HartRAO Antenna Axis Offset and its Effect on Troposphere Modelling and Antenna Coordinates

M. Nickola, A. de Witt, H. Krásná, C. Jacobs, L. Combrinck, J. Böhm

Abstract Data from geodetic VLBI sessions, which included observations with the 26-m equatorially mounted Cassegrain radio telescope at the Hartebeesthoek Radio Astronomy Observatory (HartRAO), were analysed with the Vienna VLBI Software (VieVS) to investigate the correlation between antenna coordinates and antenna axis offset. The simulation tool in VieVS was used to study the effect of the axis offset altitude troposphere correction on the estimated antenna axis offset in order to examine the 1 mm accuracy in the baseline length required by the VLBI Global Observing System (VGOS).

Keywords axis offset, altitude correction, antenna coordinates

1 Introduction

An antenna axis offset (AO) exists for radio telescopes where the rotation axes do not intersect. The antenna axis offset causes geometric and dry tropospheric delays which have to be considered in VLBI analysis.

The 26-m radio telescope at the Hartebeesthoek Radio Astronomy Observatory (HartRAO) is of equatorially mounted Cassegrain design. The rotation axes of the HartRAO 26-m radio telescope (HARTRAO) do not intersect—the 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 (see Figure 1).

The axis offset altitude correction implemented by Sovers et al. (1998) accounts for the effect of the orientation of equatorial and X-Y antennas on the tropospheric path delay. Zenith troposphere delays of 1–2 mm, increasing to 1–2 cm when mapped to low elevation angles, result for antennas with non-zero axis offsets where the secondary rotation axis (A in Figure 2) moves vertically with changing orientation, i.e. for antennas with equatorial and with X-Y mounts (Sovers et al., 1998). A correction therefore has to be added to the zenith dry tropospheric delay (Z_d) for antennas with equatorial and with X-Y mounts (Sovers et al., 1998),

$$\delta Z_d = -Z_d(L/\Delta)\psi$$

where L is the antenna axis offset, Δ the troposphere scale height ($\approx$ 8.6 km), and ψ is an angular factor that varies with the type of mount. For equatorial mounts, such as that of HARTRAO,

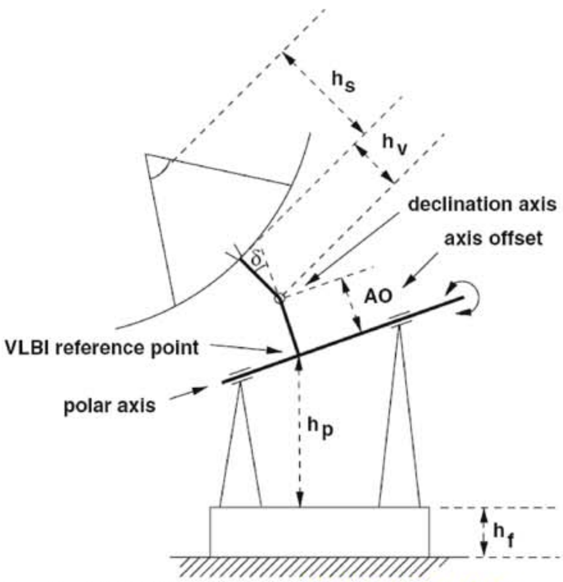

Fig. 1: Equatorial (polar) mount (Nothnagel et al., 2015).

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$$\psi = cos\ H\ cos\ \phi_{gd}$$

where ϕ_{gd} is the geodetic latitude and H the local hour angle east of the meridian. For north-south oriented X-Y mounts,

$$\psi = sin\ E\ /\ \sqrt{1 - cos^2\ \theta\ cos^2\ E},$$

while for east-west oriented X-Y mounts, such as that of the Hobart 26-m radio telescope (HOBART26),

$$\psi = sin\ E\ /\ \sqrt{1 - sin^2\ \theta\ cos^2\ E}$$

where E is the elevation angle and θ the azimuth.

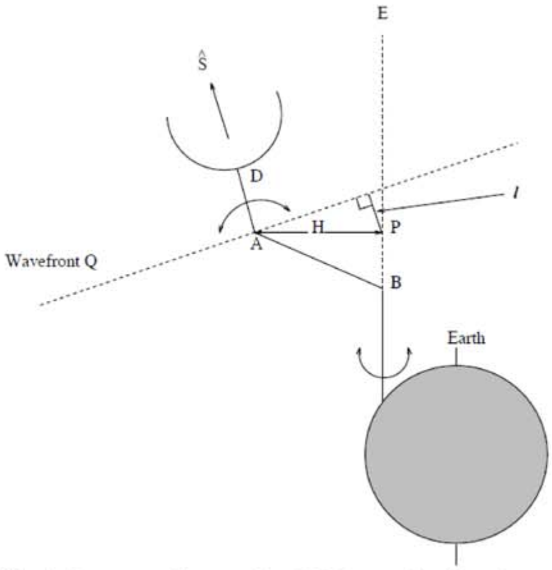


Fig. 2: Geometry of two-station VLBI network with only one station shown. Dec axis (end view represented by A) rotates in plane perpendicular to symmetry axis AD. Dec axis and polar axis (BE) are separated by distance H, the antenna axis offset. The VLBI reference point is represented by P (Combrinck and Merry, 1997).

