ISSN 1063-7729, Astronomy Reports, 2013, Vol. 57, No. 10, pp. 848–858. © Pleiades Publishing, Ltd., 2013.
Original Russian Text © V.N. Obridko, B.D. Shelting, 2013, published in Astronomicheskii Zhurnal, 2013, Vol. 90, No. 10, pp. 857–868.

Global Complexes of Activity

V. N. Obridko* **and B. D. Shelting**

N.V. Pushkov Institute of Terrestrial Magnetism, the Ionosphere, and Radio-Wave Propagation, Russian Academy of Sciences, Kaluzhskoe shosse 4, Troitsk, Moscow, 142190 Russia

Received March 19, 2013; in final form, April 4, 2013

Abstract—A new concept of "Global Complexes of Activity" on the Sun is presented, which brings together objects associated with both global and local fields in a single framework. Activity complexes have traditionally been identified purely from observations of active regions. We show here that a global complex also includes coronal holes and active regions. Our analysis is based on a large dataset on magnetic fields on various scales, SOHO/MDI observations of active regions and magnetic fields, and UV observations of coronal holes. It is shown that the evolution of coronal holes and active regions are parts of a single process. The relationships between the fields on different scales during the generation of the cycle is discussed.

DOI: 10.1134/S1063772913100041

1. INTRODUCTION

The study of solar-activity complexes has a long history, probably dating back to the work of M.N. Gnevyshev [1], who proved convincingly that, in addition to the general 11-year solar-activity cycle, there are periods of short-term increased activity, which he called "pulses of activity".

In 1938, Gnevyshev had at his disposal very sparse information on the main indices of solar activity, namely, data on the numbers and areas of sunspots, floccules, plages, and prominences. All these are the indices of the local fields. Naturally, he didn't know nothing about the characteristics of the global fields, such as the solar wind and coronal holes. However, he understood intuitively, and declared without proof, that "physically connected solar processes need not occur at the same time". On the other hand, Gnevyshev did not give much consideration to the duration of these periods of increased activity, as is reflected by the term he introduced to describe them. These results were subsequently presented by Eigenson et al. [2].

The next important step was made when Mt.-Wilson magnetographic measurements covering the entire solar surface became available. The new, more correct, term "solar-activity complexes" was then proposed to characterize a long-term (from months to years) increase of the solar activity in a certain longitudinal interval. H.W. and H.D. Babcock [3] were the first to study the distribution of the magnetic fields outside sunspot groups. They considered data for the solar minimum of 1952–1954. In addition to proving the existence of the polar magnetic field, they discovered two systems of magnetic fields at lower latitudes: bipolar magnetic regions, corresponding to active regions, and unipolar magnetic regions, which are extensive areas of the magnetic field of a single polarity.

This work was continued by Bumba and Howard [4, 5], who analyzed Mt.-Wilson magnetograph data for four and a half years from August 1959 to the end of 1962 and from June 1963 to June 1964. They showed that a complex evolves as follows. Within a certain longitude range, no activity is observed for several solar rotations except the diffuse fields of old active regions. Then, one or more new active regions appear and begin to expand gradually in both latitude and longitude. The first group to appear is usually the largest in a complex. Larger complexes have longer lifetimes and contain groups that are larger in size.

It is very important that these authors supposed implicitly that an activity complex should include both active regions and unipolar magnetic regions. This means that one must also consider coronal holes and introduce the concept of a global activity complex. The aim of our present study is to establish the concept of a global activity complex that incorporates objects associated with both local and global fields.

2. FORMULATION OF THE PROBLEM

Studies of global solar-activity complexes should be based on large datasets, including data on the characteristics of both local and global fields, information on processes in the photosphere, chromosphere, and corona, and even data on heliospheric and

*E-mail: obridko@izmiran.ru

geomagnetic disturbances, accumulated over a long time.

This is one reason why the notion of a "complex of activity" has fallen into disuse and is often replaced by that of a "complex of active regions" (or even "complex of sunspot groups"). Studies of the latter do not require extensive databases and, above all, these formations are not expected to last long. For example, Ishkov and Mogilevsky [6], Obridko [7], and Mogilevsky and Shilova [8] defined a complex of active regions as two or more active regions connected by a common magnetic field displaying interconnections and interaction of their components or parts of the complex in the course of its evolution.

An additional difficulty that arises in analyzing global activity complexes is the need to take into account the interaction of fields on different spatial scales and with different intensities. There is no doubt that large-scale fields are associated with the global magnetic field ([9–12]), and their evolution is probably controlled by processes deep beneath the photosphere, possibly at the base of the convection zone. On the other hand, the structure of a complex depends strongly on the evolution of intense. shallow fields of active regions lying at depths of 5–10 Mm.

The genetic relation between the components of a complex is not clear. On the one hand, large-scale fields are intensified by subsurface flows and appear to provide the building material for the fields of active regions. On the other hand, the weak magnetic fields remaining after the decay of active regions also form extended features that merge with the primary large-scale field.

The large-scale magnetic field is usually associated with regions of open field (i.e., field whose lines extend into interplanetary space and are tied to the solar wind). These regions are responsible for the occurrence of coronal holes (CHs). Wang et al. [13] identified CHs with regions of open field. Since then, these terms have been used equally for CHs observed in the UV and X-ray on the disk and at the limb. Of course, this coincidence is purely statistical. Regions of open magnetic field are determined via complicated calculations with a large number of additional assumptions in a model with a potential field with a source surface. The occurrence of CHs does not depend on the magnetic field structure alone. An important role is also played by the relative contribution of various coronal-heating mechanisms, which may be different in different CHs.

