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Geo-gravimetric Quasi-geoid Determination over Romania

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Abstract

The project of modelling a quasigeoid for the area of Romania will run in stages, based on the relative gravimetric measurements made on the area of every county, in gravimetric points from the 0, 1st and 2nd order gravimetric network, GNSS and precision leveling measured checkpoints and also new designed points (determined with GNSS/RTK). Remove-compute-restore algorithm will be used for compiling the geo-gravimetric quasigeoid, used prior in the pilot project of modelling a quasigeoid for Bucharest area and also the method of collocation/minimum curvature for generating the anomalies grid.

In this article are presented the main activities that took place in the period 2016-2017 for creating the projects in the first counties of Romania and the results obtained till now as well as the perspective for the next years.

Keywords

gravimetric measurements, gravimetric network, modeling, quasigeoid

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Introduction

For accomplishing the HB.13 measure about the rehabilitation and modernization of the National Geodetic Network (RNG) of the precision leveling by determining a quasi-geoid for Romania’s area, part of the Institutional Strategic Plan approved by Order no. 763/ 05.16.2014 of the Minister of Regional Development and Public Administration according the strategy of the National Agency for Cadaster and Land Registration (NACLR), regarding the recommendations of the subcommittee EUREF of the International Association of Geodesy on improving European quasigeoid EGG2008 by gravimetric determination, geometric leveling and GNSS, the National Center of Cartography (NCC) will achieve in the next years the execution of the project "The determination of a quasigeoid for Romania’s area".

The project will be gradually developed, on the territory of each county, generally, aiming to provide the necessary elements for generating the quasigeoid determined on the territory of the whole country, by implementing and using the geo-gravimetric new technologies which will stand as the basis of it. In the project, the NCC will take relative gravimetric measurements on the gravimetric points of order 0, 1 and 2 for the transmission of gravity to the new determined points, on the checkpoints and control points in which geometric leveling determinations have been done and GNSS determinations within the project “Rehabilitation of the leveling precision network order I-II through recognition and GPS determinations in specific points”, consistent with national geodetic network (NGN) class D” or the NGN class B and C, also on new designed points developed to provide a uniform density and distribution of these points in order to generate the model of a gravimetric quasi-geoid.

The project aims to improve the grid of transformation on altitudes and to improve the digital elevation model and orthophotomap through which the topographical plan of Romania’s reference TOPRO 5 is updated – support for the implementation of the *National Programme for Cadaster and Land Book* and for carrying the acceptance of works for registration of real estates in the land book. An accurate 3D geospatial network will provide support and control of the implementation of advanced technologies in order to get the cadastral plans in cities / municipalities prescribed within the project LAKI II, by LIDAR flying and digital photogrammetric restitution.

1. The design of gravimetric works

During 2016-2017 there were developed gravimetric works in the form of projects which are carried out on the counties of Bihor, Arad, Hunedoara, Alba and Cluj, each project having some features based on the location of gravimetric points and their inclusion in the measurement loops, considering the relief of area of interest, the road network to reach gravimetric points etc.

For Bihor county, it was established that the layout of the gravimetric points will be achieved in a grid of squares with sides of about 8 Km per 8 Km.

The method of measuring is that of the loops closed on starting point with checking readings in specific points. In the image below, an excerpt from the gravimetric points’ layout map from the pilot-project in Bihor county is shown.

Fig. 1 The layout of the gravimetric points in the pilot project from Bihor County

2. Performing measurements

For making the gravimetric measurements, the following conditions have been taken into consideration:

- a work session (called loop composed) closes the point of departure over at about 6 hours;
- compulsory checking of the drift every three hours (simple loops);
- for each point 7 series of successive determinations (cycles) will be done, each of the lasting 60 seconds.

In order to get the measurement’s accuracy and the control of the measurements at least two links of the current loop with neighboring loops have been provided. For performing measurements during the projects were used Scintrex relative gravimeters - Autograv CG5 with 1 microGal reading resolution.

The image below presents a sequence of gravimetric measurements in a new point of a loop from the pilot- project in Bihor County.

Fig. 2 Performing gravimetric measurements in a new point of a loop

GNSS measurements were carried out for the new designed points and for the checkpoints were also carried out measurements of precision leveling.

