European Intensive Sessions for the Estimation of UT1

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Abstract Global Navigation Satellite Systems (GNSS), such as the United States GPS, the Russian GLONASS, or the European Galileo, require accurate information about the difference between Universal Time 1 and Coordinated Universal Time (UT1–UTC) in real time for positioning and navigation purposes. This parameter can only be determined with Very Long Baseline Interferometry (VLBI), and the International VLBI Service for Geodesy and Astrometry (IVS) is providing UT1–UTC on a daily basis as derived from so-called one-hour Intensive sessions on long east-west baselines. Additionally, the U.S.A. and Russia run their own Intensive sessions and are thus not fully dependent on the UT1–UTC values from the IVS. We present the idea of European Intensive sessions on a baseline between Santa Maria (Azores, Spain) and Wettzell (Germany) and conclude from Monte Carlo simulations that we can achieve accuracies better than 40 microseconds. Real experiments to confirm those simulations are currently ongoing.

Keywords Intensive sessions, UT1–UTC, Galileo

1 Introduction

With the direct access to the International Celestial Reference Frame (ICRF), Very Long Baseline Interferometry (VLBI) is the only technique for the determination of Universal Time 1 (UT1), i.e., the Earth rotation angle with respect to Atomic Time (TAI) or the Coordinated Universal Time (UTC). The availability of this parameter with highest accuracy is essential for positioning and navigation applications on Earth and in space, because an error of one millisecond in UT1–UTC corresponds to an error of 0.5 meters at the equator and kilometers and more at distances to other planets like Mars. Satellite techniques like the Global Navigation Satellite Systems (GNSS) or Satellite Laser Ranging (SLR) are not capable of determining this parameter on their own because of the correlation of the ascending node of the satellite orbits and the Earth rotation angle which cannot be properly resolved.

The International VLBI Service for Geodesy and Astrometry (IVS) is providing UT1–UTC values, either determined from 24-hour sessions two to three times per week with an accuracy of 5 µs and a product delivery time of more than a week, or from special one-hour long Intensive sessions on a daily basis with an accuracy of 15–20 µs and a product delivery time of a day (Schlüter and Behrend, 2007 [7]). For the latter, the IVS is using long east-west baselines: currently Wettzell (Germany) to Kokee Park (Hawaii, U.S.A.) from Monday to Friday and Wettzell to Ishioka (Japan) from Saturday to Monday including Ny-Ålesund (Norway) and the northern dish of the new twin radio telescope in Wettzell on Monday.

Additionally, the U.S.A. and Russia are running their own national VLBI Intensive sessions for their GNSS, namely GPS and GLONASS, and are thus not fully dependent on UT1–UTC values from the IVS. In particular, the U.S.A. is using the Very Long Baseline Array (VLBA) with baselines from Mauna Kea (Hawaii) to stations Pie Town or Los Alamos, both in New Mexico. Now, they are considering additional

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baselines including St. Croix on the Virgin Islands (Geiger et al., this issue). Russia runs the Quasar network for the determination of UT1–UTC with the stations Badary in the Karachaevo-Cherkessian Republic, Svetloe in the Leningrad Province, and Zelenchukskaya in the Buryatiya Republic. Figure 1 depicts those baselines and Table 1 lists the baseline lengths.

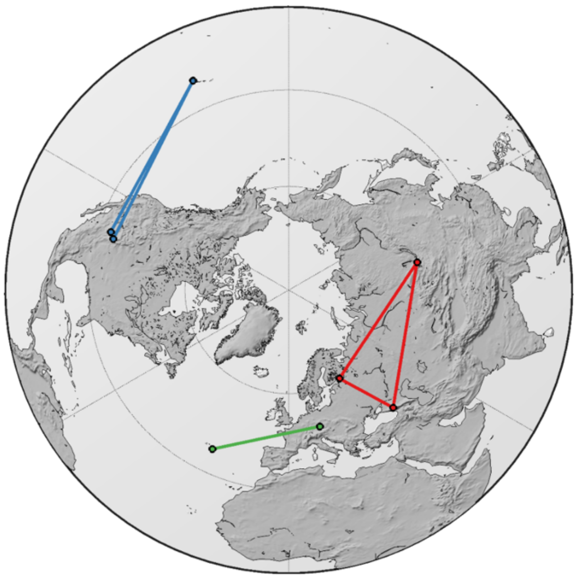

Fig. 1 VLBA baselines used by the U.S.A. (in blue) and the Russian Quasar baselines (in red). Additionally, the European baseline between Santa Maria (Azores) and Wettzell (Germany) is displayed in green.