In addition, the degree of unipolarity of CHs at the photospheric level is usually overestimated. In fact, any CH contains small regions of the opposite polarity. However, when studying the large-scale field, these irregularities are smoothed over. Obridko and Shelting [14] have recently analyzed 338 CHs distributed over all phases of Cycle 23. They calculated the unipolarity indices for all the CHs, defined as the ratio of the absolute value of the mean radial magnetic field B_R to the mean of its absolute value:

$$\mathrm{IU} = |\langle B_R \rangle| / \langle |B_R| \rangle.$$

For a strictly unipolar field, $UI = 10$, while this value will be close to zero in a multi-polar region. At a height of $11R_8$ (where R_8 is the radius of the Sun), 281 CHs (i.e., 83%) had UI values of 0.9–1.0. This agrees with the earlier result of Bugaenko et al. [15] that CHs become mainly unipolar at a height of $105R_8$.

Obridko and Shelting [14] also studied the internal structures of 18 CHs distributed over all phases of Cycle 23 in the 28.4 nm band. It was found that a CH consists of a darker and a lighter part. The brightness of the darkest part is less than 25% of the mean disk brightness in the given year. This region is surrounded by a lighter part, whose brightness is less than 50% of the annual mean brightness at the given wavelength. The darkest part of a CH is where the field is maximum, with the field lines being weakly divergent and inclined at angles of no more than 20°. Outside the darkest part of the CH, the field lines can deviate significantly from the normal direction. In general, this picture is similar to the one proposed by Wang et al. [16] to explain radio observations of CHs, which was later confirmed by Obridko and Shilova [17] and Obridko [18].

Since the relationship between regions of open field and CHs is quite clear, the it is physically justified to take these terms to be equivalent. However, analogous correspondences between other objects are not so evident. Many authors have regarded large quasi-unipolar regions as regions of open field, and identified their boundaries with the boundaries of CHs. This approach has no physical grounding. Large quasi-unipolar regions may merely be remnants of former active regions. The fields in such objects are shallow, and the field lines close inside the same region. They do not form regions of open field and have unipolarity indices much less than unity. This should be borne in mind in further comparisons.

3. GENERAL DESCRIPTION OF A GLOBAL ACTIVITY COMPLEX

In the process of their evolution, the large-scale magnetic fields of regions of open field, CHs, and active regions form a single complex with the following properties. Regions where the magnetic fields in the chromosphere and lower corona depart from the radial direction by less than 20° are sources of optical and X-ray CHs. In spite of the physical identity of the two objects, their boundaries may not coincide, and there

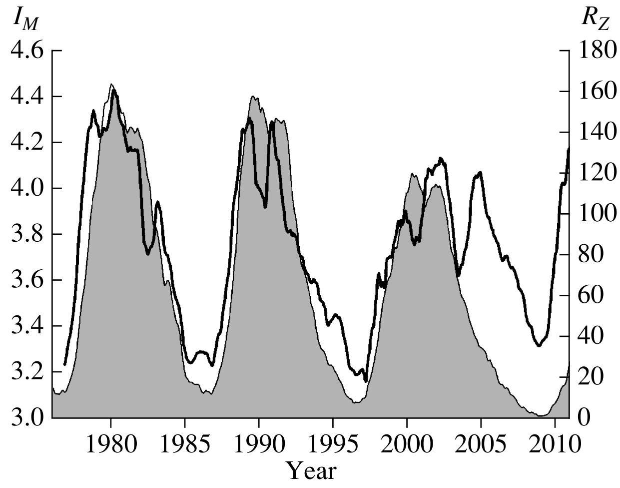

Fig. 1. The indices R_Z (shaded, right-hand scale) and I_M (bold curve, left-hand scale) in Cycles 21–23.

may be a delay in the appearance of the CH relative to the appearance of the regions of open field.

After two or three rotations following the appearance of a CH, the shape and size of the CH begins to change under the influence of the active regions situated between the conjugate CHs. As a result, a saddle-type feature appears in the transverse field at the photosphere level near the boundaries of the CHs.

Outside the photometric CH, the magnetic vectors converge to the conjugate active regions to form a single activity complex. This effect is particularly pronounced for large active regions. The relationship between large active regions and CHs was noted by McIntosh [19] and Bumba et al. [20]. It exists despite the fact that the source of the large-scale magnetic field lies deep at the bottom of the convection zone [21], and the spots in active regions are known today to be much more shallow features.

The lifetimes of CHs range from two to three rotations to 1.5 years, and therefore exceed those of the related active regions. As the active regions decay or disappear, the CHs change accordingly.

4. THE DATA USED

We chose two typical periods in Cycle 23 for the analysis: from October 1999 to March 2001 (Carrington rotations 1954–1974) and from December 2002 to December 2003 (Carrington rotations 1997–2010). These intervals were taken for the following reasons. The first covers the maximum of Cycle 23 (March 2000) and the entire period of the polar field reversal. The second displays a characteristic stable structure of the quasi-equatorial dipole that arises often in the declining phase of the activity cycle.

Figure 1 illustrates the time variations in the sunspot numbers R_Z and the effective solar multipole I_M. This index was introduced in our earlier paper [22] and described in detail in [23], where it was denoted by the abbreviation ESMI.

This index characterizes the ratio of the large-scale and small-scale fields in the Sun. When global fields with characteristic spatial scales comparable to the solar radius dominate, I_M approaches the dipolar value 3. When smaller-scale fields dominate (at the cycle maximum), it is close to 5.

