Implementation and First Results of the Local Wettzell VLBI Correlator GOWL

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Abstract The Geodetic Observatory Wettzell (GOW), jointly operated by the Federal Agency for Cartography and Geodesy (BKG) and the Technical University of Munich is equipped with three radio telescopes for Very Long Baseline Interferometry (VLBI). Extended local correlation capabilities, however, have been missing at the Observatory so far. A computing cluster forming the GO Wettzell Local Correlator (GOWL) was installed in September 2017 as well as the Distributed FX (DiFX) software correlation package and the Haystack Observatory Post processing System (HOPS) for fringe fitting and post processing of the correlated output. Data pre-processing, including ambiguity resolution (if necessary) as well as the generation of the geodetic database and NGS card files, is carried out with nuSolve. The final analysis is either performed with our local processing software (LEVIKA short baseline analysis) or with the Vienna VLBI and Satellite (VieVS) software. We present an overview of the correlation capabilities and results obtained so far. Regarding the local ties at Wettzell, we have been studying the local baseline between RTW (20 m) and TTW1 (13.2 m) in detail since 2016. These local sessions are usually scheduled with VieVS. Here we report on the method and first results of the local baseline estimated with VLBI and then compare with local tie measurements. Moreover, we also present initial results from the AGGO radio telescope testing as well as from individually scheduled sessions including the O'Higgins VLBI telescope at Antarctica. Finally, we want to present different observing prospects and future plans.

Keywords VLBI correlation and analysis, local ties, Wettzell triple radio telescope, scheduling

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1 Short Baseline Sessions

Short baseline measurements at GOW are observed between RTW and TTW1 (Figure 1). Both telescopes are currently participating in IVS sessions in legacy (S/X band) mode. Due to the presence of the phase calibration signal with the same bandwidth and spacing on both telescopes, the baseline is not usable and rejected during the analysis process. The local sessions are conducted with phase cal switched off on one of the observing telescopes to avoid interference by the phase calibration signal and to make the baseline usable for geodetic analysis. For acquiring sufficient signal-to-noise ratio and fringe quality the manual phase cal mode is applied for the same telescope in the fringe fitting process. Both telescopes are connected to separate clocks during the local sessions. One of the advantages of scheduling short baseline observations is that the number of observed sources is very high because of very good sky coverage. Keeping in mind the number of sessions observed by Wettzell telescopes on a regu-

Fig. 1 View of the GOW with RTW and TTW1.

lar basis, the scheduling software is optimized to gain the maximum number of scans possible in an hour to reduce the total observation time. Various scheduling modes used in official IVS sessions are tested and observed.

2 Long Baseline Sessions

For getting familiar with long baseline correlation and analysis, sessions with partner telescopes in the southern hemisphere (Figure 2) are also organized and observed. The long baseline sessions require ambiguity

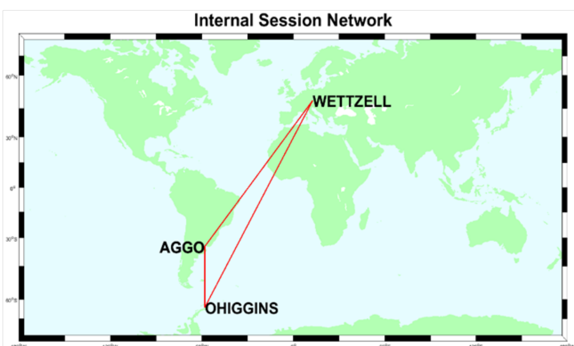

Fig. 2 Local network for long baseline sessions.

resolution and ionospheric correction before estimating geodetic parameters which includes earth orientation, station coordinates, tropospheric correction, and clock offsets. These sessions are dedicated to assuring the quality of VLBI data at the AGGO Observatory, La Plata, Argentina and the Receiving Station O'Higgins, Antarctica. Several tests were conducted in the past with variable durations for testing the VLBI system at AGGO to assess the readiness of the telescope for ob-

Table 1 List of local long baseline sessions.

Session name	Participating telescope	Duration (Hour)	No. of scans
WB015N	Ag, Wz	1	8
WB072l	Ag, Wz	5	11
WB087I	Ag, Oh, Wz	9	92
WB106S	Ag, Wn	24	221
WB136Q	Ag, Wn, Wz	24	455

serving on a regular basis. A list of long baseline sessions observed so far with AGGO and O'Higgins since January 2018 are listed in Table 1. The operation of and data transfer from the GARS O'Higgins telescope is done remotely from GOW. Few trial sessions between

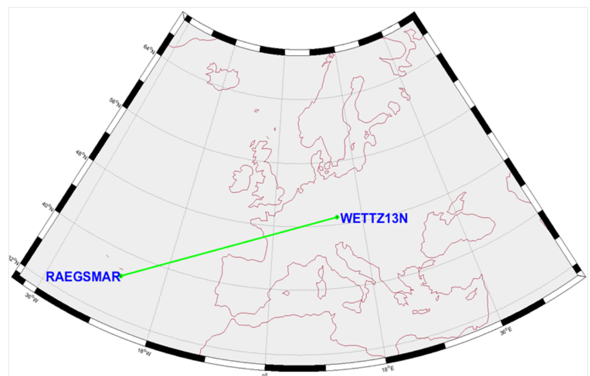

Fig. 3 Baseline for proposed European ΔUT1 estimation.