Table 1 Lengths of the baselines illustrated in Figure 1.

From	To	Length
Mauna Kea	Pie Town	4,796 km
Mauna Kea	Los Alamos	4,970 km
Pie Town	Los Alamos	237 km
Badary	Zelenchukskaya	4,405 km
Badary	Svetloe	4,282 km
Zelenchukskaya	Svetloe	2,015 km
Santa Maria	Wettzell	3,286 km

In Europe, however, there is no similar dedicated activity for Galileo. Thus, we are investigating the possible use of a European baseline for the determination of UT1–UTC from daily one-hour Intensive sessions. In particular, we are considering observations on the baseline Santa Maria on the Azores (Sa) to the northern dish of the new twin radio telescope in Wettzell (Wn) with a baseline length of 3,286 km (Figure 1). This baseline is shorter than the longest baselines in the other networks listed in Table 1. While from a geometrical point of view with the need of a long east-west baseline for the determination of UT1–UTC, it is not as suitable as the other baselines; we can expect a better common visibility of the sky. Moreover, both telescopes are very fast antennas in the VGOS-style (Petrachenko et al., 2009 [6]) with slew rates of 360 and 720 degrees per minute in elevation and azimuth, respectively, allowing for short slewing times and a high number of observations. The diameters of the dishes with 13.2 m are smaller for Sa and Wn, thus yielding higher System Equivalent Flux Densities (SEFD) with reduced sensitivity. However, this should not be a disadvantage if strong sources are selected for observation when scheduling. Technical details of the radio telescopes are summarized in Table 2. The radio telescopes Sa and Wn are currently equipped with S/X/Ka-receivers but will be equipped with broadband receivers in the coming years. In this study, for simulations and real observations, observations at X- and S-band are used.

Table 2 Technical specifications of the radio telescopes in the VLBA and the Quasar network as well as for the telescopes Santa Maria (Sa) and the northern dish of the Wettzell twin telescope (Wn).

	VLBA	Quasar	Sa	Wn
Diameter in m	25	32	13.2	13.2
Slew rate az. in deg/min	90	60	720	720
Slew rate el. in deg/min	30	30	360	360
SEFD X-band in Jy	500	400	1600	1400
SEFD S-band in Jy	400	600	1700	1050

In the following sections, we describe simulations for European Intensive sessions in comparison to IVS Intensive sessions and present the current state of real observations on the baseline Santa Maria to Wettzell. Finally, we discuss future plans and opportunities with these new observations.

2 Monte Carlo Simulations

Many different schedules for the European Intensive sessions are generated with the scheduling tool (Schartner et al., this issue) of the Vienna VLBI and Satellite

