Axis Offset Estimation of VLBI Telescopes

Hana Krásná[1], Marisa Nickola[2], Johannes Böhm[1]

Abstract Axis offset models have to be applied for VLBI telescopes with pointing axes which do not intersect. In this work, we estimated the axis offsets for VLBI antennas in a global adjustment of suitable IVS 24-hour sessions (1984.0–2014.0) with the Vienna VLBI Software (VieVS). In particular, we focused on the two radio telescopes of the Hartebeesthoek Radio Astronomy Observatory (HartRAO) in South Africa. For the older 26-m telescope we compared the estimated axis offset values before (6699.2 $\pm$ 0.5 mm) and after (6707.3 $\pm$ 0.8 mm) the bearing repair in 2010. A comparison with axis offset estimates from other geodetic techniques, such as GNSS or conventional local survey, was made. The estimated axis offset for the newer 15-m telescope (1495.0 $\pm$ 3.4 mm) agrees with the estimated value from the GPS survey in 2007. Furthermore, we assessed the influence of differences in the axis offsets on the estimated geodetic parameters, such as station coordinates or Earth Orientation Parameters.

Keywords Axis offset, Earth Orientation Parameters, global reference frames, HartRAO

1 Introduction

The antenna axis offset (AO) is the distance between the pointing axes. Moving the antenna around its pointing axes causes a change in the position of the receiver with respect to the incoming wavefront. An additional delay τ_{AO} is created, which depends on the unit vector $\boldsymbol{s}$ in the radio source direction and on the unit vector in the direction of the fixed axis $\boldsymbol{l}$ (Sovers et al., 1998 [6]; Nothnagel, 2009 [5]):

$$\tau_{AO} = \frac{1}{c} AO \cdot \sqrt{1 - (\boldsymbol{s} \cdot \boldsymbol{l})^2} \tag{1}$$

The projection of the axis offset onto the time delay depends on the mount type of the telescope. There are three major mount types: Altitude-Azimuth mount, Equatorial (or Polar) mount, and XY mount (Figure 1).

2 Estimation of Axis Offset

Using the 24-hour IVS sessions from 1984 to 2014, we estimated the axis offsets of the VLBI telescopes within a global adjustment of the measured data in an updated version of VieVS (Böhm et al., 2012 [1]). We ran three identical global solutions where we—apart from the axis offsets—determined the terrestrial reference frame (station coordinates and linear velocities) and celestial reference frame (coordinates of the distant radio sources). Earth Orientation Parameters, clock parameters, and tropospheric parameters, such as zenith wet delays and tropospheric gradients, were estimated session-wise by a reduction from the normal equation systems. We also reduced the positions of the so-called special handling sources and of stations where the time span of included data did not allow for velocity determination. The only difference between these three solutions was the selection of the telescopes for which the axis offset was computed. In the first solution S1, the axis offset was estimated for all stations in the global adjustment.

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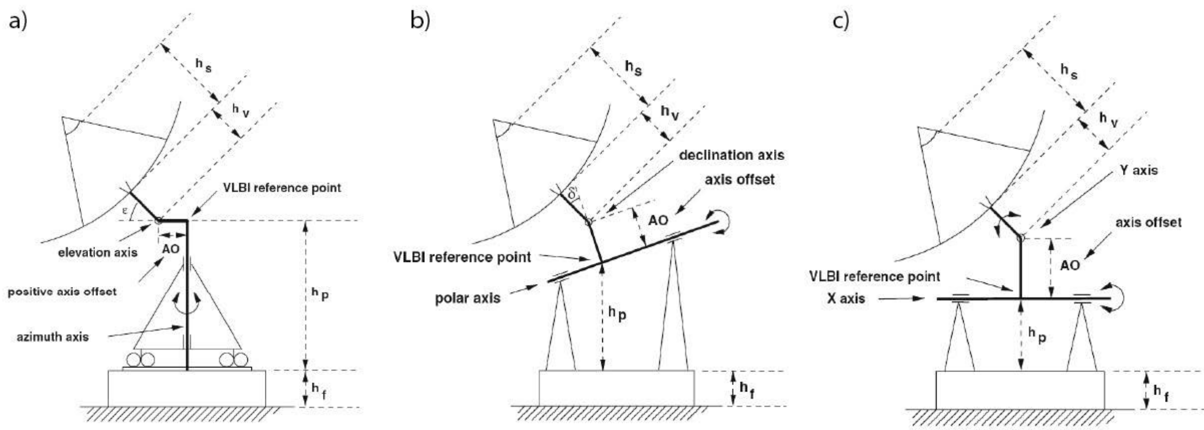

Fig. 1 (a) Altitude-Azimuth, (b) Equatorial (Polar) and (c) XY telescope mounts. Nothnagel (2009) [5].

