory) and dark blue (Mount Wilson Observatory); and solar polar field strength for southern polar field - light red (Wilcox Solar Observatory) and light blue (Mount Wilson Observatory).

Table 1. Periods of positive and negative solar magnetic field polarity for the Northern Hemisphere.

Solar cycle	Period	Polarity
20-21	Jan. 1969 - Dec. 1979	positive
21-22	Jan 1980 - Dec 1989	negative
22-23	Jan 1990 - Dec 1999	positive
23-24	Jan 2000 - Nov 2013	negative

a period of about six months (mid-1999 through early 2000) the magnitude of the magnetic field quadrupole component is comparable to the dipole component. The measurements of the solar wind parameters during the six months periods (3 months before and 3 after) over the time of reversals for the last four solar cycles are not used in the present study.

Each year the Earth crosses sector boundaries from 10 to 45 times (according to L. Svalgaard's list of the sector boundaries, http://wso.stanford.edu/SB/SB.Svalgaard.html). Considering the fact that Heliospheric current sheet is roughly $\sim$ 10000 km thick at 1 AU (Winterhalter et al., 1994) and the disturbing effects caused of its crossing to the solar wind parameters are for approximately two days (one day before and one after) (Khabarova and Zastenker, 2011), the solar wind data for that time is also removed from the used data.

After dividing the experimental data of different solar wind parameters to those which are measured during: 1) NPSC and 2) PPSC, their monthly averaged values have been found. Superposed epochs method for these values has been applied, in a way to receive one monthly averaged value for the different polarities.

Examination of monthly average values suggests that we are looking for differences between NPSC and PPSC during the seasonal Earth rotation (Fig. 2 - 5).

2. Results

The main results are presented in Fig. 2 - 5, where the seasonal behavior of the solar wind parameters are shown.

Seasonal Earth rotation is characterized with two main features - in spring and autumn Earth respectively is at the highest Southern and Northern heliolatitudes. At period of PPSC, in the Southern solar hemisphere the magnetic field is toward the Sun, so IMF B_x component near the Earth is positive during the spring. In autumn, when the Earth is at its highest Northern helioaltitudes the field is away from the Sun and B_x is negative. The behavior of the B_y component is opposite to the one of B_x. During the periods of NPSC, when in the Southern solar hemisphere the magnetic field is away from the Sun, IMF B_x component in spring is negative while in autumn B_x is positive (Fig.2).

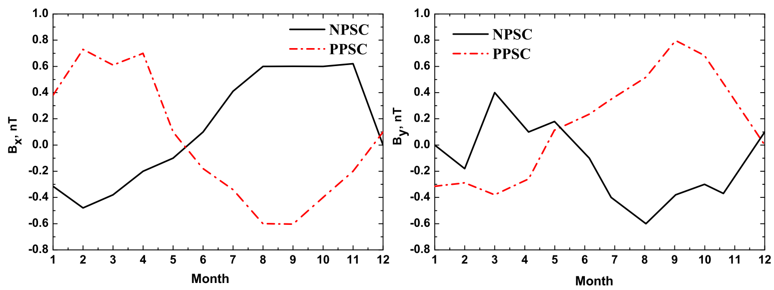

Fig. 2. Annual cycle of the IMF B_x and B_y component in PPSC (broken line) and NPSC (solid line).

Archimedean spiral model of Parker (Parker, 1965) describes the interplanetary magnetic field. This picture is confirmed by satellite measurements but some differences were found between the calculated parameters and the measured ones (Smith, 2013). Opposite to the behaviour of both IMF components B_x and B_y which demonstrate a clear 22 – year periodicity, B_z doesn't show such trend (Fig. 3).

The monthly average values of plasma speed for both negative and positive periods show an identical trend. In (Fig. 4) we can notice that the average temperature during positive periods is higher than in negative periods.

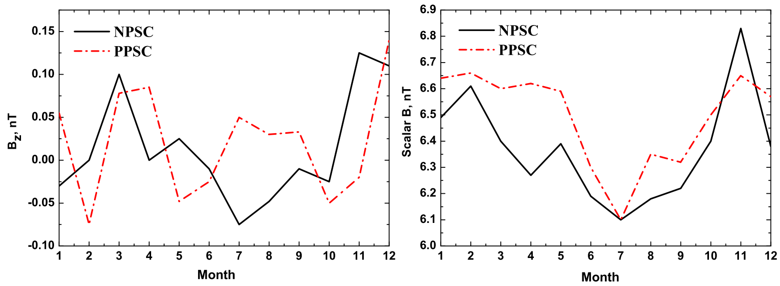

Fig. 3. Annual cycle of the IMF B_z and B_{scalar} component in PPSC (broken line) and NPSC (solid line).

