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Modern Gravity Survey of the Lithuania Territory

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Abstract

Lithuanian gravitational field researches have been conducting since 2016. The aim is to increase the accuracy of the geoid, as well as the accuracy of the normal heights determined by the methods of space geodesy. It is important to have high accuracy and dense data when simulating the field of gravity in the terrain. In order to simulate the field of gravity in the territory of Lithuania, it is necessary to include areas of lakes. The data obtained can also be used for geophysical and geodynamic studies and for precise navigation.

The methodology and technology of the gravity survey of Lithuanian territory are presented. The stress on quality parameters of the gravity survey is done.

According to the project, the standard deviation of the measured gravity at the gravity survey points should not be more than 60 μGal, and the standard deviation of Bouguer anomalies should be better than 80 μGal. The average distance between gravity points should be about 1.5 – 2 km.

Keywords: gravimetrical measurements; Bouguer anomaly; calibration; data processing

1 Introduction

Gravimetric field measurements are required to increase geodetic accuracy (*Paršeliūnas and Petroškevičius*, 2007). This is especially important for the use of various geopotential heights. For example, when determining the normal heights of points with GNSS techniques, it is necessary to know the precision of the quasigeoid surface, which is defined by the gravity field (*Paršeliūnas and Petroškevičius*, 2007). Data on the field of gravity is also required for geophysical, geodynamic, navigational and other tasks. Information on the Earth's global gravity field can be acquired by dynamic methods of space geodesy through analysis of artificial satellites orbiting the Earth. However, ground-based gravimetric measurements are required for detailed information about the gravity field on the Earth's surface (*Boedecker*, 1995; *Moritz*, 1992; *Robertson et al*. 2003).

The latest gravimetric survey of the gravity field in Lithuania's territory was carried out in 1951–1962. The reference points in Vilnius, Panevėžys, Riga, Daugavpils, Lida and Kaliningrad were used. Approximately 10000 points were observed, in total. On the basis of this gravity survey, the gravimetric map at a scale 1:200000 were gener-

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ated. Investigations have shown that the average accuracy of the gravity acceleration, detected from gravimetric map, is approximately 0.7 mGal (*Paršeliūnas and Petroškevičius*, 2007). However, in some areas, the accuracy is much worse and goes down to 3 mGal.

Old and low-quality measurements do not fit to the requirements of modern society. It was decided to carry out the modern gravity survey of the Lithuanian territory based on the reference gravity network of modern-day and using recent achievements of gravimetric science and technology (*Petroškevičius et al.* 2014, 2007). In order to collect the data of gravimetric measurements, that is sufficient to produce the required geoid model, it is necessary to design the measuring points in such a way that the observation network is as dense and reliable as possible. Similar gravity surveys are going on in neighbouring countries like Poland, Latvia, Estonia and Finland (*Dobrzycka and Cisak*, 2001; *Ellmann and Oja*, 2009; *Forsberg*, 1981; *Janpaule et al*. 2013; *Kern et al.* 2013; *Klees et al*. 2000; *Krynski and Barlik*, 2012; *Krynski and Sekowski*, 2010; *Krynski*, 2012; *Krynski et al.*, 2013; *Kuroishi*, 2000; *Mäkinen et al*., 2010; *Oja et al*., 2011; *Robertson et al*. 2003; *Torge*, 1989; *Türk et al*., 2011; *Sas-Uhrynowski et al*. 1999).

2 Design of gravity survey

In the project of gravity field study, the density of gravimetric points must be at least 1 point per 2.4 km2. During the design, an effort was made to have a gap between points of approximately 1.5–2.0 km. Such density of gravimetric points is selected in order to create a gravity map of Lithuania's territory with the scale of 1:200000. It is planned to observe more than 32000 points designed on the land and lakes. It is foreseen that in areas of disturbed gravity field the density of gravity points will be higher, and distances between points will be aproximately 1 km. Requirements for gravimetric map creation:

1) RMS error of the measured gravity at gravity survey points should not exceed 60 μGal.
2) RMS error of Bouguer anomalies at gravity points will not exceed 0.080 mGal. RMS error of interpolated values of Bouguer anomalies will not exceed 1.00 mGal.
3) Positions of gravity points are measured by the RTK method applying LitPOS service.
4) Normal heights of gravity points are calculated applying a geoid model for Lithuania LIT15G.
5) The RMS error of points coordinates will not exceed 0.20 m and normal heights 0.15m.

