Antenna Parameters and Local Tie between HartRAO 15-m and 26-m Antennas

Marisa Nickola [1,2], Aletha de Witt [1], Hana Krásná [3,4], Ludwig Combrinck [1,2], Johannes Böhm [3], Matthias Schartner [3], Christopher Jacobs [5]

Abstract In preparation for upcoming VGOS operations at HartRAO with the accompanying GGOS requirement of 1 mm accuracy in station coordinates and global baselines, a first short baseline experiment between the HartRAO 26-m legacy antenna and the co-located 15-m antenna was conducted and is described here. Antenna parameters of the HartRAO 26-m and 15-m telescopes are investigated—data from geodetic VLBI sessions are analyzed with VieVS to further estimate the antenna axis offset as well as possible seasonal variations thereof. CONT campaigns in which HartRAO participated are analyzed to compare the antenna axis offset.

Keywords VLBI, ITRF, Local tie, Axis offset

1 Introduction

In order to improve the accuracy of site coordinates and geodetic VLBI results, accurate antenna axis offsets (AO) and local ties are required. For the Global Geodetic Observing System (GGOS) goal of $\pm$ 1 mm accuracy to be achievable on global baselines (Beutler et al., 2009), it must be achievable on short baselines at least. Recently, an experiment was conducted at the Hartebeesthoek Radio Astronomy Observatory (HartRAO) on the short baseline between the HartRAO 26-m legacy antenna and co-located 15-m antenna with a view to testing this accuracy. Experiments such as these provide an opportunity to build an error budget for short baseline ties between the HartRAO antennas (including the newly built VGOS antenna) and to improve our understanding of the HartRAO complex. Running off the same clock under the same atmosphere from the same location provides a laboratory for investigating VLBI instrumental effects and antenna structure, as most geophysical and atmospheric effects mostly cancel in common mode on short baselines. The first such short baseline experiment at HartRAO is described in the sections to follow.

An antenna AO exists for radio telescopes where the rotation axes do not intersect, and AO models have to be applied for such telescopes. The AO causes geometric and dry tropospheric delays which have to be considered in VLBI analysis. Geodetic VLBI sessions are analyzed with the Vienna VLBI Software (VieVS) (Böhm et al., 2018) to estimate AO values for the HartRAO 26-m and 15-m antennas.

1. Hartebeesthoek Radio Astronomy Observatory (HartRAO)
2. University of Pretoria (UP)
3. Technische Universität Wien (TUW)
4. Astronomical Institute of Czech Academy of Sciences (ASU)
5. California Institute of Technology, Jet Propulsion Laboratory/NASA

2 Short Baseline Experiment

A first short baseline experiment between the HartRAO 26-m legacy antenna and the co-located 15-m antenna (baseline = 113 m) was conducted on the 11th of May 2018. Unfortunately, the antennas could not be run off the same clock for this first short baseline experiment, but co-location ensured common local geophysics and atmosphere at least. VieVS was used to schedule the four hour session, SBL500. ICRF-2 defining sources were observed at X-band at 2 Gbps per station. Phasecal was turned off for the 26-m antenna, which carries less cable length from receiver to backend, in order to avoid corrupting the cross-correlation. The session ran from 22 UT on the 11th of May until 2 UT the following morning, well away from sunset and sunrise to ensure temperature stability. This is necessary to minimize thermally induced changes in cables, LNAs and downconverters as well as thermal expansion of the antennas.

Scans were scheduled to cover the full range of azimuth, elevation and cable wrap. Sweeping the full range of azimuth allows for determining east and north baseline components, while sweeping the full range of elevation separates the vertical from the troposphere. Scans were scheduled so that the antennas would nod up and down in elevation in 15° steps (from 10° to 70°) as they sweep in azimuth in 30° steps. Following this approach, the older 26-m legacy antenna does not waste much time on long slews. The first scan was scheduled at a higher elevation of 55° for calibration purposes and an azimuth of 115°. It was endeavored to schedule scans over the full range of mutual visibility for the HA-Dec mounted 26-m antenna and the Az-El mounted 15-m antenna. However, for southerly azimuths, it was not possible to observe many sources at low elevations due to the 26-m antenna's polar mount.

