RESONANCE EFFECTS AND POSSIBLE EXCITATION OF FREE CORE NUTATION

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ABSTRACT. From the direct analysis of VLBI observations of celestial pole offsets in the years 1982.4 – 2005.4 we found that the period of the Retrograde Free Core Nutation (RFCN) apparently grew from 425 to 470 days during the past 10–15 years. At the same period, we also derived the varying retrograde annual term of nutation that is closest to resonance. A subsequent study of indirect determination of RFCN period from this term through the resonance effects proved that the natural resonance period remained stable and was about 430 solar days. From this follows that a geophysical excitation should exist, with a terrestrial frequency close to that of RFCN (of about -1.0049 cycles per solar day), invoking the apparent changes of the directly observed RFCN period. It is demonstrated that an excitation of a very small amplitude (on the level of observation noise) is sufficient to produce such changes.

1. INTRODUCTION

We recently studied RFCN from the combined GPS/VLBI celestial pole offsets (Vondrák et al. 2005), referred to IAU2000A model of nutation, in the interval 1994.3 – 2004.6. We found that the period of RFCN as derived from the observed forced nutation terms through resonance effects remains very stable, in spite of the fact that the direct determination from the observed celestial pole offsets implies its large changes. Here we study the same problem from VLBI-only observations, in a longer time interval. To this end, we use the IVS combined solution ivs05q2X.eops (IVS 2005) covering the interval 1979.6 – 2005.4, namely the celestial pole offsets δX, δY. Prior to analysis, the data were cleaned, i.e., all offsets greater than 1mas were removed, and the sparse and scattered data before 1982.4 were rejected.

2. DIRECT AND INDIRECT ANALYSIS OF CELESTIAL POLE OFFSETS

First of all, we divided the data into three time windows (each 7 years long), and made the spectral analysis. The result is depicted in Fig. 1, from which the apparent change of the period and amplitude of the dominant peak is clear.

Now the question arises if the moving peak, determined from this direct analysis, really represents the changes of the resonant period of RFCN. From the forced nutation terms, the retrograde annual term is the closest to the resonance and therefore most sensitive to its changes. If the resonance period changes, the amplitude of the annual term must also change. Therefore

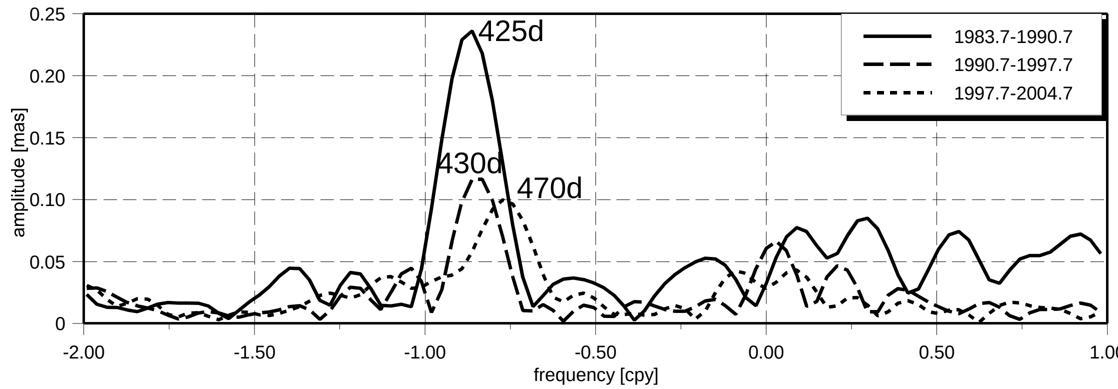

Figure 1: Spectral analysis of IVS celestial pole offsets in 3 time windows

we estimate the behavior of both RFCN and annual terms, in the running 6-year interval. We estimate both amplitude and period for RFCN, and only the amplitude for the annual term. The results are shown in Fig. 2; it is evident that all three parameters vary in time.

