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Correction of Observations When Calculating Heliospheric Magnetic Fields from Solar Magnetograph Data

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Abstract. The nature of the discovered difference between the histograms of distribution of the daily mean magnetic fields in the heliosphere near the Earth and on the source surface in the Sun is discussed. The magnetic field measured near the Earth is a bit smaller than the calculated one and has a two-peak distribution. We propose a new correction method, which takes into account the saturation of magnetographs and the contribution of high-latitude fields. The calculations carried out by this method display better agreement with observations; however a detailed distribution of fields inside the sector can not be described by a simple classical model.

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Introduction

In the 1950s, the German scientist L. Biermann got interested in the fact that no matter whether a comet is headed towards or away from the Sun, its tail always points away from the Sun. L. Biermann postulated that this happens because the Sun emits a steady stream of particles that pushes the comet's tail away [1, 2].

E. Parker realized that the heat flowing from the Sun in the Chapman's model and the comet tail blowed away from the Sun in Biermann's hypothesis had to be the result of the same phenomenon, which he termed the "solar wind". Parker showed that even though the Sun's corona is strongly attracted by solar gravity, it is such a good conductor of heat that it is still very hot at large distances. Since the gravity weakens as the distance from the Sun increases, the outer coronal atmosphere escapes supersonically into interstellar space. Furthermore, Parker was the first person to notice that the weakening of gravity has the same effect on hydrodynamic flow as a de'Laval nozzle: it incites the transition from subsonic to supersonic flow [3, 4].

In average, for a quiet out-flowing flux, the radial solar magnetic field in interplanetary space must decrease with distance as $\boldsymbol{r}^{-2}$. With the increase of the number and quality of observations, especially after many geophysical satellites had been launched, it became clear that the relationship between the solar magnetic fields and solar wind parameters is very complicated and depends strongly on time.

The next step in calculating the interplanetary magnetic field from the parameters of magnetic fields in the Sun was the concept of the so-called source surface [5-9]. Essentially, an attempt was made to pass to direct calculations based on real magnetographic observations of magnetic fields on the photosphere.

The results as a whole were very reassuring. The sign of the radial component of the interplanetary magnetic field near the Earth $\boldsymbol{B}x$ turned out to be, in general, in a good agreement with the sign of the source-surface magnetic field $\boldsymbol{B}ss$ (taking into account the transport time of 4 days). Some complication was associated with the observed field strength (intensity) in the solar wind near the Earth: the observed values appeared to be systematically lower than the calculated ones.

In this paper we have discussed the nature of the discovered difference between histograms of distribution of magnetic field daily-averaged values measured near the Earth and calculated magnetic field values based on the solar magnetograph data concerning the source surface at 2.5R, where R is the radius of the Sun. We proposed a new method of correction which took into account saturation of magnetographs and contribution of high latitude magnetic field.

Data and method of analysis

We have used synoptic data (Carrington Rotation synoptic maps) from the Wilcox Solar Observatory at the Stanford University. For each date, we calculated the field under potential approximation within the source-surface model. We have used source surface located high enough in the corona where the field lines are forced to be radial. The source surface was fixed at 2.5R.

The potential fields were calculated using 10 harmonics for daily maps.

We have used the OMNI data set for Interplanetary Magnetic Field (IMF) components retrieved from the National Space Science Data Center's (NSSDC) web server (http://nssdc.gsfc.nasa.gov/omniweb). The daily IMF components $\boldsymbol{B}_X$, $\boldsymbol{B}_Y$ (in GSE coordinate system) and Solar Wind (SW) velocity data $\boldsymbol{V}_{SW}$ were used to calculate $\boldsymbol{B}_L$ - the projection of IMF vector to the estimated spiral force line near the Earth (~1 AU)

$$\boldsymbol{B}_L = \boldsymbol{B}_X \cos(\psi)+\boldsymbol{B}_Y \sin(\psi), \qquad (1)$$

$$\psi = \mathrm{arctg}(\Omega R_E/\boldsymbol{V}_{SW}), \qquad (2)$$

where R_E is the mean distance of the Earth from the Sun and Ω is the angular rotation rate of the Sun.

