FREE CORE NUTATION – POSSIBLE CAUSES OF CHANGES OF ITS PHASE AND AMPLITUDE

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ABSTRACT. The comparison of the observed series of celestial pole offsets (CPO) and integrated atmospheric and oceanic excitation functions fitted on the different intervals corresponding with the epochs of geomagnetic jerks, major earthquakes in the last decade and natural or systematic jumps in the observed CPOs is performed.

1. INTRODUCTION

In our previous solutions, where we used integration of atmospheric and oceanic excitation function in the Celestial Reference System (Vondrák and Ron, 2010, Ron and Vondrák 2011), the comparison with the observed celestial pole offsets (CPO) became out-of-phase after some time. We suppose that other excitation could have effect and should be taken into account. Before studying the possible mechanism of the excitations of geomagnetic jerks, strong earthquakes and other events, we simply divide the integration into shorter intervals defined by these events to see possible improvements in the fit of the integrated series to the observed CPO.

2. THE METHOD USED

The excitations of the Earth rotation in celestial reference frame (nutation) by atmosphere and ocean are studied by using Brzeziński's broad-band Liouville equations (Brzeziński, 1994):

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

where $P = dX + idY$ is excited motion of Earth's spin axis in celestial frame (CRF), σ'_C, σ'_f are the complex Chandler and FCN frequencies in CRF, respectively, σ_C in terrestrial frame. The dimensionless constants are $a_{p,w}$ and χ'_p and χ'_w are the angular momentum excitation functions (presure and wind) in CRF. To solve the second order differential equation (1) we apply the substitution

$$y_1 = P, \quad \text{and} \quad y_2 = \dot{P} - i\sigma'_C P, \quad (2)$$

leading to the system of two ordinary differential equations for two complex functions y_1 and y_2:

$$\begin{aligned} \dot{y}_1 &= i\sigma'_C y_1 + y_2 \\ \dot{y}_2 &= i\sigma'_f y_2 - \sigma_C\left\{\sigma'_f(\chi'_p+\chi'_w)+\sigma'_C(a_p\chi'_p+a_w\chi'_w)+i[(1+a_p)\dot{\chi}'_p+(1+a_w)\dot{\chi}'_w]\right\}. \end{aligned} \quad (3)$$

To solve the system (3) we have to set up initial values

$$y_1(0) = P_0, \quad \text{and} \quad y_2(0) = i(\sigma'_f - \sigma'_C)P_0, \quad (4)$$

that are constrained so that the free Chandlerian motion disappears. The final choice of P_0 was done by repeating integration of (3) with different values P_0 to fit the integrated series to VLBI CPO observations so that it reaches a minimum rms difference. We applied 4-order Runge-Kutta numerical integration in

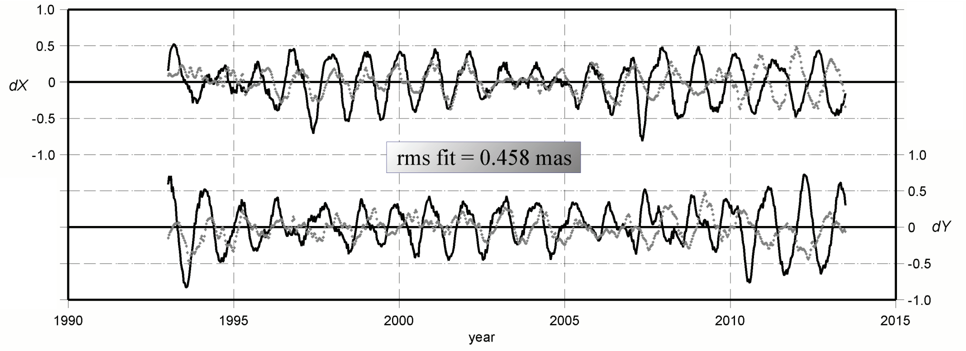

Figure 1: Observed and integrated celestial pole offsets with excitations based on ERA40 and operational model of atmosphere and ocean. The initial condition at 1993.0 only.

6-hour steps, using the procedure `rk4` from Numerical Recipes (Press et al., 1992), slightly modified for the complex domain.

