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Sub-diurnal earth rotation variations from the VLBI CONT02 campaign

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Abstract

We present results of the analysis of Earth rotation data derived from the continuous very long baseline interferometry (VLBI) campaign CONT02. The high-frequency contents of polar motion and UT1 are analyzed and compared to theoretical models. We perform signal analysis using Lomb periodograms, Wavelet analysis and a modified Fourier analysis. We find a ter-diurnal variation in polar motion close to the S_3 tide constituent.

Keywords: High-frequency earth rotation variations; Very long baseline interferometry; Angular momentum exchange

1. Introduction

The exchange of angular momentum between the ocean, atmosphere and solid Earth causes variations in Earth rotation on various time scales. Several models to describe high-frequency variations have been developed. The variations can be observed with space geodetic methods. This offers the possibility to test the theoretical models and to search for so-far unmodelled variations.

Previous studies have been using long time series of earth rotation observations using very long baseline interferometry (VLBI), e.g. Brosche et al. (1991), Sovers. et al. (1993), Herring and Dong (1994), Gipson (1996), satellite laser ranging (SLR), e.g. Watkins and Eanes (1994) and the global positioning system (GPS), e.g. Rothacher et al. (2001). The current article focuses on the analysis of a 15 days continuous VLBI campaign and addresses in particular sub-diurnal Earth rotation variations.

2. Models for high-frequency earth rotation variations

Ocean tidal influences on Earth rotation are modeled using the linearized Euler–Liouville equations. The basis for the corresponding models are hydro-dynamical calculations of inertia tensor changes and relative angular momentum (e.g. Brosche et al. (1989), Brosche and Wünsch (1994), Ray et al. (1994), Seiler and Wünsch (1995), Chao et al.

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Table 1
Predictions of amplitudes and phases of pro- and retrograde polar motion variations (A_i, α_i) and variations in UT1 (B, β) based on different theoretical models

Name	P	A_r	α_r	A_p	α_p	B	β
Atmospheric tides (de Viron et al. (2005)), ECMWF values							
S_3	8.0	0.46	11.1	0.57	317.5	0.48	346.5
Hydro-dynamical M_3-model (Wünsch (2001))							
M_3	8.28	0.43	267.7	0.30	6.7	0.57	25.2
Atmospheric tides (Brzezinski et al. (2002))							
S_2	12.0	2.9	348	2.9	168	0.8	90
S_1	24.0	–	–	7.1	137	0.8	111
Non-tidal angular momentum (de Viron et al. (2002))							
S_1	24.0	–	–	24.7	238	0.6	225

Amplitudes are given in μas for polar motion and μs for UT1, phases in degree, and the period (P) in hours.

(1995), Chao et al. (1996)). These models predict polar motion and UT1 variations in the diurnal and semi-diurnal frequency band. The predictions have amplitudes on the order of several hundreds of micro-arcseconds for polar motion, and several tens of micro-seconds for UT1 (e.g. Ray et al. (1994), IERS (2003)). Even ter-diurnal polar motion variations due to oceanic influences are predicted (Wünsch, 2001) based on the hydrodynamical ocean model by Seiler and Wünsch (1995).

Non-tidal ocean angular momentum is predicted to contribute to diurnal variations on the level of some tens of micro-arcseconds in polar motion and less than half a micro-second in UT1 (de Viron et al., 2002).

Atmospheric tides, thermal and tidal, are predicted to cause sub-diurnal variations on the level of some tens of micro-arcseconds in polar motion and on the level of a micro-second in UT1 (Brzezinski et al., 2002). Also ter-diurnal variations in polar motion and UT1 due to atmospheric effects are predicted (de Viron et al., 2005).

Furthermore, the external luni-solar torques act on the tri-axial figure of the earth (Chao et al. (1991), Wünsch (1991)) and sub-diurnal polar motion variations on the order of some tens of micro-arcseconds are predicted (Brzezinski and Capitaine, 2002).

A brief summary of predictions main terms of the recent theoretical models for sub-diurnal Earth rotation variations, except the Ray-model, is given in Table 1.

3. The VLBI CONT02 campaign and VLBI data analysis

In the last couple of years a number of continuous geodetic VLBI campaigns were conducted that aimed at deriving high-resolution polar motion and UT1 observations. These campaigns were observed with global VLBI networks and extended continuously over several days (Clark et al., 1998). In the following, we concentrate on the VLBI campaign CONT02 that provides the longest, high-quality continuous VLBI data set of all continuous VLBI campaigns. The campaign CONT02 was observed continuously in 2002 between October 16 and 31 with a network of eight globally distributed VLBI sites.