The 15-m antenna with its faster slew rate (Az = 2° s^{-1}, El=1° s^{-1}) had to wait for the slower 26-m legacy antenna (slew rate: HA = 0.5° s^{-1}, Dec = 0.5° s^{-1}) for a considerable amount of time. The only idle time experienced by the 26-m antenna was whilst waiting for the 15-m Az-El antenna to complete two cable wrap slews, lasting 211 and 220 seconds, respectively. A pre-observation time of ten seconds, to allow for settling time and calibration, and an observation time of 30 seconds per scan were scheduled. The schedule produced 95 scans and 880 GB of data per antenna. The SBL500 session has now been correlated by the Vienna correlator and will be analyzed in due course.

3 Antenna Axis Offsets

The rotation axes of the HartRAO 26-m equatorially mounted Cassegrain radio telescope do not intersect and are offset by ∼6.7 m. Its VLBI reference point is represented by the intersection of the fixed Hour Angle (HA) axis with the perpendicular plane containing the moving Declination (Dec) axis. The rotation axes of the HartRAO 15-m Azimuth-Elevation (Az-El) mounted radio telescope also do not intersect and are offset by ∼1.5 m. Its VLBI reference point is represented by the intersection of the fixed azimuth axis with the perpendicular plane containing the moving elevation axis. In October 2008, the south polar bearing of the 26-m antenna failed, and operations resumed only after bearing repair in August 2010. In October 2012, the 15 m was commissioned as a geodetic VLBI antenna.

Krásná et al. (2014), Nickola et al. (2015), and Nilsson et al. (2016) estimated the antenna AO values for the HartRAO 26 m by making use of VieVS in a global solution of geodetic VLBI sessions. The AO was estimated for sessions from before and after bearing repair as well as for the entire period of the 26-m antenna's operation (or a significant portion thereof). These VieVS estimated AO values failed to agree with values estimated with other VLBI analyses and measurements from ground surveys. Results from a co-location survey (taken to be the more accurate) performed in 2014 have since become available. Currently, additional geodetic VLBI sessions are analyzed using VieVS to estimate the AO of both the 26-m and 15-m antennas for comparison with previous values and values measured in the 2014 co-location survey as well as to further investigate possible seasonal variations in AO.

3.1 Comparison

Antenna AO values for the HartRAO 26-m antenna as determined by ground survey and estimated by VLBI solution are displayed in Table 1. The AO values from before the bearing repair (ground surveys and VLBI) are given in the top section of the table (taken from Combrinck and Merry (1997)) with the addition of the measurement from the co-location survey in 2014 after the bearing repair. The second section provides the VieVS estimates obtained by Krásná et al. (2014) for before and after bearing repair as well as for the entire period from 1986 (start of geodetic VLBI observations on the 26-m antenna) until the end of 2013. The third section provides the VieVS estimate obtained by Nickola et al. (2015) for after bearing repair with the addition of sessions from 2014. The values obtained in the current study, given in the bottom section of the table, used VieVS to estimate the AO also before and after bearing repair but with the addition of sessions for 2015. The AO was also estimated for the entire period from 1986 to the end of 2015. The AO value estimated in the current study for before the bearing repair agrees within the formal error with the a priori value (= 6695.3 mm), whilst the value for after bearing repair differs by nearly a centimeter from the a priori value. The AO value estimated in the current study for the entire period from 1986 to the end of 2015 also does not agree within the formal error with the a priori value. Except for the value from the current study for before bearing repair, the 26 m AO values estimated with VieVS and reported by Krásná et al. (2014), Nickola et al. (2015), Nilsson et al. (2016), and in the current study, differ by several millimeters from the a priori value. This a priori value was however corroborated during a co-location survey in February 2014 (Muller and Poyard, 2015).

