Strong and weak photospheric magnetic fields: time developement and longitudinal distribution

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Changes of the photospheric magnetic field are studied using synoptic maps for 1976 - 2003 (NSO Kitt Peak). Strong and weak magnetic fields are considered separately as well as magnetic fields of different polarity. For the equatorial magnetic fields, fluxes of the strong (|B| >10 mT) and the weak (|B| < 0.4 mT) magnetic fields develop in antiphase during the solar cycle. While the strong magnetic fields follow the 11-year solar cycle, the flux of the weak field reaches maximal values during solar minimum.

The following difference between the longitudinal distributions for the ascending and the descending phases of the 11-year solar cycle was found for the fields with |B|>10 mT: the maximum of the distribution is situated around 180° and 0°/360°, respectively. For the weak magnetic fields we observe opposite longitudinal distributions for the ascending and the descending phases of solar cycle too. In contrast to the strong fields, the weak fields are localized at 0°/360° for the ascending phase and 180° for the descending one, i.e. in antiphase to the strong magnetic fields. According to the phase of solar cycle, dominating longitude changes by 180° twice during a cycle.

Though fluxes of magnetic field with positive and negative polarities are closely correlated, difference between these fluxes shows systematic changes connected to the phase of the solar cycle: drastic changes accompany the transition from the ascent-maximum period to the decrease-minimum period of the solar cycle.

Introduction

It was shown in our previous work that various manifestations of the solar activity (sunspots, [1], sources of solar proton events, X-flare sources [2]) show two different types of the longitudinal distribution during the two periods of the 11-year solar cycle, namely for the ascent and the maximum (AM) and for the decrease and the minimum (DM).

The same behavior was observed for the longitudinal distribution of the photospheric magnetic field [3]: for the AM phase the active longitude is close to 180°, for the DM phase the active longitude is around 0°/360°.

Unifying the ascent phase with the solar maximum and the decrease phase with the minimum we make the difference between two periods during which a certain relation of the global and the local magnetic field polarities is preserved. Dividing points between these intervals are either the the change of the leading sunspot polarity at the cycle minimum or the change of the global magnetic field sign near the maximum. The magnetic cycle of the Sun consists of four such intervals during which the polarities of the global and the local magnetic fields are constant.

Data and method

In the present work we study the time development and longitudinal asymmetry of the photospheric magnetic field using synoptic maps produced by the National Solar Observatory Kitt Peak for 1976-2003 (http://nsokp.nso.edu/kpvt/). The spatial resolution is 1° in longitude (360 steps) and 180 equal steps in the sine of the latitude from -1 (the South pole) to +1 (the North pole).

Thus every map consists of 360 x 180 pixels of magnetic flux values. The main part of the photosphere is covered by weak fields: pixels with the modulus of the magnetic field |B|<0.4 mT constitute 53 % of their whole number, whereas the fraction of the pixels with |B|>10 mT is only 1,3 %.

From here on only equatorial magnetic fields will be considered, i.e. heliolatitudes from -40° to +40°.

Longitudinal asymmetry of the photospheric magnetic field distribution was evaluated by means of the vector summing technique [3,4]. Latitude averaged values of B_i for each 1° interval of longitude (from 1° to 360°) were considered as vector module, corresponding Carrington longitude being the phase angle of the vector $\mathbf{B}_i$. Then resulting vector sum **B** was calculated for every Carrington rotation.

Whereas the modulus of **B** can be considered as a measure of longitudinal asymmetry, the direction of the vector points to the Carrington longitude dominating during the given Carrington rotation.

By means of the technique described above dominating Carrington longitude was evaluated for each solar rotation. Longitudinal distribution of the photospheric magnetic field during 1976-2003 was studied on the base of the time series obtained in this way.

