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Investigations of High-Frequency Earth Rotation Variations from VLBI CONT Observations

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Abstract

Several theoretical models have been developed in the last decade that predict high-frequency earth rotation variations. These are induced for example by variations in the oceanic and atmospheric angular momentum. In order to investigate these geophysical phenomena, we compare observational results of polar motion and UT1 from the continuous VLBI series with these theoretical models. Also the different CONT campaigns observed in the years 1994, 1995 and 2002 are compared to each other. Different spectral analysis tools and wavelet analysis are used for the investigations.

1. Models for High-Frequency Earth Rotation Variations

High-frequency earth rotation variations are predicted by a number of theoretical models. These models are mainly based on oceanic and atmospheric dynamics and predict variations in polar motion and UT1 in the diurnal and semidiurnal frequency bands.

- Influence of oceanic tidal angular momentum:
  Oceanic tides and currents evoke oceanic tidal angular momentum, see e.g. [1]. Due to conservation of the total angular momentum of the earth-ocean system, changes in the earth's rotation are induced [2]. The oceanic tidal angular momentum can be modeled based on ocean tide models which are derived empirically from altimetric observations [3]. Earth rotation variations in the diurnal and semi-diurnal frequency bands with amplitudes of several tenths of μas are predicted.
- Influence of luni-solar gravitational tides:
  Variations in earth rotation are also induced due to the external luni-solar torques acting on the triaxial figure of the earth [4]. These torques cause small polar motion variations in the diurnal frequency band and small variations in UT1 in the semi-diurnal frequency band. All terms in these frequency bands with amplitudes larger than 0.5 μas are modeled.
- Influence of non-tidal oceanic angular momentum:
  Besides tidal influences, the oceanic angular momentum is influenced by non-tidal fluctuations in water height and currents [5]. These are partly caused by atmospheric wind and pressure variations. Diurnal variations in polar motion and UT1 with amplitudes on the order of several μas are modeled.
- Influence of atmospheric tides:
  Furthermore, thermal and tidal atmospheric tides cause variations in polar motion and UT1 [6]. These variations are in the diurnal and semi-diurnal frequency bands and have amplitudes on the order of some μas.

2. The VLBI CONT Campaigns and the Corresponding Data Analysis

In order to study the high-frequency earth rotation variations we analyzed the continuous VLBI campaigns CONT94, CONT95 and CONT02. These campaigns involved continuous VLBI observations between 7 and 14 days in dedicated multi-station VLBI networks. CONT94 was observed between January 12 and 25 in 1994, with a break of one day, CONT95 was observed between August 23 and 29 in 1995, and CONT02 was observed between October 16 and 31 in 2002. The three campaigns were analyzed using the CALC/SOLVE software [7]. Station coordinates were kept fixed to VTRF2003 [8], while radio source positions were kept fixed on ICRF [9]. Clock parameters relative to a reference clock in the network were estimated every 1 hour, atmospheric zenith wet delay parameters were estimated every 1 hour using the New Mapping Functions (NMF) [10] and horizontal delay gradients every 3 hours. Polar motion and UT1 values were estimated every 1 hour with respect to the IERS C04 series earth rotation parameters [11], and one pair of nutation corrections with respect to the IAU1980 model of nutation [12] was estimated for each 24 hour VLBI session. The resulting high-frequency earth rotation estimates with respect to the a priori values form the basis for further analysis using spectrum analysis tools.

3. Spectrum Analysis Tools

To investigate high-frequency signals in the observed time series of earth rotation parameters, spectum analysis tools can be applied. Since the CONT94 time series are not evenly sampled but have a one day gap, a usual Fourier analysis was not suitable. Instead, other spectrum analysis tools were applied that allow the analysis of unevenly sampled data, the Lomb Periodogram [13], the CLEAN algorithm [14] and Wavelet analysis [15].

- The Lomb Periodogram:

  The general expression for the normalized Lomb Periodogram is obtained from a linear least-squares estimation of the harmonic signal content. The algorithm works on a per-point basis and can be used for unevenly sampled, but not clumped data [13].

- The CLEAN algorithm:

  This algorithm uses a step-wise deconvolution of the signal to be analysed in order to avoid sampling effects on the derived spectrum. Thus, a considerable part of the noise resulting from the irregular sampling is removed [14]. The algorithm works on a per-interval basis and has a better performance than the Lomb Periodogram for unevenly sampled and highly clumped data sets.

- The Wavelet analysis:

  The Wavelet Transform allows both the detection of time varying amplitudes and frequencies, and a robust implementation for irregular sampling [15]. The Continuous Wavelet Transform (CWT) decomposes signals over a set of dilated and translated versions of a so-called mother wavelet. In geosciences the Morlet wavelet is often used which has quasi-compact support both in time and frequency domain and allows for adaptive time-frequency resolution. Furthermore, so-called cross-scalograms and the corresponding normalized coherence allow comparison of wavelet transforms of different signals [16].

