SURGES OF THE WEAK MAGNETIC FIELD IN THE PHOTOSPHERE OF THE SUN

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Aim of the Study

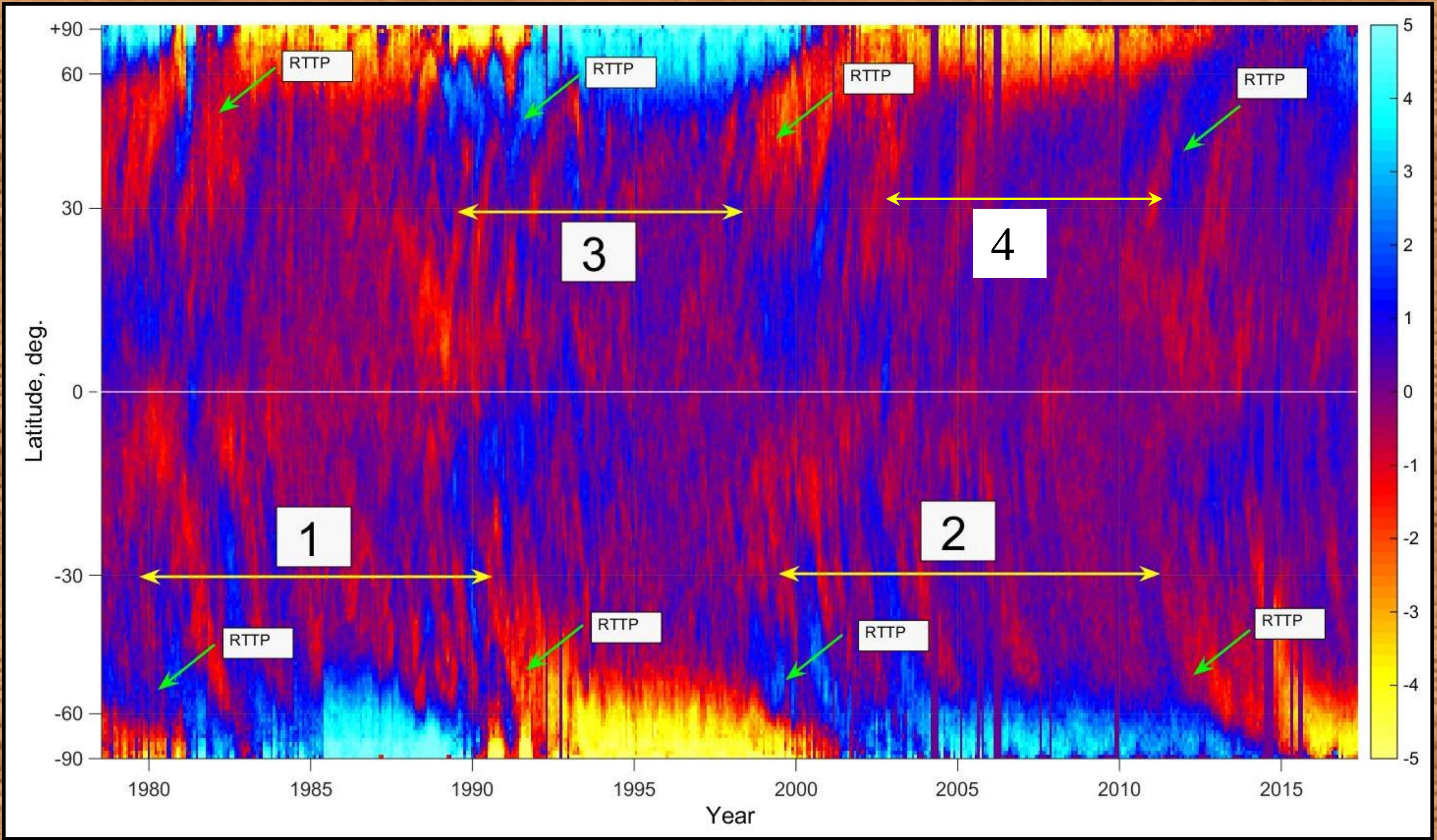
The distribution of weak magnetic fields of positive and negative polarities in the photosphere was studied.

Data

Synoptic Maps of the Photospheric Magnetic Field produced at the Kitt Peak Observatory (NSO, 1978-2016) were used. Each map contains 180 * 360 pixels - values of magnetic field in Gauss.

Method

A time-latitude diagram of the magnetic field was constructed by averaging of synoptic maps over the longitude. When averaging, the sign of the magnetic field was taken into account. The time-latitude diagram was plotted for magnetic fields from -5 to +5 Gauss with saturation at 5 Gauss. Selection of upper limit of intensity **5 G** allowed to consider distribution of weak magnetic fields showing the alternation of different polarity flows drifting towards poles.



Time-latitude diagram for the magnetic fields with B ≤ 5 G. 1, 2, 3, 4 – time intervals of the magnetic field surges with distinct alternation of the dominating positive or negative polarity. This regular pattern appears as a rule in the hemisphere with the positive polar field. Green arrows - rush-to-the-poles (RTTP) streams.