3. THE DATA USED AND RESULTS

As series of observations we used the CPO from the IVS combined solution `ivs13q2X.eops` in the interval 1984.1–2013.5. The components of CPO dX and dY are given in unequally spaced intervals, (sometimes with outliers). We cleaned the data by removing CPO $>$ 1mas and cut the data before 1993.0. Then we added into the CPO the empirical Sun-synchronous correction that is applied in the MHB nutation theory to model the atmospheric and oceanic contribution (Mathews et al., 2002). Finally the series were interpolated to regular 10-day intervals using a filter to retain only periods between 180 and 6000 days (Vondrák, 1977).

As the geophysical excitations data we used the atmospheric angular momentum excitation function (AAM), both pressure and wind terms, of European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis ERA40. We used the reanalysis model before 2001 and operational model afterwards. The oceanic angular momentum excitation functions (OAMF), both matter and motion terms, of OMCT model in 1990.0–2013.5.0 (Dobslaw et al., 2010), driven by reanalysis atmospheric model ERA40 before 2001 and by operational model afterwards, were used. Both series were taken from Data Center of IERS and the data were cut before 1993.0.

Time series of AAM and OAM χ (in complex domain) were transformed from the terrestrial reference frame to the celestial one after Brzezinski et al. (2002) by using the complex decomposition at retrograde diurnal frequency $\chi' = -\chi e^{i\Phi}$, Φ is the Greenwich sidereal time. The long periodic behavior of the AAM and OAM functions become diurnal after applying the decomposition. Since we are interested in the long-periodic motion that is present in nutation, we applied the smoothing to remove periods shorter than 10 days and calculated their time derivatives needed for the integration.

We have done four solutions in total. First the solution with fixed initial values for the whole interval 1993–2013.5 was carried out. As seen in Fig. 1, the series become out-of-phase after 2007 and the rms fit reaches 0.46mas.

Geomagnetic jerks, which are observed as rapid changes in the geomagnetic field secular variations, are indicated as possible sources of Free Core Nutation excitation by Malkin (2013). We took the epochs of jerks from the paper at 1999.0, 2003.5 and 2007.5 to carry out the second solution. The resulting series are seen in Fig. 2. The agreement of the observed and integrated series is much better. The rms fit is equal to 0.25mas which is almost a half of that of the first solution.

The method of data and velocity jumps determination, based on the linear and parabolic trends in the integrated time series of CPO, is based on the method described in Chapanov et al. (this volume). It is sensitive to any impulse in the observed variations due to various geophysical processes or systematic data deviations. The method is very sensitive to small data jumps hidden inside the random noise and high frequency oscillations. The epochs of these jumps were found in 2004.3 and 2009.3. The solution is shown in Fig. 3.

In the last solution, shown in Fig. 4, we looked for the initial values in the epochs of major earthquakes

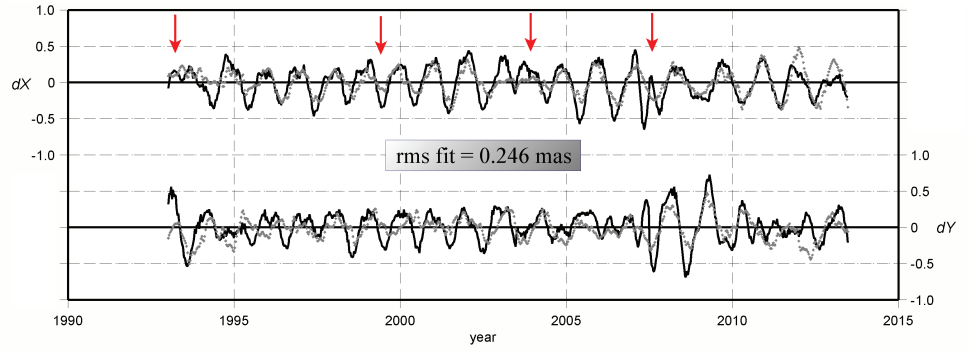

Figure 2: Observed and integrated celestial pole offsets with excitations based on ERA40 and operational model of atmosphere and ocean. The initial conditions at epochs of geomagnetic jerks after Malkin (2013).

