GEOMAGNETIC EXCITATION OF NUTATION

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ABSTRACT. We tested the hypothesis of Malkin (2013), who demonstrated that the observed changes of Free Core Nutation parameters (phase, amplitude) occur near the epochs of geomagnetic jerks. We found that if the numerical integration of Brzeziński broad-band Liouville equations of atmospheric/oceanic excitations is re-initialized at the epochs of geomagnetic jerks, the agreement between the integrated and observed celestial pole offsets is improved (Vondrák & Ron, 2014). Nevertheless, this approach assumes that the influence of geomagnetic jerks leads to a stepwise change in the position of celestial pole, which is physically not acceptable. Therefore we introduce a simple continuous excitation function that hypothetically describes the influence of geomagnetic jerks, and leads to rapid but continuous changes of pole position. The results of numerical integration of atmospheric/oceanic excitations and this newly introduced excitation are then compared with the observed celestial pole offsets, and prove that the agreement is improved significantly.

1. INTRODUCTION

Atmospheric and oceanic excitations play dominant role in polar motion and rotational velocity of the Earth. Thanks to the precise P/N model IAU2000/2006, small but non-negligible effects can be seen also in the observed celestial pole offsets (CPO), i.e. in nutation. These effects are caused by quasi-diurnal changes of angular momentum functions of the geophysical fluids (atmosphere, oceans, hydrology, ...).

In our previous study (Vondrák & Ron, 2014) we found that atmospheric/oceanic effects do not explain the observed CPO completely. The integrated excitations in celestial reference frame (CRF) in comparison with the observed CPO became out-of-phased after some period. We suppose that additional excitations have effect. In Ron et al. (2014) we tested additional events at epochs of strong earthquakes, jumps in observed data (Chapanov et al., 2014) and geomagnetic jerks (GMJ) shown in Malkin (2013). Geomagnetic jerks (or secular geomagnetic variation impulses) are relatively sudden changes in the second derivative of the Earth's magnetic field with respect to time (Olsen & Mandea, 2007). The re-initialization of the integration in the dates of these events was used in Vondrák & Ron (2014) and the best agreement has been found for the GMJ epochs. But the re-initialization of integration leads to a stepwise change in the position of celestial pole, which is not acceptable from the physical point of view.

Here we present a slightly modified approach by adding a simple continuous excitation function near GMJ epochs.

2. USED PROCEDURE

The excitations of the Earth rotation in the celestial reference frame (nutation) by atmosphere and ocean were studied 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, σ'_C, σ'_f are the complex Chandler and free core nutation frequencies in CRF, respectively, σ_C in TRF. $a_p = 9.200 \times 10^{-2}$, $a_w = 2.628 \times 10^{-4}$ are dimensionless constants (Koot & de Viron, 2011). χ'_p and χ'_w are the angular momentum excitation functions (pressure and wind) expressed in CRF.

To be able to integrate the system we need initial values P_0, $\dot{P}_0$ constrained so that the free Chandlerian term (with quasi-diurnal period in celestial frame) vanishes. The initial values are closely connected to the phase and amplitude of the integrated series. The final choice of P_0 was made by repeating integration with different values P_0 to fit the integrated series to VLBI observations so that reaches a minimum rms differences. The Runge-Kutta 4th order integration in 6-hour steps has been used to solve Eq. (1).

Procedure of searching the additional excitations. We tested several functions (an impulse, step-wise, ...) and found the double ramp function of a triangle shape as the best one. The central epochs of additional excitations around GMJ epochs have been fixed at 1991.0, 1994.0, 1999.0, 2003.5, 2004.7, and 2007.5. GMJs last typically several months so we fixed the length of excitation to 200 days. The complex amplitudes of the excitations were then estimated to lead to the best rms fit to observed CPO. In Vondrák & Ron (2014) we also tested if the excitations is preceding, delaying or corresponding to the GMJ epochs and the best agreement was found for the epochs of GMJ. The found additional excitations are shown in Fig. 1.

3. USED DATA AND RESULTS

Celestial pole offsets. We took the CPO from the last IVS combined solution `ivs14X1q.eoxy` covering the interval 1989.0-2014.0. dX and dY are given in unequally spaced intervals. We cleaned the data by removing outliers (CPO > 1mas) and then the empirical Sun-synchronous correction of IAU2000 nutation model has been added in order to be the observed CPO comparable with the atmospheric contribution. The series were filtered to retain only periods between 60 and 6000 days and interpolated at regular 10-day intervals.

