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Prospects for UT1 Measurements from VLBI Intensive Sessions

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Abstract

Very Long Baseline Interferometry (VLBI) Intensives are one-hour single baseline sessions to provide Universal Time (UT1) in near real-time up to a delay of three days if a site is not e-transferring the observational data. Due to the importance of UT1 estimates for the prediction of Earth orientation parameters, as well as any kind of navigation on Earth or in space, there is not only the need to improve the timeliness of the results but also their accuracy. We identify the asymmetry of the tropospheric delays as the major error source, and we provide two strategies to improve the results, in particular of those Intensives which include the station Tsukuba in Japan with its large tropospheric variation. We find an improvement when (1) using ray-traced delays from a numerical weather model, and (2) when estimating tropospheric gradients within the analysis of Intensive sessions. The improvement is shown in terms of reduction of rms of length-of-day estimates w.r.t. those derived from Global Positioning System observations.

1. Introduction

Very Long Baseline Interferometry (VLBI) is the primary technique for the determination of the Earth Orientation Parameters (EOP), in particular for nutation and Universal Time (UT1). Typically, 24-hour VLBI sessions with five to eight participating stations are observed on about three days per week to provide the EOP with a latency of about two weeks and a UT1 accuracy of approximately 6 to 7 μs. Additionally, so-called one-hour Intensive sessions are observed every day to provide UT1 with latencies between 3 minutes and 3 days. These Intensive sessions usually only contain single baseline observations and yield UT1 estimates with an accuracy of about 15 μs when compared to the IERS 05 C04 series (Bizouard and Gambis, 2009, [1]) from the International Earth Rotation and Reference Systems Service.

So-called INT1 sessions are observed from Monday to Friday on the baseline Wettzell (Germany) - Kokee Park (Hawaii, U.S.A.) at 18:30 UT, INT2 sessions from Saturday to Sunday on the baseline Wettzell - Tsukuba (Japan) at 7:30 UT, and additionally INT3 sessions on Monday at 7:00 UT between Wettzell, Tsukuba, and Ny-Ålesund (Spitsbergen, Norway). UT1 estimates in near-real time are crucial for the prediction of EOP, and EOP in real-time are needed for any kind of navigation and positioning on Earth and in space. In particular, the prediction of Global Navigation Satellite Systems (GNSS) orbits benefit from better EOP prediction. Luzum and Nothnagel (2010, [8]) have shown that there is an improvement of 50% in rapid combination and 20% in short term prediction if UT1 estimates are available in near real-time, which is the case for INT3 sessions and in the foreseeable future also for INT1 and INT2 sessions. In this paper, we do not assess questions of timeliness, but we discuss the accuracy of UT1 estimates from Intensive sessions.

2. VLBI Analysis

We analyzed all Intensive sessions of the International VLBI Service for Geodesy and Astrometry (IVS; Schlüter and Behrend, 2007, [12]) from 2007.0 to 2010.0 with the Vienna VLBI Software (VieVS, Böhm et al., 2010a, [3]). Station and source coordinates were fixed to VTRF2008 (Böckmann et al., 2010, [2]) and ICRF2 (Fey et al., 2009, [6]), respectively. We fixed nutation offsets and polar motion to the values provided in the IERS 05 C04 series and modeled the high-frequency variations in polar motion as recommended by the IERS Conventions 2003 (McCarthy and Petit, 2004, [9]). Five parameters were estimated for each single baseline Intensive session: offset and rate between the clocks, one zenith wet delay offset at each station, and one UT1 offset parameter. In the standard solution, no gradients were applied (neither a priori nor as estimated parameters), nor did we use a cutoff elevation angle or downweighting of low observations. Figure 1 shows UT1 estimates for the INT1 and INT2/3 sessions. (We treat the INT2 and INT3 sessions as one common series INT2/3).

