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COMPLEX DEMODULATION IN MONITORING EARTH ROTATION BY VLBI: TESTING THE ALGORITHM BY ANALYSIS OF LONG PERIODIC EOP COMPONENTS

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ABSTRACT.
The complex demodulation (CD) algorithm is an efficient tool for extracting the diurnal and subdiurnal components of Earth rotation from the routine VLBI observations (Brzeziński, 2012). This algorithm was implemented by Böhm et al (2012b) into a dedicated version of the VLBI analysis software VieVs. The authors processed around 3700 geodetic 24-hour observing sessions in 1984.0-2010.5 and estimated simultaneously the time series of the long period components as well as diurnal, semidiurnal, terdiurnal and quarterdiurnal components of polar motion (PM) and universal time UT1. This paper describes the tests of the CD algorithm by checking consistency of the low frequency components of PM and UT1 estimated by VieVS CD and those from the IERS and IVS combined solutions. Moreover, the retrograde diurnal component of PM demodulated from VLBI observations has been compared to the celestial pole offsets series included in the IERS and IVS solutions. We found for all three components a good agreement of the results based on the CD approach and those based on the standard parameterization recommended by the IERS Conventions (IERS, 2010) and applied by the IERS and IVS. We conclude that an application of the CD parameterization in VLBI data analysis does not change those components of EOP which are included in the standard adjustment, while enabling simultaneous estimation of the high frequency components from the routine VLBI observations. Moreover, we deem that the CD algorithm can also be implemented in analysis of other space geodetic observations, like GNSS or SLR, enabling retrieval of subdiurnal signals in EOP from the past data.

Keywords: Earth Orientation Parameters, Earth Rotation, Very Long Baseline Interferometry, Complex Demodulation.

1. INTRODUCTION

The complex demodulation (CD) technique is an alternative way for determination the Earth Orientation Parameters (EOP) from the routine VLBI observations. The CD allows to compute the long period components of polar motion (PM), universal time (UT1) and nutation, as well as the high frequency (diurnal, semidiurnal, ...) components of PM and UT1 (Brzeziński, 2012). The CD algorithm was implemented by Böhm et al. (2012b) into a dedicated version of the Vienna VLBI Software (VieVS). The authors processed around 3700 geodetic 24-h observing sessions in 1984.0-2010.5 and estimated the time series of the long period components as well as diurnal, semidiurnal, terdiurnal and quarterdiurnal components of PM and UT1. The long period nutation could be estimated either in standard way as time series of the celestial pole offsets, or as demodulated diurnal retrograde component of polar motion.

Böhm et al. (2012b) verified reliability of the high frequency components of the EOP demodulated by VieVS CD by estimating amplitudes and phases of harmonic components at tidal periods (diurnal/semidiurnal) and comparing them to the IERS Conventions 2010 model (IERS, 2010) and to the recent empirical solution from VLBI data derived by Artz et al. (2011). Further investigation of high frequency EOP signals demodulated by VieVS CD, including spectral analysis of irregular nontidal residua, was performed by Brzeziński and Böhm (2012).

One should bear in mind that the main advantage of the CD technique is a convenient representation of the high frequency non-harmonic signal components of the EOP induced by e.g. thermal tides in the atmosphere and the ocean. The spectral structure of thermal tides was investigated by Ray and Ponte (2003) who wrote "... the tides consist of sharp central peaks with modulating sidelines at integer multiples of 1 cycle/year, superimposed on a broad cusp of stochastic energy." This stochastic energy is manifested as quasi-periodic variability of the Atmospheric Angular Momentum (AAM) (e.g., Brzeziński et al., 2002) and, due to the atmospheric influence upon the ocean circulation, as similar variability of the nontidal Ocean Angular Momentum (OAM)(e.g., Brzeziński et al., 2004). The diurnal and subdiurnal variations of AAM and OAM contribute in turn to all EOP. The stochastic component of this variability, which is clearly seen in VLBI data (Böhm et al., 2012a), cannot be fully expressed by analytical models and needs regular monitoring. The largest term of this stochastic variability of the EOP is the Free Core Nutation (FCN) observed by VLBI since 1984. We believe that the FCN signal with variable amplitude between 0.1 and 0.5 mas and variable phase is mostly driven by the stochastic variability of diurnal atmospheric tides. Apart of the FCN, there are also diurnal/subdiurnal stochastic signals in PM and UT1 detected in VLBI observations, with the peak-to-peak size of up to 30 microarcseconds (Böhm et al., 2012b) which is only slightly below the current uncertainty level of VLBI EOP data. The removal of the harmonic model with tidal periods reduces the size of PM and UT1 variations to the level of 5 to 10 microarcseconds (Brzeziński and Böhm, 2012) which is still nonnegligible.

