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COHERENCE BETWEEN GEOPHYSICAL EXCITATIONS AND CELESTIAL POLE OFFSETS

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ABSTRACT
Celestial pole offsets are the displacements between the observed position of the Earth's spin axis in space and its position predicted by the adopted models of precession and nutation. At present, the models are IAU2006 and IAU 2000, respectively. The celestial pole offsets are regularly measured by Very Long-Baseline Interferometry (VLBI), the observations being coordinated and published by the International VLBI Service for Geodesy and Astrometry (IVS). These offsets contain a mixture of several effects: the unpredictable free term, Free Core Nutation (FCN) that is due to the presence of the outer fluid core of the Earth, forced motions excited by the motions in the atmosphere and oceans, and also imperfections of the adopted precession-nutation models. The geophysical excitations are also available, as determined by several atmospheric and oceanographic services. The aim of this paper is to compare the time series of these integrated excitations with the observed celestial pole offsets and estimate the level of coherence between them.

KEYWORDS: Geophysical excitations, celestial pole offsets, coherence

1. INTRODUCTION

We present here an addition to our previous study of atmospheric and oceanic excitations in the motion of Earth's spin axis in space (Vondrák and Ron, 2010). In principle, two approaches are possible for studying the impact of the atmospheric and oceanic excitations on the motion of Earth's spin axis in space. More often is the first method, in which the observed celestial pole offsets are used to calculate so called geodetic excitations that, in turn, are compared with time series of geophysical excitations. Another approach consists in using the numerical integration of Brzeziński broad band Liouville equations (Brzeziński, 1994) to calculate the excited motion of celestial pole which is then compared with the observed celestial pole offsets. Each approach has its advantages and disadvantages; when calculating geodetic excitations from the observed celestial pole offsets, the free component is almost completely suppressed, and therefore its excitation is difficult to study. In addition, the short-periodic noise in the data is enhanced. Therefore we prefer the second approach in this study – the integration has the tendency of smoothing out the short-periodic noise, and the long-periodic changes, including the free component, are clearly visible in the result. The disadvantage of this approach consists in the necessity of time-consuming searching for the initial values of the integration. Namely we use the integration of the series of the atmospheric (NCEP/NCAR, ERA40) and oceanic (ECCO, OMCT) excitation functions and search for the coherence between the integration and the celestial pole offsets obtained from VLBI observations

2. THE DATA - OBSERVED CPO AND THEIR EXCITATIONS

We have used the celestial pole offsets (CPO) from the recent IVS combined solution (Schlüter and Behrend, 2007) `ivs09q3X`, covering the interval 1984.1-2009.7, cleaned and interpolated to 3-day intervals. We used two pairs of the geophysical excitations data. First pair is the pressure and wind terms of atmospheric angular momentum excitation functions (AAMF) from NCEP/NCAR re-analysis, in the interval 1983.0-2009.5 (Salstein, 2005) completed by the matter and motion terms of oceanic angular momentum excitation functions (OAMF) from ECCO model in 1993-2009.7 (Gross et al., 2005). We used this series for integration and determination of the coherence, despite the fact that it presents very low diurnal and sub-diurnal fluctuations (Vondrák and Ron, 2009). We wanted to test the method used, and also to see how much these data are coherent with independent determinations.

The second pair used are the AAMF from ECMWF-ERA model, in 1979.0-2009.0 (Dobslaw and Thomas, 2007) (re-analyzed before 2001 and operational model afterwards) completed by the OAMF from the OMCT model, in 1979-2009.0 (Thomas et al., 2006; Dobslaw and Thomas, 2007) driven by re-analyzed atmospheric model before 2001.0 and by operational model afterwards. The series of effective angular momentum functions χ in terrestrial frame (in complex form) were subject to the complex demodulation (Brzeziński et al., 2002) at the retrograde diurnal frequency by removing a constant part which would lead to a big diurnal signal and by using a simple formula $\chi' = -\chi e^{i\varphi}$, where φ is the Greenwich sidereal time. The near-diurnal variations in terrestrial frame become long-periodic in celestial frame. Because we are interested in only long-periodic motion, that is comparable to nutation frequencies, we applied the smoothing (Vondrák, 1977) with parameter $\varepsilon = 1.3.10^{-4}$ to remove all periods shorter than 10 days.