The time intervals considered have different large-scale field structures. The first interval corresponds to the cycle maximum and follows soon after the reversal of the polar field. The field structure is not quite stable, and can vary on a characteristic time scale of two to three solar rotations. I_M reaches its maximum value, providing evidence for a relatively small characteristic spatial scale of the field at the photospheric level. The field structure in the second interval is quite different. A two-sector field is preserved throughout this time interval, i.e., during 14 rotations. This structure can be described as an equatorial dipole with its axis in the vicinity of the equator. The synoptic maps reveal a slight shift of the entire structure by 30°–40° west, indicating that the equatorial dipole rotates faster than the surface layers. The period of this rotation is close to the solid-body rotation period of 27 days and is lower than the classical Carrington period of 27.2753 days. This situation often takes place in the first half of the declining phase and results in an increased occurrence of solar and solar-associated geophysical events.

Comparison of the positions of CHs with those of active regions involves certain difficulties. It is not entirely clear *a priori* what should be considered to be the boundary of a CH, even when it is observed at the same wavelength. This problem was studied in detail in [14, 26, 27] for CHs observed at 284 nm. The problem becomes even more complex when comparing observations at different wavelengths.

Figure 2 represents the same CH observed at the center of the disk during May 29–30, 2000 at wavelengths of 171, 195, 284, and 1083 nm (from left to right). The first three images were obtained with the SOHO/EIT telescope and were downloaded from the site http://umbra.nascom.nasa.gov/eit/eit-catalog.html. The image at 1083 nm was taken from the Solar Geophysical Data. Despite the general similarity, the images differ significantly in detail. This is quite understandable, since the radiation at these wavelengths is determined by regions with entirely different temperatures.

Given all the above, we took the calculations of the regions of open field as the basis for our analysis.

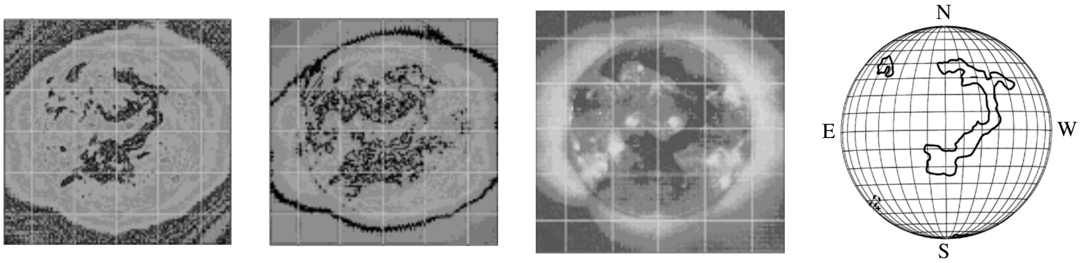

Fig. 2. The same CH observed at the center of the disk during May 29–30, 2000 at wavelengths of 171, 195, 284, and 1083 nm (from left to right).

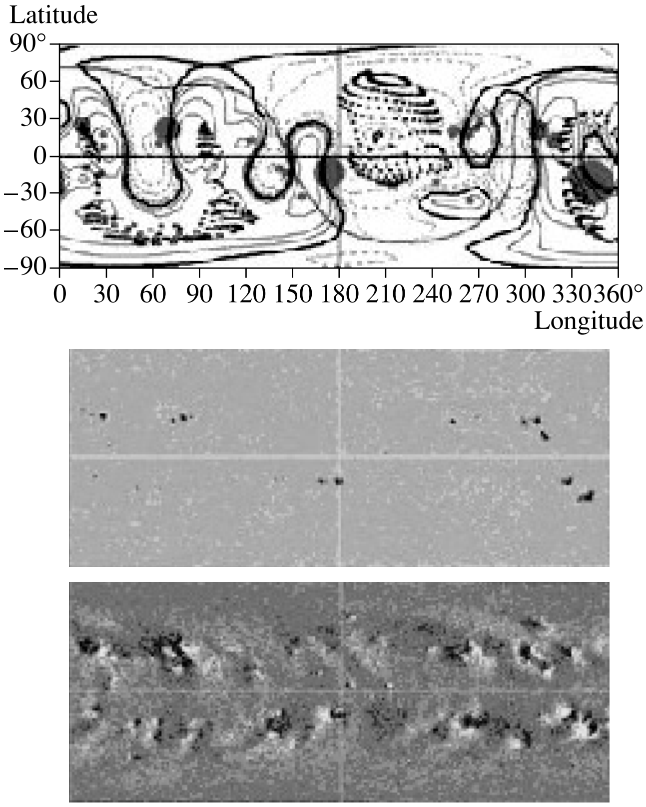

Fig. 3. Data for Carrington rotation 1963 (May 16, 2000–June 13, 2000). The upper panel shows the magnetic field structure calculated in the photosphere. The thin dashed and solid lines depict contours of the negative and positive radial magnetic field, respectively. The bold curve represents the neutral line of the radial magnetic field in the photosphere and at the source surface. The large circles mark the positions of sunspot groups according to the SGD data, with the size of the circle being approximately proportional to the group area. The second and third panels show the active regions and magnetic fields according to SOHO/MDI data.

The positions and structures of the regions of open field were determined using the standard method described earlier by Obridko and Shelting [24, 25]. The John Wilcox Observatory data of photospheric magnetic observations were downloaded from the site http://wso.stanford.edu/. We first calculated the Legendre polynomial expansion coefficients from these data via a least-square fit in a potential approximation, and then calculated all the magnetic-field components in a spherical layer from the photosphere to the source surface. The calculations were carried out for a source surface located $2.5R_\odot$ from the center of the Sun. The first ten harmonics of the expansion were taken into account. The field lines were then traced down from the nodes of the uniform grid on the source surface, where they are open by definition, to their intersection with the chosen spherical surface. We chose the photosphere surface for this purpose, in order to make a comparison with active regions. This approach enables us to outline the region of open field and, as has been shown in a number of studies (see, e.g., [14]), provides a fairly good agreement with observations of CHs in the λ284 nm line.