Comments to the time-latitude diagram

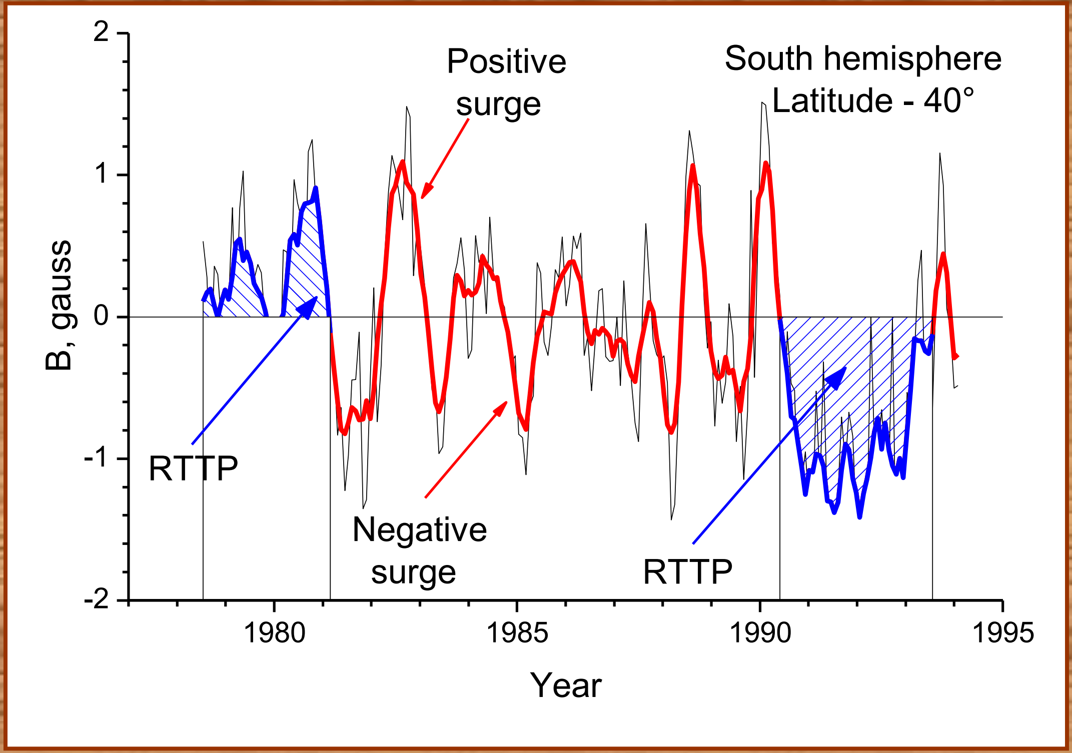
The diagram shows in the form of inclined bands of blue and red colors magnetic field flows or surges of different polarity. It is possible to distinguish:

a) flows that start from the equator and reach almost to the pole (narrow bands);

b) flows which start at latitudes about 30° – 40° (broad powerful bands: rush-to-the-poles, RTTP) that lead to the inversion of the polar field.

The narrow surges form periodic structures which persist during the time intervals ~10 years from one solar maximum to the other, i.e. during constant sign of the polar field. These surges appear as a rule in the hemisphere with positive sign of the polar magnetic field.

Cyclic changes of the magnetic flux polarity



Variations of the magnetic field strength at a fixed latitude (~40°) show that positive and negative surges alternate, forming a periodic structure. The blue shading points to the periods of RTTP.

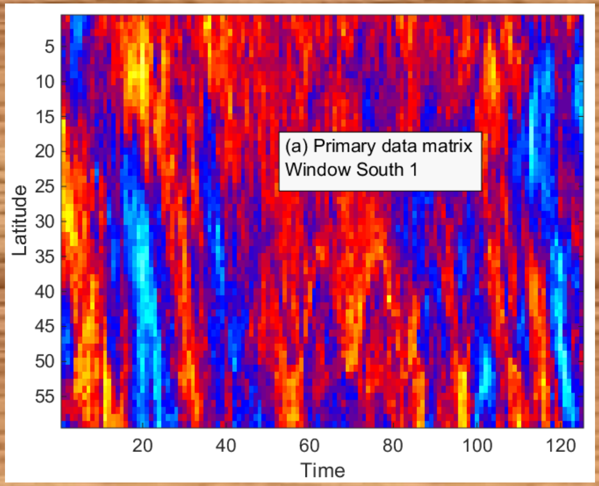
Empirical Orthogonal Functions

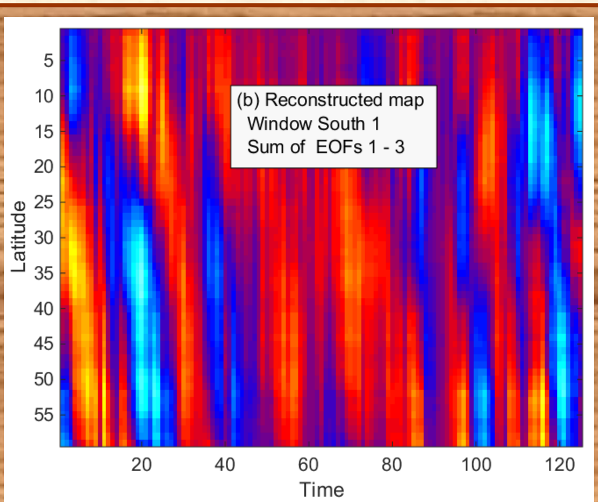
To study the cyclic structure of the magnetic field distribution the Empirical Orthogonal Functions (EOF) method was used.

