SHORT PERIODS IN EARTH ROTATION SEEN IN VLBI DATA ANALYSED BY THE LEAST-SQUARES COLLOCATION METHOD

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ABSTRACT

The least-squares collocation method (LSCM) is briefly explained. It requires the design of the a-priori correlation matrix for which examples are given. The LSCM applied on Very Long Baseline Interferometry (VLBI) data analysis allows the determination of the Earth rotation parameters with a very high temporal resolution. The results of parallel VLBI sessions which took place since 1998 using two independent VLBI networks were analyzed in the subdiurnal period range and compared by computing the wavelet cross-scalograms, the covariance spectrum and the normed coherency. Periods between 5 and 7 hours can be seen in many of the UT1-UTC data sets besides the well-known diurnal and semidiurnal periods. However, it is still questionable whether these short-period variations really exist, i.e. are due to geophysical excitation.

INTRODUCTION

Today, the Earth Rotation Parameters (ERPs) are usually estimated and published with a daily resolution. However, it is possible by VLBI to determine UT1-UTC and polar motion with a temporal resolution of as short as 3-7 minutes. This paper concentrates on ERP variations with periods shorter than 24 hours. Highly resolved ERPs monitored by VLBI were recently analyzed by Schuh and Titov (1999), Titov (2000), Schuh and Schmitz-Hübsch (2000). It is known that the strongest short-period signals are caused by oceanic tidal effects. 41 tides for UT1-UTC and 57 tides for polar motion most of them in the diurnal and semidiurnal period range were estimated from VLBI (Gipson, 1996) and from GPS observations (Rothacher et al., 2000).

Nevertheless, ERP measurements with high temporal resolution seem to reveal signals outside the semidiurnal and diurnal periods, too. These variations are supposed to be due to resonances with modes of the Earth or caused by high-frequency atmospheric oscillations. Transient and irregular variations could also be excited by episodic phenomena like strong earthquakes or typhoons.

All time series which were analyzed within the work presented in this publication were purely obtained by VLBI measurements. The eminent importance of VLBI in

geodesy and geophysics is due to its connection with an inertial reference frame formed by compact extragalactic radio sources. VLBI is unique in its ability to monitor without hypotheses all components of Earth orientation.

OBSERVATION OF EARTH ROTATION BY VLBI

For more than 20 years the technique of geodetic VLBI has been applied to measure the rotation of the Earth. The geodetic and geophysical interest in VLBI is based on the use of an inertial reference frame formed by a set of compact extragalactic radio sources. VLBI measures very accurately the angles between the Earth-fixed baseline vectors and the space-fixed radio sources. Thus, even the most subtle changes of the baseline lengths and changes of the baseline directions with respect to the inertial reference frame can be detected. Geodynamical phenomena such as polar motion, Universal Time 1 (UT1) variations, precession and nutation, Earth tides, ocean tidal response, and tectonic plate motions can be monitored with highest accuracy. The fundamentals of the VLBI technique, the main elements of a VLBI system and the most important geodetic results were described in many publications, e.g. by Schuh and Campbell (1994), Sovers et al. (1998). Schuh and Schmitz-Hübsch (2000) give an overwiew about the abilities of VLBI to monitor the ERPs and publish recent results on subseasonal time scales.

It is necessary to separate high-frequency variations of the ERPs from site dependent effects as rapid variations of the troposphere or unmodelled deformations due to oceanic or atmospheric loading. Subdiurnal variations of site dependent parameters could cause apparent subdiurnal variations of the ERPs estimated by the whole network. Fortunately, since 1998 parallel 24-hour sessions on the NEOS-A and CORE-A networks provide a good opportunity to compare the independent ERPs variations for the same epochs as will be shown later in this article.

APPLICATION OF THE LEAST-SQUARES COLLOCATION METHOD TO VLBI DATA

There are several approaches for VLBI data adjustment. All of them imply that the observables are not correlated. Thus, for VLBI data analysis usually a diagonal a-priori variance-covariance matrix is applied in the least-squares fit. But it is obvious that different reasons cause correlations between the observables: systematic errors, the stochastic nature of some parameters, etc. It was shown that an application of the full variance-covariance matrix improves the repeatability of geodetic parameter estimates (baseline lengths and station coordinates) (Schuh and Tesmer, 2000). Nevertheless, the construction of a full a-priori variance-covariance matrix is not simple because it is an iterative procedure and requires information about a-posteriori correlations.

Conventional least-squares estimation follows the formula

$$\hat{x} = (A^T Q_w^{-1} A)^{-1} A^T Q_w^{-1} l \qquad (1)$$

where
Q_W - diagonal covariance matrix of observations,
A - matrix of partial derivatives,
l - vector of observables.