The CONT02 VLBI data were analyzed with the CALC/SOLVE analysis software package (Ma et al., 1990). Solid earth tide and ocean tide loading were accounted for but atmospheric loading corrections were not applied. Station positions and velocities were apriori modelled based on their ITRF2000 values (Altamimi et al., 2002). The radio source positions were fixed on the ICRF values (Ma et al., 1998). No-net-translation and no-net-rotation conditions were applied and station coordinates of all participating stations were estimated as global parameters. Polar motion and UT1 were estimated as piecewise linear functions with 1 h updates. No model for high-frequency Earth rotation variations was applied. The standard precession and nutation models were applied (Lieske et al. (1977), Seidelmann (1982)) and one pair of nutation offsets per day was estimated. Atmospheric zenith wet delay and gradient values were estimated every hour using state of the art mapping functions (Niell, 1996).

The VLBI data analysis resulted in hourly estimates for polar motion and UT1. These values were corrected for one bias and one rate for each component and are shown in Fig. 1 together with predictions based on the extended Ray-model (Ray et al. (1994), IERS (2003)).

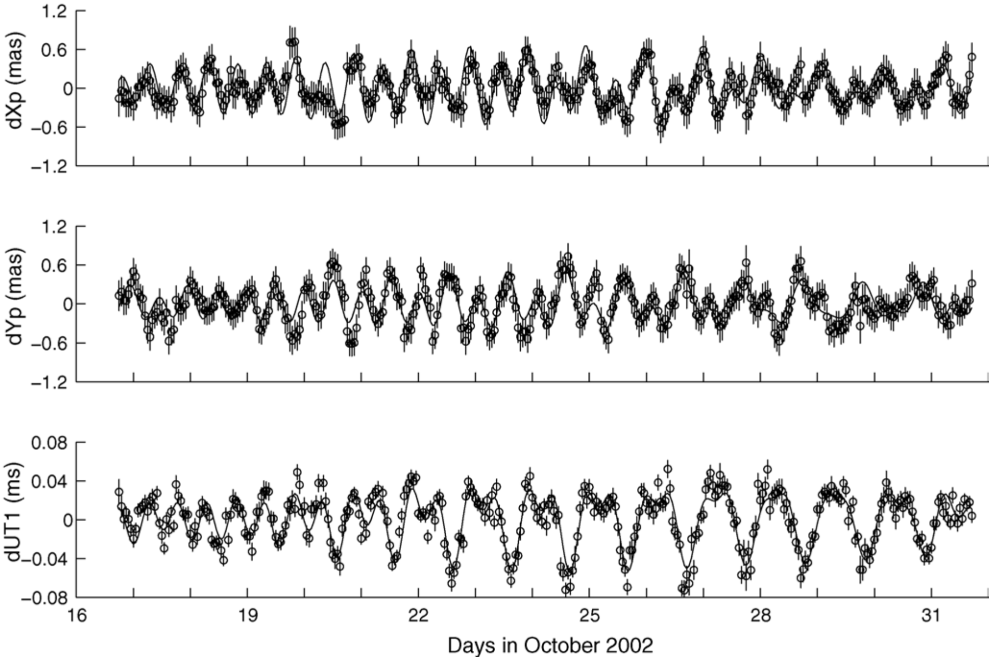

Fig. 1. Hourly estimates of polar motion and UT1 from CONT02 VLBI shown as circles with errorbars that indicate the formal errors of the analysis. The continuous thin line shows the corresponding predictions based on the extended version of the Ray-model (Ray et al. (1994), IERS (2003)).

4. Signal analysis of the high-frequency earth rotation variations

Fig. 1 shows that the observations do agree reasonably well with the model predictions based on the extended Ray-model (Ray et al. (1994), IERS (2003)) However, there are some discrepancies, e.g. the observed UT1 variations have larger diurnal amplitudes than the modeled ones.

Fig. 2 displays Lomb periodograms (Press et al., 1992) of the CONT02 high-resolution polar motion and UT1 estimates. Spectral energy in the diurnal and semi-diurnal frequency bands are clearly visible in all three earth rotation components. There is a significant spectral peak with 8 h period in the *y*-component of polar motion.

For the further investigations, we subtracted the predictions based on the extended Ray-model (Ray et al. (1994), IERS (2003)) from the CONT02 observations and analyzed the resulting residuals. This subtraction reduced significantly the variances of all three earth rotation components. The variances reduced by about 40% and 60% for the *x*- and *y*-component of polar motion, and by about 80% for UT1.