The positions and shapes of regions of open field determined in this way were compared to the SOHO/MDI data on the photospheric active regions and magnetic fields (http://soi.stanford.edu/magnetic/index5.html and http://soi.stanford.edu/magnetic/index6.html).

An example of such a comparison is given in Fig. 3, for Carrington rotation No. 1963 (May 16, 2000–June 13, 2000). The upper panel shows the calculated magnetic-field structure in the photosphere. The thin dashed and solid lines depict the contours of the negative and positive radial magnetic field, respectively. The bold curve represents the neutral line of the radial magnetic field in the photosphere and at the source surface. The large circles mark the positions of sunspot groups according to the Solar Geophysical Data, with the size of the circle approximately proportional to the group area. Active regions with areas more than 100 msh were taken into account.

The second and third panels show the active regions and magnetic fields according to SOHO/MDI data.

Note that the vertical axis in the upper panel plots heliographic latitude, while the vertical axes in the two lower panels plot the sine of the latitude.

During most of the first selected time interval, the large-scale structure is stable and, on the whole, corresponds to the field expected for a polarity reversal. During the minimum and rise of Cycle 23, the field at the north pole is positive, and fields of a single sign cover the entire disk. This is most clearly seen in rotations 1958–1959 (January–February 2000). Then, gradually, positive field begins to dominate the southern and negative field the northern pole. This process takes about a year, and only in rotations 1973–1974 is the separation of the fields completed in the equatorial zone. This means that the tilt (curvature of the heliospheric current sheet) decreases down to about 20°. In general, the pattern is quite simple and stable, and corresponds to a simple two-sector structure during most of the period. The second period is fully dominated by a stable two-sector structure.

5. EVOLUTION OF THE ACTIVITY COMPLEXES

Let us now describe the variation of the open field lines in each of the two time intervals considered in detail.

In spite of the relative simplicity of the source-surface field in the first time interval, the structure of the open field lines was not as simple at their feet, and underwent significant variations. Figure 4 represents synoptic maps of the regions of open field divided into seven periods, each characterized by relatively similar and stable regions of open field structure. In the first time interval (rotations 1954–1957), there were six regions of open field forming two giant complexes. At the center of the map, at longitudes of 120–270° (complex 1), we can see fairly large compact regions connected with each other and with the polar zones. At longitudes of 330–30°, there is another region of open field that is more loosely structured and less extensive (complex 2). We can see active regions in the vicinity of the regions of open field, the largest of which lie directly on the boundary of the central regions of open field.

In rotations 1958–1960, the regions of open field become more loosely structure and are fairly weakly pronounced. The connection with the polar zone disappears. Simultaneously, the level of solar activity decreases. There are numerous active regions, but no large ones among them.

In the following period (rotations 1960–1961) the configuration begins to change. The first complex becomes narrower and more compact. Its center of mass shifts toward longitudes 210°–270°. In addition, thin strips of regions of open field appear in the range 60°–120°. These are the remnants of the first complex and, at the same time, the seeds of a new increase of the regions of open field and complex 2. They are moving west, as is readily seen on the next panel. The large active regions are mostly located in the vicinity of regions of open field.

In the course of the variations described above, the second complex remains at the same place, but its center of mass shifts toward longitudes 30°–60°. Complex 2 expands and intensifies, most strongly beginning from rotation 1960, and many active regions appear inside the complex simultaneously. With the increase of the number of active regions in rotation 1960, the giant complex 2 divided into two equal parts, with a unipolar region of opposite (negative) polarity wedged between them. However, a CH did not arise in this location.

The eastern part of complex 1 decreases with time and nearly vanishes completely, while the western part begins to increase starting from rotation 1958 and remains in this condition during eight Carrington rotations (1958–1064), reaching longitude 150°. Large active regions that arise at the periphery of the complex reduce the size of the regions of open field. In rotation 1965, a very large number of active regions all over complex 1 changed its structure entirely. Only its left (eastern) part remained in rotations 1967–1970,

