GPS METROLOGY –
INFLUENCE OF ANTENNA CALIBRATIONS ON SHORT BASELINES

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INTRODUCTION

The Finnish Geodetic Institute (FGI) investigates crustal deformations in Olkiluoto, at a proposed disposal site for nuclear waste in Finland. The size of the research area is approximately 2x4 km^2 and consists of 10 concrete pillars on bedrock. Since 1995 the network has been measured semi-annually with GPS campaigns. The observation sessions, at least 24 hours, have been measured with dual frequency geodetic receivers and choke ring antennas and processed with Bernese software.

The scale of the GPS network has varied from one campaign to another up to ±0.5 ppm. In order to control the scale of the network, since 2002 one 511-m GPS vector has been simultaneously measured with electronic distance measurement (EDM) using a Kern ME5000 Mekometer. The Mekometer has been regularly calibrated at the Nummela Standard Baseline which is measured with the Väisälä white light interference comparator with total standard uncertainty of ±0.09 mm/km in the traceability chain to the definition of the metre. Standard uncertainty of the scale transfer to Olkiluoto baseline is approximately ±0.3 mm.

The length of the 511-m Olkiluoto baseline measured with GPS differ from the traceable EDM results an average of 0.64 mm (over 1 ppm) in 2002–2007 and the difference is of systematic nature: GPS gives longer distances. Since EDM results are traceable to the definition of metre, uncertainties well-defined and the difference is significant regarding to the uncertainty of EDM, this leads to an assumption that the GPS solution may be biased.

To study the problem the GPS antennas used in the project were sent for absolute antenna calibration and additional EDM+GPS measurements were carried out at another length standard, Kyviškės calibration baseline and test field in Lithuania in 2008. In Kyviškės we were able to do the comparison for several lengths 20...1320 m in ideal conditions (open sky, stable monumentation, etc).

KYVIŠKĖS KALIBRATION BASELINE & TEST FIELD

Table 1. *The components of the standard uncertainty (k=1) at Kyviškės calibration test field.*

Component	Uncertainty (k=1)
Nummela standard baseline	
Interference measurements of Nummela	±0.09 mm/km
Calibration of the transfer standard (ME5000)	
Projection measurements at Nummela	±0.07 mm
Determination of scale correction	±0.05 mm/km
Additive constant	±0.02 mm
At Kyviškės test field	
Temperature observations	±0.30 mm/km
Air pressure observations	±0.07 mm/km
Determination of relative humidity	±0.02 mm/km
Random errors from adjustment	±0.03-0.22 mm

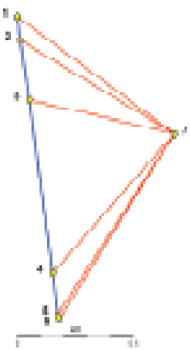

Figure 1. *Kyviškės calibration baseline (blue lines connecting pillars 1-6) and test field that includes also pillar 7.*

Table 2. *Mekometer results of the Kyviškės test field in mm.*

	Slope distance with extended uncertainties (k=2)
1 – 2	100 163.4 ±0.2
1 – 3	360 177.1 ±0.3
1 – 4	1 120 386.7 ±0.8
1 – 5	1 300 483.7 ±0.9
1 – 6	1 320 495.1 ±0.9
1 – 7	841 814.4 ±0.8
2 – 3	260 013.8 ±0.3
2 – 4	1 020 223.3 ±0.7
2 – 5	1 200 320.4 ±0.8
2 – 6	1 220 331.8 ±0.8
2 – 7	775 244.5 ±0.8
3 – 4	760 209.6 ±0.5
3 – 5	940 306.7 ±0.7
3 – 6	960 318.1 ±0.7
3 – 7	644 380.7 ±0.7
4 – 5	180 098.0 ±0.5
4 – 6	200 110.0 ±0.5
4 – 7	804 747.3 ±0.8
5 – 6	20 012.6 ±0.2
5 – 7	933 821.8 ±0.9
6 – 7	949 189.6 ±0.9

Kyviškės calibration baseline (Figure 1) was established by the Institute of Geodesy of Vilnius Gediminas Technical University (VGTU) in 1996. It originally consisted of a baseline of six observation pillars for surveying instruments. A seventh pillar extends the baseline to a triangle-shaped test field with distances between 20 and 1320 metres. The environment is treeless grassland at an airfield area. Differences in altitude are smaller than six metres.