4. Analysis Results

The time series of polar motion and UT1 derived from the three CONT VLBI campaigns were analyzed with the spectrum analysis tools described in Section 3. Figure 1 shows the spectra derived with the CLEAN algorithm. The three campaigns show similar spectral content with significant signal power in the diurnal and semi-diurnal frequency bands. However, the CONT95 campaign gives less resolution than the other two campaigns. The CONT02 campaign is the only campaign that reveals some signal power at a period of 8 hours for the Y-pole component.

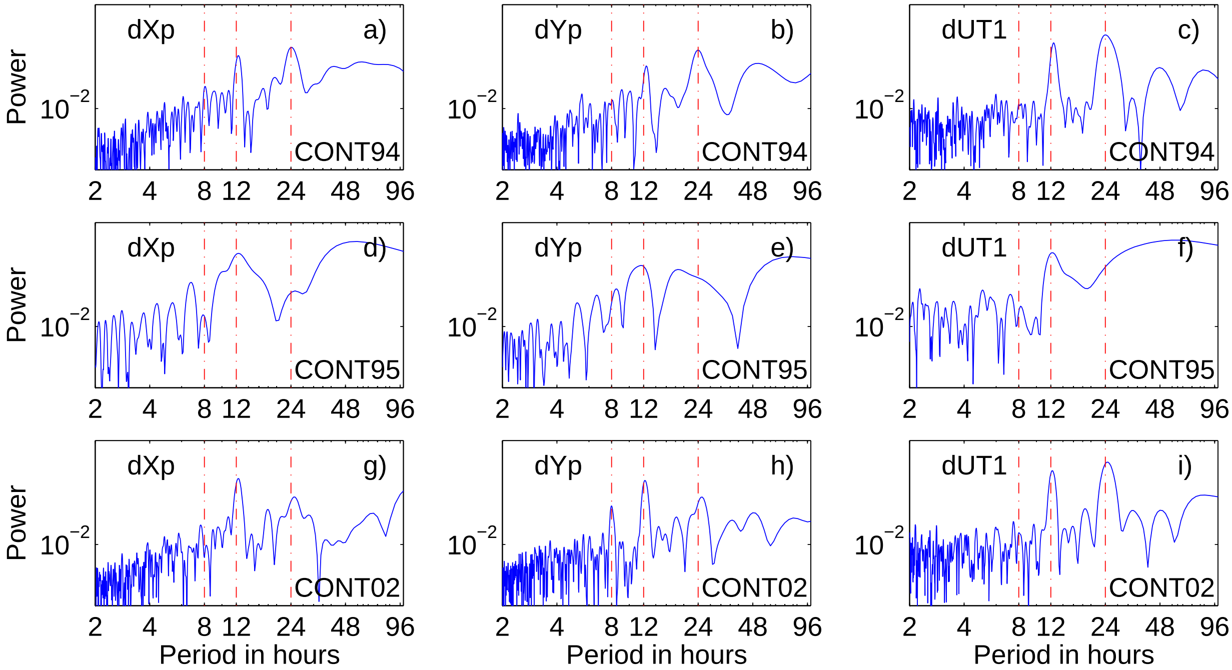

Figure 1. Spectra of polar motion and UT1 of the CONT campaigns derived with the CLEAN algorithm.

Figure 2 shows Lomb Periodograms for polar motion and UT1 during CONT02. The upper plots (a–c) show periodograms of the original CONT02 data (O.), while the lower plots (d–f) show periodograms of the original CONT02 data reduced by the theoretical model predictions (O.-M.). The horizontal lines indicate significance levels of 0.005 (dashed), 0.05 (dashed-dotted) and 0.5 (dotted). The theoretical models explain at least partly the detected signal power in the diurnal and semi-diurnal frequency bands. After removing the theoretical predictions from the observed data the diurnal and semi-diurnal signal power are reduced and the periodicity at about 8 hours for the Y-pole component becomes more clear and passes the significance level of 0.005.

Figure 3 shows Wavelet scalograms of the complex polar motion signal during CONT02 after removing the theoretical model predictions described in Section 1 from the data. The upper plots (a–b) show retrograde and prograde polar motion in the period interval 2–100 hours. Retrograde semi-diurnal, prograde semidiurnal and prograde diurnal signals are detected. The lower plots (c–d) zoom in into the period interval 5–10 hours. A retrograde signal at 8 hours is clearly visible, and there is also some prograde signal, though less clear. Polar motion variations with an 8 hour periodicity are predicted [17] based on an ocean tide model [18].