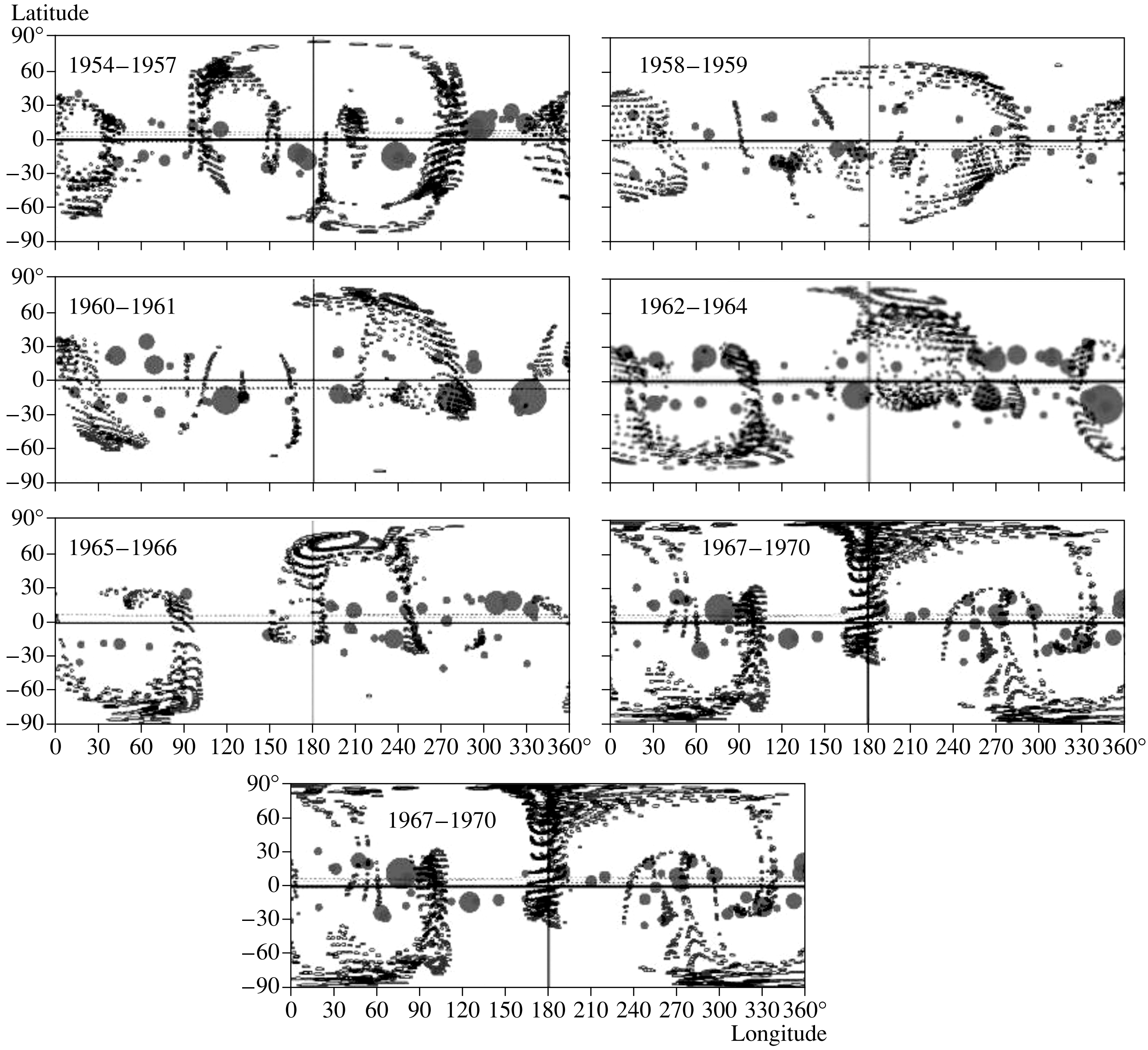

Fig. 4. Synoptic maps of regions of open field for Carrington rotations 1954–1974 (the first period considered). The dots show the feet of open field lines, and the circles show sunspot groups, with the size of the circles being proportional to the group area.

but it was very compact, covered a broad range in latitude (from −40° to +90°), merging with the polar CH, and existed for a long time (until rotation 1970).

In the last four rotations (1971–1974), the regions of open field are isolated and small in size, occasionally emerging and vanishing, and their relationship to active regions becomes less clear.

Further, the regions of open field decay gradually in the equatorial zone, nearly vanishing there by the end of the period.

During the second selected time interval (rotations 1997–2010), the activity was much lower, in terms of both CHs and in Wolf numbers. The structure of the large-scale field was extremely stable and changed little throughout the period. Therefore, we will describe this period only briefly.

Two large complexes were observed corresponding to elements of the sector structure. Both complexes remained almost unchanged during all 14 Carrington rotations.

Complex 3 corresponds to the negative sector of the global field. It contains two regions of open field

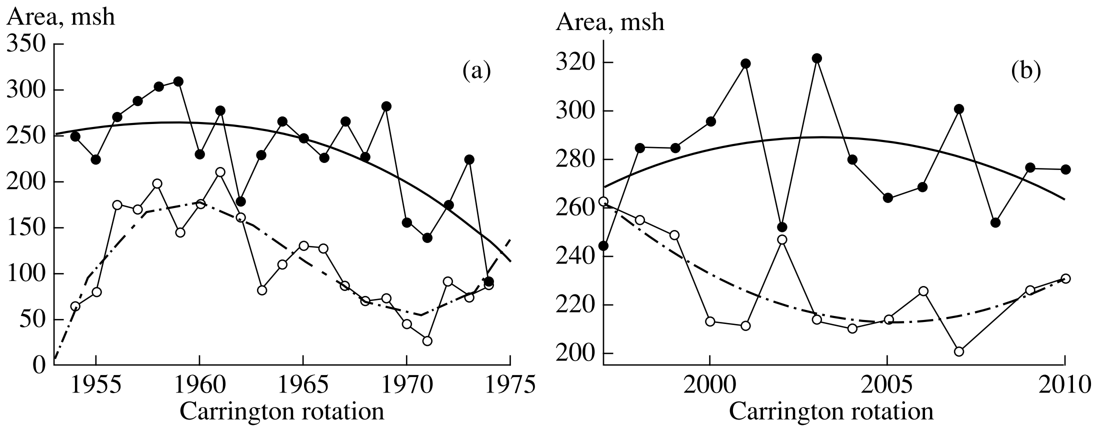

Fig. 5. Area variations of the activity complexes in the (a) first and (b) second intervals.

connected with the pole. The total area of open field increases somewhat in the middle of this period. Active regions are few and small, and their appearance and disappearance does not affect the structure of the complex. Some large active regions appeared in the last two rotations (2009 and 2010), but they also had no appreciable effect on the structure of the complex.

Complex 4 corresponds to the positive sector of the global field. It consists of two or three small regions of open field surrounded at the photospheric level by a unipolar region with a complex shape, mainly of positive sign with occasional small negative elements. Large active regions that appeared during rotations 2003 and 2004 did not significantly affect the structure of the complex. At the end of the interval (rotations 2007–2010), complex 4 contained virtually no active regions.

6. JOINT EVOLUTION OF THE TOTAL AREA OF REGIONS OF OPEN FIELD AND THE NUMBER OF SUNSPOT GROUPS IN A COMPLEX

To study the joint evolution of active regions and regions of open field in activity complexes, we analyzed the evolution of the area of regions of open field and the sunspot numbers.

