On application of the complex demodulation procedure for monitoring Earth rotation: comparison with the standard approach using the long periodic EOP components estimated from VLBI data analysis by the VieVS CD software

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Introduction

In the recent works (Böhm et al., J. Geodynamics, 62 (2012) 56–68; Brzeziński and Böhm, Proc. Journees 2011, 132–135) 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 discuss advantages of this approach over the conventional procedures applied for the EOP estimation. We also show results of an analysis of the long periodic time series dX, dY and dUT1 derived by the complex demodulation algorithm implemented in the Vienna VLBI Software (VieVS CD). Results are compared to those based on the EOP series based on the combined EOP solutions provided by the IVS and the IERS.

Paper contents

- Brief description of the CD algorithm
- Data analysis
  - VLBI parameter estimation using the VieVS CD algorithm
  - analysis of the nutation and dUT1 series
- Conclusions

Complex demodulation method

Complex demodulation (CD), general description

- a method of extracting the high frequency signals from time series (Bingham et al., 1967);
- the output 'image' of the high frequency signal is a low frequency, complex valued time series which is easy to handle in analysis;
- the procedure preserves power spectrum of the original series while moving it only along the frequency axis in such a way that the demodulation frequency becomes zero.

Detailed description of the CD method and its application for modeling Earth rotation can be found in (Brzeziński, J. Geodynamics, 62(2012) pp. 74-82). A successful application of the CD technique for VLBI estimation of the EOPs was demonstrated by Böhm et al. (2012).

Parametrization of polar motion (PM) and universal time (UT) for complex demodulation

$$\begin{bmatrix} x(t) \\ y(t) \end{bmatrix} = \sum_{\ell=-N}^{N} \left\{ \begin{bmatrix} x_\ell(t) \\ y_\ell(t) \end{bmatrix} \cos(\ell\Phi) + \begin{bmatrix} y_\ell(t) \\ -x_\ell(t) \end{bmatrix} \sin(\ell\Phi) \right\}, \quad \Delta\mathrm{UT1}(t) = \sum_{\ell=0}^{N} \left[u_\ell^c(t)\cos(\ell\Phi) + u_\ell^s(t)\sin(\ell\Phi) \right], \quad (1)$$

where $\Phi =$GMST$+\pi$, GMST stands for Greenwich Mean Sidereal Time and $x_\ell(t)$, $y_\ell(t)$, $u_\ell^s(t)$, $u_\ell^c(t)$ are assumed to not vary significantly in time. When estimated from the VLBI data these time dependent amplitudes are treated as constant during one 24-hr session.

Complex demodulation method

Remarks

- the terms $\ell = 0$ of the expansion (1) are the long periodic components of PM and UT1 which are estimated in the standard adjustment;
- the term $\ell = -1$ of polar motion is an equivalent representation of the celestial pole offsets, i.e. $[x_{-1}, -y_{-1}] = [\delta X, \delta Y]$ in the first order approximation;
- the terms $\ell = \pm 1, \pm 2, \ldots$ express quasi diurnal, semidiurnal, ..., variations in PM (retrograde/prograde for $-/+$) and in UT1.

Data analysis

- apply expansion (1) with $N = 4$ in VLBI data analysis by the modified VieVS software (Böhm et al., 2014);
- perform analysis of the nutation (PM with $\ell = -1$) and low frequency dUT1 ($\ell = 0$) series
  - the analysis has been done over the full period of data 1984.0–2010.5 as well as over the reduced period 1990.0–2010.5.
- perform similar analysis of the dX, dY and dUT1 series from the combined solutions IVS 13q2X, IERS C04, and compare results to those derived from the VieVS CD series.

