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Investigation of the Parameters of the Free Core Nutation from VLBI data

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З. Малкин, Д. Терентев. Определение параметров свободной нутации ядра Земли из РСДБ-наблюдений.

Ключевые слова: Вращение Земли, нутация, свободная нутация ядра.

Несколько серий ПВЗ, полученных в разных центрах анализа РСДБ-наблюдений использованы для определения параметров свободной нутации ядра Земли (FCN). Иследовались как амплитуда, так и период FCN двумя методами: спектральным и вейвлет-анализом. Рещультаты работы показали, что и амплитуда и период FCN испытывают значительные временны́е вариации. Амплитуда изменяется в интервале около 0.1–0.3 mas (что известно также из других исследований), а период — в интервале прмерно 415–490 средних суток. Последнее может также объясняться нестабильностью фазы FCN. Вариации амплитуды, полученные разными авторами и методами, имеют некоторые расхождения, особенно на концах исследуемого интервала.

Z. Malkin, D. Terentev. Investigation of the Parameters of the Free Core Nutation from VLBI data.

Keywords: Earth rotation, nutation, Free Core Nutation.

Several VLBI EOP series were investigated with goal of determination of parameters of the Free Core Nutation (FCN). Both the amplitude and period of the FCN were studied using spectral and wavelet analysis. Our analysis reveals a variability of both the amplitude (known also from other investigations) and period (or phase) of the FCN nutation. The FCN amplitude varies in the range about 0.1–0.3 mas, and the FCN period — in the range about 415–490 solar days. The latter may be also explained by changes in the FCN phase. Comparison of time variations of the FCN period and amplitude obtained by different authors and methods shows substantial discrepancies at the edges of the period of observations.

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Contents

1. Introduction

In this paper we investigate variability of the FCN parameters. Whereas variations of the FCN amplitude was already investigated (see e.g. [1, 2]), variations of the FCN period is not been studied yet.

Modern theory of nutation predicts the steady FCN period of 431.2 sidereal days [3]. The FCN period also have been estimated from VLBI observations, and found to be about 430–431 sidereal days or about 429–430 solar days (see, e.g. Table 4 in [4]).

In this paper we analyze four VLBI nutation series available in the IVS data base, sufficiently long and dense to obtain reliable estimates. We consider the differences between observed values of nutation angles and IAU2000A model (which is equivalent to MHB2000 model without FCN contribution). For our purpose, we interpret the unpredicted part of observed nutation series in the FCN frequency band as the FCN contribution.

2. Data used in analysis

The series used in our analysis are BKG00003, GSF2002C, IAAO0201, USN2002B. We analyzed both raw (i.e. given on original epochs) and smoothed (equally spaced by 0.05 year) differences between observed nutation angles and the IAU2000A model. For smoothed series we also computed the weighted mean one. The parameter of smoothing was chosen in such a way to suppress oscillations with periods less then 1 month. Common time span for all series is 1984.0–2002.8. Figure 1 shows smoothed series used in our analysis.

3. Analysis and results

3.1. Spectral analysis

For estimation of the power spectral density from both raw (unequally spaced) and smoothed (equally spaced) nutation series we used the Ferraz-Mello's method [5] which allows us to process both types of data. For supplement testing, we also compute the power spectral density using the Burg's method [6]. Figures 2—4 show the normalized results of spectral estimation, and Table 1 presents the estimates of the FCN period. Compar-

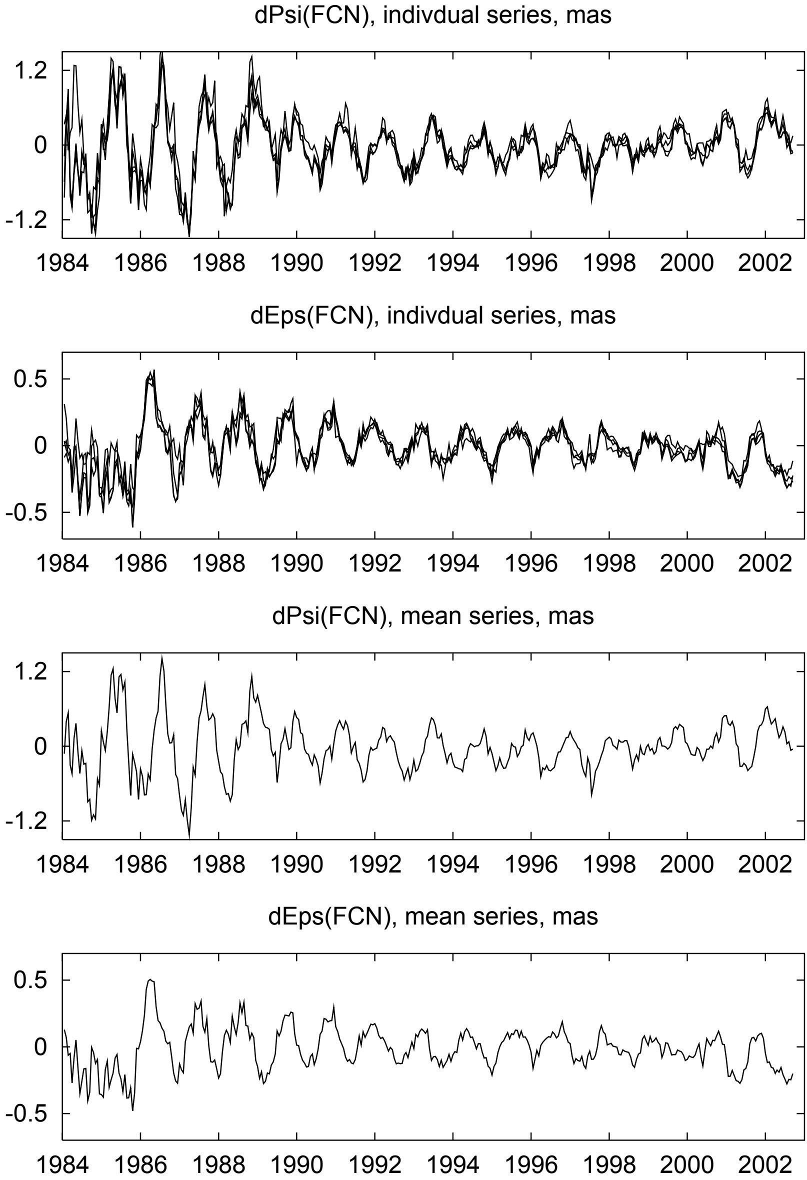


Figure 1. FCN contribution in the individual and mean series.