Then, the magnetic field calculated at the source surface was recalculated for the distance of 1 AU. Taking into account that the field on the Sun is calculated in μT and the IMF, in nT and assuming the solar wind expansion law to be r^{-2}, one obtains the conversion (from source surface to 1 AU distance) factor equal to 0.135.

However, the value of $\boldsymbol{B}_X$, calculated in terms of the standard expansion law $\boldsymbol{r}^{-2}$ proved to be considerably smaller than the directly measured one [10]. Obridko et al. [11] made an attempt to explain this discrepancy by introducing the expansion law with an exponent a bit less than 2. However, the value 1.82 did not improve the situation significantly.

In order to improve the results, we used the correction coefficients $\boldsymbol{K}_U$ by Ulrich [12] (Eq.3) and $\boldsymbol{K}_S$ by Stenflo [13] (Eq.4), which allowed us to take into account the saturation of solar magnetographs:

$$\boldsymbol{K}_U = 2 + 2.5 \cos 2(\varphi) \qquad (3),$$

$$\boldsymbol{K}_S = 2.5 + 0.5 \cos 2(\varphi) \qquad (4),$$

where φ is the heliographic latitude.

The Ulrich's correction coefficients improve the agreement with the observed IMF values in the periods of solar activity minimum, while the use of the correction coefficient by Stenflo yields better concurrence with the observed values in the epochs of solar maximum (Fig.1).

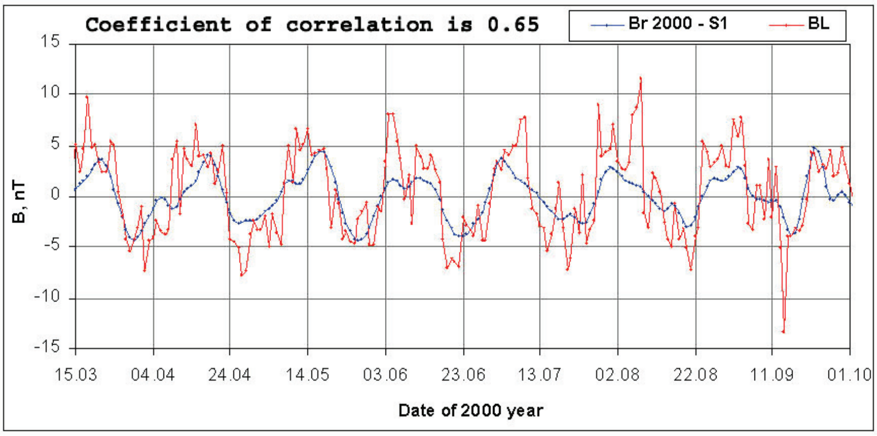

Fig.1. Comparison of calculated (B_r) and observed (B_L) IMF values in 2000. The transport time is 4 days. The correlation coefficient is 0.65.

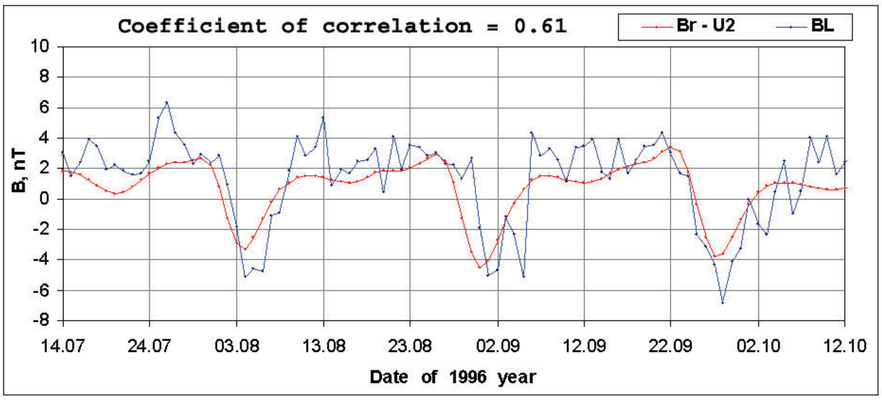

Fig.2. Comparison of calculated (B_r) and observed (B_L) IMF values in 1996. The transport time is 4 days. The correlation coefficient is 0.61.

