Asymmetry in the Inward-Outward Polarity in the Interplanetary Magnetic Field

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Distribution of the magnetic field of solar wind near the Earth was investigated and compared with one expected from the classical model. It is shown that the presence of two peaks in the distribution of interplanetary magnetic field values, founded by Belov, Obridko and Shelting (2006), is not an artefact of averaging but reflects the real structure of magnetic field inside a sector. Moreover, the magnetic field of the polarity corresponding to the leading sunspot of the Northern Hemisphere is observed more frequently. With solar activity rise the growth of both the module of a magnetic field and the fields of each polarity separately were determined. The distance between peaks increases from 6 nT to 10 nT. In alternate amplification of peaks a quasi-22-year cycle was observed while in the intensity of a field of each polarity there was revealed a 11-year cycle, and in ratio of peaks to frequency of occurrence of zero values – a quasi-2-year (2.6±0.3 year) cycle. Approximately in 25 % of all cases the classical model is violated.

Introduction

An accepted widespread concept of the quiet solar wind uses rather simple scheme of source surface according to which whole heliosphere is divided into 2 zones – the zone of free field and the zone of solar wind [1, 2]. In the classical variant it is supposed that source surface represents a sphere with radius equal to 2.5 radiuses of the Sun; on this surface it is additionally agreed that the potential is strictly equal to zero and field lines are strictly radial. Further in the interplanetary space a radial expansion takes place and the field completely is carried away by the solar wind. On the average for a quiet flowing out stream the radial solar magnetic field in the interplanetary space should decrease by distance as r^{-2}.

In papers [3, 4] for the long period (1976-2004) solar magnetic field B_S is calculated for each day for the projection of the Earth to the source surface of solar wind. These data were compared with daily averaged values of the solar wind speed and various components of the interplanetary magnetic field (IMF) near the Earth. The statistical analysis has revealed significantly high correlation between characteristics of the solar wind near the Sun and near the Earth during the periods without significant sporadic solar and interplanetary disturbances. In 84 % of all days a sign of B_S correctly defines polarity of IMF, and at quite large values of $|B_S|$ the accordance of polarities is very great. At the same time correlation of solar magnetic field B_S and radial component of IMF near the Earth B_{XE} is obviously non-linear, and at small values of $|B_S|$ the polarities are often mixed up. It is evident that close to zero values of magnetic field's strength are more often observed on the source surface than near the Earth. Distribution of the field on the source surface has one-peak centered at the zero value, while the distribution of field near the Earth has obvious two-peaks with maxima around ±2.5 *nT*.

From comparison of these distributions it follows that weak solar magnetic fields, as a rule, do not reach the Earth. Probably, this distinction partially could be explained by a smaller accuracy in definition of magnetic field on the source surface in comparison to the accuracy of interplanetary measurements, but we suggest that this distinction can have more serious physical reasons [5]. It should be mentioned that the spherical surface of a source with strictly radial magnetic field in all points is no more than abstraction. The real magnetic field cannot be strictly radial on whole sphere. It extends below a surface of a source and (in some areas, for example, above coronal holes) does not remain radial over this surface as well. In this process weak fields can be replaced by stronger ones, not always keeping initial polarity.

This paper is devoted to detailed study of this effect. In particular, it was interesting to check whether this effect is simple artefact of averaging or not and to verify whether it disappears at use of, for example, the hourly average values or not. If this effect does exist really, so it is interesting to examine how the characteristics of this effect depend on time and solar cycle phase.

Diagram of the measured hourly average values

Hourly average values of solar wind speed and characteristics of IMF from OMNI database (http://nssdc.gsfc.nasa.gov/omniweb) for 35 years (1970-2004) were used in this paper.

The diagram of ratios of measured hourly averaged values of magnetic field components B_X – B_Y for 2000 is shown in Fig.1(a). The accumulation of points in 1st and 3rd quarters is evident and corresponds to the traditional model taking into account that an average speed of solar wind is close to the angular speed of rotation of spiral. Nevertheless there are a lot of points in 2nd and 4th quarters, which generally speaking, are impossible within the framework of Parker's model at any speed of propagation.

In the case of absence of interplanetary interaction a solar radial component of field B_S near the Earth should be transformed to the field directed along a spiral field line under the angle $\psi = arctg\ (\Omega R_E / V_{SW})$ relative to the radius, where Ω - is the frequency of rotation of the Sun, R_E – is average distance between the Earth and the Sun, V_{SW} is solar wind speed near the Earth. We can calculate a projection of IMF near the Earth on expected field line according to value of V_{SW}:

$$B_L = B_{XE} \cos(\psi) + B_{YE} \sin(\psi),$$

(B_{XE} and B_{YE} are components of field on ecliptic plane); we will denote it as a longitudinal component of IMF. Signs of component B_{XE} in the last expression are chosen so that the positive values of B_L will correspond to the direction from the Sun.