Results: nutation

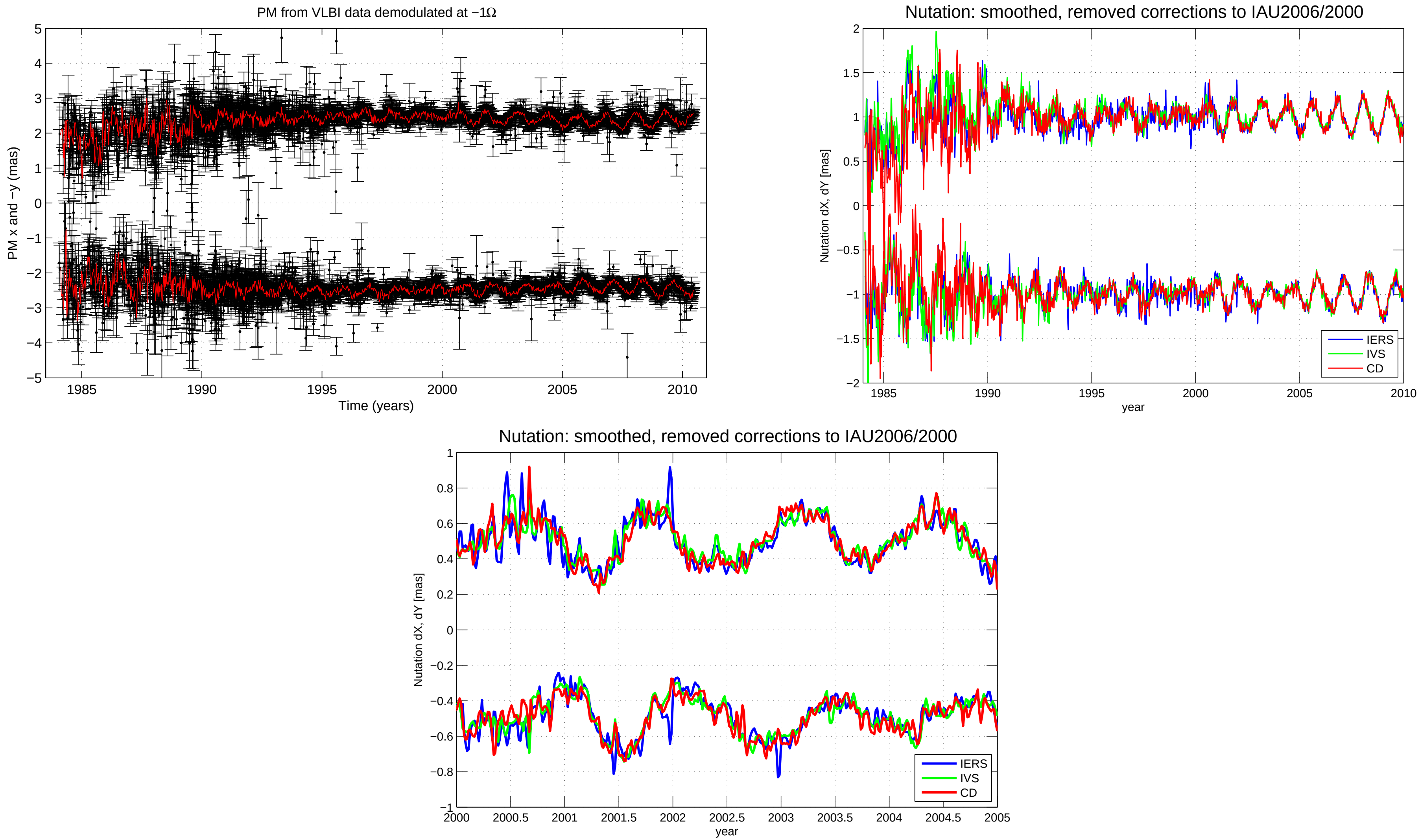

Figure 1: Nutation component (PM with $\ell = -1$) estimated by VieVS CD, original series with error bars (top left). After applying empirical corrections to the conventional p-n model and the weak smoothing, the VieVS CD series is compared to the IVS and IERS celestial pole offsets (top right - overall view, and bottom - zoom).