ison of results shows reasonable good agreement between the VLBI series, taking into account that we investigate rather week signal.

Table 1. Periods of the FCN contribution, solar days.

Series	Method	BKG	GSF	IAA	USN	Mean
			$\Delta\psi$			
Raw	Ferraz-Mello	435.0	432.2	434.4	433.7	—
Smoothed	Ferraz-Mello	434.2	432.7	430.3	433.7	432.5
Smoothed	Burg	430.6	431.0	434.3	433.1	431.9
Smoothed	Burg (–2000.2)	433.4	430.0	428.5	433.4	431.9
			$\Delta\varepsilon$			
Raw	Ferraz-Mello	435.4	432.2	435.0	432.9	—
Smoothed	Ferraz-Mello	435.4	433.1	432.9	433.5	433.5
Smoothed	Burg	438.4	438.6	436.2	438.7	438.8
Smoothed	Burg (–2000.2)	431.7	428.5	429.5	430.1	429.9
			Mean of $\Delta\psi$ and $\Delta\varepsilon$			
Raw	Ferraz-Mello	435.2	432.2	434.7	433.3	—
Smoothed	Ferraz-Mello	434.8	432.9	431.6	433.6	433.0
Smoothed	Burg	434.5	434.8	435.2	435.9	435.4
Smoothed	Burg (–2000.2)	432.6	429.2	429.0	431.8	430.9

The average estimated value of the FCN period is of about 434 solar days (about 435 sidereal days). This value is substantially greater than one found in [4] (431.0±0.6 sidereal days). However, when we used for spectral analysis only nutation series cut at the epoch 2000.2 which corresponds to the data span used in [4], we obtain the FCN period of about 432 sidereal days which is close to found in [4] (see the last line in each section of Table 1).

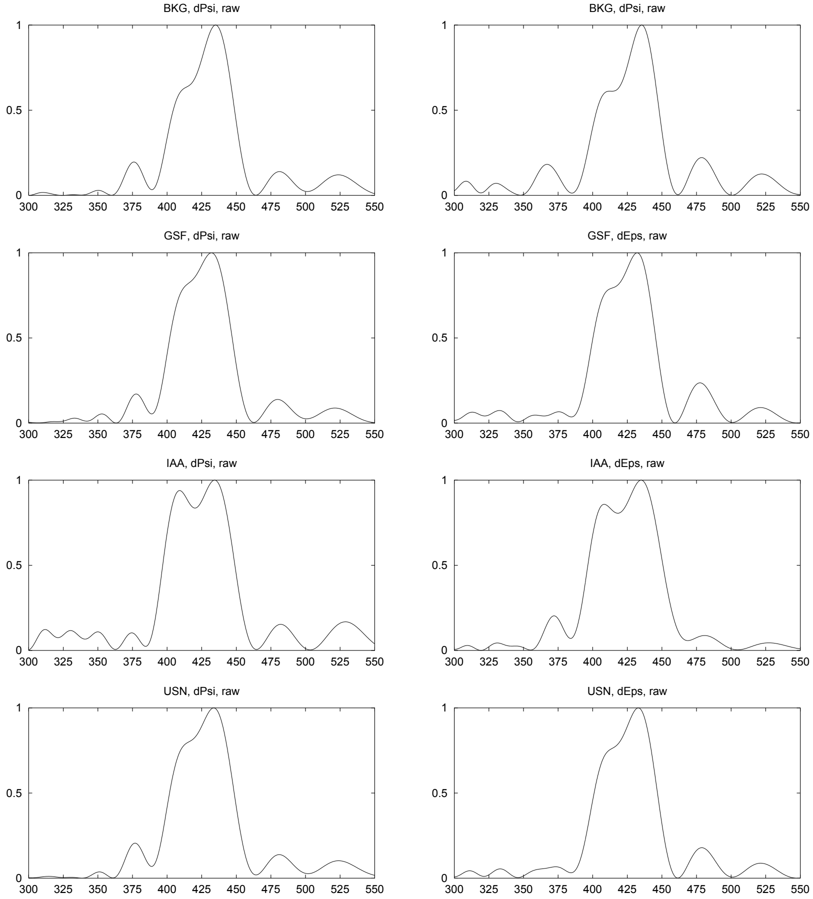


Figure 2. Spectra of raw data, Ferraz-Mello's method, solar days.

