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COMPARATIVE ANALYSES OF QUASIGEOID MODELS FOR THE REPUBLIC OF MOLDOVA TERRITORY

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Key words: quasigeoid**,** absolute gravity, relative gravity.

Introduction

Acceleration of Global Navigation Satellite Systems (GNSS) technologies increases the accuracy of coordinate determination.

Obtained from GNSS measurements heights are geodetic (ellipsoidal) heights and for practical use needs to be converted into normal heights, as a distance between point on the physical surface and quasigeoid surface at gravity vector direction.

Determination of normal heights from ellipsoidal height depends on the accuracy of GNSS measurements and height anomalies calculated from global, regional or local quasigeoid model as a distance between ellipsoid and quasigeoid surface along the gravity vector.

First quasigeoid model GM2005 for Republic of Moldova territory was calculated in 2005 by Ukrainian Research Institute of Geodesy and Cartography, using 803 GNSS/levelling sites and European Geoid Model EGG97, transformed to Baltic Sea 1977 normal height system [1].

In order to develop high accuracy local gravimetric geoid in 2006 Institute of Geodesy, Engineering Research and Cadastre INGEOCAD subordinated to The Land Relations and Cadastre Agency of Republic of Moldova in cooperation with the National Geospatial-Intelligence Agency (NGA) of United States of America performed gravity campaign to establish first order National Gravity Network with accuracy 10 μGal using three LaCoste & Romberg G meters (Fig. 1). In order to constrain the relative gravity measurements 3 absolute gravity stations were determined with accuracy 5 μGal, using FG5 absolute gravimeter [2].

The second and third order National Gravity Network (Fig. 1) with density of 1 gravity point per 15–20 square km was performed in 2007–2008 by Institute of Geodesy, Engineering Research and Cadastre (INGEOCAD) with accuracy 20 μGal and 40 μGal respectively [3].

In 2012 a new gravimetric quasigeoid model GM2012 was determined by applying the Least Squares Modification of Stokes' formula with Additive corrections (LSMSA), also called the KTH method [4].

To generate and distribute height anomalies for real time normal height determination from GNSS measurements using MOLDPOS service, height reference surface based on precise GNSS/levelling was calculated by Technical University of Moldova in cooperation with Karlsruhe University of Applied Science. The quasigeoid model GM2010 was calculated using HSKA method for digital finite element height reference surface representation as polynomial solution [5].

In 2014 the Land Relations and Cadastre Agency performed GNSS measurements on 1-st and 2-nd order levelling network benchmarks in order to estimate the accuracy of existing quasigeoid models for the Republic of Moldova territory [6].

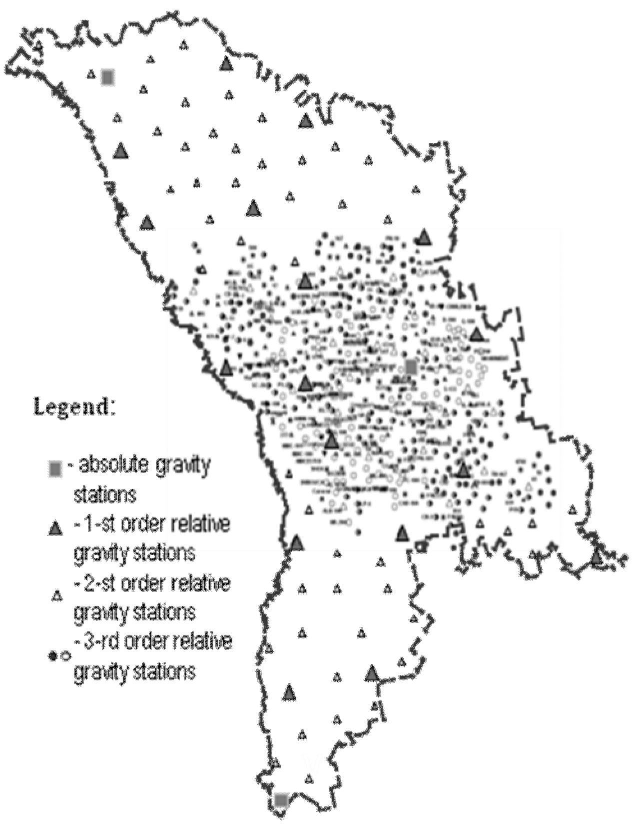

Fig. 1. National Gravity Network

Thanking in account that part of gravity data of Republic of Moldova territory were involved in calculation of

EGM2008 model it was also included in the comparative analyses.

2. Methods of quasigeoid models evaluation

For models evaluation a well know geometrical equations are used:

$$h - H - z_{\mathrm{i}}^{Model} = 0$$

$$\Delta z_{\mathrm{i}} = z_{i}^{GNSS/lev.} - z_{\mathrm{i}}^{Model} = h_i - H_i - z_{\mathrm{i}}^{Model}$$

where Dz_i is a height anomalies differences calculated between height anomalies $z_i^{GNSS/lev}$ from GNSS/levelling measurements and z_i^{Model} determined from quasigeoid models, or differences between ellipsoidal height h_i, normal height H_i and height anomalies z_i^{Model} calculated from quasigeoid models, where i =1, 2,.., n and n is the number of observations.