The area of regions of open field was estimated by tracing the field lines down from nodes of the uniform grid on the source surface, where they are open by definition, to their feet in the photosphere. This enabled us to delineate the regions of open field and, as shown in a number of studies (see, e.g., [14]), provides fairly good agreement with observations of CHs. The number of field lines that go out of a grid with uniformly distributed nodes (72×30) on the source surface and are concentrated in a given region of open field can serve as a measure of the area in question.

Figure 5 illustrates the variations of the areas of activity complexes observed in the first (left) and second (right) intervals considered. In the first interval, the complex areas change synchronously, while they change in anti-phase in the second interval.

Figure 6 shows the relationship between the area of the regions of open field and the number of sunspot groups in the complexes in the first (left) and second (right) intervals. The number of active regions in a complex increases with the area of the regions of open field (or the associated area of CHs). Although the correlation coefficient is not high (0.39 ± 0.13 in the first interval and 0.47 ± 0.15 in the second), the positive tendency is evident. This positive correlation supports the existence of a genetic relationship between regions of open field and sunspots in the early stages of their evolution. As a region of open field is formed, a CH appears over the region after one or two solar rotations, and, somewhat later, a sunspot group emerges at the periphery.

7. THE MUTUAL LOCATIONS OF REGIONS OF OPEN FIELD AND ACTIVE REGIONS

Figure 7 represents a map of the large-scale field observed on May 18, 2000. The small circles show the feet of open field lines (regions of open field). Superimposed on this map is the structure of the local magnetic fields observed by SOHO/MDI. The largest active region, at the disk center, is located at the periphery (or even inside) the regions of open field. This area also hosts numerous less powerful active regions. A few more active regions are located on the neutral line of the large-scale field in the north-east quadrant.

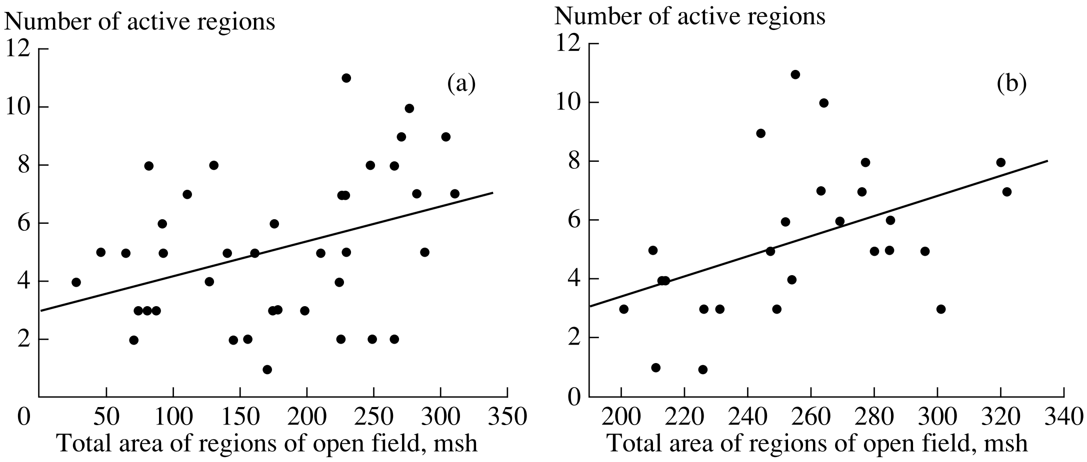

Fig. 6. Relationship between the area of the regions of open field and the number of sunspot groups in a complex in the (a) first and (b) second intervals.

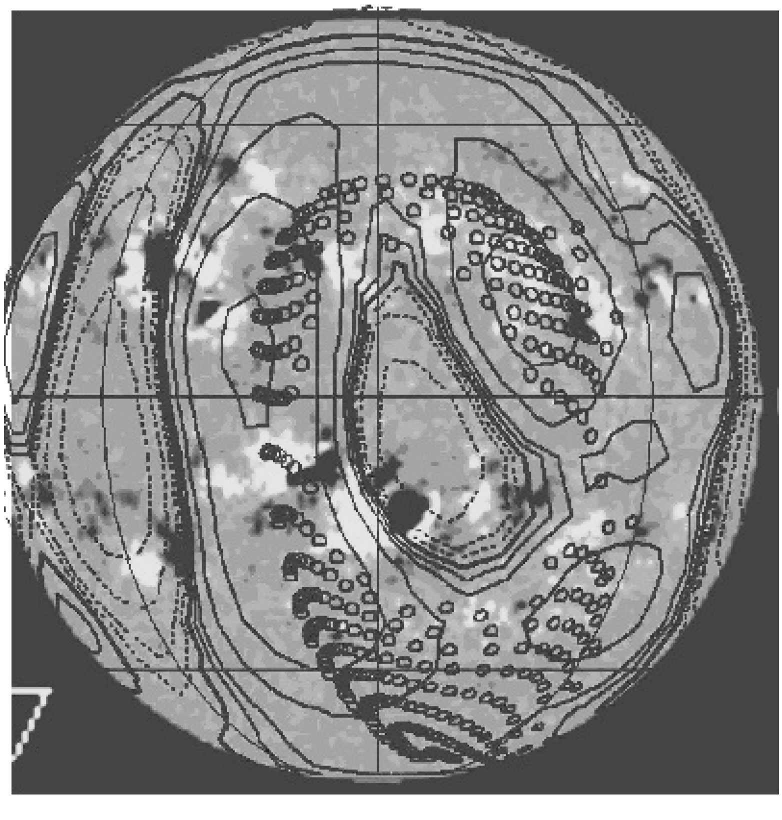

Fig. 7. The large-scale field of May 18, 2000. The small circles show the feet of open field lines (regions of open field); the light and dark areas illustrate the structure of the local magnetic fields inferred from SOHO/MDI observations.

