Title: Longitudinal structure of the photospheric magnetic field in Carrington system.
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Abstract

The observations of the Sun have been performed over the years, even centuries-Whether are there active longitudes? If yes how stable are they? One of the first The Wilcox Solar Observatory data taken over three cycles N 21, N 22, N 23 have been used to reveal the longitudinal structure of the photospheric magnetic field. Mean over three cycles magnetic field distribution has been calculated in the North and in the South hemispheres as well as at 30 levels of latitude from -75 to 75 degrees. This study was performed using observations of the magnetic field taking into account its polarity or only intensity. The longitudinal structure of the magnetic field was calculated in the coordinate system rotating with Carrington rate.

These structures were compared with a model of random longitudinal distribution of the magnetic field. Random character of the longitudinal structure was refused.

The results agree with the presence of two active meridians seen in different phenomena of solar activity at longitudes separated by 150-170 degrees in the Carrington coordinate system.

Keywords: Sun; solar variability; magnetic field; longitudinal structure; solar cycle.

1 Introduction and data

Are there active longitudes on the Sun?
If there are, how stable are they? What is the lifetime of active longitudes?
If so, which latitudes contribute the most?

On the Sun there are various dynamic processes and hundreds of articles were written about the analysis of perturbations of solar characteristics, their distribution over the surface of the Sun and their temporal behavior (see for example Bumba et all., 1965, 1969, 1987 and references there)

Magnetic fields and the rotation of the Sun are the main factors which determine the variations and activity observed on the surface of the Sun.

To study these problems, it is necessary to analyze the series of data on the magnetic fields of the Sun measured at different latitudes during several solar cycles. Observations of the photospheric magnetic field were performed by the Babcock solar magnetograph on WSO using the Zeeman splitting Fe I spectral line (Scherrer et al., 1977; Hoeksema, 1984; 1985). The data sets have 5 degree steps in heliographic longitude. But each longitudinal value is a weighted average of the measurements within 55 degrees around central meridian. Along the latitude the grid of data have 30 levels with latitude $\theta$ is changing from 75.2 North to 75.2 South degrees.

This paper is focused on study of the longitudinal structure of the photospheric magnetic field over solar cycles NN21-23.
2 Longitudinal structure of the Solar Magnetic Field

The presence of active longitudes could contribute to recurrent perturbations of the geomagnetosphere. Longitudinal activity was a subject of detailed studies with different tracers in the rigidly rotating coordinate system.

Rotation rate of the SMF depends on the level where it is originated and on the rotation of the plasma above this level.

Two approaches could be used for the analysis of the longitudinal structure of the magnetic field.

If the SMF activity is originated from a deep rigidly rotating level then the differential rotation of the upper layers would influence the original distribution of the activity. In this case the longitudinal structure reconstruction should be performed taking into account the rotational rate of the photospheric plasma. Since we know that this rotational rate is changing in time the coordinate system should follow this variation too. The results of this reconstruction can be found in the paper of Gavryuseva and Godoli (2006); Gavryuseva, (2006c, 2006e, 2008b).

If the level from which the SMF is originated is not too deep under the photospheric level and the SMF is rigidly rotating then the SMF longitudinal structure reconstruction should be performed using the SMF as they are observed. In this paper we concentrate on the global structure of the SMF in the coordinate system rigidly rotating with the Carrington period equal to 27.2753 days and we present here the results related to the longitudinal structure of the photospheric field in the same system.

It is plotted in Fig. 1 the distribution of the magnetic field on the solar surface along the latitudes from -75 to 75 degrees and the longitudes from 0 to 360 degrees mean over 260 Carrington rotations (covering two solar cycles No 21 and No 22 since CR No 1642). The yellow (blue) colors correspond to high positive (up to 170 micro Tesla) and negative (up to -125 micro Tesla) values of this SMF mean latitudinal-longitudinal distribution located around active latitudes and in pre-equatorial zones. The contours correspond to the 0, ±50, ±100 micro Tesla. The averaging over all latitudes gives the mean longitudinal distribution, which is plotted in Fig. 2 by continuous line. The deviation from zero level of this longitudinal distribution is varying from about -30 to 40 micro Tesla.

