Local Radio Telescope Ties from the Wettzell Precision Engineering Surveying Network

Torben Schüler [1,2], Thomas Klügel [1], Swetlana Mähler [1], Christian Plötz [1]

Abstract The Geodetic Observatory Wettzell is a fundamental station of Geodesy and a GGOS Core Site. This co-location site features all systems of the space-geodetic techniques, i.e., three VLBI telescopes, two operational SLR telescopes, various GNSS receivers, a DORIS beacon, and a ring laser gyro for instantaneous measurement of the Earth rotation. The existence of a geodetic co-location site is justified by the need to synergistically combine the various techniques in order to derive all geodetic parameters of interest which are needed to realize the reference system. Although VLBI is the only technique capable of providing the full set of Earth orientation parameters, the determination of the geo-center (the origin of our coordinate system) is not possible at all, and SLR will be needed for this purpose. GNSS, in the end, provides easy access to the terrestrial reference frame. These synergies can only be exploited for Geodesy if precise geometric links between the reference points of the various systems are known, the so-called "local ties". At Wettzell, these vectors are derived from a local precision engineering surveying network that is covering the entire observatory yielding a point precision around 0.2 to 0.4 mm for the majority of the points. This contribution will outline the methodology to derive the local tie vectors and to transform them into the ECEF system, present the latest results, and compare them with alternative methods like the direct local VLBI data analysis.

1. Geodetic Observatory Wettzell, Federal Agency for Cartography and Geodesy (BKG), Sackenrieder Str. 25, D-93444 Bad Kötzting, Germany
2. University of the Federal Armed Forces Munich, Faculty of Aerospace Engineering, Werner-Heisenberg-Weg 39, D-85577 Neubiberg, Germany

Keywords Local ties, precise engineering network, terrestrial surveying, network transformation

1 Local Terrestrial Network Wettzell

The local network at the Geodetic Observatory Wettzell is regularly surveyed in order to monitor the local stability at the site and, most importantly, to provide the local ties for ITRF computation. The term "local ties" denotes the connection vectors between the various systems of the space geodetic techniques co-located at Wettzell, namely

- the three VLBI telescopes Wz (7,224, RTW, 20 m), Wn (7,387, TWIN 1), and Ws (7,388, TWIN 2),
- the two SLR stations WLRS (8,834) and SOSW,
- a number of GNSS reference stations (in particular WTZR, an IGS station),
- the DORIS beacon, and
- the two SAR corner reflectors (for support of interferometric SAR applications).

As a final product, the local ties are basically a set of Earth-Centered Earth-Fixed (ECEF) coordinates provided in standard SINEX (Solution-Independent Exchange) format.

This contribution refers to the local network solution of 2012 which was used to derive the ties employed in the realization of ITRF 2014. Although more recent network measurements exist, this one is still the official release. Figure 1 portrays the local network. It covers the entire GO Wettzell. The new TWIN VLBI telescopes are located in the southern part of the network and surrounded by surveying pillars. The old SLR system WLRS is located in the center of the net,

