

An analysis of celestial pole offset observations in the free core nutation frequency band

Z. Malkin, N. Miller

Central (Pulkovo) Astronomical Observatory RAS, St. Petersburg 196140, Russia

Abstract. In this study, three empirical Free Core Nutation (FCN) models developed to the present time, MHB2000, Malkin's and Lambert's ones, are compared on the basis of representation of variations of the FCN amplitude and phase predicted by these models. It is possible to conclude, that the model of the author provides the most realistic representation of the FCN variations. However, the specified models are based on representation about single FCN rotational mode. At the same time, some results of processing of the VLBI observations made during last years, specify possible presence of two close FCN periods. A theoretical explanation to presence of a second FCN frequency FCN has been given by G. Krasinsky in his theory of rotation of the Earth with two-layer liquid core, ERA2005. In the present work, for more detailed studying this phenomenon, the IVS time series of celestial pole offset, and also those predicted by the ERA2005 theory, have been investigated by means of several statistical methods which confidently show presence of two fluctuations in nutational movement of an Earth's rotation axis with the periods about -452 and -410 solar days.

Keywords. Earth rotation, nutation, free core nutation, VLBI

1 Introduction

Free Core Nutation (FCN) is the main factor limited the accuracy of coordinate transformation between terrestrial and celestial reference frames. On the other hand, investigation of the FCN parameters obtained from the Very Long Baseline Interferometry (VLBI) observations gives an important insight in the Earth structure and dynamics. Classical theory of Earth rotation predicts existence of a single FCN mode with period about -430 sidereal days (see e.g. De-

hant, 2003; Hinderer, 2000). Making use of analysis of the VLBI observations to confirm this conclusion leads sometimes to contradictory results. Determination of the FCN period from the resonance effect gives a value close to the theory, whereas analysis of time series of differences between observed celestial pole coordinates and ones predicted by the IAU2000A precession-nutation model show substantial variations of the FCN period and phase (Malkin, 2003, 2004b; Vondrák, 2005).

In this paper, we analyze combined celestial pole offset series provided by the International VLBI Service for Geodesy and Astrometry (IVS) (Schlüter et al., 2002) by means of three methods of evaluation of harmonic components in time series: principal component analysis, spectral analysis and wavelet analysis. All the methods clearly show presence of two oscillations in the FCN frequency band, which may be a subject for further investigations.

2 Known empirical FCN models

To date, three empirical FCN models have been developed: MHB2000 (Herring, 2002), Malkin (ZM) (Malkin, 2003, 2004b), Lambert (SL) (McCarthy, 2005). Comparison of these models with results of VLBI observations shows that all three models allow one to account equally essentially for the FCN contribution. However, as can be seen from fig. 1, ZM model provides smooth and, apparently, more realistic representation of variations of the basic geophysical parameters, the FCN amplitude and phase.

It should be noted, however, that all models only approximate the observed variations in the celestial pole offset, without striking into the FCN physical properties. Further development of FCN model can be reached by consideration of a two-frequency FCN theory. Earlier, Malkin

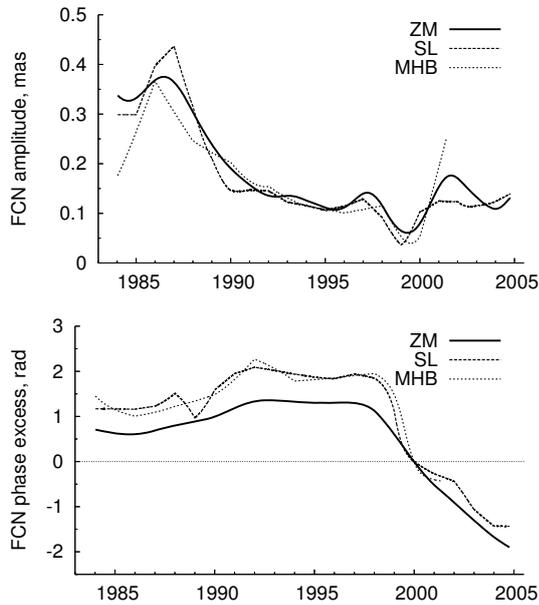


Figure 1. Variation of the FCN amplitude and phase in accordance with three FCN models.

