The 2002 Local Tie Survey at the Onsala Space Observatory

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Abstract. We describe the local tie survey work performed at the Onsala Space Observatory in the year 2002. Classical geodetic measurements and measurements with the Global Positioning System (GPS) were used to determine the local tie between the reference points at Onsala that are relevant for the International VLBI Service for Geodesy and Astronomy (IVS) and the International GPS Service (IGS) in a local and a global reference frame. The new local tie information together with the corresponding covariance information is available in SINEX format.

1 Introduction

The Onsala Space Observatory has been active in space geodesy since more than 30 years (Scherneck et al., 1998). The first geodetic Very Long Baseline Interferometry (VLBI) experiment at Onsala was already performed in the spring of 1968 (Whitney, 1974). At this time, the 25.6 m radio telescope was used for geodetic VLBI. Later, the radome enclosed 20 m telescope at Onsala was constructed and during a transition period both telescopes were used for geodetic VLBI observations, observing in parallel but separately on X- and S-band. Mark-III geodetic VLBI observations started in 1979 and since 1987 both frequency bands are observed with the 20 m telescope. GPS equipment was installed at Onsala in the 1980ies. Onsala became a CIGNET (Cooperative International GPS Network) station in 1987. A monument for a GPS antenna was constructed and acts today as reference monument for the Swedish ground-based GPS network SWEPOS and the IGS.

Figure 1: Equipment for space geodetic observations at the Onsala Space Observatory. Left: The radome enclosed 20 m radio telescope used for geodetic VLBI (IVS monument). Right: The permanently installed and radome equipped antenna used with Global Navigation Satellite Systems (GNSS) (IGS monument). The two monuments are located within about 80 m distance.

Figure 1 shows the two monuments at Onsala that are relevant for the IVS and the IGS. These are the radome enclosed 20 m telescope and the permanently installed GPS antenna, located in about 80 m distance from each other. The two international services IVS and IGS are important for the establishment and preservation of the International Terrestrial Reference Frame (ITRF) (Altamimi et al., 2001). For the comparison and combination of IVS and IGS products, it is necessary to know the so-called local tie, the exact relative position of the reference points of the corresponding monuments (e.g. Long and Bosworth, 2000).

Classical geodetic measurements and several GPS campaigns were performed in the 90ies of the last century in order to establish the local tie between the reference points at the observatory (Peterson, 1991; Johansson et al., 1992). However, for these local tie realizations, some distances in the 20 m telescope were taken from construction drawings. Furthermore, the covariance information of the local tie was not provided. When the mobile VLBI telescope MV-2 visited Onsala, a short baseline VLBI experiment was performed to determine the local tie (Potash, 1992). Also this local tie realization suffered from a lack of complete covariance information. Lidberg et al. (2003) give an overview on the history of local tie measurements at Onsala.

Since the earlier local tie information show some deficiencies, we performed a new local tie survey at the Onsala Space Observatory in the year 2002 using classical geodetic methods and GPS observations. The goal of this survey was to determine the local tie information in a local and a global reference frame with high accuracy, including the complete covariance information.

2 Special local tie difficulties at the Onsala Space Observatory

The special difficulties at Onsala are that the IVS and IGS reference points are not easily accessible and observable, see Figure 2. In general, the space geodetic reference point of azimuth-elevation radio telescopes used for VLBI is defined as the intersection of the telescopes's azimuth and elevation axes. In case these axes do not intersect, the reference is defined as the point on the azimuth axis that is closest to the elevation axis. At the Onsala 20 m telescope, the reference point does not exist as a material but is located somewhere inside the telescope receiver cabin. It thus can only be determined with indirect surveying methods. Furthermore, the telescope is surrounded by an optically opaque radome. Thus, direct observations of any part of the telescope are not possible from the survey points of the observatory's local geodetic network outside the radome building.

The IGS reference point is a steel bolt installed in solid bedrock below the GPS-antenna which is installed permanently on a concrete pillar. Thus, this steel bolt is hardly observable with survey equipment. It is only possible to observe it by viewing through two small openings in the walls of the concrete pillar that are oriented perpendicularly to each other.

