Shanghai VLBI Correlator 2019–2020 Report

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Abstract This report summarizes the activities of the Shanghai VLBI Correlator during 2019 and 2020. Highlights include preparation for VGOS data correlation, monitoring peculiar clock offsets, fringe tests of Shanghai VGOS stations, and K-band geodesy.

1 Introduction

The Shanghai VLBI Correlator is hosted and operated by the Shanghai Astronomical Observatory (SHAO), at the Chinese Academy of Sciences (CAS). It is located at the Sheshan campus, about 40 kilometers from the Xujiahui headquarters of SHAO. The Shanghai correlator has been used in the data processing of the Chinese VLBI Network (CVN), which consists of the Seshan25, Tianma65, Kunming, Urumqi, and Miyun50 stations. The Shanghai correlator was accepted as an IVS component in March 2012. It became operational for IVS data correlation in 2015.

2 Component Description

We are operating two types of correlators. The CVN correlator developed by SHAO is mainly used for spacecraft VLBI tracking by producing differential VLBI observables. The data latency is less than one minute in real time mode, and the typical accuracy is better than 1 ns. The other one is the DiFX software correlator, which is dedicated to astronomical and geodetic data correlation.

The DiFX software was installed on a powerful hardware platform, with a 420-CPU core cluster system and a 400-TB storage space. A new disk array installed in 2020 provides 1 PB of additional data storage for VGOS data correlation. Three Mark 6 units have been tested and can be used to playback VDIF data. The suite version is Mark6_1.3c with dplane as 1.22 and cplane as 1.0.26. Features of the DiFX cluster system are as follows:

- DiFX 2.6.2, HOPS 3.21, nuSolve 0.6.4
- Head nodes: DELL R820 (E5-4610 CPU, 2.4 GHz, 2*6 cores), 64 GB Memory, DELL R730 (E5-2623 CPU, 3.0 GHz, 2*4 cores), 64 GB Memory.
- Computing nodes: 20 DELL R630 nodes, two socket Intel E5-2660 CPU (2.6 GHz, ten cores), 64 GB Memory, 400 cores in total
- I/O nodes: RAID6, 1400 TB raw data storage capacity
- Data playback units: three Mark 5B and three Mark 6.
- 56 G Infiniband for internal computing network connection
- 1/10 G Ethernet for internal and external network connection

3 Staff

The people involved in the operation and development of the correlator and the VLBI digital backend are listed below.

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3.1 Operations Team

- Fengchun Shu: group head, scheduler, experiment oversight
- Zhong Chen: e-transfer support, cluster administration
- Zhanghu Chu: media library
- Shaoguang Guo: Mark 6 maintenance
- Xuan He: DiFX operation
- Yidan Huang: DiFX operation, post-correlation technique development
- Tianyu Jiang: data playback, DiFX operation
- Wu Jiang: DiFX operation for astronomical data
- Xiuzhong Zhang: VLBI terminal and correlation technique development

Xuan He is the only person to work full-time on geodetic VLBI data correlation.

3.2 Technique Development Team

- Weimin Zheng: group head, software correlator and VLBI terminal development
- Jiangying Gan: FPGA programming
- Tetsuro Kondo: wideband bandwidth synthesis
- Lei Liu: software correlator development
- Xiaochuan Qu: CDAS development
- Ping Rui: visualization programming and operation for CVN correlator
- Fengxian Tong: VLBI scheduling and modeling
- Li Tong: VLBI raw data simulation
- Juan Zhang: software correlator development and maintenance
- Renjie Zhu: CDAS development

Tetsuro Kondo from NICT joined the group in mid 2017 as a distinguished scientist, offered by the CAS President's International Fellowship. He returned to Japan at the end of 2020.

4 Summary of Activities

4.1 DiFX Correlation

We use the latest stable version of DiFX and HOPS software for regular IVS data correlation. The vgosDB files are available at our ftp site[1]. We also produce FITS-IDI files, which can be downloaded on request by the users.

We investigated the data playback rate of Mark 6 units. The connection of Mark 6 units to the cluster data storage was replaced with 56-Gb Infiniband. Thus the data rate for gathering could be up to 11 Gbps. However, the data rate for VDIF multiplex is still very slow.