The least-squares collocation method (LSCM) (Titov, 2000) as an alternative approach for VLBI data adjustment provides
- a procedure for the construction of the full variance-covariance matrix,
- an approach for the use of this matrix.

The LSCM applies the following formula for the estimation of vector $\hat{x}$

$$\hat{x} = (A^T Q_0^{-1} A)^{-1} A^T Q_0^{-1} l, \tag{2}$$

with matrix

$$Q_0 = C Q_Z C^T + Q_w, \tag{3}$$

where the matrix Q_Z can be calculated based on information about covariance functions of the stochastic parameters (see below). The matrix C contains the partial derivatives of the stochastic parameters.

Correlation functions of wet tropospheric delay and of clock offset were applied for our analysis to take into account the variability of the corresponding parameters within 24 hours. The correlation functions of stochastic parameters are approximated using eq. (4) (Gubanov, Surkis, Titov, 1997).

$$q(\tau) = \frac{1}{\cos\varphi} \exp(-\alpha\tau)\cos(\beta\tau + \varphi), \tag{4}$$

where τ is a time lag (in part of days) with $0 \le \tau \le 1$; the following sets of parameters for the clock offset ($\alpha = 2.64$ day^{-1}, $\beta = 8.64$ day^{-1}, $\varphi = 0.33$ radian) and for the wet tropospheric delay ($\alpha = 6.24$ day^{-1}, $\beta = 6.48$ day^{-1}, $\varphi = 0.82$ radian) were used. Figure 1 and figure 2 represent plots of the correlation functions.

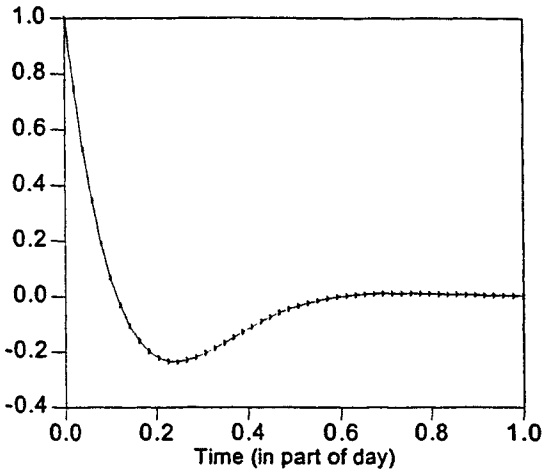

Fig. 1: Correlation function for clock offset

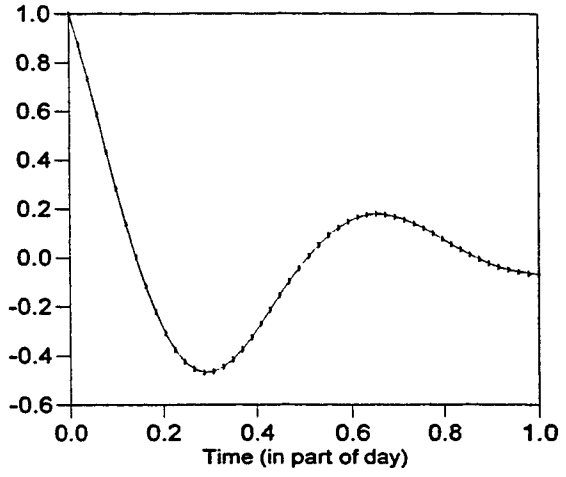

Fig. 2: Correlation function for wet tropospheric delay

FULL CORRELATION MATRIX ANALYSIS

The resulting variance-covariance matrix Q_0 eq. (3) is a full one. Non-diagonal elements of the matrix describe a mutual correlation between the observed delays. They depend on the time difference between the observations as well as on the geometry of the VLBI network The table demonstrates the correlation coefficients between five delay observables taken on five baselines at the first epoch ($\tau = 0$) during NEOS-A session (23-Feb-1999). The VLBI sites Ny-Ålesund, NRAO20, Kokee and Fortaleza were considered.

	Fortaleza-Kokee	Fortaleza-NRAO20	Kokee-NRAO20	NRAO20-Ny-Ålesund	Kokee-Ny-Ålesund
Fortaleza - Kokee	1.000	0.740	-0.505	0	-0.447
Fortaleza - NRAO20		1.000	0.185	-0.211	0

Kokee - NRAO20			1.000	-0.274	0.661
NRAO20 - Ny-Ålesund				1.000	0.520
Kokee - Ny-Ålesund					1.000

Table: Correlations between observations on different baselines for the first epoch of the NEOS-A session on Feb. 23rd, 1999.

