Tsukuba VLBI Correlator

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Abstract This report summarizes the activities of the Tsukuba VLBI Correlator during 2023 and 2024. The correlator has been regularly involved in the weekend IVS S/X Intensive sessions using K5/VSSP correlation software, VGOS-INT-B/C sessions between the Ishioka and the Onsala twin telescopes, and the Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) using the DiFX and HOPS software. The correlator began processing VGOS-INT-G sessions among Ishioka, Seshan 13 m, Santa Maria, and Yebes 13 m at the end of October 2024.

1 Introduction

The Tsukuba Correlator, located in Tsukuba, Japan, is operated by the Geospatial Information Authority of Japan (GSI). It is devoted to processing geodetic VLBI observations of the International VLBI Service for Geodesy and Astrometry (IVS). The correlator regularly processes weekend IVS S/X Intensive (IVS-INT-2) sessions and three series of VGOS Intensives: the VGOS-INT-B, VGOS-INT-C, and VGOS-INT-G series. The VGOS-INT-B/C series are performed between the Ishioka and the Onsala twin telescopes every weekend, and the VGOS-INT-G series, which started in October 2024, is carried out between Ishioka, Seshan 13 m, Santa Maria, and Yebes 13 m. Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) sessions, which have begun as regular IVS sessions since 2015, were processed by the University of Tasmania (UTAS), the Shanghai Astronomical Observatory (SHAO), and the Tsukuba correlator. All AOV sessions were conducted as mixed-mode sessions in which both S/X and VGOS stations participated and observed at S-band and X-band.

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2 Component Description

2.1 e-VLBI

The Tsukuba VLBI Correlator is connected to a broadband network, and all observed VLBI data are delivered via the network. The correlator has a 10-Gbps dedicated link to the SINET6 operated by the National Institute of Informatics (NII), which is connected to several research networks in the world. It enables us to transfer massive data between the correlator and overseas IVS components. The Ishioka VLBI station has also been connected to the correlator and SINET6 with a 10-Gbps dedicated cable.

2.2 Correlation Software

2.2.1 K5/VSSP

The correlator uses the K5/VSSP software, which was developed and has been maintained by the National Institute of Information and Communications Technology (NICT), to process IVS-INT-2 sessions. The software consists of several programs for the calculation of a priori values of delay and delay

rate (*apri_calc*), for the correlation processing for all observations (*fx_cor_new* or *cor_new*), and for monitoring the results of the correlation processing by performing a so-called "coarse search" (*sdelay*), followed by several utilities such as *komb* for the bandwidth synthesis [1]. The software can handle not only K5 format data but also Mark 5B or VDIF format data without format conversion in the latest version.

2.2.2 DiFX and HOPS

DiFX and HOPS are also installed at the correlator and used to process VGOS Intensive sessions and AOV sessions. We use DiFX in the version of 2.5.5 for correlating VGOS Intensive sessions and 2.6.3 for the AOV mixed-mode sessions, respectively, as of December 2024.

2.3 Correlation Procedure

2.3.1 IVS-INT-2 sessions

The typical process for IVS-INT-2 sessions and the programs used in each process are described below. The name of the program to be used is noted in parentheses.

1. Accessing a data server of each station and transferring data from network stations to the correlator (*tsunami* or *m5copy*).
2. Preparation of a priori parameter files (*apri_calc*).
3. Fringe search to find a clock offset at each pair of stations (*fx_cor_new* or *cor_new*).
4. Running correlation processing for all observations (*fx_cor_new* or *cor_new*).
5. Coarse search for estimating residual delay and delay rate and plotting them on a 3-D diagram (*sdelay*).
6. Bandwidth synthesis to derive a multi-band delay (*komb*).
7. Database creation to be submitted to IVS Data Centers (*vgosDbMake*).

The correlation and analysis management programs developed by GSI can run the above process consecutively and automatically. The program for the management of data transfer *rapid_transfer* can access a data server in an observing station and transfer the data automatically. It can transfer the data concurrently with the start of the session as needed. *Rapid_cor* is a program to search for a fringe for each baseline based on the clock information of each station written in the FS log, as well as the station positions and source coordinates described in the schedule file and external a priori earth orientation parameters. *Rapid_komb* executes *komb* on the stream of correlation outputs for the bandwidth synthesis process. For the weekend Intensive sessions, *rapid_c5pp*, which gives an interface to VLBI analysis software *c5++*, executes analysis automatically as the bandwidth synthesis process finishes and delivers the result to the community (refer to the report "Tsukuba VLBI Analysis Center" in this volume for more details). The database is created manually with *vgosDbMake* in the vgosDb format [2] and is submitted to IVS Data Centers.

