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COMPARISON OF OFFICIAL IVS NUTATION TIME SERIES FROM VLBI ANALYSIS

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Abstract. We carried out comparisons between the official IVS nutation time series using VLBI data. We studied differences between those time series and differences between derived products such as amplitude and phase of nutation components, including free core nutation, and noise color.

Keywords: VLBI, Analysis Strategy, Celestial Reference Frame, Precession-nutation

1 Introduction

Very Long Baseline Interferometry (VLBI) is the only technique that determines the Earth's nutation at submilliarcsecond (mas) accuracy. With its 35 years of observations and at the rate of about two sessions per week during the last decade, it allows to estimate nutation over periods from 14 days and up to almost 20 years. The quality of nutation estimates is fundamental for further use in geophysics for, e.g., inferring Earth's interior parameters relevant to the mantle, the core, and the inner core (e.g., Mathews et al. 1991, 1995, 2002). But VLBI data analysis is complex. Even if the observational data set is the same for everyone, there are as much different nutation time series that there are analysists, and therefore analysis strategies, in the International VLBI Service for Geodesy and Astrometry (IVS; Schuh & Behrend 2012). We propose here to quantify the differences.

2 Data Set

We carried out a comparison of several nutation time series provided by different analysis centers of the IVS: Geoscience Australia (AUS00007, Australia), Bundesamt für Kartographie und Geodäsie (BKG00014, Germany), Centro di Geodesia Spaziale (CGS2014A, Italy), Goddard Space Flight Center (GSF2014A, USA), Institute of Applied Astronomy (IAA2007A, Russia), Observatoire de Paris (OPA2015A, France), Astronomical Institute of St.-Petersbufg University (SPU00004, Russia), U. S. Naval Observatory (USN2015A, USA), Vienna University of Technologie (VIEEOP13, Austria) and the IVS combined time series (IVS14Q2X) which is computed with the transformed and weighted normal equations of several operational analysis center solutions (Böckmann et al. 2010). The nutation time series used in this study are offsets according to an IAU precession-nutation model in dX, dY parametrization (Capitaine et al. 1986). You can use the tool following this link to get all the previous nutation time series in the parametrization you want.

Solution technical descriptions are summarized in Table 1 where we display the analysis options that are connected to nutations. VIEEOP13 is added because it uses VieVs software but we do not know its technical details. Globally, all solutions are obtained by similar analysis strategies except for some steps concerning: **(1)** the status of radio sources (are their positions locally or globally estimated, fixed, constrained?); **(2)** the wet zenith troposphere delay a priori at the observing elevation (mapping function); **(3)** the wet zenith troposphere delay and gradient estimation strategy and interval; **(4)** the clock offset estimation strategy and interval.

Concerning the first item, several works reported a non negligible influence of the instability of the targeted radio sources in Earth orientation parameter estimates (Dehant et al. 2003; Feissel-Vernier 2003; Feissel-Vernier et al. 2005, 2006; Lambert et al. 2008). The use of the ICRF1 (Ma et al. 1998) or its extension (Fey et al. 2004), which axes stability was estimated around 0.25 mas in place of the current ICRF2 (Fey et al. 2015) which is more stable by a factor of 5 could lead to detectable perturbations in the nutation time series. Concerning the VLBI analysis software package, five analysis centers use CALC/SOLVE, three use OCCAM and one uses VieVs.