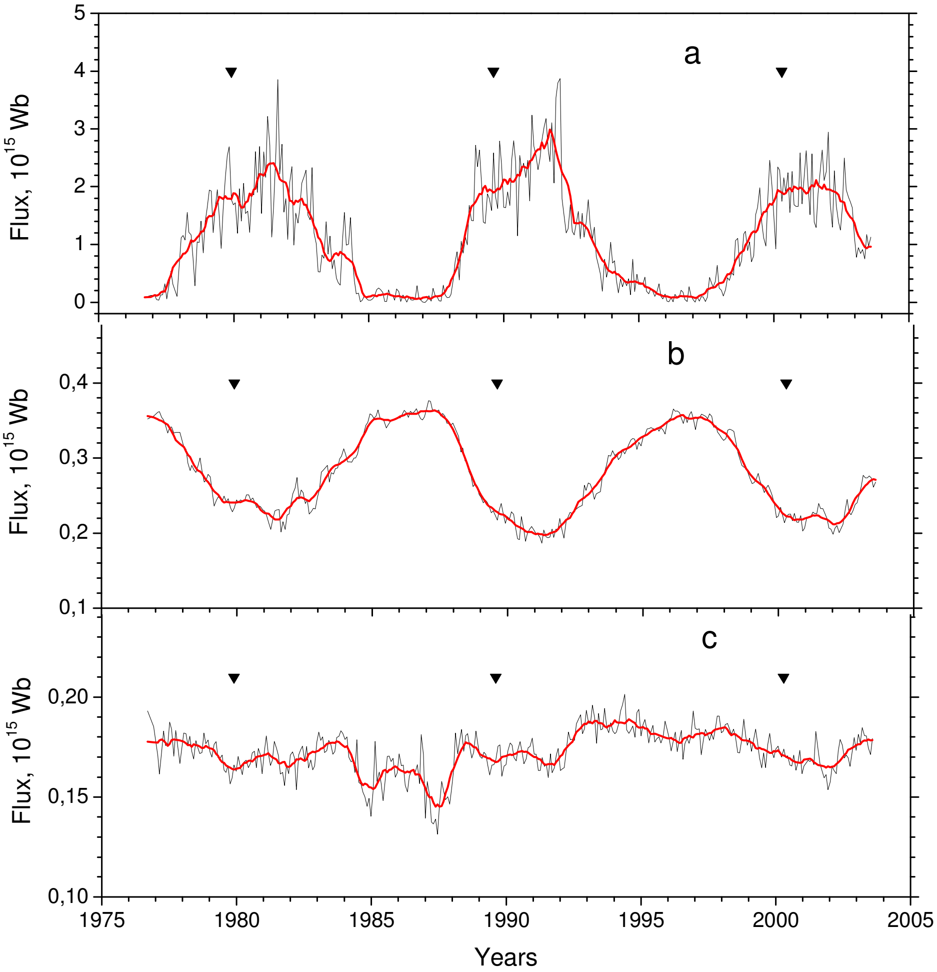

Fig.1. Photospheric magnetic flux for heliolatitudes from -40° to +40°: a) strong magnetic fields |B| > 10 mT; b) weak magnetic fileds |B| < 0.4 mT; c) intermediate magnetic field values 0.6 mT > |B| >0.4 mT. Triangles mark solar cycle maxima. Thick lines – smoothing over 10 adjacent solar rotations.

Results and discussion

In Fig. 1 photospheric magnetic flux for heliolatitudes from -40° to +40° is presented: a) strong magnetic fields |B| > 10 mT; b) weak magnetic fileds |B| < 0.4 mT; c) intermediate magnetic field values 0.6 mT > |B| >0.4 mT. Triangles mark solar cycle maxima. Thick lines represent smoothing over 10 adjacent solar rotations.

Magnetic flux of the strong photospheric fields (|B | > 10 mT, Fig. 1a) follows in the main the 11-year solar cycle, yet the flux maxima are situated near to the 2nd Gnevyshev maxima (1981, 1991, and 2001). The changes of the weak photospheric fields (|B | < 0.4 mT, Fig. 1b) are in antiphase with the changes of the strong ones: flux minima coincide with the flux maxima of strong magnetic fields. Intermediate magnetic fields (6> |B|> 0.4 mT) display no cyclic behavior (Fig. 1c). Contrast in the behavior of the strong and the weak magnetic fields manifests itself in the longitudinal distributions also. Longitudinal distribution of the photospheric magnetic field (1976 – 2003) for heliolatitudes from -40° to +40° is displayed in Fig.2: panels (a) and (b) – strong magnetic fields with |B |>10 mT; panels (c) and (d) – weak magnetic fields |B| <0.5 mT. Solar cycle periods ascent-maximum (a,c) and decrease-minimum (b, d) are considered separately. Solid lines show the second order polynomial fit. The following difference between the magnetic field longitudinal distributions for the ascent-maximum and the decrease-minimum phases of the 11-year solar cycle can be seen for the strong magnetic fields: the maximum of the distribution is situated around 180° (AM phase, Fig. 2a) and 0°/360° (DM phase, Fig. 2b). The asymmetry of the distribution is most clearly seen for the fields with |B|>10 mT, though the same phenomenon is observed also for weaker fields up to 1.5-2.0 mT.

