QUASI-BIENNIAL OSCILLATIONS IN THE N-S ASYMMETRY OF SOLAR ACTIVITY

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ABSTRACT

The north-south asymmetry of solar activity is investigated using the data on coronal green line brightness, total number and summary area of sunspots, all over 1939-2001. Typical time variations of the asymmetry are found to be consonant in these indices. Quasi-biennial oscillations (QBO) of solar activity are well recognizable in the asymmetry of the examined indices, and they are much better manifested than in the indices alone. The time variations of relative QBO power are synchronous for the asymmetry of various solar activity indices. It is revealed that the relative QBO power found in the asymmetry of the studied indices, has a negative correlation with the value of the asymmetry. The above findings should be taken into account when any dynamo theory of solar activity is constructed.

Key words: sunspots; coronal green line brightness; N-S asymmetry; quasi-biennial oscillations.

1. INTRODUCTION

For a long time it is well-understood that the cyclic variations of solar activity are not quite identical in the northern and southern hemispheres. Such a difference is manifested in many solar activity indices and is commonly referred as the north-south (N-S) asymmetry. The nature of the N-S asymmetry remains unexplained and identification of new facts reflecting various aspects of this interesting phenomenon is still in progress. Detailed reviews on the N-S asymmetry studies can be found, e.g., in Vizoso & Ballester (1990), Carbonell et al. (1993), Li et al. (2002) and Mariş et al. (2002).

Here, the N-S asymmetry in three different solar activity indices over a relatively long time interval (1939-2001) is investigated. Namely, the coronal green line brightness (CGLB) I, the total sunspot area S_p and the total number of sunspots Q were chosen to be studied. The Q-quantity represents here the total number of sunspot groups and not the traditional Wolf numbers. The total number of sunspots Q is quite independent and a very interesting index. All the data were treated by the same technique of statistical analysis. This makes it possible to compare the results obtained for the objects originating from completely different phenomena.

In our previous work (Badalyan et al., 2005) the following topics were studied:
1) The space-time distributions of the N-S asymmetry derived from different solar activity indices, and their mutual correlations on both the short and long time scales.
2) Quasi-biennial oscillations (QBO) in the N-S asymmetry of the activity indices and their space- time distribution; comparison of the QBO in the N-S asymmetry with the QBO in the indices themselves.
3) Relationship between the magnitude of the N-S asymmetry and the amplitude of its QBO.

The study in this paper represents some continuation and development of the above topics. The results of the performed analysis indicate that the N-S asymmetry is quite important and informative parameter of solar activity. It seems to represent a fundamental characteristic of solar activity, determining a degree of accordance in processes of the magnetic field generation in both hemispheres.

2. NORTH-SOUTH ASYMMETRY IN DIFFERENT SOLAR ACTIVITY INDICES

The following databases were used in our study:
(a) The coronal green line brightness in the line FeXIV 530.3 nm. This our own database contains observations obtained by a network of coronal observatories and covers the period 1939- 2001 (Sýkora (1971); Sýkora & Rybák (2005)). (b) The total area of sunspots. The monthly averaged S_p were calculated from the data by Greenwich Observatory available at Internet. (c) The total number of sunspots Q. Monthly Q- values were also calculated from Greenwich Observatory data.

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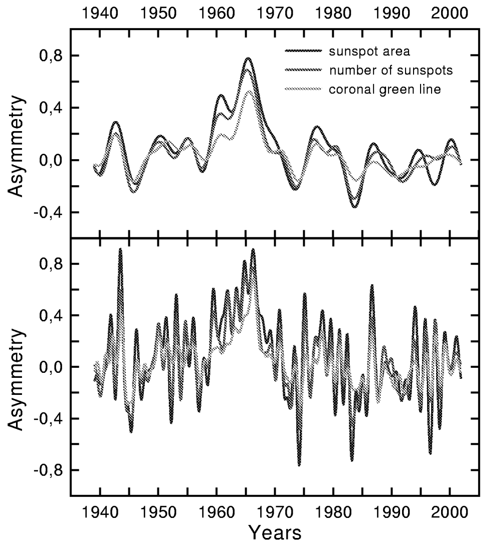

Figure 1. Time variation of the N-S asymmetry in three indices, as calculated for the $0° - 30°$ zone. The curves are obtained by a method of filtration (see the text).