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		AUS	BKG	CGS	GSF	IAA	OPA	SPU	USN
CRF	a priori	ICRF1 Ext.2	ICRF2	ICRF2	ICRF2	ICRF1 Ext.2	ICRF2	ICRF1 Ext.2	ICRF2
	NNR	ICRF1	ICRF2	ICRF2	ICRF2	ICRF1	ICRF2	ICRF1	ICRF2
	global/local	0/0	all/0	969/1720	1670/NL	0/0	all-NL/NL	0/0	846/852
Precession a priori		IAU1976	IAU2006	IAU2006	IAU2006	IAU2000A	IAU2006	IAU1976	IAU2006
Nutation a priori		IAU1980	IAU2000A	IAU2000A	IAU2000A	IAU2000A	IAU2000A	IAU1980	IAU2000A
IERS Conventions		2000	2010	2003	2010	2003	2010	2003	2010
Tropo.	mapping	VMF	VMF	VMF	VMF	VMF	VMF	VMF	NMF
	ZTD	RW	1h LS	60mn LS	20mn LS	RW	20m LS	RW	20m LS
	gradients	constant	24h offset	6h LS	6h LS	-	6h offset	constant	6h LS
Clock interval		RW	1h LS	1h Q	1h Q	RW	1h Q	RW	1h Q
Elevation cutoff		quality flag	5°	5°	5°	quality flag	5°	quality flag	5°
Software package		OCCAM	CALC/SOLVE	CALC/SOLVE	CALC/SOLVE	OCCAM	CALC/SOLVE	OCCAM	CALC/SOLVE

Table 1. Analysis strategies of different analysis centers. NNR: no-net rotation applied to the defining sources; NL: 39 sources called "non linear" in Fey et al. (2015); LS: linear spline; Q: quadratic polynomial; RW: Random Walk process; VMF/NMF: Vienna (Boehm et al. 2006)/Niell (1996) mapping function.

