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ANALYSIS OF HEIGHT DETERMINATION USING THE ASG-EUPOS NAWGEO SERVICE

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Abstract

GNSS observations carried out in a network of permanent stations are a complex systems which offer post-processing as well as corrections sent in real-time and the creation of so-called virtual observations. Currently, there are several Network-based Real Time Kinematic (NRTK) services around the world. In Poland, such a system has been in operation since June 2008, known as the Polish Active Geodetic Network (ASG-EUPOS). Three real-time correction services and two post-processing services are currently used by users.

NRTK technique uses GNSS observations gathered from a network of Continuously Operating Reference Stations (CORS) in order to generate more reliable error models that can mitigate the distance dependent errors within the area covered by the CORS. This method has been developed and tested considerably by many scientists during recent years. These studies have demonstrated the high centimeter accuracy that can be achieved using NRTK technique.

This study analyzed the accuracy of the height determination with NRTK measurements using ASG-EUPOS. The results obtained show that RTK ASG-EUPOS height measurements are characterized by high precision, but the normal height measurements compared to the height measurements obtained from precise leveling, probably due to some systematic errors (the mean of many measurements differs significantly from the actual value) are not so accurate. In this case, fitting NRTK results to a precise leveling network may significantly improve the results. In presented test this resulted in reducing NRTK normal height determination errors by 70 percent.

Introduction

The EUropean Position Determination System (EUPOS) project was started in 2002 in Berlin. It's purpose was to create a homogenous ground-based GNSS support system in Central and Eastern Europe. In Poland,

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ASG-EUPOS was launched in June 2008 (Bosy et al. 2007, 2008). The ASG-EUPOS network plays the role of a geodetic reference system in Poland. The connection of the ASG-EUPOS stations with the EUREF Permanent Network (EPN) stations in Poland allows the implementation of the European Terrestrial Reference System '89 (ETRS89) system in Poland. For this purpose, the system activity has to be constantly monitored and controlled.

The ASG-EUPOS is a multi-functional satellite positioning system. Its structure is divided into three basic segments: – reference stations, management and user segments. These segments working together support precise real-time positioning and post-processing applications. The reference stations network, presented on figure 1, currently (October 2012) consists of 99 Polish (81 with GPS module and 18 with GPS/GLONASS module) and 22 foreign stations.

Fig. 1. ASG-EUPOS point distribution
Source: ASG-Eupos, www.asgeupos.pl (access: 12.08.2012)

The mean distance between reference stations is below 70 km. The stations are regularly distributed, creating a homogenous network which covers all of Poland. The ASG-EUPOS services enable the transfer of reference frames into real applications in the field. Three real-time correction services and two post-processing services are currently used by users. Table 1 shows the real-time services available in the ASG-EUPOS system.

Table 1

Real-time ASG-EUPOS services

Service group	Data access	Service name	Survey method	Estimated precision	Minimum hardware requirements
Real-time services	GSM/ /Internet	NAWGEO	kinematic RTK	0.03 m (horiz) 0.05 m (vert.)	L1/L2 GNSS RTK receiver, communication module
		KODGIS	kinematic DGPS	0.2 – 0.5 m	L1 DGNSS receiver, communication module
		NAWGIS		1.0 – 3.0 m	

NAWGEO is a fundamental ASG-EUPOS service which provides corrections for real-time RTK positioning. It provides high accuracy (position precision about 0.03 m) for the measurement of kinematic and static objects. Other services are targeted at users who do not require such high accuracy. Recommendations for surveying measurements using ASG-EUPOS are available, among others, in Technical guidelines G-1.12, 2008 and Technical recommendations, 2011.

In the NAWGEO service the user has the possibility to choose among various types of RTK corrections: traditional corrections from a single base station and network corrections like Master and Auxiliary Concept (MAC) and Virtual Reference Station (VRS).

Single base station RTK positioning is a technique that allows centimeter level accuracy position determination in real time through differencing similar errors and biases that are caused by atmospheric effects and GNSS satellite orbit errors (so called: distance dependent errors) and clock bias in carrier phase observations at both ends of a baseline. One significant drawback of this single base RTK approach is that the maximum distance between the reference and the rover receiver must not exceed 10 to 20 km in order to be able to rapidly and reliably resolve the carrier phase ambiguities. This limitation is caused by the above-mentioned distance-dependent biases (WANNINGER 2004, WEGNER, WANNINGER 2005).

NRTK positioning overcomes such drawbacks and can increases accuracy by accurately modeling the distance dependent errors at the rover position using measurements of an array of reference stations. In order to increase the distance from the reference station for which it is possible to achieve a centimeter level solution, various methods were developed based on the use of networks of GNSS reference stations.

The essence of the VRS concept is to use real observations of several reference stations to create observations for a virtual station situated at the approximate position of the rover. This approach allows modeling of distance-dependent systematic errors a more precise than in standard RTK positioning.

The VRS technique is currently the most popular NRTK method due to the fact that it does not require modifications of the user software. The implementation of the VRS technique requires at least three reference stations which are connected to a network server, and the rover must be capable of two-way communication. The rover sends its approximate position via a wireless communication link in the NMEA format to the network processing centre where computations are carried out for each user. The processing center generates, in real time, a virtual reference station data at the initial rover position. This is done through geometrical shift of the pseudo-range and the carrier phase data from the closest reference station to the virtual location and then through adding the interpolated errors from the network error models. This generated VRS data is then sent to the user and, finally, just as if the VRS data had come from a physical reference station, the rover receiver uses standard single-baseline algorithms to determine the coordinates of the user's receiver in near-real-time kinematic or post-processed modes (EL-MOWAFY 2012, ERHU at al. 2006, WANNINGER 1997, 1999, 2002, 2003, VOLLATH et al. 2000).

The Master-Auxiliary Concept was introduced by EULER et al. (2001) and has been shown to deliver high-quality results (e.g. EULER et al. 2002, 2003). It is designed to transmit all relevant correction data from a CORS network to the rover in a highly compact form. In the MAC approach, the rover sends its approximate position to the processing centre. The centre determines for this user the appropriate master station – usually the closest reference station and identifies the auxiliary reference stations. These stations are chosen within a catch circle of a predefined radius (e.g. 70 km) around the rover, and with a pre-set number (e.g. from 3 to 7). The rover receives different types of information comprising:

– the coordinates and raw measurements of the Master station,
– measurement corrections at the Master station,
– correction differences between the Master and Auxiliary stations.

