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MEASURING CHANDLER WOBBLE AMPLITUDE VARIATIONS USING IERS EOP C04 DATA

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SUMMARY: We analyzed the Earth's long-term polar motion using the time series IERS EOP C04 (International Earth Rotation and Reference Systems Service – IERS; Earth Orientation Parameters – EOP; Combination of four (04) techniques – C04), from 1984 to 2023, to determine the variation of the Chandler wobble amplitude. To compare the results based on the C04 with the so-called Belgrade latitude data (Belgrade Lunette Zenithale – BLZ series 1949-1985) results, we calculated the latitude variations at the BLZ point using the C04 coordinates (x, y). The secular part of these latitude variations was determined by applying the least-squares method (LSM) and removed from the data to obtain the residuals. We used Direct Fourier transforms to extract annual and semiannual oscillations and to remove them from the residuals (resulting in a new set of residuals). These new residuals were divided into 33 independent 1.2-year subintervals. For each subinterval, we calculated the amplitude, period, and phase of the Chandler nutation using LSM. The quasi-periodic instability of 33 values of the Chandler wobble amplitude is detected with a period of 54.5 years using LSM (it was 38.5 years from the BLZ data 1949-1985); the amplitude of that quasi-periodic variation is $0\overset{''}{.}087$ ($0\overset{''}{.}06$ from BLZ data). The amplitude of the Chandler nutation varies between minimum of $0\overset{''}{.}012$ (at 2019.3) and a maximum of $0\overset{''}{.}23$ (at 1994.1); the period is stable, but the phase is not stable. We applied the Abbe's criterion to explain the variability in 33 values of the Chandler wobble amplitude and the hypothesis that there is no trend in these 33 values is rejected based on the criterion. The obtained amplitude modulation is in accordance with previous studies, but also with our own results based on the BLZ data. Probably, the cause lies in the hydro-atmospheric circulation that could influence calculated quasi-periodic variation. A possible explanation can be found in the change in core-mantle electromagnetic coupling (in agreement with the last few years' investigations). In recent papers, it has been indicated that the effects of geomagnetic jerks are more important for exciting a free nutation than the net effect of atmosphere and oceans.

Key words. Earth – Methods: statistical – Catalogs

1. INTRODUCTION

The measurements of the Earth's rotation angles have been collected for more than a century: optical astrometry data are at the accuracy level of tens milliarcseconds (mas), the Earth's Rotation Parameters (ERPs) achieved the accuracy level of about 0.1 mas, because after the 1980s these data started to be provided by space geodetic techniques.

The time series IERS EOP C04 data, used in this work, is a product of the International Earth Rotation and Reference Systems Service – IERS. In particular, C04 refers to the combination (C) of the EOP (Earth Orientation Parameters) series derived from four (04) astro-geodetic techniques, and thus the term C04 is coined. These four techniques are: Very Large Baseline Interferometry (VLBI) on extragalactic objects, Lunar Laser Ranging (LLR) and satellite laser ranging (SLR), and using the GPS and DORIS systems[1]. As a part of the C04, the polar motion coordinates (x, y) describe the polar motion with respect to the crust. The stability in time of the Chandler wobble amplitude and period (or phase), as an important part of the polar motion could be analysed by using different series of classical and modern astrometry data. In Damljanović et al. (1997) we used observations obtained at the single observing site, the so-called BLZ (Belgrade Lunette Zenithale[2]) data, which enabled measuring the Chandler wobble parameters. In the BLZ latitude series (from 1949 to 1985) the quasi-periodic change in the amplitude of the Chandler nutation was detected (near $0\farcs06$) with a period of about 38 years (Damljanović et al. 1997). Similar results were published in other papers (Rykhlova 1969, Zotov et al. 2022), where the period of amplitude variations was quoted to be about 40 years.

We wanted to check if our results agree with the BLZ data, because novel Earth's long-term polar motion data provide very precise time series IERS EOP C04 from 1984 to 2023 (one-day intervals), and we applied the same procedure using the C04 data to determine the Chandler wobble amplitude variations. Moreover, in comparison with classical astrometry data like the BLZ latitude series, the C04 data are free of some systematic errors and local distortions. Thus, the novel C04 data are particularly useful for study of the Chandler nutation amplitude variations.

Observational results indicating the existence of amplitude variation of the Chandler wobble (with a period of about 40 years) are not widely accepted as realistic, since the physical explanation of the phenomenon is lacking. This poses another challenge to our investigation. The homogenized and novel C04 data provide us with a good opportunity to study decadal-variations of the Chandler wobble parameters (the amplitude A_C at the first place), but also to search for a physical explanation causing aforementioned variations.

In the Section 2, we describe the procedure and present calculations of the Chandler wobble parameters, along with the main features of the amplitude variations of the Chandler wobble. In the last section (Section 3), we present conclusions and elaborate the need for further study given that physical explanation of the studied phenomenon remains unclear.

[1]DORIS is a short for Doppler Orbitography and Radiopositioning Integrated by Satellite, a tracking system used to determine the location of the particular satellite

[2]Data on Belgrade latitude were obtained at the Astronomical Observatory of Belgrade with the Zenith-telescope and archived at Bureau International de l'heure (BIH), superseded by IERS.