2.3.2 VGOS Intensive and AOV Sessions

As described above, DiFX and HOPS are used to process VGOS Intensive and AOV sessions, where VGOS stations participate. The data of VGOS Intensive sessions are processed in the way described in the manual released by the MIT Haystack Observatory [3]. In 2021, AOV sessions moved to mixed-mode sessions, which are similar to Australian mixed-mode sessions [4], and we process the data following the method (e.g., [5]) shared amongst the AOV community.

Table 1 Correlator hardware capabilities.

	Main System
# servers	11 servers: • 8 for correlation processing • 2 for controlling correlation processing • 1 for data storage
OS	AlmaLinux version 8.7, 8.8, and 8.9
CPU	Intel Xeon Gold 6130 @ 2.10 GHz 16 cores x 4 Intel Xeon Gold 6230 @ 2.10 GHz 20 cores x 11 Intel Xeon Gold 6330 @ 2.00 GHz 28 cores x 2 Intel Xeon Gold 5318Y @ 2.10 GHz 24 cores x 1 Intel Xeon Silver 4215R @ 3.20 GHz 8 cores x 2 Intel Xeon Silver 4410Y 12 cores x 1
Storage	764 Tbytes
Network	10-Gbps dedicated line connected to SINET6 by NII

2.4 Correlator Hardware Capabilities

The hardware supporting the activities of the correlator is summarized in Table 1. All these pieces of equipment are general purpose and commercially available products. The system of the correlator has been gradually updated. At present, the main system consists of ten servers and storage with a capacity of 753 TB.

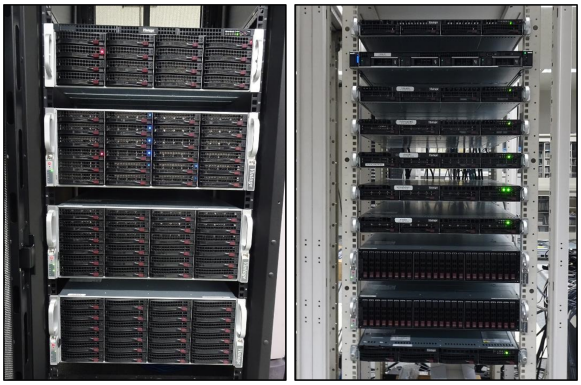

Fig. 1 View of the main system at the Tsukuba VLBI Correlator. The left is the storage, and the right is the data processing servers.

3 Staff

The technical staff at the correlator was as follows:
– Calendar year 2023:

- **Haruka Ueshiba** — correlator/analysis chief, management.
- **Hiroyuki Yoshifuji** — correlator/analysis operator, coordination.
- **Tetsuya Hara** (AES) — correlator/analysis operator, software development.

– Calendar year 2024:

- **Saho Matsumoto** — correlator/analysis chief, management.
- **Kaho Hashimoto** — correlator/analysis operator, coordination.
- **Tetsuya Hara** (AES) — correlator/analysis operator, software development.

4 Correlator Operations

4.1 IVS Intensive for UT1−UTC

Table 2 lists the number of sessions processed in 2023 and 2024. The number of sessions in 2024 is the highest since 2000. This main reason is that the VGOS-INT-B and VGOS-INT-C sessions have been regular IVS Intensive sessions since 2022.

Table 2 Intensive sessions processed at the Tsukuba Correlator.

2023	Stations	# of sessions
IVS-INT-2	IsMkWz	12
	MkWz	62
	IsWz	8
	KkWz	10
IVS-INT-3	IsNsWz	2
VGOS-INT-B	IsOeOw	41
	IsOe	10
	IsOw	3
VGOS-INT-C	IsOeOw	26
	IsOe	4
Total		178

2024	Stations	# of sessions
IVS-INT-2	MkWz	91
VGOS-INT-B	IsOeOw	66
	IsOe	16
VGOS-INT-C	IsOeOw	67
	IsOe	15
VGOS-INT-G	IsS6Sa	1
	S6Sa	2
Total		258

4.1.1 IVS-INT-2

Almost all the weekend Intensive series (IVS-INT-2) were processed at the correlator automatically in near real-time using the *rapid_* programs (see Section 2.3). The Wettzell 20 m in Germany and the VLBA antenna at Mauna Kea in Hawaii, U.S., usually participated in IVS-INT-2 sessions. Ishioka in Japan also joined while the S/X feed was installed. Since Ishioka has completely shifted to the VGOS feed, the IVS-INT-2 sessions have been observed by two stations only (usually Mauna Kea and Wettzell 20 m) from the middle of March 2023 onward. In addition, a few IVS-INT-3 sessions on Monday were processed at the correlator on behalf of the Bonn Correlator.