Fig. 3 shows amplitude spectra of these CONT02 residuals that were derived with a modified form of the Lomb periodogram (Press et al. (1992), Hocke (1998)). Clearly, significant amplitudes of about 120 μas are detectable at

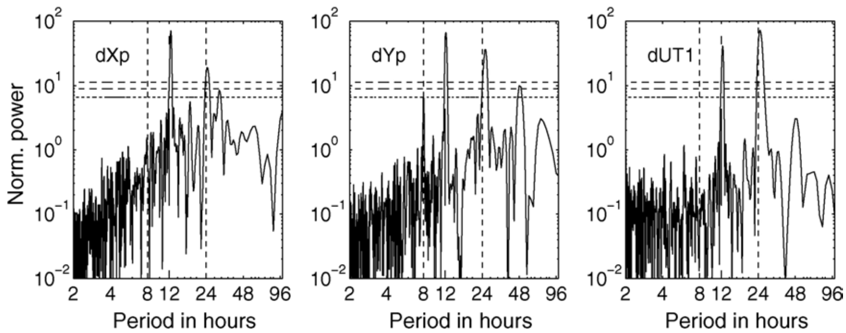

Fig. 2. Lomb periodograms of the hourly polar motion and UT1 estimates derived from CONT02. The vertical dashed-dotted lines indicate periods of 8, 12 and 24 h. The horizontal lines indicate the significance levels of 99.5% (dashed), 95% (dashed-dotted) and 50% (dotted).

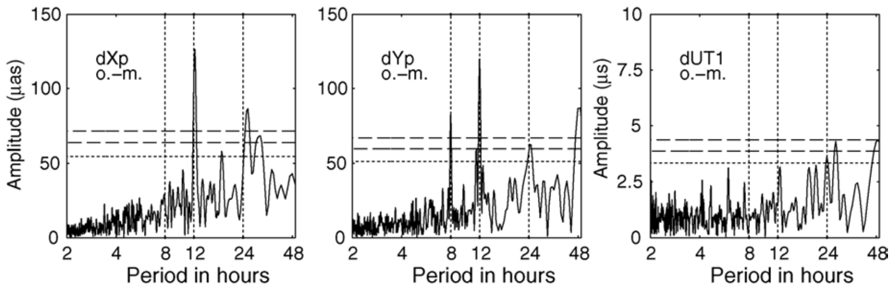

Fig. 3. Amplitude spectra of residual hourly polar motion and UT1 estimates for CONT02 after subtracting the extended Ray-model (Ray et al. (1994), IERS (2003)). The vertical dotted lines indicate periods of 8, 12 and 24 h. The horizontal lines indicate the significance levels of 99.5% (dashed), 95% (dashed-dotted) and 50% (dotted).

a period of 12 h for both components of the polar motion residuals. There are also significant amplitudes of about 60–80 μas in both components of the polar motion residuals for the 24 h period. The *y*-component of the polar motion residuals shows a significant peak at about 8 h period with an amplitude of about 75 μas. The amplitude spectrum of the UT1 residuals shows lower peaks, and significant signals are only detected close to the 24 h period.

The CONT02 residuals were also analyzed with Morlet wavelets (Foster (1996), Schmidt (2000)) and the modified Fourier analysis (Jochmann, 1993). Figs. 4 and 5 focus on the results for polar motion. The wavelet scalograms (Fig. 4) indicate significant signal power at periods of 12 and 24 h in both, retrograde and prograde polar motion. Furthermore, signal power at 8 h period is detectable which is more clear in prograde polar motion in the first part of CONT02, and more clear in retrograde polar motion in the second part of CONT02. The amplitude spectra (Fig. 5) were derived with the modified Fourier analysis and show significant signals at 24, 12 and 8 h period. The numerical results for all three earth rotation components are given in Table 2.

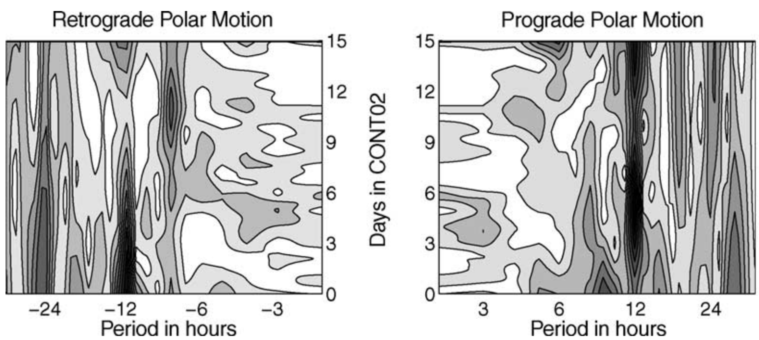

Fig. 4. Wavelet scalograms of the residual polar motion estimates for CONT02 after subtracting the extended Ray-model (Ray et al. (1994), IERS (2003)). Shown are retro- and prograde polar motion.

