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GNSS SATELLITE LEVELLING USING THE ASG-EUPOS SYSTEM SERVICES

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Key words: ASG-EUPOS, EUPOS, GBAS, GNSS satellite levelling, geoid.

Abstract

GNSS observations from a network of permanent stations are a complex system offering not only post-processing, but also corrections sent in real time and the creation of virtual observations. In Poland, such a system has been in operation since June 2008: the Polish Active Geodetic Network ASG-EUPOS. For users three services are provided for real-time corrections, and two services are offered for post-processing. In this paper, methods of normal height determination from static GPS measurements were analysed in the context of the technical capabilities of the ASG-EUPOS along with recommendations for such measurements. Particular attention is paid to the possibility of using to such calculations the Virtual Reference Stations (VRS). Studies have shown that height determination using VRS may reduce the length of observation sessions and improve accuracy compared to the results obtained from the NAWGEO or POZGEO services. In addition, because of the short vectors between the virtual station and measured points, accuracy is not dependent on the type of used receiver (L1 or L1/L2).

NIWELACJA SATELITARNA GNSS Z WYKORZYSTANIEM SERWISÓW SYSTEMU ASG-EUPOS

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Słowa kluczowe: ASG-EUPOS, EUPOS, GBAS, niwelacja satelitarna GNSS, geoida.

Abstrakt

Obserwacje GNSS realizowane na sieciach stacji permanentnych są obecnie złożonymi systemami oferującymi, oprócz postprocessingu, również korekty przesyłane w czasie rzeczywistym oraz tworzenie obserwacji wirtualnych. W Polsce systemem takim jest uruchomiona w czerwcu 2008 roku polska aktywna sieć geodezyjna ASG EUPOS. Dla użytkowników przeznaczono trzy serwisy udostępniania poprawek w czasie rzeczywistym oraz dwa serwisy dla postprocessingu. W pracy przeanalizowano sposoby wyznaczenia wysokości z pomiarów statycznych GPS w kontekście możliwości technicznych systemu ASG-EUPOS oraz niektórych zaleceń do takich pomiarów. Szczególną uwagę zwrócono na możliwość wykorzystania do takich wyznaczeń obserwacji z Wirtualnych Stacji Referencyjnych (VRS – Virtual Reference Station). Przeprowadzone analizy wykazały, że procedura wyznaczenia wysokości punktów z wykorzystaniem VRS może pozwolić na znaczne skrócenie długości sesji obserwacyjnej oraz poprawę dokładności w stosunku do wyników uzyskanych z serwisu NAWGEO czy POZGEO. Ze względu na krótkie wektory między stacją wirtualną a wyznaczanymi punktami dokładność ta nie jest uwarunkowana wykorzystanym w czasie pomiaru typem odbiornika (L1 bądź L1/L2).

Introduction

The EUPOS project (EUropean Position Determination System) was launched in 2002 in Berlin. Its purpose was to create a homogenous ground-based GNSS support system in Central and Eastern Europe. In Poland, ASG-EUPOS (ASG – Aktywna Sieć Geodezyjna) launched in June 2008 (BOSY et al. 2007, 2008). The ASG-EUPOS network assumed the role of a geodetic reference system in Poland. The connection of the ASG-EUPOS stations and the EUREF Permanent Network (EPN) stations (which are located Poland) has allowed the implementation, monitoring and control of the ETRS89 system in the territory of Poland (FIGURSKI et al. 2009).

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 work together to provide a system for precise positioning in real-time and post-processing applications. The network of reference stations (reference segment) currently (as of November 2011) consists of 99 Polish (81 with a GPS module and 18 with a GPS/GLONASS module) and 22 foreign stations (www.asgeupos.pl). The mean distance between reference stations is below 70 km. The stations are regularly distrib-

Table 1

ASG-EUPOS services

Service group	Service name	Survey method	Data access	Estimated precision	Minimum hardware requirements
Real-time services	NAWGEO	kinematic RTK	GSM/ Internet	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	
Postprocessing services	POZGEO	static	Internet	0.01–0.10 m	L1 GNSS receiver
	POZGEO D	static/ kinematic			

uted, creating a homogenous network which covers all of Poland. The ASG-EUPOS services enable transfer of reference frame into real applications in the field. Table 1 shows the real-time and post-processing services available in the ASG-EUPOS system (www.asgeupos.pl).

