ON APPLICATION OF THE COMPLEX DEMODULATION FOR MONITORING EARTH ROTATION: ANALYSIS OF THE NUTATION AND LONG PERIODIC UT1 DATA ESTIMATED BY VieVS CD

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ABSTRACT. In the recent work (Böhm et al., J. Geodynamics, 62(2012), 56–68) we demonstrated the application of the complex demodulation (CD) technique for VLBI estimation of the Earth orientation parameters (EOP). This technique enables simultaneous determination of the long period components of polar motion (x,y), universal time (dUT1=UT1−UTC) and nutation (celestial pole offsets dX,dY) as well as the high frequency (diurnal, semidiurnal, ...) components of polar motion and dUT1. In this work we perform analysis of the retrograde diurnal component of polar motion and the low frequency component of dUT1 estimated by the VieVS CD software. By comparison to the results based on the celestial pole offsets and dUT1 series from the combined solutions IVS and IERS we demonstrate consistency of the CD parametrization with the standard approach.

1. INTRODUCTION

The complex demodulation (CD) technique enables simultaneous determination of the long period components of polar motion (x,y), universal time (dUT1=UT1−UTC) and nutation (celestial pole offsets dX,dY) as well as the high frequency (diurnal, semidiurnal, ...) components of polar motion and dUT1 (Brzeziński, 2012). The algorithm of complex demodulation was implemented by Böhm et al. (2012) into a dedicated version of the Vienna Very Long Baseline Interferometry (VLBI) Software VieVS. They processed around 3700 geodetic 24-h observing sessions over 1984.0–2010.5 and estimated simultaneously the time series of the long periodic components of the Earth Orientation Parameters (EOP) and of diurnal, semidiurnal, terdiurnal and quarterdiurnal components of polar motion and dUT1.

The high frequency components of EOP estimated by Böhm et al. (2012) were analyzed by Brzeziński and Böhm (2012). The analysis reported here concerns the low frequency components of EOP estimated by the use of the VieVS CD algorithm. The purpose is twofold. First, we want to demonstrate that the long periodic components of EOP estimated with the use of CD parametrization are consistent with those obtained by the use of standard parametrization. Second, we like to show that the diurnal retrograde component of polar motion demodulated by CD is equivalent to the standard time series of the celestial pole offsets.

The results concerning low frequency polar motion were reported by Brzeziński et al. (2014). Here we confine attention to the results based on the nutation and dUT1 series.

2. DATA DESCRIPTION AND ANALYSIS

The following parametrization of polar motion (PM) and universal time (UT1) has been applied by Böhm et al. (2012) for complex demodulation of VLBI data

$$\begin{bmatrix} x(t) \\ y(t) \end{bmatrix} = \sum_{\ell=-N}^{N} \left\{ \begin{bmatrix} x_\ell(t) \\ y_\ell(t) \end{bmatrix} \cos(\ell\phi) + \begin{bmatrix} y_\ell(t) \\ -x_\ell(t) \end{bmatrix} \sin(\ell\phi) \right\}, \quad (1)$$

$$d\mathrm{UT1}(t) = \sum_{\ell=0}^{N} \left[u_\ell^c(t)\cos(\ell\phi) + u_\ell^s(t)\sin(\ell\phi) \right], \quad (2)$$

where x, y are the reported coordinates of polar motion, dUT1=UT1−UTC is the difference of UT1 and the uniform time scale UTC, ϕ =GMST+π, GMST stands for Greenwich Mean Sidereal Time and $x_\ell(t)$,

$y_\ell(t)$, $u^s_\ell(t)$, $u^c_\ell(t)$ are assumed to be slowly varying functions of time t. When estimated from VLBI data, these time dependent amplitudes are treated as constant during one 24-hour session. We also assume that the argument ϕ is a linear function of time $\phi = \Omega t + \phi_\circ$, where Ω denotes the mean angular velocity of diurnal sidereal rotation (equal 2π rad/sidereal day = $7\,292\,115 \times 10^{-11}$ rad/s) and $\phi_\circ$ is a constant phase referred to the initial epoch $t = 0$. Let us make the following remarks:

- the terms $\ell = 0$ of the expansion (1)–(2) are the long periodic components of PM and UT1 estimated in standard adjustment;
- the terms $\ell = \pm 1, \pm 2, \pm 3, \pm 4, \ldots$, express quasi diurnal, semidiurnal, terdiurnal, quarterdiurnal, ..., variations in PM (retrograde/prograde for $-/+$) and in UT1;
- the $\ell = -1$ term of the expansion (1) gives an equivalent representation of the celestial pole offsets dX, dY, in a sense that $[x_{-1}(t), -y_{-1}(t)] = [dX(t), dY(t)]$ in the first order approximation.