2 Antenna Axis Offset Altitude Correction

The antenna axis offset altitude correction has been implemented in VieVS (Böhm et al., 2012) according to Sovers et al. (1998). The simulation tool in VieVS was used to simulate the effect of the axis offset altitude correction on the estimated axis offset of HARTRAO.

All IVS geodetic VLBI sessions (Nothnagel et al., 2015) in which HARTRAO participated, from August 2010 to November 2014, were also analysed with VieVS to investigate the effect of the axis offset altitude correction on the estimated antenna axis offset.

The only other participating radio telescope that is also affected by the axis offset altitude correction, is HOBART26 with its X-Y mount. All other antennas participating in the sessions analysed have Azimuth-Elevation (AZEL) mounts for which the correction is not required.

2.1 Simulations

The simulations were based on schedules from two IVS sessions, R1663 and T2094, in which HARTRAO (but not HOBART26) participated. In the simulations, zero input observation files were generated–the measured time delay was set to be equal to the theoretical time delay without adding the noise terms. The axis offset altitude correction was applied during the analysis of the simulated sessions for HARTRAO only. A simulation with the altitude correction applied, which included HARTRAO in the datum—realised with the no-net-rotation and no-net-translation condition on the antenna coordinates w.r.t. the *a priori* TRF—was also run.

The simulations show that the axis offset altitude correction has a negligible effect on the HARTRAO axis offset estimate, being in the sub-mm region (see Table 1). The axis offset altitude correction propagates to the HARTRAO antenna coordinates, and is also at the sub-mm level (see Figure 3(a)). With HARTRAO in the datum, the antenna axis offset estimate remains the same but the altitude correction propagates to the coordinates of other antennas as well. The difference in antenna coordinates is negligible however.

Table 1: AO altitude correction results - effect on estimated axis offset (dAO - difference between *a priori* and estimated axis offset, mAO - formal error). The first column depicts the simulation runs (SIM1 based on R1663 and SIM2 based on T2094), the session analysis runs with and without the AO altitude correction applied (AO +AC and AO −AC) as well as the runs to determine the effect for HOBART26 (Ho: AO +AC and Ho: AO −AC).

Simulations /	HARTRAO		HOBART26	
Session Analysis	dAO (cm)	mAO (cm)	dAO (cm)	mAO (cm)
SIM1 (+AC)	−0.041	0.001	-	-
SIM2 (+AC)	−0.061	0.002	-	-
AO +AC	1.245	0.079	-	-
AO −AC	1.252	0.079	-	-
Ho: AO +AC	1.231	0.079	0.222	0.172
Ho: AO −AC	1.239	0.079	0.216	0.172

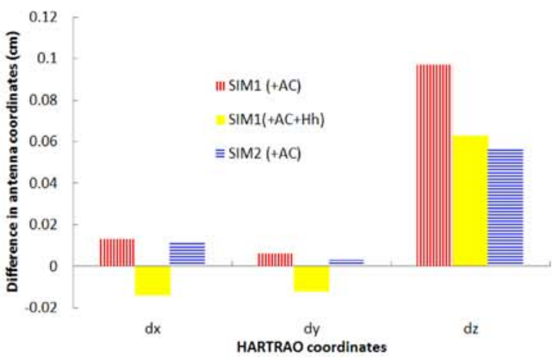
2.2 Session Analysis

Sessions stretching from August 2010 to November 2014 in which HARTRAO participated (totalling 176) were analysed with VieVS to investigate the effect of the axis offset altitude correction on the estimated antenna axis offset and antenna coordinates. HOBART26 participated in 32 of these sessions. The sessions were run with and without the axis offset altitude correction applied and also with and without HARTRAO in the datum, while HOBART26 was not included in the datum for any of the runs.

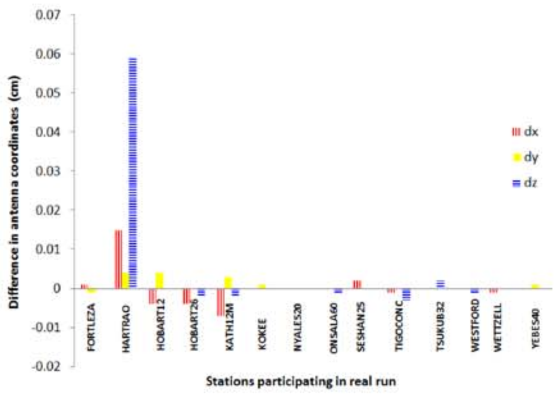
Some of the results are depicted in Figures 3(b)–3(d). Results for only a selection of antennas are displayed due to space constraints. Results for antennas that participated in 30 or more sessions are displayed, which ensures that HOBART26 is included.