This paper is an extension of the earlier work by Brzeziński et al. (2015). The analysis focuses on the low frequency components of the 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 the EOP estimated with the use of CD parametrization are consistent with those obtained by the use of standard parametrization. Second, we would 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 analysis is done as follows. For each component of low frequency EOP (PM, nutation and UT1) we find the best least-squares fit of the polynomial-sinusoidal model representing the known features of this component, and then remove this model. The same procedure is applied to the two combined EOP solutions, the IERS C04 series and the International VLBI Service for Geodesy and Astrometry (IVS) series, which are used here as external reference data sets. The parameters of the model derived from the VieVS CD and the two reference series are compared to each other. In addition, the residual series are compared in time domain.

We start with a brief description of the standard parametrization of Earth rotation and that used in the CD procedure (Sec. 2). In Sec. 3 we describe the reference EOP series (Sec. 3.1) and then show results for PM (Sec. 3.2), nutation (Sec. 3.3) and UT1 (Sec. 3.4). Finally, Sec. 4 summarizes the results of comparison and gives some conclusions.

2. PARAMETRIZATION OF EARTH ROTATION

2.1 Standard parametrization

The set of EOP consists of five parameters which describe the instantaneous orientation of the Earth in inertial space. These are

- $x, -y$ – the components of the Celestial Intermediate Pole (CIP) in the International Terrestrial Reference System (ITRS). Time variation of the vector $[x(t), -y(t)]$ is usually called *polar motion*.
- dX, dY – the so-called celestial pole offsets, which are the residual components of the CIP in the Geocentric Celestial Reference System (GCRS) with respect to their values computed using the conventional precession-nutation model. The currently recommended precession-nutation model is designated IAU 2006/2000.
- dUT1=UT1−UTC – the difference of UT1 and the uniform time scale UTC (Universal Time Coordinated), which expresses variation of the angle of the Earth's rotation around the CIP axis.

By introducing the CIP, the motion of the terrestrial pole in space, that is the motion of the z axis of the ITRS in the GCRS, has been split up into a celestial part expressed by dX, dY and a terrestrial part expressed by $x, -y$. Additional constraint was necessary to make this decomposition unambiguous. This constraint, defined by the IAU 2000 Resolution B1.7, can be expressed as follows:

- time variation of the precession-nutation parameters $dX(t), dY(t)$ is limited to the low frequencies between -0.5 cycles per sidereal day (cpsd) and $+0.5$ cpsd;
- polar motion of the CIP, expressed by $x(t), -y(t)$, includes all the terms outside the retrograde diurnal band, i.e. with frequencies lower than -1.5 cpsd or greater than -0.5 cpsd.

Further details about parametrization of Earth rotation and the use of EOP in the transformation matrix between the ITRS and GCRS can be found in Chapter 5 of the IERS Conventions 2010 (IERS, 2010). Here we make only the following two remarks:

1. by definition, only PM and UT1 can include subdiurnal variations;

2. with the standard parametrization, the high frequency irregular signals can only be represented by their subdiurnal sampling.

The last condition can hardly be accomplished with the standard VLBI observations which are usually limited to two 24-hour sessions per week.

2.2 Complex demodulation

The following alternative parametrization of PM and UT1 has been applied by Böhm et al. (2012b) for complex demodulation (Brzeziński, 2012) of VLBI data

$$\left[\begin{array}{c} x(t) \\ y(t) \end{array}\right] = \sum_{\ell=-N}^{N} \left\{ \left[\begin{array}{c} x_\ell(t) \\ y_\ell(t) \end{array}\right] \cos(\ell\phi) + \left[\begin{array}{c} y_\ell(t) \\ -x_\ell(t) \end{array}\right] \sin(\ell\phi) \right\}, \tag{1}$$

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

where ϕ =GMST+π, GMST stands for the Greenwich Mean Sidereal Time and $x_\ell(t)$, $y_\ell(t)$, $u_\ell^s(t)$, $u_\ell^c(t)$ 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 $t = 0$. For further details about the CD parametrization, its mathematical properties and practical aspects see the paper (Brzeziński, 2012). Here we make only the following remarks:

1. the terms $\ell = 0$ of the expansion (1)–(2) are the long periodic components of PM and UT1 estimated in standard adjustment;
2. the terms $\ell = \pm1, \pm2, \pm3, \pm4, \ldots$, express quasi diurnal, semidiurnal, terdiurnal, quarterdiurnal, ..., variations of PM (retrograde/prograde for $-/+$) and in UT1;
3. 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.

