THE EARTH'S NUTATION: VLBI VERSUS IAU 2000A

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ABSTRACT. The nutation measured by VLBI is compared with the IAU 2000A model. The differences are modeled empirically by adjusting the free core nutation and a number of tidal terms. The signal remaining in the residuals is discussed.

1. INTRODUCTION

Nutation time series obtained by very long baseline interferometry (VLBI) match the IAU 2000A model (Mathews et al. 2002) with differences of ∼200 microseconds of arc (μas) in rms. The main signal showing up in the residuals is due to the forced free motion associated with the retrograde free outer core nutation (FCN). It produces a quasi periodic signal of space-referred period about 430 days. The source of the excitation of the FCN is believed to be in the Earth's surface fluid layer pressure variations (e.g., Dehant et al. 2005) but remain unverified due to strong inconsistencies in the global circulation models at diurnal frequencies (de Viron et al. 2005), as well as the atmospheric contribution to the nutation (Bizouard et al. 1998, de Viron et al. 2005). In addition, several unmodeled or mismodeled tidal terms show up in the residuals at the level of a few tens of μas. The accurate determination of their amplitude is of importance to confirm the nutation theory, especially if they can constrain the geophysical parameters used in the non-rigid Earth theories. In this study, we fit corrections to IAU 2000A to VLBI data, including the FCN and several tidal terms.

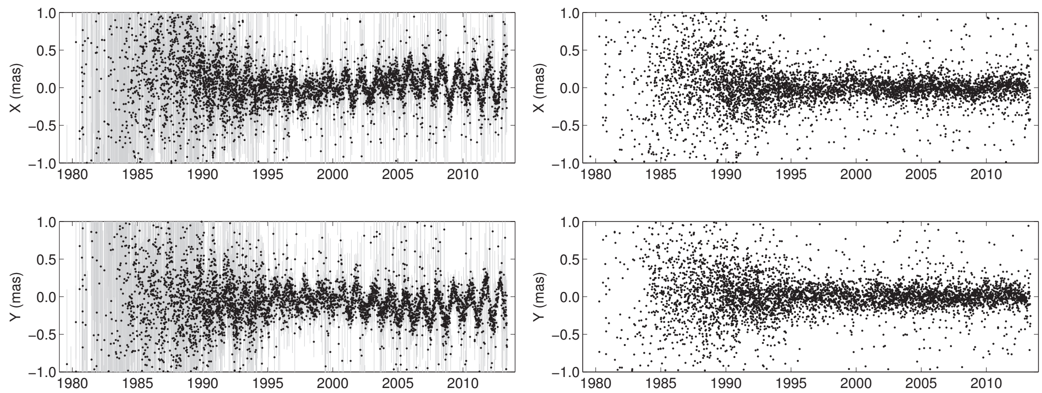

Figure 1: (*Left*) Nutation offsets to IAU 2000A as derived from VLBI observations. (*Right*) Residuals of the adjustment of the 21 tidal terms of Herring et al. (2002) (error bars were not reported).

2. ANALYSIS

We used nutation offsets to IAU 2000A as provided by the operational VLBI solution opa2013a made available by the Paris Observatory analysis center of the International VLBI Service for Geodesy and Astrometry (IVS; Schuh & Behrend 2010). To clean data from outliers, generally associated with unreliable networks or corrupted data, points whose distance to the mean is higher than 10 times the uncertainty were removed. This elimination is repeated until the χ^2 is reasonably close to unity. The obtained nutation offsets to IAU 2000A are plotted in Fig. 1 (left).

Then, the complex-valued nutation offsets $\eta = dX + idY$ were modeled by (i) a retrograde, 430-day signal with variable amplitude and phase to account for the FCN, and (ii) a number of tidal terms of fixed periods and phases of the form $\eta = Ae^{i\phi}$, where A is the complex amplitude, and ϕ the time-dependent astronomical phase given by linear combination of the Delaunay variables and mean longitudes of the planets (IERS 2010). The formal error associated with the observations was inflated by a scale factor of 1.3 and a noise floor of 60 μas. The values of the noise floor and the scale factor were determined over the period 1990–2013 by a method similar to Herring et al. (2002) and Lambert et al. (2008).

In a first step, 21 lunisolar terms used in Herring et al. (2002) and Mathews et al. (2002), were adjusted, leaving residuals displayed in Fig. 1 (right). The amplitudes are reported in Table **??**. These corrections, together with the fitted FCN signal, can be used to better predict the nutation for astro-geodetic applications. A visual inspection of the residuals in X reveals an interannual oscillation that reaches positive maxima around 2000 and 2006.

In a second step, we applied high resolution spectral methods in order to determine periods and phases of the remaining terms in the residuals. First, we used the frequency analysis mapping on unusual samplings (FAMOUS) software package developed by Mignard (2005) in a version modified by Collilieux (2008) that handles errors on observations. After first-guessing a number of spectral lines using a periodogram, FAMOUS uses nonlinear least-squares to refine the frequency of each spectral line. Alternatively, we developed a code (MIMOSA) that looks iteratively for spectral lines which minimize the χ^2 of the residuals. The frequency domain is scanned until the χ^2 is minimum. Then, the optimal frequency is fitted to the amplitude by a gaussian whose center and full width at half maximum give the central frequency and its uncertainty, respectively. The amplitudes and phase are finally adjusted by a global least-square inversion. Both FAMOUS and MIMOSA were applied to the data after 1990 and returned results in agreement within error bars (Table 2). Only three significant peaks were detected. We also check the results using the maximum of entropy method (MEM), which models the signal by an autoregressive (AR) process of order as large as the half number of samples. The power spectral density at any frequency in then deduced analytically using the set of AR coefficients. The MEM was applied to the signal preliminary regularized by taking averaged values every 15 days between 1990 and 2013, leaving about 570 points. The resulting spectrum exhibits peaks at 763 (7), 973 (28), and 2281 (199) days (the values between brackets indicate the full width at half maximum of the power spectral density peak obtained from an AR model of order 250), in agreement with the peaks detected by FAMOUS and MIMOSA.

