SPECTRAL ANALYSIS OF VARIATIONS IN THE MONTHLY TOTAL SUNSPOT AREAS AND VARIATIONS IN THE MEAN MAXIMUM SUNSPOT AREA

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ABSTRACT

Variations in the monthly total sunspot areas over the whole solar disk and separately over the northern and southern hemispheres were analyzed for the time interval 1874-1999. Sudden changes (reconstruction) were revealed in the variation spectrum of the total sunspot areas both from cycle to cycle and at the so-called cycle reference points, coinciding with the epochs of reconstruction of the large-scale solar magnetic field. We also studied the variation spectrum of the mean maximal sunspot area in Carrington rotation. Contrary to the total sunspot areas, changes of these variations occur at the maximum of the solar cycle, rather than at the minimum.

INTRODUCTION

The relationship between the local (LF) and large-scale (LSMF) solar magnetic fields is, obviously, undoubted. It is supposed that local fields are generated from large-scale fields at the base of the convection zone (under the mean-field approximation) and then emerge rapidly in the photosphere. The most evident manifestations of local fields in the photosphere are sunspots. In this paper, we study the cyclic behaviour of the variation spectrum of the total sunspot areas and its relation to the corresponding variations of the LSMF structure and energy indices (***n*** and ***I(B$_r$)***, respectively).

EXPERIMENTAL DATA

We have used here the data on sunspot areas from the bulletin Solnechnye Dannye (Solar Data), issued by the Pulkovo Astronomical Observatory, and the Greenwich Catalogue for 1874-1999. Two series of total sunspot areas have been obtained. One series comprises the monthly total values of the daily sunspot group areas for 1874-1999. Another series consists of the maximum areas of all sunspot groups summed up over each Carrington rotation for 1954-1999. As seen from Fig. 1a, the values in the second series are about 3 times as large as in the first one. It is clear that in the case of the maximum sunspot group areas summed up over a Carrington rotation, large long-lived sunspot groups, which join to form complexes of activity, mainly determine their cyclic variation. Such groups are usually clustered in the vicinity of active longitudes and are, apparently, due to global magnetic fields with a typical size of the cells ~70°-120° (supergiant granules) [1].

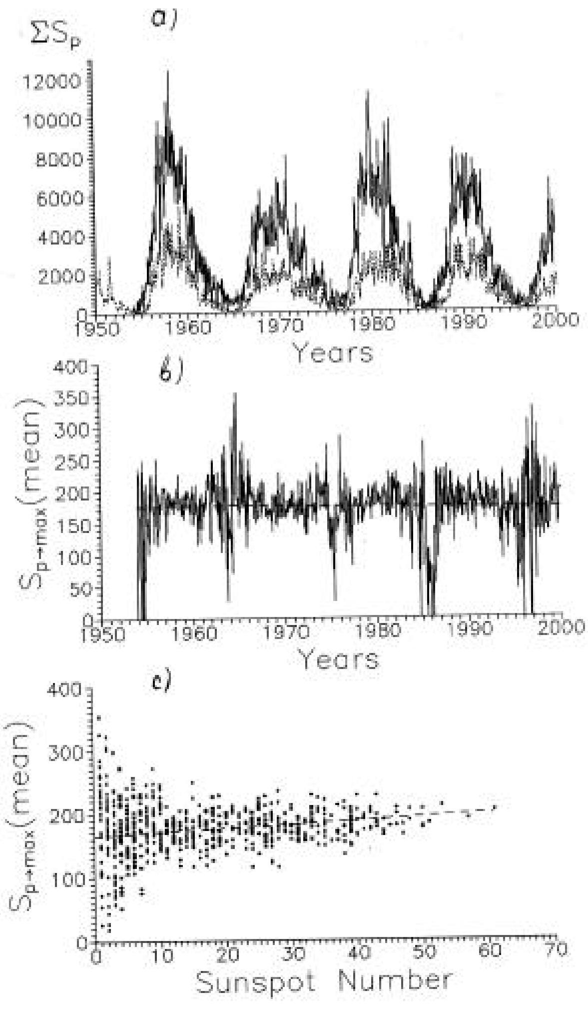

Figure 1. Cyclic variations of the monthly total sunspot areas (dashed line) and maximum sunspot areas summed over a Carrington rotation (solid line) (a); mean maximum sunspot area over a Carrington rotation (b); and rotation-mean maximum sunspot area as a function of the sunspot number observed in a given rotation.