After receiving the MAC information, the rover software is free to decide the method of interpolating the corrections at its location (BROWN et al. 2006, EL-MOWAFY 2012).

GNSS leveling

Satellite leveling is the procedure used to determination orthometric (normal) heights, on the basis of ellipsoidal heights derived from GNSS techniques and additional information which provide geoid (quasi-geoid) undulation determination. In the absolute approach, normal height can be derived from the equation (e.g. HOFMANN-WELLENHOF at al. 2008):

$$H = h - N \tag{1}$$

where:
H – normal height,
h – ellipsoidal height,
N – geoid undulation.

GNSS measurements performed in the ASG-EUPOS system and so-called "national" geoid models are connected with ETRS89 system thus the normal heights of points can be calculated from the above relation. Due to some systematic errors that may occur in the geoid model or in GNSS measurements, the Technical Instruction G-2 recommends an additional connection to the national vertical network. In such an approach, we talk about relative satellite leveling in which we compute normal height differences: $\Delta H = \Delta h - \Delta N$, where: $\Delta H = H_2 - H_1$, $\Delta h = h_2 - h_1$, $\Delta N = N_2 - N_1$. Knowing, for example, H_1 we can compute H_2 on the basis of measured Δh and ΔN. Such an approach can eliminates, especially on short distances, mentioned above systematic errors. Unfortunately, due to the fact that ASG-EUPOS stations mainly mounted on the roofs of buildings do not yet have accurate normal heights and because of the long distances between the stations, such an approach requires additional leveling measurements.

It is well-known that the measurements performed in real time are usually characterized by a lower accuracy than static measurements and the accuracy of height determination is less accurate than the horizontal position. Currently, the most accurate measurement technique in real-time is called RTK. One of the main limiting factors of the accuracy of RTK is the distance from the reference station (the impact of distance-dependent errors such as satellite orbits or propagation noise) and a solution for this problem was found in surface corrections. This involves the widely-accepted technique of using such corrections known as the NRTK system.

In the paper we analyze the accuracy of the height determination with NRTK measurements using ASG-EUPOS. Similar studies, using ASG-EUPOS services, aimed mainly at testing the accuracy of normal height determination are presented in, e.g. HADAŚ, BOSY J., 2009. In other CORS analogous research have been made in e.g. APONTE et al. 2009, EDWARDS et al. 2010, MENG et al. 2007.

Several points were selected for testing. Selected points were characterized by different distance to the nearest CORS station and the level of obstacles. On points normal heights were detrmined by precise leveling and several NRTK measurement sessions using the NAWGEO service were performed. In that measurements three types of correction were used which were available in NAWGEO. Such carried test measurements allowed in different ways examine the accuracy of height determination using NAVGEO service. It has been studied e.g. impact of the distance to the nearest CORS stations, level of obstacles, type of used corrections, method of fitting to the precise leveling network.

Test measurement

For analysis two test areas, called respectively KORTOWO and TRAVERSE, were selected (Fig. 2).

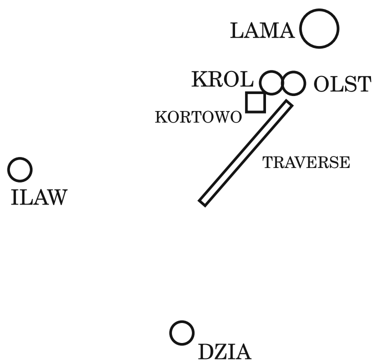

Fig. 2. Research areas and nearest ASG-EUPOS stations

The investigation in KORTOWO obiect were mainly targeted at studing the impact of level of obstacles to height determination using NAVGEO service. Two points (0001 and 0002) were marked under conditions of limited availability of satellites (nearby buildings and trees) and the remaining two points were characterized by good measurement conditions. The obstacles diagrams for KORTOWO obiect points are presented in figure 3.

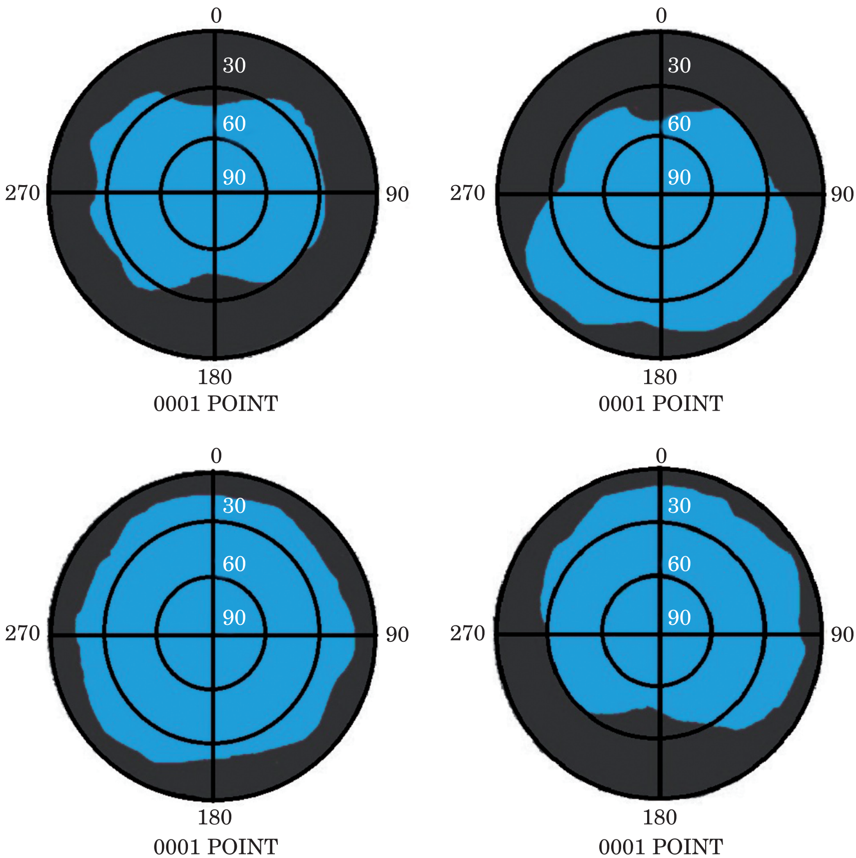

Fig. 3. The obstacles diagrams for KORTOWO points

In TRAVERSE area the main goal of the work is to show the impact of distance to the nearest ASG-EUPOS stations on NRTK heights determination. Six points were marked at different distances from OLST and KROL stations (Fig. 4).