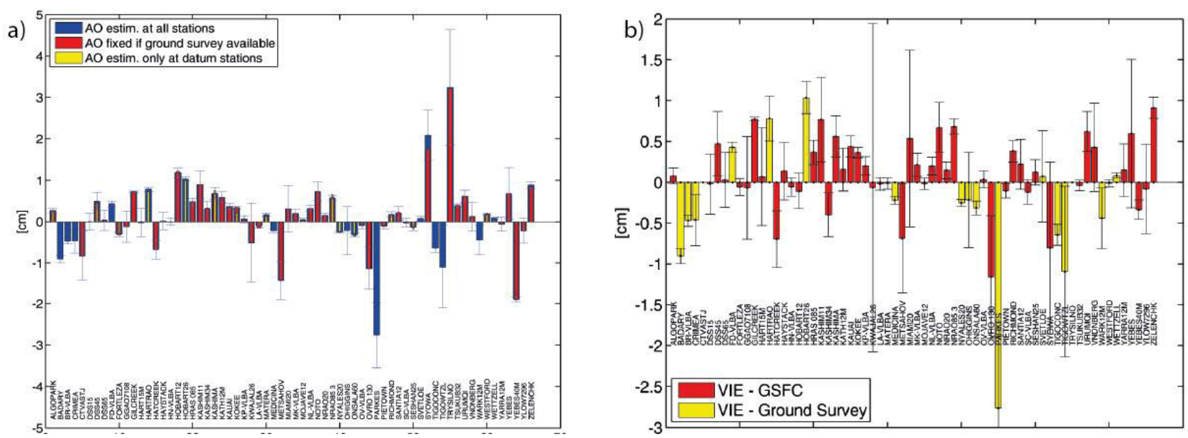

Fig. 2 a) Comparison of our three solutions: S1 (blue), S2 (red), and S3 (yellow) with respect to the a priori values of axis offsets given in `antenna-info.txt` (December 2013 version); b) Differences between our solution S2 and the solution `MacMillan2014` in red color, and between S1 and the axis offsets from ground surveys where available in yellow color.

In the second solution S2, we fixed the axis offsets to the values measured with conventional survey methods at stations where available, and in the third solution S3, the axis offset was determined only at stable stations with longer observational history used for the datum definition. The a priori values for the axis offset of the telescopes were taken from the file `antenna-info.txt` (December 2013 version) provided by the IVS analysis coordinator. In Figure 2a, the differences of the three solutions with respect to the values in `antenna-info.txt` are shown. At all stations the differences between the three individual solutions (S1, S2, and S3) agree in the range of their formal errors. Concentrating on the solution S2 (red bars)[1], where the locally estimated values were fixed to their a priori values, the largest difference w.r.t. the values given in `antenna-info.txt` is found for the telescope Trysilno, exceeding 3.2 cm (`antenna-info.txt` provides a zero value for Trysilno's axis offset). The second largest difference is found for Yebes40M, where the deviation from the reported value (value according to construction specifications) is -1.9 cm, and for the telescope Syowa we get a difference of 1.8 cm w.r.t. the value reported by L. Petrov in `antenna-info.txt`.

The file `antenna-info.txt` was updated in January 2014 with a new estimation of axis offsets by Daniel MacMillan from the GSFC VLBI Group.

[1] `http://vievs.geo.tuwien.ac.at/results`

We name this new solution MacMillan2014 in our paper. The axis offset value for the Trysilno telescope was not updated. The comparison of the axis offsets for Yebes40M and Syowa shows that the difference of our estimates to the values computed by MacMillan2014 decreases to −0.3 cm and −0.8 cm, respectively. The WRMS between our solution S2 and MacMillan2014 computed over all common stations is 3.8 mm.