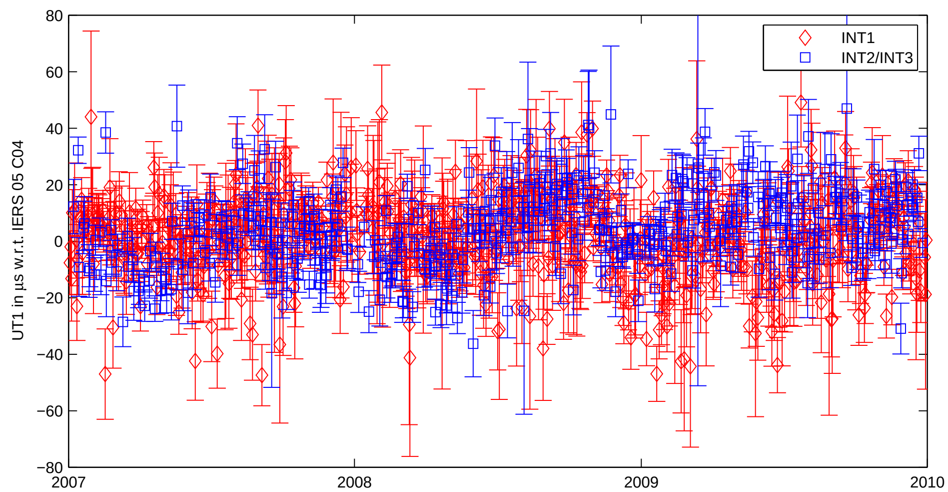

Figure 1. UT1 estimates and formal errors from IVS Intensive sessions from 2007.0 to 2010.0 w.r.t. IERS 05 C04.

We analyzed 675 INT1 sessions and 393 INT2/3 sessions from January 2007 until December 2009, from which we had to remove 17 and 9 sessions as outliers, respectively (with estimates larger than $\pm$ 50 μs or uncertainties larger than 100 μs). The median biases are 2.4 and 3.7 μs, and the rms values of the UT1 estimates are 15.0 and 14.7 μs w.r.t. the IERS 05 C04 series. On the other hand, the formal uncertainties are 10.9 and 7.3 μs, which suggests that modeling deficiencies exist and need to be investigated.

A discussion of the influence of nutation and polar motion errors on UT1 estimates from Intensive sessions was provided by Nothnagel and Schnell (2008, [11]) who report maximum values of 30 μs in UT1 per mas in nutation or polar motion. However, when using sophisticated forecasts of daily polar motion (e.g., from the International GNSS Service IGS) and nutation offsets (e.g., from the IERS), this is a minor error source. Presently more important is the high-frequency model for polar motion, which has a significant impact on UT1 estimates from Intensive sessions. Figure 2 shows the differences in UT1 when using the empirical model as provided by Englich et al. (2008, [5]) w.r.t. to applying the model recommended by the IERS 2003 Conventions (McCarthy and Petit, 2004, [9]). In recent years, general awareness has grown that there is a need to replace the IERS 2003 model ('Eanes model') by an improved high-frequency model which is either determined empirically from observations, from improved ocean models, or from a combination of both. With such a new model, the a priori high-frequency polar motion will contribute less as an error source to the determination of UT1 from Intensive sessions.

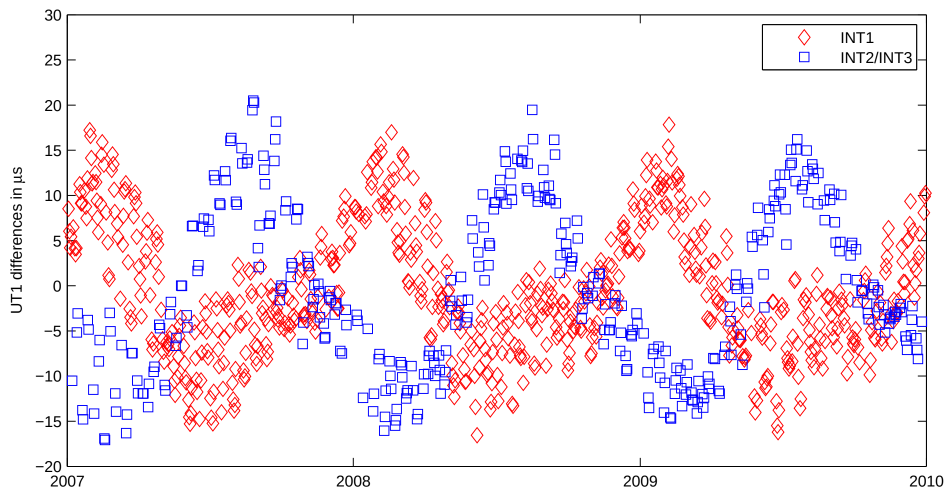

Figure 2. UT1 differences in μs when using the empirical model by Englich et al. (2003) for polar motion instead of the IERS 2003 'Eanes' model.

