UT1 Intensive Observing Program between Shanghai and Urumqi VGOS Antennas

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Abstract We present an overview of the VLBI Intensive program observed between the Shanghai (Seshan13 or Tianma13) and Urumqi (Urumqi13) VGOS antennas for the rapid determination of the Earth rotation angle. The program was initiated in May 2022 and runs three times per week since March 2023. The goal is to evaluate the performance of new VGOS stations, test new frequencies to avoid 5G RFI, and explore a data transfer/correlation pipeline for rapid product service.

Keywords UT1 Intensive, VGOS antennas, 5G RFI, Earth rotation angle

1 Introduction

A series of observing programs are coordinated by the International Very Long Baseline Interferometry (VLBI) Service for Geodesy and Astrometry (IVS), with the goal of providing high-quality data products such as Earth Orientation Parameters (EOP) and Celestial and Terrestrial Reference Frames (CRF/TRF). Among the programs, UT1 Intensives play a unique role for monitoring the Earth rotation angle, which is uniquely measured by VLBI. The UT1 Intensives are usually performed on a single baseline with one-hour duration (Nothnagel et al., 2017 [1]).

The Shanghai 25-m antenna (Seshan25) began to participate in the IVS-INT-3 observing sessions in 2011. The normal accuracy of the IVS-INT-3 observations relating to Seshan25 is at the level of 10 µs (Xu et al., 2012 [2]). The median dUT1 precision of multiple baselines estimated from INT3 sessions is at the level of 5.9 µs (Schartner et al., 2022 [3]). Considering that Seshan25 was built in 1987, it became difficult to use in regular UT1 Intensives due to frequent antenna maintenance.

Three VGOS antennas (Seshan13, Tianma13, and Urumqi13) have been built in China. On July 9, 2019, the first broadband fringes on the Tianma13–Seshan13 short baseline were obtained. In 2020, the first broadband fringes from Seshan13 to Urumqi13 were obtained.

Most of the more than 200 IVS sessions correlated at Shanghai are focused on CRF/TRF as opposed to EOP Rapid or UT1 Intensive sessions. VGOS antennas, with their smaller diameter compared to S/X VLBI antennas, exhibit rapid rotation and broad bandwidth. They are expected to yield a greater number of observations, demonstrating significant potential for monitoring Earth's rotation angle.

In order to continue contributing to UT1 monitoring, we conducted Intensive UT1 observations using the Shanghai and Urumqi VGOS antennas. We tested several new frequency sequences in order to mitigate 5G RFI, and we performed UT1 estimation. The UT1 results obtained from the current Intensive observations were compared to IERS C04, and the formal errors and Weighted RMS Residual Delays (WRMS Delays) of the UT1 estimates were analyzed.

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2 UT1 Observations and Data Processing

2.1 VGOS UT1 Observations

The UT1 Intensives were initially tested from May to August 2022. Then they were followed by regular sessions starting in March 2023 occurring three times per week. The Seshan13–Urumqi13 baseline was utilized, with occasional inclusion of the Tianma13 VGOS antenna in Shanghai. The observing start time is scheduled for 7 UT or 8 UT during regular working hours in China. The number of scans varies based on scheduled scan length and minimum SNR, typically ranging from 50 to 80 scans per session, usually including a 120-second calibrating scan. The frequency setup is standard VGOS four bands, but we have tried a few different frequency sequences due to strong RFI at Shanghai.

The VGOS stations are equipped with CDAS-2 backends and Mark-6 recorders. The data rate is 8 Gbps, and the amount of observational data per station is 1.6 TB per session. For the Urumqi13 station, the raw data needs to be transferred to the Shanghai VLBI Correlator, which takes at least 10 hours.

2.2 Data Correlation

Data processing was performed at the Shanghai VLBI Correlator, including correlation software DiFX-2.5.5, post-correlation software HOPS-3.24 (Deller et al., 2011 [4]), and the analysis software nuSolve-0.8.1 (Bolotin et al., 2014 [5]). The data format is VDIF, and data playback as single-threaded data is required before data correlation. Parameters need to be set during data correlation; thread is 8, frame is 8032, and nBand is 8. Post-correlation was performed in manual mode as the phase calibration signals (PCAL) from Seshan13 and Urumqi13 were unstable.