Atmospheric angular momentum. There are two sources of atmospheric angular momentum (AAM) data

- European Center for Medium-Range Weather Forecasts (ECMWF), ERA40
- Atmospheric and Environmental Research, USA, NCEP/NCAR reanalysis

Our previous study based on AAM/OAM function of European meteorological Center ECMWF ERA40 and on the ocean model OMCT showed not so good agreement in comparison with the NCEP/NCAR series. No model of oceanic angular momentum driven by NCEP atmosphere is available for the whole studied period. But the pressure term with inverted barometer (IB) correction implies a simple model of oceanic response on the pressure changes. The series of AAM χ (complex values) were transformed from the terrestrial frame to the celestial frame by using the complex decomposition at retrograde diurnal frequency $\chi' = -\chi e^{i\Phi}$, Φ is the Greenwich sidereal time. Because we are interested in the long-periodic motion (comparable with nutation), we applied the smoothing to remove periods shorter than 10 days and calculated their time derivatives needed for integration. The series of AAM pressure term with IB correction transformed in this way are shown in Fig. 1.

The celestial pole offsets from IVS corrected for the sun-synchronous correction was then compared with geophysically excited motion of celestial pole obtained by numerical integration of Eq. (1). To obtain the best fit to CPO values, the integration was repeated with different initial values for the first interval,

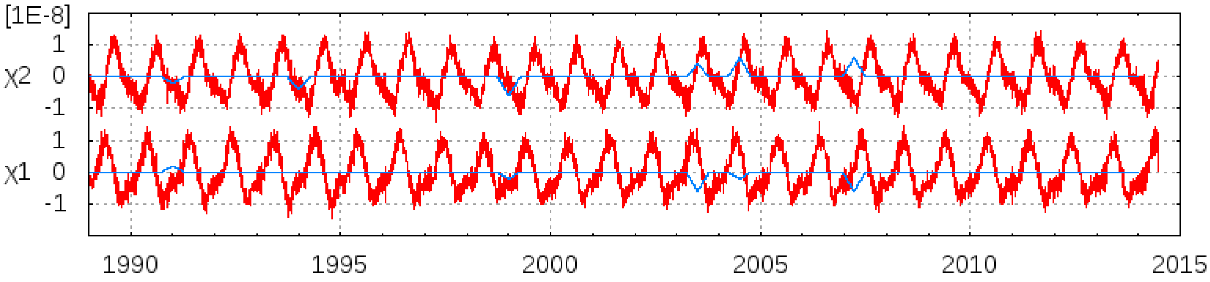


Figure 1: The AAM pressure term with IB correction in CRF (red line) and the found additional excitations at epochs of geomagnetic jerks (blue triangles).

i.e., from the beginning of the series in 1989 up to the first epoch of geomagnetic jerk 1991 and then were searched the complex values of the additional excitations for each interval between the successive geomagnetic jerks.

The integrated celestial pole offsets obtained with NCEP excitations with the inverted barometer correction and the solution with additional excitations in GMJ epochs are graphically depicted in Fig. 2.

