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The countrywide historical gravity dataset of Lithuanian territory

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Abstract. The historical gravity dataset of Lithuania consists of two files: data of second and third order gravimetric network as well as data of gravity survey. Raw data were collected by digitising the paper catalogues of gravimetric network stations and sheets of gravimetric map at a scale 1:200000. Gravity data set covers total territory of Lithuania (65 thousand square km). Raw data were collected by digitising the paper catalogues of gravimetric network stations and sheets of gravimetric map at a scale 1:200000. The digitiser CALCOMP 9600 was employed along with ARC/INFO software to detect geodetic coordinates of gravity points from the map sheets. Initially the gravity data were in Potsdam gravity system, geodetic coordinates of the gravity points – in the coordinate reference system Pulkovo 1942 (EPSG:2499), and the heights of gravity points – in the Baltic normal height system of 1977 (EPSG code 5705). In the final countrywide set the gravity data are in the International Gravity Standardization Net of 1971 gravity system, geodetic coordinates – in European Terrestrial Reference System of 1989 coordinate reference system (EPSG:4258), and geodetic heights – in the European Vertical Reference System of 2007 (EPSG:5215). Total number of gravimetric network stations is 123, and total number of gravity survey points is 10660. The data were recorded into files applying DBF (Data Base Format) format. Historical gravity data set could be used for quasi-geoid modelling and for development of Earth geopotential models. Researchers will benefit in the process of evaluation and accuracy estimation of developed products using high precision data of gravity network stations.

1 Introduction

The historical gravity survey of the Earth's gravity field in Lithuania territory was carried out in 1951–1962 (Paršeliūnas and Petroškevičius, 2007; Paršeliūnas et al., 2010; Petroškevičius, 2004; Petroškevičius et al., 2014). The reference gravity stations in Vilnius, Panevėžys, Rīga, Daugavpils, Lida and Karaliaučius were used. In total 10660 gravimetric points were observed. On the basis of this gravity survey the gravimetric map at a scale 1:200 000 was generated. The gravity data was in Potsdam gravity system, geodetic coordinates of the gravity points – in the coordinate reference system Pulkovo 1942 (EPSG:2499), and the heights of gravity points – in the Baltic normal height system of 1977 (EPSG code 5705). Investigations showed that the average accuracy of the gravity due acceleration, detected from gravimetric map, is about 0.7 mGal. However, in some areas accuracy is much worse and goes down till 3 mGal (Birvydienė, 2010). The gravimetric network of the second (18 stations) and third order (105 stations) was developed as well (Paršeliūnas and Petroškevičius, 2007; Petroškevičius, 2004). The overview of historical gravity data set is presented in Figure 1.

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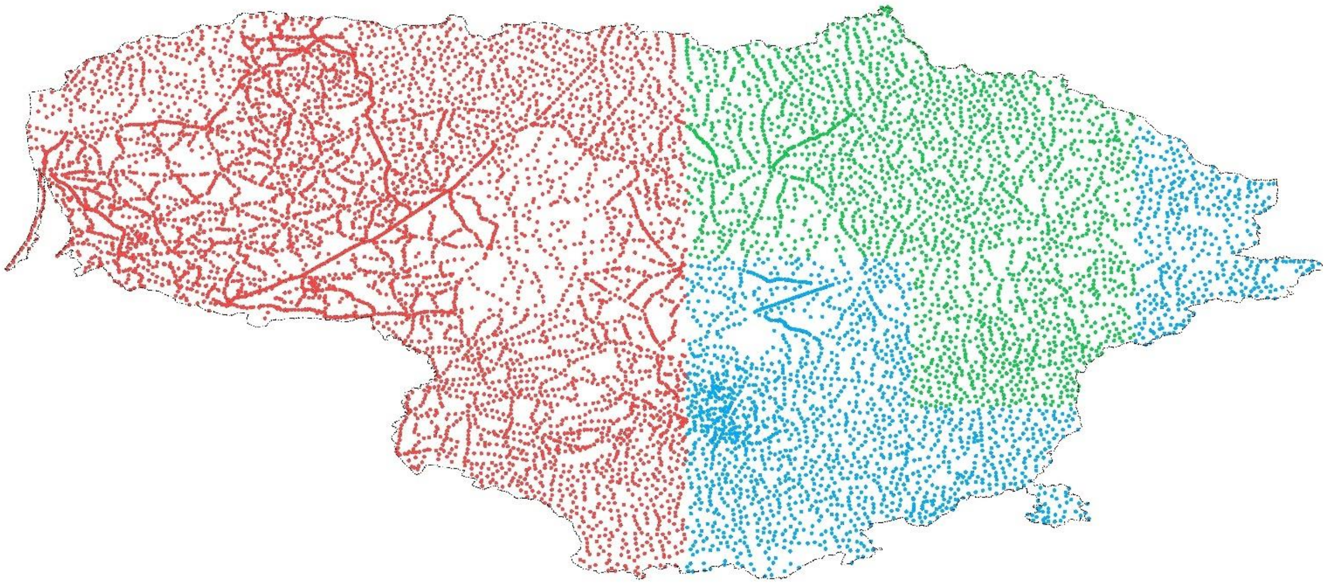

Figure 1: Distribution of the historical gravimetric points in the territory of investigation and compilation. Colours indicate the types of map sheets used in the compilation (see Figure 5).

Similar gravity data sets ~~were~~ compiled at countrywide (APAT, 2005; Basic and Bjelotomic, 2014; Csapó et al., 2000; Martelet et al., 2009; Meurers and Ruess, 2009; Stopar, 2016), regional (Zahorec, 2020; Bielik et al., 2006; Denker and Torge, 1998; Denker and Roland, 2005; Ågren et al., 2016) and global scales (Förste et al., 2014; Pavlis et al., 2012).

2 Experimental design, materials and methods

2.1 Historical gravity data sources

The historical gravity data set is based on two gravity data sources:

- Second and third order gravity network stations (18 and 105 gravimetric stations);
- Gravimetric ~~map~~ at a scale 1:200 000 (10 660 gravimetric points).

The data of the second and third order gravity network stations were collected by digitising the catalogues of the gravimetric stations. Distribution of the second and third order gravimetric stations in the territory of Lithuania is presented in the Figure 2.

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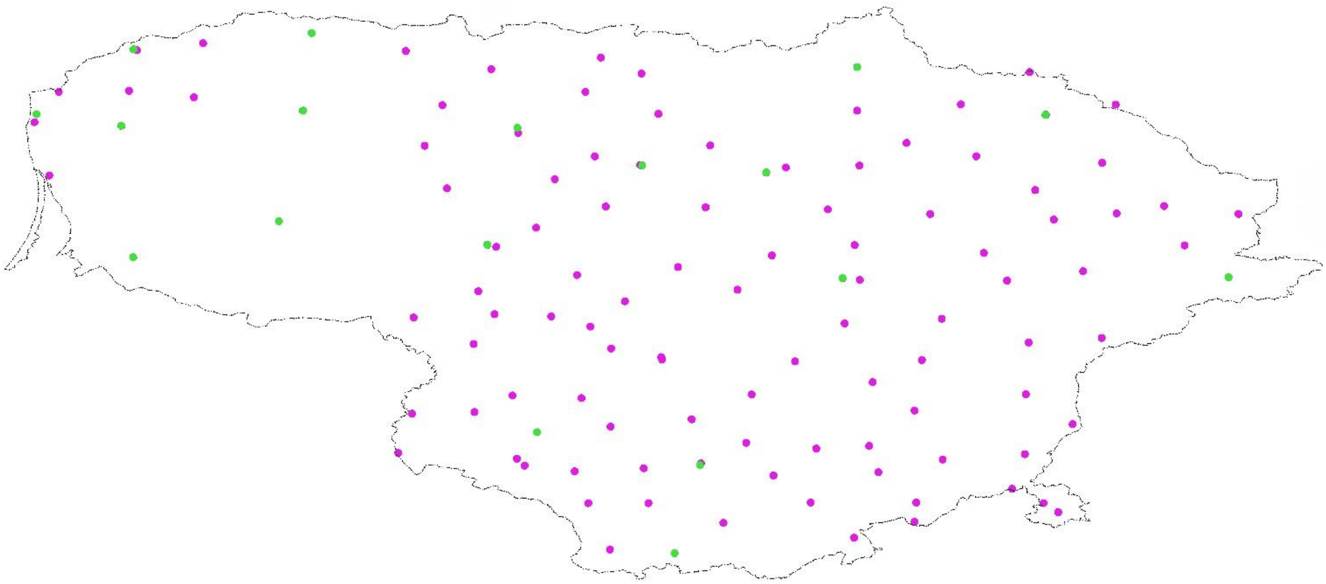

Figure 2: Distribution of the second and third order gravimetric stations (green dots – second order stations; magenta dots – third order stations).

