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Original Contribution

ANALYSIS AND COMPARISON OF GRAVITY ANOMALIES FROM THE GLOBAL GEOPOTENTIAL MODELS EGM 2008 AND EIGEN-6C4 WITH AVAILABLE GRAVITY ANOMALIES IN AN EXTREMELY MOUNTAINOUS REGION OF THE TERRITORY OF SOUTHWEST BULGARIA - RILA MOUNTAIN

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ABSTRACT: *The subject of the study is the analysis of the Bouguer gravity anomaly and its comparison by comparing the Bouguer anomaly values from the global geopotential models (GGMs) EGM 2008 and EIGEN-6C4 with data from interpolated values of 46,121 points for the Rila Mountain region, in which GNSS/leveling measurements have been carried out. The Bouguer anomaly map gives a good idea of the subsurface density [7]. In mountainous areas, topographic effects completely dominate local variations in the gravity field, so it is necessary to introduce local topographic reductions to remove this dependence on height.*

KEY WORDS: *Bouguer anomal, Mountainous area, EGM 2008, EIGEN-6C4.*

1. Introduction

For the purposes of the study, interpolated values of Bouguet anomalies from the 1:200,000 scale gravity map of Bouguet anomalies evenly distributed over the territory of the Rila Mountains were compared with corresponding values calculated with the Java application of ICGEM (International Center for global Earth Models) http://icgem.gfz-potsdam.de/ICGEM/ICGEM.htmle) from the global geopotential models EGM 2008 and EIGEN-6C4.

The data assumed and used with fixed values in the comparisons are:

- a model of the Bougue anomalies for the territory of the Rila Mountain with a resolution of 1'×1', created from a digitized map of Bougue anomalies at a scale of 1:200,000;
- interpolated values of 46,121 points for the Rila Mountain region, where GNSS/leveling measurements were carried out;
- Global geopotential models (EGM 2008, EIGEN-6C4).

2. Experiment and discussion

The Bouguer anomaly model used in the experimental study is a sample of the digitized gravimetric map at a scale of 1:200,000 of the Bouguer anomaly, with a contour section of 2 mGal, created and maintained by the Military Topographic Service (Fig. 1). The anomaly values in it are corrected for relief. For the purpose of compiling the map, the gravity force is in the Potsdam system: $g = \gamma 0 - 0.1967.H + \Delta g Б - 14$ mGal. The normal force of gravity is calculated using the Helmert formula (1901-1909). The heights are normal. The Bouguer correction factor 0.1967 is calculated with an interstitial layer density of 2.67 g/cm3. Potsdam system correction – 14 mGal.

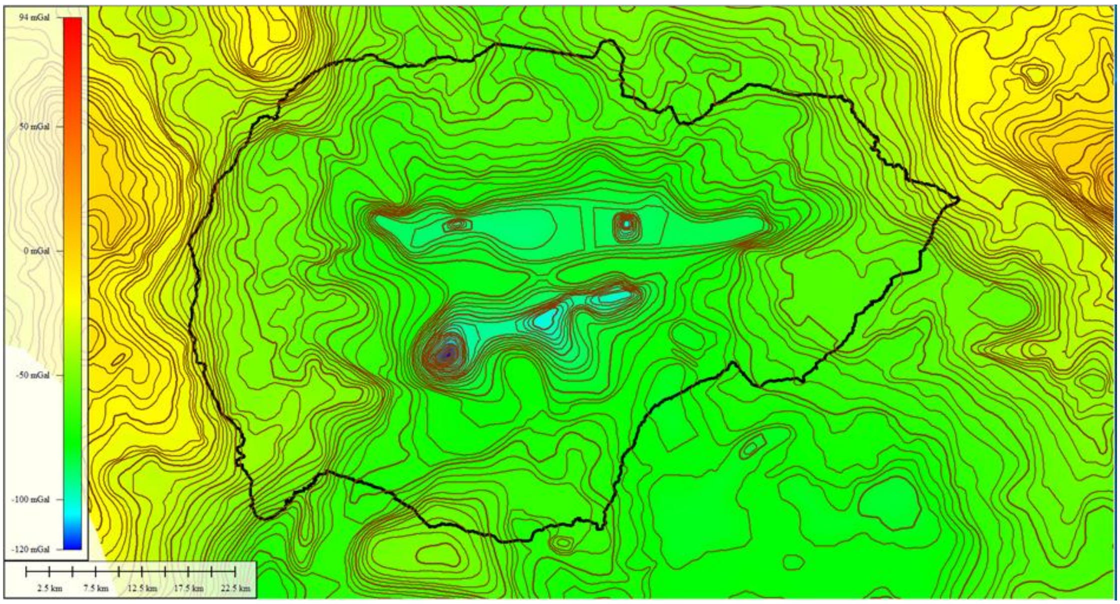

Fig. 1. Extract from the digitized map of the Buge anomaly for the Rila Mountain region with a section of the 2 mGal isolines