The geoid LIT15G model is linked to the Lithuanian height system LAS07, where geoid heights are modeled over the GRS80 ellipsoid. The accuracy (RMS) of this model is 2 cm. The geoid model covers the area between 53.0°–57.0° north latitude and 20.0°–27.0° east longitude.

The positions of the gravimetric points are planned using the QGIS program on the Lithuanian ortophotogrammetric map, made in 2012. For the design, an auxiliary layer of the grid is created, which divides the entire area into 1 × 1 km squares. The grid is used as an auxiliary information to maintain the desired point density. Additionaly, points were designed in large water bodies and swamps. When projecting points on water bodies and marshes, the density of the points and their possible measurements are taken into account. Measurements could be done only when the water body is frozen during the cold season. In addition, the possibility to determine the coordinates of a point by GNSS method in the designed area were evaluated. A fragment of the gravimetric points, projected in the QGIS environment, is depicted in Fig. 1.

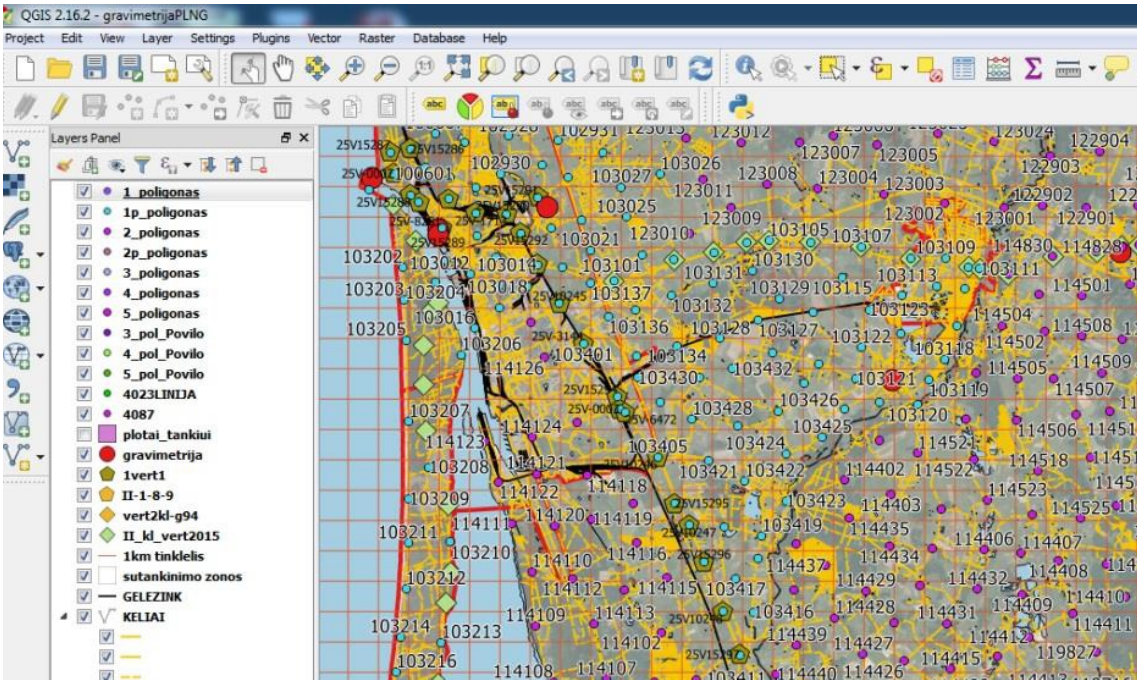

Fig. 1. Fragment from the design of the gravity survey of Lithuania.

First-order and absolute gravity points were used for this project. The first absolute ballistic gravimetric measurements were carried out at three points in 1994 (*Birvydienė et al*., 2009), other absolute measurements were made in 2002 and 2017. The national first-order gravimetric network of Lithuania was developed during the period of 1998–2001, it consists of 51 points (*Petroškevičius et al.,* 2014). Measurements were performed with 3–6 gravimeters LaCoste & Romberg. This network was densified in 2007–2009 by second-order gravity network points. Gravimetric measurements were carried out by automatic gravimeters SCINTREX CG-5 (*Petroškevičius et al.,* 2014). This is a total of 635 gravity points (Fig. 2). The average distance between points is about 10 km. RMS error of the measured gravity at these points does not exceed 10 μGal. By Decree of the Government of the Lithuanian Republic in 2014 the Lithuanian Gravity System (LSS07) was accepted [30]. Quasigeoid root mean square error m_{LIT15G} = 0,020 m. LAS07 normal heights root mean square m_{Hn} = 0,025 m.