2. THE VARIATION OF THE CHANDLER WOBBLE AMPLITUDE

The annual term presented in the polar motion (in Fig. 1) has a stable period (of one year). The Chandler wobble is slightly elliptical (Guinot 1982) or nearly circular, and it is of importance to calculate the parameter of that wobble for some specific meridian (the BLZ meridian in this paper). The period of the Chandler wobble is variable (it could vary from 1.06 years or 387 days to 1.21 years or 442 days), and the amplitude of that wobble varies from $0\farcs07$ to $0\farcs28$ (Vondrák 1985).

2.1. Latitude variations at the BLZ point using IERS EOP C04 polar motion data

First of all, we calculated the latitude variations ($\varphi - \varphi_0$) at the BLZ point (in Fig. 2) using the C04 polar motion coordinates (x, y) and Kostinski's formula (Kulikov 1962):

$$x \cos(\lambda_{\mathrm{BLZ}}) + y \sin(\lambda_{\mathrm{BLZ}}) = \varphi - \varphi_0, \qquad (1)$$

where λ is longitude, and φ is latitude.

This formalism enables comparison between the results obtained using C04 data from 1984.0 to 2023.0, with previous results (Damljanović et al. 1997) based on the Belgrade latitude data (the BLZ series from 1949 to 1985). Consequently, the parameters of the Chandler wobble (the amplitude, period, and phase) refer to the Belgrade meridian $\lambda_{\mathrm{BLZ}} = 20\fdg5$. The value of $20\fdg5$ is calculated from the Greenwich meridian to the east using Eq. (1).

2.2. Secular term of latitude variations at the BLZ point

Least-squares method (LSM) was applied to calculate the secular term coefficients ($a_1 = 0\farcs116 \pm 0\farcs002$ and $a_2 = (254 \pm 6.8)10^{-10}$ $''/y$) of C04 latitude variations at the BLZ point (see Fig. 2) using the following model: $\varphi - \varphi_0 = a_1 + a_2 t$, where t is time in years, from 1984.0 to 2023.0. Afterwards, we estimated the residuals (the data in Fig. 2 without the secular term). Direct Fourier transform – DFT (see in Fig. 1) was fed with these residuals to obtain the parameters of the Chandler wobble, annual and semiannual variations[3]. The resulting parameters are: $P_C = 1.182$ years, $A_C = 0\farcs1135$, $F_C = 236\fdg07$, $P_a = 1.000$ years, $A_a = 0\farcs0951$, $F_a = 229\fdg64$, $P_{sa} = 0.500$ years, $A_{sa} = 0\farcs0024$, and $F_{sa} = 161\fdg83$.

2.3. Amplitude periodogram using the Fourier transforms

We have applied two independent techniques (methods) to test and confirm the Chandler wobble parameter values. The amplitude periodogram

[3]The epoch for phases is 1984.0.

is presented in Fig. 1, where the annual and Chandler wobbles are dominant. After applying DFT (the first method), the standard deviations of amplitude and phase given in the previous subsection, could be calculated using the following equations:

$$\sigma_A = \sigma_0 \sqrt{(4-\pi)/N} = 0.''00009 \ , \tag{2a}$$

$$\sigma_F \approx 57.^{\circ}296(\sigma_0/A)\sqrt{2/N} \ , \tag{2b}$$

where $N = 14245$ is the total number of C04 values $(x,\ y)$ during the time interval 1984.0 – 2023.0, $\sigma_0 = 0.''012$ is the standard deviation of residuals (in Fig. 3), A is the amplitude (the Chandler A_C, annual A_a or semiannual A_{sa}), σ_A is the amplitude standard deviation, and σ_F is the phase standard deviation ($\sigma_{Fc} = 0.^{\circ}07$ for the Chandler wobble, $\sigma_{Fa} = 0.^{\circ}08$ for the annual one, and $\sigma_{Fsa} = 3.^{\circ}34$ for the semiannual one). The residuals (in Fig. 3) are obtained after removing the secular term and three oscillations (the Chandler, annual and semiannual variations) from the values presented in Fig. 2. After applying DFT, the combined curve utilizing the parameters (detailed in Subsection 2.2) of three harmonics (namely, the Chandler, annual, and semiannual) is $A_C \cos(360°(t-1984.0)/1.2 - F_C) + A_a \cos(360°(t-1984.0)/1.0 - F_a) + A_{sa} \cos(360°(t-1984.0)/0.5 - F_{sa}) = 0.''1135 \cos(360°(t-1984.0)/1.2 - 236.^{\circ}07) + 0.''0951 \cos(360°(t - 1984.0)/1.0 - 229.^{\circ}64) + 0.''0024 \cos(360°(t-1984.0)/0.5 - 161.^{\circ}83)$, where t is the time in years, starting from 1984.0.

Besides DFT, LSM (the second method) was applied to obtain the best fit solution on the C04 interval (1984.0-2023.0),using the mean period $P_C = 0.^{y}184$. To this end, the value of P_C was varied to minimize the standard deviation $\sigma = 0.''7$ (the best fit) of suitable residuals. From the best fit solution, the value of Chandler amplitude is $A_C = 0.''1131 \pm 0.''0007$ and the phase is $F_C = 221.^{\circ}5 \pm 0.^{\circ}7$ (for the epoch 1984.0). As expected, the obtained parameter values of the Chandler wobble are close to the values previously obtained applying DFT method (Subsection 2.2).