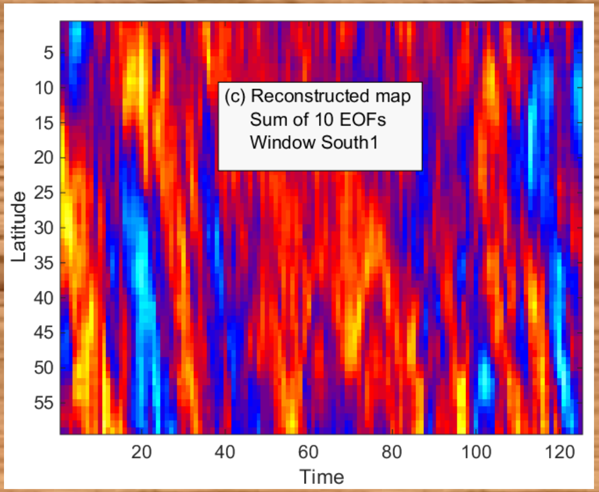
Analyzed data matrix M was defined as the window of the time-latitude diagram. Four windows (marked by numbers 1 – 4 in the diagram) with pronounced cyclic change of magnetic field polarity were selected with the dimensions PxQ (P ~ 120, Q ~ 50), where P is the number of Carrington rotations, and Q – the number of latitude rows (latitude in sine scale).

For the covariance matrix M'*M the eigenvalues and eigenvectors were calculated. EOF time series (expansion coefficients) were obtained for each of the studied windows.

Example of the time-latitude diagram expansion into EOFs



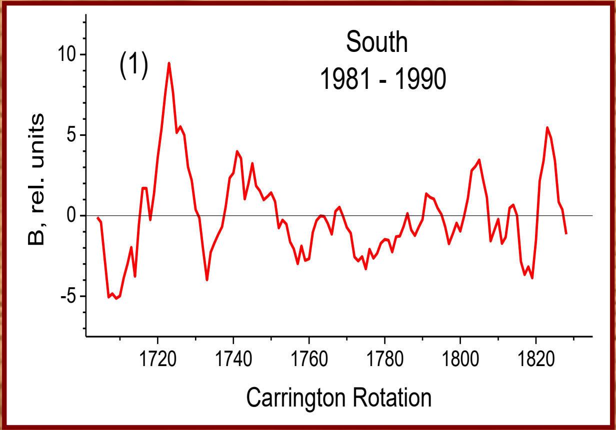


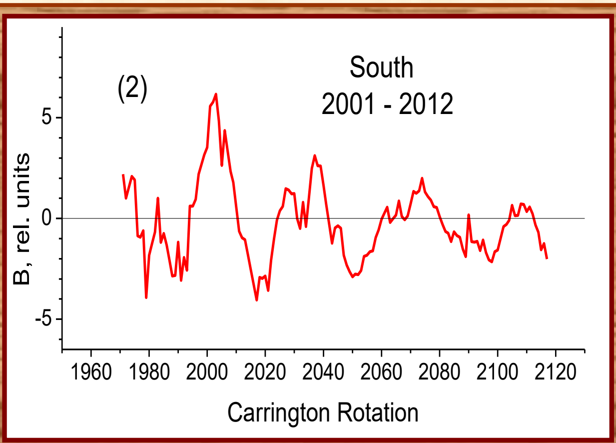


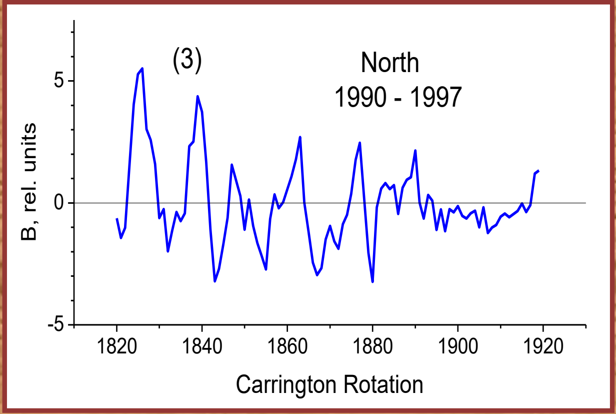
Reconstruction of the primary data matrix (left panel) as the sum of the EOFs: middle panel - the sum of 3 first EOFs and right panel - the sum of 10 EOFs . As the first eigenvalues dominate the others, most of the behavior of the data matrix can be explained by just a few eigenvectors.