As was shown by Obridko and Shelting [14], CHs originate in regions of open field where the field lines are mainly radial. With distance from the region of strictly radial field, the force lines associated with the ambient photosphere become more and more inclined. The CH continues to exist until the inclination reaches 20°, although its contrast decreases gradually. As a result, a feature appears that can be considered a sort of CH "penumbra". Further, as the inclination reaches 50°, the brightness of the vicinity of the CH becomes comparable to the brightness of the undisturbed chromosphere. The region of field

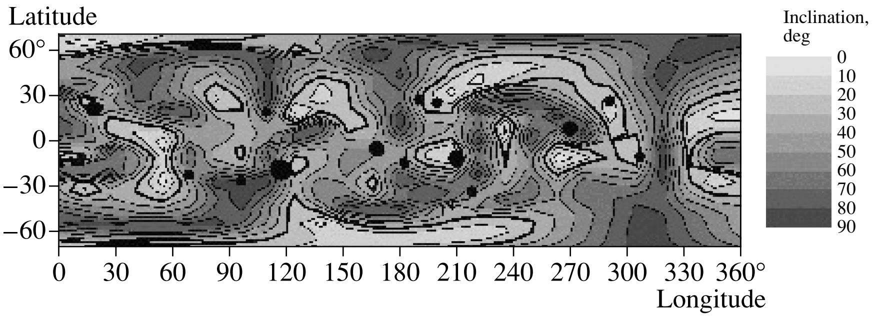

Fig. 8. Field line inclinations for rotation 1959.

lines with inclinations between 20° and 50° is where the active regions that are conjugate to the CH are located.

Figure 8 shows as an example a synoptic map of the field line inclinations for rotation 1959. The gray scale corresponds to inclinations from 0° to 90°. The 30° contour is shown as a bold line. The circles represent sunspot groups, with the size of the circle corresponding approximately to the group area. Most of the circles are located within the 50° contour, and are mainly on the 30° contour.

To quantitatively estimate how close the sunspot groups are to the CHs (which we identify with regions of open field), we analyzed the entire dataset. By "closed," we mean groups whose centers are less than 10 heliographic radii from the CH boundary.

Tables 1 and 2 show that most of the sunspot groups (both small and large) are located in the vicinity of CHs, and their total areas are larger than the total areas of groups lying far from CHs. This effect is even more pronounced if we consider large groups alone.

8. DISCUSSION

There is no doubt that activity complexes are not random combinations of several active regions in a single feature with a common location on the disk and displaying similar evolution over several solar rotations. Activity complexes are a necessary part of the overall large-scale organization of solar activity on both spatial scales and long time scales. Their formation and evolution are controlled by both local fields and global processes.

The mechanisms responsible for the global organization of solar activity are the large-scale solar dynamo and meridional flows.

It is now clear that, in addition to an open configuration of the global magnetic field, another condition for the occurrence of CHs at middle latitudes is the existence of active regions with strong local fields in their vicinity. The relationship between CHs and active regions was established in early work based on Skylab data [16, 28, 29]. The appearance of the open fields of CHs is usually accompanied by the formation of two systems of closed field lines. It was later shown [30, 31]), that the change of the boundaries and energy balance in a CH is sometimes due largely to sporadic and pulse-like fluxes of hot plasma (X-ray "jets") and regular energy fluxes from the surrounding active region. Active regions in the vicinity of CHs can be connected with the CHs either dynamically or energetically [17, 18].

The magnetic field is generated at the base of the convection zone as a result of the combined action of the toroidal magnetic field and differential rotation (the Ω dynamo). This field emerges from the tachocline mainly in the equatorial zone, possibly in the form of separate flux tubes, and is manifest as active regions. The process can be observed as a wave that runs from middle latitudes toward the equator and forms a pattern similar to the Maunder butterflies. This simple and convincing scheme was, nevertheless, criticized in detail. Let us mention some of the objections raised. First, the field generated at the base of the convection zone is somewhat too weak to provide the values of 3000 G or more that are typical for sunspots. Second, in this scheme, the magnetic field in an emerging flux tube is mainly radial, while the field in a bipolar active region is mainly transverse. The field outside the active region is also mainly transverse. The emergence of such a system through the dense plasma of the photosphere and sub-photospheric layers is severely hindered. Therefore, it is more likely that the quadrupolar (or bipolar) structure arises in the immediate vicinity of the surface. However, the central part of the flux tube remains radial, and maintains its connection with the underlying layers. Therefore, the central part of the complex is the zone of open field lines. In the process, a darker X-ray or UV feature—a CH—may appear in the vertical field. Active regions arise at the periphery of this feature, where the field lines deviate from the radial direction, which, in turn, affect and distort the regions of open field. Their rotational

Characteristics of active regions for the first and second time intervals

Parameter	All active regions	Active regions near CHs	Active regions far from CHs
Carrington rotations 1954–1974			
Sum of all active-region areas	139342	105752/139342 = 0.759	33590/139342 = 0.241
Sum of active region areas > 600 msh	68841/139342 = 0.494	55754/68841 = 0.810	13087/68841 = 0.190
Sum of active region areas < 600 msh	70501/139342 = 0.506	49998/70501 = 0.709	20503/70501 = 0.291
Total number of active regions	318	228/318 = 0.717	90/318 = 0.283
Number of active regions with areas > 600 msh	66	54/66 = 0.818	12/66 = 0.182
Number of active regions with areas < 600 msh	252	174/252 = 0.690	78/252 = 0.310
Carrington totations 1997–2010			
Sum of all active-region areas	58992	41981/58992 = 0.71	17011/58992 = 0.29
Sum of active region areas > 600 msh	24255/58992 = 0.41	21002/24255 = 0.86	3253/24255 = 0.14
Sum of active region areas < 600 msh	34737/58992 = 0.59	20979/34737 = 0.60	13758/34737 = 0.40
Total number of active regions	152	96/152 = 0.72	56/152 = 0.28
Number of active regions with areas > 600 msh	23	19/23 = 0.82	4/23 = 0.18
Number of active region with areas < 600 msh	129	77/129 = 0.60	52/129 = 0.40

period differs somewhat from that of the deep field. The surface fields rotate at the Carrington velocity, while the rotational period of the deep field is close to 27 days, i.e., to the value characteristic of rigid-body rotation. After a few solar rotations, the active regions decay. Their influence on the flux tube of the deep field gradually ceases, and the open field structure is restored. A new CH appears; however, it is not formed of the remnants of the active region, but is instead associated with the deep field.