3 The project strategy

The project strategy was to perform classical geodetic survey measurements of the telescope's reference point using an indirect survey method, to perform a classical geodetic survey of the local survey network and the IGS reference point, and to perform GPS observations in the local network (Eschelbach, 2002; Eschelbach and Haas, 2003).

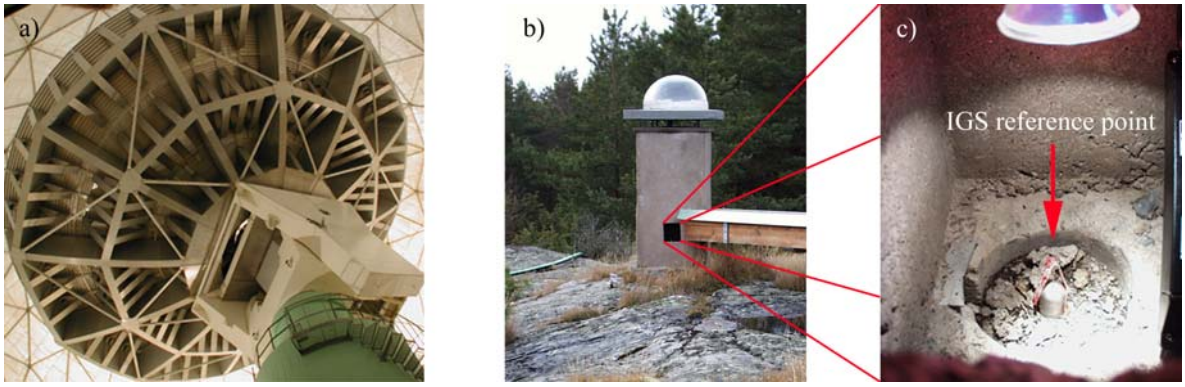

Figure 2: IVS and IGS reference points at Onsala: a) view inside the radome enclosing the 20 m radio telescope. The telescope's space geodetic reference point is the physically non-existing intersection of the telescope's azimuth and elevation axes; b) the IGS monument from the outside; c) zoom-in into the inside of the IGS monument showing the marker in solid bedrock which is the IGS reference point.

To make the necessary measurements possible, five new survey pillars inside the telescope radome and a number of new ground markers inside and outside the radome building were installed. The new survey pillars should allow the survey of the telescope in order to determine its reference point with indirect methods. They were installed on top of the radome foundation wall to allow observations of the telescope with reasonable zenith distances of about 40 gon. The new ground markers should allow a connection of the new survey pillars to the existing local survey network at the observatory. Views through opened doors and windows should allow a connection between markers inside and outside the radome building. Some of the new ground markers that were installed outside of the radome building should also be used for GPS measurements. Figure 3 shows examples of the new survey pillars and ground markers. Figure 4 shows drawings of the local survey network and its extensions by new survey pillars and ground markers.

