Current status of VLBI Intensive sessions
Aktueller Status von VLBI Intensive sessions

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Abstract

Very Long Baseline Interferometry (VLBI) is the only space-geodetic technique capable of determining the full set of Earth Orientation Parameters (EOP) and celestial reference frames and it makes important contributions to the realisation of terrestrial reference frames. Standard VLBI sessions with a duration of 24 hours are usually observed on Mondays and Thursdays with a global network of up to 15 stations. Due to the large number of observations acquired during these VLBI sessions, all of the above-mentioned parameters of interest can be determined. However, the turnaround time for product delivery of standard VLBI sessions can take up to several weeks. Intensive VLBI sessions, or short Intensives, are one-hour sessions between 2 to 3 stations used for the rapid determination of UT1-UTC. Due to their much shorter turnaround time for product delivery, they enable us to monitor the Earth's rotation phase regularly.

Keywords: VLBI, Intensives, UT1-UTC

Kurzfassung

Very Long Baseline Interferometry (VLBI) ist das einzige weltraumgeodätische Verfahren, welches in der Lage ist, alle Erdorientierungsparameter (EOP) sowie himmels- und erdfeste Referenzrahmen zu bestimmen. Standard VLBI Sessions mit einer Dauer von 24 Stunden werden in der Regel montags und donnerstags mit einem globalen Netz von bis zu 15 Stationen durchgeführt. Aufgrund der großen Anzahl an Beobachtungen, können alle oben genannten Parameter bestimmt werden, diese stehen jedoch oft erst mehrere Tage bis Wochen nach der Session zur Verfügung. Intensive Sessions oder kurze Intensives sind einstündige Beobachtungen zwischen 2 bis 3 Stationen, die vor allem für die Bestimmung von UT1-UTC verwendet werden. Diese kurzen Sessions ermöglichen es uns, die Rotationsphase der Erde regelmäßig und kontinuierlich zu überwachen.

Schlüsselwörter: VLBI, Intensives, UT1-UTC

1. Introduction

VLBI Intensive sessions are one-hour observations usually observed between 2 to 3 stations. Thus, the number of observations is very low (20-40 observations per S/X INT, 40-80 per VGOS INT; Bolotin et al (2023)), leading to a reduced number of possible parameters to be estimated. These normally include one UT1-UTC offset as well as clock offsets and zenith wet delays per participating station. The resulting low data volume makes it possible to drastically reduce the turnaround time for product delivery compared to regular 24-hour sessions. This enables us to regularly monitor the difference between the Universal Time (UT1) and the Coordinated Universal Time (UTC), representing variations or irregularities of the Earth's phase of rotation. Due to the correlation of changes in the orbital parameters of satellites, mainly the right ascension of the ascending node, and changes in the Earth's rotation phase, it is not possible to directly estimate UT1-UTC with satellite-based techniques, making VLBI the only space-geodetic technique capable of determining the full set of EOP (Rothacher et al, 1999).

To ensure high sensitivity to the Earth's rotation, Intensive baselines are usually long east-west oriented baselines. However, recent simulation studies have shown that more suitable constellations include small angles with the equatorial plane and a baseline length between 8 000 and 11 000 km (Schartner et al, 2021).

2. Types of Intensive sessions

At the moment, several types of Intensive sessions are observed regularly, which differ in the observing mode, number and selection of participating stations as well as the observation date and time. The IVS Intensive sessions (S/X legacy-band) include IVS-INT-1 (or XU), observed on weekdays at 18:30 UTC between Germany (WETTZELL, Wz) and Hawaii (KOKEE, Kk), and IVS-INT-2 (XK), usually planned for the weekends at 07:30 UTC, including WETTZELL and ISHIOKA (Is) in Japan or MK-VLBA (USA, Mk). In comparison, IVS-INT-3 (also XK) sessions include three to five stations, namely ISHIOKA, NYALES20 and/ or NYALE13S (Norway, Ny/ Ns), WETTZELL and/ or WETTZ13N (Germany, Wn) and sometimes also SESHAN25