In Table 1 we summarize estimated values of axis offset from our solutions S1 (second column) and S3 (fourth column) for telescopes where a value from a ground survey is available (third column). As mentioned before, the estimates from S1 and S3 agree with each other within the formal errors. The WRMS error for the differences between S1 and the ground survey over the 16 antennas reaches 4.3 mm. It is close to the WRMS w.r.t. MacMillan2014 and it can be understood as a real accuracy with which the axis offsets from the adjustment of VLBI data can be estimated.

Table 1 Axis offsets for stations where the value of axis offsets is known from local survey. Second column shows the estimated axis offset from solution S1, third column gives the value from ground survey (provided in antenna-info.txt), and the fourth column shows results from solution S3. Values are given in millimeters.

Telescopes	solution S1	ground survey	solution S3
Badary	-6.5 ± 0.9	$2.5 \pm$ —-	
BR-VLBA	2129.9 ± 0.7	$2134.6 \pm$ —-	
Crimea	-6.4 ± 2.9	-1.8 ± 0.2	
FD-VLBA	2134.1 ± 0.7	$2129.8 \pm$ —-	
HartRAO	6703.1 ± 0.4	6695.3 ± 2.3	6702.6 ± 0.4
Hobart26	8201.6 ± 0.4	8191.3 ± 1.5	8201.3 ± 0.4
Medicina	1827.9 ± 0.5	$1830.1 \pm$ —-	
NyAles20	521.7 ± 0.2	524.2 ± 0.2	521.6 ± 0.2
OHiggins	-2.2 ± 5.8	$0.0 \pm$ —-	
Onsala60	-9.2 ± 0.4	-6.0 ± 0.4	-9.6 ± 0.4
Parkes	-27.0 ± 7.9	0.6 ± 1.0	
Svetloe	-6.8 ± 0.6	-7.5 ± 5.0	
TigoConc	-6.4 ± 1.0	0.0 ± 0.3	
TigoWtzl	-11.0 ± 10.2	0.0 ± 0.3	
Wark12M	-3.4 ± 3.5	1.0 ± 0.2	
Wettzell	0.7 ± 0.2	-0.1 ± 0.1	0.3 ± 0.2

3 HartRAO 26-m and 15-m Telescopes

The HartRAO 26 m is an equatorially mounted Cassegrain radio telescope built by Blaw Know in 1961. In October 2008 the bearing of the polar shaft of the HartRAO 26-m telescope failed. In August 2010 the telescope took part in its first post-repair geodetic VLBI observing session. Antenna axis offset values for the 26 m determined prior to the bearing failure, as given by Combrinck (1997) [2], are displayed in Table 2. Also shown are the values as determined in our current study for the period preceding the bearing failure (6699.2 ± 0.5 mm), the period following the bearing repair (6707.3 ± 0.8 mm) as well as the entire period from 1986 to 2014 (6703.1 ± 0.5 mm). The change in the axis offset after the repair does not seem to be realistic. The most probable explanation for this discrepancy is that a change in station position occurred due to the bearing failure and replacement, which then propagated into the axis offset estimation.

Table 2 HartRAO 26-m antenna axis offset determined by independent techniques.

Method	Determined by	Value
Standard value	JPL, 1961	6 706 mm
Conventional survey	M. Newling, 1993	6695 ± 3 mm
VLBI solution	C. Ma, 1995	6693.6 ± 2.5 mm
VLBI solution	M. Eubanks, 1995	6692.5 ± 1.5 mm
HartRAO GPS	L. Combrinck, 1995	6695.6 ± 2.3 mm
VLBI solution	C. Ma, 1996	6688.8 ± 1.8 mm
Local tie survey	Michel et al. (2005) [4]	6695 ± 2.5 mm
VieVS solutions:		
Before repair (1986–2008.8)	our estimate	6699.2 ± 0.5 mm
After repair (2010.6–2014.0)	our estimate	6707.3 ± 0.8 mm
1986–2014.0	our estimate	6703.1 ± 0.5 mm

Table 3 HartRAO 15-m antenna axis offset determined by independent techniques.