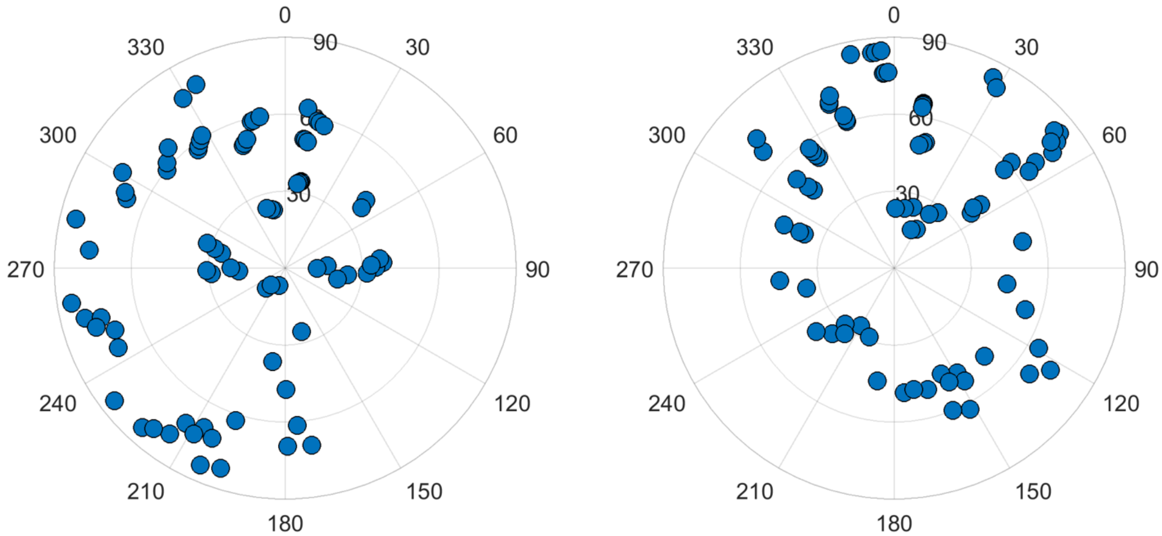

Fig. 2 Skyplot for the stations Wn (left) and Sa (right) of a one-hour European Intensive session. Due to the relatively short baseline we achieve a good sky distribution.

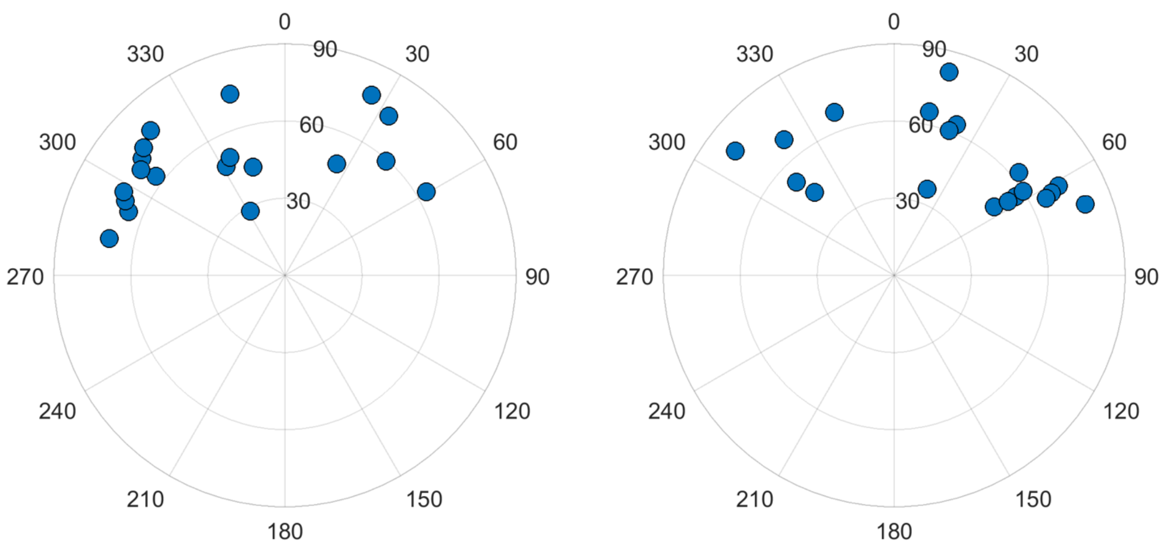

Fig. 3 Skyplot for the stations Wettzell and Kokee of an IVS Intensive session. Due to the long baseline of more than 10,000 kilometers, the part of the sky seen by both telescopes is rather small. On the other hand, from a geometrical point of view, a longer baseline is more sensitive to UT1.

Software (VieVS; Böhm et al., 2018 [1]). We assume a recording rate of 1 Gbit/s for observations in X- and S-Band and finally come up with 396 different schedules, differing in terms of weighting the parameters of sky coverage, scan duration, and minimum allowed source repeatability, and in terms of start time, which has a significant effect on the selection of sources. Without going into details here we want to stress that we are able to schedule 75 to 80 scans within one hour, which is considerably more than the current number of scans in IVS Intensive sessions (25 to 30 scans). The skyplots for one European session on the baseline Sa to Wn are shown in Figure 2, while the skyplots for a standard IVS Intensive session on the baseline Wettzell to Kokee are displayed in Figure 3 for comparison.

