SECULAR AND CYCLE VARIATIONS OF THE IMF *BZ* COMPONENT AND SOME ASSOCIATED GEOPHYSICAL EFFECTS

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ABSTRACT

It is shown that the sign and amplitude of the annual mean *Bz* component of the interplanetary magnetic field (IMF) conforms with the structure of the large-scale solar magnetic field at the poles. Therefore, the recurrence of geomagnetic activity is best pronounced in the cycles when the polar field in the Sun is positive.

1. INTRODUCTION

The IMF *Bz* component the most effective parameter of the solar wind that is used to describe the geomagnetic activity [1]. Therefore, the origin of the southward component (*Bz<0*) of the IMF vector is of particular interest. While the fast variations in the sign and amplitude of *Bz* component are directly controlled by interplanetary processes along the solar wind trajectory, the long-term structure of the IMF vector is determined by a mechanism yet to be identified. Based on the geomagnetic activity index *aa* for more than a century, we drew some conclusions concerning the role of the large-scale solar magnetic field (LSMF) in forming a definite temporal pattern of geomagnetic activity characterized by the time series of the *àà(t)* index. Moreover, the observed increase in the annual mean *àà* values suggests a twofold enhancement of LSMF for the last century [2]. The relationship between geomagnetic activity and LSMF was pointed out earlier by various authors, including the first author of this paper [3-7].

If the behaviour of the *àà* index is determined to some extent by the IMF *Bz* component, then, as follows from the papers cited above, a relationship must exist between the sign and amplitude of the IMF *Bz* component and the time variations in LSMF. This suggestion is investigated in the present study.

2. MONTHLY AND ANNUAL MEAN *Bz* VALUES AND THEIR RELATION TO THE LARGE-SCALE SOLAR MAGNETIC FIELD

It is generally believed that B_z-component of the interplanetary magnetic field does not originate in the Sun, but is rather generated on the way from the Sun to the Earth. This opinion rests on the fact that the monthly and annual mean B_z values are very small. Besides, the conventional concept of the source surface field treats it as strictly radial. In the present work, we show that B_z values agree both in magnitude and in sign with the polar solar magnetic field and, thus, are determined by the global field of the Sun. A cycle of the global field lasts from one Wolf number maximum to another. It is shown that geophysical disturbances and, in particular, recurrent events, are much stronger in the cycles when the global solar field on the poles is positive. This result can be used for super-long-term prediction of geophysical activity.

The aa index displays a significant growth in the past 130 years, which correlates with the growth of the earth temperature. Many authors [3-8] show that geomagnetic activity is closely associated with global fields in the Sun. Since the *aa*-index strongly depends on the magnitude and, especially, on the sign of B_z-component, one may expect that B_z variations are also controlled, at least partly, by the global magnetic field.

Fig. 1 illustrates the annual mean values of *Bz* in the helioequatorial reference frame based on direct observations during 1965-1996. The same figure represents variations of the polar magnetic field at the north pole of the Sun (magenta color) as calculated from Mt-Wilson, Kitt-Peak, and WSO data. Calculations were made under potential approximation at 2.5 $R_{\odot}$. The sign of the calculated polar field was changed to the opposite, and the field value was decreased by a factor of 80. One can see a very good agreement in sign and even (somewhat unexpected) in magnitude.

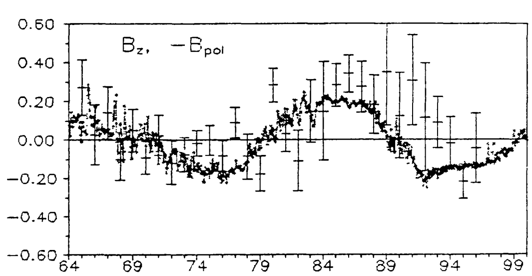

Fig. 1. Annual mean values of *Bz* in the helioequatorial reference frame based on direct observations during 1965-1996.

Proc. "SOLSPA: The Second Solar Cycle and Space Weather Euroconference", Vico Equense, Italy, 24-29 September 2001 (ESA SP-477, February 2002)

The figure represents also variations of the polar magnetic field at the north pole of the Sun (magenta color) as calculated from Mt-Wilson, Kitt-Peak, and WSO data. Note that both sets of data change the sign at the maximum of the solar local field cycle, i.e., at the reversal of the global polar field.

Thus, the long-lived large-scale magnetic field in the heliosphere is a direct extension of the high-latitude solar magnetic field, and its field lines converge to the plane of the heliographic equator. The field is rather weak and can not affect the geomagnetic conditions by itself. However, it can well account for a weak secular trend and, as a result, for an excess of the recurrent geomagnetic activity in one cycle compared to another.

The sign of B_z-component at the Earth's orbit is known to be a very important indicator of geomagnetic activity: at $B_z<0$ the geomagnetic disturbances are observed more frequently and are stronger. If all said above is correct, one can expect the *aa*-index to be greater in the periods between the field reversals, when the solar field at the north pole is positive and B_z at the Earth's orbit is negative. However, it only concerns the recurrent disturbances, since we are dealing here with the stationary large-scale field. Therefore, we have isolated the power of recurrent 27-day variations S_{27} from the *aa*-variation spectrum for 1968-2000 normalized to dispersion. Fig. 2 shows S_{27} separately for the periods of presumably negative and presumably positive B_z. One can see that S_{27} is higher when a negative B_z is expected at the Earth's orbit.