Method	Determined by	Value
GPS survey	A. Combrink, 2007	1495 mm
VLBI solution (from 1st IVS sessions)	GSFC, D. Gordon & S. Bolotin, 2012	1464 mm
VLBI solution	*MacMillan*2014	1494.1 ± 2.6 mm
VieVS solution	our estimate	1495.0 ± 3.4 mm

Hart15M is a 15-m altitude-azimuth radio telescope built as a Square Kilometre Array (SKA) prototype in 2007 and converted to an operational geodetic VLBI antenna during 2012. In October 2012, Hart15M started its observations within the IVS schedules. In Table 3, the antenna axis offset values for the 15 m as determined from a GPS survey by Attie Combrinck in January 2007 and a first VLBI solution by David Gordon and Sergei Bolotin from GSFC using data from October 2012 geodetic VLBI experiments R4554 and R4555, are taken from the HartRAO Web page [3]. Our estimate of the axis offset value 1495.0 $\pm$ 3.4 mm agrees within the formal error with the estimates from `MacMillan2014`.

4 Comparison of EOP and TRF

In Figures 3 and 4 the propagation of a mismodeled axis offset into the coordinates and velocities, respectively, of the estimated terrestrial reference frame (TRF) is shown. Plotted are the differences between our solution S2 and a solution where the axis offsets for the telescopes were fixed to the values in `antenna-info.txt`. The projection of axis offset onto the measured time delay changes with the cosine of the elevation angle; therefore, if not enough observations under various elevation angles at the particular stations are provided, it comes to the propagation of errors into the estimated coordinates and velocities of the stations. The largest difference can be seen in the height component of station Trysilno, i.e., 5.9 cm, followed by the difference at stations Yebes40M and Syowa, where the co-estimation of the axis offset changed the value of the estimated height by -2.9 cm and 2.0 cm, respectively. The differences in the horizontal plane are below 0.5 cm at all stations. The estimated velocities of the two solutions differ by up to 2 mm/yr in the height component and by up to 0.5 mm/yr in the east and north components.

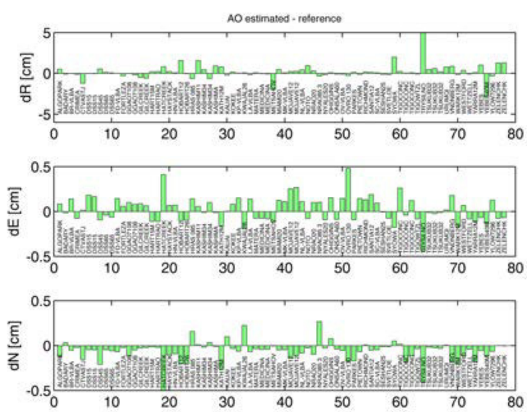

Fig. 3 Differences in the estimated TRF (coordinates): solution S2 minus solution where axis offsets were fixed to values provided in `antenna-info.txt` (December 2013 version).

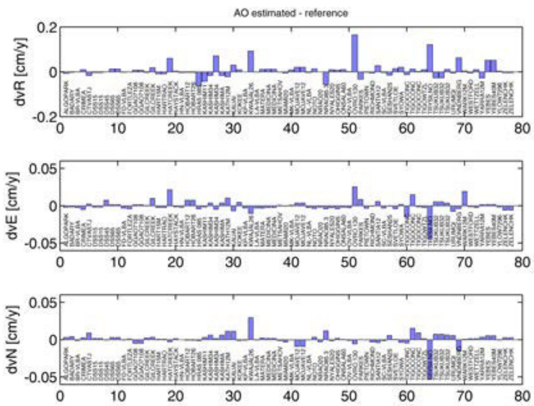

Fig. 4 Differences in the estimated TRF (velocities): solution S2 minus solution where axis offsets were fixed to values provided in `antenna-info.txt` (December 2013 version).

Differences in all five Earth Orientation Parameters estimated in solution S2 w.r.t. the solution with antenna axis offsets fixed to values given in `antenna-info.txt` are shown in Figure5. Affected are the three Earth Rotation Parameters (ERP)—x-pole, y-pole and dUT1—which are connected to the terrestrial reference frame. For sessions which included telescopes with a larger correction of the axis offset, the difference in the estimated ERP reaches up to 0.5 mas for the pole coordinates and 0.03 μs for dUT1.