3. Performing measurements

Pre-processing of gravity data involved removing erroneous measurements, the calculation of the averages of the raw readings, and applying the corrections to reduce the readings. For the accurate tidal corrections the ETGTAB, H.-G. Wenzel algorithm was used. To reduce the gravity value from the observation elevation to the top of the benchmark, free air correction was applied. To compensate long-periodic effects due to the deviations of the instantaneous pole from the Conventional International Origin, the reduction due to polar motion was applied.

4. Adjustment of relative gravity measurements

Reduced gravimetric data were placed in a functional model comprising independent readings and the form of the following equation

$$l(t) + v = g + N_0 + \Delta F(z) + D(t) \qquad (1)$$

in which:

- t - time measurement;
- l: reading low value of the instrument;
- v: correction;
- g: gravity value of the station;
- N_0: a constant bias;
- ΔF: (z) calibration function;
- z: reading gravimeter;
- *D(t):* function gravimeter drift

Gravimeter drift function was modeled with a polynomial form

$$D(t) = \sum_{p=1}^{a} d_p (t - t_0)^p \qquad (2)$$

where:

- t_0 is the initial epoch;
- a is the degree of the polynomial.

The advantage of using reduced gravity readings from functional model (1) up against the model with gravity differences in successive readings of the first model consists in the fact that the observations are uncorrelated.

Assuming that there are n number of measurements, observation equations of the form (1) are written in the form of a matrix

$\mathbf{L^b} + \mathbf{V} = \mathbf{AX}$, with the weighting matrix **P** (3)

where:

- $\mathbf{L^b}$: a vector containing the relative gravity measurements;
- V: a vector containing corrections;
- A: matrix coefficients;
- X: a vector containing the unknowns.

Using least-squares adjustment, it obtains the estimates of unknowns

$$\hat{\mathbf{X}} = (\mathbf{A^T P A})^{-1} \mathbf{A^T P L^b} \qquad (4)$$

and the a posteriori covariance matrix of $\hat{\mathbf{X}}$

$$\hat{\mathbf{\Sigma}}_{\hat{\mathbf{X}}} = \hat{\sigma}_0^2 (\mathbf{A^T P A})^{-1} \qquad (5)$$

In order to statistically test the relevance of the adopted parameters, Student test has been used, and in order to calculate a posteriori variant test χ^2 has been used. To test the existence of gross errors, test **τ** (Alan J. Pope, 1976) and the matrix of the cofactors corrections Qvv have been used.

An excerpt from the file with the results of the gravimetric network compensation from Bihor County is presented in the table below.

--- Fixed stations ---

No.	Stat. no.	g [miliGals]	σ	Weight	Station name
1	6020019	980820.4730	0.0200	1.000	BH-G2-0019
2	6020020	980795.6190	0.0200	1.000	BH-G2-0020
3	6020031	980753.0040	0.0200	1.000	BH-G2-0031
...					

--- Adjusted results and standard deviations ---

No.	Stat. no.	g [miliGals]	σ	Station name
1	6018604	980779.8986	0.0066	BH-G1-0004AF
2	6028731	980753.1504	0.0062	BH-G2-0031MO
3	6030001	980826.1773	0.0108	BH-G3-0001
4	6030002	980819.3397	0.0102	BH-G3-0002
5	6030003	980817.7988	0.0099	BH-G3-0003
...				

Table 1. The results of the gravimetric network compensation from Bihor county

5. The implementation of gravimetric quasi-geoid model

The new gravimetric quasi-geoid model for Romania will be done using the remove - compute – restore algorithm. The following flowchart summarise the strategy of processing the data for the generation of the new gravimetric geoid model