GNSS technology is currently widely used for many kinds of geodetic surveys, including height determination. Relative GNSS positioning encourages users to compute orthometric (normal) height differences, $\Delta H = H_2 - H_1$,by using the well-known relation (Fig. 1):

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

where:
$\Delta h = h_2 - h_1$ – the difference in ellipsoidal heights,
$\Delta N = N_2 - N_1$, – the difference in geoid heights.

The accuracy of the calculated ΔH depends on the accuracy of Δh and ΔN. Although it is possible to reach millimetre horizontal relative accuracy levels over tens, or even hundreds of kilometres, vertical GNSS accuracy is not so easily obtained. The baseline vertical component is more sensitive to many disturbing factors, for example: antenna phase centre variations or tropospheric refraction (DAWIDOWICZ 2010, DODSONA et al. 1996, TREGONING, HERRING 2006, WIELGOSZ et al. 2011).

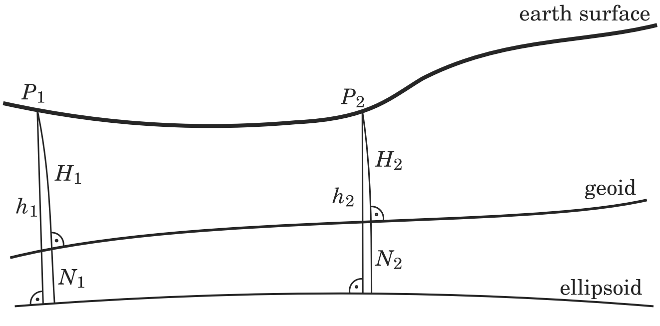

Fig. 1. The concept of GNSS satellite levelling
Source: own work.

The second factor determining the accuracy of GNSS levelling is a geoid (quasigeoid) model. The height system in Poland creates geopotencial numbers divided by the average value of the normal acceleration of gravity along the normal line between the GRS80 ellipsoid and telluroid (further reffered to as "normal heights") referenced to the average level of the Baltic Sea, set for a tide-gauge in Kronstadt near St. Petersburg (Russian Federation) (Rozporządzenie Rady Ministrów... 2000, Projekt nowelizacji RRM... 2007). Normal heights by definition, are related with a quasigeoid. Because in most areas of Poland the spacing between geoid and quasigeoid surfaces is less than 1 cm, sometimes in the literature both surfaces are identified (Banasik 1999, Pażus et al. 2002).

There are a number of categories of techniques for the computation of geoid undulation. Currently the genaral strategy for computation of geoid undulation is composed of the combination of three effects: global, regional and local, which are represented by the geopotential model, mean free-air gravity anomalies and topography respectively (Czarnecki 1994, Hofmann-Wellenhof, Moritz 2005, Torge 1991).

Precise modelling of global and regional geoids has become one of the major tasks of numerous research groups of surveying and mapping agencies. In order to provide determination of normal heights using satellite measurements techniques, the Head Office of Geodesy and Cartography in Poland in 1999 began intensive work on creating a suitable quasigeoid model. The published result of this has been the creation of two quasigeoid models. The first model, called "Geoida niwelacyjna 2000", is a purely geometric satellite-levelling quasigeoid model based on the hights of the EUREF-POL, POLREF, EUVN, WSSG and Tatry network points. This model was included in the "TRANS-POL" software, which is enclosed in the G1-10 Technical Guidelines. The second published version of quasigeoid was, approved in 2001 by the Surveyor General of Poland for use in geodetic practice, model called "Geoida niwelacyjna 2001". This model is the result of fitting the "QUASI97B" gravimetric quasigeoid model into the "QGEOID-PL'01" satellite-levelling quasigeoid model based on 752 points, of which 62 belong to the EUVN network, 11 to the EUREF-POL network, 330 to the POLREF network, 23 to the Tatry network and 326 to the WSSG network. A discrete model in the form of quasigeoid heights in 1' × 1' grid nodes was determined using the spline function of the third' degree. Together with the bilinear interpolation formula of quasigeoid heights, it was used in the "GEOIDA" software attached to the Technical Instruction G-2. ASG-EUPOS system is used ‚QGEOID-PĜ model (Instrukcja Techniczna G-2 2001, Pażus et al. 2002, Wytyczne Techniczne G1-10 2001).

Access to raw gravity data, the development of high-resolution digital terrain models and densification of precise GNSS-levelling heights have simulated extensive research into precise quasigeoid modelling in Poland. Since 2002 a team of reserchers under the leadership of the Institute of Geodesy and Cartography in Warsaw have conducted advanced research into modeling a centimetre quasigeoid in Poland (Kryński, Łyszkowicz 2006a,b).