The gravimetric measurements ~~of the acceleration due gravity~~ were carried out by relative gravimeters ГАК-3М, ГАК-4М, ГАК-ПТ, ГАК-7Т. The standard deviation of the accelerations due to gravity does not exceed 0.35 mGal (Birvydienė, 2010). The coordinate reference system of Pulkovo 1942 (EPSG code 2499), the Krassowsky ellipsoid of 1940 (EPSG code 7024) and Baltic normal height system of 1977 (EPSG code 5705) were used for positioning of gravimetric points. The accelerations due gravity were expressed in Potsdam system and ~~applying~~ Helmert normal gravity field.

The gravimetric map was based on data from the gravimetric survey carried out in period from 1951 till 1962 (Birvydienė, 2010). Gravimetric measurements ~~of the accelerations due to gravity~~ were performed by relative gravimeters СН-3, ГКА, ГАК-3М, ГАК-4М, ГКМ. Normal heights of the gravimetric points were measured by geometric - barometric levelling or ~~detected~~ from topographic ~~map~~ at a scale of 1:25000. The third class gravimetric network was used as base for the map. The coordinate reference system of Pulkovo 1942 (EPSG code 2499), the Krassowsky ellipsoid of 1940 (EPSG code 7024) and Baltic height system of 1977 (EPSG code 5705) were used for positioning of gravimetric points. On the basis of this gravity survey, the gravimetric map at a scale 1:200 000 was constructed applying Gauss-Krüger projection (EPSG code 2499). ~~The fragments~~ of the gravimetric ~~map~~ are presented in the Figure 3 and 4.

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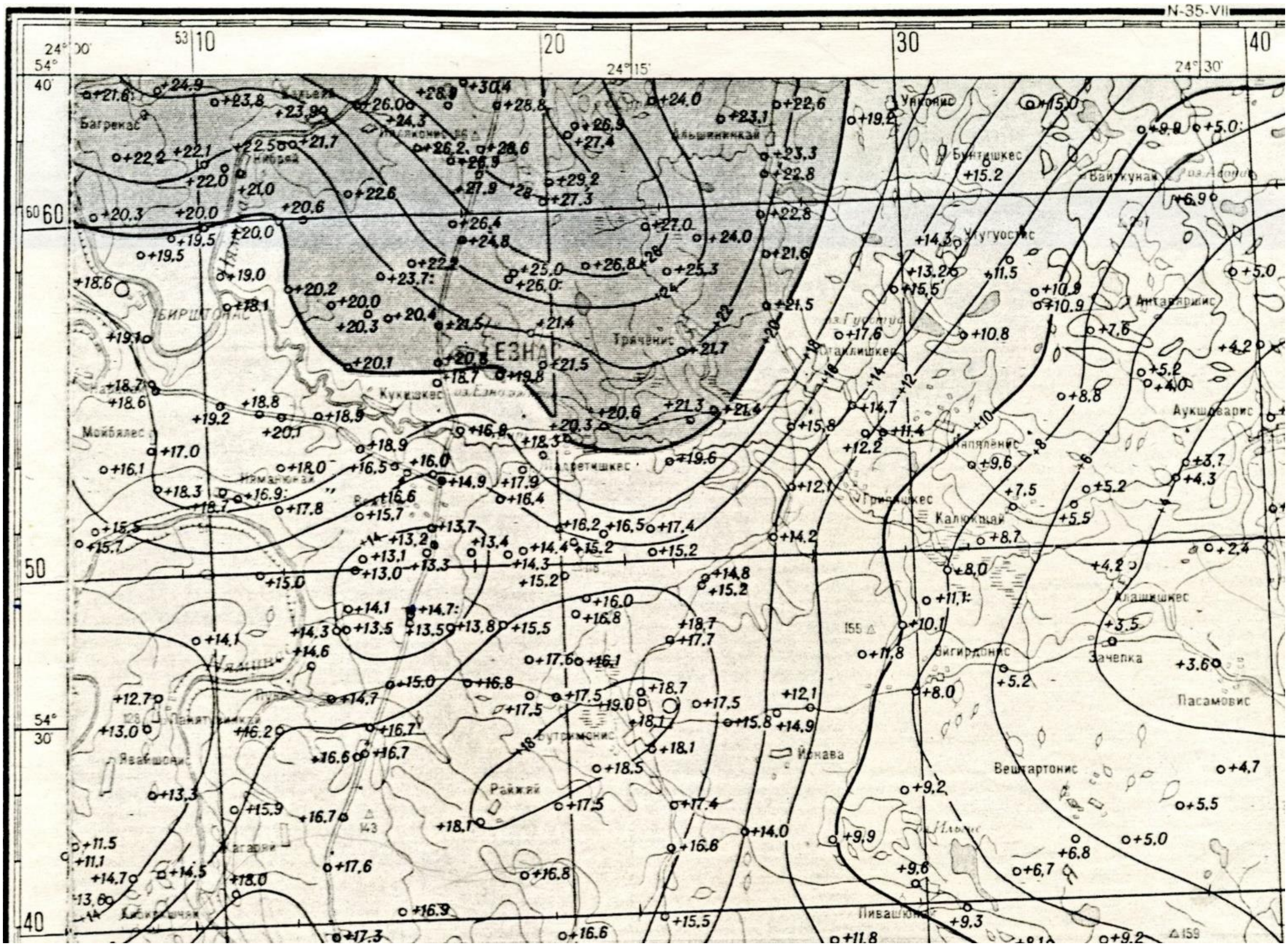

Figure 3: ~~Fragment~~ of the gravimetric map at a scale 1:200 000. (The firm, 1965).