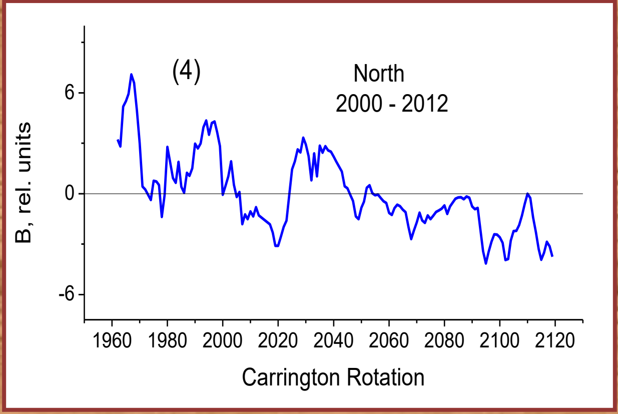
For example, the largest relative eigenvalues for the South window 1 were 0.39, 0.20 and 0.13 (72 % in total). Eigenvectors corresponding to the largest eigenvalues explain the main features of the primary data excluding the influence of random noise.

EOF expansion coefficients: 1st temporal function









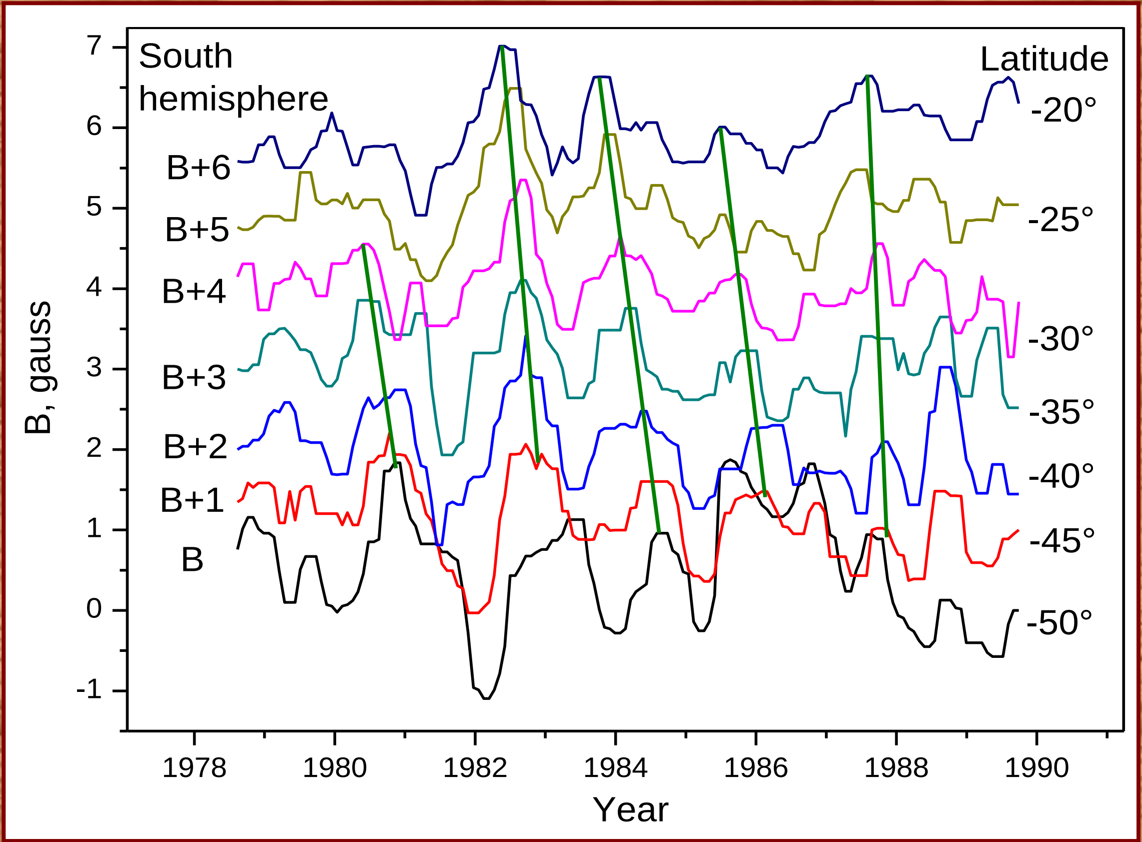
EOF decomposition confirms the presence of cyclic components in the distribution of magnetic fields. The first expansion coefficients are presented for the two windows of the S-hemisphere (1,2) and for the N-hemisphere (3,4). Though the periods of the variations differ for the windows 1 – 4 they do not show pronounced changes during each time interval (duration ~ 10 years)

Problems of the magnetic field averaging

The EOF method can be very useful as a tool of studying the cyclic patterns of the photospheric magnetic field. However, since the EOF method lacks transparency, it is desirable to compare the EOF results with similar results obtained by simpler, even less precise methods.

