Cyclic evolution and reversal of the solar magnetic field.
I. The large-scale magnetic fields

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Abstract. On the base of the solar magnetic field measurements obtained in Stanford in 1976–2003 the properties
of the cyclic evolution of the large-scale magnetic field are investigated. Some regularities are found in longitudinal
and latitudinal evolution of the magnetic field in cycles 21, 22 and 23. The cyclic development of the large-scale
magnetic field can be divided into two main phases. The phase I, which includes a period approximately from
two years before and until three years after the maximum of the solar cycle, is studied in detail. It is found that
before the reversal of the large-scale magnetic field the neutral line of the magnetic field in antipodal longitudinal
intervals shifts from the equator to opposite directions in cycles 21 and 22, but not in cycle 23. During the sign
reversal of the large-scale magnetic field in cycles 21 and 22 in the antipodal longitudinal intervals the magnetic
field of opposite polarity is observed in all latitudes, thereby forming an equatorial dipole. After the magnetic field
reversal a longitudinal oscillation of the magnetic neutral line with regard to the equator takes place, which has
a period about 2 years and damps to the minimum of the 11-year cycle. The intervening longitudinal intervals
of the large-scale magnetic field correspond to positions of the active longitudes of sunspot activity, thus indicating
a close connection of the large-scale and the local magnetic fields. In evolution of the large-scale magnetic field
a periodicity with period 1.23 ± 0.16 year is revealed, which is close to the period found by helioseismological
methods in variations of the solar rotation near the tachocline.

Keywords: Sun: magnetic fields – Sun: activity

1. Introduction

The knowledge of the large-scale magnetic field properties and its relation with the local fields
of less scales is a determinative factor for comprehension of solar cyclicity mechanism. The term
“large-scale field” is used to be referred to the global (or, in other terms, background) solar
magnetic field (Hoeksema & Scerrer (1986), Makarov & Sivaraman (1989), Obridko & Shelting
(1992), Mikhailutsa (1995)). However, isolation of the large-scale magnetic field “in a pure form”
seems to be a complicated (if possible at all) task. The reason is that on the solar surface the
magnetic field structures of different scales concurrently exist. At first sight, their distribution
seems to be rather chaotic. However, certain regularities can be found both in their dimensions
and locations.

Until 1970 three “quiet” scales of photosphere structural formations were known: a granule,
a supergranule and a giant cell. The investigations of Ikhsanov ((1970; 1975)), made in the late
60s and based upon complex analysis of data for cycles 18–20 of solar activity, found out seven
“quiet” scales from granules to superrgiant granules (for the latter the term “cells” can be only
conditionally used). The sequence numbers of the scales and their names are listed in the first
two columns of Table I (in brackets names of the scales are given that are commonly used by
now). The third column of the Table includes bounding scales, on which local formation with
greater magnetic field strength can emerge (these scales are sometimes called “magnetic scales”).
In the last column the mean dimensions of the formations are presented. It does not follows that
there are no formations of intermediate scales. For example, formations twice as large as a
mesogranule are rather often observed. However, the photospheric structures exhibit a tendency
to group in these seven scales. Therefore, the process of formation of such structures is not pure
random, but have some regularities, which are stochastically manifested as the discrete scales.
These scales reflect dynamical processes that take place both on the solar surface and, more
Table I. The structural formations in the solar photosphere (Ikhsanov (1970; 1975)).