In the meantime, the release of the EGM2008 (Earth Gravitational Model 2008 EGM2008) by the National Geospatial-Intelligence Agency (NGA) EGM Development Team was a milstone step in precise gravitational and geoidal modelling on a global scale (ŁYSZKOWICZ 2009).

Centimeter-level positioning in an array of reference stations spaced 30 to 100 kilometers apart can be achieved using virtual reference station (VRS) observations. Precise correction models for dispersive (ionospheric) and non-dispersive (tropospheric and orbit) distance-dependent biases are obtained from the real reference data and used in the calculation of the virtual observations (WANNINGER 1997). The process of creating VRS observations based on real observations, consists of several stages (WANNINGER 1997, 1999). The quality of VRS observations fundamentally depends on two aspects: firstly on station-dependent biases in the reference stations observations (mostly caused by a carrier phase multipath) and secondly on possible ionospheric and tropospheric disturbances. Small-scale and medium-scale ionospheric and tropospheric refraction may not be completely represented by the correction models of distance-dependent biases. The remaining errors affect ambiguity resolution and positioning accuracy of the baseline between VRS and the measured point. The size of these biases (and thus the quality of the VRS observations) is estimated together with the correction model parameters (WANNINGER 1999).

The VRS concept was initially dedicated to RTK (Real Time Kinematic) measurements and is now more often used in a static approach (BAKUŁA 2006, SIEJKA 2009).

Performing geodetic surveying is regulated by a number of legal acts and technical standards. At the moment there are no definitive instructions for measurements using the ASG-EUPOS. In the project phase are technical guidelines G-1.12. At the beginning of 2011, the Surveyor General of Poland published the "GNSS satellite measurements based on reference stations of ASG-EUPOS" technical recommendations, which cannot be treated as a valid technical standard for GNSS measurements. At present, the use of ASG-EUPOS services is possible, as long as it meet accuracy requirements. In such a situation, it is necessary to conduct detailed studies related to the determination of position using ASG-EUPOS.

In this paper, methods of normal heights determination from GNSSS measurements were analysed in the context of the technical capabilities of the ASG-EUPOS along with recommendations for such measurements. Particular attention was paid to the possibility of using VRS observations for such determination.

Research area

Four points situated in Kortowo (UWM Olsztyn) were selected for test measurements (Fig. 2). This location resulted in the nearest CORS stations of the ASG-EUPOS system being between 3 and 20 km distant (Fig. 3).

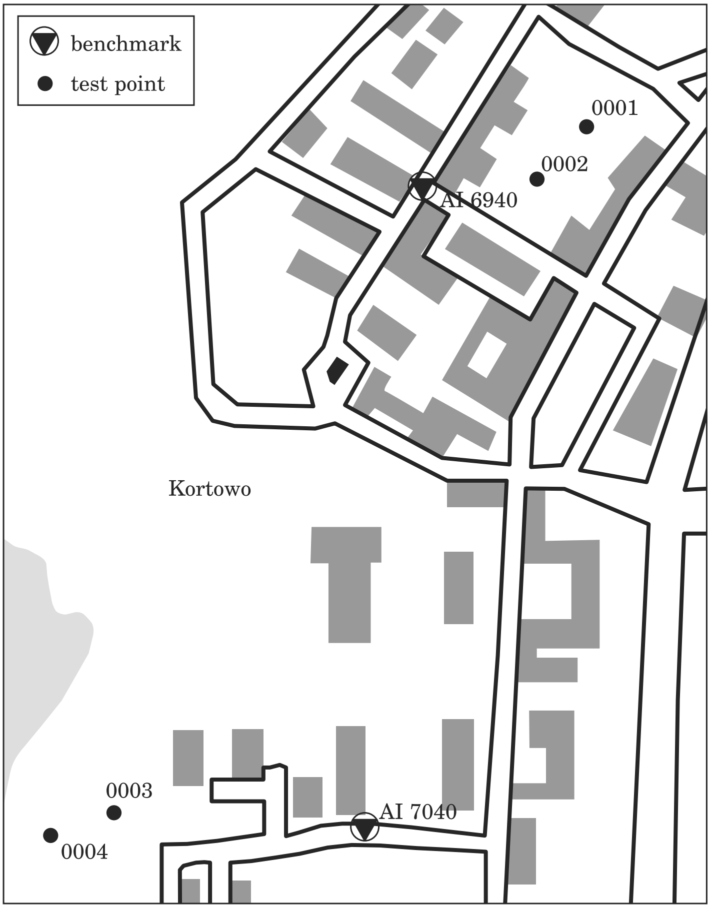

Fig. 2. The location of existing levelling benchmark and test points
Source: own work.