2.4. Study of systematic variability of the Chandler wobble amplitude using Abbe's criterion

We wanted to study the trends and low-frequency variations of the Chandler wobble amplitude values, so we used the Abbe's criterion (Malkin 2013, Damljanović et al. 2021). We applied this criterion to A_C values in order to explain variability of A_C values, i.e. whether or not existing variability could be explained by formal errors. The Abbe's criterion is aimed at testing the hypothesis that each of mathematical expectations of the analyzed values A_C (in Table 1) is equal, and the Abbe's statistic is the ratio $R = a_1/a_2$. The value a_1 is the Allan's variance and a_2 is the dispersion of the values A_C (see Eq. (4)). If there are trends and low-frequency variations in values of A_C the value of a_2 is greater than that of a_1, i.e. $R < R_0$, where R_0 is the critical value of the Abbe's distribution. We can calculate the value R_0 from the following formula:

$$R_0 = 1 + U_q/[n + 0.5(1 + U_q^2)]^{0.5}, \tag{3}$$

where U_q is the quantile of the order q of standard distribution of values A_C, and it is $U_{0.05} = -U_{0.95} = -1.64485$ for $q = 0.05$. In the case $R < R_0$, the hypothesis that there is no trend in values of A_C is rejected. The conclusion is that there are statistically significant systematic variations in A_C values.

For the probability level of 0.05, after applying the Abbe's criterion to $n = 33$ values of A_C (in Table 1), the obtained parameters are: $R = 0.055$, and $R_0 = 0.721$. Since $R < R_0$ and, in agreement with the Abbe's criterion, we conclude that values of A_C can not be explained by formal errors alone. Consequently, there is some systematic part that requires further study. In Fig. 4 there is a clear indication that systematic part is similar to a sinusoidal variation. We calculated the values of a_1, and a_2 using formulas:

$$a_1 = \frac{1}{2(n-1)} \sum_{i=1}^{n-1} (Ac_{i+1} - Ac_i)^2 \ , \tag{4a}$$

$$a_2 = \frac{1}{n-1} \sum_{i=1}^{n} (Ac_i - A_{av})^2 \ , \tag{4b}$$

where A_{av} is the average of A_C values.

To check the possible variations of the annual wobble amplitude A_a using the Abbe's criterion, we calculated the parameters of both wobbles (the Chandler and annual ones) over six-year subintervals and obtained six independent A_C and A_a values (Table 2).

Least-square method was applied to model two sinusoidal curves in order to obtain the best fit solution, where the annual period was only $1.^{y}000$ and the Chandler period was varied around $1.^{y}180$ with a small step of $0.^{y}001$. The result of applying the Abbe's criterion to $n = 6$ values of A_a was: $R = 0.910$, and $R_0 = 0.413$, i.e. $R > R_0$. In accordance with the Abbe's criterion, we conclude that values of A_a can be explained by formal errors alone. During calculation of 33 independent values of A_C (in Table 1), where the annual and semiannual wobbles were removed to get residuals (in Fig. 5), the annual amplitude was kept fixed. The amplitude A_{sa} of the semiannual wobble was very small compared to uncertainties and thus could be neglected.

Abbe's criterion applied to 33 values of the period P_C and phase F_C of the Chandler wobble (in Table 1) resulted in: $R = 1.113$ and $R_0 = 0.721$ ($R > R_0$) for the period, and $R = 0.395$ and $R_0 = 0.721$ for the phase ($R < R_0$), respectively. Consequently, the hypothesis that there is no trend in the values of F_C is rejected, but accepted for the values of P_C. The value $R = 0.395$ is close to $R_0 = 0.721$, but still it is $R < R_0$ and the F_C is variable during the period 1984-2023.

Table 1: The values of the Chandler nutation (amplitude A_C, period P_C and phase F_C) for each of $n = 1, \ldots, 33$ subintervals 1.2 years long (from 1984.0 to 2023.0) obtained by LSM; the epoch for phases is $1984^y.0$.