However, it was revealed that the total range of changes of the magnetic field measured near the Earth at the solar activity minimum was, in any case, insufficient to display the measured fields.

The inclusion of high-latitude magnetic fields in the calculations did not help either. Thus, for the period of solar minimum, we used the Ulrich's correction (3) and expansion law of $r^{-1.82}$. The latter gives the conversion factor equal to 0.3.

The results of the calculation are shown in Fig.2. The transport time was taken to be 4 days. The use of the corrections mentioned above is substantiated elsewhere [11, 14, 15].

Results

We have studied the distribution of daily values of $\boldsymbol{B}_L$, observed at the distance of 1 AU [14, 15]. It was revealed that, after introducing the aforementioned corrections, the general range of the observed values agrees fairly well with the calculated ones. However, the $\boldsymbol{B}_L$ histograms show an evident two-peak distribution.

At the same time, the distribution of the calculated values of $\boldsymbol{B}_r$ shows a single peak (Figs. 5 and 6).

This discrepancy remains even if we use data with higher time resolution (up to hourly mean values) and it is impossible to avoid it by introducing any corrections and taking into account the contribution of higher-latitude solar fields. As seen from the Figs. 1 and 2, the graphics of time dependence of BL passes through the null point much faster than those of Br; namely this fact determines the discovered discrepancy. This suggests that the boundary current sheet is narrowed down as the flux propagates from the Sun to the Earth.

We intend to study this problem in detail in the future. For the time being, we can develop the following hypotheses concerning the nature of this phenomenon:

1. Solar wind propagates in space constricted between the boundaries of the sector structure. Non-zero transverse speed of particle expansion of the order of the Alfven speed must lead to the compression of the sheet. The boundary sheet must become comparatively thinner, the compression increasing with the distance from the Sun.

2. Instabilities must develop inside the current sheet leading to the degradation of the latter. In this case, the number of values strictly equal to zero must decrease. This could be conventionally called the "instability of zero-values". This kind of instability can be independent of distance.

3. In the course of propagation, the interrelation between the magnetic-field components BX and BY changes. Their maxima and minima do not coincide. In separate distributions of BX and BY, the effect of two peaks is weak (Fig.7). However, when we bring them together to obtain the histogram for BL, the two-peak shape becomes pronounced.

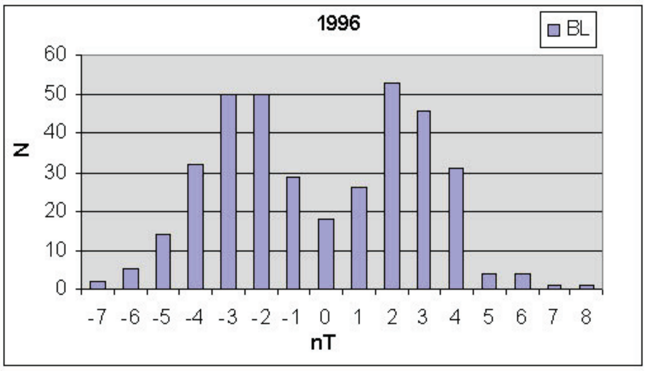

Fig.3. Histogram of distribution of observed daily values of $\boldsymbol{B}_L$ in 1996.

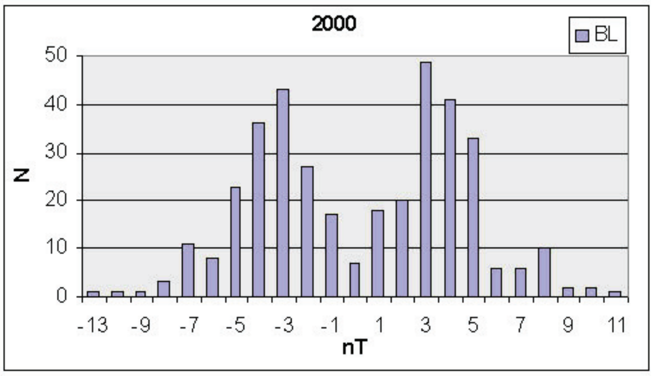

Fig.4. Histogram of distribution of observed daily values of $\boldsymbol{B}_L$ in 2000.