2.1.1. Analysis and evaluation of Bouguer anomaly values interpolated from the gravity map for all points where GNSS/levelling measurements were performed with the Global Geopotential Models - EGM 2008, EIGEN-6C4

The International Center for Global Earth Models (ICGEM) website contains information from freely available global geopotential models, as well as software for calculating geopotential-related quantities. The application allows for the calculation of pure and mixed gravity anomalies, geoid height, Bouguer anomaly, and many other geopotential-related quantities [5].

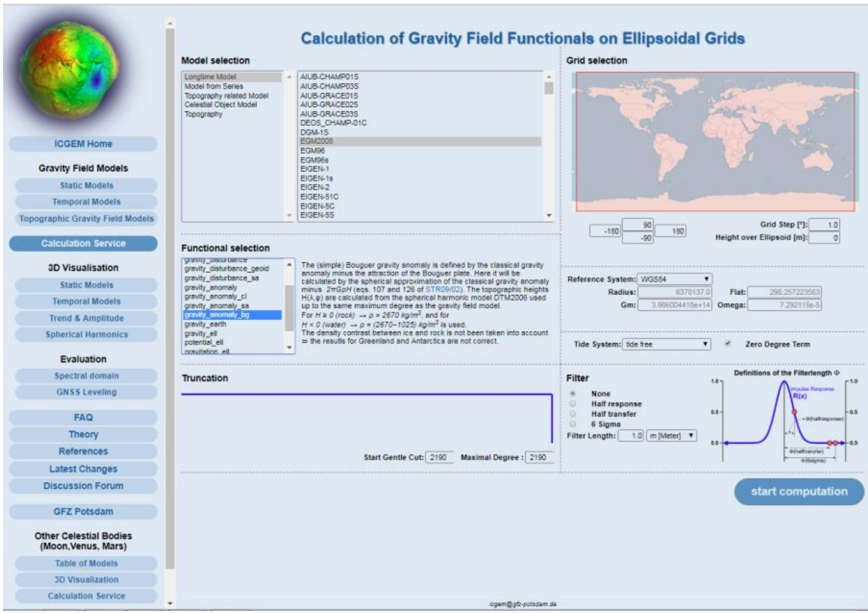

Fig. 2 View of a Java application for calculating geopotential-related quantities http://icgem.gfz-potsdam.de/ICGEM/ICGEM.html

Calculating the Bouguer anomaly using the Java application ICGEM

The Bouguer anomaly Δg_B is defined by the classical gravity anomaly minus the Bouguer plateau. In the Java implementation of ICGEM, it is calculated by spherically approximating the classical gravity anomaly minus $2\pi G\rho H$:

$$\Delta g_B(\lambda,\varphi)=\Delta g_{cl}(\lambda,\varphi)-2\pi G\rho H(\lambda,\varphi),$$

where $2\pi G\rho H$ is the formula for the attraction of the “Bouget Plateau” in the form of a plateau with thickness H (the topographic height above the geoid), constant density ρ and infinite horizontal width (e.g. Hofmann-Wellenhof & Moritz, 2005). The topographic heights H (λ, φ) are calculated from the spherical harmonic model DTM 2006, used to the same maximum extent as the gravity field model.

За H ≥ 0 (rock) → ρ = 2670 kg / m^3 и за H <0 (water) → ρ = (2670-1025) kg / m^3.

Unfortunately, this cannot be expressed in terms of potential, because the infinite plateau potential does not make sense (Van'ıcek et al., 2001 and Van'ıcek et al., 2004). The clear idea of using the spherical layer potential involves the -4πGρH, which is twice the size of the "Bouget plateau" of attraction. The plausible explanation is that the participation of the far zone of the spherical layer, the entire opposite half, cannot be neglected here (which makes this model unrealistic) [3].