In our UT1 data correlation, the peculiar clock offsets were derived from tagging along to VGOS-OPS sessions, which included vo1047, vo1287, vo2181, and vo3194. The clock offsets we used for Seshan13, Tianma13, and Urumqi13 are 1.7 µs, 1.6 µs, and 1.8 µs, respectively. Commonly, the reference station clock offset needs a constant deviation of less than 1 µs. Therefore, for domestic UT1 Intensive experiments, Seshan13 was used as the reference station for clock bias correction.

2.3 RFI at Seshan13 Caused by 5G Signals

Figure 1 shows the signal power at Seshan13 in maximum and average values. There is strong RFI at some frequencies, particularly in the vicinity of 3.4 GHz, 6.9 GHz, 10.2 GHz, and so on, which are just in the range of the frequency setup used for VGOS-OPS sessions.

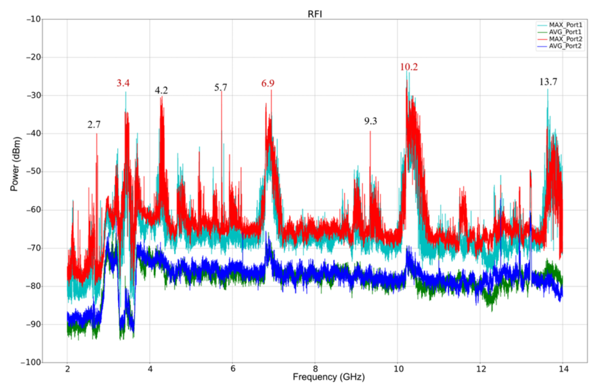

Fig. 1 RFI at Seshan13 for dual polarization in the frequency range 2–14 GHz. Port1 is vertical polarization; Port2 is horizontal polarization.

The specific performance is shown in Figure 2. VGOS contains four bands (A, B, C, and D), each with eight corresponding channels. For the Seshan13–Urumqi13 baseline, channels ghvwx and D-band have strong RFI and need to be removed before fringe fitting. Because Tianma13 had a superconductive filter installed to avoid 5G RFI and Urumqi13 is less affected by RFI, the lower panel of Figure 2 shows that all channels on the Tianma13–Urumqi13 baseline are good for fringe fitting.

Table 1 Different frequency group settings.

Band	FG1 (GHz)	FG2 (GHz)	FG3 (GHz)	FG4 (GHz)
A	3.0–3.5	3.8–4.3	2.9–3.4	2.9–3.4
B	5.2–5.7	5.2–5.7	4.4–4.9	4.4–4.9
C	6.3–6.8	6.3–6.8	6.4–6.9	6.4–6.9
D	10.2–10.7	9.5–10.0	10.3–10.8	9.5–10.0

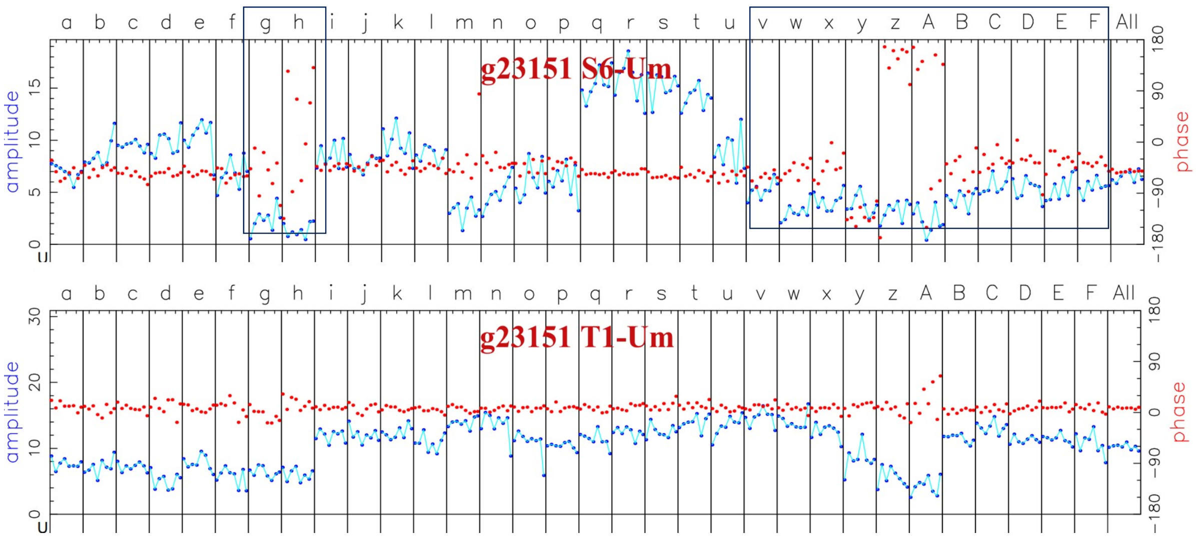

Fig. 2 RFI comparison of the S6–Um and T1–Um baselines in the g23151 experiment.