As seen from Fig. 1b, there exists some fixed value of the maximum sunspot group area averaged over one rotation that does not virtually change during the entire period under investigation 1954-1999. A noticeable scattering about this fixed value changes during the 11-year cycle and probably depends on the number of sunspots recorded in each rotation. Figure 1c illustrates this scattering as a function of the sunspot number observed. As follows from the figure, the rotation-mean maximum sunspot group area does, nevertheless, change a bit when passing from rotations with a large number of sunspots observed to those when it is small, increasing from ~170 m.v.h. at the maximum of the cycle to ~200 m.v.h. at the minimum. These values are close to the typical size of supergranules and are, probably, indicative of their variation during a cycle. Recall earlier papers by Bumba [2, 3] where the size of a sunspot group was found to be a multiple of the supergranule size.

VARIATIONS IN THE MONTHLY TOTAL SUNSPOT AREAS

The Spectrum-Time Analysis program (SVAN) has been used to plot a frequency-time diagram that illustrates the cyclic behaviour of the variation spectrum of the monthly total sunspot group areas for 1890-1995 (Fig. 2). The variation period ranges from 1 year (1 cycle/year) to 2 months (6 cycles/year). The diagram reveals sudden changes in the variation spectrum when passing from one 11-year cycle to another. To be more illustrative, we present here the diagram of the variation spectrum of the monthly total sunspot group areas for a shorter period from 1960 to 1995 (Fig. 3). The period of variations ranges from 2 years (0.5 cycles/year) to 3 months (4 cycles/year). As seen from the figure, the spectra for two different 11-year cycles overlap when passing from one cycle to another. It is, apparently, due to the fact that sunspots of a new cycle appear in that period to exist alongside with the sunspots of the previous one. Both diagrams show that abrupt changes in the variation spectrum appear to occur simultaneously in the entire spectral range.

We have also plotted diagrams for the maximum sunspot

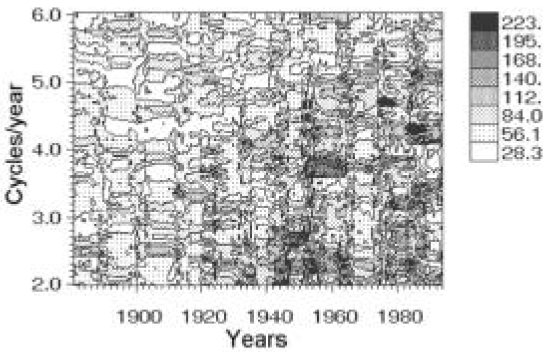

Figure 2. Variation spectrum of the monthly total sunspot areas for 1890-1995.

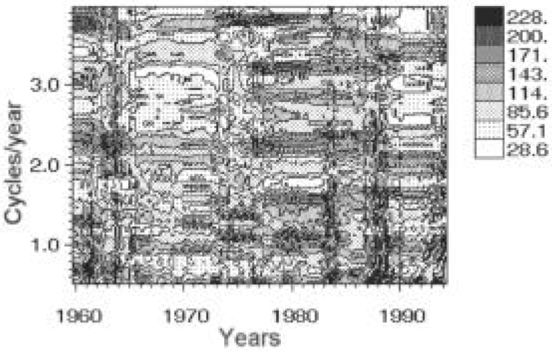

Figure 3. Variation spectrum of the monthly total sunspot areas for 1960-1995.

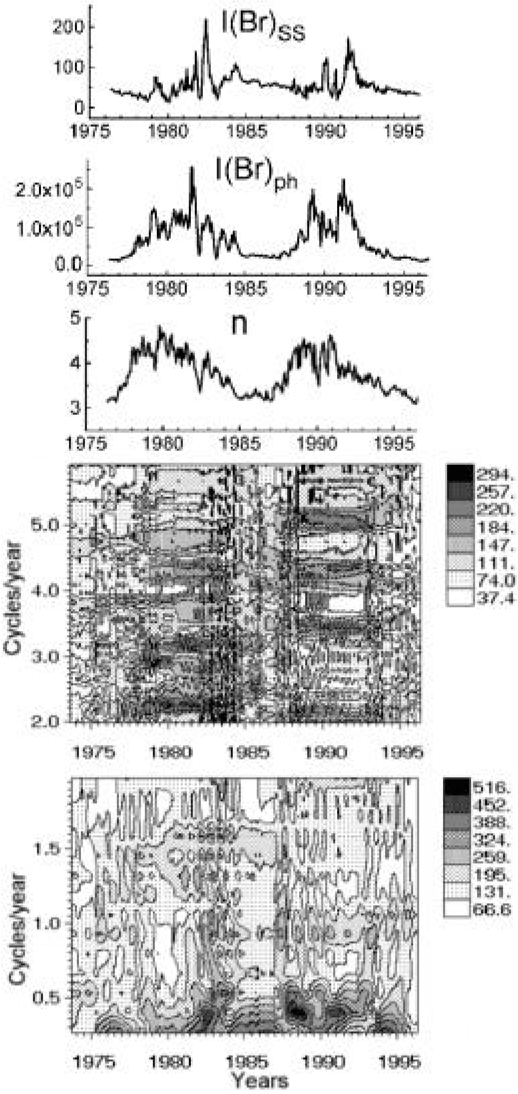

*Figure 4. Diagrams of variation spectra of the total sunspot areas and cyclic variations of the LSMF structure (**n**) and energy indices in the photosphere (**$I(B_r)_{ph}$**) and at the source surface*