and Terentev (2003) revealed a second fluctuation with the period about 410 solar days in the celestial pole offset series. However, then this fact has not been given due value. Later, Schmidt et al. (2005) have shown the presence of two periods -435 and -410 days by means of the wavelet analysis with high frequency resolution. They supposed that observed variations in the FCN amplitude and phase are caused by beating between two oscillations with close periods. A theoretical explanation of this phenomenon has been given by Krasinsky (2006) in his numerical theory of rotation of the Earth, ERA2005, considering two-layer structure of the fluid core.

In this paper, we performed more detailed analysis of the celestial pole offset time series provided by the IVS for the period 1989–2006. Earlier observations were not analyzed in view of their relatively low accuracy, see Malkin (2003, 2004a). The smoothed differences between the observed celestial pole offset values and those predicted by the IAU200A model were used in our study.

3 Spectrum analysis

Firstly, we applied the discrete Fourier spectral analysis to the analyzed time series. We computed the Schuster periodogram for complex se-

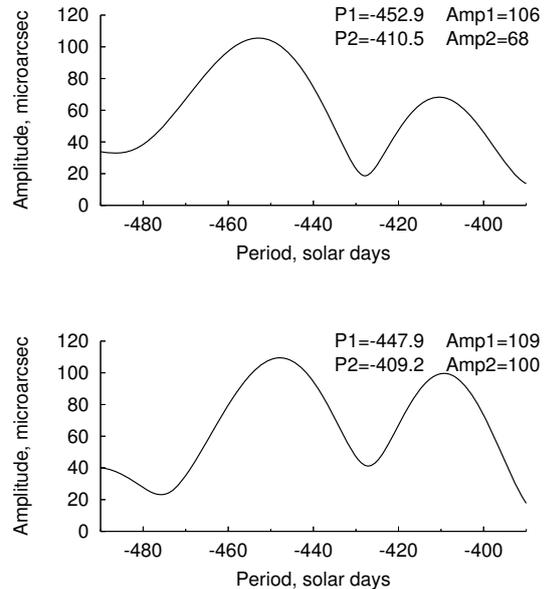


Figure 2. Spectra of the IVS (top) and ERA2005 (bottom) celestial pole offset series.

ries $X + iY$. Usually for the spectrum analysis, the Fast Fourier Transform technique, which provides calculation of the spectrum estimations on a grid of frequencies, multiple to Nyquist frequency that does not provide the detailed frequency resolution, is used. To increase the frequency resolution, we used direct calculation of spectrum estimates, which allowed us to use any, as much as dense grid of frequencies (periods). Also, for increase of the frequency resolution, a frequency window was not applied, which does not lead to deterioration of results in this case, as initial data are smooth enough, and we study narrow enough band of a spectrum. The spectra of the differences between the IVS celestial pole offset time series and those predicted by the ERA2005 model are presented in Fig. 2, which shows reasonably good agreement of the ERA2005 theory and observations. Also in the investigated time series, the annual component is surely revealed, but with essentially smaller amplitude, than the FCN components.

4 Principal components analysis

The second method we used for investigation of the celestial pole offset series was Principal Component Analysis (PCA) also known as Singular

Spectrum Analysis. The “Caterpillar” software¹ developed at the St. Petersburg State University was used for computation. It should be mentioned that, except harmonic components, PCA allow one to isolate an actual long-term trend component not burdened by any assumption about its *a priori* model. Usually, the trend contribution in an analyzed time series as determined from the PCA is large enough (40.5% in our case), and it can distort the harmonic components under investigation.

To mitigate this effect, we performed the computations in two iterations. At the first iteration, all principal components were resolved, and at second one, the main trend components found at the first iteration were removed from the input time series. Fig. 3 shows the original time series and two principal components PC1 and PC2 found from the analysis. Three most valuable harmonic components are those with periods 452 solar days (the contribution is equal to 53.8%), 409 days (19.0%) and 366 days (6.8%). Specified period values were found from the spectral analysis made in the same way as described in the previous section.

