Twin Telescopes at Onsala and Wettzell and their contribution to the VGOS System

C. Schönberger, P. Gnilsen, J. Böhm, R. Haas

Abstract During the last years the International VLBI Service for Geodesy and Astrometry (IVS) spent efforts to improve the accuracy of the geodetic Very Long Baseline Interferometry (VLBI) system to 1 mm for station positions and 0.1 mm/yr for station velocities. To achieve these ambitious goals the VLBI2010 Global Observing System (VGOS) concept was developed, which includes broadband observations with fast-slewing antennas and suggests twin telescopes to reduce the source switching interval and increase the number of observations. Wettzell in Germany has already installed a twin telescope and further twin telescopes will be built in the coming years at Onsala (Sweden) and Ny-Ålesund (Spitsbergen, Norway). In this study, the Vienna VLBI Software (VieVS) is used to schedule and simulate a global VLBI network using the sites that participated in the CONT11 campaign. We compare schedules using the legacy telescopes at Onsala and Wettzell with schedules where either one or both legacy telescopes are replaced by VGOS twin telescopes. The scheduling was done with the source based strategy with four sources at a time, and multidirectional mode for the twin telescopes. The evaluation concerns the numbers of observations and scans, as well as baseline length repeatability and atmospheric parameters.
A higher number of observations and scans can be seen at all sites for the schedules including twin telescopes. Especially at the sites with twin telescopes the number of scans and observations nearly doubles. Also the zenith wet delay (ZWD) estimation improves at sites with twin telescopes. However, so far no significant improvement was found for baseline length repeatabilities and further investigations are ongoing.

Caroline Schönberger, Paul Gnilsen, Johannes Böhm
Technische Universität Wien, Karlsplatz 13, A-1040 Wien, Austria
Rüdiger Haas
Chalmers University of Technology, Onsala Space Observatory, SE-439 92 Onsala, Sweden

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1 Introduction

Geodetic Very Long Baseline Interferometry (VLBI) is essential in providing high-precision geodetic data. It is the only technique to derive Universal Time 1 (UT1), the International Celestial Reference Frame (ICRF), and nutation over longer time spans. Beyond that VLBI plays a very important role for deriving the International Terrestrial Reference Frame (ITRF), in particular concerning its scale (Schuh and Böhm, 2013).

When the VLBI technique was developed in the 1970's, the accuracy was on the order of about one meter. Nowadays, VLBI has an accuracy of about 5 mm (Schlüter and Behrend, 2007).

This accuracy shall be improved to 1 mm in station position and 0.1 mm/yr in station velocity with the realization of the VLBI2010 Global Observing System (VGOS) concept, developed by the International VLBI Service for Geodesy and Astrometry (IVS). It includes broadband observations with fast-slewing telescopes and changes in the data management.

Also twin telescopes are suggested in the VLBI2010 design (Petrachenko et al., 2009) in order to improve the handling of atmospheric turbulence that has been identified as the limiting factor for geodetic VLBI (Nilsson and Haas, 2010). A twin telescope is a pair of identical VLBI telescopes in max 100 m distance, connected to the same frequency standard and with an accurately known local tie vector between the telescopes. Due to the short distance between the twin telescopes, the atmosphere above the telescopes can be assumed to be identical.

The first twin telescope was built at the Wettzell Geodetic Observatory, Germany, in 2011–2013. Additional twin telescopes will be installed in the coming years at the Onsala Space Observatory (Sweden) and the Ny-Ålesund Geodetic Observatory (Spitsbergen, Norway). In this study we focus on the twin telescopes at Onsala and Wettzell.

The Onsala Space Observatory is operated by the Department of Earth and Space Sciences at the Chalmers University of Technology and currently uses a 20 m radio telescope for geodetic VLBI, known as ONSALA60 telescope. A proposal to build the Onsala Twin Telescope (OTT) was submitted in 2011 to the 'Knut and Alice Wallenberg Foundation' and was accepted in 2012. The process of getting building permit was delayed due to issues concerning local wild life and archeological findings (Haas, 2013). Finally, in late 2014 two 13.2 m radio telescopes were ordered. Since these details were not known at the time when the simulations for this work were done, the simulation assumed a smaller telescope diameter of just 12 m for the OTT. The necessary infrastructure work for the OTT will be done in 2015 and installation of the twin telescopes will start in spring 2016. It is expected that OTT will be fully operational in 2017 and gradually take over the regular observations of the legacy telescope.

