Main features of the IMF sector structure during solar cycle 23

A. N. Zaitzev and V. I. Odintsov

IZMIRAN, Troitsk, Mocow region, 142190, Russia

Abstract. The sector structure of interplanetary magnetic field (SS IMF) have a strong effect on the geomagnetic field variations in the polar cap. It was discovered by L. Svalgaard and S. Mansurov and used to estimate the effects of solar wind in the near earth space. The regular definition of SS IMF was done based on the data from Resolute Bay and Vostok stations and is displayed in the table format at http://www.izmiran.rssi.ru/magnetism/SSIMF/index.htm. The regular definition of SS IMF based on the computer routine which include the adaptive filtering spectral analysis of geomagnetic variations. The main features of SS IMF are the reflections of variations in the regular heliospheric current sheet. The changes in the signs of SS IMF are most pronounced in the variations of Z-component on the geomagnetic observatories near 80 degrees of corrected geomagnetic latitudes. The changes of SS IMF also might be inferred from the geomagnetic data of the observatories in middle and low latitudes. As a sample we analyze the data of Moscow and Kakioka observatories for some chosen periods and shown a good coincidence with SS IMF in high latitudes. These results also confirm that the changes of the SS IMF signs have the global effects in the geomagnetic variations.

Index Terms. Geomagnetic variations, sector structure of interplanetary magnetic field (SS IMF), solar wind.

1. Introduction

The connection of the interplanetary magnetic field polarity with geomagnetic agitation in the polar caps is well known as Svalgaard-Mansurov effect. After its discovery and detailed studies become evident that main cause of such effect is the variations of B_y component of IMF which modulate the large-scale entry process of solar wind with magnetosphere. During such process we have the reconnection of IMF with magnetic field lines in the polar cusp region. Such process permit the solar wind plasma to enter in the outer magnetospheric regions. The topology of main solar magnetic field includes the two sectors (toward and away) separated by heliospheric current sheet. The data for the sector structure of IMF (SS IMF) are used for the correlation studies of how solar wind affects the magnetosphere-ionosphere processes as well as the basic (reaper) point in the prediction service. Although nowadays we have on the regular basis “in situ” the solar wind parameters and the solar surface magnetic field observations, the only one ground-based observations of terrestrial magnetic field variations might confirm what is happening in the real interaction process of solar wind with magnetosphere. Due to this, we need in the SS IMF according magnetic field variations in Vostok-Resolute Bay data. Such data are widely used in the scientific literature.

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2. Experimental results

In this paper we present the SS IMF on the Vostok-Resolute Bay data for 23-rd solar cycle. In addition to the direct observations of the solar wind parameters on WIND, ACE, INTERBALL satellites it appears a new possibility to search the detailed structures of SS IMF and how it is displayed in the geomagnetic and magnetosphere activity. The sector structure of IMF (SS IMF) is rather variable feature and can be described in a few patterns as: soft, regular pattern duration more than one day; sharp, shock-type pattern with duration less than one day and irregular pattern which is going on as prolonged period of unsettle sign of B_y-component. In addition to regular features of solar wind we observed as SS IMF, we pay attention to the magnetic clouds and interplanetary shocks in connection with magnetic storms which are overlapped with regular solar wind structure. According to our point of view in the table of SS IMF most of the period we have the clear manifestation of a regular pattern in the position of heliospheric current sheet. Some irregular features in our tables of SS IMF presented but they are not adequately compared/connected with solar wind data. On Fig.1 we present the table of sector structure of interplanetary magnetic field (SS IMF) for the period 1995-2005 as inferred from Vostok-Resolute Bay magnetic observatories data.