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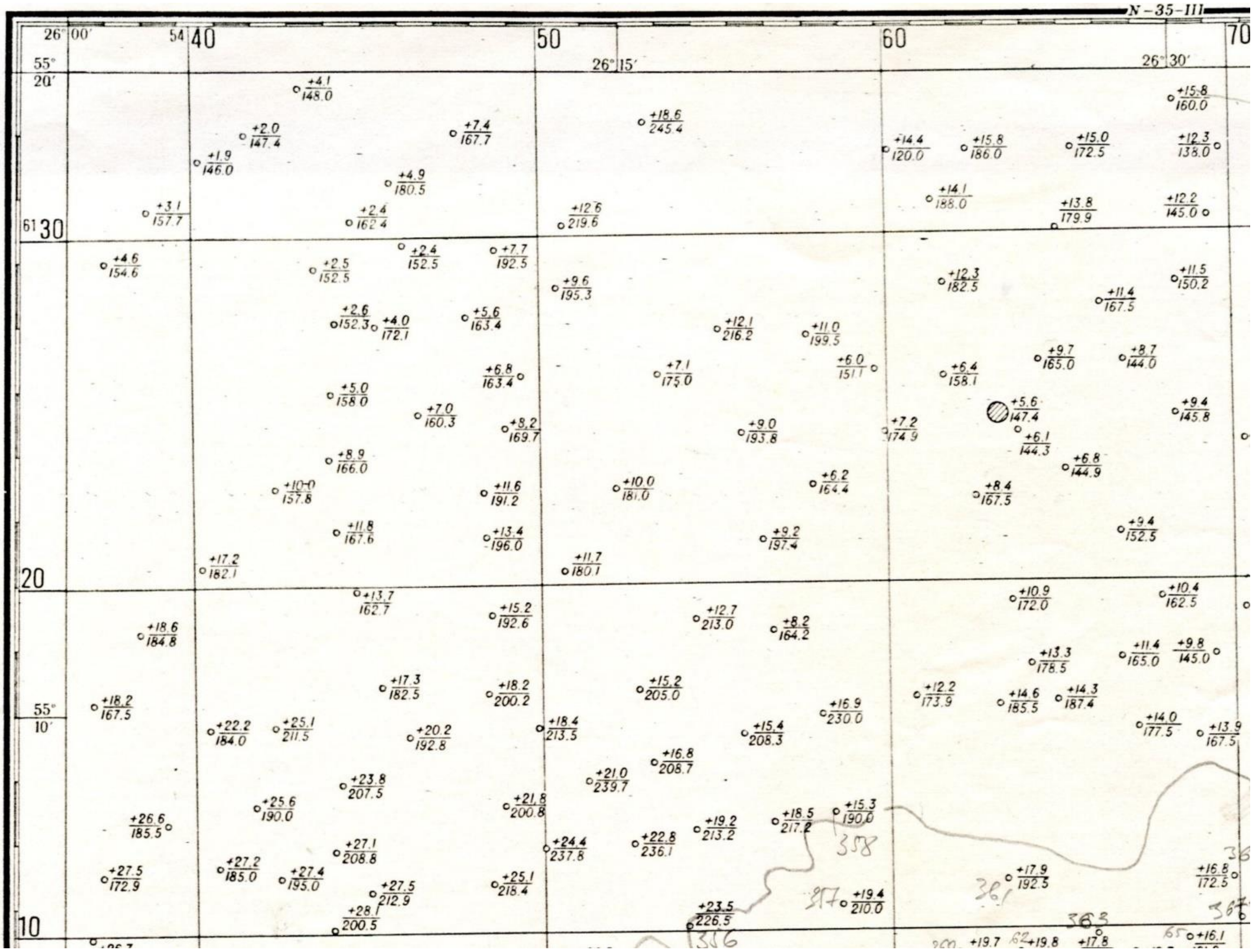

Figure 4: ~~Fragment~~ of ~~the~~ gravimetric map at a scale 1:200 000 containing the Bouguer anomalies and normal heights of gravimetric points. (The firm, 1965).

The Bouguer anomalies due to gravity were written at each point in the map. The total number of gravimetric points is 10 663. The Helmert's formula for the estimation of normal gravity field and the density of the Earth's crust $\delta = 2.3\ g \cdot cm^{-3}$ were used for calculations of the anomalies due gravity. The gravity field is presented by isolines at every 2 mGal. The Bouguer anomalies due to gravity were calculated following Eq. (1) (Torge, 1989):

$$\Delta g_P^B = g_P - \gamma_H^0 + 0.3086 H_{77} - 0.0419\ \delta \cdot H_{77}, \quad (1)$$

where g_P– Potsdam system gravity acceleration measured at the point on the Earth surface; γ_H^0– the acceleration of Helmert normal gravity field on equipotential ellipsoid surface, H_{77} - normal height at point on the Earth's surface in the Baltic Height System of 1977. The accelerations of Helmert's normal gravity field on equipotential ellipsoid surface were obtained following Eq. (2) (Petroškevičius, 2004):

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$$\gamma_H^0 = 978030\,(1 + 0.005302\,sin^2\,B_{42} - 0.000007\,sin^2\,2\,B_{42}),\qquad(2)$$

where B_{42} – the latitude of gravimetric point in Pulkovo 1942 coordinate reference system.

75 Unfortunately the number of the map sheets containing normal heights of the gravimetric points was very limited (Fig. 5).

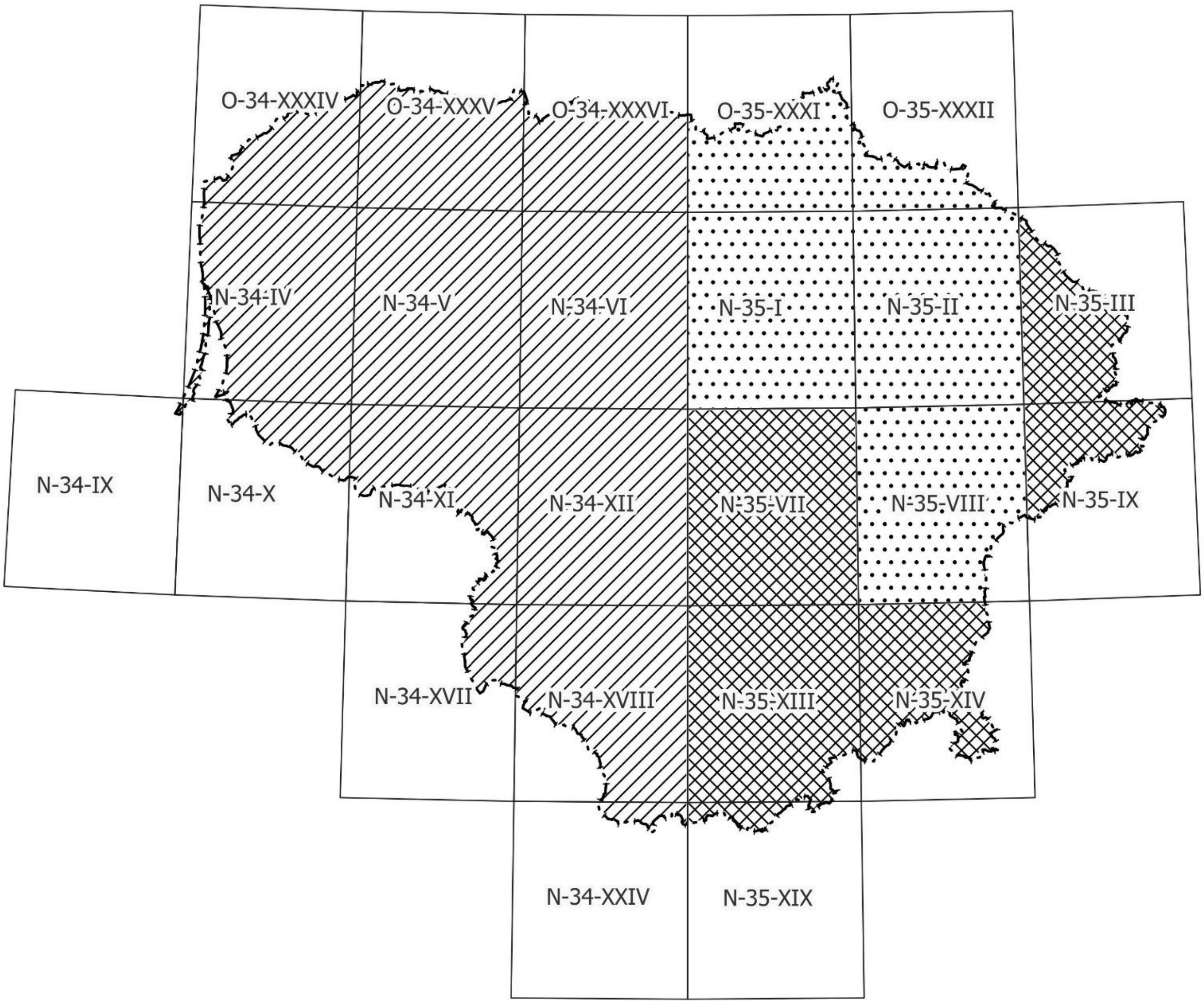

Figure 5: Types of map sheets to detect the normal heights of the gravimetric points. ~~Colours~~ indicate the types of map sheets used in the compilation: green – map sheets containing the normal heights; blue – normal heights derived from Bouguer anomalies and free air anomalies; red – normal heights interpolated from topographic map.