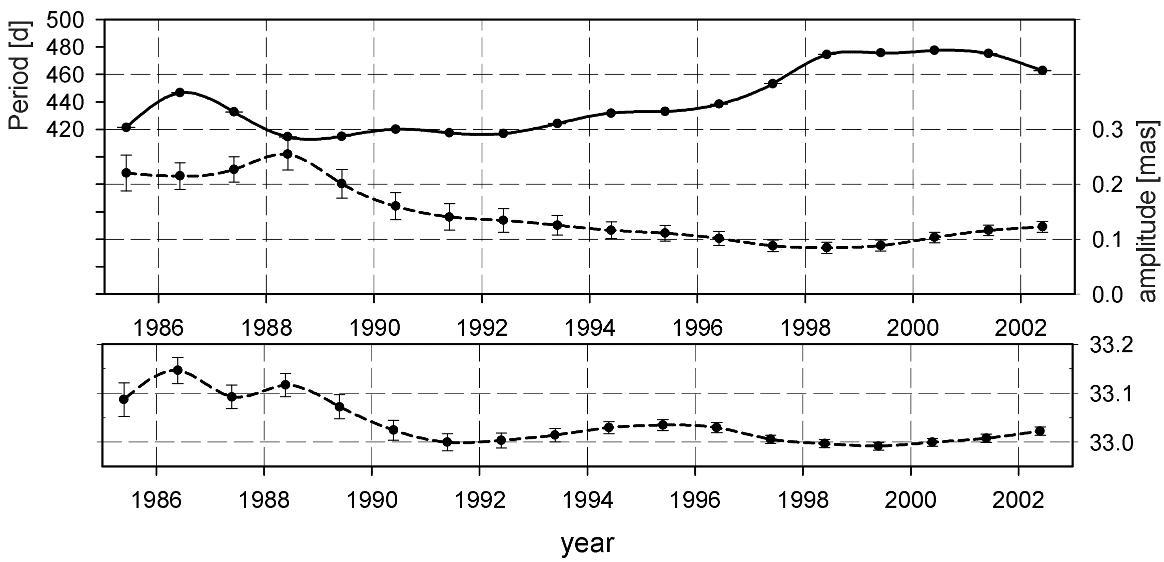

Figure 2: Variation of the period and amplitude of RFCN (upper plot) and of the amplitude of retrograde annual term (lower plot)

In order to decide if the observed variations of the annual term are in agreement with the observed variations of the RFCN period or not, we use the transfer function (giving the ratio of the amplitude of non-rigid to rigid Earth model) derived by Matthews et al. (2002)

$$T(\sigma) = \frac{e_R - \sigma}{e_R + 1} N_\circ \left[1 + (1+\sigma) \left(Q_\circ + \sum_{j=1}^{4} \frac{Q_j}{\sigma - s_j} \right) \right] \qquad (1)$$

for the indirect determination of RFCN period. Here $e_R = (C - A)/A = 0.0032845075$ is the dynamical ellipticity of the rigid Earth used to compute the 'rigid' solution. The argument σ is the terrestrial frequency in cycles per sidereal day, the other parameters are generally complex constants, among which s_j are the resonant frequencies (of Chandler wobble, RFCN, prograde FCN and Inner Core Wobble, respectively).

In our case, only s_2 is important; the period P_{RFCN} (in celestial frame and expressed in mean solar days) is tied with s_2 by a simple relation $P_{RFCN} = 0.99727/(s_2 + 1)$. We used Eq. (1) and the rigid-Earth value of the amplitude of retrograde annual nutation term to calculate its value for a non-rigid Earth, for the periods of RFCN in the range 420–460 days. The result is shown in Fig. 3 from which follows that the possible value of resonance period, implied by variations of the annual term, keeps close to 430 days, within a fraction of a day. It is in good agreement with our previous result (Vondrák et al. 2005) – we found from 5 nutation terms, observed by VLBI and GPS in 1994.3–2004.6 that $P_{RFCN} = 430.55 \pm 0.11$ days.