One hundred independent RTK measurements were performed on each test points with the NAWGEO service. Between the measurements, random breaks were made from 5 to 30 seconds. Additionally a static session was carried out on the test points . The following GNSS parameters were assumed for that session: sampling interval 5s, minimum satellite; elevation 10°, time of measurement 4 hours.

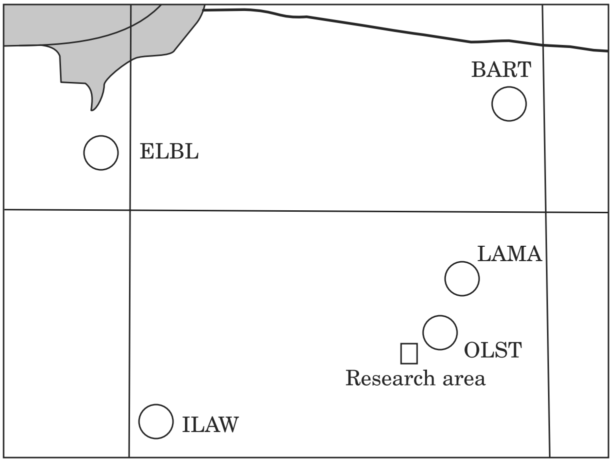

Fig. 3. The location of the research area
Source: map: http://www.asgeupos.pl

For the test points normal heights were determined by precise leveling (Tab. 2). Precise levelling was assigned to two 2nd order benchmarks of the national levelling network (AI 6940, AI 7040). Table 2 also includes the separations between quasigeoid and ellipsoid on measured points calculated with three quasigeoid models (among others the “QGEOID-PG” model which is used in the ASG-EUPOS system).

Table 2

Normal height and quasigeoid-to-ellipsoid separation on measured points

Measurement point number	Normal height [m]	Quasigeoid to ellipsoid separation from “Geoida niwelacyjna 2000” model [m]	Quasigeoid to ellipsoid separation from “Geoida niwelacyjna 2001” model [m]	Quasigoid to ellipsoid separation from “QGEOID-PG” model [m]
0001	117.234	29.816	29.815	29.805
0002	115.318	29.815	29.814	29.803
0003	104.995	29.831	29.829	29.818
0004	105.974	29.831	29.830	29.819

On all test points about a 1 cm difference between quasigeoid-to-ellipsoid separations calculated from “QGEOID-PG” model and both other models is visible. The impact of the quasigeoid model used for the normal height determination has been analysed, among others, by HADAŚ and BOSY (2009).

Analysis of results

Results of the RTK-NAWGEO measurements (normal height differences between heights obtained from precise levelling and heights obtained from satellite leveling), are presented in figure 4 (the “QGEOID-PG” model was used).

