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Some properties of latitude-time evolution of local and background solar magnetic fields

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Abstract

A comparative analysis of evolution of latitude distributions of solar magnetic fields of various scales is presented.

Using the local photospheric magnetic fields (LMF) represented by the magnetic fields of sunspots for cycles 12–23 it is found that the width of the sunspot generating zone is closely related to the magnitude of the total magnetic flux of sunspots. It is demonstrated that latitude-time distributions of the LMF and absolute strengths of the background magnetic field (BMF) in the latitude range $\pm 40^\circ$ are very similar and the time variations of power indices of the BMF and LMF are highly correlated. It is found that power characteristics of the BMF and LMF in cycles 21–23 are in close relation to the size of the low-latitude zone of solar activity.

It is shown that the speed of the polar drift of the BMF of a given polarity tends to increase in epochs of solar cycle maximums.

The obtained regularities can be used as diagnostic criteria for determination of adequate physical models of solar cyclicity.

Keywords: Sunspots; Solar magnetic field; Butterfly diagram; Solar cycle

1. Introduction

Study of latitude-time cyclic evolution of the solar magnetic fields is of essential importance for understanding of nature of the 11-year and longer cycles of solar activity. At present we know many regularities of that evolution for the local photospheric magnetic fields (LMF), which in the range of heliolatitudes $\pm 40^\circ$ are represented by magnetic fields of sunspots (Vitinskij et al., 1986; Hathaway et al., 2003; Li et al., 2003; Miletsky and Ivanov, 2009; Hathaway, 2010; Nagovitsyn et al., 2010; Sokoloff and Khlystova, 2010; Ivanov and Miletsky, 2011; Ivanov et al., 2011; Mordvinov et al., 2012).

One of well-known laws driving the latitude-time evolution of sunspots in the 11-year cycle is the Spörer law, which states that the mean latitude of the sunspot generating zone (SGZ) migrates towards the solar equator. This regularity is usually illustrated by a map of latitude-time distribution of sunspots called "the butterfly diagram".

Search for relations between a character of the latitude distribution of sunspots and the level of sunspot activity on the Sun is important for understanding of mechanisms of the 11-year cycle of solar activity.

In our previous papers (Miletsky and Ivanov, 2009; Ivanov and Miletsky, 2011) we found that the latitude extension of the SGZ and the current level of solar activity are closely related. It was also shown (Ivanov et al., 2011) that the yearly distribution of sunspot groups can be described, in a first approximation, by the normal law with dispersion that linearly depends on the level of activity. In accordance with the obtained relation both the characteristic width of the SGZ and the maximal latitude density of sunspots grow more slowly than the level of activity.

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Another type of photospheric magnetic field is the background field (BMF) which is much weaker. It is interesting to make a comparison of the latitude-time evolution of the LMF and BMF within the SGZ. Available data make it possible for the three recent 11-year solar activity cycles (Nos. 21–23). The latitude-time distribution of the BMF absolute strength in cycles 21–23 is very similar to the butterfly diagram of sunspots; besides, a fine structure can be found in it (Song, 2007; Andryeyeva and Stepanian, 2008; Minarovjech, 1975). A detailed study of the fine structure of the LNF and BMF latitude-time evolution in cycle 23 is made by Zharkov et al. (2007). In that paper, in particular, a strong positive correlation between the areas of sunspots and the solar magnetic fields is found. It is concluded that such correlation suggests a modulating effect of the symmetric component of the magnetic field on the magnitude of magnetic field in flux tubes emerging as sunspots repeating at the 2–2.5 year time lags after or before the cycle start. Similar correlations of the LMF and BMF is discussed by Mordvinov et al. (2012), where a conclusion is made that the large-scale magnetic field of the Sun is a primary physical factor that determines its local magnetic fields.