Results: nutation

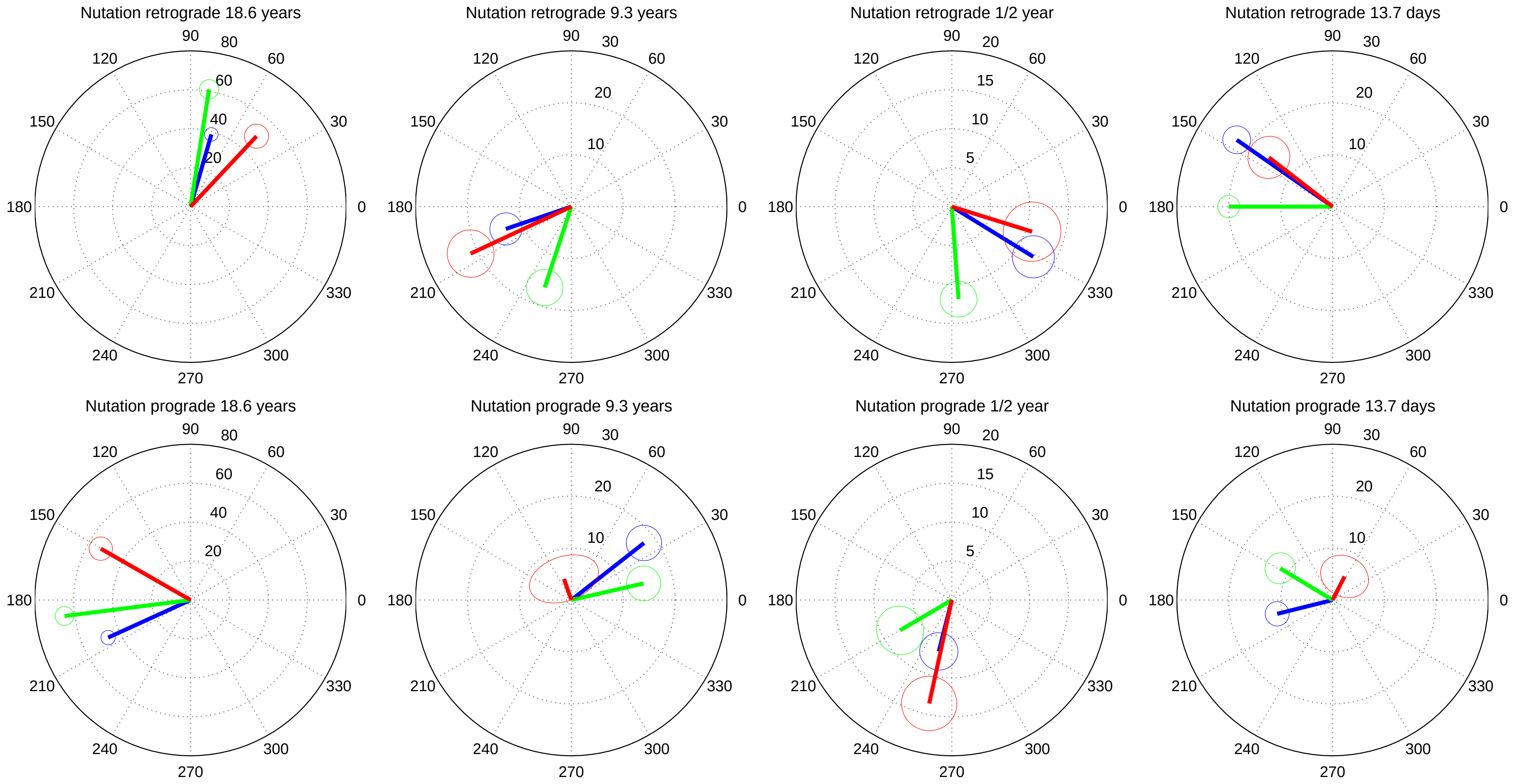

Figure 2: Estimated corrections to the selected nutation terms with standard deviations of the amplitudes shown as circles. Reference precession/nutation model: IAU 2000/2006, units: microarcseconds, input time series: CD VieVS (red), IVS 13q2X (green) and IERS C04 (blue), period of analysis: 1984.0–2010.5.