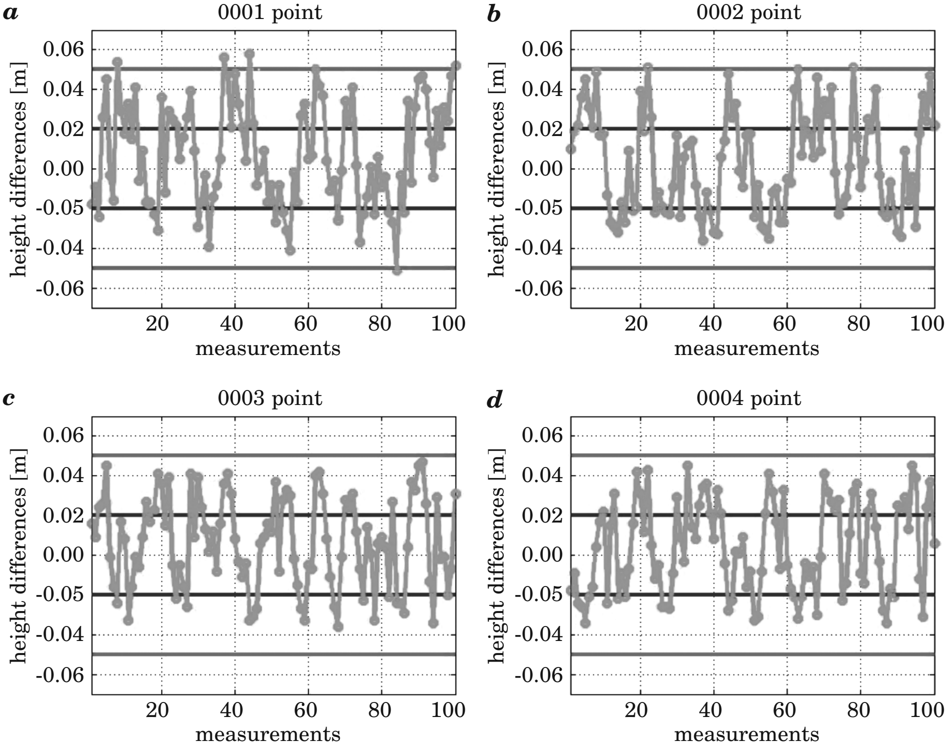

Fig. 4. Normal height differences between heights obtained from precise levelling and heights obtained from RTK-NAWGEO measurements

Figure 4 shows, that for measured points, on average, within ±2 cm was nearly half the height differences (43%), while in the range ±5 cm (accuracy of the RTK height determination declared by the ASG-EUPOS system): 98% height differences. It should be noted that the largest difference was observed for the points of nearby tall trees and buildings (0001 and 0002 points). The standard deviation, being a measure of the precision of the data, was 1.4 cm.

Observations from static measurements carried out on test points have been processed in several variants. Because cost-effectiveness is a requirement for most geodetic projects several analyses were conducted into how the accuracy depends on the baseline length and on the duration of the observing session (Eckle et al. 2001, Psimoulis et al. 2004). For this reason, four-hour session was divided into 4 one-hour sessions and 8 half-hour sessions. Next, the four and one-hour sessions were sent to the POZGEO service. Additionally, all measurement sessions were processed with Topcon Tools v7.3 software (POZGEO-D service) in three variants: with LAMA, with OLST and with VRS stations as reference stations. VRS station were created with the POZGEO-D service in the immediate vicinity of the measured points.

In Topcon Tools software, selection of processing frequency is automatic and for baselines up to 30 km, it appears as follows: 0–10 km processing on L1 frequency, 10–30 km processing in ionosphere-free combinations. To process the IGS final orbit and IGS the absolute (converted from relative) antenna phase center offset model was chosen. The results for one and half hour sessions (ellipsoidal heights and their RMS errors) are presented in figures 5–8.

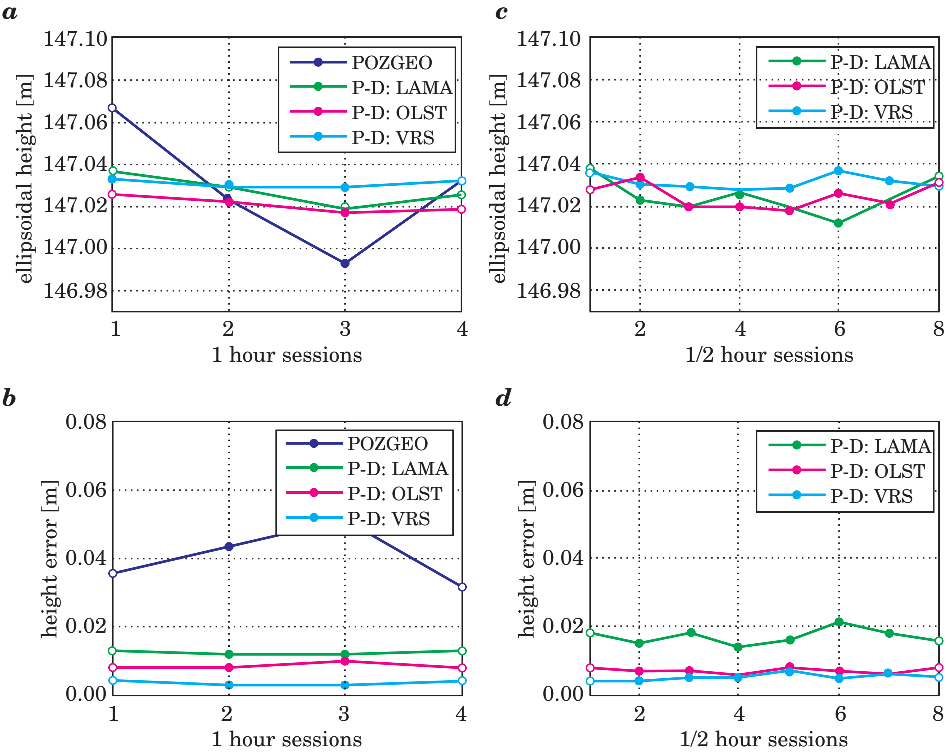

Fig. 5. Ellipsoidal height and height error for 0001 point: *a, b* – one hour sessions, *c, d* – half hour sessions