Reference layers of geoinformation system are: Gravimetric basis of Lithuanian territory, which consists of gravimetric network that connects 686 first, second order and absolute gravity points (*Birvydienė et al*. 2010a, 2010b), they are in LSS07 system; Ortophotogrammetric maps at a scale of 1:10000; Geodetic points with measured gravity values; roads; railroads; rivers and lakes; 1 km grid; regions of disturbed gravity field. Six digits identifier codes used for points of gravity survey. Geodetic coordinates of the points were imported into memories of navigators to find them easier in the field. The geodetic base of the gravimetric survey was made up of a network of permanently operating GNSS stations.

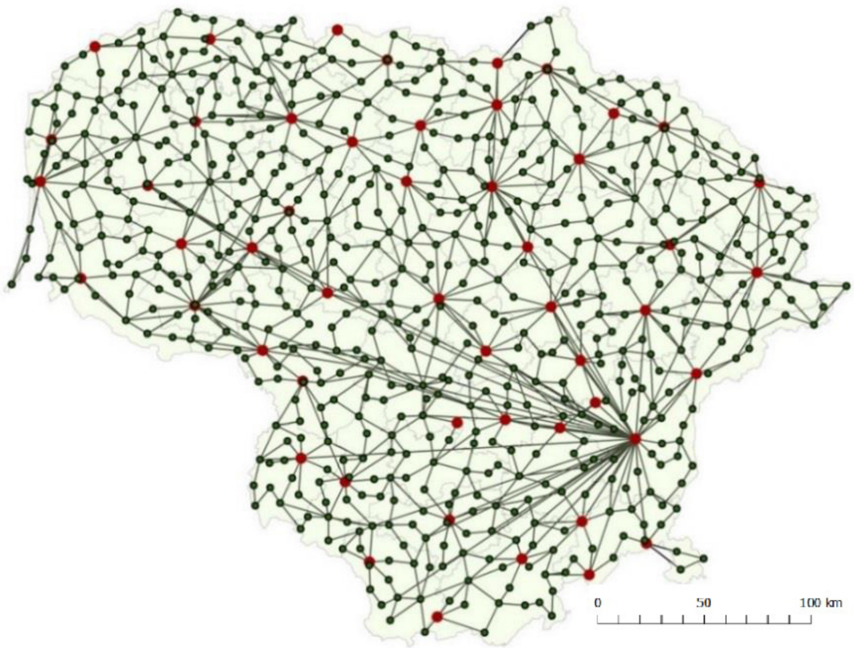

Fig. 2. Lithuanian national gravimetric network (zero and first-order points – in red color, second-order points – in black, lines mark the measured gravity differences, blue line – calibration line).

3 Calibration of gravimeters scintrex cg-5

Gravimeters have been calibrated at the gravimetric baseline connecting gravimetric points EIŠIŠKĖS, VILNIUS, PANEVĖŽYS, and SALOČIAI (*Petroškevičius et al.,* 2014). Gravimetric baseline points are located along the meridian. The baseline length is 270 km. The gravity difference between bordering baseline points EIŠIŠKĖS and SALOČIAI is 201 mGal. Detected calibration coefficients, in past few years, of all the gravimeters are presented in Table 1. Calibration date, RMS error m_k and change of calibration coefficients Δk between adjacent calibrations are presented in Table 1 as well.

RMS error of calibration coefficients is not exceeding 0.000062. The largest calibration coefficient change has been detected with gravimeter No. 185 (Fig. 3). On 2017.10.16, unusual behavior was observed, thus new measurements were made on 2017.10.30.

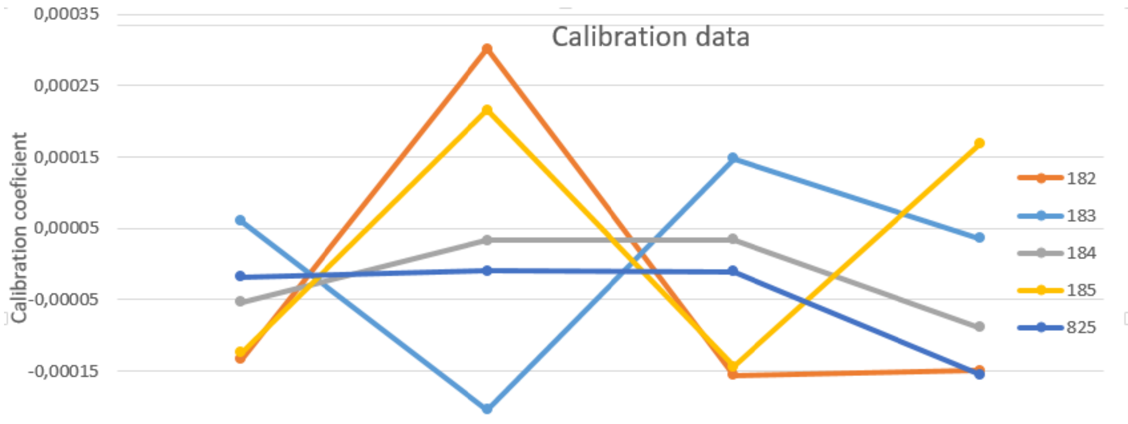

Fig. 3. The changes of the gravimeters Scintrex CG-5 calibration coefficients.