4.1.2 VGOS Intensives Series (VGOS-INT-B, VGOS-INT-C, and VGOS-INT-G)

The correlator processed 248 sessions of the VGOS-INT-B/C series from January 2023 to the end of December 2024. These are VGOS Intensive sessions in which Ishioka and the Onsala twin telescopes participated. In the VGOS-INT-B/C sessions, the processing is automatically executed until the beginning of the offset correction and finished by Monday morning. Manual processing is still necessary for the rest of the post-correlation, cable delay calibration, and database generation. The following three programs were developed by the correlator in 2023 and 2024.

Preparation Program. This program handles the preparation of the correlation process. The correlator runs the program before the observation, in which directories for the experiment are created and waiting for the data. It takes nine hours to finish the data transfer. After finishing the transfer, the program is executed again to run DiFX and fourfit. The correlation processes will have finished by Monday morning for four whole weekend sessions if there is no trouble.

Short Baseline Processing. One of the characteristic points of the VGOS-INT-B/C sessions is that they include a short baseline—between the Onsala twin telescopes. In this baseline, the program tends to detect P-cal signals and locally generated noise as pseudo-fringes. It prevents us from using all 32 channels for the baseline, in which case the quality code for each scan is generally low (from 1 to 3) with G codes shown. To improve the quality codes, we narrow down the number of adopted channels for the short baseline. The process has been automated. Previously, the correlator manually selected the channels, while now we select the adopted channels with criteria based on single band delay, fringe rate, quality code, and signal-to-noise ratio. With this program, most scans have quality codes greater than 5, and the total number of scans with G codes decreases.

Phase Correction. We sometimes failed to estimate *pc_phase_x* and *pc_phase_y* by HOPS post-processing. It is one of the barriers to completely automate the correlation processes. We attempted to estimate *pc_phase_x* and *pc_phase_y* from a good scan which has stable phases for whole channels in fourfit outputs and apply the method of phase correction in parallel to HOPS. This method is applied and its results are submitted to IVS when the HOPS post-processing has failed.

In addition to regular observations, we processed 24-hour VGOS-INT-B/C sessions for the first time in the middle of August 2024; the session names are BX4230 and CX4231.

Unlike the VGOS-INT-B/C sessions, almost all processes are still manually executed for the VGOS-INT-G. Correlation tasks are shared by Tsukuba, the Shanghai Correlator operated by SHAO, and the correlator at the Yebes Observatory (YEBS). The Tsukuba Correlator plans to fully automate the VGOS Intensive series and prepares programs to respond to increasing the processing sessions and various station data formats. Other than IVS observing, a test session between Ishioka, Hobart 13 m, and Katherine (Australia) was performed in August 2024. This test was planned to check the feasibility to conduct 1-GHz-bandwidth sampling in these three stations. The correlator successfully detected fringes. This is also referenced in the report "Ishioka Geodetic Observing Station."

4.2 IVS AOV Sessions

The AOV is a regional subgroup of the IVS established in 2014 to foster and encourage closer collaboration in VLBI in the Asia-Oceania region. It has been coordinating regular VLBI observing sessions since 2015, and eighteen sessions were organized in 2023 and 2024. Correlation tasks were shared by Tsukuba, SHAO, and UTAS. The sessions processed at the Tsukuba VLBI Correlator in 2023 and 2024 are listed in Table 3. Most of the data, not only from Japan, but also from China, Korea, Australia, and New Zealand, were transferred via the broadband network, while the data of Syowa in Antarctica and Usuda were physically shipped to Tsukuba.

Table 3 AOV sessions processed at the Tsukuba Correlator.

Year	Name	Date	Stations
2023	AOV079	Jan 17	HbIsWwKgYgSyUr
	AOV083	May 17	HbIsKeKvWwVmKgShUr
	AOV085	Jul 18	IsKeKvWwVmKgShUr
	AOV088	Oct 25	HbIsKeWwKgUr
2024	AOV092	Feb 4	IsKmSyUr
	AOV094	Aug 29	HbIsKeKmKvUrYgUd

5 Outlook

We will continue to process both S/X and VGOS Intensive sessions and AOV sessions. In addition to improving the existing programs for real-time processing and maintaining the hardware and network, we will develop some tools and programs to process VGOS Intensive series fully automatically. With these developments, we will be able to provide results more stably and quickly.

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