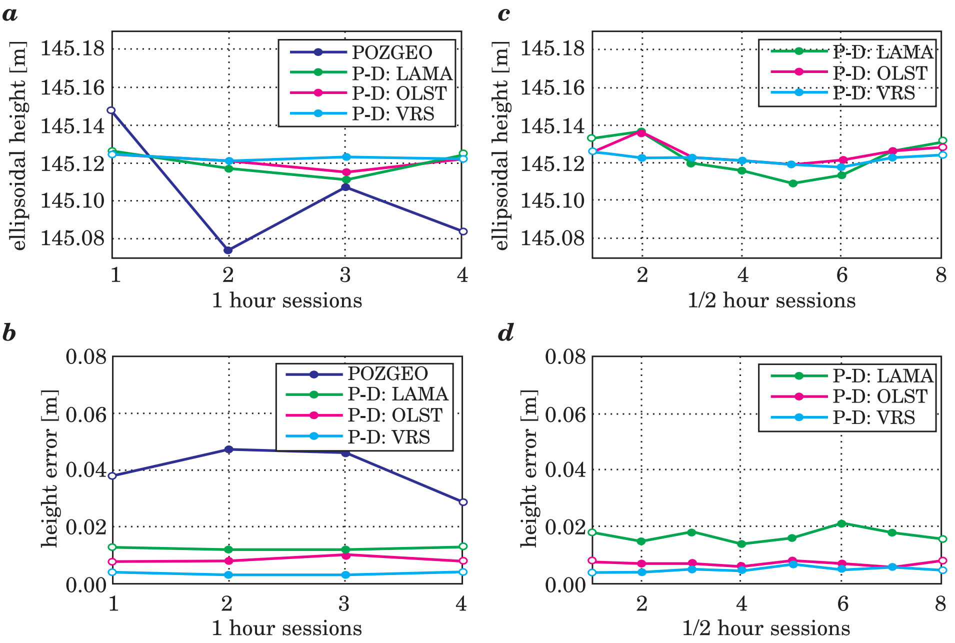

Fig. 6. Ellipsoidal height and height error for 0002 point: *a, b* – one hour sessions, *c, d* – half hour sessions

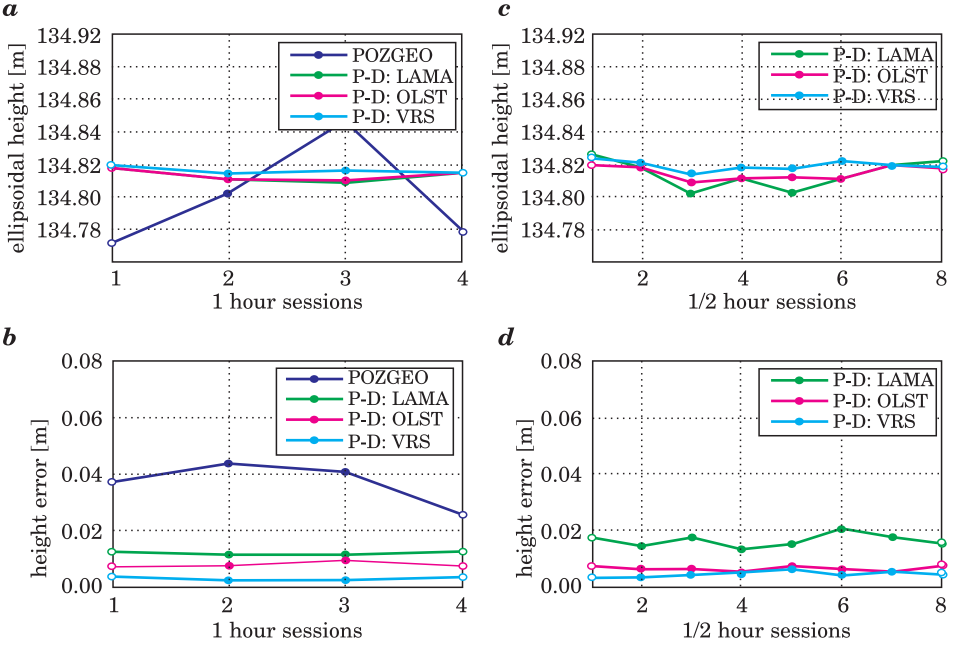

Fig. 7. Ellipsoidal height and height error for 0001 point: *a, b* – one hour sessions, *c, d* – half hour sessions