80 To ~~detect~~ the normal heights of gravimetric points ~~the additional two sources were employed~~:

- Paper map sheets at a scale 1:200 000 ~~containing the~~ free air anomalies ~~due gravity~~ (Fig. 6) leading by maps sheets, containing the normal heights of gravimetric points (Fig. 7).

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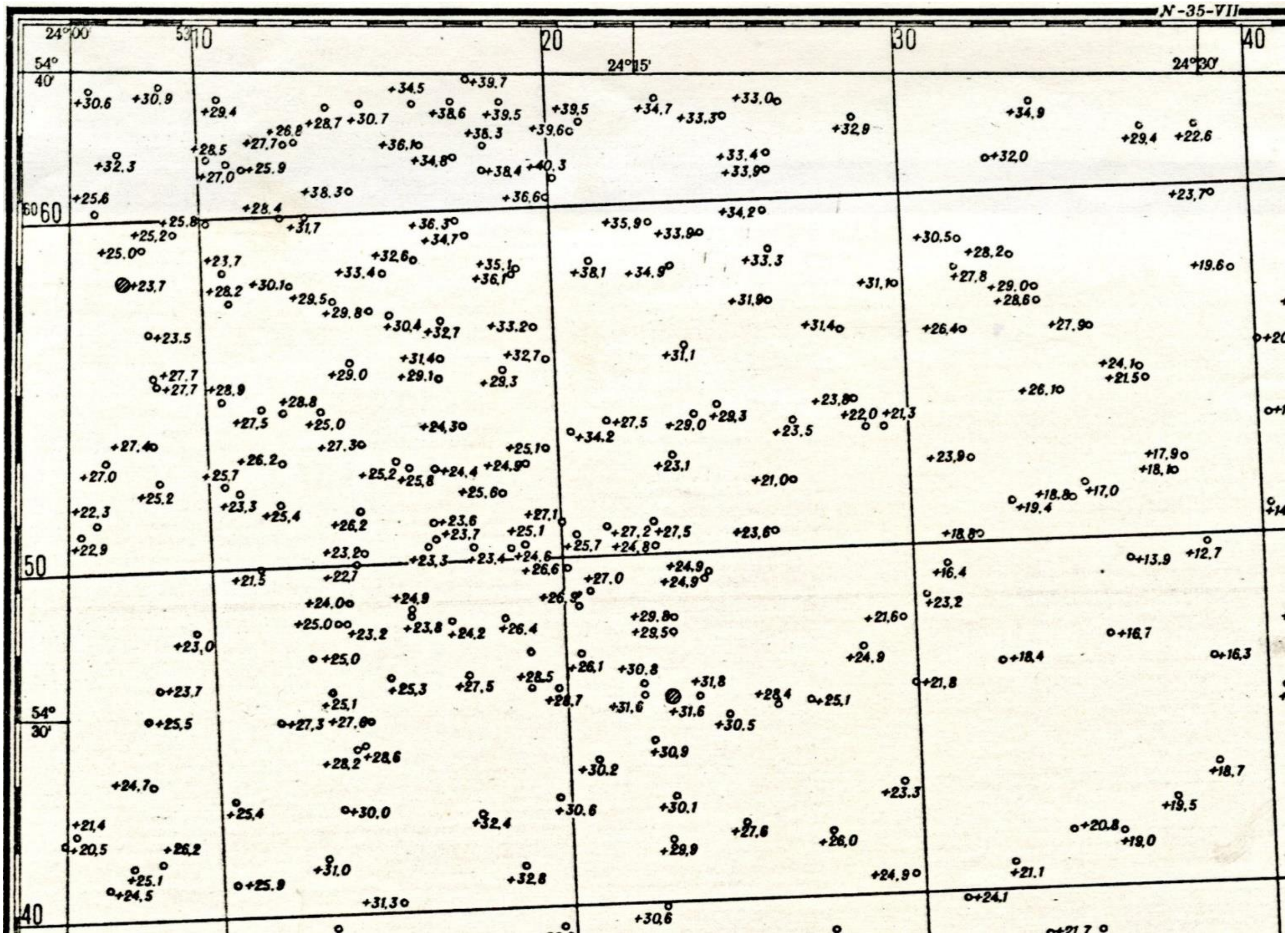
- Paper map sheets of the topographic map at a scale 1:10 000 (Fig. 8).



85 **Figure 6: ~~Fragment~~ of ~~the~~ map sheet containing the free air anomalies ~~due gravity~~. (The firm, 1965).**

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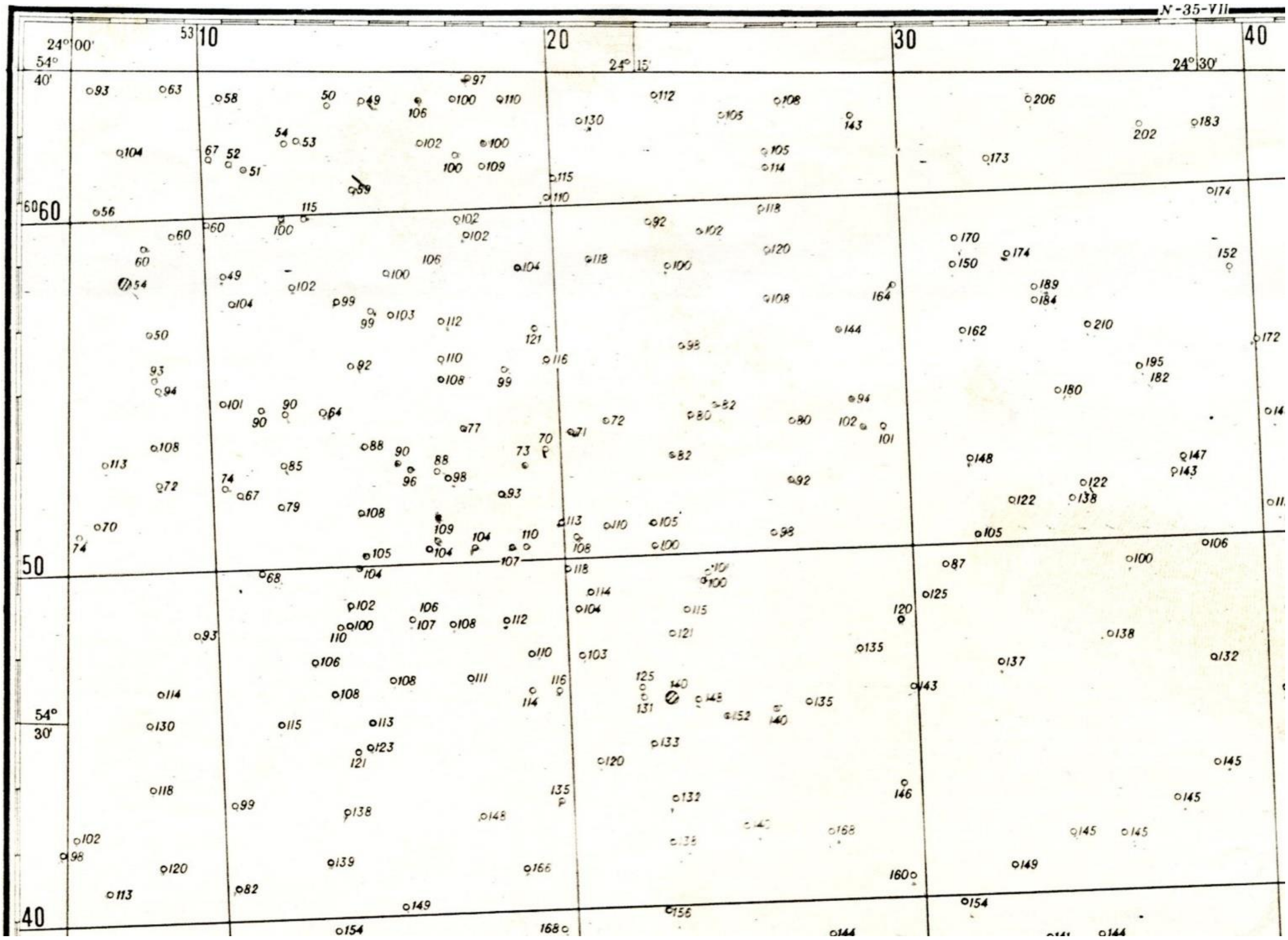

Figure 7: ~~Fragment of the~~ map sheet containing the normal heights of gravimetric points. (The firm, 1965).

