INT9 - ΔUT1 Determination Between the Geodetic Observatories AGGO and Wettzell

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Abstract The AGGO radio telescope, located at La Plata in Argentina, comprises together with the radio telescopes in Wettzell, Germany a baseline configuration spanning a longitude difference of 71°. Therefore, starting in the middle of 2018, tests were initiated to prove the usability for ΔUT1 determination between the traditional S/X VLBI systems at AGGO and Wettzell. The 6 m AGGO radio telescope was scheduled in combination with the 20 m radio telescope Wettzell (RTW) and the 13.2 m Wettzell North (WETTZ13N) in weekly VLBI tests for ΔUT1 determination, named INT9. The scheduling of INT9 sessions was done with *sked* and the time duration was set to be two hours each. The sessions were conducted mostly on Thursdays, just before the normal INT-1 Intensive session takes place. The recording mode needed to be evaluated step by step to increase gradually from a standard 256 Mbit/s recording mode to 1 Gbit/s. The latter mode yields a higher amount of scans in a given time period. The goal is to exploit the highest ΔUT1 determination accuracy between AGGO and Wettzell as possible. We will report our initial experiences with the VLBI operation at both observatories and compare first results between official ΔUT1 measurements and the INT9 derived values as well as a potential future outlook of this INT9 VLBI application.

Keywords Intensive · ΔUT1 · Geodetic Observatory Wettzell · AGGO

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1 Introduction

The Argentinean German Geodetic Observatory (AGGO) was successfully re-initiated after the transport from Chile to Argentina. Due to the extended idle period, several components of the VLBI system were defect or showed malfunctions.

In particular, the analog baseband converters and the up-converter of the analog backend had failures and needed to be repaired. After this maintenance, the VLBI system at AGGO became operational in spring 2018. The VLBI system needed to be tested carefully and its stability had to be evaluated, before taking part again in the normally scheduled VLBI sessions within the International VLBI Service (IVS) (Nothnagel et al., 2017). This was done first with test sessions coordinated between the Bundesamt für Kartographie und Geodäsie (BKG) radio telescopes of the Geodetic Observatory Wettzell and AGGO. When the first fringes were successfully found, the demand came up to evaluate geodetic VLBI applications. A ΔUT1 determination is a favorable geodetic application, due to the longitude difference of 71° between AGGO and Wettzell. Therefore, a demonstration program including a series, consisting of test sessions was initiated to prove that this baseline configuration is sufficient for the ΔUT1 determination.

Fig. 2: The 20 m radio telescope Wettzell (RTW).

The 20 meter radio telescope Wettzell (RTW or Wz) of the geodetic observatory Wettzell constitutes a stable reference station within the VLBI community since 1983. Especially, the ΔUT1 Intensive measurement INT-1 with a one hour session between the RTW and the 20 meter radio telescope of Kokee Park is normally observed every week from Monday until Friday. Thus, a comparison of the ΔUT1 performance of the Wettzell to AGGO baseline in relation to the frequently observed baseline Wettzell to Kokee Park would be of high interest. Another aspect is that the most VLBI stations are located on the northern hemisphere, including VLBI stations that are involved in frequent Intensive ΔUT1 VLBI measurements, whereas AGGO is located on the southern hemisphere. Additionally, the difference in latitude of 84° might provide information about an estimate of the polar motion. Though, the pole position was held fixed in those initial investigations.

The challenges to overcome were to establish the complete processing chain, i.e. scheduling the Intensive session, correlating with the *DiFX* software correlator (Deller et al., 2007) and obtaining results from analysis. The main limitation is the rather high system equivalent flux density (SEFD) of the AGGO radio telescope. Therefore, with the same observing mode (256 Mbit/s) as for an INT-1 Intensive observation, a rather long observation time on a radio source is necessary to reach a minimum signal to noise ratio (SNR) goal of 20 in X-band and 15 in S-band. The tests were then focused to test the 1 Gbit/s mode, which is also feasible with the old analog backend of AGGO. This 1 Gbit/s mode is used successfully with the weekly INT-3 Intensive observations.

Fig. 1: The 6 m radio telescope AGGO.

Fig. 3: The 13.2 m twin radio telescopes Wettzell.