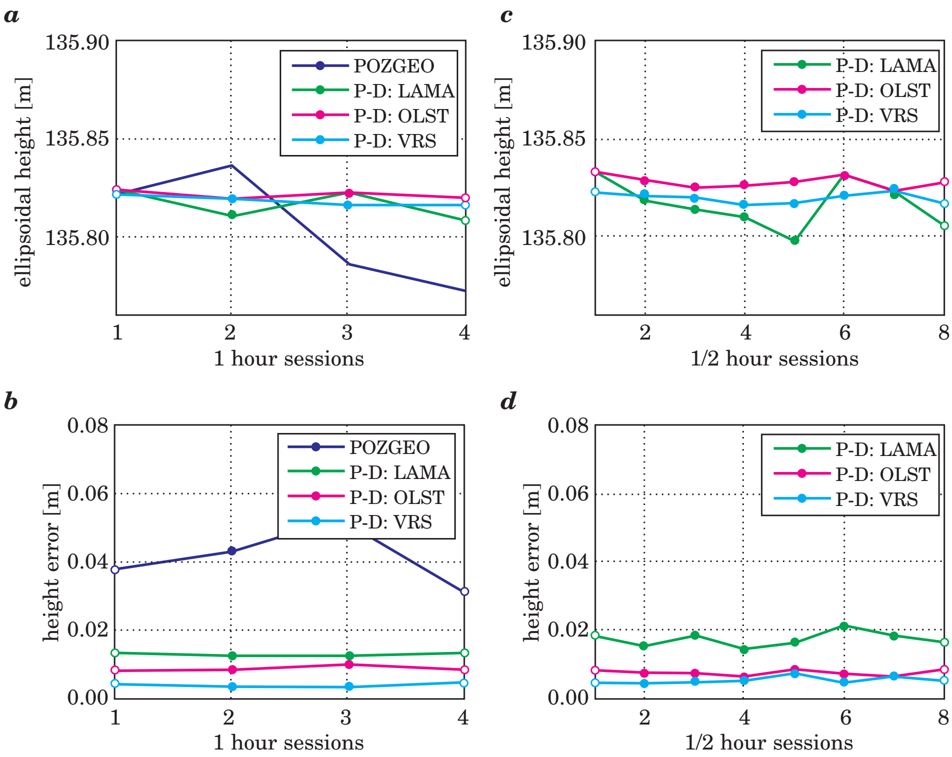

Fig. 8. Ellipsoidal height and height error for 0002 point: *a, b* – one hour sessions, *c, d* – half hour sessions

Anlysing the results on figures 5–8, it is visible that the ellipsoidal heights obtained from the POZGEO service are characterized by the lowest stability and the highest value of RMS error (one hour session variants – min. 720 epoch needed). It is clear that there is a tendency to increase stability and reduce the RMS error by shortening the distance between measured points and reference station. The best results were obtained for the variants using the OLST or VRS stations as reference points. It should be noted that this solution was obtained for L1 processing.

For all processing variants the normal heights were calculated. The "QGEOID-PG" model was used to calculate the distances between the quasigeoid and ellipsoid. The normal height differences between heights obtained from precise levelling and the heights obtained from satellite levelling are presented in figure 9.

