ON EVOLUTION OF THE PHOTOSPHERIC MAGNETIC FIELDS ON THE SUN: SEPARATION OF ACTIVE/DISSIPATIVE/BACKGROUND FIELDS BY OPTIMUM THRESHOLDS

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ABSTRACT

The distribution of the magnetic flux in the Sun's photosphere is studied using NSO/Kitt Peak Carrington rotation maps of the magnetic flux in the period from 1975 to 2003. In principle it is possible to separate the magnetic fields using these magnetic data into three types: background fields, dissipative fields coming from the active regions and the active region fields themselves. This contribution discusses determination of the optimum thresholds for such separations of the magnetic fields. The threshold between background fields and dissipative fields is derived from the average minimal values of the magnetic flux measured in high latitudes where/when no active region flux and only minimum of the dissipative flux are detected. It's value is 2.8 Gauss. Contrary it is presented that there is no common value of the threshold between the dissipative fields and the active regions fields valid for the whole period under study. It is shown that value of this threshold is in fact unique not only for each Carrington rotation map but that it is specific even for each particular active region. Usually accepted value of 25 Gauss seems to be only the minimal limit of this threshold. Its maximal limit is exceeding value of 110 Gauss. Nevertheless just separation between the background fields and the sum of the dissipative and the active region fields allows to discuss the temporal and latitudinal behaviour of these two types of the magnetic fields during evolution of the solar cycles.

1. INTRODUCTION

The primary objective of this contribution is to study the large-scale structural patterns of the magnetic fields on the solar surface over the solar cycle. Nowadays there is an advantage of availability of the magnetic synoptic charts of the Sun over more that 25 years. This allows to continue in work of Bumba and Howard (1965) searching for behaviour of the magnetic activity with the temporal and spatial resolution better than ever before over the sufficiently long time interval to reveal the global properties of the solar dynamo manifestations on the solar surface (e.g. Howard and LaBonte, 1981, Gaizauskas et al., 1983, Howard, 1992), Harvey, 1992, DeToma et al. (2000)). Generally, evolution of solar cycles is instructive in understanding processes of the magnetic flux emergence and dissipation as like as a phenomenon of the polar magnetic reversal. Patterns of emergence of the active regions are important in characterization of the most strongest magneto-hydrodynamic activity on the Sun and the dissipative fields are vital for understanding of the magnetic diffusion and flux transport on the solar surface (Wang and Sheeley, 1994). Additionally the background fields show the large-scale behavior of the background magnetic fields created on scales smaller than the resolution of the used Carrington rotation maps belonging to network around supergranular cells. This work presents the first results of an attempt to find a behaviour scheme of the three types of the specified photospheric magnetic fields deriving the time-latitude maps of their total and net magnetic fluxes.

The magnetic data used in this contribution are described in Sect.2. In Sect.3 an analysis of the magnetic fields is performed in order to derive the actual value of threshold to separate the background and the dissipative magnetic fields. Discussion on the threshold between the dissipative and active regions magnetic fields are presented here as well. The time-latitude maps for the background fields and the sum of the dissipative fields and the active magnetic fields are presented in Sect.4 and discussed in Sect.5 for both the total and the net magnetic fluxes.

2. DATA

The present analysis is based on the patrol measurements of the photospheric magnetic fields regularly obtained at Kitt Peak Observatory (National Solar Observatory, USA)[1]. Data in the form of the Carrington rotation (CR) magnetic maps are used

[1]ftp://argo.tuc.noao.edu/kpvt/synoptic/mag/

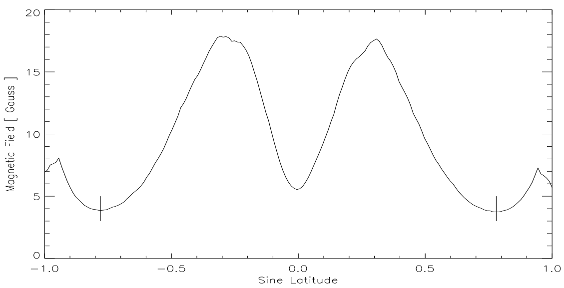

Figure 1. Latitudinal behaviour of the total magnetic flux density averaged over the whole epoch from 1975 to 2003. Positions of the minimal values are marked with the short vertical line.