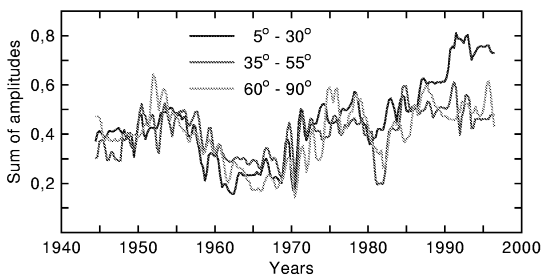

Figure 2. The sum of QBO amplitudes of 3 harmonics.

We determined the N-S asymmetry in the standard way as $A = (N - S)/(N + S)$, where N and S are values of the corresponding activity indices for the northern and southern hemispheres, respectively. Throughout the whole analysis in this paper the monthly-averaged values of all the indices were used.

In Fig. 1 we show variations of the N-S asymmetry on both the long (upper panel) and short (lower panel) time scales for the above-mentioned indices, all within the low-latitude zone $0° - 30°$. The curves are obtained by a method of the spectral filtration (i.e. spectral synthesis). In this method the original distribution containing n terms is subjected to Fourier expansion consisting of $n/2$ terms. Then, an inverse summation of a certain number of harmonics (less than $n/2$) is performed. Reduction of the number of harmonics, used in the inverse summation, allows us to cut the harmonics with the periods less than a preset one. The summations of 15 harmonics (periods above 50 months) and of 50 harmonics (periods above 15 months) are shown in the upper and lower panels, correspondingly. Fig. 1 demonstrates very similar behavior of the N-S asymmetry both on the long and short time scales. In addition to Badalyan et al. (2005), the method of filtration shows that a spectral distribution

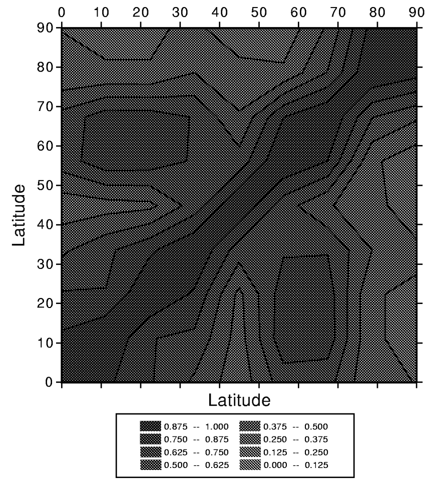

Figure 3. The paired correlation of the sums of QBO amplitudes derived from the CGLB asymmetry within $10°$ latitude zones. Three harmonics of the QBO were summed.

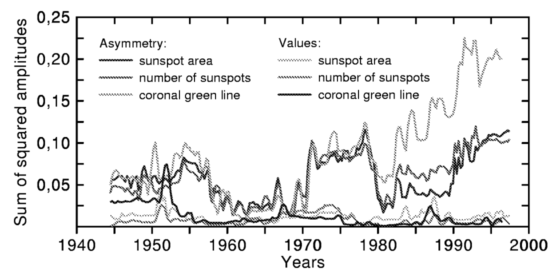

Figure 4. The sums of three QBO squared amplitudes as obtained within the sunspot formation zone $0° - 30°$ for the asymmetry of the three indices (three upper curves) and for the indices alone (three lower curves).

of the N-S asymmetry in different indices is practically identical. The paired correlation coefficients are in the range of 0.93-0.96 for the upper panel and they are within 0.84-0.93 for the lower panel.

Fig. 1 demonstrates that variations of the A quantity are essentially simultaneous for all three indices and well-correlating on both the long and short time scales. At the same time, as shown in Badalyan et al. (2005) the asymmetry variations are almost synchronous at all latitudes.

3. QUASI-BIENNIAL OSCILLATIONS IN THE N-S ASYMMETRY AND IN THE ACTIVITY INDICES

The QBO belong to the most interesting phenomena among the periodic oscillations observed in the Sun's activity. There are reasons to assume that the QBO are related to similar periodic processes at the base of the convective zone.