Based on the 396 schedules, 300 realizations are generated per schedule using a structure constant C_n of $1.8 \cdot 10^{-7} m^{-1/3}$ and a scale height of 2 km for the description of tropospheric turbulence, an Allan Standard Deviation of 10^{-14} at 50 minutes for the clocks and a white noise of 30 picoseconds per observation (Pany et al., 2011 [5]). The analysis of the simulated observations is also carried out with VieVS fixing station and source coordinates along with a priori values of polar motion and nutation. We estimate one linear clock between the two stations, constant zenith wet delay offsets for the stations, and a constant value of UT1–UTC for the session. Due to the higher number of scans and the good sky coverage for the European baseline, we also test the estimation of zenith wet delays every 30 minutes as piecewise linear offsets and the additional estimation of constant tropospheric gradients per station and session. Table 3 summarizes the simulation results in terms of repeatability and formal error. There is a notable decrease in the difference between repeatability and formal error when estimating a larger number of parameters and we reach a repeatability of less than 30 µs when estimating gradients.

Table 3 Results of UT1–UTC from simulated European Intensive sessions. The values are based on 396 (schedules) times 300 (realizations) sessions and different parametrization in terms of zenith wet delays (ZWD) and gradients.

	Repeatability	Mean formal error
60 min ZWD	34.6 µs	15.9 µs
30 min ZWD	33.0 µs	15.4 µs
60 min ZWD and gradients	26.9 µs	20.5 µs
30 min ZWD and gradients	26.3 µs	20.1 µs

In order to better assess and understand the numbers in Table 3, we also carry out identical Monte Carlo simulations for observed schedules of IVS Intensive sessions between Wettzell and Kokee. Based on the same simulation parameters and 300 realizations, we find a repeatability of 16.6 µs and a mean formal error of 12.7 µs. From comparisons against UT1–UTC parameters from 24-hour sessions during CONT08, Nilsson et al. (2011 [4]) found RMS values of about 23 µs, i.e., 40% above the repeatability of the simulated sessions. If we apply the same ratio on the repeatabilities of the European Intensive sessions, we arrive at UT1–UTC values better than 40 µs.

3 Real Experiments

After a first session on March 1, 2018 (V012), a series of six one-hour test experiments were observed between Sa and Wn in April and May 2018. Santa Maria (Sa) is a new station with first light in early 2018, and unfortunately our observations in April and May are affected by low SNR at X-band. On the other hand, we could use X-band data (without S-band data) of session V012 to work on the procedures necessary to derive UT1–UTC. We correlated the session with DiFX (Deller et al., 2007 [2]) on the Vienna Scientific Cluster (VSC-3) (Gruber et al., this issue) and used HOPS/Fourfit for fringe-fitting the data before writing vgosDB files with VieVS for 73 scans. However, at this stage the estimation of UT1–UTC is not yet possible, because we do not have accurate station coordinates of Sa and we lack the S-band information for the ionosphere calibration.

4 Conclusions and Outlook

Sophisticated simulations suggest that we can derive UT1–UTC from a European baseline between Santa Maria and Wettzell with an accuracy better than 40 µs. Although this is worse compared to standard IVS Intensive sessions, European Intensive sessions present a very valuable alternative or backup solution with even greater value if provided in near real time. Luzum and Nothnagel (2010 [3]) have demonstrated the positive impact on combination and prediction products of the International Earth Rotation and Reference Systems Service (IERS), if UT1–UTC estimates from Intensives between Wettzell, Tsukuba (Japan), and Ny-Ålesund are available eight hours after observation.

Currently, we are observing new test experiments of European Intensive sessions and we are optimistic to sort out final technical problems. We will then be able to estimate station coordinates of Sa and to determine a time series of UT1–UTC to finally confirm the expected accuracy. Thereafter, we will look into improved turnaround times between the observation and the provision of results. For example, Sekido et al. (2008 [8]) have reduced the turnaround time for Intensives between Kashima in Japan and Onsala in Sweden to less than 30 minutes. Of course, the availability of accurate polar motion values for the analysis becomes a critical factor then.

In combination with length-of-day and polar motion values from GNSS and with forecast geophysical angular momentum functions, UT1–UTC values from European Intensives in near real time will certainly be a very valuable contribution to combined and predicted Earth orientation parameters.

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