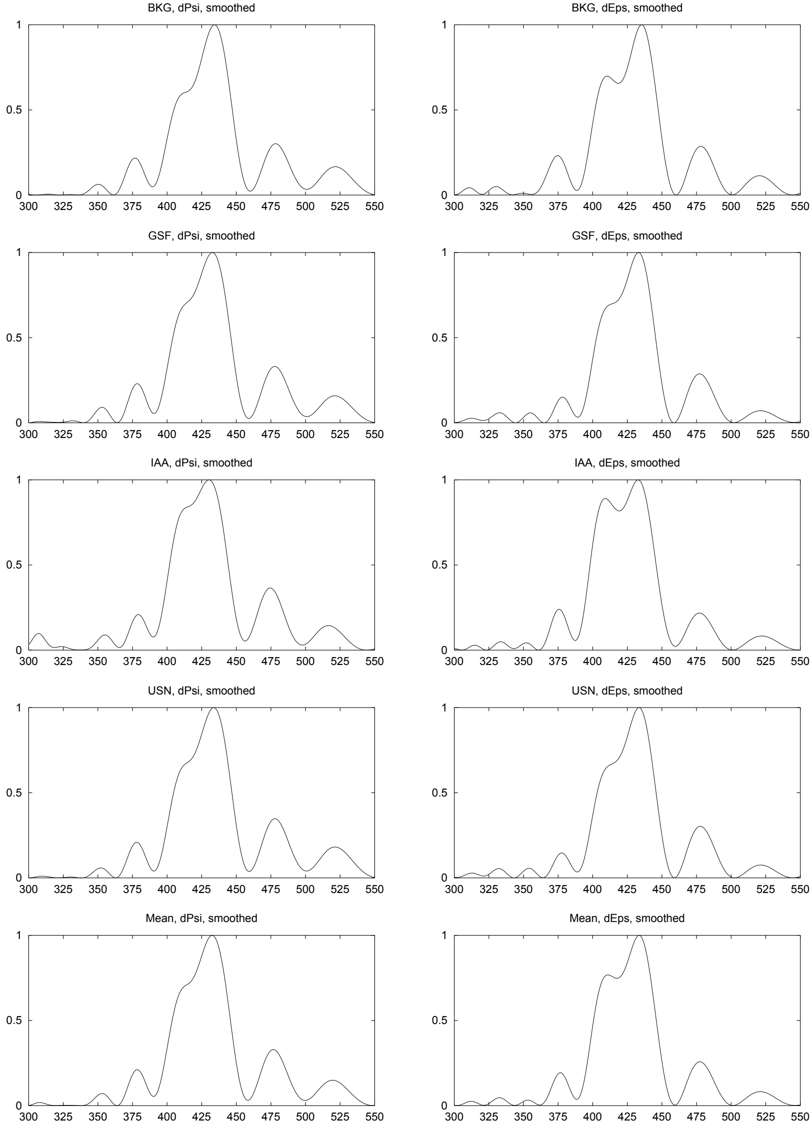


Figure 3. Spectra of smoothed data, Ferraz-Mello's method, solar days.

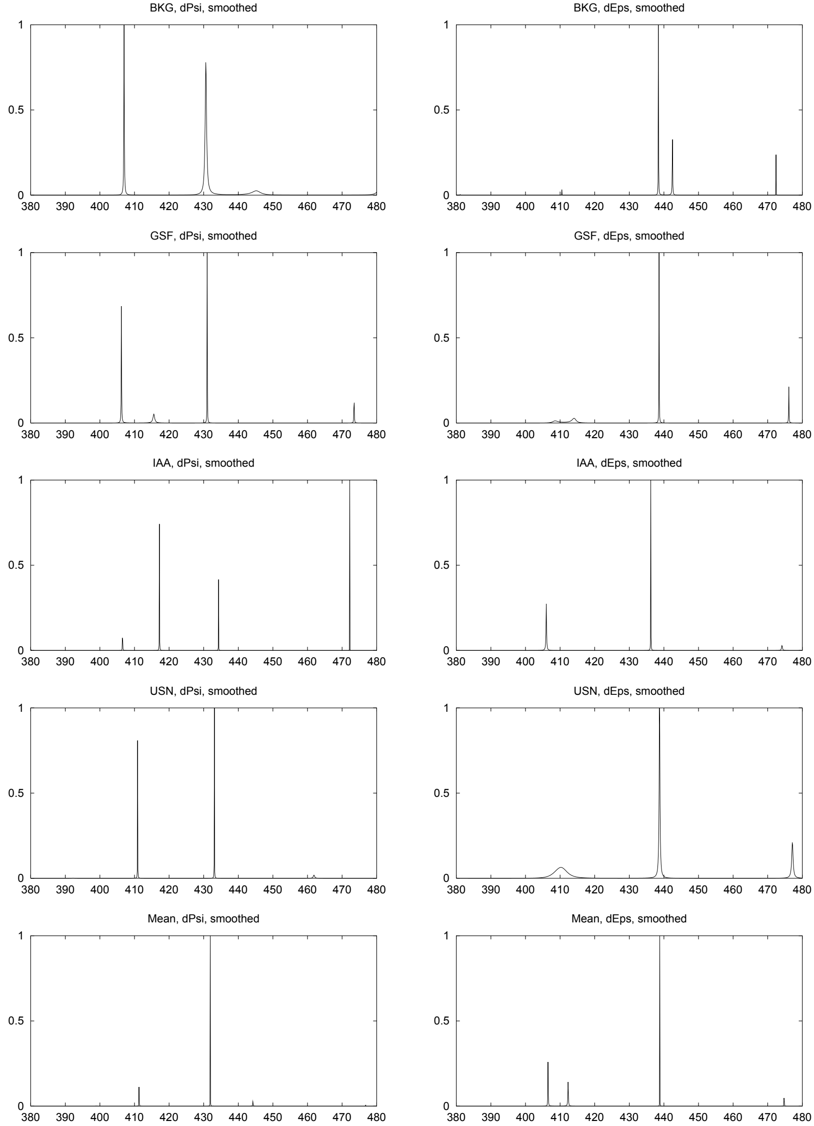


Figure 4. Spectra of smoothed data, Burg's method, solar days.