5 Wavelet analysis

To investigate how the two FCN components vary with time, the wavelet technique was applied to the IVS celestial pole offset, two harmonic principal components found from the PCA and ERA2005 time series. The WWZ software² developed at the American Association of Variable Star Observers was used for analysis. The mathematical background of this method is described in (Foster, 1996). Results of the wavelet analysis are presented in Fig. 4. Two periodic components can be clearly seen at both observed and theoretical time series. For better comparison, we applied the wavelet with the same parameter $\sigma=10$ as was used in (Schmidt et al., 2005), which provides high frequency resolution. The time resolution is rather pure in such a case however. So, wavelet estimates, in fact, are averaged for several-year interval.

6 Discussion and conclusion

In this paper, we investigated the IVS celestial pole offset time series as well as theoretical

¹<http://www.gistatgroup.com/cat/>

²<http://www.aavso.org/>

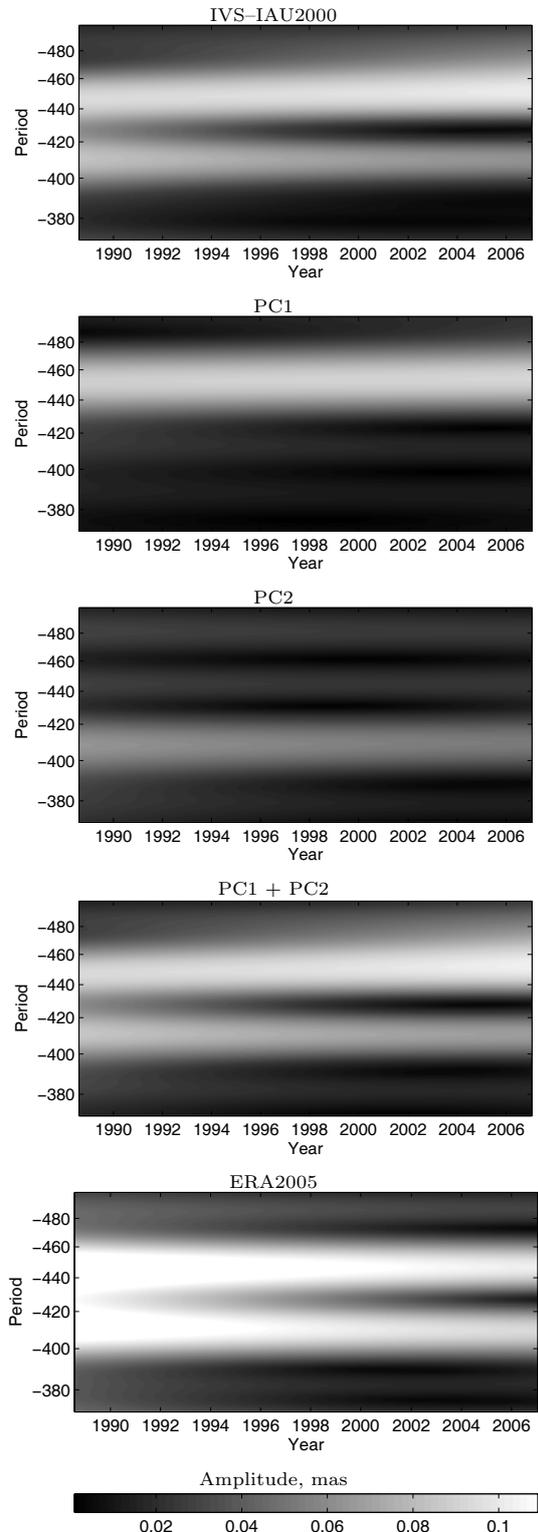


Figure 4. Results of the wavelet analysis of the input time series, its principal components and ERA2005 series.