Table 1. Calibration coefficients of the gravimeters Scintrex CG-5 and their accuracy.

Gravimetr Nr	182	183	184	185	825
2017.07.24	1.012804	0.999144	1.000158	0.999618	0.999709
m_k	0.000060	0.000058	0.000058	0.000059	0.000058
Δk	-0.000134	0.000060	-0.000053	-0.000124	-0.000018
2017.10.16	1.013105	0.998940	1.000191	0.999834	0.999699
m_k	0.000059	0.000058	0.000058	0.000058	0.000058
Δk	0,000301	-0,000204	0,000033	0,000216	-0,00001
2017.10.30	1.012949	0.999088	1.000225	0.999690	0.999688
m_k	0.000063	0.000059	0.000059	0.000059	0.000060
Δk	-0.000156	0.000148	0.000034	-0.000144	-0.000011
2018.04.03	1.012800	0.999124	1.000136	0.999858	0.999533
m_k	0.000059	0.000059	0.000059	0.000062	0.000058
Δk	-0.000149	0.000036	-0.000089	0.000168	-0.000155

4 *Some features of gravity survey method*

The gravity acceleration at survey points was observed with a single SCINTREX CG-5 gravimeter. In total, we used five SCINTREX CG-5 gravimeters. Based on the first measurement results the standard deviation of the measured gravity is roughly 20 μGal. The standard deviation of calculated Bouguer anomalies is approximately 23 μGal. Data were taken from about 16000 pts of the whole project (32000 pts) points. Gravimetric reference points were used at the beginning and end of the day. In midday, the trip control measurements were performed at the points of gravimetric reference as well.

At every point, two cycles of measurements, 25 s duration each, saving readings each 5 s, were carried out. If gravimeter readings differ more than 15 μGal, one additional cycle of observation is performed.

The geodetic coordinates of the gravity survey points are determined applying LitPOS RTK service. To increase the accuracy of coordinates and height determination, double measurements were performed at every point. According to ongoing measurements the accuracy of the horizontal position is better than 0.03 m, and the accuracy of the ellipsoid heights, applying geoid model LIT15G, is better than 0.05 m.

5 Adjustment of gravimetric measurements

Day trip measurements were transferred from the gravimeter to the computer, whereunnecessary data were rejected and sent to the Geodesy Institute for further processing. Coordinate file, from the GPS receivers, and notes on day measurements were also sent.

Gravimetric measurements were processed using the GRAVSOFT software package procedures GRREDU and GRADJ written by R. Forsberg (*Forsberg*, 1981). The data was processed by estimating the gravitational calibration coefficient values with corrections of Lunar and Solar attractions and gravimeters drift (*Ågren and Sjöberg*, 2015). The daily trip data was then adjusted using two reference points and the detection of errors in checkpoints. If the tolerances were accepted, the final alignment was carried out using both the control points as supports. The values of smooth measured gravity and their errors were obtained. Sometimes there was no way to measure the point at the same position as planned, displacement of designed and measured points does not exceed 1 km.

The accuracy of gravimetric measurements was evaluated according to measured gravity values at different control points. Measured gravity differences of 454 control points for gravimetric measurements are shown in Fig. 4. The mean square error of the measured gravity (m_g) calculated from the difference in gravity at the control points is 20.7 μGal. The mean square error of a single measurement (m_{dg}) is 18.2 μGal.

$$m_{dg} = \sqrt{m_g^2 - m_{ga}^2}, \tag{1}$$

where, m_{ga} – RMS error of gravity accelereration at the second order control points.

$$m_g = \sqrt{\frac{[d^2]}{n}}, \tag{2}$$

where, d – differences in control points, n – amount of control points.

