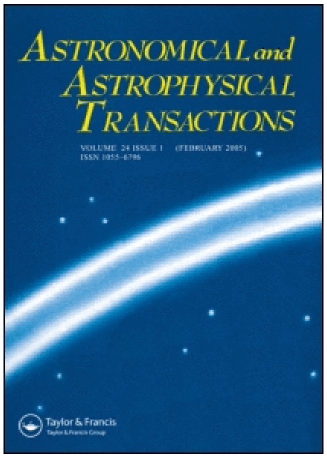

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

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Online Publication Date: 01 January 1992
To cite this Article: Ivanov-Kholodny, G. S. and Chertoprud, V. Ye. (1992) 'Analysis of extrema of quasi-biennial variations of the solar activity', Astronomical & Astrophysical Transactions, 3:1, 81 - 84
To link to this article: DOI: 10.1080/10556799208230542
URL: http://dx.doi.org/10.1080/10556799208230542

Astronomical and Astrophysical Transactions, 1992,
Vol. 3, pp. 81–84
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ANALYSIS OF EXTREMA OF QUASI-BIENNIAL VARIATIONS OF THE SOLAR ACTIVITY

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(Received May 21, 1991; in final form January 13, 1992)

Scheme for treatment of the activity indices aimed at the study the QBV of the solar and geomagnetic activity is proposed and its efficiency is shown. Analysis of the moments of the QBV extrema suggests that the QBV in various geomagnetic and solar indices manifest similar behavior.

KEY WORDS Solar and geomagnetic activity, quasi-biennial variations (QBV), QBV extrema.

1. INTRODUCTION

Even though quasi-biennial variations (QBV) of the solar activity are known to be hardly noticeable under Blackman–Tukey spectral analysis of monthly sunspots series (Berger *et al.*, 1990), they have a the subject of numerous investigations (see, e.g., Apostolov and Letfus 1985; Apostolov 1985, 1988; Rivin, 1987). The interest in the QBV was stimulated by the following three findings: Kalinin (1952) detected the QBV in the Earth's magnetic field; Reed *et al.* (1961) discovered quasi-biennial oscillations (QBO) of stratospheric winds at low latitudes and, finally, Labitzke (1987) found characteristics of the solar-tropospheric relation (for monthly data) to be dependent on the phase of QBO (see also Labitzke *et al.*, 1990).

The QBV in solar and geomagnetic activity wide of harmonical oscillations. This is why the QBV are difficult to detect by spectral analysis of original (unfiltered) time series of solar and geomagnetic activity (see, e.g., Shapiro and Ward 1961; Berger *et al.*, 1990; Currie, 1966). As shown by Rivin (1987) and Apostolov *et al.* (1988), suitable filtration and application of appropriate statistical methods make possible successful studies of QBV. In spite of some advance in the QBV investigations, some problems still remain to be solved. For example, Currie (1966) noted that results of Kalinin (1952) can be merely an effect of filtration. Still more important is the question of relationship between manifestations of QBV in different indices of the solar and geomagnetic activity. These and other similar questions can be solved with the help of the methods used to study relaxation oscillations. A simple scheme of such analysis is discussed below.

2. THE PROCEDURE OF ANALYSIS

The following scheme has been used to analyze activity indices.

1) Calculation of 1-yr running averages of the activity indices: $L_k(t) \rightarrow \bar{L}_k(t)$ (the 1-, 1/2-, 1/3 and 1/4-yr harmonics are thus excluded from $\bar{L}_k(t)$).

2) Filtering: $\Delta L_k(t) = 2\bar{L}_k(t) - \bar{L}_k(t-1\text{ yr}) - \bar{L}_k(t+1\text{ yr})$ (the maximum of the amplitude–frequency characteristic of this difference filter is at about two years).

3) Choosing (according to certain criteria) the sets of minima and maxima in the time series $\Delta L_k(t)$.

4) Statistical analysis of the moments $t_j(L_k)$ of extrema in the data $\Delta L_k(t)$ (here j is the ordinal number of extrema).

In the framework of this scheme one can treat and compare indices records having different time steps (e.g. monthly, quarterly, semi-annual or annual average values).

The following parameters have been analyzed: (i) the mean time interval between the minima or maxima, $T(L) = \bar{T}_j(L)$, where $T_j = t_{j+1} - t_j$ is the running period measured in years; (ii) the mean relative time separation of the corresponding moments of extrema in two indices L_1, L_2 defined as $\rho(L_1, L_2) = \sigma[t_j(L_1) - t_j(L_2)]/T$; (iii) the correlation coefficient $r(L_1, L_2)$ between the corresponding running periods $T_j(L_1)$ and $T_j(L_2)$ of two indices L_1, L_2 and (iv) the variances $D_\tau(L) = \sigma^2[t_{j+\tau}(L) - t_j(L)]$, where σ is the standard deviation, τ is the phase expressed in terms of the number of full oscillations.