The main features in the SS IMF variations were as follows. In the period of 1995-1996 we have the minimum solar activity, so the table presents the two-stream, four-sector structure of IMF. Same results were obtained on the WIND measurements for the Bartels rotations 2204-2211 (Crooker et al., 1996). The beginning of 23rd solar cycle activity was counted from May 1996 (BR 2223) when we observe two sector structures which correspond to simple configuration in the solar wind with flat position of heliospheric current sheet

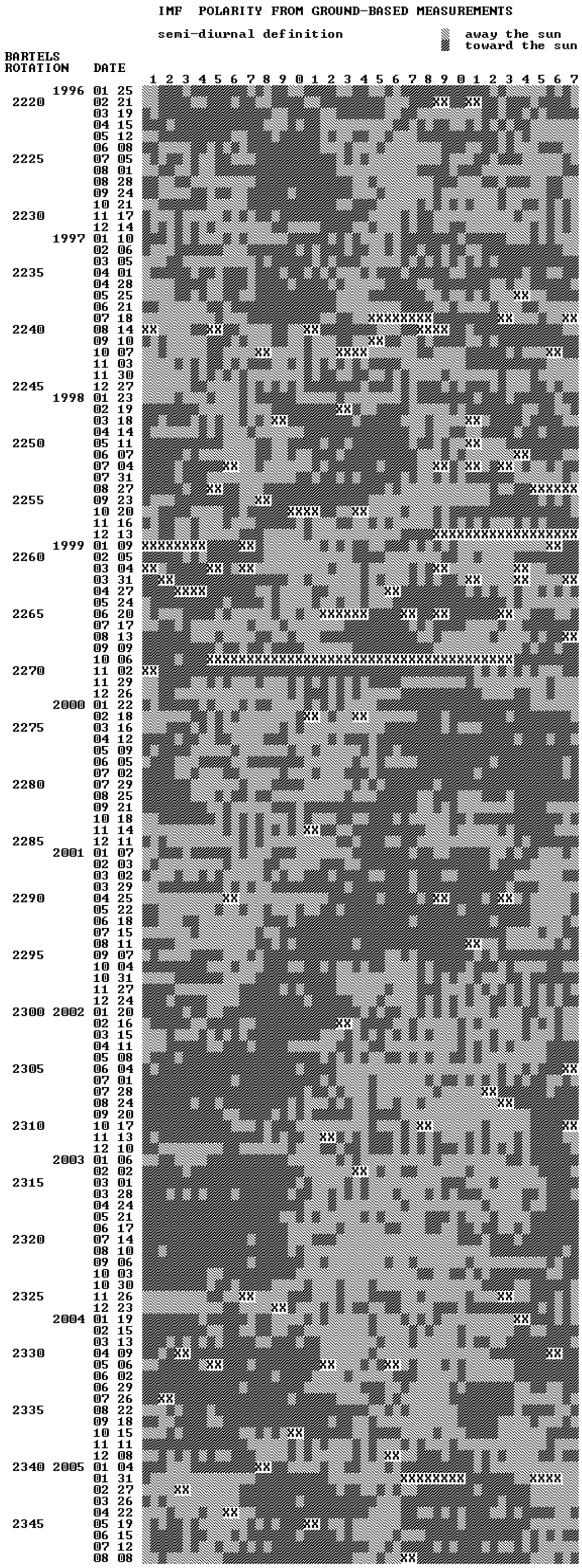

Fig. 1. The sector structure of IMF for the period 1995-2005.

(HCS). As solar activity was in progress we see the changes in the SS IMF lead to the four-sector pattern, which has happened already on growing phase in second part of 1997. We also observe the steady drift of general SS IMF pattern regarding the solar surface untill the change in the sign in main magnetic field of the Sun. Such change was observed at the BR 2283-2285, although optical observations of the Sun display the changes in the sign from June 2000. After this interval the HCS divide main solar field in the pattern where we have above HCS the sector toward the Sun, negative B_y, and bottom of HCS we have the sector away the Sun, positive B_y. For that period of time shown in Fig. 1, we have simple two-sector structure, which correspond to the position of HCL almost perpendicular to ecliptic plane, BR 2290-2293.

In view of the fact that SS IMF data presents the continuous monitoring of large scale solar wind dynamics, such information might be used for space weather services. But in view that the data from Vostok-Resolute bay is not so easily available for service in real time, so we decide to search the SS IMF effect in the data of the magnetic observatories located in middle latitudes. The confirmation of such a guess we find from simple comparison of middle latitudes magnetograms with SS IMF tables as we get for 1995. To make sure that our definitions are based on analytical method, we used the procedure which we developed for correlative studies between magnetic field components in the problem of magnetotelluric monitoring of geodynamic processes (Svetov et al., 1997). The main feature was in the use of adaptive filtering of data and transfer function.