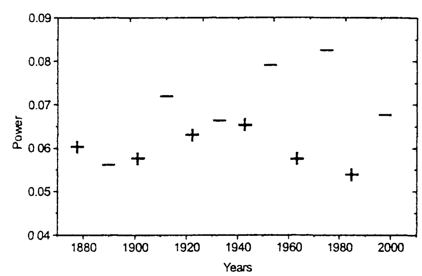

Fig. 2. Variation of recurrent geomagnetic disturbances in the normalized power spectrum separately for the periods of presumably negative (red bars) and positive (blue crosses) B_z. The sign of B_z was determined from the global magnetic field polarities.

3. RELATIONSHIP BETWEEN THE DAILY MEAN B_X AND B_Z AND THE FIELD LINE DIRECTION IN THE SOLAR WIND

A different pattern appears if we analyze short-term variations in B_x and B_z. It is well known that the direction of $\hat{A}_x$ is determined reliably enough by the large-scale solar field. This is a fundamental feature responsible for the occurrence of the heliospheric current sheet and so-called sector structure. It is shown (e.g., see [9]) that the sign and, to a great extent, the value of B_x depend on the sign and value of the radial component of the large-scale solar magnetic field B_r on a sphere of radius 2.5 R_o at its intersection with the Archimedean spiral passing through the Earth, i.e., with a time delay of 4.5 days. The value and sign of B_r are, in turn, controlled by the global solar field. In the epochs of solar minimum in spring, when the Earth is over the equatorial plane of the Sun, the sign of B_r (and hence, of B_x) coincides with the sign of the solar field at the south pole. In autumn, the situation is vice versa. The behavior of the daily mean B_z in helioequatorial coordinates is more complicated.

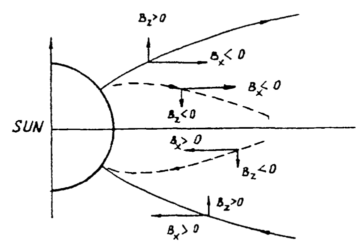

Fig .3 Correlation of B_x and B_z signs for the models with divergent and convergent field lines

In order to analyze the field structure in the solar wind, Kuklin and Obridko [10, 11] suggested a new method. They proposed to use the correlation of B_x and B_z signs to ascertain the field structure at the Earth's orbit. It is necessary to calculate the monthly mean value:

$$A=(N_+-N_-)/(N_++N_-),$$

where N_+ is the number of days when B_x and B_z have equal sign and N- is the number of days when they have opposite sign. The cases when one of the values was 0 were included in N_+ and N- with the weight ? and, thus, did not affect but denominator in the formula for A.

As seen from Fig. 3, the sign of $\acute{A}$ is determined by the near-Earth field structure alone and does not change during the field reversals. Taking into account the sign of B_x in helioequatorial coordinates, (X-axis is pointed toward the Sun from the Earth) one should expect, for diverging field, A positive in spring and negative in autumn. In the case of converging field, the signs must be vice versa.

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The quantity A was calculated for 1966-1998. It follows from Fig. 4 that the field lines of the large-scale solar field slightly diverge near the Earth.

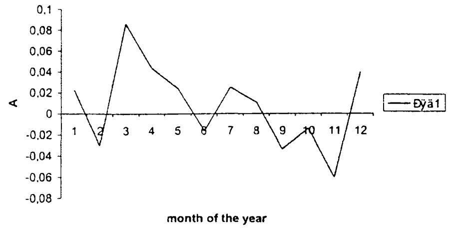

Fig. 4. Annual variation in A for 1966-1998.

Ponyavin and Usmanov [12] obtained a similar result using a smaller database.

4. DISCUSSION OF RESULTS

At first sight, the results obtained by direct comparison of the annual mean B_z with the polar magnetic field in the Sun contradict the results obtained by correlating the daily signs of B_x and B_z. The first method provides evidence for the field lines converging, while the second one displays a divergence, though rather weak and observed only in the vicinity of the equatorial plane.

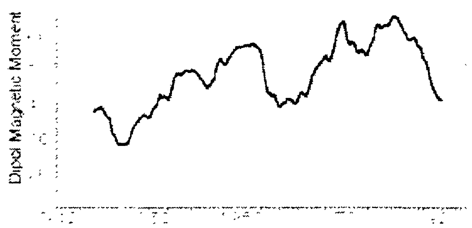

Fig. 5. Magnetic moment of the solar dipole smoothed over 10 years

As a matter of fact, however, it is a seeming contradiction. In the first case, we calculate the annual mean fields in the heliosphere and in the Sun and then compare them, thus revealing the slowly changing quasi-stationary field structure. In the second case, we compare the daily values and then average the correlation coefficients. In such a way, we can visualize the field lines in the solar wind, which are mainly radial (to be more exact, are directed along the Archimedean spiral). However, due to superradial expansion of the flux, the field lines somewhat depart from the equatorial plane. Thus, we obtain evidence that the heliospheric magnetic field actually consists of two field systems. To analyze and predict geomagnetic disturbances, we have to take into account the more intensive second system of diverging fields, while the first, quasi-stationary system is more important in analyzing the long-term trends.

Coming back to the Fig.2 we should note a systematic growth of S_{27} in the periods of negative B_z. This is, probably, the factor that determines the systematic trend in the *aa*-index revealed in [2]. It may be due to systematic increase in the magnetic moment of the solar dipole, smoothed over 10 years (see Fig. 5 borrowed from [13].

5. REFERENCES

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