Since the Bouguet anomaly model is a sample of the digitized Bouguet anomaly map created and maintained by the Military Topographic Service, the anomaly values in it are corrected for relief. Given the above calculations of Δg_B the geopotential model with the ICGEM software, in order to correctly compare the anomaly values, the influence of relief corrections must be removed. For this purpose, the topographic correction model for near and far zones for the territory of Bulgaria with a resolution of $1' \times 1'$, created on the basis of geological surveys of the territory of Bulgaria [4], is used;

2.2. Calculation of the differences in the geoid models for the study area

2.2.1. Calculation and comparison of the Bouguer Δg_B anomalies interpolated from the gravity map for all points where GNSS/levell measurements were made with the Global Geopotential Models - EGM 2008, EIGEN-6C4

Given the developed method [2], for the selection of an optimal model of the Earth's Global Gravity Field, the EGM 2008 and EIGEN-6C4 models were selected for further studies of the geometric geoid on the territory of the Rila mountains.

When calculating Bouguer anomalies with the ICGEM application, the following parameters are entered as input data:

-reference system-GRS80;

-long-period models [6];

- calculated quantity - Bouguer anomaly (gravity_anomaly_bg);
- tidal system - tide free;
- using the zero degree of the model;

Since Bouguer anomalies calculated from the GGM refer to a simple spherical layer, for a correct comparison of the data from the values interpolated from the gravity map Δg_B, topographic corrections for near and far areas must be subtracted. This was done with the Global Mapper program. In all calculations and comparisons, the difference in the source systems in which the anomalies were determined was taken into account. For all GGMs, the global orthometric relief model ETOPO1 was used.

The comparison algorithm is as follows:

1) the desired value of the Bouguer anomaly is calculated at the nodes of a spatial grid with dimensions $1'' \times 1''$ of the given Global Geopotential Model. The calculations are performed up to degree 2190 with a calculation period of 5 min to 12 h depending on the desired value. The ICGEM software outputs a

*.gdf file with the results of the calculations. This format is divided into two parts: a header block and a results block.

2) an *.shp file is extracted from the ICGEM software and introduced into the Arc GIS environment;

3) with input data the planar coordinates (№, NUTM, EUTM) of the GNSS points in the same Arc GIS environment, in which the results of the calculations from the ICGEM software are also contained, information on the values of the Bouguer anomaly for all GNSS points is extracted by interpolation from grida;

4) based on the interpolated values in the Arc GIS environment, a TIN model of the area with Bouguer anomalies is created, calculated from the selected Global Geopotential Models, visualized with the Global Mapper software tool.

Processing large volumes of data requires not only computing power, but also significant storage capacity [1]. Data storage in GIS is organized as a set of layers with ground gravimetric measurements and GNSS/leveling data, global geopotential models, Bouguer anomaly model, topographic correction model, digital elevation model.

3. Results

The comparison was performed by forming differences between the interpolated values of Bouguer anomalies from the gravimetric map with the values of the anomaly interpolated for the same points from a spatial grid with dimensions $1'' \times 1''$ from the given GGMs. The results of the differences in the values of the three models are shown in Table 1.

Table 1 Comparison of the obtained values of the differences between the interpolated Bouguer anomalies from the map with those calculated from the global geopotential models

Global geopotential model	Minimum difference value [mGal]	Maximum difference value [mGal]	Average of differences [mGal]	SD [mGal]
$\Delta g_B^{GRM\_18} - \Delta g_{изч.}^{\mathrm{EGM08}}$	21.621	-73.951	-13.790	20.552
$\Delta g_B^{GRM\_18} - \Delta g_{изч.}^{\mathrm{EIGEN-6C4}}$	21.545	-73.497	-12.926	20.528

The calculated values of the differences of Bouguer anomalies for the studied area show the difference between $\Delta g_B^{GRM\_18} - \Delta g_{изч.}^{\mathrm{EGM08}}$ and $\Delta g_B^{GRM\_18} - \Delta g_{изч.}^{\mathrm{EIGEN-6C4}}$ – minimum value 21 mGal, maximum -74 mGal. The negative Bouguer anomalies are obtained due to the high altitudes. The analysis of the results confirms the conclusion that the maximum differences in the values of Bouguer anomalies between the models are in the zones of the Eastern Rila Mountain, and the minimum ones are located in the lowest parts of the four separate Rila Mountain sections. The accuracy obtained when calculating Bouguer anomalies from the combined models (standard deviation of the order of 20 mGal) is insufficient for precise practical applications in inaccessible areas - such as the studied area.

The models for comparing the Bouguer anomaly for the territory of the Rila Mountain with the global geopotential models, together with the results of the calculations for the different models, are given in the following figures.