Mid-subinterval (years)	n	P_C (years)	$A_C \pm \sigma_{A_C}$ ($''$)	$F_C \pm \sigma_{F_C}$ (°)
1984.55	1	1.1870	0.1822 ±0.0014	208.5 ±0.3
1985.7	2	1.1787	0.1733 ±0.0014	211.5 ±0.5
1986.9	3	1.1885	0.1666 ±0.0012	213.6 ±0.4
1988.1	4	1.1787	0.1872 ±0.0010	208.0 ±0.3
1989.3	5	1.1814	0.1801 ±0.0009	215.9 ±0.3
1990.5	6	1.1892	0.1618 ±0.0017	221.5 ±0.5
1991.7	7	1.1863	0.1857 ±0.0011	216.3 ±0.4
1992.9	8	1.1838	0.2260 ±0.0010	221.1 ±0.3
1994.1	9	1.1878	0.2299 ±0.0006	224.1 ±0.1
1995.3	10	1.1870	0.2080 ±0.0007	212.7 ±0.2
1996.5	11	1.1821	0.1702 ±0.0010	221.1 ±0.3
1997.7	12	1.1838	0.1359 ±0.0010	244.5 ±0.3
1998.9	13	1.1838	0.1390 ±0.0008	237.1 ±0.3
2000.1	14	1.1814	0.1335 ±0.0013	238.3 ±0.5
2001.3	15	1.1821	0.1824 ±0.0012	239.0 ±0.3
2002.5	16	1.1834	0.1569 ±0.0016	228.5 ±0.3
2003.7	17	1.1821	0.1174 ±0.0007	223.0 ±0.3
2004.9	18	1.1842	0.1289 ±0.0009	242.5 ±0.4
2006.1	19	1.1885	0.1147 ±0.0008	256.3 ±0.4
2007.3	20	1.1842	0.1192 ±0.0014	239.8 ±0.5
2008.5	21	1.1855	0.1258 ±0.0006	263.3 ±0.1
2009.7	22	1.1855	0.1061 ±0.0009	251.7 ±0.5
2010.9	23	1.1826	0.0920 ±0.0011	230.9 ±0.5
2012.1	24	1.1859	0.0506 ±0.0013	221.6 ±0.5
2013.3	25	1.1859	0.0420 ±0.0008	212.1 ±0.5
2014.5	26	1.1851	0.0408 ±0.0005	210.8 ±0.1
2015.7	27	1.1821	0.0205 ±0.0004	225.4 ±0.2
2016.9	28	1.1821	0.0254 ±0.0009	216.7 ±0.3
2018.1	29	1.1826	0.0178 ±0.0008	251.2 ±0.3
2019.3	30	1.1855	0.0119 ±0.0006	251.2 ±0.1
2020.5	31	1.1821	0.0156 ±0.0004	216.9 ±0.2
2021.7	32	1.1821	0.0408 ±0.0010	211.3 ±0.2
2022.65	33	1.1821	0.0755 ±0.0006	217.0 ±0.1
Average		1.1842 ±0.0005	0.1201 ±0.0116	227.4 ±2.7

2.5. Parameters of the Chandler wobble of the 1.2-year subintervals over the C04 period 1984.0-2023.0

After removal of the annual and semiannual variations (obtained using DFT) we get new residuals with Chandler variations mostly (see Fig. 5), which are suitable for measurement of the Chandler wobble parameters: the so-called "instantaneous" amplitude, period, and phase. The LSM was applied (for the epoch 1984.0) on the 1.2-year subintervals (of interval presented in Fig. 5), and the results are presented in Table 1 (and also in Figs. 4 and 6). The Chandler period P_C was varied from $1^y.1700$ to $1^y.2000$ (with a step of $0^y.0001$) to get the best fit solution (using LSM) for each of 33 subintervals, i.e. the minimum of standard deviation between the residuals (presented on Fig. 5) and corresponding sinusoidal approximation on each subinterval. LSM was applied to amplitude values from Table 1 to model variations with sinusoidal curve in Fig. 4. The resulting parameters of the Chandler wobble are: $P = 54.5$ years, $C_1 = 0''.115 \pm 0''.005, A = 0''.087, F = 49^\circ.9, C_2 = 0''.056 \pm 0''.008, C_3 = 0''.066 \pm 0''.007$, with standard deviation $\sigma = 0''.023$. This best fit solution is marked by dots in Fig. 4, while the Chandler amplitude values for each of the 33 subintervals are designated by lines and are given in Table 1.

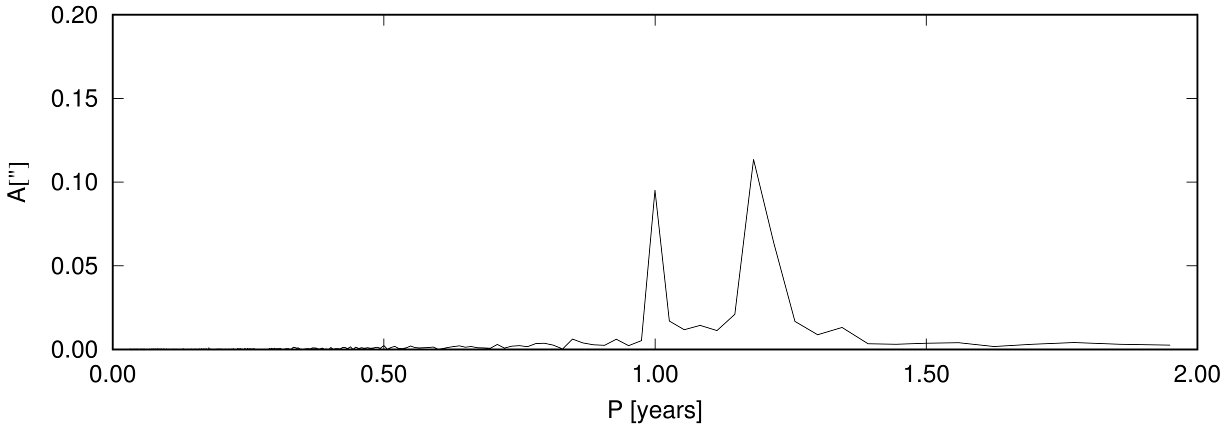

Fig. 1: Amplitude periodogram of latitude variation at the BLZ point (using the IERS EOP C04 polar motion data).