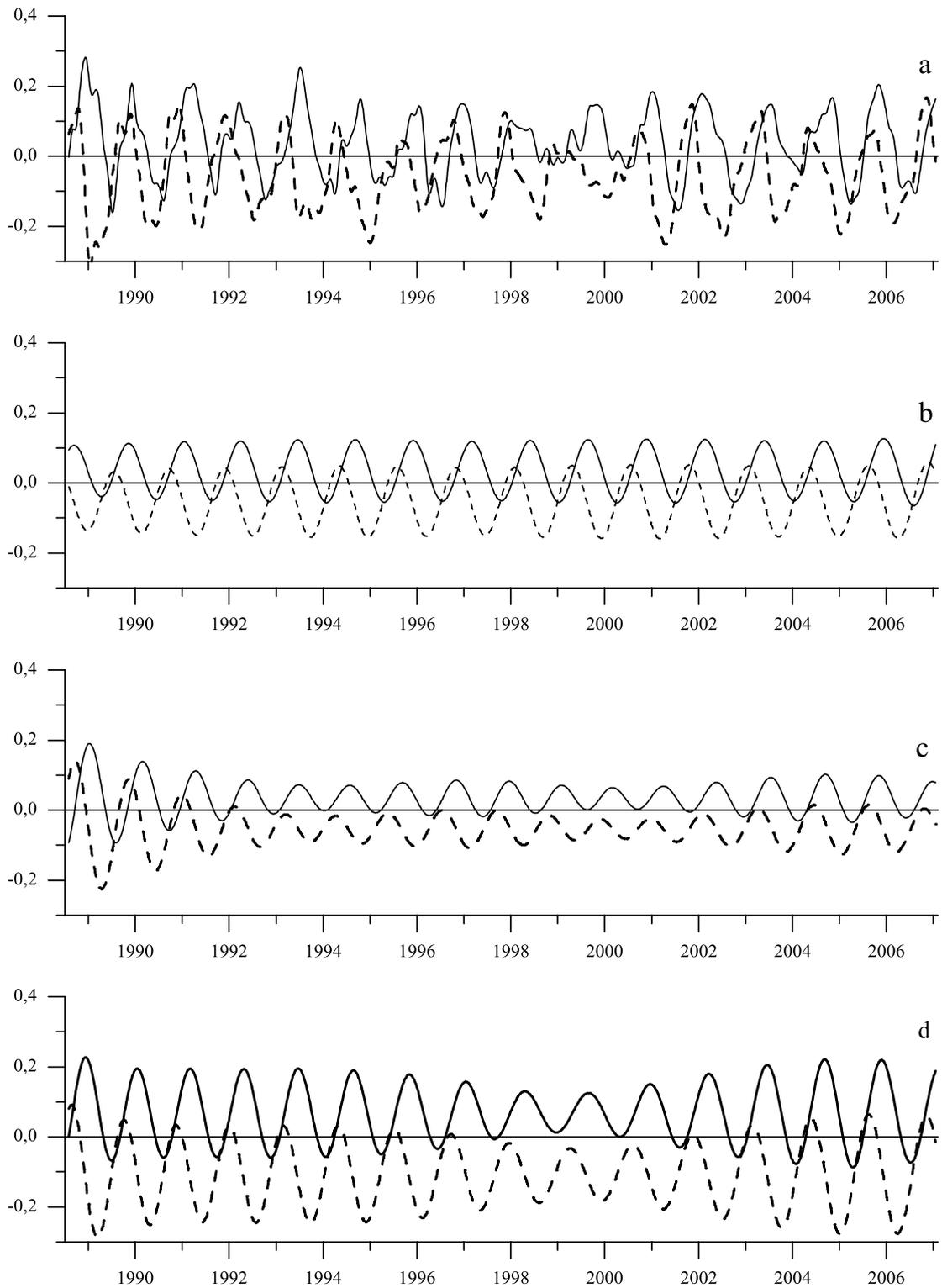


Figure 3. Input time series and main harmonic principal components obtained from the PCA (X — solid, Y — dashed): a — input, b — first principal component with period 452 days, c — second principal component with period 409 days, d — sum of two principal components.

ERA 2005 time series by means of three statistical tools, Discrete Fourier Transform, Principal Component Analysis and wavelet analysis, in the FCN frequency band. The results obtained with all the methods definitely show presence of two harmonic components with periods about -410 and -452 solar days, yet these methods are not fully independent.

