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Original scientific paper

INTERACTION BETWEEN VARIABLE SOLAR UV RADIATION AND TROPOSPHERIC CIRCULATIONS AS A POSSIBLE CAUSE OF FIVE YEAR OSCILLATION IN EARTH ROTATION

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SUMMARY: It is shown that Five Year Oscillation in Earth rotation is possibly caused by variable solar UV radiation and a corresponding perturbation mechanism is suggested.

1. INTRODUCTION

The existence of Five Year Oscillation (FYO) in the solar activity was not accepted for a long time for reasons of irregular geometrical structure of the main 11-year cycle and its significant variations. However, Bloomfield (1976) showed that the solar activity main cycle could be better modeled by a sum of two, 11 and 5.5-year sinusoids, rather than only by one 11-year component. The first indication of FYO presence in the solar activity was given in 1965 in Mitchell's analysis of Zürich sunspot number series, but a small 5.7-year peak could not be considered as a certain proof of FYO existence. This doubt was present until the last decade of the 20^{th} century, when Djurović and Pâquet (1990, 1993, 1995, 1996) finally detected FYO in the solar activity, Earth rotation, geomagnetic field and atmospheric circulations. Dickey *et al.* (1994) confirmed their discovery and connected FYO to El Niño/Southern Oscillation (ENSO) and stratospheric Quasi Biennial Oscillation (QBO). In Polar Motion, FYO together with QBO, was detected by Abarca *et al.* (1994) in the form of 1.6-2.5, 3.5-4 and 5-6-year oscillations, where the last one was almost completely replaced by the 3.5-4- year oscillation after 1970. It was shown in the same paper that $x-$coordinate and atmospheric angular momentum changed coherently, but the same conclusion could not be derived in the case of $y-$coordinate of Polar Motion. FYO was also observed in some other geophysical and meteorological phenomena like atmospheric pressure differences between Madeira and Iceland as well as between Siberia and Iceland, Tertiary and Mesozoic strata, Baltic ice thickness, etc. The discovery of FYO in geomagnetic field perturbations, measured at 30 observatories, is of particular importance. In these values Courtillot and Le Mouël (1976) found the oscillations with periods of 11, 5.5 and 3.7 years.

In 1995, Djurović and Pâquet gave the statistical proof of FYO existence in UT1-TAI differences, geomagnetic index Aa, sunspot areas, Wolf number, 10.7 cm solar radio flux, corona index and χ_3 effective angular momentum function. The same authors found a significant correlation between UT1-TAI and solar activity as well as its equivalence with correlation between geomagnetic index and solar activity. Therefrom, it could be concluded that the possible cause of FYO in Earth rotation can be found in Earth's response to the solar corpuscular irradiation which results in the occurrence of the geomagnetic storms. It will be shown below that the existence of FYO in UT1-TAI differences can also be the consequence of the solar variable UV radiation and its interaction with atmospheric ozon.

2. DATA

The UT1-TAI differences are derived from the UT1-UTC differences which represent one of the Earth Orientation Parameters (EOP), published by International Earth Rotation Service (IERS). The derivation is made according to the relationships given in "1997 IERS Annual Report". 2620 observations from 1962 to 1998 with 5-day spans are used.

U.S. National Centers for Environmental Prediction (NCEP) values for χ_1 effective atmospheric angular momentum function, obtained by NCEP/NCAR re-analysis (Kalnay *et al.* 1996; Salstein and Rosen, 1997), are analysed. Global values for wind+pressure are calculated from 1958 to 1998 with 5-day spans. The number of the used data is 2970.

2800 MHz (10.7 cm) solar flux (SF) measures, provided by National Geophysical Data Center, Boulder, Colorado, are averaged over 5-day spans from 1947 to 1998 and 3704 obtained values are used for further analysis.

3. COMPUTATIONAL METHODS

In order to eliminate the well known oscillations, such as seasonal ones in UT1-TAI and χ_1, the input data are filtered using Fourier series expansion. After the Fourier coefficients with periods outside the 500-3000 days interval are calculated, the residuals of their sum and the input data are found. The amplitudes of oscillations from the above interval are practically not changed, while all the other oscillations are totally eliminated from the resulting residuals.