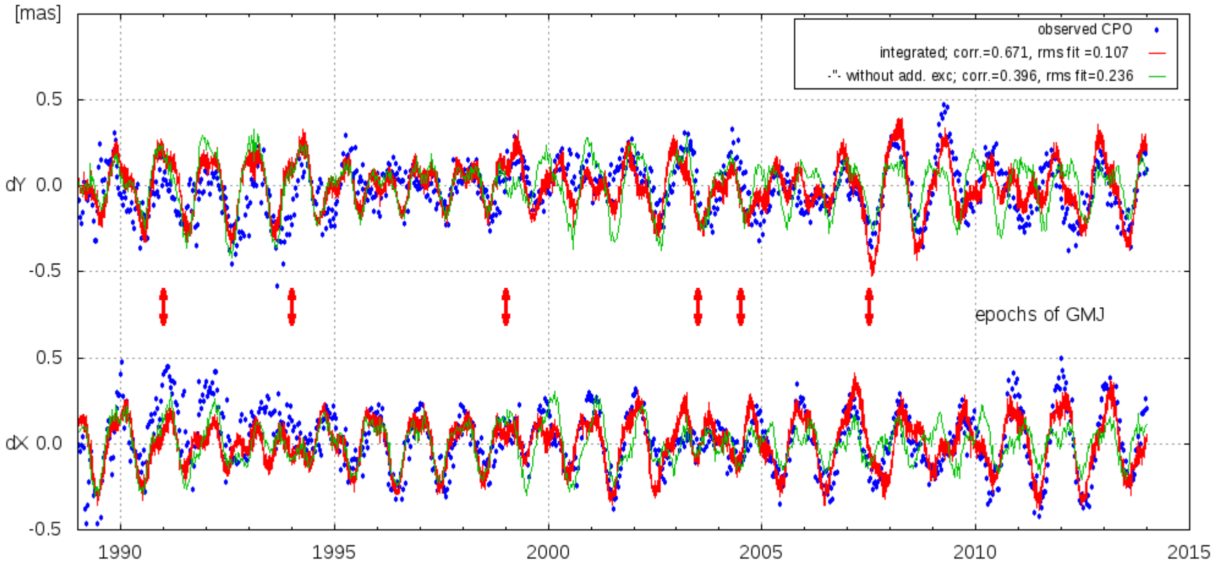


Figure 2: Observed (dots) and integrated celestial pole offsets. The green line corresponds to the solution of AAM with IB correction and the red line corresponds to the solution with additional excitations in GMJ epochs.

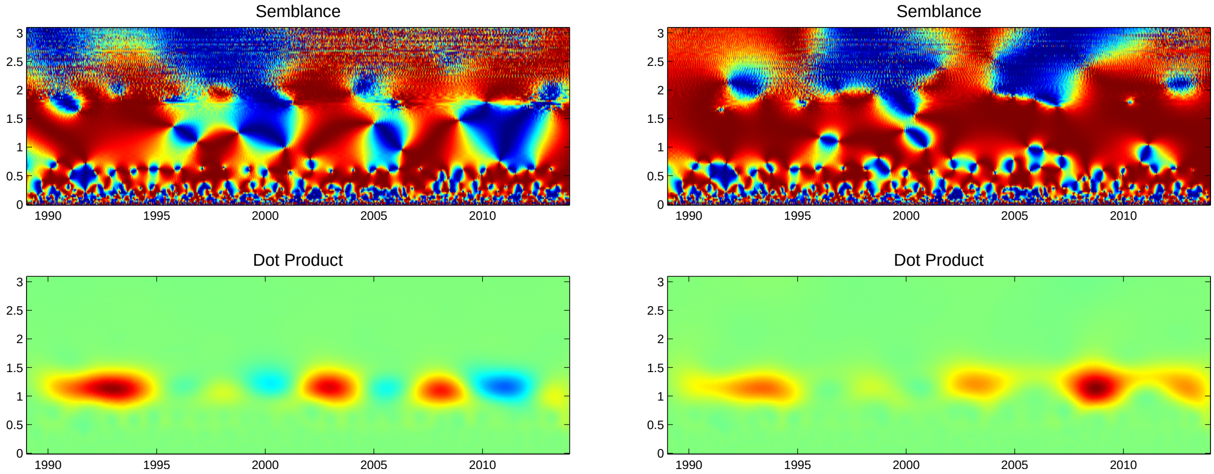
Series	without add. exc.		with add. exc.	
	rms [mas]	corr.	rms[mas]	corr.
NCEP with IB	0.236	0.396	0.107	0.671

Table 1: The rms fit and the correlation between integrated and observed celestial pole offsets with and without additional excitations.

In the process of searching the best rms fit we used the procedure of wavelet based semblance analysis (Cooper & Cowan, 2008) to compare the integrated and observed series of celestial pole offsets. The semblance measure $S = \cos(\theta)$, where θ is a local phase between the real and imaginary part of the cross wavelet transform, can reach the values between $< -1, +1 >$. The value $+1$ means correlated, 0 uncorrelated and -1 inversely correlated series, respectively. An example of the value of semblance and its multiplication by an amplitude of the cross-wavelet power (marked as 'Dot product') is shown at Fig. 3. The y-axis shows the width of the studied window in years. The improvement due to the application of the additional excitation is then clearly seen in the figure.

4. CONCLUSIONS

Geophysical excitations can yield significant contribution to nutation, of the order of 0.1mas. NCEP solution with the inverted barometer correction leads to better agreement than ERA solution. The influence of motion (wind) terms is one order of magnitude smaller than that of matter (pressure) terms. The application of schematic additional excitations at epochs of geomagnetic jerks improve the agreement of integrated celestial pole position with VLBI observations. The interpretation of the physical nature of the GMJ effect on nutation requires more study in future.


Semblance

Semblance

Dot Product

Dot Product

Figure 3: The wavelet semblance analysis of the the observed and integrated series of CPO (here Y axis only) without (left) and with the additional excitation at GMJ epochs (right). White (bright red in online version) color corresponds to a semblance +1 (correlated), black (dark blue in online version) to a semblance -1 (inversely correlated), gray (green in online version) to a semblance 0 (uncorrelated).

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