The Wettzell Geodetic Observatory in Germany is operated by the Bundesamt für Kartographie und Geodäsie (BKG) and the Forschungseinrichtung Satellitengeodäsie (FESG) of the Technische Universität München. It is equipped with a legacy 20 m radio telescope and since 2013 with two 13.2 m radio telescopes, the Twin Telescope Wettzell (WTT) (Kronschnabl et al., 2014).

This work compares the results that can be achieved if the 20 m legacy telescopes at Onsala and Wettzell were replaced by twin telescopes following the VGOS concept.

For this work existing telescopes used in the CONT11 campaign were used, since this is a network that has produced results which can be used as a reference. A map of the CONT11 network is presented in Figure 1. The station WARK12M in New Zealand had to cancel its participation because of technical problems and it is thus not included in this study. Details on each station are given in Table 1.

Fig. 1 The stations participating in the CONT11 campaign. The station WARK12M in New Zealand had to cancel its participation because of technical problems (http://ivscc.gsfc.nasa.gov/program/cont11/ cont11.jpg)

The scheduling, simulation and analysis for this study was done using the Vienna VLBI Software (VieVS) (Böhm et al., 2013).

The scheduling was done with the vie_sched module (Sun, 2014) using a source-based strategy. In this approach the scheduling program selects two or four sources at a time (SAAT) in a way to achieve the

Table 1 Stations participating in the CONT11 campaign with information on the telescope diameter, d, and the slewing velocity in azimuth and elevation, v_α and v_ϵ, respectively. The corresponding information for the twin telescopes is given, too.

Station	d [m]	v_α [°/min]	v_ϵ [°/min]
BADARY	32.0	72	48
FORTLEZA	14.2	40	20
HOBART12	12.0	300	75
HARTRAO	26.0	240	120
KOKEE	20.0	117	117
NYALES20	20.0	120	120
ONSALA60	20.0	144	60
OTT	12.0	720	360
TIGOCONC	6.0	360	180
TSUKUB32	32.0	180	180
WESTFORD	18.0	200	120
WETTZELL	20.0	180	90
WTT	13.2	720	360
YEBES40M	40.0	60	60
ZELENCHK	32.0	72	48

best distribution of sources on the celestial sphere. The sources are selected without considering any effects on individual stations. In the 2-SAAT approach the two selected sources are as far apart as possible and for the 4-SAAT approach the sources form a regular tetrahedron (Sun, 2013). For this study we used the 4-SAAT approach.

A twin telescope allows two additional observing modes, namely the multidirectional mode and the continuous mode. In the multidirectional mode, the two telescopes are part of different subnets at the same time by observing separately different sources in different directions. To operate a twin telescope in the multidirectional observing mode the 4-SAAT strategy has to be chosen, because for the 2-SAAT approach one of the two sources will be blocked by the Earth. In the continuous mode one telescope observes while the other one slews to the next radio source. This leads to continuous observations without temporal gaps (Sun, 2013). However, since previous studies showed that the multidirectional mode gave better results that the continuous mode, we focussed in this study on the multidirectional mode.

All schedules were finalized with the fill-in mode and a cut off elevation angle of 5° was applied. Sources with a minimum source flux density of 0.5 Jansky (Jy) were included in the scheduling and the minimum Sun distance chosen was 4°.

With the vie_sim (Pany et al., 2011) module the observations of the first day of the CONT11 campaign were simulated 25 times, artificially generating a wet troposphere using the turbulence parameter listed in Table 2, clock errors corresponding to an Allan Standard Deviation (ASD) of 1e-14 @ 50 min, and white noise with 32 ps standard deviation.

The parameters listed in Table 3 were estimated in a least-squares adjustment using the vie_lsm module.

The four schedules listed in Table 4 are compared to each other in Section 2. The comparison parameters are the numbers of observations, the number of scans, as well as the baseline length repeatabilities, and zenith wet delay estimates. Sky plots are presented in Fig. 4.

2 Results

The figures in this section depict results for the schedules listed in Table 4.

