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SUB-DIURNAL EARTH ROTATION VARIATIONS OBSERVED BY VLBI

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ABSTRACT. We analyse sub-diurnal Earth rotation variations obtained from the continuous VLBI experiments CONT02, CONT05, and CONT08. We find that the Earth rotation parameters estimated from these campaigns contain signals with periods ±12 hours, +24 hours, and in CONT02 also −8 hours, which cannot be explained by the current IERS sub-diurnal pole model. We investigate if these signals could be caused by atmospheric excitations, but find that these excitations are too small.

Keywords: Earth Rotation, VLBI

1. INTRODUCTION

The rotation of the Earth is varying at different time scales: from sub-daily periods up to several decades. These variations are caused by excitations of the Earth rotation by different sources, for example the atmosphere and the oceans. For variations at diurnal and sub-diurnal scales the most important excitations are those caused by ocean tides. By using ocean tidal models it is possible to generate a model of the diurnal and sub-diurnal Earth rotation variations (Ray et al., 1994).

Variations in Earth rotation can be measured by space geodetic techniques like the Global Navigation Satellite Systems (GNSS), Satellite Laser Ranging (SLR), and Very Long Baseline Interferometry (VLBI). Of these VLBI is the only technique able to determine the full set of Earth Orientation Parameters (EOP), i.e. polar motion, Universal Time (DUT1=UT1-UTC), and nutation/precession. Normally, there are only two or three 24-hour VLBI sessions per week, and the participating radio telescopes change between the sessions. However, occasionally special continuous VLBI campaigns over 15 days have been performed within the International VLBI Service for Geodesy and Astrometry (IVS) (Schlüter and Behrend, 2007), the so-called CONT campaigns. These campaigns provide excellent data for studying diurnal and sub-diurnal EOP variations. In this work we investigate the sub-diurnal EOP variations estimated from the last three CONT campaigns: CONT02, CONT05, and CONT08. For a more detailed description of these campaigns, see e.g. Artz et al. (2010).

2. DATA ANALYSIS

The data from the CONT campaigns were analysed by the Vienna VLBI Software (VieVS) (Boehm et al., 2009). VieVS is a new VLBI data analysis software being developed at the Vienna University of Technology. It is based on classical least-squares adjustment and it implements the latest IERS (International Earth Rotation and Reference System Service) Conventions (McCarthy and Petit, 2004). First, we analysed each 24-hour session individually. Then, for each campaign, we stacked the normal equations of all the 15 sessions in the campaign. This was done in order to get a continuous time series for the EOP (and other parameters like the tropospheric delays). In the analysis station clock offsets, zenith wet delays, and tropospheric gradients were estimated with resolutions of 1 hour, 30 minutes, and 2 hours, respectively. One set of station coordinates per CONT campaign was estimated, using a no-net translation/no-net rotation condition relative to VTRF2008 (VLBI Terrestial Reference Frame 2008) (Böckmann et al., 2010). The radio sources were fixed to their ICRF2 (International Celestial Reference Frame 2) positions (Fey et al., 2009).

The EOP (i.e. polar motion, DUT1, nutation) were estimated as piece-wise linear functions in one hour intervals. However, in order to estimate EOP with such a high resolution we need to apply constraints or conditions to separate polar motion and nutation; otherwise the problem will be ill-conditioned due to the high correlations that exist between polar motion and nutation when these are estimated with sub-daily resolution (Tesmer et al., 2001). In fact, from the VLBI analysis it is impossible to distinguish a retrograde diurnal polar motion signal from a constant nutation offset (more generally, a polar motion signal is indistinguishable from a nutation signal with a frequency 1 cycle per day higher). Because of this, the Celestial Intermediate Pole (CIP) has been defined to have no nutation signals with periods shorter than two days (Capitaine, 2002). Correspondingly, by definition there should not be any retrograde polar motion signals with periods between −48 and −16 hours. The problem is to implement this condition in the data analysis. One way to do this is to apply constraints to suppress certain frequencies (Hefty et al., 2000). However, only specific frequencies can be blocked by this method, not a whole frequency band. Another approach is simply to fix nutation to good a priori values (see e.g. Artz et al., 2010), but any error in these values will cause an error in polar motion.

In this work we use another approach. The pole coordinates x_p and y_p at time t can equivalently be described by a Fourier series:

$$x_p(t) = \sum_{k=0}^{N-1} \left[a_k \cos(\omega_k t) + b_k \sin(\omega_k t)\right], \quad (1)$$

$$y_p(t) = \sum_{k=0}^{N-1} \left[-a_k \sin(\omega_k t) + b_k \cos(\omega_k t)\right], \quad (2)$$

where $\omega_k = 2\pi\,(k - N/2)/T$, N the number of estimation epochs, and T the length of the CONT campaign (e.g. 15 days). Similarly, we can express the nutation offsets (dX and

