Planetary and Space Science 63–64 (2012) 158–163

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

# Interplanetary magnetic field and solar rotation

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ARTICLE INFO

*Article history:*
Received 7 March 2011
Received in revised form
1 June 2011
Accepted 18 June 2011
Available online 6 July 2011

*Keywords:*
Interplanetary magnetic field
Solar rotation
Autocorrelation
Solar magnetic field
Interplanetary medium

ABSTRACT

This article presents analysis of interplanetary magnetic field (IMF) B measured at the $L_1$ point outside the geo-magnetosphere. The autocorrelation of daily values of the $B_x$ and $B_y$ component of the IMF reveal clear solar rotational modulation. The $B_z$ ($z$-component of IMF) mostly do not show any such modulation. The sidereal solar rotation period are estimated from the IMF data of ACE satellite during 1998–2009. These estimates vary from 24.1 to 25.8 days with a mean value ~25 days. These annual values are compared with the estimates by the similar method using solar disk integrated radio flux at 2.8 GHz and solar images. The images used are (1) Radio images at 17 GHz and (2) X-ray images by Yohkoh satellite. The comparison reveals evidence that the IMF seems to mostly originate from the low latitude regions in the solar atmosphere rather than from higher latitudes. The results contradict the existing solar magnetic field model.

## 1. Introduction

The observations of ion tails of comets revealed that there is a continuous flow of magnetized solar plasma moving radially away from the Sun. Parker (1958) showed that the hydrodynamic expansion of the coronal plasma would result in continuous flow in the form of solar wind. The large electrical conductivity would mean that some of the solar magnetic field lines will be frozen into the streaming plasma and stretch out radially away from the Sun. He further showed that the combination of radial solar wind velocity and the solar rotation will cause the IMF lines to be stretched out into Archimedes spirals. Thus IMF is the magnetic field that originates from the Sun and is convected out into space by the solar wind. The solar wind is composed of ionized particles that move away from the Sun at supersonic speed. As the magnetic field lines are entangled in the solar wind, they are convected outwards with it. We know from observations that, depending on the hemisphere and phase of the solar cycle, the magnetic field spirals inward or outward; the magnetic field follows the same shape of spiral in the Northern and Southern parts of the heliosphere, but with opposite field direction. The form of this magnetic field is easy to derive if we make some preliminary assumptions (Parker, 1958). The assumptions are (1) steady-state and (2) the solar gravitation and the acceleration of the solar wind flux can be neglected beyond some distance. Thus we can approximate the outward radial velocity as uniform. The tangential component of the velocity is given by the Sun's rotation. In ideal magneto-hydrodynamics, we assume that the plasma is a perfect conductor, that is, the interaction between the charged particles can be neglected relative to the much stronger interaction with the magnetic field. This implies that the magnetic field lines move with the plasma, in other words, they are "frozen" into the plasma, and thus the magnetic field streamlines are always parallel to the velocity streamlines. The 3D view of IMF is shown in Fig. 1.

Near the orbit of the Earth the average angle between IMF and Earth–Sun direction is about $45^0$. Ahluwalia and Dessler (1962) argued that in the photosphere there are regions of varying sizes in which solar magnetic field is predominantly directed either out of the Sun or into the Sun. They gave useful analogy of the phonograph for the understanding of this phenomenon. This was later proved by observations (Wilcox et al., 1967). Spacecraft observations of the average direction of the interplanetary magnetic field near the Earth during the sunspot maximum year 1968 showed a deviation from the spiral field of Parker's classical description (Svalgaard and Wilcox, 1974). The ultimate source of the IMF is the solar dynamo, which generates a magnetic field on the Sun that typically has opposite polarities in the Northern and the Southern hemispheres. Thus IMF has a "toward" polarity in one half of the heliosphere and "away" polarity in the other, with a three-dimensional Archimedean spiral orientation beyond the radius where the flow becomes super-Alfvenic. The spiral pattern and hence the azimuthal field components, are explained by Parker's original theory based on uniform radial flow of the solar wind plasma from the rotating Sun, combined with a uniform radial field at some "source surface" in the corona. Complications of this picture contribute to the variability of the IMF resulting from non-coincident magnetic and heliographic coordinates

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0032-0633/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.pss.2011.06.008

(Svalgaard and Wilcox, 1978). Severny et al. (1970) compared the mean field of the Sun as a star with the IMF measured near the Earth orbit. They showed that each change in polarity of the mean solar field is followed by about 4.5 days later by a change in polarity of the IMF. Rosenberg (1970) proposed a unified theory of the interplanetary magnetic field to explain its heliographic dependence. Russell et al. (1980) compared ISEE-1 and ISEE-3 observations of IMF and emphasized the need of such measurements for the better understanding of the interplanetary medium and possible prediction of geomagnetic activity.

