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 1st and 2nd order gravimetric network, GNSS and precision leveling measured checkpoints and also new designed points (determined with GNSS/RTK).*

"Remove-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 2016 for creating the pilot projects in three 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.*

1. Introduction

For accomplishing the HB.13 measure about the rehabilitation and modernization of the National Geodetic Network (RNG) of the leveling, precision by determining a quasigeoid 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 experimentally 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.

2. The design of gravimetric works

During 2016 there were developed gravimetric works in the form of three pilot-projects which are carried out on the counties of Bihor, Arad and Hunedoara, each project having some features based on the location of gravimetric points and their inclusion in the measurement loops.

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.

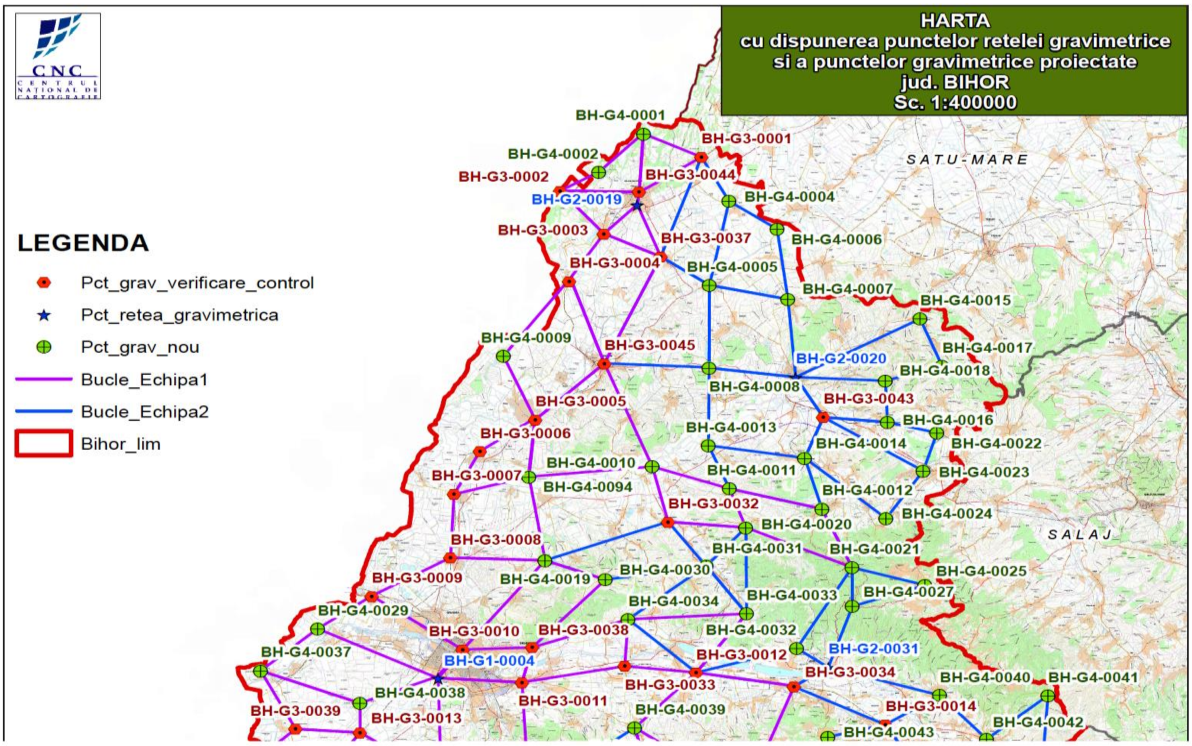

Fig. 1. The layout of the gravimetric points in the pilot project from Bihor County

For placing the projected gravimetric points, the following rules have been taken into consideration:

- to locate the new points in a area of level ground, without sudden changes on altitude around it;
- not to choose as places of materializing areas next or rivers or lakes;
- to avoid areas exposed to strong winds or next to big trees;
- not to choose places next to excavations (shafts, tunnels, subways, underground parking etc.);
- to avoid the placement next to dams, drains, groundwater etc.;
- no to choose places near tall buildings, towers, water towers etc.;
- to avoid the placement near major roads, railways, factories or heavy equipment, which can be submitted to high vibrations etc.