Table 2 Turbulence parameters Cn (assumed constant up to 2 km) in 10^{-7} $m^{-1/3}$ and wind velocities in north and east direction v_n and v_e in m/s for all sites participating in the CONT11 campaign (Nilsson and Haas, 2010).

Station	Cn	v_n	v_e
BADARY	1.37	0.24	4.74
FORTLEZA	2.46	2.93	-7.11
HOBART12	1.60	3.03	11.14
HARTRAO	1.34	2.03	-2.84
KOKEE	1.39	4.38	-3.35
NYALES20	0.65	7.46	0.53
ONSALA	2.19	7.46	0.53
TIGOCONC	2.08	1.21	4.96
TSUKUB32	3.45	1.03	10.49
WESTFORD	2.30	5.39	11.88
WETTZELL	1.50	7.75	4.22
YEBES40M	1.48	7.75	4.22
ZELENCHK	1.86	4.66	4.15

Table 3 Estimated parameters in the least-squares adjustment. The time interval is given in column 2. Column 3 states constraints using the same unit as the parameter. ZWD: zenith wet delay; NGR/EGR: north/east gradients; EOP: earth orientation parameters.

Parameter [Unit]	interval	constraint
ZWD [cm]	10 min	1.5
NGR [cm]	15 min	0.05
EGR [cm]	15 min	0.05
Station coord.[cm]	24 h	NNT/NNR
EOP [mas/ms]	24 h	1.0 e-4
Clock offset [cm]	1 h	1.3

Table 4 The four different schedules that were compared in this study. All four were scheduled using the 4-SAAT strategy and the twin telescopes used the multidirectional observing mode.

Schedule	explanation
CONT11	original CONT11 network
OTT	OTT replacing ONSALA60 in CONT11
WTT	WTT replacing WETTZELL in CONT11
OTT & WTT	OTT and WTT replacing ONSALA60 and WETTZELL in CONT11

Figures 2 and 3 depict the number of observations and scans for Onsala and Wettzell, and the average number of the other stations. The number of observations declares how often baselines are formed during a session.

The number of observations for this session varies between 700 and 20100 per site with 5000 observations on average. With a VGOS twin telescope, nearly twice as many observations can be carried out at that site, compared to using a 20 m legacy telescope, and also the average value for the other sites increases. The

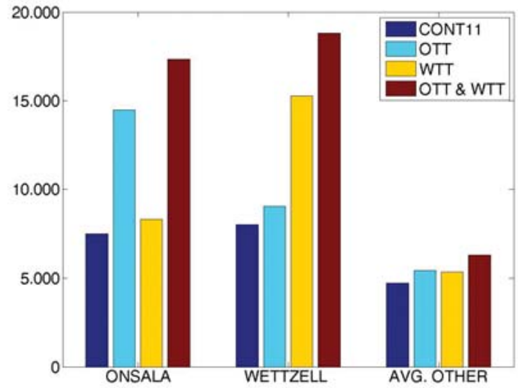

Fig. 2 Number of observations at Onsala and Wettzell and the average number over all other sites. The value for Onsala and Wettzell is the sum of the two single telescopes. With a VGOS twin telescope, nearly twice as many observations can be carried out at that site than with a 20 m legacy telescope.

largest number of observations is achieved with both twin telescopes in the network.

The number of scans varies between 150 and 900 per day with an average value of around 400. This result is in accordance with the number of observations with a high increase at the site using a twin telescope and the highest increase with both twin telescopes in the network.

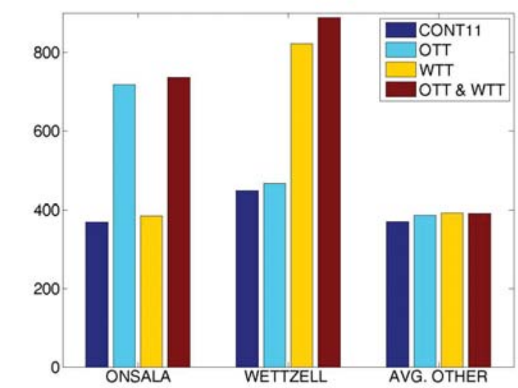

Fig. 3 Number of scans at Onsala and Wettzell and the average over all other sites. The value for Onsala and Wettzell is the sum of the two single telescopes. With a VGOS twin telescope, nearly twice as many scans can be carried out at that site than with a 20 m legacy telescope.