In practice these equations are never satisfied due to a number of factors like random errors of measurements and approximations, datum and deformations which can affect the height systems, datum and benchmarks.

The parametric observations model could be written as following:

$$\Delta\zeta_{\mathbf{i}} = \mathbf{a_i x} + \mathbf{v_i},$$

where $\mathbf{x}$ are unknown parameters, $\mathbf{v_i}$ are residuals and $\mathbf{a_i}$ are observation coefficients corresponding to the number of parameters [7]:

for the 3 parameter model

$$\mathbf{a_i x} = (\cos f_i \cos l_i) x_1 + (\cos f_i \sin l_i) x_2 + (\sin f_i) x_3,$$

Where as the 4-parameter model is given by

$$\mathbf{a_i x} = (\cos f_i \cos l_i) x_1 + (\cos f_i \sin l_i) x_2 + (\sin f_i) x_3 + x_4,$$

the 5-parameter model is

$$\mathbf{a_i x} = (\cos f_i \cos l_i) x_1 + (\cos f_i \sin l_i) x_2 + (\sin f_i) x_3 + (\sin^2 f_i) x_4 + x_5,$$

while the 7 parameter model is

$$\mathbf{a_i x} = (\cos f_i \cos l_i) x_1 + (\cos f_i \sin l_i) x_2 + (\sin f_i) x_3 + \frac{\cos f_i \cos l_i \sin f_i}{W_i} x_4 + \frac{\cos f_i \sin l_i \sin f_i}{W_i} x_5 + \frac{\sin^2 f_i}{W_i} x_6 + x_7,$$

where

$$W_i = \sqrt{1 - e^2 \sin^2 f_i}.$$

The matrix form for the system of observation equations follows:

$$\Delta\zeta = \mathbf{Ax} + \mathbf{v},$$

where $\mathbf{x}$ is a vector of unknown parameters, $\mathbf{v}$ is vector of residuals and $\mathbf{A}$ is the design matrix that contains for each observation coefficients.

The parameters were estimated by least squares method:

$$\mathbf{x} = (\mathbf{A}^T \mathbf{A})^{-1} \mathbf{A}^T \Delta\zeta,$$

Introducing the vector of estimated parameters $\mathbf{x}$ into the system of observation equations, is obtained the vector of estimated residuals

$$\mathbf{v} = \Delta\zeta - \mathbf{Ax},$$

The estimated residuals $\mathbf{v}$ are used to calculate the standard deviation:

$$s_0 = \sqrt{\frac{\mathbf{v^T v}}{n - m}},$$

where n is the number of GNSS/levelling observations and m is the number of estimated parameters.

3. Accuracy evaluation of quasigeoid models

For accuracy evaluation of existing quasigeoid models were selected 40 first and second order levelling benchmarks of National Levelling Network (Fig. 2).

The GNSS measurements on levelling benchmarks were carried out in 2014 by INGEOCAD specialists, using GNSS receivers in static mode with duration 90 min and postprocessed with a connection to MoldPos GNSS Network.

The preliminary estimation of quasigeoid models was done by INGEOCAD [7]. The results of calculations are shown in Tab. 1.

Table 1

The results of preliminary estimation of quasigeoid models

	GM2005	EGM2008	GM2010	GM2012
min	–0,096	–0,124	–0,050	–0,079
max	0,246	0,195	0,290	0,280
mean	0,014	–0,007	0,026	0,014
σ	0,053	0,058	0,063	0,060

The results of quasigeoid models estimation using the 3, 4, 5, 7 parameters equations are shown in Tab. 2–4.

Table 2

The results of estimation of quasigeoid models using 3 parameters equations

	GM2005	EGM2008	GM2010	GM2012
min	–0,086	–0,101	–0,084	–0,086
max	0,236	0,204	0,259	0,252
mean	0,000	0,000	0,000	0,000
σ	0,051	0,055	0,062	0,055

Table 3

The results of estimation of quasigeoid models using 4 parameters equations

	GM2005	EGM2008	GM2010	GM2012
min	–0,076	–0,102	–0,095	–0,079
max	0,210	0,202	0,239	0,231
mean	0,000	0,000	0,000	0,000
σ	0,048	0,056	0,062	0,054

Table 4

The results of estimation of quasigeoid models using 5 parameters equations

	GM2005	EGM2008	GM2010	GM2012
min	–0,076	–0,102	–0,094	–0,079
max	0,210	0,203	0,239	0,231
mean	0,000	0,000	0,000	0,000
σ	0,049	0,057	0,063	0,055

Table 5

The results of estimation of quasigeoid models using 7 parameters equations

	GM2005	EGM2008	GM2010	GM2012
min	–0,080	–0,087	–0,078	–0,071
max	0,210	0,199	0,241	0,232
mean	0,000	0,000	0,000	0,000
σ	0,050	0,055	0,062	0,054