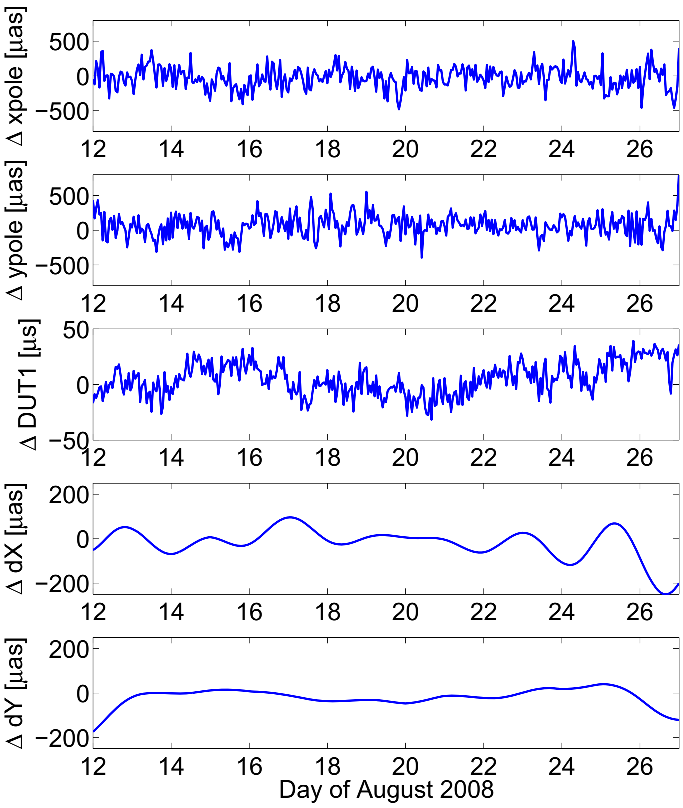

Fig. 1. Polar motion, DUT1, and nutation estimated from CONT08.

dY) as:

$$dX(t) = \sum_{k=0}^{N-1} \left[c_k \cos(\omega_k t) - d_k \sin(\omega_k t) \right], \quad (3)$$

$$dY(t) = \sum_{k=0}^{N-1} \left[c_k \sin(\omega_k t) + d_k \cos(\omega_k t) \right]. \quad (4)$$

We use this representation of polar motion and nutation by Fourier series in the least-squares adjustment, i.e. we estimate a_k, b_k, c_k, and d_k instead of x_p, y_p, dX, and dY. Thus it is simple to block the frequencies that should be zero in the CIP. We just force a_k and b_k to be zero for $-3\pi < \omega_k < -\pi$, and c_k, and d_k to be zero for $-\pi < \omega_k < \pi$, in the least-squares adjustment.

3. RESULTS

Figure 1 shows the estimated EOP from the CONT08 campaign. From this time series we have removed the EOP from the IERS 05 C04 series (Bizouard and Gambis, 2009) as well as the IERS recommended model for high frequency Earth rotation variations (McCarthy and Petit, 2004) which is an extended version of the model of Ray et al. (1994). Thus, what remains are mostly the errors in the IERS model as well as the noise in the EOP estimates. From figure 1 it can be seen that the nutation offsets (dX

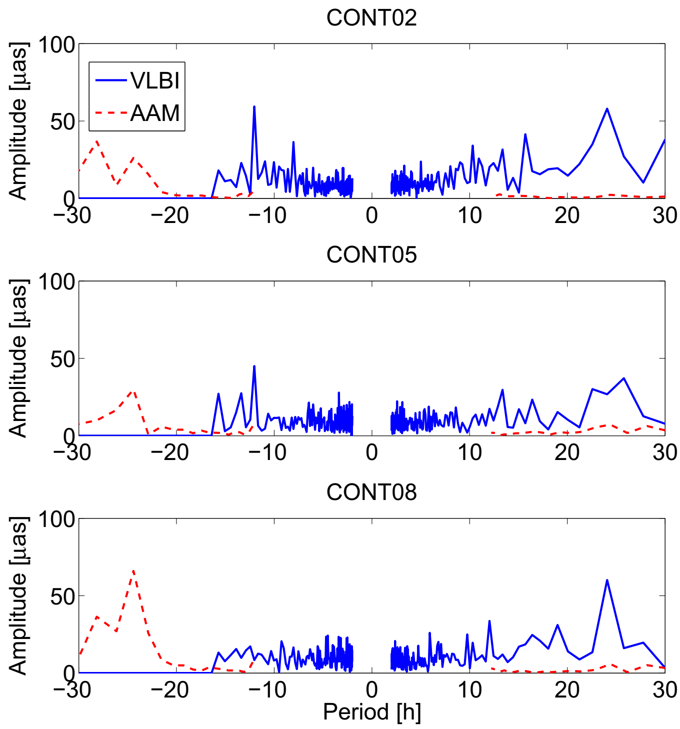

Fig. 2. Polar motion spectra from CONT02, CONT05, and CONT08 estimated from VLBI data and from Atmospheric Angular Momentum (AAM) data.

and dY) are varying very slowly in time. This is because the high frequencies in the nutation (< 48 h) have been blocked in the estimation procedure. The polar motion and DUT1, however, contain high frequency variations. In the following investigations of the sub-diurnal EOP variations we only show the results for polar motion and DUT1, since nutation does not contain any signals with periods shorter than two days.

