# Tsukuba VLBI Correlator

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**Abstract** This report summarizes the activities of the Tsukuba VLBI Correlator during 2019 and 2020. The correlator has been regularly involved in the weekend IVS intensive (INT2) sessions as well as the Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) sessions using the K5/VSSP correlation software.

## 1 Introduction

The Tsukuba VLBI Correlator, located in Tsukuba, Japan, is operated by the Geospatial Information Authority of Japan (GSI). It is fully devoted to processing geodetic VLBI observations of the International VLBI Service for Geodesy and Astrometry (IVS). Almost all of the weekend IVS intensive (INT2) sessions for UT1−UTC (=dUT1) estimation and about half of the Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) sessions, which began in 2015 as regular IVS sessions, were processed at the correlator. The K5/VSSP correlation software developed by the National Institute of Information and Communications Technology (NICT) was used for processing of all the regular sessions.

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## 2 Component Description

### 2.1 e-VLBI

The Tsukuba VLBI Correlator has been connected to a broadband network, and all of the observed VLBI data are basically delivered via the network. The correlator has a 10-Gbps dedicated link to the *SINET5* operated by the National Institute of Informatics (NII), which is connected to several research networks in the world such as *Internet2* in the U.S., *GÉANT* in Europe, and *TEIN4* in Asia. It enables us to transfer a massive amount of data between the correlator and overseas IVS components. The Ishioka VLBI station has also been connected to the correlator and *SINET5* with a 10-Gbps dedicated cable since 2014.

### 2.2 K5/VSSP Correlation Software

The K5/VSSP correlation software, which was developed and has been maintained by NICT, is adopted at the correlator. 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.

**Table 1** Hardware capabilities of the Tsukuba VLBI Correlator.

| | **Main System** | **Backup System** |
|---|---|---|
| Number of servers | 16<br>– 14 for correlation processing<br>– 2 for controlling correlation processing | 8<br>– 5 for correlation processing<br>– 2 for controlling correlation processing<br>– 1 for data storage |
| Operating System | Red Hat Enterprise Linux 6.3 | CentOS version 6.10, 7.7, and 7.8 |
| CPU | Intel Xeon X5678 @3.60 GHz 4 cores x 2 x 16 | Intel Xeon X3360 @2.83 GHz 4 cores x 2<br>Intel Xeon Gold 6130 GHz @ 2.10 GHz 16 cores x 2<br>Intel Xeon Gold 6230 GHz @ 2.10 GHz 20 cores x 3<br>Intel E5-2609v4 @1.70 GHz |
| Total storage capacity | 513 Tbytes | 273 Tbytes |
| Network | 10 Gbps dedicated line connected to SINET5 by NII | |

## 2.3 Correlation Procedure

The typical correlation process at the correlator and programs used in each process are as follows:

1. Transferring data from network stations to the correlator (*tsunami* and *tsunamid*, 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 processes consecutively and automatically. The program for the management of data transfer *rapid_transfer* accesses a data server in an observing station, executes *tsunamid* there, and then executes *tsunami* at the correlator side to transfer data automatically. As a result of its update in July 2020, automatic data transfer using *m5copy* is now available. 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. Once the fringe is detected, the main correlation processing runs one after another with the clock offset and rate information derived from the fringe search process until the last observation.

*Rapid_komb* executes *komb* on the stream of correlation outputs for bandwidth synthesis process. For the weekend Intensive sessions, *rapid_c5pp*, which gives an interface to VLBI analysis software *c5++* [2], 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* for the vgosDB format [3] and is submitted to IVS Data Centers. Although the Mark III format databases had also been created based on requests from a few Analysis Centers, only vgosDB format databases have been created since September 5, 2020; there have been no more requests since then.

## 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. It means that no dedicated hardware is required in the K5 correlation processing. The main system consists of sixteen IBM X3650 servers and a Data Direct Networks storage system with a capacity of 513 TB (Figure 1).

The backup system was expanded during 2019–2020 and currently consists of seven servers and 273 TB data storage. At present, some test correlation

processing using DiFX and HOPS software is carried out on this system (see Section 5).