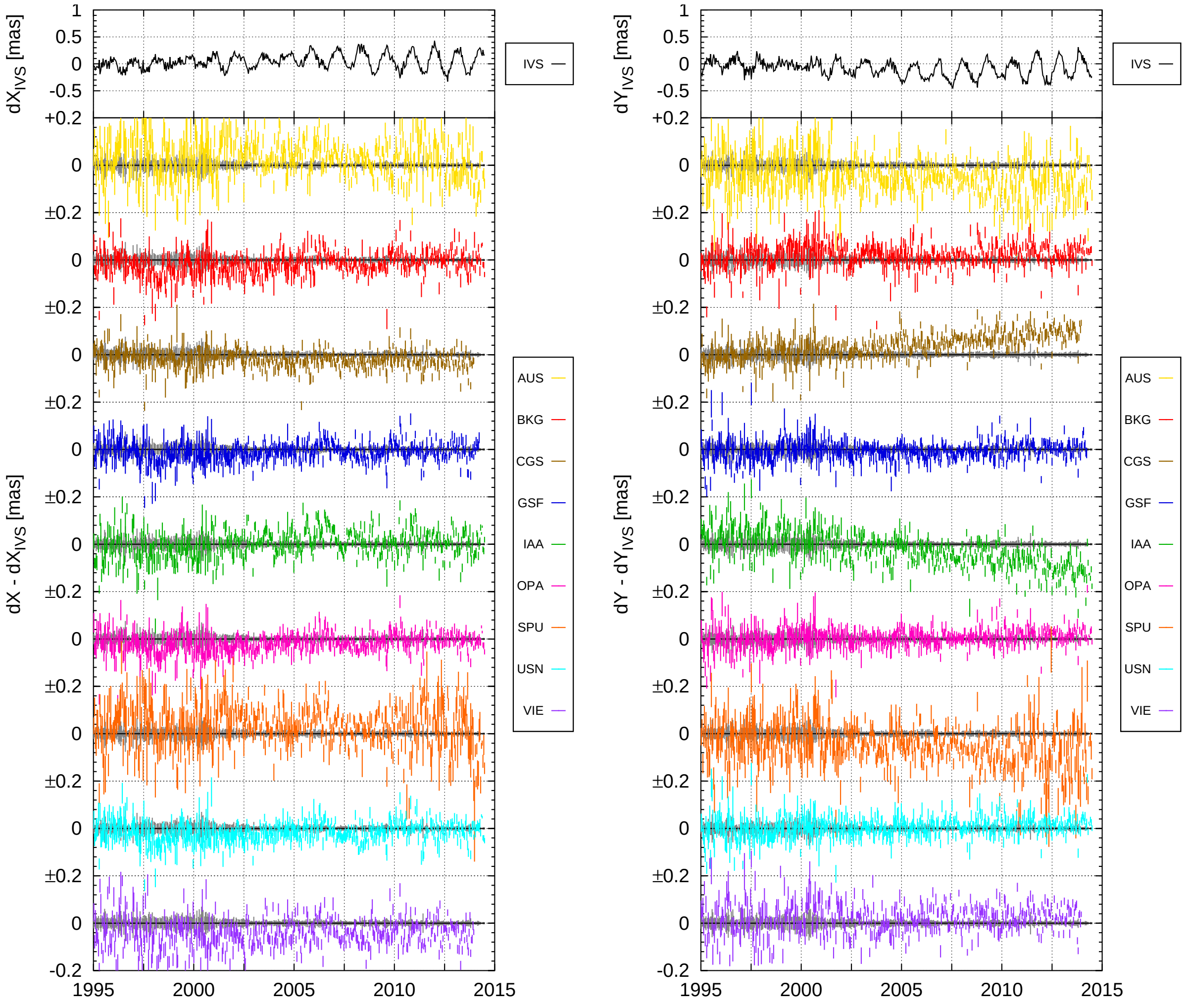

Fig. 1. Differences of nutation time series with respect to the IVS combination. The reference IVS time series is shown on the top.

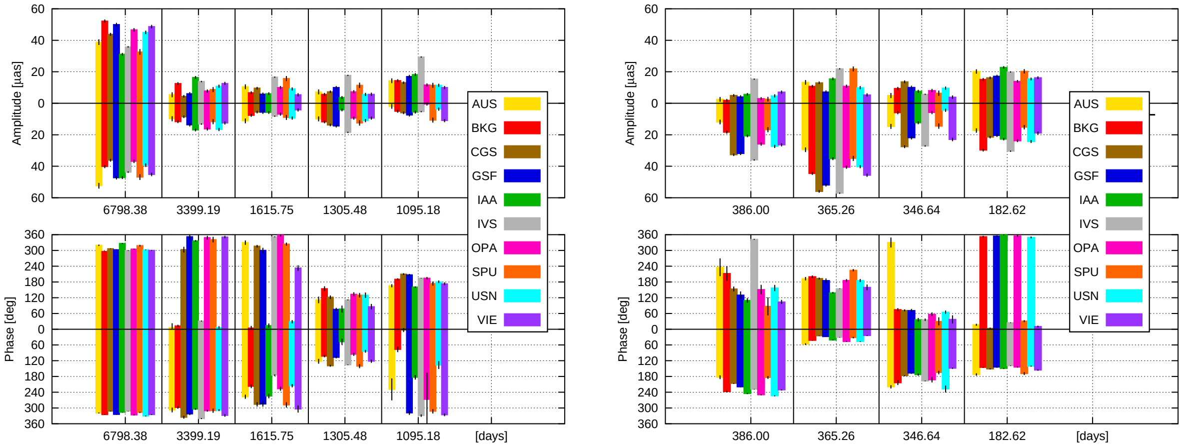

Fig. 2. Least Square adjustment of amplitude and phase of principal nutations.