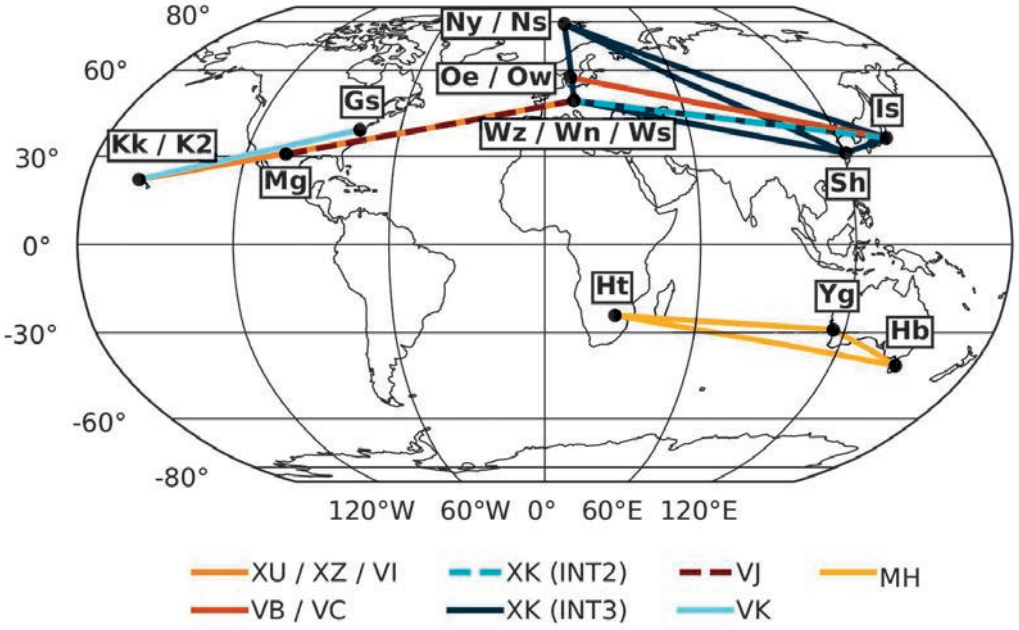

Fig. 1: Intensive session baselines/ networks

(China, Sh). IVS-INT-3 sessions are usually performed on Monday mornings to supplement the IVS Intensive series (Landskron and Böhm, 2019; Böhm et al, 2010). Starting in March 2022, IVS-INT-00 (XZ) sessions between WETTZELL and KOKEE are observed regularly on weekdays, prior to the IVS-INT-1 sessions (IVS, 2022).

Due to new findings regarding the improvement of Intensive sessions and the development of the next-generation VLBI system (VLBI Global Observing System (VGOS), formerly VLBI2010), there has been an upsurge in new Intensive experiments in recent years.

The era of VGOS Intensive sessions started in 2020 with a few VGOS-INT-A (VI) sessions, which are scheduled between KOKEE12M (USA, K2) and WETTZ13S (Germany, Ws) and are simultaneous to IVS-INT-1 sessions (Baver et al, 2023; Gipson et al, 2023), and VGOS-INT-B (VB) sessions. The VB station network includes ISHIOKA and the twin telescopes ONSA13NE and ONSA13SW (Sweden, Oe/ Ow), and these sessions are usually observed concurrently with the IVS-INT-1 sessions. In 2021, the VB sessions were supplemented by VGOS-INT-C (VC) sessions which observe the same network and are scheduled after the VB/ IVS-INT-1 sessions (Haas et al, 2021). Furthermore, VGOS-INT-S (VJ) sessions between MACGO12M (USA, Mg) and WETTZ13S are observed as a backup VGOS baseline whenever the VI baseline might be unavailable (Baver et al, 2023; Schartner et al, 2022). Additional VGOS Intensive sessions, VGOS-INT-G (VK), between GGAO12M (USA, Gs) and KOKEE12M were scheduled in 2022 (Gipson et al, 2023).

In Figure 1, the network constellations of the above-mentioned Intensive session types are shown. As one can see, all stations currently participating in Intensive sessions are located in the northern hemisphere. In late 2019, we initiated the Southern Intensives (MH) program, which resulted in approximately 50 sessions by the end of 2021 (Böhm et al, 2022). Since 2022 the Southern Intensives are regularly observed every Monday at 6:30 on the baseline from HOBART12 (Tasmania, Hb) to HART15M (South Africa, Ht) under the designation IVS-INT-S.