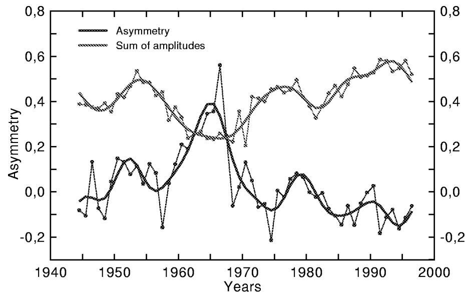

Figure 5. Time course of the asymmetry (blue points) and the sums of QBO amplitudes (red points), as averaged over the entire range of latitudes, are plotted. The thick smoothed lines are obtained by a method of filtration.

The time variations shown in Fig. 1 (lower panel) indicate that the short-term oscillations with the periods of 1.5 - 3.0 years are apparently present in the N-S asymmetry. For a detailed analysis of the time and latitude QBO variations a method of "spectral variation analysis" (SVAN) is used. Here, we have employed a modified SVAN which, in contrast to that commonly used and widely described in the literature (e.g., Dziewonski et al. (1969)), includes some normalization to a standard (i.e., dividing by the mean-square deviation). Such a normalization reduces all the oscillations to a common scale, and the sum of the squares of all the amplitudes is equal to 1 in each spectrum. This enables to compare the SVAN results of the different processes irrespectively to their units and scales.

The SVAN of any sample consists of the successive Fourier expansion realized within a running time intervals. The set of the resulting expansions are then used to construct a general map (the so-called *SVAN-diagram*) of amplitudes in the time-period coordinates. In our analysis, the running window of 132 months in length was shifted successively by 12 months. As a result the amplitudes of oscillations with the periods from 6 to 44 months were identified.

In Fig. 2 we show time dependence of the sums of amplitudes of the harmonics in the QBO range for the studied latitude zones of three periods of oscillations, approximately corresponding to the QBO (18.86, 22.0 and 26.4 months). One can see that the sums of the QBO amplitudes vary at all the latitudes almost identically with the correlation coefficient of ~ 0.7. A distinctive decrease of the QBO in the middle of 1960s is visible, as well.

Fig. 3 demonstrates comparison of the sums of QBO amplitudes in the CGLB asymmetry as derived within the 10° latitude zones. On this map the paired correlation coefficients of the QBO amplitude sums are displayed. Evidently, the diagonal between the low-left and the upper-right corners represents as if correlation of a given zone with itself, and, understandably, is equal to 1.0. In this map the amplitudes of those three harmonics are summed as in Fig. 2. Naturally, one could expect a decrease of the correlation coefficients with enlarging

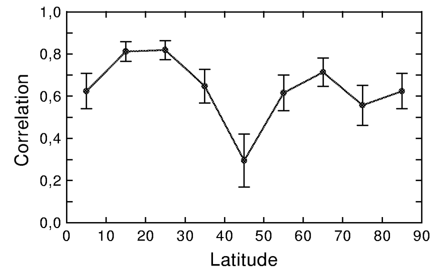

Figure 6. The latitude dependence of the negative correlation coefficient between the CGLB asymmetry and the sum of three QBO amplitudes.

distance of one zone from another. However and surprisingly, rather high correlation is observed also between relatively high latitudes $55° - 70°$ and the low-latitude zone. In another way, this effect can be explained also as a consequence of the substantially reduced correlation of the middle-latitude zones ($35° - 50°$) with both the lower and higher latitude zones. Any correct interpretation of this effect remains now unclear. It only can be noticed that according to the helioseismic measurements a narrow zone is situated at middle latitudes where rotation rate in the convective zone stops to depend on the radius. In addition, there are reasons to assume that namely middle latitudes represent the boundary of the local magnetic fields generation (see Belvedere et al. (2000)). A mutual relation of these phenomena with the found by us effects is worth of further investigation.

The QBO amplitudes for the asymmetries of the S_p, Q and I indices and for these indices themselves are compared in Fig.4. Calculations were performed for the sunspot formation zone $0° - 30°$. Here, in difference to other figures in this paper, the sums of squared amplitudes are given. We remind that the sum of all the squared amplitudes is equal to 1 in each spectrum. As it was pointed above, this allows us to compare a relative power of different oscillations in heterogeneous indices.