3. 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.

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 performed for each of the new designed points. Registering were carried out in two successive series each of 15 epochs, on a difference of a few minutes. The receivers were set up with the recording time for a period of one second.

Geometric leveling measurements will be made by the traverse, meaning round trip and tolerance allowed for the measurement results will be ± 1.25 mm $\sqrt{L}$, where L represents the distance in kilometers for traverse leveling.

For performing measurements during the pilot-projects, the following equipment will be used:

- Scintrex relative gravimeters - Autograv CG5 with 1 microGal reading resolution;
- Leica GS15 GNSS receivers – RTK, for performing GNSS - Static and GNSS - RTK measurements, with two frequencies, which creates the possibility (during processing time) to make linear combinations between the measurements of phase, resulting in reducing or eliminating the ionosphere effect;
- Electronic levels Leica Sprinter 250M type, for transmitting the level to the new points which have been determined (checkpoints, control points and in other specific points, as well).

4. Primary processing of gravimetric data

Pre-processing of the gravimetric data involved the calculation of the averages of the raw readings, the application of the calibration corrections and, also, the removing of the erroneous measurements from the data set.

Calibration correction applied for Scintrex gravity meter - Autograv CG5 has the form of polynomial functions type (Torge, 1989)

$$\Delta F(z) = \sum_{l=1}^{r} b_l z^l \quad (1)$$

where:

- b_l are coefficients of the polynomial;
- z^l are gravimeter readings.

It was critical to remove any known disturbing environmental effect from the observation data before the calibration and network adjustment.

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.

An excerpt from a file with the reductions shown in the table below.

Table 1. The reductions applied to raw gravimetric readings(microGal)

Station code	Data	Time	No.	Raw reading	Stdev	Tides	Free air	Polar motion	Red. readings	Station
6030044	2016-06-07	08:58:44	1	4429.7990	24.0	39.9	64.5	1.5	4429.9049	BH-G3-0044
6030044	2016-06-07	09:00:00	2	4429.7970	27.0	40.8	64.5	1.5	4429.9038	BH-G3-0044
6030044	2016-06-07	09:01:05	3	4429.7960	18.0	41.6	64.5	1.5	4429.9036	BH-G3-0044
6030044	2016-06-07	09:02:10	4	4429.7950	36.0	42.3	64.5	1.5	4429.9033	BH-G3-0044
6030044	2016-06-07	09:03:15	5	4429.7930	17.0	43.1	64.5	1.5	4429.9021	BH-G3-0044
6030044	2016-06-07	09:04:20	6	4429.7920	15.0	43.9	64.5	1.5	4429.9019	BH-G3-0044
6030044	2016-06-07	09:05:25	7	4429.7920	13.0	44.6	64.5	1.5	4429.9026	BH-G3-0044
6030001	2016-06-07	09:37:50	8	4434.2530	11.0	66.8	76.8	1.5	4434.3982	BH-G3-0001
6030001	2016-06-07	09:39:04	9	4434.2520	13.0	67.6	76.8	1.5	4434.3980	BH-G3-0001
6030001	2016-06-07	09:40:09	10	4434.2490	15.0	68.3	76.8	1.5	4434.3957	BH-G3-0001
6030001	2016-06-07	09:41:15	11	4434.2490	13.0	69.0	76.8	1.5	4434.3964	BH-G3-0001
6030001	2016-06-07	09:42:20	12	4434.2480	12.0	69.7	76.8	1.5	4434.3961	BH-G3-0001
6030001	2016-06-07	09:43:24	13	4434.2460	13.0	70.4	76.8	1.5	4434.3948	BH-G3-0001
6030001	2016-06-07	09:44:30	14	4434.2460	10.0	71.1	76.8	1.5	4434.3955	BH-G3-0001

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

$$l(t) + v = g + N_0 + \Delta F(z) + D(t) \qquad (2)$$

in which:

- *t*: time measurement;
- *l*: reading low value of the instrument;
- *v*: it's 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

$$D(t) = \sum_{p=1}^{a} d_p (t - t_0)^p \qquad (3)$$

where:

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

The advantage of using reduced gravity readings from functional model (2) up against the model with gravity differences in successive readings of the first model consists in the fact that the observations are uncorrelated, while the model with differences in readings has a statistical correlation of 0.5.