3.2. Wavelet analysis

At the next step we had applied the wavelet analysis to all the nutation series to investigate the time variations of the FCN period (phase) and amplitude, which is the main goal of our study. For this analysis we used program WWZ, developed by the American Association of Variable Star Observers and available as executable at the http://www.aavso.org/cdata/wwz.shtml. Theoretical background of this method can be found in [7]. The results of the wavelet analysis are presented in Figures 5–8.

Figure 9 presents the final results of the present investigation. It should be mentioned that based on the comparison of FCN amplitudes found here and previous investigations [8], we consider the results obtained before 1990 seems to be not very reliable.

Of course, an important question arising from the obtained result is whether the variations of the period found from our analysis is an actual geophysical signal or an artifact caused by inadequate computational procedures. One can see that large increasing of the FCN period after ≈1998 corresponds to relatively low amplitude of the FCN oscillation. We have performed some tests to estimate how result of wavelet analysis depends on variable amplitude of input signal.

For test purposes we used several artificial signals, and also we constructed new series as original one normalized by found variations of the FCN amplitude. The latter provides the FCN contribution series with near-unity amplitude with all other peculiarities inherited from real nutation series. The variations of the period found for the test series are practically the same as for real data.

After all test, our conclusion is that found variations of the FCN period cannot be explained by computational errors. Besides, the results of spectral analysis made for different subset of data also corroborate our conclusion.

One of the important points to be investigated is the edge effect which may lead to misinterpreting of the results of the wavelet analysis for the first and the last epochs. For this purpose we performed a special test with WWZ. We computed the FCN period and amplitude variations for several series starting with original one and cutting the first and the last 200 points from it. Then this process was repeated and in that way four test series were obtained, each starts 200 days later and ends 200 days earlier than previous one. Figures 10 and 11 show the result of this test.

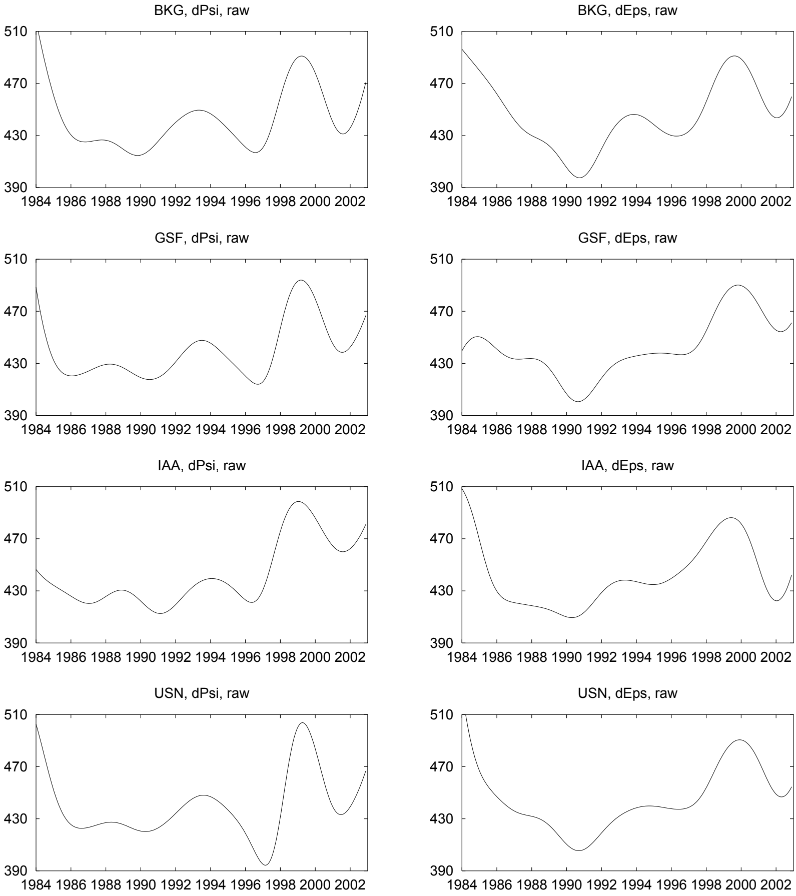


Figure 5. Variations of the FCN period with time, raw data, solar days.