Antenna AO values for the HartRAO 15-m antenna as determined by ground survey and estimated by VLBI solution are displayed in Table 2. The AO values, obtained by using either method, are given in the top section of the table. The bottom section provides the VieVS estimates obtained by Krásná et al. (2014), Nickola et al. (2015), and in the current study for the periods indicated. While the VieVS estimates of Krásná et al. (2014), Nilsson et al. (2016), and of the current study agree within the formal error with the a priori value, all these estimates, as well as the estimate of Nickola et al. (2015) and, most importantly, the a priori value itself (determined by VLBI analysis), differ by several millimeters from the value measured during the co-location survey of 2014 (Muller and Poyard, 2015).

The difference between the a priori value and VieVS estimated value of the AO for the Continuous (CONT) VLBI campaigns in which HartRAO participated (CONTnn, nn=year) are displayed in Table 3. The CONT02, CONT05 and CONT08 campaigns were all observed with the 26-m antenna before bearing repair, whilst CONT11 was observed after bearing repair. CONT14 was observed by the 15-m antenna. None of the VieVS estimates for the CONT campaigns before bearing repair agree within the formal error with each other. Only the VieVS estimate for CONT05 agrees within the formal error with the a priori value. None of the VieVS estimates for any of the CONT campaigns agree within the formal error with the 2014 ground survey measurement. The VieVS estimate for the CONT14 campaign of the 15-m antenna does not agree within the formal error with either the a priori value or the 2014 ground survey measurement.

Table 1 HartRAO 26 m antenna axis offset determined by independent techniques (a priori value = 6695.3 mm).

Method	Determined by	Value (mm)
Standard value	JPL (1961)	6706
Conventional survey	M. Newling (1993)	6695 ± 3
VLBI solution	C. Ma (1995)	6693.6 ± 2.5
VLBI solution	M. Eubanks (1995)	6692.5 ± 1.5
HartRAO GPS	L. Combrinck (1995)	6695.6 ± 2.3
VLBI solution	C. Ma (1996)	6688.8 ± 1.8
Local tie survey	Michel et al. (2005)	6695 ± 2.5
Local tie survey	Muller and Poyard (2014)	6694.0
VieVS solutions: Before repair - 1986-2008.8 After repair - 2010.8-2014.0 1986-2014.0	Krásná et al. (2014)	6699.2 ± 0.5 6707.3 ± 0.8 6703.1 ± 0.5
VieVS solution: After repair - 2010.8-2014.11 (180 sessions)	Nickola et al. (2015)	6707.9 ± 0.7
VieVS solutions: Before repair - 1986.1-2008.9 (757 sessions) After repair - 2010.8-2015.12 (227 sessions) 1986.1-2015.12 (984 sessions)	Current study	6697.8 ± 2 6705.5 ± 0.7 6700.5 ± 1.3

Table 2 HartRAO 15 m antenna axis offset determined by independent techniques (a priori value = 1494.1 mm).

Method	Determined by	Value (mm)
GPS survey	A. Combrinck (2007)	1495
VLBI solution	D. MacMillan (2014)	1494.1 ± 2.6
Local tie survey	Muller and Poyard (2014)	1490.9
VieVS solutions: 2012.10-2013.9 (12 sessions)	Krásná et al. (2014)	1495.0 ± 3.4
2012.10-2015.03 (134 sessions)	Nickola et al. (2015)	1499.8 ± 1.1
2012.10-2015.12 (272 sessions)	Current study	1496.5 ± 0.8

Table 3 HartRAO 26 m and 15 m difference in antenna axis offset (dAO) between a priori value and VieVS estimated value for the CONT campaigns.

Campaign	dAO (mm)
26 m: CONT02 (Oct 2002)	13.67 ± 2.65
26 m: CONT05 (Sep 2005)	1.41 ± 1.53
26 m: CONT08 (Aug 2008)	4.47 ± 1.43
26 m: CONT11 (Sep 2011)	13.71 ± 1.60
15 m: CONT14 (May 2014)	-9.01 ± 2.44

3.2 Seasonal Variation

In Table 4 and Table 5, the sessions in which the 26-m antenna participated during various periods (before and after bearing repair, entire period) are divided into seasonal groupings and into two six month periods, respectively, to investigate the possibility of seasonal variations in antenna AO. The difference in AO between the a priori value and VieVS estimates from the current study for after bearing repair are also compared with the corresponding differences reported in Nickola et al. (2015).