As we have presented earlier, the convolution of Brzeziński transfer function (Brzeziński, 1994) has been used to estimate atmospheric and oceanic contribution to annual and semiannual nutation terms (for more details see Vondrák and Ron, 2010). Another possibility of comparing the excitations with the observed CPO is the numerical integration of the Brzeziński broad-band Liouville equations

$$\ddot{P} - i(\sigma'_C + \sigma'_f)\dot{P} - \sigma'_C\,\sigma'_f\,P = \\ = -\sigma_C \left\{ \begin{matrix} \sigma'_f(\chi'_p + \chi'_w) + \sigma'_C(a_p\chi'_p + a_w\chi'_w) + \\ +i[(1+a_p)\dot{\chi}'_p + (1+a_w)\dot{\chi}'_w] \end{matrix} \right\}, \tag{1}$$

where $P = dX + idY$ is the excited motion of Earth‘s spin axis in celestial frame, σ'_C, σ'_f are the complex Chandler and FCN frequencies in celestial frame, respectively, σ_C is the complex Chandler frequency in terrestrial frame and $a_{p,w}$ are dimensionless constants, the index p for load (or pressure) term and w for motion (or wind) term. To obtain two first-order equations instead of a second-order one given by Eq. (1), we made the substitutions y_1=P and y_2= $\dot{P} - i\sigma'_C P$ which lead to the system of two ordinary differential equations for two complex functions y_1, y_2:

$$\dot{y}_1 = i\sigma'_C y_1 + y_2\,, \\ \dot{y}_2 = i\sigma'_f y_2 - \sigma_C \left\{ \begin{matrix} \sigma'_f(\chi'_p + \chi'_w) + \sigma'_C(a_p\chi'_p + a_w\chi'_w) + \\ +i[(1+a_p)\dot{\chi}'_p + (1+a_w)\dot{\chi}'_w] \end{matrix} \right\}. \tag{2}$$

To integrate the system by the fourth-order Runge-Kutta method with 6-hour steps we need to choose the initial values, $y_1(0) = P(0)$, and $y_2(0) = i(\sigma'_f - \sigma'_C)P(0)$. The initial values are constrained so that the Chandlerian amplitude disappears. The final choice of $P(0)$ was made by two methods; we find the values for which

- the fit of the integrated motion to VLBI observations reaches a minimum as it has been done in (Vondrák and Ron, 2010), or
- the magnitude squared coherence estimate (MSC) C_{xy} of the input signals of integration and observation near FCN and annual terms reaches a maximum (this study).

Totally we performed 2500 integrations with initial values taken from the square net (-0.5, -0.5; 0.5, 0.5) mas with the step 0.02 mas.

3. TESTS AND RESULTS

3.1. *TEST WITH SIMULATED DATA*

The magnitude square coherence is a function of frequency with values between 0 and 1 that indicates how well two input signal or series correspond at each frequency *f* and is defined by the equation

$$C_{xy}(f) = \frac{\|D_{xy}(f)\|}{D_{xx}(f)D_{yy}(f)}, \tag{3}$$

where $D_{xx}(f), D_{yy}(f)$ are power spectral densities of signals x and y, $D_{xy}(f)$ is the cross power spectral density of x and y. We used the procedure `mscohere` of MATLAB® for complex signals that estimates the magnitude squared coherence function using Welch's averaged periodogram method (Kay, 1988) for 3 day smooth samples of celestial pole offsets. First we checked the sensitivity of the procedure `mscohere` for modeled signals. We prepared the series with synthetic data that are similar to the real series, IVS EOP and integrated AAMF in length, density and shape. First one is composed of the prograde annual and retrograde FCN waves, the second one has a semiannual wave in addition. Both series have different amplitudes and phases of the waves and a relatively large noise (the standard deviation of the noise is about one half of the annual term amplitude) with normal distribution. The parameters of the procedure `mscohere` were used as follows: the FFT length is equal to 256, the Hanning window over 256 samples, and number of samples that overlap next section is equal to 64. The results are shown at Figure 1. It is evident that the maximum coherence of both series is found correctly to be close to the prograde annual and retrograde FCN frequencies only.

3.2. *RESULTS*

Here we compare the results obtained under the two above mentioned conditions: minimum root-mean-squares (rms) fit and maximum coherence. For ERA+OMCT - the results of both approaches are