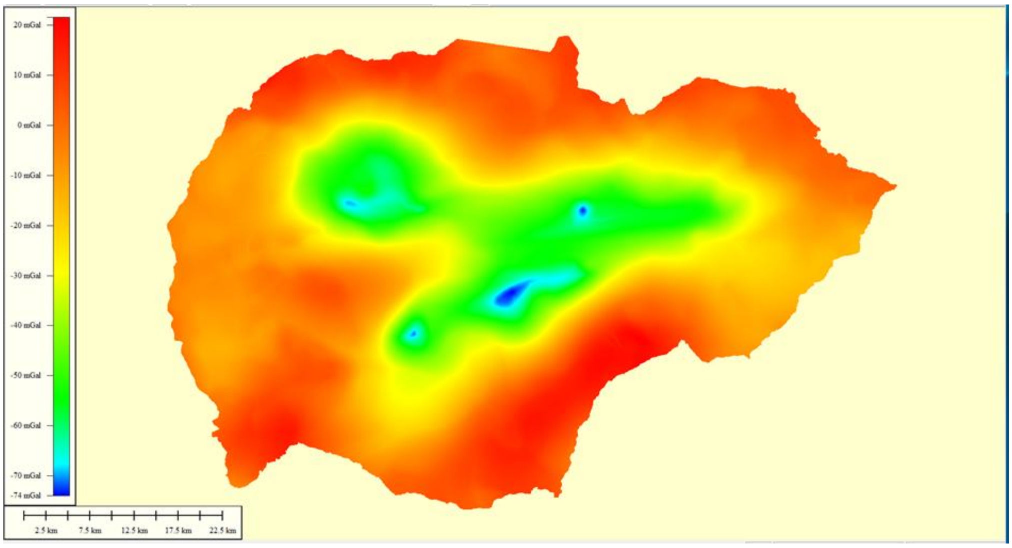

Fig. 3. Model of the differences in Bouguer anomalies calculated between the Rila Mountain model and EGM2008

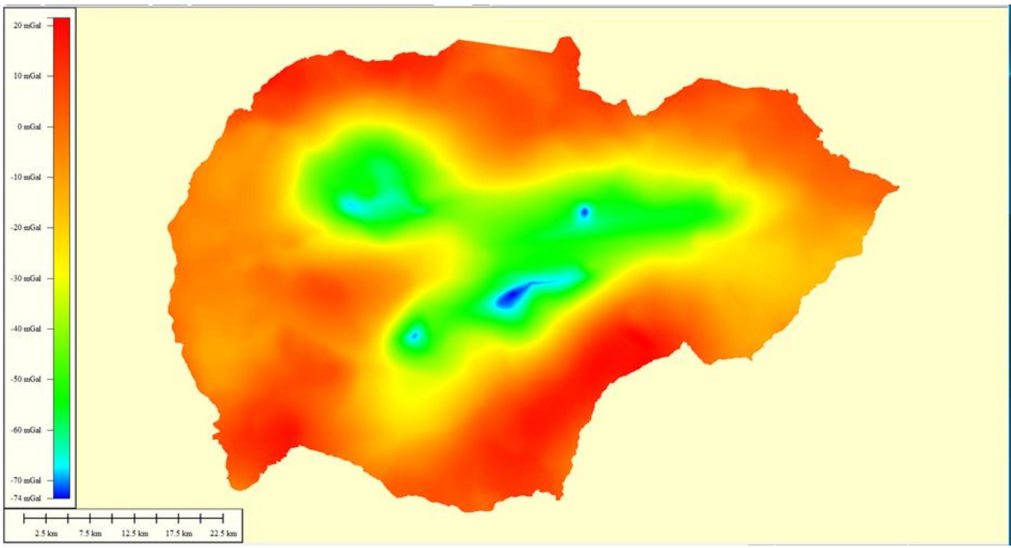

Fig. 4.Model of the differences in Bouguer anomalies calculated between the Rila Mountain model and EIGEN-6C4

4. Conclusion

Density anomalies related to topography include the direct gravitational effects of continental topography, ocean bathymetry, the influence of ice sheet, and isostatic compensation. These effects together account for a major part of the variation in the Earth's gravity field, especially at shorter wavelengths, where directly calculated topographic effects only slightly counteract the effect of isostatic compensations. In mountainous regions, topographic effects completely dominate local variations in the gravity field, so it is necessary to introduce local topographic reductions to remove this dependence on height - in general, gravity stations are set at different topographic heights, rather than at a single average topographic height for the region.

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