Results: low frequency dUT1

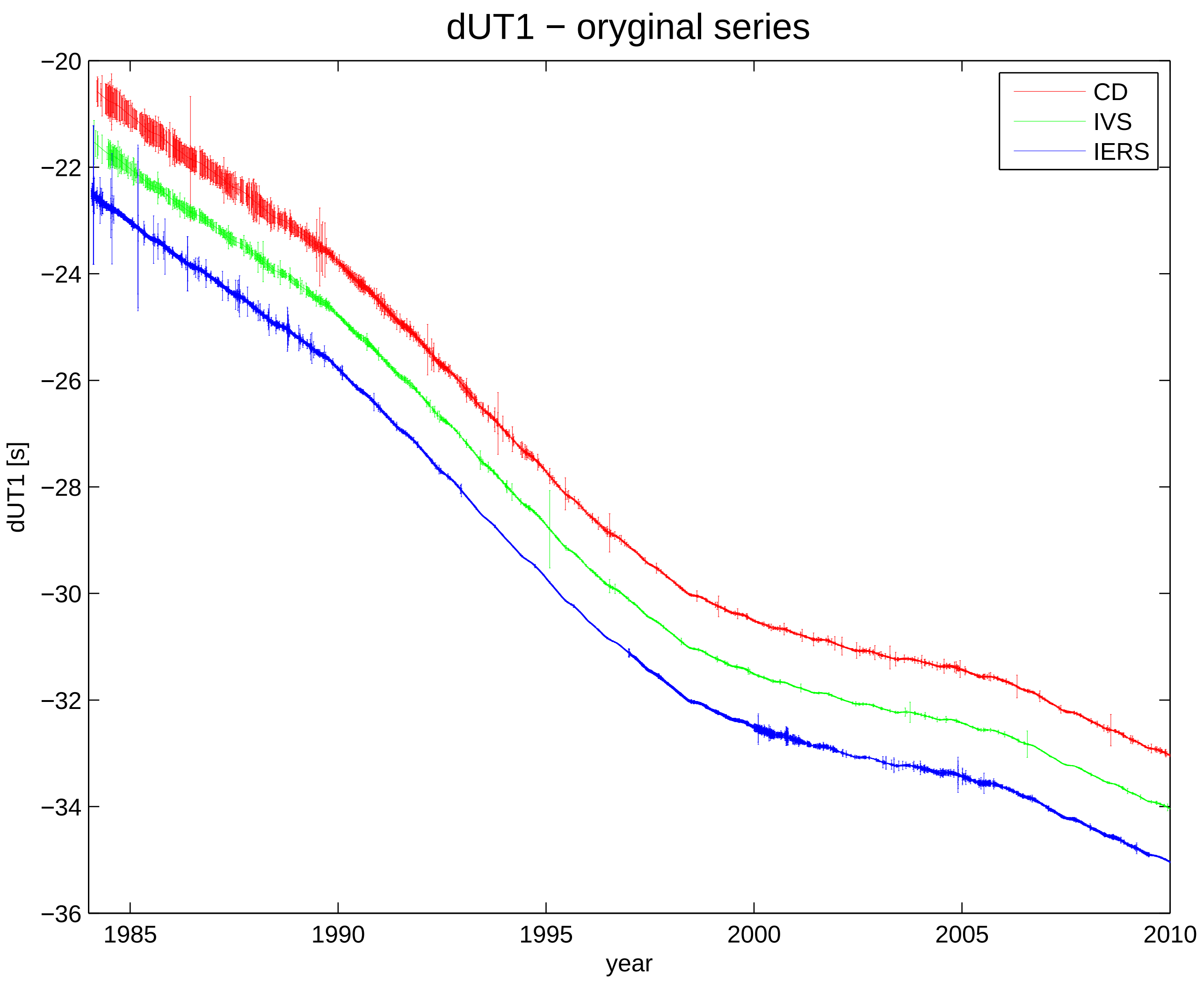

Figure 3: Low frequency component of dUT1 estimated by VieVS CD (dUT1 with $\ell = 0$), compared to the IVS and IERS series. Shown are the original series with error bars.