3. DATA ANALYSIS AND RESULTS

3.1 Input data sets

Böhm et al. (2012b) 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 use PM estimated in standard adjustment $[x_0(t), -y_0(t)]$, the diurnal retrograde component of PM $[x_{-1}(t), -y_{-1}(t)]$ representing nutation, and the low frequency of dUT1, expressed by $u_0^c(t)$. As an external reference we use the PM $[x(t), y(t)]$, the nutation offsets $[dX(t), dY(t)]$ and $dUT1(t)$ series from the following two combined solutions:

– IVS series bases on the VLBI technique only. It is available for the over thirty-year period (about 1980 - now) with irregular sampling and is posted on the IVS web page (http://ivscc.gsfc.nasa.gov).

– IERS C04 series computed on the basics of combination of the data from all space geodetic techniques. It covers the period from 1962 up to now (see IERS, 2013) with 1-day sampling interval (www.iers.org).

In this investigation all the series (CD, IVS, IERS) were analysed over the common time interval 1984.0-2010.5 and by applying the same procedure.

3.2 Polar motion

The observed PM is mostly driven by the angular momentum exchanges between the solid Earth and the external geophysical fluid layers including the atmosphere, the ocean and the land hydrosphere. Only a small part of PM, below the level of 1 milliarcsecond (mas), is a well predictable effect associated with tidal gravitation, which is expressed by conventional models (IERS, 2010).

The largest component of PM is a free Chandler wobble (CW), a quasi-circular motion of the pole in prograde (counterclockwise) direction. During over 110 years of observation, the mean period of CW was 433 days and the mean amplitude about 170 mas (Brzeziński et al., 2012). The Chandler wobble can be adequately modeled as a randomly excited free oscillation with damping. Over the time intervals of several years this free motion can be approximated by a simple sinusoidal model. However, we should bear in mind that both the instantaneous frequency and amplitude estimated in such model can be different than the estimates based on multi-decadal observation series.

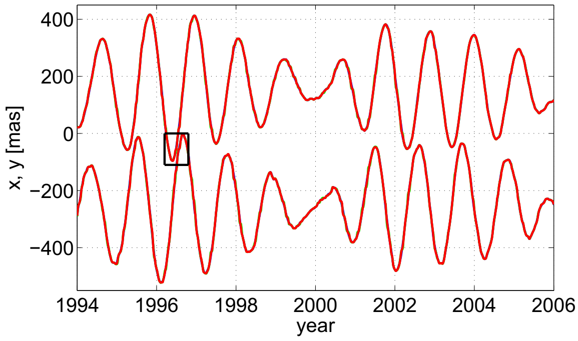
Important components of PM are the seasonal wobbles, with the atmospheric pressure variation being the main excitation mechanism. The largest seasonal term is a weakly elliptical annual motion in prograde direction with amplitude of about 90 mas. There are also higher harmonics of the annual wobble, the semiannual and terannual terms with much smaller amplitudes, below 5 mas.

PM contains also a decadal variations (known as Markovitz wobble) having amplitudes of about 30 mas, as well as a linear trend with mean rate of about 3.5 mas/year and a direction 79°W longitude (Gross, 2007), which is caused by a combination of glacial isostatic adjustment, changes in glacier and ice sheet mass and tectonic processes.

In analysis of PM data we applied the model accounting for most of the components mentioned above. This model consists of a linear trend accounting for the decadal drift, and a sum of sinusoids representing periodical components: Chandler – period 433.3 days, annual – 365.25 days, semiannual – 182.625 days, and terannual – 121.75 days. We applied this model to both components of PM allowing in this way an elliptical shape of the periodic terms. Parameters of the model have been estimated by the weighted least-squares fit applied to the PM series. Then we computed for each periodical term parameters of the retrograde and prograde circular terms.

In Figure 1 (left) we show the original PM time series after a weak smoothing. The differences between three curves are below the line width, therefore we shown also their zoom (right). The residuals (not shown here), obtained by removing the estimated components of polynomial-sinusoidal model from original PM series, also do not exhibit any significant difference between the three series.