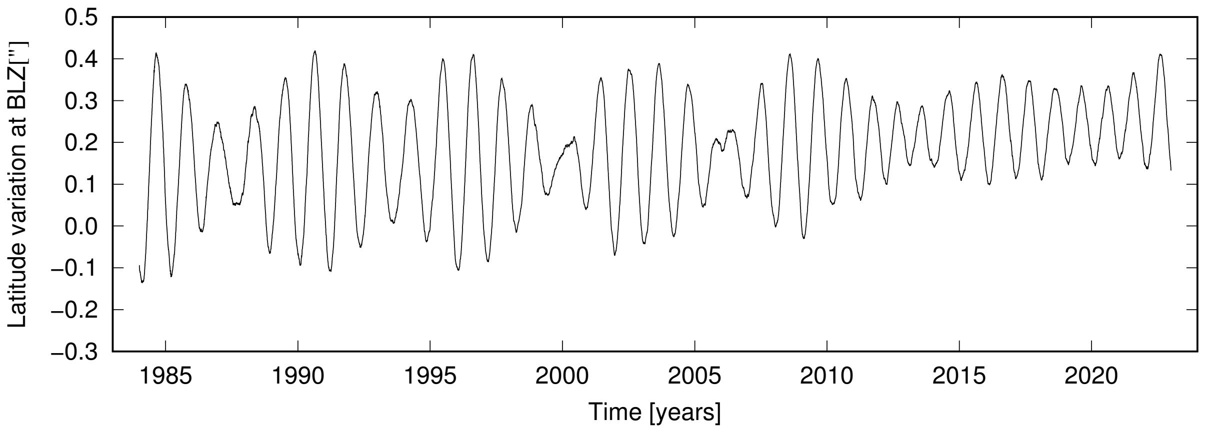

Fig. 2: Latitude variation at the BLZ point (using the IERS EOP C04 polar motion data).

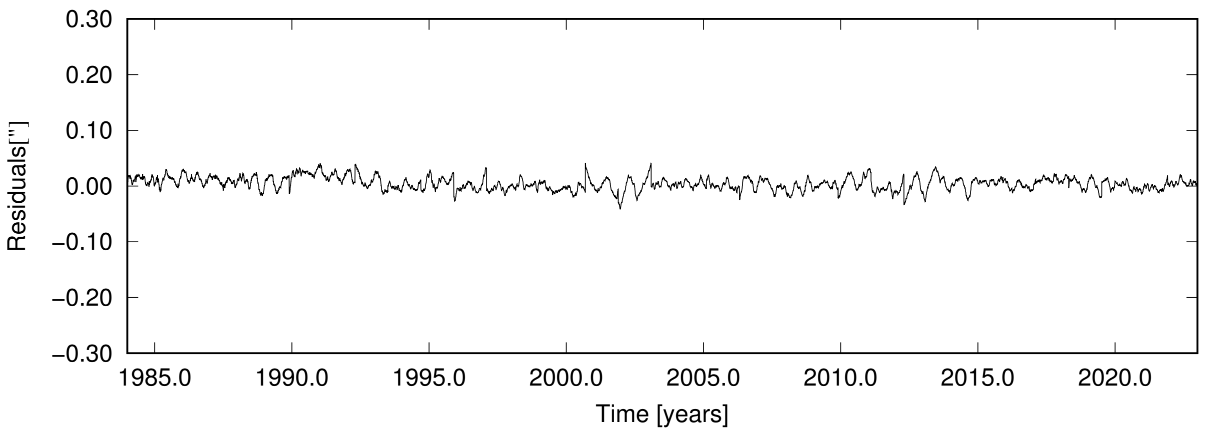

Fig. 3: Residuals (latitude variation at the BLZ point without linear, semiannual, annual and Chandler terms) during the period 1984.0-2023.0.

2.6. Variations of the Chandler amplitude

The first column in Table 1 contains the mid-subintervals (in years) of 1.2 years long subintervals over the period of 1984.0-2023.0. Only the first subinterval is $1\overset{y}{.}1$ long (of the subperiod 1984.0-1985.1) and the last one is $0\overset{y}{.}7$ (2022.3-2023.0) for technical reasons. In the second column of Table 1, n is the index value (from 1 to 33) used to enumerate subintervals. The next three columns are (for each subin-

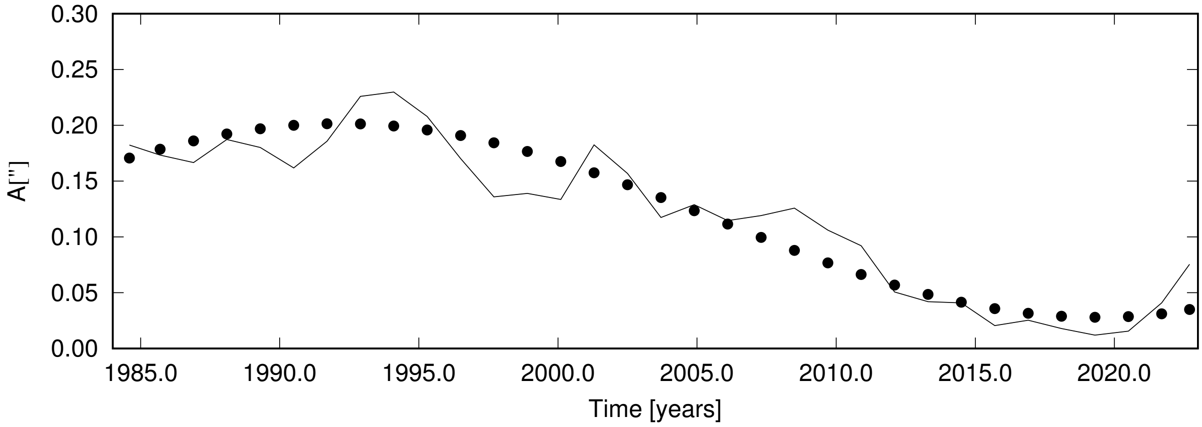

Fig. 4: Amplitude variation of Chandler nutation during the period 1984.0-2023.0 and corresponding sinusoidal fit (using the LSM).