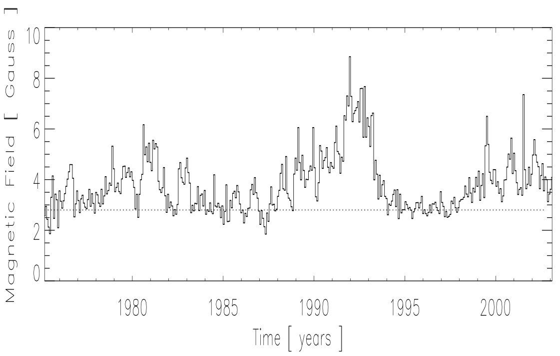

Figure 2. Average course of the total magnetic flux density in the latitudes +51°. The final value of the threshold is marked with the dashed lines.

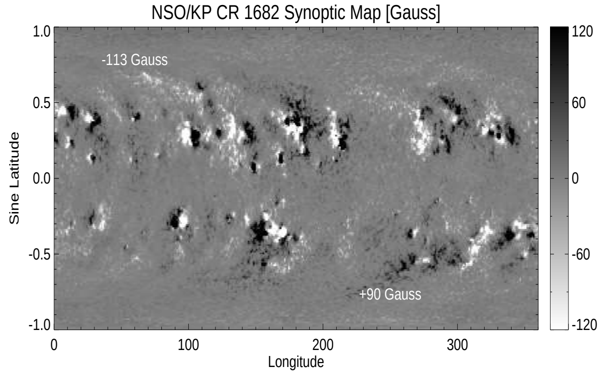

Figure 3. The synoptic map for CR 1682, where structures of very strong dissipative fields are present. The maximal values of the magnetic flux density (-113 and +90 Gauss are labeled for two particular streamers of the dissipative magnetic fields.

covering the time interval from February 1975 until January 2003 for Carrington rotation numbers 1625-1999. These 375 Carrington maps were created using magnetic measurements of regions near the central meridian in the individual daily magnetograms. These data were merged into a synoptic Carrington coordinate system with 180 bins in sine of latitude each covering an equal projected (line of sight) area and with 360 longitude bins along a complete rotation of the Sun (e.g. Schatten et al., 1969). Data have been reduced to provide the best estimate of the average magnetic flux density at each pixel of the Carrington map. Changes of the spectromagnetographs and the spectral lines used to measure the surface magnetic fields were considered. The following corrections were applied: 1. measured signals were converted to Gauss units applying different factors/zero levels for different periods; 2. assuming that the fields are radial to the solar surface the observed fields were divided by the cosine of the heliographical latitude; 3. noisy values near the poles were detected and replaced by a cubic spline fit to the valid values in the polar regions.[1]

3. ESTIMATION OF THRESHOLDS

Estimating the first threshold which separates the background fields from the dissipative fields of the active regions (and the active region magnetic fields themselves) we have concentrated on the magnetic fields at the high latitudes where no active regions fields and only minimum of the dissipative fields are observed. Minima of the latitudinal average of the total magnetic flux density were detected for the latitudes near ±51° (Fig.1). These minimum values are 3.7 and 3.8 Gauss for the northern and the southern hemispheres respectively. Examining the temporal behaviour of the total magnetic flux density at these latitudes for the time interval from 1975 to 2003 it was found that these average values are not enough reliable estimations of the threshold for several Carrington rotations due to presence of the relatively strong dissipative fields during maxima of solar activity at the considered latitudes (Fig.2). In order to avoid a crosstalk between the background and the dissipative fields only the Carrington rotations from minima of solar activity were chosen for determination of the threshold when minimum of the dissipative fields are present. The average values of the total magnetic flux density from just those Carrington rotations in which no structural patterns of the dissipative fields were found CRs 1750-1790 – years 1984-1987 and CRs 1895-1925 – years 1995-1997) were used for calculations. The particular hemispheric values of the total flux density for these intervals were derived for two solar minima (tab.1). The final value of the threshold of 2.8 Gauss was adopted as an approximative average of these values. This value is in agreement with estimation of Schrijver and Harvey (1989) who showed that the mean absolute magnetic flux density measured at moderately low resolution is about 3 Gauss when no active regions are present.