Therefore, we tested a few frequency sequences to avoid RFI, as listed in Table 1. Four different frequency groups (FG) were used for UT1 observations at different time periods.

The FG1 is the frequency sequence used in the VGOS-OPS sessions; it was used as a reference sequence for our domestic UT1 Intensive observations. A-band and D-band contain strong RFI at exactly 3.4 GHz and 10.2 GHz. Therefore, FG2 has been designed to avoid these interferences and has been used for the test UT1 sessions in 2022. In the experiments, four channels in B and C-band had no fringes, and B-band had very weak fringes. The FG3, suggested by Bill Petrachenko, was tested and verified during UT1 Intensives from May to June 2023. There were two channels in A-band and three channels in B-band with unstable fringe phase, and there were no fringes for D-band. Taking into consideration FG2 and FG3, FG4 was designed and used for UT1 observations since July 2023. There were still a few channels near 3.4 GHz and 6.9 GHz that need to be removed before fringe fitting.

3 Results and Analysis

All useful sessions were analyzed using the nuSolve software (Bolotin et al., 2014 [5]). The standard data analysis parameters for UT1 sessions were applied, including a second order polynomial clock function per station with respect to the reference clock, one zenith wet delay per station, and one UT1–UTC offset. The reference epoch of UT1–UTC is situated in the midst of the valid observations of the session. In the a priori files, the station velocity for the VGOS station is the same as the co-located legacy S/X station in ITRF2020, and the a priori station coordinates were estimated from a few tagalong VGOS-OPS sessions. Earth orientation parameter series are updated with the latest USNO series in each session analysis. The coordinates of the radio sources are from ICRF3.

Using the observational data of the 2023 UT1 Intensives, dUT1 values were estimated and compared, including to UT1 values from IERS C04, and formal errors and WRMS Delays were analyzed. The valid observational data have 92 sessions, after removing those sessions with formal errors greater than 33.0 µs. Excluding four outliers, the results of the UT1 estimation are shown in Figures 3 and 4.

Figure 3 shows that the UT1 differences are mainly distributed between −100.0 µs and 100.0 µs, with several larger values from June to August. The RMS of the UT1 differences is 59.8 µs.

The upper panel of Figure 4 shows the UT1 formal errors. The median formal error of the 2023 UT1 Intensive experiments is 10.4 µs. The errors vary between 4.0 µs and 26.5 µs, while the majority of the formal error values are between 5.0 µs and 15.0 µs. The station performance is sometimes not so good, resulting in fewer observations and worse UT1 errors.

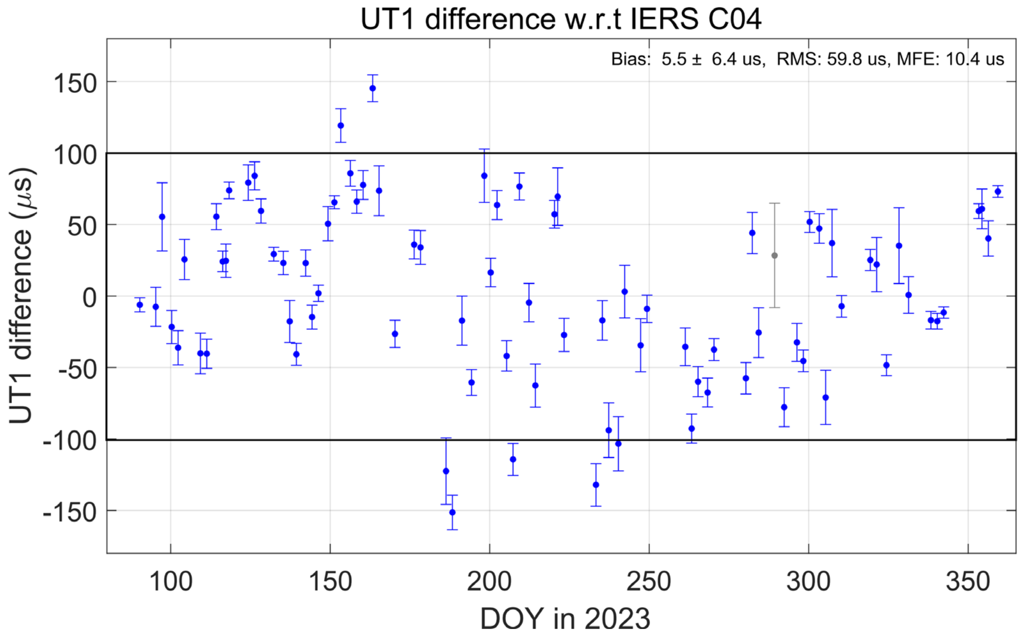

Fig. 3 UT1 estimates compared to IERS C04 on the baseline Seshan13–Urumqi13 in the 2023 UTI Intensive experiments.