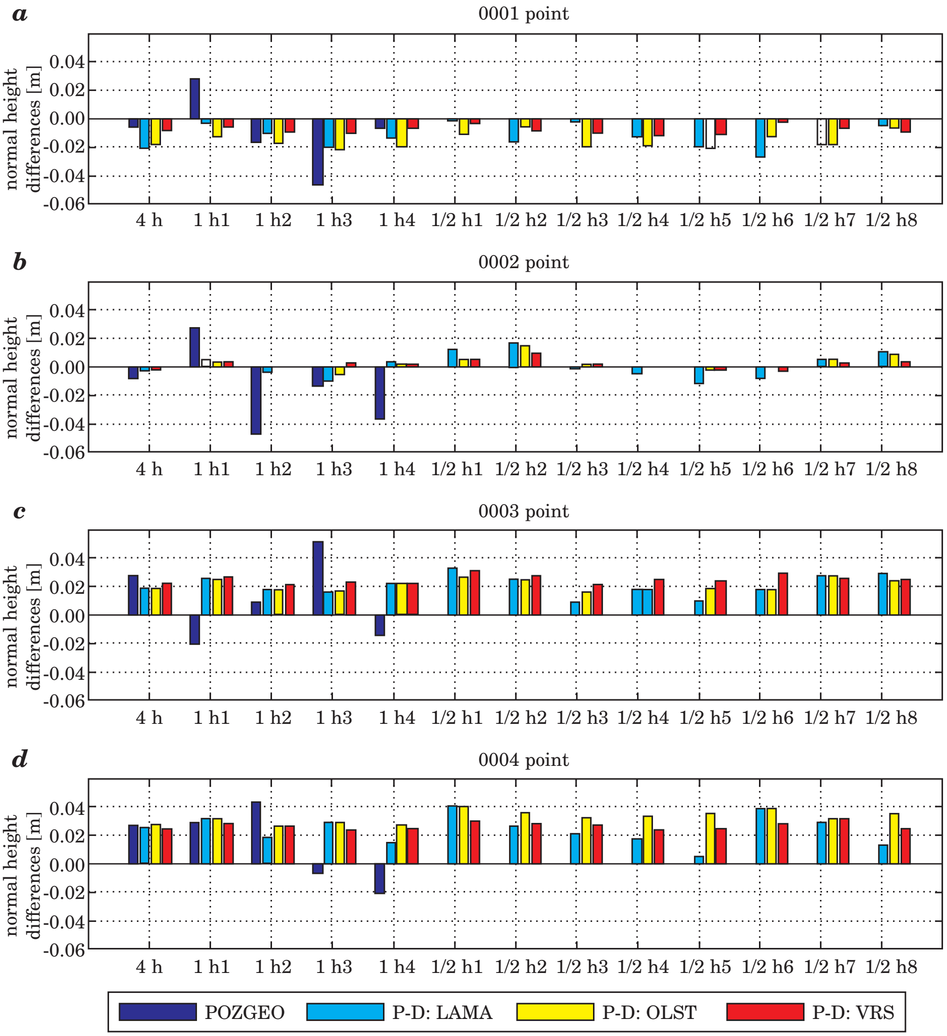

Fig. 9. Normal height differences between heights obtained from precise levelling and heights obtained from satellite levellin

Height differences calculated from the results from one-hour sessions were within ±2 cm range for 44% of the POZGEO solution, for 75% of the POZGEO-D LAMA (P-D LAMA) solution, for 56% of POZGEO-D OLST (P-D OLST) solutions and for 50% of POZGEO-D VRS (P-D VRS) solutions. With ±3 cm range were 69% of the POZGEO solution, 94% of the POZGEO-D LAMA solution, 94% of POZGEO-D OLST solutions and 100% of POZGEO-D VRS solutions.

Height differences calculated from the results of half-hour sessions were within ± 2 cm range for 68% of the POZGEO-D LAMA solution, for 59% of POZGEO-D OLST solutions and for 50% of POZGEO-D VRS solutions. With ±3 cm range were 90% of the POZGEO-D LAMA solution, 75% of POZGEO-D OLST solutions and 90% of POZGEO-D VRS solutions.

Conclusions

This paper presents an analysis of normal height determination using the services of the ASG-EUPOS system (NAWGEO, POZGEO, POZGEO-D).

In the case of RTK satellite levelling, the low accuracy of ellipsoidal height determination (dispersion of the range of 10 cm) has a significant impact on the value of normal height calculation. A one-hour static session also proved to be too short for accurate determination of heights in the POZGEO service (ellipsoidal height dispersion in the range of 7 cm). Neither method provides determination of normal heights with ±2–3 cm accuracy.

A better solution at the moment is either extending the measuring session for processing in the POZGEO service or own observation post-processing (POZGEO-D service). A half-hour session was sufficient to determine ellipsoidal heights with ±1 cm accuracy (variants with OLST or VRS as reference station). Additionally, because of the short vectors between the measured points and the reference station, the accuracy of the calculations did not depend on the type of receivers used for the measurement (L1 or L1/L2). For those processing variants, the accuracy of quasigeoid model has a significant impact on the value of normal height calculation. It is hoped that this accuracy will be improved with the newest quasigeoid model for Poland.

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