Publications of the Department of Astronomy - Beograd, № 17, 1989

UDC 521.93 OSP

ATMOSPHERIC EXCITATION AND VARIATIONS IN THE LENGTH OF DAY

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Received May 10, 1988

Summary: The LOD (length of day) and χ_3 spectra were computed using the maximum entropy method (MEM). The comparisons show excellent correlation between the axial component of the atmospheric EAMF (χ_3) and the changes in the Earth's rotation rate corrected for the effects of the lunar and solar tides. The most important changes are the seasonal variations with annual and semi-annual periods, and a cluster of small peaks with periods between 40 and 70 days i both spectra (LOD and χ_3).

key words: atmospheric excitation, length of day

N. Pejović: ATMOSFERSKA EKSCITACIJA I PROMENE U TRAJANJU DANA - Spektri LOD i χ_3 računati su korišćenjem metoda maksimalne entropije (MME). Uporedjenja pokazuju odličnu korelaciju izmedju osne komponente atmosferske EAMF (χ_3) i promena u brzini Zemljine rotacije korigovane za efekte Mesečevih i Sunčevih plima. Najznačajnije promene su sezonske varijacije sa godišnjom i polugodišnjom periodom i grupom malih pikova sa periodama izmedju 40 i 70 dana u oba spektra (LOD i χ_3).

1. INTRODUCTION

It is well known that the atmosphere has a dominant influence on the changes of the Earth's rotation parameters (polar motion and variations in the length of day). More recent and more detailed information about the atmosphere has given in many papers. We should mention authors considering the atmospheric influence on the variations in the day-length variations (e. g. Lambeck and Cazenave, 1973, 1974, 1975; Sidorenkov, 1973, 1979; Okazaki, 1977; Rosen and Salstein, 1983, 1985; Djurović, 1983, 1986, 1987; Vondrak, 1987; Feissel and Nitschelm, 1985). A very important paper providing a solid basis for computations of the so-called effective angular momentum functions (EAMF) of the atmosphere based on global meteorological data collected at the European Centre for Medium-Range Weather Forecasts (ECMWF) has been published by Barnes, Hide, White and Wilson (1983).

Briefly summarizing the results obtained as yet one may say that the short-periodic variations in the day length are caused by the atmospheric and tidal effects; comparisons show an excellent correlation between the axial component of the atmospheric EAMF and the changes in the velocity of the Earth's rotation corrected for the lunar and solar tidal effects. The EAMF axial component is dominant in the zonal wind effects. Seasonal variations (with annual and semi-annual periods) and short-periodic ones (with a group of periods between 40 and 70 days) are the most important. There is a reliable proof that a close correlation between the solar activity and the global atmospheric circulation exists (Djurović, 1987).

2. THEORETICAL BACKGROUND

Vondrak (1987) introduced in the well-known third Liouville equation of the rotation Earth's model

$$\dot{m}_3 = \dot{\psi}_3 \tag{1}$$

excitations depending on m_3 which are due to:

a) fluid core:

$$\Delta\psi_3^c \approx \frac{C_c}{C}\dot{m}_3$$

where C_c is the principal moment of inertia of the core and C is the principal inertia moment of the Earth,

b) rotational deformation of the mantle:

$$\Delta\psi_3^{rd} = \frac{-4k\Omega^2 R^5}{9GC}\dot{m}_3$$

where k is the elastic Love number, Ω is the mean angular velocity of the Earth's rotation, R is the mean terrestrial radius and G is the gravitation constant,

c) ocean:

$$\Delta\psi_3^o = \frac{-4\Omega^2 R^5 0.040}{9GC}\dot{m}_3.$$

Then, by introducing the function of the axial atmosphere angular momentum χ_3 (Barnes et al., 1983) instead of the excitation function

$$\psi_3' = \psi_3 - (\Delta\psi_3^c + \Delta\psi_3^{rd} + \Delta\psi_3^o) \tag{2}$$

and more realistic numerical values of the constants, Vondrak (1987) obtained the equation:

$$m_3 = -\frac{\Delta LOD}{LOD_0} = 0.993\chi_3 + const \tag{3}$$

where $\Delta LOD/LOD_0$ is the relative change in the day length taken with respect to the mean value $LOD = 86400s$. From equation (3) one obtains the calculated value of LOD which should be compared to the observed one obtained from $UT1 - UTC$.