Besides these global Intensive sessions, experiments including more national networks have been tested. For example, since 2011, Intensive sessions within the USA between Very Long Baseline Array, short VLBA, stations MK-VLBA (Mk), PT-VLBA (Pt) and SC-VLBA (Sc) are observed and used for the determination of a fully independent UT1-UTC solution for the corresponding GNSS system, GPS (Geiger et al, 2018). Furthermore, also Russia has its own Intensive sessions between the stations BADARY (Bd), ZELENCHK (Zv)

and SVETLOE (Sv) (Shuygina et al, 2018). Only a few years ago, a European Intensive baseline has been investigated by Böhm et al (2018). The baseline included a station in Santa Maria (Portugal, Sa) and WETTZELL. Unfortunately, simulations did not lead to promising accuracy levels, nor an observation in March 2018. Nevertheless, a European Intensive session would be beneficial for the European GNSS system, GALILEO. Since these national sessions are not routinely analysed at our Vienna VLBI Analysis Center, they will not be further discussed.

3. Data

At the VLBI Analysis Center in Vienna, all sessions which are available at the Crustal Dynamics Data Information System (CDDIS) (Noll, 2010) are downloaded daily (at 5 a.m). An automated analysis processing pipeline makes it possible to immediately process Intensive sessions using the Vienna VLBI and Satellite Software (VieVS) and publish the results on www.vlbi.at/products in the form of a daily updated, IVS formatted EOP file (current version vie2023a.eopi).

In 2022, there were nearly 900 sessions of the featured Intensive types scheduled. Compared to the previous year, this corresponds to an increase in the number of sessions of approximately 70 %. For 2023, over 950 Intensive sessions are planned. The analysis of the latency and performance of Intensive sessions in the next section refers to the sessions of 2022.

4. Latency and Performance

As already mentioned, the sole purpose of VLBI Intensive sessions is the rapid determination of UT1-UTC. Therefore, a short turnaround time for product delivery is of high importance. In the following Table 1, the average turnaround time for the different types of Intensive sessions as well as for the S/X 24 hour VLBI sessions, namely R1 and R4, can be found. To ensure a fair comparison, latencies over a certain threshold (90 % quantile) per type are defined as outliers and are removed from the estimation of the mean value.

With a mean latency of only 9 hours and a standard deviation of 3 hours, the results of IVS-INT-1 sessions can be retrieved soon after the end of the session, whereas some of the VGOS Intensive sessions require up to a month or more to be processed. However, this comparison should be treated with caution, as most of these session types are experimental sessions that are not intended for operational purposes, yet. But, it can be shown that the results of Intensive sessions can be retrieved significantly earlier than those of standard 24 hour sessions, which makes Intensive sessions, besides their reduced precision, essential for monitoring the highly variable Earth's phase of rotation.

Over the years, many studies on Intensive sessions have shown that the performance strongly depends on the geometry of the observing network (Schartner et al, 2021), the selection and distribution of observed sources (Baver and Gipson, 2014; Baver and Gipson, 2020; Kern et al, 2023a), the scheduling optimization algorithm (Nothnagel and Campbell, 1991; Uunila et al, 2012; Gipson and Baver, 2015; Corbin et al, 2020; Kern et al, 2023a}, the duration of the session (Artz et al, 2012) and the accuracy of the a priori values (Kern et al, 2022a; Kern et al, 2022b; Kern et al, 2023b). In the following, the ΔUT1 estimates with respect to the IERS finals series were calculated for all discussed Intensive session types of 2022 as well as for R1 and R4 sessions. It has to be noted that outlier sessions with high weighted root mean squared (WRMS) values have been removed to ensure a fair comparison. In Table 2 the mean ΔUT1 values and the standard deviations of all types are displayed, whereas in Figure 2, the ΔUT1 and corresponding accuracies are displayed for selected Intensive session types.