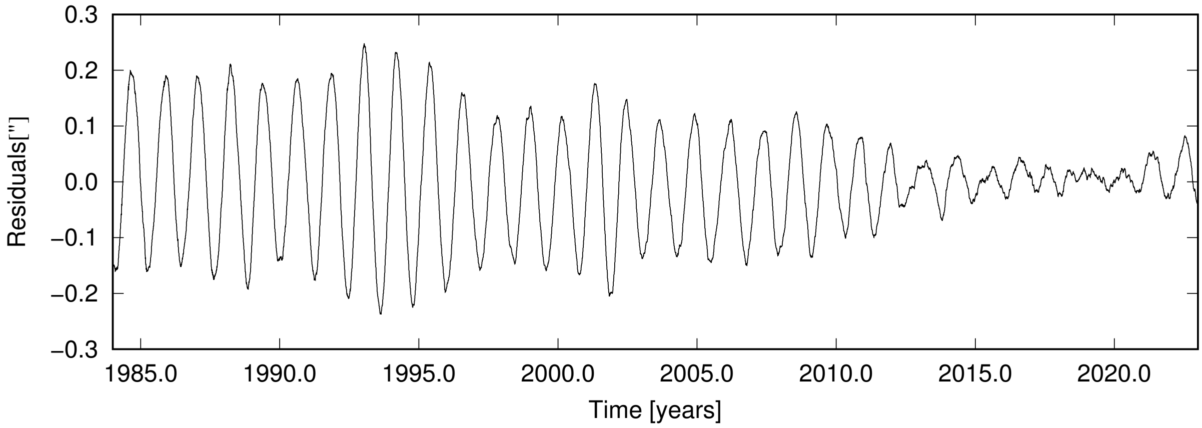

Fig. 5: Residuals (latitude variation at the BLZ point without linear, semiannual, and annual terms) during the period 1984.0-2023.0.

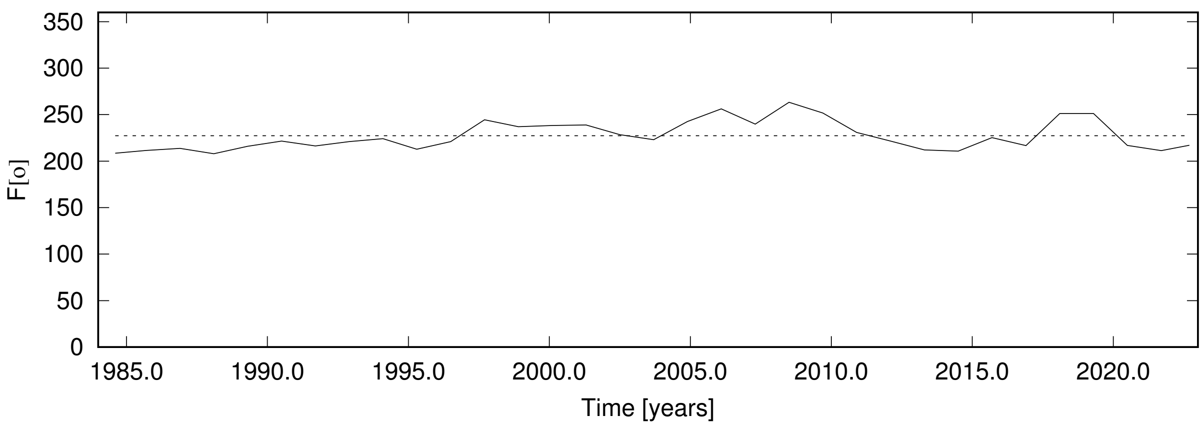

Fig. 6: Phase of Chandler nutation during the period 1984.0-2023.0 and its average value.

terval): the Chandler period P_C (in years), amplitude A_C (in arcseconds), and phase F_C (in degrees) for the epoch 1984.0. The variations of the Chandler amplitude (lines) and suitable sinusoidal approximation (black dots) are presented in Fig. 4.