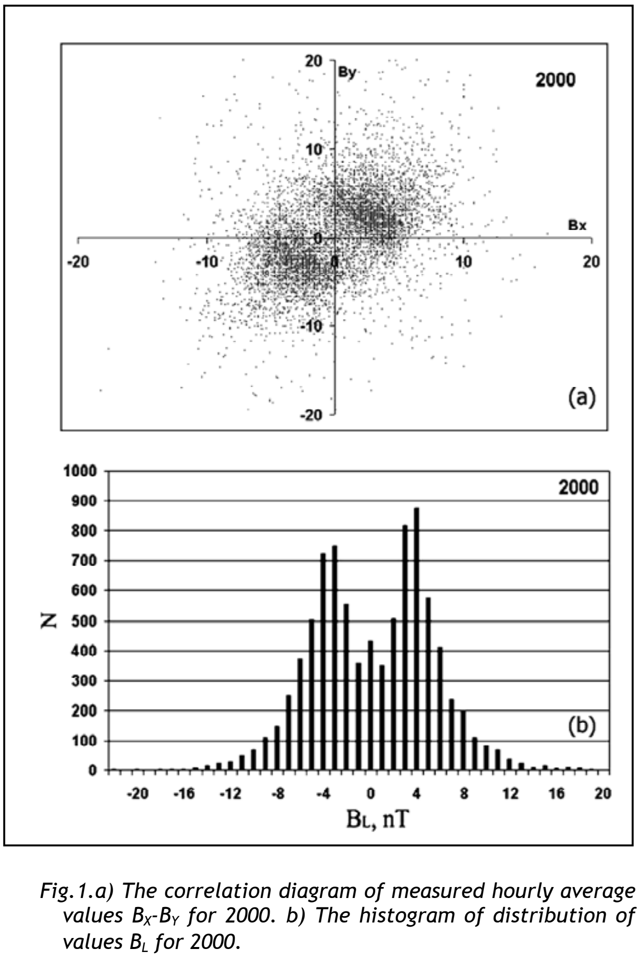

Fig.1.a) The correlation diagram of measured hourly average values B_X-B_Y for 2000. b) The histogram of distribution of values B_L for 2000.

The histogram displaying a distribution of the values of B_L calculated for 2000 by this way is shown in Fig. 1(b).

It is evident that using hourly averaged values does not remove double-peaks in the histogram of distribution of B_L. Moreover, the histogram became wider and values of maxima (peaks) in the diagram of hourly averaged values correspond to ±4.5 *nT*. It is important to note that the heights of these maxima (*max*1 and *max*2) are not identical and their ratio varies with time.

For better study of dynamics of B_L peaks, the picture of changes of these peaks relative to each other and relative to zero value was drawn. Graphics of changes of ratio N(*max*1)/N(*max*2) are shown in Fig. 2(a), where black continuous line is an approximating polynomial of 6th order and dashed line is sinusoid with the period of approximately 17.25 year.

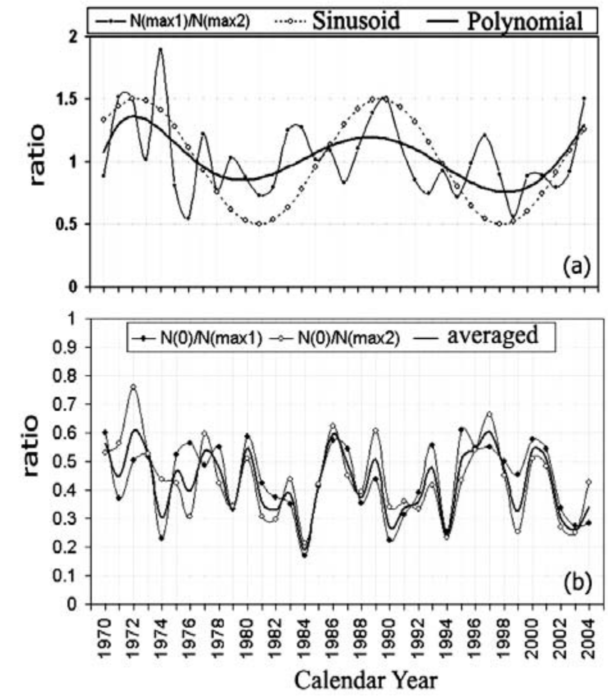

Fig.2.a) The curve of ratios of heights of peaks of the histogram. b) Changes of ratios of heights of histogram corresponding to the zero value of B_L and the heights of peaks of histogram.

It is obvious that within the framework of the limited realization the period of ~17 year is statistically indistinguishable from 20 years' period that stands on the basis of Hale's solar cycle in last years. One can easily see that the maximal deviations from equality of peaks (i.e., from unit) correspond to maxima of sunspot numbers (Wolf numbers) and passage through the unit - to phases of minima of solar activity cycle.

It is important to note, that periodicity in figure is close to 20 years; it means, that the sign of local field takes part in formation of double-peaks (i.e., Hale law). Really, taking into account Hale law it is possible to state that within last 35 years the interplanetary magnetic fields with a direction coinciding with the polarity of the field in the head spot of groups of Northern Hemisphere were observed much more frequently.