Results: low frequency dUT1

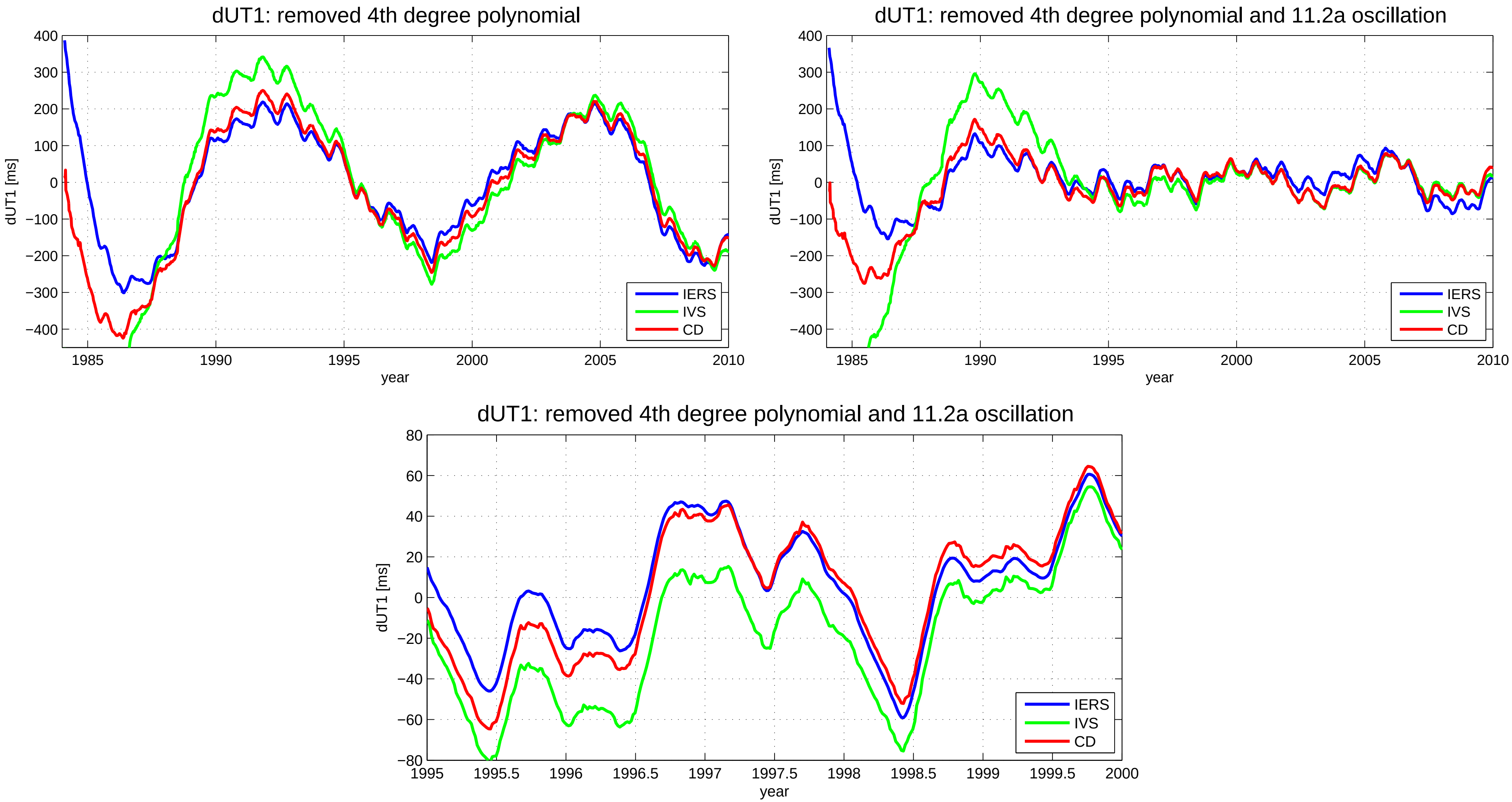

Figure 4: Low frequency component of dUT1 after removal of the 4th order polynomial (top left), 4th order polynomial and the 11yr sinusoid (top right) and its zoom (bottom).