3. USED DATA

The data of the axial atmosphere EAMF calculated on the basis of Barnes' algorithm (Barnes et al., 1983) at the US National Meteorological Center obtained by the courtesy of Vondrak (1986a) are used here. The daily values of χ_3 for the period 1976.5–1986.0 are analysed in the following three combinations:

a) $\chi_3^p + \chi_3^w$

b) $\chi_3^{p'} + \chi_3^w$

c) χ_3^w

where the indices p and w denote the pressure and wind terms, respectively, and p' denotes the pressure term calculated on the inverted barometer hypothesis. The data corresponding to all the three combinations are presented in Fig. 1 and Fig. 2; the wind term is in the lower part of Fig. 1 and its sums with both pressure terms (with and without the inverted barometer correction) are in the lower and upper parts of Fig. 2, respectively. By inspecting the Figures one easily finds out that all the three data sets are periodic functions of time with a prominent annual term. The wind term dominates over the axial component of the atmosphere angular momentum. The second group of the used data are the combined solutions of the UT1-UTC values obtained and published for the period 1976-1986 by BIH (BIH Annual Reports) for the same time interval as for the EAMF data. One should note that the combined solutions in the beginning were mostly based on optical astrometry gradually becoming more and more based on observations performed by using modern technics which are more accurate, especially within the short-periodic part of the spectrum (Vondrak, 1986b). The changes of the day length (LOD) calculated from UT1-UTC are presented in the upper part of Fig. 1; their more complex structure is caused by combination of changes due to tidal effects (Yoder et al., 1981) and to the atmospheric excitation.

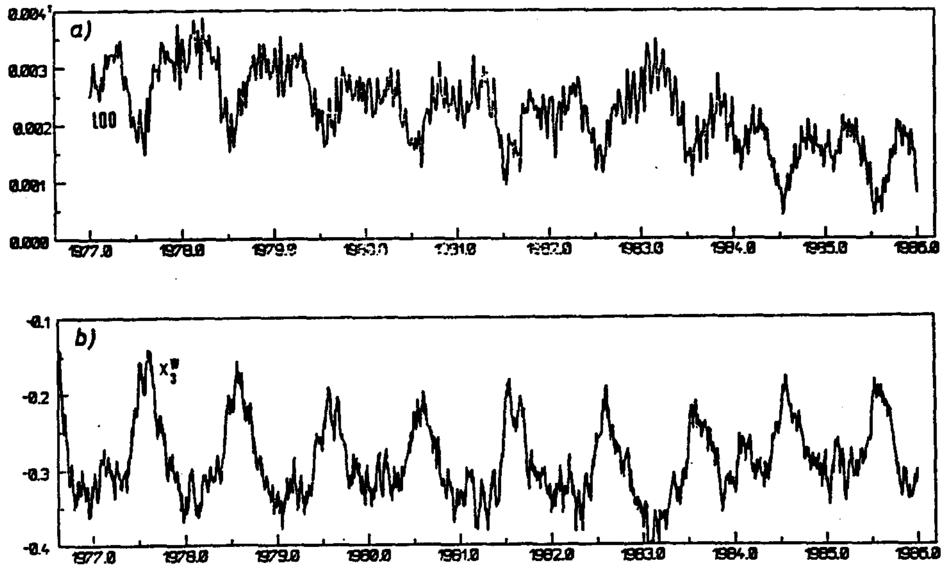

Fig. 1 a) The excess of length of day over the nominal 86400^s (*LOD*) as determined from astronomikal observations at the *BIH* in Paris.
b) The axial component of the wind term of the atmospheric *EAMF* as determined by the *NMC*.