Assuming that there are n number of measurements, observation equations of the form (2) are written in the form of a matrix

$$\mathbf{L}^{\mathbf{b}} + \mathbf{V} = \mathbf{AX}\text{, with the weighting matrix } \mathbf{P} \qquad (4)$$

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

$$\hat{\mathbf{X}} = (\mathbf{A}^{\mathrm{T}}\mathbf{PA})^{-1}\mathbf{A}^{\mathrm{T}}\mathbf{PL}^{\mathbf{b}} \qquad (5)$$

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

$$\hat{\mathbf{\Sigma}}_{\hat{\mathrm{x}}} = \hat{\sigma}_0^2 (\mathbf{A}^{\mathrm{T}}\mathbf{PA})^{-1} \qquad (6)$$

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

Table 2. The Results of the gravimetric network compensation from Bihor County

--- Fixed stations ---

No.	Stat. no.	g [microGal]	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 [microGal]	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
...				

The table below shows the calibration coefficients resulted from the compensation and the statistical situation of the compensation.

Table 3. Calculation of calibration coefficients

Instrum. no.	Scale corr.	Calibration coefficient	σ
1	0.224415E-03	0.9997755849	0.132901E-03
2	-0.586511E-03	1.0005865106	0.133147E-03

Total number of observations:	3137
Stations number:	143
Total number of unknown:	255
Degrees of freedom:	2882
σ_1 (priori standard deviation of unit weight):	0.0200
σ_2 (posteriori standard deviation of unit weight):	0.0157

6. The implementation of gravimetric quasi-geoid model

The new gravimetric quasi-geoid model for Romania will be done in a similar way as the pilot-project of the Municipality of Bucharest (2012), using the algorithm "remove - compute - restore". The strategy of processing the data is shown in the logical flowchart of achieving of a quasigeoid model in the figure below.