Böhm et al. (2012) performed VLBI data processing over 1984.0–2010.5 based on the complex demodulation model described by equations (1)–(2) with $N = 4$. In the following analysis we will use the diurnal retrograde component of polar motion $[x_{-1}(t), -y_{-1}(t)]$ representing nutation, and the low frequency of dUT1, $u^c_0(t)$. As an external reference we use the nutation $[dX(t), dY(t)]$ and dUT1(t) series from the following two combined solutions

- IVS 13q2X (http://ivscc.gsfc.nasa.gov) which is based on VLBI technique only;
- IERS C04 (www.iers.org) which is a combined solution from all space geodetic techniques, nevertheless the computations of nutation and UT1 series rely also basically on VLBI measurements.

All three time series have been reduced and analyzed in the same way.

Nutation component. We estimated corrections to the precession (1-st order polynomial) and 6 largest components of nutation – 18.6 yr, 9.3 yr, 1 yr, 0.5 yr and 13.7 d. As there is a strong interference between the FCN signal and the retrograde annual nutation, we removed the FCN empirical model recommended by the IERS Conventions (2010) prior to the least-squares adjustment of the nutation harmonics. The nutation series, after removal of the estimated corrections to the conventional precession-nutation model and adding back the FCN empirical model, are compared in Fig. 1. The estimated corrections to the forced nutation terms are illustrated by the phasor diagrams in Fig. 2.

From Fig. 1 it can be seen that the early nutation data is noisy and contains variability which is not consistent with the rest of the series. When the data analysis does not include weighting it is recommended to remove data prior to 1990. But also after 1990 the reduction of noise level and of difference between the three series with time is clearly seen. We can conclude that when considering the residual nutation signal in time domain, the VieVS CD series is consistent with both the IVS and IERS combination series.

The estimated corrections of the forced nutation terms, shown in Fig. 2, based on the VieVS CD series are also consistent with those derived from the IVS and IERS series. The largest corrections are to the main term of nutation with period of 18.6 years. The amplitude of the VieVS CD correction term ($\approx$50 μas) is between the result of IVS ($\approx$60 μas) and IERS ($\approx$40 μas), while the difference of phase is about 30° with respect to IVS and up to 60° with respect to IERS. The other correction terms do not exceed the level of 20μas; the difference of results based on VieVS and the two combined solutions is generally not larger than the difference of results from the two combined series.

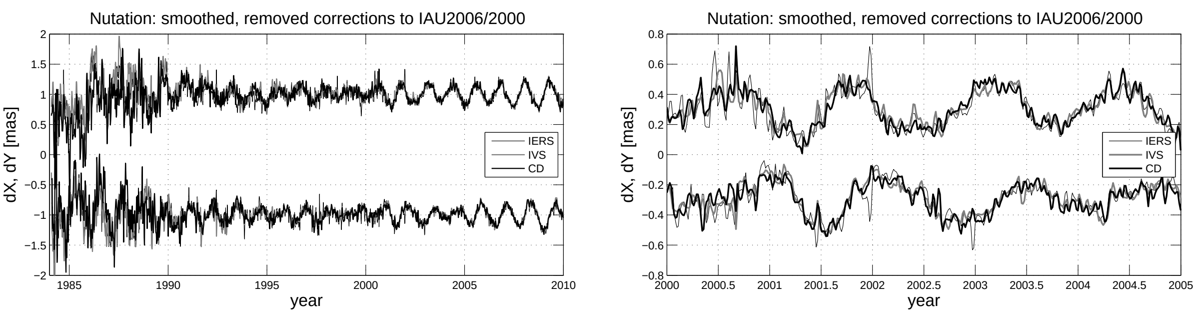

Figure 1: Nutation component (PM with $\ell = -1$) estimated by VieVS CD after applying empirical corrections to the conventional precession-nutation model and a weak smoothing (left) and its zoom (right). The VieVS CD series is compared to the combined solutions IVS 13q2X and IERS C04.