Parameters of particular components are presented in Figure 2 and coefficients of linear trend are given in Table 1. It could be seen that there is a good agreement between CD, IVS and IERS PM series especially in main prograde components (in CW and annual oscillation) and the uncertainty of the estimated parameters are relatively small. There is a lower consistency of the parameters of the semiannual and terannual terms, which could



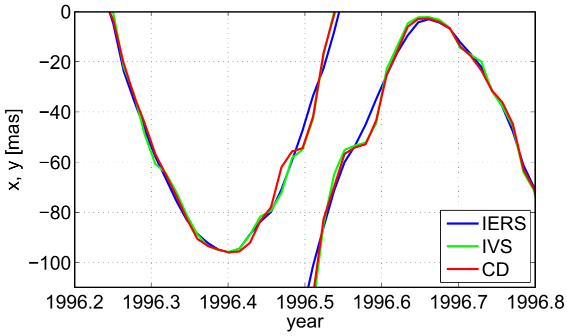


Fig. 1. x and y components of PM after applying a weak smoothing (left) and their zoom (right). The VieVS CD series is compared to the combined solutions IVS and IERS C04. For better visibility only the data over the 12-year period between 1994 and 2006 are shown.

be caused by the use of different space geodetic techniques: the PM series of IVS and CD are based only on VLBI data while the IERS series is constrained mainly by GNSS observations. Nevertheless the differences of results based on CD and the reference IVS and IERS series are not greater than the difference between results derived from the two reference series.

Table 1. Parameters of the linear trend $a_0 + a_1 t$ in the observed PM, estimated by the best least-squares fit. Units: a_0-mas, a_1-mas/yr.

	CD VieVS			IVS			IERS		
a_0^x	45.75	±	0.76	44.84	±	0.89	45.37	±	0.52
a_1^x	2.74	±	0.12	3.38	±	0.15	3.41	±	0.07
a_0^y	-343.18	±	0.79	-342.17	±	0.89	-338.51	±	0.50
a_1^y	-1.19	±	0.12	-0.97	±	0.15	-1.49	±	0.07

3.3 Nutation

Precession-nutation is a large variation almost entirely driven by the lunisolar and planetary torques upon the equatorial bulges of rotating Earth. This effect is expressed by the conventional model adopted by the IAU and IUGG resolutions, the IAU 2006/2000 precession-nutation model. There is also a small geophysical component associated with the atmospheric and oceanic excitations with nearly diurnal Earth-referred periods. It includes the FCN which is a retrograde motion in the GCRS with space-referred period of about 430 days. Its amplitude and phase vary in time. The maximum values of the amplitude, up to 0.5 mas, occur before 1990; its mean value over 1984.0-2011.1 is found to be 0.17 mas (Brzeziński et al., 2014). As a randomly excited free signal, the FCN cannot be perfectly modeled, therefore it is not a part of the conventional precession-nutation model.

The observed time series of celestial pole offsets $[dX(t), dY(t)]$ expresses the FCN signal, but also imperfections of the conventional model. Hence, we modeled the celestial pole offsets series by implementing a linear trend as correction to precession model, and a sum of sinusoids representing main periodical nutation components with periods of 18.6, 9.3, 1 and 0.5 years, and 13.7 days. As there is a strong interference between the FCN

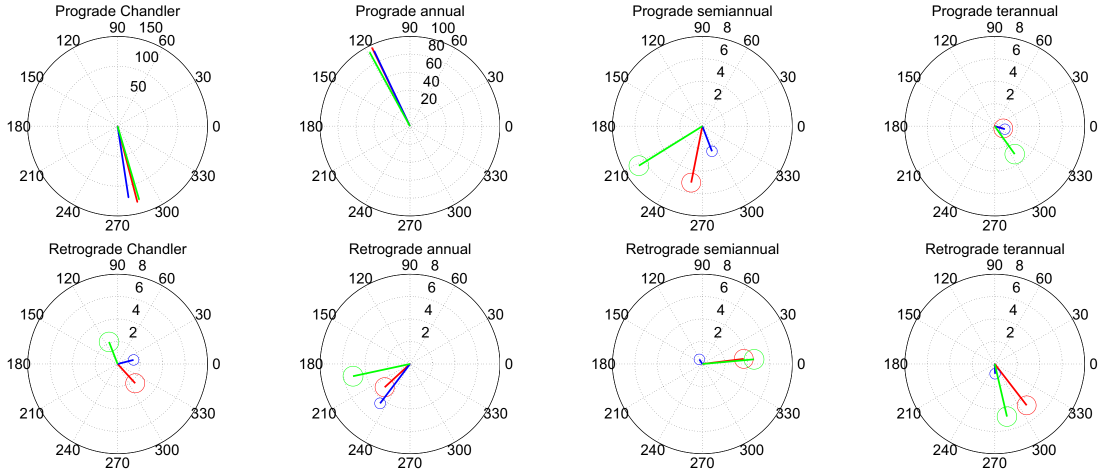


Fig. 2. Estimated parameters of the periodic components of PM with standard deviations of estimates shown as circles. Units: mas, the input time series: VieVS CD in red, IVS in green, IERS in blue, period of analysis: 1984.0-2010.5.

signal and the retrograde annual nutation, we removed the empirical FCN model recommended by the IERS (2010). Then in all celestial pole offsets time series (Figure 3) the coefficients of polynomial-sinusoidal model were estimated by the weighted least-squares fit. The model was removed from the input time series while the empirical FCN model was added back to it. It can be seen that the early nutation data is noisy, therefore we recommend to remove data prior 1990 when the data analysis does not include weighting. Also after 1990 the difference between three series 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.