In Table 6 and Table 7, the sessions in which the 15-m antenna participated are divided into seasonal groupings and into two six month periods, respectively, to investigate the possibility of seasonal variations in antenna AO. The difference in AO between the a priori value and VieVS estimates from the current study are also compared with the corresponding differences reported in Nickola et al. (2015).

In the current study, for the period before the bearing repair on the 26-m antenna, the largest deviation occurs in winter. For the period after bearing repair, the largest deviation occurs in summer, and the smallest deviation in autumn, similar to the findings of Nickola et al. (2015). Over the entire period, spring and summer produce the largest deviations. For before and after bearing repair as well as over the entire period, the largest deviation occurs September to February, again corresponding to the finding of Nickola et al. (2015). For the 15 m, the largest deviations occur in spring and summer and September to February, all corresponding to the findings of Nickola et al. (2015).

In general, differences between a priori AO and VieVS estimates from the current study are smaller than corresponding differences reported by Nickola et al. (2015).

Table 4 HartRAO 26 m difference in antenna axis offset (dAO) between a priori AO value (= 6695.3 mm) and VieVS estimated value for specified months/seasons.

Month/Season	Before repair	After repair	All
Summer - DecJanFeb			
Current study:	1986.1-2008.9	2010.8-2015.12	1986.1-2015.12
26 m dAO (mm)	4.70 ± 0.92	12.55 ± 1.41	7.03 ± 0.77
No. of sessions	230	59	289
2015 study:		2010.8-2014.11	
26 m dAO (mm)		17.30 ± 1.67	
No. of sessions		46	
Autumn - MarAprMay			
Current study:	1986.1-2008.9	2010.8-2015.12	1986.1-2015.12
26 m dAO (mm)	4.26 ± 1.07	3.45 ± 1.69	3.94 ± 0.90
No. of sessions	160	37	197
2015 study:		2010.8-2014.11	
26 m dAO (mm)		5.77 ± 1.97	
No. of sessions		31	
Winter - JunJulAug			
Current study:	1986.1-2008.9	2010.8-2015.12	1986.1-2015.12
26 m dAO (mm)	-2.12 ± 6.26	9.78 ± 1.40	1.49 ± 4.51
No. of sessions	179	54	232
2015 study:		2010.8-2014.11	
26 m dAO (mm)		13.25 ± 1.56	
No. of sessions		44	
Spring - SepOctNov			
Current study:	1986.1-2008.9	2010.8-2015.12	1986.1-2015.12
26 m dAO (mm)	4.67 ± 0.82	10.88 ± 1.04	7.64 ± 0.66
No. of sessions	189	77	266
2015 study:		2010.8-2014.11	
26 m dAO (mm)		12.03 ± 1.06	
No. of sessions		59	

4 Conclusions

The antenna AO values show statistically significant differences between various data sets that are not well understood. For the VieVS estimated AO values of the 26-m antenna, there appears to be a significant change from before to after bearing repair, but this is not reflected in the corresponding ground survey values. For both the 26-m and 15-m antennas, the AO estimated with VieVS differ considerably from the values measured during the 2014 co-location survey. Possible correlation of AO with station position, tropospheric delay, clock parameters, structural deformation, hydrology loading etc. needs to be investigated.

With regard to the short baseline sessions, future efforts will be directed towards running the 26-m and

Table 5 HartRAO 26 m difference in antenna axis offset (dAO) between a priori AO value (= 6695.3 mm) and VieVS estimated value for specified six month period.