A zero element means that both baselines are made up by independent stations. A negative element means that the first station of the one baseline is the second station of the other baseline (e.g. the combination Fortaleza – Kokee and Kokee – NRAO20 in the table). Then, the elements of the partial derivatives matrix for the clock offset are equal to +1 and –1, correspondingly.

The dependence of the correlation coefficients on the time difference between the first epoch observation and the other observations on the baseline Fortaleza - Kokee is shown in fig. 3.

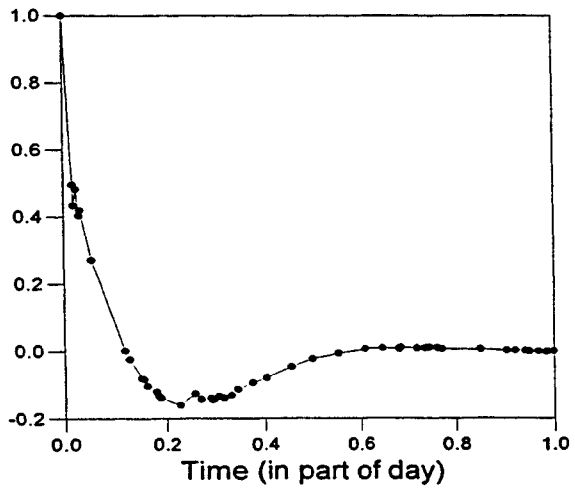

Fig. 3: Correlation function for baseline Fortaleza – Kokee (see text)

The application of the LSCM provides a way for increasing the repeatability of geodetic parameters such as baseline lengths or station coordinates. By the LSCM approach we can obtain global parameters, too (see paper "Estimation of subdiurnal tidal terms in UT1–UTC from VLBI data analysis" by Titov this volume).

DIURNAL AND SUBDIURNAL VARIATIONS OF EARTH ROTATION PARAMETERS

Very high temporal resolution of the Earth rotation parameters can be achieved by VLBI using the least-squares collocation method (LSCM) described in the previous paragraphs. Almost 400 VLBI experiments (NEOS-A from 1993 till 1999, CONT'96, CORE) each of them covering 24h (NEOS-A and CORE) or 120h (CONT)

were analyzed by Titov (2000) using the OCCAM VLBI software (Titov and Zarraoa, 1997) yielding time series of UT1-UTC and of polar motion with a resolution of 3-7 minutes. In this paragraph some examples for UT1-UTC will be given.

First, the main diurnal and semidiurnal variations due to the ocean tides were removed using the IERS Conventions (1996) correction model. The residuals, i.e. after correction of oceanic tidal terms and subtraction of a constant bias, were submitted to the wavelet transform (e.g. Schmidt, 2000; Schmidt and Schuh, 2000; both in this volume). Although ocean tidal influences had been corrected already according to the model recommended in the IERS Conventions (1996), many of the wavelet scalograms of the UT1-UTC series show residual energy in the diurnal and semidiurnal period range. Additionally, most of the data sets revealed irregular quasi-periodic fluctuations which are non-diurnal and non-semidiurnal. From the 120h CONT sessions very often (but not always) periods at 20 hours and 40 hours, around 8 hours and between 5 and 7 hours were found which are above the error level of the individual UT1-UTC parameters of better than ±10-15 microseconds of time. For more details see Schuh (1999).

Parallel sessions on different VLBI networks which took place since 1998 offer the opportunity for independent observations of the Earth rotation and hence the corresponding wavelet scalograms should show similar variations of the Earth rotation parameters. In figure 4 the UT1-UTC results obtained simultaneously by the VLBI NEOS-A network (Green Bank - Fortaleza - Kokee - Ny Ålesund - Wettzell) and the CORE-A network (Fairbanks - Hartebeesthoek - Hobart - Matera - Westford - Algonquin Park) are plotted; both started from July, 28th, 1998, 18.00 to observe simultaneously for 24h (NEOS-A274 and CORE-A041). It should be noted that the two networks form two completely different VLBI 'observing systems', i.e. different radio sources were observed by different stations. As we are mainly interested in the short-period variations a comparison in the frequency domain was carried out. The two upper plots of figure 5 show the wavelet scalograms of the UT1-UTC series obtained by the two VLBI sessions. Both are quite similar: a dominant variation around 5-6 hours can be seen in the NEOS-A session results and in the CORE-A session results. The correspondence between the two scalograms is confirmed by the squared wavelet cross-scalogram (fig. 5, bottom). Additional information can be obtained from the normed coherencies and the covariances. The normed coherency function (fig. 5, bottom, right side) shows the generally good agreement between the two time series (NEOS-A and CORE-A) for the period range from 5-8 hours whereas the covariance function (fig. 5, bottom, left side) leads to the conclusion that the period around 5-6 hours is the most prominent one in the squared wavelet cross-scalogram. Both time series obviously contain also small variations around 3 hours.