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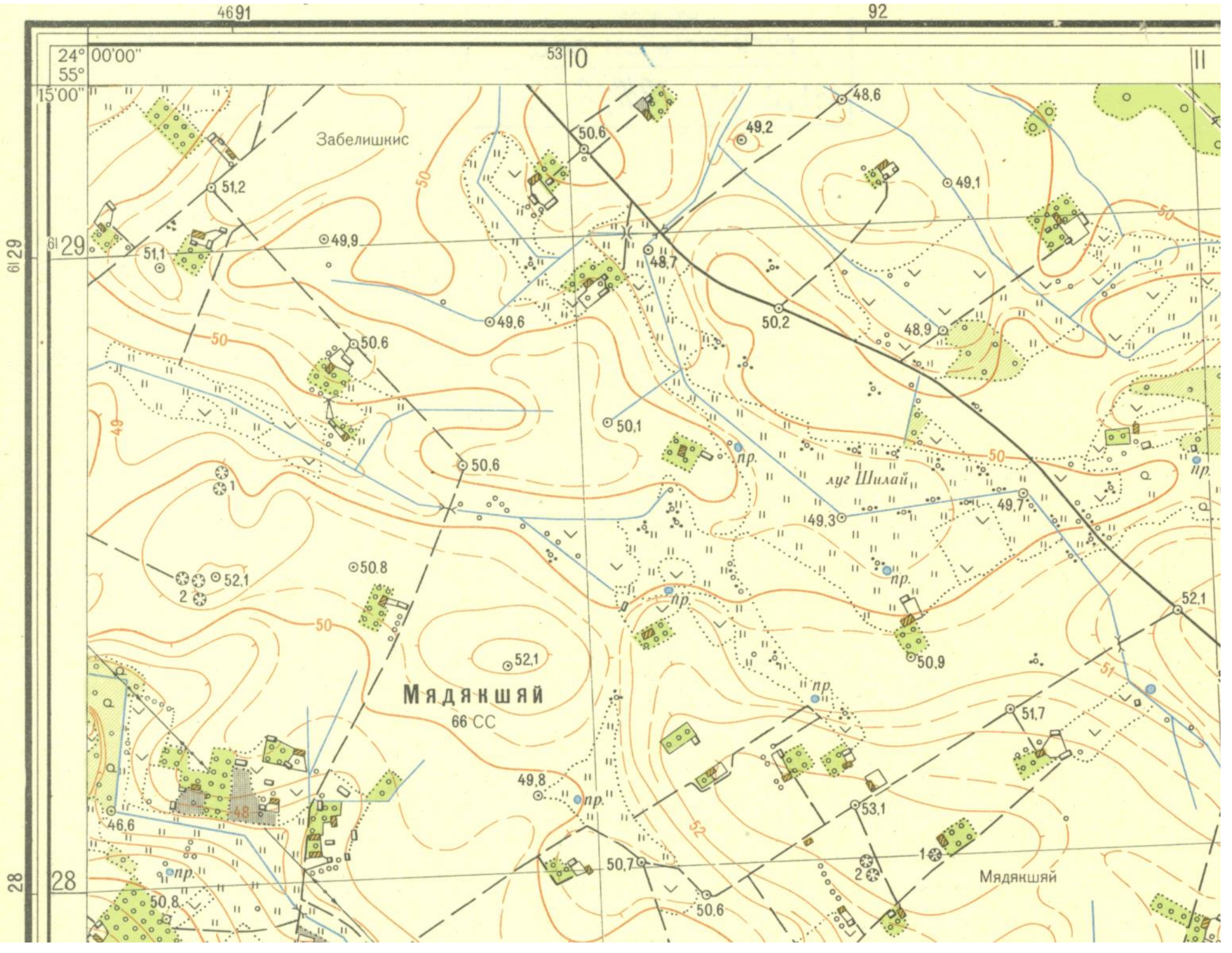

Figure 8: ~~Fragment of the~~ topographic map sheet at a scale 1:10 000. (Topographic, 1958)

2.2 Modern compilation of the historical gravity data set

~~Modern~~ compilation of the historical gravity data set includes three items:

- Introduction the European Terrestrial Coordinate System of 1989 (ETRS89).
- Introduction the European Vertical Reference System of 2007 (EVRS07).
- Introduction the International Gravity Standardization Net of 1971 gravity system (IGSN71).

2.2.1 Introduction the coordinate reference system ETRS89

One of the key problems in the unification of gravimetric databases is the homogenization of position, height and gravimetric coordinate systems used in each database. Through its historical development, each country has used and sometimes still uses

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local systems and their realisation (frame), which are often based on the established principles of reference systems using older ellipsoids or older geodetic reference networks and projections. These systems and their realisations thus contain several differences, which are responsible for large inhomogeneities, shifts, errors in position, height, and gravity. These errors are most evident in the mutual comparison of data from individual countries.

To avoid these problems in the position of gravimetric points, all position data were transformed from local systems to the global system, i.e., the European Terrestrial Reference System 1989, which is accurate, homogeneous, and recommended for all European countries (Altamimi and Collilieux, 2024). A similar situation is in the height systems where countries use different types of physical heights, they are linked to different tide gauges and each country has a different practical implementation of the relevant height system (EVRS, 2020). The solution is again transformation to a uniform platform in the form of ellipsoidal heights in the ETRS89 system based on the ellipsoid GRS80 (Moritz, 1984; Moritz, 2000). The situation is similar in gravimetric reference systems, where especially the gravimetric databases that have been created for decades often use old gravimetric systems connected to the Potsdam system. An important step was therefore to convert these data into gravimetric systems, which are connected to absolute gravimetric points and measurements, such as IGSN71 (Morelli et al., 1972) or modern national systems connected with the recent absolute measurements, which are verified by international comparisons of absolute gravimeters (Francis et al., 2015).

The Coordinate Reference System of gravimetric points both from the catalogues and from gravimetric map was Pulkovo 1942 system (EPSG code: 2499). To express the geodetic coordinates of the points in modern European Terrestrial Reference System of 1989 (ETRS89, EPSG code: 4258) the three steps algorithm was employed. In the first step the geocentric coordinates of the gravimetric points were calculated from the geodetic ellipsoidal coordinates expressed in Pulkovo 1942 system applying formulas from (Schödlbauer, 1981; Schödlbauer, 1982; Annoni et al., 2001).

Algorithm. Conversation the ellipsoidal coordinates to the rectangular geocentric coordinates.

Input. The ellipsoidal coordinates: geodetic latitude B_{42}, geodetic longitude L_{42}, ellipsoidal height H_e^K and parameters of ellipsoid a and f (in our case – Krassowsky 1940 ellipsoid: a=6378245 m, f=298.3).

Output. The rectangular geocentric coordinates $X'_{42}, Y'_{42}, Z'_{42}$.