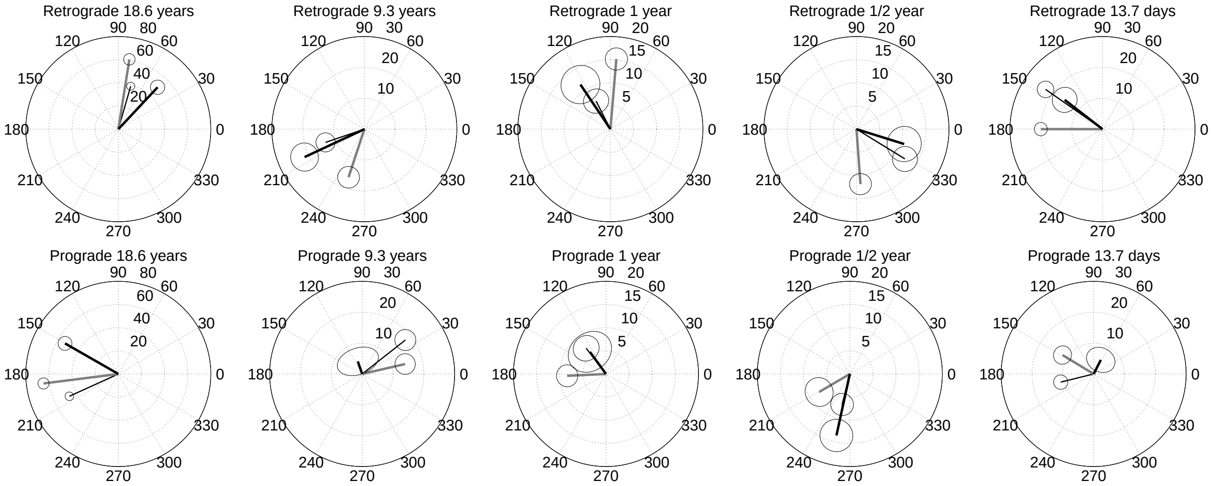

Figure 2: Estimated corrections to the selected nutation terms of the conventional model with standard deviations of estimates shown as ellipses. Reference precession/nutation model: IAU 2000/2006, units: microarcseconds, input time series: CD VieVS – thick black, IVS 13q2X – thick gray, and IERS C04 – thin black, period of analysis: 1984.0–2010.5.

Low frequency component of UT1. Comparison of the low frequency component of dUT1 is shown in Fig. 3. We started from adding back the leap seconds and removing the model of variation due to the zonal tides (IERS Conventions, 2010). The three curves are very similar. The only difference is in the error bars which are larger in case of VieVS CD, particularly in the first part of data. Next, we estimated by the weighted least-squares adjustment the model comprising the 4-th degree polynomial and the sum of harmonics with periods of 11.2, 2, 1, 1/2 and 1/3 years.