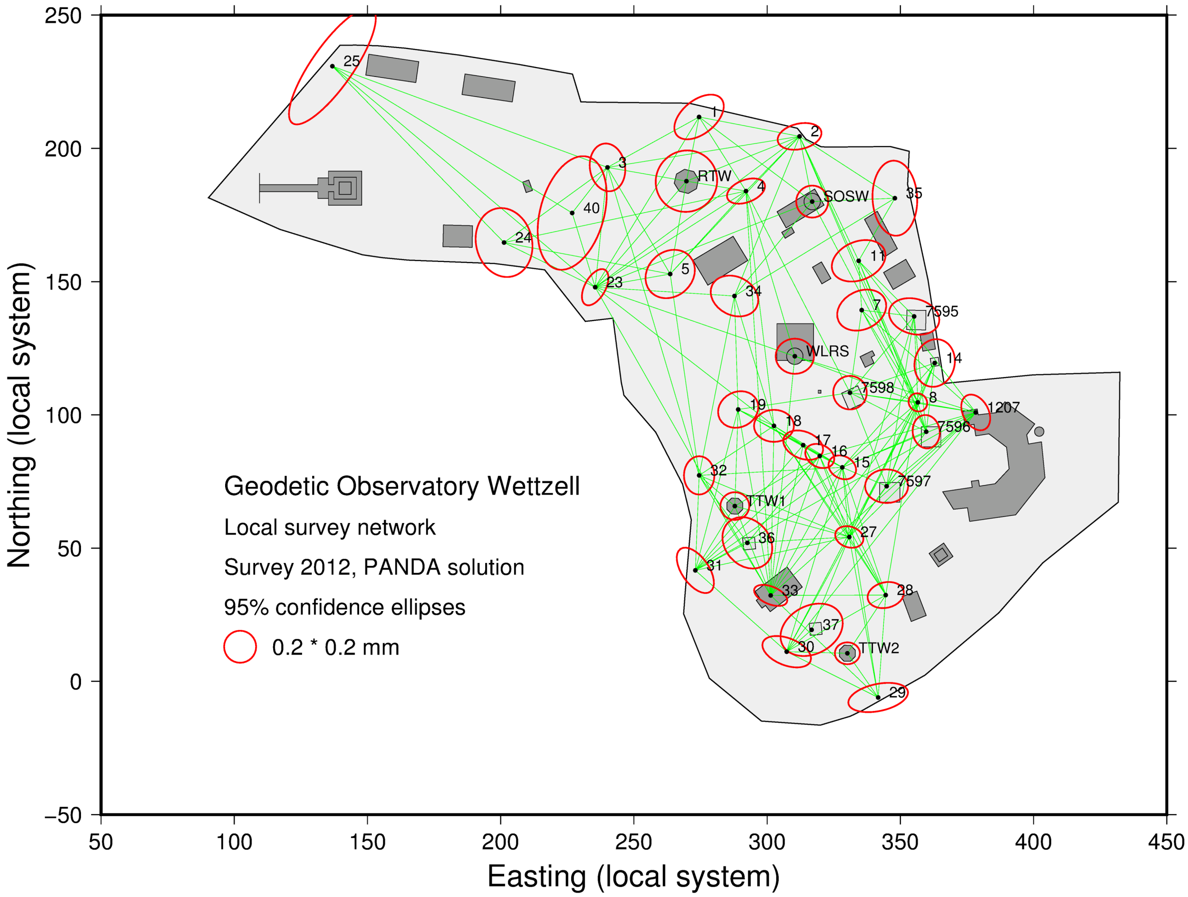

Fig. 1 Local precision engineering surveying network of the Geodetic Observatory Wettzell with a selected set of observations (baselines measured by terrestrial total station) and confidence ellipses (precision at a level of 95% probability). This network plot is related to the measurement epoch 2012 that was used to derive the local ties for the computation of ITRF 2014.

whereas the old VLBI telescope Wz (RTW, 20 m) and the new SLR station SOSW are visible at the northern periphery of the network.

2 Procedures and Notes on Processing

Deriving highly precise coordinates from terrestrial measurements is a discipline of craftsmanship and requires meeting rigorous surveying procedures. Though it is not possible to go into any details in this paper, it is worth mentioning the following notes:

- *Terrestrial survey:* The precise terrestrial survey is carried out in a local coordinate system. The radial coordinate channel is supported by precision levelling wherever feasible. The local network adjustment is currently carried out in 3D mode.
- *Surveying equipment:* The terrestrial measurements are carried out using a precision total station with an angular standard deviation of $\sigma_r = 0.5''$ (one single direction observation) and a distance precision of $\sigma_s = 0.6$ mm. In addition, a precise digital levelling device with an invar rod is in use.
- *System reference points:* Several reference points are not directly accessible, e.g., those of the new TWIN telescopes. Separate procedures are employed to indirectly determine these points [Maehler et al., 2018]. In these cases, zenith angle measurements contribute in major parts to the determination of the height component, because spirit levelling is not a practicable means. The reference points of the TWIN telescopes are regularly mon-