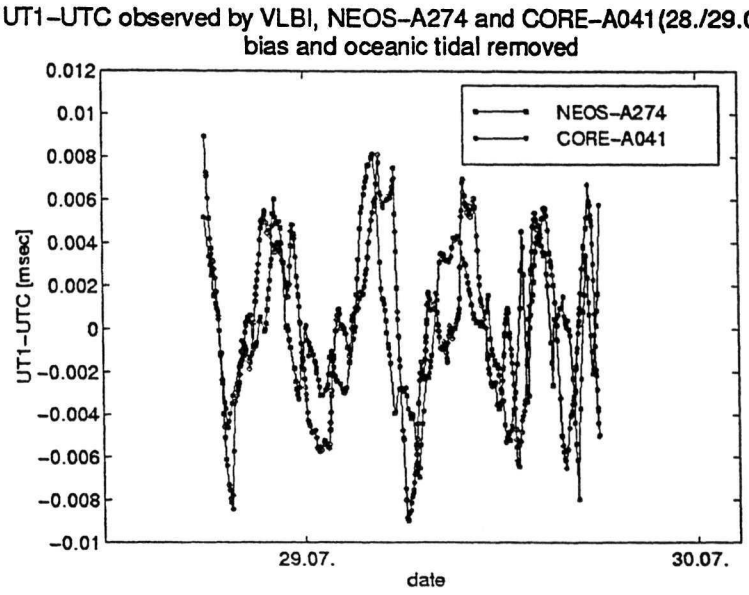

Fig.4: UT1-UTC parameters with high temporal resolution determined by two simultaneous VLBI sessions (NEOS-A274, CORE-A041) starting on July 28th, 1998 with a duration of 24 hours; a bias and ocean tidal terms were removed from the observations using the IERS Conventions (1996) model.

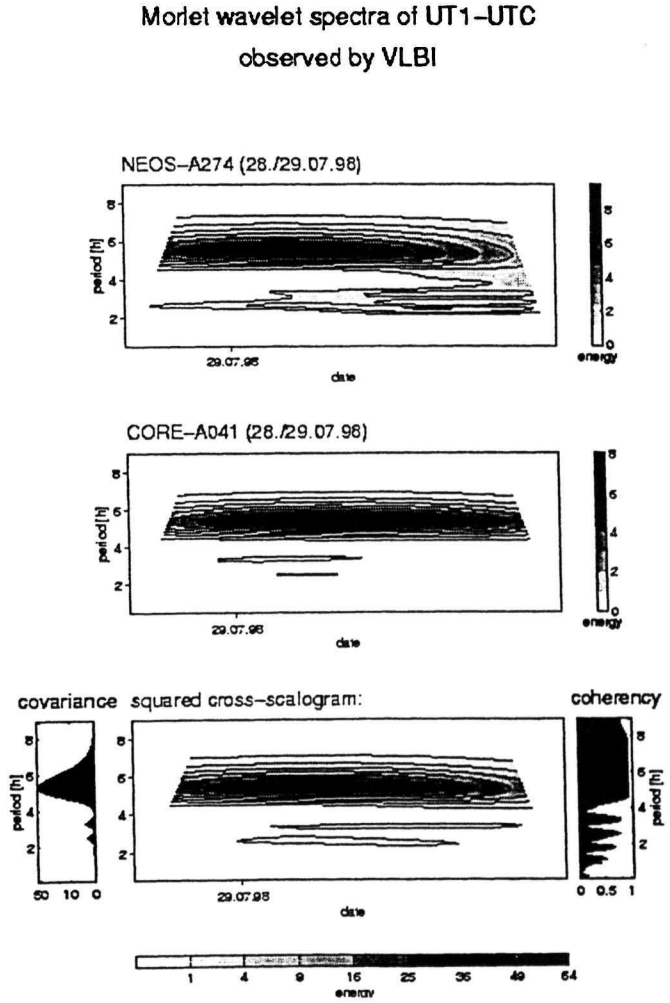

Fig. 5: Wavelet scalograms for periods shorter than 12 hours of two time series shown in figure 4, the squared wavelet cross-scalogram, the covariance (left) and the normed coherency (right).