We introduced peculiar clock offsets to compensate instrumental delays of reference stations in early 2018. As shown in Figure 1, we analyzed all 36 correlated sessions, and derived a mean clock bias for each session, i.e., clock compensation errors with respect to the peculiar clock offset table. In most of cases, the mean clock bias is less than 0.5 µs. Only one session, CRF111, has a clock bias of 1 µs due to human error. Judging from nine sessions in 2020, we found Urumqi had a jump in the peculiar clock offset of about 1.1 µs. The mean clock bias should be much smaller, if only the most stable stations are used in the calculation.

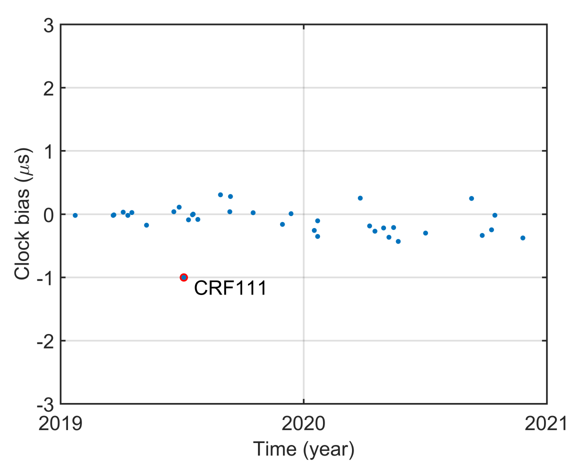

Fig. 1 Mean clock bias for each of the 36 sessions correlated at Shanghai.

[1] http://202.127.29.4/vgosDB/

4.2 Spacecraft Tracking

We performed regular VLBI tracking of the Tianwen-1 Mars spacecraft in its Earth-Mars transfer orbit. The typical RMS delay residual is about 0.1 ns.

The Chang'e-5 is the most complicated mission for our group. It is a big challenge for differential VLBI scheduling and data correlation. In one tracking session, sometimes we need to track two objects alternatively or in the same beam. The correlation model polynomials for two objects need to be calculated before timeshare data correlation.

In addition, there are regular tracking sessions for the Chang'e-4 data relay satellite. The sessions for tracking spacecraft are so frequent that they made an impact on geodetic or astronomical observations.

4.3 e-VLBI

The network links to Seshan25 and Tianma65 are 10 Gbps. The network links to the Urumqi, Kunming, and Beijing stations are 200 Mbps for tracking spacecraft. In the Chang'e-5 lunar mission and Tianwen-1 Mars mission, we made real-time data transfer at a 128-Mbps data rate for each station. However, for regular geodetic observations, the Chinese stations always ship modules to the Shanghai correlator.

In order to process IVS global sessions, we have established network links to most of the IVS stations and correlators. The regular data rate is 2 Gbps. Only two international stations, Matera and Kokee, need to ship modules.

4.4 Experiments Correlated

We correlated 20 IVS sessions in 2019 and 16 sessions in 2020. Most of them are focused on VLBI absolute astrometry. There were no stringent requirements on data latency. We aimed to deliver the correlation products in three months. More details can be found in Table 1.

We have correlated 134 IVS sessions since 2015, with 33 participating stations distributed over the globe. The cumulative data volume is approximately 4.2 PB, collected from more than 850 station days. The top five stations with the most observing days are Yarragadee, Hobart26, Katherine, Kunming, and Warkworth. More details were shown in Figure 2.

Table 1 Statistics of experiments correlated.

Session Name	2019	2020
AOV	6	5
APSG	2	2
IVS-CRF	6	6
IVS-R&D	6	3
Total	20	16

It is worth noting that all APSG sessions and some AOV sessions were scheduled by SHAO. The APSG observing sessions are dedicated to measure positions and velocities of stations in the Pacific Rim. The AOV sessions organized by SHAO are focused on astrometry of weak sources in the ecliptic plane and southern hemisphere. Two stations belonging to the National Time Service Center (NTSC), Jilin and Sanya, participated in the APSG44 and APSG46 sessions as tag-along stations.

4.5 VGOS Correlation Campaign

We took part in the VGOS Intensive blind test. The data set is V19290 observed with Kokee12m and Wettz13s. We managed to finish data correlation, fringe fitting, and generation of database file independently.