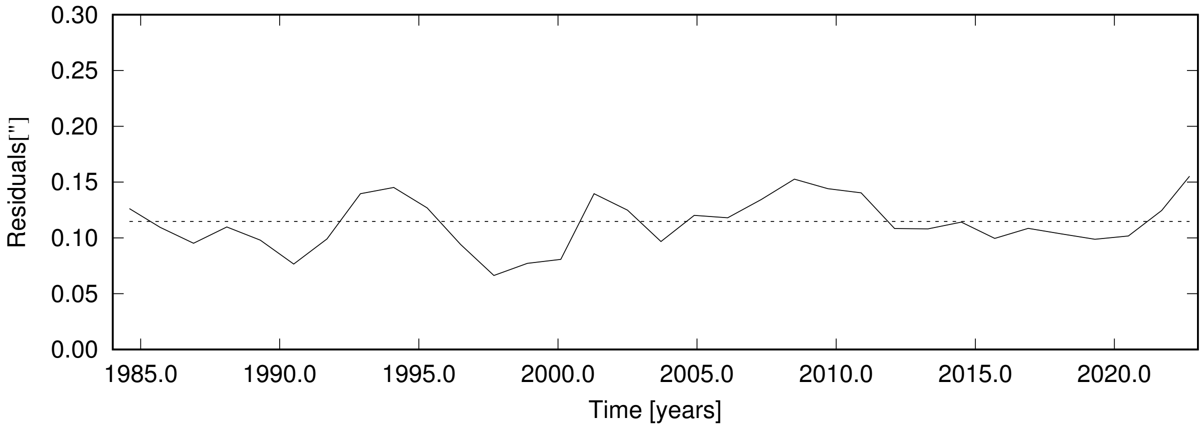

Fig. 7: Residuals of amplitude of Chandler nutation (differences between the obtained values of Chandler nutation amplitude and corresponding sinusoidal fit presented in Fig. 4) during the period 1984.0-2023.0.

Table 2: The Chandler and annual amplitudes over six years subintervals using LSM.

i	$A_{C,i}$ ($''$)	$A_{a,i}$ ($''$)	Mid-subinterval (years)
1	0.1767	0.0905	1987.0
2	0.2031	0.0600	1993.0
3	0.1526	0.0931	1999.0
4	0.1213	0.1047	2005.0
5	0.0731	0.1297	2011.0
6	0.0166	0.1038	2017.0

In Fig. 6 the variations of the Chandler phase (lines) are presented, along with their average value (the dashed horizontal line at 227°). In Fig. 7 the residuals (between the Chandler amplitudes and suitable sinusoidal values over 1984.0-2023.0) are presented. The corresponding sinusoidal values over 1984.0-2023.0 are given in Fig. 4), and their average value of $0.''12$ is indicated.

The sinusoidal fit represents a good model to the Chandler amplitude A_C values (see in Fig. 4). After removing the sinusoidal part, the behavior of the corresponding residuals are presented in Fig. 7. The period of those sinusoidal variations is 54.5 years and its amplitude is $0.''087$, i.e. the best fit solution is given by formula: $f(A_C) = 0.''087\cos(360^\circ(t - 1984.0)/54.5 - 49^\circ.9)$. The Chandler wobble amplitude varies within its minimal value of $0.''012$ at 2019.3 and its maximal value of $0.''230$ at 1994.1. In our previous paper (Damljanović et al. 1997), the sinusoidal variations were calculated from the BLZ data (from 1949 to 1985), and the resulting period was 38.5 years, while the amplitude was measured to be $0.''06$. The period of $54^{y}.5$ (based on the C04 data) is much longer than $38^{y}.5$ (by about 42%), and also the amplitudes differ a lot (about 45%). On the contrary, in agreement with the C04 data, the average value of the Chandler wobble amplitude is $0.''1132$ and of the annual wobble – $0.''0949$ (in the case of BLZ, the corresponding values are $0.''164$ and $0.''057$, respectively). The amplitude of the Chandler wobble from the BLZ data (for the period of 1949-1985) is greater than the one from the C04 data (1984.0-2023.0) for the amount of about 31%, but in the case of the annual wobble it is the opposite (it is less than about 66%).

In the paper Zotov et al. (2022), it has been shown that near 2019, the Chandler wobble amplitude reached its minimum since the 1930s. Also, in the paper Wang et al. (2016), using the interval 1900-2015 it was found that the Chandler wobble amplitude is currently at a historically minimal level. Our results presented here – based on C04 from 1984 to 2023 – during the last few years of 1984-2023 the Chandler wobble amplitude is bigger than the minimal value of $0.''012$ at $2019^{y}.3$ (in Figs. 4 and 5), and it is $0.''076$ at $2022^{y}.7$ (in Table 1).

The values of the period P_C vary only slightly: the minimum is $1^{y}.1787$ at 1986.9 and 1989.3 (it is $430^{d}.52$), and the maximum is $1^{y}.1892$ at 1991.7 (it is $434^{d}.36$). The value of $430^{d}.23$ (close to our results here) is obtained from similar data and published in the paper Vondrák and Ron (2020). Also, the value of $432^{d}.3$ (from the interval 1962-2021) is close to our results and it is published in An and Ding (2022). On the contrary, the values of the phase F_C show more variability (Fig. 6).

After removing the Chandler wobble from residuals presented in Fig. 5, using the results of the parameters of the Chandler wobble for each subinterval (Table 1), the final residuals are presented in Fig. 3. These residuals should be free of systematic variations, and are an order of magnitude smaller than those including all known systematics including Chandler wobble.