Spectral analysis of the filtered data is performed by two methods:

a) Discrete Fourier Transforms (DFT), whereby the statistical significance of obtained peaks is estimated according to the expression:

$$P_r\left(\left(\frac{A}{s}\right)^2 > A_0\right) = e^{-x}, \quad A_0 = \frac{4x}{2N+1}. \tag{1}$$

The quantity A_0 represents the upper limit for the random peaks, and any peak for which $\left(\frac{A}{s}\right)^2 > A_0$ is statistically significant with probability $1 - P_r$. The above expression is derived from the original Schuster's formula (Djurović *et al.* 1994):

$$P_r\left(S(\omega) > \frac{xs^2}{2\pi}\right) = e^{-x}, \tag{2}$$

and formula:

$$S(\omega) = \frac{2N+1}{8\pi}A^2, \tag{3}$$

where $S(\omega)$ represents spectral density for angular frequency ω, s - standard deviation of the data, x - arbitrarily chosen number, and $2N+1$ - total number of the data. Only the peaks with statistical significance greater than 99% ($P_r = 0.01$, $x = 4.6$) are taken into account.

b) Wavelet transforms (WT), defined by the following convolution (Popiński and Kosek, 1994):

$$C(a,b) = \frac{1}{\sqrt{|a|}}\int_{-\infty}^{\infty} \overline{w}\left(\frac{t-b}{a}\right) s(t)\ dt, \tag{4}$$

where $s(t)$ is the input signal, $a \neq 0$ - scaling parameter, b - translating parameter, $\overline{w}(t)$ - complex conjugate of the Morlet wavelet function $w(t) = \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} e^{ipt}$ with Morlet parameter $p = 2\pi$.

In order to examine the correlation between two data series, the correlation coefficient r and the cross-correlation function R are calculated. The significance level (probability P_0) at which the null hypothesis of zero correlation coefficient is disproved, is calculated using the error function $erf(x)$ (Press *et al.* 1992):

$$P_0 = 1 - erf\left(\frac{|r|\sqrt{N}}{\sqrt{2}}\right), \qquad erf(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}dt. \tag{5}$$

The statistical significance of the cross-correlation function extrema is examined assuming its mathematical expectation equal to zero (analyzed data sets are mutually independent). Let $U = |W\sqrt{n} - 3|$, where $W = \frac{1}{2}\ln\left|\frac{1+R}{1-R}\right|$, and n is the number of the pairs used for calculation of R. Then, the given data series are mutually dependent with probability 0.99 if the corresponding $U > 2.6$ (Djurović and Pâquet, 1993).

Cross-spectra are also calculated in order to find the periods of common oscillations in the considered correlation pairs.

4. RESULTS

The amplitude periodograms of the filtered data, obtained by DFT, are presented in Figs. 1a - 3a, and the corresponding numerical results in Table 1. Except FYO peaks which are clearly pronounced, QBO peaks are also noticeable and statistically significant in all data.

Table 1. Periods (P), amplitudes (A) and phases (Φ) of QBO and FYO peaks (with significance level greater than 99%). A_0 is the upper limit of random peaks, s - standard deviation of the data.

Data	$P(^y)$	A	$\Phi(^o)$	$(A/s)^2$	s	A_0 (Schuster)
$UT1-TAI$	2.38	0.01524	352.89	0.15288	±0.03898	0.00703
	3.57	0.01959	136.51	0.25248		
	5.98	0.03703	116.71	0.90243		
χ_1	1.40	0.08469	61.88	0.13214	±0.23298	0.00620
	2.18	0.11018	219.23	0.22364		
	3.39	0.11170	94.99	0.22985		
	4.63	0.11427	328.14	0.24054		
	5.63	0.11301	274.25	0.23527		
SF	1.48	4.47057	31.10	0.09917	±14.19649	0.00497
	3.16	6.32250	325.98	0.19834		
	5.37	12.06016	187.02	0.72168		

The peaks are wider when the observational interval is shorter due to DFT method's deficiency when dealing with finit length time series. The presence of several peaks between 2 and 6 years as well as the instability of the spectra, especially in the case of χ_1, could be interpreted as an argument for doubting FYO and QBO existence. However, this characteristic is the consequence of the relatively significant variations in FYO and QBO periods, making these oscillations quasi-periodic. This statement is more obvious from the WT spectrograms presented in Figs. 1b - 3b, where the darker shades correspond to the greater amplitudes and vice versa. In the case of χ_1, a remarkable fluctuation of the FYO period between 3 and 6 years is recorded, while the QBO period is quite stable. Taking into account that DFT method is not suitable for application in case of time-varying signals, it could be concluded that the great instability of χ_1 amplitude periodogram is due to this deficiency. The above FYO period variation in χ_1 is in accordance with Torrence and Compo's (1998) meteorological analysis of the famous ENSO phenomenon, where it was shown that ENSO frequency varies in the similar interval. It indicates that ENSO origin could also be in the solar activity.