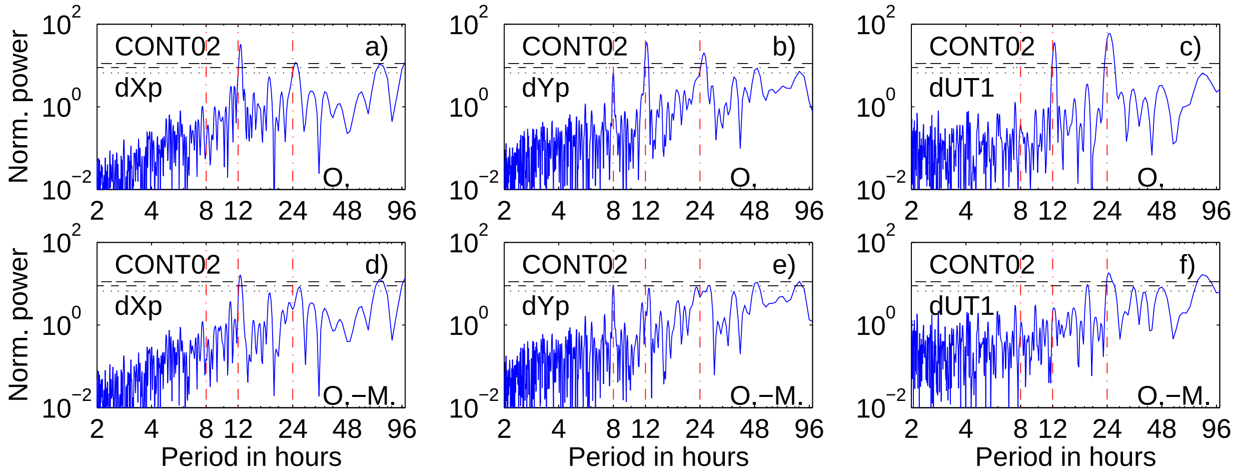

Figure 2. Lomb Periodograms of polar motion and UT1 during CONT02. See text for further explanations.

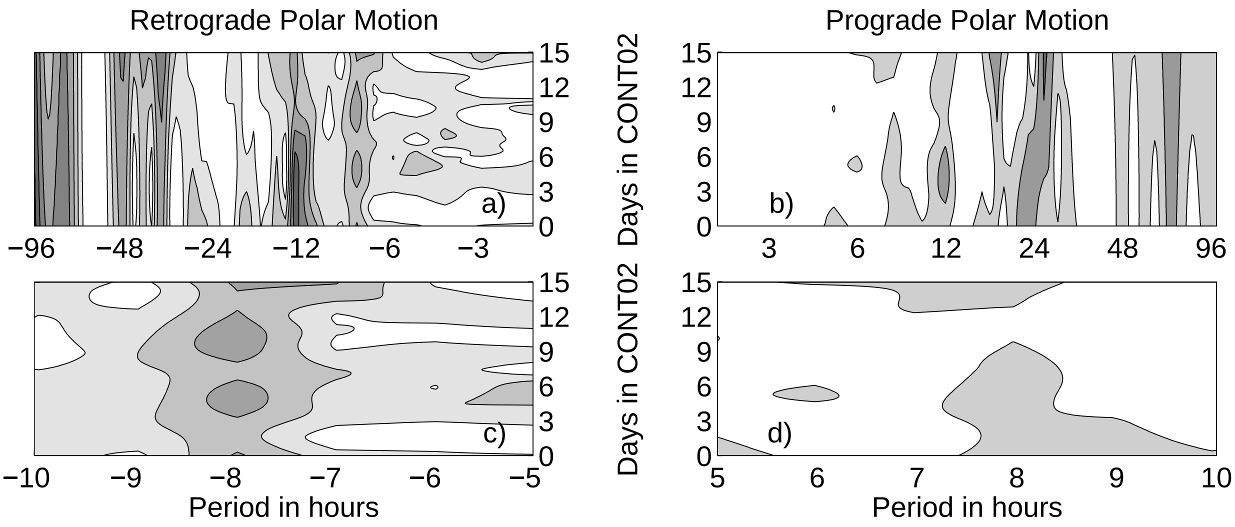

Figure 3. Wavelet scalograms of reduced polar motion during CONT02. See text for further explanations.

5. Conclusions and Outlook

The analysis of earth rotation parameters derived from the VLBI campaigns CONT94, CONT95 and CONT02 shows clearly that variations in the diurnal and semi-diurnal frequency bands exist. Different spectrum analysis tools give similar results, and the three campaigns also display similar signal content when compared to each other. However, the resolution of CONT95 is worse than for the other two campaigns, and only CONT02 shows a significant signal in polar motion with a periodicity of 8 hours. The existing theoretical models for high-frequency earth rotation variations partly explain the observed signals and signal power is reduced for these periods when the predictions are removed from the observations. Nevertheless, there is still remaining significant signal power at some periods and for some earth rotation parameters. The CONT02 campaign reveals signal power for retrograde and prograde polar motion around 8 hours period. We plan to continue the investigations concerning high-frequency earth rotation variations. Future continuous VLBI campaigns with high data quality will be very helpful for this work.

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