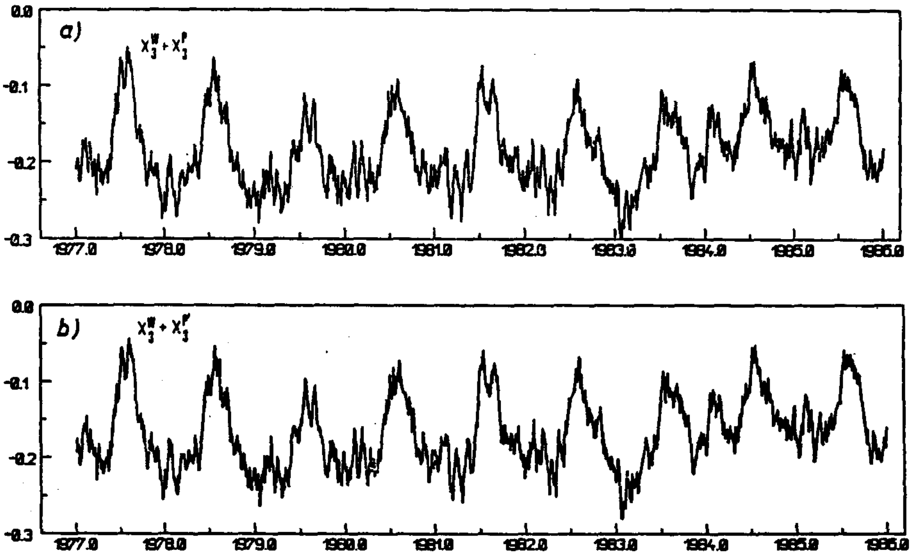

Fig. 2 a) The axial component of the sum of wind and pressure term of the atmospheric *EAMF* as determined by the *NMC*.
b) The axial component of the sum of wind and pressure term with the inverted barometer correction of the atmospheric *EAMF* as determined by the *NMC*.

4. RESULTS

On the basis of equation (3) one can write the UT1-UTC approximation which is

$$UT1 - UTC = A + Bt + Ct^2 + 0.993\int_0^t \chi_3 \mathrm{d}t + (CT) \tag{4}$$

where with *CT* are denoted 62 tidal terms determined by Yoder et al. (1981), A, B and C are constants determined by using the least-square-method (LSM). Their values are presented in Table 1.

By obtaining the time derivative of equation (4) one finds the LOD approximation

$$\frac{\mathrm{d}}{\mathrm{d}t}(UT1 - UTC) = -LOD = -(a + bt + 0.993\chi_3 + CD), \tag{5}$$

TABLE 1.

A, B, C are constants of the UT1–UTC approximation calculated by using LSM for all the three variants of χ_3

	A	B	C
χ_3^{w+p}	0.0135324	−0.0011113	0.00000015
$\chi_3^{w+p'}$	0.0192252	−0.0012234	0.00000013
χ_3^{w}	0.0375353	−0.0003767	0.00000019

where the tidal terms (Yoder et al., 1981) are denoted as $CD = \mathrm{d}(CT)/\mathrm{d}t$, and a, b are constants determined by using LSM. The obtained values are given in Table 2.

It is seen from the Tables that for the coefficients a, b, A, B and C one obtains approximate values following from the derivation of (4) aimed at obtaining expression (5), i.e. $-a \approx B$, $-b \approx 2C$.

TABLE 2.

Coefficients a, b determined by using LSM for LOD approximation, δ is the root-mean-square deviation.

	a	b	δ
χ_3^{w+p}	0.0011815	−0.0000003	$\pm 0^s.00028$
$\chi_3^{w+p'}$	0.0012905	−0.0000003	$\pm 0^s.00027$
χ_3^{w}	0.0004083	−0.0000003	$\pm 0^s.00029$

In Fig. 3 (wind term plus pressure term), Fig. 4 (wind term plus pressure term with invertive barometer correction applied) and Fig. 5 (wind term only) all the three combinations of χ_3 in the LOD approximation (5) and the observed LOD are presented. It is seen from these Figures that the agreement between the two curves is excellent. In order to obtain a better estimate of this agreement one calculates the root-mean-square deviation δ between the two curves (observed LOD and atmosphere function χ_3) by using the following