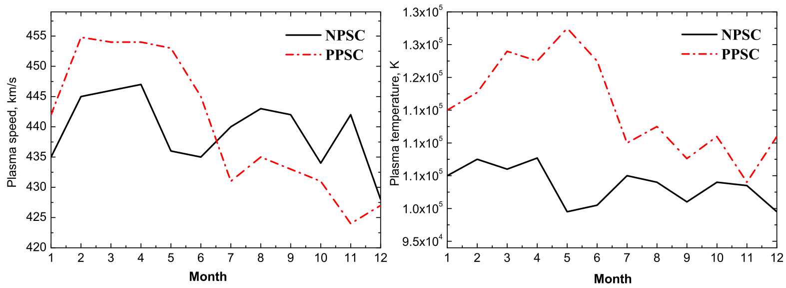

Fig. 4. Annual cycle of Plasma speed and Temperature in PPSC (broken line) and NPSC (solid line).

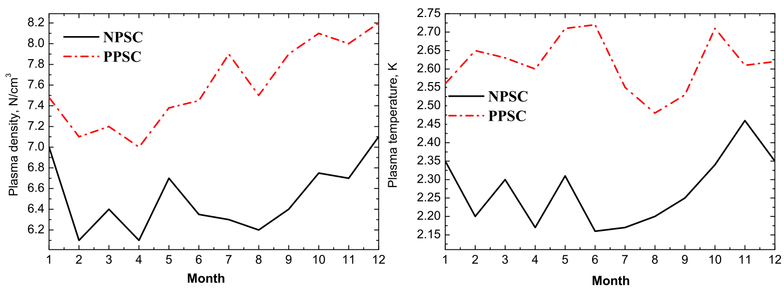

Fig. 5. Annual cycle of Plasma density and Flow pressure in PPSC (broken line) and NPSC (solid line).

The monthly average values of plasma density and flow pressure are higher in positive periods than in negative periods of solar cycle. There isn't any seasonal trend during both periods in these two parameters.

Conclusion

This work observes into the behavior of the main solar wind physical parameters - speed V, temperature T, magnetic field B, density ρ and pressure P in the last four large-scale solar magnetic field reversals – negative and positive polarities. The configuration of the large-scale solar magnetic field influences the measured solar wind parameters, as the main results can be summarized in the following statements:

1. The magnetic field B_x, B_y and B_{scalar} components as well as solar wind speed V have a clear seasonal trend (Figs. 2, 3, 4).

2. The magnetic field B_z does not have seasonal trend during different large-scale solar magnetic field polarities.

3. The average temperature T, pressure and density during the PPSC are higher than those in NPSC period (Figs. 4, 5).

Acknowledgments

This work was supported by the "*Competition for financial support for projects of junior researchers – 2016*" under grant DM 04/4 "Investigation of the impulsive solar activity agents throughout the 11-year solar cycle".

References

Babcock H.D., 1959, *Astrophysical Journal* 130, 364.
Cliver E.W., Ling A.G., 2001, *The Astrophysical Journal* 551, L189.
Gushchina R.T., Belov A.V., Obridko V.N., Shelting B.D., 2009, *Advances in Space Research* 43, 673.
Gopalswamy N., Yashiro S., Mäkelä P., Michalek G, Shibasaki K., Hathaway D.H., 2012, *The Astrophysical Journal Letters* 750, L42.
Hoeksema J. T., 2012, *BAAS* 44(4), 206.07.
Jokipii J.R., Levy E.H., 1977, *Astrophysical Journal* 213, 861.
Khabarova O., Zastenker G., 2011, *Solar Physics* 270, 311.
Kirov B., Georgieva K., Javaraiah J., 2003, *International Solar Cycle Studies (ISCS) Symposium Ed.: A. Wilson. ESA SP-535* ISBN 92-9092-845-X, 366.
Lyatsky W., Tan A., Lyatskaya S., 2003, *Geophys. Res. Lett* 30(24), 2258.
Makarov V.I., Tlatov A.G., Sivaraman K.R., 2001, *Solar Physics* 202, 11.
Makarov V.I., Tlatov A.G., Sivaraman K.R., 2003, *Solar Physics* 214, 41.
Miyaharaa H., Yokoyamaa Y., Masudab K., 2008, *Earth and Planetary Science Letters* 272, 290.
Parker E.N., 1965, *Space Science Reviews* 4, 666.
Shiota D., Tsuneta S., Shimojo M., Sako N., Orozco Suárez D., Ishikawa R., 2012, *The Astrophysical Journal* 753(2), 157.
Smith E.J., 2011, *Journal of Atmospheric and Solar-Terrestrial Physics* 73, 277.
Smith E.J., 2013, *Journal of Geophysical Research: Space Physics* 118,58.
Sidorenkov N.S., 1978, *Trudy Gidrometcentra SSSR* 205,48. (In Russian)
Wang Y.-M., Sheeley N.R., Andrews M.D., 2002, *Journal of Geophysical Research* 107, 1465.
Winterhalter D., Smith E.J., Burton M.E., Murphy N., McComas D.J., 1994, *Journal of Geophysical Research* 99, 6667.
Xu D., Chen T., Zhang X.X., Liu Z., 2009, *Planetary and Space Science* 57, 1500.
Youssef M., Mahrous A., Mawad R., Ghamry E., Shaltout M., El-Nawawy M., Fahim A., 2012, *Advances in Space Research* 49, 1198.