| N | Formation: “quiet” scale (a) | Bounding formation: “active” scale (b) | Mean dimension (km) |
|---|-----------------------------|---------------------------------|------------------|
| I | Supergiant granule SgG | × × × | $1 \cdot 10^6$ |
| II | Giant granule gG | Very large and complex sunspot group | $3 \cdot 10^5$ |
| III | Group of supergranules (intermediate-sized cell) | GsG | Large and medium sunspot groups | $1 \cdot 10^5$ |
| IV | Supergranule sG | Medium and small sunspot groups | $3 \cdot 10^4$ |
| V | Group of complexes of granules GCG (mesogranule) | | Very small sunspot groups and pores | $1 \cdot 10^4$ |
| VI | Complex of granules CG (protogranule) | Small-scale magnetic formations | $3 \cdot 10^3$ |
| VII | Granule G | | | $1 \cdot 10^3$ |
| VIII | × × × | | | $3 \cdot 10^2$ |

importantly, in the deep layers of the Sun. So, the scale CG was later found out by Kawaguchi ((1980)), GCG (mesogranules), by November et al. ((1981)), Oda ((1984)), CsG, by MacIntosh & Wilson ((1985)), who called it “intermediate-sized cell”, etc.

These scales, taken separately, are undoubtedly of a strong interest, and at present a great attention is focused to their investigation. However, another important feature of Table I is that it indicates existing of a certain hierarchical network in the structure of the solar photosphere. Later a similar hierarchy of formations was proposed by MacIntosh ((1992)), but he gave only five of the seven scales of Table I (G, CGG, sG, CsG, Gg).

However, taking into account the “quiet” scales only, without their relation with the bounding (“magnetic“) ones, does not give an authentic picture of the solar surface structure. One of essential features of the structure is that on the boundary of a cell of some given scale local magnetic fields can emerge, mainly in a form of sunspot groups and centres of activity. It follows from Table I that the dimensions of the boundary formations are shifted one step below with respect to the “quiet” scales. Hence, these formations do not exceed the dimensions of the preceding “quiet” scale. For example, on the boundary of a supergranule, if it is not sited on the borderline of greater scales, pores or very small sunspot groups can emerge, and on the border of a supergiant cell, along with smaller scales, the largest and the most complex sunspot groups and the corresponding active centres are used to be formed. These complex sunspot groups, especially when they emerge at a joint of supergiant cells, are analogues of active longitudes (Ikhsanov (1973)). They rotate as a solid body (Vitinsky & Ikhsanov (1972)), as distinct from smaller sunspot groups, which are formed on boundaries of smaller scales and manifest differential rotation. It follows that the largest scale of Table I has a character of global scale. We should note that there are another important conclusions that can be derived from Table I, but in this paper we are interested, first of all, in separation of the large-scale magnetic field.

Thus, if to treat the bounding scales with strong magnetic fields as medium-scale (local) formations, then, according to Table I, the large-scale magnetic field is to be carried only by formations with dimensions that are essentially larger than the dimension of the largest bounding
Cyclic evolution and reversal of the solar magnetic field, I

(“magnetic”) scale, i.e. is to have size close to that of the supergiant cell, which occupies an area comparable with the radius of the Sun.

Hence, to a first approximation, all formation on the solar surface, as well as photospheric magnetic fields, can be divided into three types, which correspond to the small-scale, medium-scale and large-scale magnetic fields. The boundary between the first and the second scale is the supergranule, on border of which pores are formed. Therefore, formations in the range of scales between the supergranule and the giant cell can be treated as medium-scale formations in the photosphere. Some questions of organization of the small-scale formation, their properties and relations with magnetic fields was discussed in the paper of Ikhsanov et al. ((1997)). In this paper we shall examine regularities in the structure and evolution of the large-scale magnetic fields.

2. The latitudinal distribution of the large-scale magnetic field and its cyclic evolution

For study of the solar magnetic field evolution over the 11-year cycle we use as a starting material the long uniform series of the magnetic field measurements, which was obtained in Stanford in 1976–2003 on a magnetograph with 3-minute resolution. Thereby, the data include the large- and medium-scale magnetic fields, which correspond at least to the three largest scales of Table I. The task to separate the large-scale magnetic field comes, in the main, to removal of the local magnetic fields. To do it we used two method. The first one is a simple averaging with the window size equal to the radius of the Sun. The second method is based on the fact that the local magnetic field, at least in an early stage, have a bipolar structure, i.e. their strength lines are closed. In order to remove such local fields, one can use the magnetic field distribution, reconstructed on the supposition that the strength lines of the field on some spherical surface that is sufficiently distant from the Sun (“source surface”) are radial (Hoeksema & Scerrr (1986)). Hereafter we shall use the magnetic field distribution on the source surface with radius equal to 2.5 solar radii. On such a distance from the photosphere the local magnetic fields fade out. Therefore, the latter method can isolate open magnetic fields of the largest scale, whereas the former one allows to account the large-scale fields both with open and closed strength lines.