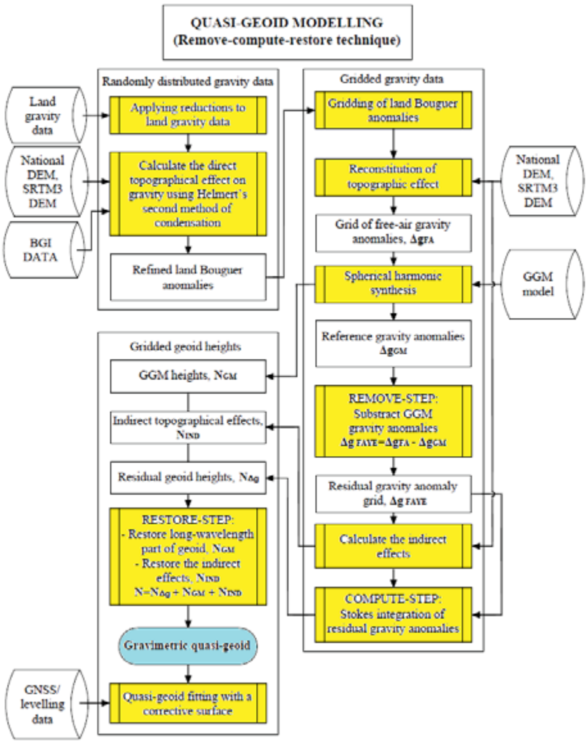

Fig. 3 Logical flowchart of a quasigeoid model

The following are the most important steps of data processing to achieve quasi-geoid in Bihor according to the procedure mentioned above.

a) Preparation of digital terrain models for the calculation of the relief corrections and indirect effect

In the process of calculating the corrections were used two digital models:

- A more detailed model with a higher resolution, which is used for the nearest area of the calculated point (Fig. 4);
- A less detailed model with lower resolution, which is used for the farthest area of the calculated point (SRTM3 DEM).

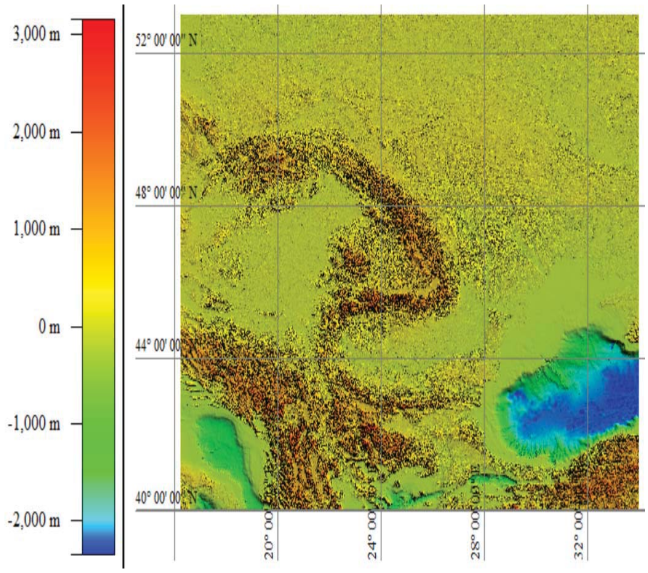

Fig. 4 Detailed digital terrain model

b) Calculation of free-air anomalies, terrain corrections and Bouguer anomalies in gravimetric points

To calculate the terrain effects on gravity anomalies disturbance), were used homogeneous rectangular prisms method (Forsberg, R. 1985):

$$\delta g_m = G\rho \Big|\Big|\Big| \, x\log(y+r) + y\log(x+r) - z\arctan\frac{xy}{zr} \Big|_{x_2}^{x_1}\Big|_{y_2}^{y_1}\Big|_{z_2}^{z_1} \quad (6)$$

c) Generating refined Bouguer anomalies grid

To generate the grid, were used the principles of collocation method combined with minimum curvature method.

d) Reconstitution of topographic effects at the grid points to get a grid of Faye gravity anomalies

e) Determination of long wavelength components in grid points using global geopotential coefficients model GGM

f) The calculation of residual gravity anomalies in the grid nodes

GGM gravity anomalies were subtracted from free-air gravity anomalies resulting residual Faye anomalies in the grid nodes (Fig. 4):

$$\Delta g_{FAYE} = \Delta g_{FA} - \Delta g_{GM}\,. \quad (7)$$

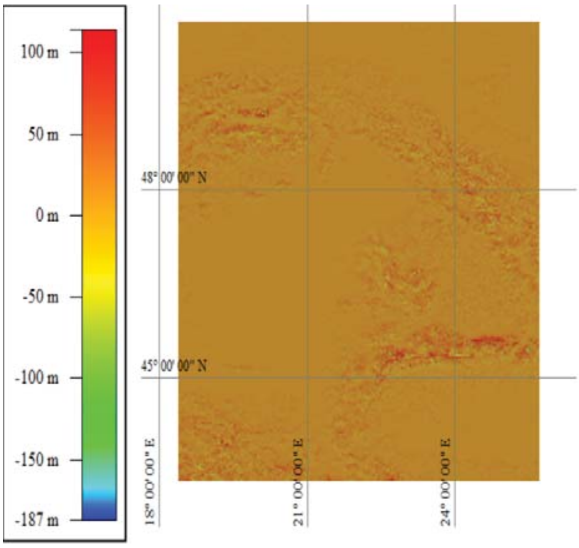

Fig. 5 Faye anomalies in the grid nodes

g) Determining the medium-wavelength part of the geoid undulation ($N_{\Delta g}$) by using spherical form of Stokes's integral:

$$N(\varphi,\lambda) = \frac{R}{4\pi\,\gamma_0}\int_{\lambda'=0}^{2\pi}\int_{\varphi'=-\pi/2}^{\pi/2}\Delta g(\varphi',\lambda')\,S(\psi)\cos\varphi'\,d\varphi'\,d\lambda' \quad (7)$$

h) The calculation of the indirect effect of grid nodes (N_{IND}):

$$N_{ind} = -\frac{\pi G\rho}{\gamma}h_p^2 - \frac{G\rho}{6\gamma}\iint_E \frac{h^3 - h_p^3}{s^3}dxdy\,. \quad (8)$$

i) Calculation of the final values of the geoid undulations in grid nodes

The final values of the geoid undulations are obtained by adding the medium-wavelength component ($N_{\Delta g}$), the long-wavelength component (N_{GM}) and indirect effect (N_{IND}):

$$\mathbf{N = N_{\Delta g} + N_{GM} + N_{IND}} \quad (9)$$

j) Determining and applying a corrective surface to the gravimetric quasi-geoid

For fitting the quasigeoid model to the Romanian vertical datum, additional GNSS observations on levelling benchmarks are performed. Moreover, these measurements also contribute to improving the estimation of the accuracy and precision of the gravimetric quasi-geoid.

The Quasigeoid performed for Bihor county is represented below (Fig. 4).

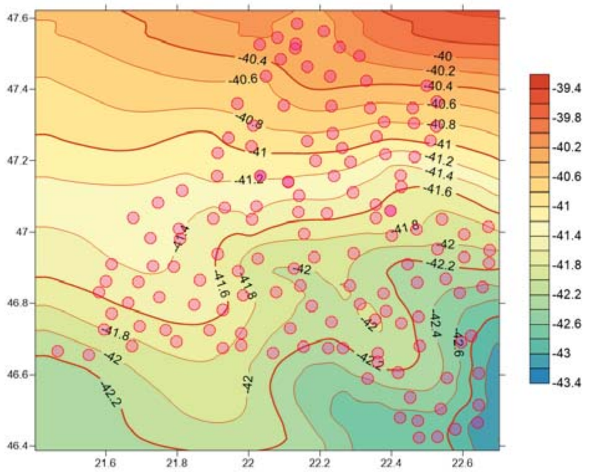

Fig. 5 The altitude anomalies for Bihor area

Table 2 shows the statistics of the differences between the altitude anomalies derived from 31 co-located GNSS-levelling benchmarks and those derived from the quasi-geoid model for Bihor county.

Table 2. Statistics of the differences between the altitude anomalies derived from GNSS-levelling benchmarks and those derived from the quasi-geoid model for Bihor county

Statistics	Value [m]
Maximum	0.132
Minimum	-0.107
Mean	-0.005
Standard deviation	0.039

6. Conclusions

By achieving the new gravimetric quasigeoid model, with higher accuracy than the existent geometric quasigeoid model, a more accurate coordinate transformation on altitudes will be provided, based on ellipsoidal altitudes gotten with GNSS technology, making important steps forwards, as well, to get a more accurate digital elevation model for the achievement of the orthophotomap and for carrying out the systematic cadastral activities included in the National Programme for Cadastre and Land Book 2015-2023.

By comparing the efficiency criteria, i.e. economic and precision, regarding the method of achieving a gravimetric quasigeoid up against a geometric quasigeoid, we conclude that, concerning the achievement of gravimetric measurements, expenditures, both material, time and human resources are being reduced significantly compared with those allocated for a determinations GNSS – leveling campaign.

The new quasigeoid model and its applications will have implications in most areas of investment and achievement of national projects including those relating to agricultural work, the water management, studies concerning hydro and hydropower accumulation, transport, air navigation, satellite remote sensing, achieving of GIS specialized sites, environmental issues and ecology, seismic and geodynamic phenomena, achieving hazard and risk maps etc.

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