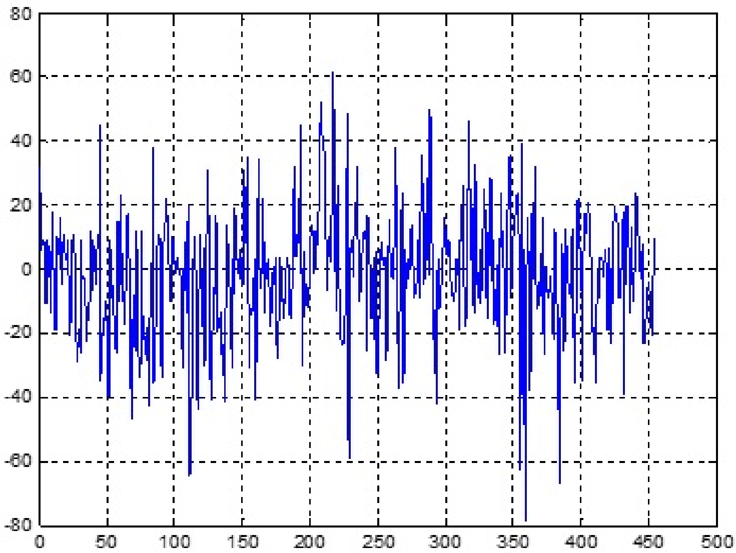

Fig. 4. Gravity values differences at control points, μGal.

A standard deviation of 20 μGal is achieved. However, range of gravity values differences is ±60 μGal. Having gravity acceleration at the point on the Earth's surface and point normal height mixed anomaly of free air is computed from formula (*Paršeliūnas et al.*, 2017):

$$(g-\gamma_{80}) = g_z - \gamma_{80}^{0} + \Delta\gamma_{80}(H) + \Delta g_a(H), \tag{3}$$

where γ_{80e}^{0} acceleration of normal field GRS 80 (*Oja et al.*, 2011):

$$\gamma_{80}^{0} = \gamma_{80\mathrm{e}}^{0}\,\frac{1+k_{80}\sin^2 B_{94}}{\sqrt{1-e_{80}^2\sin^2 B_{94}}}, \tag{4}$$

where γ_{80e}^{0}, γ_{80e}^{0}, e_{80}, k_{80} – parameters of the normal field of gravity GRS 80; $\gamma_{80e}^{0} = 978032{,}677\ 15$ mGal; $e_{80}^2 = 0{,}00669438\ 002290$, $k_{80} = 0{,}001931851353$;

B_{94} – geodetic latitude of LKS 94, Δγ80(H) is height correction in the GRS80 normal field, Δg_δ (H) – atmospheric attraction correction (*Moritz*, 1989, 1990; *Rapp*, 1983).

Bouguer anomalies are determined by formulae (*Petroškevičius et al.,* 2004):

$$(g-\gamma_{80})_\delta = (g-\gamma_{80}) - \Delta g_\delta(H) + \Delta g_r \tag{5}$$

where, $\Delta g_\delta(H) = 2\pi G\delta H$ – endless interim layer correction, here δ – Earth's crust density; Δgr is correction of terrain influence.

From results of measurements at gravimetric points, the RMS error of determined Bouguer anomalies is 23 μGal (without an estimation of the terrain corrections).

One of the main accuracy characteristics of gravity survey is the precision of the interpolated Bouguer anomalies at certain places in between of measured gravity survey points. Standard deviation, calculated from the 140 differences of interpolated Bouguer anomalies and values, calculated from the measured gravity, equal to 0.30 mGal, was received. However, differences between interpolated Bouguer anomalies and values, calculated from the measured gravity, are in a range from –1.0 to +0.8 mGal.

6 Conclusions

Gravity survey from the Lithuania territory is almost completed. Gravimetric measurements were processed using the GRAVSOFT software package procedures GRREDU and GRADJ. Gravity survey accuracy from available gravimetric data meets the requirements.

1. RMS error of measured gravity determined at gravimetric survey points and computed from gravity value differences at control points is 20 μGal. A range of measured gravity values differences is ±60 μGal.
2. RMS error of calibration coefficient of gravimeters SCINTREX CG-5 is below 0.000062. The largest calibration coefficient change of gravimeter during measurements period reached 0.000168. The largest calibration coefficient change is with gravimeter No. 185.
3. RMS error of the gravimetric point coordinates determined using rover GNSS receivers and RTK method applying LitPOS service is below 0.03 m. RMS error of ellipsoid heights determined in the same way and using LIT15G geoid model is below 0.05 m.
4. RMS error of Bouguer anomalies determined at gravimetric survey points equal to 23 μGal (without an estimation of the terrain corrections).
5. Displacement, between projected and measured points, does not exceed 1 km.

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