Calculation formulaes (CRS-Geo, 2025):

$$X'_{42} = (N_K + H_e^K) \cos B_{42} \cos L_{42}, \tag{3}$$

$$Y'_{42} = (N_K + H_e^K) \cos B_{42} \sin L_{42}, \tag{4}$$

$$Z'_{42} = (N_K + H_e^K - N_K e^2) \sin B_{42}, \tag{5}$$

where

$$N_K = \frac{a}{\sqrt{1 - e^2 \sin^2 B_{42}}}, \tag{6}$$

$$e^2 = 2 \cdot f - f^2. \tag{7}$$

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Example. The Pulkovo 1942 (Krassowsky 1940 ellipsoid) ellipsoidal coordinates of gravimetric point are: B42 = 55° 15' 22.9", L42 = 23° 52' 26.1", H_e^K = 22.4 m. Calculated rectangular geocentric coordinates are:

X'_{42} = 3331529.1 m, Y'_{42} = 1474516.4 m, Z'_{42} = 5217810.9 m.

In the second step the geocentric coordinates of the gravimetric points expressed in Pulkovo 1942 system were transformed to ETRS89 geocentric coordinates applying standard Helmert's seven parameters transformation formula (Reit, 2009)

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} \delta x \\ \delta y \\ \delta z \end{pmatrix} + R \begin{pmatrix} X' \\ Y' \\ Z' \end{pmatrix} (1 + \delta m), \tag{8}$$

where X_{89}, Y_{89}, Z_{89} – rectangular geocentric coordinates of the points in ETRS89 system, X'_{42}, Y'_{42}, Z'_{42} – rectangular geocentric coordinates of the same points in Pulkovo 1942 system, R – matrix of rotations:

$$R = \begin{pmatrix} 1 & +\omega_z & -\omega_y \\ -\omega_z & 1 & +\omega_x \\ +\omega_y & -\omega_x & 1 \end{pmatrix}. \tag{9}$$

Values of the transformation parameters between Pulkovo 1942 and ETRS89 systems were derived by analysing the geocentric coordinates of 45 geodetic points, evenly distributed ~~in the territory of a country~~ (Fig. 9).

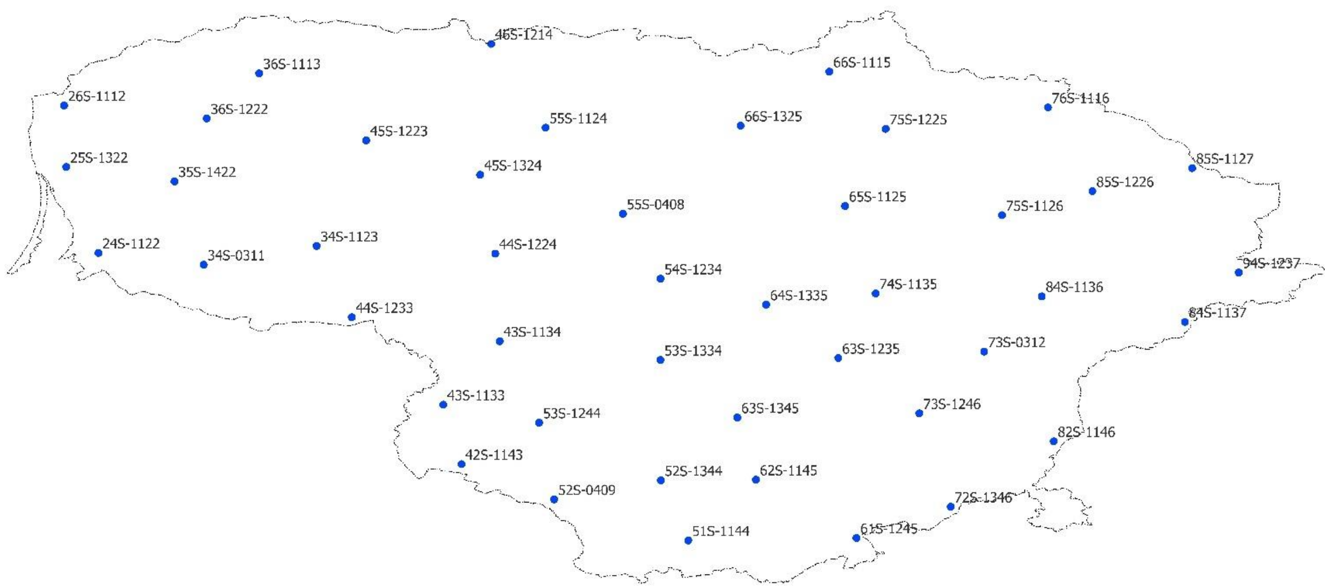

Figure 9: Distribution of geodetic points used for the transformation parameters calculation

Values of the transformation parameters applied to geodetic coordinates of the gravimetric points ~~of~~ gravity data set:

δx = -40.5953 m;

δy = -18.5498 m;

δz = -69.3396 m;

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ω_x = -0.0000121590 rad;

ω_y = -0.0000088812 rad;

ω_z = +0.0000126606 rad;

δm = -0.0000042991.

Example. Input: geocentric coordinates in CRS Pulkovo 1942:

X'_{42}= 3331529.1 m, Y'_{42} = 1474516.4 m, Z'_{42} = 5217810.9 m.

Output: geocentric coordinates in CRS ETRS89:

X_{89} = 3331567.8 m, Y_{89} = 1474398.6 m, Z_{89} = 5217752.3 m

In the third step the ETRS89 ellipsoidal coordinates were calculated from the ETRS89 geocentric coordinates applying formulas from (Schödlbauer, 1981; Schödlbauer, 1982; Annoni et al., 2001):

Algorithm. ~~Conversation~~ the rectangular geocentric coordinates to the ellipsoidal coordinates.

Input. The rectangular geocentric coordinates X_{89}, Y_{89}, Z_{89} and parameters of ellipsoid a and f (in our case parameters of GRS80 ellipsoid, a= 6378137 m, f =298.257222101 (Moritz, 1984; Moritz, 2000).

Output. The ellipsoidal coordinates: geodetic latitude B_{89}, geodetic longitude L_{89} and ellipsoidal height H_e^{80}.

Calculation formulaes:

$$L_{89} = arctg(Y_{89}/X_{89}); \tag{10}$$

Initial geodetic latitude:

$$B_0 = arctg(Z_{89}/\ ((1 - e_{80}^2)\ (X_{89}^2 + Y_{89}^2))^{1/2}); \tag{11}$$

where

$$e_{80}^2 = 2 \cdot f - f^2. \tag{12}$$

Iterations till $B_i - B_{i-1} > \Delta$, where Δ is appropriately chosen value defining the necessary precision of latitude B (in our case Δ *=0.1"*):

$$N_i = \frac{a}{\sqrt{1 - e_{80}^2 \sin^2 B_{i-1}}}; \tag{13}$$

$$H_i^e = \frac{Z}{\sin B_{i-1}} - (1 - e_{80}^2) N_i, \tag{14}$$

$$B_i = arctg\left(\frac{Z_{89}}{(X_{89}^2 + Y_{89}^2)^{1/2}} \cdot \frac{1}{1 - (e_{80}^2 N_i)/(N_i + H_i^e)}\right). \tag{15}$$

Example. The rectangular geocentric coordinates of gravimetric point are:

X_{89} = 3331567.8 m, Y_{89} = 1474398.6 m, Z_{89}= 5217752.3 m.

Calculated ETRS89 (GRS80 ellipsoid) ellipsoidal coordinates are:

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$B_{89} = 55°15'22.2''$, $L_{89} = 23°52'19.1''$, $H_e^{80} = 77.1$ m.