All investigations was intended to evaluate the quality of NAWGEO service from the end users' pointof view: the corrections received using the tests were the same as any other subscribers would have received.

For selected test points, normal heights were determined by precise leveling (Tab. 2) on the basis of 2nd order benchmarks of the national leveling network. Table 2 also includes the separations between a quasi-geoid and an ellipsoid on the measured points calculated with the "QGEOID-PG" model used in the ASG-EUPOS system.

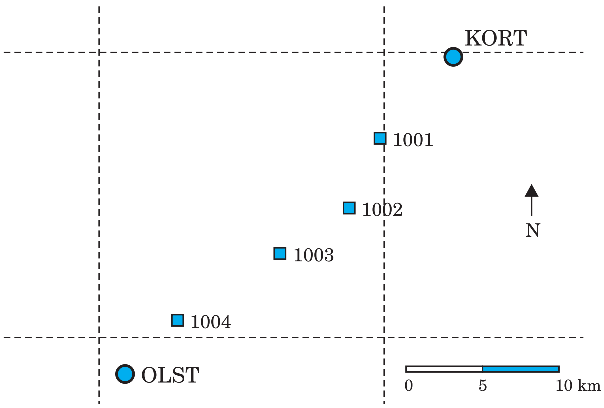

Fig. 4. TRAVERSE test area

Table 2

Normal height and quasi-geoid to ellipsoid separation on selected points

Point number	0001	0002	0003	0004	KORT	OLST
Normal height [m]	117.234	115.318	104.995	105.974	122.446	172.564
Geoid undulation [m]	29.805	29.803	29.818	29.819	29.794	30.206

A Leica Viva receiver integrated with a pole carbon fiber (with a 20^{cc} circular level) was used for measurements collection. Measurement parameters: antenna height 2.00 m; elevation angle 10^{o}; number of RTK measurements which averaged position 5 (KORTOWO) and 15 (TRAVERSE). Position averaging mode: weighted average – an average in which position to be averaged is assigned a weight calculated using e.g. distances to CORS stations, RMS values. Sessions were made between 9:00 and 15:00 local time one by one on individual points in accordance with their numbers. The Ionosphere Index I95 RTK–VRS in each session was between normal and medium activity. Index 95 values reflect the intensity of ionospheric activity. The I95 values are computed from the ionospheric corrections for all satellites at all network station for the respective hour – the worst 5% of data are rejected. The values of the I95 have the following meaning: 2 – normal activity, 4 – medium activity, 8 – high activity.

The PDOP coefficient never exceeded 2.5. In the measurements, three types of correction were used which were available in NAWGEO: Single Stations (**SS**), Virtual Reference Stations (**VRS**), Master-Auxiliary Concept (**MAC**). The measurement session program is presented in table 3. The transition between each type of corrections take place every 10 individual measurements.

Table 3

Measurement session program

Correction type	Number of NRTK measurements for each point in session				
	KORTOWO				TRAVERSE
	24 March	25 March	24 May	28 May	18 October
SS	100	100	–	–	50
VRS	100	100	100	100	50
MAC	–	–	100	100	50

All measurements were done in a field by surveyor – only fixed ambiguity solutions were recorded.

Analysis of results

Normal heights obtained from geometric precise leveling and heights obtained from RTK-NAWGEO leveling in KORTOWO area are presented in Figures 5–8. Black solid lines indicate heights obtained from precise leveling, green solid lines represent heights obtained from NRTK leveling using VRS corrections, blue – using SS corrections and red – using MAC corrections. In all approaches "real" errors were calculated as difference between the normal heights obtained from precise leveling and heights obtained from successive epochs of NRTK. Additionally for individual sessions the following information are presented in table 4: maximum height change, standard deviation, average normal height difference between geometric leveling and NRTK leveling.

From Figures 5–8 it can be seen that there are clear systematic differences between solutions using various types of correction. The biggest occurred in 24 May sessions, the smallest – in 28 May sessions. Generally it can be assumed that, except 28 May sessions where very small height differences were obtained, depending on the used type of correction heights differ up to several centimeters.

It is also a noticeable that heights obtained from NRTK measurements are significantly smaller than heights derived from geometric leveling.

For point 1 in MAC 24.05 session, at the end of the session, an unexpected jump in height in the 17 cm size occurred. The reason for this jump is unclear. This can be due to undetected cycle slip or wrong ambiguity solutions. Points measured under conditions of limited availability of satellites can usually have problems both with the visibility of satellites and the receiving of the correction message. Further investigation needs to be carried out in order to check reasons for this type of jumps.

