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Solar magnetic cycle and longitudinal distribution of solar activity

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Abstract. The problem of the preferred solar longitudes is studied on the base of various manifestations of solar activity: sunspot data for 1917-1995; solar proton event sources (1976-2003) and X-ray flare sources (1976-2003). Solar activity distributions behave differently during the ascending phase and maximum (AM) of the solar cycle on one hand and during the declining phase and minimum (DM) on the other depicting maxima around roughly opposite Carrington longitudes (180° and 0°). Longitudinal distribution of the photospheric magnetic field studied on the base of Wilcox Solar Observatory data also displays the above structure during two characteristic periods. The observed change of active longitudes may be connected with the polarity changes of Sun's magnetic field in the course of 22-year magnetic cycle.

Key words. Solar activity – Sun: preferred longitudes – Sun: 22-year cycle

1. Introduction

The problem of active longitudes has been investigated by various techniques and for various indices of solar activity (e.g., Bumba et al. 1996; Benevolenskaya et al. 1999). The lifetime of the observed active longitudes varies from several years to several solar cycles. Though some authors have found active zones separated by 180° (e.g., Bai 1987), the tendency of the active longitudes towards antipodal arrangement remains to be one of disputable points.

In this work the emphasis is put on the longterm asymmetry of solar activity persisting for several solar cycles. Connection of the asymmetry with development of Sun's magnetic fields during 22-year cycle is considered.

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2. Solar activity distribution

For our study we have used following data (Fig. 1): sunspots, 1917-1954 (Greenwich Royal Observatory) and 1955-1995 (Pulkovo observatory); X-ray flares of M&X classes, 1976-2003 and sources of solar proton events with flux of protons (E_p >10 MeV) - F >10 particles cm^{-2} sr^{-1} s^{-1}, 1976-2003 (ftp : $//ftp.ngdc.noaa.gov/STP/SOLAR\_DATA/$). Distribution of these events relative to Carrington longitude was studied. To evaluate quantitatively the longitudinal asymmetry of the sunspot distribution the vector summing of the data was used (Vernova et al. 2002). Each sunspot group is presented as a polar