group areas summed up over a Carrington rotation. In spite of different summation methods applied, noticeable changes in the variation spectrum of the total sunspot areas occur at the same instant in both cases. Thus, we shall henceforth use only the data on the monthly total sunspot group areas.

Figure 4 represents changes in the variation spectra of the total sunspot areas in the high- and low- frequency parts of the spectrum and variations of the LSMF indices that characterize its structure (***n*** index) and energy (***I(B**$_r$**)*** index) in the photosphere ($I(B_r)_{ph}$) and at the source surface ($I(B_r)_{ss}$). One can see that changes in the variation spectra of the total sunspot areas correlate much better with the LSMF structure index (***n***) than with the energy index ($I(B_r)_{ph}$) in the photosphere. It is most pronounced in the high-frequency part of the spectrum with the variations periods of the order of a few months. The instants of abrupt changes of index ***n*** (reconstruction of LSMF), corresponding to the so-called cycle reference points [4], are manifested in the diagrams of total sunspot areas as changes in the variation spectrum as a whole and its separate harmonics. One can also notice that the variation spectrum of the total sunspot areas intensifies in the low-frequency range (from one to three years) when the ***n*** index is minimum, i.e., when the dipole and quadrupole LSMF components are predominant (global field). At the same instants, the maximum values of the LSMF energy index ($I(B_r)_{ss}$). are observed at the source surface. Thus,

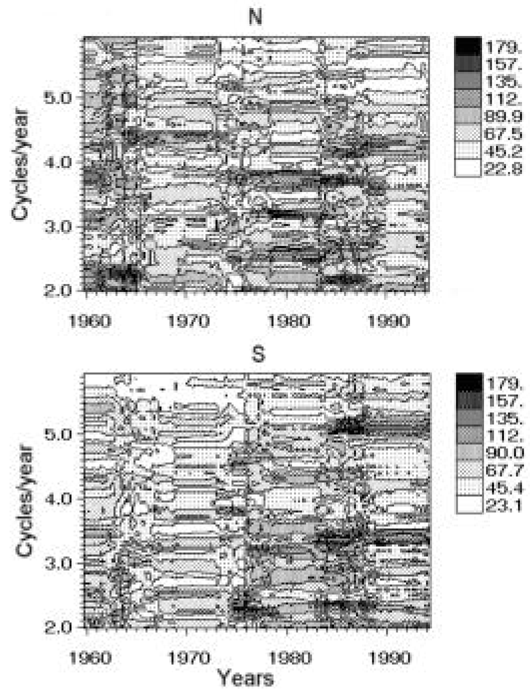

Figure 5. Diagrams of variation spectra of the total sunspot areas in north (N) and south (S)

the behaviour of the variation spectrum of the total sunspot areas is mainly controlled by the magnetic field structure, although the energy of the emerging magnetic fields plays a certain part in the low-frequency part of the spectrum. It should also be noted that the structure index ***n*** is determined to a large extent by LSMF structure variations in the mid-latitude region, where sunspots are observed, while the energy index $I(B_r)$ is determined by the energy of magnetic fields both at mid and high latitudes. Therefore, it is natural that the variation spectrum of the total sunspot areas correlates better with ***n*** than with $I(B_r)$. At the same time, it displays a fairly good correlation with the source-surface values of the energy index ($I(B_r)_{ss}$, because the local fields of sunspots are generated at the base of the convection zone out of large-scale (global) magnetic fields, which determine $I(B_r)$ at the source surface.

The diagrams of the variation spectra of total sunspot areas plotted separately for the north and south hemispheres do not display significant differences. Noticeable changes of the spectra in both hemispheres occur simultaneously all over the spectral range (Fig. 5).