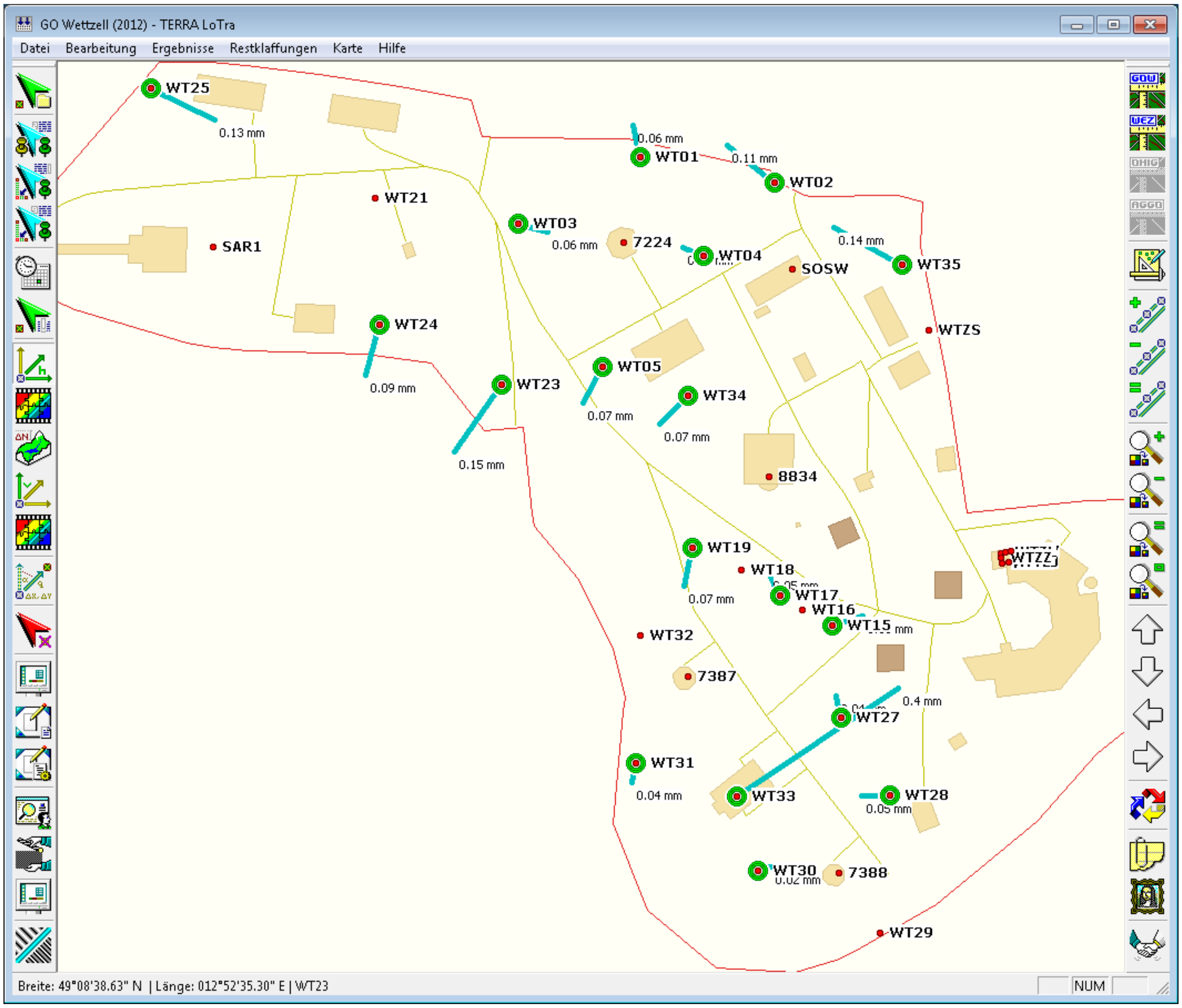

Fig. 2 Horizontal residuals à posteriori for the transformation points showing a very good agreement between the local survey and the GPS positioning results (thanks to manual screening of the GPS residuals).

itored. A monitoring session close in time to the network survey was used to inject the associated data into the overall network adjustment.