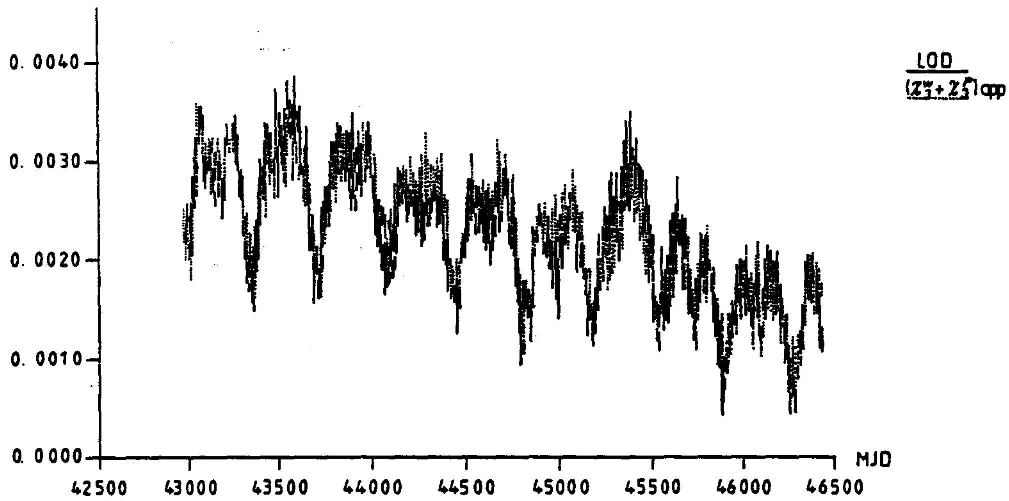

Fig. 3 Comparison of fluctuation in the observed *LOD* with corresponding fluctuations in the axial component of the sum of wind and pressure term of the atmospheric *EAMF* [see equ. (5); $(\chi_3^w + \chi_3^P)_{app} = a + bt + 0.993(\chi_3^w + \chi_3^P) + CD$].

equation

$$\delta = \sqrt{\frac{\sum \nu^2(t)}{n-2}}$$

where $\nu(t) = LOD - (a + bt + \chi_3 + CD)$, n is the number of data.

The values obtained for δ for all the three considered variants of χ_3 are presented in Table 2. The best agreement is achieved in the case of variant b, i. e. for $\chi_3^{w+p'}$ (wind term plus pressure term with invertive barometer correction applied) which is equal to $\pm 0^s,00027$. It follows from this that the LOD and χ_3 data can be directly compared unlike the polar motion data and the equatorial EAMF (Vondrak and Pejović, 1988).

The comparison between the observed LOD and the atmospheric χ_3 will be given also through a comparison of their spectra.

Since the root-mean-square deviation between the two curves (LOD and χ_3) (Table 2) is about $\pm 0^s.0003$, the spectral analysis will be carried out for all the three variants.

The Maximum Entropy Method (MEM)

The parameter analysis of time series and also the spectral analysis as a part of it, is a qualitatively new phase in the theory of stochastic processes and in solving practical problems. The fist steps are due to Yule (1927) who was

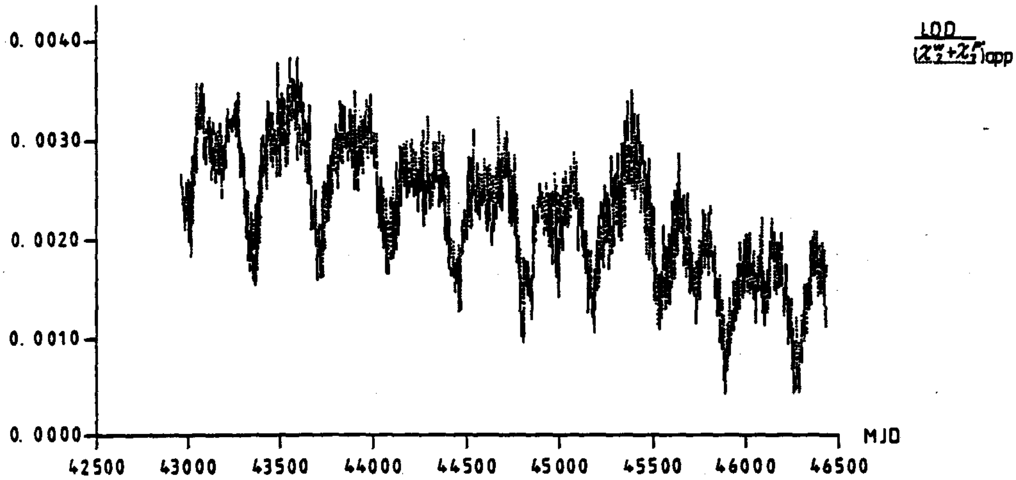

Fig. 4 Comparison of fluctuation in the observed LOD with corresponding fluctuations in the axial component of the sum of wind and pressure term with the inverted barometer correction of the atmospheric $EAMF$
[see equ. (5); $(\chi_3^w + \chi_3^{P'})_{app} = a + bt + 0.993(\chi_3^w + \chi_3^{P'}) + CD$].

