ANALYSIS OF THE HIGH FREQUENCY COMPONENTS OF EARTH ROTATION DEMODULATED FROM VLBI DATA

A. BRZEZIŃSKI[1,2] and S. BÖHM[3]

[1] Faculty of Geodesy and Cartography, Warsaw University of Technology, Warsaw, Poland

[2] Space Research Centre, Polish Academy of Sciences, Warsaw, Poland
e-mail: alek@cbk.waw.pl

[3] Institute of Geodesy and Geophysics, Vienna University of Technology, Vienna, Austria

ABSTRACT. In the recent work (Böhm et al., 2011) we demonstrated the application of the complex demodulation technique to Very Long Baseline Interferometry (VLBI) parameter estimation for the determination of high frequency signals in Earth rotation. Here we present preliminary results of the analysis of diurnal, semidiurnal, terdiurnal and quarterdiurnal components of polar motion and UT1, demodulated from VLBI data.

1. INTRODUCTION

Polar motion and universal time UT1 contain high frequency signals (diurnal and subdiurnal) which are predicted by physics. This is not the case for precession-nutation which, by definition, does not contain variations with periods shorter than 2 days. Note, however, that when precession-nutation is expressed in the Earth-fixed reference system it becomes a nearly diurnal phenomenon.

The high frequency signals in Earth rotation are relatively small, not exceeding the level of 1 milliarcsecond (mas), nevertheless already well measurable and important for understanding the high frequency dynamics of the Earth and its fluid layers. The main contributions are from diurnal and semidiurnal ocean tides. Significantly smaller (< 0.1 mas) are the so-called librations in polar motion and UT1 caused by direct influence of the tidal gravitation upon the triaxial figure of the Earth, and less regular signals associated with the atmospheric thermal tides.

Early attempts to estimate high frequency signals in Earth rotation were concentrated on the determination of the parameters of strictly harmonic models with known tidal arguments. However, this approach is not adequate for the investigation of atmospheric and nontidal oceanic effects which are irregular to a certain extent and thus should be expressed by time series. One method to describe high frequency variations is to shorten the sampling interval of polar motion coordinates and UT1 to the hourly level. An alternative method is to introduce as additional parameters, the instantaneous amplitudes and phases of the sinusoidal terms with frequencies of exactly 1 and 2 cycle per sidereal day – cpsd (with possible extension to 3, 4, ..., N cpsd), while keeping the basic sampling interval of 1 day. The last method, originally proposed by Herring and Dong (1994), is an application of the so-called complex demodulation method; see (Brzeziński, 2012) for a detailed description of the theoretical background of complex demodulation and its application for the analysis of Earth rotation and corresponding geophysical excitation data. Recently, the algorithm of complex demodulation was implemented by Böhm et al. (2011) into a dedicated version of the Vienna VLBI Software VieVS. They processed all VLBI sessions over 1984.0-2010.5 and estimated simultaneously the time series of the celestial pole offsets and of diurnal, semidiurnal, terdiurnal and quarterdiurnal components of polar motion and UT1. We will discuss here preliminary results of the analysis of those high frequency signals demodulated from VLBI data.

2. COMPLEX DEMODULATION IN VLBI DATA ANALYSIS

The following parametrization of polar motion (PM) and universal time (UT1) has been applied for complex demodulation of VLBI data

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

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

where x, y are the reported coordinates of polar motion, ΔUT1=UT1$-$UTC is the difference of UT1 and the uniform time scale UTC, Φ =GMST+π, GMST stands for Greenwich Mean Sidereal Time and $x_\ell(t)$, $y_\ell(t)$, $u_\ell^s(t)$, $u_\ell^c(t)$ 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 $t = 0$. Let us make the following remarks:

– the terms $\ell = 0$ of the expansion in Equations (1)–(2) are the long periodic components of PM and UT1 estimated in standard adjustment;
– the terms $\ell = \pm1, \pm2, \pm3, \pm4, \ldots$, express quasi diurnal, semidiurnal, terdiurnal, quarterdiurnal, ..., variations in PM (retrograde/prograde for $-/+$) and in UT1;
– adding the $\ell = -1$ term to the expansion (1) gives an equivalent representation of the celestial pole offsets δX, δY, in a sense that $[x_{-1}(t), -y_{-1}(t)] = [\delta X(t), \delta Y(t)]$ in the first order approximation;
– the high frequency components ($\ell \neq 0$) of UT1 are expressed by two parameters, the time dependent cosine and sine amplitudes $u_\ell^c(t)$, $u_\ell^s(t)$.

