MODELLING AND PREDICTION OF THE FCN

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ABSTRACT. In this paper we investigated the Free Core Nutation (FCN) which is the most significant oscillation in the celestial pole offset residuals with respect to the current IAU 2000 precession-nutation model. A wavelet phase spectrum analysis of the IERS C04 (IAU 2000) data was performed in order to determine areas of stable phase, which would be seen as times of constant period of the FCN. The results show that the retrograde period of the FCN appears to be a function of time, apparently changing between 410 and 490 days. These “changes" are correlated with Niño 4 data as well as with C_{20} coefficients of the gravity field. The wavelet modulus for the FCN period is correlated with negative change of the pressure term of the Atmospheric Angular Momentum excitation function. In order to fit the data, a combination of complex least-squares solutions was used to model and predict the FCN oscillation.

1. INTRODUCTION

Free core nutation (FCN) is a free motion of the celestial intermediate pole (CIP) in inertial space due to the interaction of the mantle and the fluid, ellipsoidal core as the Earth rotates. Because this effect is a free motion with time-varying excitation and damping resulting in a variable amplitude and phase, a FCN model was not included in the IAU 2000A nutation model. As a result, a quasi-periodic unmodeled motion of the CIP in inertial space at the 0.1–0.3 mas level still exists after the IAU 2000A model has been taken into account.

This study examined the nature of the FCN oscillation, particularly looking into the stability of the motion. A model was generated to approximate the FCN motion. Additional studies were performed in an effort to understand possible causes of the FCN.

2. WAVELET ANALYSIS

In the wavelet technique the formula for the transform coefficients are computed as the convolution of the complex-valued signal $z(t)$ and the wavelet analyzing function:

$$\hat{W}(T,t_j) = \sqrt{1/|T|}\int_{-\infty}^{+\infty} z(t)\overline{\psi}[(t-t_j)/T]dt, \tag{1}$$

where t_j is the translation parameter and T is the dilation (or period) parameter and

$$\psi(x) = \sqrt{1/(f_b\pi)}\exp(i2\pi f_c x)\exp(-x^2/f_b) \tag{2}$$

is the Morlet wavelet function applied (Chui 1992), in which $f_b > 0$ is the bandwidth parameter and f_c is the wavelet center frequency.

The wavelet transform modulus and phase are defined as $mod[\hat{W}(T, t_j)]$ and $\arg[\hat{W}(T, t_j)]$, respectively. When the gradient of the wavelet transform phase defined as

$$\hat{G}(T, t_j) = \frac{d}{dt_j}\{\arg[\hat{W}(T, t_j)] - 2\pi t_j/T\} \tag{3}$$

is equal to zero, then apparent variations of the period T can be detected.

3. DATA

The following time series were used in the analysis: 1) Nutation-precession residuals IERS C04 (1984 – August 2005) with the sampling interval of 1 day (IERS 2005), 2) Atmospheric Angular Momentum NCEP/NCAR data reanalyses (1984 – August 2005) at a sampling interval of 6 hours (Kalney et al. 1996), 3) Gravity field C_{20} (1984 – December 2002) (Cox and Chao 1998).

4. MODELLING AND PREDICTION

Initial use of the Morlet wavelet on the FCN residuals showed that there was significant power in the retrograde period range from 400 to 500 days. In an effort to isolate this phenomenon, the gradient of the phase was computed. The results of this computation are shown in the Fig. 1 below.

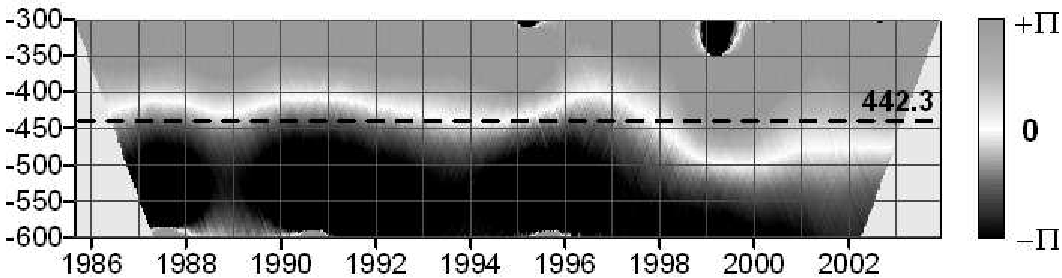

Figure 1: The gradient of the wavelet transform phase of the nutation precession corrections.

This figure shows the nonstationary character of the FCN as it was previously shown by Malkin (2004). Note that due to the way in which the FCN motion is realized, it is mathematically impossible to distinguish between a change in period with a change in the phase of the motion. In fact, from a geophysical point of view, it is unreasonable to expect that the period of the FCN could vary as is implied in the graph. Instead, it is likely that the variation is being caused by changes in the phase.