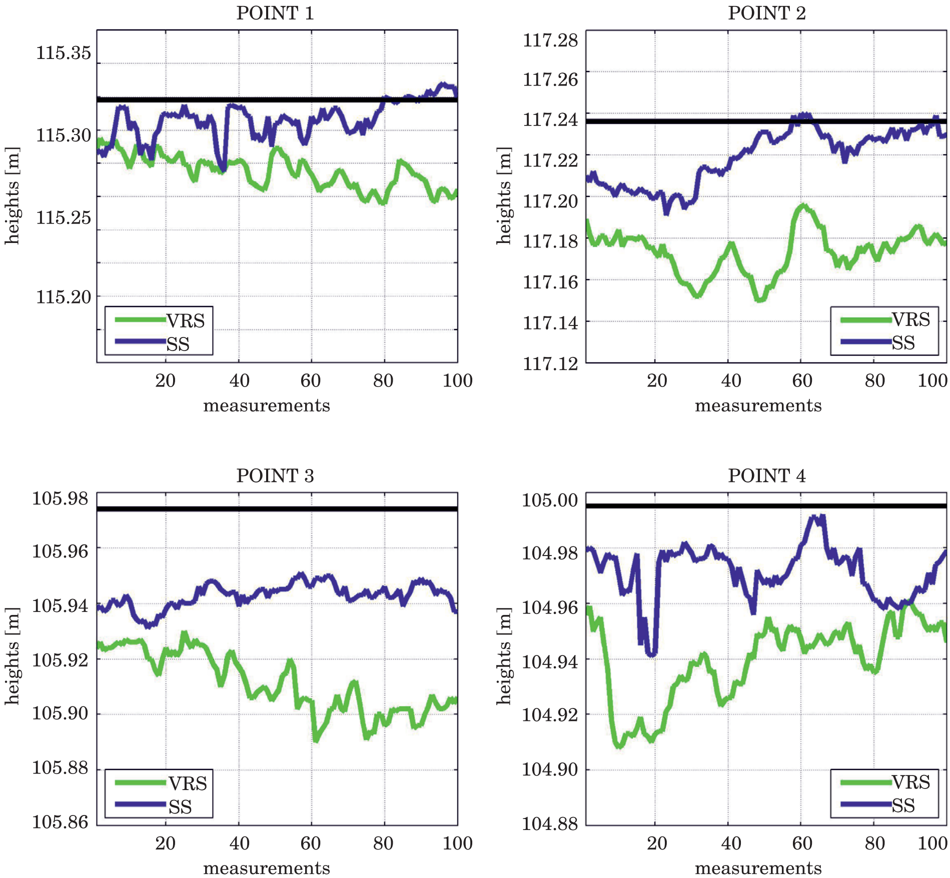

Fig. 5. Normal heights obtained from precise leveling and heights obtained from NRTK measurements in 24 March sessions

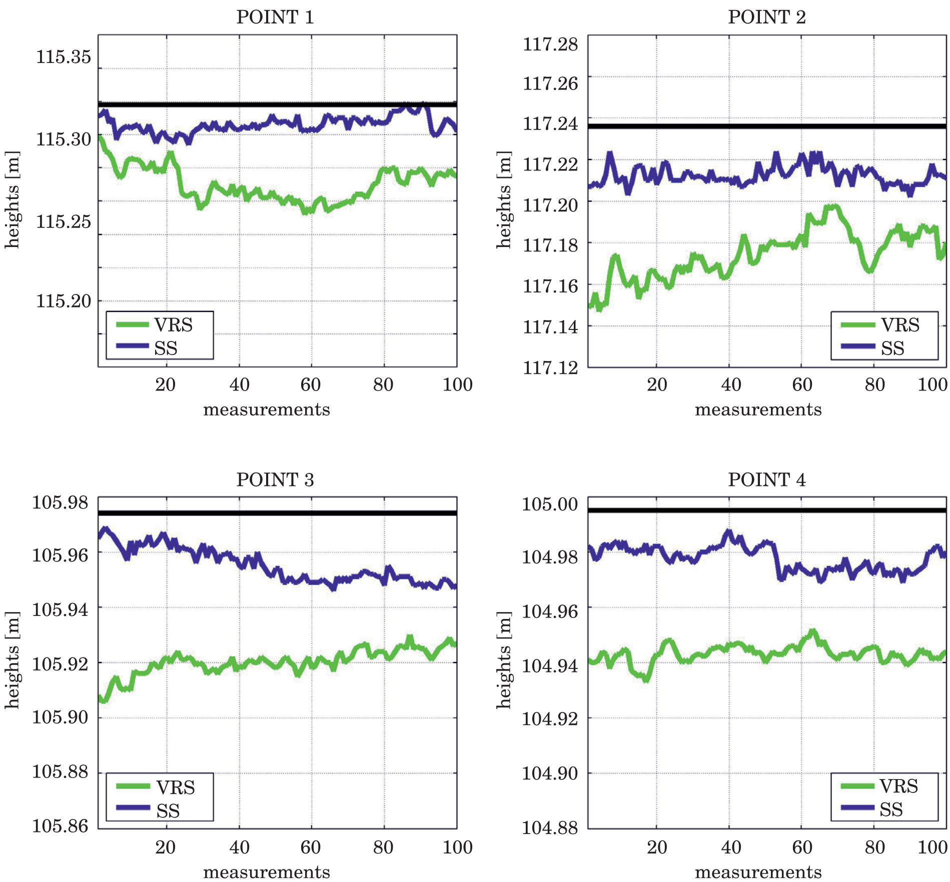

Fig. 6. Normal heights obtained from precise leveling and heights obtained from NRTK measurements in 25 March sessions