ACKNOWLEDGMENTS

The work was partially supported by the Russian Foundation for Basic Research (project no. 11-02-00259) and the Basic-Research Program of the Presidium of the Russian Academy of Sciences P-22. We thank the SOHO and WSO teams for making their data available through the Internet.

REFERENCES

1. M. N. Gnevyshev, Izv. Glavn. Astron. Observ. Pulkovo **16**, 36 (1938).
2. M. S. Eigenson, M. N. Gnevyshev, A. I. Ol', and B. M. Rubashev, *Solar Activity and Its Terrestrial Manifestations* (Gos. Izdat. Tekhn.-Teor. Liter., Moscow, 1948) [in Russian].
3. H. W. Babcock and H. D. Babcock, Astrophys. J. **121**, 349 (1955).
4. V. Bumba and R. Howard, Astrophys. J. **141**, 1492 (1965).
5. V. Bumba and R. Howard, Astrophys. J. **141**, 1502 (1965).
6. V. N. Ishkov and E. I. Mogilevsky, *Evolution of Complexes of Eruptive Active Regions on the Sun. Solar Activity* (Izd-vo KazSSR, Alma-Ata, 1983), p. 3 [in Russian].
7. V. N. Obridko, *Sunspots and Activity Complexes* (Nauka, Moscow, 1985), p. 255 [in Russian].

8. E. I. Mogilevsky and N. S. Shilova, Izv. Krymsk. Astrofiz. Observ. **94**, 60 (1998).
9. V. N. Obridko and B. D. Shelting, Astron. Rep. **44**, 103 (2000).
10. V. N. Obridko and B. D. Shelting, Astron. Rep. **47**, 333 (2003).
11. E. V. Ivanov and V. N. Obridko, Solar Phys. **206**, 1 (2002).
12. M. L. Demidov and V. M. Grigor'ev, Soln.-Zemn. Fiz. **6**, 10 (2004).
13. Y.-M. Wang, S. H. Hawley, and N. R. Sheeley, Science **271**, 464 (1996).
14. V. N. Obridko and B. D. Shelting, Solar Phys. **270**, 297 (2011).
15. O. I. Bugaenko, I. A. Zhitnik, A. P. Ignat'ev, et al., Izv. Krymsk. Astrofiz. Observ. **100**, 123 (2004).
16. Z. Wang, M. R. Kundu, and H. Yoshimura, in *Solar and Stellar Coronal Structure and Dynamics,* Ed. by R. C. Altroc (Nat. Solar Observ., Sunspot, NM, USA, 1988), p. 458.
17. E. I. Mogilevsky, V. N. Obridko, and N. S. Shilova, Solar Phys. **28**, 247 (1997).
18. V. N. Obridko, in *Advances in Solar Connection with Transient Interplanetary Phenomena,* Ed. by X. H. Feng, F. S. We, and M. Dryer (Internat. Acad. Publ., Beijing, 1998), p. 41.
19. P. S. McIntosh, in *The Solar Cycle*, Ed. by K. L. Harvey, ASP Conf. Ser. **27**, 14 (1992).
20. V. Bumba, Klvana, and J. Sykora, Astron. Astrophys. **298**, 923 (1995).
21. E. E. DeLuca and P. A. Gilman, in *Solar Interior and Atmosphere*, Ed. by A. N. Cox, W. C. Livingstone, and M. S. Matthews (Univ. Arizona Press, Tucson, AZ, USA, 1991), p. 275.
22. E. V. Ivanov, V. N. Obridko, E. V. Nepomnyashchaya, and N. V. Kutilina, Solar Phys. **184**, 369 (1999).
23. V. N. Obridko, E. V. Ivanov, A. Ozguc, et al., Solar Phys. **281**, 779 (2012).
24. V. N. Obridko, B. D. Shelting, I. M. Livshits, and A. B. Asgarov, Solar Phys. **260**, 191 (2009).
27. V. N. Obridko, B. D. Shelting, I. M. Livshits, and A. B. Askerov, Astron. Rep. **53**, 1050 (2009).
26. V. N. Obridko and B. D. Shelting, Solar Phys. **184**, 187 (1999).
27. V. N. Obridko and B. D. Shelting, Solar Phys. **187**, 185 (1999).
28. R. H. Levine, in *CHs and High Speed Wind Streams*, Ed. by J. B. Zirker (Colorado Associated Univ. Press, Boulder, USA, 1977), p. 103.
29. R. H. Levine, M. D. Altschuler, J. W. Harvey, and B. V. Jackson, Astrophys. J. **215**, 636 (1977).
30. K. Shibata, T. Yokoyama, and M. Shimojo, in *New Look at the Sun with Emphasis on Advanced Observations of Coronal Dynamics and Flares,* Ed. by S. Enome and T. Hirayama (Nobeyama Radio Observ., Nagano, Japan, 1994), p. 75.
31. E. I. Mogilevsky, Geomagn. Aeron. **3(6)**, 11 (1995).

Translated by V. Obridko