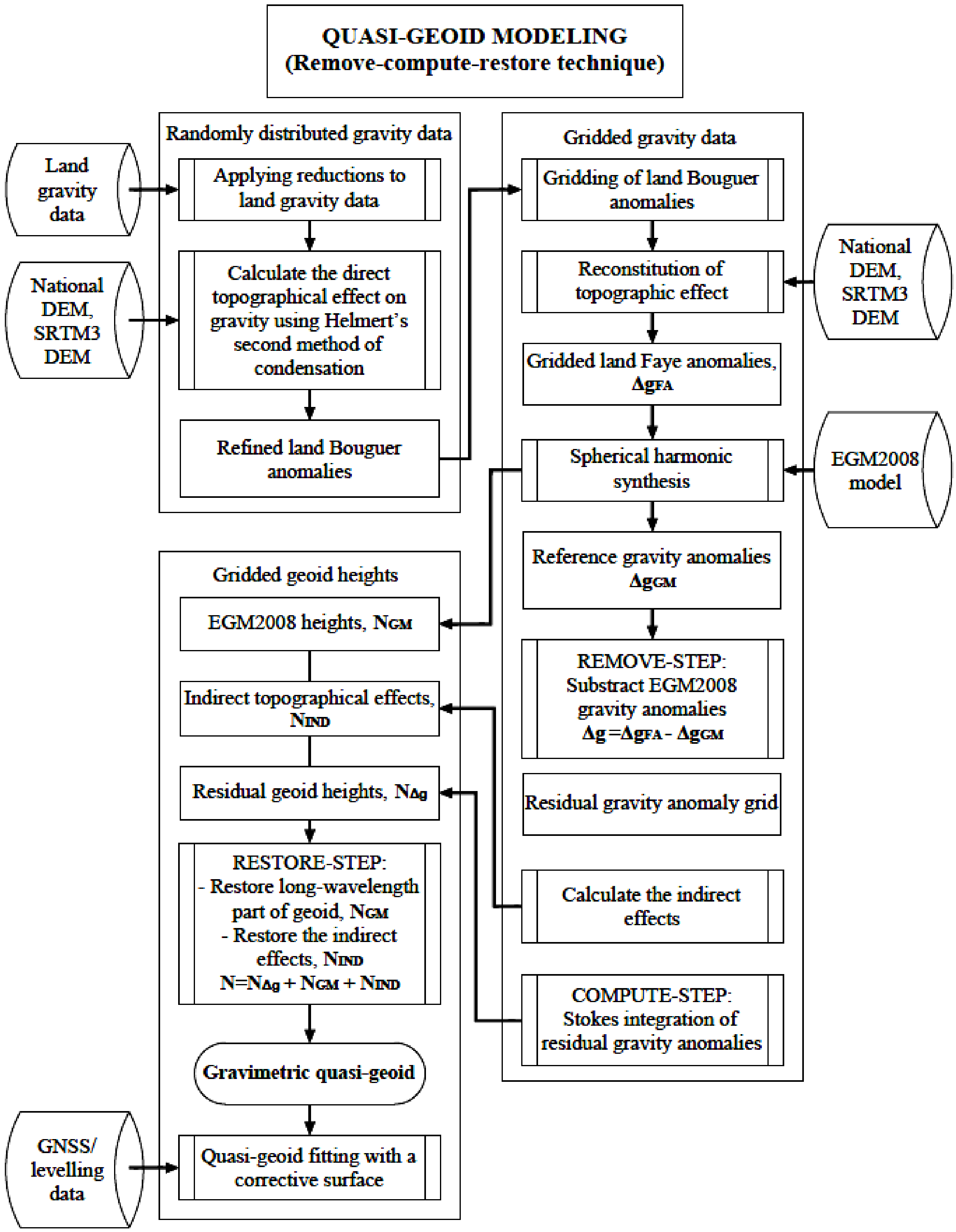

Fig. 3. Logical Flowchart of a quasigeoid model

The main steps of data processing involved in the performing of quasigeoid are:

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

Use two types of digital terrain models:

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

b) Calculation of Faye anomalies, calculation of corrections relief and improved calculation of Bouguer anomalies in gravimetric points

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

$$\delta g_m = G\rho \Big| \Big| \Big| \, x\log(y+r) + y\log(x+r) - z\arctan\frac{xy}{zr} \Big|_{x_2}^{x_1} \Big|_{y_2}^{y_1} \Big|_{z_2}^{z_1} \quad (7)$$

c) Generating refined Bouguer anomalies grid

To generate the grid, use the principles of co-location method combined with minimum curvature method.

d) Reconstitution of topographic effects at the grid points to get a grid of free-air gravity anomalies

e) Determination of long wavelength components in grid points using global geopotential coefficients model EGM2008

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

Faye anomalies obtained from grid nodes minus EGM2008 gravity anomalies resulting residual gravity anomalies in the grid nodes ($\Delta g = \Delta g_{FA} - \Delta g_{GM}$).

g) Calculation of average wave length component of the geoid undulation grid nodes ($N_{\Delta g}$)

Determining the medium-wavelength part of the geoid undulation by using the spherical Stokes method.

h) The calculation of the indirect effect of grid nodes (NIND)

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}):

$$\mathbf{N = N_{\Delta g} + N_{GM} + N_{IND}} \quad (8)$$

j) To calculate altitude anomalies in grid nodes use the recommended formula by W. A. Heiskanen and H. Moritz (1993):

$$N - \zeta = \frac{\bar{g} - \bar{\gamma}}{\bar{\gamma}} H = H^* - H. \quad (9)$$

k) 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 fitting trend model adopted corresponds to the following regression equation (Heiskanen and Moritz 1967):

$$\Delta N_i = \Delta a + \Delta X_0 \cos \varphi_i \cos \lambda_i + \Delta Y_0 \cos \varphi_i \sin \lambda_i + \Delta Z_o \sin \varphi_i + a\Delta f \sin^2 \varphi_i \quad (10)$$

l) Estimation of the altitude anomalies accuracy

Altitude anomalies resulted in grid nodes for Bucharest test area is schematically represented by isolines in the following figure.