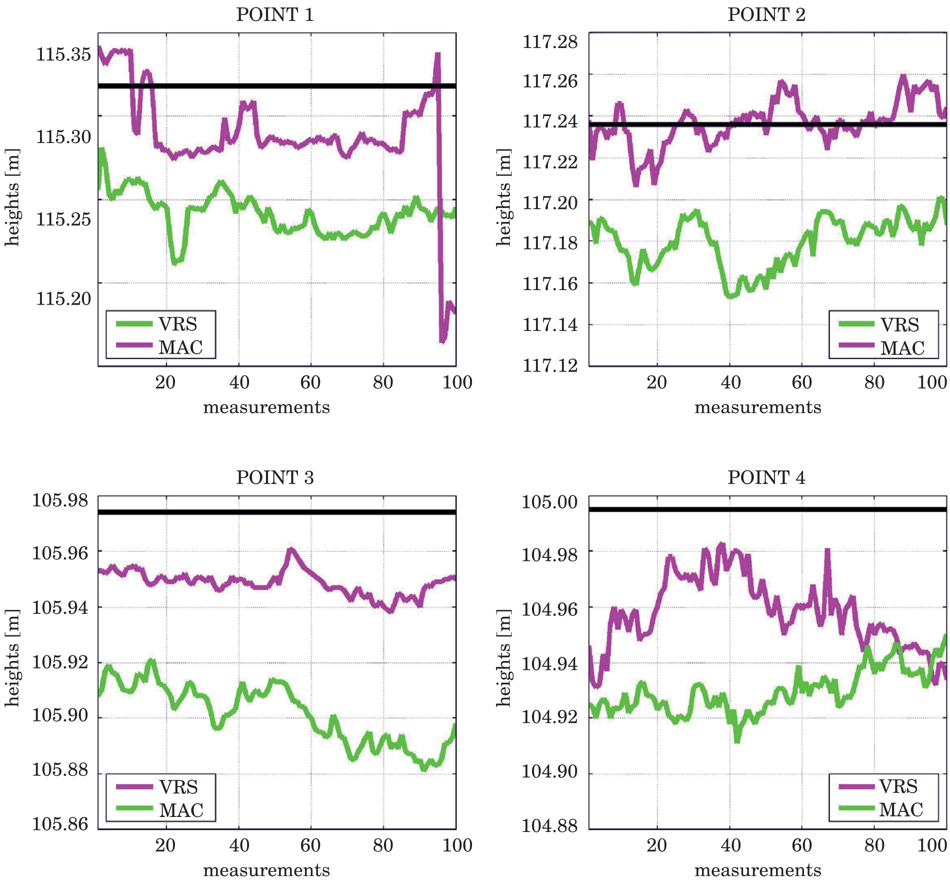

Fig. 7. Normal heights obtained from precise leveling and heights obtained from NRTK measurements in 24 May sessions

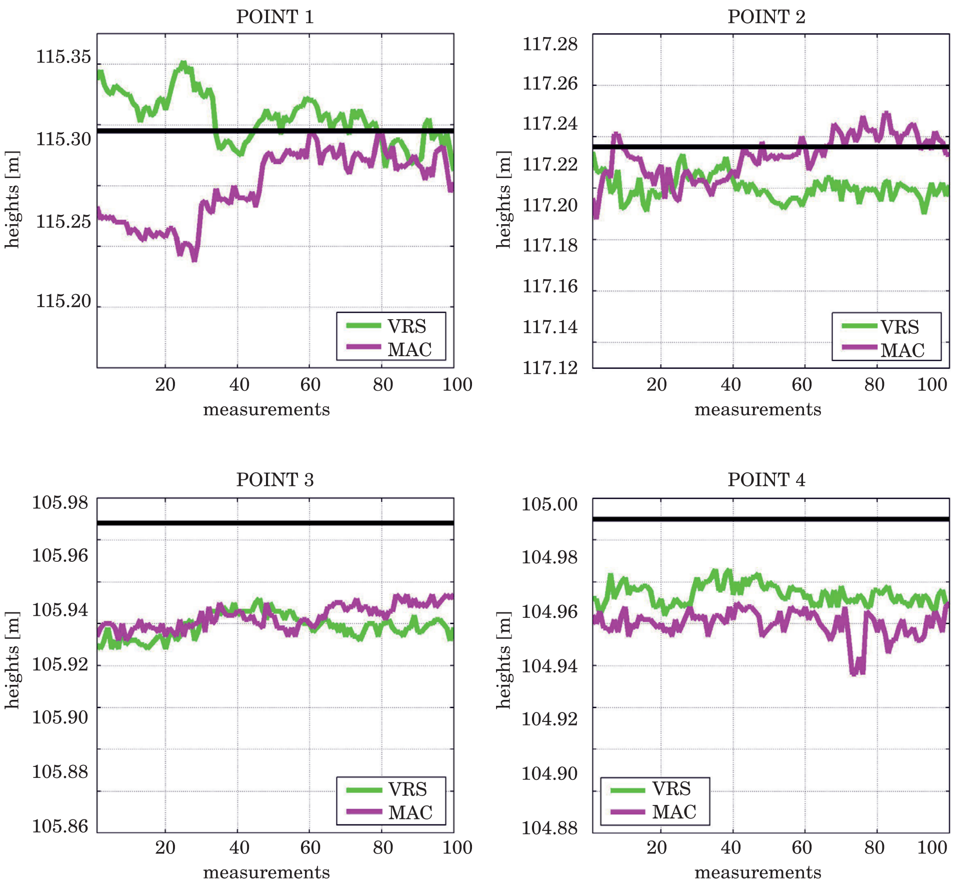

Fig. 8. Normal heights obtained from precise leveling and heights obtained from NRTK measurements in 28 May sessions

Except this case it is difficult to observe a clear effect of the level of obstacles to height determination using NAVGEO service. Results obtained for all the points have similar height variation characteristics.

It is well-known that accuracy, in our test, can be defined as how far the heights calculated during testing are from the true values for which heights from geometric leveling was adopted. Precision is a degree of repeatability that repeated measurements display, and is therefore used as a means to describe the quality of the data with respect to random errors. It was represented by the standard deviation of the solutions.

The accuracy and precision obtaining during KORTOWO test are summarised in Table 4 and Figure 9. The total accuracy of a respective point was determined as the average of the accuracy values in each session.

Table 4

Sessions statistical characteristics in KORTOWO test

Specification	Session identification							
	24 March		25 March		24 May		28 May	
	VRS	SS	VRS	SS	VRS	MAC	VRS	MAC
POINT 1								
Max. height change	0.039	0.053	0.047	0.025	0.070	0.178	0.036	0.042
Standard deviation	0.010	0.011	0.010	0.005	0.012	0.032	0.008	0.011
Average height diff.	0.043	0.012	0.048	0.012	0.076	0.030	0.004	0.018
POINT 2								
Max. height change	0.046	0.049	0.051	0.022	0.048	0.054	0.041	0.024
Standard deviation	0.011	0.013	0.012	0.005	0.012	0.011	0.005	0.009
Average height diff.	0.063	0.017	0.062	0.024	0.057	0.001	0.016	0.004
POINT 3								
Max. height change	0.040	0.020	0.024	0.023	0.040	0.023	0.012	0.011
Standard deviation	0.011	0.004	0.005	0.006	0.011	0.004	0.003	0.003
Average height diff.	0.063	0.031	0.054	0.019	0.073	0.025	0.025	0.022
POINT 4								
Max. height change	0.053	0.051	0.019	0.019	0.052	0.039	0.011	0.017
Standard deviation	0.014	0.010	0.003	0.004	0.013	0.008	0.002	0.003
Average height diff.	0.056	0.024	0.052	0.017	0.037	0.066	0.018	0.025

Table 4 presents statistical analysis for the heights obtained using NRTK measurements. Analyzing results presented in Table 4 it is visible that the standard deviation, being a measure of the precision of the data, is generally in the range from 0.002 to 0.014 m (except 0001 point – MAC 24.05 session). This is due to maximum height changes from 0.011 to 0.070 m (0.178 m for 0001 point in MAC 24.05 session). Generally it can be concluded that precision of the KORTOWO test was at the centimeter level.