Another approach, more straightforward, of the data averaging was used for comparison with the results of EOF analysis. To reduce the effect of fluctuations in the analysis of magnetic field distribution, the data matrix (the window of the time-latitude diagram) should be averaged by latitude.
Yet the drift of the magnetic field surges towards the poles (seen as inclination of the dominating polarity bands) does not allow the direct latitudinal averaging.

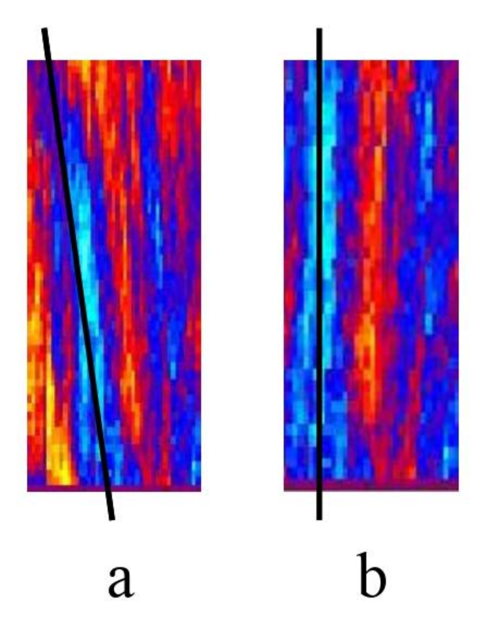
Latitude shift of the magnetic fields over time



Time profiles of the magnetic field B≤5 G are shown for latitudes 20°-50° with 5° increments. Time profiles of the successive latitude intervals were offset by 1 G relative to each other.
The maxima and minima of the profiles correspond to the flows of positive and negative fields drifting towards the poles.

To obtain time pattern of the magnetic field analogous to the expansion coefficients of the EOF method the data matrix should be averaged over the same latitude range. Latitude shift of the time profiles requires the correction of the time-latitude diagram before averaging the data for a range of latitudes.

Averaging of magnetic field profiles of different latitudes

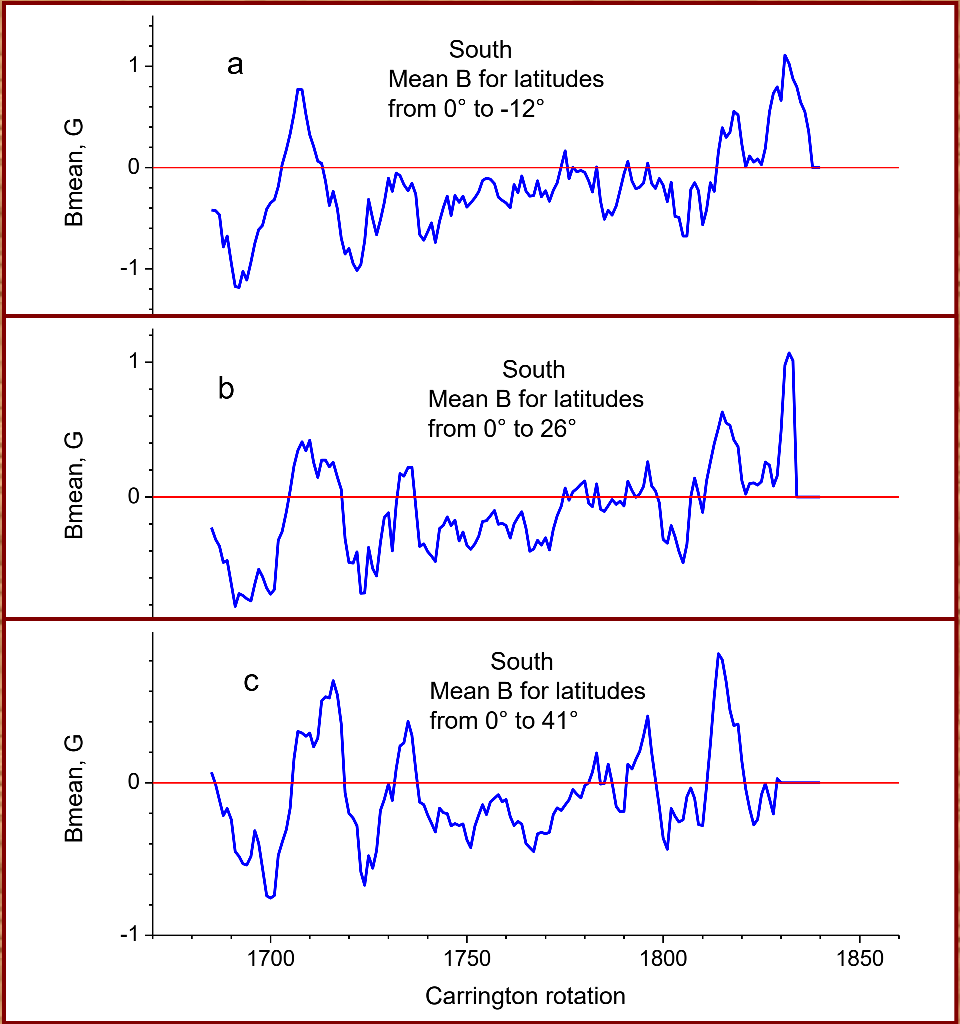


To reduce the effect of fluctuations in the analysis of magnetic field distribution, sections of the time-latitude diagram (intervals 1 - 4) were averaged by latitude. Before that, the diagram was adjusted so that the inclined image of the flow became oriented along the vertical axis.