The large-scale magnetic fields filtered out by these two methods are presented in Fig. 1 as latitude-time maps for the time interval 1976–2003. One can see that, being different in some details, these two maps are as a whole rather similar.

It is evident from Fig. 1b that two different phases exist in the 11-year magnetic field evolution. The phase I includes the part of the solar cycle approximately from 2 years before its maximum to 2–3 years after it. On this phase polarity reversals happens frequently, which look like long latitudinal bands on the maps and cross the equator quite often. It is especially prominent in low latitudes ($0^\circ - \pm 30^\circ$). So in cycle 21 in the north hemisphere the bands of positive polarity predominate, and in cycle 22, on the contrary, ones of negative polarity. It is to be noted that the polarity of the north hemisphere predominates in each of the three investigated cycles. In particular, it is manifested as “spilling over” of the magnetic fields of the north hemisphere to the south one. The final sign reversal of the large-scale magnetic field in the 11-year cycle takes place on the phase I. This reversal completes consecutively in high, next in middle, and finally in low latitudes, having total duration about 1.5–2 years. We should note that estimating the moment of the reversal in high latitudes one must bear in mind that the measurements were made in latitude range $\pm 75^\circ$, thus the polar reversal can really occur slightly later than it can be observed on the maps. On the phase II in all latitudes of either hemisphere the magnetic field of the uniform polarity is observed, with the maximum of the field strength being in heliolatitudes $40^\circ-60^\circ$. As approaching to the equator, the field strength decreases smoothly. In some moments
Figure 1. The latitude-time maps of the large-scale solar magnetic field: the filtered photosphere field with scale \( \geq 120^\circ \) (a) and the field on the source surface (b). The light areas correspond to the positive-polarity magnetic field, the dark areas, to the negative-polarity one. The borders between the phases I and II are marked by vertical dotted lines.

The polarity of the north hemisphere crosses the equator and intrudes into the south one up to latitudes \(-10^\circ\) and farther.

The above mentioned regularities can be seen as well in Fig. 1b, which was obtained by the photospheric magnetic field averaging with the window size 120°. It is important that on the phase I during 2–3 years from its beginning and until the magnetic field reversal the areas of uniform polarity with the latitudinal dimension 25° -- 30° are observed in Fig. 1b, as distinct from the latitudinal bands in Fig. 1a. In either of the hemispheres there are three such areas of alternating polarity. It can be interpreted as existing of regions of the large-scale magnetic field with closed strength lines before the cycle maximum,
The division of the phase I into two epochs, before and after the magnetic field reversal, will be discussed later. We also shall discuss it in more detail in the next paper.

3. Longitudinal and latitudinal evolution of the large-scale magnetic field in cycles 21–22

One of the most important problems of investigation of the large-scale solar magnetic field is looking for the cause of the longitudinal non-uniformity, which first was found in sunspot distribution, and later, in other indices of the solar activity (see, e.g., Vitinsky et al. (1986), Vitinsky (1997), Ivanov & Ikhsanov (1998)).

To study the longitudinal and latitudinal variations of the large-scale magnetic field we divided the solar surface into 30-, 45- and 90-degree longitudinal intervals and constructed for every interval and for time range 1976–2003 a latitude-time magnetic field distribution. In Fig. 2 the case of the eight 45-degree intervals and the time step of 1/3 year is presented. First of all, it follows from Fig. 2 that the picture of evolution of the magnetic field neutral line varies from one interval to another. In the distribution of the positive- (light areas) and negative-polarity (dark areas) magnetic field some regularities can be observed.