type	#sess	latency	type	#sess	latency
XU	195	9h ± 3h	VI	155	2d 7h ± 1d 7h
XK (INT2)	82	1d 22h ± 16h	VB	34	35d 23h ± 20d 16h
XK (INT3)	27	20h ± 3h	VC	31	34d 6h ± 21d 10h
XZ	52	1d 3h ± 1h	VJ	22	3d 18h ± 3d 8h
MH	38	6d 23h ± 14d 3h	VK	8	1d 8h ± 0h
R1	83	29d 18h ± 24d 9h	R4	45	12d 21h ± 2d 16h

Tab. 1: Mean latencies

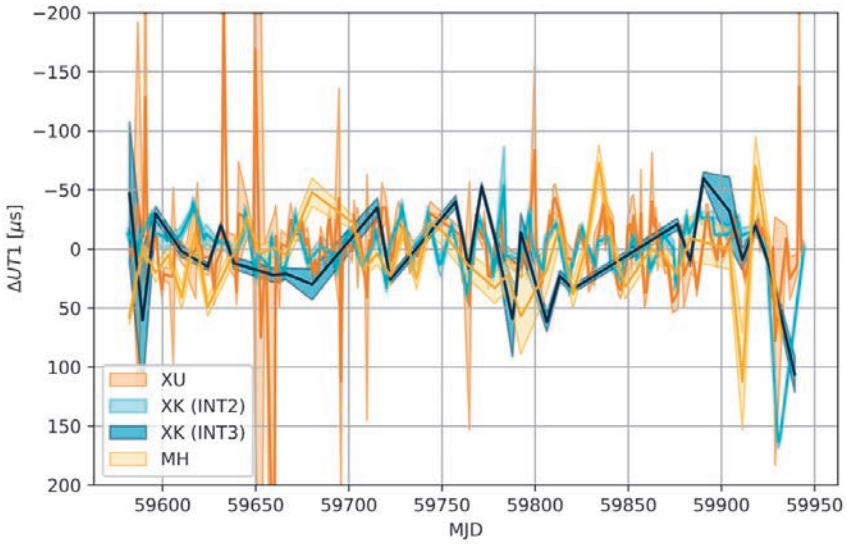

Fig. 2: ΔUT1 estimates w.r.t. IERS finals series of selected Intensive session types in 2022

type	#sess	ΔUT1 [μs]	type	#sess	ΔUT1 [μs]
XU	195	22 ± 33	VI	155	20 ± 18
XK (INT2)	82	19 ± 23	VB	34	30 ± 24
XK (INT3)	27	31 ± 22	VC	31	36 ± 29
XZ	52	22 ± 18	VJ	22	11 ± 9
MH	38	25 ± 25	VK	8	14 ± 11
R1	83	17 ± 16	R4	45	13 ± 12

Tab. 2: ΔUT1 values (absolute bias and standard deviation) w.r.t. IERS finals series

On average, S/X (VGOS) Intensive sessions yield UT1 values with respect to the IERS finals series that are 57 % (50 %) worse than estimates provided by 24 hour sessions. Comparing the performance of IVS-INT-2 sessions and 24 hour sessions, the accuracy is reduced by only 26 %, and in the case of VGOS-INT-A sessions, the estimates fit the IERS final series even better. In the worst case (IVS-INT-3 and VGOS-INT-C, respectively), the differences with respect to the IERS final series are 107 % and 140 % worse. However, the turnaround time for product delivery is reduced by approximately 38 % – or when excluding the VB and VC sessions – even 63 %.

5. EOP files at the Vienna VLBI Analysis Center

At the Vienna VLBI Analysis Center, we implemented an automated processing pipeline to analyze the Intensive sessions downloaded from CDDIS. In this process, potential problems with outliers and cable calibration are iteratively addressed to ensure an optimal and automated UT1 determination. Due to an in-house study on the effect of the accuracy of the a priori values on the UT1 estimation (see Kern et al (2022a; 2022b; 2023b), Intensive sessions are now reprocessed after 3 to 4 weeks so that updated and estimated EOP are available at that time.

6. Conclusion

Compared to the usual 24 hour sessions, Intensive sessions have 57 % lower accuracy for S/X and 50 % for VGOS sessions on average. However, the shorter turnaround time for product delivery is critical for monitoring the highly variable Earth rotation and makes Intensive sessions an important tool.

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