First, three sets of monthly average values of the following parameters have been treated: the Wolf number W (1750–1989), the geomagnetic index A_p (1884–1989) and the random sampling numbers Z, simulating the 260-yr period. After that other indices of the solar and geomagnetic activity have been considered.

3. RESULTS

The following estimates for the random sampling numbers Z have been obtained: $T(Z) = 2.03 \pm 0.05$; at $\tau \leq 18$ $D_\tau(Z) \simeq D_\tau^0(Z) = 0.38\tau$ within the 15% accuracy; $\rho(Z_1, Z_2) = 1.1$ for two independent 50-yr Z-sets. Thus, the sample function $D_\tau(Z)$ agrees with the expected linear behavior for the random sampling numbers, i.e. the sample function $D_\tau(Z)$, computed for the 50–100-yr interval of observations, can be considered to be representative characteristics of the considered QBV.

Results of the W and A_p analysis differ substantially from those of Z: $T(W) \simeq T(A_p) = 2.25 \pm 0.07$; at $\tau \leq 10$ $D_\tau(W) \simeq D_\tau^0(W) = 2.75[1 - \exp(-b\tau)]$ within the 15% accuracy and $D_\tau(A_p) \simeq D_\tau^0(A_p) = 2.4[1 - \exp(-b\tau)]$ with $b \simeq 0.2$. Sample estimates of $D_\tau(W)$ and $D_\tau(A_p)$ are shown in Figure 1. The period T for A_p and W significantly exceeds that for Z and, hence, it is not a spurious result of the applied procedure. However, the difference between the variances $D_\tau(Z)$ and $D_\tau(W)$ is even more noticeable. In contrast to $D_\tau^0(Z)$, the growth of the variances $D_\tau^0(W)$ and $D_\tau^0(A_p)$ is not linear but rather slows down at the time scale of the solar cycle ($(1 \div 2)\ T/b \simeq 11 \div 2$ yr). Thus, the phase characteristics of QBV in W and A_p differ from those of the random sampling numbers and are probably related to the solar cycle. Therefore, the doubts of Currie (1966) are not confirmed.

To verify the relationship between the QBV in A_p and in W, the 50-yr sets of moments of the extrema of these inndices have been analyzed. The following estimates have been obtnained: $\rho(A_p, W) = 0.3$; $\rho(A_p, W)/\rho(Z_1, Z_2) \approx 1/4$; $r(A_p, W) = 0.61$. These estimates manifest a connection betwenen the moments of the extrema of QBV in W and in A_p, while a correlation of the amplitudes of

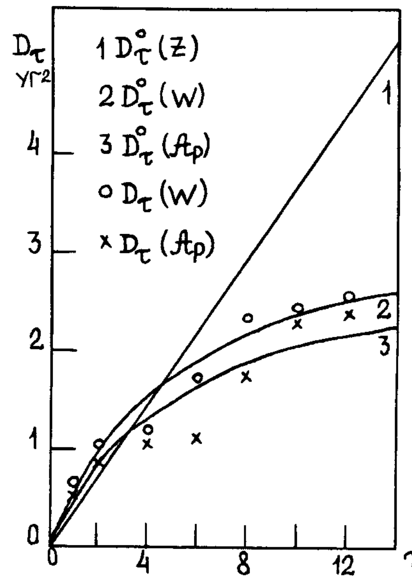

Figure 1 Sample estimates of the variances $D_\tau(W)$, $D_\tau(A_p)$ and the approximating functions $D^0_\tau(Z)$, $D^0_\tau(W)$, $D^0_\tau(A_p)$.

QBV in W and in A_p has not been observed (see, e.g., Rivin 1987). This means that the relationship between the QBV in A_p and W is not linear.

To verify that the estimates of the moments t_j are representative, four sets of geomagnetic indices $L_g = \{A_p, C_9, K_p, aa\}$ and two sets of solar indices (W and $F_{10,7}$) have been treated. The following estimates have been obtained: $\rho(W, F_{10,7}) = 0.076$; $r(W, F_{10,7}) = 0.97$; $\rho(L'_g, L''_9) \simeq 0.05 - 0.07$; $r(L'_g, L''_g) \geqslant 0.92$, where L'_g, L''_g are two different geomagnetic indices; here the intervals of observations exceed 50 yr. These estimates confirm that our results are independent of the particular conditions of observations.

Similar analyses of other solar data, such as the I–8 Å solar soft X-ray flux, the total number of high-speed solar wind streams detected near the Earth, the equatorial rotational velocity of the Sun, the north–south asymmetry coefficient of the green corona, revealed the QBV extrema which occur nearly simultaneously with those of W or $F_{10,7}$.

4. SUMMARY

A simple scheme for treatment of the activity indices aimed at the study the QBV of the solar and geomagnetic activity is discussed and its efficiency is demonstrated. Analysis of the moments of the QBV extrema suggests that the QBV in various solar and geomagnetic indices manifest similar behavior. They have common (solar) origin. There is a connection between the QBV phases of the solar and geomagnetic activity. This relation can be interpreted as nonlinear (trigger) influence of some quasi-periodical factor on the processes responsible for the activity indices.

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