The baseline has been calibrated three times in co-operation between the VGTU and FGI. Scale transfer has been performed using high precision EDM instruments calibrated at the Nummela Standard baseline of the FGI. The primary transfer standard has been a Kern ME5000 Mekometer EDM instrument with a prism reflector. Accurate results and traceability to the definition of metre with well-defined uncertainty can be achieved through Väisälä interference measurements at Nummela Standard Baseline, quartz gauge system and metrological EDM measurements.

In order to study the scale of GPS baselines a new calibration of the Kyviškės calibration baseline was performed in 2008. One day of EDM observations was made before and after the GPS observations. Typically one day is sufficient for a measurement, in which all the 21 distances between the seven baseline pillars are measured from both ends.

The components of standard uncertainty (k=1) of the scale transfer are summarized in Table 1. The extended uncertainties (k=2) of the distances between baseline pillars at Kyviškės are shown in Table 2.

Congruent results from the four calibrations show that the baseline is stable. The results shown in Table 2 are used as true values in comparison with GPS results.

GPS OBSERVATIONS AT KYVIŠKĖS TEST FIELD

We used Ashtech Z-XII3 GPS receivers and ASH7000936C_M Choke ring antennas. Two 24-hour sessions of GPS data were processed with Bernese 5.0 software using different processing methods (L1, L1&L2, QIF, and Narrow-Lane). All cases were processed with three different cut off angles (3, 10 and 20 degrees), two different ionosphere models and three antenna tables. Ionosphere models were a local model (produced using dual-frequency data of pillar 4) and global (CODE) ionosphere model. Relative and absolute antenna calibration tables of the IGS were used, as well as individual calibration tables from Geo++.

Figures 3a-b show the results for relative type and absolute individual antenna calibration solutions with global ionosphere model and 3 degree cut off angle. Results are differences between the mean of two 24-hour GPS sessions and the Mekometer true values (Table 2). Uncertainty bars are standard uncertainties (k=1) of the Mekometer scale transfer. Relative antenna calibrations (Fig. 3a) give similar results as absolute calibration which is not shown here. One individually calibrated antenna caused significant deviations and is therefore left out from the results. Figure 3b (note the difference in scale), show the results without that antenna. Results with different cut off angles and local ionosphere model are almost identical to the ones shown here.

Figures 4a-b show the L1 and QIF solutions of figure 3b, where individual antenna calibrations were used. The uncertainties represent the repeatability of the two 24-hour GPS solutions. L1&L2 and Narrow lane solutions are not shown, but the results are similar to L1 and QIF results respectively. The uncertainties of L1 solutions are clearly distance dependent even if the ionosphere model was used. The uncertainties of QIF are smaller and not distance dependent. However, the QIF results deviate more from true values than L1 solution. This may indicate small uncertainties in antenna calibration that escalate when linear combinations of L1 and L2 are created.

The difference between daily GPS results show that L1 and L1&L2 solutions have a distance dependence of approx. 0.5 ppm (Fig. 5) with both global and local ionosphere model when all the baselines are considered. QIF and Narrow-lane techniques do not have statistically significant distance dependence.

In Figure 6 the metrological accuracy of the GPS solutions can be seen. The Mekometer results of table 2 were used as true values in comparison. When type calibrated antennas were used L1&L2 gives the best results with rms of 0.4-0.5 mm. The rms of L1 is 0.7 mm and of QIF and Narrow-lane between 1.9 and 2.0 mm. When individually calibrated antennas were used the rms values decreased to 0.3 mm for L1 and L1&L2 solution and to 0.5-0.6 mm for QIF and Narrow lane solution. The ionosphere model or cut off angle did not have significant influence on the results.