Average height difference, calculated as differences between geometric leveling and NRTK leveling heights, varies from 0.001 m to 0.076 m. It is noticeable that, the differences obtained in the same sessions, in most cases, are similar. This can be due to some systematic errors.

Results presented in Table 4 slightly better visualized the effect of the level of obstacles on height determination using NAVGEO service. In session VRS 25 March, MAC 24 May, VRS 28 May and MAC 28 May it visible that points marked under conditions of limited availability of satellites have worse statistical characteristics (max. height change, standard deviation) than points characterized by good measurement conditions. For the remaining four sessions results obtained for all the points have similar characteristic.

Percentage summary of difference between geometric leveling and NRTK leveling heights are presented in Figure 9.

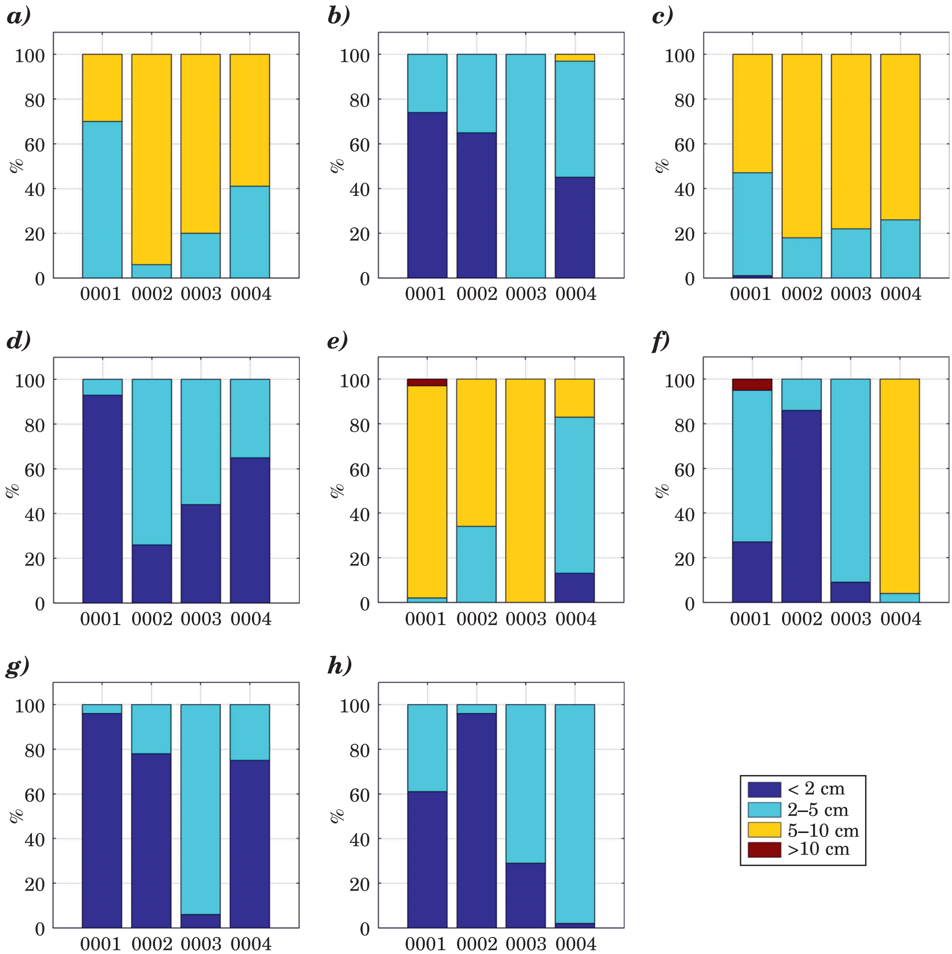

Fig. 9. Accuracy of solutions from each session for the height coordinate component: *a* – VRS 24.III, *b* – SS 24.III, *c* – VRS 25.III, *d* – SS 25.III, *e* – VRS 24.V, *f* – MAC 24.V, *g* – VRS 28.V, *h* – MAC 28.V

The accuracy obtained for the KORTOWO test varies significantly depending on the meseuring session. Generally the accuracy was better than 2 cm for an average of 31% and better than 5 cm of 71 % of the NRTK measurements.

ASG-EUPOS system uses ‚QGEOID-PG̀ model (Technical Instruction G-2, 2001; Technical Guidelines G1-10, 2001, PAŻUS et al. 2002). Although this model is the result of fitting the gravimetric quasigeoid model into the satellite-levelling quasigeoid model based on points belong to e.g. the EUVN network, the EUREF-POL network or the POLREF network, almost in all sessions the systematic difference between geometric leveling and NRTK leveling heights were observed. As mentioned earlier satelite leveling can be