So, on the phase II one can see oscillations of the neutral line. The oscillations in the different longitudes are not synchronous, being sometimes in antiphase (e.g., in 1984 or 1993–1994). However, these oscillations occur only in low latitudes. Quite different picture is observed on the phase I, which occupies time interval of the ascending, the maximum and the beginning of descending of the solar activity, including the epoch of the magnetic field reversal. In this period the boundary line of the polarities changes, moving to high latitudes. Thus the phase II demands a more detailed study.

In Fig. 3 the magnetic field evolution on the source surface for cycle 21 is shown with more details in time. In each of the 45-degree intervals the field reversal in the north and south hemispheres can be distinctly observed. In the first three intervals (330°–105°) the neutral line, after some incursion into the south hemisphere in 1978, abruptly rises to the north one, and in the first half of 1979 the negative polarity attains the N-pole region. In the south hemisphere the negative polarity exists until 1980.0, whereupon the total polar reversal is observed at both poles.

In the longitudinal range 150°–285° the process of the sign reversal looks differently. Here, on the contrary, motion of the north polarity into the south hemisphere is observed, and the sign reversal in the south hemisphere takes place one year earlier than in the north one.

In the ranges 105°–150° and 285°–330° the picture is intermediate in character, but in these intervals the motion of the neutral line in the opposite directions can be also observed.

Therefore, the magnetic field reversal continues during the whole year 1979. It must be underlined that after the polar reversal the boundary line between polarities is not stable, oscillating with regard to the equator. One can see that in the 135-degree intervals mentioned above the latitudinal oscillations initially take place with larger amplitude and with phase that is opposite to the phase of the oscillations during the polar reversal. This antiphase behaviour is especially evident in the longitudinal intervals 15°–60° and 195°–240°, which are 180 degrees away one from another. Note, that in the first range the magnetic field has a negative polarity in 1980 ± 1 year, while in the second one, on the contrary, a positive polarity.

Hence, the magnetic field reversal in cycle 21 continues approximately one year. In the first longitudinal interval (330°–105°) the reversal manifests itself in transition of the negative polarity from the north to south hemisphere, and in the second interval (150°–285°), the positive-polarity field transfers in the opposite direction. During approximately half a year in either hemisphere a uniform polarity exists. We should mark that this regularity is manifested
in all eight longitudinal intervals, with the magnetic field having an opposite sign in the two described above 135-degree intervals.

To the right from Fig. 3a the similar Fig. 3b is shown, which was obtained by the second method, i.e. by simple averaging of the photospheric magnetic field. One can see that, in spite of some fuzziness of the picture (which is especially well seen in high latitudes), the figure reveals the similar regularities.

From study of the evolution of the magnetic field polarity on the phase I of cycle 22 (Fig. 3c) the similar conclusions can be made, if to account that the polarity borderline moves in the opposite direction with regard to cycle 21 and, besides, a remarkable predominance of the negative-polarity fields are observed in this cycle.
Combining the successive 45-degree intervals into 90-degree ones (Fig. 4), one can see that, both for cycles 21 and 22, in the first interval the motion of the neutral line is opposite to the third one, and in the second, to the fourth. Therefore, in the 90-degree intervals the neutral line on the phase I evolves in antiphase with the next nearest interval, rather than with the nearest. This regularity is evident for cycle 21, and can be also observed for cycle 22, though in the latter it is noticeably weaker. In every of the 90-degree intervals, both on the phases I and II, the
oscillation of the polarity borderline with regard to the equator are observed (Fig. 4). During the polar field reversal the oscillations have maximal amplitudes and spread to all latitudes up to the poles. Later the amplitude decreases, and on the phase II the oscillations take place in low latitudes only. This process can be interpreted as emerging of a powerful magnetic field impulse during the polar reversal and its relaxation oscillations of period 1.5–2.5 years, with the large-scale magnetic field of the middle and high latitudes participating in the process only on the phase I.