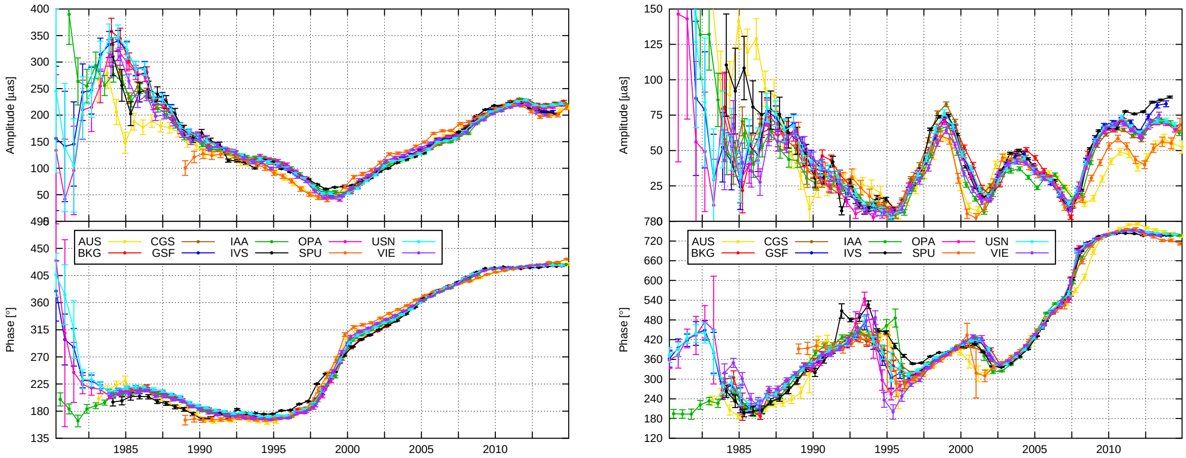

Fig. 3. Least square adjustment over a 7-yr sliding window every 0.6 years of amplitude and phase of the free core nutation (FCN) and retrograde annual nutation.

3 Analysis and results

Figure 1 displays differences of each center's time series with respect to the IVS combined series. For each graph, we plot error bars of center's solution in color and error bars of IVS-combined's solution (top plot) in grey. We use the IVS combined time series as references purely for sake of clarity. At no time, we consider the IVS combined time series better than the others. Drifts that appear on AUS, IAA and SPU graphes are likely due to the use of a different precession model as a priori precession : IAU1976 (Lieske et al. 1977), IAU2000 (Mathews et al. 2002) or IAU2006 (Capitaine et al. 2005). Drift on CGS graph comes from another unknown origin.

Even if, globally, time series are similar at the level of tenths of a mas, we can see that they significantly diverge at some dates in the sense that error bars do not account for the differences. Figures 2 show adjustments of principal lunisolar nutations and figures 3 show more detailed on the time-variable amplitudes and phases of the free core nutation (FCN), known at period of 430.21 days in retrograde motion, and the annual retrograde nutation. The complete adjustment is composed of 21 prograde and retrograde waves of prominent amplitudes used in the latest Earth nutation theory of Mathews et al. (2002). They were adjusted by least square method over all the available data between 01.01.1979 and 01.01.2015. For the FCN and annual nutation, the least square adjustment was done over a 7-yr sliding window every 0.6 years between those dates.

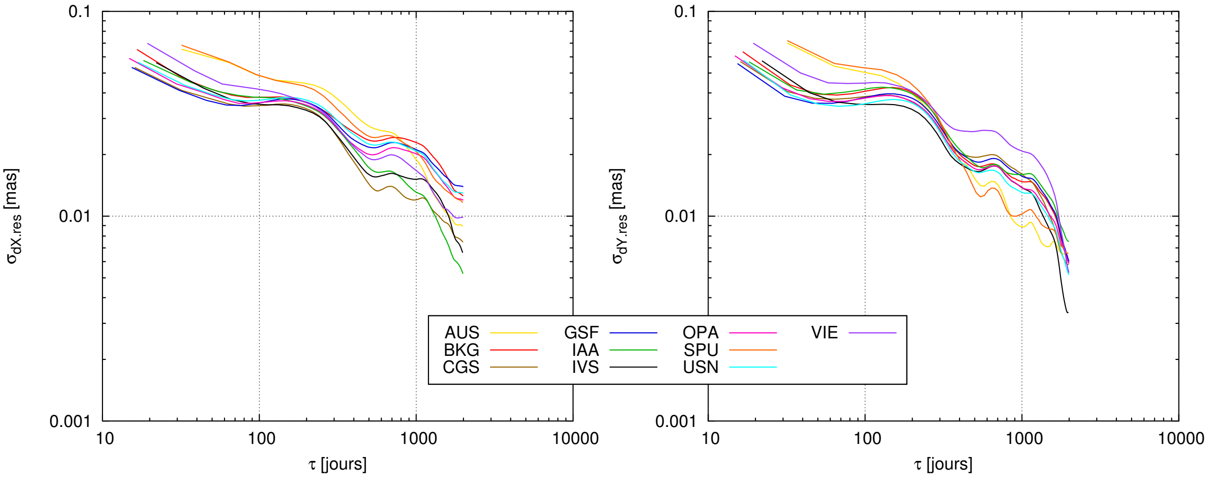

Fig. 4. Allan standard deviation of residual nutation time series.

