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# Implementation of a geodetic path at the JIVE correlator

M. E. Gomez, M. Kettenis, P. Charlot, R. M. Campbell, A. Keimpema

**Abstract** This paper reports on the progress towards the implementation of a complete geodetic path for the EVN Software Correlator at JIVE (SFXC). It is conducted as part of the JUMPING JIVE project funded by the Horizon 2020 Framework Programme of the EU. JUMPING JIVE is dedicated to enhance the position of JIVE and the European VLBI Network (EVN) within the future of radio astronomy. This includes implementation of new capabilities, among which is the possibility to correlate geodetic-type experiments and export them in a standard fashion so that they can be further processed by the usual geodetic software packages. The implementation of this new capability requires (i) to make SFXC able to handle complex geodetic-like schedules with sub-netting, and (ii) to incorporate total quantities and measured phase-cal values in the data provided to the users. To facilitate post-processing, it was also decided to convert the correlator output to the standard geodetic Mark4 format. All such developments are now complete. To test the implementation, we have reprocessed IVS session R1872 and compared the output from SFXC with that obtained at the DIFX correlator in Bonn, where the session was originally processed. The methodology is explained here and partial results of the comparison are given. These indicate a 5.5 ps wrms for the Total Multiband Delay difference between the two correlators.

**Keywords** JUMPING JIVE, EVN, VLBI

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## 1 Introduction

JUMPING JIVE is the acronym for Joining up Users for Maximizing the Profile, the Innovation and Necessary Globalization of JIVE, a project funded by the European Union's Horizon 2020 programme. The project<sup>1</sup> is divided into ten work packages (WP) that cover various aspects from dissemination to technical developments and future science with the European VLBI Network (EVN). In this paper we are concerned with WP6 activities which have to do with the implementation of full geodetic capabilities at the EVN software correlator at JIVE (SFXC). This means that the correlator should be able to:

1. Correlate data with proper handling of geodetic sessions which are scheduled with sub-netting;
2. Attach the correlator model to the correlator output;
3. Attach phase-calibration information to the correlator output;
4. Provide correlator output in the appropriate format for further geodetic post-processing.

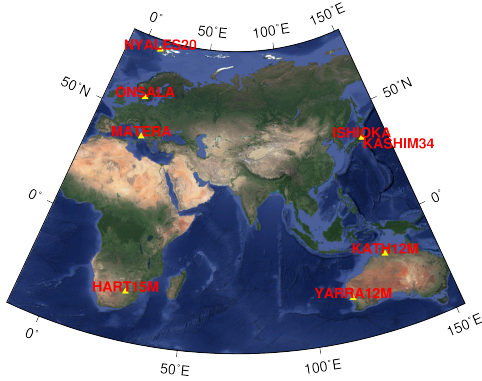
From the correlator output, an analysis center should then be able to:

5. Post-process and export the data.

The items listed above constitute also the steps of the procedure followed to validate the whole implementation at JIVE. The first step was accomplished at the end of 2017: one hour of an IVS-R1 session (which included sub-netting) was successfully correlated (Colomer et al., 2018). Steps 2 to 4 were also accomplished and are described in Keimpema et al. (2019).

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<sup>1</sup> <https://jive.eu/jumping-jive>



**Fig. 1** Stations involved in IVS-R1872 session

In the following, we will focus on step 5. For that purpose, a whole 24-hour IVS session, IVS-R1872 (held on December 10, 2018) was selected. This experiment involved eight IVS stations (Fig. 1) and observed a total of 1069 scans.

## 2 Methodology

### 2.1 Correlation

IVS-R1872 was originally correlated with the DIFX correlator in Bonn. For the purpose of the project, it was also subsequently correlated at JIVE with SFXC. Both correlator outputs were exported into the standard geodetic Mark4 format. Additionally, the Bonn correlator center further exported the data into vgosDB format (version 1), which is the newest and current format for geodetic datasets, after post-processing. A difference in the processing is that SFXC used a delay model based on CALC 10 whereas the delay model used with DIFX was CALC 11.

### 2.2 Post-processing and data export

In order to check the Mark4 implementation and post-processing, we devised a validation procedure in two stages. The first stage comprised checking our ability to find fringes and to produce vgosDB file version 1. This was done using the correlated Mark4 files provided by the Bonn Correlator Center for IVS-R1872.

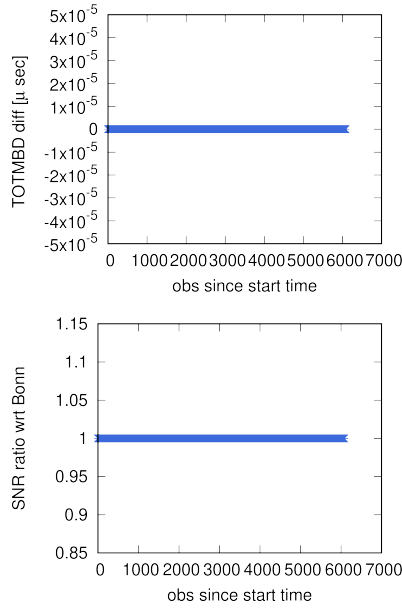
They also provided us with post-processed data and the vgosDB file version 1 so that we could check our results against theirs. The comparison was done at the level of vgosDB files. The second stage of the validation comprised post-processing JIVE-correlated data for that session and compare our results with respect to those obtained in Bonn.