The complex parameters

$$p_n(t) = x_n(t) - iy_n(t); \qquad \Delta \mathrm{UT1}_n(t) = \left[u_n^c(t) - iu_n^s(t) \right]/2, \tag{3}$$

are designated as complex demodulate of polar motion and UT1, respectively, at frequency $\ell\Omega$.

3. DATA ANALYSIS

Böhm et al. (2011) performed several runs of VLBI data processing over 1984.0–2010.5 based on the complex demodulation model described by Equations (1)–(2) with $N = 4$ and adopting different additional assumptions. In the following analysis we will use the high frequency components of polar motion and UT1 demodulated by applying the modified VLBI Software VieVS under the following assumptions:
– Equation (1) includes the $\ell = -1$ term of PM while the celestial pole offsets δX, δY are not estimated;
– the estimation incorporates all a priori models recommended by the IERS Conventions 2010 (Petit and Luzum, 2010), including the IAU 2006/2000A precession-nutation model, the model of diurnal and semidiurnal variations due to ocean tides and the model of libration in UT1 and PM.

The output comprises 12 complex-valued time series expressing diurnal, semidiurnal, terdiurnal and quarterdiurnal components of retrograde PM, prograde PM, and UT1. Each series contains about 3500 data points with irregular sampling. At first we apply a least-squares algorithm with weighting to estimate corrections to the main tidal constituents, including the S_1, S_2 and S_3 terms associated with the atmospheric thermal tides. Further analysis includes both the original demodulated series and their reduced version derived by removal of the estimated corrections to the tidal terms. The next step is the application of a Gaussian low-pass filter with full width at half-maximum (FWHM)=10 days to simultaneously smooth and interpolate the time series at 5-days intervals. Finally we perform the maximum entropy method (MEM) spectral analysis (Brzeziński, 1995) of the smoothed original and reduced time series. The spectral analysis has been done over the entire time interval 1984.0–2010.5, as well as over different sub-intervals obtained by removal of certain parts of early data.

The demodulated components of polar motion and UT1, raw original data with the error bars and smoothed values, are shown in Figure 1. A first simple observation is that the time series are not homogeneous in time. There are much higher errors in early data. Moreover, the smoothed signals contain in the first years some variability which is not confirmed by more recent data. The last conclusion is also confirmed by the MEM analysis which produces very complicated power spectra (not shown here) when computed over the entire interval, and more and more smooth spectra after removal of early data. Our conclusion is that an acceptable homogeneity of data is reached after rejection of all data prior to 1990.0. Table 1 shows that for the smoothed signals the sample standard deviations computed over 1984.0–2010.5 and over 1990.0–2010.5 differ by the factor of two to three.

Based on the above conclusion we show in Figure 2 the MEM power spectra estimated only over the reduced time interval 1990.0–2010.5. We compare in the plots the spectra of the original series and after removal of the estimated correction model.