A second campaign was the post-processing comparison of the multiple-station 24-hour VGOS session VO0009. The control files were provided by the Haystack correlator group. We gained experience in how to perform calibration at different stages.

The database files were submitted to the Haystack group who made correlation comparisons of the participating IVS correlators. More details can be found in the Haystack memos.

4.6 Fringe Tests of Shanghai VGOS Stations

We have performed a few fringe tests with the Shanghai VGOS stations.

We obtained first broadband fringes on the baseline Seshan13–Tianma13 on July 9, 2019. The IVS-VT ob-

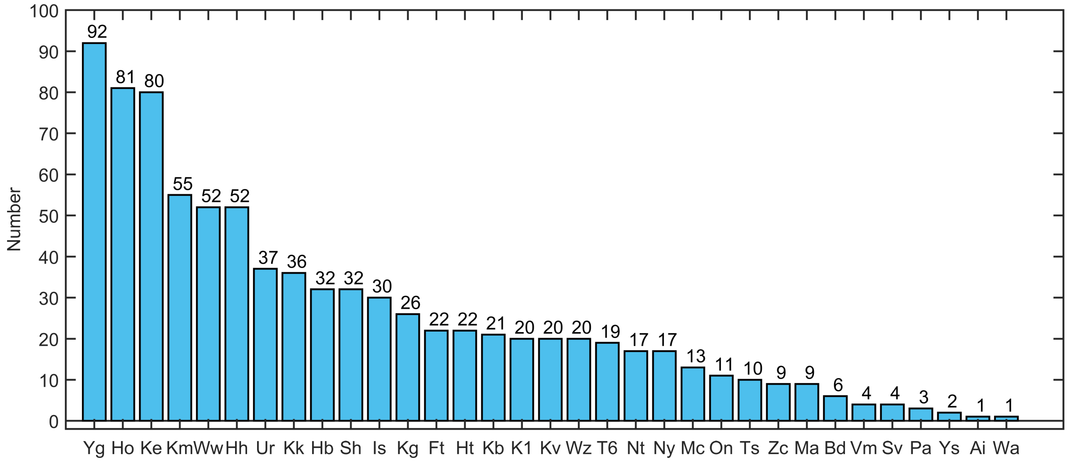

Fig. 2 Statistics of total session number for each station correlated at Shanghai over the last six years.

serving mode was used. Serious RFI caused by a 5G base station was detected at channels G and H.

Seshan13 was tagged along to VT9329. Tianma13 was tagged along to VT9343 and VT9360. Unfortunately, there was no opportunity to perform fringe tests with the other participating stations.

The first international fringe test was performed on July 7, 2020. Seshan13, Tianma13, and Ishioka observed for one hour using IVS-VT mode. Fringes were detected successfully. A misalignment of the polarizer of Seshan13 was detected, and then corrected a few months later.

The second international fringe test was performed on September 3, 2020. Seshan13, Tianma13, Hobart12, and Kath12m observed three hours. As the Australian VGOS stations have only three bands available due to a limitation of their DBBC3, the frequency sequence was re-designed to span over three bands with frequency coverage of 3.6–10.7 GHz.

On December 18, 2020, we obtained first broadband fringes between Shanghai and Urumqi antennas.

4.7 K-band Geodesy

We performed K-band geodesy using the East Asian VLBI Network (EAVN) plus some IVS stations. Following the standard geodetic VLBI data processing path, we added K-band observing mode in the schedule catalogs. Thus we could schedule K-band geodetic experiments similar to S/X band.

We performed a fringe test using EAVN stations, Russian stations, and Hobart26 on 19 November 2019, followed by a 24-hour session on 25 May 2020. The experiments were observed at a 1024-Mbps data rate, with eight IF channels (four USB and four LSB) and 2-bit sampling. Only LCP was used. Each IF channel was 32 MHz wide. We processed the data with DiFX and HOPS. The results of further data analysis are very promising; thus, more experiments will be conducted later on.

5 Future Plans

We plan to correlate some IVS VGOS sessions. For testing purposes, the Shanghai VGOS stations could be scheduled in those sessions as tag-along stations. With more VGOS stations coming online, the observing network can be optimized to alleviate the bottleneck pressure of data transfer.

Acknowledgements

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