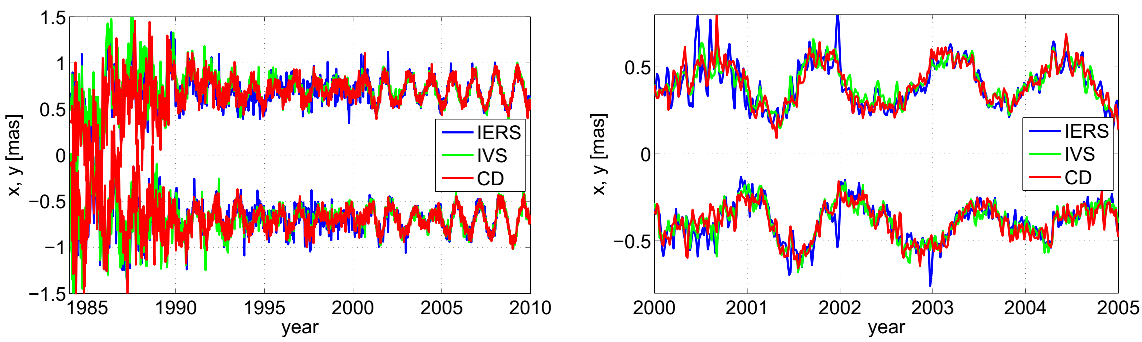


Fig. 3. Nutation component estimated by VieVS CD as the retrograde diurnal component of PM after removal of the empirical corrections to the conventional precession-nutation model and a weak smoothing (left) and its zoom (right). The VieVS CD series is compared to the combined solutions IVS and IERS C04.

The estimated corrections of the forced nutation terms, shown in Figure 4, based on the VieVS CD series are also consistent with those derived from the IVS and IERS series. The largest corrections are to the principal nutation term 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 20 μas; 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. It aslo should be indicated here, that the uncertainties presented in Figure 4 are formal errors which could be too optimistic. As suggested by Herring et al. (2002), those errors should be scaled by the factor 2 or 3 to be more realistic. The coefficients of the polynomial are presented in Table 2. It shows that the differences between coefficients are bigger than their uncertainties, what could be caused by the strong dependence in the weighting algorithm on the later data having smaller uncertainties.

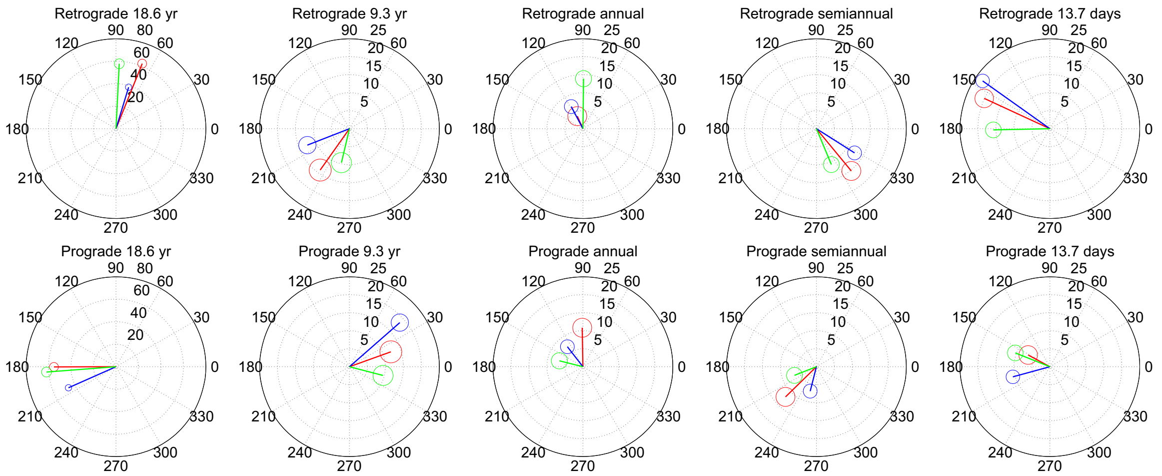


Fig. 4. Estimated corrections to the selected terms of the conventional precession-nutation model IAU 2006/2000 with standard deviations shown as circles. Units:μas, input time series: VieVS CD in red, IVS in green, IERS in blue, period of analysis: 1984.0-2010.5.