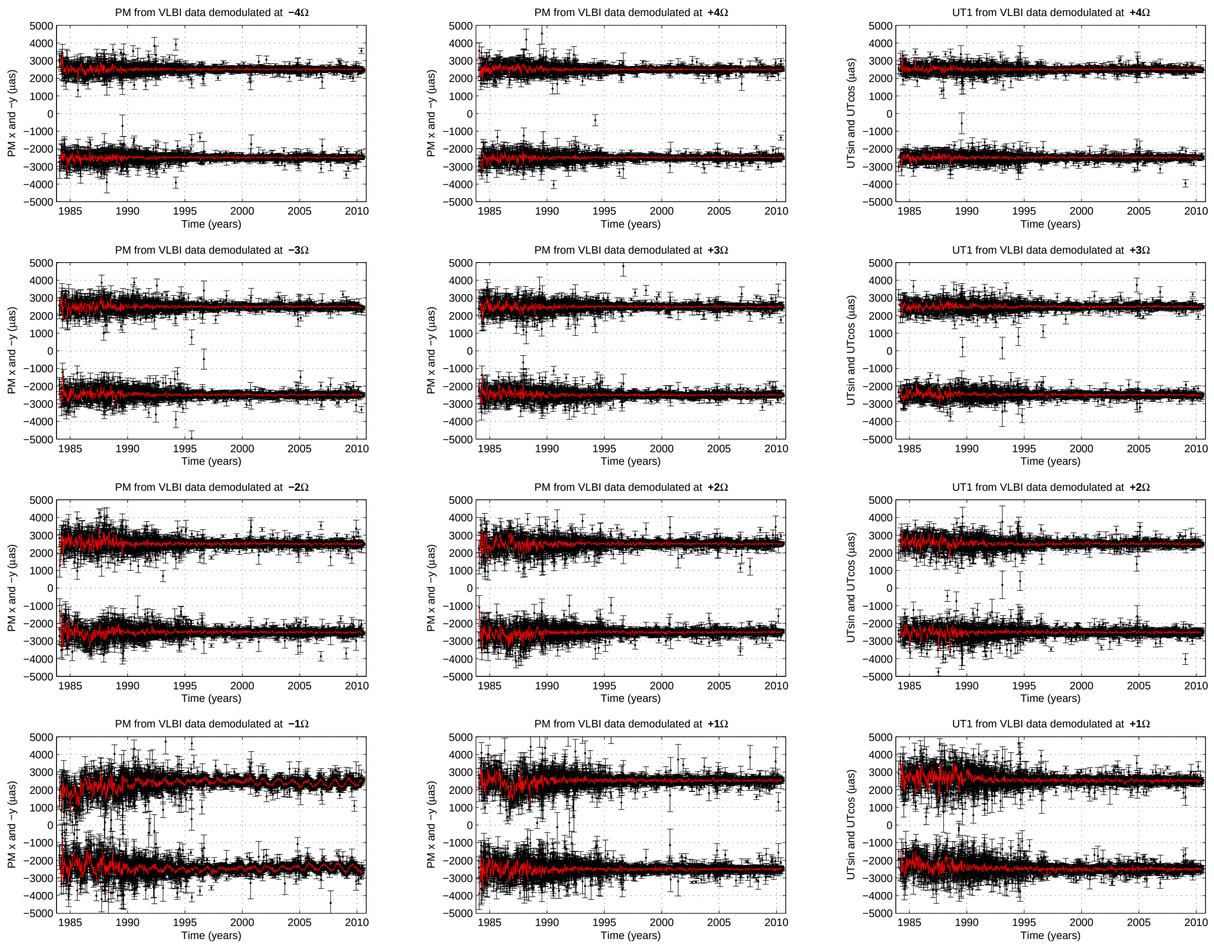

Figure 1: Demodulated high frequency components of retrograde (left) and prograde (middle) polar motion, and UT1 (right). Shown are raw values with 1-σ error bars and smoothed values. Analysis has been done over 1984.0–2010.5 with the a priori IERS models applied.

Another observation from Figure 1 and Table 1 is that the signals demodulated at $\ell\Omega$ decrease in size with increasing ℓ. The retrograde diurnal component of polar motion, which expresses the residual precession-nutation including the free core nutation signal, exceeds in size all other signals considered here by the factor of at least two. The corresponding power spectrum shown in Figure 2 does not differ from earlier results based on the analysis of the celestial pole offsets.

The MEM power spectra of all series representing the terdiurnal and quarterdiurnal components of PM and UT1 and the prograde semidiurnal component of PM, do not show any significant spectral feature. Moreover, removal of the empirical correction model does not introduce any important change to the spectral plots. Hence, our analysis does not confirm earlier claims based on Earth rotation data from the CONT campaigns about the existence of the 8-hour oscillation in polar motion and/or in UT1.

The most important change introduced by removal of the empirical correction model is in case of prograde diurnal and retrograde semidiurnal components of PM and in diurnal and semidiurnal components of UT1. It consists in smoothing the spectrum and reduction of its power.

4. SUMMARY AND CONCLUSIONS

The high frequency components of polar motion and UT1, diurnal, semidiurnal, terdiurnal and quarterdiurnal, have been demodulated from VLBI data using the modified Vienna VLBI Software VieVS. Our analysis of demodulated data sets shows

– data prior 1990 is too noisy and, therefore, should not be used for the time domain analysis and geophysical interpretation;

	Demodulation frequency							
Series	-4Ω	-3Ω	-2Ω	-1Ω	Ω	2Ω	3Ω	4Ω
PM (1984.0–2010.5)	114	142	189	336	236	189	135	114
PM (1990.0–2010.5)	47	59	73	174	84	66	56	46
UT1 (1984.0–2010.5)					86	54	38	32
UT1 (1990.0–2010.5)					37	25	21	17