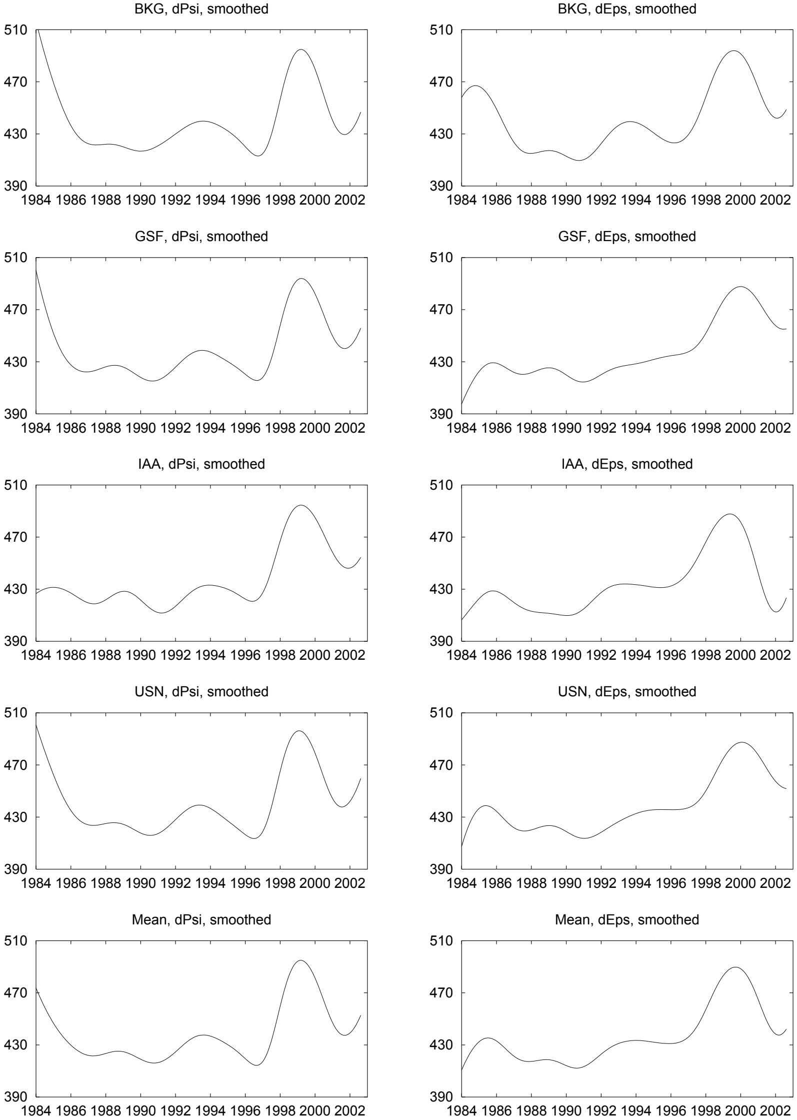
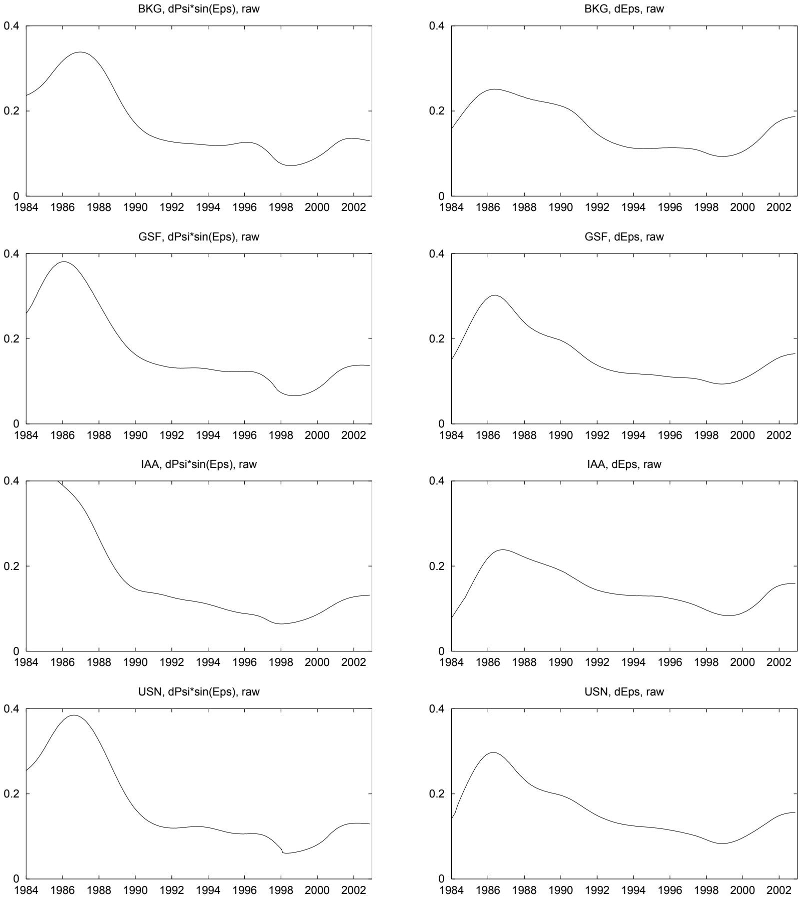


Figure 6. Variations of the FCN period with time, smoothed data, solar days.



BKG, dPsi*sin(Eps), raw

BKG, dEps, raw

GSF, dPsi*sin(Eps), raw

GSF, dEps, raw

IAA, dPsi*sin(Eps), raw

IAA, dEps, raw

USN, dPsi*sin(Eps), raw

USN, dEps, raw

Figure 7. Variations of the FCN amplitude with time, raw data.