From one solution to another, figures reveals that the difference in amplitude for a given nutation do not exceed 30 μas. Surprisingly, IVS often present the furthest value with respect to the others. It seems that the combination process creates artifacts that affect the nutation components. SPU, AUS and IAA show also some divergences at some dates. Those three are using the OCCAM software (see table 1). Software may also affect results of nutation adjustment. Notice that the annual nutation shows a period of phase instability between 1992 and 1997. The excitation mechanism of both the FCN and the annual retrograde nutation should be investigated in the future, especially to understand their amplitude variability and the cancellation of the annual retrograde nutation amplitude in 1995, 2002(?) and 2007.5. This mechanism likely originates in external fluid layer mass exchanges but the difficulty in modeling high frequency behavior of the atmosphere prevents one from any verification (de Viron et al. 2005; Lambert 2006).

4 Noise characterization

In the previous section, we adjusted a number of prominent nutation components and removed them from the time series, such that residuals can be considered as close to a noise. We computed Allan standard deviation samples $\sigma_{\rm A}$ defined for a time sampling interval τ as (Allan 1966; Rutman 1978)

$$\sigma_{\rm A}^2(t,\tau) = \frac{1}{2}\left(\bar{y}_t + \bar{y}_{t+\tau}\right)^2 , \tag{4.1}$$

where y is a data set and $\bar{y}_t$ is the mean of data along the τ-duration interval which begins at t. Then we computed the Allan standard deviation by averaging over time using overlapped samples. This algorithm is called AVAR in the litterature. It provides an unbiased estimator for the true variance in the case of white frequency noise modulation. The Allan standard deviation of the residual series are displayed in Fig. 4. We investigate noise on time scales from 15 days and up to about 5 years. In the graphes, a slope of -0.5 indicates the presence of a white frequency noise, while a constant reveals a flicker noise and a slope of 0.5, a random walk noise.

At low time scales, residual nutation time series can be considered as a white noise. After a 500 days time scale, it is difficult to distinguish between white noise and colored noise because of the bumps. Those successive bumps indicate the presence of a residual periodic signal. The time scale for the top of the first bump gives us the half-period of this signal, the time scale of the second bump gives three halves times the period, etc... In our case the period is approximately 450 days. Solutions are also gathered between software users (see table 1), that means BKG, CGS, GSF, OPA, USN (CALC SOLVE users), AUS, IAA, SPU (OCCAM users) and VIE (VieVs user). This fact is remarkable on the dY graph at 1000 days. Only IAA do not follow its group and CGS do not follow CALC/SOLVE group for the dX component. It means that the noise amplitude certainly be software dependent.

5 Conclusion

We compared the nutation time series made available by different analysis centers using their own VLBI analysis configurations. These differences affect the nutation at the level of 30 μas. No analysis configuration shows up in this study. But a dependance on software used appears, especially on the noise characterization. More thorough analyses are needed to separate the effects due to delay modeling, constraints, and parameterization.

Although small compared to, e.g., the stability of the current celestial reference frame (Fey et al. 2015), differences between nutation series raise some questions about the observability of tiny phenomenon that are currently under investigation by the geophysical community. In particular, we can cite **(1)** the determination of the quality factor (damping factor) of the FCN which is linked to deformability of the core-mantle interface as well as possible topographic and electromagnetic couplings (Mathews et al. 2002; Koot et al. 2008, 2010), and **(2)** the determination of the period of the free inner core nutation (FICN) which is currently very uncertain (Rogister & Valette 2009). In a work in preparation, we also include multi-techniques combination EOP in our comparison and we consider a more thorough spectral analysis to extract periodic components, so that the characterization of the internal noise of each series is more relevant.

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