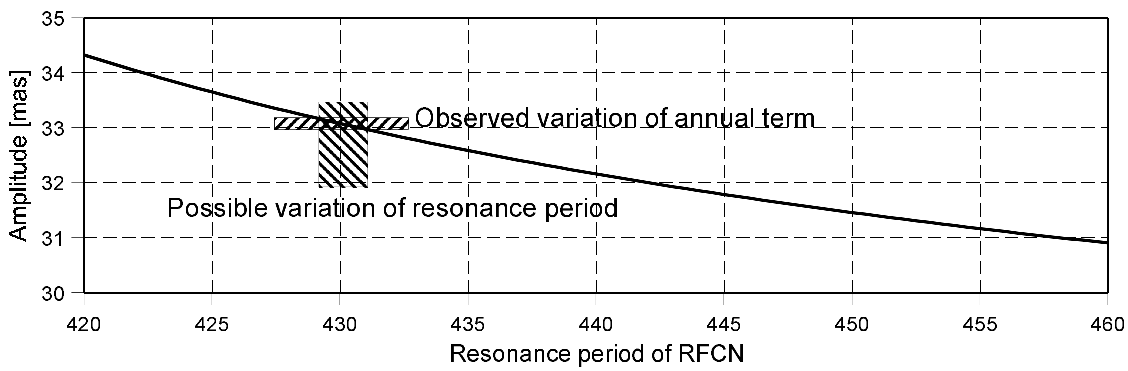

Figure 3: Amplitude of retrograde annual nutation in terms of RFCN period

3. LOOKING FOR POSSIBLE EXCITATION

The resonance frequency is given by internal structure of the Earth – mainly by the flattening of the core and electromagnetic coupling between the mantle and the core. Therefore the apparent difference between the direct and indirect determination of the RFCN period must be due to an excitation produced by outer parts of the Earth (atmosphere, ocean) – see also Dehant et al. (2003). Its period in celestial system should be in the range 420–460 days (retrograde), corresponding to terrestrial frequency around −1.0049 cycles per solar day. The amplitude of this *forced* nutation is of the order of 0.1–0.2 mas, so we must look for a very small excitation. In order to estimate its magnitude, we use Brzezinski's (1994) broadband Liouville equation in frequency domain, expressing the ratio between the amplitude of polar motion and atmospheric excitation. As the influence of atmospheric wind excitation is negligible (two orders smaller than the influence of the pressure term), we consider here the pressure term χ^P only, in complex form

$$p(\sigma) = \chi^P \left[\frac{\sigma_{CW}}{\sigma_{CW} - \sigma} + \frac{9.509 \times 10^{-2} \sigma_{CW}}{\sigma_{FCN} - \sigma} \right], \tag{2}$$

where σ_{CW} stands for Chandler frequency. The absolute value of the complex expression inside the brackets (for the periods in question) ranges from 2 to 12, so the amplitude of the excitation needed to produce the observed nutation is of about $10 - 50\mu as$.

The spectrum of atmospheric angular momentum function (Salstein 2005), sampled at 6-hour interval (pressure term only), is depicted in Fig. 4, both with (IB) and without (NIB) inverted barometer correction. Although no evident peak is visible in the close vicinity of required frequency, the amplitude of the necessary excitation is on the same (noise) level of the spectrum.

The atmospheric pressure excitation without inverted barometer correction seem to be sufficient to produce such amplitude.

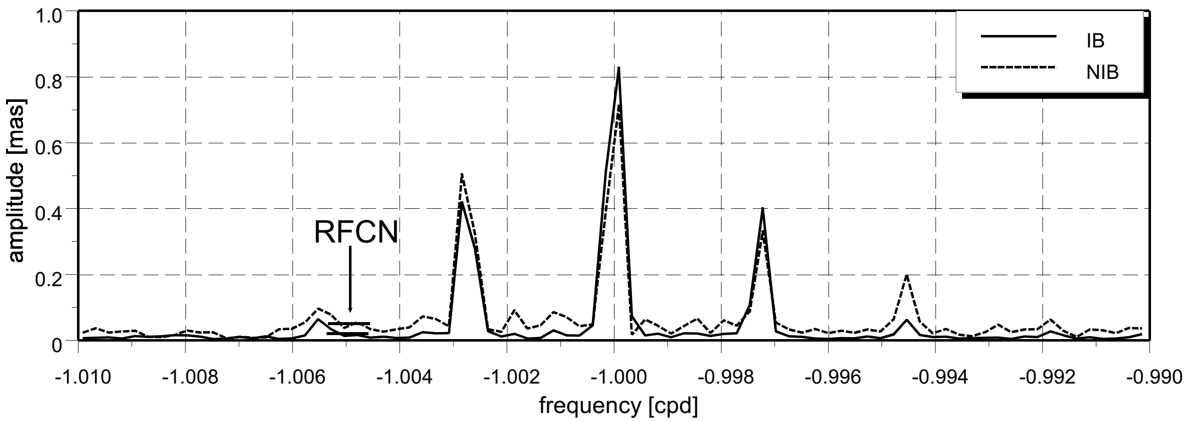

Figure 4: Spectrum of AAM pressure term (1980–2004). Required level of excitation to produce observed changes of RFCN period is marked by short horizontal lines.

4. DISCUSSION AND CONCLUSIONS

Based on indirect determination through the observed variations of the retrograde annual term of nutation, it follows that the resonance period, given by internal structure of the Earth, is relatively stable. Its variation is very small, smaller than one day, so that the period remains between 429.5 and 431.0 days. The apparently large observed change of the RFCN period (a few tens of days), obtained from direct analysis of celestial pole offsets, can be most probably ascribed to additional excitation by external parts of the Earth (atmosphere, oceans). The terrestrial period of the required excitation must be close to -23h 53min (mean solar time), and its amplitude of about $10-50\mu$as (i.e., close to the noise level in atmospheric data) is probably sufficient to produce the observed changes.

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