For the second threshold separating the dissipative magnetic fields and the magnetic fields of the active regions we have started our analysis using the common threshold value of 25 Gauss which was used by Rabin et al. (1991) and several other authors (e.g. Harvey, 1992, DeToma et al., 2000) in order to separate weak and strong magnetic fields. No additional criteria were applied for this selection contrary to

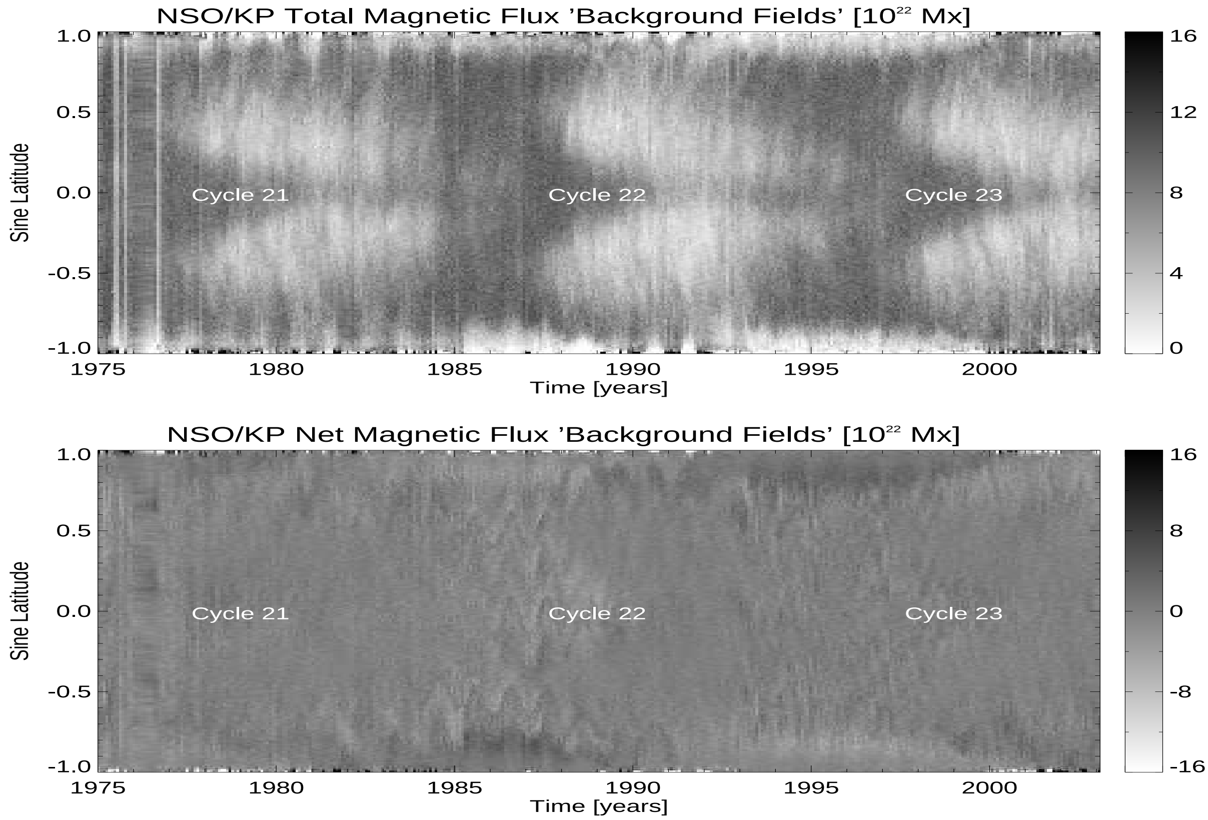

Figure 4. The 2D maps of the photospheric background magnetic fields for the total magnetic flux (upper panel) and for the net magnetic flux (bottom panel).

work of Harvey (1994). This means that the dissipative fields would be identified only within the interval of the magnetic flux density from 2.8 Gauss up to 25 Gauss. Nevertheless checking several CR maps separately it was found that this 25 Gauss threshold is satisfactory only during minima of solar activity. On the other hand in maxima of solar activity values of the magnetic flux density exceed even level of 100 Gauss inside some streamers of the dissipative fields. Example of such case (CR 1682) is shown in Fig.3. Moreover a detail study of several CR maps have revealed that the flux density of the dissipative fields vary in fact from one particular active region to another one (see Fig.3). Therefore there is no sense to determine the constant value of the second threshold not only for the whole time interval under study but also for each particular CR map as well.