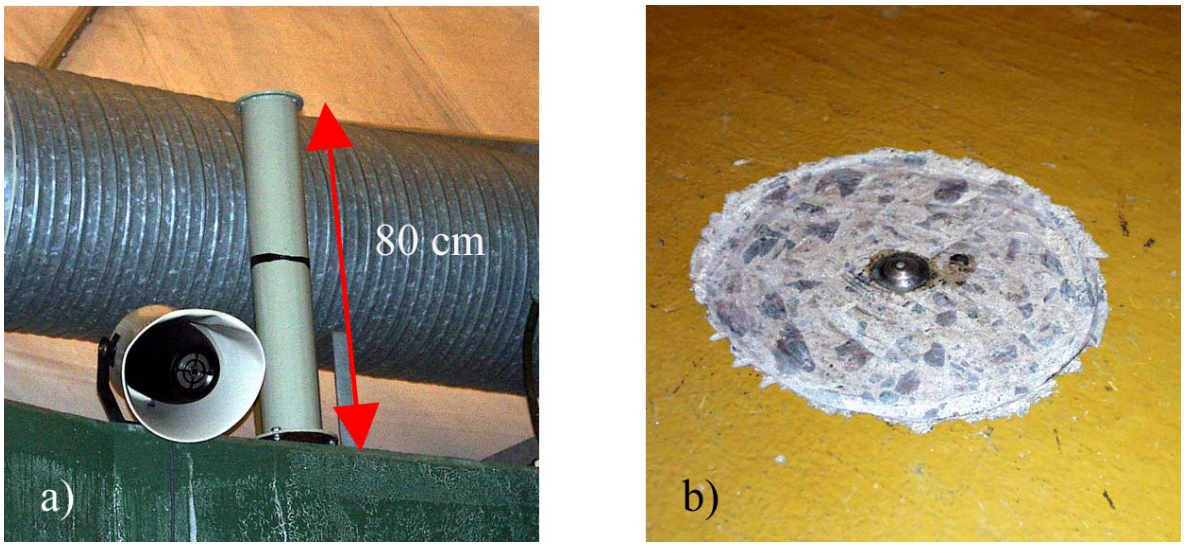

Figure 3: a) example of a new survey pillar installed on the radome foundation wall in about 3 m height; b) example of a new ground marker.

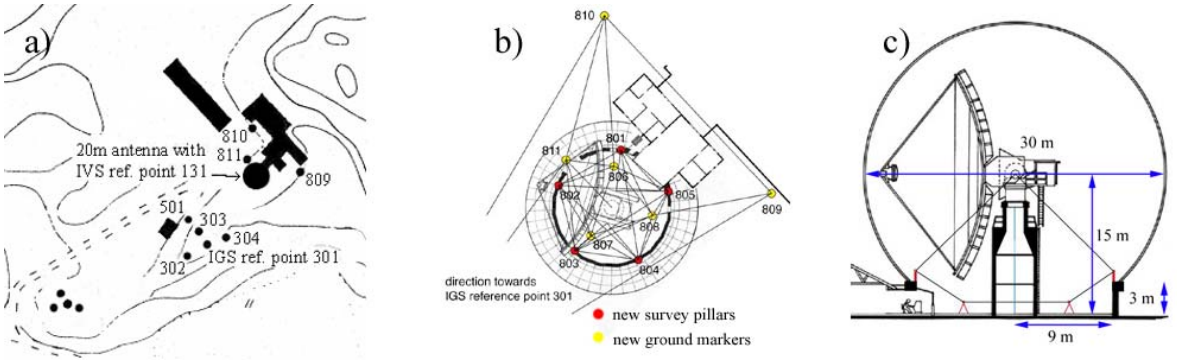

Figure 4: a) map of the local survey network at the Onsala Space Observatory, extended by the new ground survey markers 809, 810 and 811; b) drawing of the radome building showing the new survey pillars and ground markers; c) cross-section through the radome building showing the telescope, and the new survey pillars and ground markers.

4 Measurements

The first and most time consuming part of the project was to perform the measurements inside the radome building in order to be able to determine the telescope's reference point. The second part of the project was the measurement of the local network, including the connection of the new markers and survey pillars and the survey of the IGS reference point. The last part of the project included the GPS-observations on several markers in the local network. All details on the measurements are described in Eschelbach (2002) and Eschelbach and Haas (2003).

4.1 Telescope measurements

Since the telescope's reference point at Onsala is not directly observable, an indirect survey method had to be used for its determination. The idea was to survey the endpoints of the elevation axis when the telescope was positioned to different azimuth directions in order to be able to determine the reference point in a following step. However, the endpoints of the elevation axis are not directly observable either at Onsala. Thus, to determine these endpoints, additional survey markers were installed on the telescope cabin that could be observed from the five new survey pillars on the radome foundation. For the Epoch-1 survey, in total eight survey markers were installed in a distance of some decimeters from the elevation axis on both sides of the telescope cabin. Observation of four of these markers, two on each side, under different elevation positions of the telescope should allow the determination the elevation axis endpoints by fitting 3D-circles. For the Epoch-2 survey, magnetic survey markers were installed on both sides of the telescope cabin that should act as synthetic elevation axis endpoints. Figure 5 shows the survey markers used for the Epoch-1 and Epoch-2 measurements.