In the post-processing, we applied exactly the same control file as that used at the Bonn Correlation Center because there was no reason to introduce changes when processing the data correlated at JIVE. We used Fourfit (HOPS 3.18 rev 2251) for that purpose and vgosDbMake-0.4.3 to transform the data into vgosDB format. The selected version of each software was not arbitrary: it was the same as that employed in Bonn in order to avoid potential differences due to software version or other issues. Netcdf library and Octave tools were used to extract and plot the data.

According to Corey & Titus (2012), differences at the ps level between results from the two correlators should be expected. Because of differences in the correlation process and correlator architecture, the comparison was not straightforward. The time of each observation is tagged according to what is called the Fourfit Reference Time (FRT) which may differ from one correlator to the other, due to differences in how the correlators search for the first valid input data for each scan. This situation causes natural discrepancies in the Total Multiband Delay (TOTMBD) just because we are evaluating this quantity at different FRTs. For this reason, in the section below, we just show results concerning those observations that end up with the same FRT in Bonn and JIVE.

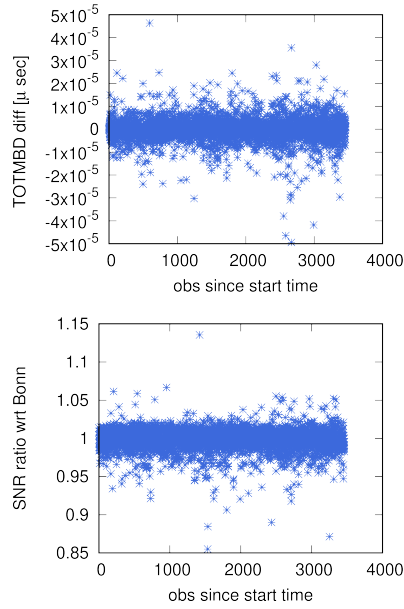
## 3 Results

Figure 2 shows results after comparing the vgosDB file sent by Bonn and our own vgosDB file obtained from Bonn correlated data (stage 1). The plots are for the TOTMBD and Signal to Noise Ratio (SNR) quantities in X-band. There are no appreciable differences between the two datasets at the 15-digit significance level for any observation. This is replicated for S-band and for all the other observables like e.g. single-band delays. This initial check guarantees that no bias will come from local implementation or software version differences.



**Fig. 2** Differences in TOTMBD and SNR ratios wrt Bonn obtained after comparing the original and reproduced vgosDB files from Bonn for IVS-R1872 session.

In order to reproduce the previous analysis, but now comparing the output of both correlators, we took all those observations that have the same FRT and a quality code greater than zero and we plotted the TOTMBD differences and SNR ratios for this subset of data (Fig. 3). There are 3462 of such observations within a total of 5826 observations in the session. Statistics of the TOTMBD differences indicate a 5.5 ps wRMS (weighted RMS) with all values below 50 ps and 80% of them below 5 ps. In the case of the SNR ratio, the average value is 0.998, which means that there is no bias between SFXC and the Bonn DiFX correlator. The magnitudes of the differences between the two correlators, for the TOTMBD and SNR quantities, are according to what is expected (see Corey & Titus, 2012) and confirm that the geodetic path is correctly implemented on SFXC. The corresponding vgosDB file for IVS session R1872 is the first dataset produced in standard geodetic format after correlation with SFXC. Further study is being done on the remaining observations (i.e. those that do not have the same FRTs) in order to complete comparisons for the entire session.



**Fig. 3** Differences in TOTMBD and SNR ratios ( $SNR_{JIVE}/SNR_{Bonn}$ ) obtained after comparing the vgosDB files produced by SFXC and the Bonn DiFX correlator for IVS session R1872. The comparison is limited to those observations that have the same FRTs.

## 4 Conclusions

We have shown that the EVN Software Correlator at JIVE (SFXC) has the capability to correlate data from a standard geodetic session and its output can be fully analysed with the most common geodetic tools. Using data correlated through SFXC we were able to produce the first dataset in the vgosDB standard geodetic format. SNR ratios and TOTMBD differences between SFXC and the Bonn DiFX correlator were analysed for those observations that have the same FRTs and are at the anticipated level. The comparison for the rest of the observations (those that do not have the same FRTs) will also be accomplished after devising a proper scheme in order to fully complete the work.

## 5 Acknowledgement

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