One can see in Fig. 4 that time peculiarities of the QBO amplitudes are contemporary for all three indices (three upper curves). The corresponding correlation coefficients are given as follows:

Paired indices	Asymmetry	Values
$S_p - Q$	0.88	0.56
$S_p - I$	0.67	0.47
$Q - I$	0.85	0.26

At the same figure, the sums of squared amplitudes of three QBO harmonics calculated for S_p, Q and I are also shown (three lower curves in Fig. 4). Evidently, the QBO amplitudes for the indices are substantially less in comparison with the QBO amplitudes found from their N-S asymmetries. Moreover, coefficients of the paired correlations between the sums of squares of the QBO amplitudes in the indices alone are also considerably less (the last column).

Summarizing, our study in this Section shows that the long-term increases and decreases of the QBO take place synchronously in the N-S asymmetry of three investigated indices. At the same time, the QBO are much better expressed in the N-S asymmetry of the indices than in the indices themselves.

4. RELATION BETWEEN MAGNITUDE OF THE N-S ASYMMETRY AND AMPLITUDE OF ITS QBO

Fig. 5 shows a general anticorrelation between the CGLB asymmetry and the power of its QBO. Time course of the N-S asymmetry values and the sums of QBO amplitudes, both averaged over all latitudes, are presented. The blue points denote the yearly-averaged values of the N-S asymmetry while the red points represent the sum of QBO amplitudes obtained by the SVAN (132-monthly window and 12-monthly successive shifting of it were used). The thick lines were obtained by the method of filtration (see above) and the harmonics with the periods more than 6.6 years were summed only.

The negative correlation between the sum of QBO amplitudes in the asymmetry and the magnitude of the asymmetry itself is observed for all three indices. In CGLB this effect exists at all the latitude zones. A detailed latitude dependence of this anti-correlation is shown in Fig. 6. The highest correlation coefficients occur in the $10° - 20°$ and $60° - 70°$ zones. These two bands of latitudes are separated by a narrow zone $40° - 50°$, where the correlation coefficient is distinctly lower. Note that namely the $40° - 50°$ zone represents a boundary separating the regions of the low-latitude local magnetic fields and the large-scale polar fields.

An investigation of this problem was treated by using a long series data on the areas and total numbers of sunspots covering 1874-2002 (Badalyan & Obridko (2003), Badalyan & Obridko (2005)).

5. CONCLUSIONS

We have analyzed the N-S asymmetry using three different indices of solar activity. The conclusions are as follows: (a) Similar time variations on both the short (1.5-3.0 years) and long ($\sim$ 12 years) time scales are identified in the N-S asymmetry of all studied indices within the sunspot formation zone $0° - 30°$. It is shown that the spectral distribution of the N-S asymmetry of different indices is identical; (b) Quasi-biennial oscillations (QBO) in the N-S asymmetry of all indices were detected and analyzed. Within the sunspot formation zone $0° - 30°$ specific features of the QBO variations in the N-S asymmetry of all indices are very similar. It is revealed that the QBO are much better expressed in the N-S asymmetry of the indices than in the indices themselves; (c) Manifestations of the QBO in the N-S asymmetry of three studied indices appear to be in an anti-phase with the magnitude of the N-S asymmetry itself. This effect is evident for all three studied indices over the whole range of solar latitudes, and decreses distinctly only at the range of $40° - 50°$.

Generally speaking, nature of the N-S asymmetry of different solar activity indices remains unexplained. As a rule, the most dynamo theories do not consider the N-S asymmetry, assuming completely identical behavior of activity in both solar hemispheres. Nevertheless, investigation performed in our paper strengthens an idea that generation and manifestations of solar activity proceed, to a large extent, independently of two sun's hemispheres and are governed by some laws specific for a given moment in each of the hemispheres. Since, however, activity in the solar hemispheres exhibit general temporal and energetic coincidence of the cyclic variations, one can assume that some currently unknown mechanism can exist which determines the actual degree of similarity in evolution of the active processes in the two hemispheres. This mechanism seems to exist apparently out of the activity generation and is independent of it. Probably, the N-S asymmetry may represent a quantitative description reflecting the properties of such a mechanism.

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