This result confirms ones obtained in (Malkin, 2003; Schmidt, 2005) from VLBI data processing, and in (Krasinsky, 2006; Krasinsky and Vasilyev, 2006) in the framework of the ERA2005 theory. However, the values of the FCN component periods found here and obtained in the previous papers are substantially different. Moreover, supplement study has shown that the period of FCN components depend on the time span of data used for analysis. So, further investigations are needed before making a final conclusion. Also, it's important to compare these results with the resonance FCN period, see e.g. (Vondrák et al., 2005), in particular, considering a two-component resonance model.

Finally, there are grounds for hope that using two-component empirical FCN model, in case it is proved to be real, will allow us to predict the FCN contribution to the nutation series with better accuracy than existing models.

References

- Dehant, V., K. Creager, S. Karato, and S. Zatman (eds.) (2003). The Earth's Core: Dynamics, Structure, Rotation. *AGU Geodynamics Series*, Vol. 31.
- Foster, G. (1996). Wavelets for period analysis of unevenly sampled time series. *Astron. J.*, Vol. 112, pp. 1709-1729.
- Herring, T.A., P.M. Mathews, and B.A. Buffet (2002). Modelling of nutation-precession: Very long baseline interferometry results. *J. Geophys. Res.*, Vol. 107, pp. 2069-2080.
- Hinderer, J., J.P. Boy, P. Gegout, P. Defraigne, F. Roosbeek, and V. Dehant (2000). Are the Free Core Nutation parameters variable in time?, *Phys. Earth Planet. Int.*, Vol. 117, pp. 37-49.
- Krasinsky, G.A. (2006). Numerical theory of rotation of the deformable Earth with the two-layer fluid core. Part 1: Mathematical model. *Cel. Mech. Dyn. Astr.*, Vol. 96, pp. 169-217.
- Krasinsky, G.A., and M.V. Vasilyev (2006). Numerical theory of rotation of the deformable Earth with the two-layer fluid core. Part 2: Fitting to VLBI data. *Cel. Mech. Dyn. Astr.*, Vol. 96, pp. 219-237.
- Malkin Z., and D. Terentev (2003). Preliminary analysis of the Free Core Nutation from VLBI data. In: *Proc. 16th Working Meeting on European VLBI for Geodesy and Astrometry*, Leipzig, Germany, 9-10 May 2003, pp. 227-235.
- Malkin, Z.M. (2003). Comparison of VLBI nutation series with the IAU2000A model. In: *Proc. Journées Systèmes de Référence Spatio-temporels 2003*, St. Petersburg, Russia, 22-25 Sep 2003, Eds. A. Finkelstein, N. Capitaine, pp. 24-31.
- Malkin, Z. (2004a). 5,000,000 Delays—Some Statistics. In: *IVS 2004 General Meeting Proc.*, Eds. N. R. Vandenberg, K. D. Baver, NASA/CP-2004-212255, pp. 47-51.
- Malkin, Z. (2004b) A New Free Core Nutation Model with Variable Amplitude and Period. In: *IVS 2004 General Meeting Proc.*, Eds. N. R. Vandenberg, K. D. Baver, NASA/CP-2004-212255, pp. 388-392.
- McCarthy D.D. (2005). The free core nutation. In: *Proc. Journées Systèmes de Référence Spatio-temporels 2004*, Paris, France, 20-22 Sep 2004, Ed. N. Capitaine, 2005, pp. 101-105.
- Schlüter, W., E. Himwich, A. Nothnagel, N. Vandenberg, A. Whitney (2002). IVS and Its Important Role in the Maintenance of the Global Reference Systems. *Advances in Space Research*, Vol. 30, pp. 145-150.
- Schmidt, M., V. Tesmer, and H. Schuh (2005) Wavelet analysis of VLBI nutation series with respect to FCN. *EGU 2nd General Assembly*, Vienna, Austria, 24-29 Apr 2005, Geophysical Research Abstracts, Vol. 7, 04555, SRef-ID: 1607-7962/gra/EGU05-A-04555
- Vondrák, J, R. Weber, and C. Ron (2005). Free core nutation: direct observations and resonance effects. *Astron. Astrophys.*, Vol. 444, pp. 297-303.