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Estimation of the free core nutation period by the sliding-window complex least-squares fit method

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Abstract

Estimation of the free core nutation (FCN) period is a challenging prospect. Mostly, two methods, one direct and one indirect, have been applied in the past to address the problem by analyzing the Earth orientation parameters observed by the very long baseline interferometry. The indirect method estimates the FCN period from resonance effects of the FCN on forced nutation terms, whereas the direct method estimates the FCN period using the Fourier Transform (FT) approach. However, the FCN period estimated by the direct FT technique suffers from the non-stationary characteristics of celestial pole offsets (CPO). In this study, the FCN period is estimated by another direct method, i.e., the sliding-window complex least-squares fit method (SCLF). The estimated values of the FCN period for the full set of 1984.0–2014.0 and four subsets (1984.0–2000.0, 2000.0–2014.0, 1984.0–1990.0, 1990.0–2014.0) range from −428.8 to −434.3 mean solar days. From the FT to the SCLF method, the estimate uncertainty of the FCN period falls from several tens of days to several days. Thus, the SCLF method may serve as an independent direct way to estimate the FCN period, complementing and validating the indirect resonance method that has been frequently used before.
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1. Introduction

The precession–nutation phenomenon, which describes the time-varying orientation of the celestial intermediate pole in the celestial reference system, has been monitored with a very high and increasing precision using the technique of very long baseline interferometry (VLBI) (Schuh and Behrend, 2012). The variability is usually divided into regular and irregular parts. The regular part, whose influence is exerted by the lunar, solar and planetary gravity fields, can be computed from the IAU 2006/2000A precession–nutation model (Mathews et al., 2002; Capitaine et al., 2003; Dehant et al., 2003; Petit and Luzum, 2010).

The IAU 2006 precession model provides improved polynomial expressions for the precession of the ecliptic and the precession of the equator. The IAU 2000A nutation model is based on the Mathews–Herring–Buffett nutation model (Buffett et al., 2002; Mathews et al., 2002; Herring et al., 2002), which convolves the rigid Earth nutation model (Souchay et al., 1999) with a transfer function accounting for the response of a realistic Earth.

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The transfer function involves physical properties of the Earth's interior and the resonance phenomena. And then the nutation model evaluates the effects of external global geophysical fluids (atmosphere, ocean, hydrosphere) at several given frequencies.

The irregular residual part of the precession–nutation is generally called the celestial pole offsets (CPO). The CPO includes the free core nutation (FCN), trends and harmonics caused by deficiencies of the IAU precession–nutation model and by geophysical excitations, as well as the noise of observations (Bizouard et al., 1998; Yseboodt et al., 2002; Dehant et al., 2003; Vondrák and Ron, 2009, 2010, 2014; Malkin, 2010, 2013).

The FCN, a dominant term of the CPO, is a rotational normal mode of the Earth, whose source is the ellipsoidal liquid core inside the visco-elastic mantle. Its period is associated with the flattening of the core-mantle boundary, elastic parameters of the mantle, and magnetic coupling of the fluid core to the mantle (Mathews et al., 2002; Lambert and Dehant, 2007).

Estimating the FCN period has been challenging for the geoscience community. Different approaches have brought considerably different results. The approach of theoretical analysis computes the FCN period by solving equations for nutation based on Earth models. It has yielded the value of ∼−460 mean solar days (e.g., de Vries and Wahr, 1991; Mathews et al., 1991; Rogister and Valette, 2009; Huang et al., 2011; Crossley and Rochester, 2014).

For the approach of analyzing the observed Earth orientation parameters, mostly, two methods, one direct and one indirect, have been applied in the past. The indirect method estimates the FCN period from resonance effects of the FCN at forced nutation periods, by applying the transfer function to the CPO series. A second, direct approach, is to estimate the FCN period using the Fourier Transform (FT) technique.

Table 1 lists the FCN periods estimated by the direct and indirect methods. For consistency, a simple unit transformation (1 sidereal day = 0.99727 mean solar days) is used when the period in some references is given in the unit of sidereal day. With respect to different study spans, the FCN period from the indirect resonance method is fairly tightly centered around −430 mean solar days, while that from the direct FT method scatters much more widely with the period, varying up to a few tens of days. Such a rapid large variation of the FCN period obtained by the FT method should be physically unrealistic, because it would imply excessively fast convection in the mantle, which would reach three orders of magnitude higher than that predicted by mantle convection models (Roosbeek et al., 1999).

In this study, we estimate the free core nutation period by another direct method, i.e., the sliding-window complex least-squares fit (SCLF) method, using the EOP 08 C04 (IAU 2000A) CPO data set. A comprehensive investigation is made for the full set of 1984.0–2014.0 and four subsets to see the effect of data quality on determination of the FCN period.

2. Data set

We employ the IERS "EOP 08 C04" CPO series during the epoch 1984.0–2014.0 (Bizouard and Gambis, 2009), which is processed with respect to the IAU 2006/2000A precession–nutation model and are consistent with ITRF2008 (http://www.iers.org) (Altamimi et al., 2011). They are shown in the top left panel of Fig. 1 (a1, dotted black line). Clearly, the CPO varies significantly with time, especially during the time before 1990. This non-stationary behavior of the CPO series might be a major reason to explain why the estimated value of the FCN period by direct FT is so sensitive to the particular time span (Malkin, 2010).

3. The SCLF method

To reduce the influences from the IAU precession–nutation modeling errors, geophysical excitations, as well as high-frequency noise of observations, we remove a quadratic term and a 18.6-year harmonic from the CPO series, and put it through a Butterworth low-pass filter of order 2. The filter is set in both forward and reverse directions to eliminate any phase distortion (Wiley, 1979).

Table 1
The FCN period, the estimation methods with references.

FCN period (mean solar day)	Estimation method	References
−430 to −433	Indirect-resonance	Roosbeek et al. (1999)
−430.21	Indirect-resonance	Mathews et al. (2002)
−430.55	Indirect-resonance	Vondrák et al. (2005)
−429.75	Indirect-resonance	Lambert and Dehant (2007)
−427.8 to −431.4	Indirect-resonance	Rosat and Lambert (2009)
−429.8 to −430.5	Indirect-resonance	Vondrák and Ron (2010)
−410 to −490	Direct-FT	Malkin (2004)
−425 to −470	Direct-FT	Vondrák et al. (2005)
−428.8 to −434.3	Direct-SCLF	This study

Indirect-resonance: estimating the FCN period from resonance effects; Direct-FT: estimating the FCN period by the Fourier Transform (FT) method; Direct-SCLF: estimating the FCN period by the sliding-window complex least-squares fit (SCLF) method. A simple unit transformation (1 sidereal day = 0.99727 mean solar days) is used when the FCN period in some references is given in the unit of sidereal day.

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