the first to construct an autoregressive model of a stochastic process (AR). In 1967 Burg (1967) and independently Parzen (1967) proposed using of the AR model for the purpose of a spectrum estimate, and Burg demonstrated then that such an estimate corresponds to the requirement for a maximal entropy of unknown values of the covariant function. Such a property of the spectral density removes the necessity of making weakly assumptions on a periodical character of a process beyond the interval observed. This is especially important in the case of short time series which are known to be difficult for Fourier analysis method due to leakage and aliasing. We have used the subroutines and the main program written by Privalski (1985) for the autoregressive analysis of an equidistant time series. Parameters of the autoregressive model (M, L...) are estimated by the Burg-Lewinson method (Privalski 1985) and the optimal order of the model ($IBEST$) is chosen by the Parzen's criterium.

The Spectra of the Data Obtained with MEM

The results of the spectral analysis are presented in Figs. 6-10. Along the axis of abscissae is the logarithmic scale of the period expressed in years and along the one of ordinates are logarithmic power density. Computing is done using the parameters of the autoregressive model $M = 60$ and $L = 30$. The optimal order by the Parzen's criterium is $IBEST = 23, 44, 44, 27,$ and 25 for the

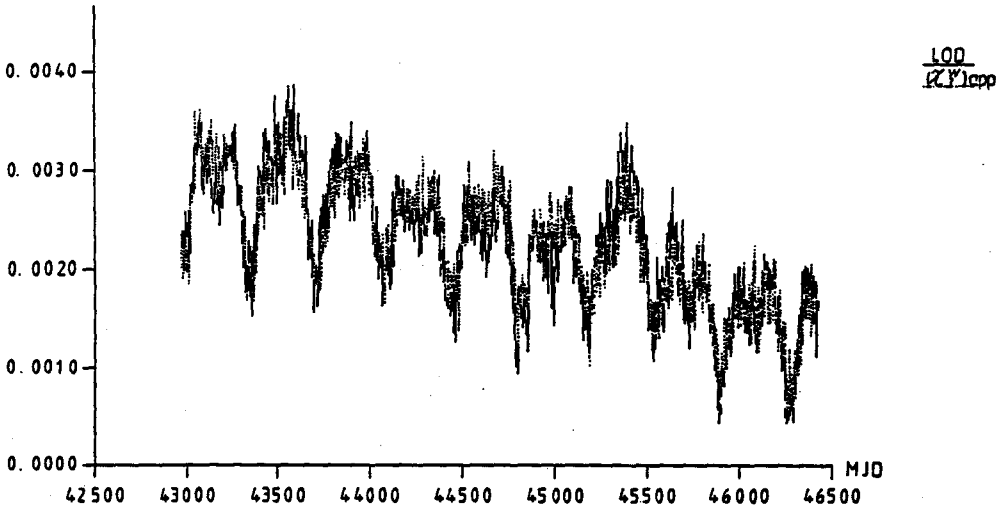

Fig. 5 Comparison of fluctuation in the observed *LOD* with corresponding fluctuations in the axial component of the wind term of the atmospheric *EAMF* [see equ. (5); $(\chi_3^w)_{app} = a + bt + 0.993\chi_3^w + CD$].