CD	polynomial coefficients					11.2 year		biennial		annual		semiannual		terannual	
polynomial coefficients	1,000	0,261	0,791	0,385	0,680	0,458	0,165	0,110	0,082	0,102	0,014	0,066	0,044	0,029	0,080
	0,261	1,000	0,210	0,851	0,214	0,406	0,385	0,082	0,020	0,099	0,077	0,122	0,010	0,001	0,063
	0,791	0,210	1,000	0,474	0,956	0,740	0,107	0,101	0,111	0,029	0,046	0,009	0,064	0,055	0,095
	0,385	0,851	0,474	1,000	0,407	0,582	0,416	0,087	0,078	0,084	0,091	0,068	0,012	0,001	0,082
	0,680	0,214	0,956	0,407	1,000	0,754	0,035	0,099	0,110	0,029	0,053	0,013	0,054	0,048	0,097
11.2 year	0,458	0,406	0,740	0,582	0,754	1,000	0,086	0,105	0,105	0,036	0,012	0,011	0,024	0,012	0,157
	0,165	0,385	0,107	0,416	0,035	0,086	1,000	0,006	0,022	0,070	0,131	0,006	0,015	0,039	0,106
biennial	0,110	0,082	0,101	0,087	0,099	0,105	0,006	1,000	0,080	0,054	0,060	0,090	0,152	0,056	0,083
	0,082	0,020	0,111	0,078	0,110	0,105	0,022	0,080	1,000	0,027	0,058	0,071	0,069	0,037	0,021
annual	0,102	0,099	0,029	0,084	0,029	0,036	0,070	0,070	0,054	1,000	0,039	0,157	0,011	0,122	0,004
	0,014	0,077	0,046	0,091	0,053	0,012	0,131	0,131	0,060	0,039	1,000	0,069	0,030	0,096	0,085
semiannual	0,066	0,122	0,009	0,068	0,013	0,011	0,006	0,006	0,090	0,157	0,069	1,000	0,053	0,053	0,031
	0,044	0,010	0,064	0,012	0,054	0,024	0,015	0,015	0,152	0,011	0,030	0,053	1,000	0,040	0,142
terannual	0,029	0,001	0,055	0,001	0,048	0,012	0,039	0,039	0,056	0,122	0,096	0,053	0,040	1,000	0,013
	0,080	0,063	0,095	0,082	0,097	0,157	0,106	0,106	0,083	0,004	0,085	0,031	0,142	0,013	1,000

Figure 5: Error correlation matrix of the estimated parameters of the polynomial-sinusoidal model.