- *GPS control network:* A number of survey pillars were occupied by GPS yielding a set of identical points. The control points were used to derive transformation parameters in order to refer the local coordinates to ECEF. The GPS measurements were collected for at least 24 hours or longer (1.5 days). The same antenna type was used at both the central point and on the control points in order to avoid/to minimize antenna phase center uncertainties.
- *Manual screening of GPS residuals:* Most importantly, we used an in-house GNSS processing software that is optimized for interactive data editing. Manual editing of all GPS baselines was carried out removing suspected unhealthy data. This is a tedious and highly long, drawn-out effort, but many of the control point locations were optimized for terrestrial surveying rather than GPS observing. As a consequence, signal blocking, multipath, and also signal bending were visible in the data. Figure 2 nicely illustrates that the major effort of manual editing was worth being spent. Automatic outlier removal yields approximately three times less precise results than manual data editing.

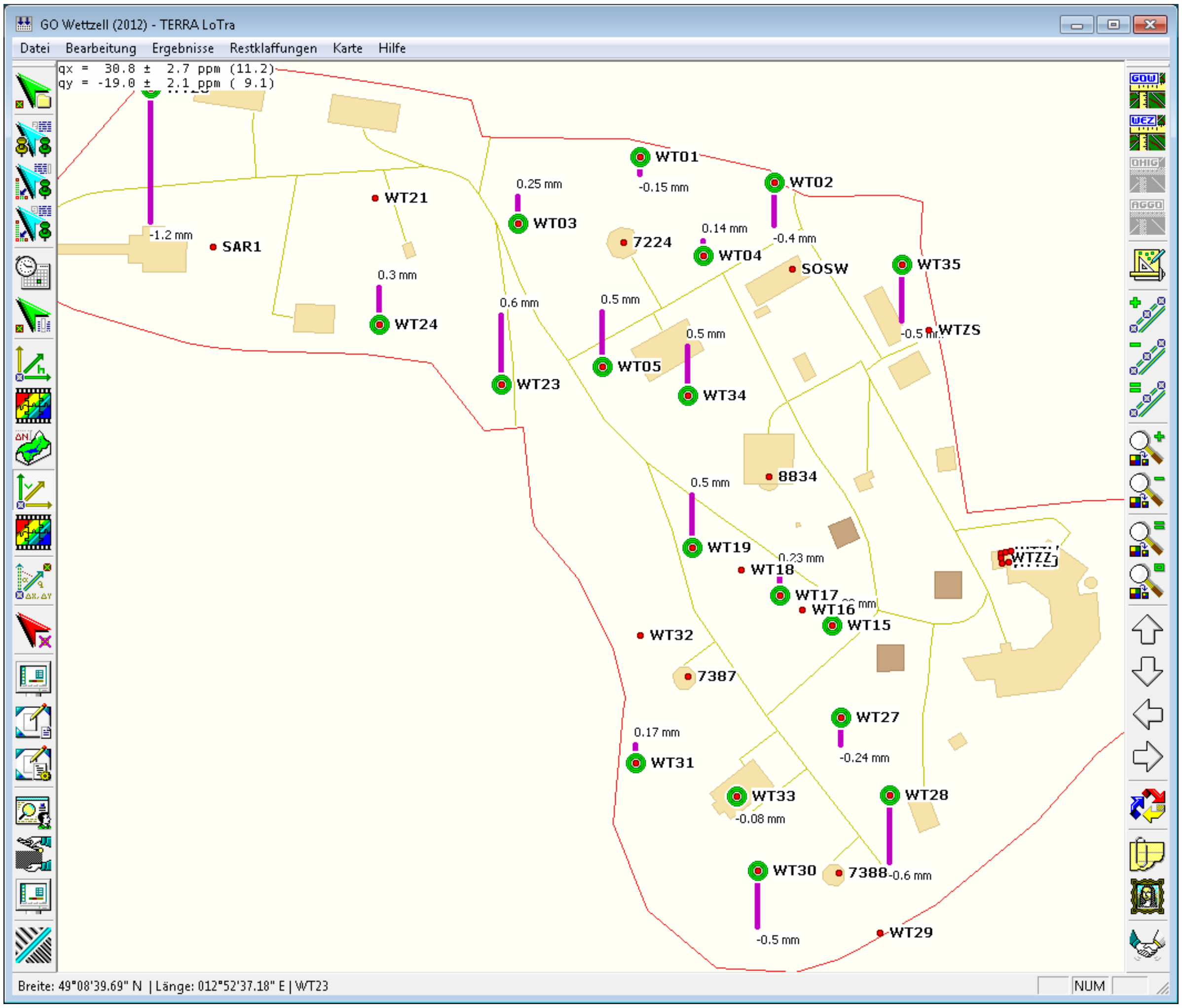

Fig. 3 Vertical residuals à posteriori for the transformation points. It was essential to estimate a pair of horizontal gradients in addition to the vertical offset in order to reduce these residuals to a level coinciding with the measurement precision. The gradient components are numerically given in the upper left part of the screen-shot.

3 Transformation Approach

We strictly separated the horizontal and vertical coordinates and derived independent sets of transformation parameters. This procedure is necessary at Wettzell due to a special treatment of the radial channel, possibly due to changes of the geoidal separation over relatively small horizontal distances.

The horizontal transformation coefficients consist of a classical set of datum transformation parameters, i.e., two translations, one net rotation, and a scaling factor. Figure 2 reveals small residuals, not to say a fantastic agreement, except for pillar WT33 on the TWIN operating building's terrace which is not a perfect geodetic monument, and surrounded by the telescopes yielding GPS signal blockage and related effects. The other points usually stay around 0.1 to 0.2 mm. These nice results should not hide the fact that a theoretical control point on the GNSS tower (where WTZZ and WTZR are located with WTZR being an important point for ITRF computation) would, most likely, have revealed a higher residual due to extrapolation geometry.