Figure (a) shows a clipping of the time-latitude diagram with inclined magnetic field bands; and (b) the same area after image correction.

Time-latitude diagram represents a matrix with 180 rows of the field series. Each row of the matrix can be interpreted as a time profile of the magnetic field at the fixed latitude. After the correction described above, the profiles were averaged for each of the time intervals 1, 2 - South hemisphere, and intervals 3,4 - North hemisphere.

Averaging of magnetic field profiles of different latitudes (South hemisphere, interval 1)



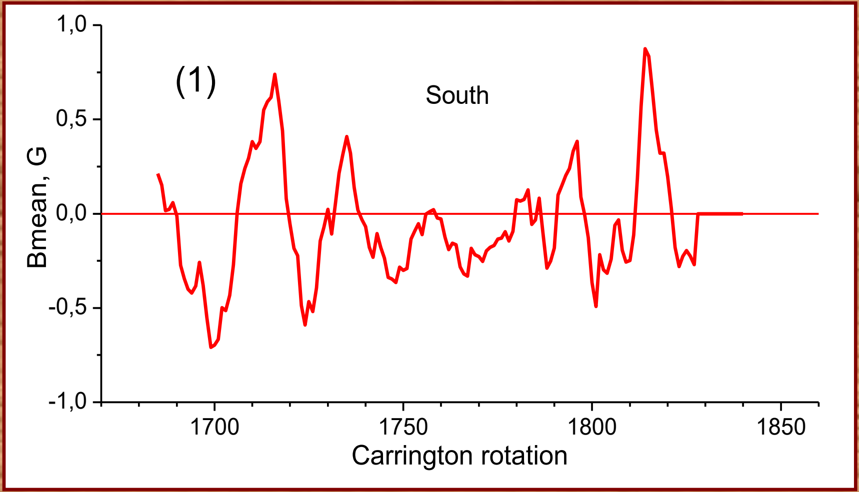
For the period 1980-1991 are given:

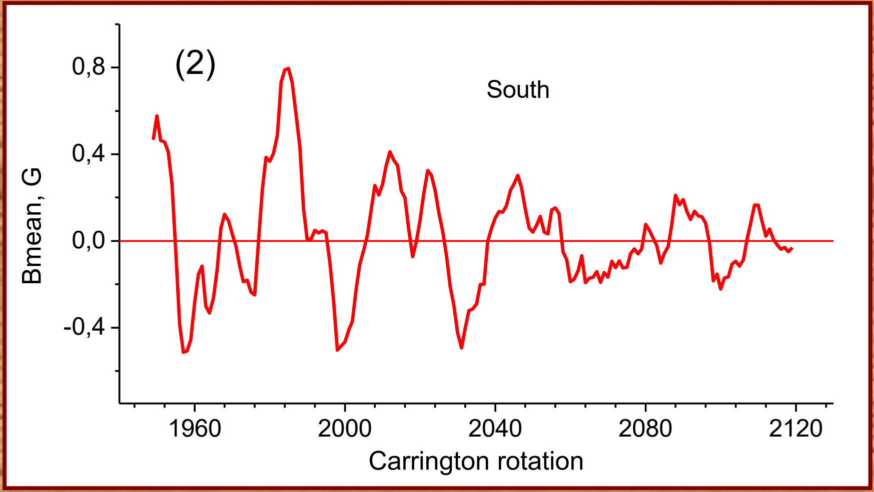
(a) the sum of 20 profiles corresponding to latitudes from equator to -12°;

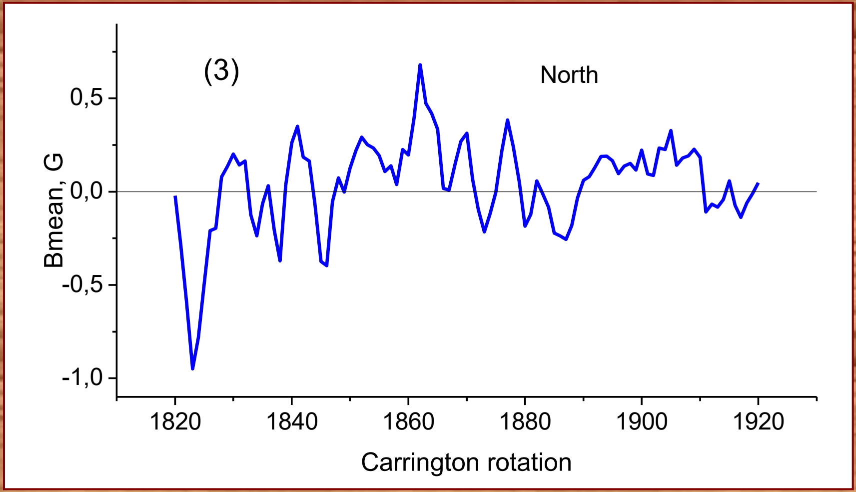
(b) the sum of 40 profiles from the equator to -26°;