In 1971, 1990 (solar cycles 20 and 22) this ratio >1, i.e. *max*1 (with -B_L)> *max*2 (with +B_L) while in 1980, 1998 (solar cycles 21 and 23) this ratio <1, i.e. *max*1 (with -B_L) <*max*2 (with +B_L). In the ratio of heights of the histogram corresponding to the zero value of B_L and heights of peaks (see: Fig. 2(b)) we did not see any significant regularity except well-known quasi-2-years oscillations with the period of 2.6±0.3 year.

Changes of distances between peaks (ΔB_L) by time are shown in Fig.3. One can see here exact regularity: peaks diverge in periods of maxima up to 9-10 *nT*, and come together in minima periods up to 6 *nT*. All 4 solar cycles in this respect are equivalent irrespective of signs of global and local fields on the Sun.

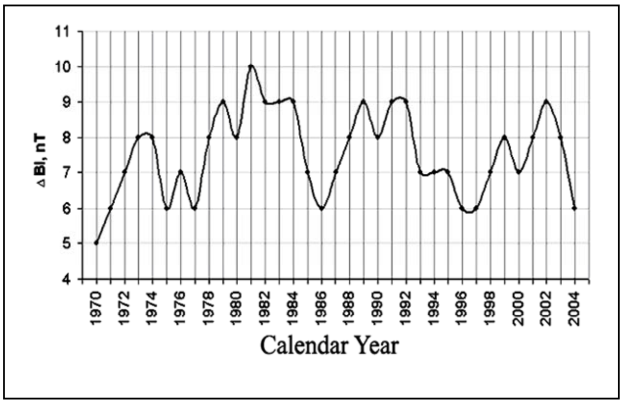

Fig. 3. Changes of distances between peaks (ΔB_L).

Comparison of Angles of the Direction of Speed and the Magnetic Field

As solar wind speed V_{SW} as components of magnetic field B_X and B_Y are known from independent observations, so knowing an average speed of rotation of the Sun, we can calculate the direction of "plasma" ψ and magnetic field lines γ : $\psi = arctg\ (\Omega\ R_E\ /\ V_{SW})$ $\gamma' = arctg(B_X/B_Y)$, where:

a) If $B_X > 0$ and $B_Y > 0$ then $\gamma = \gamma'$ i.e., angle γ is in interval 0-90 degrees;

b) If $B_X < 0$ and $B_Y > 0$ then $\gamma = 90 - \gamma'$ i.e., angle γ is in interval 90-180 degrees;

c) If $B_X < 0$ and $B_Y < 0$ then $\gamma = 180 + \gamma'$ i.e., angle γ is in interval 180-270 degrees;

d) If $B_X > 0$ and $B_Y < 0$ then $\gamma = 360 + \gamma'$ i.e., angle γ is in interval 270-360 degrees.

The majority of points are located in the 1st and 3rd quarters and their statistics well agreed with the classical theory. But large number of points (about 25 %) is concentrated in the 2nd and 4th quarters; it is not in accordance with the classical theory.

The statistics of distribution of these angles (in %) for year of 2000 are shown in Table 1.

TABLE 1

Relative number of points in all (1-4) quarters for 2000

Quarters	1st	2nd	3rd	4th
Intervals of γ, *degrees*	0-90	90-180	180-270	270-360
Number of points, *%*	40.9	13.1	34.4	11.6

Discussion and conclusions

The deviation of the interplanetary magnetic field from the classical Parker spiral was reported in [6-9].

In this paper we have investigated distribution of the solar wind's magnetic field near the Earth and compared with one expected from the classical model. The asymmetry in the inward-outward polarity in the interplanetary magnetic field and its dependence on solar cycle is studied. For these purposes we have used hourly average values of solar wind speed and characteristics of IMF for 35 years (1970-2004) which enabled us to conduct a quantification of the deviation from the Parker spiral.

Results obtained in this paper are in agreement with results of [10-13]. These papers show that there has been a systematic southward depression of the heliospheric current sheet over the last four solar cycles. This would automatically lead to the polarity asymmetry reported in the present paper since a southward displacement of the heliospheric current sheet means that the Northern-Hemisphere dipole polarity will dominate the statistics of IMF polarities. The leading sunspot in the Northern Hemisphere has the same polarity as the solar dipole in Northern Hemisphere, which accounts for the correspondence between the dominant IMF polarity and the leading sunspot polarity that our paper reports.

In this paper it is shown, that the presence of two peaks in the distribution of interplanetary magnetic field values, found by Belov et al [4], is not an artefact of averaging, but reflects the real structure of magnetic field inside a sector. Moreover, the magnetic field of the polarity corresponding to the leading sunspot of the Northern Hemisphere is observed more frequently. With solar activity rise the growth of both the module of a magnetic field and the fields of each polarity separately was determined. The distance between peaks increases from 6 *nT* to 10 *nT*. In alternate amplification of peaks there is observed a quasi-22-year cycle while in intensity of a field of each polarity - 11-year cycle, and in ratio of peaks to frequency of occurrence of zero values – quasi-2-year (2.6 ± 0.3 year). Approximately in 25 % of all cases the classical model is violated.

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