For the purposes of generating a FCN model, a constant, best-fit, period of 442.3 days is assumed. The following least-squares model similar to the model used by Lambert (2005) was fit to the IE RS C04 data set:

$$FCN(MJD) = A_n exp(i2\pi f_{FCN}) + b \cdot MJD + a. \tag{4}$$

Using this model, predictions of the FCN were made. The rms of the differences between the predictions and the IERS C04 data for various prediction lengths are shown in Fig. 2. These rms errors are of the same order as those obtained earlier by Brzeziński and Kosek (2004).

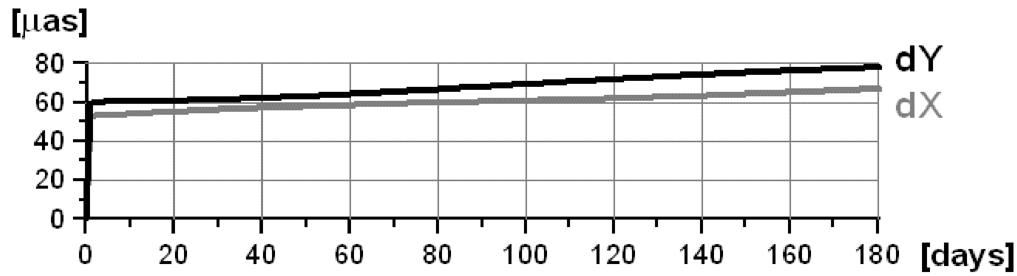

Figure 2: The RMS prediction error of the FCN model.

5. POSSIBLE EXCITATION

To understand the cause of the FCN, and therefore possibly improve the predictions, efforts were made to identify geophysical factors that were possibly related. For instance, both the Niño 4 and C_{20} coefficient show significant correlation with the calculated change in the FCN period, as shown in Fig. 3.

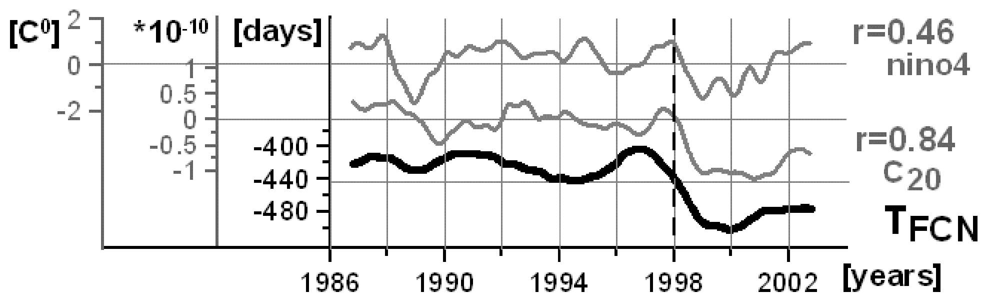

Figure 3: Niño 4 index (upper curve), gravity field C_{20} (middle curve) and the FCN period (bottom curve). The correlation coefficients are given to the right of the graph.

The AAM pressure term, on the other hand, shows a significant negative correlation with the apparent change of the FCN modulus (Fig. 4). Atmospheric and nontidal oceanic contributions of the order of $0.1mas$ to nutation was previously found by Bizouard et al. (1998).

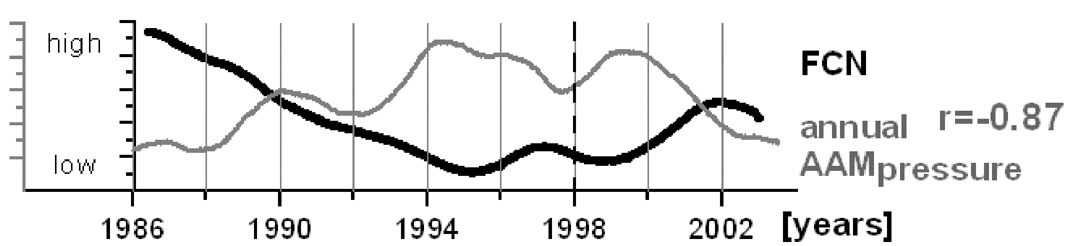

Figure 4: Wavelet transform modulus for the FCN period (black line) and for the annual oscillation in the pressure component of the AAM excitation function (grey line). The correlation coefficient is given to the right of the graph.

6. CONCLUSIONS

The general characteristic of the FCN model are that it has a variable amplitude and period (phase), a mean prediction error of roughly 70-80 μas for 180 days in the future, and an apparent relationship to geophysical phenomena.

Some possible excitation of the FCN explored in this analysis include global mass redistribution, land hydrology, and perturbations of the annual atmospheric circulation. Significant correlations were found between the apparent variations of the retrograde FCN period and C_{20} coefficients of the gravity field as well as Niño 4 data. The wavelet transform modulus for the FCN period is correlated with negative change of the pressure term of the Atmospheric Angular Momentum excitation function.

Other possible sources of excitation include subpolar glacial melting (Dickey et al. 2002), earthquakes (Shirai and Fukushima 2001), and anomalous fluctuations in the core (Cox and Chao 2002, Holme and de Viron 2005).

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