In Fig. 2 we present the data of Moscow magnetic observatory (upper part) and results of adaptive filtering in the combination of the components H - Z and D - Z. The difference in the transfer function modes is presented at bottom line. The SS IMF for BR 2205 was taken from Crooker et al. (1996). The time changes of transfer functions between pairs of components Z-H (Whz) and Z-D (Wdz) are presented on 4 and 5 lines, and line 6 present the mean-square deviation in original Z-component and its synthetic values (RMS). The SS IMF presented on the same line is according to ground-based definition and WIND satellite (Crooker et al., 1996). Simple comparison confirm the good correspondence between changes observed in magnetic field variations in Moscow magnetic observatory inferred by the cross-correlation after adaptive filtering and SS IMF values. In Fig. 3, we present the SS IMF data for interval of BR 2205-2210. The upper part is the standard data according to the Resolute Bay, the lower part is the SS IMF which we get from the Moscow magnetic observatory. The general features of both the graphs are very close to each other. The differences might be in the range of accuracy of calculations.

3. Discussion

As we stated above the tables of SS IMF according to ground-based data display the results of real interaction of the solar

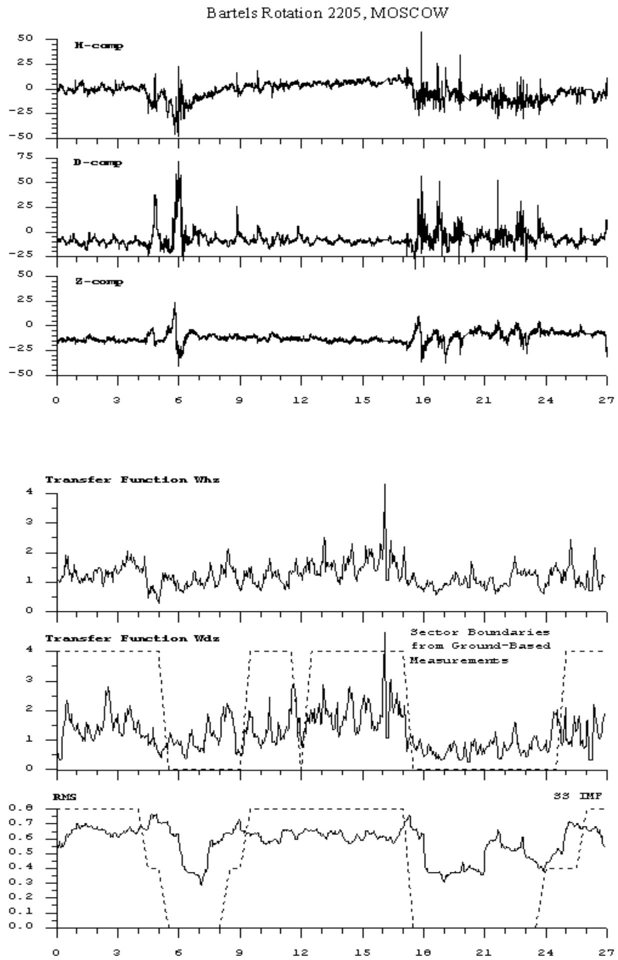

Fig. 2. The top – Moscow original geomagnetic data, bottom – the processed data (Svetov et al., 1997), which display the sector structure of IMF (dotted line).

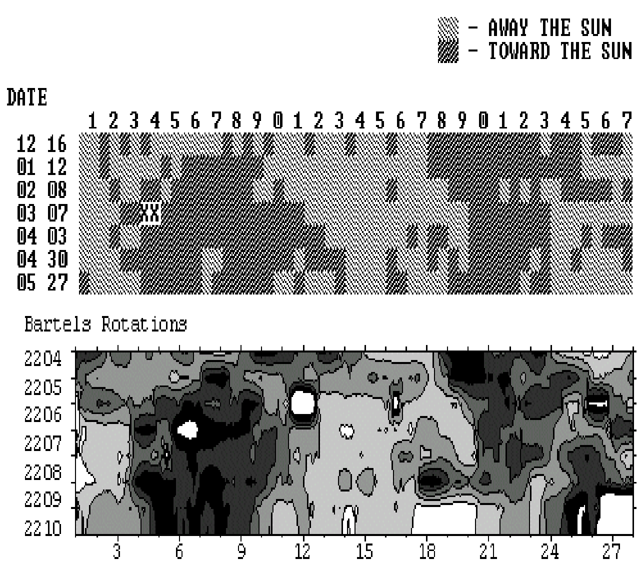

Fig. 3. The sector structure of IMF for Bartels rotations 2204 – 2210 as inferred from Resolute Bay magnetic observatory (top) and Moscow magnetic observatory (bottom).