2 Method

Several issues needed to be solved in order to reach Intensive observation capability. The scheduling was done initially with the scheduling program *sked* (Gipson, 2010) and later on with *VieSched++* (Schartner and Böhm, 2019). As a first approach, the formerly proven VLBI mode with 256 Mbit/s and one-bit sampling was chosen. This is a standard mode in R1 sessions and was frequently used before with IVS-R1 sessions at AGGO. Hence, the first test observation resulted in immediate fringes and analysis results. The SEFD of the 20 meter RTW is 750 Jy in X-band and 1000 Jy in S-band. In contrast, the values of AGGO are 10000 Jy in X-band and 15000 Jy in S-band. The only way to achieve more scans per observation time is to increase the total data rate to yield a reasonable number of scans within two hours of Intensive observation time, with the given antenna characteristics. Thus, the use of the 1 Gbit/s mode was clearly the preferred observation mode, because this one enables more scans and leads to better analysis results as the 256 Mbit/s total data rate mode. However, it was quite tricky to set up the backend properly with the VLBA4 analog backend of AGGO during these tests. In particular the trackform layout for the DiFX software correlator, which has to be set up in the session vex file, turned out to be more complicated than expected. The raw data was correlated at the VLBI correlator in Bonn first and then some sessions were correlated at Wettzell. The analysis of the INT9 sessions was done with *VieVS* (Böhm et al., 2018) at the TU Vienna.

Fig. 4: Baseline configuration of AGGO and Wettzell. The distance between Wz and Ag appears as surface distance.

Table 1: Characteristic antenna parameters.

	RTW (Wz)	TTW1 (Wn)	AGGO (Ag)
antenna diameter (m)	20	13.2	6
S-SEFD (Jy)	1150	1050	15000
X-SEFD (Jy)	750	1400	20000
Az-speed ($^\circ s^{-1}$)	4	12	6
El-speed ($^\circ s^{-1}$)	1.5	6	2

The twin radio telescope TTW1 (WETTZ13N or Wn) is equipped with a S/X/Ka-band receiving system and scheduled regularly in the IVS observation program. Depending on the availability of the respective telescopes, this Wettzell radio telescope was also scheduled alone or even together with the 20 m radio telescope in conjunction with AGGO. This leads to three different baseline configurations.

- Ag – Wz
- Ag – Wn
- Ag – Wn – Wz

In general, the session scheduled with all three radio telescopes is expected to give the best accuracy of the UT1 formal error. Most of the observations were scheduled on Thursdays between 16 and 18 UT before the regular INT-1 session between Wettzell to Kokee Park takes place.

3 Results

The first analysis results of the session wb207q, observed with the 256 Mbit/s mode, showed an UT1 formal error of 105 µs. The number of scans is very low, only 25 scans in two hours and no further improvements like consolidated coordinates of AGGO were applied.

The next milestone could be achieved when the 1 Gbit/s observation mode worked correctly. The session wb213q consisted of 35 scans within two hours of observation. This caused the UT1 formal error to decrease by almost 50 % to 56 µs. Consequently, the