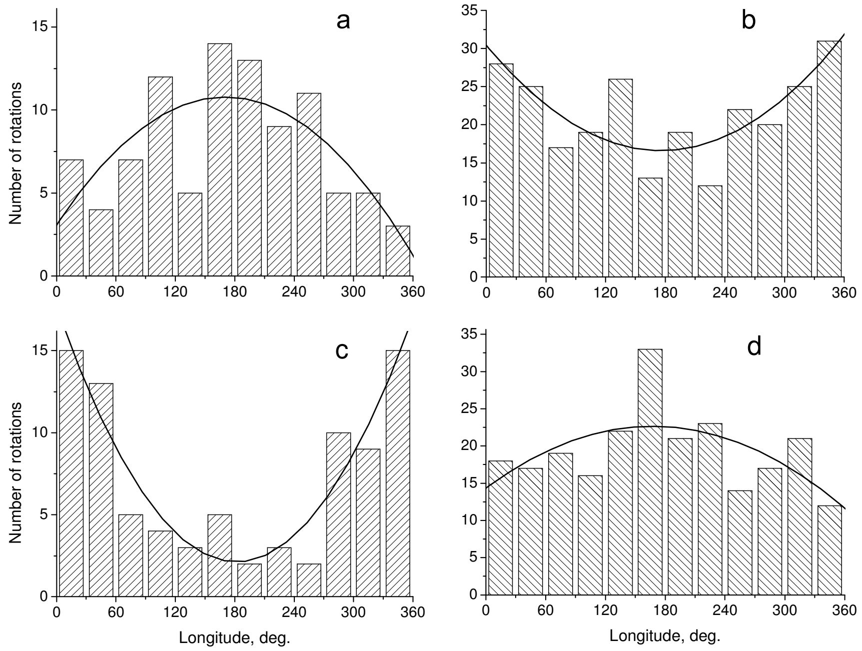

Fig.2. Longitudinal distribution of the photospheric magnetic field (1976 – 2003) for latitudes from -40° to +40°: a) and b) – strong magnetic fields $|B|>10$ *mT; c) and d) weak magnetic fields* $|B|<0.5$ *mT. Solar cycle periods ascent-maximum (a ,c) and decrease-minimum (b, d) are considered separately. Solid lines –* 2^{nd} *order polynomial fit.*

For the weak magnetic fields we observe opposite longitudinal distributions for the ascending and the descending phases of solar cycle too. In contrast to the strong fields, the weak fields are localized at 0°/360° for the AM phase (Fig. 2c) and 180° for the DM phase (Fig. 2d), i.e. in antiphase to the strong magnetic fields.

Two characteristic periods (ascent-maximum, decrease-minimum) correspond to different situations occurring in the 22-year magnetic cycle of the Sun, in the course of which global magnetic field polarity and polarity of the leading sunspot change twice. During the ascending phase and the maximum polarities of the global magnetic field and those of the leading sunspots coincide, whereas for the declining phase and the minimum the polarities are opposite.

The connection of two characteristic periods with changes of the global magnetic field polarity and those of the leading sunspot polarities is unlikely to be a coincidence. It was shown by [5] that relation between the polarity of Sun's global magnetic field with the sign of following sunspots is of principal importance.

Using soft X-ray data from the Yohkoh soft X-ray telescope for the period of 1991–2001 they discovered giant magnetic loops connecting the magnetic flux of the following parts of the active regions with the magnetic flux of the polar regions that have the opposite polarity. These large-scale magnetic connections appear mostly during the rising phase of the solar cycle and its maximum.

These connections did not appear or were very weak during the declining phase of the solar cycle. Thus two characteristic periods AM and DM correspond to radically different patterns of the large-scale magnetic field of the Sun.

Fluxes of the strong magnetic fileds $|B| > 10$mT with different polarities are shown in Fig. 3 for heliolatitudes from -40° to +40°: (a) positive (upper panel) and negative (lower panel) magnetic fluxes; (b) smoothed difference between positive and negative fluxes Δ. For comparison with the solar activity development Wolf numbers Rz are presented. The time-dependence for strong equatorial fields (heliolatitudes from -40° to +40°) demonstrate the different behavior for the magnetic fields of the opposite polarities. Roughly the time-dependencies of the positive and negative fluxes show only a close correlation with each other and the global relation with the solar cycle (Fig. 3 a).