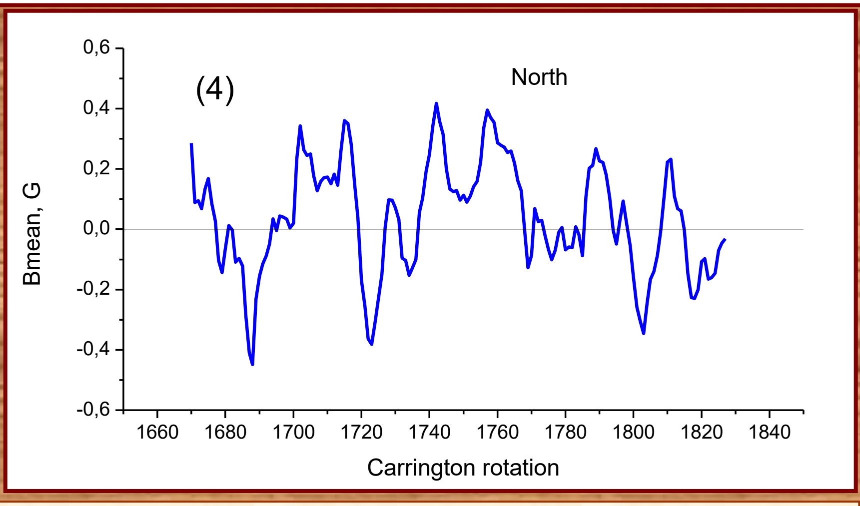
(c) the sum of 60 profiles from equator to -41°.

Fluctuations decrease as the number of summed profiles increases and the cyclic structure of the field appears more clearly.







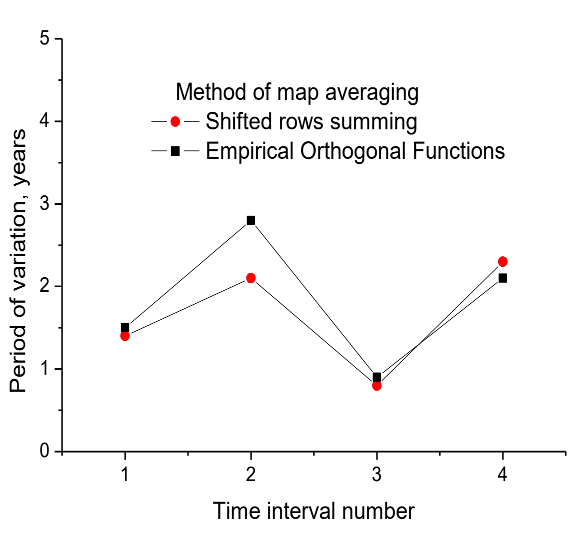


After image correction magnetic field was averaged over latitude range from 0 to ± 50°. Numbers 1 – 4 correspond to the time intervals of the time-latitude diagram.

Upper panels – South hemisphere, time intervals 1 and 2;

Lower panels – North hemisphere, time intervals 3 and 4.

Periodicity of magnetic field surges



Hemisphere	Period	*T, yrs	**T, yrs
S	1981.1 - 1990.3	1.4	1.5
S	2001.1 - 2012.0	2.1	2.8
N	1989.8 - 1997.2	0.8	0.9
N	2000.4 - 2012.1	2.3	2.1

