GEODESY AT K-BAND WITH THE EUROPEAN VLBI NETWORK

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ABSTRACT. The paper presents the current status of adding geodetic capabilities to the European VLBI Network (EVN) software correlator at JIVE (SFXC), which is accomplished as part of the JUMPING JIVE project. Even though the EVN is not a geodetic array, there are many reasons why accurate radio telescope positions are desirable, including frequent observations using the phase-referencing technique to detect weak radio sources. Several changes were made at the SFXC so that the correlator can successfully correlate geodetic experiments. Detailed testing using data from the International VLBI Service for geodesy and astrometry (IVS) was performed to check the implementation. Additionally, a non-standard geodetic VLBI experiment was carried out at K-band (22 GHz) in June 2018 using 14 radio telescopes from the EVN. The purpose of this experiment was to determine accurate geodetic positions for those EVN telescopes that do not possess S/X receivers and hence do not participate in regular experiments organized by the IVS. The experiment was fully correlated with SFXC and exported into Mk4 format so that it can be further processed with standard geodesy software packages. That experiment is used as another means to demonstrate the full geodetic capabilities of the JIVE correlator.

1. INTRODUCTION

The EVN software correlator at JIVE (SFXC) has recently been upgraded with a new capability permitting to correlate and to export VLBI data acquired in geodetic mode. Thanks to this upgrade, the correlator is now able to handle sessions conducted with sub-netting (as is usually the case in geodesy) and export the data in a suitable format for post-processing and analysis in a geodetic way. The validation of this new capability was achieved in two ways, (i) by reprocessing completely an IVS-R1 session from beginning to end, and (ii) by processing a dedicated EVN geodetic experiment at K-band aimed to measure the positions of non-geodetic EVN telescopes. This paper describes the methodology used for this validation and presents initial analysis results of the acquired K-band data.

2. A NEW GEODETIC CAPABILITY FOR THE JIVE CORRELATOR

The SFXC correlator at JIVE was upgraded in order to handle geodetic sessions scheduled with sub-netting and to attach the correlator model and phase-calibration information to the correlator output. As HOPS is the standard software package for fringe-fitting geodetic data, a new path was added so that the correlator data can be exported into Mk4 format which is the proper format to be used with HOPS.

In order to test the pipeline implemented at JIVE, a 24-hour IVS session, IVS-R1872, originally correlated with the DiFX Bonn correlator, was selected. This experiment involved eight IVS stations and comprised 1069 scans. The Bonn correlator group provided us with the correlated data along with the fringe-fitted data and the vgos data base files (vgosDB), which is the new geodetic format to store VLBI data. The same processing was done at JIVE, i.e., the observed sampled data were independently correlated with SFXC, post-processed and exported into vgosDB format. For the post-processing and data export we used the same version of HOPS as that used in Bonn to avoid

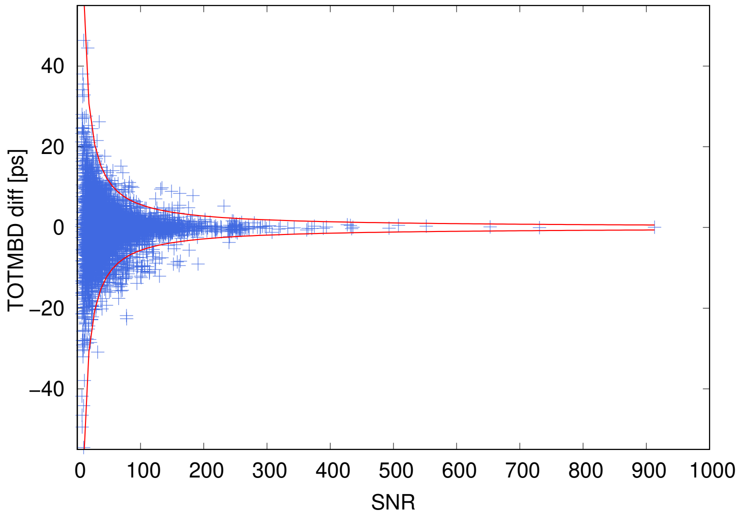

Figure 1: TOTMBD differences vs. SNR for X-band. The red curves represent $\pm 1\sigma$; 95 % of the differences are below this standard error.

potential differences due to software changes. In terms of models, it must be noted that SFXC uses a delay model based on CALC 10 whereas the delay model used with DiFX is CALC 11.