5 Conclusions

An axis offset is projected onto the time delay with the cosine of the elevation angle; therefore a correlation with tropospheric delay, clock parameters, and station position can occur. We compared our estimates of the axis offsets with the latest values (January 2014) provided by D. MacMillan (GSFC VLBI Group). The largest differences reach up to 1 cm. The WRMS between both solutions for common stations is 3.8 mm. We focused on the HartRAO 26-m telescope, which had undergone a critical south polar bearing failure

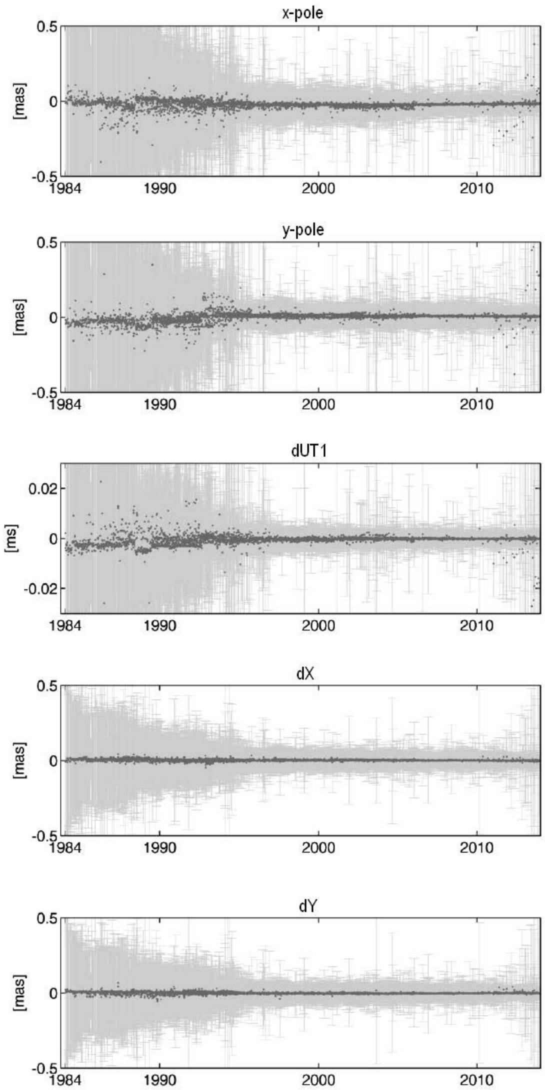

Fig. 5 Differences in the Earth Orientation Parameters estimated in solution S2 w.r.t. a solution with fixed antenna axis offsets to values given in `antenna-info.txt` (December 2013 version).

in 2008, and on the newly operational Hart15M. The estimated axis offset of the 26-m telescope before and after the bearing repair in 2010 differs by 8.1 ± 1.3 mm, while the estimated value for the 15 m agrees to within its formal error with the values obtained by `MacMillan2014` and by GPS (HartRAO Web page [3]). Our estimates will be compared with values from a local tie survey, which took place at HartRAO during March 2014, as soon as the survey results become available.

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References

1. Böhm J., S. Böhm, T. Nilsson, A. Pany, L. Plank, H. Spicakova, K. Teke and H. Schuh. The new Vienna VLBI Software VieVS. *IAG Symposium 2009*, 136. Ed. Kenyon S., M.C. Pacino and U. Marti, 1007–1012, 2012.
2. Combrinck W. L. and C. L. Merry. Very long baseline interferometry antenna axis offset and intersection determination using GPS. *J Geophys Res*, 102(B11), 24,741–24,743, 1997.
3. Hartebeesthoek Radio Astronomy Observatory (HartRAO). HartRAO 15m radio telescope details. *http://www.hartrao.ac.za/ht15m_factsfile.html*
4. Michel V., G. Roesch and J. Long. Hartebeesthoek Colocation Survey. *IERS Technical Note*, 33, 100–109, 2005.
5. Nothnagel A. Conventions on thermal expansion modelling of radio telescopes for geodetic and astrometric VLBI. *J Geodesy*, 83(8), 787–792, 2009.
6. Sovers O. J., J. L. Fanselow and C. S. Jacobs. Astrometry and geodesy with radio interferometry: experiments, models, results. *Rev. Mod. Phys.* 70(4), 1393–1454, 1998.