If to examine the picture of the latitude-time magnetic field evolution after combining of the 90-degree intervals into the 180-degree ones (the bottom panel of Fig. 4), it can be seen that the neutral line oscillations in the west and east hemispheres of the Sun are in antiphase, forming thereby an equatorial (horizontal) dipole. In the first half of the phase I the sign reversal (“flipping”) of the equatorial dipole takes place. It is especially well manifested in cycle 21.

More evident antiphase development of the large-scale magnetic field neutral line in the longitudinal intervals can be observed in two 135-degree and two intervening 45-degree intervals, rather than in 90-degree (as it was marked above in the discussion of Fig. 3). In this case (Fig. 5) the evolution of the horizontal dipole on the phase I and its “flipping” in the 135-degree intervals with one-year duration is well revealed, while in the intervening intervals the picture is more complicated. These intervals, namely 105°–150° and 285°–330° in cycle 21, 60°–105°
Figure 5. The latitude-time maps of the neutral line evolution in 135-degree and 45-degree longitudinal intervals for the phase I of cycles 21 (top) and 22 (bottom).

and 240°–285° in cycle 22 possess a very important feature: they coincide well with the active longitudes of sunspot activity. According to estimates of Vitinsky ((1997)), the most stable active longitudes of sunspots in cycles 21–23 are sited in intervals 80°–120° and 280°–320°. The similar positions, 90° and 270° correspondingly, were obtained by Mordvinov & Plusnina ((2001)), which fairly agrees with places of the above obtained transitional intervals for the large-scale magnetic field evolution, if to account that the accuracy of the longitudinal intervals localization is about ±25°. Such an agreement between the intervening intervals and the active longitudes indicates a close relation of the global and local magnetic fields.
4. Properties of the large-scale magnetic field evolution in cycles 21–23

In Fig. 3 one can readily see a difference between evolution of the large-scale magnetic field in cycles 21 and 23. First, in the 21th (and 22nd) cycles before the magnetic field reversal in the above mentioned antipodal (shifted by $\sim 180^\circ$) 45-degree longitudinal intervals the neutral lines moves from the equator in opposite directions, while in cycle 23 in all longitudinal intervals the shift of the neutral line is directed to the south pole of the Sun. As a result, in the middle of 1999 in almost all longitudes the large-scale magnetic field of mainly positive polarity was observed. The reversal of polarity in all longitudes finished as late as in the beginning of 2001, i.e. it prolonged up to almost two years as compared with one year in cycle 21. By the way, the anomaly in evolution of the cycle 23 is observed in the sunspot component as well. In particular, one of the Gnevyshev-Ohl rules was violated in this cycle (Vitinsky et al. (1986)). The rule states that the height of an odd cycle maximum must exceed one of the previous even cycle. In cycle 23 the maximum of sunspot numbers proved to be lower than in cycle 22 (121 and 156 correspondingly). What is the reason of this anomaly? The analysis of the large-scale evolution shows that it is, possibly, caused by some peculiarities of the large-scale field development in cycle 22. In particular, in cycle 21 the polarity reversal on all longitudes was observed during approximately one year, while both in cycles 22 and 23 it lasted almost two years. Besides, in cycle 21 the areas of the solar surface occupied by a certain polarity in the epoch of the magnetic field reversal were approximately equal, while in cycle 22 in the second year of the reversal (1990) the negative polarity notably predominated. It is demonstrated by Fig. 6, where the large-scale solar magnetic field evolution in the 90-degree longitudinal intervals on the phase I is sketched. The arrows indicate direction of the neutral line motion. In cycle 21 before and during the magnetic field reversal the opposite motion of the neutral line in the next nearest 90-degree intervals is evident (in 1978), and in 1979 the field in these intervals has supplementary signs. In cycle 22 this regularity is violated (in 1990), while in cycle 23 it completely disappears. Besides, during the field reversal in the pair of cycles 22–23, in contrast to the pair 21–22, in the most part of the 90-degree intervals the field polarity reversal is evidently observed.