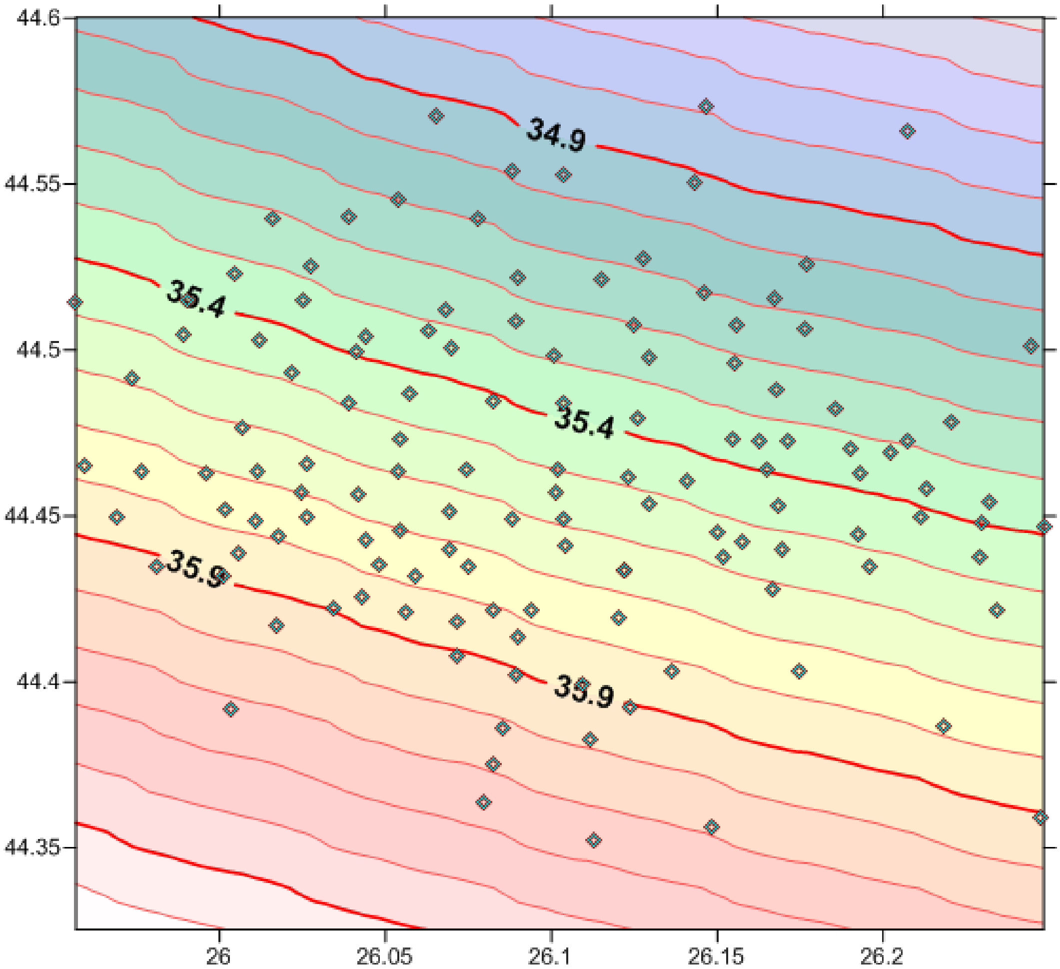

Fig. 4. The altitude anomalies for Bucharest area

7. 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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