Month/Season	Before repair	After repair	All
Spring and Summer - Sep - Feb			
Current study:	1986.1-2008.9	2010.8-2015.12	1986.1-2015.12
26 m dAO (mm)	4.85 ± 0.61	11.46 ± 0.83	7.50 ± 0.50
No. of sessions	419	136	555
2015 study:		2010.8-2014.11	
26 m dAO (mm)		13.14 ± 0.91	
No. of sessions		105	
Autumn and Winter - Mar - Aug			
Current study:	1986.1-2008.9	2010.8-2015.12	1986.1-2015.12
26 m dAO (mm)	0.06 ± 3.75	7.32 ± 1.07	2.04 ± 2.72
No. of sessions	338	91	429
2015 study:		2010.8-2014.11	
26 m dAO (mm)		9.75 ± 1.23	
No. of sessions		75	

Table 6 HartRAO 15 m difference in antenna axis offset (dAO) between a priori AO value (= 1495.0 mm) and VieVS estimated value for specified months/seasons.

Month/Season	Current study 2012.10-2015.12	2015 study 2012.10-2014.11
Summer - DecJanFeb		
15 m dAO (mm)	5.46 ± 1.68	7.09 ± 2.12
No. of sessions	73	42
Autumn - MarAprMay		
15 m dAO (mm)	-2.88 ± 1.58	1.41 ± 2.22
No. of sessions	57	27
Winter - JunJulAug		
15 m dAO (mm)	-2.81 ± 1.51	6.67 ± 2.37
No. of sessions	64	27
Spring - SepOctNov		
15 m dAO (mm)	5.96 ± 1.56	6.02 ± 2.47
No. of sessions	78	38

15-m antennas off the same clock and conducting these short baseline sessions at least once a month to detect possible seasonal variations. An error budget for short baseline ties will be drawn up, and each term will be investigated. The newly built VGOS antenna also needs to be accurately tied to the 26-m legacy antenna.

Table 7 HartRAO 15 m difference in antenna axis offset (dAO) between a priori AO value (= 1495.0 mm) and VieVS estimated value for specified six month period.

Month/Season	Current study 2012.10-2015.12	2015 study 2012.10-2014.11
Spring and Summer - Sep - Feb		
15 m dAO (mm)	5.73 ± 1.14	7.11 ± 3.78
No. of sessions	151	80
Autumn and Winter - Mar - Aug		
15 m dAO (mm)	-2.73 ± 1.09	3.74 ± 1.64
No. of sessions	121	54

Acknowledgements

 A portion of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The authors acknowledge the IVS and all its components for providing VLBI data (Nothnagel et al., 2015). The authors wish to thank Jakob Gruber (TU Wien) and Jonathan Quick (HartRAO) for their contribution to the first HartRAO short baseline session.

References

1. G. Beutler et al. Global Geodetic Observing System - Meeting the Requirements of a Global Society on a Changing Planet in 2020. *Towards GGOS in 2020*, Chapter 10, 273–281, 2009.
2. J. Böhm et al. Vienna VLBI and Satellite Software (VieVS) for Geodesy and Astrometry. *Publications of the Astronomical Society of the Pacific*,130(986), 10.1088/1538-3873/aaa22b, 044503, 2018.
3. W.L. Combrinck and C.L. Merry. Very long baseline interferometry antenna axis offset and intersection determination using GPS. *J. Geophys Res.*, 102(B11):24741–24744, 1997.
4. H. Krásná, M. Nickola, and J. Böhm. Axis offset estimation of VLBI telescopes. *IVS 2014 General Meeting*, Shanghai, 339–343, 2014.
5. J.M. Muller and J-C. Poyard. Hartebeesthoek local tie survey. *IGN report*, 2015.
6. M. Nickola et al. Determining HartRAO antenna parameters with VieVS. *EVGA 2015 Working Meeting*, 140–144, 2015.
7. T. Nilsson et al. Antenna axis offsets and their impact on VLBI derived reference frames. *REFAG 2014*, International Association of Geodesy Symposia, 146, 53-58, 2016.
8. A. Nothnagel et al. The IVS data input to ITRF2014. *International VLBI Service for Geodesy and Astrometry*, doi:10.5580/GFZ.1.1.2015.002, 2015.