Table 1. The particular values of the averaged latitudinal total magnetic flux density for the latitudes ±51°. The standard deviation of 0.2 Gauss was found to be common for all average values.

Minimum of cycles	Hemisphere	Number of CRs	Average [Gauss]
21/22	N	16	2.7
	S	12	2.6
22/23	N	15	2.9
	S	15	2.8

4. 2D MAPS OF THE BACKGROUND AND THE ACTIVE/DISSIPATIVE FIELDS

The 2D (time-latitude) maps were created for the background magnetic fields and the mix of the active region fields and the dissipative fields separated by the first threshold. The maps were calculated for the sum of the absolute values of the magnetic flux - the total flux, and the sum of the actual (positive and negative) values of the magnetic flux - the net flux, for each latitude bin in all Carrington rotations. The 2D maps constructed for the time period from 19/2/1975 - 24/1/2003 and the whole latitude range from the north to the south pole are shown in Fig.4 where upper and bottom panels represent the maps of the background fields for the total and the net flux respectively. Missing CR data are linearly interpolated.

5. DISCUSSION AND CONCLUSIONS

Decomposition of the magnetic flux to the background magnetic fields and the dissipative/active region magnetic fields shows global behaviour of the total flux and the net flux patterns in time and latitude. Several types of structures are revealed on the 2D maps.

Firstly, narrow (temporal length of 1CR) vertical strips, seen especially in the 2D maps of the total flux (not shown here) seems to be caused by the particular data reduction. (It should be mentioned here that no smoothing of the magnetic flux results has been performed while constructing the 2D maps.) Secondly, some wavelet structures are visible in the 2D maps of the net flux of the background fields (Fig.4, bottom panel), e.g. in the time-latitude area since 3/1984 till 5/1989 within the latitude range from -40° up to +40°. Locations, phases and amplitudes of these wavelet patterns are in agreement with the changes of the tilt of the solar rotation axis in time. Therefore we suppose that these structures are probably just remnants of the basic data processing applied during reduction of the original magnetic measurements. Finally latitudes very near poles show clearly the significant periodicity of 1 year both in the total and net flux results of the both types of the magnetic fields until the year 1992. Since 1993 this reduction artifact is corrected in almost optimal way.

Besides of these data reduction artifacts the following conclusions can be drawn: 1/ the 2D map of the total flux of the background fields (Fig.4 upper panel) shows that the background fields seem to be preferred on the solar surface in minima of solar activity with maximal total magnetic flux reaching 16×10^{22}Mx; 2/ Almost no presence of the background fields is visible during the enhanced solar activity in the latitudes of the sunspot emergence; 3/ the 2D map of the net flux of the background fields (Fig.4, bottom panel) displays (except of data processing remnants visible as the wavelet structures) the polar crown changes of the background field in agreement with the polar magnetic field reversal connected with the solar magnetic cycle; 4/ Besides these polar large-scale structures the background fields are almost of a constant flux without remarkable structures over the whole time and latitude domain. This is in agreement with previous studies on this type on the magnetic fields (e.g. LaBonte and Howard, 1982, White and Livingston, 1981); 5/ the 2D maps of the total and net fluxes of the active/dissipative fields (not shown here) present the following basic patterns of activity: active regions in the latitude range bordered by ±45°, polar reversal process changing the polarity of the dissipative magnetic fields around the poles, transport of flux of the dissipative fields in several branches from the middle latitudes to poles; 6/ The maximal values of total magnetic flux of the active/dissipative fields are around 5×10^{24}Mx while the maximal values of the net flux are reaching level of $\pm1.7\times10^{24}$Mx.

It has to be mentioned here that our background fields are defined in other way than the weak magnetic fields described in the past by Rabin et al. (1991), Harvey (1992, 1994) or DeToma et al. (2000). These works and our approach use quite different definitions of the weak/strong and background/dissipative/active fields what makes previous and our results incompatible. In fact their term weak is more related to the sum of our background and dissipative fields but then the described limitations of the 25 Gauss limit have to be taken into account.

In future an attempt will be made to derive a method for determination of the optimum threshold which should objectively separate the dissipative fields from the active region fields in each active region. This would allow to study connection between all three types of the solar magnetic activity over the solar cycles 21, 22 and 23.

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