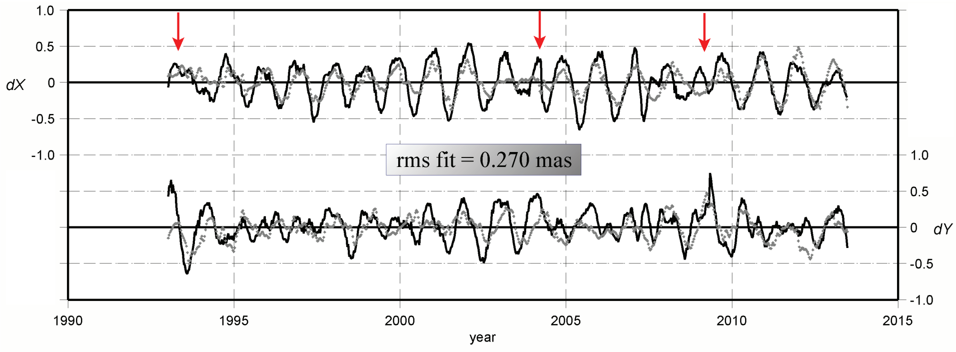

Figure 3: Observed and integrated celestial pole offsets with excitations based on ERA40 and operational model of atmosphere and ocean. The initial conditions at epochs of natural or systematic jumps in CPO derived after Chapanov et al. (this volume).

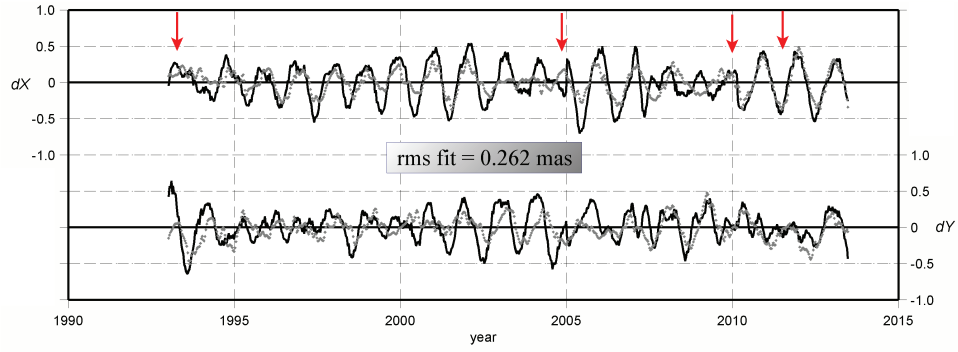

Figure 4: Observed and integrated celestial pole offsets with excitations based on ERA40 and operational model of atmosphere and ocean. The initial conditions at epochs of major earthquakes with $M_s > 8.8$.

larger than 8.8 magnitude scale during last decade. These are the Sumatra (2005.0), Chile (2010.2) and Japan (2011.9) earthquakes. The solutions are summarized in Table 1.

Table 1: Summarized results of all solutions; all values are in mas.

	interval	initial values	σ	$\overline{\sigma}$	shift
gm jerks	1993.0-1999.0	(-0.12; 0.41)	0.245	0.246	–
	1999.0-2003.5	(0.25; 0.26)	0.246		(0.09; 0.21)
	2003.5-2007.5	(0.02; 0.04)	0.248		(0.22; 0.29)
	2007.5-2013.5	(0.05;-0.32)	0.248		(0.19;-0.48)
jumps	1993.0-2004.3	(-0.12; 0.52)	0.279	0.270	–
	2004.3-2009.3	(-0.24; 0.19)	0.284		(-0.46;-0.19)
	2009.3-2013.5	(-0.18; 0.74)	0.228		(-0.03; 0.48)
earthquakes	1993.0-2005.0	(-0.10; 0.52)	0.286	0.262	–
	2005.0-2010.2	(0.33;-0.14)	0.276		(0.50;-0.20)
	2010.2-2011.9	(-0.28; 0.02)	0.158		(-0.35;-0.16)
	2011.9-2013.5	(0.35; 0.16)	0.189		(0.20; 0.07)

4. CONCLUSIONS

We detected considerable differences between ERA40 and ERAinterim in the wind term of AAM data (30% relative difference in amplitude of the semi-annual term of wind). Three different solutions were performed with the initial values valid in the intervals defined by consecutive dates of geomagnetic jerks, detected jumps in CPOs and large earthquakes. The solution with the geomagnetic jerks leads to the best agreement with observed CPO.

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