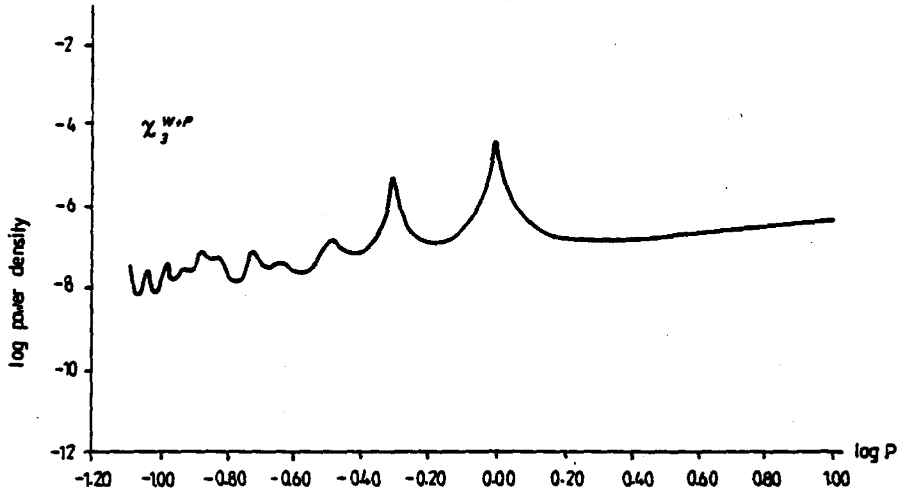

Fig. 6 The spectrum of the axial component of the sum of wind and pressure term of the atmospheric *EAMF*, calculated by the *MEM*.

spectra on the Figures 6-10,respectively. It is seen from LOD and the various combinations of χ_3 that the pressure term with inverted barometer correction has no important influence on the day duration. If one compares the spectrum

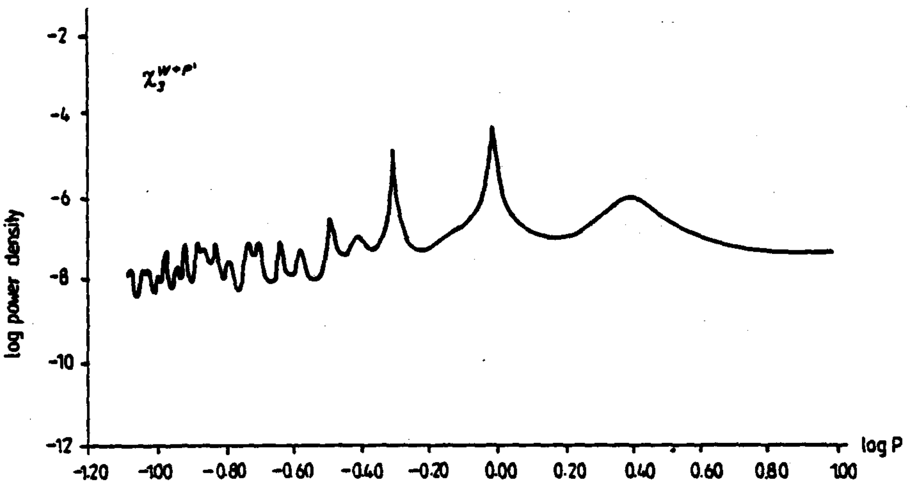

Fig. 7 The spectrum of the axial component of the sum of wind and pressure term with the inverted barometer correction of the atmospheric *EAMF*, calculated by the *MEM*.

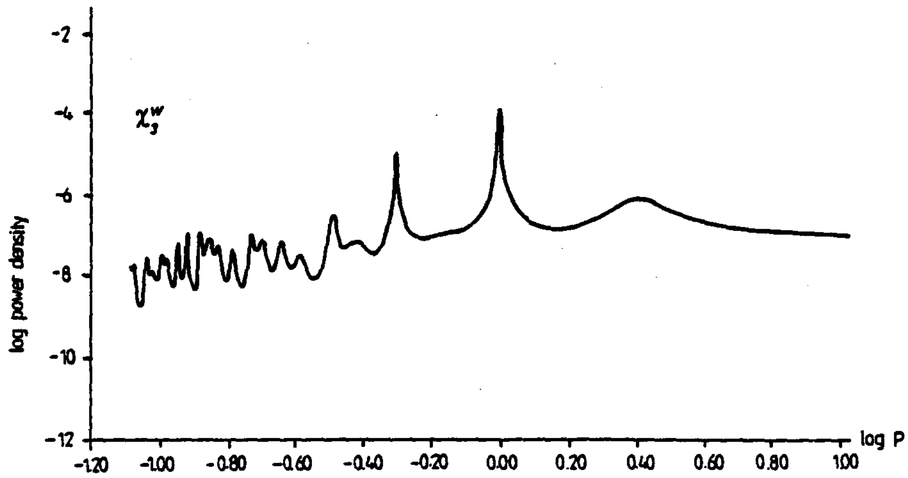

Fig. 8 The spectrum of the axial component of the wind term of the atmospheric *EAMF*, calculated by *MEM*.