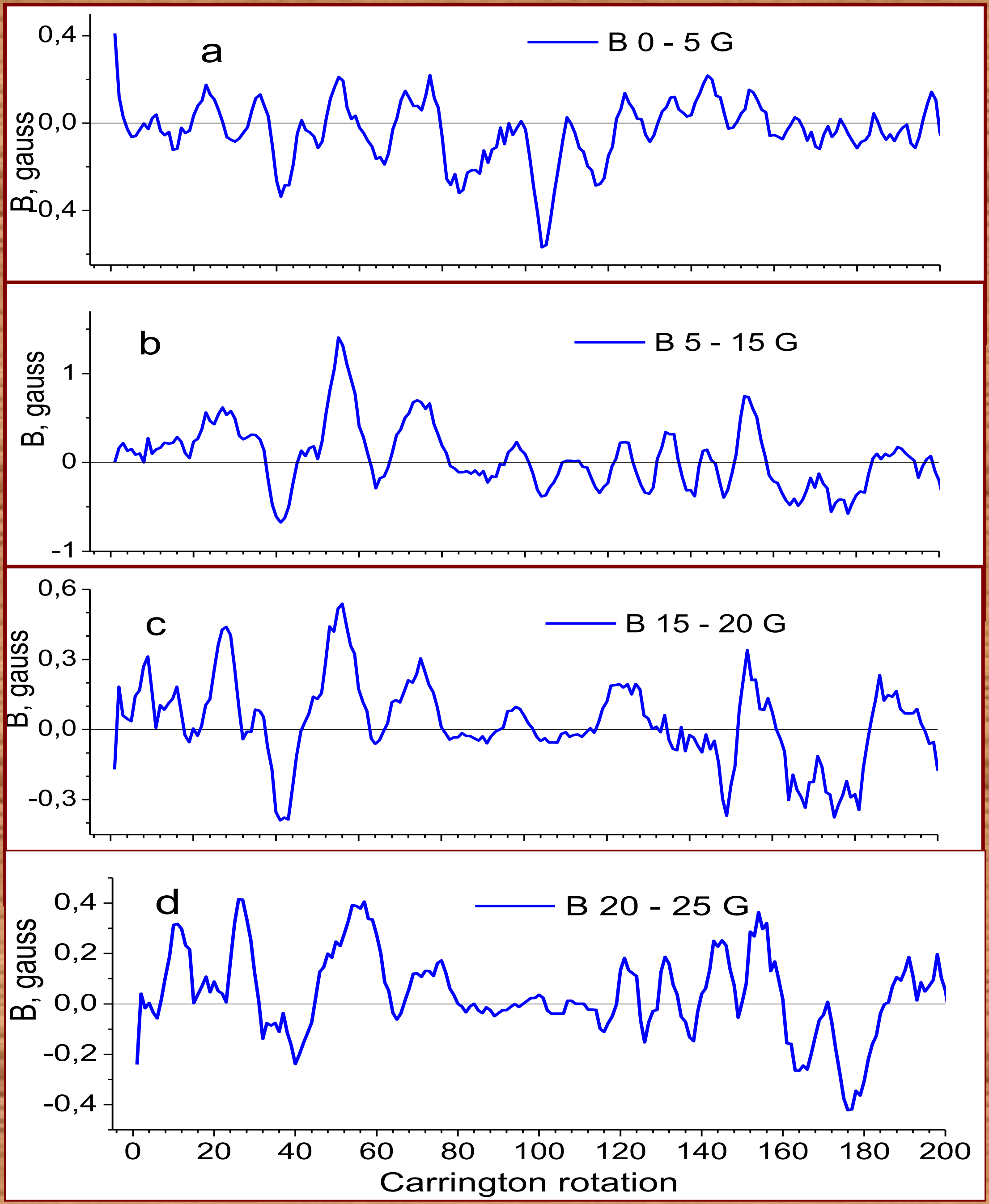
The cyclic change of the dominating polarity was most pronounced in time intervals 1 - 4 (see time-latitude diagram). For each of intervals, an average period of the sign change was estimated by two methods: (a) averaging of the time profiles for a number of latitudes (*T) and (b) the Empirical Orthogonal Functions decomposition (**T).

The variation periods obtained by two methods show a good agreement. These periods of variation are nearly constant during each of intervals. The observed periodicities may be attributed to the quasi-biennial oscillations of magnetic field.

Periodic structure of the different magnetic field groups

To exclude the influence of the strong magnetic fields appearing as butterfly diagrams and suppressing the manifestation of the weaker fields we limited our study by the fields of B<5 G. Yet there arises a question: which groups of fields create structured magnetic patterns with alternately dominating positive and negative polarity instead of uniform distribution.

We have plotted time-latitude diagrams for the following groups of magnetic fields: 5>B>0 G; 15>B>5 G; 20>B>15 G; 25>B>20 G. As an example, time profiles for the latitude -35° (South hemisphere) and time interval 1979 – 1992 were analyzed.



Large amplitudes of variations for 0-5 G and 5-15 G are observed throughout the time interval of decline-minimum-rise of solar activity.

Starting from 15-20 G, the variations near the minimum decrease, which is even more noticeable for 20-25 G and higher thresholds. For B greater than 50 G, there are no variations for 6 years from 1981 to 1987.

Thus, we can conclude that the alternation of positive and negative bands is present from the maximum of the cycle to the next maximum only for the weakest fields of B<5 G and 15>B>5 G.

Conclusions

Periodic patterns of magnetic field flows with successive changes of the dominating polarity were found in the time-latitude diagram of the weak magnetic fields B<5 G. These flows or surges appeared irrespective to the level of solar activity and persisted during the time intervals ~10 years from one solar maximum to the other. In three out of four cases the discovered periodic structures were observed in the hemisphere with positive sign of the polar magnetic field.

Reasonably close values were obtained by two independent methods - the latitude averaging of the adjusted time-latitude diagram and the Empirical Orthogonal Functions method for the periods of the dominating field sign alternation. The periods of the sign change fell into the range from 1 to 3 years, which is near to the periodicity of the quasi-biennial oscillations of the solar magnetic field.

The search for the similar periodic structures in the stronger magnetic fields showed that at the magnetic field strength higher than 15 G the variations became unstable disappearing for the magnetic fields of B>50 G.

Thank you for your attention!