Figure 2 shows the Fourier spectra of $p = x_p - i\,y_p$ for CONT02, CONT05, and CONT08. As the IERS sub-diurnal pole model has been subtracted from the time series we would not expect to see any significant signal if this model would be correct. However, there are several different periodic signals in the spectra, typically at the periods +24 h and ±12 h. In CONT02 there is also a strong signal at −8 h which cannot be seen in any of the other campaigns. Also a signal with period +6 h can be noticed in CONT08, although it is hardly significant. The 8 h retrograde signal was commonly seen in other investigations of sub-diurnal EOP from CONT02 (Haas and Wünsch, 2006; Nastula et al., 2007; Artz et al., 2010). Models predicting ter-diurnal polar motion exist, but the predicted magnitude is much lower than what can be seen in the CONT02 spectrum (e.g. de Viron et al., 2005; Haas and Wünsch, 2006). Artz et al. (2010) also noted signals with six-hour periods in CONT08.

One possible reason for the signals in the spectra could be that they are caused by other excitations than ocean tides and thus not being modelled in the IERS sub-daily pole model. For example, there could be excitations by the atmosphere. We investigate this by analysing time series of Atmospheric Angular Momentum (AAM) estimated from ECMWF data (Boehm et al., 2008). To calculate the contribution from the atmosphere to

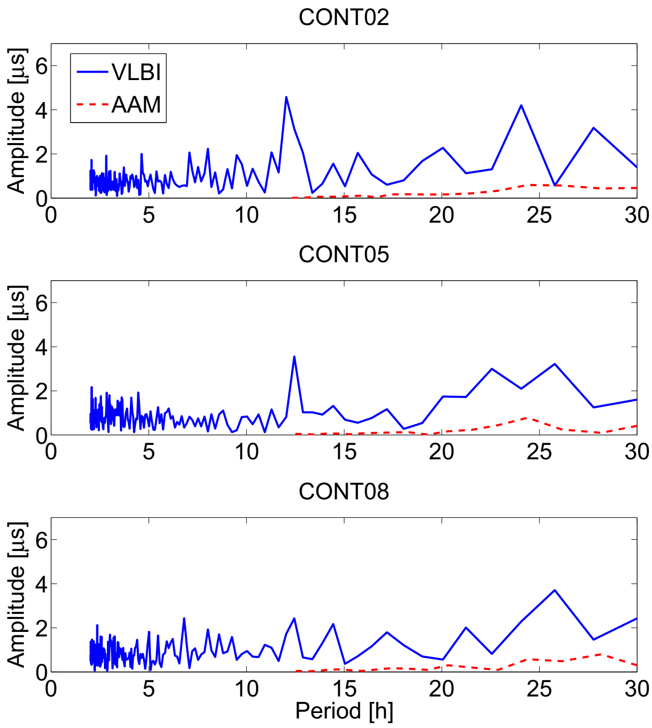

Fig. 3. DUT1 spectra from CONT02, CONT05, and CONT08 estimated from VLBI data and from Atmospheric Angular Momentum (AAM) data.

polar motion we used the transfer functions presented by Brzezinski (1994). The spectra of the atmospheric contribution are also plotted in figure 2. The contribution is much lower than what is estimated from VLBI except in the retrograde diurnal band. However the excitation at these frequencies will go into the nutation and not to polar motion. It should be noted that the AAM time series only have 6 h resolution, thus we will have aliasing problems if there are signals with periods shorter than 12 h present in the AAM time series (according to the Nyquist theorem). For example, an 8 h retrograde signal would show up in the spectra as a 24 h prograde signal. However, since the −8 h signal in CONT02 is much smaller than what is seen in the AAM spectrum at +24 h for this campaign, it is very unlikely that this signal is mainly of atmospheric origin.

Figure 3 shows the Fourier spectra of the estimated DUT1 values, along with the contribution from the atmosphere. Also here maxima at periods of 12 and 24 h exist. As in the case of polar motion we find that the contribution from the atmosphere is much too small to explain the signals in the spectra.

5. CONCLUSIONS

We have investigated the sub-diurnal EOP variations for three continuous VLBI campaigns. The observed variations cannot completely be described by the IERS sub-diurnal Earth rotation model, which seems to be not accurate enough. This can either be due to inaccurate modelling of the effect of ocean tides on Earth rotation, or due to other sources causing sub-diurnal Earth rotation variations. As seen from the investigation of the AAM data there is a small contribution from the atmosphere, although it is too small to explain most of the observed variations. Finally, it should be noted that the signals seen in the spectra of the VLBI data could also be caused by systematic error in the VLBI data analysis.

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