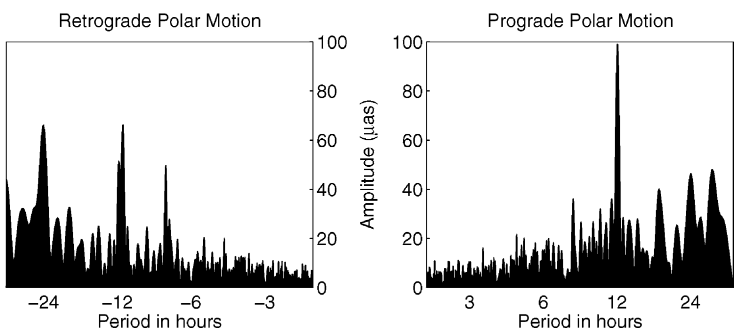

Fig. 5. Amplitude spectra of the residual polar motion estimates for CONT02 after subtracting the extended Ray-model (Ray et al. (1994), IERS (2003)) derived with the modified Fourier analysis (Jochmann, 1993). Shown are retro- and prograde polar motion.

Table 2
Estimates of amplitudes and phases of pro- and retrograde polar motion variations (A_i, α_i) and variations in UT1 (B, β) derived from the CONT02 residual data

P	A_r	α_r	A_p	α_p	B	β
7.96	47.0 ± 11.4	314	37.5 ± 11.4	283	–	–
12.05	61.5 ± 11.4	203	98.6 ± 11.4	69	–	–
23.76	–	–	–	–	3.1±1.0	53
24.75	64.5 ± 11.4	75	36.7 ± 11.4	220	–	–
27.12	–	–	–	–	4.4 ± 1.0	134

Amplitudes are given in μas for polar motion and μs for UT1, phases in degree, and the period (P) in hours.

The detected ter-diurnal polar motion signal is several times larger than the values reported previously by Gipson (1996) and Rothacher et al. (2001). It is much larger than the oceanic M_3-model predictions by Wünsch (2001) and the period is closer to S_3 than to M_3. This supports the findings reported by Petrov and Ray (2004). However, the detected retro- and prograde amplitudes are several magnitudes larger than the corresponding model predictions by de Viron et al. (2005), and the phases do not agree with the model predictions. The detected semi-diurnal retrograde and prograde signals in polar motion are much larger than the model predictions due to atmospheric tides (Brzezinski et al., 2002). The detected prograde diurnal signal in polar motion agrees reasonably well with the sum of the model predictions based on non-tidal oceanic and atmospheric angular momentum effects (de Viron et al., 2002) and atmospheric tides (Brzezinski et al., 2002). However, there are no corresponding model predictions for the detected retrograde signal.

The detected signals in the UT1 residuals in the diurnal frequency band are much larger than the model predictions. No significant semi-diurnal or ter-diurnal signal can be detected.

5. Conclusions

The continuous VLBI CONT02 campaign produced high-resolution polar motion and UT1 results that allow to investigate high-frequency earth rotation variations. The Ray-model for earth rotation variations due to ocean tides explains the observed results to 40–60% for polar motion and about 80% for UT1. The remaining residuals are on the level of several tens of micro-arcseconds. So far they cannot be explained completely by models based to non-tidal angular momentum, atmospheric tides and luni-solar torques acting on the tri-axial earth. However, the diurnal signal detected in the polar motion residuals can partly be explained by models due to non-tidal angular momentum and atmospheric tides.

The CONT02 polar motion residuals reveal ter-diurnal variations with retro- and pro-grade amplitudes on the order of 40 μas. The oceanic M_3-model predictions by Wünsch (2001) are much smaller than the empirically derived amplitudes. We find a ter-diurnal period that is closer to S_3 than to M_3. However, the observed signals are much larger than the predictions by de Viron et al. (2005) that are based on atmospheric effects. Neither the oceanic M_3-model predictions nor the atmospheric S_3-model predictions can explain our observations.

We did observe signals in the diurnal frequency band in the UT1 residuals. The agreement with the theoretical models is poor and the empirical values are larger than the modeled ones. Future VLBI CONT campaigns will allow to continue this research.

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