The question comes now on giving a physical meaning to the peaks revealed by spectral methods. A methods is to compare periods and phases with those of IAU 2000A or the Rigid Earth Nutation (REN 2000; Souchay et al. 1999) tables. However, one cannot identify strictly each fitted term to one frequency. Each fitted term should rather be identified with a group of nutations whose frequencies are close each other around the relevant frequency. The shortest period could correspond to a group including the 727-day terms relevant to the interaction between Venus and the Earth ($4\mathrm{Ve} - 6\mathrm{Ea}$). The longest period could be associated with a group including the 2165-day term relevant to the interaction between the Earth and Jupiter ($F - D + \Omega - \mathrm{Ea} + \mathrm{Ju}$). Finally, the remaining period could correspond to the 943-day purely lunisolar period ($2l - 2F + \Omega$). The rigorous understanding of these terms is part of an ongoing research program.

3. REFERENCES

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l	l'	F	D	Ω	Period	Re(A)	$\pm$	Im(A)	$\pm$
0	0	0	0	1	−6798.3837	41.8	2.3	−19.9	2.3
0	0	0	0	−1	6798.3837	24.3	2.3	−34.1	2.3
0	0	0	0	2	−3399.1919	3.2	2.2	−8.2	2.2
0	0	0	0	−2	3399.1919	10.9	2.2	−5.5	2.2
2	0	−2	0	−2	−1615.7478	−2.6	2.1	−7.6	2.1
−2	0	2	0	2	1615.7478	−2.0	2.1	−10.2	2.1
2	0	−2	0	−1	−1305.4792	−0.5	2.2	8.1	2.2
−2	0	2	0	1	1305.4792	1.7	2.2	5.2	2.2
2	0	−2	0	0	−1095.1750	0.6	2.1	0.4	2.1
−2	0	2	0	0	1095.1750	−5.2	2.1	−2.7	2.1
0	−1	0	0	−1	−385.9983	−1.8	2.1	0.7	2.1
0	1	0	0	1	385.9983	−6.2	2.1	0.6	2.1
0	−1	0	0	0	−365.2596	2.8	2.2	1.8	2.2
0	1	0	0	0	365.2596	−1.0	2.2	−1.3	2.2
0	−1	0	0	1	−346.6358	−1.1	2.3	−1.0	2.3
0	1	0	0	−1	346.6358	−1.4	2.3	−0.1	2.3
0	0	−2	2	−2	−182.6211	−11.9	2.1	4.8	2.1
0	0	2	−2	2	182.6211	6.5	2.1	−2.3	2.1
0	−1	−2	2	−2	−121.7493	0.1	2.1	2.4	2.1
0	1	2	−2	2	121.7493	2.4	2.1	2.2	2.1
1	0	0	−2	0	−31.8119	0.7	2.1	−1.9	2.1
−1	0	0	2	0	31.8119	−1.8	2.1	1.3	2.1
−1	0	0	0	0	−27.5545	−15.8	2.1	−7.3	2.1
1	0	0	0	0	27.5545	−1.0	2.1	0.3	2.1
−1	0	−2	2	−2	−23.9421	−1.0	2.1	0.7	2.1
1	0	2	−2	2	23.9421	−3.0	2.1	−1.8	2.1
0	0	0	−2	0	−14.7653	−2.7	2.0	4.1	2.0
0	0	0	2	0	14.7653	−1.7	2.0	0.4	2.0
−2	0	0	0	0	−13.7773	−1.0	2.1	0.7	2.1
2	0	0	0	0	13.7773	−0.6	2.1	−0.3	2.1
0	0	−2	0	−2	−13.6608	−10.1	2.1	−9.5	2.1
0	0	2	0	2	13.6608	−6.5	2.1	14.3	2.1
1	0	−2	−2	−2	−9.5569	0.5	2.1	−1.3	2.1
−1	0	2	2	2	9.5569	1.2	2.1	0.3	2.1
−1	0	−2	0	−2	−9.1329	−2.1	2.1	0.0	2.1
1	0	2	0	2	9.1329	−3.0	2.1	3.2	2.1
−1	0	−2	0	−1	−9.1207	2.1	2.1	2.6	2.1
1	0	2	0	1	9.1207	1.5	2.1	−2.1	2.1
0	0	−2	−2	−2	−7.0958	−4.3	2.1	−1.6	2.1
0	0	2	2	2	7.0958	−2.7	2.1	2.0	2.1
−2	0	−2	0	−2	−6.8594	−1.5	2.3	1.0	2.3
2	0	2	0	2	6.8594	0.3	2.3	−0.9	2.3

Table 1: Adjustment of the 21 tidal terms of Herring et al. (2002) to the nutation offsets to IAU 2000A. Uncertainties are formal errors corrected by the reduced χ^2 of the adjustment. Unit: μas.

Period (days)	±	Amplitude (μas)	±	Phase ($^\circ$)	±
		FAMOUS			
2210	57	17	3	-93	11
764	9	13	4	-129	17
978	24	8	3	-173	24
		MIMOSA			
2222	378	16	3	-104	14
766	34	13	4	-121	19
962	65	8	4	173	20

Table 2: Terms detected by the FAMOUS and MIMOSA software packages. Units: amplitudes in μas, periods in days, and phases with respect to J2000.0 in degrees.