Table 1: Standard deviation of the smoothed high frequency components of polar motion and UT1 (μas)

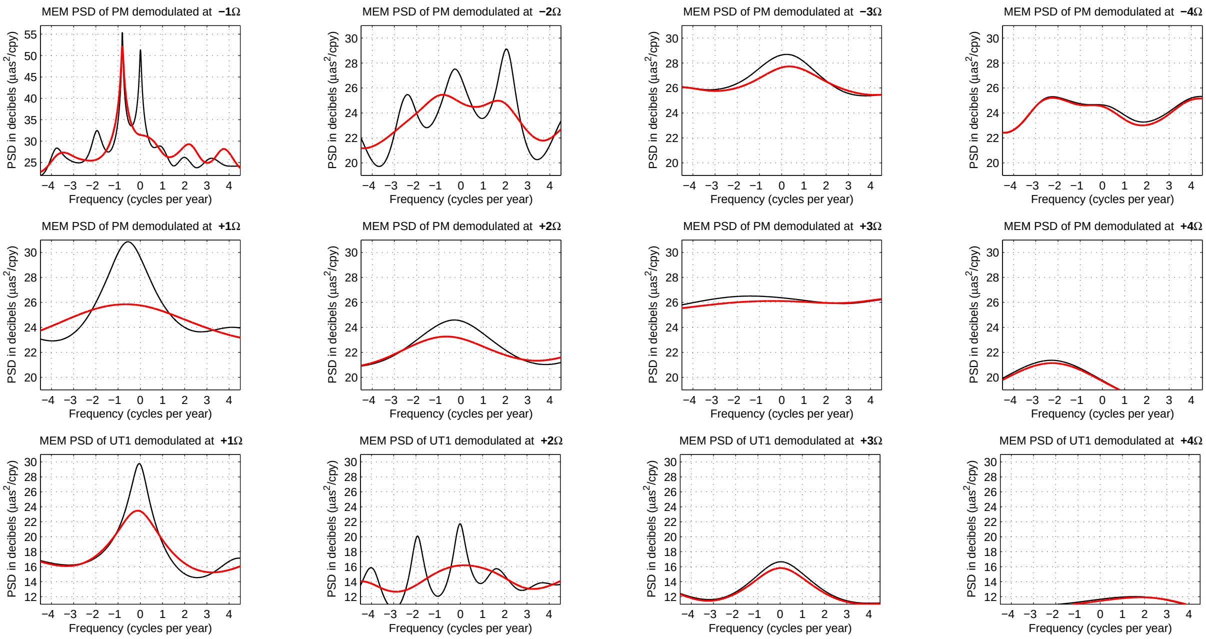

Figure 2: Maximum entropy power spectra of demodulated high frequency components of Earth rotation, thin black – with the a priori IERS models applied, thick red – after additional removal of the residual tidal terms. Period of analysis 1990.0 – 2010.5.

– spectral analysis of terdiurnal and quarterdiurnal terms does not reveal any sharp spectral line; hence, our analysis does not confirm the existence of 8-hour oscillation either in PM or in UT1.

A future task is the comparison of demodulated PM and UT1 series to the corresponding components demodulated from atmospheric and nontidal oceanic angular momentum data.

Acknowledgments. Participation of A.B. in the Journées 2011 has been supported by the Polish National Science Centre under grant No. 1570/B/T02/2011/40.

5. REFERENCES

Böhm, S., Brzeziński, A., and Schuh, H., 2011, "Complex demodulation in VLBI estimation of high frequency Earth rotation components", J. Geodynamics, doi: 10.1016/j.jog.2011.10.002.

Brzeziński, A., 2012, "On estimation of high frequency geophysical signals in Earth rotation by complex demodulation", J. Geodynamics, doi: 10.1016/j.jog.2012.01.008.

Brzeziński, A., 1995, "On the interpretation of maximum entropy power spectrum and cross-power spectrum in earth rotation investigations", manuscripta geodaetica, 20, pp. 248–264.

Herring, T. A., and Dong, D., 1994, "Measurement of diurnal and semidiurnal rotational variations and tidal parameters of Earth", J. Geophys. Res., 99(B9), pp. 18,051–18,071.

Petit, G., and Luzum, B. (eds.), 2010, "IERS Conventions (2010)", IERS Tech. Note no. 36, Bundesamts für Kartographie und Geodäsie, Frankfurt, Germany, 179 pp.