3. CONCLUSIONS

We analyzed the Chandler wobble amplitude variations using the polar motion coordinates (x, y) on the time series IERS EOP C04 from 1984 to 2023 (one-day intervals). Using the C04 coordinates (x, y) and Kostinski's formula we calculated variations of the latitude at the BLZ point to compare with our previous results published in the paper (Damljanović et al. 1997), where the same technique was applied to the BLZ data. The secular part of these latitude variations was calculated by LSM and removed from the data to obtain the residuals. By applying DFT to these residuals, we successfully modeled and removed the annual and semiannual oscillations to get a new set of residuals. The new residuals were divided into 33 independent 1.2-year subintervals. For each subinterval, using the LSM we calculated: the amplitude, period, and phase of the Chandler nutation. Applying the Abbe's criterion, we analysed the trends and low-frequency variations in 33 values of the Chandler wobble amplitude. The Abbe's criterion confirmed the existence of periodic variations. Modelling sinusoidal function by LSM resulted in the parameters of the quasi-periodic instability of the Chandler wobble amplitude (Fig. 4) with the period of 54.5 years (in comparison, from BLZ data in the period 1949-1985 it was measured to be 38.5 years), and amplitude of $0''.087$ ($0''.06$ – from the BLZ data, for comparison). The minimum of the Chandler nutation amplitude was $0''.012$ (at $2019^{y}.3$) and maximum was $0''.230$ (at $1994^{y}.1$). Using C04 data (1984-2023), the period of the Chandler wobble varies within a few days between its minimum of $1^{y}.1787$ or $430^{d}.52$ (at $1986^{y}.9$ and $1989^{y}.3$) and maximum of $1^{y}.1892$ or $434^{d}.36$ (at $1991^{y}.7$). In agreement with Abbe's criterion, the P_C (in Table 1) is stable during 1984-2023. It is in accordance with the result of $430^{d}.23$ from the paper Vondrák and Ron (2020), which also refers to the similar polar motion data. In addition, the value of $432^{d}.3$ obtained for the interval 1962-2021 published in the paper An and Ding (2022) is in agreement with our results, too. Conversely, the F_C (in Table 1 and Fig. 6) is proven to be variable during 1984-2023, after applying the Abbe's criterion.

It was indicated in the paper Zotov et al. (2022) that during the last few years, Chandler wobble amplitude reached its minimum since the 1930s. Using the interval 1900-2015, in the paper (Wang et al. 2016) it was concluded that the Chandler wobble amplitude is currently at a historically minimal level. Here, based on C04 data from 1984 to 2023, we see that the Chandler wobble amplitude (at the end of the interval 1984-2023) is larger than the minimum value of $0''.012$ at $2019^{y}.3$ (in Figs. 4 and 5), and it is equal to $0''.076$ at $2022^{y}.7$ (in Table 1).

Measurements of the Chandler wobble amplitude modulation presented in this work and based on the novel C04 data are in agreement with the results obtained using a single instrument (Belgrade Zenith-Telescope) which was used to acquire BLZ data (Damljanović et al. 1997), but also with results published in Zotov et al. (2022). However, the geophysical explanation of these periodic variations remains elusive and thus a further study is needed to identify a possible cause. Some results indicate that the cause is lying in the hydro-atmospheric circulation that could influence the calculated quasi-periodic variation (Zotov et al. 2022, Gross 2000), but in recent papers (Cui et al. 2020) a possible explanation can be found in the change of core-mantle electromagnetic coupling. It has been indicated that the effects of geomagnetic jerks are more important for exciting free core nutation than the atmosphere and oceans, in agreement with recent results (Vondrák and Ron 2020, An and Ding 2022). A further study is needed to shed more light on this controversy.

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ПРОМЕНЕ АМПЛИТУДЕ ЧЕНДЛЕРОВЕ НУТАЦИЈЕ КОРИСТЕЋИ ВИШЕДЕЦЕНИЈСКЕ ПОДАТКЕ IERS EOP C04 ПОЛАРНОГ КРЕТАЊА

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Оригинални научни рад

Користили смо вишедеценијске податке поларног кретања Земље (x, y) серије IERS EOP C04 (од 1984. до 2023. године) да бисмо испитали промене амплитуде A_C Чендлерове нутације. Да бисмо поредили резултате добијене из C04 са ранијим резултатима добијеним из ширинских података Београда (BLZ серија од 1949. до 1985. године) рачунали смо промене ширине за BLZ тачку користећи C04 координате (x, y). Секуларни члан смо израчунали користећи методу најмањих квадрата (LSM) и одстранили из промена ширине за BLZ тачку да бисмо добили одговарајуће остатке. Применили смо на те остатке Fourier transforms (DFT) да бисмо израчунали и одстранили из поменутих остатака годишњу и полугодишњу осцилацију. Добили смо нове остатке које смо поделили на 33 независна подинтервала од по 1.2 године. За сваки подинтервал смо рачунали амплитуду A_C, периоду и фазу Чендлерове нутације користећи LSM. Квазипериодичне промене A_C смо рачунали са LSM и добили периоду од 54.5 година (из BLZ је била 38.5 година за интервал 1949-1985) и амплитуду те промене од $0''.087$ ($0''.06$ из BLZ података). Вредности A_C су варирале од $0''.012$ (2019.3 године) до $0''.230$ (1994.1 године); период је стабилан, али не и фаза. Применили смо Абеов критеријум, и хипотеза да нема тренда у поменуте 33 вредности A_C је одбачена. Наши резултати су у сагласности са другим публикованим резултатима, као и са резултатима које смо добили користећи BLZ податке. Неки аутори узрок добијене квазипериодичне промене проналазе у воденим и ваздушним циркулацијама. У складу са новијим резултатима, могући узрок би могао бити у променама електромагнетне спреге језгра и омотача Земље. Последњих година се ефекат електромагнетних скокова (енг. *geomagnetic jerks*) истиче као значајнији узрок поменуте појаве него атмосфера и океани. Неопходна су даља слична истраживања.