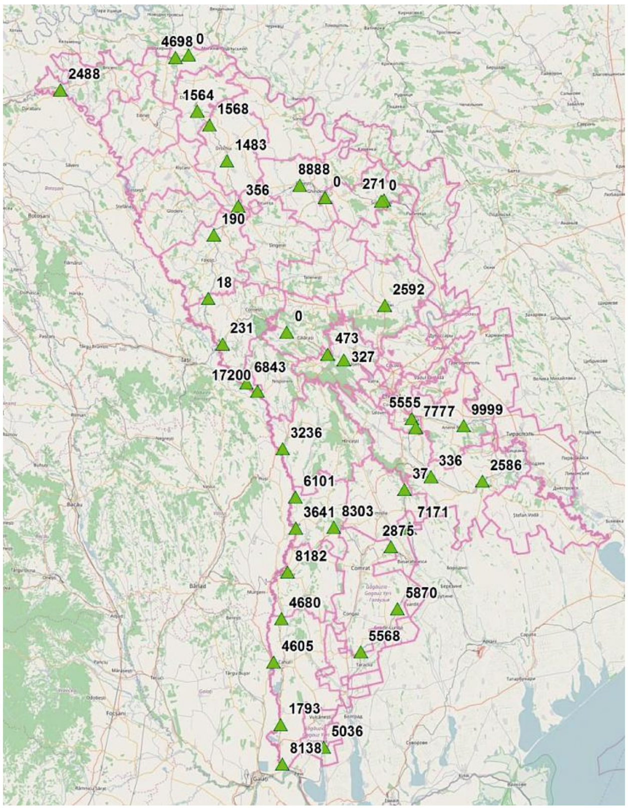

Fig. 2. GNSS/Levelling measurements

In Fig. 3 is showed diagram of quasigeoid models accuracy comparison without parameter model (0P) and using parameter models (3P, 4P, 5P, 7P).

Comparative study of existing quasigeoid models shows the best accuracy of GM2005 with 4 parameters.

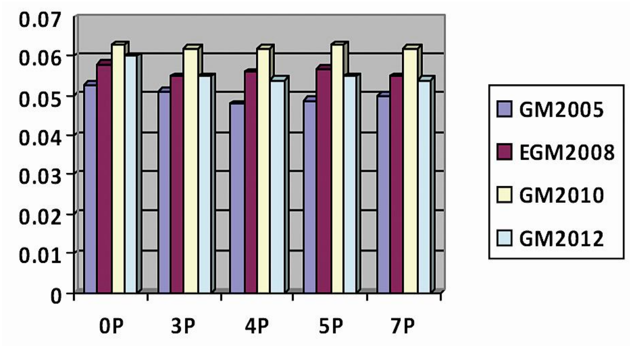

Fig. 3. Diagram of quasigeoid models accuracy comparison using different parameter equations

Conclusions

Comparative study of existing in Republic of Moldova quasigeoid models shows the best accuracy of GM2005 with 4 parameters, about 4.8 cm that could be used for large scale mapping for all territory of the country.

The analyses of GM2005 residuals showed the best results in the middle and eastern part of country territory and the worse on the western borders were is a lack of high quality data.

The results of this study could be used by Land Relation and Cadastre Agency for argumentation of necessity to continue third order National Gravity Network with density of 1 gravity point per 15–20 square km in order to achieve 1–2 cm accuracy quasigeoid model.

In order to improve the accuracy of height anomaly determination along the state border a vertical deflection to be determined from GNSS/astronomical measurements and included in quasigeoid modeling procedure.

For future improvement of quasigeoid model a fitting GNSS/Leveling points related to 1st, 2nd order leveling networks, and carefully selected 3rd and 4th order leveling benchmarks have to be used taking in account weights corresponding to the accuracy of leveling benchmarks determination.

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Comparative analyses of quasigeoid models for the Republic of Moldova territory

V. Chiriac

Starting from 2011 a GNSS reference stations network reference system and MoldPos service was established by Land Relation and Cadastre Agency financed by Norwegian Government. In order to provide all necessary information not only for 2D positioning, but also for GNSS-based normal height computation the quasigeoid model was integrated in RTCM transformation messages to allow real time normal height determination for large scale mapping.

This paper presents the results of comparative study of existing quasigeoid models on territory of our country using control GNSS/Levelling measurements. Comparative study between GM2005, GM2010, GM2012 and EGM2008 quasigeoid models, currently used for large scale mapping, showed the best accuracy 4,8 cm of GM2005 with 4 parameters that could be used for large scale mapping for all territory of the country. The analyses of GM2005 residuals showed the best results in the middle and eastern part country territory and the worse on the western borders were is a lack of high quality data. The results of this study could be used by Land Relation and Cadastre Agency for argumentation of necessity to continue densification of National Gravity Network in order to achieve high accuracy quasigeoid model.

Порівняльний аналіз моделей квазігеоїда для території Республіки Молдова

В. Киріяк

В даній статті представлені результати порівняння моделей квазігеоїда для території Республіки Молдова з використанням GNSS-вимірювань для нівелювання.

Сравнительный анализ моделей квазигеоида для территории Республики Молдова

В. Кирияк

В данной статье представлены результаты сравнения моделей квазигеоида для территорий Республики Молдова с использованием GNSS-измерений для нивелирования.