In the case of UT1-TAI and SF, two components of FYO are detected. The first one is concetrated between 3 and 4 years, and the second, much stronger, between 5 and 6 years. Djurović and Pâquet (1999) showed that FYO is less concetrated during the periods of lower solar activity, when the maximum of its power varies between 3 and 8 years. During the periods of higher solar activity, FYO power is more concetrated near 5.5 years.

Numerical results of the mutual dependence of the solar and geophysical data are presented in Table 2, while the corresponding cross-spectra are shown in Figs. 4 and 5, where the FYO and QBO peaks are very remarkable. The periods of the cross-spectra common oscillations are also given in Table 2. Linear and functional correlation is statistically significant in both correlation pairs. The maxima of cross-correlation function are approximately equal to 0.4, and greater than the corresponding correlation coefficients. Such, relatively high level, of correlation confirms that some kind of solar flux influence on geophysical data exists, but the concrete dependence is more complex, rather than linear. Comparison of lags τ in Table 2, as well as phases Φ in Table 1, did not lead to any relevant conclusion because of small amplitudes and very disturbed signals.

Table 2. Correlation coefficients, cross-correlation function maxima and periods of cross-spectrum peaks

Data	r	P_0	R_{max}	$\tau(^d)$	U	$P_1(^y)$	$P_2(^y)$	$P_3(^y)$
$SF/UT1-TAI$	-0.33674	0.00000	0.41	2860	19.3	2.38	3.53	5.31
SF/χ_1	-0.09224	0.00000	0.39	-405	18.9	2.38	3.09	5.39

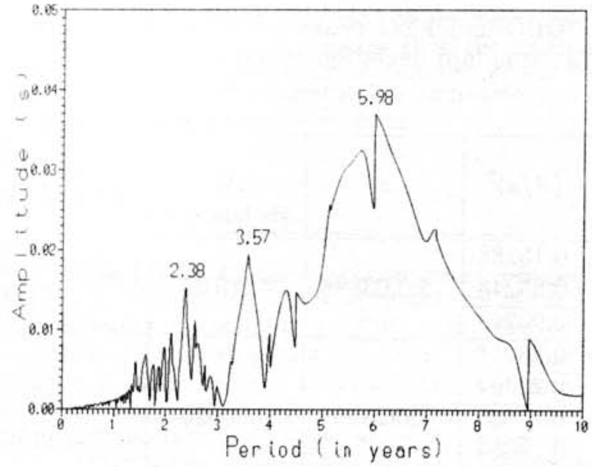

Fig. 1a. - *Amplitude periodogram (DFT) of UT1 - TAI residuals after filtering from* 500^d *to* 3000^d

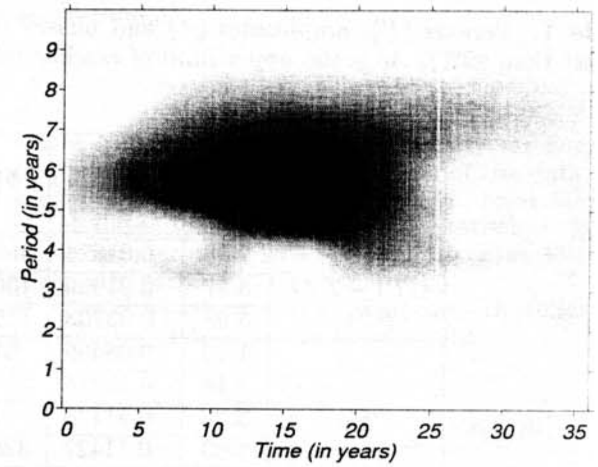

Fig. 1b. - *Spectrogram (WT) of UT1 - TAI residuals after filtering from* 500^d *to* 3000^d