Results: low frequency dUT1

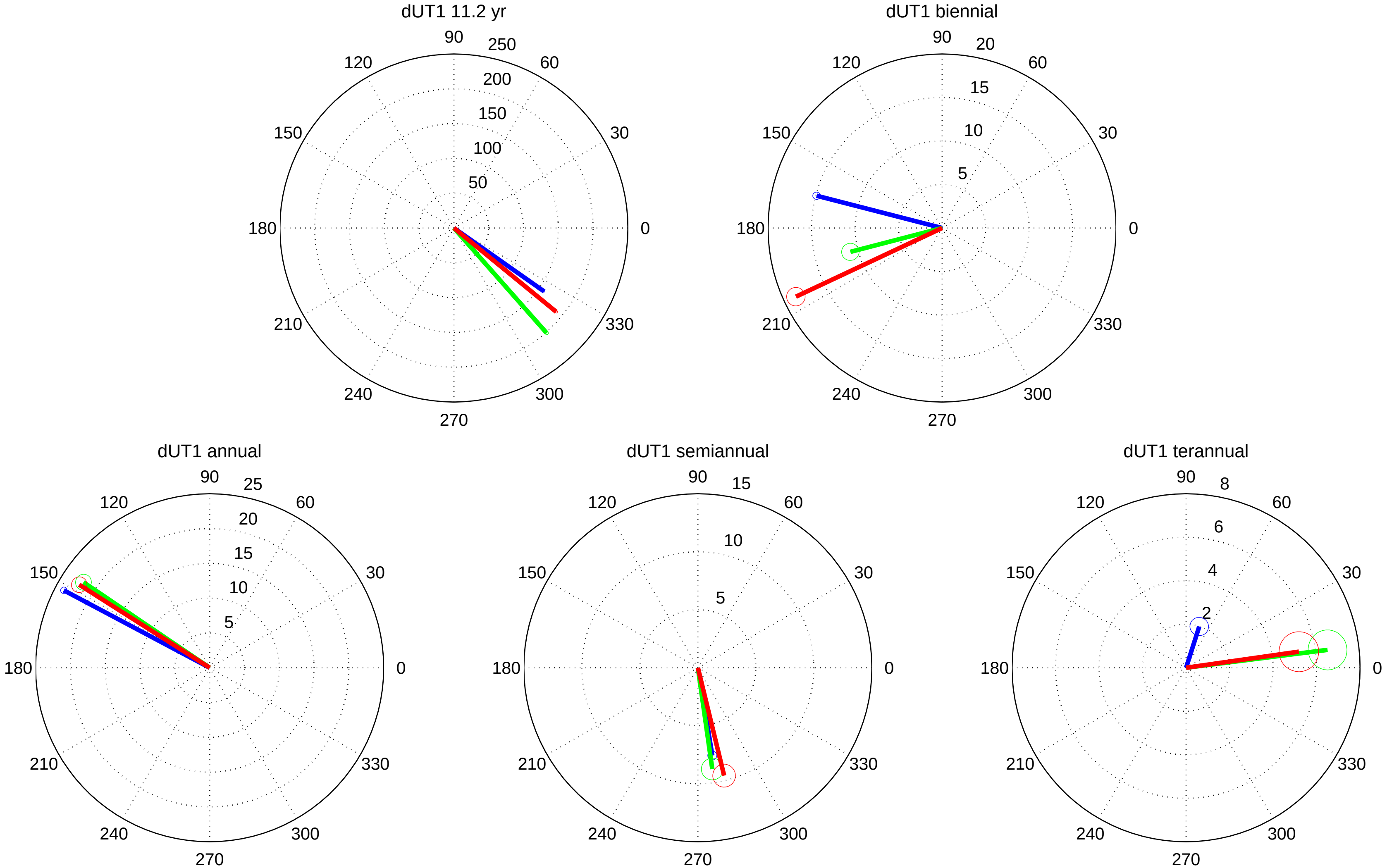

Figure 6: Estimated parameters of the periodical components of dUT1 with standard deviations of the amplitudes shown as circles. Units: milliseconds, input time series: CD VieVS (red), IVS 13q2X (green) and IERS C04 (blue), period of analysis: 1984.0–2010.5.

Conclusions

General:

- 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.

Nutation component:

- The $\ell = -1$ term of polar motion in the CD scheme is an equivalent representation of the celestial pole offsets.
- The early nutation data is very noisy and contains variability which is not consistent with the rest of the series. When analysis of data does not include weighting it is recommended to remove data prior to 1990.
- The VieVS CD series yields the results which are consistent with those following from the IVS and IERS combination series.
- More detailed analysis shows closer agreement of the results based on the VieVS CD and IVS series, as expected. Exceptions are only the retrograde semiannual and fortnightly nutations where the VieVS CD estimates agree better with those of the IERS.

Conclusions

Low frequency dUT1:

- Analysis of the VieVS CD dUT1 series shows good overall agreement with the two combination series, but also high correlation at seasonal frequencies.
- The polynomial-sinusoidal model is not appropriate for separating the long periodic trend and the decadal variability.
- There is also quite good agreement of te parameters of the periodical terms. The largest difference is found for the biennial and terannual terms for which the IERS results are not consistent with those based on the VieVS CD and IVS.