Unlike the error sources described above, asymmetries in the tropospheric delays cannot be accounted for easily. Böhm et al. (2010b, [4]) show that the influence of those asymmetries of the tropospheric delays on UT1 estimates from Intensive sessions is about ± 10 μs but can be as large as 50 μs during extreme weather conditions. As a rule of thumb, an unmodeled east gradient of 1 mm (= sum of total east gradients at both stations) causes UT1 to change by about 15 μs. Considering that gradients can reach values of up to 3 mm (corresponding to about 0.3 m delay at 5 degrees elevation) this is a very large error source, which needs to be considered. Böhm et al. (2010b, [4]) investigated the application of external information about tropospheric delays for the analysis of INT2 sessions, and they found a slight improvement when applying ray-traced delays at Tsukuba (Hobiger et al., 2008, [7]). Since the IERS 05 C04 series is not good for comparison as they already contain information from a standard analysis of Intensive sessions (Bizouard and Gambis, 2009, [1]), Böhm et al. (2010b, [4]) compared length-of-day (LOD) between two Intensive sessions on consecutive days to LOD derived from Global Positioning System (GPS) observations, and the rms of LOD decreased from 23.7 to 22.8 μs for a sample of 70 LOD values when using ray-traced delays.

3. Estimation of Gradients

Nilsson et al. (2010, [10]) investigated single baseline observations over time spans of two hours that were extracted from CONT08, which was a special VLBI campaign over 15 days in August 2008 to demonstrate the best accuracy that can presently be achieved with VLBI. This procedure allowed Nilsson et al. (2010, [10]) not only to have optimum reference values for UT1 from the full CONT08 solution but also to have good a priori values for zenith wet delays or gradients. However, one of their findings was that there is an improvement in the estimation of UT1 when gradients are estimated from those single baseline two-hour sessions, in particular when Tsukuba is one of the observing stations.

Although the number of observations is small (below 30), we followed the findings by Nilsson et al. (2010, [10]) and tested the estimation of gradients in 'real' IVS Intensive sessions. In a first run, we estimated north and east gradient offsets which are constrained to zero by ±1 mm. In a second test, we only estimated east gradient offsets (constrained to zero by ±1 mm), because the east component is most important for UT1. The constraints are necessary to avoid singularity of the normal equation matrix. As already mentioned above, a quality assessment of the UT1 estimates cannot be done by comparison to the IERS 05 C04 values because the latter already contain UT1 information from a standard solution of IVS Intensive sessions without the estimation of gradients. Thus, we again compare LOD values from Intensive sessions on consecutive days to LOD values from the GPS solution as provided by the Center for Orbit Determination (CODE) in Bern. Table 1 shows that we find a considerable improvement when estimating gradients in the INT2 sessions, and even more improvement when only estimating east gradients. The reduction in rms of LOD values is from 24.1 to 21.6 μs when estimating east gradients at Tsukuba and Wettzell in the INT2 sessions. On the other hand, there is hardly any improvement when estimating gradients in INT1 sessions. This is due to the fact that the largest gradients are at Tsukuba, which also confirms the findings by Nilsson et al. (2010, [10]).

Table 1. Rms of UT1 and LOD w.r.t. IERS 05 C04 and GPS, respectively. Considerable improvement is found for the rms of LOD w.r.t. LOD from GPS when only east gradients are estimated.

	rms w.r.t. UT1 from IERS 05 C04		rms w.r.t. LOD from GPS	
	INT1	INT2/3	INT1	INT2/3
samples	657	384	258	224
no gradients	15.0 μs	14.7 μs	27.6 μs	24.1 μs
north and east gradients	16.1 μs	15.6 μs	27.9 μs	22.3 μs
east gradients	16.2 μs	15.9 μs	27.0 μs	21.6 μs

4. Summary and Outlook

We discussed possible error sources for the estimation of Universal Time (UT1) from Intensive sessions, and we identified the asymmetry of tropospheric delays as one—if not the most important—of these error sources. Although the number of observations is typically small (below 30) we found an improvement when estimating (constrained east) gradients in INT2 sessions including Tsukuba. In future investigations we will determine the improvement when estimating east gradients only at one station (e.g., Tsukuba). Complementarily, we recommend to continue the research in using ray-traced delays for the analysis of IVS Intensive sessions. In future accuracy assessments we plan to use different UT1 reference series, e.g., a Kalman Filter series which does not include information from IVS Intensive sessions (Ray, 2010, personal communication).

5. Acknowledgements

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