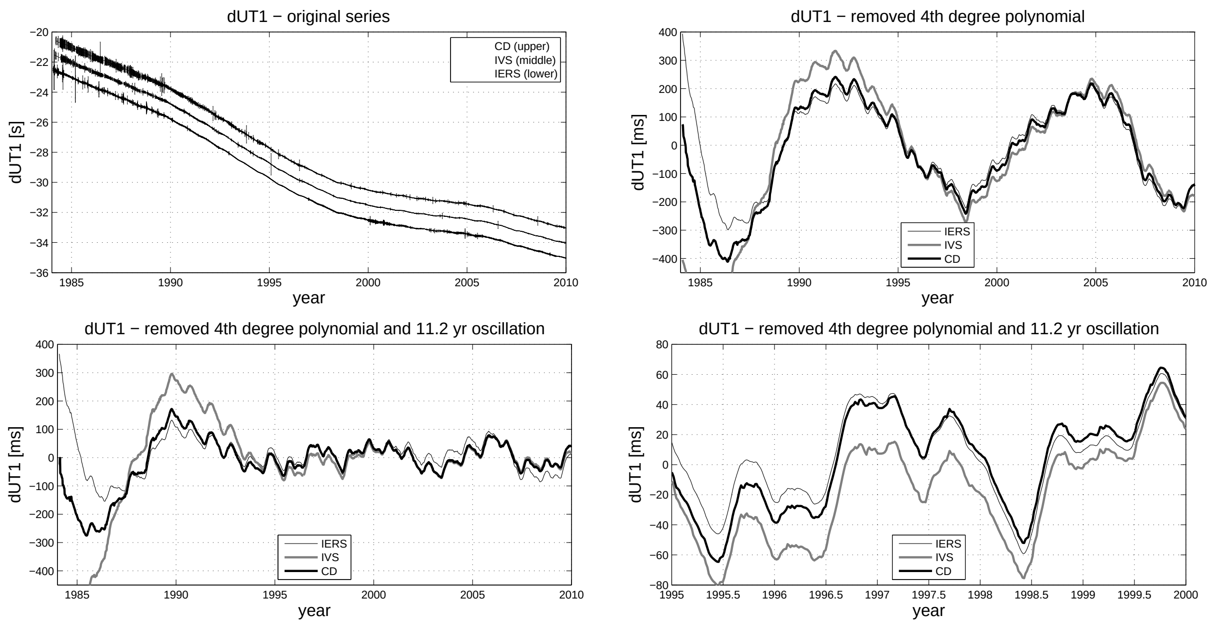

Figure 3: Low frequency component of dUT1: original series with the error bars after adding back the leap seconds and removal of the conventional tidal model (top left), after additional removal of the 4th order polynomial (top right) and the 11.2-year sinusoid (bottom left), and its zoom (bottom right).

From the comparison shown in Fig. 3 it can be seen that there is a good agreement of dUT1 data at seasonal and subseasonal frequencies. The difference is in the long periodic behavior. One reason of that can be the decrease of formal errors with time causing that the estimation of the model depends heavily on the recent data. It is particularly well seen in the left lower plot where the large decadal variability still exists prior to 1995. Another reason is the high correlation of errors between the estimated coefficients of the polynomial and 11.2-yr sinusoid. Clearly, a more refined model is needed for representing the long periodic variation in dUT1.

An excellent agreement is also found from comparison of the harmonic terms of the model (Fig. 4), with a higher consistency between results from VieVS CD and IVS.

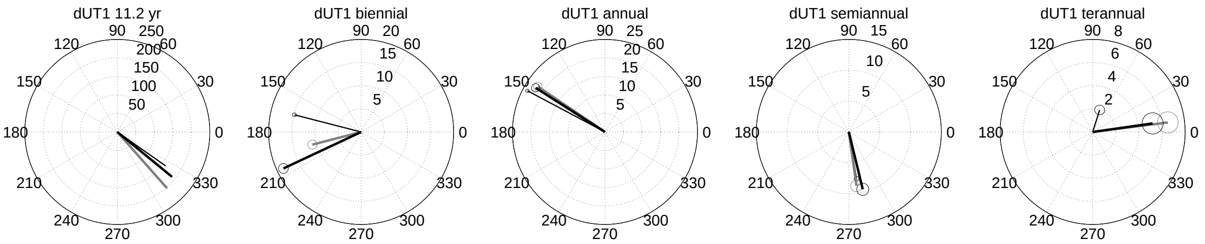

Figure 4: Estimated parameters of the periodical components of dUT1 with standard deviations of estimates shown as ellipses. Units: milliseconds, input time series: CD VieVS – thick black, IVS 13q2X – thick gray, and IERS C04 – thin black (cf. Fig. 3), period of analysis: 1984.0–2010.5.

3. SUMMARY AND CONCLUSIONS

The complex demodulation algorithm is an efficient tool for extracting the high frequency signals in Earth rotation from the VLBI observations. Its application to the EOP determination by other space geodetic techniques is also possible. Here we perform analysis of the retrograde diurnal component of polar motion and of the low frequency component of dUT1 estimated by the VieVS CD software (Böhm et al., 2012). Results have been compared to those based on the celestial pole offsets and dUT1 series from the combined solutions IVS and IERS in order to check the consistency of the CD parametrization with the standard approach.

When considering the residual nutation signal in time domain, the VieVS CD series is found to be consistent with both the IVS and IERS combination series. The differences between series are larger for early data and decrease with time reaching very low level after 2005. The estimated corrections of the forced nutation terms based on the VieVS CD series are also consistent with those derived from the IVS and IERS series in a sense that the difference is not larger than the difference of results from the two combination series.

Comparison of the low frequency component of dUT1 shows a good agreement of the three curves at seasonal and subseasonal frequencies. The differences of the long periodic variation could be attributed to inadequate modeling. An excellent agreement is found for the parameters of the harmonic terms of the model, particularly between those from VieVS CD and IVS.

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