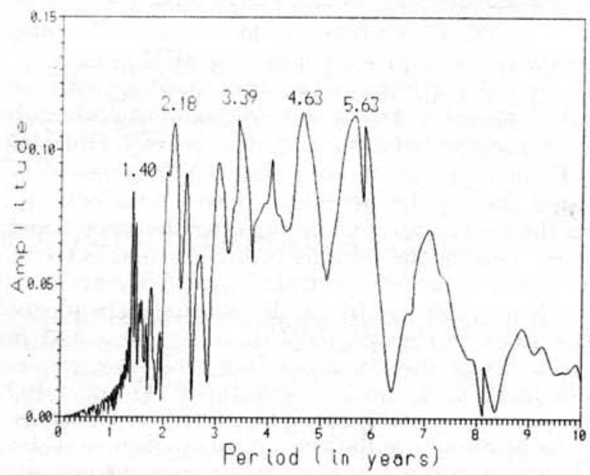

Fig. 2a. - *Amplitude periodogram (DFT) of* χ_1 *residuals after filtering from* 500^d *to* 3000^d

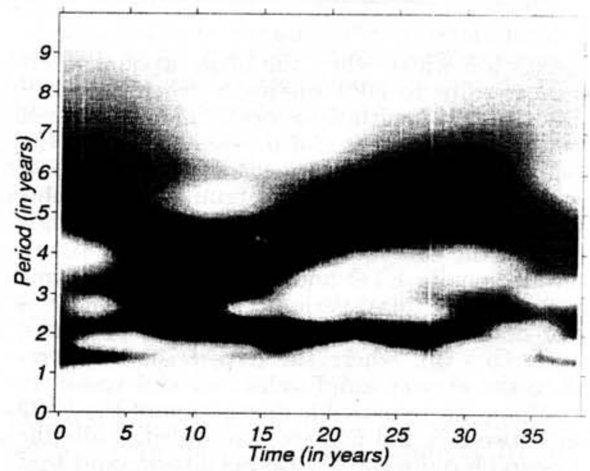

Fig. 2b. - *Spectrogram (WT) of* χ_1 *residuals after filtering from* 500^d *to* 3000^d

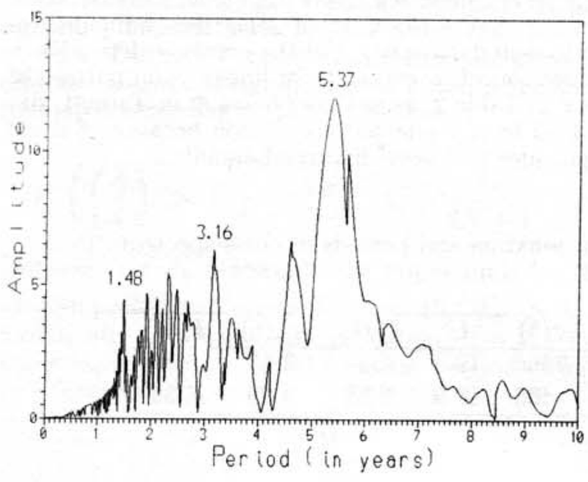

Fig. 3a. - *Amplitude periodogram (DFT) of 2800 MHz solar flux residuals after filtering from* 500^d *to* 3000^d

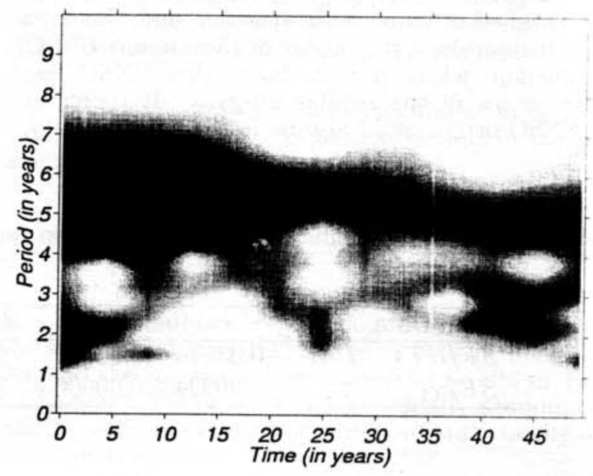

Fig. 3b. - *Spectrogram (WT) of 2800 MHz solar flux residuals after filtering from* 500^d *to* 3000^d