The vertical transformation might consist of a mere offset describing the average geoid height in the area. Whilst this approach appears to be suitable for O'Higgins as well as TIGO, the spatial variation of the geoid at Wettzell is significant, and a horizontal

Fig. 4 Local ties for the three Wettzell VLBI telescopes from terrestrial surveying (official local ties solution for ITRF2014).

gradient even persists when newest geoid models are employed. Consequently, the vertical transformation parameters are the vertical offset plus a pair of horizontal gradients, amounting to a considerable value of approximately 30 ppm, i.e., 3 cm of change in geoid height over one km of horizontal distance. As can be seen in Figure 3, the vertical residuals are higher compared to the horizontal ones. This is the nature of GPS: GPS is less precise in height (extrapolation geometry) compared to horizontal coordinates (interpolation geometry). Nevertheless, the residuals usually stay below the desired limit of 1 mm for the majority of the points. WT25 features a discrepancy of -1.2 mm, but this point is not of concern for the VLBI and SLR reference points.

4 Results and Future Work

The results of the local tie vectors between the three Wettzell telescopes are illustrated in Figure 4. We have carried out short baseline VLBI group delay analysis for baseline Wz-Wn [Phogat et al., 2018] and can confirm an agreement between VLBI and terrestrial residuals in the sub-millimeter domain for the 3D distance, though a few millimeters can be seen in the height component. However, we suspect that the major source of uncertainty is currently within the VLBI systems.

Although the precision of the local survey network at Wettzell is sufficient at the moment, a number of small improvements are foreseen in the near future. One topic requiring attention is the computation of a local fine structure geoid and the derivation of deflections of the vertical in order to verify the nature of the significant changes in the geoidal separation over Wettzell. Furthermore, network configuration enhancements can reduce precision losses at the GNSS tower due to extrapolation, and experiments with direct datum parameter injection like scale and azimuth are envisaged.

References

[Maehler et al., 2018] S. Mähler, T. Klügel, M. Lösler, T. Schüler. Permanentes Referenzpunkt-Monitoring der TWIN-Radioteleskope am Geodätischen Observatorium Wettzell. Allgemeine Vermessungsnachrichten 127 (7).

[Phogat et al., 2018] A. Phogat, C. Plötz, T. Schüler, H. Hase, G. Kronschnabl, A. Neidhardt, J. Kodet, U. Schreiber, W. Alef, H. Rottmann, L. La Porta, S. Bernhart. Implementation and First Results of the Local Wettzell VLBI Correlator GOWL. In Proceedings of the IVS 2018 General Meeting, Svalbard, Norway, 3–6 June 2018.