Latitudinal Distribution of the Photospheric Magnetic Fields of Different Magnitudes

E.S. Vernova\textsuperscript{1} · M.I. Tyasto\textsuperscript{1} · D.G. Baranov\textsuperscript{2}

\textsuperscript{1}IZMIRAN, SPb. Filial, St. Petersburg, Russian Federation
e-mail: helena@ev13934.spb.edu
\textsuperscript{2}A.F. Ioffe Physical-Technical Institute, St. Petersburg, Russian Federation
e-mail: d.baranov@mail.ioffe.ru

Abstract Photospheric magnetic fields are studied using synoptic maps for 1976–2003 (NSO, Kitt Peak). Synoptic maps were averaged over the period of nearly 3 solar cycles (Solar Cycles 21–23). The change of latitudinal distribution was considered for the following groups of magnetic fields: $B = 0 - 5$ G; $B = 5 - 15$ G; $B = 15 - 50$ G and $B > 50$ G. Magnetic fields in each of the groups have common features of latitudinal distribution, while for different field groups these features change significantly. Each of the groups is closely related to a certain manifestation of the solar activity.

Strong magnetic fields are connected with two manifestations of activity on the Sun: active regions (magnetic fields $B > 15$ G) occupy sunspots zones and polar faculae (magnetic fields $50$ G $> B > 15$ G) occupy latitudes around $65^\circ$–$75^\circ$. Fields from 5 to 15 G occupy the polar regions and are connected with polar coronal holes (solar global dipole). Fields with $B < 5$ G occupy: a) equatorial region; b) latitudes $40^\circ$–$60^\circ$ connected with the solar global dipole.

Keywords: Solar cycle; Magnetic field, Photosphere; Latitudinal Distribution, Sunspot Zone, Polar Faculae

1. Introduction

Magnetic fields of different magnitudes correspond to different manifestations of the activity of the Sun. Sunspots, polar faculae, etc. have different time and space distributions.

Latitudinal distribution of different manifestations of solar activity was extensively studied, see Hathaway [2010] and reference therein. The main feature of the change of the sunspot latitudinal distribution is Spörer’s law which defines the correspondence between the phase of the cycle and the mean latitude of sunspots. Another manifestation of the solar activity at high latitudes are the polar faculae (see, e.g., Sheeley [2008]). It was noted that the polar faculae precede the sunspot activity by approximately 6 years.
Figure 1. Method: summing synoptic maps of the magnetic field.

(Makarov and Makarova, 1996). The fine structure of latitudinal distribution was considered in Ivanov et al. (2011) and Miletsky and Nagovitsyn (2012).

A novel feature of the present work is that we study latitudinal distribution of the photospheric magnetic fields obtained by averaging of the data over the years 1976–2003. Thus, we do not consider time-dependency of the latitudinal distribution and study only those characteristics which persist even after averaging over three solar cycles.

2. Data and Method

For this study we used synoptic maps of the photospheric magnetic field produced at the National Solar Observatory/Kitt Peak (available at nsokp.nso.edu). These data cover the period from 1975 to 2003 (Carrington Rotations 1625–2006). Because the data have many gaps during the initial period of observations, we included in our analysis the data starting from Carrington Rotation 1646. Synoptic maps have the following spatial resolution: 1° in longitude (360 steps); 180 equal steps in the sine of the latitude from −1 (south pole) to +1 (north pole). Thus every map consists of 360 × 180 pixels of magnetic-flux values.

Strong magnetic fields of both polarities occupy a relatively small part of the Sun’s surface. The magnetic-field strength for the period 1976–2003 shows a nearly symmetric distribution with 60.3% of values in the 0 – 5 G interval, whereas pixels with magnetic strength above 50 G occupy only 3.3% of the solar surface. Magnetic field values 5 – 15 G and 15 – 50 G occupy 26.9% and 9.5% respectively.

We used the summation of synoptic maps over the period of nearly 3 solar cycles (Cycles 21–23) to obtain one averaged synoptic map for the whole period under consideration. In Figure 2 the scheme of the summation is presented. Averaging the summary map over the longitude, we obtain the latitudinal profile of the magnetic flux for the period from 1976 to 2003. Our main goal is to compare the summary synoptic maps and the latitudinal profiles for different groups of magnetic fields.

To give an idea of the character of the data we use and of the order of the magnitude of magnetic fluxes we show in Figure 2 the change of the magnetic flux for years 1976–2003 evaluated for each synoptic map and then averaged by running means over 20 rotations. Photospheric magnetic flux changes in phase with the solar activity. The maximum of the flux coincides with the second
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Figure 2. Photospheric magnetic flux during Solar Cycles 21–23.

Figure 3. Latitudinal profile of magnetic field averaged over Solar Cycles 21–23.

Gnevyshev maximum: the years of the maximum of the flux are 1981.4; 1991.6; 2002.2.

Averaged latitudinal profile of the magnetic field (Figure 3) shows two domains of increase of the magnetic flux: at the latitudes of the sunspot zone and at the latitudes of the polar faculae zone. The flux in the sunspot zone exceeds considerably the flux in the polar faculae zone.

It should be mentioned that at each latitudes there exist some minimal (background) flux (approximately $1.3 \times 10^{21}$ G). The maximum at the sunspot zone exceeds 5 times the background flux. One can note that the total flux averaged over three cycles for the South hemisphere exceeds the flux in the North hemisphere.
3. Results and Discussion

In the study of the latitudinal distributions of magnetic fields of different magnitudes we discovered that there are four characteristic groups of fields. These are the fields with the strength in the intervals $0 - 5$ G, $5 - 15$ G, $15 - 50$ G, and $B > 50$ G. Magnetic fields in each of the groups have common features of latitudinal distribution, while for different field groups these features change significantly. Each of the groups is closely related to a certain manifestation of the solar activity.