A link between these two types of solar magnetic fields is both confirmed by observations and seems obvious from general considerations. However, details of this relationship are still unclear. Various models of generation of the solar magnetic field assume different schemes of such link: the large-scale photospheric magnetic fields can be treated either as a product of diffusion of the sunspot fields (Wilson and Giovannis, 1994; Choudhuri and Dikpati, 1999; Parker, 2009; Baumann et al., 2004), or, on the contrary, as a manifestation of large-scale magnetic fields rooted deeply in the convection zone, which cause sunspots to emerge (Zharkov et al., 2007; Mordvinov et al., 2012).

Therefore, study of relations between solar magnetic fields of different scales is an important task, and we analyse these relations in this work.

2. Description of data

We use as a source of data on sunspot groups Greenwich catalogue and its USAF/NOAA extension[1] for years 1874–2006. Data on the BMF are extracted from Kitt-Peak observations of the photospheric magnetic field,[2] which has the form of synoptic maps for the Carrington rotations Nos. 1625–2007 (years 1975–2003). Latitude distributions of the magnetic fields are obtained by averaging of the magnetic field strength (either absolute or with sign) over longitudes.

A latitude distribution of solar activity events in a given hemisphere for a given time range can be approximately described by the following parameters: (1) the mean latitude of the events ϕ_0; (2) the characteristic width of the distribution represented by one of the following parameters: (a) the (doubled) standard deviation $\Delta = 2\sigma$, (b) the width of the zone DB (ρ), where the density of events is higher than a given level ρ, (c) the difference D between the highest and lowest latitudes of events. These parameters are described in details in our previous papers (Miletsky and Ivanov, 2009; Ivanov and Miletsky, 2011).

3. Results and discussion

3.1. The latitude size of the sunspot generating zone and the magnetic flux of sunspots

Previously (Miletsky and Ivanov, 2009; Ivanov and Miletsky, 2011) we described solar activity by the sunspot indices W (the sunspot number) and G (the sunspot group number). In the present paper we also use for this purpose the magnetic flux of sunspots (MFX).

It was shown by Nagovitsyn (2005) that the total magnetic flux of sunspots can be expressed via the index of their total area S by the relation

$$\mathrm{MFX}\ [\mathrm{Mx}] = 2.49 \cdot 10^{19} \cdot \mathrm{S}\ [\mathrm{msh}]. \tag{1}$$

Using this relation and 133 yearly averages of the corresponding parameters we obtain a regression equation (see Fig. 1)

$$\mathrm{MFX(D)} = 0.205 + 0.350 \cdot \mathrm{D}, \tag{2}$$

relating the width D of the SGZ and the total magnetic flux with the correlation coefficient R = 0.958 and the confidence level much higher than three standard deviations.

Correlation coefficients between various parameters of the width (D, σ, σ^2, DB, DB^2) and indices G and MFX are listed in Table 1. One can see that the width of the SGZ is closely related both to the level of solar activity (Miletsky and Ivanov, 2009; Ivanov and Miletsky, 2011) and to the total magnetic flux of sunspots. Note that in

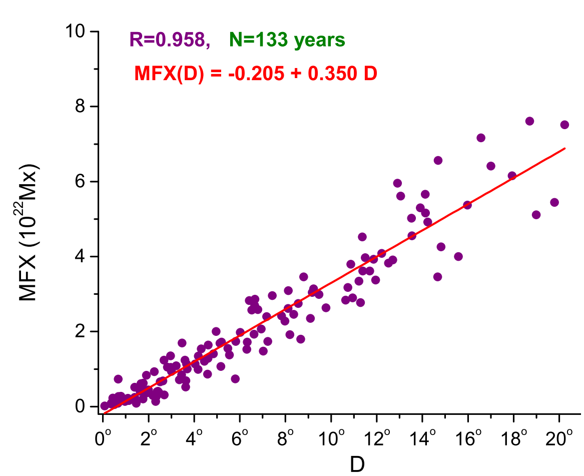

Fig. 1. The relationship between the width of the SGZ (D) and the yearly averages of the sunspot magnetic flux (MFX).

[1] http://solarscience.msfc.nasa.gov/greenwch.shtml.
[2] ftp://nsokp.nso.edu/kpvt/synoptic/mag.