VARIATIONS OF THE MEAN MAXIMAL SUNSPOT AREA IN CARRINGTON ROTATION

Figure 6 represents the cyclic behaviour of the variation spectrum of the mean maximum sunspot group area obtained by dividing the sum of the maximum sunspot areas for a Carrington rotation by the number of sunspots in that rotation. The cyclic curves of the LSMF structure (***n***) and energy indices in the photosphere ($I(B_r)_{ph}$) and at the source surface ($I(B_r)_{ss}$) are shown in the same figure. Unlike the variation spectrum of the total sunspot areas, whose change occurs at the minimum of the 11-year cycle, the spectrum of the mean maximum sunspot areas changes at the cycle maximum. A comparison of variations in the mean maximum sunspot area with the ***n*** and $I(B_r)$ indices reveals that the best correlation is obtained with the LSMF energy index $I(B_r)_{ph}$ in the photosphere. It implies that variations in the mean maximum sunspot area are more closely associated with the LSMF energy variations than with the magnetic field reconstruction determined by convection. The increase of LSMF energy results in the growth of the mean maximum sunspot group area in the rotation.

CONCLUSIONS

Each 11-year sunspot cycle is characterized by its individual variation spectrum of the total sunspot areas. Abrupt changes of the spectrum are virtually simultaneous all over the spectral range and occur at the minimum of the 11-year cycle (when passing from one

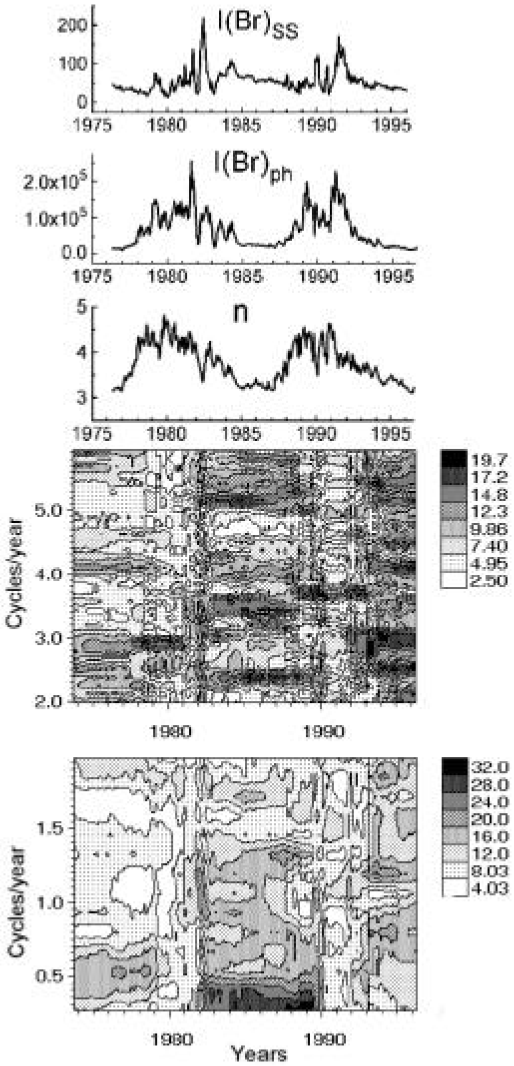

*Figure 6. Variation spectra of the maximum sunspot areas averaged over a Carrington rotation and cyclic curves of the LSMF structure (**n**) and energy indices in the photosphere (**$I(B_r)_{ph}$**) and at the source surface (**$I(B_r)_{ss}$**).*

cycle to another) and at the instants of LSMF reconstruction coinciding with the cycle reference points. The variation spectrum of the total sunspot areas in the low-frequency region (QBO region) intensifies in the epochs of the minimum ***n*** index, i.e., when the dipole and quadrupole LSMF moments (global field) are predominant. Simultaneously, the maximum values of the energy index (**$I(B_r)_{ss}$**) are observed at the source surface. Thus, the behaviour of the variation spectrum of the total sunspot areas is mainly controlled by structural changes in the magnetic fields due to convection. The LSMF energy variations at the base of the convection zone (and accordingly, (**$I(B_r)_{ss}$**) variations at the source surface) play the leading part in the low-frequency range (~2-3 years) of the spectrum.

A comparison of variations of the mean maximum sunspot group area with the ***n*** and **$I(B_r)$** indices reveals that the best correlation is obtained with the LSMF energy index (**$I(B_r)$**) in the photosphere. It implies that variations in the mean maximum sunspot group area are more closely associated with the LSMF energy variations than with the magnetic field reconstruction determined by convection. Besides, the variation spectrum of the mean maximum sunspot areas changes at the cycle maximum, unlike the spectrum of the total sunspot areas, whose change occurs at the minimum of the 11-year cycle. This indicates that the appearance of major sunspot groups and complexes is governed by the cycle of global magnetic fields, which is shifted by ~5-5.5 years with respect to the local field variation [5, 6] and starts at the maximum of the 11-year cycle.

It is interesting to note that the rotation-mean maximum sunspot group area has some fixed value close to the size of a supergranule that does not virtually change during the entire period under investigation (1955-2000), although its dispersion varies noticeably during the 11-year cycle.

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