Table 2. Parameters of the linear trend $a_0 + a_1 t$ in the time series of the celestial pole offsets, estimated by the best least-squares fit. Units: a_0-μas, a_1-μas/yr.

	CD VieVS			IVS			IERS		
dX: a_0	31.72	±	2.32	42.23	±	2.68	35.23	±	1.95
dX: a_1	-0.10	±	0.64	-3.49	±	0.90	0.27	±	0.29
dY: a_0	-87.63	±	2.44	-94.23	±	2.70	-84.99	±	2.05
dY: a_1	5.71	±	0.68	3.65	±	0.91	-0.68	±	0.30

3.4 Low frequency component of UT1

UT1 is a linear function of the Earth Rotation Angle (ERA) reckoned around the CIP axis; for details see Sec. 5.5.3 of the IERS Conventions 2010 (IERS, 2010). It is expressed as the difference UT1-UTC measured directly by VLBI technique with accuracy of tens of microseconds.

Variations in UT1 and its time derivative (Length of Day (LoD) measured by the satellite techniques), extend on all time scales and have a wide range of causes; for review see e.g. (Gross, 2007). The secular trend in dUT1 is caused by tidal dissipation in the oceans with additional recent contribution from the glacial isostatic adjustment. Superimposed on the trend is a large decadal variation driven mostly by the core-mantle interactions. An interesting quasi-periodic component is an 11 year variation which may be correlated with the sunspot cycle (Chapanov et al., 2008). Observed seasonal variations in dUT1 (annual and semiannual) are highly correlated with changes in the angular momentum of the zonal winds (e.g. Lambeck, 1980; Höpfner, 1999). Variations on interannual time scales are associated with anomalous wind patterns during El Niño-Southern Oscillation (ENSO) and the Quasi-Biennial Oscillation. Finally, there are periodic changes due to the zonal tides in the solid Earth and oceans with periods between 1 week and 18.6 years, as well as diurnal and semidiurnal variations due to the ocean tides. The tidal effects in UT1/LoD are described by the models recommended by the IERS Conventions 2010 (IERS, 2010).

We started analysis of the dUT1 data from adding back the leap seconds and removing the model of zonal tides variation according to Chapter 8 of the IERS Conventions (IERS, 2010). The resulting time series are compared in Figure 5 (top left). 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. Then we estimated for each series by the weighted least-squares fit the model consisting of 4th degree polynomial and a sum of sinusoids with seasonal (annual, semiannual and terannual) periods. In order to improve the fit, we extended the model by adding two sinusoidal components with periods 11.2 years and 2 years.