Figure 7 shows the precision of GPS solutions of the subsequent processing days. QIF and Narrow-lane solutions have the best repeatability with rms of 0.2 mm. Rms of L1 solutions is 0.4-0.5 mm and of L1&L2 0.5-0.6 mm. By using the global ionosphere model the rms of L1 and L1&L2 solutions is 0.1 mm smaller.

Figure 2. *GPS measurements at pillars 5 and 6. The environment is excellent for satellite positioning, offering unobstructed visibility at most pillars.*

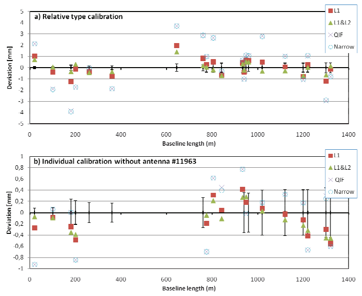

Figure 3a-b. *The deviation of GPS results from the Mekometer results with a) relative, and b) individual antenna calibrations. One antenna was rejected. Note that the scale in b is different. The results were obtained using global ionosphere model and 3 degree cut off angle. The uncertainty bars are standard uncertainties (k=1) of Mekometer solutions.*

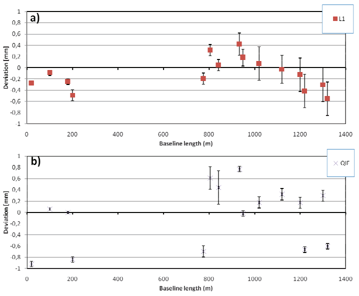

Figure 4a-b. L1 and QIF solutions of Figure 3b, with the uncertainties derived from the repeatability of two GPS solutions. The figures show clearly a distance dependent increase of uncertainty in L1 solution. The uncertainty of QIF solution is not distance dependent, but the results deviate more from Mekometer results than L1 solution.

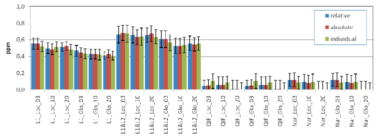

Figure 5. *The distance dependence of the repeated GPS solutions for different processing strategies is shown as ppm.*

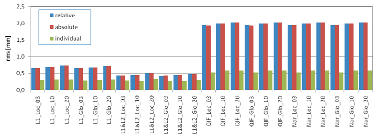

Figure 6. *Accuracy of GPS. The rms values of the different processing strategies. The Mekometer results (Table 2) have been used as true values.*

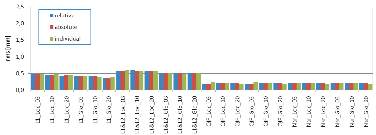

Figure 7. *Repeatability of GPS. The rms values of differences between subsequent GPS solutions indicating the precision of GPS solutions.*

CONCLUSIONS

When the best possible metrological accuracy is required the use of individually calibrated GPS antennas is strongly recommended. Especially if linear combinations of L1 and L2 are used the daily GPS results with type calibrated antennas may differ over 4 mm from the true values. With individually calibrated antennas all daily solutions were within ±1.1 mm from the true values.

In the Kyviškės test field, with baseline lengths between 20 and 1320 metres, metrologically the best GPS accuracy was obtained with L1 solution using an ionosphere model and individually calibrated GPS antennas. If only type calibrations are available the best accuracy is obtained with L1&L2 solution and ionosphere model. The cut off angle did not have significant effect on the results.

QIF and Narrow-lane results deviate more from true values than pure L1 or L1&L2 solution. Possibly small uncertainties in antenna calibration influence the phase centre of a linear combination of L1 and L2 and the problem is clearly visible especially with very short baselines. However, the precision of QIF and Narrow-Lane is very high and it seems that already on distances of 1 km they fall within the extended uncertainties of Mekometer results, when at the same time the uncertainties of L1 and L2 become larger due to the ppm-effect.

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