of $\chi_3^{w+p'}$ (wind term plus pressure term with inverted barometer correction) presented in Fig. 7 with the one of χ_3^w (wind term only) presented in Fig. 8, one finds a wonderful similarity. They are practically identical. For the

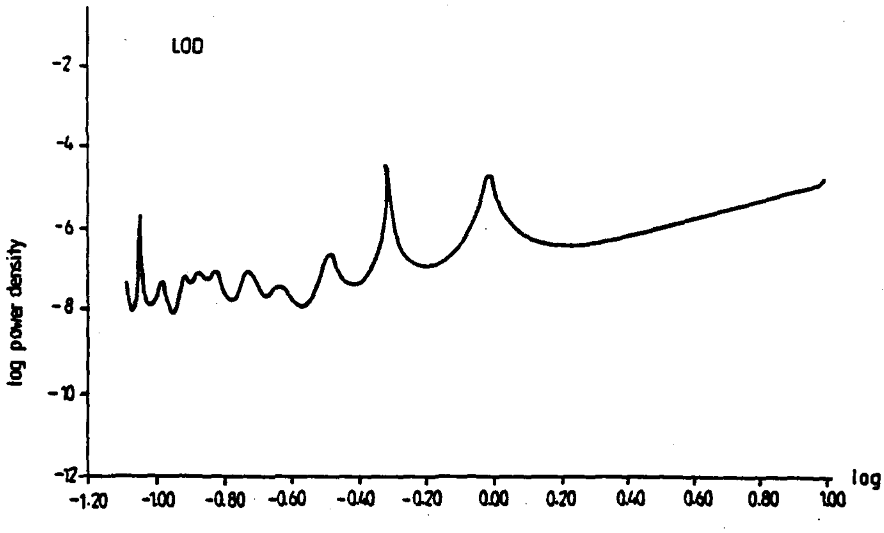

Fig. 9 The spectrum of the observed *LOD*, calculated by the *MEM*.

Fig. 10 The spectrum of the observed *LOD* with tidal variations removed, calculated by the *MEM*.

axial component χ_3 the pressure term is so small, that the inverted barometer hypothesis causes no essential changes in the total angular momentum function. Generally speaking by combining the wind term with the pressure term (χ_3^{w+p}) in Fig. 6, one obtains a better agreement with the observed LOD

TABLE 3.

Periods, amplitudes and phases obtained by applying FFT method for all the three combinations χ_3, LOD and LOD-tides are presented. The phases are with respect to modified Julian dates (MJD)=42963.

	Period [*yr*]	*Amplitude* [*s*]	*Phase* [°]
χ_3^{w+p}	0.50	0.000246	164.23
	1.00	0.000368	331.74
$\chi_3^{w+p'}$	0.50	0.000246	167.28
	1.00	0.000363	331.84
χ_3^{w}	0.50	0.000253	165.25
	1.00	0.000406	335.74
LOD	0.50	0.000361	159.29
	1.00	0.000354	301.25
LOD-tides	0.50	0.000293	160.92
	1.00	0.000328	327.79

with tides subtracted (compare the spectra LOD and LOD-tide in Figs. 9 and 10) than by using solely the wind term. The similarity of the LOD spectrum (without tides) with $\chi_3^{w+p}, \chi_3^{w+p'}$ is remarkable; they are practically identical. There are some small differences in amplitudes for both dominant terms: the annual and the semi- annual ones(Table 3);χ_3 yields a smaller semi-annual-term amplitude and a larger annual-term amplitude than the observed LOD without tides, but these differences are within a 10% level. Larger differences appear in the case of longer periods. The amplitudes of the observed LOD (without tides) corresponding to periods exceeding one year seem to be in a better agreement with a combination of the wind term and the pressure term alone than with χ_3^w and $\chi_3^{w+p'}$. This could mean that the pressure term with inverted barometer correction applied in its long-periodic part is not reliable, or (more probably), that another source of long-periodic change excitation responsible for these variations in the angular velocity of the Earth's rotation (e.g. an electromagnetic coupling between the core and the mantle) is present.

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