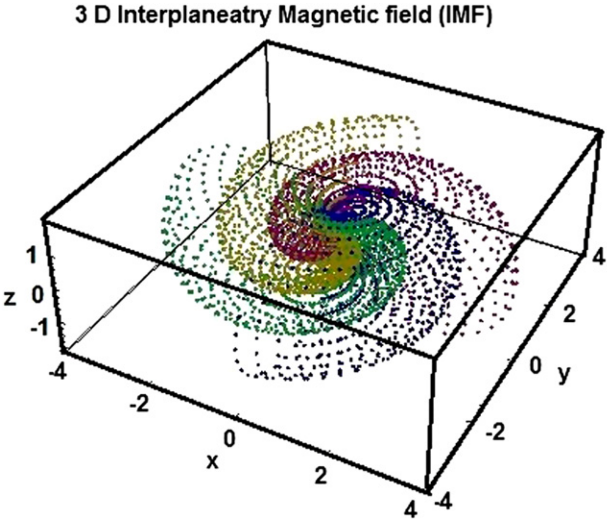

**Fig. 1.** Three-dimensional view of Interplanetary Magnetic Field (IMF).

Detailed study of solar magnetic features is an important area of research not only for its intrinsic interest, but also because solar magnetic fields have a profound and far-reaching influence on the Earth's near-space environment. With society's increased dependence on Space-based technology, much of which is at risk due to solar activity that waxes and wanes with the sunspot cycle, it is imperative that we understand the solar magnetic cycle and its effects on the near-space environment. The evolution of the large-scale solar magnetic field is attributed to a solar magneto hydrodynamic dynamo operating inside the Sun, which involves three basic processes. The generation of toroidal fields by shearing pre-existing poloidal fields, the regeneration of poloidal fields by twisting toroidal flux tubes (the $\alpha$ effect) and finally, flux transport by meridional circulation to carry background magnetic fields pole wards from the Equator are considered (Parker, 1955a, 1955b; Steenbeck and Krause, 1969; Wang et al., 1991; Choudhuri et al., 1995; Dikpati and Charbonneau, 1999). With the measurement of the Sun's polar field (Babcock and Babcock, 1955) and the subsequent proposal of polar-field reversal during the maximum of each solar cycle (Babcock, 1959), research on solar magnetic fields and their effect on subsequent cycles was channeled in a new direction. Since then, many investigations have been carried out to explore the relation between evolution of large-scale magnetic fields and their association with polar-field structures (Fox et al.,

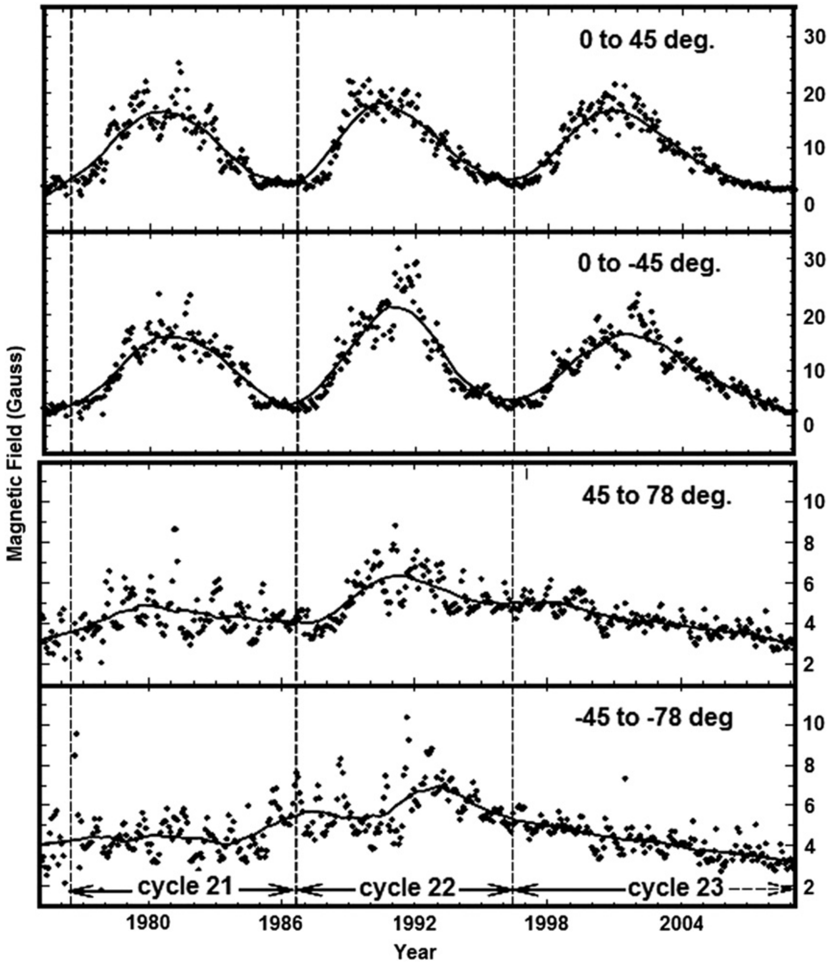

**Fig. 2.** Temporal variation of average magnetic field in four regions of the Sun (Janardhan et al., 2010).