The survey markers were observed from baselines formed by pairs of the new survey pillars for different elevation and azimuth positions of the telescope (Epoch-1), respectively different azimuth positions (Epoch-2). For Epoch-1 a total number of about 600 new points was observed. Survey instruments of type Leica T2002 and a Leica TCR1102 were used for these measurements. The measurement procedure and all details on the Epoch-1 and Epoch-2 measurements are described in Eschelbach (2002) and Eschelbach and Haas (2003).

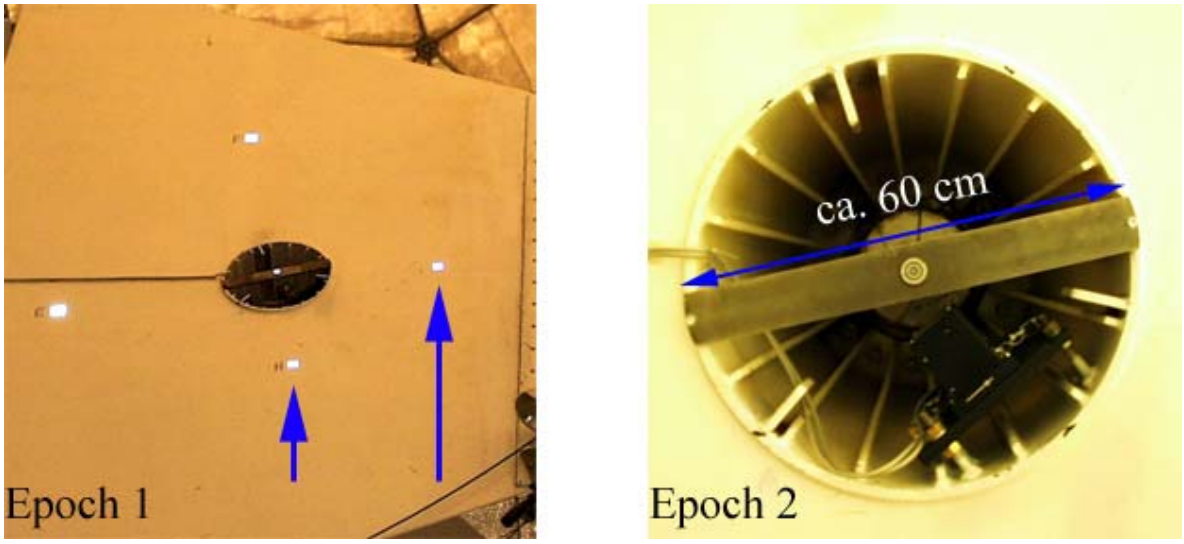

Figure 5: Survey markers on one side of the telescope cabin: markers used for the Epoch-1 measurements (left, marked with arrows) and the synthetic endpoint of the elevation axis (magnetic marker in the centre) used for the Epoch-2 measurements (right).

The observational data were analysed with the network adjustment program Netz3D (Jäger, 1995). The mean position error of the new points at the telescope was below 0.2 mm. These coordinates were used in a further step to derive the elevation axis endpoints and the telescope's reference point by three dimensional circle fits (Eschelbach, 2002; Eschelbach and Haas, 2003).

4.2 Measurements of the local network and IGS reference point

The new survey pillars were connected to the local network at the observatory. Additionally, the IGS reference point was connected to the local network. The observations included horizontal direction measurements with a Leica T2002 instrument, horizontal distance measurements with a Leica TCR1102 instrument, and digital levelling with a Zeiss DINI 10 instrument. The observational data were analysed with the Netz2D software (Jäger et al., 1996). Mean accuracies of 0.2 mm for the horizontal position and 0.1 mm for the vertical position were achieved. Due to the difficult observation situation at the IGS reference point, its vertical component was determined with a standard deviation of 0.6 mm only. Details on the measurements and analysis can be found in Eschelbach (2002) and Eschelbach and Haas (2003).

4.3 GPS-observations in the local network

GPS-observations on four ground markers of the local network were performed for a total of 55 days. The data were analysed together with data from the IGS station using the GPS analysis software package Bernese version 4.2 (Hugentobler, et al., 2001). The coordinates of the markers in the local network were determined from a L1-only solution. The achieved repeatabilities were on the order of 0.6 mm and 1.0 mm for the horizontal components, and 1.7 mm for the vertical component. Some details on the GPS-measurements and the corresponding data analysis can be found in Eschelbach and Haas (2003).