Comparisons of a dozen simultaneous VLBI sessions observed in 1998 and 1999 by the NEOS-A and the CORE-A networks have been done. Not for all of them the agreement of the high-resolution Earth rotation time series is sufficiently good neither in time domain nor in frequency domain. Some of the parallel sessions give results which – even after subtraction of a constant bias - differ by more than two or three times the formal errors. This could be due to strong local atmospheric variations at one or some of the stations of a VLBI network what could influence the determination of the Earth rotation parameters by the whole VLBI network and hence cause apparent variations of the ERPs obtained by the LSCM. Indeed, wavelet analyses of highly-resolved tropospheric zenith delay parameters determined for the VLBI sites showed strong temporal and sometimes high frequency variations at some of the stations. However, a clear picture, i.e. correlation between tropospheric parameters and the ERPs estimated during a VLBI session could not be obtained.

CONCLUSIONS

Highly-resolved Earth rotation parameters were obtained by application of the LSCM on VLBI data. Irregular quasi-periodic variations of UT1-UTC can be seen in the wavelet scalograms besides the well-known diurnal and semidiurnal periods caused by the ocean tides. Although the tiny subdaily variations which could be seen in the VLBI results are above the error level of the observations and are statistically significant further careful tests have to be done to check whether they are real, i.e. caused by geophysical excitation.

REFERENCES

Gipson, J.M.: 1996, Very long baseline interferometry determination of neglected tidal terms in high-frequency Earth orientation variation, Journ. of Geophys. Res., 101(B12), 28051-28064.

Gubanov, V., I. Surkis and O. Titov: 1997, 'Interday troposphere path length fluctuations', Communications of IAA, 103, Saint-Petersburg.

MacMillan D.S., W.E. Himwich, C.C. Thomas, N.R. Vandenberg, J.M. Bosworth, B. Chao, T.A. Clark and C. Ma: 'CORE: 1999, Continuos, High-Accuracy Earth Orientation Measurements', Proceedings of the 13th Working Meeting on European VLBI for Geodesy and Astrometry, Viechtach, Feb. 12-13, 1999, ed. by W. Schlüter and H. Hase, Bundesamt für Kartographie and Geodäsie, Wettzell, 166-171.

Rothacher M., G. Beutler, R. Weber and J. Hefty: 2000, 'High-Frequency Earth Rotation Variations From Three Years of Global Positioning System Data', subm. to Journal of Geophysical Research.

Schmidt M.: 2000, 'Wavelet Analysis of Stochastic Signals', IERS Technical Note No 28, (this volume).

Schmidt, M. and H. Schuh: 2000, 'Abilities of Wavelet Analysis for Investigating Short-Period Variations of Earth Rotation', IERS Technical Note No 28, (this volume).

Schuh, H.: 1999, 'The Rotation of the Earth Observed by VLBI', Acta Geod. Geoph. Hung., 34(4), 421-432.

Schuh, H. and J. Campbell: 1994, 'VLBI in geodynamical investigations', Acta Geod. Geophys. Hung., 29 (3-4), 397-420.

Schuh, H. and O. Titov: 1999, 'Short-period variations of the Earth rotation parameters as seen by VLBI', Proc. of the 13th Working Meeting on European VLBI for Geodesy and Astrometry, Viechtach, Feb. 1999, ed. by W. Schlüter and H. Hase, 172-177.

Schuh, H. and H. Schmitz-Hübsch: 2000, 'Short Periods in Earth Rotation as seen by VLBI', submitted to Surveys in Geophysics.

Schuh, H. and V. Tesmer: 2000, 'Considering A-Priori Correlations in VLBI Data Analysis', IVS 2000 General Meeting Proceedings ed. by N.R. Vandenberg and K.D. Baver, NASA/CP-2000-209893, 237-242.

Sovers, O.J., J.L. Fanselow and C.S. Jacobs: 1998, 'Astrometry and geodesy with radio interferometry: experiments, models, results', Rev. of Modern Physics, 70, No. 4, 1393-1454.

Titov, O.: 2000, 'Estimation of the subdiurnal UT1-UTC variations by least squares collocation method', Astronomical and Astrophysical Transactions, V. 19, 113-126.

Titov, O. and N. Zarraoa: 1997, 'OCCAM 3.4 User's Guide', Communications of the Institute for Applied Astronomy (IAA), St. Petersburg, No. 69.

... IERS Conventions (1996): 1996, ed. by D. D. McCarthy, IERS Technical Note 21, Observatoire de Paris.