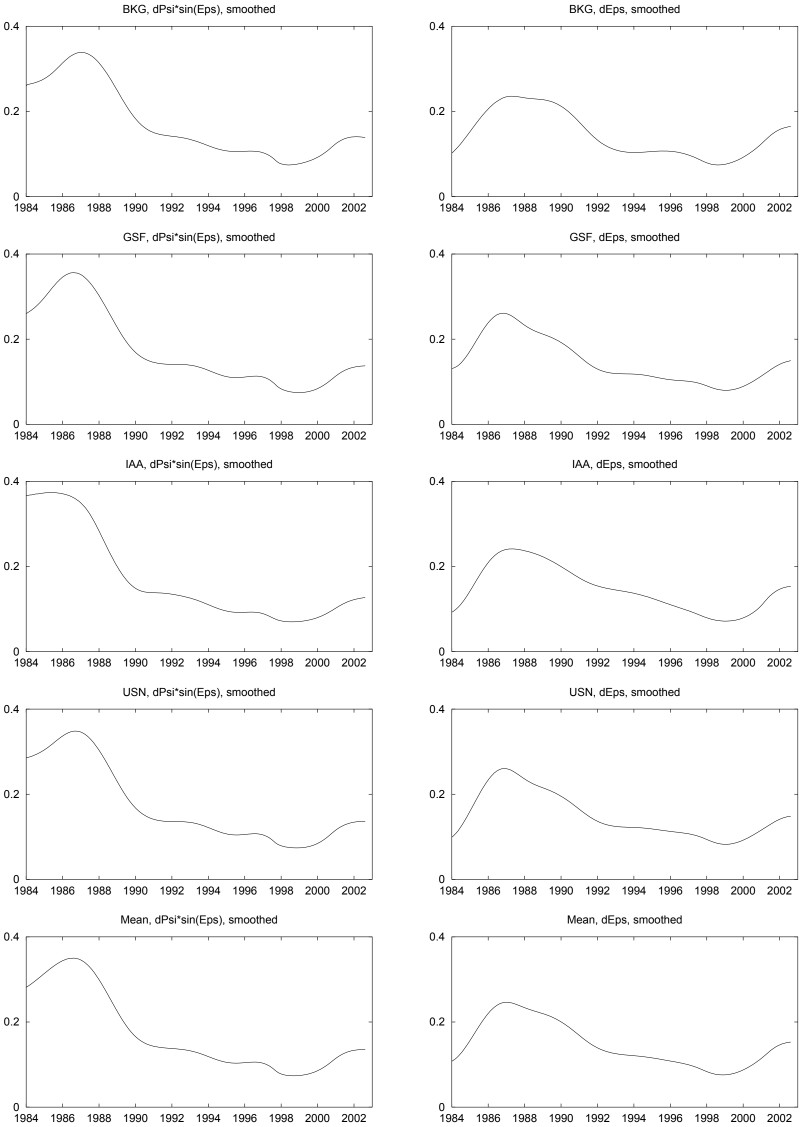
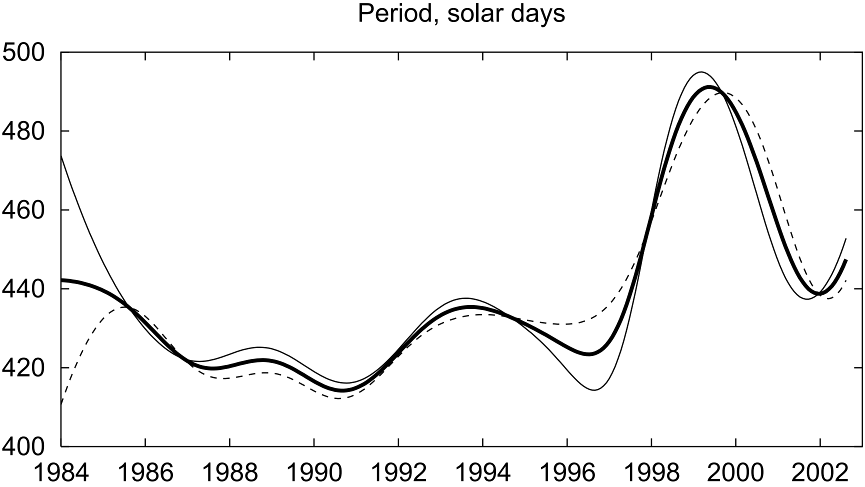


Figure 8. Variations of the FCN amplitude with time, smoothed data.



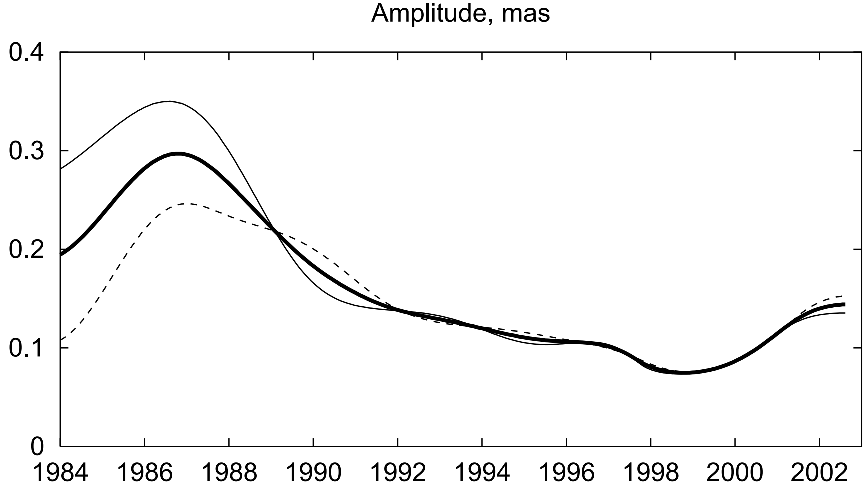


Figure 9. Variations of the FCN period and amplitude with time; $\Delta\psi * \sin(\varepsilon)$ (solid line), $\Delta\varepsilon$ (dashed line), and mean of $\Delta\psi$ and $\Delta\varepsilon$ (bold line).