WETTZ13N and RAEGSMAR are also observed for the determination of ΔUT1 between fast moving telescopes. Both participating telescopes as shown in Figure 3 are within European territory; hence, these sessions are titled as the European Intensive sessions. The hardware configuration for both the telescopes is very similar as they are built as per the VLBI2010 [Niell et al., 2005] specifications (fast moving, small dish, broader frequency coverage). The number of observed scans is much higher in this case as compared to other Intensive sessions as a consequence of better sky coverage [Boehm et al., 2018].

3 Scheduling, Correlation, and Analysis

Before scheduling a local session they have to be requested via BKG CVC [Schüler et al., 2018b] to keep track of the status of each session and proper communication between scheduler, operator, correlator, and analyst. The Vienna VLBI and Satellite Software (VieVS 3.0) [Sun et al., (2012)] and Sked [Gipson et al., 2012] are installed for scheduling local sessions. Figure 4 depicts the statistics of local sessions scheduled in the last two years. It is clearly seen that the short baseline sessions between TTW1 [Schüler et al., (2015)] and RTW are in the majority as compared to the long baseline sessions. The baseline between O'Higgins and Wettzell was scheduled a few times in the past to monitor the health of the VLBI system in Antarctica and to collect data sets for educational purposes. Including TTW2 in the short baseline network is one of the priorties and it is still under investigation and testing. After schedule preparation and observation, raw data is transferred in real time via a 10-Gbps optical link to the high speed data recorder and streamer (flexbuff) with total storage space of 100 TB. It is connected to the computing cluster (Figure 5) on which the DiFX [Deller et al., (2011)] and the HOPS package is installed. Fringe fitting software (HOPS) accounts for insufficiencies in the correlator model and integrates the interferometer signal. Data transmission to and from the observatory is done via a 1-Gbps Internet link. The local correlator GOWL serves three main purposes:

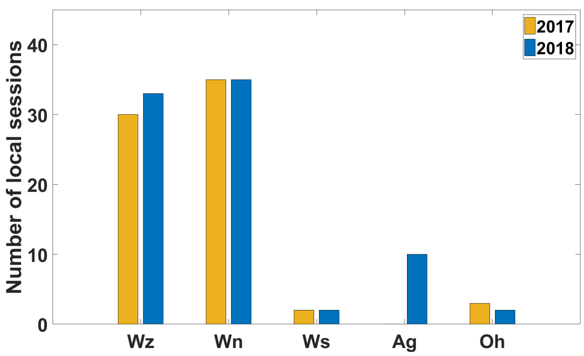

Fig. 4 Local session statistics.

Fig. 5 Image of the computing cluster installed at the TWIN operations room with the spare nodes.

1. It is primarily designed for relative positioning of the three Wettzell radio telescopes, i.e., to derive the local ties between the three telescopes from VLBI raw data in addition to the conventional terrestrial surveys carried out.
2. The local correlator closes the gap between the observation work and geodetic analysis. The closure of this missing piece in the measurement/analysis chain is important to provide timely quality feedback to the VLBI engineers regarding the status of their telescopes.
3. Finally, GOWL serves as a critical backup infrastructure. This means that it is not foreseen to carry out routine operational work, which resides with the Bonn Correlator operated at the Max-Planck-Institute for Radio Astronomy, but is available in case of dedicated and special needs.

Thereafter, the fringe fitted output is processed in νSolve [Bolotin et al., (2014)] to produce vgosDB and NGS (ASCII) card files for an individual session. These ASCII files are input to VieVS and the in-house short baseline software (LEVIKA) [Schüler et al., 2018a] developed for estimating station coordinates and comparing them with the results of local survey measurements. In case of a long baseline session, station coordinates and other geodetic parameter estimation is done either by νSolve or by VieVS [Boehm et al., (2012)].