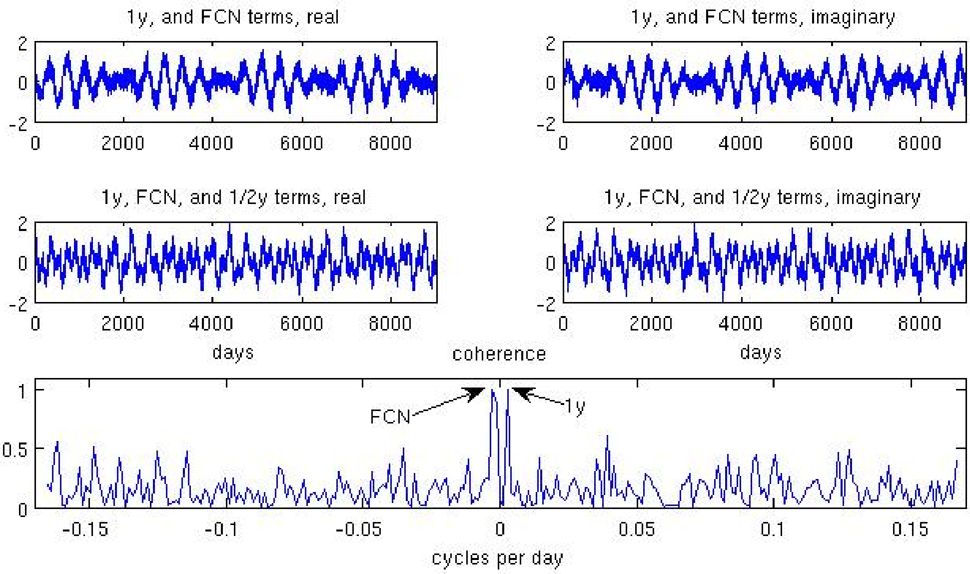

Fig. 1 Test for the coherence with the synthetic data of a signal with a random noise. Annual (prograde) and FCN (retrograde) terms above; annual, FCN and semiannual terms in the middle. The maximum coherence of both series is found correctly at the prograde annual and retrograde FCN frequencies.

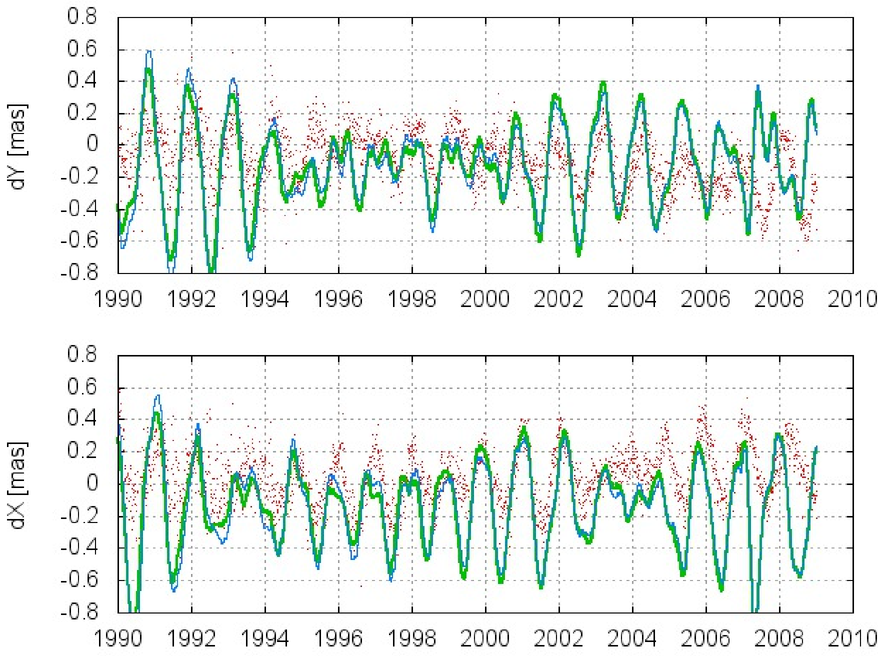

Fig. 2 CPO from IVS solution (dots), numerical integration of the excitations of ERA+OMCT fitted to IVS CPO (bold line), numerical integration of the excitation with maximum spectral coherence with the IVS CPO (thin line).

almost the same (see Fig. 2). The coherence calculated for the series of integrated CPO obtained with different initial values was very stable for annual frequency and fluctuating for the FCN frequency. The solution with initial values $P(0) = (0.40, -0.42)$ mas reaches the maximum coherence at FCN frequency. The coherence is shown in Figure 3.

The results for NCEP+ECCO, shown in Figure 4 and Figure 5, are rather different. Similarly to the solution with ERA+OMCT the coherence at annual

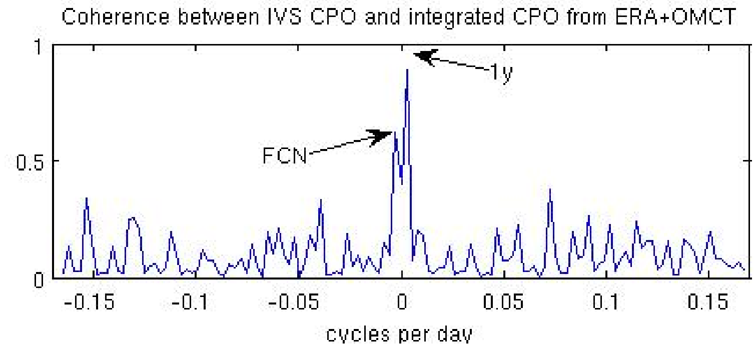

Fig. 3 Coherence between IVS CPO and integrated CPO from ERA+OMCT excitations at the interval 1990-2009.