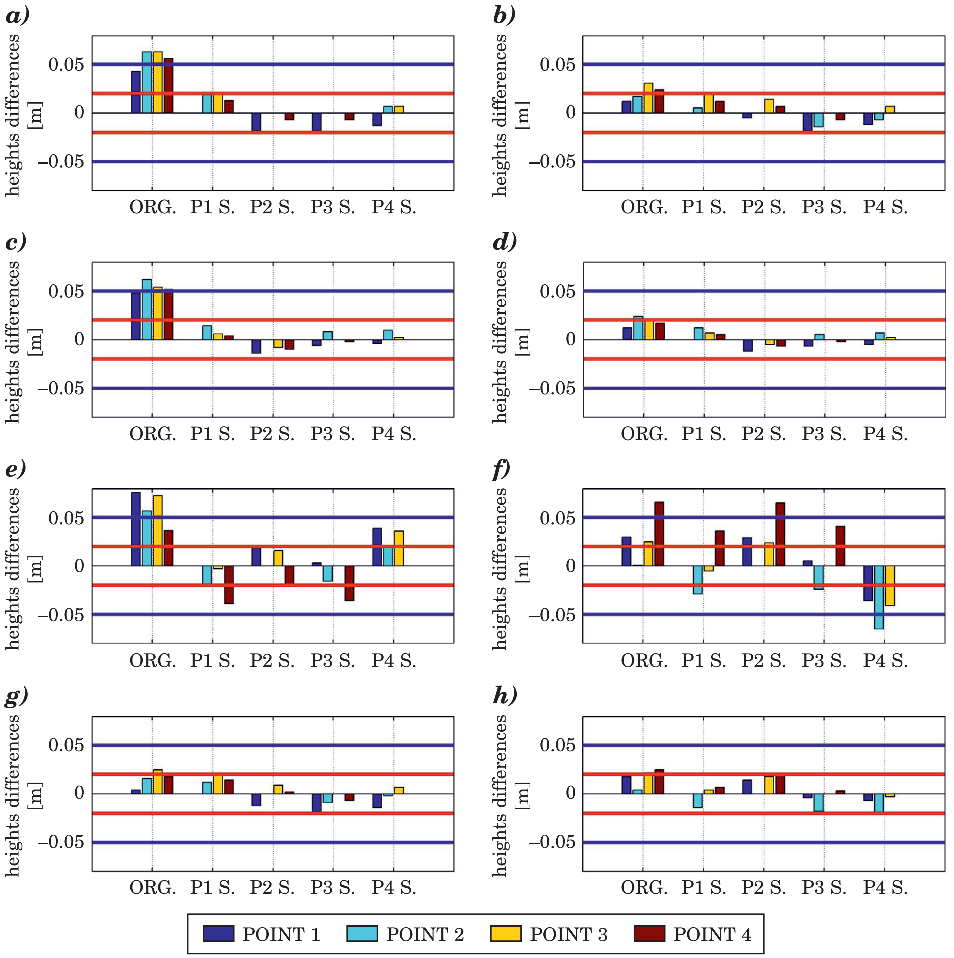

Fig. 10. Accuracy of NRTK leveling in relative approach: *a* – VRS 24.III, *b* – SS 24.III, *c* – VRS 25.III, *d* – SS 25.III, *e* – VRS 24.V, *f* – MAC 24.V, *g* – VRS 28.V, *h* MAC 28.V

done in the absolute approach, most often used in the NRTK measurements, or in relative, which due to some systematic errors that may occur in the geoid model or in GNSS measurements, is recommended by the Technical Instruction G-2. This was the reason to some additional analysis. Fitting the NRTK results to a precise leveling network was done by calculating the shift between precise leveling network surface and the NRTK height surface. The shift was calculated as the difference between the normal height from geometric leveling and height from NRTK measurements on a reference station, where each test point was successively adopted as the reference stations. Calculations were done for all measuring epochs. The shift was then used to calculate the normal heights of the measured points – by removing it as a systematic error. Such simple fitting was done because of the small measurements area and a small number of test points. To verify the accuracy improvement the normal heights calculated in such a way were compared with the heights received from precise leveling, which were considered true. Figure 10 presents the difference between geometric leveling heights and the average NRTK fitted heights: *ORG.* – without fitting; *P1 S*, *P2 S*, *P3 S*, *P4 S* – fitted on points 0001, 0002, 0003 and 0004, respectively. Additionally, red solid lines indicate ±2 cm and blue solid lines ±5 cm differences.

From figure 10 it can be seen that fitting, as described previeously, NRTK heights to a precise leveling network, improve the heights accuracy. In the analyzed case, it is especially true for a three sessions where the worst results were obtained in *ORG.* solutions (VRS 24.III, VRS 25.III, VRS 24.V). After fitting, the height differences generally were reduced from above ±5 cm to ±2 cm. Such approach is possible only if we have bench marks in the area of our measurements. In the case where there is no possibility to connect NRTK results to leveling network a solution could be measurement using all available types of corrections. The analysis of obtained differences in the results could be helpful in identifying the best solution. In authors opinion issue of the impact of using different types of corrections in NRTK heighting is worth futher testing and analysing.

Normal heights obtained from RTK-NAWGEO leveling in TRAVERSE area are presented in figure 11. As previously, green solid lines represent heights obtained from NRTK leveling using VRS corrections, blue – using SS corrections and red – using MAC corrections. Black solid lines indicate heights obtained from precise leveling.

In analyzing the results presented in Figure 11 there are also seen some systematic differences between solutions using various types of correction. Additionally a clear trend is noticeable. Measurements done near the reference station are characterized by a higher repeatability of results than measurements made at points located more than 15 km from it. What's interesting – regardless of the type of used correction. Accuracy of NRTK heighting, which can be analyzed for the points KORT and OLST, was respectivelly ±2.6 and ±1.6 cm for VRS, ±3.0 and ±4.4 cm for SS, ±3.2 and ±4.3 cm for MAC corections.

Table 5 presents statistical analysis for the heights obtained in TRAVERSE test.