To validate the procedure, we compared our results with those from Bonn at the level of the vgosDB data set. This was not straightforward because of differences in the correlation process and correlator architecture. 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. For the present case, there was a difference of 0.5 s between FRTs for some observations which caused discrepancies when comparing the Total Multiband Delay (TOTMBD) just because this quantity was being evaluated at different FRTs. To remove that effect, we shifted the FRTs of the TOTMBDs of JIVE to the Bonn FRTs and we corrected the TOTMBD derived at JIVE with the delay rate estimated during the fringe-fitting done with HOPS.

For the comparison, we divided the data into two subsets: one that includes the data that have the same FRTs (3462 out of 5826 observations) and one that includes the data that have different FRTs. When the FRT is the same, 80 % of the TOTMBD differences are below 5 ps. The ensemble has a mean of -0.09 ps and a wRMS of 5.5 ps. In the case of those observations that had different time tags (2364 observations), the ensemble of TOTMBD differences, after correction, has a mean of -1.0 ps and a wRMS of 8.5 ps. The wRMS is thus similar, although slightly larger, to that derived for those observations without time tag discrepancies. The level of the differences is consistent with the expected size of second-order residuals arising from the use of a linear correction to the TOTMBDs of JIVE, based on propagating the delay-rate over the 0.5 s FRT difference. As a further check, we inspected the relationship between the standard error of the TOTMBD (σ_{MBD}) and the SNR. According to Rogers et al. (1993),

$$\sigma_{\mathrm{MBD}} \propto \mathrm{SNR}^{-1} \tag{1}$$

For the IVS session R1872, with a spanned bandwidth of 720 MHz and an RMS bandwidth of 280.4 MHz, this equation can be written as $\sigma_{\mathrm{MBD}}[\mathrm{ps}] = 567/\mathrm{SNR}$. Figure 1 show the results of this check for all observations. As expected, the TOTMBD differences decrease as the SNR increases and 95 % of them are below the 1σ standard error value. Further details on the validation process

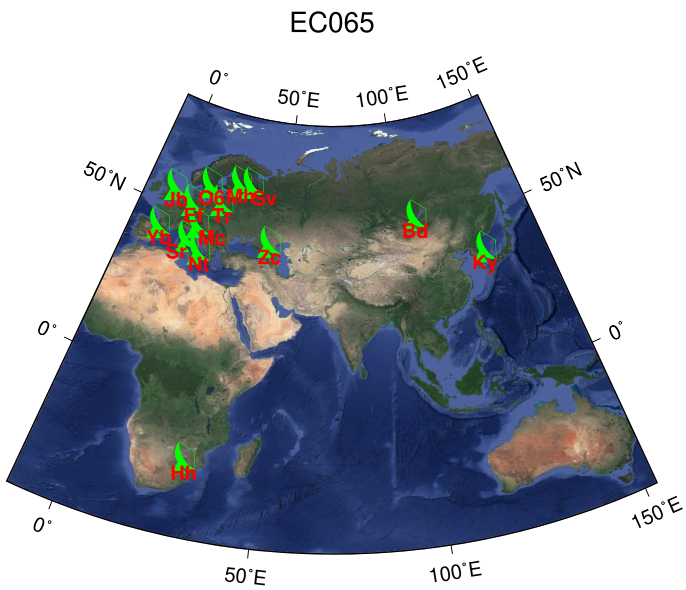

Figure 2: Stations that have participated in the EC065 experiment.

can be found in Gomez et al. (2019).

3. PRELIMINARY ANALYSIS OF EVN GEODETIC DATA ACQUIRED AT K-BAND

A non-standard EVN geodetic experiment at K-band, coded EC065, was carried out on June 13, 2018. Data from 14 EVN telescopes, including Sardinia, Jodrell2, KVN-Yonsei and Torun which are non-geodetic, were acquired (Fig. 2). A total of 478 scans spread over the 24-hour duration of the experiment were observed. The data were correlated with SXFC and post-processed with HOPS following the established path.

The geodetic analysis was conducted with VieVS (Böhm et al., 2018) in a standard way with models and apriori data as in Table 1.