3 Random magnetic field distribution

This latitudinal-longitudinal distribution should be compared with the ones corresponding to models with random SMF longitudinal distributions shown in Fig. 3 by dots. (The adequate model of the random SMF longitudinal distribution should have all the main characteristics of the solar activity (discussed in Gavryuseva (2018a, 2018b)). The models of the random SMF longitudinal distribution models were calculated by randomization of the real SMF for each Carrington Rotation at each latitude. With this procedure all the important characteristics (latitudinal distribution, activity cycles, etc.) are present in the model. The only difference is the random character of the SMF longitudinal distribution. Longitudinal mean of the random SMF over two cycles of activity No 21 and No 22 was calculated. Both longitudinal distributions mean over 260
CR since 1642 CR are plotted in Fig. 3 for the real SMF by continuous line and for ten models of the random SMF longitudinal distributions by dots. The amplitude of the longitudinal distribution of the real SMF is 7-10 time higher than the amplitude of the models of the random SMF. This confirms that the real SMF longitudinal distribution cannot be described by the models of the random SMF distribution.

4 Longitudinal structure of the Magnetic Field intensity

The longitudinal activity is characterized by the amplitude of the magnetic field and not only by its polarity which is changing in time. To prevent the reduction (or even annihilation) of the mean magnetic field over 28-year interval due to the various inversions of polarity, the longitudinal distribution of the absolute value of the SMF averaged over all the latitudes and over 260 CR rotations (longitudinal distribution of the magnetic field intensity), has been computed and plotted in Fig. 4. This curve could be compared with the distributions corresponding to the ten models of the random longitudinal distribution of the SMF intensity shown by dots on the same plot. The random longitudinal SMF distribution is 6.5 times lower than the longitudinal distribution of the absolute values of the measured SMF.

The longitudinal distribution of the intensity of the solar magnetic field shows that there are two active longitudes around 10 and 220 degrees. This result is in a good agreement with the conclusions of other studies related to the longitudinal distribution of different characteristics of solar activity (Vitinsky, 1969; Bai, 1988; Mordvinov and Plyusnina, 2000; Ivanov et al., 2001).

These results exclude the possibility of the interpretation of the longitudinal distribution of the photospheric magnetic field by the models of fully random perturbations or, that is more interesting, by the models of fully stochastic origin of the solar magnetic field longitudinal distribution on the time scale significantly shorter than duration of solar cycle and on the spacial scale less than solar radius.

An additional recent study confirmed the existence of long living magnetic field meridional structures (longer than 20 years) originated from the bottom of the convective zone and rotating rigidly with the period corresponding to the latitude of 55 degrees about Gavryuseva, (2008a,b).

5 Summary

Longitudinal structure that is quasi-stable over several years has been found in the Carrington coordinate system in the large scale magnetic field observations and compared with models of a random longitudinal SMF distribution.

This magnetic field topology, highly-organized over the solar surface and over time, must be considered as a basic structure with a major influence on the solar corona and solar wind propagation, and is fundamental for the understanding of the heliospheric structure and for the prediction of the magnetospheric perturbations.
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Figure 1: Distribution in longitude and in latitude of the mean over 260 Carrington rotations real magnetic field on the solar surface. The yellow (blue) colors correspond to high positive and negative values of this SMF distribution. The contours correspond to the 0, ±50, ±100 micro Tesla.
Figure 2: Longitudinal distribution of the mean over all latitudes and averaged over two solar activity cycles (No 21 and No 22) is shown by continuous line. The longitudinal distributions of ten models of the SMF randomly distributed along the longitudes are plotted by dots.
Figure 3: Distribution in longitude and in latitude of the mean over 260 Carrington rotations magnetic field on the solar surface for the model with random longitudinal SMF distribution. The contours correspond to the 0, ±50, ±100 micro Tesla.
The mean longitudinal distribution averaged over all latitudes and two solar activity cycles (No 21 and No 22) for the photospheric magnetic field intensity is shown by continuous line. The longitudinal distributions of ten models of the SMFI randomly distributed along the longitudes are plotted by dots.

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