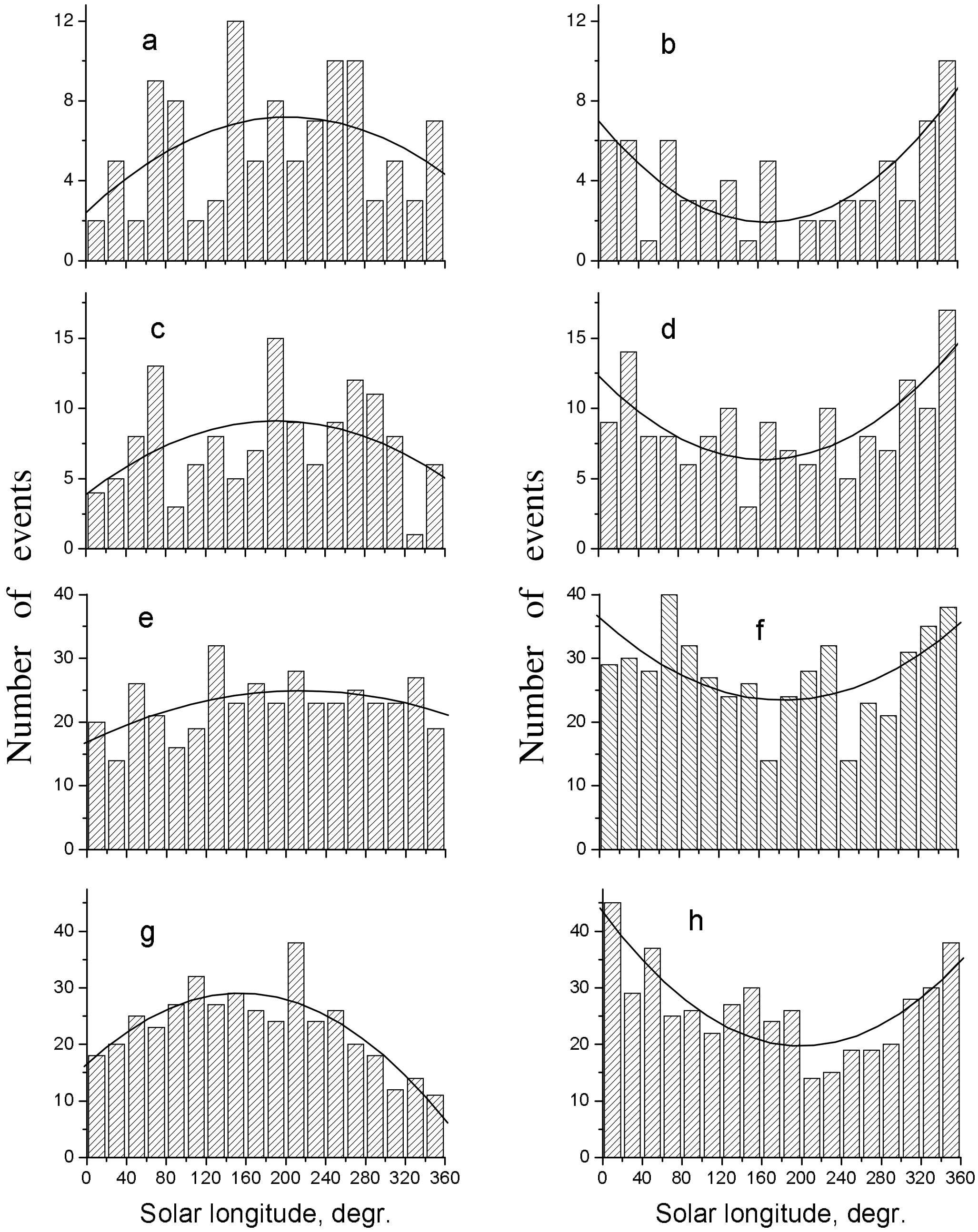

Fig. 1. Heliolongitudinal distribution of various manifestations of solar activity. (a, b) Sources of the solar proton events. (c, d) X-ray flares of M&X classes. (e, f) Sunspots of the North hemisphere. (g, h) Sunspots of the South hemisphere. Data sets were divided in two groups according to different periods of the solar cycle: increase and maximum of the solar activity - left panels (a, c, e, g); decrease and minimum of the solar cycle - right panels (b, d, f, h). Two types of enveloping curves are characteristic of the distributions for two periods - convex for the increase and maximum period, concave for the decrease and minimum one.

vector in the heliographic plane whose length equals the sunspot area and whose phase corresponds to the Carrington longitude of the group. A vector sum is calculated using all sunspot groups observed during each day of the Bartels rotation under consideration. Whereas the modulus of the vector can be considered as a measure of longitudinal asymmetry, the direction of the vector determines the Carrington longitude dominating during the given rotation. Calculating the vector sum of sunspots strongly reduces the stochastic, roughly symmetric sunspot activity and emphasizes therefore the more systematic and ordered part of the longitudinally asymmetric sunspot activity. In the same way the longitudinal asymmetry of X-ray flare distribution was calculated using intensity of the flare instead of sunspot area.

Long-term changes of the longitudinal asymmetry were studied by plotting heliolongitudinal distributions (Fig. 1) for different manifestations of solar activity (sources of solar proton events, X-ray flares of M&X classes, sunspots). Data sets were divided in two groups according to AM and DM periods of the solar cycle (Vernova et al. 2004). Two opposite types of the distribution were found for all manifestations of solar activity: while the histograms for AM period (Fig.1 a, c, e, g) are convex (maximum close to 180° of Carrington longitude), they are concave (Fig.1 b, d, f, h) for the DM period (maximum close to 0/360° longitude).

3. Solar magnetic cycle

Longitudinal distribution of the photospheric magnetic field was studied on the base of Wilcox Solar Observatory data for 1976-2004 (http://quake.stanford.edu/wso/wso.html).

Being interested primarily in the longitudinal distribution of magnetic field we have averaged values of $|B|$ over latitude interval (-70°, +70°). Resulting diagram for Carrington rotation No 1936 is presented in Fig. 2.