Another possible reason of such a behaviour of the large-scale magnetic field is that in cycle 23, as distinct from the 22nd one, an abrupt and early (in 1992) decreasing of the solar activity was observed. Possibly, it accounts for the fast motion of the negative-polarity magnetic field to the south pole after 1996. To the contrary, both in cycles 21 and 22 to the beginning of the phase I the neutral line oscillated in the region of the equator (see Fig. 2). Therefore, in cycle 23 during the magnetic field reversal an evident deficit of the negative-polarity magnetic field was observed. Thus, one can say that in cycle 22, and particularly in cycle 23, an essential reorganization of the large scale magnetic field, as compared with the 21st cycle, took place.

Therefore, we can state that the essential changes in the large-scale magnetic field evolution began in 22nd, i.e. even, cycle, thus confirming one of the Gnevyshev-Ohl rules.

We should also remark that there is a possibility that the Stanford data for cycle 23 have some error in position of the zero point for the magnetic field measurements. This fact can lead to the neutral line shift and dominating of the positive polarity in the 23rd cycle. However, the new recalibrated Stanford data do not reveal notable deviations from the data we used.

We also made a comparison of the Stanford data with the data for magnetic field of the Sun as a star and found a qualitative agreement between these two methods of solar magnetic field observations.

5. The large-scale magnetic field oscillation with period around 1.3 years

We have mentioned above that the period between the individual eruptions of a certain magnetic field polarity in the 45-degree intervals equals approximately 2 years. But in Fig. 3 one more
periodicity can be observed. In fact, calculation of the time distance between the successive
tops of isogauss in the north and south hemispheres exhibits recurrence with a period about
1.22 ± 0.13 years. On the other hand, one can see, particularly on the plots for cycle 21, that the
successive centres of amplitude maxima of the large-scale magnetic field are separated by the
similar time intervals \( \sim 1.3 \) years. More evidently it can be seen on another presentation of the
magnetic field evolution in Figs. 7 and 8, where longitude-latitude maps of the magnetic neutral
line position for successive 4-month intervals are presented. So in cycle 21 (Fig. 7) the maps are
arranged in groups of some duration ("patterns"), in which the line practically does not change
its longitudinal position. However, on the adjacent maps with different patterns the neutral line
change its longitudes rather abruptly. The moments of transition of one pattern into another
are marked by the bold arrows in Figs. 7 and 8. With use of more detailed resolution in time
one can reveal that the transitional period between the patterns is about 2–3 solar rotations.
These patterns are especially evident in epoch after the reversal, but before this moment they
also can be observed rather confidently, in spite of the fact that the transition from the four- to
two-sector structure of the large scale magnetic field takes place near this moment.

Every pattern in Figs. 7 and 8 is presented by three or four maps, each corresponding to
time interval about 4 months. One can see that six successive shifts by longitude happens
during 7.33 years, i.e. the process has an oscillation period of about 1.22 year. The longitudinal
magnitude of the shifts are either 90° or 180°. The same picture can be observed for cycle 22
(Fig. 8). During five years four patterns can be observed, thus the periodicity is about 1.25 years,
with the mean for the two cycles being 1.23 ± 0.16 years. One can note that, in spite of abrupt
decreasing of the neutral line oscillation amplitude in 1992, afterwards the patterns can still be
observed, though not so clearly.

Therefore, all three method used above show that in evolution of the large-scale magnetic
field the periodicity of 1.0–1.3 years (1.23 ± 0.16 years) exists. The period is close in magnitude
(and, possibly, in origin) to the period \( \sim 1.3 \) years, which was observed in variations of the solar
rotation by helioseismological methods. This periodicity is found in the regions of the tachocline (Howe et al., (2000)), which separates the differentially rotating solar convection zone from more deep region of the Sun with solid rotation. Thus we obtain an independent confirmation of the statement that the large-scale magnetic field reflects, to a greater extent, processes taking place near the lower boundary of the solar convection zone.