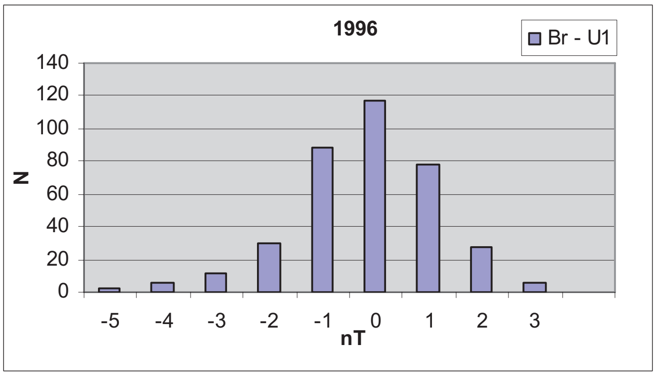

Fig.5. Histogram of distribution of calculated daily values of $\mathbf{B}_r$ for 1996.

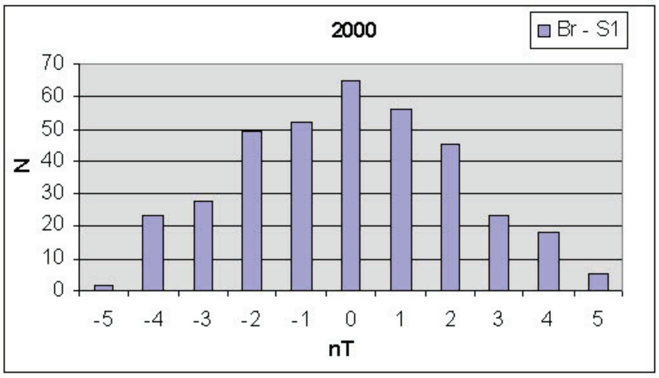

Fig.6. Histogram of distribution of calculated daily values of $\mathbf{B}_r$ for 2000.