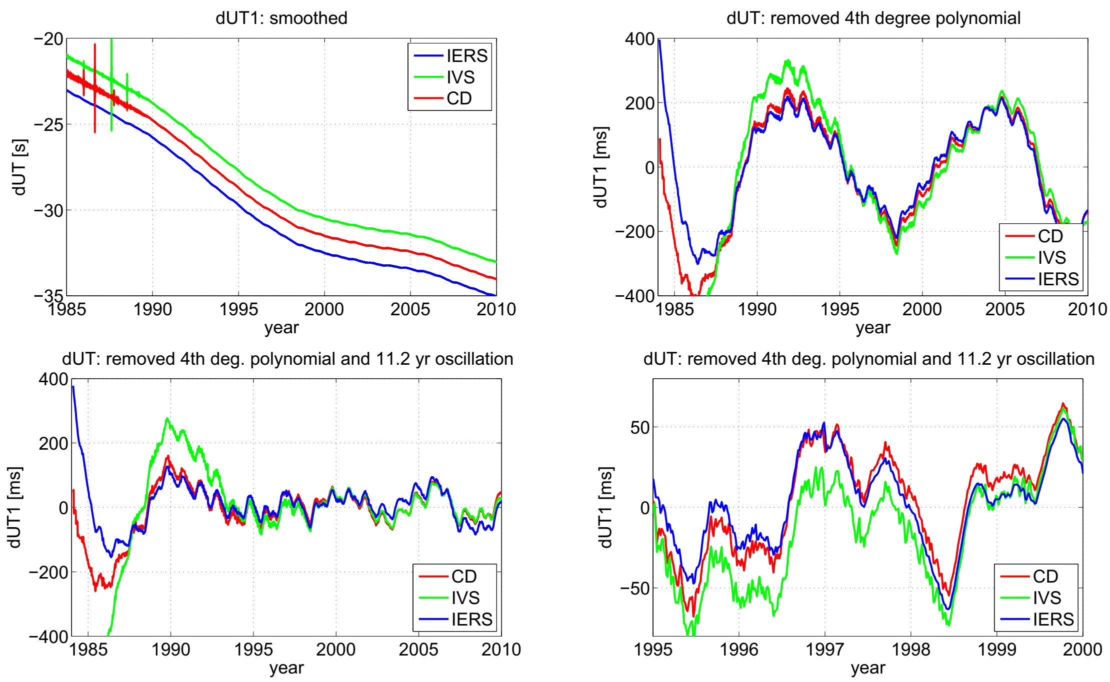


Fig. 5. Low frequency component of dUT1: original series with the error bars (the error bars are small and not visible here exept for those for CD and IVS series in early data) after adding back the leap seconds and removal of the conventional tidal model (top left), after additional removal of the 4th order polynomial (top right) and of the 11.2-year sinusoid (bottom left), and its zoom (bottom right).

In Figure 6 it can be seen that there is a good agreement between three series at seasonal and subseasonal frequencies, which are consistent in terms of the estimated phase and amplitude. Again, the differences between CD and the reference series are not greater than between the IERS and IVS time series. The difference between the three detrended

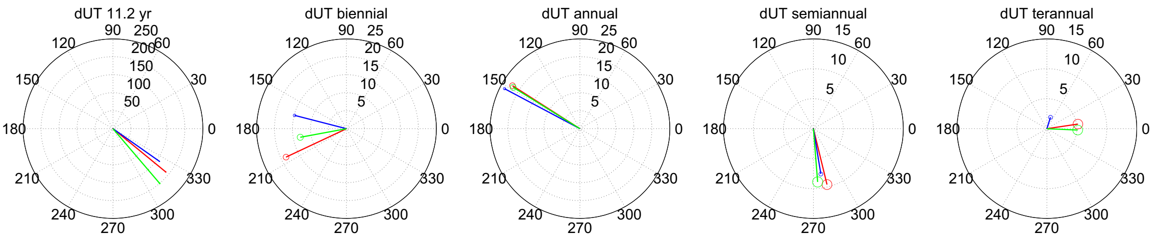


Fig. 6. Estimated parameters of the periodic components of dUT1 with standard deviations of estimates shown as circles. Units: ms, input time series: VieVS CD in red, IVS in green, IERS in blue, period of analysis: 1984.0-2010.5.

dUT1 series (Figure 5, top right) is clearly in the long periodic behaviour. An additional subtraction of the 11.2-year oscillation (Figure 5, bottom left) removes most of the decadal variability, nevertheless there are still large discrepancies between the series in the early part of data, prior to 1995. A closer look at the series between 1995 and 2000 (Figure 5, bottom right) clearly shows that the differences are due to the decadal or interannual variability.

We can see the following reasons for the differences of dUT1 series at long periods:

1) The model applied can be still incomplete. In particular, the 11.2-year term may be not adequate representation for the decadal variation.

2) The weighting of data by formal uncertainties causes that the estimates depend mostly on recent, considerably more accurate data that cannot properly express the difference between various long periodic components.

The problem with estimation of the long periodic variability is clearly seen from the error correlation matrix shown in Figure 7 (correlation matrices for IVS and IERS series are not shown because are very similar to that of CD). The correlation coefficients between different components of polynomial (listed in Table 3), as well as between those of the polynomial and the 11.2-year oscillation are quite large.

Despite of the problem with modeling the long periodic variability, the main conclusion of the section remains valid: the differences between CD and the reference series IVS and IERS are not greater then those between the two reference series.

Table 3. Parameters of the polynomial trend $a_0 + a_1t + a_2t^2 + a_3t^3 + a_4t^4$ in the observed dUT1 series, estimated by the least-squares fit. Units: a_0-ms, a_1-ms/yr, a_2-ms/yr^2, a_3-ms/yr^3, a_4-ms/yr^5.