However, the difference of these two fluxes exhibit systematic changes corresponding to the certain phases of the solar cycle (Fig. 3 b). It can be seen that the sign of the difference changes near the period of the global magnetic field inversion. The difference is close to zero for small values of the Wolf numbers. For the greater Wolf numbers the correlation between the sign of the difference and the sign of the polar field is observed.

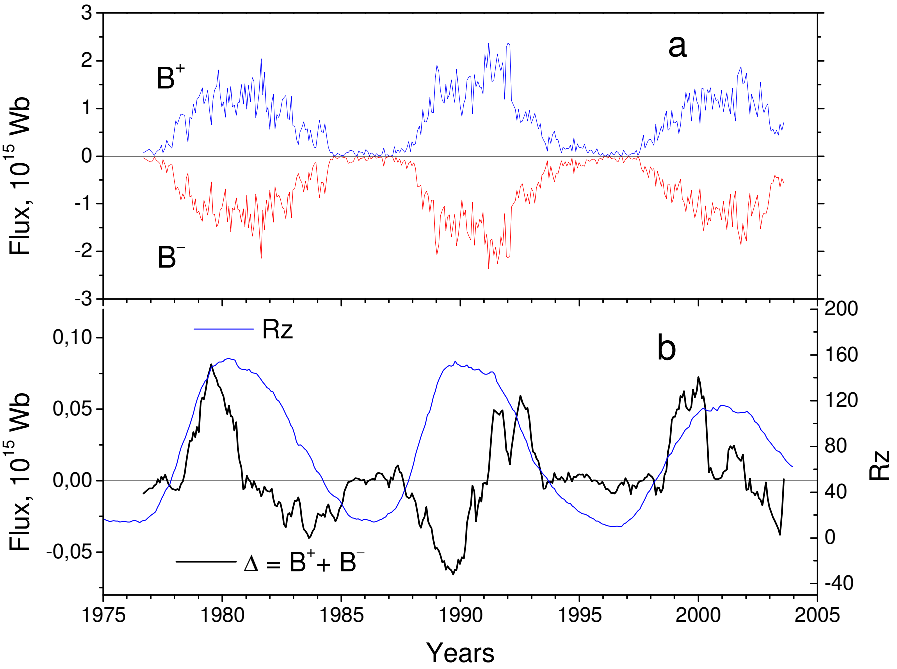

Fig.3. Fluxes of the strong magnetic fileds |B| > 10mT for heliolatitudes from -40° to +40°: a) positive (upper panel) and negative (lower panel) magnetic fluxes; b) smoothed difference between positive and negative fluxes Δ along with the Wolf number Rz.

For the years whith the negative polarity of the Northern hemisphere the difference is negative also. When the Northern hemisphere changes its polarity to the positive one, the difference becomes positive also. As was the case for the magnetic field longitudinal distribution, the difference of the positive and negative fluxes depends on the quarter of the magnetic cycle. Indeed, for odd cycles the difference is positive during AM phase, whereas during the DM the difference is negative. For the 22nd cycle we observe an inverse picture: the difference is positive for the phase decline-minimum and negative for the phase ascend-maximum. Thus, for the period 1976 – 1996 the sign of the difference was constant in each quarter of the 22-year magnetic cycle.

Conclusions

Following peculiarities in the change of photospheric magnetic field of the Sun were observed. The below conclusions refer to the equatorial fields only (Latitudes ±40°).

Antiphase development was observed for strong and weak magnetic fields. Intermediate magnetic fields (0.6 mT> |B|> 0.4 mT) display no cyclic behavior.

Dominating longitudes are opposite for strong and weak magnetic fields. According to the phase of solar cycle dominating longitude changes by 180° twice during a cycle. Fluxes of magnetic field with positive and negative polarities are closely correlated, yet difference between these fluxes shows systematic changes in accordance with the phase of the solar cycle. Thus, both the longitudinal distribution and the time-dependence of the photospheric magnetic fields have certain peculiarities related to the development of the solar cycle. The regular appearance of these features suggest that they are not random but form a part of the magnetic cycle of the Sun.

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