Earlier the period of $\sim 1.3$ years was discovered by various authors in different indices of solar activity. For instance, it was found in sunspot numbers and areas (Kandaurova (1971),

Figure 7. The longitude-latitude maps of the magnetic neutral line position for successive 4-month intervals in phase I of cycle 21. The values to the left mark time, corresponding to the intervals. The bold lines and arrows to the right indicate boundaries between the different patterns of the neutral line.
Figure 8. The same as in Fig 7 for the phase $i$ of cycle 22.

Akioka et al. (1987), in solar flares (Ishimoto et al. (1985), Ikhsanov et al. (1988)), in synoptic $H_{\alpha}$-charts (Tavastsherna et al. (2001)).

It was demonstrated by Ikhsanov ((1993)), that variation of number of large sunspot groups with areas more than 1000 m.s.h. in 1980.0–1984.5 reveals a 158–160-day periodicity. It was also found that the peaks of this oscillation tend to group by three, with the first peak being the highest, i.e. the triple period of 474–480 days ($\sim 1.3$ year) can be observed. The investigated time interval 1980.0–1984.5 corresponds to the epoch when the 150–160-day oscillation was found in X-ray and gamma-ray radiation of solar flares (Rieger et al. (1984), Dennis (1985)). On the other hand, the identification of the sunspot groups with the X-ray bursts in this epoch exhibits a clear relation between the bursts and the largest sunspot groups. According to Table I, the largest sunspot groups concentrate near the boundary of the largest scale (SgS), thereby manifesting a direct relation with the large-scale magnetic field.
6. Conclusions

It follows from the above analysis of latitudinal and longitudinal evolution of the large-scale solar magnetic field during three 11-year cycles (1976–2003 years) that there are certain regularities in their cyclic variations. Below we list some of them.

1. The large-scale magnetic field evolution in 11-year cycle, according to type of its activity, can be divided into two phases. The phase I includes time interval of \( \sim 2-3 \) years near the cycle maximum. In the rest of the cycle (phase II) in either hemisphere the magnetic field of a certain polarity predominates. Besides, the phase I can be divided into two subphases, which are separated by the moment of the magnetic field reversal.

2. Before the sign reversal in cycles 21 and 22 in all antipodal (i.e. shifted by 180° in longitude) 45-degree intervals the neutral line moves from the equator in opposite directions.

3. In cycles 21 and 22 in epoch of the large-scale magnetic field reversal in the antipodal longitudinal intervals with dimension about 135° the magnetic field of opposite signs is observed in all latitudes. Thus, in this part of the phase I the equatorial dipole of the large-scale magnetic field is evidently manifested.

4. After the polarity reversal the latitudinal oscillation of the large-scale magnetic field with regard to the equator is observed, which has a period 1.5–2.5 years and damps to the 11-year cycle minimum.

5. The transitional longitudinal intervals of the large-scale magnetic field correspond to the positions of the active longitudes of solar activity, indicating close relation between the large-scale and the local magnetic fields.

6. There are many similar features between cycle 22 and the anomalous cycle 23 in evolution of their large-scale magnetic field, including the fact that the regions filled by the negative-polarity magnetic in the 22nd cycle are filled by the positive-polarity one in the 23rd cycle.

7. The period about 1.3 years (1.23 ± 0.16 years) is found in evolution of the large-scale magnetic field. The period is close to one found in the region of the solar tachocline by helioseismological methods. Therefore, one can assume that the above-mentioned regularities in the large-scale magnetic field evolution reflect processes, which take place near the lower boundary of the solar convection zone.

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Cyclic evolution and reversal of the solar magnetic field, I

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