	CD VieVS			IVS			IERS		
a_0	-31422	±	1.32	-31390	±	1.87	-31445	±	0.61
a_1	-363.96	±	0.28	-364.75	±	0.42	-363.18	±	0.14
$a_2 * 10^4$	870	±	2.47	792	±	4.13	908	±	1.16
$a_3 * 10^8$	-641	±	3.72	-590	±	6.17	-655	±	1.83
$a_4 * 10^{11}$	-238	±	1.64	-192	±	2.69	-261	±	0.73

polynomial coefficients	0	1,00	0,26	0,79	0,39	0,68	0,46	0,17	0,11	0,08	0,10	0,01	0,07	0,04	0,03	0,08
	1	0,26	1,00	0,21	0,85	0,21	0,41	0,39	0,08	0,02	0,10	0,08	0,12	0,01	0,00	0,06
	2	0,79	0,21	1,00	0,47	0,96	0,74	0,11	0,10	0,11	0,03	0,05	0,01	0,06	0,06	0,10
	3	0,39	0,85	0,47	1,00	0,41	0,58	0,42	0,09	0,08	0,08	0,09	0,07	0,01	0,00	0,08
	4	0,68	0,21	0,96	0,41	1,00	0,75	0,04	0,10	0,11	0,03	0,05	0,01	0,05	0,05	0,10
11.2 year	s	0,46	0,41	0,74	0,58	0,75	1,00	0,09	0,11	0,11	0,04	0,01	0,01	0,02	0,01	0,16
	c	0,17	0,39	0,11	0,42	0,04	0,09	1,00	0,01	0,02	0,07	0,13	0,01	0,02	0,04	0,11
biennial	s	0,11	0,08	0,10	0,09	0,10	0,11	0,01	1,00	0,08	0,05	0,06	0,09	0,15	0,06	0,08
	c	0,08	0,02	0,11	0,08	0,11	0,11	0,02	0,08	1,00	0,03	0,06	0,07	0,07	0,04	0,02
annual	s	0,10	0,10	0,03	0,08	0,03	0,04	0,01	0,01	0,02	1,00	0,04	0,16	0,01	0,12	0,00
	c	0,01	0,08	0,05	0,09	0,05	0,07	0,13	0,01	0,02	0,04	1,00	0,07	0,03	0,10	0,09
semi annual	s	0,07	0,12	0,01	0,07	0,01	0,05	0,06	0,09	0,15	0,16	0,07	1,00	0,05	0,05	0,03
	c	0,04	0,01	0,06	0,01	0,05	0,03	0,06	0,07	0,07	0,01	0,03	0,05	1,00	0,04	0,14
ter annual	s	0,03	0,00	0,06	0,00	0,05	0,00	0,00	0,00	0,00	0,12	0,10	0,05	0,04	1,00	0,01
	c	0,08	0,06	0,10	0,08	0,10	0,00	0,00	0,00	0,00	0,00	0,09	0,03	0,14	0,01	1,00

Fig. 7. Correlation matrix between the parameters of main components of sinusoidal-polynomial model in the observed CD dUT1 time series, estimated by the weighted least-squares fit.

5. SUMMARY AND CONCLUSIONS

The CD 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 performed analysis of the low frequency component of PM and dUT1, and of the retrograde diurnal component of PM estimated by the VieVS CD software by Böhm et al. (2012b). For each component we estimated parameters of the polynomial-sinusoidal model representing the known physical terms, then removed the model and analyzed the residual series in time domain. Results were compared to those based on the PM, the dUT1 and the celestial pole offsets series from the IVS and IERS combined solutions. Our main purpose was to check the consistency of the CD parametrization with the standard approach, including the equivalence of the diurnal retrograde component of PM demodulated by the VieVS CD and the time series of the celestial pole offsets included in the standard adjustment.

In case of the low frequency PM component we found a good consistency between the VieVS CD, IVS and IERS time series, especially for main prograde periodical components, the CW and the annual oscillation. This consistency is reflected in small differences between coefficients of the polynomial and parameters of the periodic components as well as in the residuals having the same order for all three series.

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 series at seasonal and subseasonal frequencies. The differences of the long periodic (interannual and decadal) variation could be attributed to inadequate modelling. An excellent agreement is found for the parameters of the harmonic terms of the model, particularly between those from VieVS CD and IVS.

An application of the CD parametrization in VLBI data analysis does not change those components of EOP which are included in the standard adjustment, while enabling estimation of the high frequency componets (diurnal and semidiurnal in dUT1, prograde diurnal and retrograde/prograde semidiurnal in PM) from the routine VLBI observations performed since 1984. Those components are represented by time series of the length exceeding 30 years that yields high frequency resolution, enabling e.g. direct estimation of the tidal terms separated by 1 cycle in 18.6 years; see (Böhm et al., 2012b) for details. Moreover, we believe that the CD parametrization can be implemented also in analysis of other space geodetic observations, like GNSS or SLR, enabling retrival of subdiurnal signals in EOP from the past data.

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