Permanent Reference Point Monitoring of the TWIN Radio Telescopes at the Geodetic Observatory Wettzell

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Abstract The reference point determination of VLBI telescopes is usually done every couple of years and allows for the identification of long-term drifts. In order to detect short-term motions like seasonal deformations, a monitoring system allowing more frequent measurements has to be established. At the Geodetic Observatory Wettzell a quasi-permanent reference point monitoring system was set up at the TWIN telescopes TTW-1 and TTW-2 in 2015 and 2013, respectively. The in-house software package called HEIMDALL allows the coordination of the VLBI and tacheometer schedules, the management of the moving targets, and the acquisition and storage of tacheometer and meteorological data in a database. The obtained data sets spanning a period of 1.5 and 3.5 years provide an insight into the three-dimensional motion of the invariant point. As expected, the largest motions occur in the vertical with an annual period, a maximum in the second half of July, and a peak-to-peak amplitude of nearly 2 mm. In addition, a weak seasonal signal of less than 1 mm is also visible in the horizontal component of both telescopes pointing towards southeast and showing a delay of two months with respect to the thermal peak. The correlation of the height variations with temperature records obtained from sensors inside the TTW-2 telescope structure yields correlation coefficients of up to 0.98 and coefficients of thermal expansion of 1.3 to 1.6 $\times 10^{-5}\,\mathrm{K}^{-1}$. These very high correlations allow the correction of thermoelastic height variations using the records of properly installed temperature sensors with RMS errors of the residuals of less than 0.15 mm.

Keywords Local ties, reference point, permanent monitoring, Geodetic Observatory Wettzell, TWIN radio telescopes

1 Introduction

The long-term stability of reference points of geodetic space techniques is crucial, since any temporal variation has a direct impact on the reference frame itself. Regular monitoring is thus an important task to prove the monument stability or to identify reference point motions. A local survey network being made up of deeply founded stable pillars provides the physical reference. A full survey is usually done every couple of years and allows for the identification of long-term drifts; however, short-term drifts like seasonal driven motions cannot be identified in this way. A quasi-continuous monitoring is required for this purpose.

While the terrestrial survey of reference points at non-rotating structures like GNSS and DORIS antennas or their reference markers can be done directly, the geometric reference point of VLBI and SLR telescopes has to be inferred indirectly. A convenient way to determine the reference point of VLBI antennas is the derivation of the invariant point (that is, the intersection of the azimuth and elevation axes) from numerous measurements of points on the moving telescope struc-

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ture. Since several hundred observations from different positions are usually done, a continuous monitoring is a time-consuming task. Therefore, an automated system was used for the permanent monitoring of the reference points. An appropriate procedure and corresponding software was tested and optimized during various campaigns at several radio telescopes; for instance, at Wettzell [Lösler 2008, Lossin et al. 2014], at Onsala [Lösler et al. 2013], and at Metsähovi [Kallio et al. 2016]. In this work, the Wettzell Twin Telescopes TTW-1 and TTW-2 were continously monitored over several years, yielding the most extensive data set in the context of reference point determination of radio telescopes.

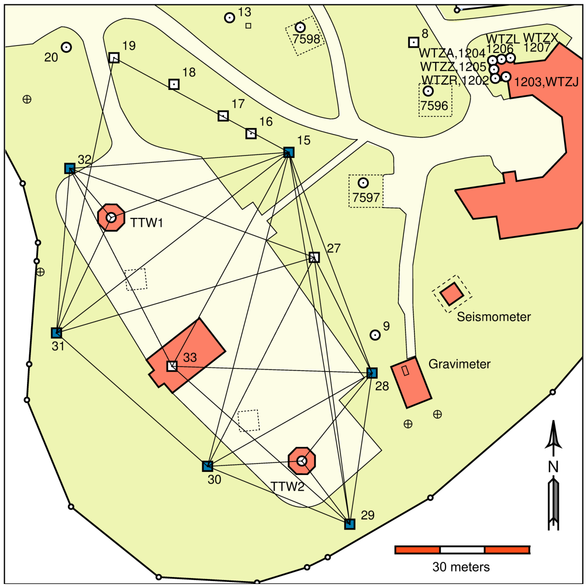

Fig. 1 Monitoring sub-network with used reference pillars, tacheometer positions (blue), and the telescope reference points.

2 3D-Monitoring Concept

For every reference point determination a full day of VLBI session time was required. A dedicated VLBI schedule was generated for this purpose, while a second schedule controls the tacheometer. Each telescope was observed from three different positions, which is a good compromise between accuracy and time consumption. The positions of the survey stations and the reference pillars, which are measured at regular intervals, are shown in Figure 1. There were 24 (TTW-1) and 26 (TTW-2) magnetic prisms attached to the telescopes back structure to serve as targets for the tacheometer measurements (Figure 2). The used in-house software package called HEIMDALL allows the coordination of the VLBI and tacheometer schedules, the management of the moving targets, and the acquisition and storage of the tacheometer and meteorological data in a database. Each session comprises about 700 single observations and takes nine hours per telescope. A detailed description of the measurement and analysis concept as well as the mathematical model is given in [Mähler et al. 2018, Lösler et al. 2013, Lösler 2008].