We expect the results from the session analysis to be similar to that from the simulations. From the results, we see that the difference in HARTRAO antenna coordinates for the session analysis is indeed similar to that for the simulation results (see Figures 3(a) and 3(b)). However, the difference in the estimated antenna axis offset (with and without the altitude correction applied) for the session analysis is smaller than that for the simulations, although also at sub-mm level (see Table 1). This may be caused by the propagation of the correction to the coordinates of other antennas.

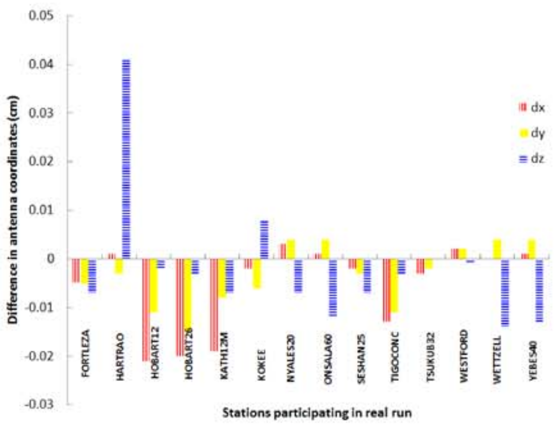
The difference in antenna coordinates for stations where the correction does not apply, should theoretically be zero as is seen in Figure 3(b). The presence of HARTRAO in the datum does not affect the antenna axis offset estimates, but coordinate corrections propagate to the coordinates of other antennas, albeit only at sub-mm level (see Figures 3(c) and 3(d)).



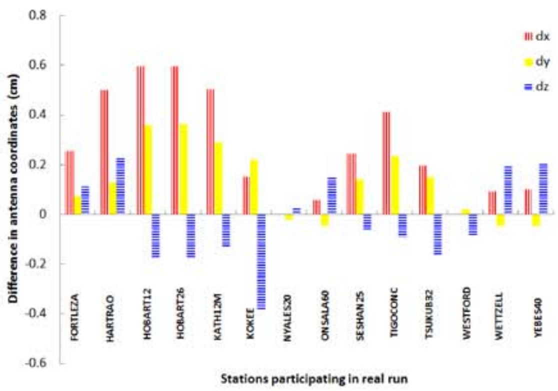
(a) Simulations



(b) Session Analysis Run 1



(c) Session Analysis Run 2



(d) Session Analysis Run 3

Fig. 3: Effect of the AO altitude correction on the estimated antenna coordinates with the difference in antenna coordinates plotted for a selection of stations: (a) simulations with AO altitude correction applied to HARTRAO only, (b) session analysis with and without AO altitude correction applied, (c) with and without AO altitude correction applied with HARTRAO in datum, and (d) with AO altitude correction applied with and without HARTRAO in datum.

3 Conclusions

The effect of the axis offset altitude correction on the estimated antenna axis offset and antenna coordinates was investigated. The axis offset altitude correction has bearing on HARTRAO (equatorial mount) and HOBART26 (X-Y mount) only, as all other stations in these sessions have telescopes with AZEL mounts to which the correction does not apply.

The axis offset altitude correction changes HARTRAO coordinates and axis offset by less than 1 mm. These preliminary results provide a smaller change in the estimated antenna coordinates than expected from the theoretical model of the axis offset altitude correction, which predicts a change of 1–2 cm in the slant troposphere delay at low elevations. We are investigating the reason for the smaller than expected shifts. We intend comparing results from VieVS and the JPL VLBI modelling and estimation software "MODEST" (Sovers et al., 1998) for a few observations to search for any inconsistencies in the coding.

A large correction to the antenna axis offset *a priori* value exists for HARTRAO in general (~1 cm) compared to that of HOBART26 (~1 mm). A difference of several millimetres between the *a priori* value for the antenna axis offset of HARTRAO and the value estimated with VieVS was also reported by Nilsson et al. (2016) and Krásná et al. (2014). The *a priori* value of the antenna axis offset was however corroborated during a recent (February 2014) local co-location survey (Muller and Poyard, 2015).

Future efforts will include analysis of CONT campaigns in which HARTRAO participated to compare the antenna axis offset estimated from CONT02, CONT05, CONT08 and CONT11. The minor influence of the axis offset altitude correction on the antenna coordinates of HOBART26 will also be investigated in our upcoming work.

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