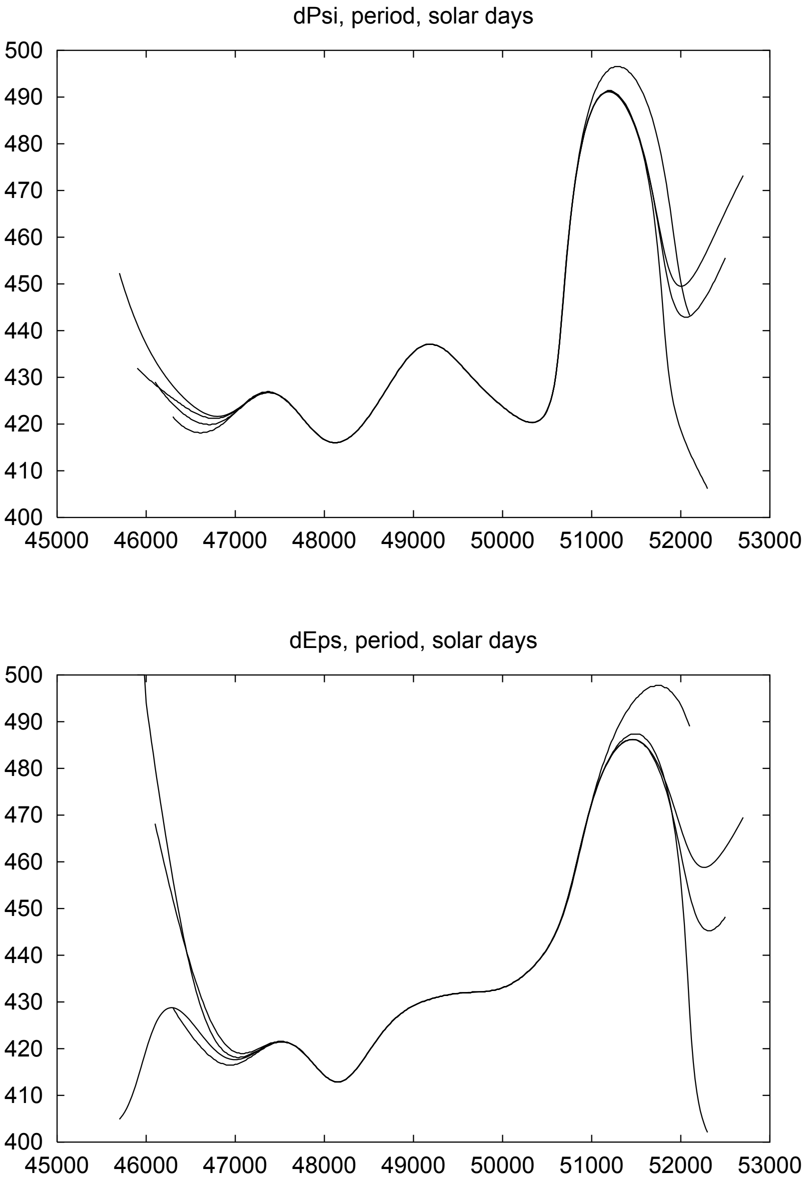
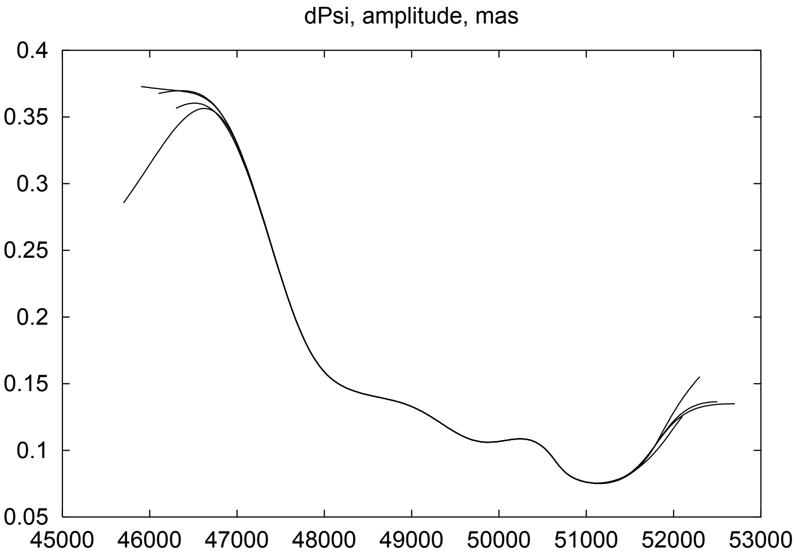


Figure 10. The edge effect in the wavelet analysis, the FCN period.



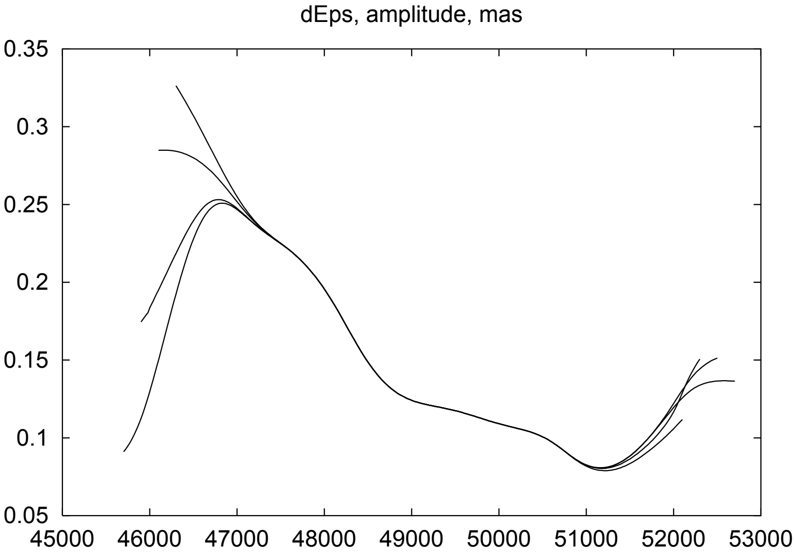


Figure 11. The edge effect in the wavelet analysis, the FCN amplitude.

From this test, we can conclude that the edge effect may affect the result at the first and the last 500–1000 days of the interval under investigation. Evidently, this fact should be accounted for to determinate the start point for prediction of the FCN contribution to nutation.

4. Discussion and conclusions

Variations of the FCN amplitude found in this investigation are close to ones used in the MHB2000 model, except the edge intervals (see Figure 12). A reasons of these discrepancies may be insufficient quality of the VLBI data in the earlier 1980th and the edge effect present in the wavelet analysis results, as discussed above.

As a supplement test, we computed variations of the FCN amplitudes immediately from the VLBI series. For this purpose we used the smoothed differences between observed nutation angles and model described above.