Fig. 2 Distribution of target prisms (bright spots) at TTW-2. The inset shows a prism in detail.

3 Results

The data sets obtained span a period of 1.5 and 3.5 years for TTW-1 and TTW-2, respectively. The standard deviations are in the order of 0.05–0.1 mm for the horizontal and 0.1–0.2 mm for the vertical component. The largest motions occur in the vertical with an annual period, a maximum in the second half of July, and a peak-to-peak amplitude of nearly 2 mm (Figure 3). In addition, a weak seasonal signal of less than 0.5 mm is also visible in the horizontal component of both telescopes.

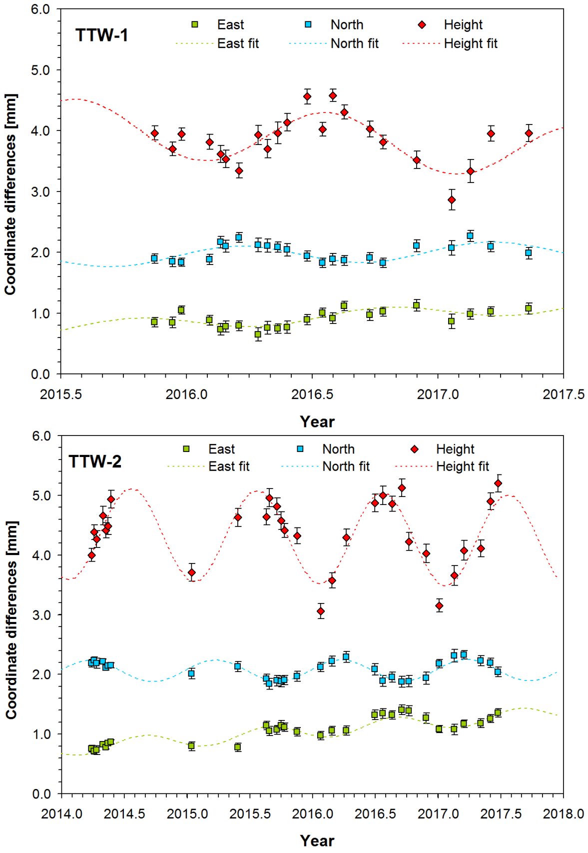

Fig. 3 Time series of the computed reference points for TTW-1 (above) and TTW-2 (below) with fitted annual sine curves. Series are vertically shifted, error bars are 1 sigma.

Phases and amplitudes of the annual signals and a linear drift were estimated using the approach

$$y = a + b \cdot t + c \cdot cos(\omega t) + d \cdot sin(\omega t)$$

with $\omega = 2\pi/year$ and the time t in years. The least-squares fit yields parameters given in Table 1. The offset a is irrelevant in this context. The linear drifts expressed by the parameter b are very small and only in the east component of both telescopes slightly significant. In contrast, the annual signal is significant in all components. The clear difference in the height component between both telescopes is not fully understood yet. It should be noted, however, that the short time span of 1.5 years at TTW-1 only allows a poor determination of the annual amplitude.

When combining the east and north components, the resulting amplitudes and directions of motions are very similar at both telescopes. The maximum occurs in the second half of September pointing towards the southeast with single amplitudes of 0.18 and 0.21 mm for TTW-1 and TTW-2, respectively.

Table 1 Parameters of the least-squares fits.

Component	b [mm/y]	c [mm]	d [mm]	Ampl [mm]	Phase [deg]	RMS err. [mm]
TTW1 East	0.18	0.031	−0.108	0.11	285.9	0.086
TTW1 North	0.07	0.037	0.147	0.15	76.0	0.091
TTW1 Height	−0.22	−0.405	−0.193	0.45	205.4	0.246
TTW2 East	0.15	−0.070	−0.105	0.13	236.4	0.066
TTW2 North	0.01	0.019	0.178	0.18	83.9	0.080
TTW2 Height	−0.03	−0.717	−0.284	0.77	201.6	0.232

4 Conclusions

The annual signal in the vertical component of both telescopes with its maximum at the thermal peak is compatible to the idea of thermoelastic deformations of the telescope structure. In order to confirm this assumption, linear regressions between temperature records from inside the telescope structure and the height variations were performed (Figure 4 and Table 2).

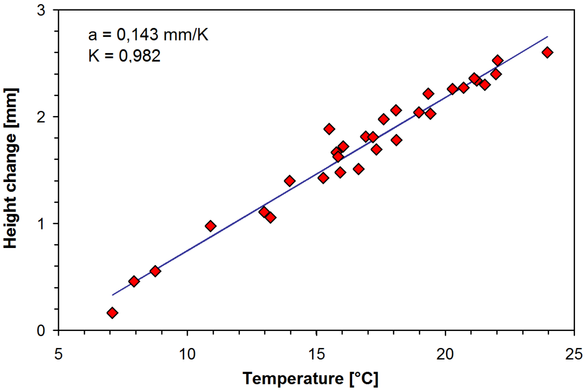

Fig. 4 Linear regression between the mean temperature record from the sensors T3E and T3W (see Table 2) and the measured height variations from TTW-2.