2.2.2 Introduction the European Vertical Reference System EVRS07

EVRS07 (EPSG: 5215) is realized by geopotential numbers and normal heights of the United European Levelling Network (UELN) (Sacher et al., 2008; Ihde et al., 2008; Dragomir et al., 2011). The newest realisation of EVRS is EVRF2019 (EPSG: 1274). EVRF2019 is a zero-tide surface (Sacher and Liebsch, 2019). It should be noted~~,~~ that difference between two ~~realisation~~ in Lithuania ~~territory~~ is about 1 cm only and for calculations of ~~histrical~~ gravity data set is negligible. Federal Agency for Cartography and Geodesy (BKG – Bundesamt für Kartographie und Geodesie), Germany, and the Reference Frame Sub-Commission for Europe (EUREF) have developed a formulae for transformation between the local height (vertical) systems and European Vertical Reference System of 2007 (Celms et al., 2014; Kadaj, 2018; Dragomir et al., 2011). In the historical gravity data set the normal heights of gravity points were expressed in Baltic Heights System of 1977 referred to tide gauge Kronstadt (BHS77). Formulae to transform BHS77 normal height to EVRS07 normal height is as follow Eq. (16):

$$H_{07} = H_{77} + \alpha_1 + \alpha_2 M_0 (B_{89} - B_0) + \alpha_3 N_0 (L_{89} - L_0) cos B_{89}, \quad (16)$$

where

H_{07} – normal height referred to EVRS07 vertical system;

H_{77} – normal height referred to BAS77 height system;

$P_0(B_0, L_0)$ – origin for the height transformation in Lithuania with geodetic latitude and longitude in ETRS89 CRS;

M_0 – radius of curvature in the meridian at the point P_0;

N_0 – radius of curvature of the prime vertical at the point P_0;

α_1 – coefficient of the displacement in vertical direction;

α_2 – coefficient of the slope along meridian;

α_3 – coefficient of the slope along prime vertical;

B_{89} – latitude of the point to transform;

L_{89} – longitude of the point to transform;

The formulas for M_0 and N_0 can be found in number of sources, for example (Tobler, 1964; Lenart, 2013; Lenart, 2017):

$$N_0 = \frac{a}{\sqrt{(1 - e_{80}^2 sin^2 B_0)}};$$

$$M_0 = \frac{a(1 - e_{80}^2)}{(1 - e_{80}^2 sin^2 B_0)^{3/2}} = \frac{N_0(1 - e_{80}^2)}{1 - e_{80}^2 sin^2 B_0}$$

where a – semimajor axis and e_{80}^2 – squared first eccentricity of GRS80 ellipsoid (Eq. 12).

Distribution of the common points used for calculation of the transformation parameters is shown in Fig. 10.

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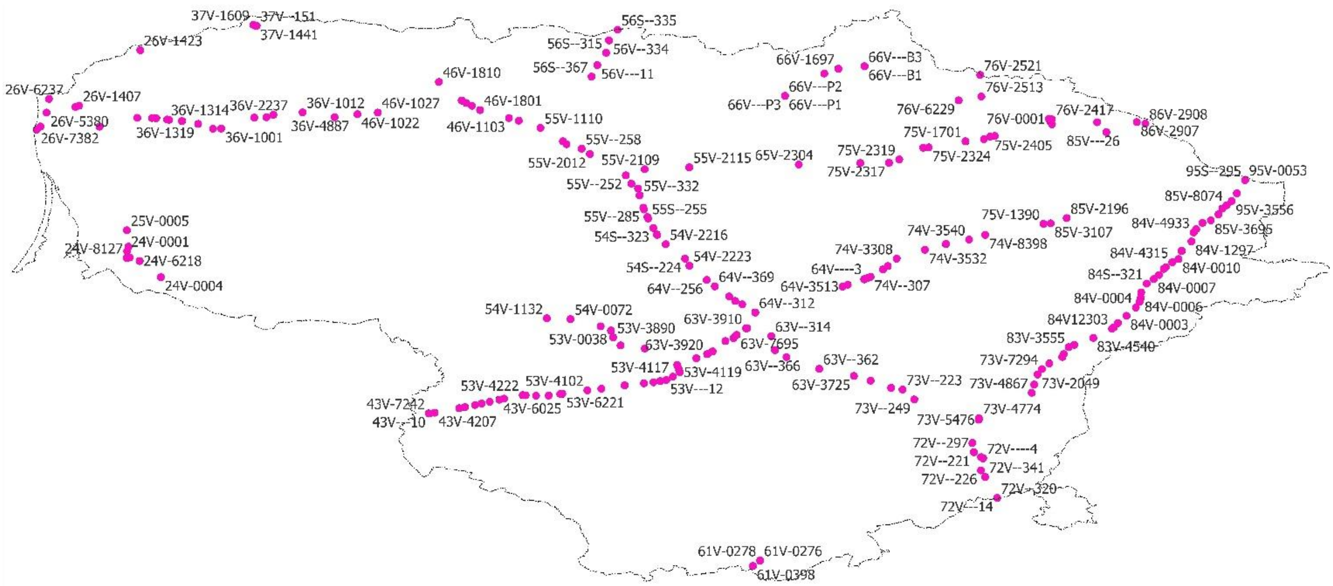

Figure 10. Distribution of the common points used for calculation of the transformation parameters (233 points)

In total there are 233 height benchmarks in ~~the territory of~~ Lithuania for which normal heights could be found in both height systems. Parameters of transformation between BHS77 and EVRS07 were received as follow:

$B_0 = 55°18'$; $L_0 = 24°01'$; $\alpha_1 = 0.1425$ m; $\alpha_2 = 0.06076"$; $\alpha_3 = 0.03375"$.

The minimum value of residuals equal to -0.025 m and maximum value equal to +0.024 m were obtained. The standard deviation of transformation equal to 0.013 m was derived.

Example:

$B_{89} = 55°42'$; $L_{89} = 24°21'$; $H_{77} = 55.90$ m ; $H_{07} = 56.06$ m.

2.2.3 Introduction the Gravity system IGSN71

The values of accelerations due to gravity g_p, digitised from catalogues and referred to the Potsdam gravity system were recalculated to the IGSN71 system (g_{71}) by simple deduction of 14.0 mGal as a difference between two gravity systems (Wollard, 1979; Torge, 1989; Petroskevicius, 2004):

$$g_{71} = g_p - 14.0, \tag{17}$$

Further, the free air anomalies due to gravity were calculated following Eq. (18):

$$\Delta g_{71}^F = g_{71} - \gamma_{80}^0 - \Delta\gamma, \tag{18}$$

where γ_{80}^0 – the accelerations of GRS80 normal gravity field on equipotential ellipsoid surface:

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$$\gamma_{80}^{0} = \gamma_{80e}^{0} \frac{1+k_{80} \sin^2 B_{89}}{\sqrt{1-e_{80}^2 \sin^2 B_{89}}}, \quad (19)$$

where γ_{80e}^{0}, e_{80}, k_{80} – parameters of GRS80 normal gravity field (Moritz, 2000); γ_{80e}^{0}= 978032.67715 mGal; e_{80}^{2}= 0.00669438002290; k = 0.001931851353; B_{89} – latitude of gravimetric point in ETRS89 system.

Corrections due normal heights H_{07} were calculated following Eq. (20):

$$\Delta\gamma = -0.30855(1 + 0.00071 \cos(2B_{89}))H_{07}. \quad (20)$$

Standard deviations of free air gravity anomalies were calculated following Eq. (21):

$$m_l = \sqrt{m_g^2 + m_{\gamma^0}^2 + m_{\Delta\gamma}^2}, \quad (21)$$

where m_g - standard deviation of measured gravity acceleration (from the catalogue), m_{γ^0} - standard deviation of normal gravity acceleration ($m_{\gamma^0} = 1.4m'_B$, m'_B - standard deviation of geodetic latitude in minutes), $m_{\Delta\gamma}$ - standard deviation of free air reduction ($m_{\Delta\gamma} = 0.30855\, m_H$, m_H – standard deviation of normal height in meters).

Bouguer anomalies due to gravity were calculated following Eq. (22):

$$(\Delta g_{71}^{B})_{2.67} = \Delta g_{71}^{F} - \Delta g_{2.67}, \quad (22)$$

where correction for ~~endless intermediate layer~~ was calculated following Eq. (23):

$$\Delta g_{2.67} = -2\pi \cdot G \cdot \delta \cdot H_{07}, \quad (23)$$

where Newtonian gravitational constant $G = 6.6743 \cdot 10^{-8} cm^3 g^{-1} s^{-2}$, density of the Earth's crust $\delta = 2.67\ g \cdot cm^{-3}$.