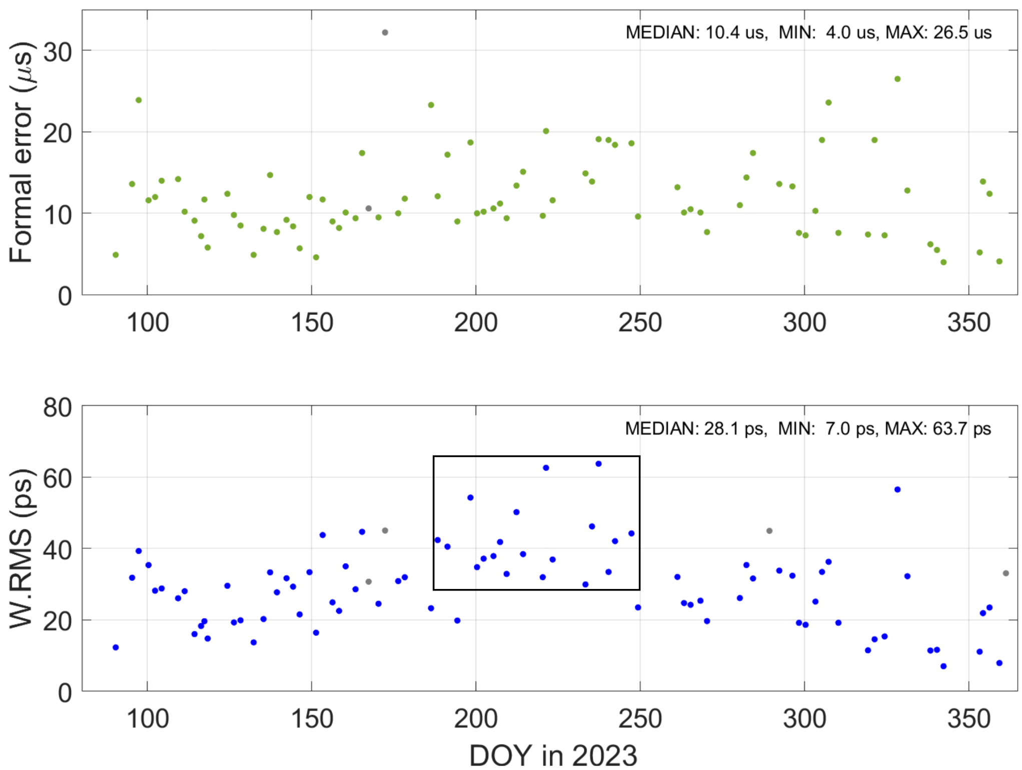

Fig. 4 UT1 formal errors (upper panel) and post-fit delay residuals (lower panel) on the baseline Seshan13–Urumqi13 in the 2023 UT1 Intensive experiments.

The lower panel of Figure 4 shows the WRMS Delays. The median WRMS Delay of the 2023 UT1 Intensive experiments is 28.1 ps; the delays vary from 7.0 ps to 63.7 ps. Post-fit delay residuals became larger from June to August, needing more testing and investigation.

4 Conclusions

On the Shanghai–Urumqi VGOS baseline, we successfully performed a series of UT1 Intensive observations. The results of the 2023 Intensive observations show that the RMS of UT1 differences compared to IERS C04 is 59.8 µs, the median formal error of the UT1 estimates is 10.4 µs, and the median WRMS delay is 28.1 ps. The minimum latency from observation to UT1 estimation is mainly limited by the raw data e-transfer rate from Urumqi to Shanghai. The issue of unstable PCAL still exists. In the four frequency sequences used in the UT1 experiments, the FG4 basically avoids the interference effects of nearby 3.4 GHz and 10.2 GHz in the 5G RFI at Shanghai. Based on our experience, we will move forward to perform more international UT1 experiments, with the goal of establishing an operational UT1 baseline.

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