Correlation coefficients between 0.92 and 0.98 underline the strong linear relationship between temperature and height. The resulting slope parameter a translates into coefficients of thermal expansion between 1.3

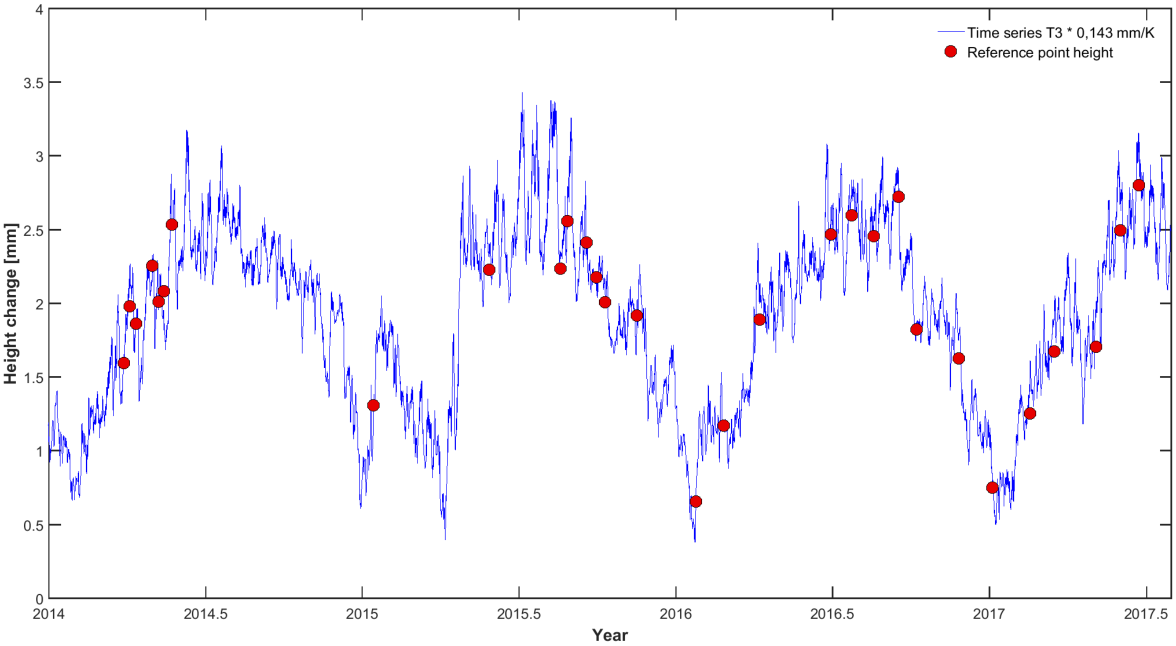

Fig. 5 Comparison of the reference point heights for TTW-2 and height variations resulting from temperature records taken in the wall of the TTW-2 tower.

Table 2 Regression parameters a and correlation coefficients r of linear least-squares fits between time series of different temperature sensors and measured height variations at TTW-2.

T-sensor	Position	a [mm/K]	r
T1E	Tower basement East	0.184	0.958
T1W	Tower basement West	0.163	0.951
T2E	Tower 1st floor East	0.181	0.940
T2W	Tower 1st floor West	0.190	0.925
T3E	Steel plate at tower top East	0.144	0.982
T3W	Steel plate at tower top West	0.143	0.980

and $1.6 \times 10^{-5}\,\mathrm{K}^{-1}$ when dividing by the total height of the telescope tower of 10.9 m.

Multiplying the regression coefficient of the most representative sensors T3E and T3W with their mean temperature record, the resulting linear expansion is opposed to the measured height variations in Figure 5. The height variations excellently fit the temperature time series and even identifies outliers as thermoelastic deformations. The resulting coefficient of thermal expansion of the best fitting time series (sensor T3) agree very well with common values for concrete and steel, which are in the order of $1.1–1.3 \times 10^{-5}\,K^{-1}$.

In the horizontal component, the origin of the annual signal is less clear. The delay of two months with respect to the thermal peak excludes an instantaneous thermoelastic distortion of the telescope structure as a direct cause. Small tilts of the telescopes' foundation caused by differential thermoelastic expansions in the underground could be a possible explanation of the seasonal horizontal motion of the reference point. However, the magnitude of motion being less than 0.5 mm is below the GGOS goal of 1 mm.

5 Outlook

The very high correlation between height and temperature allows the correction of height variations using the records of appropriately installed temperature sensors with RMS errors of the residuals of less than 0.15 mm. In this context the choice of the temperature measuring point is crucial, since it must represent the average internal temperature of the telescope structure. This height correction can also be applied to other radio telescopes using proper coefficients of thermal expansion or, in order to achieve higher accurary, performing a measuring campaign over 1–2 years using the monitoring system proposed in this paper to obtain these coefficients.

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