To study the latitudinal distributions of these groups we obtained summary magnetic field maps for each of the above field intervals separately. Before the summation, each synoptic map is transformed in such a way that only the pixels in the interval under consideration are taken into account. Namely, the value of $B$ for each pixel was replaced by 1 or 0 according to whether $B$ falls into the $B_{\text{min}} - B_{\text{max}}$ interval or not respectively. Thus, we obtain the summary map for the three solar cycles for the given interval of magnetic fields strengths. This map shows the proportion of time when the fields of the given group were present on the Sun’s surface.

In Figure 4.a the summary map for the group of the strongest magnetic fields over 50 G is shown. It is seen that such fields occupy the sunspot zone and, obviously, are connected with the active regions on the Sun. On the right, the scale is given, which shows the percentage of time when the fields from this group were observed. The maximum of the scale is about 15%. Averaging the summary map over the longitude, we obtain the latitudinal profile of the magnetic flux (Figure 4.b). (The magnitude of the magnetic flux was normed by the number of rotations included into the map.) The latitudinal profile for this group of fields shows that strong magnetic fields are observed at the sunspot zones only.

In Figure 5 the next group of magnitudes from 15 to 50 G is considered. It is seen on the summary map that in each hemisphere there are two dominating regions corresponding to the sunspot zone and the polar faculae zone. The sunspot zone occupies a wider strip of latitudes and exists up to 25% of time. The polar faculae zone occupies a narrow strip, however it is clearly seen. This zone is even more pronounced in the latitudinal profile (Figure 5.b), where it
**Figure 5.** Latitudinal distribution of magnetic fields 15 — 50 G. a. Summary map for 3 solar cycles. Colorbar – percentage of time when the fields with strength $B = 15 – 50$ G were observed. b. Latitudinal profile of the magnetic flux. Dominating regions: sunspot zone and the zone of polar faculae.

**Figure 6.** Latitudinal distribution of magnetic fields 5 — 15 G. a. Summary map for 3 solar cycles. Colorbar – percentage of time when the fields with strength $B = 5 – 15$ G were observed. b. Latitudinal profile of the magnetic flux. The strength and localization of these fields point to their connection with the polar coronal holes.

is seen that the maxima of faculae concentration appear around latitudes $+70^\circ$ and $-70^\circ$.

The group of fields of smaller magnitude from 5 to 15 G appears in the summary map (Figure 5a) at the highest latitudes only and exists up to 55% of time. Latitudinal profile of the magnetic flux (Figure 6b) shows sharp increase of the flux from latitudes around $60^\circ$ towards the poles. The strength and localization of these fields point to their connection with the polar coronal holes.

The weakest magnetic fields (less than 5 G) occupy three regions in the summary map (Figure 7a): the equatorial region $\pm 5^\circ$ and latitudes from $60^\circ$ down to the sunspot zone in each of the hemispheres. As the colorbar shows, weak fields are present more than 80% of time. Latitudinal profile of the flux (Figure 7b) shows maxima at latitudes $0^\circ$ and $53^\circ$.

In Figure 8 the latitudinal profiles of the magnetic field for various intervals of strength are presented. The weakest (background) fields are concentrated near the Equator and at the latitudes about $50^\circ$. In these regions stronger fields are almost absent. Latitudinal profile for the 10 — 15 G field group changes in antiphase with the weakest magnetic fields ($B = 0 – 5$ G). Flux minima for the 10 — 15 G fields nearly coincide with the weak field maxima.
Figure 7. Latitudinal distribution of weak magnetic fields ($B < 5$ G). a. Colorbar – percentage of time when the fields with strength $B < 5$ G were observed. b. Latitudinal profile of the magnetic flux.

Figure 8. Latitudinal profiles for field groups from $0 − 5$ G to $45 − 50$ G (1976–2003).

In the polar regions the fields of strength $5 − 10$ G dominate (polar coronal holes); their concentration decreases sharply when we move from the poles. As the strength of the magnetic field increases, two zones of concentration appear in the latitudinal distribution: the polar faculae zone (maximum at $∼ 70^\circ$) and the sunspot region (maximum at $∼ 20^\circ$). This two-zone structure (sunspot region and polar faculae zone) is seen especially clearly in Figure 8b for magnetic fields from $25 − 30$ G to $45 − 50$ G.

4. Conclusions

Latitudinal distribution of photospheric magnetic fields was considered on the base of synoptic maps of the NSO Kitt Peak (1976–2003). A close coupling between the value of the magnetic field and its latitudinal localization was discovered, which persisted after the averaging of the magnetic fields over three solar cycles.

The following groups of fields were shown to be dominating at different latitudes:

(a) from the equator to $5^\circ$ – the weakest fields ($B = 0 − 5$ G);
(b) the latitude interval $5^\circ − 40^\circ$ – strong fields ($B > 15$ G) – sunspots and active regions;
(c) the latitude interval $40^\circ − 60^\circ$ – the weakest fields ($B = 0 − 5$ G);
(d) the narrow strip of latitudes around 70° – magnetic fields from 15 to 50 G – polar faculae;
(e) high latitude regions (latitudes higher than 60°) – magnetic fields from 5 to 15 G – polar coronal holes.

The analysis of summary synoptic maps allowed us to distinguish four characteristic groups of fields: $B = 0 - 5$ G, $B = 5 - 15$ G, $B = 15 - 50$ G, and $B > 50$ G. Within each of these intervals, the magnetic fields have common features of latitudinal distribution, while for different field groups these features change significantly. For each of these groups of fields, their latitudinal localization persists when we average the magnetic fields over three solar cycles. Each of the considered groups of fields is closely related to a certain manifestation of the solar activity.

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