Table 1 Initial values, coherences and rms fit for different solutions.

solution	initial values [mas]	coherence annual	coherence FCN	rms [mas]
ERA+OMCT/RMS	(0.28, -0.38)	0.89	0.57	±0.287
ERA+OMCT/MSC	(0.40,- 0.42)	0.90	0.62	±0.294
NCEP+ECCO/RMS	(-0.30, 0.30)	0.93	-	±0.250

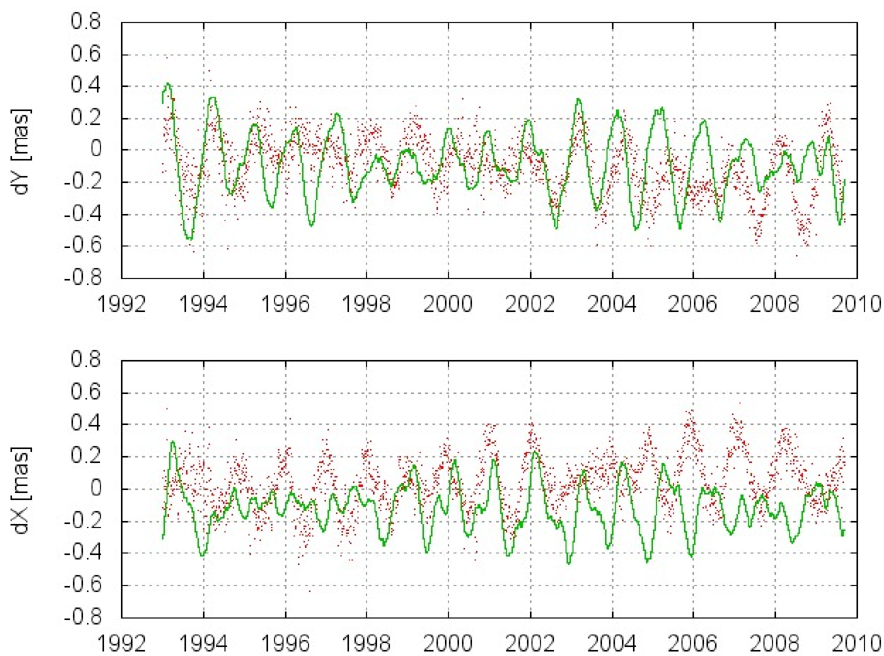

Fig. 4 CPO from IVS solution (dots), numerical integration of the excitations of NCEP+ECCO fitted to IVS CPO (line), numerical integration of the excitation with maximum spectral coherence was not derived.

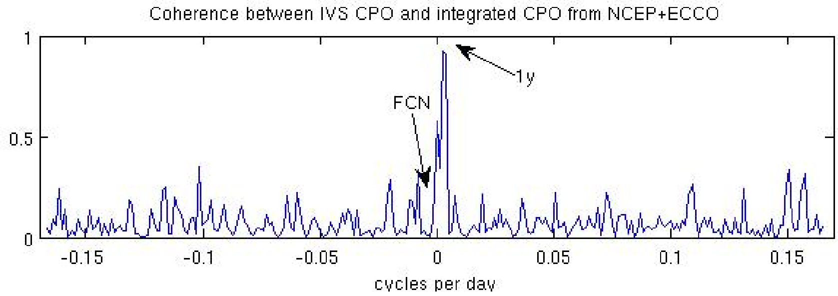

Fig. 5 Coherence between IVS CPO and integrated CPO from NCEP+ECCO excitations at the interval 1993-2009.7, a typical case, here for P(0,0).

frequency is stable, but we did not find any coherence close to the retrograde FCN frequency higher than the noise. The maximum coherence can be found for annual term, but this solution leads to improbably large values of rms fit. Therefore, we find this solution not acceptable. Table 1 displays the values of $P(0)$, coherence at annual and FCN frequencies and rms fit, for the solutions in which maximum square coherence (MSC) or minimum fit (RMS) was applied. In case of NCEP+ECCO only the second approach was applied, due to negligible coherence around FCN.

4. CONCLUSIONS

We can conclude that forced nutations due to excitation by the atmosphere and ocean are significant, especially at annual and semi-annual periods. The different models of series of geophysical excitations give slightly different results. The initial values of the integration are close each other for both version of their choosing, by the method of the maximum coherence or minimum root-mean-square differences. The NCEP+ECCO is probably a special case, since the quasi-daily signal in terrestrial frame of ECCO oceanic model is very weak, probably due to its atmospheric forcing only once a day. This is in agreement with our previous results (Vondrák and Ron, 2010) where the FCN amplitude for NCEP+ECCO is about two times smaller than the one for ERA+OMCT.

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