Peaks exceeding mean level of $|B|$ by more then 1.5 standard deviations were selected for further analysis. Carrington longitudes of these peaks were used for plotting distribution of so-

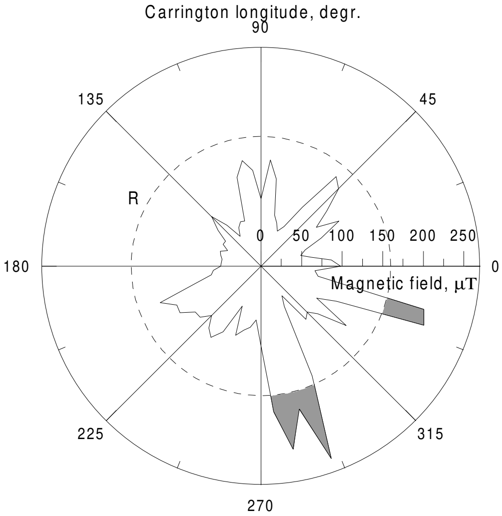

Fig. 2. Polar diagram: module of the solar magnetic field $|B|$ for Carrington rotation No 1936. Two peaks (shadowed regions) can be seen above the level $R = \overline{(|B|)} + 1.5\sigma(|B|)$ (dashed line).

lar magnetic field during AM and DM periods of the solar cycle (Fig. 3). As well as for the solar activity two opposite types of the distribution - convex (a), and concave (b) can be seen for two parts of the 11-year cycle.

The times separating two characteristic periods are important intervals in the solar cycle. The time between solar maximum and the beginning of the declining phase coincides with the inversion of Sun's global magnetic field. On the other hand, the time between the solar minimum and the ascending phase is related to the start of the new solar cycle and the change of the magnetic polarity of sunspots according to Hale's law. Accordingly, we have found that the 22-year solar cycle can be divided into four intervals (depicted in the Table 1) which have definite characteristics in longitudinal asymmetry.

The common property of those intervals (periods I and III) where the longitudinal maximum is at 180° is that the polarity of the global magnetic field and the polarity of the leading sunspot are the same (within one hemisphere). On the other hand, these polarities are opposite during those intervals (periods II and IV) where the maximum is close to 0°.

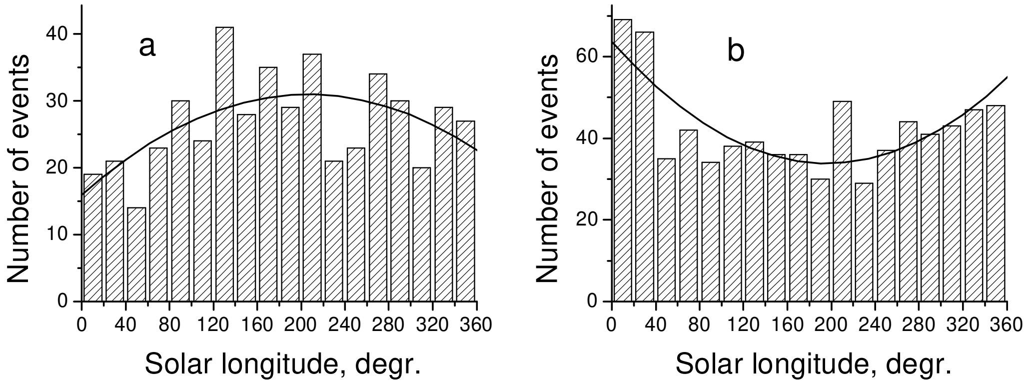

Fig. 3. Heliolongitudinal distribution of the photospheric magnetic field in 1976-2004 at different periods of the solar cycle. (a) Increase and maximum of the solar activity; (b) Decrease and minimum. Two opposite types of the distribution - convex (a), and concave (b) can be seen for two parts of the 11-year cycle.

Table 1. Solar magnetic field polarities: North hemisphere

Period	Global magnetic field	Leading sunspot polarity	Active longitude
AM of even cycle	−	−	180°
DM of even cycle	+	−	0°
AM of odd cycle	+	+	180°
DM of odd cycle	−	+	0°

4. Conclusions

Various manifestations of the solar activity considered here (sunspot areas, X-ray flares, solar proton event sources) as well as photospheric magnetic field show long-term asymmetry with similar features of the heliolongitudinal distribution. For two parts of the 11-year solar cycle all parameters under consideration display opposite types of the longitudinal distribution: convex for the AM period, concave for the DM period. While in the AM period of the solar cycle the maximum of the distribution is situated at around 180°, in the DM period the maximum is close to 0/360°. Two characteristic periods belong to different epochs of the Sun's magnetic cycle. AM period corresponds to the epoch of coincidence of the global magnetic field polarity with the polarities of the leading sunspots (for each of the hemispheres). DM period corresponds to epoch with opposite signs of the global magnetic field and of the leading sunspots. The observed coincidence of the photospheric magnetic field longitudinal distribution with the features of various manifestations of the solar activity supports the idea of two opposite types of distribution being connected with the polarity change of local and global magnetic field of the Sun.

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