5 Data analysis and results for the local tie

For each azimuth position, the telescope markers observed in Epoch-1 for different elevation positions describe quarter circles around the elevation axis endpoints. One-step 3D-circle fits were applied to determine the elevation axis endpoints and their complete covariance information. The in this way determined endpoints of Epoch-1 and also the directly observed synthetic endpoints of Epoch-2 describe horizontal 3D-circles around the azimuth axis when the telescope is moved in azimuth. Thus, one-step 3D-circle fits to the elevation axis endpoints resulted in coordinates for the telescope's reference point. Details on the 3D-circle fits and the data analysis are given in Eschelbach (2002) and Eschelbach and Haas (2003). Thermal deformation of the concrete telescope tower and the radome foundation were taken into account in the data analysis so that all results refer to a temperature of 0° Celsius. As an example, Figure 6 shows the relative vertical height measurements of the concrete telescope tower as observed with the invar rod measurements system installed at the Onsala 20 m telescope (Johansson et al., 1996). The coordinates of the reference point in the local reference frame were derived with standard deviations on the order of 0.1 mm in all three components for Epoch-1 and 0.1 mm for the horizontal components and 0.3 mm for the vertical component in Epoch-2. The coordinates of the reference point agree between the two epochs within their formal error bars.

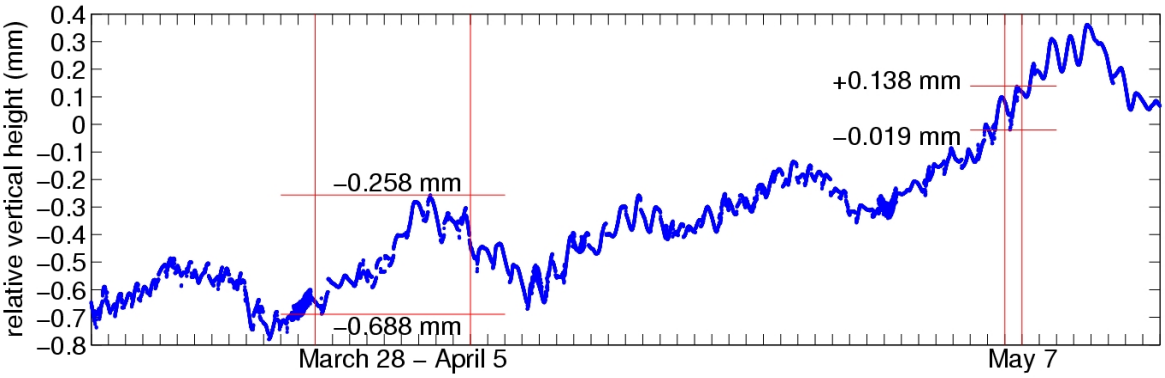

Figure 6: Relative vertical height of the concrete telescope tower as measured with the invar rod measuring system. Epoch-1 was observed between March 28 and April 5, 2002, and Epoch–2 on May 7, 2002.

The coordinates of the reference points were transformed to ITRF using a Helmert transformation with four identical points in the local network that had coordinates given in both frames. The mean residual of the transformation was 0.8 mm. Table 1 lists the coordinates for the IGS and IVS reference points in both reference frames. Table 2 gives the local tie as a SINEX-file including the complete covariance information.

Table 1: Coordinates of the IGS- and the IVS-reference points and their standard deviations

Local reference frame	x [m]	σ_x [mm]	y [m]	σ_y [mm]	z [m]	σ_z [mm]
IGS 301	12.7535	± 0.2	23.3877	± 0.2	9.0455	± 0.6
IVS 311	90.1237	± 0.1	35.9493	± 0.1	22.7594	± 0.1

ITRF	X [m]	σ_X [mm]	Y [m]	σ_Y [mm]	Z [m]	σ_Z [mm]
IGS 301	3370658.5879	± 0.3	711877.1097	± 0.2	5349786.9288	± 0.5
IVS 311	3370605.9602	± 0.1	711917.5650	± 0.1	5349830.8018	± 0.1

Table 2: SINEX file with the local tie information for the Onsala Space Observatory