4 Results

Radio frequency interference (RFI) is another limiting factor for short baseline observations. Most of the scans in S-Band are affected by RFI mainly due to overlapping with Wi-Fi and other telecommunication signals. This causes a hindrance in terms of accessing the data quality of the affected channels as they have to be flagged in the correlation process and are not contributing in further analysis. Figure 6 depicts the output after post-processing a VLBI session where the local baseline is also included. When S-band is se-

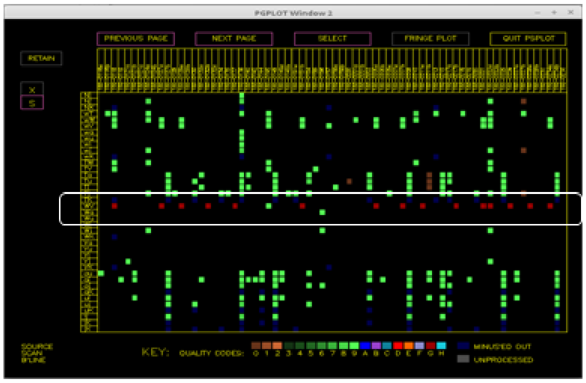

Fig. 6 This figure is produced using post-processing software showing the fringe quality of all the scans (x-axis) corresponding to S-band for all participating baselines (y-axis). The quality code or fringe quality is represented by different colors. Green is an indicator of fringe quality between three to nine, G-code is shown in red, and blue represent scans for which correlation was not attempted due to problems at the station.

lected, the local baseline is visible with red dots for most of the scans which are an annotation for G-code. G-code for a scan is an indication that the fringe amplitude is less than 0.5 times the mean amplitude of the received signal which is in most of the cases due to internal or external interferences. For a 123-m baseline an additional delay due to ionosphere is considered negligible; hence, observing with S-band is of no real importance except quality control. This makes the further procedure simpler as only group delays from X-band are used for analyzing the sessions. Figure 7 illustrates the analysis results from the sessions observed in 2017. Red dots represent the baseline length (3-D) estimated from an individual session with error bars (uncertainties) in cyan. The local survey measurement result is delineated in pink. Improvement in terms of estimated baseline length is expected after implementation of a common clock framework between all three telescopes. The common clock will provide equal delays in the time regime if all systematic biases are correctly addressed. Figure 8 gives an overview of the stability of the pulse per second signals when transferred using coaxial cable and optical cable. The dataset for these tests was collected by transferring the pps signals between two buildings at the Geodetic Observatory Wettzell [Schreiber et al., 2018] to make a comparison between the two approaches.

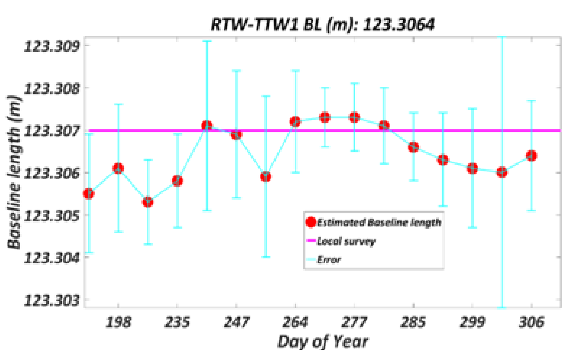

Fig. 7 3-D distance estimated with local sessions between RTW and TTW1 with the mean offset of 0.6 mm from the local survey measurement taken in the year 2017.

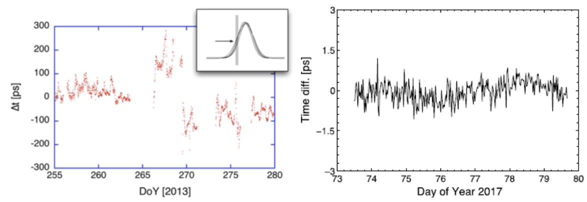

Fig. 8 Stability of pps signal transferred via coaxial cable (left) and optical fiber cable (right) is illustrated in this figure.

5 Conclusions and Outlook

The availability of a correlation capability fulfills multiple roles and it is of the utmost importance in terms of quality assurance. Further research and development work is being carried out on a regular basis at all three VLBI sites. Geodetic sessions are conducted on a regular basis to estimate baseline length between all the possible telescopes operated by GOW. Results presented in this paper show sub-millimeter accuracy of the baseline length between RTW and TTW1. Further improvement is foreseen after the implementation of a common clock. The comparison between the time transfer via coaxial cable and optical fiber gives a clear picture about the stability of both methods. The pps signal transmission via optical fiber seems to have a better stability in contrast to the coaxial cable.

The introduction of TTW2 into the short baseline network is in the initial stages. The availability of the Eleven feed with the possibility to observe only with linearly polarized signal makes it challenging to include it into the network where all the other telescopes are equipped with a receiving unit with the capability to observe a circularly polarized signal only. Several tests were conducted in the past to accomplish common clock modes and it is likely that there will be more tests in the future for finalizing the most efficient scheme amongst the two. The absence of the phase calibration signal in one of the telescopes for each short baseline session also deteriorates the results. There are a few solutions suggested to avoid such a set-up for short baseline observation and this is also in the list of future work to further improve the solution. A tri-band feed is installed at the TTW1, giving the possibility to observe with Ka-band in addition to S and X frequency bands. Incorporating Ka-band channels with the existing setup will be part of future research. Considering the fact that the hardware design of RAEGSMAR is similar to WETTZ13N, this scientific work will be part of the European Intensive sessions.

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