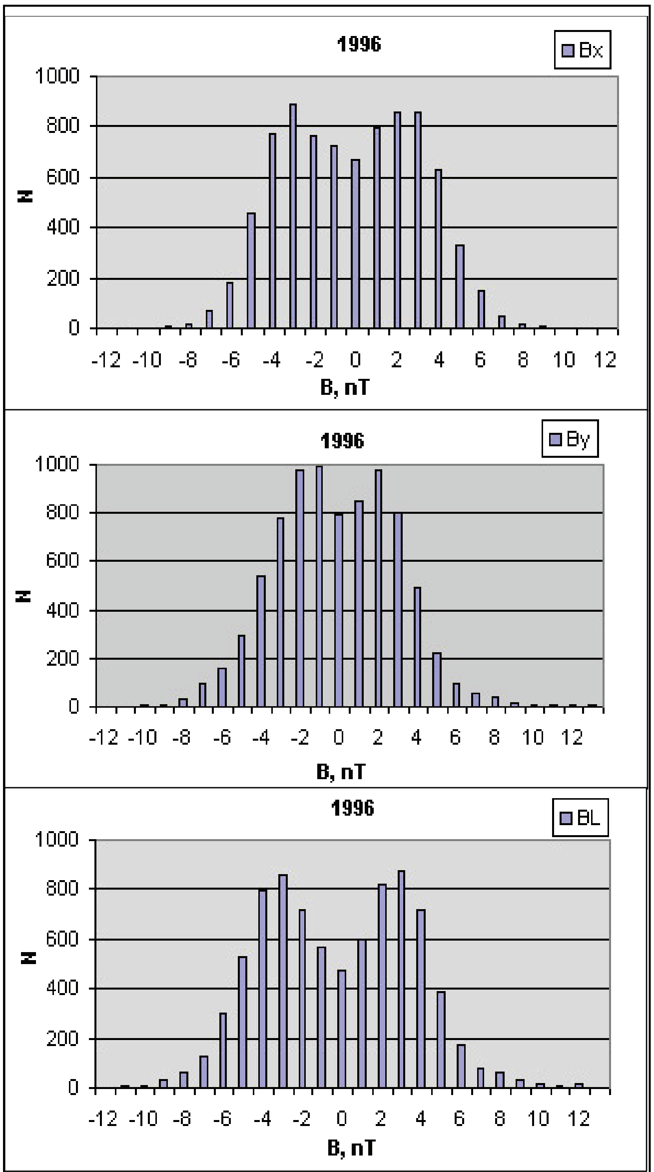

Fig.7. Histograms of distribution of the observed hourly values of the IMF components B_X, B_Y, and B_L in 1996.

Conclusions

Two-peak distribution of the solar wind magnetic field near the Earth was observed.

We have developed some hypotheses concerning the nature of the two-peak distributions. This means that the simple classical model does not describe in detail the distribution of fields inside the sectors.

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References

[1] Biermann L., “Kometschweife und solare korpuskularstrahlung”, Z. Astrophys., 1951, vol.29, p.274.
[2] Biermann L., “Solar corpuscular variation and the interplanetary gas”, Observatory, 1957, vol. 77, pp. 109-110.
[3] Parker E.N., “Dynamics of the interplanetary gas and magnetic fields”, 1958, Astrophys. J., vol.128, pp. 664–676.
[4] Parker E. N., “Extension of the solar corona into interplanetary space”, 1959, J. Geophys. Res., vol. 64, p.1675.
[5] Altschuler M.D., Newkirk G. Jr., “Magnetic fields and the structure of the solar corona”, Solar Phys., 1969, vol.9, pp. 131- 149.
[6] Shatten R. H., Wilcox J. M., Ness N.F., “A model of interplanetary and coronal magnetic fields”, Solar Phys., 1969, vol. 19, pp. 442-455.
[7] Hoeksema J. T., Scherrer P. H., “The solar magnetic field”, 1986, Rep. UAG-94, NOAA, Boulder, Colo.
[8] Wang Y. M., Sheeley N. R., “On potential field models of the solar corona”, Astrophys. J., 1992, vol. 392, pp. 310-319.
[9] Wang Y.M., Sheeley, N.R., “The long-term variation of the Sun’s open magnetic flux”, Geophys. Res. Lett., 2000, vol. 27, pp. 505-508.
[10] Obridko V. N., Kharshiladze A. F., Shelting B. D., “On calculating the solar wind parameters from the solar magnetic field data”, Astron. Astrophys. Trans., 1996, vol. 11, pp. 65-79.
[11] Obridko V. N., Shelting B. D., Kharshiladze A. F., “Multiparameter computations of solar wind characteristics in the near-earth space from the data on the solar magnetic field”, Solar System Research, 2004, vol. 38, No.3, pp. 228-237.
[12] Ulrich R.K., “Analysis of magnetic flux tubes on the solar surface from observations at Mt. Wilson of λ5250 and λ5233”, in: “Cool Stars, Stellar Systems and the Sun”: Seventh Cambridge Workshop (ISBN: 0-937707-45-7), 1992, vol. 26, p.265.
[13] Stenflo, J.O., “Magnetic field structure of the photospheric network”, Solar Phys., 1973, vol.32, pp. 41-63.
[14] Belov A.V., Obridko V.N., Shelting B.D., “Correlation between the near-earth solar wind parameters and the source surface magnetic field”, Geomagnetism and Aeronomy, 2006, vol. 46, No.4, pp. 430-437.
[15] Askerov A.B., Obridko V. N., “Magnetic field in the solar wind: a comparison with the classical model”, Geomagnetism and Aeronomy, 2007, vol. 47, No.3, pp. 285-290.