## 3 Staff

The technical staff at the Tsukuba VLBI Correlator are:

- **Yu Takagi** — correlator/analysis chief, management.
- **Kyonosuke Hayashi** — correlator/analysis operator, coordination.
- **Tetsuya Hara** (AES) — correlator/analysis operator, software development.

## 4 Correlator Operations

### 4.1 IVS Intensive for UT1−UTC

Almost all of the weekend Intensive series (INT2) were processed at the Tsukuba VLBI Correlator automatically in near real time using the *rapid_* programs (see Section 2.3). The number of sessions processed in 2019 and 2020 is listed in Table 2. Ishioka in Japan and Wettzell 20-m in Germany have usually participated in INT2 sessions.

Kokee Park or the VLBA antenna at Mauna Kea in Hawaii, U.S., was involved when Ishioka was not available because of its VGOS period for a few months per year or antenna mechanical trouble. Ny-Ålesund in Norway also filled in the absence of Wettzell 20-m. In addition, a few INT3 sessions on Monday were processed on behalf of the Bonn Correlator. Please refer to the report "Tsukuba VLBI Analysis Center" in this volume for results and more details.

**Table 2** Intensive sessions processed at the Tsukuba VLBI Correlator.

| 2019 | Stations | Period | # of sessions |
|---|---|---|---|
| Intensive 2 | IsWz | Jan 5 – Dec 1 | 91 |
| | IsNy | Jan 6 | 1 |
| | MkWz | Dec 7 – Dec 28 | 4 |
| | KkWz | Dec 15 – Dec 29 | 3 |
| Total | | | 99 |
| 2020 | Baseline | Period | # of sessions |
| Intensive 2 | IsWz | Mar 7 – Jun 14 | 29 |
| | MkWz | Jan 4 – Dec 27 | 43 |
| | KkWz | Jan 5 – Dec 13 | 25 |
| Intensive 3 | NyShWnWz | Jul 27 | 1 |
| | ShWnWz | Dec 21 | 1 |
| Total | | | 99 |

### 4.2 IVS AOV Sessions

The Asia-Oceania VLBI Group for Geodesy and Astrometry (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 the number of sessions was twelve per year in 2019 and 2020. Correlation tasks are shared by the Tsukuba VLBI Correlator, the Shanghai Correlator operated by Shanghai Astronomical Observatory (SHAO), and the University of Tasmania. The sessions processed at the correlator in 2019 and 2020 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 only the data of Syowa in Antarctica were shipped to Japan.

**Table 3** AOV sessions processed at the Tsukuba VLBI Correlator.

| Year | Name | Date | Stations |
|---|---|---|---|
| 2019 | AOV032 | Feb 12 | HoIsK1KeKgKvVmWwYg |
| | AOV035 | May 14 | HoIsK1KeKgSyWwYg |
| | AOV038 | Aug 7 | HoIsKeKgKvShUrWwYg |
| | AOV039 | Sep 17 | HoIsSyVmWwYg |
| | AOV041 | Nov 12 | HoIsKgYg |
| | AOV042 | Dec 3 | HoKgKvVmWwYg |
| 2020 | AOV044 | Feb 11 | HoKgKmVmWwYg |
| | AOV048 | Jun 16 | HoKgKmShSyVmWwYg |
| | AOV049 | Jul 22 | HoKgKvShWwYg |
| | AOV050 | Aug 10 | HoKgShSyWwYg |
| | AOV054 | Dec 8 | HoKgKmSyWwYg |

## 5 Correlation and Data Processing Using DiFX and HOPS Software

For the VGOS correlation, the DiFX and HOPS software were installed on the backup system. Some correlation processing tests were carried out using DiFX and HOPS software. In 2020, the Tsukuba VLBI Correla-

**Fig. 1** View of the main system (data processing servers and storage) at the Tsukuba VLBI Correlator.

tor participated in the blind-test exercise of the VGOS Intensive session VI9290 and obtained similar results to the other correlators [4].

## 6 Outlook

We will continue to process the IVS Intensive and AOV sessions. For more stable operation of especially near real time processing, we will make further improvements to the *rapid_* programs and maintain hardware and network. In addition to the regular S/X sessions, we are planning to learn the correlation processing techniques and enhance the hardware for the processing of the VGOS data.

## References


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