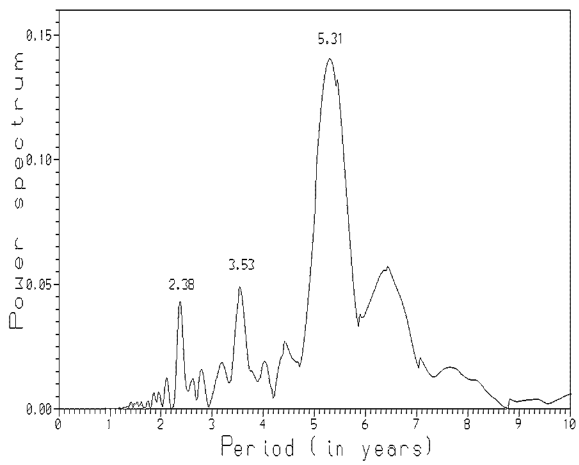

Fig. 4. - *SF / UT1 - TAI cross-spectrum*

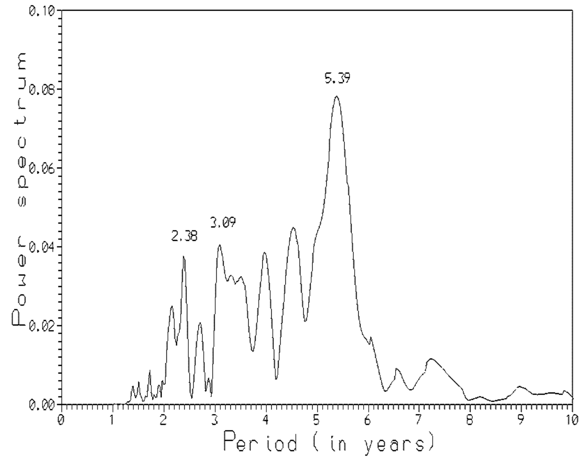

Fig. 5. - *SF / χ_1 cross-spectrum*

5. DISCUSSION

The above results lead us to assume that the solar activity disturbs the Earth rotation through its atmosphere as a mediator. The atmosphere is a complex system with its own variations which arise as reactions to various excitations. Therefore, a general theory explaining a whole set of processes which act on atmosphere, and indirectly, on Earth rotation, does not exist yet.

According to obtained results, one possible physical mechanism causing the perturbations in the Earth rotation due to variations in the solar activity, could be represented by interaction between variable solar UV radiation, atmospheric ozon and tropospheric circulations. Systematic variations of the total solar irradiance during the 11-year solar activity cycle are insufficient to produce reactions in Earth's atmosphere, suspected for causing of FYO in its rotation. More likely is the hypothesis that the variations in the structure of irradiation, especially the significant fluctuations of UV radiation during the main cycle, could produce the corresponding tropospheric fluctuations. The main source of the solar UV radiation is the corona due to its high temperature of approximately 1.500.000 K (Djurović and Pâquet, 1993). UV emission is the most important cause of high atmosphere perturbations through the ozon which strongly depends on this emission. If we assume the interaction between higher and lower atmospheric layers (Trenberth, 1980), then the correlation between the solar flux and the variations in Earth rotation could be explained by angular momentum exchange between the atmosphere and the solid Earth. The fact that 10.7 cm solar flux is strictly correlated with solar UV radiation which disturbs the global atmospheric circulation (McCormac and Seliga, 1978), confirms the suggested mechanism.

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ИНТЕРАКЦИЈА ИЗМЕЂУ ПРОМЕНЉИВОГ СУНЧЕВОГ UV ЗРАЧЕЊА И ТРОПОСФЕРСКИХ ЦИРКУЛАЦИЈА КАО МОГУЋИ УЗРОК 4-6-ГОДИШЊЕ ОСЦИЛАЦИЈЕ У ЗЕМЉИНОЈ РОТАЦИЈИ

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Оригинални научни рад

Показано је да се узрок 4-6-годишње осцилације у Земљиној ротацији највероватније налази у промењивом Сунчевом UV зрачењу, а предложен је и одговарајући пертурбациони механизам.