wind with the magnetosphere. On the other hand we have tremendous progress in outer space observations when we have the continuous parameters of solar wind at ACE satellite including sector structure of IMF. In addition, the solar observatories WSO (Wilcox (Stanford) Solar Observatory), NSO (Kitt Peak Solar Observatory) and MWO (Mount Wilson Solar Observatory) provide the solar magnetic field data which is used to calculate the "source surface" field in the form of space maps. Such maps clearly demonstrate what we might expect in the vicinity of Earth. The analysis of such complex data will lead to the good prediction of solar wind speed, IMF polarity and Kp-index (Arge and Pizzo, 2000).

The role of SS IMF as the “reference point” for the magnetospheric studies was confirmed many times. The detailed research of polar cusp dynamics lead to conclusion that interplanetary magnetic field azimuthal component (B_y component in SS IMF) is found to be the critical value in the polar cusp configuration (Candidi et al., 1989). Every sector structure crossing lead to the forcing of substorm activity which is usually observed during the passage of an interplanetary magnetic cloud (Farruga et al., 1993). SS IMF regular structure displayed also has the seasonal effects in the location of auroral substorm onset (Liou et al., 2001) and in the global auroral pattern (Shue et al., 2001). These samples clearly confirm the scientific value of SS IMF as the “reference point” which lead to the usage of SS IMF for space weather services. Arge and Pizzo (2000) also discussed the improvements in the prediction of solar wind conditions using near-real time solar magnetic field updates i.e. SS IMF.

The further improvements in the definition of the SS IMF tables, we connect with our new method to see the forcing due to sector structure in the middle latitudes as we demonstrate for the Moscow observatory. For the same interval we search the Kakioka magnetic observatory and we obtain the same results. Main clue lies in the comparative studies of satellite and ground-based observations. Accordingly from ACE data it is possible to infer the regular (large-scale) structure of IMF (as it is already done in Japan, see http://www2.nict.go.jp/dk/c231/ace/27day) and compare it with the table already inferred from ground-based data, and to estimate the long-range changes in solar wind dynamics. Next is the search of fine structure of sector boundary (heliospheric current sheet) as it is displayed on the high-latitude magnetogrammes, first of all on the Nostok-Resolute Bay on the data according to special MACCS network (Magnetometer Array for Cusp and Cleft Studies with data available from Augsburg College via Internet). Such studies can help us to understand some changes in the fine structure of SS IMF.

In view of this, we need to look further improvements in the definitions of SS IMF, which might be based on the next data sources: observations of magnetic field of Sun, solar wind data from L1, and continues data from magnetic observatories in polar caps. The differences in the data sets arise first of all due to differences in the accuracy of observational methods. The calculations of heliospheric magnetic field distribution strongly depend on the fidelity of data. Now we have 3 observatories, WSO, NSO, and MWO which provide continues data. The accuracy of calculations for the SS IMF can exceed plus/minus one day, see http://solar.sec.noaa.gov.

4. Conclusions

1. The definition of SS IMF based on the Vostok-Resolute Bay stations served as the primary source of information how solar wind interacts with the magnetosphere.
2. The data set of SS IMF for 1995-2005 display dynamical features of 23 solar cycle, confirm the main peculiarities which were observed in previous solar cycles. The reverse of polarity for main magnetic field of the Sun was observed in SS IMF with a small delay relative to optical observations and corresponds to the maximum of solar activity.
3. The influence of SS IMF on general state of Earth's magnetic activity can be found in the data of all magnetic observatories, including middle and low latitudes. This fact can be used to detect SS IMF accordingly in magnetic observatories in middle and low latitudes.

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