Example: $g_p = 981552.8$ mGal ; $H_{07} = 125.0$ m ; $B_{89} = 55°59.3'$; $g_{71} = 981538.8$ mGal ; $\Delta g_{71}^{F} = -13.67$ mGal ; $(\Delta g_{71}^{B})_{2.67} = -27.67$ mGal; $m_B = 0.1$'; $m_H = 0.5$ m; $m_l = 0.7$ mGal.

~~In case of gravimetric map~~ the values of accelerations due to gravity in IGSN71 system were calculated following Eq. (24):

$$g_{71} = (\Delta g_{P}^{B})_{2.3} + \gamma_{H}^{0} - \Delta\gamma - \Delta g_{2.3} - 14.0, \quad (24)$$

where $(\Delta g_{P}^{B})_{2.3}$ – Bouguer anomalies due gravity digitised from gravimetric map sheets and referred to the Potsdam gravity system, γ_{H}^{0} – normal gravity value, $\Delta\gamma$ – correction due normal height (Eq. 20), $\Delta g_{2.3}$ – correction for ~~endless intermediate layer~~:

$$\gamma_{H}^{0} = 978030 \cdot (1 + 0.005302 \sin^2 B_{89} - 0.0000070 \sin^2(2B_{89})), \quad (25)$$

$$\Delta g_{2.3} = -0.0419277 \cdot \delta \cdot H_{07}, \quad (26)$$

where density of the Earth's crust $\delta = 2.3\ g \cdot cm^{-3}$.

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In case when the normal heights of the gravimetric points are unknown, the normal heights in BHS77 system were calculated from values of free air anomalies and Bouguer anomalies following Eq. (27):

$$H_{77} = [\Delta g_P^F - (\Delta g_P^B)_{2.3}]/0.09637 \quad (27)$$

where Δg_P^F – free air anomaly ~~due gravity~~ (from gravimetric map of free air gravity anomalies ~~due gravity~~), $(\Delta g_P^B)_{2.3}$ – Bouguer anomaly ~~due gravity~~ (from gravimetric map of Bouguer anomalies due gravity).

Example: $\Delta g_P^F = 4.1$ mGal; $(\Delta g_P^B)_{2.3} = 3.1$ mGal; $H_{77} = 10.4$ m.

Further, the free air and Bouguer anomalies ~~due to gravity~~ were calculated following Eq. (18 and 22).

Example: $B_{89} = 55°59.1'$; $H_{07} = 10.4$ m; $(\Delta g_P^B)_{2.3} = 3.1$ mGal; $\Delta g_{71}^F = -13.8$ mGal; $(\Delta g_{71}^B)_{2.67} = -14.99$ mGal; $m_{Bg} = 0.7$ mGal; $m_H = 0.5$ m; $m_l = 0.7$ mGal.

Figure 11 shows the spatial distribution of gravimetric points of all countrywide historical gravity data set.

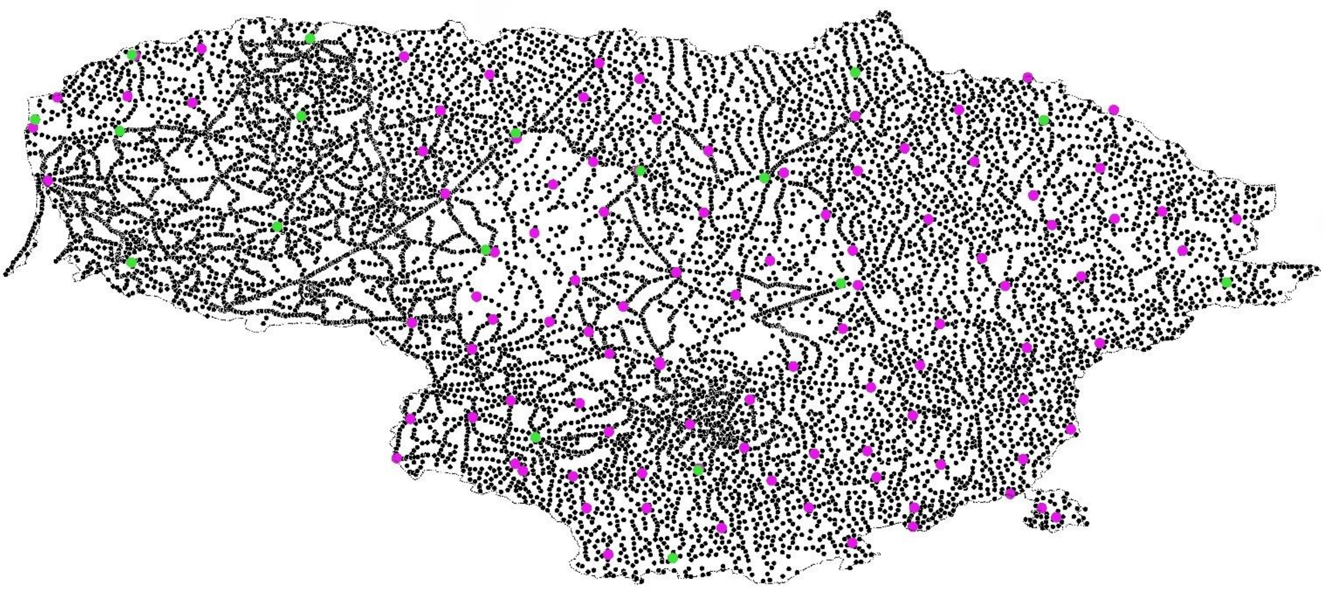

Figure 11. Spatial distribution of gravimetric points of all historical gravity data set (green dots – second order stations; magenta dots – third order stations; black dots – gravity survey points).

3 Data availability

The historical gravity data set is available in the ZENODO repository at https://doi.org/10.5281/zenodo.15090241 (Šlikas et al., 2025). The data were recorded into files applying DBF (Data Base Format) format (Digital, 2012). The database structure is presented in Table.

The database structure of the historical gravity data set

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No.	Field name	Field type	Data format	Description	Example
1	PNUMB	N	8	Point number	100002
2	B_89	N	8,5	ETRS89 latitude, degrees	55.330333
3	L_89	N	8,5	ETRS89 longitude, degrees	21.342667
4	HN_07	N	6,2	EVRS07 normal height, m	1.04
5	GA_71	N	9,2	IGSN71 Gravity acceleration, mGal	981510.96
6	FAA	N	6,2	Free air anomaly due to gravity, mGal	-24.24
7	ABUG_27	N	6,2	Bouguer anomaly due to gravity, mGal	-24.36
8	GA_RMSE	N	4,2	Root mean square error of gravity acceleration, mGal	0.70

4 Conclusions

1. In this study, the countrywide historical gravity data set was compiled. It consists of two database files: data of gravity network points (123 stations) and data of gravity survey (10660 points). The estimated accuracy of gravity network stations is about 0.2 mGal (second order stations) and 0.35 mGal (third order stations), and accuracy of the gravity survey points is about 0.7 mGal.
2. The transformation parameters and algorithms to introduce the European Terrestrial Coordinate System of 1989 (ETRS89), European Vertical Reference System of 2007 (EVRS07) and International Gravity Standardization Net of 1971 gravity system (IGSN71) were defined.
3. These data are useful in understanding the gravity field of territory of the entire country and could be used for quasi-geoid modelling and creating the geopotential models. Researchers will benefit during evaluation and accuracy estimation of developed products using high precision data of gravity network points.

Author contributions. All the authors contributed to recovering historical gravity data set and editing the manuscript. EP and RO designed the study, writing the manuscript. RB and DS did analysis and interpretation of the data. DS did compiled DBF files.

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