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*-------------------------------------------------------------------------------
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* File created on June 25, 2003
* CONTACT            eschelbach@gik.uni-karlsruhe.de
-FILE/COMMENT
*-------------------------------------------------------------------------------
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ONSG  A 10402M004   Onsala 301              57 23 43.1  11 55 31.9  45.543
ONSV  A 10402M006   VLBI 7211               57 23 45.0  11 55 34.9  59.254
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*-------------------------------------------------------------------------------
+SOLUTION/ESTIMATE
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2 STAY   ONSG  A    1 02:193:00000 m    2   .7118771097 0000E-06 .18811E-03
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5 STAY   ONSV  A    1 02:193:00000 m    2   .7119175650 0000E-06 .99995E-04
6 STAZ   ONSV  A    1 02:193:00000 m    2   .534983080180000E-07 .99995E-04
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*-------------------------------------------------------------------------------
+SOLUTION/MATRIX_ESTIMATE L COVA
*PARA1 PARA2 ____PARA2+0__________ ____PARA2+1__________ ____PARA2+2__________
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2     1  .135390000000000E-07  .353860000000000E-07
3     1  .149774000000000E-06  .344200000000000E-07  .261655000000000E-06
4     1  .000000000000000E+00  .000000000000000E+00  .000000000000000E+00
4     4  .999900000000000E-08
5     1  .000000000000000E+00  .000000000000000E+00  .000000000000000E+00
5     4  .000000000000000E+00  .999900000000000E-08
6     1  .000000000000000E+00  .000000000000000E+00  .000000000000000E+00
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-SOLUTION/MATRIX_ESTIMATE L COVA
%ENDSNX
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6 Results concerning the telescope geometry

The performed measurements allowed to derive more information concerning the telescope geometry than just the telescope's reference point. By an analysis of the vertical height of the elevation axis endpoints as a function of azimuth position of the telescope, the divergence of the telescope's azimuth axis from the local vertical could be determined. The results show, that the adjustment of the telescope balance weights that was performed between the Epoch-1 and the Epoch-2 measurements reduced the divergence from the local vertical considerably. The analysis of the mean difference between elevation axis endpoints at opposite sides of the telescope cabin also allowed to derive a value for the non-orthogonality between the azimuth and elevation axes. Furthermore, since the Epoch-2 measurements included observations of 10 pairs of diametral elevation axis endpoints, these measurements allowed to determine the telescope's axes offset. All details on these results concerning telescope geometry are given in Eschelbach (2002) and Eschelbach and Haas (2003). The results are summarized in Table 3. Note that the sign of the axes offset in Eschelbach (2002) and Eschelbach and Haas (2003) is wrong.

Table 3: Results concerning the telescope geometry

Parameter	Measurements	Value
Divergence of the azimuth axis from the local vertical.	Epoch-1	21 ± 6 arc-seconds
Divergence of the azimuth axis from the local vertical.	Epoch-2	13 ± 6 arc-seconds
Non-orthogonality of azimuth and elevation axis.	Epoch-1	40 ± 8 arc-seconds
Axes offset.	Epoch-2	–6.0 ± 0.4 mm

7 Conclusions and outlook

The local tie survey performed at the Onsala Space Observatory in the year 2002 was very successful. The IVS reference point was determined with a standard deviation in three dimensions of about 0.25 mm in the local reference frame. The three-dimensional local tie between the IVS and IGS reference points was determined on the sub-mm level in both the local and the global reference frame. During the analysis the thermal deformation of the telescope tower and the radome foundation has been corrected for so that this local tie refers to a temperature of 0° Celsius. The complete covariance information was preserved in this real 3D-determination of the reference points and the local tie and the complete local tie information is available in SINEX format. Besides the pure local tie information, several previously unknown geometrical properties of the radio telescope have been determined, too. An axes offset of –6.0 mm ± 0.4 mm has been detected which should be used in the analysis of geodetic VLBI data. So far in the VLBI data analysis it was assumed that the axes offset was zero at the 20 m telescope. A repeated local tie survey in a couple of years is highly desirable to investigate whether the local tie and the telescope geometry are changing over time.

Acknowledgements

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