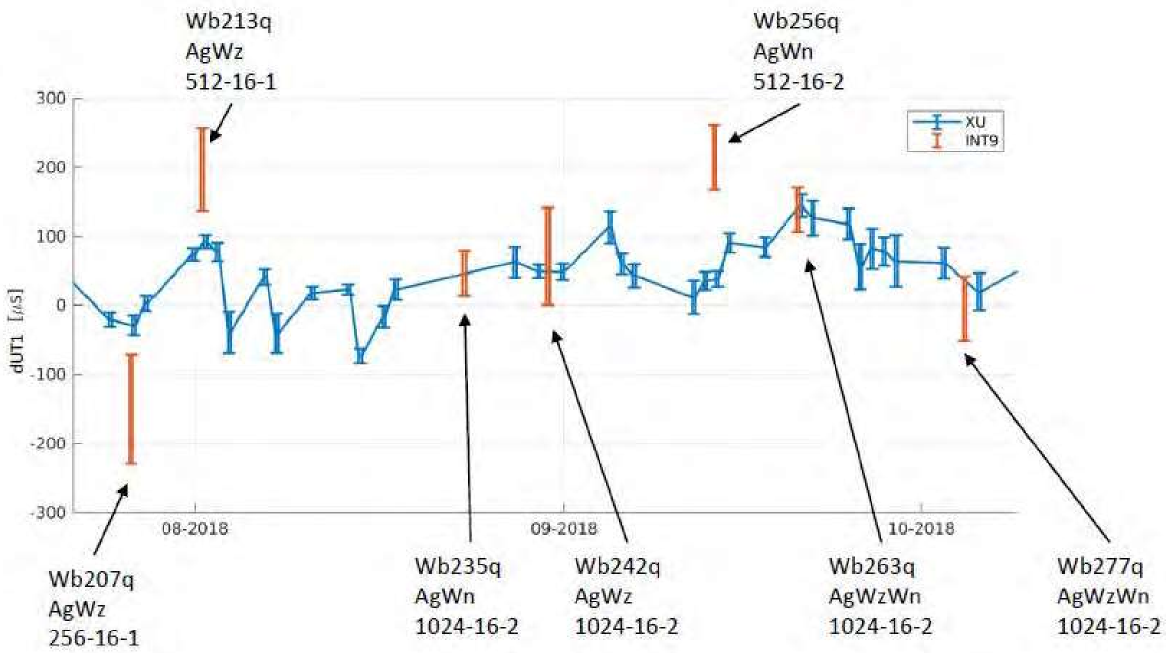

Fig. 5: ΔUT1 with respect to C04.

triple configuration with both radio telescopes involved at Wettzell and AGGO lowered the formal error of UT1 to 48 µs again.

Figure 5 depicts the UT1 estimates as well as their formal uncertainties in contrast to the IERS-C04 time series. For comparison, the INT-1 estimates (XU) and their formal uncertainties are displayed as well. It can be seen that the estimates of the 1 Gbit/s agree quite well with the INT-1 results. The formal uncertainties tend to be a bit higher than their INT-1 counterparts. It is expected that the accuracy increases as soon as the station coordinates of the relatively new AGGO station are known more precisely. Additionally, further improvement is expected as soon as the scheduling is fine-tuned.

Simulations of this triple configuration yield a UT1 formal error of about 30 µs. The simulations were made using VieVS according to Pany et al. (2011) and include tropospheric time delays, clock drifts and white noise. The troposphere was simulated with C_n values of $1.8 \cdot 10^{-7}$ $m^{-1/3}$, a scale height of 2 km and a constant wind velocity of 8 m/s towards east (Nilsson et al., 2007). The clock was simulated as the sum of a random walk and an integrated random walk with an Allan standard deviation (ASD) of 1×10^{-14} seconds after 50 minutes (Herring et al., 1990). Finally, 30 ps of white noise was added to the observations.

Unfortunately, it turned out that the schedules of the observed sessions were not fully optimized for the sessions. Figure 6 compares the simulated formal errors between different scheduling approaches. By using VieSched++, optimized schedules are generated and compared with the observed schedules based on simulations. It can be seen that it is possible to increase both, the number of observations per session as well as the expected formal uncertainties of the UT1 estimate.

4 Conclusions and outlook

The initial performance of the INT9 test sessions between AGGO and both Wettzell radio telescopes is encouraging. If everything is settled a formal UT1 error of about 30 µs appears to be feasible. The upgrade of the analog VLBA4 backend system with a DBBC2 is planned by the end of 2019 or the beginning of 2020. This might improve the system performance and stability of AGGO. Further improvements can be expected by optimizing the scheduling and selecting the sources more carefully as done in Gipson and Baver

Sessions	Optimized schedule for simulation		Observed schedule for initial phase of INT9			
	Number of Observations	UT1 formal error [µs]	Number of Observations	UT1 error [µs]	Stations	Mode / Mbps
wb207q	28	79.2	25	104.7	AgWz	256
wb213q	52	44.7	35	55.7	AgWz	1024
wb256q	36	55.4	29	53.5	AgWn	512
wb263q	129	30.8	123	47.9	AgWnWz	1024
wb277q	129	34.3	102	70.1	AgWnWz	1024

Fig. 6: INT9 comparison between simulation and measurement. The indicated *UT1 formal error* was determined by simulation. The *UT1 error* shows the results gained by the observations.

(2015). Then a test of even 2 Gbit/s total data rate might be an option to get more scans per observation. Further careful evaluation of important parameters like source selection, correct application of the radio telescope specific peculiar time offsets, radio frequency interference (RFI) avoidance zones, consolidated coordinates of AGGO could improve the results of ΔUT1. A routine setup of a triple radio telescope configuration, consisting of RTW, TTW1 and AGGO might yield the best formal errors. Regularisation of the INT9 campaign including a rapid correlation and subsequent data analysis is foreseen in 2019 and 2020. Finally, AGGO demonstrated its potential to a self-contained estimation of ΔUT1.

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