Taking into account that the FCN contributions in $\Delta\psi$ and $\Delta\varepsilon$ are two projections of the same variations in the Earth rotation velocity, we can compute the FCN amplitude as $Amp(FCN) = \sqrt{d(\Delta\psi)^2 + d(\Delta\varepsilon)^2}$. Figure 13 shows the result of comparison. Comparing Figures 12 and 13 one can see that the direct computation of the FCN amplitude shows better agreement with the MHB2000 model. We can expect that amplitude estimates obtained with WWZ method are not good enough at the edges of the time interval (see also the discussion of the edge effect in wavelet analysis above).

Comparison of the FCN phase variations found in this study and computed from the amplitudes of sine and cosine FCN terms of the MHB2000 model is presented in Figure 14, after removing the linear phase change corresponding to the FCN with permanent period. One can see that the FCN phase variations are similar in two approaches, though ours provides more smooth variations, and so for the FCN period variations.

The FCN period (phase) most likely varies with time. Probably, change in the period is physically connected with change in amplitude. On the other hand, one can see that the variations of the FCN period show clear periodicity with a period about 5 years, whereas variations of the FCN amplitude does not show such an effect.

Another reason of the observed behavior of the FCN period maybe variability of the FCN phase. Analogous effect was found also at the Chandler frequency [9], for which dependence of the period on amplitude,

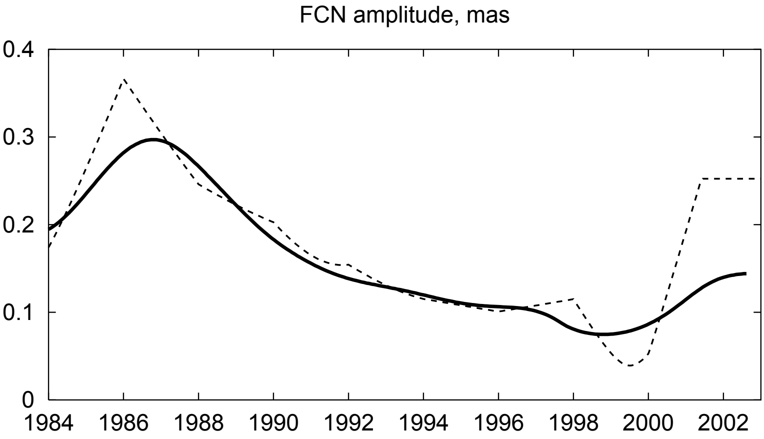


Figure 12. Variations of the FCN amplitude with time found in the present study (solid line) and implemented in the MHB2000 model (dashed line).

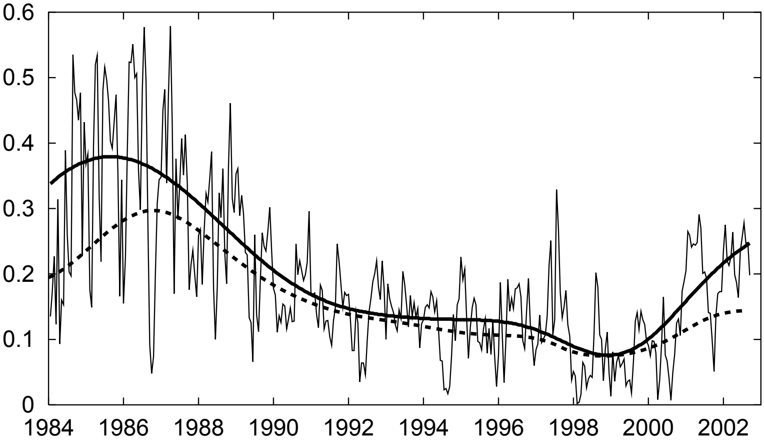


Figure 13. Variations of the FCN amplitude with time: solid line — original amplitudes, bold line — smoothed amplitudes, bold dashed line — amplitude variations found from the wavelet analysis.

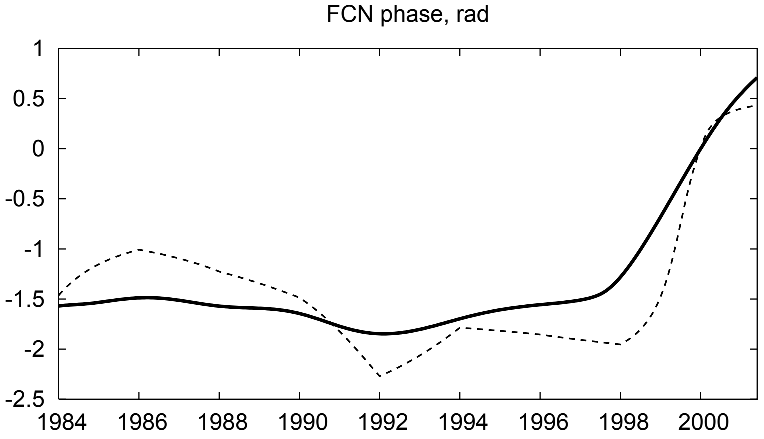


Figure 14. Variations of the FCN phase with time found in the present study (solid line) and computed from the MHB2000 model (dashed line).

and the phase jump occurred during the period of the lowest amplitude were also found.

It is interesting, that the Chandler wobble period also decreased in ≈1986–1988, and increased in ≈1989–1996 (see [10, 11]). Unfortunately, Polar Motion series studied in those papers are much shorter than one analyzed here to perform a reliable comparison.

Variations of FCN amplitudes show several possible epochs of the excitation of the FCN, most of them are close to ones detected in [2].

Some tests we performed allow us to make a conclusion that investigated nutation series really contain such a signal with variable amplitude and period (phase). However, as stated above, we interpret the differences between observed nutation and the IAU2000A model as the FCN contribution, which may be too strong assumption. Possible interference of the FCN and other nutation frequencies should be carefully investigated. In particular, the authors of [1] pointed out a possible interference with near-yearly nutation terms, but the investigated period of observations seems to be long enough to separate these frequencies by spectral and wavelet analysis.

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