Data/Models	Comments
Ephemeris	JPL421
Earth Orientation Parameters	IERS C04
Terrestrial Reference Frame	ITRF2014
Celestial Reference Frame	ICRF3(K)
Ocean Tide Loading	FES2004
Ionospheric correction	CODE
Galactic Acceleration	YES
Tropospheric hydrostatic model	Saastamoinen
Tidal atmospheric loading	Vienna
Non-tidal atmospheric loading	Vienna
Tropospheric Mapping function	VMF3

Table 1: Models (non-exhaustive) used for the analysis of the EC065 experiment.

As only a single frequency was observed, correction of ionospheric effects was necessary. For this purpose we used total electron content maps produced by the Center for Orbit Determination in Europe (CODE) based on data from the Global Navigation Satellite Systems. A trial using

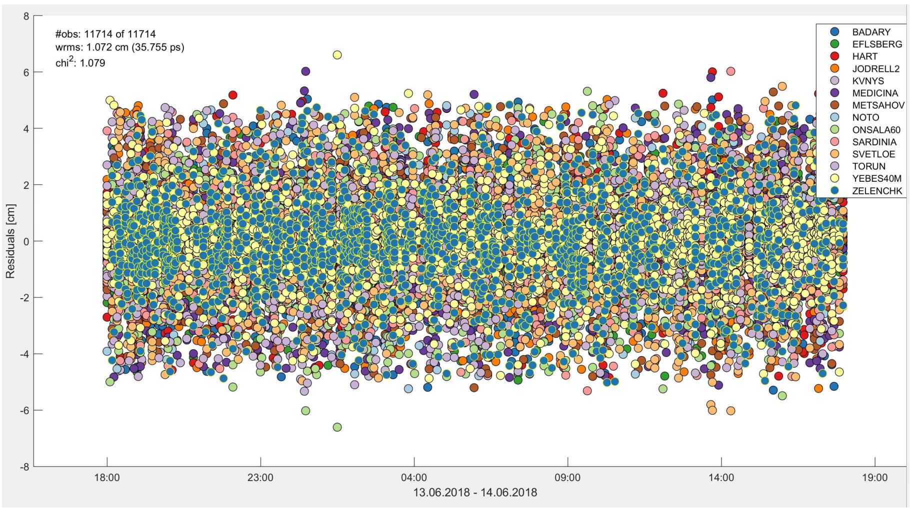

Figure 3: Post-fit delay residuals resulting from the VieVS analysis.

ionospheric maps from the Jet Propulsion Laboratory (JPL) showed insignificant differences in the results as previoulsy noted by Langi et al. (2010).

The post-fit residuals are plotted in Figure 3. These have an wRMS of about 1 cm which brings a promising perspective for the estimation of station positions with these data.

4. CONCLUSION

We have shown that a typical 24-hour IVS session can be fully processed with the EVN software correlator at JIVE (SFXC), post-processed and analyzed with standard geodetic tools. Comparison of the correlator output with that from the DiFX correlator at the Bonn correlation center indicates an agreement at the 5 ps level in total multiband delay, which is the level of consistency expected. We have further demonstrated that the pipeline from correlation to session analysis works also for a non-standard geodetic session like EC065. These two end-to-end tests show that the SFXC correlator is now technically capable to process and export geodetic data.

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5. REFERENCES

Böhm, J., Böhm, S., Boisits, J., Girdiuk, A., Gruber, J., Hellerschmied, A., Krásná, H., Landskron, D., Madzak, M., Mayer, D., McCallum, J., McCallum, L., Schartner, M., Teke, K., 2018, "Vienna VLBI and Satellite Software (VieVS) for Geodesy and Astrometry", Publications of the Astronomical Society of the Pacific 130(986), 044503.

Gomez, M.E., Kettenis, M., Charlot, P., Campbell, R.M., Keimpema, A., 2019, "Implentation of a geodetic path at the JIVE correlator", Proceedings of the 24th European VLBI Group for Geodesy and Astrometry Working Meeting (CNIG-Madrid, Spain), pp. 112–115.

Lanyi G. E. et al.., 2010, AJ 139, 1695.

Rogers, A.E.E. et al.., 1993, "Improvements in the Accuracy of Geodetic VLBI". Smith D. E. and Turcotte D. L. Eds., Geodynamics Series.