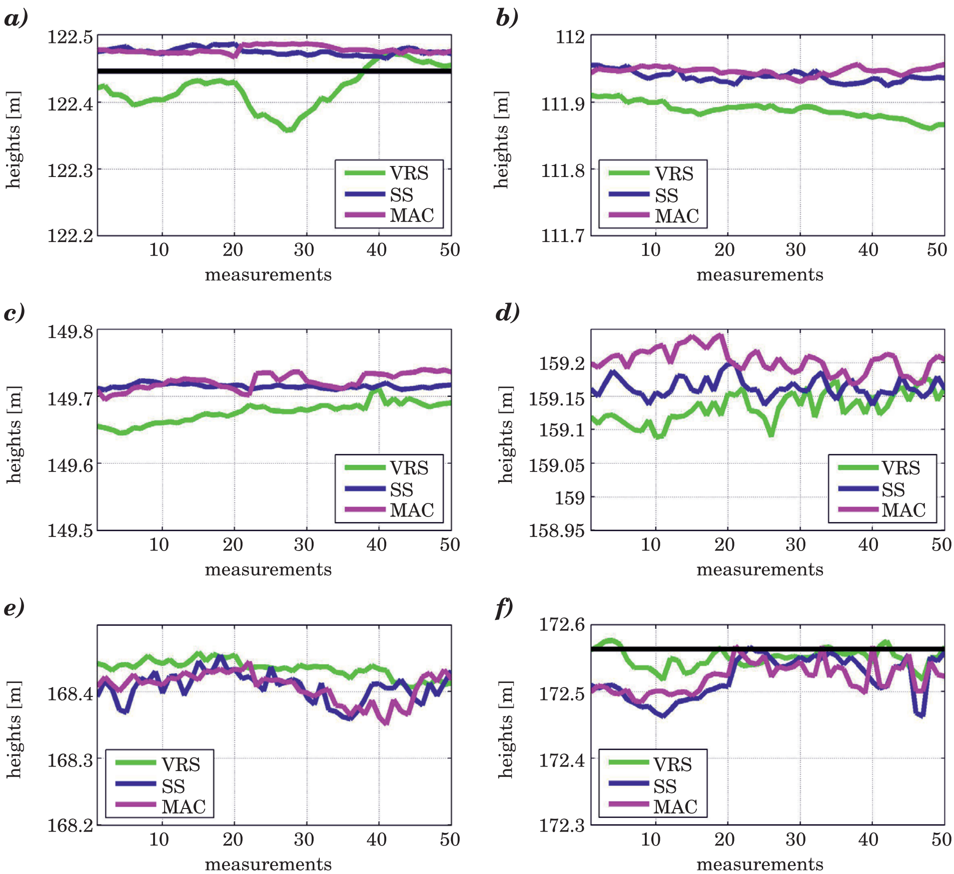

Fig. 11. Normal heights obtained from NRTK measurements in TRAVERSE area: *a* – KORT, *b* – 1001, *c* – 1002, *d* – 1003, *e* – 1004, *f* – OLST

Table 5

Statistical characteristics in TRAVERSE test

Correction typy	Point name / Characteristic type					
	KORT	1001	1002	1003	1004	OLST
Maximum height change [cm]						
VRS	11.4	5.0	6.6	8.7	4.2	5.9
SS	2.2	3.1	1.3	6.2	8.6	10.4
MAC	2.0	2.6	4.5	7.4	9.4	8.3
Standard deviation [cm]						
VRS	3.1	1.2	1.5	2.3	1.3	1.4
SS	0.5	0.8	0.3	1.4	2.2	3.2
MAC	0.5	0.6	0.9	1.9	2.2	2.2
Average normal height difference [cm]						
VRS – SS	–5.5	–5.0	–3.9	–3.5	2.8	3.0
VRS – MAC	–5.8	–5.8	–4.6	–6.9	2.7	2.9
SS – MAC	–0.3	–0.8	–0.7	–4.0	–0.1	–0.1

Results presented in Table 5 show that the distance from the nearest reference station affects the final results. It is especialy true for SS and MAC corections. The max. height changes increas from 2.2 to 10.4 cm for SS, and from 2.0 to 8.3 cm for MAC corections. For VRS corection max. height changes are at a stable, high level 7 cm on average.

In the case of standard deviation increase in value is from 0.5 to 3.2 cm for SS, and from 0.5 to 2.2 cm for MAC corections. For VRS it is generally stable and equals an average 1.8 cm.

Obtained height differences reveal also, that there are clear systematic differences between heights obtained using different types of corections. In TRAVERSE test it is especially true for VRS and other two types of corections. Heights obtained using SS and MAC corrections, unexpected because of the obvious differences in their creation, gave mostly similar results. Explanation of the reasons requires additional tests and analyzes.

Conclusions

In this paper the accuracy of the NRTK height measurements using ASG-EUPOS system was analyzed. For analysis ten points in two test areas were selected. On points some RTK measurement sessions, using three types of correction available in the NAWGEO service, were conducted. All investigations was intended to evaluate the quality of NAWGEO service from the end users' pointof view: the corrections received using the tests, accuracy analysis and additional characteristics were the same as any other subscribers would have received.

Generally, it can be conclude that RTK-NAWGEO height measurements have good precision. The standard deviations in KORTOWO test did not exceed 1.4 cm (with one exception) and the maximum height changes (with the same exception) were within 5 cm range. In one case (MAC 24.05 session), an unexpected jump in height in the 17 cm size occurred. The reason for this jump is unclear. This probably was done by undetected cycle slip or wrong ambiguity solutions. Further investigation is needed to check reasons for this type of jumps. Except this case an effect of the level of obstacles to height determination using NAVGEO service were not observed. Results obtained for all the points have similar height variation characteristics. The standard deviation in TRAVERSE test in the case of two types of corrections clearly increases with the distance to the nearest CORS station, for VRS correction it is on almost stable and equols 1.8 cm on average.

Because of the relatively low and similar value of Ionosphere Index I95 in all sessions analysis of its impact on the presented results was unjustified. The same applies to the PDOP ratio.

It was noted whereas that, there were some systematic differences between heights obtained using different types of corrections. Generally it can be assumed that, depending on the used type of correction heights can differ up to several centimeters. In authors opinion that impact of using different types of corrections in NRTK heighting requires futher testing and analysing. Performed studies are insufficient to forming the final conclusions.

In KORTOWO area there are also clear systematic differences between heights obtained using NRTK and precise leveling. This means that used type of corection can have a significant impact on obtaining heights.

The normal height accuracy, measured as a difference between NRTK and precise leveling heights, obtained for the KORTOWO test varies significantly depending on the meseuring session. The accuracy was better than 2 cm for an average of 31% and better than 5 cm of 71% of the NRTK measurements. For measurements where the largest differences occurred, fitting NRTK heights to a precise leveling network significantly improved the results. This can be done through normal height determination at least of the one point using geometric leveling. But we should remember that NRTK measurements often are fluctuating and their average also can be biased. So it would be better to used two or more points. Such approach allows for better control and adjustment of results.

If we perform measurements in the area where there are not bench marks a solution could be measurement using all available types of corrections. The analysis of obtained differences in the results could be helpful in identifying the best solution.

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