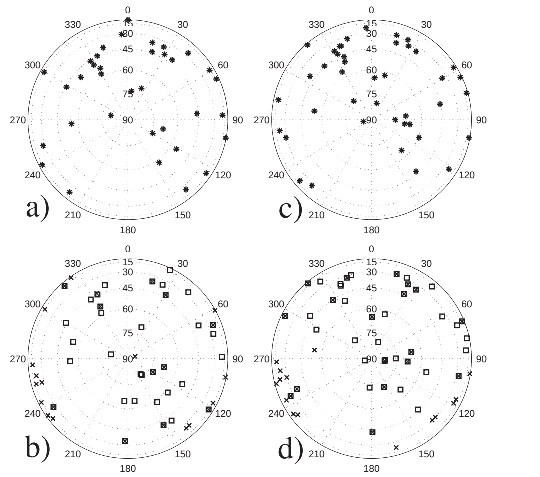

Fig. 4 Sky plot of the first 2 hours for Onsala (left column) and Wettzell (right column). Shown are the sky plots for the CONT11 schedule (upper row) with a asterisks (∗) and the schedules OTT and WTT (lower row) are with crosses (×) and squares (□) for each twin telescope. When both telescopes observe the same source simultaneously the symbols are plotted on top of each other and create crossed box (⊠). With the twin-telescope schedules (OTT Fig. 4b, WTT Fig. 4d) more sources are observed in different elevation and azimuth angles, which leads to an improved sky coverage and furthermore to improved ZWD estimations.

Figure 4 depict the sky plot of the first 2 hours for stations Onsala and Wettzell with the legacy 20 m antenna or the corresponding VGOS twin telescopes. Since the baseline between the two stations is less than 1000 km and they are mainly part of the same subnets.

The increased number of scans with the VGOS twin telescopes is clearly visible and the sky coverage is obviously improved, which leads to a better zenith wet delay (ZWD) estimation, as shown in Fig. 5. However there is still room for improving the sky coverage with twin telescopes.

The RMS values of the ZWD are calculated between the estimated ZWD compared to the simulated ZWD shortly after the estimation time, and varies between 4 mm and 14 mm, with an average value of 9 mm. As seen in Fig. 5, the use of a VGOS twin telescope improves the ZWD estimation at that site. As stated in Section 1, the main goal for twin telescopes is the improved handling of the atmospheric turbulence, which can be seen as achieved.

The results for baseline length repeatability show no significant improvement yet. Further investigations are ongoing.

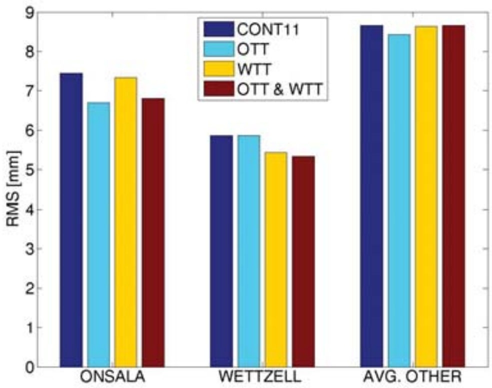

Fig. 5 RMS between estimated ZWD and simulated ZWD for Onsala and Wettzell and the average of the other stations in mm. An improvement with twin telescopes is clearly visible.

3 Conclusions

Replacing the legacy 20 m telescopes at Onsala and/or Wettzell by VGOS twin telescopes has significant effects on the investigated parameters.

The analysis of the schedules shows that more scans and observations are obtained for all stations in the investigated network if the legacy telescopes at Onsala and/or Wettzell are replaced by VGOS twin telescopes. Especially the stations with twin telescopes benefit from an increase in the number of scans and observations by almost a factor of two. This is an important goal in the VGOS concept and yields improved sky coverage and improved zenith wet delay estimation.

The presented results are based on the current version of VieVS. However, the scheduling for twin telescopes needs to be optimized in the next years. Besides that, the continuous realization of the VGOS concept with the introduction of broadband observations and more antennas on the southern hemisphere will point out advantages of twin telescopes clearer.

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